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SPIE Astronomical Instrumentation

Observational Frontiers of Astronomy for the New Decade

Contents

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Conference 7731: Space Telescopes and Instrumentation 2010: Optical, Infrared, and Millimeter Wave

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Space Telescopes and Instrumentation 2010: Optical, Infrared, and Millimeter Wave

7731-01, Session 1

Key enabling technologies for the next generation of space telescopes

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The next generation of large space telescopes, including ATLAST, SAFIR, IXO and Generation-X will require the development of key technologies to enable their development at an affordable cost. This includes technologies for the rapid, low cost fabrication of ultra-light weight primary mirror segments, active figure control of primary mirror segments, high speed wavefront sensing and control, highly-packageable and scalable deployment techniques, and active vibration and thermal control for light weight structural elements to supply good pointing stability. In this paper we discuss the current state-of-the-art for these technologies and roadmaps for future development in these areas.

7731-02, Session 1

Early results from NASA's assessment of satellite servicing

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Following recommendations by the NRC, NASA's 2008 Authorization Act and the FY 2009 Omnibus Appropriations directed NASA to assess the use of the human spaceflight architecture to service existing/future observatory-class scientific spacecraft. This interest in space servicing, either with astronauts and/or with robots, reflects the success that NASA has achieved with the Shuttle program and HST on behalf of the astronomical community. This study, led by NASA GSFC, will last about a year, leading to a final report to NASA. We will report on its status, results from the winter 2010 workshop, and recent concepts for serviceable scientific missions.

7731-03, Session 1

Preliminary multivariable cost model for space telescopes

H. P. Stahl, NASA Marshall Space Flight Ctr. (United States)

Parametric cost models are routinely used to plan missions, compare concepts and justify technology investments. Previously, the authors published two single variable cost models based on 19 flight missions. The current paper presents the development of a multi-variable space telescopes cost model. The validity of previously published models are tested. Cost estimating relationships which are and are not significant cost drivers are identified. And, interrelationships between variables are explored.

7731-04, Session 1

International Space Station Observatory

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Lightweight actively controlled optics are key to realizing large space telescopes. To demonstrate this enabling technologies, we propose the International Space Station Observatory (ISSO). It is a 50cm telescope with a highly actuated primary mirror coupled to a high resolution, framing camera. With this system critical wavefront sensing and control technologies will be proven. Beyond these demonstrations we envision the ISSO being a facility for observational science as well as for testing future instrument concepts. In this paper, we will describe the key trades affecting both the location of the ISSO facility as well as its capabilities.

7731-05, Session 2

Science with the James Webb Space Telescope

J. P. Gardner, NASA Goddard Space Flight Ctr. (United States)

The scientific capabilities of the James Webb Space Telescope (JWST) fall into four themes. The End of the Dark Ages: First Light and Reionization theme seeks to identify the first luminous sources to form and to determine the ionization history of the universe. The Assembly of Galaxies theme seeks to determine how galaxies and the dark matter, gas, stars, metals, morphological structures, and active nuclei within them evolved from the epoch of reionization to the present. The Birth of Stars and Protoplanetary Systems theme seeks to unravel the birth and early evolution of stars, from infall onto dust-enshrouded protostars, to the genesis of planetary systems. The Planetary Systems and the Origins of Life theme seeks to determine the physical and chemical properties of planetary systems around nearby stars and of our own, and investigate the potential for life in those systems. A description of these themes was published in 2006 in Space Science Reviews, 123, 485. Since that paper was published, we have further developed the science goals of JWST in several areas, including first light, stellar populations, extra-solar planets and Solar System objects. I will review the main science goals of the observatory and discuss recent progress.

7731-06, Session 2

Overview of the James Webb Space Telescope Observatory

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The James Webb Space Telescope (JWST) is a large-aperture (6.5 meter), cryogenic space telescope with a suite of near and mid-infrared instruments covering the wavelength range of 0.6 µm to 28 µm. JWST's primary science goal is to detect and characterize the first galaxies. It will also study the assembly of galaxies, star formation, and the formation of evolution of planetary systems. In this paper we will present an overview of recent progress on JWST including a summary of the final design presented at its Mission Preliminary Design Review last year. We will review recent progress on the key hardware development including a discussion of the status of JWST's optical system and mirror fabrication, progress with sunshield prototypes, and plans for observatory level testing of JWST at the Johnson Space Center. We also review the expected scientific performance of the observatory based on predictions made by integrated, structural/thermal/optical models of the observatory.

The goal of this paper is to provide a high level overview of the observatory and its performance to complement the science paper by Gardner, and provide an introduction for the anticipated JWST submission which will cover project management to engineering in more detail.

7731-07, Session 2

The James Webb Space Telescope integrated science instrument module

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The Integrated Science Instrument Module (ISIM) of the James Webb Space Telescope (JWST) is discussed from a systems perspective with emphasis on development status and advanced technology aspects. The ISIM is one of three elements that comprise the JWST space vehicle and is the science instrument payload of the JWST. The major subsystems of this flight element and their build status are described.

7731-08, Session 2

James Webb Space Telescope (JWST) project overview and status

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The James Webb Space Telescope (JWST) project office at the National Aeronautics and Space Administration (NASA) Goddard Space Flight Center (GSFC) is responsible for the development, launch, flight and science operations for the James Webb Space Telescope. The JWST project is currently in its development phase with launch scheduled for June 2014. The project is a partnership between NASA, the European Space Agency (ESA) and the Canadian Space Agency (CSA). This paper will provide an overview of the JWST mission. It will also provide the current status of the progress made over the last couple of years.

7731-09, Session 3

Results, status, and plans for the James Webb Space Telescope optical telescope element

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The James Webb Space Telescope (JWST) Optical Telescope Element has completed its Critical Design Review and is well into fabrication. This paper will summarize efforts to date in the design, manufacturing and planning for integration and testing. This will include a top level summary of mirror performance to date, hardware results, and planning status for the integration and testing program. The future plans for manufacturing, assembly, alignment and testing will also be summarized at a top level.

7731-10, Session 3

Optical performance for the actively controlled James Webb Space Telescope

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The James Webb Space Telescope (JWST) is a large space based astronomical telescope that will operate at cryogenic temperatures. The telescope by virtue of its size must be stowed in an inoperable configuration for launch and remotely reconfigured in space to meet the operational requirements using active Wave Front Sensing and Control (WFSC). This paper will report on the optical budgeting process used to manage the performance of the active system. The current status of the design and verification of the optical hardware, the WFSC processes, and the total system verification modeling will be presented. More detailed discussions of the system verification by analysis will be presented in separate accompanying papers.

7731-11, Session 3

NIRCam: development and testing of the JWST near-infrared camera

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The Near Infrared Camera (NIRCam) is one of the four four science instruments of the James Webb Space Telescope (JWST). Its high sensitivity, high spatial resolution images over the 0.6 - 5 micron wavelength region will be essential for making significant findings in all of JWST's major science areas. It will image a 2.2 x 4.4 arc-minute field of view at two wavelengths onto a total of 10 2048 x 2048 pixel HgCdTe near-infrared detector arrays. Two wavelengths will be observed simultaneously via the use of dichroic beam-splitters working at 2.4 microns wavelength. NIRCam will also have unique capabilities for measuring and phasing the JWST telescope, obtain slitless spectra, and making corona graphic imaging observations. NIRCam is currently being assembled and tested in preparation for JWST's launch in 2014. Initial results from testing the engineering test unit and the status of building the flight model will also be reported.

7731-12, Session 3

Status of the JWST NIRSpec instrument

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The Near Infrared Spectrograph (NIRSpec) is one of four science instruments aboard the James Webb Space Telescope (JWST) scheduled for launch in 2014. NIRSpec is sensitive in the wavelength range from ~0.6 to 5.0 micron and will be capable of obtaining spectra from more than a 100 objects simultaneously, as well as fixed slit high contrast spectroscopy of individual sources. It also features an integrated field unit for 3D spectroscopy. The key scientific objectives of the instrument include studies of star formation and chemical abundances of young distant galaxies and tracing the creation of the chemical elements back in time. We will present the status of the NIRSpec instrument as it is currently being prepared for its extensive ground calibration campaign later this year.

7731-13, Session 3

Progress with the design and development of MIRI, the mid-IR instrument for JWST

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MIRI is one of four instruments to be built for JWST, James Webb Space Telescope. It provides imaging, coronography and integral field spectroscopy over the 5-28.5um wavelength range. MIRI is the only instrument which is cooled to 7K by a dedicated cooler, much lower than the passively cooled 40K of the rest of JWST, and consists of both an Optical System and a Cooler System. This paper will describe briefly the key features of the overall instrument design and then concentrate on the status of the MIRI Optical System development. The flight model design and manufacture is completed, and final assembly and test of the integrated instrument is now underway.

Prior to this integration, all of the major subassemblies have undergone individual environmental qualification and performance tests and end-end testing of a flight representative model has been carried out. Considerable progress has been made in detailing the definition of the operational modes and calibration pipeline processes. We will provide an overview of these together with the results from the testing to date. The paper will then describe the current status of the Flight Model build and the plan for performance verification and ground calibration.

7731-14, Session 3

The JWST tunable filter imager (TFI)

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The Fine Guidance Sensor (FGS) of the James Webb Space Telescope (JWST) features a tunable filter imager (TFI) module covering the wavelength range from 1.5 to 5.0 μm at a resolving power of ~100 over a field of view of 2.2'x2.2'. TFI also features a set of occulting spots and a non-redundant mask for high-contrast imaging, This paper will review the current status of TFI and will highlight its key science programs, from the detection of first light, high-redshift Ly emitters to the detection and characterization of exoplanets.

7731-15, Session 4

Design status and performance of the James Webb Space Telescope

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The James Webb Space Telescope (JWST) is NASA's next great astronomical mission. At the time of this paper, the mission will have just passed critical design review. This paper will visit the main features of the JWST design: the telescope, sunshield, spacecraft, science instrument module orbit and operating concept. This paper will share the current expectations for JWSTs performance, design status and discuss the challenges that lay ahead on the path to, assembly integration and test and ultimately flight.

7731-16, Session 4

Phase retrieval for characterizing the optical performance of the James Webb Space Telescope (JWST) integrated science instrument module (ISIM)

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The science instruments (SIs) for the James Webb Space Telescope (JWST) will be incorporated into the Integrated Science Instrument Module (ISIM) and tested at NASA's Goddard Space Flight Center. Focus-diverse phase retrieval, a form of image-based wavefront sensing, will be used to assess the optical performance of each SI as integrated into the ISIM, with three broad goals: (1) to determine the plane of best focus for each SI individually and the best composite focus for the ISIM as a whole, (2) to confirm that each SI meets its image-quality requirements after delivery to NASA and integration into ISIM, and (3) to characterize the low-order Zernike aberrations of the wavefront of each SI at points across its field of view, for use by the Multi-Instrument Multi-Field (MIMF) alignment procedure on orbit.

This paper gives an overview of the architecture of these phase-retrieval-based tests. Many activities done in preparation for these optical-performance tests will be discussed, including phase-retrieval algorithm development, Monte Carlo and "blind" phase-retrieval simulations, and phase-retrieval analysis on focal-sweep data taken from engineering test units (ETUs) of the SIs.

7731-17, Session 4

Successful production of the engineering development unit (EDU) primary mirror segment and flight unit tertiary mirror for JWST

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During 2009, Tinsley finished most of the Configuration 1 pre-cryo test Computer Controlled Optical Surfacing (CCOS) operations on the

James Webb Space Telescope primary mirror segments and in mid-2009 we began the Configuration 2 post-cryo test CCOS operations. After completing the grinding and polishing operations, including final figuring to a cryo-null target, we delivered the finished Engineering Development Unit (EDU) to Ball Aerospace Technology Corporation on 4 December 2009. Achieving fabrication and metrology conditions to meet the specifications for this off-axis ~1.5 m hexagonal point-to-point segmented mirror required special methods. Achieving repeatable and accurate interferometric alignment of the off-axis aspherical mirror surface and stable thermal gradient control of the beryllium substructure during tests required rigorous component and system-level validation. Final optical wavefront measurements over the various spatial frequency ranges have demonstrated that all of the requirements are met. This success has validated our processes of fabrication and metrology and allows us to proceed with the production of the 18 flight mirror segments. The first finished flight mirror, the Tertiary Mirror, was shipped to BATC on 24 February, 2010. Performance of that mirror is reported here also.

7731-18, Session 4

First results from JWST/MIRIM flight model testing: high-resolution PSF analysis at 5.6 microns

P. Guillard, Institut d'Astrophysique Spatiale (France)

The Mid Infra Red Instrument (MIRI) is one of the four instruments for the James Webb Space Telescope (JWST). It provides imaging, coronagraphy and spectroscopy over the 5-28 micron band.

The first tests, at cryogenic temperatures and in the infrared, have been performed on the flight model (FM) of the Mid-InfraRed IMager (MIRIM), from December 2008 to April 2009 at CEA, France. This paper reports the first results of the High-Resolution (HR) image of the MIRIM Point Spread Function (PSF) at 5.6 microns, the only filter available at that time. At this wavelength, the PSF is not Nyquist-sampled. The HR technique we use allows to characterize the MIRIM optical quality with an unprecedented accuracy. The HR PSF is obtained through a microscanning, which consists in a sub-pixel scanning of a point source on the focal plane. A deconvolution algorithm is used to reconstruct HR PSFs, oversampled up to a factor of 10. We pay attention to the non-linear response of the MIRIM detector and we correct for it. We compare our results to Zemax simulations and show that the FWHM of the HR PSFs are 5-10% wider than the simulations. The main cause was identified as an out-of-specification tilt of the M4 mirror of MIRIM. After correction of the tilt, a second test campaign was performed, and we show that the measured FWHM of the PSF is 0.19"-0.20", and that 73% of the energy is inside the central lobe, which is within specifications. This analysis of the MIRIM PSF is of particular importance, not only for optical quality checks and MIRI calibration, but also for potential scientific applications.

7731-19, Session 4

The throughput and sensitivity of the JWST mid-infrared instrument

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The Verification Model (VM) of MIRI (the Mid-InfraRed Instrument for the JWST) has recently completed an extensive programme of cryogenic testing, with the Flight Model (FM) now being assembled and made ready to begin performance testing in the next few months.

By combining those VM test results which influence MIRI's scientific performance with measurements made on FM components and sub-assemblies, we have been able to refine and develop the existing model of the instrument's throughput and sensitivity.

We present the main components of the model, its correlation with the existing test results and its predictions for MIRI's performance on orbit.

7731-20, Session 4

Testing a critical stray light path of the James Webb Space Telescope

T. L. Whitman, ITT Corp. (United States)

The James Webb Space Telescope (JWST) requires cryogenic testing of a critical stray light path, named as the Rogue Path. Although blockage of this path is verified during fabrication and assembly of JWST, simple passive components added to the test configuration provide an opportunity to check for successful blockage at the system level in the cryogenic environment. Although the test occurs in the largest environmental chamber at the NASA Johnson Space Center, the size of the chamber challenges this test by placing the origin of the Rogue Path within the collimated beam of the telescope. The design of the test overcomes this challenge with sufficient signal to noise ratio and without interference with the optical test of the system.

7731-95, Poster Session

AKARI infrared bright source catalogues

S. Oyabu, Japan Aerospace Exploration Agency (Japan)

Bright source catalogues based on the new all-sky survey by the infrared astronomical satellite AKARI will be released to public early 2010. The mid-infrared catalogue will include more than 870 thousand sources observed at 9 and 18 μm, and the far-infrared catalogue will provide information of about 290 thousand sources at 65, 90, 140, and 160 μm. The detection limits are 50 and 120 mJy at 9 and 18 μm, and 0.56 Jy at 90 μm, respectively. The errors in the position and the flux density are ≤ 2 arcsec and 2-4 % in mid-infrared, and 5 arcsec and 20-35 % in far-infrared. The AKARI catalogues will replace the IRAS catalogues and will become the most important catalogue in astronomy.

We present the procedures to make the infrared source catalogue and its characteristics.

7731-96, Poster Session

Spacecraft conceptual design for the 8-meter Advanced Technology Large Aperture Space Telescope (ATLAST)

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While the scientific benefit of space-based telescopes is well established, designing spacecraft to point and control large monolithic telescopes is challenging. In particular, the 8-meter monolithic Advanced Technology Large Aperture Space Telescope, with its 26 metric ton primary mirror and more than 50 metric ton total observatory mass, poses many pressing design constraints on a spacecraft.

The Advanced Concepts Office at Marshall Space Flight Center completed a brief spacecraft design study. This spacecraft concept provides all power, communication, telemetry, avionics, guidance and control, and thermal control for the observatory, and inserts the observatory into a halo orbit about the second Sun-Earth Lagrange point. The multidisciplinary design team included structures, avionics, power, guidance and control, propulsion, thermal, and trajectory disciplines, and created a simple spacecraft design that enables component and science instrument servicing, employs articulating solar panels for help with momentum management, and provides precise pointing control while at the same time fast slewing for the observatory.

This paper summarizes the study goals, ground rules and assumptions, spacecraft requirements, the conceptual design by subsystem, and provides a mass and power budget.

7731-97, Poster Session

Thermal analysis of the Advanced Technology Large Aperture Space Telescope (ATLAST): 8 meter primary mirror

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The Advanced Technology Large Aperture Space Telescope (ATLAST) preliminary design concept consists of an 8 meter diameter monolithic primary mirror enclosed in an insulated, optical tube with stray light baffles and a sunshade. ATLAST will be placed in orbit about the Sun-Earth L2 and will experience constant exposure to the sun. The insulation on the optical tube and sunshade serve to cold bias the telescope which helps to minimize thermal gradients. The primary mirror will be maintained at 280K with an active thermal control system.

The geometric model of the primary mirror, optical tube, sun baffles, and sunshade was developed using Thermal Desktop®. SINDA/FLUINT® was used for the thermal analysis and the radiation environment was analyzed using RADCAD®. A 2000 node model was executed in order to characterize the static performance and thermal stability of the mirror during maneuvers. This is important because long exposure observations, such as extra-solar terrestrial planet finding and characterization, require a very stable observatory wave front. Steady state thermal analyses served to predict mirror temperatures for several different sun angles. Transient analyses were performed in order to predict thermal time constant of the primary mirror for a 20 degree slew or 30 degree roll maneuver.

This paper describes the thermal model and provides details of the geometry, thermo-optical properties, and the environment which influences the thermal performance. All assumptions that were used in the analysis are also documented. Parametric analyses were performed for design parameters including primary mirror coatings and sunshade configuration. Estimates of mirror heater power requirements are reported. The thermal model demonstrates results for the primary mirror heated from the back side and edges using a heater system with multiple independently controlled zones.

7731-98, Poster Session

Coronagraphic wavefront control for the ATLAST Telescope

R. G. Lyon, W. R. Oegerle, L. D. Feinberg, M. R. Bolcar, B. H. Dean, G. E. Mosier, NASA Goddard Space Flight Ctr. (United States)

The Advanced Technology for Large Aperture Space Telescope (ATLAST) concept was assessed as one of the NASA Astrophysics Strategic Mission Concepts (ASMC) studies. Herein we discuss the 9.2-meter diameter segmented aperture telescope wavefront sensing and control (WFSC) with regards to coronagraphic detection and spectroscopic characterization of exoplanets. It is currently envisioned that WFSC would consist of at least two levels of sensing and control: (i) an outer coarse level of sensing and control to phase and control the segments and the secondary mirror in a manner similar to the James Webb Space Telescope but operating at higher temporal bandwidth, and (ii) an inner fine level of sensing and control that senses and controls both amplitude and wavefront errors operating at temporal bandwidths approaching ~1 Hz. The outer loop would control rigid-body actuators on the primary and secondary mirrors while the inner loop would control one or more deformable mirror to suppress the starlight within the coronagraphic focal plane. Herein we discuss the flow down of science requirements to system level and wavefront sensing and control requirements and show the results of closed-loop simulations to assess performance and evaluate the trade space of system level stability versus control bandwidth.

7731-99, Poster Session

Euclid ENIS spectrograph focal-plane design

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The ENIS spectrograph is part of the instrument package on board of the European space mission Euclid devoted to map the dark universe and proposed for launch in 2017. ENIS will operate in the near-IR spectral region (0.8-2 μ) and will provide in 4-5 years an accurate and extremely large survey of cosmological redshifts.

The ENIS focal-plane, based on a combination of state of the art detectors, will be fed by a slitless or, possibly, a DMD based spectrograph allowing coverage and analysis of a high number of targets per cycle. A description of the focal-plane study is here presented.

7731-100, Poster Session

A frame simulator for data produced by ‘multi-accumulation’ readout detectors

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In the framework of the design study for the ENIS spectrograph, part of the European Euclid mission, we developed a simulator of data frames produced by ‘multi-accumulation’ readout detectors. The software can emulate various readout strategies, allowing to compare the efficiency of different sampling techniques. Special care is given to two crucial aspects: the minimization of the noise and the effects produced by cosmic hits.

The resulting RON is analyzed as a function of the background sources, detector native characteristics and readout strategy, while the image deterioration by cosmic rays covers the simulation of hits and the possible correction efficiency as a function of the selected readout strategy and data processing.

Simulated images are an ideal tool for testing the efficiency of cosmic ray rejection techniques. In the present case cosmic rays are added to each raw frame conforming to the rates and energy expected in the operational L2 region and in the chosen exposure time. Procedures efficiency for cosmic ray identification and correction can also be easily tested in terms of memory and telemetry occupancy.

7731-101, Poster Session

The Euclid near-infrared calibration source

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The Euclid dark energy mission is currently competing in ESA's Cosmic Vision program. Its two imaging instruments, one visible and one infrared, will survey the entire extragalactic sky during the 5 year mission. The near-infrared imaging photometer (NIP), operating in the 0.92-2µm spectral range, will be used in conjunction with a visible imaging instrument to determine some of the most fundamental physical parameters in the Universe. To meet the stringent overall photometric calibration requirement the NIP instrument requires a dedicated on-board flat-field source to calibrate the large, 18 detector focal plane.

It is proposed that a 180 mm Spectralon diffuser plate, mounted to a pre-existing shutter mechanism outside the instrument, is used as a flat-field calibration target, negating the need for an additional single-point-failure mechanism. The 117 x 230 mm focal plane will therefore be illuminated through all of the instrument's optical elements and will allow flat-field measurements to be taken in all wavelength bands. A ring of low power tungsten lamps, with custom reflecting elements optimised for optical performance, will be used to illuminate the diffuser.

This paper details the end-to-end optical simulations of this concept, a potential mechanical implementation and the initial tests of the proposed key components.

7731-102, Poster Session

The data handling unit of the Euclid imaging channels: from the observational requirements to the unit architecture

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The Euclid Imaging Channels Instrument of the Euclid mission is designed to study the weak gravitational lensing cosmological probe. The combined Visible and Near InfraRed imaging channels will be controlled by a common data handling unit (PDHU), implementing onboard the instrument digital interfaces to the satellite. The PDHU main functionalities include the scientific data acquisition and compression, the instrument commanding and control and the instrument health monitoring.

The unit design has been driven by a set of requirements mainly related to the type and number of detectors present in the two instrument channels, to the mission observing modes and to expected scientific data production rates. In particular, the high number of CCDs and the related read out electronics modules defined the minimum number of digital interfaces to be used onboard in order to meet the instruments needs: 12 SpaceWire links for the VIS channel and 2 SpaceWire links for the NIP channel respectively.

The high scientific data rates and the overall mission telemetry budget defined the target lossless data compression factors: 2.8 for VIS instrument and 2.5 for NIP instrument. The PDHU design included an evaluation of the algorithms to be used onboard to accomplish these factors and the related necessary computing power.

To couple with these high demanding requirements an innovative architecture, based on the use of several computing and interface modules, considered as building blocks of a modular design has been proposed and is presented in this poster.

7731-103, Poster Session

The ground support equipment for the E-NIS instrument on-board the ESA-Euclid Dark Energy Mission

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Euclid is a high-precision survey mission to map the geometry of the Dark Universe.

The baseline payload developed by the ENIS Consortium in the context of the ESA Cosmic Vision Programme, consists of a Korsch telescope with a primary mirror of 1.2 m diameter. The focal plane hosts three scientific instruments each with a field of view of 0.5 sq. deg: (1) E-VIS: a CCD based optical imaging channel, (2) E-NIP: a NIR imaging photometry channel, and (3) E-NIS: a NIR slitless (baseline) or multi-object slit (optional) spectrometric channel.

In this paper we present the conceptual design for the E-NIS Ground Support Equipment required to support the assembly, integration and verification operations at E-NIS system level, with particular regards to the scientific and calibration activities.

7731-104, Poster Session

EUCLID: design of the prism DMD NIR spectrograph

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EUCLID, the ESA Dark Energy Mission, contains a NIR and a visible imagers (NIP & VIS), and an NIR spectrograph (NIS). Three designs of the NIS have been studied: a slitless design, a Digital Micromirror Device (DMD) design using grisms and another using prisms. We present the design of the prism DMD NIS. This design has the advantage over the slitless design of the DMD mask which reduces the background by a factor of more than 100 and all the advantages over the grism DMD NIS that a prism gives over a grism as a higher and more uniform transmission, the absence of parasite orders, and a choice of the slope of the spectral resolution with wavelength. The field per spectrograph was made sufficiently large to reduce the number of spectrographs to two. The design was made so that the mapping of the sky of the NIS is easily compatible with the mapping strategy of the NIP and VIS. Two designs were made. In one, the field is larger but the surface shapes of the optics are complex which makes manufacturing more challenging. In the other, the design was made to be fully compatible with the manufacturing criteria of SESO after extensive discussions to carefully understand the manufacturing limitations especially the formula for highly aspheric surface shapes as biconics. This was done by directly integrating the criteria into the optimization process of ZEMAX. A calibration system that uses the DMD with the micromirrors in their OFF positions was also developed.

7731-105, Poster Session

Opto-mechanical design of a DMD multislit spectrograph for the ESA Euclid Mission

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The Euclid mission proposed in the context of the ESA cosmic vision program is aimed to study the challenging problem of the Dark Energy responsible of the apparent acceleration of the universe. One of the three probes of Euclid is dedicated to study the Baryonic Acoustic Oscillations by means of spectroscopic observations of millions of galaxies in the Near Infrared. One option for the Euclid Near Infrared Spectrograph (ENIS) is a multi-slit approach based on Digital Mirror Device (DMD) used as reconfigurable slit mask. The Texas Instrument 2048*1080 DMD with 13.7 micrometers pitch has been chosen. We present the ENIS optical design composed of four arms each using one DMD to cover a total FOV of 0.48 square degree. We first describe the fore-optic design to cope with the difficult task of having simultaneously a fast beam (F/2.7) and a quasi-diffraction limited image on a 24 deg tilted plane. We then present the compact three mirror spectrograph using a grism in convergent beam for simplicity and compactness purposes. We finally show the mechanical structure based on a common carbon honeycomb bench to reach the challenging requirements of volume and mass.

7731-106, Poster Session

Space evaluation of 2048 x 1080 mirrors DMD chip for ESA EUCLID Mission

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EUCLID mission from ESA will study the dark universe by characterizing a very high number of galaxies in shape and in spectrum. The high precision spectra measurements could be obtained via multi-object spectroscopy (MOS) using Digital Micro-Mirror Arrays. These arrays would act as objects selection reconfigurable masks.

ESA has engaged with Visitech and LAM a technical assessment of a DMD chip from Texas Instruments for space application. The selected component is a DMD chip in a 2048 x 1080 micromirrors format, with a pitch of 13.68µm. Usual operational parameters are room temperature, atmospheric pressure and mirrors tilting several hundreds times in a second, while for EUCLID, the device should work in vacuum, at low temperature, and each MOS exposure should last 1500s with mirrors frozen in one state (either ON or OFF) during that duration.

A specific thermal / vacuum test chamber has been developed for test conditions down to -40°C at 10-5 mbar vacuum. Imaging capability for resolving each micro-mirror has also been developed for determining any failure for a single mirror. A dedicated electronics and software permit to freeze any pattern on the device for duration as long as 1500s.

Tests in vacuum at low temperature, TID radiations, vibrations, thermal cycling, and life tests have been performed. First results do not reveal any fundamental show-stopper concerning the ability of the DMD chip to survive an EUCLID type environment. Fine analysis of the results will be presented. In addition, MOS-like tests on a specific optical bench are also scheduled.

7731-107, Poster Session

AIM software tool for GAIA data reduction: challenges and implementation

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AIM gathers several tasks with the goal to perform checks on the functioning of the Gaia Astro instrument: monitoring and diagnostics of the astrometric instrument response during in-flight operations; calibration of the astrometric instrumental effects.

The AIM system is a hierarchy of software modules each one dedicated to perform a specific analysis and extract calibration information from the data during in-flight operation: procedures and tools for instrument diagnostic and calibration with the goal to decrease the parameter space and solve degenerations and optimize the parameter estimation process with respect to computation load, precision, or both.

An important step is the definition and maintainance of a very physical instrument model fitting the science data, able to accomodate non nominal configurations, using as far as possible the modeling tools developed within the Data Processing Astrometric Consortium and in particular in the Astrometric Verification Unit.

Indeed precise modelling of the astrometric response is required for optimal definition of the data reduction and calibration algorithms, in order to ensure high sensitivity to the astrophysical source parameters and in general high accuracy.

The definition (forward analysis) is comparably straightforward from sufficiently detailed design data. The inverse problem (backward analysis) of disentangling both astrophysical and instrumental parameters from the set of science and auxiliary data is much more challenging.

We describe the goals behind AIM, the challenges and the development criteria and the implementation results.

7731-108, Poster Session

Towards a demonstrator for autonomous object detection on board GAIA

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ESA’s cornerstone mission Gaia aims at autonomously building a billion-star catalogue by detecting them on board. The scientific and technical requirements make this an engineering challenge. We have devised a prototype to assess achievable performances and assist in sizing the on-board electronics (PDHE TDA). It is based on a sequence of four tasks: calibrating the CCD data, estimating the sky background, identifying the objects and, finally, characterising them. Although inspired by previous similar studies (APM, Sextractor), this approach has been thoroughly revisited and finely adapted to Gaia.

A mixed implementation is proposed which deals with the important data flow and the hard real-time constraints in hardware (FPGA) and entrusts more complex or variable processing to software. The segmentation also corresponds to subdividing the previous operations in pixel-based and object-based domains. Our hardware and software demonstrators shows that the scientific specifications can be met, as regards completeness, precision and robustness while, technically speaking, our pipeline, optimised for area and power consumption, allows for selecting target components. Gaia’s prime contractor, inspired by these developments, has also elected a mixed architecture, so that our R&D has proven relevant for the forthcoming generation of satellites.

7731-109, Poster Session

Monitoring, diagnostic, and calibration of the astrometric response of the GAIA astro instrument within the astrometric verification unit

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The goals of micro-arcsecond level precision space mission rely on the limiting performance associated to the selected instrumental configuration and observing conditions. In particular, variation of the instrumental response over the field, with wavelength and in time, are potentially critical and quite unavoidable.

Appropriate modelling of the astrometric response is required for optimal definition of the data reduction and calibration algorithms, in order to ensure high sensitivity to the astrophysical source parameters and in general high accuracy.

The definition (forward analysis) is comparably straightforward from sufficiently detailed design data. The inverse problem (backward analysis) of disentangling both astrophysical and instrumental parameters from the set of science and auxiliary data is much more challenging.

We describe selected topics in the framework of the astrometric instrument modelling for the Gaia mission, evidencing their role in the data reduction chain and for definition of the Reference Frame at micro-arcsecond level.

We discuss the impact on the data quality and how the science data can be used to trace directly the instrument response, taking advantage of the repeated measurements of stars over the field and how it is one of the driver philosophies behind the Astrometric Instrument Model (AIM) concept in the context of the Verification Unit.

We describe the goals and concepts behind AIM, the challenges and the development criteria and the first achieved results.

7731-110, Poster Session

The data processing pipeline for the Herschel/SPIRE imaging Fourier transform spectrometer

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The data processing pipeline to generate calibrated data products from the SPIRE imaging Fourier Transform Spectrometer is presented. This pipeline processes telemetry packets from SPIRE point source and jiggle-map observations, producing calibrated spectra in low-, medium-, high-, and mixed low- and high-resolution modes. The spectrometer pipeline shares some elements with the SPIRE photometer pipeline, such as the conversion of telemetry packets into data timelines and the calculation of bolometer voltages from the raw telemetry. Those processing elements unique to the spectrometer that are presented here are: first and second level glitch identification and removal; temporal and spatial interpolation of the stage mechanism and detector data; apodization; and the Fourier transform. We also describe the corrections for various instrumental effects including removal of the effects due to the Herschel primary mirror and the spectrometer calibrator, interferogram baseline correction, channel fringe correction, temporal and spatial phase correction, non-linear response of the bolometers, variation of instrument performance across the focal plane arrays, and the spectral efficiency of the spectrometer. Astronomical calibration will be empirically based on a combination of observations of dark patches in the sky and standard astronomical sources. Once the Herschel-SPIRE system has been fully characterized in flight, the pipeline may be refined to incorporate an absolute calibration scheme based on physical modeling of the telescope and internal calibrator and of the detectors.

7731-111, Poster Session

In-flight characterisation of Herschel-SPIRE optical performances

M. Ferlet, Rutherford Appleton Lab. (United Kingdom)

The Spectral and Photometric Imaging Receiver (SPIRE) is one of three scientific instruments on ESA's Herschel Space Observatory, launched in May 2009 and now orbiting L2. This long wavelength instrument covers 200 to 670 microns with a three band photometric camera and a two band imaging Fourier Transform Spectrometer.

We discuss the in-band SPIRE optical performances as obtained from measurements made during in-orbit Commissioning and Performances Verification Phases. Complementary to the characterization of the instrument spectral characteristics, attention is focused here on a set of dedicated observations made of unresolved bright sky targets mainly obtained through the use of standard operating mode such as scan mapping. These tests were aimed at measuring the geometry of the respective Photometer and Spectrometer field-of-views as well as the spatial response of the end-to-end optical chain, from telescope to focal plane detectors in all spectral bands. Implications for instrument flight calibration parameters are reported. Finally comparison with model-based results from design & build expectations and previously reported ground-measured characteristics is given before concluding on the excellent state of the in-flight Herschel/SPIRE optical performances; one of the key factors in the realization of the full scientific potential of the Herschel observatory in the SPIRE spectral bands.

7731-112, Poster Session

Status of the SPIRE photometer data processing pipeline during the early phases of the Herschel Mission

C. D. Dowell, Jet Propulsion Lab. (United States); M. J. Griffin, Cardiff Univ. (United Kingdom)

We describe the current state of the ground segment of Herschel-SPIRE photometer data processing, approximately one year into the mission. The SPIRE photometer operates in two basic modes: scan mapping and chopped compact source photometry. For each mode, the basic analysis pipeline — which follows in reverse the effects from the incidence of light on the telescope to the storage of samples from the detector electronics — is the same as described pre-launch. However, the calibration parameters and detailed numerical algorithms have advanced due to the availability of commissioning and early science observations. The result is a reliable pipeline which produces accurate and sensitive photometry and maps at 250, 350, and 500 microns with a very low level of residual artifacts. We discuss some detailed aspects of the pipeline on the topics of: detection and removal of cosmic ray glitches, linearization of detector response, relative and absolute flux density calibration of detectors, correction for focal plane temperature drift, subtraction of detector baselines (offsets), and basic map making.

7731-196, Poster Session

Characterization of the Herschel Space Observatory Telescope using a Hartmann wavefront sensor

G. Dovillaire, Imagine Optic SA (France); J. Ballesta, Imagine Optic Inc. (United States)

In this poster, we will present the metrological system used by the EADS Astrium crew to characterize the silicon carbide based telescope of the Herschel space observatory. The Herschel space observatory telescope is the first of its kind to cover the 60-670 µm far infra-red band. Its optical characterization, performed in the visible band, was a true technological challenge and could only be achieved using a specifically designed Hartmann WFS conceived to simultaneously provide high dynamic range and high accuracy of measurement.

The metrological system, as well as the different techniques developed to overcome the metrological challenge, will be described in detail. The expected, large WaveFront Error was measured in a double path set-up using the HWFS positioned in an extrafocal plane and a point source in the focal plane. The auto-collimation was carried out thanks to several liquid mirrors covering the M1 pupil plane and located in the conjugation plane of the WFS sub-apertures.

As a conclusion, we will present the complete characterization process and associated results obtained at the Centre Spatial de Liege (CSL) in

Belgium. Possible further discussions will include the comparison of "in-flight" and experimental Point Spread Functions and the characterization of the thermally induced focal length variations.

7731-113, Poster Session

WFC3 detectors: on-orbit performance

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Installed in the Hubble Space Telescope (HST) in May 2009, the Wide Field Camera 3 (WFC3) is performing well. Designed to complement the other instruments on-board HST and enhance the science performance of the observatory, the WFC3 possesses both a UVIS channel (200-1000nm and an IR channel (800-1700nm). The UVIS channel contains a pair of 4096x2051 pixel e2v CCDs, covering a 162x162 arcsec field of view at 0.04 arcsec/pixel. On-orbit performance is excellent: readnoise is 3.1e-, dark current is ~1-2 e-/pix/hr, and the QE is superb in the UV.

The charge transfer efficiency, though declining as expected due to the radiation environment, is 0.99999. Periodic anneals fix a large fraction of the hot pixels and a successful strategy for mitigating quantum hysteresis is in place. The IR channel contains a 1024x1024 pixel HgCdTe focal plane array from Teledyne Imaging Sensors, covering a 123x136 arcsec field of view (0.13 arcsec/pixel). The dark current is 0.04-0.05 e-/s/pixel and the QE is exceptional. The correlated double sampling (CDS) read noise is 20.5 - 21.4 e-, and the effective read noise is about 12 e- in sample up-the-ramp exposures. As with other HgCdTe arrays, the WFC3 IR detector exhibits both persistence as well as a count rate non-linearity. This report discusses the on-orbit performance characteristics of the WFC3 detectors.

7731-114, Poster Session

Commissioning of the cosmic origins spectrograph on the Hubble Space Telescope: an overview of COS servicing mission observatory verification

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The Cosmic Origins Spectrograph (COS) was installed into the Hubble Space Telescope (HST) during Servicing Mission 4 (SM4) in May 2009. COS is designed to obtain spectra of faint objects at moderate spectral resolution (R > 16,000) in two channels: FUV, covering wavelengths from 1150 to 1450 Å; and NUV, covering 1700 - 3200 Å. Two low resolution gratings (R > 1500) cover the < 900 - 2050 Å (FUV) and 1650 - 3200 Å (NUV) wavelength regions. An imaging capability is also available on the NUV channel.

As part of the Hubble Servicing Mission Observatory Verification (SMOV) program, an extensive period of checkout, fine-tuning and preliminary characterization began after the installation of COS. The COS SMOV program was a cooperative effort between the Space Telescope Science Institute and the Instrument Definition Team based at the University of Colorado.

Nearly 2800 COS exposures in 34 separate observing programs were obtained during the course of SMOV. Early activities included an initial instrument functional checkout, turn-on and initial characterization of the detectors, NUV and FUV channel focus and alignment, and target acquisition verification and assessment. Once this initial period was completed, science-related calibrations and verifications were performed in order to prepare the instrument for normal science operations. These activities included wavelength calibration, flux calibration, detector flat field characterization, spectroscopic performance verification, high S/N operation, and thermal and structural stability measurements.

We discuss the design, execution and results of the SMOV program, including the interrelationships between the various tasks, and how the pre-launch plan was adjusted in real-time due to changing conditions.

7731-115, Poster Session

HST/WFC3 in-orbit grism performance

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The HST Wide Field Camera 3 (WFC3) is fitted with three grisms for slitless spectroscopy. In the UVIS channel there is one grism, G280, for the near-UV to visible range (200 - 400nm; 1.4nm/pix). The IR channel has two grisms: G102 for the shorter (800-1150nm; 2.45nm/pix)

and G141 for the longer (1100-1700nm; 4.65nm/pix) NIR wavelengths. Using SMOV and Cycle 17 calibration data taken on WR stars, planetary nebulae and flux standard stars, we have assessed the performance of the grisms. We have measured the field-dependent trace locations and dispersion solutions and determined the throughputs. The trace and wavelength solutions for the IR grisms were found to be linear functions, varying smoothly as a function of field of view. The UVIS grism exhibits a highly bent trace and significantly non-linear dispersion solutions. The maximum throughputs for the G102 and G141 grisms, including the telescope optics, are 42% at 1100 nm and 48% at 1450 nm, respectively. Limiting magnitudes at S/N=5 and a 1h exposure are J_AB=22.6 and H_AB=22.9 for the G102 and G141 grisms, respectively. For the IR grisms, we provide aperture corrections as a function of wavelength and determine the cross-dispersion PSF, which agrees well with design expectations and ground calibration measurements. The results are published as sensitivity and configuration files that can be used with our dedicated extraction software aXe to reduce WFC3 slitless data. Current HST grism programs focus on studies to measure the evolution of cosmic star formation over the redshift range z=0.3 to 7.

7731-116, Poster Session

Monitoring of the wavelength calibration lamps for the Hubble Space Telescope

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The Space Telescope Imaging Spectrograph (STIS) is a versatile imaging UV-visible spectrograph on board the Hubble Space Telescope (HST). STIS operated on-orbit from Feb 1997 until a malfuntion in August 2004, but resumed operations in May 2009 after a successful repair during Hubble Servicing Mission 4 (SM4). During SM 4, a new UV instrument, the Cosmic Origins Spectrograph (COS) was also installed.

For wavelength calibration, STIS contains three hollow cathode PtCr/Ne arc lamps, while COS contains two similar Pt/Ne lamps. To allow the wavelength scale for individual science observations to be corrected for non-repeatability and drifts in the optical alignment, most observations of external targets are accompanied by one or more wavelength calibration spectra. This provides a large data set for monitoring on-orbit lamp performance over time. Here we present a detailed analysis of changes in the COS and STIS lamp fluxes and spectra over time, and also provide comparisons with results from pre-launch ground testing, and with laboratory testing of similar lamps. Of particular note, one of the STIS PtCr/Ne lamps shows a much larger decrease in throughput below 1300 Angstrom than does the other similar lamp with comparable on-orbit usage. We discuss the possible causes of this difference and the implications for further use of this lamp.

We also provide new recommendations for the minimum exposure times per setting to perform adequate wavelength registration with STIS and COS.

7731-117, Poster Session

Persistence and count rate non-linearity in the HST WFC3 IR detector

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We now know that the flux of a source measured with HgCdTe arrays is not a simple, linear function, but rather seems to depend not only on the number of counts but also on the count rate. That is, the flux of faint objects appear fainter than they should, and the flux of bright objects are larger than expected from a simple linear fit. Prior experience with the HST NICMOS detectors indicate that the count rate non-linearity is also wavelength dependent. In addition to the count rate non-linearity (and probably related to the same physical mechanism), HgCdTe detectors are also susceptible to image persistence. During ground tests and on orbit, we observe afterglows that are typically 6 magnitudes fainter than or 0.3% of rate in the first image. They are particularly evident in dithered exposures of objects near or above saturation. Most of the persistence image fades in a few minutes, but there is a longer term component that can result in faint afterimages in the next orbit, approximately 45 minutes later. The effect is usually modest. Tools exist to identify areas affected by afterglows and are being developed to lessen their effects.

This report describes the on-orbits tests we have designed to characterize the persistence and the count rate non-linearity in the WFC3 IR channel during its first year of operation, and the results of our analysis.

7731-118, Poster Session

Development of a point spread function for the extrasolar planet observation characterization and the deep impact extended investigation missions

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The Extrasolar Planet Observation Characterization and the Deep Impact Extended Investigation missions (EPOXI) are currently observing the transits of exoplanets, two comet nuclei at short range, and Earth and Mars using the High Resolution Instrument (HRI) - a 0.3 m f/35 telescope - on the Deep Impact flyby spacecraft. The HRI is in a permanently defocused state with the instrument point of focus about 0.6 cm before the focal plane due to the use of a reference flat mirror that suffered temperature dependent distortion during thermal-vacuum testing. Consequently, the point spread function (PSF) covers approximately nine pixels FWHM at the focal plane and is characterized by a patch with three-fold symmetry due to the three-point support structures of the primary and secondary mirrors. The PSF is also strongly color dependent varying in shape and size with change in filtration and target color. While defocus is highly desirable for exoplanet transit observations to limit sensitivity to intra-pixel variation, it is suboptimal for observations of spatially resolved targets. Consequently, all images used in our analysis of such objects were deconvolved with an instrument PSF. The instrument PSF is also being used to optimize transit analysis. We discuss the techniques used in extracting the instrument PSF as a function of color and application of the derived PSF in addressing the mission's scientific goals.

7731-119, Poster Session

The ring of fire: an internal illumination system for detector sensitivity and filter bandpass characterization

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We describe a prototype of an illumination system (the Ring of Fire [ROF]) that is used as part of an internal calibration system for large focal plane detector arrays in TMA (Three Mirror Anastigmat) telescope designs. Such designs have been proposed for the SNAP (SuperNova Acceleration Probe) version of a Joint Dark Energy Mission (JDEM). The ROF system illuminates the focal plane with a light beam the closely matches that of the telescope and is used for creating high spatial frequency flatfields and monitoring filter bandpasses for experiments that demand a highly accurate characterization of the detectors. We present measurements of a mockup of this prototype ROF design including studies in variations in illumination across a large focal plane.

7731-120, Poster Session

Monte Carlo simulations as a tool for radiation damage evaluation

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One critical aspect in designing a space mission is the assessment of the level of radiation damage to the equipment that one can expect during the course of the mission; in particular, for an astronomical space telescope, one is interested in the effects of radiation on detectors as well as on board electronics and other parts of the instrument, such as the mirror coatings. The radiation environment in L2 orbit, moreover, has not been studied as extensively as in the Low Earth Orbit case.

Fluka is a Montecarlo software developed by CERN and INFN and extensively used in high energy experimental physics and engineering, shielding, detector and telescope design, and cosmic ray studies. Moreover it is being currently used at CERN to simulate LHC beam interactions.

Our purpose is to take advantage of the detailed and benchmarked interaction models used in FLUKA in order to verify various aspects of a space mission, like instrumental behaviour during its lifetime. We make use of FLUKA to model the geometry of the structures surrounding the detector to analyze the mitigation strategy (i.e.: shielding of the detector assembly) in a well defined case (the Euclid-NIS instrument, which is in the early design phase). By using a realistic cosmic ray spectrum and composition, and considering the effects of primary and secondary particles, we analyze the resulting dose of ionizing and non-ionizing radiation on the Euclid-NIS detectors.

7731-123, Poster Session

An attitude control testbed for JDEM

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The strongest pointing, jitter and PSF requirements for JDEM come from the weak lensing science mission. Even in space, achieving diffraction limited observation requires that all contributing systematic uncertainties be well understood.

In order to retire the mission risk associated with spacecraft pointing, an attitude control testbed was developed. The testbed consists of a full scale spacecraft structure with expected vibration modes, a flight-like attitude control system and science instrument to provide pointing information.

Testbed results show the ability to perform both coarse maneuvers and fine guidance is demonstrated. The ability for spacecraft and science instruments to work together as the fine guidance system is another important achievement. The testbed performance results are applicable to any space based mission requiring fine guidance including weak lensing, exo-planet searches and deep fields.

7731-124, Poster Session

Simple optical designs for a three probe space dark energy mission

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The dark energy responsible of the apparent acceleration of the universe is one of the most challenging questions of our time. On both side of the Atlantic a great deal of effort has been spent to design and optimize space missions able to determine the nature of this dark energy. These missions will use at least three different probes: Baryonic Acoustic Oscillation (BAO), Weak Lensing (WL) and Type Ia Supernovae (SNe). Most of the proposed missions rely on the concept of having three different instruments sharing a common optical interface and thus leading to a highly complex system. By adopting a different conceptual approach we studied two fully integrated optical designs yielding to a simple and cost effective mission. The survey strategy will also benefit from this design which offers a better time sharing between the probes.

7731-184, Poster Session

ACCESS: design and preliminary performance

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Improvements in the precision of the astrophysical flux scale are needed to answer fundamental scientific questions ranging from cosmology to stellar physics.

ACCESS, Absolute Color Calibration Experiment for Standard Stars, is a series of rocket-borne sub-orbital missions and ground-based experiments that will enable improvements in the precision of the astrophysical flux scale through the transfer of absolute laboratory detector standards from the National Institute of Standards and Technology (NIST) to a network of stellar standards with a calibration accuracy of 1% and a spectral resolving power of 500 across the 0.35 to 1.7 micron bandpass.

The telescope is a Dall-Kirkham Cassegrain with a 15.5-inch primary mirror and a feedback controlled optical-NIR performance monitoring system located near the secondary. The spectrograph design is based on a Rowland circle mount concave grating operating as a low order (m=1-4) echelle, employs a Fery prism for cross dispersion, and a HST/WFC3 heritage HAWAII-1R HgCdTe array for a compact spectrograph spanning the optical to NIR wavelength region from 0.35-1.7 microns.

The flight detector has been selected based upon initial performance characteristics. Goddard Space Flight Center (GSFC) is tuning the electronics and conducting measurements to confirm and further characterize detector performance. Delivery of the optical system components is expected over the next few months.

The ACCESS design, calibration strategy, and an updated preliminary performance estimate will be presented.

Nasa sounding rocket grant NNX08AI65G and DOE DE-FG02-07ER41506 support this work.

7731-125, Poster Session

The JWST/NIRCam coronagraph flight occulters

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The NIRCam instrument on the James Webb Space Telescope will have a Lyot coronagraph for high contrast imaging from 2 - 5 microns of extrasolar planets and circumstellar disks. Half-tone patterns are used to create graded-transmission image plane masks. These are generated using electron beam lithography and reactive ion etching of a metal layer on an anti-reflection coated sapphire substrate. We report here on the manufacture and evaluation of the flight occulters.

7731-126, Poster Session

Simulation and image reconstruction of IFU-spectrometer data from JWST-MIRI

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The Mid Infrared Instrument (MIRI) of the James Webb Space Telescope is equipped with an integral field unit (IFU) spectrometer. The optical distortion in the image slicing and dispersive optics leads to non-uniform sampling and a catenation of the spatial and spectral information on the detector. Consequently, the reconstruction of an image or the extraction of a spectrum for a constant field position relies on accurate knowledge of the instrumental distortion.

For MIRI we are planning to carry out the necessary calibration measurement during the cryogenic performance test campaign of the flight model (currently scheduled for the second term in 2010). To set-up the right measurement strategy as well as to support the data processing for the image and spectrum reconstruction, we are using two software packages.

The first tool is a new version of SpecSim, a software simulator for IFU spectrometers, which we extended by implementing instrumental distortion and dispersion maps. These maps are based on optical models of the instrumental performance using ZEMAX. With this approach, we can study the complexity of the nominal IFU data and determine the appropriate calibration strategy.

The second tool is the reconstruction software, miri_cube, developed specifically for onground-testing of MIRI. This software translates the detector data back into a three dimensional data cube, representing the two spatial and the spectral dimensions. With these two software tools, we have a complete end-to-end simulation of astronomical objects being observed by the MIRI spectrometer and processed by the reconstructing pipeline. We validate this approach by analyzing measurement results obtained with the Verification Model of MIRI, where we used distortion maps, which are a hybrid of ZEMAX models and optical alignment measurements.

7731-127, Poster Session

Characterization of the tunable filter imager Etalon on the JWST fine guidance sensor

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The Fine Guidance Sensor (FGS) on the James Webb Space Telescope (JWST) has a science observing capability provided by the Tunable Filter Imager (TFI). The TFI measures over the wavelength range 1.5 to 5.0 microns with a spectral resolution of R~100. The TFI incorporates dielectric coated Fabry-Perot etalon plates with a small air gap. The finesse is ~30 and the etalon is operated in the 1st and 3rd order. The etalon is tuned using low voltage piezo-electric (PZT) actuators that apply a displacement of 3 um. Eight blocking filters are used to suppress unwanted orders.

The Etalon is controlled using custom hardware: the Etalon Control Electronics (ECE) board. The sole function of the ECE is the precise and accurate maintenance of a commanded spacing between the two Etalon plates. A digital control loop is employed to adjust the plate position using three pairs of PZTs. To maximize drive range and minimize hardware, a pseudo H-Bridge configuration was developed to drive each pair differentially. Feedback to the control loop is provided by three capacitance displacement sensors (CDS), located on the Etalon itself.

Characterization of the system is split into Electrical and Optical phases. In the Electrical phase, the dynamic range on a series of digital to analog converters (DAC) is linearized. During normal operation, these DACs are instrumental in the drive capability of the ECE gap displacement control loop. In the Optical phase, various parallel gap positions are determined and located within the now linear DAC range. During operation, both the ECE and Etalon will experience temperature variations on the order of 273-293 K and 35-40 K, respectively. As such, both electrical and optical phases are repeated for various temperature permutations.

We present the results of cryogenic testing of the TFI etalon. We demonstrate the successful characterization of the etalon and ECE to achieve and maintain the required parallel air gap range. The tuning performance combined with the characteristics of the dielectric coatings and blocking filters is shown to produce the required tuneable, narrow-and spectral performance.

7731-128, Poster Session

Performance comparison between JWST/MIRI and VLT/SPHERE for exoplanet detection

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In the context of exoplanet detection, a large majority of the 400 detected exoplanets have been found by indirect methods. Today, progress in the field of high contrast imaging has allowed direct images of several exoplanetary systems to be taken (cf. HR 8799, Fomalhaut). In the near future, several new instruments are going to dramatically improve our sensitivity to exoplanet detection. Among these, SPHERE (Spectro Polarimetric High contrast Exoplanet REsearch) at the VLT and MIRI (Mid Infra-Red Instrument) onboard JWST will both be equipped with coronagraphs to reveal faint objects in the vicinity of nearby stars. In this paper, we make use of the most recent evolutionary models of young (sub-)stellar objects and exoplanets to derive their luminosities in order to compare the sensitivity of SPHERE to that of MIRI. From this comparison, we present a catalogue of targets which are particularilly well suited for MIRI with possible detections of planets down to (sub-) Saturn masses.

7731-129, Poster Session

Performance verification of the MIRI imager flight model at CEA

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MIRIM is the imager of the Mid Infrared Instrument (MIRI), one of the three scientific instruments on the James Webb Space Telescope (JWST). MIRIM will provide imaging between 5.6µm and 25.5µm, low resolution spectroscopy (LRS) between 5 and 10µm, and coronagraphy at 10.65µm, 11.4µm, 15.5µm and 23µm.

The Optical bench Assembly of MIRIM Flight Model (FM) has been integrated and tested between 2008 and 2009 at CEA (Saclay, France). The tests consist in characterisation of optical performances at all wavelengths and in all three modes (imaging, spectroscopy and coronagraphy), using a test bench (or Ground Support Equipment - GSE) that has been developed for this purpose. The GSE comprises a helium cooled cryostat for the instrument itself, a proto IR focal plane module (with JPL sensor chip and CEA electronics and housing), a warm telescope simulator that delivers a JWST-like beam, and computers and software for running automatic test procedures. It is designed to allow a large set of performance verifications, such as high resolution PSF measurements, coronagraphic sensitivity to alignment of the star, response to monochromatic line or characterisation of spectroscopy mode, some being unique along the test program of the instrument.

After a short description of the test bench, this paper focuses on the tests results. A full assessment of performances is given. When applicable, performances are cross checked with requirements.

Imaging mode and coronagraphy had already been validated on optically representative models along the MIRIM development plan, especially with the Engineering and Test Model (ETM) of MIRIM, early 2008. The FM test campaign allowed us to confirm that the flight model behaves as expected in these two modes. We also tested for the first time, and validated, the low-resolution spectroscopy mode.

7731-130, Poster Session

OGSE Telescope WFE testing at 30K

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James Webb Space Telescope (JWST) is an international collaboration among National Aeronautics and Space Administration's (NASA), the European Space Agency (ESA), and the Canadian Space Agency (CSA) to study the first galaxies that formed in the early Universe. An Optical Telescope Element (OTE) will gather the light coming from the space and provide it to four scientific instruments, including the Fine Guidance Sensor (FGS) and Tunable Filter Imager (TFI) which CSA is responsible for. OGSE (Optical Ground Support Equipment) telescopes are used as a simulator for the image from OTE to verify the optical performance of FGS and TFI meets the requirements. Therefore, the performance of the OGSE telescopes is very important since their WFE will contribute to the overall WFE budget. This paper presents WFE testing for one type of the telescopes over a temperature range from ambient to cryogenic operating temperatures (30 K).

The WFE of the OGSE Telescope has been tested using Zygo interferometer with standard Zygo transmission sphere replaced by a custom-made Transmission Sphere located in the cryo chamber. In the same time, image position displacements during cooling down with respect to ambient are also obtained. The results show that the WFE degrades from 19 nm (RMS) at ambient to 42 nm (RMS) at 30 K, while the image displaces about 5.6 mm at 30 k with respect to ambient temperature. The reason for the focus displacement is discussed and its effect of WFE is predicted. The testing results match the prediction well.

7731-131, Poster Session

Optical wavefront characterization using phase retrieval for the NIRSpec demonstration model for the James Webb Space Telescope

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Phase retrieval results are presented for the James Webb Space Telescope (JWST) Near InfraRed Spectrograph (NIRSpec) demonstration model (DM). NIRSpec is one of five science instruments (SIs) comprising the Integrated Science Instrument Module (ISIM); the NIRSpec is being built for the European Space Agency by a consortium led by EADS Astrium. During this initial DM test campaign, focal-sweep images were collected over the science field of view (FOV) for determining best focus at both ambient and cryogenic temperature environments, and these images were then used as input to the Hybrid Diversity Algorithm (HDA) for phase retrieval, using Variable Sampling Mapping (VSM). Wavefront estimates from phase retrieval are presented, and diagnostics used to assess phase retrieval stability and convergence are discussed. The phase retrieval results were compared against wavefront measurements taken with a Shack-Hartmann wavefront sensor.

7731-132, Poster Session

Wavelength and spectral resolution calibrations of the JWST-mid-infrared instrument medium resolution spectrometer

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We present the wavelength and spectral resolution characterisation of the Integral Field Unit (IFU) Medium Resolution Spectrometer for the Mid-infraRed Instrument (MIRI), to fly onboard the James Webb Space Telescope in 2014. We use data collected using the Verification Module of the instrument and develop an empirical method to calibrate wavelength properties such as dispersion and resolving power in a portion of the spectrometer's full spectral range (5-28 microns). We test our results against optical models to check the fulfilment of the system requirements and combine them with a study of the fringing pattern in the instrument's detector to provide a more accurate calibration. We show that MIRI's IFU spectrometer will be able to produce spectra with a resolving power above R=2500 at a wavelength of 8 microns.

7731-134, Poster Session

Speckle suppression performance of a JWST prototype low-order Fabry-Perot etalon

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One of the four science instruments aboard the James Webb Space Telescope (JWST) is the Tunable Filter Imager (TFI) provided as part of the Canadian contribution of the JWST Fine Guidance Sensor. The TFI features a low-order Fabry-Perot etalon which enables imaging spectroscopy at an average resolving power of 100. TFI also includes a coronagraph for high-contrast imaging applications such as exoplanet imaging. In this paper we report on the test-bed results from a TFI prototype etalon to perform speckle suppression through multi-wavelength imaging, a technique widely used by existent and future ground-based high contrast imaging instruments.

The greatest challenge in high contrast imaging is overcoming the speckle noise caused by non-common path errors along the optical path. To overcome this we capitalize on a CO absorption feature between 4 and 5 microns present only in cool companions, but not the star. Normally, observing this feature requires the subtraction of images slightly offset narrowband filters however large amounts of speckle noise is introduced by this change. For TFI, altering the etalon gap acts as the necessary tunable narrowband filter to directly image stellar companions, without changing the optical path. This offers great improvement to past results (Marois et al 2005). We demonstrate this method on a test bench using a TFI-prototype etalon.

Because our prototype possesses a similar capacitive feedback system as the flight TFI etalon, it has been used testing speckle suppression as well as verifying the etalon calibration and alignment technique and testing JWST's etalon control electronics.

7731-135, Poster Session

JWST-MIRI spectrometer main optics flight model realization and performance test results

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MIRI ('Mid Infrared Instrument') is the combined imager and integral field spectrometer for the 5-29 micron wavelength range under development for the James Webb Space Telescope (JWST). In the scope of the Flight Model (FM) development program of the Spectrometer Main Optics (SMO) and Grating Wheel Assemblies (GWA), a Structural Thermal Model, a Qualification Model and a Verification Model were built and tested. These test results were used to optimize the FM design in terms of optical performance, structural (dynamic) behavior and ease of integration. A full test program was performed in order to minimize test efforts at the next higher MIRI integrated level. The FM underwent full optical as well as mechanical and thermal vacuum qualification testing. In August 2008 the SMO and GWA's where shipped for final integration within the MIRI instrument.

This paper will describe the Flight Model improvements, the problems and issues that were encountered during integration and verification and the verification test results.

7731-136, Poster Session

Use of a pathfinder optical telescope element for James Webb Space Telescope risk mitigation

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A Pathfinder of the James Webb Space Telescope (JWST) Optical Telescope Element is being developed to check out critical ground support equipment and to rehearse integration and testing procedures. This paper provides a summary of the baseline Pathfinder configuration and architecture, objectives of this effort, limitations of Pathfinder, status of its development, and future plans. Special attention is paid to risks that will be mitigated by Pathfinder.

7731-138, Poster Session

Applying the tool: stray light cross-checks of the James Webb Space Telescope

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System modeling of space observatories too large for end-to-end ground testing includes assessing levels of unwanted radiant energy on focal plane arrays, commonly called "stray light." The need for stray light analyses parallels the need for large telescope collecting apertures; both seek to maximize sensitivity.

Mathematical modeling of stray light is unlike other engineering analyses, and the differences often lead to unfamiliarity and subsequent underrating of its importance. Fortunately, the JWST Project undertook these analyses early enough to guide important aspects of the optical and thermal control designs.

Software tools of unprecedented power continue in use to model the stray light performance of the James Webb Space Telescope (JWST). This paper describes how one such tool is used by NASA's Goddard Space Flight Center (GSFC) to provide cross-checks of analyses performed by JWST's industry partners. The methods described for JWST are broadly applicable to other astronomical instrumentation.

7731-139, Poster Session

Manufacturing and integration status of the JWST OSIM optical simulator

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OSIM is a full field, cryogenic, optical simulator of the James Webb Space Telescope (JWST) Optical Telescope Element (OTE). It provides simulated point source/star images for optical performance testing of the JWST Integrated Science Instrument Module (ISIM). OSIM is currently being assembled at the Goddard Space Flight Center. In this paper, we describe the capabilities, design, manufacturing and integration status, and uses of the OSIM during the optical test program of ISIM and the Science Instruments. Where applicable, the ISIM tests are also described.

7731-140, Poster Session

Non-redundant masking on the James Webb Space Telescope

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Non-redundant masking (NRM) is a high contrast high resolution technique relevant for future space missions dedicated to either general astrophysics or extrasolar planetary astronomy. The non-redundant

mask (NRM) in the Fine Guidance Sensor Tunable Filter Imager (FGS-TFI) on the James Webb Space Telescope (JWST) opens a search space between 50 and 400 mas in the 3.8 to 5 micron wavelength range, enabling exciting planetary and star formation science otherwise inaccessible to JWST. FGS-TFI's NRM meshes well with JWST's other high resolution modes, as well as with next-generation ground-based extreme adaptive optics coronagraphs. Thus a careful delineation of NRM's search space is an important exercise. We present a detailed analysis of the dynamic range we expect from NRM on JWST. While image stability is far better in space than from the ground, calibration of the detector may ultimately limit JWST NRM's dynamic range. Photon noise limits the dynamic range to 10,000 in a 10 ks exposure of an M=7 star, using only closure phase data. Some improvement on this is possible using fringe amplitudes. We quantify the effects of flat field errors on the instrument's performance, and present observing strategies that mitigate this source of noise. We also consider NRM's dynamic range in the presence of detector read out noise, intrapixel sensitivity, and guiding errors during the exposure. We provide performance estimates that can be folded into observing strategies, survey design, and operational plans for NRM with JWST's FGS-TFI.

7731-141, Poster Session

Phase retrieval analysis of the JWST NIRCam optical system

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A phase retrieval analysis of the James Webb Space Telescope (JWST) Near InfraRed Camera (NIRCam) Engineering Design Unit (EDU) optical system is presented using data collected in the e Optical Metrology Assembly (OMA) test configuration. Lessons learned are discussed in addition to recent developments and updates made to the JWST flight phase-retrieval algorithm.

7731-142, Poster Session

Development and tests of interferometry facility in 6-m diameter radiometer thermal vacuum chamber in Tsukuba Space Center

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We introduce the development and tests of the interferometriy facility to test large-aperture optics in the 6-m radiometer thermal vacuum chamber (6-m chamber) of Tsukuba Space Center of JAXA.

In order to obtain techniques of testing space-borne large-aperture optics for future astronomical or earth-observation missions, we are developing a test bench for interferometric metrology of large optics with an auto-collimation method in the 6-m chamber. A high-speed interferometer is used so that we could curry out wavefront measurements even while the vacuum pump of the 6-m chamber is working. To avoid significant repairs of the facility and complexities of optical alignments, we suppose both the interferometer and sample optics are placed in the 6-m chamber, and prepared an aluminum and titan-made pressure vessel that contains the interferometer. The pressure vessel is mounted on a five-axis stage, and the diverger lens is set on the optical window of the vessel from outside of it if we measure a wavefront as a spherical configuration. The heat generated from the interferometer in the vessel is conducted away outside the 6-m chamber by means of the air that is blown into the vessel through a tube.

Test measurements were done by placing sample mirrors in front of the pressure vessel. Alignment changes of tilts about a few arcminutes occurred while the pressure of the chamber was sharply reducing at the start of the experiment or rising at the end. After we re-aligned the optical axis using the 5-axis stage for each measurement, the wavefronts under vacuum were confirmed to be distorted by less than a few hundredths of wave from those under atmosphere.

7731-143, Poster Session

ZERODUR 8m mirror for space telescope

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In 2010 there will be the 10th anniversary of ESO's fourth 8 m telescope Yepun's first light event. Together with the other VLT telescopes it has accumulated more than 40 years of extremely successful operation time for astronomy. Progress in rocket technology and in Zerodur lightweighting gives reason for contemplating about the use of the last currently available 8.2 m blank for a space telescope. This talk will review the outstanding quality of the first four mirror blanks and present the quality of the blank still available. Additionally we will give an overview over the progress in the last decade in technology and knowledge and how they might support the use of the 8 m blank as space telescope mirror.

7731-144, Poster Session

Nano-JASMINE: current status and data output

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The current status of the Nano-JASMINE project is reported. Nano-JASMINE is a very small-sized (50 cm3) satellite that is expected to carry out astrometric observations of nearby bright stars. The satellite will determine distances of more than 10000 stars by performing annual parallax measurements, which is the only direct method to measure the distance of an astronomical object. In addition, Nano-JASMINE will serve as a preliminary to the main JASMINE mission. We expect that Nano-JASMINE will be launched in August 2011 from the Alcantara Space Center in Brazil using the Cyclone-4 rocket.

Nano-JASMINE will survey the entire sky using a 2k×1k fully depleted CCD, which has been developed by Hamamatsu Photonics K.K.; in actual practice, only 1k × 1k part of the CCD will be used. The CCD will be operated in the time-delay integration mode wherein the speed of the satellite's field of view will be synchronized with the CCD transfer rate so that efficient undisrupted observations are possible. Nano-JASMINE consists of a 5-cm telescope equipped with a beam combiner that provides two large separate fields of view. This will enable us to separate the spin rate from the stellar distribution position. This technique was originally adopted in HIPPARCOS. The all-aluminum 5-cm telescope equipped with the beam combiner provides sufficiently good quality images and it is tolerant to high-accuracy position measurements.

We have conducted thermal and structural tests for the engineering model and plan to develop a flight model.

7731-145, Poster Session

A very small astrometry satellite, Nano-JASMINE: performance evaluation of telescope

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Nano-JASMINE is a very small satellite for space astrometry. It has only 25 kg and aims to carry out astrometry measurement of nearby bright stars (z<7.5mag) with an accuracy of 3 milli-arcseconds. The objective of this project is a scientific astrometry, technical demonstration for JASMINE (Japan Astrometry Satellite Mission for INfrared Exploration) and a first experience of space astrometry in Japan. In this paper, the outline of Nano-JASMINE project and results of performance evaluation of the telescope are presented.

This satellite adopts the same observation technique used by HIPPARCOS satellite. In this technique, two different fields of view are observed by beam-combiner simultaneously. Its telescope is based on a standard Ritchey-Chretien type optical system and has a beam-combiner, a 5 cm effective aperture, a 167 cm focal length and a field of view of 0.5x0.5 degree. Almost all of the structures and the optical elements of the telescope, including two aspherical mirrors, were made out of aluminum alloy. The telescope only occupies a volume about 17x12x12 cm, and weighs about two kilograms.

The current status of Nano-JASMINE is in the process of evaluating the performances. A series of performance tests and numerical analysis were conducted. As a result, the engineering model (EM) of the telescope was measured to be achieving a diffraction-limited performance and confirmed that it has an enough performance for scientific astrometry.

7731-146, Poster Session

CCD centroiding analysis for Nano-JASMINE observation data

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Nano-JASMINE is a very small satellite mission for global space astrometry with milli-arcsecond accuracy, which will be launched in 2011. In this mission, centroids of stars in CCD image frames are estimated with sub-pixel accuracy. In order to realize such a high precision centroiding an algorithm utilizing a least square method is employed. One of the advantages is that centroids can be calculated without explicit assumption of the point spread functions of stars. CCD centroiding experiment has been performed to investigate whether this data analysis is available, and centroids of artificial star images on a CCD are determined with a precision of less than 0.001 pixel. This result indicates parallaxes of stars within 300 pc from Sun can be observed in Nano-JASMINE.

7731-147, Poster Session

The telescope and the double Fabry-Perot interferometer for the ADAHELI Solar Space Mission

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ADAHELI (ADvanced Astronomy for HELIophysics) is a mission to study the structure and dynamics of Sun's lower atmosphere performing Visible-NIR broad-band and monochromatic observations and millimeter observations. ADAHELI is an Italian Space Agency (ASI) project, approved for Phase-A, feasibility study within ASI's "Small Missions" call.

ISODY (Interferometer for SOlar DYnamics) on board of ADAHELI satellite is the the gregorian telescope and its focal plane suite. The focal plane suite is composed of a spectral camera, based upon a tandem of Fabry-Perot interferometers operating in the Visible-NIR regions on selected photospheric and chromospheric lines, a broad band channel for high resolution imaging, and a correlation tracker used as image stabilization system. During nominal mission, ADAHELI shall constantly point the Sun, except during maneuvers, eclipses or contingencies. The satellite radial velocity in the Sun-ward direction, shall not exceed ±4 km/s, during 95% of the yearly orbit to allow a continuous use of on board interferometers.

7731-148, Poster Session

The thermo optical design and experiment research on H   and white light telescope

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The H-alpha and White Light Telescope (HWT), one of the five payloads on board the Space Solar Telescope (SST), is mainly for the observation of the chromosphere, solar flares and white light of the full solar disc, also as a location reference for the detailed Main Optical Telescope (MOT). To study the Structural-Thermal- Optical Performance (STOP) of the HWT, the temperature conditions of the thermo-optical testing are designed on the basis of the measurement and numerical simulation of the ground observing condition. A thermo-optical testing system is established to test the optical performance of the HWT under a thermal vacuum condition. The thermo-optical testing system comprises mainly four sub-systems: an optical system to be tested, a vacuum system, a temperature measurement and control system, and a wavefront sensing system. The optical performance of the five important structures in the HWT system at the different temperature conditions is investigated, including the wedges, secondary mirror, primary mirror, collimation lens, and the imaging lens. An integrated STOP test based on the HWT is performed. The optical performances of the HWT under different vacuum degree and different thermal control conditions are tested using the wavefront sensing system constructed. The results show that when the temperature of the secondary mirror is lower than 40°, the optical performance of HWT is about λ8, which satisfies the requirement of λ6.

7731-149, Poster Session

Simulation of the metrology of the PROBA-3/ASPIICS formation flying solar coronagrah

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Formation Flying is now considered to be the most promising and effective approach to deploy the forthcoming generation of very large instruments in space. PROBA-3 is a technology mission devoted to the in-orbit demonstration of formation flying techniques and technologies. PROBA-3 will implement a giant coronagraph (called ASPIICS) that will both demonstrate and exploit the capabilities and performances of formation flying. ASPIICS is distributed on two spacecraft separated by 150m, one hosting the external occulting disk and the other the optical part of the coronagraph. ASPIICS will incorporate metrology units which will allow determining both the absolute pointing and the relative alignment of the formation. Photosensors located around the entrance pupil of the coronagraph will determine the absolute positioning of the instrument by sensing the penumbra behind the occulting disk. Light sources located on the rear-side of the occulting disk will allow verifying the alignment of the formation. We carried out a complete numerical simulation of the metrology system and showed how corrections are derived from the measurements to be applied to each spacecraft in case

of misalignments. This simulation was validated by a scaled model of the coronagraph developed at Laboratoire d'Astrophysique de Marseille. This study has been conducted in the framework of an ESA "STARTIGER" Initiative, a novel approach aimed at demonstrating the feasibility of a new and promising technology on a very short time scale (six months).

7731-150, Poster Session

The space instrument SODISM and the ground instrument SODISM

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PICARD is a French space scientific mission. Its objectives are the study of the origin of the solar variability and the study of the relations between the Sun and the Earth's climate. The launch is foreseen by the end of 2009 on a Sun Synchronous Orbit at 725 km altitude. The mission life time is two years, however to be extended to three years. The payload consists in two absolute radiometers measuring the TSI (Total Solar Irradiance) and an imaging telescope to determine the solar diameter, the limb shape and asphericity. SOVAP (SOlar VAriability PICARD) is an absolute radiometer provided by the RMIB (Royal Meteorological Institute of Belgium) to measure the TSI. It also carries a bolometer used for increasing the TSI sampling and ageing control. PREMOS (PREcision MOnitoring Sensor) radiometer is provided by the PMOD/WRC (Physikalisch-Meteorologisches Observatorium Davos / World Radiation Center) to measure the TSI and the Spectral Solar Irradiance. SODISM (SOlar Diameter Imager and Surface Mapper), is an 11-cm Cassegrain imaging telescope developed at CNRS (Centre National de la Recherche Scientifique) by LATMOS (Laboratoire, ATmosphere, Milieux, Observations Spatiales) associated with a 2Kx2K CCD (Charge-Coupled Device), taking solar images at five wavelengths. It carries a four-prism system to ensure a metrological control of the optics magnification. SODISM allows us to measure the solar diameter and shape with an accuracy of a few milliarcseconds, and to perform helioseismologic observations to probe the solar interior. In this article, we describe the SODISM telescope and its thermoelastic properties. We also present the PICARD data and the PICARD ground instruments which will observe together with the space instrument.

7731-151, Poster Session

Stray light analysis and optimization of the ASPIICS/PROBA-3 formation flying solar coronagraph

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PROBA-3 is a technology mission devoted to the in-orbit demonstration of formation flying techniques and technologies. PROBA-3 will implement a giant coronagraph (called ASPIICS) that will both demonstrate and exploit the capabilities and performances of formation flying. ASPIICS is distributed on two spacecraft separated by 150m, one hosting the external occulting disk and the other the optical part of the coronagraph. This part implements three-mirror-anastigmat (TMA) telescope. Its pupil is placed about 800mm in front of the primary mirror, a solution allowing an efficient baffling and a high reduction of the stray light inside the instrument. A complete stray light analysis of the TMA has been performed to design the baffles and to establish the required roughness of the mirrors. The analysis has been performed in two steps: first, by calculating the diffraction pattern behind the occulter due to an extended monochromatic source having the diameter of the Sun; second, by propagating that diffraction pattern, through all the telescope optical components, to the prime focal plane. The results obtained are described in this article.

7731-152, Poster Session

Demonstrator of the formation flying solar coronagraph ASPIICS/PROBA-3

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Formation Flying opens the possibility to conceive and deploy giant solar coronagraphs in space permanently reproducing the optimum conditions of a total eclipse of the Sun ("artificial" eclipse) thus giving access to the inner corona with unprecedented spatial resolution and contrast (low stray light). The first opportunity to implement such a coronagraph "ASPIICS" will be offered by the European Space Agency (ESA) PROBA-3 technology mission devoted to the in-orbit demonstration of formation flying technologies. Two spacecrafts separated by about 150 m form a giant externally-occulted coronagraph: the optical part hosted by one spacecraft remains entirely protected from direct sunlight by remaining in the shadow of an external occulter hosted by the other spacecraft. We developed and tested a scale-model 'breadboard' (i.e., 30m) of the PROBA-3/ASPIICS Formation Flying coronagraph. The investigations focused on two metrology systems capable of measuring both the absolute pointing of the coronagraph (by sensing the projected shadow and penumbra produced by the external occulting disk) and the alignment of the formation (by re-imaging light sources located on the rear-side of the occulting disk with the optical part of the coronagraph). In this contribution, we will describe the demonstrator and report on our results on the crucial question of the alignment and pointing in space of long instruments (> 100 m) with an accuracy of a few arcsec. This study has been conducted in the framework of an ESA "STARTIGER" Initiative, a novel approach aimed at demonstrating the feasibility of a new and promising technology on a very short time scale (six months).

7731-153, Poster Session

Calibration and alignment of the demonstrator of the PROBA-3/ASPIICS formation flying coronagraph

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This article describes the calibration and the alignment procedures of a demonstrator for the ASPIICS coronagraph proposed to the ESA technology mission PROBA-3 aimed at demonstrating Formation Flying.

ASPIICS is distributed on two spacecraft separated by 150m, one hosting the external occulting disk and the other the optical part of the coronagraph.

The purpose of the demonstrator is to reproduce on ground the metrology systems that will equip the coronagraph in order to realize the alignment of the two spacecraft and the absolute pointing to the center of the Sun.

The demonstrator is composed of a device that reproduces the solar umbra/penumbra created by the solar occulter and a Three Mirror

Anastigmatic (TMA) telescope mounted on a hexapode, a new-generation platform that allows 6 degrees of freedom. A large plane folding mirror is used to double the baseline up to 30m.

Photosensors located around the entrance pupil of the TMA determine the absolute positioning of the instrument by sensing the penumbra behind the occulting disk. Light sources (LEDs) located on the rear-side of the occulting disk allow verifying the alignment of the formation.

The paper will describe the whole demonstrator, its integration, its calibration, and the performances of the metrology systems of the coronagraph.

This study has been conducted in the framework of an ESA “STARTIGER”

Initiative, a novel approach aimed at demonstrating the feasibility of a new and promising technology on a very short time scale (six months).

7731-154, Poster Session

Analytic and experimental determination of ghosts in the Rosetta narrow-angle camera and their impact on imaging performances

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The Rosetta cometary rendezvous mission, one of ESA’s cornerstone missions, was launched in 2004 and will be inserted in orbit around comet 67P/Churyumov-Gerasimenko in 2014. One of its instruments, the Osiris Narrow Angle Camera (NAC), will take high-resolution images of the comet and map its nucleus as well as the jets of gas and dust emanating from localized areas. This is quite challenging as the contrast between the radiance of these jets and that of the nucleus is expected to be of the order of 1/1000. A major limitation comes from the presence of multiple ghosts which results from the presence of two filters and a protective window in front of the CCD detector. Rigorous knowledge of these instrumental ghost images is therefore required.

We will present analytical models of the structure and intensity of these ghosts, compare them with pre and post-launch observations, and describe image analysis tools developed to handle them.

7731-155, Poster Session

Optical architecture of mid-infrared instruments (MIRACLE/MIRMES/MIRHES) on board SPICA

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SPICA (Space Infrared Telescope for Cosmology and Astrophysics) is an astronomical mission optimized for mid- and far-infrared astronomy, envisioned for launch in 2018. Mid-infrared instruments for SPICA are required to have three basic capabilities; a wide-field imaging, spectroscopic capability, and coronagraphic capability as an option. First two capabilities are implemented by three instruments; MIRACLE(Mid-infRAred Camera w/o Lens), MIRMES(Mid-IR Medium-resolution Echelle Spectrometer), and MIRHES(Mid-IR High-resolution Echelle Spectrometer). Here, we present a optical architecture of the union of MIRACLE, MIRMES, and MIRHES. MIRACLE has two channels (-S for short wavelength and -L for long wavelength) to cover the wavelength range 5 to 40 micron. MIRACLE-L and MIRMES are packaged into one unit with common optical bench and MIRACLE-S and MIRHES are packaged into another unit. Two units are independent with each other and occupy different field of the SPICA telescope. Each unit has common fore-optics shared by MIRACLE and MIR(M/H)ES. This fore-optics is designed using reflective mirror optics only, and has wide filed of view(FOV). Most of the FOV is used by MIRACLE and small part of the FOV is used by MIRMES or MIRHES. This structure of the instruments reduces the size and weight of the optics. This benefit outweigh the complexity of the instruments.

7731-156, Poster Session

The digital processing unit of the SPICA SAFARI instrument: an FPGA based architecture using the Leon2-FT processor

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The Digital Processing Unit (DPU) of the SAFARI instrument on board the SPICA satellite will be part of the Warm Electronics and will be the bridge between the S/C CDMU and various subsytems: Detectors Control Unit (DCU), Mechanism Control Unit (MCU), Cooler Control Unit (CCU). The DPU will implement Telemetry and Telecommand exchange with the CDMU, commanding and control of the subsystems, housekeeping data acquisition and overall instrument health monitoring, scientific data acquisition, compression and formatting into telemetry packets.

The DPU design study has been driven by the requirements for processing power, memory resources, expected data rates and protocols at the interfaces, as well as mass and power budgets. The DPU will be based on a Leon2-FT processor and all of its data interfaces will be implemented using the SpaceWire standard protocols. Based on these essential decisions, a range of architectural solutions have been identified. The choice among these possible solutions is determined by many considerations, among which fundamental is the examination of the available hardware components and their characteristics.

7731-157, Poster Session

Mid-IR high-resolution Echelle spectrometer (MIRHES) for SPICA

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We present the updated optical design and layout for mid-infrared(5-20um) high-resolution spectrograph for SPICA, Japanese next-generation space IR observatory with a 3-m class telescope. MIR high-resolution spectroscopy is a powerful probe to study gas-phase molecules/atoms in a variety of astronomical objects. Space observation provides a great opportunity to study many molecular lines that can nerver be observed from the ground. Thanks to the large telescope aperture and the compact instrument volume using a novel immersion grating (see Ikeda/Kuzmenko’s presentations in another session), SPICA can realize MIR high-resolution spectroscopy in space for the first time. With unpresedented spectral resolution of ~30,000 in space, which is 10-times higher than ISO-SWS, SPICA-MIRHES could be a quite unique instrument that can provide most sensitive and clear spectra of this kind. We show the sensitivity comparison with ground-based instruments, such as MIRES for TMT, and discuss how those instruments work complementary.

7731-158, Poster Session

Precision pointing control for SPICA: requirements and feasibility study

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SPICA (Space Infrared Telescope for Cosmology and Astrophysics) is the next-generation infrared astronomy mission that has a 3-m class telescope cooled to be less than 6 K. This cryogenically cooled large space telescope aims to achieve high spatial resolution and unprecedented sensitivity in the mid to far-infrared wavelength astronomy.

First, we derived a set of pointing requirements from mission requirements for Focal Plane Instruments (FPIs). As a result, spectroscopic and imaging observation modes except coronagraph mode must satisfy 135 milli-arcsec (3-sigma) as absolute pointing control accuracy and 75 milli-arcsec over 200 seconds (0-Peak, 3-sigma) as pointing stability. Coronagraph mode must satisfy 30 milli-arcsec control accuracy and 30 milli-arcsec stability over 20 minutes respectively.

SPICA has mechanical coolers to achieve the unprecedented sensitivity. But the coolers' disturbances could generate much larger vibration compared to the pointing stability requirements. Therefore, disturbance management over the SPICA system and an implementation of isolators which alleviate adverse effects of the cooler disturbance on the telescope are necessary.

To improve pointing determination accuracy, the Focal Plane Camera for Guidance is installed and combined with a conventional strapdown attitude determination system based on star trackers and an inertial reference unit. With this system, alignment errors and random pointing errors for FPIs are reduced.

Furthermore, to suppress pointing vibration due to micro-disturbances in the coronagraph mode, special high-bandwidth Focal Plane Camera (C-FPC) and a tip-tilt mirror actuator to control optical axis (C-TTM) are installed. And a closed-loop control that detects pointing error with C-FPC and corrects the error with C-TTM is performed.

This paper presents an overview of the SPICA pointing requirements and a feasible study to achieve the requirements. Some key issues extracted from the study, such as disturbances suppression and ground test verification are described.

7731-159, Poster Session

Polarization-interferometric eight-octant phase-mask coronagraph using ferroelectric liquid crystal for exoplanet detection

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We report laboratory demonstrations of an eight-octant phase-mask (8OPM) coronagraph for direct detection of exoplanets.

The 8OPM coronagraph is a family of a well-known four-quadrant phase-mask (4QPM) one, but shows better coronagraphic performance for partially resolved nearby stars.

We manufactured an eight-octant ferroelectric liquid-crystal (FLC) mask.

The FLC mask is composed of eight-segmented half-wave plates whose principal axes are different between adjacent segments.

When the FLC mask is put between crossed polarizers, the mask operates as a fully achromatic 8OPM due to a principle of polarization interferometry.

We carried out laboratory experiments on the 8OPM coronagraph by using partially resolved broadband light source, and compared the coronagraphic performance with that of the 4QPM one.

As a result, we confirmed that the 8OPM shows better coronagraphic performance than the 4QPM.

A drawback of the proposed method is that the FLC mask can be used only for one polarized component of incoming light because it is necessary to use the polarizer in front of the FLC mask.

To solve this problem and conduct more efficient observations, a two-channel coronagraph is proposed, which utilizes two polarizing beam splitters instead of the polarizers.

Thus, observational efficiency can significantly be improved because it is expected that the two-channel coronagraph enables us to detect both components of polarizations from exoplanets.

We also report preliminary experimental results of laboratory demonstrations of the two-channel coronagraph.

7731-160, Poster Session

Development of a wavefront correction system for the SPICA coronagraph instrument

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We present the laboratory demonstration of a wavefront correction system for the SPICA (Space Infrared telescope for Cosmology and Astrophysics) project. SPICA is a next-generation space infrared observatory with a 3-meter class telescope which will be launched around 2018 and it is a cooperated mission between JAXA and ESA. One of the goals of SPICA is the direct detection and spectroscopic characterization of Jupiter-like extrasolar planets around nearby stars at infrared wavelengths. We have been developing SPICA Coronagraph Instrument (SCI) for very high-contrast range imaging up to 10^6 dynamic range. One of the unique features of SCI is to employ a wavefront correction system with a 1024-element MEMS deformable mirror. We describe a laboratory demonstration of speckle nulling experiments by using a DM and a checker-board type binary pupil mask. We successfully achieved a 10^6 dynamic range at a 3.5 lambda/D region at the He-Ne laser wavelength. This is a 1000 times improvement in dynamic range compared to a non-corrected image. We have also started a wide-band wavefront correction experiment in the visible wavelengths. Thanks to a purely achromatic nature of our binary pupil mask, it is possible to achieve high-dynamic range at wide-band. We also develop a wide-band speckle nulling algorithm with a DM. The combination of wide-band speckle nulling algorithm and a binary pupil mask will lead to a very wide-band, high contrast imaging system which is required to achieve direct spectroscopic observations of exoplanet atmosphere.

7731-161, Poster Session

Conceptual design of cryogenic system for the next-generation infrared space telescope SPICA

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Conceptual design of Space Infrared Telescope for Cosmology and Astrophysics (SPICA) has been studied as the pre-project of Japan Aerospace Exploration Agency (JAXA) under collaboration with ESA to be launched in 2018. The SPICA is transferred into a halo orbit around

the Sun-Earth second Lagrangian point, where effective radiative cooling is available. The SPICA has a large IR telescope of 3 m diameter, cooled to lower than 5 K by radiative and mechanical cooling without cryogen. Therefore, SPICA mission will cover for mid and far-IR astronomy with high sensitivity and spatial resolution during a long period of over 5 years for goal.

The Scientific Instrument Assembly (SIA), composed of the primary mirrors and optical benches equipped with the Focal Plane Instruments (FPIs), is refrigerated by 4K-class Joule-Thomson (JT)

mechanical cryocooler. The cooling power of 40mW for the 4K-JT cooler at the end of life is required to absorb 15 mW heat generation of the FPIs and 25 mW parasitic heat load to the SIA. The SPICA cryogenic system must be satisfied thermal and structural requirements simultaneously.

The most heat radiation from solar and spacecraft is blocked by the sun shield and the outer radiation shield with the Multi-Layer Insulation and exhausted to deep space through the side radiators. Main parasitic heat load to the SIA is determined by the conductive heat flow through its CFRP truss assembly.

Thermal analysis result indicates that SPICA cryogenic system works effectively to limit total heat load to the SIA to be less than 40mW.

7731-195, Poster Session

Kinetic inductance detectors (KIDs) for the SAFARI instrument on SPICA

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Kinetic Inductance Detectors (KIDs) with frequency domain read-out are intrinsically very suitable to use as building blocks for very large arrays. KIDs therefore are an attractive detector option for the SAFARI instrument on SPICA and also for large scale ground based imaging arrays.

To study the properties of large KID arrays we have fabricated 400 pixel arrays made from 40 nm thick Al films on high resistivity Si substrates. These arrays are made with and without lithographic air bridges over the coplanar waveguide feedline. The air bridges are designed to suppress the slot line mode in the feedline. The arrays are tested in a dry dilution refrigerator at 100 mK. We present the device design and experimental results which indicate that the pixel to pixel reproducibility of large arrays can be improved considerably by using air bridges to suppress the odd mode in the feedline.

7731-162, Poster Session

Past and future space missions dedicated to exoplanet research

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As more and more exoplanets are being discovered, and the detections of the first molecules in their atmosphere are being announced, there is a strong motivation for pushing the limits of current detection methods and atmosphere characterization techniques. The scientific goal is ultimately to discover smaller rocky exoplanets in the habitable zone of their host star and to determine whether their atmosphere contains any bio-markers. Space observatories play an important role in this field, especially in the IR where ground telescopes are limited by atmospheric absorption and where the star/exoplanet contrast is the lowest. This paper provides an overview of past and current efforts in the field of space telescopes dedicated to exoplanet research, with a special emphasis on ESA missions. The results of a preliminary radiometric model aiming at determining how well the spectrum of which exoplanets could be obtained are discussed. The model assumes differential measurements (in-out of transit) for known transiting exoplanets can be obtained in order to reveal the spectrum of the exoplanet's atmosphere. A preliminary mission concept dedicated to spectroscopic measurements of known exoplanets with the capability to observe several transits of a few hundred exoplanets is outlined and the key design challenges shortly discussed.

7731-163, Poster Session

Exploring the diversity of extrasolar planets

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The past 15 years have seen a dramatic expansion in our knowledge and understanding of planetary systems around stars other than our Sun. The richness of the 'discovery space' allows a variety of observational techniques to be applied to advance the field. They include reflect motion (radial velocity and astrometry), gravitational microlensing events, direct detection (high contrast imaging), photometry ('combined light') of primary and secondary transits, and spectroscopy during transit events. We have also learned much about the formation and evolution of systems and their chemistry through imaging and spectroscopy of debris disks, and spectroscopy of low-mass stars and brown dwarfs. Each of these techniques has a role to play.

In this paper, we summarize the synergies between the various techniques and observing platforms. We show how the multi-dimensional parameter space of exoplanets (e.g. age, stellar mass, metallicity, planet mass, orbit radius, multiplicity, presence of dust, etc.) is being explored - graphically where possible. Instruments under development, and proposed, will continue to expand our knowledge. But they have a wide range of costs and development times, and advocates for specific instruments often emphasize only their strengths. We show how different approaches are complementary and can help overcome the limitations, including selection effects, of different techniques. These considerations are important in setting observing strategies, and for defining performance requirements of the generation of instruments.

7731-164, Poster Session

An alternative architecture for the PlaTO mission

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PlaTO (Planetary Transits and Oscillations of stars) is one of the class M missions proposed to ESA for the Cosmic Vision 2015-2025 program. It aims to find exoplanets by the transit method and to understand the hosting stars by measuring their oscillations (asterosismology). The same wide field of view of about 1800 deg^2 will be observed during 3 years to achieve high precision photometry for a large number of stars (> 250 000). 42 telescopes, each one having 4 CCDs of 3584 x 3584 pixels will be read every 25 seconds generating a huge amount of data which cannot be downloaded to Earth and represents a challenge for the classical software-based data treatment solutions.

We present in this paper an alternative architecture based on FPGAs for the payload of the PlaTO satellite. The capabilities of the FPGA allows to treat tens of megabits per second through a pipeline driven by the pixel arrivals so that no buffering nor high speed clocks are required. This allows for treating multiple telescopes with a single FPGA and reduce the mass and power budgets by about 100 kg and 200 W respectively. The software resources can then be used to perform photometry. Our alternative concept thus achieves precision at the theoretical limit together with major system-level improvements on the satellite. It opens the opportunity to achieve the science requirements with a comfortable margin of about 20% or to observe more stars.

7731-165, Poster Session

The Plato Telescope prototype alignment procedure

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PLATO is the acronym of PLAnetary Transits and Oscillations of stars, and it is a mission proposed for the ESA Cosmic Vision program in the Medium size program, with the target to detect and characterize exoplanets by the means of their transit on a bright star.

The instrumental overall layout proposed by the Plato Payload Consortium consists in a multi-telescope concept instrument, composed by several tens of telescope units, for which we are developing an all refractive optical solution. These devices are characterized by a very large Field of View (more than 20 degrees on one side) with an optical quality that fits most of the energy into a single CCD's pixel. Such a goal can be achieved in a variety of solutions, some including aspheric elements as well. A complete prototype of one telescope unit is foreseen to be built initially (during phase B1) to show the alignment feasibility and, only in a second moment (Phase B2), to perform full environmental and functional test. The aim of this article is to describe the alignment, integration and verification strategy of the opto-mechanics of the prototype.

Both the approaches of testing the telescope at the target working temperature or to test it at ambient temperature around a displaced zero point taking, into account the effects of thermal deformations, are considered and briefly sketched in this work.

7731-166, Poster Session

Optical design and performance of MIRIS near-infrared camera

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Multi-purpose Infra-Red Imaging System (MIRIS) is a near-infrared camera onboard on the Korea Science and Technology Satellite 3 (STSAT-3). The MIRIS is a wide-field (3.67° X 3.67°) infrared imaging system which employs very fast (F/2) refractive optics with 80mm diameter aperture. The MIRIS optics consists of five lenses, among which the rear surface of the fifth lens is aspherical. By passive cooling on a Sun-synchronous orbit, the telescope will be cooled down below 200K in order to achieve the designed performance. As the fabrication and assembly should be carried out at room temperature, however, we convert all the lens data of cold temperature to that of room temperature. The sophisticated opto-mechanical design accommodates the effects of thermal contraction after the launch, and the optical elements are protected by flexure structures from the shock and vibration during the launch. The MIRIS incorporates the wide-band filters, I (1.05μm) and H (1.6μm), for the Cosmic Infrared Background observations, and also the narrow-band filters, Pa (1.876μm) and a specially designed dual-band continuum, for the emission line mapping of the Galactic interstellar medium. We present the optical design, fabrication of components, assembly procedure, and the performance test results of MIRIS near-infrared camera.

7731-167, Poster Session

Development of mechanical structure for the compact MIRIS space IR camera

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MIRIS is a compact near-infrared camera with a wide field of view 3.67deg. X 3.67deg. in the Korea Science and Technology Satellite 3 (STSAT-3). MIRIS will be warm launched and then chill the telescope optics below 200K by pointing to the deep space of 3K on Sun-synchronous circular orbit. In order to enable this passive cooling, the mechanical structure was designed with a thermal analysis model of MIRIS. Structural analysis of MIRIS was also conducted to ensure safety and stability in launching environments. From these results, we fabricated the thermal shielding parts such as the GFRP (Glass Fiber Reinforced Plastic) pipe support, a Winston cone baffle, the aluminum-shield plates, a sun-shade, a radiator and the MLI (Multi Layer Insulation) 30 layers. These structures prevent the heat load from the spacecraft and the earth effectively, and maintain the temperature of the telescope optics within operating range. A micro cryocooler with the cooling capacity of 220mW at 77K cools down a cold box to operate a PICNIC detector and a filter wheel while the MIRIS experiences the passive cooling. We tested the passive cooling after configuration of the similar space conditions in a thermal-vacuum chamber. Driving mechanism of the filter wheel and the detector box structure were also developed for the compact space IR camera. We present the assembly procedures of MIRIS and the cooling result.

7731-169, Poster Session

Achieving milli-arcsecond residual astrometric error for the JMAPS mission

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The Joint Milli-Arcsecond Pathfinder Survey (JMAPS) is a Department of Navy bright star astrometric survey mission designed to observe tens of millions of stars (and other objects) in approximately Cousins I magnitude 1 to 14, with a reference accuracy of < 1 milliarcsecond (mas) position, < 1 mas/year proper motion, and < 1 mas parallax.

Targeted observations will allow the system to be placed on the International Celestial Reference System via observations of approximately 30 quasars on the International Celestial Reference Frame.

Two areas of concern for an astrometric telescope are the ability to measure and validate the optical distortions inherent from the transformation from the spherical sky to the focal plane, and the shape of the point spread function. We report JMAPS ability to achieve 2 milliarcsecond-level (per observation) residuals from the desired gnomonic projection, and the expected wave front error in specified

Zernike terms. We discuss the pixel phase errors and strategies for their mitigation based on the expected sampling.

7731-171, Poster Session

Enhancing undergraduate education in aerospace engineering and planetary sciences at MIT through the development of a CubeSat Mission

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CubeSats are a class of extremely small satellites that conform to a standardized 10 cm x 10 cm x 10 cm, 1 kg form factor. This miniaturization, along with a standardized deployment device for launch vehicles, allows CubeSats to be launched at low cost by sharing the trip to orbit with other spacecraft. Part of the original motivation for the CubeSat platform was also to allow university students to participate more easily in space technology development and to gain hands-on experience with flight hardware. The Department of Aeronautics and Astronautics along with the Department of Earth, Atmospheric, and Planetary Studies (EAPS) at the Massachusetts Institute of Technology (MIT) recently initiated a three semester-long course that uses the development of a CubeSat-based science mission as its core teaching method. Serving as the capstone academic experience for undergraduates, the goal of this class is to design and build a CubeSat spacecraft that serves a relevant science function, such as the detection of exoplanets transiting nearby stars. This project-based approach gives students essential first hand insights into the challenges of balancing science requirements and engineering design. Students are organized into subsystem-specific teams that refine and negotiate requirements, explore the design trade space, perform modeling and simulation, manage interfaces, test subsystems, and finally integrate prototypes and flight hardware. In this work we outline the heritage of capstone design/build classes at MIT, describe the class format in greater detail, and give first semester results on the ability to meet learning objectives using this pedagogical approach.

7731-172, Poster Session

Practical numerical propagation of arbitrary wavefronts through PIAA optics

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The phase-induced amplitude apodization (PIAA) coronagraph utilizes highly aspheric optics to produce a strongly apodized beam without the large loss of light that would result from using a graded transmission mask. The rapid variations in surface curvature at the edge of the PIAA apodizing optic creates large wavefront phase changes that cannot be adequately represented in conventional Fourier-based diffraction propagation algorithms. A rapid technique is required for propagating arbitrarily-aberrated wavefronts through the system. An alternative numerical method has been proposed that combines a high-accuracy algorithm to compute edge diffraction effects with a quick modified angular spectrum propagator that handles wavefront errors. We present the results of applying this method to realistically aberrated wavefronts as compared to more complex and time consuming techniques.

7731-173, Poster Session

A coronagraph system with unbalanced nulling interferometer: progress of wavefront correction

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We proposed a four-stage coronagraph system with an unbalanced nulling interferometer (UNI). The coronagraph system can be composed using the UNI effectively as a following configuration after collimation from a telescope focus, where no secondary obscuration is assumed. It consists of a first adaptive optics (AO), the UNI, a second AO for phase and amplitude correction (PAC) with two DMs, and a coronagraph. Here wavefront corrections and star light rejections are made twice in turn in the four-stage optics. One of many kind of coronagraph can be selected as the last stage. The most interesting and important phenomenon is a magnification of the wavefront aberrations in the UNI stage which can be explained by changes of the complex amplitude of the electric field, which enable us to compensate for the wavefront aberrations beyond the AO systems capabilities. In our experiments, we observed the aberration magnification of about 6 times and compensated to about lambda/100 rms which means that we reached to lambda/600 level virtually. We put a 3-dimensional Sagnac interferometric coronagraph at the final stage of the system which has an achromatic performance of about 1E-5 nulling at the central part of the image without the AO. At the focal plane of the coronagraph we are confirming the speckle reduction of better than 1/5 with the UNI-PAC coronagraph system.

7731-174, Poster Session

A multi-color coronagraph experiment in high-thermal stability environment

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The enormous contrast in flux between the central star and associated planets is the primary difficulty in the direct observation. The typical contrast is 10^{-10} at visible light wavelength and 10^{-6} in the mid-infrared wavelength region (Traub & Jucks 2002). One of the methods the enormous contrast can be improved is a stellar coronagraph. The coronagraph can change the PSF and reduce the gap of luminosity between an extra-solar planet and its central star. We focused on binary shaped pupil coronagraph that there is a plan to install in Next-generation infrared space telescope SPICA. A contrast of 1.8x10^{-9} was achieved for the PSF subtraction as the results of our laboratory experiments on the coronagraph which was implemented inside a vacuum chamber in order to achieve higher thermal stability and to avoid air turbulence (Haze et al. 2009). We utilized only the He-Ne laser for our coronagraph experiments that aimed to improve the contrast. However, we take the flux with wavelength interval in an actual observation. In principle, we know the binary shaped pupil coronagraph produces similar results at various wavelength bands. The aim of this work is to demonstrate it using a SLED (Super luminescent Light Emitting Diode), with wavelengths of 650nm, 750nm, 800nm and 850nm, as light sources.

7731-175, Poster Session

The CIAXE test bench

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In 1996, Jean Gay and Yves Rabbia presented their Achromatic Interferential Coronagraph (AIC) for detecting and imaging faint companions, ultimately exoplanets, in the neighbouring of a star. As presented then, the Michleson-like Interferometer configuration of the AIC hardens its insertion into an existing coaxial optical train, the output beam of the AIC being delivered at right angle from the input beam.

To overcome this, they reconfigured the AIC into a compact and fully axial coronagraph : the CIAXE, which main feature consists of using two thick lenses machined in the same optical material. For the CIAXE to deliver the output beam along the same axis as the input beam, the two lenses are coaxially disposed on the optic axis and are separated, at their common spherical contact surface, by a thin air gap acting like a beamsplitter.

We have set up a laboratory experiment aiming at validating the principle of the concept. Our first step was to equalize the thicknesses of the two lenses, so as to make zero the Optical Path Difference (OPD) between both arms. For this, the residual value of the OPD has been evaluated and then the lenses have been re-machined to decrease, as far as it is technologically possible, the thicknesses' mismatch. In a second step, a micro-controlled rotation around the common curvature center of the spherical surfaces of the lenses is applied, allowing a fine tuning of the residual OPD at the required accuracy level. The test bench, steps and results are presented here.

7731-176, Poster Session

The extrasolar planetary imaging camera (EPIC)

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EPIC is a NASA mission being studied to detect and characterize Jovian and superEarth planets, and the dust/debris disks surrounding the parent star. EPIC will launch to a heliocentric Earth trailing orbit and is designed to operate for 5 years. EPIC operates over the wavelength range of 480 - 960 nm with spectral resolutions of R < 50 and employs a visible nulling coronagraph (VNC) to suppress the starlight, yielding contrast ratios of greater than 9 orders of magnitude. We will discuss the science mission, spacecraft and instrument, and laboratory testbed efforts to demonstrate the critical VNC technology.

7731-177, Poster Session

Progress on broadband control and deformable mirror tolerances in a 2-DM system

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For detection and characterization of an earth-like target it is ideal for wavefront correction to be over as broad of a bandwidth as possible. When correcting for quasi-static speckles, this control must be done via focal plane wavefront estimation and would ideally also be done over as broad a bandwidth as possible. Lacking this capability, the next best thing is to achieve correction over a larger bandwidth given a single monochromatic estimation. Two deformable mirrors in series can correct for both amplitude and phase aberrations, and by taking a linear approximation of the propagation between the deformable mirrors we show an approach for broadband correction given a monochromatic estimate. We present our experimental results and discuss some of the limitations due to aberrations from spatial frequency folding that exhibit a wavelength squared dependence, which requires a third deformable mirror to correct in broadband. From these results we also discuss controllability of spatial frequencies and show its consequences for both monochromatic and broadband correction when using two deformable mirrors in series. Including the effect of spatial frequency folding at low inner working angles in the controllability analysis is also used to define tolerances on surface quilting and reflectivity variation across the deformable mirrors when they are located in a non-pupil plane. This allows us to define correctable bandwidths given tolerances on the deformable mirror surfaces when Fresnel propagation is introduced between the two deformable mirrors.

7731-178, Poster Session

Wavefront correction using the electric field conjugation algorithm for phase induced amplitude apodization coronagraphs

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In this paper we describe simulations and initial lab results of the Electric Field Conjugation (EFC) broadband correction algorithm used with a Phase Induced Amplitude Apodization (PIAA) coronagraph. The EFC algorithm is a general correction methodology for high contrast imaging systems that works in broadband light with one or multiple deformable mirrors by conjugating the electric field in a predefined region in the image where terrestrial planets would be found. We demonstrate the effectiveness of this algorithm through simulations comparing correction results placing the PIAA mirrors before, after and in between a pair of deformable mirrors that are separated to provide both amplitude and phase controllability. We provide initial laboratory results from the Jet Propulsion Laboratory High Contrast Imaging Testbed (HCIT) for phase retrieval using defocused images and for both monochromatic and narrow-band light (2%) correction.

7731-179, Poster Session

Studies of the effects of actuator errors on the PIAA/HCIT contrast performance

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The High Contrast Imaging Testbed (HCIT) Phase Induced Amplitude Apodization (PIAA) coronagraph system at Jet Propulsion Laboratory relies on a broadband wavefront correction algorithm called Electric Field Conjugation (EFC) to obtain the required 10-10 contrast. This algorithm works with one or multiple deformable mirrors (DM's) to create a "dark-hole" in a predefined region of the image plane where terrestrial planets would be found. It achieves the desired high contrast level in two stages. The first is the reconstruction stage. In this stage, the algorithm provides an estimate of the aberrated complex electric field in the image plane based on pairs of images taken at the final image plane using different DM configurations. The second is the correction or the electric field conjugation stage. In this stage the algorithm generates a correction based on the electric field estimated in the first stage. The correction is then applied to the DM actuators to null the image electric field in the predefined dark-hole region.

We have investigated the effects of the DM actuator errors on the efficiency of the EFC algorithm. Considered cases include random actuator gain errors, and the nonlinearity and the hysteresis in DM actuator response to the applied control voltages. The structural design of the optical system as well as the parameters of various optical elements used in the analysis are drawn from those of the PIAA/HCIT system that have been and will be implemented with one or two DM's. The simulation takes into account the surface errors of various optics. The optical simulation algorithm uses MACOS (Modeling and Analysis for Controlled Optical Systems) as its analytic tool. Hence it is capable of performing full three-dimensional near-field diffraction analysis on HCIT's optical model.

7731-180, Poster Session

Design, fabrication, and lithographic finish of high-precision PIAA optics for high-contrast imaging of exo-planets

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PIAA optics for high contrast imaging present challenges in manufacturing and testing due to their large surface deformations from aspheric profiles at the aperture edges. With smaller form factors and consequently smaller surface deformations (<40 microns), fabrication of these mirrors with diamond turning followed by electron beam lithographic techniques becomes feasible. Though such a design reduces the system throughput to ~ 60%, it still provides 2lambda/D inner working angle. With Guyon's new achromatic focal plane mask designs, the system performance can be further improved. We report on the design, expected performance, fabrication challenges, and initial assessment of the novel PIAA optics.

7731-181, Poster Session

ACCESS pointing control system

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The Actively-corrected Coronagraph Concept for Exoplanetary System Studies (ACCESS) is a space observatory for exoplanet discovery and exploration. It employs a telescope with a coronagraphic instrument to capture images of exoplanets in a star system. For this technique to be successful, it requires very fine pointing stability. This paper describes the Pointing Control System (PCS) used to achieve it. The PCS has a three-stage pointing control system; a fine guidance camera design within the coronagraphic instrument; and an extensive disturbance rejection strategy to minimize the environmental jitter. The three-stage pointing system starts with a standard 3-axis stabilized spacecraft bus and it is augmented with a hexapod telescope pointing system and a fine steering mirror. For fine guidance sensing we take advantage that coronagraphic observations have a bright star in the center of field of view. We have studied three different concepts for a fine guidance camera that guides from this bright star. The strategy towards disturbances is to minimize the jitter at the source. We have selected a quiet orbital environment (L2), designed a thermally controlled telescope and instrument, planned operational constraints during science observations, and added reaction wheel isolators, solar array dampers and a vibration suppression capability within the hexapod. We have studied two possible options for the hexapod system.

7731-182, Poster Session

Experimental verification of Bayesian planet detection algorithms with a shaped pupil coronagraph

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We evaluate the feasibility of applying Bayesian detection techniques to discovering exoplanets using high contrast laboratory data with simulated planetary signals. Background images are generated at the Princeton High Contrast Imaging Lab (HCIL), which uses a shaped pupil and two deformable mirrors (DMs) in series to produce dark regions in the image plane up to contrasts of 7x10^-7. Planetary signals are added in software, or via a physical star-planet simulator which adds a second off-axis point source before the coronagraph with a beam recombiner, calibrated to a fixed contrast level relative to the source. We produce a variety of images, with varying integration times and simulated planetary brightnesses using monochromatic and broadband light. We then apply automated Bayesian detection algorithms such as matched filtering to attempt to extract the planetary signals. This allows us to evaluate the efficiency of these techniques in detecting planets in a high noise regime and eliminating false positives, as well as to test existing algorithms for calculating the required integration times for these techniques to be applicable.

7731-183, Poster Session

Annular groove phase mask coronagraph in diamond for mid-IR wavelengths: manufacturing assessment and performance analysis

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Phase-mask coronagraphs are known to provide high contrast imaging capabilities while preserving a small inner working angle. Scientifically speaking, it allows observing the close environments of stars, enabling the search for exoplanets or circumstellar disks. On the technical side, it can be used with smaller telescopes or at longer wavelengths. The AGPM (Annular Groove Phase Mask, Mawet et al. 2005) consists of an optical vectorial vortex induced by a rotationally symmetric subwavelength grating (i.e. with a period smaller than /n, being the observed wavelength and n the refractive index of the grating substrate). In this paper, we present the manufacturing and measurement results obtained with our first mid-infrared AGPM prototype imprinted on a diamond substrate. Diamond is a prime material for near- to mid-infrared wavelengths owing to its high transparency, small dispersion, thermal and mechanical properties. In order to reach the needed subwavelength resolution, diamond-optimized micro-fabrication techniques have been used such as Nano-Imprint Lithography (NIL) and Reactive Ion Etching (RIE). The grating profile metrology is also challenging. We combine surface metrology on molded replica with diffraction analysis: experimental performance measured on a visible and near-infrared optical polarimetric bench and cross correlation with theoretical simulations using rigorous coupled wave analysis (RCWA). We conclude with the ultimate coronagraph performance in several IR spectral bands thanks to diamond AGPM and the related manufacturing optimization plan.

7731-185, Poster Session

Simulations of coronagraphy with an adaptive hologram for the direct detection of exo-planets

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In the framework of exoplanet detection technologies, we present an original solution to improve the performances of coronagraphs, by adding an adaptive hologram in the optical scheme.

In the traditional Lyot, coronagraph device, the starlight is blocked by a dark mask in the focal plane and by an annular stop in the relayed pupil image. The image is subsequently refocused on the detector.

We simulate a scheme in which the dark mask is replaced by a microprism that recuperates part of the starlight, in order to provide a reference beam to record an adaptive hologram, located close to the annular stop.

The hologram removes most of the residual speckle starlight by adding, in complex amplitude, a copy of its wavefront, phase-shifted by pi.

In our simulations, the detection limit in the flux ratio between a host star and a very near planet observed with an apodized Lyot coronagraph characterized by wavefront bumpiness imperfections of lambda/20 (resp. lambda/100) improves by over a factor 1000 (resp. 10000) when equipped with a hologram.

This technique could provide direct imaging of an exo-Earth at a distance of 11 parsec with a ~6.0m space telescope, with the optical quality of HST.

We also discuss the practical implementations of this technique as well as the technologies able to reach these results.

7731-186, Poster Session

Design and implementation of the NUV/ optical widefield star formation camera for the Theia Observatory

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The Star Formation Camera (SFC) is a wide-field (~15'×19', >280 arcmin2), high-resolution (18×18 mas pixels) UV/optical dichroic camera designed for the Theia 4-m space-borne space telescope concept. SFC will deliver diffraction-limited images at > 300 nm in both a blue (190-517nm) and a red (517-1075nm) channel simultaneously. Our aim is to conduct a comprehensive and systematic study of the astrophysical processes and environments relevant for the births and life cycles of stars and their planetary systems, and to investigate and understand the range of environments, feedback mechanisms, and other factors that most affect the outcome of the star and planet formation process. This program addresses the origins and evolution of stars, galaxies, and cosmic structure and has direct relevance for the formation and survival of planetary systems like our Solar System and planets like Earth. We present the design and performance specifications resulting from the implementation study of the camera, as part of a larger program intended to assemble realistic options for mission development over the next decade. The result is an extraordinarily capable instrument that will provide deep, high-resolution imaging across a very wide field enabling a great variety of community science as well as completing the core survey science that drives the design of the camera. The technology associated with the camera is next generation but still relatively high TRL, allowing a low-risk solution with moderate technology development investment over the next 10 years.

7731-187, Poster Session

Orbiting starshade's performance in observations of potential Earth-like planets

S. H. Pravdo, S. Shaklan, P. D. Lisman, Jet Propulsion Lab. (United States)

We present a study of an orbiting starshade's performance in observations of potential Earth-like planets around nearby solar-like stars. We use Monte Carlo techniques to simulate planetary systems and with assumptions about the signal-to-noise performance of the instrument we determine the significance of planetary system parameter determinations-for example, can we conclude that a particular planet's semi-major axis (SMA) is in the star's habitable zone? In addition to studying the number of visits needed to determine the SMA and other parameters, we present results on the optimization of the timing of the visits after an initial detection, and we examine multiple-planet systems. For the latter we will address the value added of constraints from radial velocity (e.g., ruling out Jupiters), astrometry (e.g. GAIA), and the allowed stable orbits.

7731-188, Poster Session

Error analysis on the NWO starshade

T. Glassman, A. M. J. Johnson, A. S. Lo, Northrop Grumman Aerospace Systems (United States); W. C. Cash, Jr., Univ. of Colorado at Boulder (United States)

The New Worlds Observer enables high-contrast imaging by placing a space telescope in the dark shadow cast by an apodized starshade. This starshade is fully opaque and its performance is determined by the precise shape of the petal-like structure. In this paper, we describe our preliminary efforts to determine the tolerance of the starshade performance to errors in this shape.

7731-189, Poster Session

An experimental approach to starshades

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A starshade is an external occulter that flies tens of thousands of kilometers in front of a space telescope, along the line-of-sight of a star. A starshade blocks starlight before it enters the telescope - controlling diffraction - and making Earth-like planets observable. The starshade testbed at Northrop Grumman Aerospace Systems (NGAS) is capable of testing the performance of sub-scale starshades in mission-similar configurations. Thus far at NGAS, starshades have suppressed an artificial star to the 10-7 contrast level across a broad, white light bandpass. The goal of the testbed has been to achieve deep starlight contrast, but it is also important to understand the effects of starshade shape errors on contrast performance. The purpose of this paper is to summarize our approach and initial results of assessing the impact of starshade shape errors on performance using the testbed and computer simulations. We are working toward a convergence of experimental results and theoretical predictions.

7731-190, Poster Session

Performance verification for stationkeeping control of O3

D. Sirbu, N. J. D. Kasdin, Princeton Univ. (United States)

A proposed mission concept for the direct imaging of exoplanetary

systems involves the usage of a specially-shaped external occulter that suppresses starlight to reduce the high-contrast with the planetary signal, which reduces the optics requirement compared to a coronagraphic mission but introduces the challenge of precise formation flight. O3 is a lightweight mission proposal that uses a small 1.5 meter telescope with a dedicated occulter placed at the Sun-Earth L2 point. We are interested in assessing this concept in terms of stationkeeping performance.
In particular, we have developed a three-body nonlinear model in conjunction with an extended kalman filter (EKF) that we utilize to determine the worst-case sensing accuracy and update rates required for the mission sensors to maintain alignment within acceptable tolerances. We also investigate the performance of the out-of-band shadow sensor when used at the image plane versus the pupil plane, as well as in the red versus blue ends of the spectrum. Lastly, we investigate the benefits and downsides of stationkeeping actuation at the telescope as opposed to the usual occulter placement.

7731-191, Poster Session

Occulting Ozone Observatory starshade design and development

M. W. Thomson, P. D. Lisman, Jet Propulsion Lab. (United States)

We present an occulting starshade design and development plan that meets all requirements for the Occulting Ozone Observatory mission to find and characterize earth-like planets. The starshade consists of a 15m inner disc and 24 outboard petals for a combined tip to tip diameter of 30 m. The starshade integrates 3 proven technologies for large deployable structures. It stows compactly, allowing a single combined launch of the occulter and observatory, which then separate after reaching L2. The petals unfurl and rigidize using wrap-rib technology. The petals deploy to the desired shape using springback technology. The inner disc deploys and extend the petals outward using perimeter truss technology. There is extensive flight heritage for each of these technologies and the required tolerances have all been demonstrated. The development and verification plans follow proven processes and timelines.

7731-192, Poster Session

First steps of the development of a piston sensor for large aperture space telescopes

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Nowadays spaceborne missions for astronomy or Earth imaging need high resolution observation which implies the development of large aperture telescopes. This can be achieved by multi-aperture telescopes or large segmented telescopes. One of the major issues is the phasing of the sub-apertures or the segments of such telescopes. A cophasing sensor is therefore mandatory to achieve the ultimate resolution of these telescopes.

In this framework, Liège Space Center concern is the development of a compact cophasing sensor to phase new large lightweight segmented mirrors for future space telescopes. The sensor concept has its origins in new phase retrieval algorithms which have been recently developed.

In this paper, we outline the concept and the experimental validation results of our piston sensor breadboard which is currently in development in our laboratory. Finally, the future prospects and the further developments of our experiment are presented.

7731-193, Poster Session

Angular DFS: a dispersed fringe sensing algorithm insensitive to small rotational calibration errors

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Dispersed Fringe Sensing (DFS) is an elegant method of coarse phasing of segmented mirrors. DFS performance is dependent upon careful calibration of the system as well as other factors such as internal optical alignment, system wavefront errors, and detector quality.
Novel improvements to the calibration method have led to substantial enhancements in DFS algorithm performance. In this paper we present Angular DFS, which allows the overall operation to be less dependent upon calibration. This is achieved by dithering the fringes by small angles with respect to the extraction axis. We will present both an analytical explanation of the improvements and results of Angular dithering DFS modeling.

7731-194, Poster Session

False diamond turning artifacts in phase retrieval results

T. P. Zielinski, J. R. Fienup, Univ. of Rochester (United States)

Many modern telescope designs employ diamond-turned optical components and utilize phase retrieval for metrology during testing, assembly, and commissioning. The accuracy of the wavefronts obtained by phase retrieval depends on the fidelity of the system model used during the retrieval, including knowledge of the pupil amplitude and sampling relationship between the pupil and each point spread function (PSF), i.e., the plate scale. However, recent simulations have shown that errors in the estimation of the PSF sampling rate and unknown pupil vignetting could both lead to mid-spatial-frequency groove-like errors in the wavefront maps obtained by phase retrieval. In particular, these errors manifest themselves as concentric rings resembling diamond-turning tooling marks, and can therefore easily confound metrology results involving diamond-turned components. Furthermore it was found that only moderate amounts of pupil vignetting, and errors in sampling rate as low as 2% produced groove errors consistent in magnitude with typical diamond-turning specifications. This paper presents the results of this study on the magnitude and nature of these false errors and their impact on telescope metrology.

7731-21, Session 5

AKARI warm mission

T. Onaka, The Univ. of Tokyo (Japan); H. Matsuhara, T. Wada, Japan Aerospace Exploration Agency (Japan); D. Ishihara, Nagoya Univ. (Japan); Y. Ita, National Astronomical Observatory of Japan (Japan); Y. Ohyama, Academia Sinica (Taiwan); T. Ootsubo, S. Oyabu, Japan Aerospace Exploration Agency (Japan); I. Sakon, T. Shimonishi, The Univ. of Tokyo (Japan); S. Takita, F. Usui, H. Murakami, Japan Aerospace Exploration Agency (Japan)

AKARI, the Japanese satellite mission dedicated for infrared astronomy launched in 2006 February, exhausted its 180 litter liquid helium in 2007 August. After the exhaustion, the telescope and focal plane of AKARI have still been kept less than 50K owing to the onboard cryocooler and near-infrared (NIR: 2--5 micron) imaging and spectroscopic observations with the Infrared Camera (IRC) are continuing. The in-flight operation and data reduction software optimized for the warm mission enable us to carry out efficient and sensitive observations in the NIR despite the increase of hot pixels. In particular the NIR spectroscopic mode of the

IRC is providing a unique capability of acquiring 2.5--5 micron spectra of faint (down to a few mJy) objects of low spectral resolution (R ~ 80). We present an overview of the AKARI warm mission and report the performance of the IRC together with observational results taken during the warm mission.

7731-22, Session 5

Calibration and data quality of warm IRAC

S. J. Carey, J. A. Surace, W. J. Glaccum, J. Ingalls, J. Krick, California Institute of Technology (United States); M. D. Lacy, National Radio Astronomy Observatory (United States); P. J. Lowrance, S. J. Laine, J. C. O'Linger, J. R. Stauffer, California Institute of Technology (United States); S. P. Willner, J. L. Hora, Harvard-Smithsonian Ctr. for Astrophysics (United States); W. F. Hoffmann, The Univ. of Arizona (United States); M. L. N. Ashby, J. Huang, Harvard-Smithsonian Ctr. for Astrophysics (United States); M. Marengo, Iowa State Univ. (United States); M. A. Pahre, Z. Wang, Harvard-Smithsonian Ctr. for Astrophysics (United States); M. W. Werner, Jet Propulsion Lab. (United States); G. G. Fazio, Harvard-Smithsonian Ctr. for Astrophysics (United States)

We present an overview of the calibration and properties of data from the IRAC instrument aboard the Spitzer Space Telescope taken after the depletion of cryogen. The cryogen depleted on 15 May 2009, and shortly afterward a two-month-long calibration and characterization campaign was conducted. The array temperature and bias setpoints were revised on 19 September 2009 to take advantage of lower than expected power dissipation by the instrument and to improve sensitivity. The final operating temperature of the arrays is 28.7 K, the applied bias across each detector is 500 mV and the equlibrium temperature of the instrument chamber is 27.55 K. The final sensitivities are essentially the same as the cryogenic mission with the 3.6 micron array being slightly less sensitive (10%) and the 4.5 micron array within 5% of the cryogenic sensitivity. The current absolute photometric uncertainties are 5-7% and 4% at 3.6 and 4.5 microns, respectively, and better than milli-mag photometry is achievable for long-stare photometric observations. With continued analysis, we expect the absolute calibration to improve to the cryogenic value of 3%. Warm IRAC operations fully support all science that was conducted in the cryogenic mission and all currently planned warm science projects (including Exploration Science programs). We expect that IRAC will continue to make ground-breaking discoveries in star formation, the nature of the early universe, and in our understanding of the properties of exoplanets. Support for this work was provided by NASA.

7731-23, Session 6

The next-generation infrared astronomy mission SPICA

T. Nakagawa, Japan Aerospace Exploration Agency (Japan)

We present the current status of the next-generation infrared astronomy mission SPICA (Space Infrared Telescope for Cosmology and Astrophysics). SPICA will feature a 3-m class telescope (3.5 m in the current design) cooled to <6 K. The cryogenically cooled, large telescope on SPICA enables us to achieve high spatial resolution and unprecedented sensitivity in the mid- and far-infrared. With this capability, we plan to address a number of key problems in present-day astronomy, ranging from the study of our own solar system, the recipe of formation processes of planetary systems in other solar systems, and the interplay of star-formation and active galactic nuclei in the formation and evolution of galaxies. To reduce the mass of the whole mission, SPICA will be launched at ambient temperature and cooled down on orbit by mechanical coolers on board with an efficient radiative cooling. These coolers will be used also to cool the focal plane instruments thus avoiding the use of consumables and giving the mission a long lifetime. SPICA is proposed as a Japanese-led mission together with international collaboration. Europe is expected to play a key role in the SPICA project, and European participation to SPICA has been studied extensively under the framework of the ESA Cosmic Vision. US and Korean participations are also being discussed. The target launch year of SPICA is 2018.

7731-24, Session 6

System requirements and design concept of the SPICA Mission

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SPICA is a next generation infrared astronomy mission to reveal the origin of planets and galaxies. This is a mission of Japan Aerospace Exploration Agency (JAXA) in collaboration with the European Space Agency (ESA) and international consortium in Japan, Europe, USA, and the Republic of Korea. SPICA is an "observatory" based on the heritage of AKARI's "all sky survey". ESA provides 3m class telescope from technology heritage of Herschel. The SPICA telescope will be the most advanced telescope for mid- to far- infrared astronomy launch into space. Warm telescopes (>>10K) emit infrared radiation much stronger than any astronomical diffuse radiations, limiting the sensitivity for faint astronomical sources. SPICA has a completely new cooling system, which utilizes efficient mechanical coolers. This technology enables a large, cryogenically cooled telescope in space. SPICA system concept and requirements are clear, but its system design is not straightforward. SPICA spacecraft consists of the Payload Module (PLM) and the Bus Module (BM). The PLM includes mechanical coolers and passive thermal shields, which enable to cool down the telescope and scientific instruments below 6K. The PLM is connected to the BM with low thermal conductivity truss structure to keep PLM cool and BM warm. Total mass ratio of the PLM to the BM is 2 to 1 and volume ratio of the PLM to the BM is 4 to 1. This paper describes how to meet the system requirements to establish the feasible design of SPICA spacecraft. SPICA is planned for a launch in 2018.

7731-25, Session 6

Conceptual design for the mid-infrared medium-resolution Echelle spectrometer (MIRMES) on SPICA Mission

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The Mid-Infrared Medium-Resolution Echelle Spectrometer (MIRMES) is one of the focal plane instrument onboard SPICA mission in the pre-project phase. MIRMES is the all reflective crossed echelle grating spectrometer and is designed mainly for measuring the intensity and the profile of lines from ionized gas and molecules as well as the detailed spectral structure of dust band features of various compositions in the wavelengths from 10 to 40 micron with moderate spectral resolution power that is almost comparable to SAFARI in the far-infrared. MIRMES is expected to play an important role, especially, towards understanding the cosmic recycling history of interstellar and circumstellar medium, i.e., the condensation and the destruction processes of dust grains, in galaxies. MIRMES consists of two channels; Arm-S covers from 10.3 to 19.3 micron with the resolution power of R~1500 and Arm-L covers from 19.2 to 36.0 micron with R~900. They share the same field of view (FOV) by using a beam splitter. Each FOV size is ~12 arcsec by 5.5 arcsec and ~24 arcsec by 18 arcsec for Arm-S and Arm-L, respectively, and each FOV is split into 5 slit rows (each slit row has ~12 arcse by 1.1 arcsec and ~24 arcsec by 3.6 arcsec for Arms-S and -L, respectively) by using the integral field spectroscopy (IFU) unit. This configuration minimizes the uncertainty in the absolute flux calibration for a spectrum of point source

and enables us to examine two dimensional spectral variations for diffuse sources.

7731-26, Session 6

The SAFARI far infrared imaging Fourier transform spectrometer for the SPICA Mission

B. M. Swinyard, SRON Netherlands Institute for Space Research (Netherlands)

The Japanese Space Exploration Agency (JAXA) led SPace Infrared telescope for Cosmology and Astrophysics (SPICA) will be the next generation far infrared space mission with a 3.5 metre telescope cooled to less than 6-K to provide Zodiacal Light limited sensitivity up to ~200 microns. To take advantage of this potential major increase in sensitivity requires a sophisticated instrumentation suite employing the very latest in broad band imaging detector arrays and an innovative approach to providing spectroscopy and photometric imaging within a limited budget for mas, power and thermal dissipation. The Dutch led SAFARI consortium has studied an imaging Fourier Transform Spectrometer instrument design under the aegis of the European Space Agency (ESA) Cosmic Vision programme with a view to providing the core far infrared instrument for SPICA. We describe the state of the instrument design and the ongoing development of the critical sub-systems such as the detectors, the cryogenic drive mechanisms and the sub-kelvin cooler.

7731-27, Session 7

The background-limited infrared-submillimeter spectrograph (BLISS) for SPICA: a design study

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We are developing the Background-Limited Infrared-Submillimeter Spectrograph (BLISS) for SPICA to provide a breakthrough capability for far-IR survey spectroscopy. SPICA's large cold aperture allows mid-IR to submm observations which are limited only by the natural backgrounds, and BLISS is designed to operate near this fundamental limit. BLISS-SPICA is 6 orders of magnitude faster than the spectrometers on Herschel and SOFIA in obtaining full-band spectra. It enables spectroscopy of dust-obscured galaxies at all epochs back to the first billion years after the Big Bang (redshift 6), and study of all stages of planet formation in circumstellar disks.

BLISS covers 38-433 microns using ten grating spectrometer modules coupling 2 sky positions in 5 wavelength bands. The instrument is cooled to 50 mK for optimal sensitivity with an on-board dual-stage sorption + adiabatic demagnetization refrigerator (ADR). The detector package is 4224 silicon-nitride micro-mesh leg-isolated bolometers with superconducting transition-edge-sensed (TES) thermistors, read out with a cryogenic time-domain multiplexer. All technical elements of BLISS have heritage in mature scientific instruments, and many have flown. We report on our design study in which we are optimizing performance while accommodating SPICA's constraints, including the stringent cryogenic mass budget. We present our progress in all key aspects: 1) science requirements and the opto-mechanical instrument architecture, 2) detector and readout approach, and 3) sub-K cooling approach.

7731-28, Session 7

WISPIR: a wide-field imaging spectrograph for the infrared for the SPICA Observatory

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We have undertaken a study of a far infrared imaging spectrometer based on a Fourier transform spectrometer that uses well-understood, high maturity optics, cryogenics, and detectors to further our knowledge of the chemical and astrophysical evolution of the Universe as it formed planets, stars, and the variety of galaxy morphologies that we observe today. The instrument, Wide-field Imaging Spectrometer for the InfraRed (WISPIR), would operate on the SPICA observatory, and will feature a spectral range from 35 - 210 microns and a spectral resolving power of R=1,000 to 6,000, depending on wavelength. WISPIR provides a choice of full-field spectral imaging over a 2'×2' field or long-slit spectral imaging along a 2' slit for studies of astrophysical structures in the local and high-redshift Universe. WISPIR in long-slit mode will attain a sensitivity two orders of magnitude better than what is currently available.

7731-29, Session 7

Mid-InfRAred Camera w/o LEns (MIRACLE) for SPICA

T. Wada, H. Kataza, Japan Aerospace Exploration Agency (Japan)

Mid-InfRAred Camera w/o LEns (MIRACLE) is a focal plane instrument for the future JAXA/ESA infrared astronomical mission, SPICA.

MIRACLE is designed for wide field imaging (6'x6') and low-resolution spectroscopic observations (R~100) over a wide spectral range in the mid-infrared wavelengths (5-38um).

Thanks to the SPICA's large aperture (3-m class) and cold (<6K) telescope, MIRACLE has a better sensitivity than JWST/MIRI at the wavelength over 20um (3.5 uJy at 20um, R=5, S/N=5, 3600 seconds) and its wider field of view (FOV) provides a faster mapping speed in its full spectral range for the point sources.

Confocal off-axis reflective imaging system provides a wide FOV with diffraction limited image quality over wide spectral range.

MIRACLE consists of two channels, MIRACLE-S and MIRACLE-L, which are optimized for 5-26um and 20-38um, respectively.

Each of them consists of a fore-optics and a rear-optics, each of which has a pupil position equipped with a filter wheel and a grating wheel, respectively.

A field stop wheel, which provides optimal slits in the spectroscopic mode and a wide FOV in the imaging mode, is installed at the focal plane of the fore-optics.

A large format array detector (Si:As 2Kx2K for MIRACLE-S and Si:Sb 1Kx1K for MIRACLE-L) is installed at the focal plane of the rear-optics in order to achieve Nyquist sampling of the point spread function.

Contiguous wavelength coverage is considered in choice of the filter bands from the experiences in the Spitzer and AKARI observations.

We will present the results of conceptual design study including sensitivity analysis.

7731-30, Session 7

Optical testing activities for the SPICA Telescope

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SPICA (Space Infrared Telescope for Cosmology and Astrophysics) is a Japanese infrared astronomical satellite project with a 3-m-class telescope. The target year for launch is 2018. The telescope is cooled down to temperature below 6 K in space by a combination of newly-developed mechanical coolers with an efficient radiative cooling system at the L2 point. The SPICA telescope has requirements for its total weight to be lighter than 700 kg and for the imaging performance to be diffraction-limited at 5 micron at 6 K.

The mirrors will be made of silicon carbide (SiC) or its related material, which has large heritages of the AKARI and Herschel telescopes. The design of the telescope system has been studied by the Europe-Japan telescope working group led by ESA with the European industries to meet the requirements, the result of which will be presented in another paper. As for optical testing, responsibilities will be split between Europe and Japan so that final optical verification at temperatures below 10 K will be executed in Japan.

We here present our recent optical testing activities in Japan for the SPICA telescope, which include the numerical and experimental studies of stitching interferometry as well as modifications of the 6-m-diameter radiometer space chamber facility at Tsukuba Space Center in JAXA. We also show results of cryogenic optical testing of the 80-cm lightweight mirror made of a C/SiC material called HBCesic, which is a candidate mirror material for the SPICA telescope. These activities are performed within the framework of the JAXA large-optics study program for astronomy and earth observations.

7731-31, Session 7

SPICA coronagraph instrument for the direct imaging and spectroscopy of exo-planets

K. Enya, Japan Aerospace Exploration Agency (Japan)

We present the SPICA Coronagraph Instrument for the direct detection and characterization of exo-planets by imaging and spectroscopy) of exo-planets.

The SPICA mission will give us an unique opportunity for making high-contrast observations because of the large telescope aperture, the simple pupil shape, and the capability for infrared observations from space.

The primary target of this coronagraph is the direct detection and spectroscopy of Jovian exo-planets.

The specifications, performance, and especially recent progress of the design of the instrument are shown.

The instrument will include active optics and will have coronagraphic spectroscopy mode.

We also show the current progress in the development of key technologies to realize this instrument.

7731-32, Session 8

Pre-launch characterization of the WISE payload

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The Wide Field Infrared Survey Explorer (WISE), due to launch in December 2009, is a NASA-funded Explorer mission that will provide an all-sky survey in the mid-infrared with far greater sensitivity and resolution than any previous IR survey mission. The Utah State University Space Dynamics Laboratory designed, fabricated, and characterized the science payload, which is a cryogenically cooled infrared telescope with four 1024x1024 infrared focal plane arrays covering from 2.8 to 26 μm. Pre-launch charaterization included measuring focus, repeatability, response non-linearity, saturation, latency, absolute response, flatfield, point response function, scanner linearity, and relative spectral response. This paper will provide a brief overview of the payload, discuss pre-launch characterization methods, and present performance results from ground characterization and early on-orbit performance.

7731-33, Session 8

Hardware results for the Wide-field Infrared Survey Explorer (WISE) Telescope and scanner

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On December 14, 2009 NASA launched the Wide-field Infrared Survey Explorer (WISE), a NASA MIDEX mission within the Explorers program that will perform an all-sky survey in four infrared bands. L-3 Integrated Optical Systems/SSG designed, built, and tested the telescope, scanner, and aft imaging optical system for WISE under contract to the Space Dynamics Laboratory. Hardware and test results for those subsystems are presented, as well as an on-orbit status of their imaging performance. The WISE payload includes a 40 cm afocal telescope, a scan mirror for back-scan during integration, and an aft optics imager assembly. All modules operate below 17 Kelvin. The all-reflective system uses aluminum mirrors and metering structures. The afocal telescope provides distortion control to better than two parts in a thousand to prevent image blur during internal scanning. The one-axis scan mirror at the exit pupil scans the detectors' field-of-view across the telescope field-of-regard, countering the orbital motion and freezing the line of sight during the multi-second exposure period. The five-mirror imaging optics module follows the scan mirror and feeds dichroic beamsplitters that separate the energy into four channels between 2.8 and 26 microns. Once initial on-orbit checkout and calibration is complete, WISE will begin a 6-month mission performing an all-sky survey in the four infrared bands.

7731-34, Session 9

On-orbit performance of HST/wide field camera 3

J. W. MacKenty, Space Telescope Science Institute (United States); R. A. Kimble, NASA Goddard Space Flight Ctr. (United States); R. W. O'Connell, Univ. of Virginia (United States); J. A. Townsend, NASA Goddard Space Flight Ctr. (United States)

The Wide Field Camera 3 (WFC3) was installed into the Hubble Space Telescope during Servicing Mission 4 in May 2009. This panchromatic camera considerably improves the ultraviolet, visible, and infrared imaging capabilities of HST. Commissioned over the summer of 2009, WFC3 is now fully functional and responsible for approximately half of the Cycle 17 HST Science Program. This paper will review the scientific performance of WFC3 including its sensitivity in absolute terms and relative to other HST instruments. The paper will also discuss the calibration programs for WFC3 and the achieved photometric and astrometric calibration accuracies. Lessons learned from the ground calibration and in-flight commissioning will also be considered.

7731-35, Session 9

On orbit performance of the cosmic origins spectrograph

J. C. Green, C. S. Froning, S. N. Osterman, Univ. of Colorado at Boulder (United States)

The Cosmic Origins Spectrograph was installed in the Hubble Space Telescope during servicing Mission 4 in May, 2009. We will report on the sensitivity, spectral resolution, and other capabilities of the instrument as measured on orbit. Initial science results form the COS GTO program will aslo be presented.

7731-36, Session 9

The feasibility of exoplanet coronagraphy with the Hubble Space Telescope

R. G. Lyon, NASA Goddard Space Flight Ctr. (United States); R. A. Woodruff, Lockheed Martin Space Systems Co. (United States); R. A. Brown, Space Telescope Science Institute (United States); M. C. Noecker, Ball Aerospace & Technologies Corp. (United States); E. S. Cheng, Conceptual Analytics, LLC (United States)

Herein we discuss the use of the Hubble Space Telescope (HST) for the direct detection and spectroscopic characterization of exoplanets and debris disks - an application for which HST was not originally designed. Coronagraphic advances may enable the design of a science instrument that could achieve limiting contrasts ~109 beyond 275 milli-arcseconds (4 /D at 800 nm) inner working angle, thereby enabling detection and characterization of several known jovian planets and imaging of debris disks. There are significant advantages of using HST: it already exists in orbit, it's primary mirror is thermally stable and it is the most characterized space telescope ever flown. However there is drift of the HST telescope, likely due to thermal effects crossing the terminator. The drift, however, is well characterized and consists of a larger deterministic components and a smaller stochastic component. It is the effect of this drift versus the sensing and control bandwidth of the instrument that will likely limit HST coronagraphic performance. Herein we discuss the science case, quantify the limiting factors and assess the feasibility of using HST for exoplanets.

7731-37, Session 10

Herschel-HIFI: design, in orbit performance, and scientific capabilities

F. Helmich, SRON Netherlands Institute for Space Research (Netherlands)

The Herschel Space Observatory will be described by Goeran Pilbratt, the PACS and SPIRE instruments are described by Albrecht Poglitsch and Matt Griffin. This talk on HIFI will make the picture complete.

Compared with the last SPIE paper we now have the full overview of the final, as launched, design and this will be described in some detail. At the time of conference the Performance Verification period will have been concluded. Current data show that HIFI is the most versatile and sensitive heterodyne instrument ever designed for space, but this implies that new effects are found, which need to be calibrated out. On August 3 HIFI experienced the LCU-anomaly. A short description will be given, just as for the mitigation measures. Finally the science capabilities will be described in quite some detail, illustrated by measured HIFI spectra.

7731-38, Session 10

The Herschel photodetector array camera and spectrometer (PACS): design and in-flight operation and scientific performance

A. Poglitsch, Max-Planck-Institut für extraterrestrische Physik (Germany)

The Photodetector Array Camera and Spectrometer (PACS) is one of the three science instruments for ESA's far infrared and submillimeter observatory Herschel. It employs two Ge:Ga photoconductor arrays (stressed and unstressed) with 16 × 25 pixels, each, and two filled silicon bolometer arrays with 16 × 32 and 32 × 64 pixels, respectively, to perform imaging line spectroscopy and imaging photometry in the 60 - 210µm wavelength band. In photometry mode, it simultaneously images two bands, 60 - 85µm or 85 - 130µm and 130 - 210µm, over a field of view of ~1.75' × 3.5', with full beam sampling in each band. In spectroscopy mode, it images a field of ~47"×47", resolved into 5×5 pixels, with an instantaneous spectral coverage of ~1500 km/s and a spectral resolution of ~175 km/s.

After the launch in May 2009 we have successfuly completed the commissioning, calibration and performance verification of the instrument on Herschel in all of its observing modes. We find that the in-orbit performance is close to or even better than predicted from ground tests. We describe the observing modes as offered to the user after in-flight optimization and report the actual performance achieved in each mode with scientific observations.

7731-39, Session 10

Herschel-SPIRE: design, in-flight performance and scientific capabilities

M. J. Griffin, Cardiff Univ. (United Kingdom)

SPIRE, the Spectral and Photometric Imaging REceiver, is the submillimetre camera and spectrometer on board the Herschel Space Observatory. It comprises a three-band camera operating at 250, 350 and 500 microns, and an imaging Fourier Transform Spectrometer covering 194-671 microns. The photometer field of view is 4 x 8 arcmin., viewed simultaneously in the three bands. The FTS observes its whole wavelength range simultaneously. It has an approximately circular field of view of 2.6 arcmin. diameter and spectral resolution adjustable between 0.04 cm-1 (1.2 GHz) and 0.83 cm-1 (25 GHz). Following the successful launch, commissioning and performance verification of Herschel, SPIRE is fully functional with performance meeting or exceeding pre-flight estimates in all respects. The main design features of SPIRE will be reviewed, and the achieved instrument performance levels and scientific capabilities will be summarised.

7731-40, Session 10

In-flight commissioning and calibration of the Herschel SPIRE instrument

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The Spectral and Photometric Imaging Receiver (SPIRE) is one of three scientific instruments on ESA's Herschel Space Observatory, launched ion May 2009 and now orbiting L2. This long wavelength instrument covers approximately 200 to 670 um with a three band photometric camera and a two band imaging Fourier Transform Spectrometer (IFTS). Since launch on May 14th 2009 the satellite and its instruments have undergone an extensive series of functional and scientific commissioning and calibration procedures culminating in the observation of a series of astronomical targets with known spectral energy densities. In this paper we describe how the commissioning has been carried out and report on the operation and functional performance of the instrument sub-systems. We also report on the initial calibration activities and compare the in-flight calibration with results obtained pre-flight.

7731-41, Session 10

In-orbit performance of the Herschel/SPIRE imaging Fourier transform spectrometer

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The Spectral and Photometric Imaging Receiver (SPIRE) is one of three scientific instruments onboard the European Space Agency's Herschel Space Observatory launched on 14 May 2009. The low to medium resolution spectroscopic capability of SPIRE is provided by an imaging Fourier transform spectrometer of the Mach-Zehnder configuration. Results from the in flight performance verification phase of the SPIRE spectrometer will be presented and conformance with the instrument design specifications reviewed. Topics to be discussed include: spectral range, resolution, wavelength accuracy, instrumental lineshape and sensitivity.

7731-42, Session 11

Kepler instrument performance: an in-flight update

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The Kepler Mission is designed to detect the 80 parts per million (ppm) signal from an Earth-Sun equivalent transit.

Such precision requires superb instrument stability on time scales up to 2 days and systematic error removal to better than 20 ppm. The sole scientific instrument is the Photometer, a 0.95 m aperture Schmidt telescope that feeds the 94.6 million pixel CCD detector array, which contains both Science and Fine Guidance Sensor (FGS) CCDs. Since Kepler's launch in March 2009, we have been using the commissioning and science operations data to characterize the instrument and monitor its performance. We find that the in-flight detector properties of the focal plane, including bias levels, read noise, gain, linearity, saturation, FGS to Science crosstalk, and video crosstalk between Science CCDs, are essentially unchanged from their pre-launch values. Kepler's unprecedented sensitivity and stability in space have allowed us to measure both short- and long-term effects from cosmic rays, see interactions of previously known image artifacts with starlight, and uncover several unexpected systematics that affect photometric precision, including unexplained diffuse illumination events that occur at significant levels ~10 times per month. Based on early results, we expect to attain Kepler's planned photometric precision over 90% of the field of view.

7731-44, Session 12

ASPIICS: a giant coronagraph for the ESA/PROBA-3 Formation Flying Mission

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Classical externally-occulted coronagraphs are presently limited in their performances by the distance between the external occulter and the front objective. The diffraction fringe from the occulter and the vignetted pupil which degrades the spatial resolution prevent useful observations of the white light corona inside typically 2-2.5 Rsun. Formation flying offers and elegant solution to these limitations and allows conceiving giant, externally-occulted coronagraphs using a two-component space system with the external occulter on one spacecraft and the optical instrument on the other spacecraft at a distance of hundred meters. Such an instrument has just been selected by the European Space Agency (ESA) to fly (by the end of 2013) on its PROBA-3 mission of formation flying demonstration which is presently in phase B. It will perform both high spatial resolution imaging of the solar corona as well as 2-dimensional spectroscopy of several emission lines (in particular the forbidden line of FeXIV at 530.285 nm) from the coronal base out to 3 Rsun using an étalon Fabry-Perot interferometer. The classical design of an externally-occulted coronagraph is adapted to the formation flying configuration allowing the detection of the very inner corona as close as 0.05 Rsun from the solar limb. By tuning the position of the occulter spacecraft, it may even be possible to reach the chromosphere and the upper part of the spicules.

7731-45, Session 12

The narrow angle camera of the MPCS suite for the MarcoPolo ESA Mission: requirements and optical design solutions

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Possible optical designs of a Narrow Angle Camera (NAC) suitable for being the high resolution channel of the MarcoPolo Camera System for the MarcoPolo ESA mission are presented.

The MarcoPolo mission objective is the rendezvous with a Near Earth Asteroid in order to fully characterize the body, to land on the surface and to return to Earth a sample of the asteroid soil.

Science goals for the NAC are global mapping of the object, detailed investigations of the surface at high spatial resolution (order of millimeters), and deep examination of possible landing sites from a close distance.

The instrument has a 3"/pixel scale factor, corresponding to 80 mm/px at 5 km from the surface, on a 1.7° x 1.7° FoV; imaging in 5 to 8 different spectral bands (panchromatic and broadband), in the range between 400 and 900 nm, is foreseen.

Since the target is an extended low contrast object, to avoid image contrast degradation, only off-axis unobstructed optical layouts have been considered.

Solutions with two mirrors plus a refractive corrector, or all-reflective three mirrors ones, have been studied, both allowing to reach good aberration balancing over all the field of view: the diffraction ensquared

energy inside one pixel of the detector is of the order of 70%. To cope with the hazardous radiation environment in which the spacecraft will be immersed in during the mission, all the glasses selected for the design are rad-hard type.

7731-46, Session 12

Stray light characterization of the LORRI Telescope on New Horizons

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The New Horizons mission to the Pluto system and the Kuiper Belt carries a narrow angle visible camera, the Long Range Reconnaissance Imager (LORRI). At Jupiter encounter in 2007, LORRI successfully imaged the faint rings of Jupiter, volcanic plumes of Jupiter's moon Io, the night side of Io illuminated by Jupiter shine, lightning on Jupiter, mesoscale waves in Jupiter's visible cloud layer, and emissions from satellites of Jupiter while in Jupiter's shadow. Many of these observations were made under challenging stray light conditions, with the Sun or the bright crescent of Jupiter just outside the field of view. More such observations are planned at Pluto, where we will search for atmospheric features and haze layers in forward scattered light and attempt to image the night side of Pluto. We will discuss the stray light characteristics of LORRI as determined in ground and flight tests, including ghost images, other stray light features, and diffuse stray light. We will show LORRI's point source transmittance function.

7731-47, Session 12

SPEX: the spectropolarimeter for planetary exploration

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SPEX (Spectropolarimeter for Planetary EXploration) is an innovative, compact instrument for spectropolarimetry, and in particular for detecting and characterizing aerosols in planetary atmospheres. With its 1-liter volume it is capable of full linear spectropolarimetry, without moving parts. The degree and angle of linear polarization of the incoming light is encoded in a sinusoidal modulation of the intensity spectrum by an achromatic quarter-wave retarder, an athermal multiple-order retarder and a polarizing beam-splitter in the entrance pupil. A single intensity spectrum thus provides the spectral dependence of the degree and angle of linear polarization.

While SPEX can be used to study any planetary atmosphere, including those of the Earth, Mars, Jupiter, and Titan, it is also applicable to Moon-based measurements of the Earth as an exoplanet and may potentially be useful as a space-based exoplanet spectropolarimeter.

The SPEX concept has been verified with an end-to-end simulation and a prototype that has successfully detected aerosols in polarized spectra of the blue sky.

7731-48, Session 13

1000 million stars with 100 CCD detectors

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No abstract available

7731-49, Session 14

Joint Dark Energy Mission optical design studies

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We present the latest optical design concepts for the Joint Dark Energy Mission (JDEM). This mission will tightly constrain the cosmological parameters describing the recently discovered accelerated expansion of the universe. The current candidate designs are based on extensive examination of the interplay of requirements for the leading techniques applicable to space borne observation: Baryon Acoustic Oscillation, BAO (galaxy redshift survey), Type 1a Supernovae (SN), and gravitational Weak Lensing (WL). All techniques require very large fields of view across the visible and near infrared spectrum; BAO uniquely requires a moderate dispersion wide field spectroscopy capability. Weak lensing requires very good stability and knowledge of the point spread function in order to enable detection of statistical changes in galaxy ellipticities by intervening dark matter. SN imaging spectroscopy should be done to high photometric signal to noise in order to make best use of these 'standard candles.' We have studied both medium and smaller, "Probe" class implementations which would enable from one to three of these techniques. Trade studies among aperture, field of view, number and type of instrument channel are identified and discussed.

7731-50, Session 14

Optical performance budgeting for JDEM weak-lensing measurements

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Weak gravitational lensing of galaxies is a versatile probe of the distribution of gravitating matter, both visible and invisible, and the influence of cosmological dark energy on that distribution for redshift $z<1.5$. The weak lensing method is under consideration as an element of the NASA-DOE Joint Dark Energy Mission (JDEM). The measurements are challenging, because of an ambitious goal for sensitivity to feeble gravitational shear and a competing goal for an extremely large statistical sample of galaxies. This motivates an instrument design which has very few pixels across each galaxy image and yet must extract galaxy shape information with very high precision and accuracy. This in turn places stiff requirements on calibration during observations and on instrument stability. We present a tool for estimating the impact of telescope and detector physics on the estimated lensing shear, in a way that permits us to propagate the instrument performance allocations all the way to bias uncertainties in gravitational shear. This tool can be validated against integrated modeling, and would allow powerful capability for system engineering trades.

7731-51, Session 14

Multiple plate scales for wide-field NIR and visible spaceborne telescopes

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The discovery of Dark Energy in the late 1990s led to a number of proposed techniques to constrain the associated cosomological

parameters. Three of the most promising observational techniques include Baryon Acoustic Oscillation, Supernovae and Weak Gravitational Lensing. Although these surveys are complimentary is most aspects, optimal plate scales vary by roughly a factor of two. We discuss the various challenges associated with a wide-field, mixed spectroscopic and imaging survey with widely-varying plate scales. Optical configurations involving an afocal telescope and reimaging cameras, as well as strictly focal designs, are examined for applicability to a wide-field grism or prism spectroscopic survey.

7731-52, Session 14

Off-axis telescopes for dark energy investigations

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It is well known that a telescope with an unobstructed circular pupil delivers a smaller diffraction pattern than one centrally obstructed by its secondary mirror. Spaceborne dark energy investigations require measuring targets over a wide range of redshifts, with the most distant galaxies being the reddest, faintest, and smallest. For any given signal-to-noise (SNR) requirement, these highest redshift targets are the most demanding in terms of mission cost (time, aperture, etc), not only because they are faint but also because the diffraction pattern is largest at the longest wavelengths being observed.

At the same time, the telescope's field of view must be large --- the order of a square degree --- to survey the entire extragalactic sky in reasonable time. The large field of view imposes a minimum requirement on the size of the secondary mirror baffle. For a centrally obstructed telescope, an enlarged secondary mirror will further enlarge the diffraction pattern.

We have explored unobstructed telescope designs because these can have a nearly ideal Airy diffraction pattern, limited only by optical manufacturing and alignment errors. They therefore can deliver the best possible SNR for a given aperture. Examples are shown illustrating these findings.

7731-53, Session 15

The Euclid Mission

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Euclid is a proposed ESA Cosmic Vision M-class mission to investigate dark energy and dark matter by means of weak lensing and baryonic acoustic oscillations experiments. The capabilities of Euclid are such that it will also address other cosmological and astronomical topics, providing an unprecedented science legacy. The mission will carry out an imaging and spectroscopic survey of the entire extragalactic sky (20000 deg2). The imaging survey is driven by the weak lensing experiment to perform shape measurements of galaxies in the visible and photometry in 3 near-infrared bands of at least 30 galaxies/arcmin2. The near-infrared spectroscopic survey will yield redshifts with accuracy $dz/(1+z) < 0.001$ of at least 70 million galaxies. Euclid carries a meter class telescope which feeds three instruments: a visible imager, a near-infrared photometer and a medium resolution spectrometer. The instruments have identical sized field of views (0.5 deg2) and will operate simultaneously in step-and-stare mode. The nominal mission period is 5 years. We will describe the mission, the satellite system, and the payload.

7731-54, Session 15

Euclid imaging channels: from science to system requirements

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Euclid is an ESA Cosmic Vision wide-field space mission concept dedicated to the high-precision study of Dark Energy and Dark Matter. The mission relies on two primary cosmological probes: Weak gravitational Lensing (WL) and Baryon Acoustic Oscillations (BAO).

The first probe requires the measurement of the shape and photometric redshifts of distant galaxies. The second probe is based on the 3-dimensional distribution of galaxies through spectroscopic redshifts. Additional cosmological probes are also used and include cluster counts, redshift space distortions, the integrated Sachs-Wolfe effect (ISW) and galaxy clustering, which can all be derived from a combination of imaging and spectroscopy.

The Euclid Imaging Channels Instrument of the Euclid mission is designed to study the weak gravitational lensing cosmological probe. The combined Visible and Near InfraRed imaging channels form the basis of the weak lensing measurements. The VIS channel provides high-precision galaxy shape measurements for the measurement of weak lensing shear. The NIP channel provides the deep NIR multi-band photometry necessary to derive the photometric redshifts and thus a distance estimate for the lensed galaxies.

This paper is showing the process through which the science requirements are expressed and decomposed into instrument requirements using a set of simulation pipelines. This process is also used to close the instrument performance evaluation loop and compare the designed instrument with respect to science requirements.

7731-55, Session 15

VIS: the visible imager for Euclid

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Euclid-VIS is a large format visible imager currently under investigation for the ESA Euclid space mission in their Cosmic Vision program. Together with the near infrared photometer (NIP) it forms the basis of the weak lensing measurements of Euclid. VIS will image in a single R+I+Z band from 550-920 nm over a field of view of ~0.5 deg^2. Over 4 exposures totalling 1800 sec, VIS will reach to V=24.5 (10) for sources with extent ~0.3 arcsec. The image sampling is 0.1 arcsec. VIS will provide deep imaging with a tightly controlled and stable PSF over a wide surcey area of of 20000 deg^2 to measure the cosmic shear from over 2 billion galaxies to high levels of accuracy, from which the cosmological parameters will be measured. In addition, VIS will also provide a legacy deep imaging dataset of unprecedented spatial resolution over the entire extra-Galactic sky. Here we will present the results of the study carried out by the Euclid Imaging Consortium during the Euclid assessment phase.

7731-56, Session 15

NIP: the near-infrared imaging photometer for Euclid

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The NIP is a near infrared imaging photometer which is currently under investigation for the ESA Euclid space mission in context of the 2015 Cosmic Vision program. Together with the visible camera (VIS) it forms the basis of the weak lensing measurements of Euclid. The NIP will perform photometric imaging in 3 near infrared bands (Y, J, H) covering a wavelength range from ~ 0.9 to ~2 µm over a field of view of ~ 0.5 deg^2. With the required limiting point source magnitude of 24 mAB (5 sigma) NIP will be used to determine the photometric redshifts of over 2 billion galaxies collected over a wide survey area of 20000 deg^2. In addition to the photometric measurements the NIP will deliver unique near infrared imaging data over the entire extragalactic sky, enabling a wide variety of ancillary astrophysical and cosmological studies. Here we will present the results of the study carried out by the Euclid Imaging Consortium (EIC) during the Euclid assessment phase.

7731-58, Session 15

The E-NIS instrument on-board the ESA Euclid Dark Energy Mission: a general view

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We present in this paper the conceptual design for the E-NIS spectrograph on-board the ESA-Euclid Dark Energy mission. Developed by the ENIS Consortium in the context of the ESA Cosmic Vision Programme, ENIS has been studied in a baseline slitless configuration and in an optional multi-slit configuration, based on Digital Micro-Mirror Devices (DMDs). ENIS is conceived to collect between 107 and 108 measured redshift of galaxies, patrolling 20,000 sqdeg of sky in 5 year of observations. Together with the weak lensing instrument EIC, ENIS will contribute to the success of Euclid in the multi-approach addressing of the investigation of Dark Energy. This contribution describes the general configuration of the spectrograph, the technical solutions adopted and the subsystem of highest relevance. Expected performances, evaluated via dedicated simulation, are also discussed in details.

7731-59, Session 16

Phase A/B1 activities for ESA Cosmic Vision Mission

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PLATO - PLAnetary Transits and Oscillations of stars - is a Cosmic Vision 2015-2025 M-class mission candidate of ESA's future Science and Robotic Exploration programme. The scientific goals are to detect exoplanetary transits and to characterize the parent stars using astero-seismology. This is achieved through high-accuracy, high time-resolution photometry in the visible waveband. An assessment study was carried out for all M-class missions during 2008-2009 in order to design a basic spacecraft configuration and identify critical areas. Following a possible down-selection in the beginning of 2010, PLATO will enter into a phase A/B1 study phase in which the spacecraft design will be consolidated and optimized. The proposed payload will use a multi-aperture approach in which the combined observations of 30-40 telescopes with individual pupil sizes of 90-120 mm will produce very accurate light curves of the target stars. Since the orbital periods of the exoplanets should preferably be in or close to the habitable zone, an observation period of several years per sky field is required to detect repeated transits of the exoplanets around the parent stars. This requires a stable spacecraft with a high pointing accuracy and a benign operating environment. It is foreseen to launch PLATO using a Soyuz 2-1b via a direct insertion into a large amplitude orbit around Sun-Earth L2. This paper will give an overview of the current and planned activities during the phase A/B1 studies.

7731-60, Session 16

A 4-meter, wide-field coronagraph space telescope for general astrophysics and exoplanet observations

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This paper presents a design for a 4-m diameter, off-axis space telescope designed as a flagship class mission to succeed the Hubble and James Webb Space Telescopes. It offers high performance in both wide field and coronagraphic imaging modes. The 4 m primary mirror provides a 3.8 x 3.3 m unobstructed elliptical pupil for direct coronagraphic imaging of exoplanets at optical wavelengths and a notched 4-m diameter pupil for wide field imaging from far-ultraviolet (UV) to near-infrared (IR).

We focus on the optical design that allows uncompromised performance in both modes combined in single telescope, and give a preliminary spacecraft design and costing, assuming a Earth trailing orbit. The science case and possible instrument suite are based on other more detailed mission concept studies in which several of the authors have participated. We believe the concept is worth exploring as a potentially less-expensive, single-spacecraft alternative to formation flying systems aimed at similar scientific goals. The team estimates a lifetime costs of $4.2 B, including $3.3B for development and $900 M development reserve.

In both operational modes, light from the 4-m diameter off-axis primary strikes a secondary mirror at the edge of the entrance aperture, and is reflected down the side of the tube to a folding flat behind the primary. For wide field imaging, a tertiary mirror is brought into play to form an all-reflective three-mirror anastigmat. The 6 x 24 arcminute field of view (FOV) has an average wavefront aberration of 12 nm. The resulting images are thus diffraction-limited down to 300 nm wavelength across the field, and at shorter wavelengths (down to the ~ 100 nm cut-off set by the mirror coatings) have a PSF of ~15 mas.

The WFCT wide field instruments are based on designs developed in detail for the THEIA mission concept studies.

Exoplanet imaging will use the Pupil mapping Exoplanet Coronagraphic Observer (PECO) instrument, developed with NASA JPL and NASA Ames, similar to the PIAA coronagraph instrument for WFCT. The exoplanet science case is substantially extended from that given in the PECO report.

7731-61, Session 16

A space imaging concept based on a 4m structured spun-cast borosilicate monolithic primary mirror

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Lockheed Martin Corporation tasked the University Of Arizona Steward Observatory (UASO) to conduct an engineering study to examine the feasibility of creating a 4m space telescope based on further light-weighting of mature borosilicate technology developed at the UASO for ground-based telescopes. UASO has completed this study and concludes that existing launch vehicles can deliver a 4m monolithic telescope system to a 500 km circular orbit and provide reliable imagery diffraction-limited imagery. An analysis of such an imager based on a lightweight, high-performance, structured 4m primary mirror cast from borosilicate glass is described. The relatively high CTE of this glass is used to advantage by maintaining mirror shape quality with a thermal figuring method. Placed in a 270 K thermal shroud (similar to the Hubble Space Telescope), the orbit averaged figure error is 6nm rms. Analysis shows that a 3-point bipod mount will provide launch survivability with ample margin. Existing stressed-lap polishing technology at the University of Arizona can create f/1 mirrors of advantageous length for existing EELV fairings and on-orbit pointing control. The primary mirror naturally maintains its shape at 1g allowing excellent end-to-end pre-launch testing with the LOTIS 6.5m Collimator. The telescope includes simple insurance-policy systems to measure and correct mirror shape and alignment errors incorporating technologies already proven on the 6.5m LOTIS Collimator built for Lockheed Martin. The conclusions form this engineering study are derived from knowledge of our mature spin-casting mirror fabrication and public domain information available about the DELTA IV EELV fairing.

7731-62, Session 16

GPA-SS: an approach to low-cost space telescope design using space-qualified ground telescopes

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The General Purpose Astronomy - Small Satellite (GPA-SS) project studied the feasibility of developing a space telescope which could be used for a range of useful astronomical observations at a relatively low cost of $100 million. The two potential astronomy missions costed were a near-infrared imaging mission (1.1m diameter primary mirror) and an exoplanet microlensing observation mission (0.8m).

Each of the missions was based on an optical telescope assembly (OTA) designed for ground use to take advantage of the economies of scale in existing mirror fabrication processes. This paper details the additional design, manufacture and test tasks required to flight-qualify the ground telescope. These additional tasks were each costed in terms of labor time to evaluate the savings relative to conventional space telescope design. Vendor quotes were used to improve the estimate of cost in some areas.

Key subsystems were also designed at a conceptual level. This design was used both to estimate subsystem costs and to inform the science achievable from a given telescope design, for example by analyzing the achievable pointing stability or OTA temperature. Subsystem costs were estimated from the design through a combination of previously published cost estimating relationships and vendor quotes.

The paper concludes that the space-qualification of an existing ground telescope is a potential approach for making significant cost savings when designing a low cost space telescope. Additional work on design and cost estimation around the framework presented in this paper could be undertaken to add certainty to the cost estimate.

7731-63, Session 16

WISH: wide-field imaging surveyor at high redshift

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WISH, Wide-field Imaging Surveyor for High-redshift is a newly developed concept of the space science mission whose primary goal is to reveal the first-generation galaxies in the very early and young universe. The WISH Working Group was founded under the Japanese JAXA/ISAS Space Science Committee in Sept. 2008, and is leading the on-going R and D processes. In this paper, we would like to present the major science goals and the survey strategy, required capability, and the summary of the specification as well as the results of the design study including the optical layout and the performance, mirrors and telescope structure, wide-field filter-exchange system.

In summary, the 1.5m-aperture telescope equipped with the wide-field NIR camera with ~1000 sq. arcmin FoV will be launched by late 2010's in order to conduct ultra-deep and wide-area sky surveys. The primary wavelength coverage is 1-5 micron and the focal plane is very flat achieving the deflection-limited images over the range, while the pixel scale is 0.15 arcsec optimized at 1.5 micron. We consider the orbit of SE-L2 and HIIA rocket as the launcher. The telescope will be passively cooled to 90K. Multi-band ultra-deep survey covering 100 sq. deg down to AB 28mag as well as wide-area survey covering 1000 sq. deg down to 24-25mag will be conducted within its mission lifetime of 5 years. WISH should be a very powerful and unique mission not only to study the first-generation objects but also for study of dark energy and many other fields in astronomy.

7731-64, Session 17

The experimental probe of inflationary cosmology intermediate mission concept

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We discuss the Experimental Probe of Inflationary Cosmology - Intermediate Mission, a concept for the NASA Einstein Inflation Probe satellite. The theory of Inflation, now a cornerstone of modern cosmology, has strong experimental support from precision measurements of the cosmic microwave background (CMB). Measurements of CMB polarization can probe the physical basis of Inflation by searching for the telltale ‘B-mode’ polarization signature from Inflationary gravitational waves. Our design is based on a wide-field 1.4 m crossed-Dragone telescope. More than 10,000 detectors in 9 wavelength bands provide a factor of 30 leap in sensitivity relative to the currently operating Planck satellite. Compared to our earlier designs, the larger telescope allows not only comprehensive measurements of Inflationary B-mode polarization, but also enables measurements of the E-mode and lensing polarization signals to cosmological limits, as well as all-sky maps of Galactic polarization with unmatched sensitivity and angular resolution. We have carried out a detailed design and analysis of the polarization and sidelobe properties of the telescope. We have developed a 3-stage radiative/cryocooler/ADR cooling system which cools the telescope optics to 4 K and the large focal plane assembly to 100 mK. We describe the design for a 4-stage deployed sunshield to accommodate EPIC-IM’s spinning/precessing scan strategy from L2, a pattern which covers more than half the sky in a single day, allowing for highly cross-linked and redundant map making. EPIC-IM has the necessary combination of sensitivity, band coverage, angular resolution, all-sky coverage and control of systematic errors for definitive space-borne measurements of CMB polarization.

7731-65, Session 17

The absolute spectrum polarimeter (ASP)

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The Absolute Spectrum Polarimeter (ASP) is an Explorer-class mission to map the absolute intensity and linear polarization of the cosmic microwave background and diffuse astrophysical foregrounds over the full sky from frequencies 30 GHz to 5 THz (1 cm to 60 micron wavelength). ASP uses a polarizing Michelson interferometer with 2.7 K optics to measure the difference spectrum between two orthogonal linear polarizations from two independent beams. Either input can view either the sky or a temperature-controlled absolute reference blackbody calibrator. The multi-moded optics and high entendu provide sensitivity comparable to kilo-pixel focal plane arrays, but with greatly expanded frequency coverage while using only 4 detectors total. ASP builds on the highly successful COBE/FIRAS design by adding large-area polarization-sensitive detectors whose fully symmetric optics are maintained in thermal equilibrium with the CMB. The highly symmetric nulled design provides redundant rejection of major sources of systematic uncertainty. The principal science goal is the detection and characterization of linear polarization from an inflationary epoch in the early universe, with tensor-to-scalar ratio r << 10^{-3}. However, ASP will also return a rich data set constraining physical processes ranging from Big Bang cosmology, reionization (Compton distortion y < 10^{-6}), large-scale structure (amplitude and power spectrum of the cosmic infrared background), and the interstellar medium (synchrotron and dust continuum, multiple molecular and atomic lines). We describe the ASP instrument and mission architecture needed to detect the signature of an inflationary epoch in the early universe using only 4 semiconductor bolometers.

7731-66, Session 17

LEGOLAS (localizing evidence of gravitational waves by observations of light source astrometric signature)

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Improvement of our understanding of Fundamental Physics is more and more based on high precision measurements over significant fractions of our Universe.

Among the crucial tests of General Relativity and competing theories is the detection of gravitational waves, which is the subject of advanced modern experiments (LISA, VIRGO, LIGO).

Our investigation is focused on a novel concept for pointed observations of selected astronomical objects in our Galaxy, like compact binary systems, neutron stars and compact white dwarf binaries, which are expected to be sources of gravitational waves in the Very Low Frequency range, i.e 10-4 Hz < fg < 10-1 Hz.

The detection mechanism is based on indirect astrometric observations by a spaceborne dedicated instrument, monitoring the astrometric light deflection of the photons crossing the buffer zone of the gravitational source at the microarcsec level accuracy.

We discuss the class of potential candidates, the mission concept and its high level specifications; furthermore, we present an implementation concept including basic instrument characteristics (system configuration, telescope size and constraints, operating wavelength, detector, operation).

7731-67, Session 17

Design of a four mirror astrometric telescope for light bending measurements

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We present a new design of a four mirror telescope for astrometric measurements to be used in the GAME mission, currently under study at the Astronomical Observatory of Turin, Italy. GAME, (Gamma Astrometric Measurement Experiment), aims to measure the gamma parameter of the parameterized post-Newtonian formulation by looking at the deflection of light produced by the Sun's gravitational curvature, as in the Dyson, Eddington et al., experiment, using a dedicated, space based dual-field telescope.

A first design has been presented in recent years, based on a Cassegrain scheme; the new design still works as Fizeau interferometer, but the optical scheme of the telescope is based on a Korsh-like design with long focal length and with four conical mirrors, without the use of exotic surfaces as adopted in other long focal astrometric instruments. A different combination scheme of the two Lines of Sight makes the dimensioning of the primary mirror more relaxed allowing us to work with smaller surfaces and therefore to fullfil more easily the requirements for a small mission. The design of the instrument and the masked interferometry approach allow us to maximize the astrometric performances and at the same time to improve the baffling, thus minimising the amount of straylight from the sun.

In this paper we describe the mission profile, the observation principle and the instrument layout. We also analyze the impact of the improved baffling on the expected performances of the instrument.

7731-68, Session 17

Achieving high-precision pointing stability on ExoplanetSat

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ExoplanetSat is a proposed three-unit CubeSat designed to detect exoplanets via the transit method. To achieve the required photometric precision to make these measurements, the pointing of the spacecraft must be controlled to about 0.3 arcseconds. The satellite will use a two-stage control system: coarse control down to 60 arcseconds will be performed by a set of reaction wheels, desaturated by magnetic torque coils, and fine control down to 0.3 arcseconds will be performed by a piezoelectric translation and rotation stage. Since no spacecraft of this size has previously demonstrated this high level of pointing stability, we have been conducting analyses to prove the feasibility of creating such a system. Two separate techniques, a linear frequency-domain analysis and a nonlinear time-domain analysis, are used to analyze the angular jitter induced by any disturbance acting on the satellite. These two techniques are described, explaining their various features and limitations. In addition, these techniques are applied to estimate the angular jitter induced by reaction wheel imbalances, one of the largest disturbances acting on the satellite. Results from these analyses are used to determine the feasibility of obtaining the required pointing stability as well as to drive requirements on the necessary state estimation rate.

7731-69, Session 18

System design of a compact IR space imaging system, MIRIS

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Multi-purpose Infra-Red Imaging System (MIRIS) is the main payload of the Korea Science & Technology Satellite-3 (STSAT-3), which is being developed by Korea Astronomy & Space Science Institute (KASI). MIRIS is a small space telescope mainly for astronomical survey observations in the near infrared wavelengths of 0.9~2 µm. A compact wide field (3.67 x 3.67 degree) optical design has been studied using a 256 x 256 Teledyne PICNIC FPA IR sensor with a pixel scale of 51.6 arcsec. The passive cooling technique is applied to maintain telescope temperature below 200 K with a cold shutter in the filter wheel for accurate dark calibration and to reach required sensitivity, and a micro stirling cooler is employed to cool down the IR detector array below 100K in a cold box. The science mission of the MIRIS is to survey the Galactic plane in the emission line of Pa (1.88 µm) and to detect the cosmic infrared background (CIB) radiation. Comparing the Pa map with the H data from ground-based surveys, we can probe the origin of the warm-ionized medium (WIM) of the Galaxy. The CIB is being suspected to be originated from the first generation stars of the Universe and we will test this hypothesis by comparing the fluctuations in I (0.9~1.2 um) and H (1.2~2.0 um) bands to search the red shifted Lyman cutoff signature. Recent progress of the MIRIS system design will be presented.

7731-70, Session 18

The design and capabilities of the EXIST optical and Infra-Red Telescope (IRT)

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The IRT is a 1.1m visible and infrared passively cooled telescope, which can locate, identify and obtain spectra of GRB afterglows at redshifts up to z~20. It will also as optical-IR imaging and spectra of AGN and transients discovered by the EXIST survey. The IRT provides autonomous VIS-IR imaging and spectra of GRB afterglows or targeted objects, with exceptional near infrared sensitivities (AB=24 in 100s) surpassing Hubble space telescope in the infrared. The IRT instrument has both imaging and spectroscopic capabilities that cover a broad spectral range from 0.3–2.2µm in four bands centered at: 0.41, 0.71, 1.14 and 1.71µm. Each band covers the same field of view and it is read-out by its own dedicated detector. This allows the instrument to do simultaneous broadband photometry and spectroscopy of the same object simultaneously, thus greatly improving the efficiency of the observatory and its detection limits. The identical fields of view in the four instrument bands are each split in three subfields: imaging, objective prism slitless for the field and objective prism single object slit low resolution spectroscopy, and high resolution long slit on single object. The images and spectra are acquired by two infrared and two visible detectors. All 4 detectors are 2K×2K with the plate scale 0.15” per pixel.

7731-71, Session 18

Actuated hybrid mirrors for space telescopes

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This paper describes new, large, ultra-lightweight, replicated, actively controlled mirrors, for use in space telescopes. These mirrors utilize SiC substrates, with embedded solid-state actuators, bonded to Nanolaminate metal foil reflective surfaces. Called Actuated Hybrid Mirrors (AHMs), they use replication techniques for high optical quality as well as rapid, low cost manufacturing. They enable an Active Optics space telescope architecture that uses periodic image-based wavefront sensing and control to assure diffraction-limited performance, while relaxing optical system fabrication, integration and test requirements. The proposed International Space Station Observatory seeks to demonstrate this architecture in space.

7731-72, Session 18

Shape correction of thin mirrors in a reconfigurable space telescope array

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As part of a study sponsored by the Keck Institute for Space Studies (KISS), a space telescope mission is envisioned whose primary mirror segments are attached to independent spacecraft to allow for different configurations of the telescope. These spacecraft would be able to undock, re-arrange themselves into a new configuration, and then re-dock. The primary mirror segments would be thin, lightweight, active mirrors. A small-scale demonstration mission is being planned in the near-term, while this study is done with a large-scale mission in mind.

To allow for operation in the different configurations, the segments' actuators must be able to do relatively large corrections between different mirror shapes suited for different positions within the parent array. The difficulty of providing both this coarse correction for reconfiguration, and also the necessary fine correction during observations, presents challenges for the design of the mirror, its actuators, and supporting structure.

Some early results of the investigation of such an architecture will be reported in this paper. Models of the mirror segments have been constructed and analyzed in order to optimize the placement of the actuators and the design of the mirror itself.

7731-73, Session 18

Minimizing actuator-induced errors in active space telescope primary mirrors

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No abstract available.

7731-74, Session 18

Membrane photon sieve telescopes

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We are investigating new technologies for creating ultra-large apertures (>20m) for space-based imagery. Our approach has been to create diffractive primaries in flat membranes deployed from compact payloads. Our research has led us to the development of photon sieves in which millions of holes of a well-determined size are positioned over an otherwise opaque background. High resolution focusing is obtained for transmitted light.

We have analyzed the theoretical performance of several types of photon sieves to improve both efficiency and bandwidth. We have also created several prototype devices in both rigid and flexible substrates. In our largest test to date we have constructed a lightweight telescope with a 0.56m membrane photon sieve and a graphite composite truss. The entire telescope had a mass of less than 10kg and produced high quality images in ground-based tests.

7731-75, Session 19

PLATO: detailed design of the telescope optical units

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The project PLAnetary Transits and Oscillations of stars (PLATO) is one of the six medium class (M class) missions selected for assessment study in the framework of the ESA Cosmic Vision 2015-2025 program. The mean scientific goal of PLATO is the discovery and study of extrasolar planetary systems by means of planetary transits detection. According to the study made by the PLATO Payload Consortium (PPLC), the scientific payload consists of 42 all refractive telescopes having small aperture (120mm) and wide field of view (greater than 28 degree) observing over 0.45-1 micron wavelength band. The telescopes are mounted on a common optical bench and are divided in four families with an overlapping line-of-sight in order to maximize the science return. We will describe the detailed design of the Telescope Optical units (TOUs) focusing on the selected optical configuration and the expected performances.

7731-76, Session 19

THESIS: the terrestrial habitable-zone exoplanet spectroscopy infrared spacecraft

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THESIS is a concept for a MIDEX/Discovery class exoplanet mission. Building on the recent Spitzer and Hubble successes in exoplanet characterization and molecular spectroscopy, THESIS would extend these types of measurements to a large population of planets including non-transiting planets and super-Earths. The ability to acquire high-stability, spectroscopic data from the visible to the mid-infrared is a unique aspect of THESIS. A strength of the THESIS concept is simplicity low technical risk, and modest cost. By enabling molecular spectroscopy of exoplanet atmospheres, THESIS mission has the potential to dramatically advance our understanding of conditions on extrasolar worlds while serving as a stepping stone to more ambitious future missions.

7731-77, Session 19

Polarimetric and spectral characterization of exoplanets with small space telescopes

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To characterize atmospheres of exoplanets with large orbits (>10 AU), direct imaging is nowadays the sole way. From space, this involves high contrast techniques as coronagraphy, differential imaging or wavefront control. Several methods exist or are under development and a few small (~1.5m) space telescope missions are proposed. One of them is See-coast which will be proposed to the next ESA Cosmic Vision. It is designed to provide polarimetric and spectral characterization of exoplanets. We use numerical simulations to properly define science cases of exoplanet characterization with a small space telescope for different instrumental configurations. Results of this study will help us to answer questions as: To detect Super-Earths or even Earths, is a wavefront correction system required or is a very-well polished mirror sufficient ? What physical parameters of planet atmospheres can we extract from real data (low spectral resolution) ?

7731-78, Session 19

ExoplanetSat: detecting and monitoring exoplanets using a low-cost, CubeSat platform

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Nanosatellites, i.e. spacecraft that weigh between 1 and 10 kg, are drawing increasing interest as platforms for conducting on-orbit science. This trend is primarily driven by the ability to piggyback nanosatellites on the launch of large spacecraft and hence achieve orbit at greatly reduced cost. The CubeSat platform is a standardized nanosatellite configuration, consisting of one, two, or three 10 cm x 10 cm x 10 cm units (Us) arranged in a row. We present a CubeSat-based concept for the discovery of transiting exoplanets in the habitable zones of the nearest and brightest sun-like stars. The spacecraft prototype termed ExoplanetSat is a custom built 3U space telescope capable of monitoring a single target for 18 months from low Earth orbit. Given the volume limitations of the CubeSat form factor, designing a capable spacecraft requires overcoming significant challenges. This work presents the initial satellite configuration along with several subsystem-specific solutions to the aforementioned constraints. An optical design based on a modified commercial off-the-shelf telephoto camera lens is given. We also describe a novel two-stage attitude control architecture that combines 3-axis reaction wheels for coarse pointing with a piezoelectric translation stage at the focal plane for fine pointing. Test results on the attitude control hardware, optical layout, and other components are presented along with integrated modeling and simulation outputs. These results are used to demonstrate feasibility by quantifying ExoplanetSat pointing accuracy, signal-to-noise ratio, minimum guide star magnitude, and additional design parameters which determine system performance.

7731-79, Session 20

ACCESS: a concept study for the direct imaging and spectroscopy of exoplanetary systems

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ACCESS is one of four medium-class mission concepts selected for study in 2008/9 by NASA's Astrophysics Strategic Mission Concepts Study program. In a nutshell, it evaluates a space telescope designed

for extreme high-contrast imaging and spectroscopy of exoplanetary systems. An actively-corrected coronagraph is used to suppress the glare of diffracted and scattered starlight to the levels required for exoplanet imaging. The ACCESS study asks: what is the most capable medium-class coronagraphic mission that is possible with telescope, instrument, and spacecraft technologies available today?

The ACCESS study has compared the performance and readiness of four major coronagraph architectures. It defined a conceptual space observatory platform as the “level playing field” for comparisons among coronagraph types. And it uses laboratory validation of four representative coronagraph types as a second “level playing field” for assessing coronagraph hardware readiness. ACCESS identifies a genre of scientifically compelling mission concepts built upon mature (TRL6+) subsystem technologies, and evaluates science reach of a medium-class coronagraph mission. Using demonstrated high-TRL technologies, the ACCESS minimum science program surveys the nearest 120+ AFGK stars for exoplanet systems, and surveys the majority of those for exozodiacal dust to the level of 1 zodi at 3 AU. Discoveries are followed up with R=20 spectrophotometry.

7731-80, Session 20

The pupil mapping exoplanet coronagraphic observer (PECO)

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The Pupil-mapping Exoplanet Coronagraphic Observer (PECO) mission concept is a 1.4-m space-based coronagraphic telescope optimized to image exoplanets and disks at optical wavelengths and characterize them through low resolution spectroscopy and polarimetry. Thanks to a high efficiency Phase-Induced Amplitude Apodization (PIAA) coronagraph, PECO can deliver 1e10 contrast at 2 lambda/D separation (0.15”). This efficient coronagraph is combined with a multi-wavelength imaging system which splits with dichroics incoming light into 16 spectral channels. PECO thus utilizes nearly all available visible photons from 0.4 to 0.9 micron for maximum wavefront sensing and sensitivity for imaging and spectroscopy. Coronagraph and wavefront control technologies essential to PECO are currently under development and performance validation in laboratories at NASA Ames and NASA JPL.

PECO will image the habitable zones of about 20 known F, G, K stars at a spectral resolution of R~15 with sensitivity sufficient to detect and characterize Earth-like planets and to map dust disks to within a fraction of our own zodiacal dust cloud brightness. A possible astrometric mode, detailed in a separate paper and currently under study, could also allow measurement of the exoplanets’ masses.

7731-81, Session 20

Optical design of dilute aperture visible nulling coronagraph imaging (DAViNCI)

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This paper presents the optical design of the Dilute Aperture Visible Nulling Coronagraph Imaging (DAViNCI). DAViNCI’s dilute aperture approach to the TPF-C extra-solar earth-like detection mission reduces cost and technical risk compared to other filled aperture approaches. DAViNCI has been studied in an ASMCS (Astrophysics Strategic Mission Concept Study and is included within the ASTRO2010 Decadal review.

Since such planets would lie very close to their parent star, large telescope apertures are required to achieve the needed small value for Inner Working Angle (IWA). The DAViNCI is a phased-dilute-aperture-array telescope with the Visible Nulling Coronagraphic (VNC) in a Dual Visible Nulling Interferometer (DVNI) configuration designed to detect and study extra-solar earth-like planets. It uses the VNC technique to reject the bright parent star and reveal dim companions, even earth-like planets in their habitable zone.

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7731-82, Session 20

Visible nulling coronagraphy testbed development for exoplanet detection

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We report on the laboratory development of two Visible Nulling Coronagraph (VNC) testbeds at the NASA/Goddard Space Flight Center. The first testbed is vacuum testbed with a modified “W” configuration to accommodate a hex-packed MEMS-based 16-bit deformable mirror, coherent fiber bundle and achromatic phase shifters. The 2nd testbed is the compact nuller, a textbook sized dimensionally stable and athermally designed VNC. Discussed will be recent narrow- and broad-band results from the first testbed operating in closed-loop for wavefront and amplitude and we discuss the ongoing development of the compact nuller and its possible application to ground, space and balloon-borne missions.

7731-83, Session 20

Single aperture imaging astrometry with a diffracting pupil: application to exoplanet mass measurement with a small coronagraphic space telescope

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High precision (micro-arcsecond) astrometry of nearby bright stars is theoretically (in the photon noise limit) possible with a space coronagraph with the addition of a wide field diffraction limited camera imaging an annulus of background stars around the central coronagraphic field. The astrometric measurement is performed by simultaneously imaging a large number of faint background stars and diffraction spikes from the bright coronagraphic target on the same focal plane array. The diffraction spikes are generated by a series of small dark spots on the primary mirror. Because the diffraction spikes used for astrometric reference are created

on the primary mirror, this scheme provides some immunity to distortions of the telescope optics, the camera optics or the camera focal plane array.

With micro arcsecond accuracy on a 1.4-m telescope, the mass of all planets that can be imaged by the coronagraph would be estimated. Simultaneous imaging and astrometric measurements would reduce the number of astrometric measurements necessary for mass determination, and reduce confusion between multiple planets and possible exozodiacal clouds.

While scientifically attractive, this measurement is technically very challenging, and must overcome astrometric error terms, which, in conventional telescopes, are several orders of magnitude above the photon noise limit. This paper investigates how some of these limitations could be overcome with new technical approaches, and identifies outstanding issues.

7731-84, Session 20

Laboratory demonstration of high-contrast imaging at 2 lD enabled by temperature stabilization of the testbed

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Direct imaging of extrasolar planets in visible light, and Earth-like planets in particular, is an exciting but difficult problem requiring a telescope imaging system with 1e10 contrast at separations of 100mas and less. Furthermore, only a small 1-2m space telescope may be realistic for a mission in the foreseeable future, which puts strong demands on the performance of the imaging instrument. Fortunately, an efficient coronagraph called the Phase Induced Amplitude Apodization (PIAA) coronagraph may enable Earth-like planet imaging for such small telescopes if any exist around the nearest stars. In this paper, we report on the latest results from a new testbed at NASA Ames focused on testing the PIAA coronagraph. This laboratory facility was built in 2008 and is designed to be flexible, operated in a highly stabilized air environment, and to complement efforts at NASA JPL's High Contrast Imaging Testbed. For our wavefront control we are focusing on using small Micro-Electro-Mechanical-System deformable mirrors (MEMS DMs), which promises to reduce the size of the beam and overall instrument, a consideration that becomes very important for small telescopes. During last year's SPIE meeting, we presented a demonstration of ~1e-7 contrast between 2 and 5 l/D in monochromatic light. At this meeting, we will present our new results enabled by active temperature stabilization of our testbed. In addition, we will present an analysis of our current limits and solutions to overcome them.

7731-85, Session 21

The new worlds probe

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The New Worlds Observer is a flagship-scale terrestrial planet finding and characterizing mission using an external occulter known as a starshade. The starshade is a separate space vehicle from the observing telescope; the starshade performs all the necessary starlight suppression to enable high contrast imaging of terrestrial exo-planets. While effective as a flagship-scale mission designed to fulfill and exceed the requirements of the TPF mission, the starshade architecture is flexible and can accommodate a variety of design and cost categories, including working with an existing telescope. We present in this paper the an architecture designed to fly a starshade with JWST, a mission concept we call New Worlds Probe, that can deliver many of the TPF mission requirements for significantly lower mission cost. We give an overview of the science capabilities, the starshade design, and starshade-JWST cooperative operation.

7731-86, Session 21

Demonstration of polychromatic suppression and occulter position sensing at the Princeton occulter testbed

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The Princeton occulter testbed uses long-distance propagation with a diverging beam and an optimized occulter mask to simulate the performance of external occulters for finding extrasolar planets. We present new results from the testbed using upgraded silicon masks, both in monochromatic and polychromatic light. In addition, we show sensing and control of occulter position using out-of-band spectral leak around the occulter, and examination of tolerancing on occulter positioning. These results are validated by numerical simulations of propagation through the system.

7731-87, Session 21

Error budgeting and tolerancing of starshades for exoplanet detection

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A starshade positioned between a star and a space telescope may be a viable means of blocking the starlight to reveal the faint reflected light of an orbiting Earth-like planet. The starshade payload is an opaque central disk surrounded by tapered petals with a science-dependent total diameter of 30-80 m. The shade is placed 30,000-80,000 km in front of the telescope and within ~ 1 m of the line of sight to the star. The petal shape diffracts the starlight creating a dark shadow surrounding the telescope. Planet light goes around the starshade and directly enters the telescope where it is seen against a background of scattered light from the occulter. In this paper we describe the error budgeting process and tolerancing of starshades for Earth-imaging systems. We discuss the various perturbations and imperfections that scatter starlight, including global petal motions, individual petal deformations, manufacturing, deployment, dynamic errors, and starshade alignment. We present a case for allocations based on likely manufacturing approaches and show that the occulter tolerances appear to be within the state of the art.

7731-88, Session 21

Occulting ozone observatory science overview

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We present an analysis of the Occulting Ozone Observatory (O3) - a $1 billion class mission dedicated to finding extra-solar planets down to Earth size, performing photometric characterizations of planets and disks, and general astrophysics. We present trade studies for the observatory, composed of a 1.1 to 1.5m telescope based on heritage imaging systems and complementary sized free-flying occulter spacecraft, to maximize the expected science yield for this intermediate mission class. We explore the possible science returns from photometric characterization in four filters each in the 250-550nm and 500-1100nm bands, including the detection of atmospheric ozone in Earth-like planets, methane in gas giants, determination of spin rotation periods, characterization of surface composition of rocky planets and the observatory's expected orbital fitting capability. We present multiple different mission designs along with the expected number of planetary detections and characterizations. These are compared with the expected results from a similar class of exoplanet missions.

7731-89, Session 21

Direct imaging and spectroscopy of terrestrial planets using a starshade with JWST

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In this paper we discuss the science goals and capabilities of the New Worlds Probe (NWP) for the James Webb Space Telescope. This concept uses an external occulter (or starshade) to cast a shadow from the star onto the telescope, therefore canceling the direct star light while the light from a planet is not affected. We discuss the sensitivity of JWST with a starshade and show that this concept enables JWST to take images and spectra of extrasolar planets with sufficient contrast and inner working angle to be able to discover planets down to the size of the Earth in the habitable zone around nearby stars. We discuss imaging capabilities using broadband filters with NIRCam and spectroscopic capabilities using the NIRSpec spectrograph. We present simulations results for giant planets and terrestrial planets images and spectra and discuss a design reference mission for the mission lifetime.

7731-90, Session 21

Alternative starshade missions

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Starshades have been shown to hold the potential to reveal Earth-like planets around nearby stars and allowed detailed follow-up study including spectroscopy. Ideally this would be performed with starshade in excess of 50m diameter and a telescope over 4m in diameter. However, such a flagship-class mission is unlikely to be realized in under fifteen years. But much can be accomplished in substantially less expensive missions. I will review the alternatives and provide an assessment of various architectures and what they can accomplish. These alternatives will include using JWST as the telescope, using small dedicated telescopes, and using smaller starshades.

7731-91, Session 22

Science flowdown requirements for ATLAST: implications for technology development and synergies with other future facilities

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The Advanced Technology Large-Aperture Space Telescope is a concept for an 8-meter to 16-meter UVOIR space observatory for the 2025-2035 era. ATLAST will allow astronomers to perform some of the most challenging observations to answer some of our most compelling questions, including "Is there life elsewhere in the Galaxy?" We present here the science drivers that flowdown into the performance requirements for ATLAST (8 to 16 milliarcsec angular resolution, diffraction limited imaging at 500 nm, minimum collecting area of 45 square meters, sensitivity from 110 nm to 2400 nm, high stability in WF control). We will also discuss the synergy between ATLAST and other anticipated future facilities (e.g., TMT, EELT, GSMT, and ALMA).

7731-92, Session 22

Comparative concepts for ATLAST optical designs

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The ATALST (Advanced Technology for Large Aperture Space Telescopes) effort has presented several design incarnations, including monolithic, segmented, and off-axis concepts. Each presents various attributes to the optical design process, including sensitivities and alignment/wavefront sensing characteristics and science instrument compliments. Here we will compare the similarities and differences between three specific designs, the 9.2m segmented concept, the 8m monolithic on-axis and 8m x 6m off-axis concepts.

Details of design process will be discussed, including size, packaging, and science instrument constraints. Analysis will be given of the wide-field wavefront and the component sensitivities analysis. The wavefront-based alignment processes will be discussed and its impact on the design parameters.

7731-93, Session 22

ATLAST-9.2m: a large aperture deployable space telescope

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We present the results of a study of a deployable version of the Advanced Technology Large Aperture Space Telescope (ATLAST), designed to operate in a Sun-Earth L2 orbit. This non-cryogenic telescope will have unprecedented spatial resolution and sensitivity from the ultraviolet to near infrared. The observatory design includes significant heritage from JWST, as well as several changes to the JWST architecture, some of which are required in order to meet the demanding wavefront error requirements at visible wavelengths. The primary mirror of the segmented 9.2-meter aperture has 36 hexagonal 1.315m (flat-to-flat) glass mirrors. The folding of the telescope is similar to JWST, allowing it to fit into the 6.5m fairing of a modest upgrade to the Delta-IV Heavy version of the Evolved Expendable Launch Vehicle (EELV). We discuss the overall observatory design, optical design, instruments, stray light, wavefront sensing and control, pointing and thermal control, and in-space servicing options.

7731-94, Session 22

ATLAST-8 Mission concept study for 8-meter Monolithic UV/Optical Space Telescope

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ATLAST-8 is an 8-meter monolithic UV/optical/NIR space observatory to be placed in orbit at Sun-Earth L2 by NASA's planned Ares V cargo launch vehicle. ATLAST-8 will yield a broad range of astronomical breakthroughs. This paper summarizes the results of a mission concept study which developed detailed point designs for the optical telescope assembly and spacecraft. Specific study areas included optical design, structural design, thermal performance and control, pointing control, wavefront sensing and control, spacecraft design, momentum management, mass and power budgets, etc. For the optical design, both on-axis and off-axis configurations were examined. ATLAST-8 is specifically designed to be serviceable.

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SPIE Astronomical Instrumentation

7732-01, Session 1

Fabrication of FORTIS

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The Johns Hopkins University sounding rocket group is building the Far-ultraviolet Off Rowland-circle Telescope for Imaging and Spectroscopy (FORTIS), which is a Gregorian telescope with rulings on the secondary mirror. FORTIS will be launched on a sounding rocket from White Sand Missile Range to study the relationship between Lyman alpha escape and the local gas-to-dust ratio in star forming galaxies with non-zero redshifts. It is designed to acquire images of a 30' x 30' field and provide fully redundant "on-the-fly" spectral acquisition of 43 separate targets in the field with a bandpass of 900 — 1800 Angstroms. FORTIS is an enabling scientific and technical activity for future cutting edge far- and near-uv survey missions seeking to: search for Lyman continuum radiation leaking from star forming galaxies, determine the epoch of He II reionization and characterize baryon acoustic oscillations using the Lyman forest. In addition to the high efficiency "two bounce" dual-order spectro-telescope design, FORTIS incorporates a number of innovative technologies including: an image dissecting microshutter array developed by GSFC; a large area (~ 45 mm x 170 mm) microchannel plate detector with central imaging and "outrigger" spectral channels provided by Sensor Sciences; and an autonomous targeting microprocessor incorporating commercially available field programable gate arrays. We discuss progress to date in developing our pathfinder instrument. NASA sounding rocket grant to JHU NNG08AM68G supports this work.

7732-02, Session 1

Large-format, high-spatial, and temporal resolution cross-strip readout MCP detectors for UV astronomy

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Most space-based UV missions (eg. FUSE, GALEX and COS) have employed microchannel plate (MCP) imaging detectors with delay line readouts in their focal planes to take advantage of their photon counting sensitivity and large (and flexible) formats. Future missions (THEIA, NWO, HORUS and ATLAST) require even larger formats (> 100 mm) with higher event rate throughput (~ MHz). To address this issue we have been developing the cross-strip (XS) readout anode, which can encode an MCP event position and time (X,Y,T) to better than 20 microns and 1 ns resolution respectively. This is achieved using ASIC amplifiers and ADCs (one per strip) and a massively parallel input to a high speed FPGA which calculates the centroid and time of every event. In the laboratory, we have achieved this resolution at output rates exceeding 2 MHz.

We will present these imaging and timing results for our 40 mm XS detector and describe an ASIC development effort to design and fabricate a new front end ASIC that combines a state of the art, fast charge sensitive amplifier with fast sampling analog storage and built in ADCs. The strip signals from this ASIC(s) go directly to a flight-qualified FPGA through high speed LVDS lines, gaining a factor of 10 in throughput without sacrificing spatial resolution or low gain operation capability. These ASICs will form the foundation of a set of flight qualified electronics that can support > 100 x 100 mm detector formats at photon rates of > 30 MHz with low power and mass.

7732-03, Session 1

Ultraviolet detectors for low surface brightness astronomy

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We report on an on-going program to develop photon counting detectors for ultraviolet imaging and spectroscopy. Experience with MCP-based detectors on GALEX and high altitude balloon payloads underscores the necessity of high QE and zero read noise for detection of low surface brightness astronomical sources. Even the low read noise of modern solid state detectors renders these faint features undetectable. We are therefore engaged in a program to advance the current state of the art by combining mature technologies in a new way to improve detector sensitivity over what has recently been available for flight programs. In our paper we will report on the design of our detector, first results from laboratory characterization, and prospects for a flight demonstration.

7732-04, Session 1

FIREBALL-the faint intergalactic redshifted emission balloon: an overview

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The Faint Intergalactic Redshifted Emission Balloon (FIREBALL) is a balloon borne 1 meter UV alt-azimuth mount telescope and integral field spectrograph. It takes advantage of the atmospheric UV window around 200 nm allowing the use of the OVI, Lyman alpha and CIV transitions to probe diffuse emission from the Intergalactic and Circumgalactic media in the redshift range $0.3 < z < 1.2$. The 2.5' diameter field of view is sampled by 400 closely packed optical fibers which inject the collected photons into a modified Offner spectrograph based on a holographic

diffraction grating yielding spectral resolution R~5000. The light is collected by a legacy GALEX NUV microchannel-plate detector. Sub-fiber telescope pointing accuracy is achieved using a series of sensors, feedforward and feedback loops. The gondola is constructed as a carbon fiber and aluminum space-frame that serves as the mechanical skeleton and a athermalized optical bench for the instrument. FIREBALL had its second flight on June 9th, 2009. It collected data for approximately 6 hours. We present an overview the instrument goals, design, in-flight performance and outline planned improvements.

7732-05, Session 1

The Colorado high-resolution Echelle stellar spectrograph (CHESS) concept and design

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We discuss the design of a new high efficiency, high resolution far ultraviolet echelle spectrograph. Our project concentrates on utilizing new technologies for gratings and detectors to reduce the impact of scattered light and maximize quantum efficiency over a large bandpass. Advances in a vast number of astrophysical subjects will be enabled by this program. Topics ranging from protoplanetary disks to the intergalactic medium can be addressed by incorporating such a spectrograph into a future, long duration mission.

7732-06, Session 1

The diffuse interstellar cloud experiment: integration and first-look data

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We present the Diffuse Interstellar Cloud Experiment (DICE) integration and first-look data. DICE consists of a Cassegrain telescope followed by a modified Rowland spectrograph. Our design is a spherical grating followed by a spherical magnifying optic, to achieve an effective 7 meter throw in a 1 meter spectrograph. Our design provides spectral resolution (lambda/dlambda) of 60,000 in our bandpass, 1020 - 1040 Angstroms. DICE observed two stars on opposing sides of the Local Bubble wall. The spectra of the OVI doublet in absorption towards these stars provides new insight into the processes governing hot gas near the cavity wall.

7732-07, Session 2

XMM-Newton: ESA's X-ray Observatory ready for the next decade

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ESAs XMM-Newton space observatory is the flagship of European X-ray astronomy. After launch from Kourou, French Guiana on 10 December 1999, it is the most powerful X-ray telescope ever placed in orbit. The mission is solving many cosmic mysteries of the hot X-ray universe observing objects like neutron stars, black holes or active galaxies.

The mission was originally designed for a 10 years life time, however since space craft and instruments are operating admirably without major degradation it is planned to operate the observatory long into the next decade, our only limitation being the hydrazine resources.

In 2008 due to an antennae switch problem contact was lost to the satellite. However after a major recovery XMM-Newton is back online to serve the X-ray community with unaffected efficiency.

We will describe the health status of space craft (AOCS, power, thermal, R/F) and instruments with a special view on energy resolution and cleanliness status. The 2008 recovery will be described and the lessons learned during 10 years of operations which lead to the operations strategies to operate XMM long into the next decade.

7732-08, Session 2

X-ray telescope design and technology: what the future may hold

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The great X-ray Observatories of the 20th Century relied exclusively on the Wolter Type I optics design to provided true imaging in the energy band 0.1-10 keV. What are the prospects for continued development of the W-I geometry in the 21st Century and what alternative designs, technologies and bright ideas maybe poised to make an impact in the future.

7732-09, Session 2

Foil x-ray mirrors for astronomical observations: still an evolving technology

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Foil X-ray mirrors, introduced by the Goddard X-ray Group in the late 1970s, were envisioned as an interim and complementary approach toward increased sensitivity for small inexpensive astronomical instruments. The extreme light weight nature of these mirrors dovetailed beautifully with Japan's small payload missions, leading to several collaborative, earth orbiting observatories, designed primarily for spectroscopy, of which SUZAKU is still in earth orbit. Astro-H is the latest joint instrument with Japan, presently in the implementation phase. At Goddard, some 30 years after we introduced them, we are involved with four separate flight instruments utilizing foil X-ray mirrors, a good indication that this technology is here to stay. Nevertheless, an improved spatial resolution will be the most welcomed development by all. The task of preparing upwards of 1000 reflectors, then assembling them into a single mirror with ~arcmin resolution remains a formidable one. Many, performance limiting approximations become necessary when converting commercial aluminum sheets into 8 quadrant segments, each with ~200 nested conical, ~4Å reflectors, which are then assembled into a single mirror. In this paper we will describe the mirror we are presently involved with, slated for the Goddard high resolution imaging X-ray spectrometer onboard Astro-H. Improved spatial resolution will be an important enhancement to the science objectives from this instrument. We are accordingly pursuing and will briefly describe in this paper several design and reflector assembly modifications, aimed toward that goal.

7732-10, Session 2

Light-weight optics made by thermal glass forming for future x-ray telescopes

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Future X-ray observatory missions, such as IXO or Gen-X, require grazing incidence optics of large collecting area in combination with a very good

angular resolution. Wolter type I X-ray telescopes made of slumped glass segments could be a possible alternative to silicon pore optics. To achieve these requirements we develop slumping methods for high accuracy segments by experimental means. In particular, we follow the approach of indirect slumping and make segments with parabola and hyperbola part in one piece.

In order to avoid internal stress in the glass segments the thermal expansion coefficient of the glass must closely match the thermal expansion of the mould material. After studies of different mould/glass materials we find the combination of the alloy KOVAR for the mould and D263 for the glass fulfils this requirement.

The design of different metrology methods to measure the figure and thickness variations of the glass segments in visual light, e.g. interference, is under way. We report on our laboratory experiments and on the current studies to build up a design model for X-ray tests.

7732-11, Session 2

Hot slumping glass technology for the grazing incidence optics for future missions

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The requirements on the mirror effective area of the International X-ray Observatory (IXO) mission are of >3 m2 at 1.25 keV, with an angular resolution better than 5 arcsec. Two technical solutions are under investigation for these mirrors, either the use of “Pore Optics” or of “thin glass foils”. In the latter case these foils are bended above a suitable mould in order to copy its optical geometry and preserving the good initial micro-roughness typical of the glass. The activities ongoing in Europe on thin glass foils, financed by ESA and led by the Brera Astronomical Observatory, foresee the development of 200x200 mm thin glass Mirror Plates (MP) in Wolter-I configuration. We are investigating two approaches: the Direct Slumping, that needs a convex mould, and the Indirect Slumping, that needs a concave mould. In the first case the optical surface of the glass is put in direct contact with the convex surface of the mould during the thermal cycle. In the second case the back of the optical surface of the glass is put in contact with the concave surface of the mould. After the thermal cycle the slumped MPs will be optically characterized to define their optical quality and micro-roughness. Here we will report the results obtained with both approaches, discussing their pros and cons and selecting the one that provides the best results. We will also present the results, including X-ray tests, obtained for a demonstrative module consisting of 3+3 (parabola+hyperbola) MPs fabricated with the selected approach.

7732-12, Session 2

Design and development by direct polishing of the polynomial mirror shells

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The Wide Field X-ray Telescope (WFXT) is a medium class mission addressing key questions about cosmic origins and physics of the cosmos through an unprecedented X-ray survey. In order to get the desired angular resolution on the entire 1 degree FOV, the design is based on polynomial profiles, focal plane curvature and plate scale corrections. This design guarantees an increased angular resolution at large of-axis position with respect to the usually used Wolter I configuration. The telescope assembly is composed by three identical modules of around 80 shells each, with diameter up to 1.1 m. A deterministic direct polishing method to manufacture large size grazing-incidence mirrors made by Silicon Carbide or Quartz could meet the requirements in terms of angular resolution and mass. Our approach is based on two main steps: first the shells are grinded to conical profiles, and then they are polished to the required polynomial profiles by CNC polishing machine. In this paper, the results of the grinding and polishing of prototypes made by SiC and Fused Quartz with low thickness representative of the optical design will be presented together with x-ray measurements and calibration performed in full illumination configuration. An assessment on the two materials will also be presented based both on technical and cost-schedule evaluation.

7732-13, Session 3

Figures of merit for detection and measurement of x-ray polarization

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Over 3 decades ago, we introduced the “Minimum Detectable Polarization” (MDP) as a figure of merit for detection of polarization in data governed by Poisson statistics. Since then, however, the MDP has on occasion been used implicitly to characterize the sensitivity for measurement of polarization. Here, we review the (Poisson) statistical properties of polarization data, and show examples which illustrate the distinction between MDP and measurement sensitivity.

7732-14, Session 3

Broad-band soft x-ray polarimetry

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We developed an instrument design capable of measuring linear X-ray polarization over a broad band using conventional spectroscopic optics. A set of multilayer-coated flats reflects the dispersed X-rays to the instrument detectors. The intensity variation with position angle is measured to determine three Stokes parameters: I, Q, and U — all as a function of energy. By laterally grading the multilayer optics and matching the dispersion of the gratings, one may take advantage of high multilayer reflectivities and achieve modulation factors >50% over the entire 0.2 to 0.8 keV band. This instrument could be used in a small orbiting mission or scaled up for the International X-ray Observatory. Laboratory work has begun that would demonstrate the capabilities of key components.

7732-15, Session 3

Hard x-ray polarimetry with HX-POL

A. B. Garson III, K. Lee, J. Martin, M. Beilicke, H. S. Krawczynski, Washington Univ. in St. Louis (United States); E. Wulf, E. Novikova, U.S. Naval Research Lab. (United States)

X-ray polarimetry offers a unique vantage to investigate particle acceleration from compact objects and relativistic outflows. The HX-POL concept uses a combination of Si and Cadmium Zinc Telluride (CZT) detectors to measure the polarization of 50 keV - 500 keV X-rays from cosmic sources through the azimuthal distribution of Compton scattered events. HX-POL would allow us to measure the polarization degrees of

Crab-like sources well below 10% for a one day balloon flight. A longer (15-30 day) flight would improve the polarization degree sensitivity to a few percent. In this contribution, we discuss the sensitivity of a space-borne HX-POL payload, and compare the sensitivity achieved with other hard X-ray polarimeters discussed in the literature. Furthermore, we present new results from laboratory tests of the HX-POL Si and CZT detectors.

7732-16, Session 4

The building of Fermi-LAT

W. B. Atwood, Univ. of California, Santa Cruz (United States)

The path which resulted in GLAST, now Fermi-LAT, is reviewed. The interplay between simulations and design choices is shown through examples. How the completed instrument compared to expectations once on orbit is discussed. Also considered are the “lessons learned” by way of providing guidance for future high energy gamma ray missions. Lastly we discuss what the lasting impacts of Fermi-LAT on High Energy Gamma Ray Astronomy maybe.

7732-17, Session 4

The tracker of the Fermi Large Area Telescope

R. P. Johnson, Univ. of California, Santa Cruz (United States)

The Large Area Telescope (LAT) is the primary instrument on the Fermi Gamma-ray Space Telescope (Fermi), an orbital astronomical observatory that was launched on 11 June 2008. Its tracker is a solid-state instrument that converts the gamma rays into electron-positron pairs which it then tracks in order to measure the incoming gamma-ray direction. The tracker comprises 36 planes of single-sided silicon strip detectors, for a total of 73 square meters of silicon, read out by nearly 900,000 amplifier-discriminator channels. The system operates on only 160 W of conditioned power while achieving >99% single-plane efficiency within its active area and better than 1 channel per million noise occupancy. It has operated flawlessly, with excellent stability, on orbit since launch. We describe the tracker’s design and performance and discuss improvements still in progress to improve the offline reconstruction of gamma-ray events.

7732-18, Session 4

The calorimeter for the Fermi Large Area Telescope

J. E. Grove, W. N. Johnson III, U.S. Naval Research Lab. (United States)

The Large Area Telescope (LAT) is the primary instrument on the Fermi Gamma-ray Space Telescope (Fermi), an orbital astronomical observatory that was launched on 11 June 2008. Its calorimeter is a 4-by-4 array of 16 modules supporting spectral measurements in the LAT’s 20 MeV to 300 GeV energy range. Each calorimeter module contains 96 CsI crystals mounted in a carbon fiber composite structure, for a total of 1536 crystals. The relative pulse heights of the signals acquired from silicon PIN photodiodes at each CsI crystal end yield the position of charge deposition to within 9 mm for a singly charged minimum ionizing particle, and better for larger energy deposits. The hodoscopic crystal stack allows crude tracking complementary to that provided by the LAT silicon tracker. The signals are processed by custom analog ASICs and commercial ADCs, and calibrated using cosmic ray muons and charge injection. Repeated environmental tests demonstrated stable functioning over the years of assembly and test. It has been operating stably on orbit since launch. Various accelerator particle beams were used to further verify performance, and to compare the response with predictions from detailed Monte Carlo simulations. We describe the calorimeter design and its performance.

7732-19, Session 4

Performance of the anti-coincidence detector for the Fermi Large Area Telescope

E. Hays, NASA Goddard Space Flight Ctr. (United States) and Fermi LAT Collaboration (United States)

The Large Area Telescope (LAT) on the Fermi Gamma-ray Space Telescope provides survey coverage of the entire sky in gamma rays from energies of 20 MeV to >300 GeV. The Anti-Coincidence Detector (ACD), one of three LAT subsystems, plays a key role in identifying and rejecting cosmic rays, which dominate the detected event population. The ACD combines 89 plastic scintillator tiles and 8 scintillating fiber ribbons into a segmented shell surrounding the LAT Tracker subsystem. The efficiency for detection of charged particles exceeds 99.97%. This paper will review the key design considerations for the ACD and present the in-flight performance since launch in June 2008. We will highlight the importance of monitoring and calibration of the ACD to maintaining the high quality of the LAT data throughout the lifetime of the mission.

7732-20, Session 5

The origin of the elements as seen through supernova remnants

A. C. Decourchelle, Commissariat à l’Énergie Atomique (France)

Supernovae are the main site of heavy element production in galaxies. Observing their remnants at a relatively early stage of a few hundred years after the explosion provides a direct view of the main elements synthesized by various supernova types. While current observations offer a number of diagnostics and relevant information on the ejected material, further progress is hampered by the performance of current instruments. I will discuss the main science drivers in the field of supernova remnants and the scientific requirements for their study with future instruments.

7732-21, Session 5

Black hole astrophysics: future perspectives

K. Nandra, Imperial College London (United Kingdom)

The last 15 years have seen a revolution in our understanding of both the near environment of black holes, and their role in the wider universe. Despite major progress, many questions remain. We are only beginning to understand how observations can be used to determine the fundamental black hole parameters, the nature of the inner accretion flow, and the influence of black hole growth on galaxy evolution. I will review current observations and look forward to how future facilities can contribute towards addressing these key questions in black hole astrophysics.

7732-22, Session 5

What we do not know yet, and need to know, about clusters of galaxies

M. L. Markevitch, Harvard-Smithsonian Ctr. for Astrophysics (United States)

Clusters of galaxies are the most massive gravitationally bound structures in the Universe, sitting at the intersections of giant filaments of cosmic matter. They can be used for sensitive cosmological tests. Such tests require much larger cluster samples at different redshifts, and a much better understanding of the cluster physics than we have today. I will discuss what X-ray instrumentation we would like to have to realize the clusters’ cosmological potential.

7732-23, Session 5

Annihilation of positrons in the galaxy: new physics or conventional astrophysics?

E. Churazov, Max-Planck-Institut für Astrophysik (Germany)

Although the annihilation line at 511 keV is the brightest gamma-ray line in the Galaxy, the origin of the positrons, powering this line, is not firmly established. The reason for the uncertainty is the abundance of widely different channels of positron production, ranging from the dark matter annihilation to beta decay of radioactive isotopes. Some of these channels are known to be real, while others are hypothetical and require new physics. The current status of observations and theoretical models will be discussed. We also speculate on what observations might provide a definitive answer.

7732-24, Session 6

First lights of SWAP on-board PROBA2

J. A. Halain, Ctr. Spatial de Liège (Belgium); D. Berghmans, Royal Observatory of Belgium (Belgium); J. Defise, E. Renotte, T. Thibert, E. Mazy, P. L. P. M. Rochus, Ctr. Spatial de Liège (Belgium); B. Nicula, A. De Groof, Royal Observatory of Belgium (Belgium); U. H. Schühle, Max-Planck-Institut für Sonnensystemforschung (Germany); M. Ravet-Krill, Institut d'Optique (France)

The SWAP telescope (Sun Watcher using Active Pixel System detector and Image Processing) is an instrument launched on 2nd November 2009 on-board the ESA PROBA2 technological mission.

SWAP is a space weather sentinel from a low Earth orbit, providing images at 175nm of the solar disk. The instrument concept has been adapted to the PROBA2 mini-satellite requirements (compactness, low power electronics and a-thermal opto-mechanical system). It also takes advantage of the platform pointing agility, on-board processor, Packetwire interface and autonomous operations.

The key component of SWAP is a radiation resistant CMOS-APS detector combined with onboard compression and data prioritization. SWAP has been developed and qualified at the Centre Spatial de Liège (CSL) and calibrated at the PTB-Bessy facility. After launch, SWAP has provided its first images on 14th November 2009 after 1 month of commissioning.

This paper summarizes the SWAP development and qualification and presents the first light results.

7732-25, Session 6

Development of double-sided silicon strip detectors for solar hard x-ray observation

S. Saito, I. Shin-nosuke, Japan Aerospace Exploration Agency (Japan) and The Univ. of Tokyo (Japan); S. Watanabe, Japan Aerospace Exploration Agency (Japan); H. Odaka, S. Sugimoto, T. Fukuyama, Japan Aerospace Exploration Agency (Japan) and The Univ. of Tokyo (Japan); M. Kokubun, Japan Aerospace Exploration Agency (Japan); T. Takahashi, Japan Aerospace Exploration Agency (Japan) and The Univ. of Tokyo (Japan); Y. Terada, Saitama Univ. (Japan); H. Tajima, T. Tanaka, Stanford Univ. (United States); S. Krucker, Univ. of California, Berkeley (United States); S. Christe, NASA Goddard Space Flight Ctr. (United States); S. McBride, L. Glesener, Univ. of California, Berkeley (United States)

The Focusing Optics X-ray Solar Imager (FOXSI) is a rocket experiment scheduled for late 2010 launch, which intends to explain coronal heating mechanism by observations of 5-15 keV hard X-ray emission from the quiet-region solar flares.

For observing faint hard X-ray emission, FOXSI uses telescopes and attains 50 times higher sensitivity than RHESSI, the present solar HXR observing satellite. Now our group is working on the development of both Double-sided Silicon Strip Detector (DSSD) used in the focal plane and the readout ASIC.

Our DSSD has a very fine pitch of 75 um, which makes the angular resolution of the telescope less than 7 arcseconds. It also has a high spectral resolution and efficiency in the FOXSI's energy range of 5-15 keV, combined with our 64 channel analog ASIC with the function of parallel AD conversion.

In advance of the FOXSI launch, we have established and tested a setup of the detector bonded with ASIC. We have successfully read out from almost all the channels of the detector, and proved the ability to make a shadow image. We also confirmed that our DSSD has the energy resolution of 1.0 keV, that means we have the low energy threshold suited for FOXSI.

In the presentation, we will explain the latest performance of our DSSD also with the detail of our readout system.

7732-26, Session 6

The technical challenges of the solar-orbiter EUI instrument

J. A. Halain, P. L. P. M. Rochus, L. Jacques, E. Renotte, Ctr. Spatial de Liège (Belgium); D. Berghmans, J. Hochedez, A. Zhukov, E. Pylyser, Royal Observatory of Belgium (Belgium); U. H. Schühle, Max-Planck-Institut für Sonnensystemforschung (Germany); L. Harra, T. E. Kennedy, Mullard Space Science Lab. (United Kingdom); T. P. Appourchaux, F. Auchère, Institut d'Astrophysique Spatiale (France)

The Extreme Ultraviolet Imager (EUI) onboard Solar Orbiter consists of a suite of two high-resolution imagers (HRI) and one dual-band full Sun imager (FSI) that will provide EUV and Lyman- images of the solar atmospheric layers above the photosphere.

The EUI instrument is based on a set of challenging new technologies allowing to reach the scientific objectives and to cope with the hard space environment of the Solar Orbiter mission.

The mechanical concept of the EUI instrument is based on a common structure supporting the HRI and FSI channels, and a separated electronic box. A heat rejection baffle system is used to reduce the Sun heat load and provide a first protection level against the solar disk straylight. The spectral bands are selected by thin filters and multilayer mirror coatings. The detectors are 10µm pitch back illuminated CMOS Active Pixel Sensors (APS), best suited for the EUI science requirements and solar radiation harness.

This paper presents the EUI instrument concept and its major sub-systems. The current developments of the instrument technologies are also summarized.

7732-27, Session 7

The nuclear spectroscopic telescope array (NuSTAR)

F. A. Harrison, California Institute of Technology (United States); S. E. Boggs, Univ. of California, Berkeley (United States); F. E. Christensen, DTU Space (Denmark); W. W. Craig, Univ. of California, Berkeley (United States); C. J. Hailey, Columbia Univ. (United States); D. Stern, Jet Propulsion Lab. (United States)

The Nuclear Spectroscopic Telescope Array (NuSTAR) will be the first focusing telescope on orbit to image the hard X-ray (6 0 80 keV) sky. Using grazing incidence optics with multilayer coatings for enhanced high energy reflectance and field of view, NuSTAR will provide an unprecedented combination of sensitivity and spectral and angular resolution. The NuSTAR instrument consists of two coaligned telescopes with a 10.14-m focal length. The primary objectives of the two-year primary science mission include surveying extragalactic fields to constrain the evolution of super massive black holes, deep observations of the Galactic center region to study compact stellar remnants, and mapping young supernova remnants in the radioactive lines from 44Ti.

7732-28, Session 7

The nuclear spectroscopic telescope array (NuSTAR): optics overview and current status

H. An, K. L. Blaedel, Columbia Univ. (United States); N. F. Brejnholt, F. E. Christensen, DTU Space (Denmark); W. W. Craig, Univ. of California, Berkeley (United States); J. Cushman, T. A. Decker, M. Doll, L. Fishenfeld, C. J. Hailey, Columbia Univ. (United States); C. Jensen, DTU Space (Denmark); J. E. Koglin, K. Mori, Columbia Univ. (United States); M. J. Pivovaroff, Lawrence Livermore National Lab. (United States); M. Stern, G. Tajiri, Columbia Univ. (United States); W. W. Zhang, NASA Goddard Space Flight Ctr. (United States)

We present an overview of the design, fabrication and testing of the optics for the Nuclear Spectroscopic Telescope Array (NuSTAR). NuSTAR will be the first hard X-ray (6-78 keV) mission to employ focusing (Wolter-I) optics. Two flight optics and a third calibration optic are under construction. The thermally-slumped glass is produced at NASA Goddard Space Flight Center, coated with multilayers at the Danish Technical University and assembled and calibrated at Columbia University. In addition to discussing the details of the optics design, we will present preliminary results on the X-ray characterization of the first flight optic including angular resolution and effective area. These results will be compared with predictions based on laser and interferometric metrology of the free-standing glass and mechanical metrology of the mounted glass in each shell. The status of the second flight optic and calibration optic will be given.

7732-29, Session 7

eROSITA on SRG

P. Predehl, Max-Planck-Institut für extraterrestrische Physik (Germany)

eROSITA (extended ROentgen Survey with an Imaging Telescope Array) will be the core instrument on the Russian Spektrum-Roentgen-Gamma (SRG) mission which is scheduled for launch in 2012. eROSITA is completely approved and funded by the German Space Agency DLR. The design driving science is the detection of 100 thousands Clusters of Galaxies up to redshifts z > 1 in order to study the large scale structure in the Universe and test cosmological models including the Dark Energy. This will be accomplished by an all-sky survey lasting for four years plus a phase of pointed observations on selected objects. eROSITA consists of seven Wolter-I telescope modules, each equipped with 54 Wolter-I shells having an outer diameter of 360 mm. In the focus of each mirror module, a framestore pn-CCD provides a field of view of 1° in diameter.

eROSITA is fully approved and funded by the German Space Agency DLR and Max-Planck-Society. As a recent major milestone, a “Detailed Agreement” between DLR and Roskosmos was signed on August 18, 2009. The instrument is in part (e.g., the mirror production) in phase C/D.

7732-30, Session 7

Studying neutron stars with IXO and eROSITA

W. Becker, Max-Planck-Institut für extraterrestrische Physik (Germany)

Optical and X-ray astronomy has made great progress in the past several years thanks to telescopes with larger effective areas and greatly improved spatial, temporal and spectral resolutions. The next generation instruments like eROSITA and IXO are supposed to bring again a major improvement in sensitivity. These new instruments will allow us to address the many open questions related to the neutron star equation of state, the many different manifestations of neutron stars which we observe and the pulsar emission mechanisms with adequate sensitivity. In my talk I will summarize the recent results on the X-ray emission properties from neutron stars with the prospects for studying these sources with IXO and eROSITA.

7732-31, Session 7

The gravity and extreme magnetism small explorer

K. Jahoda, NASA Goddard Space Flight Ctr. (United States)

The Gravity and Extreme Magnetism Small Explorer (GEMS) was selected by NASA for flight in 2014 to make a sensitive search for X-ray polarization from a wide set of source classes, including stellar black holes, Seyfert galaxies and quasars, blazars, rotation and accretion-powered pulsars, magnetars, shell supernova remnants and pulsar wind neulae. Among the primary scientific objectives are determining the effects of the spin of black holes and the geometry of supermassive black hole accretion, determining the configurations of the magnetic fields and the X-ray emission of magnetars, and determining the magnetic structure of the supernova shocks in which cosmic rays are accelerated. The GEMS prime mission includes 35 targets observed over a 9 month period, with exposures that will be able to reach predicted levels of polarization. The mission can be extended to provide a 15 month guest observer phase. The GEMS instrument has time projection chamber polarimeters with high 2-10 keV efficiency at the focus of thin foil mirrors. In order to be launched as a Small Explorer, the the mirrors will be deployed on an extendable boom after launch. The spacecraft and instrument will be rotated with a period of about 10 minutes to enable measurement and correction of systematic errors. A small Bragg reflection soft X-ray experiment takes advantage of this rotation to obtain a measurement at 0.5 keV. The scientific program and the requirements that drive the mission and instrument design will be discussed.

7732-32, Session 7

The GEMS photoelectric x-ray polarimeters

J. K. Black, Rock Creek Scientific (United States) and NASA Goddard Space Flight Ctr. (United States); R. G. Baker, P. V. Deines-Jones, NASA Goddard Space Flight Ctr. (United States); E. E. Faust, SGT, Inc. (United States) and NASA Goddard Space Flight Ctr. (United States); K. J. Gregory, NASA Goddard Space Flight Ctr. (United States); J. E. Hill, CRESST & Univ. Space Research Association (United States) and NASA Goddard Space Flight Ctr. (United States); K. M. Jahoda, P. J. Jordan, NASA Goddard Space Flight Ctr. (United States); P. Kaaret, Z. R. Prieskorn, The Univ. of Iowa (United States); J. H. Swank, NASA Goddard Space Flight Ctr. (United States)

The Gravity and Extreme Magnetism Small Explorer (GEMS) will realize its scientific objectives through high sensitivity X-ray polarization measurements in the 2-10 keV band. The GEMS X-ray polarimeters, based on the photoelectric effect, provide a strong polarization response with high quantum efficiency over a broad bandpass by a novel implementation of the time projection chamber (TPC).

This paper will discuss the basic principles of the TPC polarimeter and describe the details of the mechanical and electrical design of the GEMS polarimeter, including signal processing. We will present performance measurements from a GEMS engineering unit in response to polarized and unpolarized X-rays.

7732-33, Session 8

Fast results of MAXI (monitor of all-sky x-ray image) on ISS

M. Matsuoka, Japan Aerospace Exploration Agency (Japan)

MAXI, the first astronomical payload to JEM-EF of ISS, began operation on August 3, 2009 for monitoring all-sky X-ray images every ISS orbit (92 min). All instruments as well as two main X-ray slit cameras, the GSC and SSC, worked for one month test operation as expected. We have learned of the high background situation on the ISS with large inclination of 51.6 degrees and with background of secondary cosmic rays produced from massive satellite (ISS). Nevertheless, MAXI has been operated since August, 2009 and monitored more than 200 X-ray sources, which include Galactic compact objects: BHC, transient X-ray pulsars, X-ray novae, X-ray bursts, CVns and considerable number of AGN. Automatic nova-alert and rapid report system are starting up, but we have published several results on GCN and ATEL with manual analysis.

In this paper we report the operation status of MAXI on the ISS as well as astronomical results.

7732-34, Session 8

The ASTRO-H Mission

T. Takahashi, K. Mitsuda, Japan Aerospace Exploration Agency (Japan); R. Kelley, NASA Goddard Space Flight Ctr. (United States)

ASTRO-H, the new Japanese X-ray Astronomy Satellite following Suzaku, is an international X-ray mission, planed for launch in 2014. ASTRO-H is a combination of wide band X-ray spectroscopy (3 - 80 keV) provided by focusing hard X-ray mirrors and hard X-ray imaging detectors, and high energy-resolution soft X-ray spectroscopy (0.3 - 10 keV) provided by thin-foil X-ray optics and a micro-calorimeter array. The mission will also carry an X-ray CCD camera as a focal plane detector for a soft X-ray telescope and a non-focusing soft gamma-ray detector based on a narrow-FOV semiconductor Compton Camera. With these instruments, ASTRO-H covers very wide energy range from 0.3 keV to 600 keV. The simultaneous broad band pass, coupled with high spectral resolution of ~ 7 eV by the micro-calorimeter will enable a wide variety of important science themes to be pursued. The ASTRO-H mission objectives are to study the evolution of yet-unknown obscured super massive Black Holes in Active Galactic Nuclei; trace the growth history of the largest structures in the Universe; provide insights into the behavior of material in extreme gravitational fields; trace particle acceleration structures in clusters of galaxies and SNRs; and investigate the detailed physics of jets. In this presentation, we will describe the mission and report the current status.

7732-35, Session 8

Soft x-ray imager (SXI) onboard ASTRO-H

H. Tsunemi, Osaka Univ. (Japan); T. Dotani, Japan Aerospace Exploration Agency (Japan); T. G. Tsuru, Kyoto Univ. (Japan); K. Hayashida, Osaka Univ. (Japan)

The ASTRO-H satellite will be launched in the year of 2014. It will carry 4 X-ray telescopes one of which is used for the X-ray CCD camera, Soft X-ray Imager (SXI). We will employ the P-channel CCD (signal carries are holes rather than electrons) fabricated in Hamamatsu Photonics. The chip is back-illuminated and has a depletion layer of about 200um. The chip has 31mm square imaging area with a pixel size of 24um square. Each chip is equipped with an optical blocking layer that consists of Al (about 100nm) and plastic (about 100nm) so that it will block UV and visible lights. We will employ 4 chips covering the FOV about 40' square. The CCD will be cooled down to -120C by using mechanical coolers. We will employ a modulated X-ray source (MXS) for in-orbit calibration that makes us possible to irradiate the whole imaging area with controlled intensity of designed characteristic X-rays. We will employ an ASIC that performs the digitalization of signal just below the CCD. The ASIC uses the delta-sigma modulator and runs in very low noise (a few electrons) with moderate pixel rate (SXI runs at about 140kHz). The SXI has a space-wire interface for easy installation into the satellite system. There are four types of detectors onboard ASTRO-H: X-ray micro-calorimeter, hard X-ray imager with super-mirror and gamma-ray detector. The SXI has various advantageous points: wide field of view, low energy coverage and high position resolution. We will report the SXI status, its concerns/resolutions and schedule.

7732-36, Session 9

The high-resolution x-ray microcalorimeter spectrometer system for the SXS on ASTRO-H

K. Mitsuda, Japan Aerospace Exploration Agency (Japan); R. L. Kelley, K. R. Boyce, M. J. DiPirro, NASA Goddard Space Flight Ctr. (United States); Y. Ezoe, Tokyo Metropolitan Univ. (Japan); R. Fujimoto, Kanazawa Univ. (Japan); J. A. den Herder, SRON Netherlands Institute for Space Research (Netherlands); Y. Ishisaki, Tokyo Metropolitan Univ. (Japan); M. Kawaharada, RIKEN (Japan); S. Kitamoto, Rikkyo Univ. (Japan); C. A. Kilbourne, NASA Goddard Space Flight Ctr. (United States); D. McCammon, Univ. of Wisconsin-Madison (United States); H. Murakami, Rikkyo Univ. (Japan); M. Murakami, Univ. of Tsukuba (Japan); T. Ohashi, Tokyo Metropolitan Univ. (Japan); M. Pohl, S. Paltani, Univ. of Geneva (Switzerland); F. S. Porter, NASA Goddard Space Flight Ctr. (United States); K. Sato, Kanazawa Univ. (Japan); Y. Sato, Japan Aerospace Exploration Agency (Japan); P. J. Shirron, NASA Goddard Space Flight Ctr. (United States); K. Shinozaki, Japan Aerospace Exploration Agency (Japan); G. A. Sneiderman, NASA Goddard Space Flight Ctr. (United States); H. Sugita, Japan Aerospace Exploration Agency (Japan); A. E. Szymkowiak, Yale Univ. (United States); Y. Takei, Japan Aerospace Exploration Agency (Japan); T. Tamagawa, RIKEN (Japan); M. Tashiro, Y. Terada, Saitama Univ. (Japan); M. Tsujimoto, Japan Aerospace Exploration Agency (Japan); C. P. de Vries, SRON Nationaal Instituut voor Ruimteonderzoek (Netherlands); H. Yamaguchi, RIKEN (Japan); N. Y. Yamasaki, Japan Aerospace Exploration Agency (Japan)

We present the science and an overview of the Soft X-ray Spectrometer onboard the Astro-H mission with emphasis on the detector system. The SXS consists of X-ray focussing mirrors and a microcalorimeter array and is developed by international collaboration lead by JAXA and NASA with European participation. The detector is a 6x6 format microcalorimeter array operated at a cryogenic temperature of 50 mK and covers a 3.0 x 3.0 arcmin2 filed of view of the X-ray telescope of 5.6 m focal length. We expect an energy resolution better than 7 eV (FWHM, requirement) with a goal of 4 eV. The effective area of the instrument will be 225 cm2 at 7 keV; by a factor of about two larger than that of the X-ray microcalorimeter on board Suzaku. One of the main scientific objectives of the SXS is to investigate turbulent and/or macroscopic velocities in the hot gas of clusters of galaxies. Together with the hard X-ray observations of other instruments, Astro-E will try to constrain the total energy budget of cluster.

7732-37, Session 9

Design of a 3-stage ADR for the soft x-ray spectrometer instrument on the ASTRO-H Mission

P. J. Shirron, M. Kimball, D. Wegel, E. Canavan, M. J. DiPirro, NASA Goddard Space Flight Ctr. (United States)

The Japanese Astro-H mission will include the Soft X-ray Spectrometer (SXS) instrument, whose 36-pixel detector array of ultra-sensitive x-ray microcalorimeters will be cooled to 50 mK. This will be accomplished using a 3-stage adiabatic demagnetization refrigerator (ADR). The design is dictated by the need to operate with full redundancy with both a superfluid helium dewar at 1.3 K or below, and with a 4.5 K Joule-Thomson (JT) cooler. The ADR is configured as a 2-stage unit that is located in a well in the helium tank, and a third stage that is mounted to the top of the helium tank. The third stage is directly connected through two heat switches to the JT cooler and the helium tank, and manages heat flow between the two. When liquid helium is present, the 2-stage ADR operates in a single-shot using the superfluid helium as a heat sink. The third stage may be used to reduce the time-average heat load on the liquid to extend its lifetime. When the liquid is depleted, the 2nd and 3rd stages operate as a continuous ADR to maintain the helium tank at as low a temperature as possible - expected to be 1.2 K - and the last ADR stage provides detector cooling. The ADR's design and operating modes are discussed, along with test results of the prototype 3-stage ADR and HTS leads used to power the magnets.

7732-38, Session 9

Filters and calibration sources for the soft x-ray spectrometer (SXS) instrument on ASTRO-H

C. P. de Vries, J. A. den Herder, E. Costantini, H. J. M. Aarts, P. Lowes, J. S. Kaastra, SRON Netherlands Institute for Space Research (Netherlands); R. L. Kelley, K. C. Gendreau, Z. Arzoumanian, R. G. Koenecke, NASA Goddard Space Flight Ctr. (United States); D. A. Haas, S. Paltani, Univ. of Geneva (Switzerland); K. Mitsuda, N. Y. Yamasaki, Institute of Space and Astronautical Science (Japan)

The SXS instrument is the Soft X-ray microcalorimeter Spectrometer planned for the Japanese ASTRO-H satellite, scheduled to be launched in 2014. In this presentation, the tradeoff and modelling for the X-ray absorption and optical blocking filters will be described. The X-ray absorption filter will optimize the efficiency for high spectral resolution observations at higher energies (notably around the Fe-K line at 6.4 KeV), given the characteristics of the instrument while the optical blocking filter allows X-ray observations of optically bright sources.

For this mission a novel type of on-off-switchable X-ray calibration source, using light sensitive photo-cathodes, is being developed, which will be used for gain calibration and contamination monitoring. These sources will be used by both the SXS and SXI (Soft X-ray Imager) instruments and have the capability to be pulsed at millisecond intervals. Details of these sources will also be discussed.

7732-39, Session 9

Current status of the Hard X-ray Telescope onboard ASTRO-H

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The new Japanese X-ray Astronomy satellite, Astro-H is an international X-ray mission which is currently planned to be launched in 2014.

One of the unique features of the mission is an imaging spectroscopy in the hard X-ray band above 10 keV. Astro-H will carry two identical hard X-Ray telescopes (HXTs), which have the Wolter I optics, implemented in approximate scheme with nested conical reflectors. The HXT mirrors employ Pt/C depth-graded multilayers.

We are preparing the Astro-H flight-model (FM) production. The FM housing of HXT is being designed based on prototype-model housing studies, e.g., structure analysis and thermal analysis. The production facility for the HXT multi-layer reflector at Nagoya University is in the final tuning stage for the mass-production of Astro-H HXT reflectors from April 2010. We are also making a plan for ground calibration of the Astro-H HXT at a synchrotron facility SPring-8 from October 2011.

This paper is dedicated for the status report of the development of the entire Astro-H/HXT system.

7732-40, Session 9

Hard x-ray imager for the ASTRO-H Mission

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The Hard X-ray Imager (HXI) is one of three focal plane detectors on board the ASTRO-H mission (6th Japanese X-ray satellite), which is scheduled to be launched in 2014. By use of the hybrid structure composed of double-sided silicon strip detectors and a cadmium telluride strip detector, it fully covers the energy range of photons collected with the hard X-ray telescope up to 80 keV with a high quantum efficiency. High spatial resolutions of 250 micron pitch and energy resolutions of 1-2 keV (FWMH) are at the same time achieved with low noise front-end ASICs. In addition, thick BGO active shields compactly surrounding the main detection part, as a heritage of the successful performance of the Hard X-ray Detector (HXD) on board Suzaku satellite, enable to achive an extremely high background reduction for the cosmic-ray particle background and in-orbit activation.

We will present the detector concept/design, latest results of the detector development research, and the current status of the hardware.

7732-41, Session 9

Soft gamma-ray detector for the ASTRO-H Mission

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The Soft Gamma-ray Detector (SGD) on board the ASTRO-H mission to be launched in 2014 is a Compton telescope with narrow field of view

(FOV), which utilizes Compton kinematics to reject background events that is inconsistent with gamma-ray coming from its FOV. It is realized as a hybrid semiconductor detector system which consists of silicon and CdTe (cadmium telluride) detectors. The Compton camera is surrounded by BGO active shield to minimize particle backgrounds. It can detect photons in a wide energy band (40-600 keV) with the S/N ratio >10 times better than Suzaku HXD, which is complimentary to the Hard X-ray Imager (HXI) on board ASTRO-H with an energy coverage of 5-80 keV. Excellent energy resolution is the key feature of the SGD, allowing it to achieve good background rejection capability taking advantage of good angular resolution.

Main science drivers for SGD include studies of particle acceleration in various sources and associated non-thermal emissions and high-energy cutffs. An additional capability of the SGD, its ability to measure gamma-ray polarization, opens up a new window to probe unique properties of gamma-ray emission processes.

We will present the development of key technologies to realize the SGD: high quality semiconductor detectors (Si and CdTe), low noise front-end ASIC (Application Specific Integrated Circuits) with integrated AD converter and zero suppression. Compact mechanical structure of the Compton camera with proper cooling is another critical development effort to maximize the reconstruction efficiency of Compton kinematics.

7732-42, Session 10

NHXM: a New Hard X-ray Imaging and Polarimetric Mission

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The Italian New Hard X-ray Mission (NHXM) has been designed to provide a real breakthrough on a number of hot astrophysical issues that includes: black holes census, the physics of accretion, the particle acceleration mechanisms, the effects of radiative transfer in highly magnetized plasmas and strong gravitational fields. NHXM is an evolution of the HEXIT-Sat concept and it combines fine imaging capability up to 80 keV, today available only at E<10 keV, with sensitive photoelectric imaging polarimetry. It consists of four identical mirrors, with a 10 m focal length, achieved after launch by means of a deployable structure. Three of the four telescopes will have at their focus identical spectral-imaging cameras, while a X-ray imaging polarimeter will be placed at the focus of the fourth. In order to ensure a low and stable background, NHXM will be place placed in a low Earth equatorial orbit. Here we will provide an overall description of this mission that is currently in phase B.

7732-43, Session 10

The optics system of the New Hard X-ray Mission: design and development

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The New Hard X-ray Mission (NHXM) Italian project will be operated by 2016; the Phase B study of the mission is currently going on. It is based on 4 hard X-ray optics modules, each formed by 60 evenly spaced multilayer coated Wolter I mirror shells. For the achievement of a long focal length (10 m) an extensible bench is used. The pseudo-cylindrical Wolter I monolithic substrates where the multilayer coating is applied will be produced using the Ni electroforming replica approach. For three of the four mirror modules the focal plane will host a hybrid a detector system, consisting in the combination of a Si-based low energy detector (efficient from 0.5 up to ~ 15 keV), on top of a high energy CdTe pixellated detector (efficient from 10 keV up to ~ 80 keV); the two cameras will be surrounded by both a passive shield and an anticoincidence shield. The total on axis effective area of the three telescopes at 1 keV and at 30 kev is of 1500 cm2 and 350 cm2 respectively. The angular resolution requirement is better than 20 arcsec HEW at 30 keV, while the Field of View at 50% vignetting is 12 arcmin (diameter). The payload is finally completed with the fourth telescope module, that will have as a focal plane detector a high sensitivity imaging photoelectric polarimetric system, operating from 2 up to 35 keV. In this paper, after an overview of the mission configuration and its scientific goals, we report on the design and development of the multilayer optics of the mission, based on thin replicated Ni mirror shells, including the latest results on the achieved with the measurements of breadboard calibrated up to 50 keV in full illumination configuration at Panter-MPE.

7732-44, Session 10

The NHXM spectral-imaging cameras

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The New Hard X-ray Mission (NHXM) is conceived to extend the grazing-angle reflection imaging capability up to energy of 80 keV. The NHXM payload consists of four telescopes. Three of them have at their focal plane three identical spectral-imaging cameras operating between 0.2 and beyond 80 keV, while the fourth has a X-ray imaging polarimeter. The spectral-imaging cameras are constituted by two detection layers: a Low Energy Detector (LED) and a High Energy Detector (HED) surrounded by an Anti Coincidence (AC) system. Here we will present the preliminary design and the solutions that we are currently studying to meet the top level system requirements of these cameras.

7732-45, Session 10

Polarimetry with the New Hard X-ray Mission

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Hard X-ray spectroscopy and polarimetry are complementary to improve our knowledge of physics and geometry of X-ray sources: non thermal processes, accretion disks and the presence of extreme gravitational and mgnetic fields. The Italian New Hard X-ray Mission, now in B-phase, consists of four identical mirrors, with a 10 m focal. Three telescopes have at the focus spectral-imaging cameras. One is dedicated to polarimetry. A Gas Pixel Detector with a filling based on DME, will perform polarimetry in the band 2-10 keV, on a f.o.v.of 6x6 arcminutes, with the angular resolution of 15". A sliding device can alternate in the focus another detector tuned on the 5-35 keV band. It is based on high

pressure Ar (3 atm, absorption gap of30 mm. The sensitivity, f.o.v. and angular resolution are comparable to those of the low energy polarimeter. The measurement of polarization simultaneous to spectra and imaging and the Hard band will be absolutely unique when compared with other future missions.

7732-46, Session 11

An overview of the International X-ray Observatory (IXO)

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The International X-ray Observatory (IXO) project is the result of a merger between the NASA Con-X and ESA/JAXA XEUS mission concepts. A facility-class mission, IXO will address the leading astrophysical questions in the “hot universe” through its breakthrough optics with 20 times more collecting area at 1 keV than any previous X-ray observatory, its 3 m2 collecting area with 5 arcsec angular resolution will be achieved using a 20m focal length deployable optical bench. To reduce risk, two independent optics technologies are currently under development in the U.S. and in Europe. Focal plane instruments will deliver a 100-fold increase in effective area for high-res¬olution spectroscopy, deep spectral imaging over a wide field of view, unprecedented polarimetric sensitivity, microsecond spectroscopic timing, and high count rate capability. IXO covers the 0.1-40 keV energy range, complementing the capabilities of the next generation observatories, such as ALMA, LSST, JWST, and 30-m ground-based telescopes. These capabilities will enable studies of a broad range of scientific questions such as what happens close to a black hole, how supermassive black holes grow, how large scale structure forms, and what are the connections between these processes?

This talk presents an overview of the IXO mission science drivers, its optics and instrumental capabilities, the status of its technology development programs, and the mission implementation approach.

7732-47, Session 11

ESA assessment study activities on the International X-ray Observatory

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IXO (International X-ray Observatory) is an L class mission candidate within the science programme Cosmic Vision 2015-2025 of the European Space Agency, with a planned launch by 2020. IXO is an international cooperative project, pursued by ESA, JAXA and NASA. By allowing astrophysical observations between 100 eV and 40 keV, IXO would represent the new generation X-ray observatory, following the XMM-Newton, Astro-H and Chandra heritage. The main scientific objectives of IXO include the study of large scale structures, the evolution of black holes, strong gravity effects, neutron star issues as well as investigations on dark matter.

The present IXO mission concept is based on a deployable instrument module and a single, large aperture, x-ray telescope. The telescope, with a focal length baseline of 20 m, would illuminate different focal plane instruments, located at the optical focus via a moving platform. These instruments are a cryogenic imaging spectrometer (XMS), a wide field imager (WFI), a hard x-ray imager (HXI), a high time resolution spectrometer (HTRS) and an X-ray polarimeter (XPOL). In addition, a grating spectrometer (XGS) would be continuously illuminated by the x-ray optics.

The design of IXO will be remain compatible with both an Ariane 5 and an Atlas V launch. The observatory would operate at L2, with a nominal lifetime of 5 yr.

This paper provides a summary of the preliminary results achieved during the assessment activities presently ongoing at ESA. An overview of the spacecraft design and of the payload characteristics is provided, including both telescope and instruments aspects, with specific emphasis on spacecraft accommodation issues and overall resource budgets.

7732-48, Session 11

Payload study activities on the International X-ray Observatory

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The International X-ray Observatory (IXO) is an L class mission candidate within the science programme Cosmic Vision 2015-2025 of the European Space Agency, with a planned launch by 2020. IXO is an international cooperative project, pursued by ESA, JAXA and NASA. By allowing astrophysical observations between 100 eV and 40 keV using a very large effective collecting area mirror and state-of-the art instruments, IXO would represent the new generation X-ray observatory, following the XMM-Newton, Astro-H and Chandra heritage.

The IXO mission concept is based on a single aperture telescope with an external diameter of about 4 m and a focal length of 20 m. The focal plane consists of a fixed and a moveable instrument platform (FIP and MIP respectively). The model payload consists of a suite of five instruments which can each be located at the telescope’s focus by the MIP, these are:

1. a wide field imager (WFI) based on a silicon DEPFET array;
2. a Hard-X-ray Imager (HXI), which will be integrated together with the WFI;
3. a cryogenic imaging spectrometer (XMS) based on microcalorimeters;
4. a X-ray Polarimeter camera (X-POL) based on a gas cell with integrated anode array;
5. a High-Time Resolution Spectrometer (HTRS) based on a silicon drift detector array.

In addition, the FIP will carry a grating spectrometer mounted in a fixed position and which will allow simultaneous observations with the on-axis instrument.

This paper provides a summary of the preliminary results achieved during the assessment activities presently ongoing at ESA. Whereas we will provide a brief overview on the spacecraft design, we will focus on the payload description, characteristics and used technology

7732-49, Session 11

ESA optics technology preparation for IXO

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The International X-ray Observatory (IXO) is a candidate mission in the ESA Space Science Programme Cosmic Visions 1525. IXO is being studied as a joint mission with NASA and JAXA.

The mission is building on novel optics technologies to achieve the required performance for this demanding astrophysics observatory. The European X-ray optics technology baseline is the Silicon Pore optics (SPO), which is being developed by an industrial consortium. In a phased approach the performance, environmental compatibility and industrial production aspects are being addressed.

As a back-up technology ESA is also investigating slumped glass optics, which forms the baseline for the NASA approach.

The paper will present a summary of the ESA led optics technology preparation activities and the associated roadmap.

7732-50, Session 11

Silicon pore x-ray optics for IXO

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Silicon pore optics is a technology developed to enable future large area X-ray telescopes, such as the International X-ray Observatory (IXO), a candidate mission in the ESA Space Science Programme 'Cosmic Visions 2015-2025'. IXO uses nested mirrors in Wolter-I configuration to focus grazing incidence X-ray photons on a detector plane. The IXO mirrors will have to meet stringent performance requirements including an effective area of ~3 m2 at 1.25 keV and ~1 m2 at 6 keV and angular resolution better than 5 arc seconds. To achieve the collecting area requires a total polished mirror surface area of ~1300 m2 with a surface roughness better than 0.5 nm rms. By using commercial high-quality 12" silicon wafers which are diced, structured, wedged, coated, bent and stacked the stringent performance requirements of IXO can be attained without any costly polishing steps. Two of these stacks are then assembled into a co-aligned mirror module, which is a complete X-ray imaging system. Included in the mirror module are the isostatic mounting points, providing a reliable interface to the telescope. Hundreds of such mirror modules are finally integrated into petals, and mounted onto the spacecraft to form an X-ray optic of four meters in diameter.

In this paper we will present the silicon pore optics mass manufacturing process and latest X-ray test results of mirror modules mounted in flight configuration.

7732-51, Session 12

Fabrication of glass mirror segments for the International X-ray Observatory

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As the next major X-ray astronomical mission of NASA, ESA, and JAXA, the International X-ray Observatory (IXO) requires a mirror assembly that has an unprecedented effective area and an angular resolution better than all past missions except Chandra. This mirror assembly consists of approximately 15,000 mirror segments, which need to be fabricated, measured, aligned and integrated. In this talk we will present the latest results from our effort of developing an efficient and fast process of making these mirror segments by slumping commercially available glass sheets. We will report on our progress both in terms of perfecting the slumping process as well as the metrology process. In particular, we will discuss what additional work needs to be done to fully facilitate the manufacture of these mirror segments, meeting both budgetary and schedule requirements.

7732-52, Session 12

The x-ray microcalorimeter spectrometer onboard of IXO

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One of the instruments on the International X-ray Observatory, under study with NASA, ESA and JAXA, is the X-ray Microcalorimeter Spectrometer (XMS). This imaging instrument, which will provide high spectral resolution spectra, is based on X-ray calorimeters with Transition Edge Sensor thermometers with metallic absorbers and multiplexed SQUID readout. The requirements for this instrument are demanding. In the central array an energy resolution of < 2.5 eV for 1600 pixels is required whereas the energy resolution of the outer array is more relaxed but the detection elements have to be a factor 16 larger in order to keep the number of read-out channels acceptable for a cryogenic instrument. Due to the large collection area of the IXO optics, the XMS instrument must be capable of processing high counting rates while maintaining the spectral resolution with low deadtime. In addition, an anti-coincidence detector is required to suppress the particle-induced background.

In this paper we will summarize the instrument status and performance. We will focus on our structured approach to quantitatively compare the options available as a framework for an eventual instrument concept, including (a) the physical parameters and geometry of the pixels, (b) the different read-out topologies (Frequency Domain Multiplexing, Time Domain Multiplexing and Code Division Multiplexing), (c) the different options for the mounting of the detector in the cryostat, (d) the different options to optimize the onboard data processing and (e) the options and optimizations for the background suppression.

7732-53, Session 12

A wide field imager for IXO: status and future activities

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For the development of a Wide Field Imager (WFI) aboard the International X-ray Observatory (IXO) a consortium was founded which develops an active pixel sensor as a focal plane detector behind the

X-ray optics with 18 arcmin FoV at a focal length of 20 m. The energy bandwidth ranges from 100 eV to 15 keV due to its back-illuminated 450 μm thick device topology. The pixel size is 100 x 100 μm2 in a format of 1024 x 1024 pixel. The DePFET based detector will be monolithically fabricated on a 6 inch high resistivity wafer with no insensitive gaps in the whole field of view. The position resolution in the focal plane will be better than 25 μm leading to approximately 3000 x 3000 resolution points. Due to the excellent noise figures at short signal processing times the energy resolution is Fano limited, i.e. around 50 eV at 300 eV X-ray energy and 130 eV at 6 keV. Optical light will be attenuated by a factor of 105 by an integrated blocking filter. In the standard full frame read mode 1.000 frames will be read out, corresponding to a frame time of 1 ms. In a windowing mode the frame time can be reduced to approximately 20 μs. The status of the device and system development will be shown as well as the technological challenges ahead of us. Progress on device and system performance with prototypes of a format of 256 x 256 pixels will be presented.

7732-54, Session 12

Critical-angle transmission grating spectrometer for high-resolution soft x-ray spectroscopy on the International X-ray Observatory

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High-resolution spectroscopy at energies below 1 keV covers the lines of C, N, O, Ne and Fe ions, and is central to studies of the Interstellar Medium, the Warm Hot Intergalactic Medium, warm absorption and outflows in Active Galactic Nuclei, coronal emission from stars, etc. The large collecting area, long focal length, and 5 arcsecond telescope point-spread function of the International X-ray Observatory will present unprecedented opportunity for a grating spectrometer to address these areas at the forefront of astronomy and astrophysics. We present the current status of a transmission grating spectrometer based on recently developed high-efficiency critical-angle transmission (CAT) gratings that combine the traditional advantages of blazed reflection and transmission gratings. The optical design merges features from the Chandra HETGS and the XMM-Newton RGS, and provides spectral resolution $R = E/\Delta E > 3000$ and effective area > 1,000 cm2 in the soft x-ray band. We shall discuss recent results on grating fabrication and diffraction efficiency, as well as on the design of the readout camera and grating array structures.

7732-55, Session 12

Developments of the off-plane x-ray grating spectrometer for the International X-ray Observatory

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The International X-ray Observatory (IXO) is a collaborative effort between NASA, ESA, and JAXA. The IXO science goals are heavily based on obtaining high quality X-ray spectra. In order to achieve this goal the science payload will incorporate an array of gratings for high resolution, high throughput spectroscopy at the lowest X-ray energies, 0.3 - 1.0 keV. The spectrometer will address a number of important astrophysical goals such as studying the dynamics of clusters of galaxies, determining how elements are created in the explosions of massive stars, and revealing most of the "normal" matter in the universe which is currently thought to be hidden in hot filaments of gas stretching between galaxies. We present here a mature design concept for an Off-Plane X-ray Grating Spectrometer. This concept has seen recent advancements in mechanical design, technology development, and empirical results. Furthermore, we present simulations of key grating spectroscopy science targets. These simulations use detailed ray tracing of the entire observatory with accurate response matrices for the optics, gratings, and CCDs.

7732-56, Session 12

The hard x-ray imager onboard IXO

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Wide-band X-ray spectro-imaging up to ~40 keV enables observing objects hidden behind thick gas and to identify their nature via resolving multiple spectral components. For the International X-ray Observatory (IXO), we are proposing the Hard X-ray Imager (HXI) to provide this capability. The HXI, in current design, is mounted behind the Wide Field Imager (WFI) working at 0.1-15 keV, to simultaneously cover the energy band up to 40 keV. It consists of imaging spectrometer based on a stack of 2 double-sided Si strip detectors (DSSDs) and a double-sided strip detector using Cadmium Telluride (DS-CdTe). A pixel CdTe imager is also an option. It will cover a field of view of 8x8 arcmin with position resolution of 2.6-6 arcsec, while the mirror optics provides 5-30 arcsec resolution. Active shielding for low background in orbit is also employed.

The HXI design is based on similar instrument onboard the ASTRO-H mission (2014-) and other recent hard X-ray technologies. By this approach, we can provide mature design with optimized configuration, i.e. most of the components will be flight-proven in both technical and performance aspects before the actual fabrication work starts. In this talk, we present the scientific aim, over-all concept, and current design of the IXO/HXI. Results from working DSSD and DS-CdTe imager test devices, preliminary analysis of shielding design, basic mechanical, thermal and optical solutions to realize this instrument will also be included.

7732-57, Session 12

The high time-resolution spectrometer of the International X-ray Observatory

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The High Time Resolution Spectrometer (HTRS) is one of the five focal plane instruments of the International X-ray Observatory (IXO). The HTRS is the only instrument matching the top level mission requirement of

handling a one Crab X-ray source with an efficiency greater than 10%. It will provide IXO with the capability of observing the brightest X-ray sources of the sky (e.g. black hole X-ray binaries, type I X-ray bursters), with sub-millisecond time resolution, low deadtime, low pile-up (less than 2% at 1 Crab), and CCD type energy resolution (~150 eV at 6 keV). This is achieved by placing an array of 31 low capacitance silicon drift detectors out of focus, in such a way that the focal beam is distributed uniformly over the whole array. As part of the assessment study carried by ESA on IXO, the HTRS is currently undergoing a phase A study led by CNES and CESR. In this paper, we will present the current mechanical, thermal and electrical design of the HTRS, emphasizing on the performance of a digital shaper that we foresee as the readout electronics of the SDD array.

7732-78, Poster Session

FIREBALL: integral field spectrograph

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The FIREBall (Faint Intergalactic Redshifted Emission Balloon) spectrograph is the first ultraviolet fiber-fed integral field unit.

The modified Offner spectrograph combines a holographic grating (R~5000) with a NUV microchannel plate legacy detector from GALEX. 280 science fibers are combined with calibration and alignment fibers in a close packed bundle filling a 2.3’ diameter field of view. We will detail instrument construction and testing as well as performance during the science flight of June 2009.

7732-79, Poster Session

FIREBALL: flight 2 data analysis and results

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FIREBALL, an integral field spectrograph, was successfully launched for its second flight. We launched on June 08, 2009 and observed for approximately 6 hours total on 5 fields which includes Groth and Deep 2 fields. We observed in the wavelength band of 198 to 226nm with a resolution of R ~ 5000. Here we present data reduction pipeline and the initial science results obtained.

7732-80, Poster Session

FIREBALL: telescope pointing and aspect reconstruction

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The Faint Intergalactic Redshifted Emission Balloon (FIREBALL) is a balloon borne 1 meter UV altazimuth telescope and fiber based integral field spectrograph. It is designed to target diffuse emission from the Intergalactic and Circumgalactic Media. A detection of this signal requires careful background and point source subtraction from data obtained in a naturally unstable observing environment. That requirement places a stringent constraint of about ½ fiber diameter, or roughly 4” on the sky, accuracy on the telescope pointing and aspect reconstruction. The FIREBALL telescope uses a series of feedforward and feedback loops to control the tip-tilt of the sidereostat mirror. The coarsest pointing solution is achieved with a set of inclinometers, potentiometers, magnetometers and gyros. A DTU large field camera provides a lost-in-space mode and pointing accurate to about 1 arc-minute. A video-rate guider camera yields the desired sub-fiber pointing performance. Finally, FIREBALL is equipped with a legacy GALEX micro-channel plate photon-counting detector which allows for post-flight corrections to be applied to remove excessive jitter, in flight target dithering and natural and artificial field rotation. We describe the design of the FIREBALL tracking system and discuss its in-flight performance and planned improvements.

7732-81, Poster Session

Earth-orbiting Extreme Ultraviolet Spectroscopic Mission

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An earth-orbiting Extreme Ultraviolet spectroscopic mission, EXtreme ultraviolet spectrosCope for ExosphEric Dynamics explore (EXCEED) that will be launched in 2012 is now under development. The EXCEED mission will carry out observations of Extreme Ultraviolet (EUV) emissions from tenuous plasmas around the planets. It is essential for planetary EUV spectroscopy to avoid the Earth’s atmospheric absorption, therefore it should be mandatory to observe above the Earth’s atmosphere. In this paper, we will introduce the general mission overview, the instrument, and the scientific targets.

7732-82, Poster Session

Efficient EUV transmission gratings for plasma diagnostics

C. Braig, E. Kley, Friedrich-Schiller-Univ. Jena (Germany)

We report on a theoretical study of binary phase transmission gratings for high-resolution EUV spectroscopy and investigate its optical properties. Designed for wavelengths betweeen about 2 and 40 nm, the devices may provide a first order diffraction efficiency beyond 30%. We use numerical finite difference techniques in order to explore the electromagnetic diffractive near field and discuss special features of segmented grating arrays. Several elemental as well as compound materials like Be, Mo, LiF and PMMA are considered with respect to their theoretical potential and practicability.

Simulations of feasible samples are performed on the radiation produced by a table-top EUV plasma source.

7732-83, Poster Session

Description and ray-tracing simulations of HYPE: a far-ultraviolet polarimetric spatial-heterodyne spectrometer

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Temperature and velocity-distribution remote-sensing of faint diffuse sources such as the interplanetary medium (IPM), comets and planetary atmospheres, is an instrumental challenge that becomes more pronounced in the ultraviolet. All-reflective Spatial-Heterodyne Spectrometers (SHS), an emerging new class of instruments that combines both high étendue and high resolving power (greater than 10000), are ideally suited to these types of observations. Their all-reflective configuration and their self-compensating monolithic design enable them to operate under the tight tolerances of the ultraviolet and to survive the rigors of space launch. An in-development sounding-rocket experiment, the Hydrogen Polarimetric Explorer (HYPE), will merge an all-reflective SHS with a half-wave Brewster reflection polarimeter to obtain the first interferometric polarimetry of an ultraviolet emission line source. Its initial flight will target the IPM at the hydrogen Lyman-alpha transition (121.6nm). HYPE's novel optical configuration also combines several improvements in reflective SHS design, including true zero-path interferometry, no aliasing, and one-dimensional imaging. The optical layout and performance of the HYPE prototype will be described along with simulation results from ray-tracing computations.

7732-85, Poster Session

Visible and UV Fresnel imagers

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A Fresnel imager is proposed for a 3 to 4 meters aperture space mission in the UV domain. Fresnel imagers focus light by diffraction through a thin "binary" Fresnel array instead of reflection on a mirror, and due to relatively long focal lengths, they require two spacecraft formation flying.

Fresnel arrays deliver high quality wavefronts in the UV, and relatively good throughput: 7 to 8% of the light is focussed, providing images of high dynamic range (high contrast). Chromatism correction allows several relatively broad spectral bands, partly covering the 120-350 nm spectral range. A Fresnel imager providing 7 to 10 milli arc seconds resolution is ideally suited for imaging of close binaries, accretion disks and jets in protoplanetary and young planetary systems, and AGNs.

We will present science cases in the UV for this instrument, numerical simulations made on protoplanetary systems, and the results that we obtained on optical testbeds for concept validation in close IR (on the sky) and in UV (for lab targets).

7732-86, Poster Session

It's time for a new EUV mission

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The J-PEX high-resolution EUV spectrometer has made a breakthrough in capability with an effective area of 7 cm2 (220-245 Å) and resolving power of 4000, which exceed EUVE by factors of 7 and 20 respectively, and cover a range beyond the 170-Å cutoff of the Chandra LETG. The EUV includes critical spectral features containing diagnostic information often not available at other wavelengths (e.g., He II Ly series), and the bulk of radiation from million degree plasmas is emitted in the EUV. Such plasmas are ubiquitous, and examples include the atmospheres of white dwarfs; accretion phenomena in young stars, CVs and AGN; stellar coronae; and the ISM of our own galaxy and of others. However, sensitive EUV spectroscopy of high resolving power is required to resolve source spectral lines and edges unambiguously, to identify features produced by the intervening ISM, and to measure line profiles and Doppler shifts.

J-PEX has flown twice on NASA sounding rockets. NASA has approved no new EUV mission, but it is time for one. Here we describe the scientific case for high-resolution EUV spectroscopy, summarize the technology that makes such measurements practical, and present a concept for a ~3-month orbital mission, in which J-PEX is modified for a low-cost orbital mission to acquire sensitive high-resolution spectra for ~30 white dwarfs, making an important contribution to the study of white dwarf evolution and hence the chemical balance of the Galaxy, and to the understanding of structure in the LISM. We also outline larger missions.

7732-87, Poster Session

FIRE: a Far-Ultraviolet Imaging Sounding Rocket Telescope

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These are the initial results from the first flight of the Far-ultraviolet Imaging Rocket Experiment (FIRE), a space telescope flown on a sounding rocket from White Sands Missile Range. FIRE is a single optic prime focus telescope with a 1.75m focal length. Its bandpass of 900-1000 angstroms is determined by a combination of the mirror coating of silicon carbide, the thin-film indium filter and the RbBr salt coating on the detector's face. The imaging band of FIRE will help fill the current wavelength imaging observation hole existing from ~620 angstroms to the GALEX band near 1350 angstroms.

The scientific purpose of the first flight in April 2010 was to image the Whirlpool galaxy (M51) for the first time at these wavelengths. FIRE was designed to match the resolution and field-of-view of GALEX in order to compile three-color UV images of galaxies. When fully analyzed, these data will help determine the quantity and location of O stars, the youngest, hottest stars whose emission peaks at these wavelengths. As well as furthering understanding of star-forming regions and galactic star formation histories, FIRE will help determine the extinction of the optical path to M51 due to dust.

7732-88, Poster Session

Improving EUV filter transmission by cleaning with activated species

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As-fabricated free-standing indium foils were found to have transmission values in the 90nm to 120nm band ranging from 10% to 70% of theoretical transmission. Auger depth profiling of the as-deposited indium showed little surface contamination and high purity. However, final free-standing filters were found to have heavy contamination, both on the surface and in the bulk. An argon/hydrogen bombardment was developed which did not cause pinholes to develop in the foils, did not appreciably affect optical density, but improved EUV transmission from 50% to 500% in the finished filters.

7732-89, Poster Session

HST-COS FUV detector initial on-orbit performance

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The Cosmic Origins Spectrograph (COS) was installed on the Hubble Space Telescope (HST) in May 2009 during Servicing Mission 4 (SM4). This paper discusses the initial on-orbit performance of the HST-COS far ultraviolet (FUV) detector designed and built by the Experimental Astrophysics Group at Univ. of California, Berkeley.

The HST-COS FUV detector is an open face, photon counting, microchannel plate (MCP) based device employing a cross delay line readout (XDL). The detector consists of two separate, end-to-end segments (2x 85mm x 10mm - 180mm x 10mm total with a gap between segments), each digitized within a 16384x1024 space. The input surface is curved to match the Rowland circle of HST-COS. The CsI photocathode and open face nature result in sensitivity from <900Å to ~1750Å. Spatial resolution is approximately 25-30µm.

Comparisons of on-orbit behavior relative to expectations from ground testing are performed. Areas of discussion include background (rate and morphology), sensitivity (system throughput, detector deadtime, and short wavelength response), and imaging performance (apparent spatial resolution and flat field fixed pattern). A measured increase in the MCP gain relative to ground testing is also discussed.

7732-90, Poster Session

Using ACIS on the Chandra X-ray Observatory as a particle radiation monitor

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The Advanced CCD Imaging Spectrometer (ACIS) is one of two focal-plane instruments on the Chandra X-ray Observatory. During initial radiation-belt passes, the exposed ACIS suffered significant radiation damage from trapped soft protons scattering off the x-ray telescope's mirrors. The primary effect of this damage was to increase the charge-transfer inefficiency (CTI) of the ACIS 8 front-illuminated CCDs. Subsequently, the Chandra team implemented procedures to remove the ACIS from the telescope's focus during high-radiation events: planned protection during radiation-belt transits; autonomous protection triggered by an on-board radiation monitor; and manual intervention based upon assessment of space-weather conditions. However, as Chandra's multilayer insulation ages, elevated temperatures have reduced the effectiveness of the on-board radiation monitor for autonomous protection. Here we investigate using the ACIS CCDs themselves as a radiation monitor. We explore the 10-year database to evaluate the CCDs' response to particle radiation and to compare this response with other radiation data and environment models.

7732-91, Poster Session

On-orbit calibration status of the hard x-ray detector (HXD) onboard Suzaku

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Hard X-ray Detector (HXD) onboard Suzaku, the Japanese 5th X-ray observatory, consists of 64 2 mm-thick PIN photo diodes(10-70 keV) and 16 phoswich detectors using 5 mm-thick GSO scintillators and BGO active collimators(40-600 keV), and these are surrounded by 20 units of BGO Active shields. All the detector units have been working well with no significant troubles in four and a half years since the launch on July 2005, and given many important scientific results. Here, we report the status of on-orbit calibrations for PIN/GSO detectors.

For PIN detectors, the increment of noise rate, due to on-orbit radiation damage, has been confirmed in some PIN detectors, and it causes dead time growth and saturation of telemetry data. To avoid such situations, we HXD-team routinely monitor and raise up analog and digital threshold levels in the orbit, and furthermore lower discriminator levels in the software, so as to minimalize the affect of noise events to clean events used for the PIN analysis.

For GSO detectors, we are working on improvements of energy linearity and modeling of on-orbit gain variation. Therefore, the accuracy of the energy calibration of GSO is expected to remarkably improve. Now, performance verifications of new response and background model are going on. These progress will be also reported.

7732-92, Poster Session

Computation and optimization of the off-axis effective area of Wolter-I x-ray mirrors: an analytical approach

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One of the most important parameters determining the sensitivity of X-ray telescopes is their effective area as a function of the X-ray energy. The computation of the effective area of a Wolter-I mirror, with either a single layer or multilayer coating, is a very simple task for a source on-axis at astronomical distance. Indeed, when the source moves off-axis the calculation is more complicated, in particular, for new hard X-ray imaging telescopes (NuSTAR, NeXT, HEXIT-SAT, IXO) beyond 10 keV that will use multilayer coatings to extend the reflectivity band in grazing incidence. Unlike traditional single-layer coatings (in Ir or Au), graded multilayer coatings exhibit an oscillating reflectivity as a function of the incidence angle, which makes the effective area not immediately predictable for a source placed off-axis within the field of view. For this reason, the computation of the off-axis effective area has been so far demanded to ray-tracing codes, able to sample the incidence of photons onto the mirror assembly. Even if this approach should not be disdained, it would be interesting to approach the same problem from an analytical viewpoint. This would speed up and simplify the computation of the effective area as a function of the off-axis angle, a considerable advantage especially whenever the mirror parameters are still to be optimized. In this work we present the results of the application of a novel, analytical formalism to the optimization of the NHXM optical modules, requiring only the standard routines for the multilayer reflectivity computation. Validations with the findings of a ray-tracing routine are also presented.

7732-93, Poster Session

Methods of optimizing x-ray optical prescriptions for wide-field applications

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We are working on the development of a method for optimizing wide-field x-ray telescope mirror prescriptions, including polynomial coefficients, mirror shell relative displacements, and (assuming 4 focal plane detectors) detector placement and tilt, that does not require a search through the multi-dimensional parameter space. Under the assumption that the parameters are small enough that second order expansions are valid, we show that the performance at the detector surface can be expressed as a quadratic function of the parameters with numerical coefficients derived from a ray trace through the underlying Wolter I optic. The best values for the parameters are found by solving the linear

system of equations creating by setting derivatives of this function with respect to each parameter to zero. We describe the present status of this development effort.

7732-94, Poster Session

Multiband imaging with Fresnel x-ray telescopes

C. Braig, Friedrich-Schiller-Univ. Jena (Germany); P. Predehl, Max-Planck-Institut für extraterrestrische Physik (Germany)

We present a diffractive-refractive X-ray telescope for simultaneous imaging in multiple energy bands. Based on segmented dispersion corrected hybrid lenses, the system yields an angular resolution around 1 mas for photon energies between 5 and 10 keV. The total sensitivity, measured in terms of effective area times spectral bandwidth, reaches several 10^3 cm^2 keV. The suggested arrangement exploits Fresnel lenses used in higher diffraction orders for orderly protection from scattered radiation as well as reduced refractive profiles for an enhanced throughput. The telescope whose focal plane detector is mounted on a separated spacecraft may be re-oriented to new astrophysical targets on short timescales due to a focal distance of a few 10^2 km. Scientific applications are briefly discussed for active galactic nuclei (AGN).

7732-95, Poster Session

Fresnel telescope arrays for x-ray imaging spectroscopy

C. Braig, Friedrich-Schiller-Univ. Jena (Germany); P. Predehl, Max-Planck-Institut für extraterrestrische Physik (Germany)

Arrays of achromatic Fresnel lenses are investigated for future high-resolution X-ray imaging missions. Unlike single-focus instruments, parallel arrangements of numerous tiny telescopes provide an easy and natural approach to spectroscopic observations in several energy bands at an unprecedented short focal length of few 10^3 m. We suggest an optimized design with an angular resolution around 1 mas between 5 and 10 keV and analyze its optical capabilities as well as issues like the background problem which affects the achievable signal-to-noise ratio. An astronomical simulation is performed on the sun-like star Capella.

7732-96, Poster Session

High-energy astrophysics at the diffraction limit

C. Braig, Friedrich-Schiller-Univ. Jena (Germany); P. Predehl, Max-Planck-Institut für extraterrestrische Physik (Germany)

We discuss various astrophysical science drivers for upcoming high-resolution X-ray instruments on the mas scale. Even more than current missions like Chandra and XMM-Newton, planned diffraction-limited telescopes would provide unprecedented insights into hot physical processes in the universe. We apply an efficient and simple Fresnel lens design to samples of well-known targets like stellar coronae, X-ray binaries, AGN and supernovae. The cosmological impact of deep observations is discussed as well as potential applications to gravitational lenses. Aspects of separated spacecraft dynamics are briefly investigated with respect to alignment accuracy and gravitational forces.

7732-97, Poster Session

Effects of the coating optimization on the field of view for a Wolter X-ray Telescope

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Multilayer coatings can be used for the realization of broad-band X-ray focusing instruments. The coating design can be optimized with the aim of enhancing the effective area. Usually the best design is selected to maximize the on-axis effective area. The change of effective area over the field of view is determined by the energetical and angular dependence of the reflectivity, with a different behaviour than in the case of monolayer coating.

We explore the possibilities of optimizing the coating over the whole field of view by means of a new method: a formula for the distribution of incidence angles is used to optimize the multilayer structure. The results are verified by a comparison with ray-tracing results, and compared with the results of optimizations that maximize the on-axis area alone, to determine the possibilities of improvements.

7732-98, Poster Session

Self-consistent treatment of figure errors and scattering in the angular resolution degradation of x-ray mirrors

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The angular resolution degradation of an X-ray mirror, represented by its Point Spread Function (PSF), is usually simulated accounting for geometrical deformations and microroughness of its surface. When the surface profile is analyzed in terms of Fourier components, figure errors comprise the spectral regime of long spatial wavelengths, whilst microroughness falls in the regime of high spatial frequencies. The first effect is in general simulated along with geometrical optics, while the second contribution - that heavily depends on the energy of X-rays - is derived from the known scattering theory, i.e., from physical optics. A drawback of this method, indeed, is that the separation between the geometrical and physical optics regime is not abrupt. Moreover, it is not clear how one should merge the PSFs derived from the two computations to retrieve an affordable reconstruction of the PSF of the mirror. In this paper we suggest a method to compute the mirror PSF from longitudinal profiles of a grazing incidence mirror, based uniquely on physical optics. The treatment makes use of Fresnel diffraction from measured profiles or simulated from the PSD (Power-Spectral-Density) of surface roughness. Even though this approach was already adopted in the past to simulate the sole X-ray scattering, in this work we show, along a series of simulations, that it can be applied to reproduce the effect of scattering, aperture diffraction and figure errors as well. The computation returns the PSF at any X-ray energy, it is self-consistent and does not require setting any boundary between figure errors and roughness.

7732-99, Poster Session

Thin gold layer in NiCo and Ni electroforming process: optical surface characterization

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Mandrel replication by NiCo electroforming is an upgrade of the well-suited X-ray mirrors manufacturing process with pure Nickel. In this process, a Gold layer deposited on the mandrel acts as release agent and, at the same time, as reflective coating. To increase the optical performances of X-ray mirrors, the replicated optical surface is meant to reproduce the smooth topography of the mandrel: a surface degradation is commonly observed, indeed. A factor leading to surface smoothness worsening can be the spontaneous roughness growth of the Gold layer itself; therefore, the optical quality of the reflecting surface might be improved by optimizing the Gold layer thickness. A preliminary study, aimed at investigating the effects of Gold thickness reduction (< 100 nm Vs. the usual 200 nm), had already been dealt in the spectral range 0.02-1000 μm: measurements performed on flat electroformed samples showed that the Gold thickness reduction chiefly affects the roughness around 1 μm. This paper reports a new study, performed by characterising X-ray mirrors manufactured using Gold layers with 3 different thickness values. After the characterization of the mandrel surface, we show the comparison of the microroughness of replicated mirrors. Finally, as a technological validation of the NiCo electroforming process, we compare the microroughness of a NiCo mirror and of another in pure Ni, with the same Gold layer thickness.

7732-100, Poster Session

Wavefront sensing of x-ray telescopes

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Phase Retrieval analysis of off-axis or defocused focal-plane data from telescope optics has been proven effective in understanding misalignments and optical aberrations for normal incidence. The approach is used, e.g., in commissioning of the James Webb Space Telescope (JWST) primary mirror array. There is a similar need for evaluating low-order figure errors of grazing incidence mirrors and nested assemblies. When implemented in these systems, phase retrieval does not depend on normal incidence access to each mirror (shell) surface and, therefore, provides an effective means for evaluating nested x-ray telescopes during integration and test.

We have applied a well-known phase retrieval algorithm to grazing incidence telescopes. The algorithm uses the Levenberg-Marquardt optimization procedure to perform a non-linear least-squares fit of the telescope Point Spread Function (PSF). The algorithm can also retrieve low order figure errors at visible wavelengths where optical diffraction is the dominant defect in the PSF.

In this paper we will present the analytical approach and its implementation for grazing incidence mirrors of the International X-Ray Observatory (IXO). We analyze the effects of low order axial surface errors individually, and in combination on the system PSF at 633 nanometers. We demonstrate via modeling that the wavefront sensing algorithm can recover axial errors (of the grazing incidence mirrors) to a small fraction of the known axial figure errors using simulated PSFs as input data to the algorithm.

7732-103, Poster Session

Improving the ruggedness of silicon pore optics

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Silicon Pore Optics (SPO) have been developed in close collaboration between ESA, cosine and several European partners to reach the challenging goals of future space-based X-ray missions. Some key advantages of Silicon Pore Optics are their light weight and high stiffness. This not only lowers the weight of the mirror assembly and allows for a distortion-free mounting of the mirror modules, but also gives the mirror modules an inherent ruggedness. A dedicated effort has now been initiated by ESA to demonstrate that these mirror modules and their dedicated mounting system can meet the thermal and mechanical requirements of the IXO telescope, including the high strains experienced at launch. The first step in this development programme was to further ruggedize the mirror modules mounting system to cope with the launch loads and simultaneously to improve the mounting system to a fully isostatic mount. We furthermore have developed extensive mechanical and thermal models of the mirror module. These models are used to calculate the optical and mechanical response of the mirror modules under various operating and non-operating conditions. In order to validate these models, thermal and vibration tests combined with X-ray metrology will be performed on mounted mirror modules in a flight representative configuration.

In this paper we will present the first optical performance measurements under X-rays of the ruggedized Silicon Pore Optics mirror module. We will also present the outline of mechanical and thermal tests on levels relevant to the IXO mission, that will be performed on these mounted optics.

7732-104, Poster Session

Lunar liquid mirror telescope: structural concepts

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A liquid mirror telescope provides a significant advantage over other ultraviolet / visible deployable telescopes since the rotating liquid will very accurately follow an equipotential surface, providing a highly smooth surface suitable for the shortest wavelengths. A large lunar liquid mirror telescope (LLMT) with ultraviolet imaging capability has the potential for three orders of magnitude sensitivity increase over JWST and Hubble and an order of magnitude sensitivity greater than even the forward looking plans for large space-borne telescopes. This is possible due to the potential mass savings of an LLMT, when compared to current large space-borne deployable telescope technology. Implementing a large aperture deployable telescope with JWST technology (mass to mirror areal ratio of 15 kg/m^2) limits the aperture to ~16m even with the availability of a heavy lift launcher like NASA's proposed Ares V. We describe structural concepts for a LLMT which provide mass to area ratios in the range of 8 to 10 kg/m^2, thus enabling apertures as large as 24 m, assuming a single Ares V launch and the availability of lunar infrastructure to facilitate the assembly. Such an aperture increase and the addition of capability down to 0.3 mircons wavelength could outweigh the disadvantage of the liquid telescope's requirement for zenith pointing. A large liquid mirror telescope located near a lunar pole could survey as much as 2.4 square degrees, more than 300 times the area of the Hubble ultra-deep field (UDF).

7732-105, Poster Session

Effects of contamination upon the performance of x-ray telescopes

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Both particulate and molecular contamination can impact the performance of x-ray telescope systems. Furthermore, any changes in the level of contamination between on-ground calibration and in-space operation can compromise the validity of the calibration. Thus, it is important to understand the sensitivity of telescope performance---especially the net effective area and the wings of the point spread function---to contamination. Here, we quantify this sensitivity and

discuss the flow-down of science requirements to contamination-control requirements. As an example, we apply this methodology to the International X-ray Observatory (IXO), currently under joint study by ESA, JAXA, and NASA.

7732-106, Poster Session

Uniform coating of high aspect ratios surface through atomic layer deposition

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Innovative x-ray ray imaging optic technologies are often characterised by large length to pore diameter aspect ratios. Such ratios present challenges to the deposition of metallic coatings onto the mirror substrate surfaces, aimed at increasing the surface reflectivity. The technique of Atomic Layer Deposition is perfectly suited to addressing this challenge due to the inherent self limiting nature of the process which yields highly conformal coatings with surface roughness compatible with the requirements of high resolution X-ray imaging. We will present an overview of efforts aimed at developing an optimised process to coat samples with a uniform and smooth metallic layer. Particular effort is spent on in-situ metrology and analysis instrumentation for achieving increased quality of the deposited layers. The design of a custom ALD reactor system and preliminary coating results will be discussed.

7732-107, Poster Session

The x-ray advanced concepts testbed (XACT) sounding rocket payload

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The X-ray Advanced Concepts Testbed (XACT) is a sounding rocket payload that is scheduled to fly in December 2011 and again in July 2012. XACT will demonstrate three technologies that promise exciting new capabilities for future NASA astrophysics endeavors.

Grazing-incidence X-ray “concentrator” optics, optimized for point sources, will deliver large effective area (roughly 400 sq-cm at 4 keV), representing the highest throughput-to-mirror mass ratio ever flown. Behind these concentrators, time-projection photoelectric polarimeters will capture X-rays and provide polarization information with energy and time resolution. A compact, low-power, modulated electronic X-ray source will produce calibration photons on demand. With observations of the Crab and Her X-1, XACT will provide unique new insights, through time- and energy-resolved polarimetry, of the high-energy emission processes acting in the magnetospheres and nebulae of rotation-powered pulsars, and in accreting neutron stars.

7732-108, Poster Session

Soft x-ray polarimeter laboratory tests

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Multilayer-coated optics can stongly polarize X-rays and are central to a new design of a broad-band, soft X-ray polarimeter. We have begun laboratory work to verify the performance of components that could be used in future soft X-ray polarimetric instrumentation. We have reconfigured a 17 meter beamline facility, originally developed for testing transmission gratings for Chandra, to include a polarized X-ray source, an X-ray-dispersing transmission grating, and a multilayer-coated optic that illuminates a CCD detector. The X-rays produced from a Manson Model 5, multi-anode source are polarized by a multilayer-coated flat mirror and the design allows for 180 degree rotation of the source in order to change the direction of polarization. We will present progress in source characterization and system modulation measurements as well as null and robustness tests.

7732-109, Poster Session

The development of a negative ion time projection chamber (NITPC) polarimeter for energetic transients

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A negative ion time projection chamber (NITPC) has been developed for measuring the X-ray polarization of energetic transients in the 2 - 10 keV energy range. The primary goal is to measure the prompt X-ray emission from gamma-ray bursts (GRBs) in order to distinguish between the possible emission mechanisms. Using negative ions as a charge carrier enables a TPC polarimeter with a large (3 cm) drift distance, allowing for a sensitive, large area, wide-field of view instrument.

Initial measurements of gas gain with Nitromethane, CO2 and Neon, indicate that a TPC with a single gas electron multiplier (GEM) will not achieve sufficient gain to measure the photoelectron emission direction accurately. A double GEM setup has been implemented and is shown to produce the required signal to noise.

Measurements with the NITPC have been made at multiple energies from 2.5 - 10 keV at the Brookhaven National Laboratory (BNL) National Synchrotron Light Source (NSLS). We show the dependency of photoelectron track length on energy and report modulation versus energy for different beam positions in the drift region.

We will also discuss future mission potential for the GRB Polarimeter (GRBP).

7732-110, Poster Session

‘Rolling and tumbling’: status of the SuperAGILE experiment

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The SuperAGILE experiment is the hard X-ray monitor of the AGILE mission. It is a 2 x one-dimensional imager, with 6-arcmin angular resolution in the energy range 18-60 keV and a field of view in excess of 1 steradian. SuperAGILE is successfully operating in orbit since Summer 2007, providing long-term monitoring of bright sources and prompt detection and localization of gamma-ray bursts.

Starting on October 2009 the AGILE mission lost its reaction wheel and the satellite attitude is no longer stabilized. The current mode of operation of the AGILE satellite is a Spinning Mode, around the Sun-pointing direction, with an angular velocity of 1 degree/s (corresponding to 10 times the SuperAGILE point spread function every second). In these new conditions, SuperAGILE continuously scans a much larger fraction of the sky, with much smaller exposure to each reagion. In this paper we will review the results of the first 2.5 years of “standard” operation of

SuperAGILE, and show how new implementations in the data analysis software allows to continue the hard X-ray sky monitoring by SuperAGILE also in the new attitude conditions.

7732-111, Poster Session

Science simulations and data challenges for the Fermi Gamma-ray Space Telescope

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The Fermi data challenges were a sequence of end-to-end simulation studies. These included a complete detector simulation with realistic orbit and attitude profile, full cosmic-ray background model with South Atlantic Anomoly and a detailed model of the gamma-ray sky including time variable sources. Simulated Gamma-ray Burst Monitor (GBM) data for gamma-ray bursts were also produced. The resulting simulation data were pushed through an analysis chain which included direction and energy reconstruction, background rejection and event classification algorithms allowing the identification of well-reconstructed gamma-ray events. The astrophysical contents of the sky were kept secret and the simulated data were made available to the LAT collaboration. At the end of the exercise, the analysis results obtained by the collaboration were compared to the true sky model. The data challenges were a stringent test the of data processing pipeline, data servers and analysis software. Furthermore, it provided an opportunity to explore a gamma-ray sky which included a variety of known and potential classes of sources that Fermi was likely to detect, allowing the development of realistic analyses prior to launch.

7732-174, Poster Session

SIDERALE and BIT: a small stratospheric balloon experiment for polar gamma background

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SIDERALE is an experiment that was hosted as a piggy back payload on SoRa LDB (Sounding Radar Long Distance Balloon) mission by the Italian Space Agency (ASI).

SIDERALE was aimed at testing a detector for high energy astrophysics applications based on a 4x4 pixel CZT solid state sensor. An onboard data handling computer, a mass memory and a power supply units were integrated in SIDERALE.

Furthermore an innovative telemetry system BIT (Bi-directional Iridium Telemetry) was used in order for SIDERALE to be autonomous and independent from the hosting payload.

The detector had been measuring X and Gamma radiation for the whole flight according to dynamically set operating modes. Four/six events per second were measured over a 0.25 cm2 sensitive detector area and in an energy range of between 40 keV and 400 keV. Acquired data were stored on board and partially transmitted in real time to ground for a quick look.

The balloon was launched on July 1st from Longyearbyen, Svalbard, and flew for 4 days at a float altitude of about 39 km along the 78° North parallel and landed on Baffin Island on July 4th at 10:30 UTC. In the paper the experiment will be presented and a preliminary analysis of flight and scientific data will be discussed. Data analysis will provide the first measurement of X and Gamma background at those latitude and elevation.

7732-112, Poster Session

Stigmatic grazing-incidence x-ray spectrograph for solar coronal observations

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We present the design for a high spatial and spectral resolution stigmatic grazing-incidence soft X-ray spectrograph, designed for use in the soft X-ray spectral range to observe the high-temperature solar corona. The spectrograph is composed of a slit, a pair of paraboloid mirrors and a planar varied-line-space grating. All reflective surfaces operate at a graze angle of 2 degrees. The spectrograph is designed to produce a flat spectrum on a detector, covering a wavelength range of 0.6 to 2.4 nm (0.5 to 2.0 keV). The design achieves 1.5 pm spectral resolution and 15 um spatial resolution over a 5 mm long slit. The spectrograph is currently being fabricated as a laboratory prototype. The design can fit in a sounding rocket payload behind a 1.2 m focal length grazing incidence X-ray telescope, and this combination will have a 2.5 arcsecond spatial resolution and a 15 arcminute slit length.

7732-113, Poster Session

The high-resolution coronal imager

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The High Resolution Coronal Imager (Hi-C) is a high-resolution EUV imaging telescope developed as a sounding rocket payload. It is designed to achieve a spatial resolution of 0.2 arcsecond. The Hi-C telescope is a normal-incident EUV telescope using multilayer-coated mirrors, with two passbands. The two passbands are realized by using different coatings on two halves of each mirror, and a focal-plane filter is used to select between the passbands. The telescope is a 220mm aperture Ritchey-Chrétien design with an F/9.1 primary mirror and a secondary magnification of 12, resulting in an effective focal length of 23,900 mm. A 4096x4096 CCD with 12 um pixels will be used. The instrument is scheduled for completion and flight in 2012.

7732-114, Poster Session

HiRISE Space Mission to address the dynamical chromosphere-corona interface

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Several ground facilities and space missions are currently dedicated to the study of the Sun and of the solar corona in particular. However, and despite significant progress with the advent of space missions and UV, EUV and XUV direct observations of the million degrees coronal plasma, much is yet to be achieve in the understanding of these high temperatures and of the coronal heating in general. Recent missions have shown the definite role of waves and of the magnetic field deep in the inner corona, at the chromosphere-corona interface, where dramatic changes occur.

The dynamics of the corona is controlled by the emerging magnetic field, guided by the coronal magnetic field. Accordingly, the direct measurement of the chromospheric and coronal magnetic fields is of prime importance. The solar corona consists of many thin loops or

threads with the plasmas brightening and fading independently. The dynamics in each thread is believed to be related to the formation of filaments, each one being dynamic, in a non-equilibrium state. The mechanism sustaining that dynamics, oscillations or waves (Alfvén or MHD?), require both very high-cadence, multi-spectral observations, and high resolution. This is - partly - available during rare, unique, but time-limited, total solar eclipses, and foreseen in future Space Missions in formation flying, noticeably HiRISE, the ultimate new generation ultrahigh resolution, interferometric and coronagraphic, Solar Physics Mission, proposed for ESA Cosmic Vision (pre-selected in 2007).

HiRISE (High Resolution Imaging and Spectroscopy Explorer), at the L1 Lagrangian point, provides meter class FUV imaging and spectro-imaging, EUV and XUV imaging and spectroscopy, and ultimate coronagraphy by a remote external occulter (satellites in formation flying 280 m apart) allowing to characterize temperature, densities and velocities in the solar transition zone and inner corona with, in particular, direct coronal magnetic field measurement: a unique set of tools to understand the onset of coronal heating. We give a detail account of the proposed mission profile, major scientific objectives and model payload of HiRISE, a natural complement to the Solar Probe type missions lacking duty cycle, high resolution, spatial, spectral and temporal multi-temperature diagnostics and full coronal magnetometry. HiRISE is to be re-proposed to the second ESA Cosmic Vision Call in 2011/2012.

7732-176, Poster Session

The definition of an imaging spectrometer meeting the needs of UV solar physics

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The study of the outer solar atmosphere requires to combine fast imaging and spectroscopy in the UV lines formed in the high chromosphere and the transition region to the corona.

We start from the science requirements and define the instrumental specifications in terms of field-of-view, spatial and spectral resolution and bandpass. We propose two different all-reflection optical architectures based on interferometric techniques: Spatial Heterodyne Spectroscopy (SHS) without Integral Field Units, on one hand, and an Imaging Fourier Transform Spectrometer (IFTS) on the other hand. We describe the different set-ups, compare the potential performances of the two types of solutions and discuss their feasibility. We conclude that the IFTS appears to be the best solution meeting the needs of UV solar physics. However, we point out the many difficulties to be encountered, especially as far as metrology is concerned.

7732-177, Poster Session

A novel forward-model technique for estimating EUV imaging performance: design and analysis of the SUVI telescope

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The Solar Ultraviolet Imager (SUVI) is one of several instruments being fabricated for use on board the upcoming Geostationary Operational Environmental Satellites, GOES-R and -S platforms, as part of NOAA's space weather monitoring fleet. SUVI is a Generalized Cassegrain telescope that employs multilayer coatings optimized to operate in six extreme ultraviolet (EUV) narrow bandpasses: 9.4, 13.1, 17.1, 19.5, 28.4 and 30.4 nm. Over the course of its operational lifetime SUVI will image and record full disk, EUV spectroheliograms of the sun approximately every few minutes, and telemeter the data to the ground for digital processing. This data will be useful to scientists and engineers wanting to better understand the effects of solar produced EUV radiation with the near-Earth environment. At the focus of the SUVI telescope is a thin, back-illuminated CCD sensor with 21 μm (2.5 arc sec) pixels. At the shortest EUV wavelengths, image degradation from mirror surface scatter effects due to residual optical fabrication errors dominate the effects of both diffraction and geometrical aberrations. Discussed herein, we present a novel forward model technique that incorporates: (i) application of a new unified surface scatter theory valid for moderately rough surfaces to predict the bi-directional reflectance distribution function (BRDF) produced by each mirror (which uses optical surface metrology to determine the power spectral density, PSD, that characterizes the "smoothness" of an optical surface); (ii) use of the BRDF for each mirror at each wavelength, in tandem with the optical design, to calculate the in-band, EUV point spread function (PSF); (iii) use of the PSF to calculate the fractional ensquared energy in the focal plane of SUVI; and (iv) comparison of BRDF measurements taken at 9.4 nm with the forward model predictions.

7732-178, Poster Session

High-spectral resolution, high-cadence, imaging x-ray microcalorimeters for solar physics

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We have been developing transition-edge-sensor (TES) based x-ray microcalorimeter arrays for future solar physics missions where imaging and high energy resolution spectroscopy will enable definitive studies of the dynamics and energetics of the solar corona. The characteristics of these x-ray microcalorimeters are significantly different from conventional microcalorimeters developed for astrophysics because they need to accommodate much faster count rates (~ 300-1000 cps) while maintaining high energy resolution of better than 4 eV FWHM in the X-ray energy band of 0.2-10 keV. The other main difference is a smaller pixel size than is typical for x-ray microcalorimeters in order to provide angular resolution less than 1 arcsecond. We have achieved an energy resolution of 2.15 eV at 6 keV in a pixel with a 12 x 12 micron TES sensor and 34 x 34x 9.1 micron gold absorber, and a resolution of 2.30 eV at 6 keV in a pixel with a 35 x 35 micron TES and a 57x57x9.1 micron gold absorber. This performance has been achieved in pixels that are fabricated directly onto solid substrates, ie. they are not supported by silicon nitride membranes. We will describe the characteristics of these detectors and their expected performance at high count rates. We have also demonstrated an array heat-sinking technique that is necessary for high-count rate operation, and shown that this heat-sinking significantly reduces the thermal cross-talk between pixels compared with previous microcalorimeters, to a level that is less than one part in 10^4 for nearest neighbors pixels 150 microns apart.

7732-115, Poster Session

The Monte Carlo simulation framework of the ASTRO-H X-ray Observatory

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ASTRO-H is the 6th Japanese X-ray astronomy satellite, which is scheduled to be launched in 2014 and will be operated as an observatory open to the global astronomy community. We are developing the data analysis framework with the Geant4-based Monte Carlo simulation core and the numerical models of the on-orbit environmental radiation and the full-satellite mass structure, in order to construct high SNR detectors, their high precision response matrices and background databases.

The satellite will carry 4 kinds of detectors, an X-ray calorimeter (SXS), X-ray CCDs (SXI), Si strip + CdTe detectors (HXI) and Compton telescopes (SGD), each of which uses different photon detection technology and has different sensitivity for background radiation field from each other. In addition to this, the X-ray mirrors and SGD have complicated focusing feature and FOV response, respectively, for their extremely light weight and small size compared to their effective area and energy range. In order to simulate and evaluate the particle transportation and energy deposition in such a satellite and sensors, not only the simulator core and the proper models but also other software components such as filtering, data fitting and downstream evaluation processes are essential.

The framework thus has the mechanism to connect and control data processing modules developed independently and data communication channel among them, which has been technically proven by simulations and analysis of Suzaku HXD, many other detectors and astrophysical issues.

7732-116, Poster Session

The thermal analysis of the Hard X-ray Telescope (HXT) and the investigation of the deformation of the mirror foil due to temperature change

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The thin film technology called "depth-graded multi-layer" is used to manufacture reflector foils, which are inserted in a hard X-ray telescope. The foil is constructed of an aluminum substrate, epoxy adhesion layer and a platinum/carbon multi-layered reflecting surface. When the temperature of the foil changes from the temperature at which the foil was produced; thermal deformation is induced due to difference of linear coefficient of expansion of its constituents. The deformation causes performance of X-ray image formation to deteriorate. Therefore, it is absolutely imperative to estimate the amount of deformation quantitatively and to establish a method of temperature control for the foil under the thermal environment on orbit. We used the hard X-ray telescope, which is part of the currently-projected the ASTRO-H X-ray satellite, as an example for investigation. The effective method of the HXT thermal control was examined with the thermal analytical software, "Thermal Desktop". The deformation of the foil when the temperature was changed by 1 degree C was predicted by a finite element analysis (FEM). The experiment on the foil was also performed and the test results were compared with the FEM analysis. The thermal desktop analysis shows that the overall foil temperature in orbit can be close to the temperature at which the foils were produced (~22degree C) by the newly developed thermal control method. The FEM analysis shows that the prediction of the foil deformation due to a temperature change of 1 degree C is about 8 μm. We will measure the influence of the deformation on performance of the X-ray image formation in the future.

7732-117, Poster Session

Development of BGO active shield for the ASTRO-H soft gamma-ray detector

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Soft Gamma-ray Detector (SGD:10-600keV) will be mounted on the 6th Japanese X-ray observatory ASTRO-H to be launched in 2014. The main part of the SGD is a Compton Cameras with narrow field of view, surrounded by BGO active shields (SGD-BGO). By this combination, we can achieve more than ten times better sensitivity than Suzaku/HXD.

The BGO active shield will also work as a gamma-ray burst monitor as proven by wide-band all-sky monitor (WAM) of the Suzaku/HXD.

To reduce the space and power, we employ Avalanche Photodiodes (APDs) for detection of scintillation lights from the BGO. We also use waveform sampling by flash-ADC and digital filter to replace conventional analog filter and ADC scheme to further reduce the space and power with increased flexibilities. As an active shield, we need to achieve the threshold level of 50-80 keV for the BGO readout system. Since the size of APD is small, we need to pay close attention on the light collection from BGO blocks with a large size and a complex shape. Due to large leakage current of the APD, lower temperature is preferred to minimize the noise while higher temperature is preferred to simplify the cooling system. In order to optimize the BGO shape and the operating temperature, we tested the performance of the BGO readout system with various BGO shapes under different operating temperatures. Here, we report the results of above optimization efforts.

7732-118, Poster Session

Monte Carlo simulation study of in-orbit background for the soft gamma-ray detector on-board ASTRO-H

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The Soft Gamma-Ray Detector (SGD) on-board ASTRO-H satellite, scheduled to be launched in 2014, is a Si/CdTe Compton telescope surrounded by thick BGO active shield. The SGD covers the energy range from 40 keV to 600 keV and studies non-thermal phenomena in the universe. Although this energy band is expected to provide vital information of high energy phenomena, the sensitivity of past and existing missions is limited due to large background in orbit. The SGD

adopts the concept of a narrow field-of-view Compton camera to achieve very low background and improve the sensitivity by 1-2 orders of magnitude compared to the Suzaku-HXD. For the success of the SGD mission, we need to evaluate the expected performance, especially the instrumental background, through careful Monte Carlo simulation and beam tests, and optimize the detector design before the launch We are developing a Geant4-based Monte Carlo simulation framework for the SGD (and HXI on-board ASTRO-H). It is with a modular architecture and enables us to conduct an End-to-End simulation from the particle generation to the event analysis. We also utilize the MGGPOD package to predict radioactivation in orbit, which is one of major background sources for HXI/SGD. We have been performing a detailed validation of the system through comparison with the beam test data. Here we will describe the simulation framework and expected background/ performance of the SGD in orbit. Our system will be integrated into the ASTRO-H simulation framework described in M. Ozaki's constribution.

7732-119, Poster Session

Measuring the EUV and optical transmission of optical blocking layer for x-ray CCD camera

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We have newly developed the back-illuminated (BI) X-ray CCD which has an Optical Blocking Layer (OBL) directly coating its X-ray illumination surface with Aluminum-Polyimide-Aluminum instead of Optical Blocking Filter (OBF). OBL is composed of a thin polyimide layer sandwiched by two Al layers. Polyimide and Al has a capability to cut EUV and optical light, respectively. The X-ray CCD is affected by large doses of extreme ultraviolet (EUV) radiation from Earth sun-lit atmosphere (airglow) as well as optical light in orbit. To evaluate the performance of polyimide that cut off EUV, we measured the EUV transmission of OBL at various energy range between 15-72eV by utilizing beam line located at the Photon Factory in High Energy Accelerator Research Organization (KEK-PF), and obtained the EUV transmission to be ~3% at 41eV which is as same as expected transmission from the designed thickness (~1100A) of polyimide layer. And we are going to measure the optical transmission of OBL at various wave length between 400-950nm. We will present these result in the meeting.

7732-120, Poster Session

Current status of the pre-collimator development for the ASTRO-H X-ray telescopes

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We present the current status of the pre-collimator for the stray-light reduction, mounted on the Astro-H X-Ray Telescope (XRT). Astro-H, the 6th Japanese X-ray satellite, has four XRTs; two of which consist of a number of thin-nested Au coating mirrors and the others utilizes depth-graded Pt/C multilayer mirrors to enhance the energy coverage up to 70keV. Since the XRTs adopt the Wolter-I type grazing incident optics, X-rays from a source located far from the telescope boresight also reach the detector field of view (FOV). These X-rays, called stray lights, create a ghost image and then reduce the signal-to-noise ratio. Major component of the stray lights passes through just above the primary mirror and is reflected on the secondary mirror only.

We examined the observational effects by the stray lights in some scientific cases, using the ray-tracing simulator. We found that the Galactic center is mostly covered with the stray lights from the well-known bright X-ray sources even in the hard X-ray band (> 10keV). In addition, the flux estimation of the extended X-ray emission such as the Cosmic X-ray Backgrounds is also found to have large uncertainty due to the stray lights from the outside of the XRT FOV. We thus plan to mount the pre-collimator, which is comprised of cylindrical blades aligned with each primary mirror, onto the XRTs to reduce these stray lights. We report the reduction effect and the improvement of the observational performance by the pre-collimator.

7732-121, Poster Session

The current status of the reflector production for ASTRO-H/HXT

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We present the current state of the development of the hard ray telescope onboard ASTRO-H satellite.

Japan's 6th X-ray satellite mission ASTRO-H, which is planed to be launched in 2014, will carry two hard X-ray telescopes (HXT) using depth-graded multilayer reflectors which provide us the capability of hard X-ray imaging observation upto 80 keV. ASTRO-H/HXT is the light-weight hard X-ray telescope using Pt/C depth-graded multilayer and high-throughput thin-foil optics. The basic technology for fabricating ASTRO-H/HXT has been established through the balloon borne experiments, InFOCuS and SUMIT mission. The HXT consists of about 1300 foil reflectors of which a size of the 200 mm mirror length and the diameter range of 60--450 mm which is much larger that those for the balloon borne experiments. To clear the requirements of the angular resolution and the effective photon collecting area for ASTRO-H/HXT, we should produce twice the total number of reflectors, and screen and select them. Therefore we need to produce more than 5000 foil reflectors for the two flight telescopes.

The installation of the production line and optical evaluation system dedicated to the ASTRO-H/HXT has been almost done. We are testing and improving the production line through productions of several sizes of reflectors. The mass production of the reflectors for the flight model is scheduled to start from the beginning of the fiscal year 2010.

7732-122, Poster Session

Vibration properties of Hard X-ray Telescope on board satellite

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ASTRO-H is the new Japanese X-ray astronomy satellite which is planed for launch in 2013. Hardware on board ASTRO-H must be designed

for passing vibration testing required by JAXA. In this study, vibration properties of a mirror housing of Hard X-Ray Telescope (HXT) are investigated by analytical and experimental approaches. A mirror housing of HXT is a cylindrical case and contains reflection mirror foils. The housing consists of three layers - precolimator, primary and secondary. These layers are divided into three sections by 120 degrees and 216 foils are placed concentrically in the section. The foils are constrained by alignment bars in order to keep distance between neighboring foils. At first, vibration analysis of the housing containing foils was conducted by FEA software (ABAQUS). In the analysis, equivalent material properties were used for representing 216 foils by 6 equivalent foils. These foils were fixed to alignment bars in this simulation. The results showed that shape of the alignment bar strongly affected eigenfrequencies. It was found that the 1st eigenmode was circumferential deflection of the alignment bars. It also appeared that the minimum eigenfrequency is lower than the required values when thickness of the bar is small. However, it is expected that the minimum frequency is larger than the simulated value because the foils are not adhered to the alignment bars in a real structure. It is planed to conduct vibration tests of the housing in December 2009, so the test results will be described in a full paper.

7732-123, Poster Session

Cooling system for the soft x-ray spectrometer (SXS) onboard ASTRO-H

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The Soft X-ray Spectrometer (SXS) onboard Astro-H is a high resolution spectrometer utilizing an X-ray microcalorimeter array. Operated at 50 mK, it achieves resolving power of 1000 or larger at 6 keV. The SXS is developed under US-Japan collaboration with European contribution. The detector array, the ADR, and their control electronics are developed by NASA, while the cooling system down to 1.3 K/4 K and the signal processing electronics are developed by JAXA.

One of the critical parts of the SXS is its cooling system. A requirement for the SXS cooling system is to provide 50 mK heat sink temperature to the detector for more than 3 years. 50 mK is achieved by a three-stage ADR, and the heat sink for the ADR is provided by liquid He (LHe). To keep 30 liter LHe for more than 3 years, heat load to the He tank must be extremely reduced (less than 1 mW). For that purpose, a He4 Joule-Thomson cooler system and double-stage Stirling coolers are used, to provide 4K shield and 20K/100K shields, respectively. From a reliability point of view, two double-stage Stirling coolers are used to cool 20K/100K shields. A precooler for the JT system is also composed of two double-stage Stirling coolers. They are operated with 50% power in the normal case. The JT system works as a functional redundancy for LHe, i.e., cryogen-free operation is possible. As a result, the cooling system is redundant down to 1.3 K.

7732-124, Poster Session

Current status of hard x-ray characterization of ASTRO-H HXT at SPring-8

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We present the current status of hard X-ray telescope developments of ASTRO-H. ASTRO-H is Japan's 6th X-ray satellite mission following to Suzaku. It will be lauched in 2014.

ASTRO-H is designed to carry a pair of hard X-ray imaging system, another pair of soft X-ray imaging systems, and soft gamma-ray detector to cover the wide energy range between 0.3 keV to 600 keV. One of the key instruments of ASTRO-H is HXT (Hard X-ray Telescope) to cover hard X-rays up to 80 keV. HXT is thin-foil, multi-nested conical optics as well as Suzaku XRT. To reflect hard X-rays efficiently, reflector surfaces are coated with depth-graded Pt/C multilayer (supermirror). Reflectors are fabricated by the epoxy-replication method.

Currently, we have finished the preparation of mirror production facility at Nagoya University, and started test production of reflectors for HXT. We have fabricated three different sizes of reflectors (r=65 mm, 105 mm, and 160 mm), the selected 19 pairs of multilayer mirrors which consist of three bands (4 pairs at 65 mm in radius, 10 pairs at 105 mm, 5 pairs at 160 mm, respectively) have been characterized at the SPring-8 beamline BL20B2. We have obtained an angular resolution of 1.7 arcmin (HPD) in total bands, and local spot properties of each reflector in preliminary analysis. Moreover, We have confirmed the effectiveness of the active tuning procedure to improve the off-roundness of focused image for HXT housing.

7732-125, Poster Session

The detector subystem for the SXS instrument on the ASTRO-H Observatory

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The Soft X-ray Spectrometer (SXS) instrument on the Astro-H observatory is based on a 36 pixel x-ray calorimeter array cooled to 50 mK in a sophisticated spaceflight cryostat. The SXS is a true spatial-spectral instrument, where each spatially discrete pixel functions as a high resolution spectrometer. Here we discuss the SXS detector subsystem that includes the detector array, the anticoincidence detector, the first stage amplifiers, the thermal and mechanical staging of the detector, and the cryogenic bias electronics. The design of the SXS detector subsystem has significant heritage from the Suzaku/XRS instrument but has some important modifications that increase performance margins and simplify the focal plane assembly. Notable improvements include x-ray absorbers with significantly lower heat capacity, improved load resistors, improved thermometry, and a decreased sensitivity to thermal radiation. These modifications have yielded an energy resolution of 3.5-4.0 eV FWHM at 6 keV for representative devices in the laboratory, giving considerable margin against the 7 eV instrument requirement. We expect similar performance in flight. Here we discuss the design of the SXS detector subsystem, the performance of prototypes in the laboratory, and the development of the engineering model unit that will be qualified for flight.

7732-126, Poster Session

Operation of the x-ray telescope eROSITA

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The X-ray telescope eROSITA is the core instrument on the Russian Spektrum-Roentgen-Gamma satellite which will be launched in 2012 to an orbit around the L2 point of the Earth-Sun-system. It will perform the first all-sky-survey with an imaging telescope in the energy range between 0.3 - 10 keV and will also do pointed observations.

The main objective of this mission is the detection of 100.000 galaxy clusters in order to constrain cosmological parameters, amongst others the density and evolution of dark energy.

Besides this, a lot of other science will be possible, for example on AGN, supersoft sources, neutron stars, cataclysmic variables and diverse transient sources.

In comparison to previous and present missions, eROSITA has a higher spatial resolution and/or a higher grasp and is therefore predestined for these tasks.

During both survey and pointing phase the solar panels and the antenna constrain the possible mission scenario. The scan axis will point constantly towards the earth in the survey phase. In combination with the orbit, the points of largest exposure - the scan poles - will be areas of a few hundred deg^2 instead of small singularities.

The background as a permanent interference factor is limiting the performance as well as transient disruptions like solar flares. Constraints on the instrument's side are amongst others vignetting, effectivity and aligning of the different components.

Therefore it is very important to maintain certain requirements. Mechanical requirements have to be fulfilled during integration. Thermal requirements have to be controlled during the whole mission. The extreme conditions in space demand an accurate thermal design. Mirrors, CCD-cameras and camera electronics all have their own, partly stringent working temperature ranges.

Objectives of this work are to find the optimum mission scenario as well as certain operating parameters, taking into account all environmental boundary conditions.

7732-127, Poster Session

The GEMS x-ray polarimeter instrument

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The Gravity and Extreme Magnetism SMEX (GEMS) is the first dedicated X-ray polarimetry space mission. It has been selected by NASA's Small Explorer program for launch in 2014. The X-ray polarimeter instrument on GEMS consists of three telescopes utilizing identical sets of conical grazing incidence mirrors and time-projection polarimeters. This combination allows GEMS to achieve polarization sensitivity to sources as faint as 1 mCrab in the 2-10 keV band within the constraints imposed by a small mission. We outline the instrument's design, deployment, and operation, emphasizing aspects that limit background and systematic effects to enable measurement of small polarizations. For example, the entire instruments rotates with a 10 minute period to separate source polarization from instrumental effects that slowly vary in the instrument frame of reference stationary to the instrument. We then describe the instrument's expected performance.

7732-128, Poster Session

Solid-state slit camera (SSC) onboard MAXI

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Monitor of All-sky X-ray Image (MAXI) is an astrophysical payload for the Japanese Experiment Module (Kibo) on the International Space Station (ISS) launched in July 2009.

MAXI is designed for monitoring all sky in the X-ray band. MAXI consists of two X-ray detector systems: the Gas Slit Camera (GSC) and the Solid-state Slit Camera (SSC). The SSC consists of two CCD cameras: each contains 16 CCD chips. The CCD chip has 1024 x 1024 pixels and covers 25mm square. The thickness of depletion layer is 70 um. These CCD chips are cooled down to -60 degree using a combination of the radiator and the peltier cooler.

During the initial check out phase of the SSC, we found that all 32 CCD's and peltier coolers are working correctly and have achieved a good energy resolution (150 eV in FWHM at MnK-alpha). We also found that Cu emission line originated from the collimator can be seen in all 32 CCD's. The acquired image shows more than 40 X-ray sources including several extragalactic source. From the spectrum, emission lines of Mg, Si, Fe(L) can be seen from several SNR's. We report the current status of the MAXI/SSC.

7732-129, Poster Session

VELA: a fast DEPFET readout circuit for the NHXM Mission

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We report on the development of high-speed and low-noise readout of a monolithic array of DEPFET detector. NHXM, under study by ASI (Agenzia Spaziale Italiana), will be operated as an X-ray observatory in the energy band between 0.5 and 80 keV; the 4 telescopes will have a field of view diameter of 12 arcmin and a focal length of 10 m.

The challenging requirements of the NHXM cameras regard the necessity to obtain images and spectra with nearly Fano-limited energy resolution (FWHM 150 eV @ 6 keV) with an absolute time resolution of about 100 µs. The DEPFET based detectors, thanks to an intrinsic low anode capacitance, can provide excellent energy resolution and high frame rate at the same time. Thus, they are suitable as the low-energy detectors (from 0.5 to 10 keV) of the new NHXM telescopes.

In order to fully exploit the speed capability of the DEPFET array, it has been developed a new readout architecture (different from the ones employed up to now) based on the readout VELA circuit.

VELA (VLSI Electronic for Astronomy) is a CMOS circuit developed to operate the DEPFET pixels in a new current readout configuration in order to implement an extremely fast readout (2 µs/row) and preserve the excellent noise performance of the detector.

In the paper, the VELA performances reading out a prototype 64 x 64 DEPFET matrix will be discussed. The measures at the maximum achievable frame-rate and the best energy resolution will be presented in order to assert the VELA suitability for X-ray imaging and spectroscopy.

7732-130, Poster Session

The high-energy detector of the New Hard X-ray Mission (NHXM): design concept

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The new hard X-ray mission (NHXM) is conceived to extend the grazing-angle reflection imaging capability up to energy of 80 keV. The NHXM payload consists of four telescopes. Three of the them have at their focal plane three identical spectra-imaging cameras operating between 0.2 and 80 keV, while the fourth has a X-ray imaging polarimeter. These cameras are constituted by two detection layers: a Low Energy Detector (LED) and a High Energy Detector (HED) surrounded by an Anti Coincidence (AC) system.

Here we will present the preliminary design and the solutions that we are currently studying to meet the requirements for the high energy detectors.These detectors will be based on CdTe pixel sensors coupled to pixel read-out electronics using custom CMOS ASICs

7732-131, Poster Session

Technologies for manufacturing of high angular resolution multilayer coated optics for the New Hard X-ray Mission a status report II.doc

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Focusing mirrors manufactured via galvanic replication process from negative shape mandrels is the candidate solution for some of next future X-ray missions. Media Lario Technologies (MLT) is the industrial enabler developing, in collaboration with Brera Astronomical Observatory (INAF/OAB) and Italian Space Agency, the Optical Payload for the New Hard X-ray Mission (NHXM) Italian project that will be operated by 2016. The current and ongoing development activities in Media Lario Technologies complement the electroforming technology with a suite of critical manufacturing and assembly of the Mirror Module Unit. In this paper, the progress on mandrels manufacturing, mirror shell replication, multilayer coating deposition and mirror module integration, leading to the manufacturing and testing of some astronomical Hard X-ray Engineering Models, is reported. Mandrel production is a key point in terms of performances and schedule; the results from mandrels fabricated using a proprietary multistep surface finishing process are reported. The progress in the replication of ultrathin Nickel and Nickel-Cobalt substrates gold coated mirror shells is reported together with the results of MLT Magnetron Sputtering multilayer coating technology for the hard x-ray waveband and its application to Pt/C.

7732-132, Poster Session

Mounting of mirror segments for IXO

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A “suspension mounting” scheme is developed for the IXO mirror segments in which the figure of the mirror segment is preserved. The mirror, first fixed on a thermally compatible strongback, is subsequently aligned and transferred onto its mirror housing. Recent progress of this process and results of measurements and x-ray tests will be presented.

7732-135, Poster Session

Fabrication and characterisation of TES anti-coincidence cryogenic detector for IXO

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We present the structural design of the cryogenic anti-coincidence for vetoing the signal of energetic charged particles hitting the X-ray microcalolorimeter array for the IXO mission. The anticoincidence is based on Ir-Au TES sensors growth onto a silicon absorber that will be operated at 50mK and mounted very close to the X-ray microcalorimeter array. The detector will be built as a 2x2 plane array of about 18x18 mm silicon absorber. We have fabricated prototypes with different configurations of the thermal link and of TES Ir-Au sensors, with the purpose of tailoring the response signal to the requirements of the X-ray instrument. The detector will work by properly mixing the fast a-thermal and slower thermal phonon signal in order to achieve fast rise-time (a-thermal component) at the level of the microsecond and, at the same time, a good linearity of the response vs energy (thermal component)that will ensure high detection efficiency of the minimum ionizing particles at the threshold energy. Fast risetimes of few microsecond have been obtained but with a large amplitude spread due to the position sensitive machanism of a-thermal phonon excitation of the TES sensor. The detector prototypes were thermally simulated through FEM models in order to disentangle the thermal contribution from the a-thermal one and compare them with the pulse shape and the noise characteristics for the different detector configurations.

7732-136, Poster Session

Performance of kilo-pixel arrays of transition-edge-sensor x-ray microcalorimeters for the International X-ray Observatory

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We are developing kilo-pixel arrays of high-performance superconducting transition-edge-sensor (TES) microcalorimeters suitable for the focal plane of the International X-ray Observatory (IXO) X-ray Microcalorimeter Spectrometer (XMS). The XMS reference design consists of a 40x40-pixel core array of 300 micron devices with 2.5 eV energy resolution (at 6 keV) surrounded by a 2304-element array of 600 micron pixels with 10 eV energy resolution, the latter of which is required to extend the field-of-view with minimal impact on instrument complexity and power. In 2008 we demonstrated uniform, high-resolution, high-fill-factor 8x8-pixel arrays read out using a state-of-the-art, time-division SQUID multiplexer. Since then, we have focused our efforts toward our next milestone of producing kilo-pixel arrays and the associated multiplexer readout electronics. Here we report on detector characterization of 32x32 arrays of 300 micron pixels suitable for the XMS core array, including the X-ray

spectral resolution at 6 keV, stability, pixel uniformity, and thermal and electrical cross-talk, as well as the current status of our efforts toward an integrated 3-row by 32-column multiplexer demonstration. In addition, we will discuss the development of arrays of larger pixels implemented with various electrical and thermal multiplexer readout schemes for the XMS outer array.

7732-137, Poster Session

Platinum as a release layer for thermally formed glass optics for the International X-ray Observatory

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Platinum and boron nitride are two of the materials being considered as release layers for thermally slumping glass substrates for the International X-Ray Observatory (IXO) mirror. SAO is using a direct slumping method to investigate the use of platinum as a release layer for IXO glass substrates. Recent experimental results characterizing dc magnetron sputtered platinum coatings using XRR, AFM, WYKO before and after thermally forming to a fused silica mandrel will be presented.

7732-138, Poster Session

Multilayer coatings for IXO optics

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The requirements for the IXO (International X-ray Observatory) telescope are very challenging in respect of resolution and effective area.
Within a clear aperture with 1.8m < R < 0.25m that is dictated by the spacecraft envelope, the optics technology must be developed to satisfy simultaneously requirements for effective area of 3m^2 at 1.25keV, 0.65 m^2 at 6keV and >150cm^2 at 30keV. The reflection properties of candidate glass and silicon substrate materials do not allow to meet these requirements. We show that this performance over a very broad energy range can only be achieved by paying particular attention to coatings, and we describe the processes for coating both high density metal and graded depth multilayers onto glass and silicon samples, and how this must be carefully considered in the optics assembly flow. We describe measurements of candidate coatings and provide projections of performance when applied to an optimised telescope design

7732-139, Poster Session

Enhancing the International X-ray Observatory

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We present results of systems studies expected to significantly enhance the science utility and reduce technical as well as cost risks for the International X-ray Observatory (IXO). We describe (a) an optical bench concept that has the potential to increase the focal length from 20 to 25 m within the current mass and stability requirements, (b) an instrument and system layout that increases the accessible field of regard and (c) a number of design choices based on flight proven concepts that reduce cost risk.

Our concept for the IXO deployable bench is a Tensegrity structure formed by two telescoping booms (compression) and a hexapod cable (tension) truss. This arrangement achieves the required stiffness for the optical bench at minimal mass while employing only high TRL components and flight proven elements. While the overall concept is innovative and will require further evaluation, it is based on existing elements, can be fully tested on the ground and does not require any new technology.

We have also explored the options opened by using hinged, articulating solar panels, an optical bench fully enclosed in MLI and an instrument module utilizing radially facing radiator panels. We have found that the enhanced configuration will greatly increase IXO's field of regard without distorting the optical bench beyond acceptable tolerances and will make more of the sky accessible for observations at any given time.

7732-140, Poster Session

A tower concept for the off-plane x-ray grating spectrometer for the International X-ray Observatory

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An Off-Plane X-ray Grating Spectrometer (OP-XGS) concept is being developed to meet the needs of the International X-ray Observatory (IXO). The OP-XGS will provide the required spectral resolution of R >3000 over the 0.3 - 1 keV band with >1000 cm2 effective collecting area, using experience gained with the current generation of reflection gratings already flown on rocket experiments. We have developed several potential configurations that meet or exceed these requirements. This paper will focus on the mechanical design and requirements for one of these configurations, the "tower" concept. This configuration mounts the grating modules to the instrument platform via a tower, allowing direct alignment with the camera module. This reduces the complexity of the alignment problem while also minimizing the overall mass of the XGS. We have developed an initial interface concept and resource requirements for this option to be reviewed by the mission teams for design drivers. We contrast the resource requirements for this concept with those required for other concepts which have been reviewed by the OP-XGS team. Further, we have identified those portions of the tower design concept that will require potential technology demonstration to reach TRL 6 prior to sensor Preliminary Design Review.

7732-141, Poster Session

Background simulations for the IXO-XMS instrument

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We present a study of the background induced by cosmic particles in the XMS Microcalorimeter Array of the International X-Ray Observatory, that is aimed at defining the configuration of the anticoincidence instrument that maximizes the rejection efficiency. For this purpose we use a ray-tracing code to model the low energy (up to 100 MeV) solar protons that are focused onto the focal plane by the telescope, and the GEANT4 toolkit to simulate the interactions of high energy cosmic protons (up to 100 GeV) with the detector and the anticoincidence.

7732-142, Poster Session

The TES-based cryogenic anticoincidence detector for IXO: results from the high-area breadboard

C. Macculi, L. Colasanti, S. Lotti, L. Natalucci, L. Piro, INAF -

IASF Roma (Italy); D. Bagliani, L. Ferrari, F. Gatti, Univ. degli Studi di Genova (Italy); G. Torrioli, Istituto di Fotonica e Nanotecnologie (Italy); P. Bastia, A. Bonati, Thales Alenia Space (Italy); M. Barbera, Univ. degli Studi di Palermo (Italy); G. La Rosa, T. Mineo, E. G. Perinati, INAF - IASF Palermo (Italy)

The technique which combines high resolution spectroscopy with imaging capability is a powerful tool to extract fundamental information in X-ray Astrophysics and Cosmology.

TES (Transition Edge Sensors)-based microcalorimeters match at best the requirements for doing fine spectroscopy and imaging of both bright (high count rate) and faint (poor signal-to-noise ratio) sources. For this reason they are considered among the most promising detectors for the next high energy space missions and are being developed for use on the focal plane of the IXO (International X-ray Observatory) mission.

In order to achieve the required signal-to-noise ratio for faint or diffuse sources it is necessary to reduce the instrumental background by a factor of 10 or more. This reduction can only be achieved by adopting an active anticoincidence technique.

In this paper, we will present a novel anticoincidence detector based on a TES sensor developed for the IXO mission.

Due to both the fast response time and the high area of the IXO main TES-array (XMS X-ray Microcalorimeter Spectrometer) attention has been put in designing the detector to cover all XMS area, without compromise the velocity of the anticoincidence, so developing it in a four-pixel design.

Experimental results from the high-area one-pixel breadboard for IXO will be discussed. In the discussion some emphasis will be put also on its design.

7732-143, Poster Session

Arc-second alignment and bonding of International X-Ray Observatory mirror segments

T. C. Evans, SGT, Inc. (United States)

The optics for the International X-Ray Observatory (IXO) require alignment and integration of about fourteen thousand thin mirror segments to achieve the mission goal of 3.0 square meters of effective area at 1.25 keV with an angular resolution of five arc-seconds. These mirror segments are 0.4 mm thick, and 200 to 400 mm in size, which poses a challenge since they are easily distorted. This paper outlines the precise alignment, automated testing, and automated permanent bonding techniques developed at NASA's Goddard Space Flight Center (GSFC). These techniques are used to overcome the challenge of transferring thin mirror segments from a temporary mount to a fixed structure with arc-second alignment and minimal figure distortion. The integration of different research has made possible the alignment and transfer to a permanent fixture. This paper will highlight the recent advances in automation as well as the results they have produced.

7732-144, Poster Session

An assessment of the problem of stray light in the optics of the International X-ray Observatory (IXO)

F. H. P. Spaan, R. Willingale, Univ. of Leicester (United Kingdom)

Different optical designs are under consideration for the International X-ray Observatory (IXO). In this paper we show results of simulations of the segmented shell Wolter-I design, of the Silicon Pore Optics (SPO) conical Wolter-I approximation and of the Silicon based Kirkpatrick-Baez design. We focus particularly on the issue of stray light. When a source is off axis such that it is not imaged on the detector, some of its light may still be directed by the optics into the detector plane. Sources close to the pointing direction can thereby introduce a extra background radiation level in the detectors. This phenomenon is investigated by numerical ray tracing of the three designs, yielding detector images of the stray light, and an indication of which part of the mirror that light originates. Results show the similarities and differences of the designs with respect to stray light, and give a quantitative indication of the level of background radiation in different cases. Furthermore, for the SPO conical Wolter-I approximation, two different ways of partially blocking the stray light have been modelled, indicating that a moderate reduction of the stray light can be achieved. In general, the results that have been found indicate that the stray light levels are compliant with the scientific and design specifications of the International X-ray Observatory.

7732-145, Poster Session

Improving the angular resolution of the conical Wolter-I silicon pore optics (SPO) mirror design of the International X-ray Observatory (IXO)

R. Willingale, F. H. P. Spaan, Univ. of Leicester (United Kingdom)

The mirror design for the International X-ray Observatory (IXO) follows two paths: a segmented slumped glass shell Wolter-I design, and a Silicon Pore Optics (SPO) conical approximation to the Wolter-I design. The conical approximation imposes a lower limit to the angular resolution of the SPO, and in this paper we describe ways in which this can be circumvented. We present numerical simulations to estimate the improvement in angular resolution which should be achievable and discuss the ways in which this can be implemented in the manufacture of the SPO. We provide a comparison between the expected angular resolution performance of the slumped glass and SPO designs.

7732-146, Poster Session

IXO x-ray mirrors based on glass slumped segments with reinforcing ribs: scientific and mechanical design, image error budget and optical unit integration process

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The International X-ray Observatory (IXO) is being studied as a joint mission by the NASA, ESA and JAXA space agencies. The main goals of the mission are large effective area (about >3m^2 at 1 keV) and a good angular resolution (<5" at 1keV). This paper reports on an activity ongoing in Europe, supported by ESA and led by the Brera Astronomical Observatory, aiming at providing an alternative method for the realization of the mirror unit assembly. This is based on the use of thin glass segments and an innovative assembly concept making use of reinforcing ribs that connect the facets to each-other. A fundamental challenge is the achievement with hot slumping technique of the required surface accuracy on the glass segments.

Equally challenging will be the alignment of the mirror segments and co-alignment of the mirror pairs. In this paper we present the mirror assembly conceptual design, starting from the design of the optical unit, the error budgets contributing to the image degradation and the performance analysis to assess error sensitivities. Furthermore the related integration concept and the preliminary results already obtained are presented.

7732-147, Poster Session

Advances in the active alignment system for the IXO optics

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The next large x-ray astrophysics mission launched will likely include soft x-ray spectroscopy as a primary capability. A requirement to fulfill the science goals of such a mission is a large-area x-ray telescope focusing sufficient x-ray flux to perform high-resolution spectroscopy with reasonable observing times. The IXO soft x-ray telescope effort in the US is focused on a tightly nested, thin glass, segmented mirror design. Fabrication of the glass segments with the required surface accuracy is a fundamental challenge; equally challenging will be the alignment of the ~7000 secondary mirror segments with their corresponding primary mirrors, and co-alignment of the mirror pairs. We have developed a system to perform this alignment using a combination of a coordinate measuring machine (CMM) and a double-pass Hartmann test alignment system. We discuss the technique, its ability to correct low-order mirror errors, and results of repeated pair alignments to the required alignment accuracy of < 2 arcseconds, as well as progress toward aligning multiple pairs and the scalability to the task of building the IXO telescope.

7732-148, Poster Session

Impacts on the IXO observing efficiency

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We define a working definition of observing efficiency for the International X-ray Observatory mission, and then describe operational impacts on that efficiency. Operational impacts include slew time, telescope settling, instrument set-up, increased radiation due to solar flares, and other similar items. To the extent possible, we derive values for these impacts from existing missions (Chandra and XMM), and make comparisons to the anticipated values for IXO. We describe a straw-man observing program based on inputs from the Science Definition Team and estimate the range of possible efficiency of that program.

7732-149, Poster Session

X-ray resolution tests of an off-plane reflection grating for IXO

B. R. Zeiger, A. F. Shipley, W. C. Cash, Jr., Univ. of Colorado at Boulder (United States); R. L. McEntaffer, The Univ. of Iowa (United States)

We present the results of x-ray resolution tests of an off-plane reflection grating suitable for use in the converging beam of the X-ray Grating Spectrometer (0.3-1.0 keV) on the International X-ray Observatory (IXO). The grating was holographically ruled by Jobin Yvon and was tested at a graze angle of 1.6 degrees in the 7.5 m converging beam created with two large-radius spheres.

7732-150, Poster Session

Predicted x-ray backgrounds for the International X-ray Observatory

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The X-ray background that will be observed by IXO's detectors naturally separates into two components:

A Cosmic X-ray Background (CXB), primarily due to unresolved point sources at high energies (E>2 keV), along with Galactic component(s) at lower energies, generated in the disk and halo as well as the Local Bubble and charge exchange in the heliosphere.

A Non-X-ray Background (NXB) created by unvetoed particle interactions in the detector itself. These may originate as relativistic particles from the Sun or Galactic Cosmic Rays (GCR), creating background events due to both primary and secondary interactions in the spacecraft itself.

These two components have distinct effects on observations. The CXB is a sum of power-law, thermal, and charge exchange components that will be vignetted by the IXO mirrors. This emission will show emission (and absorption) features. The NXB, in contrast, is due to particle, not photon, interactions (although there will be some fluorescence features induced by particle interactions), and so will not show the same effects of vignetting or trace the effective area response of the satellite.

We present the overall background rates expected from each of these processes, show how they will impact observations, and discuss what mitigation might be done in order to maximize the scientific return of the mission.

7732-151, Poster Session

Design and analysis of the IXO soft x-ray mirror modules

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The Soft X-Ray Telescope (SXT) modules are the fundamental focusing assemblies on NASA's next major X-ray telescope mission, the International X-Ray Observatory (IXO). The preliminary design and analysis of these assemblies has been completed, demonstrating that the slumped glass X-ray optics being developed for the mission can be used to construct modules meeting IXO requirements. Each of the 60 modules in the Flight Mirror Assembly (FMA) supports 200-300 densely packed 0.4 mm thick glass mirror segments in order to meet the unprecedented effective area required to achieve the scientific objectives of the mission. Detailed Finite Element Analysis (FEA), materials testing, and environmental testing have been completed to ensure the modules can be successfully launched. Resulting stress margins are positive based on detailed FEA, a large factor of safety, and a design strength determined by robust characterization of the glass properties. FEA correlates well with the results of the successful modal, vibration, and acoustic environmental tests. Deformation of the module due to on-orbit thermal conditions is also a major design driver. A thermal control system has been designed and the module performance under the resulting thermal distortion has been determined using optomechanical analysis methods developed for this unique assembly. This design and analysis furthers the goal of building a module that demonstrates the ability to meet IXO requirements, which is the current focus of IXO FMA technology development team.

7732-152, Poster Session

The advanced x-ray timing array (AXTAR)

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AXTAR is a NASA mission concept for X-ray timing of compact objects that combines very large collecting area, broadband spectral coverage, high time resolution, highly flexible scheduling, and an ability to respond

promptly to time-critical targets of opportunity. It is optimized for submillisecond timing of bright Galactic X-ray sources in order to study phenomena at the natural time scales of neutron star surfaces and black hole event horizons, thus probing the physics of ultradense matter, strongly curved spacetimes, and intense magnetic fields. AXTAR's main instrument is a collimated, thick Si pixel detector with 2-50 keV coverage and over 3 square meters effective area. For timing observations of accreting neutron stars and black holes, AXTAR provides at least a factor of five improvement in sensitivity over the Rossi X-ray Timing Explorer PCA. AXTAR also carries a sensitive wide-angle monitor that acts as a trigger for pointed observations of X-ray transients in addition to providing frequent X-ray spectra for every bright source. We review the science goals and technical concept for AXTAR and present initial results from a preliminary mission design study at the MSFC Advanced Concepts Office.

7732-153, Poster Session

Development of the XRDPIX 32 CdTe matrix for the ECLAIRs X/Gamma camera

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ECLAIRs, a 2D coded-mask imaging telescope on the Sino-French SVOM space mission, will detect and locate gamma-ray bursts, between 4 and 250 keV. The ECLAIRs detector array is an assembly of 6400 4x4x1 mm3 Schottky CdTe semi-conductor detectors, biased at -600V and operated at -20°C. The unprecedented low-energy threshold for space instrument is achieved through a careful selection of detectors, a low noise 32 channels ASIC readout, and an innovative hybridization of two ceramics, a thick film one holding the 32 CdTe detectors with the high voltage grid and an HTCC ceramic housing the ASIC and its passive components inside a cavity providing the front-end electronics. To dialog with the back-end electronics, 2 qualified Z-Axis Interposers are positioned on this ceramic. In this paper, we will describe the XRDPIX matrix and summarize the tests on development steps such as capacitances and noise measurements on routed ceramics, the leakage current after sticking detectors on ceramic, without delay and at a long time polarization and the ASIC ceramic tests of good slow control and analogue measurements versus peaking time to detect noisy pixels.

After independent tests on half modules, energy spectra of XRDPIX matrix are made with calibrated radioactive sources, inside a dedicated vacuum chamber at -20°C to get the lowest electrical noise and to control stability of low energy thresholds to prove the best performance and detect any cross talk between channels. Finally, we will present the results of all these measurements, including the qualification tests and mechanical and thermal simulations.

7732-154, Poster Session

The development of DIOS-FXT (Four-stage X-ray Telescope)

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To search for warm-hot intergalactic medium (WHIM), a small satellite mission DIOS (Diffuse Intergalactic Oxygen Surveyor) is planned and a specially designed four-stage X-ray telescope (FXT) has been developed as the best fit optics to have a wide field of view and large effective area.

Based on the previous design work and mirror fabrication technology used in the Suzaku mission, we made small demonstration model of DIOS FXT. This model has focal length of 700 mm consisting of quadrant housing and four-stage mirror sets with different radii of 150 - 180 mm and each stage mirror hight of 40 mm. Based on the first result of X-ray measurement, we changed several processes in replica mirror fabrication to get accurate conical shape for the mirrors with large conical angle. We will report on the present status of the DIOS FXT development including results of optical and X-ray measurements of element mirrors and assembled telescope.

7732-155, Poster Session

The x-ray camera for the EXIST/SXI telescope

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The Energetic X-ray Imaging Survey Telescope (EXIST) mission, submitted to the Decadal Survey, is a multiwavelength observatory mainly devoted to the study of SuperMassive Black Holes, Gamma Ray Bursts and other transient sources. The set of instruments foreseen for EXIST includes a soft x-ray telescope (SXI), proposed as a contribution of the Italian Space Agency (ASI).

We will present the preliminary design of the X-Ray camera for SXI telescope, that we are developing under ASI contract. The camera is based on a focal plane detector consisting of a 450 um thick silicon pixel sensor sensitive, with high QE, in the full SXI range (0.1-10 KeV), and capable of high energy resolution when operated in photon counting mode (E/dE ~ 47 at 6 keV), frame rate ~ 100-200 frames/s (enabling timing in the ms range), and spatial resolution matching the optical characteristics of the mirror module. We will provide an overview of the mechanical, thermal and electrical concept of the camera

7732-156, Poster Session

The x-ray mirrors for the EXIST/SXI telescope

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The Energetic X-ray Imaging Survey Telescope (EXIST) will continuously survey the full sky by scanning for 2-years (with 2-3 interruptions per day for GRB follow-up) followed by a 3-years pointing phase. The mission includes three instruments: a High Energy coded mask Telescope; a 1.1m aperture optical-IR Telescope; and a Soft X-ray Imager (SXI), sensitive in the 0.1-10 keV band. SXI is proposed as a contribution of ASI-Italy, fully developed by Italian institutes. Here we will present the optical design of the SXI mirror module, that includes also a pre-collimator and a magnetic diverter to ensure a low background on the detector. In particular we will describe the mirror module characteristics in term of effective area, imaging capability, thermal requirement and mechanical properties.
The current optical design foresees 26 shells providing an effective area comparable to one XMM-Newton mirror module up to 3 keV and somewhat lower from 3 to 10 keV. The realization of these shells is based on the well-proven Nickel replication-process technology.

7732-157, Poster Session

PROTOEXIST: prototype CZT coded aperture telescope development for EXIST

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ProtoEXIST1 is the initial pathfinder for the HET (High Energy Telescope), the primary instrument and 4.5m^2 imaging CZT coded aperture telescope for the EXIST mission proposed to Astro2010. The HET would image the full sky every 3h in the 5-600 keV band with 2arcmin resolution and <20arcsec source locations to discover high redshift GRBs and Blazars as well as numerous other black hole survey objectives.

ProtoEXIST1 consists of a 256 cm^2 close-tiled CZT detector plane containing 4096 pixels from an 8x8 array of individual 2.0x2.0 cm^2 CZT detector modules, each with a 8x8 anode pixels (2.5mm pitch).

The detector plane reads out a coded aperture telescope with a fully coded 10 x 10 deg field of view (and 20 x 20deg, FWHM) employing a 2 x 2 cycle URA mask (etched Tungsten-laminate) for imaging with 18arcmin pixels. The telescope employs passive side shielding (Pb-Sn-Cu) and an active CsI anti-coincidence rear shield. We report on the detector and telescope development and results from the first ProtoEXIST1 balloon flight test, launched from Ft. Sumner, NM, on 9 October 2009 with the newly re-furbished Harvard gondola employing a copy of the MSFC-HERO pointing system and star camera.

During the duration of its 6 hour flight at 3mb (40km), on-board calibration of the detector plane was carried out with a single tagged 198 nCi Am-241 source along with the simultaneous measurement of the background spectrum and a successful imaging observation of Cygnus X-1.

We report the events of the flight and describe the detector and telescope performance in a near space environment.

We also discuss ProtoEXIST2, the next stage of detector-telescope development, which employs the NuSTAR ASIC to enable the full resolution (32 x 32 pixels with 0.6mm pitch on each close-tiled CZT crystal), as proposed for EXIST. ProtoEXIST2 will consist of a 256 cm^2 tiled array and a correspondingly finer-pitch etched URA mask to yield 4arcmin imaging over the same FWHM 20 x 20deg field. It will be flown simultaneously with the ProtoEXIST1 telescope.

7732-158, Poster Session

Preparations for the first balloon flight of the gamma-ray polarimeter experiment (GRAPE)

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We have developed a design for a hard X-ray polarimeter operating in the energy range from 50 to 500 keV. This modular design, known as GRAPE (Gamma-Ray Polarimeter Experiment), has been successfully demonstrated in the lab using partially polarized gamma-ray sources and using fully polarized photon beams at Argonne National Laboratory. In June of 2007, a GRAPE engineering model, consisting of a single detector module, was flown on a high altitude balloon flight to further demonstrate the design and to collect background data. We are currently preparing a much larger balloon payload for a flight in the fall of 2011. Using a large (16-element) array of detector modules, this payload is being designed to search for polarization from known point sources of radiation, namely the Crab and Cygnus X-1. This first flight will not only provide a scientific demonstration of the GRAPE design (by measuring polarization from the Crab nebula), it will also lay the foundation for subsequent long duration balloon flights that will be designed for studying polarization from gamma-ray bursts and solar flares. Here we shall present data from calibration of the first flight module detectors, review the latest payload design and update the predicted polarization sensitivity for both the initial continental US balloon flight and the subsequent long-duration balloon flights.

7732-159, Poster Session

The x-ray coded aperture telescope on the JANUS Mission

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The JANUS mission concept is designed to study the high redshift universe using a small, agile explorer-class space observatory. The primary science goals of JANUS are to use high redshift (6<z<12) gamma ray bursts and quasars to explore the formation history of the first stars in the early Universe and to study contributions to reionization. The X-Ray Coded Aperture Telescope (XCAT) and the Near-IR Telescope (NIRT) are the two primary instruments on JANUS. XCAT will detect bright X-ray flashes (XRFs) and gamma ray bursts (GRBs) in the 1-20 keV energy band over a wide field of view (4 steradians), thus facilitating detection at high redshifts (z>6). XCAT will use a coded mask aperture design with Si hybrid CMOS detectors. It will be sensitive to XRFs/GRBs with flux in excess of approximately 250 mCrab. The spacecraft will rapidly slew to source positions following a GRB trigger from XCAT. We present instrument design parameters and science goals of the mission.

7732-160, Poster Session

Focal plane instrumentation for the Wide-Field X-ray Telescope Mission

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The X-ray imaging focal planes of the Wide-Field X-ray Telescope Mission will each have a field of view up to 1.5 degrees in diameter, pixel pitch of order 1 arcsec, excellent X-ray detection efficiency and spectral resolving power near the theoretical limit for silicon over the 0.2 - 6 keV spectral band. We describe the baseline concept for the WFXT focal planes. The detectors are derived from MIT Lincoln Laboratory CCDs currently operating in orbit on Chandra and Suzaku. We identify major design trades and challenges for the WFXT focal plane instrumentation, discuss technology development plans, and consider options for alternative detector technologies.

7732-161, Poster Session

Ground calibrations of Nuclear Compton Telescope

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The Nuclear Compton Telescope (NCT) is a balloon-borne soft gamma ray (0.2-10 MeV) telescope designed to study astrophysical sources of nuclear line emission and polarization. The heart of NCT is an array of 12 cross-strip germanium detectors, designed to provide 3D positions for each photon interaction with full 3D position resolution to < 2 mm^3. Tracking individual interactions enables Compton imaging, effectively reduces background, and enables the measurement of polarization. The keys to Compton imaging with NCT's detectors are determining the energy deposited in the detector at each strip and tracking the gamma-ray photon interaction within the detector. The 3D positions are provided by the orthogonal X and Y strips, and by determining the interaction depth using the charge collection time difference (CTD) between the anode and cathode. Calibrations of the energy as well as the 3D position of interactions have been completed, and extensive calibration campaigns for the whole system were also conducted using radioactive sources prior to our flights from Ft. Sumner, New Mexico, USA in Spring 2009, and from Alice Springs, Australia in Spring 2010. Here we will present the techniques and results of our ground calibrations, and then compare the calibration results of the effective area throughout NCT's field of view with Monte Carlo simulations using a detailed mass model.

7732-163, Poster Session

A cryo-amplifier working in a double flux locked loop scheme for SQUID readout of TES detectors

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TES detectors are generally readout by means of SQUID devices working in the standard feedback circuit called Flux Locked Loop. To get image capability it is necessary to use arrays of TES, this also requires a multiplexed readout scheme to reduce the heat load and complexity of the needed cryo-harness. Among the schemes proposed so far, one promising scheme is the Frequency Division Multiplexing (FDM). When SQUIDs systems are used in FDM schemes, they need to achieve high loop gain at high frequencies. Such requirement is difficult to achieve because of the distance between the SQUID and the room temperature electronics which adds a propagation delay in the feedback loop that can affect the system stability. To solve this issue we propose a low power dissipation cryo-amplifier capable to work at cryogenic temperatures so that it can be placed close to the SQUID to reduce the propagation delay along the loop.

Further on, an alternative readout technique called Double Loop-Flux Locked Loop (DL-FLL) based on the use of this amplifier is also presented. Such technique allows a simpler local feedback where the cryo-amplifier is AC-coupled, not requiring the features of a precision DC amplifier working at cryogenic temperatures. This result in a reduction of the cryogenic component count so increasing the system reliability.

In this work we present the experimental results on both the cryo-amplifier and on the DL-FLL Scheme.

7732-164, Poster Session

Camera structure: the second flight heritage of Cesic

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One of the core payload elements of the TET-1 mission, a satellite mission of the German Aerospace Center (DLR), is the Hot Spot Recognition Sensor (HSRS). Based on the flight experience with the Bispectral Infrared Detection microsatellite (BIRD), the HSRS instrument will be re-used after a comprehensive design update, whose objectives are a significant reduction of the overall mass budget and an integrated design approach for the co-registration of two cooled infrared and one visible camera systems. To reach a co-aligned assembly with high accuracy, a minimized camera structure for all lenses and detectors has been designed.

In close collaboration with the DLR, ECM manufactured the new camera structure of the HSRS using its ceramic composite material, Cesic®, in order to achieve the required low coefficient of thermal expansion at low mass.

In this paper, we describe the space-qualified process of manufacturing such high-precision space structures and Cesic®'s advantages compared to competing materials, especially with respect to material properties and versatility of engineering design.

We also present the results of testing the Cesic® camera structure under launch and space environmental conditions, including vibration, shock, and thermal vacuum exposures.

The results presented here demonstrate that our Cesic® composite has great potential in the manufacture of light-weighted, stiff, and low-CTE space structures to improve performance compared to aluminum and other traditional metal materials.

7732-165, Poster Session

A modulated x-ray source for in-flight calibration of high-energy astrophysics instrumentation

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We have developed a novel electron-impact X-ray source for the purpose of calibrating high-energy astrophysics instrumentation.

Through stimulation of a photocathode using fast UV LEDs, the output X-ray flux of our source can be modulated to follow an arbitrary waveform on timescales as short as nanoseconds.

Because it can be turned "off" on command, the modulated source is useful for calibrating the timing, gain, and efficiency characteristics of X-ray detectors and optical systems.

Traditional radioactive sources employed for these purposes produce an "always on" background flux that can reduce the sensitivity of the instrument by exceeding—sometimes by large margins—the ambient particle background rate. Also, the highest energy-resolution detectors, such as those proposed for the International X-ray Observatory, require precise knowledge of the gain over a broader range of energies than are available from typical radioactive sources, in order to achieve their design spectroscopy objectives. A modulated electronic X-ray source designed to complement a given detector would provide essential calibration information without degradation of the energy resolution or sensitivity. We have made steady progress in reducing the mass, volume, and power consumption of modulated X-ray sources, including the use of UV optical fibers, vacuum getters, and optimization of the source geometry. Continuing photocathode efficiency and lifetime tests also show great promise. A modulated X-ray source will be flown as part of the X-ray Advanced Concepts Testbed (XACT) sounding rocket payload.

7732-166, Poster Session

Concept for an innovative wide-field camera for x-ray astronomy

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The use of large-area, fine-pitch Silicon detectors has demonstrated the feasibility of wide field imaging experiments requesting very low resources in terms of weight, volume, power and costs.

The flying SuperAGILE experiment is the first such experiment, adopting large-area Silicon microstrip detectors coupled to one-dimensional coded masks. With less than 10 kg, 12 W and 0.04 m3 it provides 6-arcmin angular resolution over >1sr field of view.

Due to unfavourable operational conditions, the energy range of SuperAGILE is limited to 20-60 keV.

In this paper we show that the use of innovative large-area Silicon drift chambers allows to design experiments with arcmin-imaging performance over steradian-wide fields of view, in the energy range 2-50 keV, with spectroscopic resolution in the range of 300-500 eV (FWHM) at room temperature.

We will show the concept, design and readiness of such an experiment, supported by laboratory tests on large-area prototypes. We will quantify the expected performance in potential applications on X-ray astronomy missions for the observation and long-term monitoring of Galactic and extragalactic transient and persistent sources, as well as localization and fine study of the prompt emission of Gamma-Ray Bursts in soft X-rays.

7732-167, Poster Session

X-ray imaging and spectroscopy performance of a large area silicon drift chamber for wide-field x-ray astronomy applications

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In the context of the design of wide-field experiments for X-ray astronomy we studied the response to X-rays between 2 and 60 keV of large area Silicon drift chambers originally designed for particle tracking in high energy physics.

We demonstrated excellent imaging and spectroscopy performance of monolithic 50 cm2 detectors, with position resolution as high as 30 um and energy resolution in the range 300-500 eV full width at half maximum obtained at room temperature.

In this paper we will show the results of test campaigns at the X-ray facility at INAF/IASF Rome, aimed at characterizing the detector performance by scanning the detector area with highly collimated spots of monochromatic X-rays. In these tests we used a detector prototype equipped with discrete read-out front-end electronics. We also designed and manufactured the first prototype of a dedicated ASIC read-out chip for which we will report about preliminary test results.

7732-168, Poster Session

EUV spectroscopy of high-redshift x-ray objects

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As astronomical observations are pushed to cosmological distances (z>3) the spectral energy distributions of X-ray objects, AGNs for example, will have their maxima redshifted into the EUV waveband (~90-912 Å/0.1-0.01 keV). Consequently, a wealth of spectral diagnostics, provided by, for example, the Fe L-shell complex (~60-6 Å/0.2-2.0 keV) and the O VII/VIII lines (~20 Å/0.5 keV), will be lost to X-ray instruments operating at traditional (~0.5-10 keV) and higher X-ray energies. Despite the successes of EUVE, the ROSAT WFC, and the Chandra LETG, the EUV continues to be unappreciated and under-utilized, partly because of a preconception that absorption by neutral galactic Hydrogen in the ISM prevents any useful extragalactic measurements at all EUV wavelengths and, until recently, by a lack of a suitable enabling technology.

Thus, future planned X-ray missions (e.g., IXO, Gen-X) may be cut off at ultrasoft X-ray energies or at best be radically reduced in the EUV. This opens up a critical gap in performance located right at short EUV wavelengths, where the critical X-ray spectral transitions occur in high-z objects. However, normal-incidence multilayer-grating technology, which performs best precisely at such wavelengths, together with advanced nano-laminate fabrication techniques have been developed and are now mature to the point where advanced EUV instrument designs with performance complementary to IXO and Gen-X are practical. We present here a critical examination of the limits placed on extragalactic EUV measurements by ISM absorption, the range where high-z measurements are practical, and the requirements this imposes on next-generation instrument designs.

7732-169, Poster Session

X-ray pencil beam facility for optics characterization

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The Physikalisch-Technische Bundesanstalt (PTB) is using synchrotron radiation for the characterization of optics and detectors for astrophysical X-ray telescopes for more than 20 years. At a dedicated beamline at BESSY II, a monochromatic pencil beam is used by ESA and cosine Research since the end of 2005 for the characterization of novel silicon pore optics, currently under development for the International X-ray observatory (IXO). At this beamline, a photon energy of 2.8 keV is selected by a Si channel-cut monochomator. Two apertures at distances of 12,2 m and 30,5 m from the dipole source form a pencil beam with a typical diameter of 100 µm and a divergence below 1”. The optics to be investigated is placed in a vacuum chamber on a hexapod, the angular positioning is controlled by means of autocollimators to below 1”. The reflected beam is registered at 5 m distance from the optics with a CCD-based camera system.

This contribution presents design and performance of the upgrade of this beamline to cope with the updated design for IXO. The distance between optics and detector can now be 20 m. For double reflection at an X-ray optical unit (XOU) and incidence angles up to 1.4°, this corresponds to a vertical translation of the camera by 2 m. To achieve high reflectance at this angle even with uncoated silicon, a lower photon energy of 1 keV is available from a pair of W/B4C multilayers. For coated optics, a high energy option can provide a pencil beam of 7.6 keV radiation.

7732-170, Poster Session

Research and development of a gamma-ray imaging spectrometer in the MeV range in Barcelona

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Gamma-ray astrophysics in the MeV energy range plays an important role for the understanding of cosmic explosions and acceleration mechanisms in a variety of galactic and extragalactic sources, e.g., Supernovae, Classical Novae, Supernova Remnants (SNRs), Gamma-Ray Bursts (GRBs), Pulsars, Active Galactic Nuclei (AGN).

Through the development of focusing telescopes in the MeV energy range, it will be possible to reach unprecedented sensitivities, compared with those of the currently operating gamma-ray telescopes. In order to achieve the needed performance, a detector with mm spatial resolution and very high peak efficiency is required. It will be also desirable that the detector could detect polarization of the source.

Our research and development activities in Barcelona aim to study a gamma-ray imaging spectrometer in the MeV range suited for the focal plane of a gamma-ray telescope mission, based on CdTe pixel detectors arranged in multiple layers with increasing thicknesses, to enhance gamma-ray absorption in the Compton regime. We have developed an initial prototype based on several CdTe module detectors, with 11x11 pixels, a pixel pitch of 1mm and a thickness of 2mm. Each pixel is stud-bump bonded to a fanout board and routed to a readout ASIC to measure pixel position, pulse height and rise time information for each incident gamma-ray photon.

We will report on the results of an optimization study based on simulations, to select the optimal thickness of each CdTe detector within the module to get the best energy resolution of the spectrometer. We will present as well the measurements performed with a set of radiation sources at different operating temperatures.

7732-171, Poster Session

The Livermore calibration facility

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We are developing a calibration facility using the Lawrence Livermore National Laboratory's electron beam ion traps EBIT-I and SuperEBIT. This facility, known as the Livermore Calibration Facility (LCF), has at its disposal a full suite of X-ray instrumentation, including an absolutely calibrated X-ray calorimeter spectrometer that can be used to calibrate a wide range of instrumentation over the 0.10 to 20 keV energy band. A variety of instrument parameters and components can be characterized and calibrated at this facility. These include instrument line profiles, absolute transmissivity of optical blocking filters, and quantum efficiency of grating and crystal spectrometers and solid state detectors. The LCF can be used to calibrate spectrometers and detectors to be flown on orbiting observatories, sounding rockets, ground support equipment used to verify flight instrumentation, and also instrumentation used in laboratory astrophysics experiments conducted to interpret data from celestial sources. An overview of the LCF will be presented including calibration results for instruments used in high energy density physics experiments. Prepared by LLNL under Contract DE-AC52-07NA27344.

7732-172, Poster Session

Reflectivity and polarization sensitivity of a bended crystal with DLC deposition

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We report on a development of a bended crystal for use of X-ray polarimetry. A Si(100) crystal sheet was deposited with DLC (Diamond-like Carbon) and bended by the difference in the internal stress between the DLC and Si. An angular reflectivity of the crystal was measured at 8 keV (Cu-Ka). The center of the reflection peak appears at the Bragg angle expected for the (400) plane of Si(100). Possibly due to the bending of the crystal, the angular width of the peak is found as broadened. For a sample, it was as large as 2 degree which is equivalent to the energy width of 0.4 keV.

The Bragg angle of plane (400) of Si(100) becomes as large as 38 degrees at 7 keV. The high sensitivity for the polarization is hence expected at Fe-K lines. The modulation factor (M) was then measured at 8 keV and was confirmed as high as 0.8. For this measurement, we developed a simplified X-ray beamline in our small laboratory. By rotating the stage of the X-ray generator and DCM simultaneously, any plane of polarization can be chosen without moving the sample.

The broaden sensitivity with the high modulation factor indicates that the bended crystal can be a new tool for the X-ray polarimetry. A preliminary design of the polarimetric optics using the Si(100) crystal will be presented. Any kind of crystals can be bended with our method. A combination of different crystals will largely improve the performance of the polarimetric optics.

7732-173, Poster Session

A numerical tool for the simulation of next generation x-ray telescopes

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The next generation of X-ray space telescopes will be very large compared to thus actually in operation (XMM, Chandra).

This significant growth of their structure is the consequence of the long focal length needed to increase the telescope performance. As a consequence, these new observatories will be very sensitive to the deformations of their large structure. We present a numerical tool able to simulate the behavior and the performance of an X-Ray telescope for any configuration and deformations.

7732-175, Poster Session

Gallium nitride photocathodes for imaging photon counters

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Gallium Nitride (GaN) is an effective photocathode material for UV detectors for future astrophysical instruments. Typically GaN and AlN/GaN coatings grown are by molecular beam epitaxy on sapphire substrates. A functional GaN photocathode layer has an AlN "reflective layer on the substrate material, and graded P doped (Mg) GaN above that. Considerable work has been done for photocathode process optimization,and one of the important issues is high P dopant concentrations (~4 x 10^19 /cm^3 - Mg). Conventional semitransparent photocathode geometry GaN works best with thin GaN layers of 150nm or so. The response of such photocathodes can reach 20% efficiency between 200nm and 400nm. The highest efficiency is still limited by the electron transport of photoelectrons to the surface, and the quality of the

surface termination with Cs to provide negative electron affinity. Photon counting imaging detectors have been extensively used, comprising a MgF^2 entrance window, a Sapphire/GaN semitransparent cathode mounted close to a MCP stack and read out with a cross delay line anode. Photon counting experiments with these detectors show good uniformity of the GaN and allow the intrinsic background for GaN cathodes to be measured. GaN has also been deposited on glass micropore substrates. These micropore substrates have been coated with sapphire using atomic layer deposition. This provides a suitable substrate for GaN, which we are attempting to duplicate >70% efficiency in the UV (~200nm), as we have done for opaque GaN layers on planar sapphire substrates.

7732-58, Session 13

An overview of high-resolution, non-dispersive, imaging spectrometers for high-energy photons

C. A. Kilbourne, NASA Goddard Space Flight Ctr. (United States)

High-resolution x-ray spectroscopy has become a powerful tool for studying the evolving universe. The grating spectrometers on the XMM and Chandra satellites initiated a new era in x-ray astronomy. Despite their successes, there is still need for instrumentation that can provide higher spectral resolution with high throughput in the Fe-K band and for extended sources. What is needed is a non-dispersive imaging spectrometer - essentially a 14-bit x-ray color camera. And a requirement for a non-dispersive spectrometer designed to provide eV-scale spectral resolution is a temperature below 0.1 K. The required spectral resolution and the constraints of thermodynamics and engineering dictate the temperature regime nearly independently of the details of the sensor or the read-out technology.

Low-temperature spectrometers can be divided into two classes — equilibrium and non-equilibrium. In the equilibrium devices, or calorimeters, the energy is deposited in an isolated thermal mass and the resulting increase in temperature is measured. In the non-equilibrium devices, the absorbed energy produces quantized excitations that are counted to determine the energy. The two approaches have different strong points, and within each class a variety of optimizations have been pursued. I will present the basic fundamentals of operation and the details of the most successful device designs to date. I will also discuss how the measurement priorities (resolution, energy band, count rate) influence the optimal choice of detector technology.

7732-59, Session 13

MIS micro-calorimeters arrays: an alternative to IXO/XMS TES/Squids baseline

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The IXO/XMS instrument baseline is an array of TES sensors with Squid readout. An excellent spectral resolution of 2-3 eV on an array has been demonstrated. However these TES/Squids chains exhibit high power dissipation at the 50 mK stage, the number of readout chains is limited to one per 4 pixels in the exterior array, consequently degrading its resolution to worse than 10 ev.

Several successful development programs have been conducted on Infra-Red bolometer arrays at the French Atomic Energy Commission (CEA LETI Grenoble&SAp Saclay). Capitalising on our PACS/Herschel experience, we are now developing a monolithic silicon μ-calorimeters based on Silicon doped sensors as an alternative to these TES-based μ-calorimeter arrays.

The full detector assembly is composed of a mosaic of 2-sided butable 32x32 detectors in a planar configuration (Pixel size is 500x500 μm2, adaptable). The strength of our development stands in a very low power consumption at 50 mK, allowing us to have more than 4000 readout channels in the limited power budget of the IXO/XMS cryostat. This allows a Field of View as large as 6'x6' square while keeping the same spectral resolution across the FoV, in contrast to the XMS/TES baseline.

We have build a detector matrix (a 8x8 and a 16x16 is currently under development) using collective approaches only. In parallel, we develop the associated cold (2-4K) front electronics based on High Electron Mobility Transistors (HEMTs, with an hetero-junction AsGa/AlAsGa) and SiGe ASIC electronics to readout, amplify and multiplex the signals. We present the status of our development as well as our current design study.

7732-60, Session 13

Progress on the Micro-X Sounding Rocket X-ray Telescope: completion of flight hardware

P. Wikus, Massachusetts Institute of Technology (United States)

Micro-X is a rocket-borne X-ray telescope which will use an array of Transition Edge Sensor (TES) microcalorimeters to obtain high resolution X-ray spectra of extended astronomical sources.

The microcalorimeter array consist of 128 pixels with a size of 590 μm × 590 μm each, and has an energy resolution better than 4 eV at 1 keV. The TESs are read out with a time-division Superconducting Quantum Interference Device (SQUID) multiplexing system. The instrument's front end assembly, which contains the microcalorimeter array and two SQUID amplification stages, is located at the focal point of a conically approximated Wolter mirror with a focal length of 2100 mm and a point spread function of 2.6 arcmin half-power diameter. The telescope's effective area amounts to ~ 300 cm^2 at 1 keV. The TES array is cooled to its operating temperature of 50 mK with an Adiabatic Demagnetization Refrigerator.

The first flight of the Micro-X telescope is scheduled for the year 2011, and is likely to target the recently discovered Si knot in the Puppis A supernova remnant. The time available for the observation above an altitude of 160 km is expected to be in excess of 300 seconds.

The design, manufacturing and assembly of the flight hardware has recently been completed, and system testing is underway. We describe the final design of the Micro-X instrument, and report on the overall status of the project.

7732-61, Session 13

High-resolution microcalorimeter development for gamma-ray astronomy

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Cryogenic microcalorimeter sensors offer a unique combination of spectral resolution and absorption efficiency. Here, we describe recent progress developing microcalorimeters based on superconducting transition-edge sensors for high resolution gamma-ray spectroscopy. Individual sensors have demonstrated a spectral resolution as good as 22 eV FWHM at 100 keV, a resolving power high enough to detect kinematic broadening of astronomical gamma-ray lines. Recently, terrestrial materials analysis applications have motivated the development of close-packed arrays of up to 256 sensors with a total collecting area of 5.76 cm^2. The arrays are fabricated by a flip-chip process in which bulk absorbers, typically of superconducting tin, are attached to thin-film sensors. These arrays open the possibility of an imaging gamma-ray array for astronomical applications. In this presentation, we review the state of gamma-ray microcalorimeter technology and its applicability to astronomical problems such as the measurement of 44^Ti radioactivity from supernova remnants. We also discuss ongoing efforts to improve the resolution, absorption efficiency, and size of gamma-ray microcalorimeter arrays.

7732-62, Session 14

Spectrum from the extended x-ray off-plane spectrometer (EXOS) sounding rocket payload

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We present results from the Extended X-ray Off-Plane Spectrometer (EXOS) sounding rocket payload. The payload was launched on November 13, 2009 and successfully obtained a spectrum of the Cygnus Loop Supernova Remnant. The instrument observed in the ~20 - 100 Angstrom bandpass with high resolution (~50) by utilizing an off-plane reflection grating array. This payload is also the 2nd flight for a relatively new type of detector, the Gaseous Electron Multiplier (GEM) detectors. We discuss the performance of these technologies in flight, as well as an overview of our plans for the next flight of this design.

7732-63, Session 14

DIOS-the diffuse intergalactic oxygen surveyor: status and prospects

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We describe the status and prospects of the small X-ray mission DIOS (Diffuse Intergalactic Oxygen Surveyor), which will be proposed for the 3rd mission in JAXA's small satellite series aiming for launch in 2016. DIOS will perform survey observations of warm-hot intergalactic medium using OVII and OVIII emission lines, with the energy coverage up to 2 keV. The instrument will consist of a 4-stage X-ray telescope and an array of TES microcalorimeters, cooled with mechanical coolers, with a total weight of about 400 kg. The mission will offer a wide field of view of about 50' diameter, an effective area larger than 100 cm^2, energy resolution close to 2 eV FWHM, and very low non X-ray background due to short focal length of the telescope. An extensive simulations indicate that, even DIOS is a small satellite, it will be capable of detecting and mapping baryon concentrations which have never been observed in other methods. The wide field of view and low background of DIOS will together enable us a wide range of spectroscopic science for diffuse X-ray sources, such as clusters of galaxies, supernova remnants, and the hot Galactic interstellar medium.

7732-64, Session 14

Xenia: cosmo-chemical evolution of the Universe

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Xenia is a medium-sized mission optimized to study cosmic reionization, cluster formation and evolution, and the WHIM, following cosmo-chemical evolution from the very earliest times to the present. Reconstructing the cosmic history of metals, from the first population of stars to the processes involved in the formation of galaxies and clusters of galaxies, is a key observational challenge. Most baryons reside in diffuse structures, in (proto)-galaxies and clusters of galaxies, and are predicted to trace the vast filamentary structures created by the ubiquitous Dark Matter. X-ray spectroscopy of diffuse matter has the unique capability of simultaneously probing a broad range of elements (C through Fe) in all their ionization stages and all binding states (atomic, molecular, and solid), and thus provides a model-independent survey of the metals. Xenia - proposed to the Astro2010 Decadal Survey - will combine cryogenic imaging spectrometers and wide field X-ray optics with fast repointing to collect essential information from three major tracers of metals: Gamma Ray Bursts (GRBs), Galaxy Clusters, and the Warm Hot Intergalactic Medium (WHIM). We will give an overview of the mission and will discuss the instruments designed to carry out these observations.

7732-65, Session 14

JANUS: exploring the high redshift universe

D. N. Burrows, The Pennsylvania State Univ. (United States)

Gamma-ray bursts (GRBs) provide extremely luminous background light sources that can be used to study the high redshift universe out to z~12. Identification of high-z GRBs has been difficult to date because no good high-z indicators have been found in the prompt or afterglow emission of GRBs, so ground-based spectroscopic observations are required. JANUS is a small Explorer mission that incorporates a GRB locator and a near-IR telescope with low resolution spectroscopic capability so that it can measure the redshifts of GRBs immediately after their discovery. It is expected to discover 50 GRBs with z>5 as well as hundreds of high redshift quasars. JANUS will facilitate study of the reionization phase, star formation, and galaxy formation in the very early universe. I will present an update of the mission design and status.

7732-66, Session 14

LOFT: a large observatory for x-ray timing

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The X-ray sky in high time resolution holds the key to physical

diagnostics that are unaccessible to other types of investigations (e.g. imaging, spectroscopy and polarimetry).

A veriety of strong field gravity effects, the measurement of the mass and spin of black holes, the equation of state of ultradense matter are among the objectives of high-throughput fast-timing X-ray observations.

After the exciting age of RXTE/PCA, the prospects for future, non-focussing X-ray timing experiments are uncertain, mainly due to technological limitations in the development of experiments with effective area of several square meters.

We are developing large-area monolithic Silicon drift detectors offering high time and energy resolution at room temperature, with modest operational complexity (e.g., read-out) and resources per unit area. Based on the properties of the detector and read-out electronics we measured in the laboratory, we built a concept for a realistic, unprecedentedly large mission devoted to X-ray timing in the energy range 2-30 keV. We will show that effective areas in the range of 15-20 square meters are within reach by using a conventional spacecraft platform.

7732-67, Session 14

The Wide Field X-ray Telescope (WFXT) Mission

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Sensitive surveys of the X-ray universe have been limited to small areas of the sky due to the intrinsically small field of view of Wolter-I X-ray optics, whose angular resolution degrades with the square of the off axis angle. High angular resolution is needed to achieve a low background per source, minimize source confusion, and distinguish point from extended objects. WFXT consists of three co-aligned wide field X-ray telescopes with a 1 deg field of view and a <=10 arcsec (goal of 5 arcsec) angular resolution (HEW) over the full field. Total effective area at 1 keV will be >5000 sq. cm. WFXT will perform three extragalactic surveys that will cover most of the sky to 100—1000 times the sensitivity of the ROSAT

All Sky Survey, ~2000 sq. deg to deep Chandra or XMM-Newton sensitivity, and ~100 sq. deg to the deepest Chandra sensitivity. WFXT will generate a legacy X-ray dataset of >500,000 clusters and groups of galaxies to z~2, also characterizing the physics of the intracluster gas for a significant fraction of them, thus providing an unprecedented data set for cosmological applications; it will detect >10,000,000 AGN to z>6, again obtaining spectra for a substantial fraction; it will detect >100,000 normal/starburst galaxies; and it will detect and characterize star formation regions across the Galaxy. WFXT is the only X-ray survey mission that will match, in area and sensitivity, the next generation of wide-area optical, IR and radio surveys.

7732-68, Session 15

Hard x-ray imaging scanning-sky surveys: from the farthest to nearest black holes to EXIST

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The Energetic X-ray Imaging Survey Telescope (EXIST) mission has been proposed to Astro2010 to conduct the deepest full-sky hard X-ray (5-600 keV) survey for black holes on all scales. With its combination of a very large area (4.5m^2), wide-field (90 x 70deg) High Energy Telescope (HET; 1.5arcmin imaging from 5-600 keV, with <20” source positions), Soft X-ray Imager (SXI; 0.1-10keV focusing telescope with 15” PSF and 20arcmin FoV) and 1.1m optical-IR Telescope (IRT; 0.3-2.3 microns, with 4 x 4arcmin FoV and 0.15” pixels), the EXIST mission has unsurpassed multiwavelength capabilities. It is designed to detect the highest redshift Gamma-ray Bursts (GRBs), with predicted rates of ~600/year and >20/y at z >7 and with prompt SXI localization (<1arcsec) and IRT imaging and spectra to determine redshifts and spectra that are sensitive to the ionization state of the host galaxy IGM and thus epoch of reionization. Its capability for AGN are similarly impressive, with known Blazars detectable out to z ~8 if they exist, which may provide the best constraints on the early growth of SMBHs.

For ULX and stellar mass black holes in the Local Group and Milky Way, the deepest inventory as well as long term variability studies are possible, as well as the first survey for isolated stellar BHs and IMBHs accreting from GMCs. The mission combines both orbital scanning (like Fermi/LAT) for increased sensitivity (vs. pointing) and sky coverage as well as autonomous prompt and scheduled followup pointings. The science, instrumentation, and mission overview are presented. As a Medium class mission, and with no new technology required, EXIST could be launched by 2017 to complement Fermi, JWST, ALMA, LOFAR and LSST and other wide-field surveys as well as followup studies planned for the coming decade.

7732-69, Session 15

The proposed High-Energy Telescope (HET) for EXIST

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The hard X-ray sky now being studied by INTEGRAL and Swift and soon by NuSTAR is rich with energetic phenomena and highly variable non-thermal phenomena on a broad range of timescales. The High Energy Telescope (HET) on the proposed Energetic X-ray Imaging Survey Telescope (EXIST) mission will repeatedly survey the full sky for rare and luminous hard X-ray phenomena at unprecedented sensitivities. It will detect and localize (<20arcsec, at 5sigma threshold) X-ray sources quickly for immediate followup identification by two other onboard telescopes - the Soft X-ray imager (SXI) and Optical/Infrared Telescope (IRT). The large array (4.5 m^2) of imaging (0.6mm pixel) CZT detectors in the HET, a coded-aperture telescope, will provide unprecedented high sensitivity (~0.06 mCrab Full Sky in a 2 year continuous scanning survey) in the 5-600 keV band. The large field of view (90x70 deg) and zenith scanning with alternating-orbital nodding motion planned for the first 2 years of the mission will enable nearly continuous monitoring of the full sky. A 3y followup pointed mission phase provides deep UV-Optical-IR-Soft X-ray and Hard X-ray imaging and spectroscopy for thousands of sources discovered in the Survey. We review the HET design concept and its expected performance in discovering black holes on all scales, from BH binaries and ULX sources in the Local Group, to the most distant cosmic Gamma-ray Bursts as probes of the Early Universe. Details of the detector design and scanning-imaging are presented.

7732-70, Session 15

Design and scientific performance of the soft x-ray imager on board EXIST

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The EXIST mission has been recently re-designed prior to being proposed to the ASTRO2010 Decadal Survey. One of the most recent improvements has been the addition of a third instrument consisting of a powerful Soft X-ray Imager (SXI) that will study in detail and help characterizing the high energy sources detected by the High Energy Telescope (HET). The EXIST concept fully exploits the heritage of Swift in the fast followup of transients and in particular GRBs, with 10 to 20 times more sensitivity in the high energy band (from 0.1 to 600 keV) and exceptional performance in the near-IR/optical provided by the Infrared Telescope (IRT). SXI has an important role in extending by more than one decade in energy, down to the soft X-rays the coverage of HET. Such combination will be fully exploited when performing pointed observations. Within the EXIST follow-up program, foreseen during the second part of the mission, SXI and HET will be able to collect high quality spectra for thousands of sources covering the energy range 0.1-hundreds keV. Furthermore, while working in survey mode SXI will cover about half the sky in 2 years and will be able to improve the location accuracy of many faint HET sources (reducing the positional uncertainty from 20 arcsec to about 3 arcsec). In this paper we will address the performance and the main scientific contributions expected from SXI.

7732-71, Session 15

EXIST deep observations of the Galactic Center Region

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The EXIST observatory planned for launch in the next decade will carry outstanding contributions in both Galactic and Extragalactic science with a sensitivity about 10-20 better respect to the flown hard X-ray missions and full sky survey capability.

Designed mainly for the survey of SMBH and transients, thanks to the wide field of view (~90deg) and large effective area of the High Energy Telescope (HET), the study of spectra and variability at all timescales of all types of Galactic compact objects will be made possible. EXIST will be also capable to study in detail the Galactic Center (GC) in the hard X-rays. This crowded region as observed recently by Chandra, Integral and Swift has been found to possibly host a high number of high energy sources potentially identified as magnetic CVs. These objects have been studied in detail by INTEGRAL and their emission mechanism is relatively well understood.

In this work we report on the capabilities of EXIST to image the GC region and to detect and characterize the different classes of sources, including the magnetic CVs and other sources of the LMXB and HMXB classes on the basis of their known spectral and variability properties.

7732-72, Session 16

Development of a telescope for medium-energy gamma-ray astronomy

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Since the launch of AGILE and FERMI, the scientific progress in high-energy (E > ~200 MeV) gamma-ray science has been, and will continue to be dramatic. Both of these telescopes cover a broad energy range from ~20 MeV to >10 GeV. However, neither instrument is optimized for observations below ~200 MeV where many astrophysical objects exhibit unique, transitory behavior, such as spectral breaks, bursts, and flares. Hence, while significant progress from current observations is expected, there will nonetheless remain a significant sensitivity gap in the medium-energy (~0.1-200 MeV) regime; the lower end of this range remains largely unexplored whereas the upper end will allow comparison with FERMI data.

Tapping into this unexplored regime requires significant improvements in sensitivity. A major emphasis of modern detector development, with the goal of providing significant improvements in sensitivity in the medium-energy regime, focuses on high-resolution electron tracking. The Three-Dimensional Track Imager (3-DTI) technology being developed at GSFC provides high resolution tracking of the electron-positron pair from gamma-ray interactions from 5 to 200 MeV. The 3-DTI consists of a time projection chamber (TPC) and 2-D cross-strip micro-well detector (MWD). The low-density and homogeneous design of the 3-DTI, offers unprecedented sensitivity by providing angular resolution near the kinematic limit. Electron tracking also enables measurement of gamma-ray polarization, a new tool to study astrophysical phenomenon.

We describe the design, fabrication, and performance of a 30x30x30 cm3 3-DTI detector prototype of a medium-energy gamma-ray telescope.

7732-73, Session 16

A fast scintillator Compton Telescope for medium-energy gamma-ray astronomy

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The field of medium-energy gamma-ray astronomy urgently needs a new mission to build on the success of the COMPTEL instrument. This mission must achieve a sensitivity significantly greater than that of COMPTEL in order to advance the science of relativistic particle accelerators, nuclear astrophysics, and diffuse backgrounds and bridge the gap between current and future hard X-ray missions and the high-energy Fermi mission. Such an increase in sensitivity can only come about via a dramatic decrease in the instrumental background. We are currently developing a concept for a low-background Compton telescope that employs modern scintillator technology to achieve this increase in sensitivity. Specifically, by employing LaBr3 scintillators for the calorimeter, one can take advantage of the unique speed and resolving power of this material to improve the instrument sensitivity and simultaneously enhance its spectroscopic performance and thus its imaging performance. We present calibration results from a laboratory prototype of such an instrument, including time-of-flight, energy, and angular resolution, and compare them to simulation results using a detailed Monte Carlo model. We also describe the balloon payload we have built for a test flight of the instrument in the fall of 2010.

7732-74, Session 16

Balloon-borne sub-MeV/MeV gamma-ray observation using a Compton camera with a gaseous TPC and a scintillation camera

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We have developed a sub-MeV and MeV gamma-ray imaging Compton camera that consists of a gaseous time-projection chamber (TPC) as a converter of the Compton scattering and a scintillator array as an absorber of the scattered gamma ray for use in MeV gamma-ray astronomy.

The TPC measures the energy and 3D track of the Compton-recoil electron, while the pixel scintillator arrays, GSO(Ce) crystal, measure the energy and position of the scattered gamma ray. By combining these measurements, our camera can reconstruct the incident gamma ray, event by event, with a wide field of view of approximately 3str. Although conventional Compton cameras such as the COMPTEL detector onboard the CGRO satellite do not measure the 3D track of the Compton-recoil electron and only localize the incident direction of a gamma ray to an event circle. However, our Compton camera can reduce this circle to a small segment “arc” on the circle and thus obtain a finer image with a strong background rejection. Owing to the background rejection capability of our camera, we will be able to conduct an all-sky survey with 10 times higher sensitivity than COMPTEL. In 2006, we demonstrated gamma-ray detection using our camera onboard a balloon, named SMILE experiment. Now we are developing a larger Compton camera for the a second balloon-borne experiment in order to detect Crab or Cyg X-1 (SMILE-2). We present our camera and the experiments.

7732-75, Session 16

The spring 2010 balloon flight of the Nuclear Compton Telescope

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The Nuclear Compton Telescope (NCT) is a balloon-borne soft gamma-ray telescope. Its compact design uses cross-strip germanium detectors, allowing for wide-field imaging with excellent efficiency from 0.2-10 MeV. Additionally, the Compton imaging principle employed by NCT provides polarimetric sensitivity above 200 keV. NCT is optimized for the study of astrophysical sources of nuclear line emission. It also may perform novel polarimetric measurements on point sources like the Crab Pulsar. After a successful 38-hour flight from Ft. Sumner, NM on May 17-18, 2009, the ten-detector instrument was flown from Alice Springs, Australia in early 2010 and conducted observations of the Galactic Center Region. We discuss the design, calibration, and performance of the instrument and present preliminary results from the balloon campaign.

7732-76, Session 16

ECLAIRs: the X- and Gamma-ray Telescope for the SVOM mission

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ECLAIRs is an X- and gamma-ray telescope aboard the future mission for gamma-ray burst studies SVOM (Space-based multi-band astronomical Variable Objects Monitor) that is foreseen to operate in low earth orbit (630 km) from 2014 on.

Within the SVOM mission, ECLAIRs has the key role to provide fast and accurate GRB triggers to other onboard telescopes (Soft X rays and visible), as well as to the whole GRB community, in particular ground-based follow-up telescopes.

One of the main improvements of ECLAIRs with respect to previous GRB missions is to be particularly well suited for the detection of highly redshifted GRBs. This is achieved thanks to its very low energy threshold (4keV).

ECLAIRs consists in a X- and Gamma-ray imaging Camera (CXG) with a wide field of view of 2 sr. The CXG is a 2D-coded mask imager with a ≈1000 cm² detector plane made of 80 x 80 CdTe pixels, sensitive from 4 keV to 250 keV, with imaging capabilities up to about 50 keV and a localization accuracy better than 10 arcmin.

ECLAIRs also includes a triggering electronics which uses the photon data (from CXG) and that detects GRB as a new source in cyclic sky images or as a count-rate increase. GRB alerts are transmitted to observers within tens of seconds via a VHF network and all detected photons are available on ground hours later.

In this talk we present the latest developments of the ECLAIRs design in correlation with the expected scientific performances.

7732-77, Session 16

Development of efficient Laue lenses: experimental results and projects

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Laue lenses are an emerging technology allowing the concentration of soft gamma rays in the ~ 100 keV - 1.5 MeV energy range. This optic relies on Bragg diffraction in the volume of a large number of crystal slabs properly oriented to coherently diffract a parallel beam onto a unique focal spot. For the very first time in this energy range, Laue lenses offer the possibility of decoupling the signal collection area from the sensitive area, allowing the realization of high-sensitivity and high-angular resolution telescopes.

Crystals are the corner stone of Laue lenses. We will present in this paper our latest results obtained at the European Synchrotron Radiation facility (ESRF) concerning the development of high-reflectivity crystals. We will also present the new X-ray beamline that we are building at UC Berkeley’s Space Sciences Laboratory, which is entirely dedicated to the development of Laue lenses. Finally, future projects featuring a Laue lens will be presented.

Conference 7733: Ground-based and Airborne Telescopes III

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7733-01, Session 1

The GTC project, from commissioning to regular science operation: current performance and first science results

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The GTC (Gran Telescopio Canarias) is an optical and IR telescope, with a 10,4 meter segmented primary, installed at the Observatorio del Roque de Los Muchachos (ORM) on the island of La Palma.

GTC commissioning started in July 2007 when GTC First Light was achieved. GTC regular operations started at the beginning of 2009 with its first science instrument: OSIRIS, a visible camera with tunable filter and a low-resolution multi-object spectrograph. Since that time regular science operation and telescope and instrument development works alternate in using the available telescope time. Early in 2010 the second science instrument will be commissioned: CanariCam, a thermal-IR camera and low-resolution spectrograph with polarimetric and coronagraphic capabilities.

This paper present the telescope commissioning process, the problems encountered and the performances achieved. First science results will also be presented to demonstrate the current capabilities of the GTC facility.

7733-02, Session 1

VISTA: status and performance

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VISTA, the Visible and Infrared Survey Telescope for Astronomy, was accepted as a part of ESO's Cerro Paranal Observatory on 10 December 2009. VISTA is a 4-m class wide field survey telescope for the southern hemisphere located on its own peak some 1500m from the VLT. VISTA is equipped with the world's largest near-IR camera, with 1.65-degree diameter field of view camera containing 16 2kx2k detectors with 0.34arcsec pixels and seven near-infrared filter trays covering Z-Ks (0.88-2.15 micron). The telescope has an azimuth-altitude mount, and quasi-Ritchey-Chretien optics with a fast f/1 primary mirror giving an f/3.25 focus to the near-IR camera at Cassegrain. The near-IR camera mounts to the rotator on the back of the primary mirror cell, and includes a wide-field corrector lens system (3 infrasil lenses), autoguider and active optics sensors. The system image quality specification of 50% encircled energy diameter of 0.51 arcsec or better over the field (without seeing) was met, and the system throughput is excellent. VISTA was a UK in-kind contribution on its accession to ESO.

We report on developments since the 2008 SPIE to completion, including the commissioning and the as-built status. Specification and construction of the Facility were not managed by the eventual owner and operator, and lessons learnt working within such an arrangement will be discussed. VISTA is spending most of its first five years carrying out six large-scale public surveys to a variety of depths and areas and we report on the on-sky performance.

7733-03, Session 1

The compact, low scattered-light 2m Wendelstein Fraunhofer Telecope

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Ludwig-Maximilians-Universitaet Muenchen operates an astrophysical observatory on the summit of Mt. Wendelstein which will be equipped with a modern 2m-class, robotic telescope. We plan to install one of topmost efficient robotic telescopes within Europe in order to maintain our international reputation and competitiveness in both the fields of science and education. The 2m "Fraunhofer" telescope in its new 8.5m dome has a modern, very compact alt.-azimuth design. Two Nasmyth ports will harbour a wide-field camera (WWFI, also presented at this conference), a medium field multi-channel camera (3kk, also presented at this conference), a low resolution IFU spectrograph (VIRUSW presented at SPIE2008) and a high resolution spectrograph (upgraded FOCES). All instruments will be simultaneously ready for remote or robotic observations. The telescope is designed as a 3-mirror f/7.8 system and should deliver the excellent (< 0.7" median) seeing of the site over a FoV of 0.2 deg^2 with a field corrector for the wide field port at optical wavebands. The second port still gives a FoV of 60 arcmin^2 without any corrector optics. It is optimised for simultaneous optical and NIR imaging as well as field spectoscopy and echelle high resolution spectroscopy over the full optical wavelength regime. Here we present the design of the telescope as well as the scope and projected timeline of the overall project.

7733-04, Session 1

The University of Tokyo Atacama Observatory 6.5m Telescope project

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The University of Tokyo Atacama Observatory (TAO) is a project to construct a 6.5m infrared-optimized telescope at the summit of Co. Chajnantor (5640m altitude) in the northern Chile. It is lead by Institute of Astronomy, University of Tokyo. Thanks to the high altitude and low water vapor, continuous window from 0.9 to 2.5 micron as well as new windows at wavelength longer than 20 micron appear. The site shows extremely low perciptable water vapor (PWV) of 0.5mm (25 percentile), and fraction of usable night is more than 80%. Measured median seeing is 0.69 arcsec, which is comparable or better than major observatories over the world.

In prior to the 6.5m telescope, a 1m pathfinder telescope called miniTAO is installed and started observation in 2009. Its success of Paschen alpha imaging at 1.875 micron and MIR observatoins at 38 micron confirm the promising capability of the site. The 6.5m telescope is now at the design phase, and its two instruments are now being constructed. They are a near-infrared imager/multi-object spectrograph with 9.6arcmin FOV, and a mid-infrared imager/spectrograph from 10 to 40 micron. We will present the project overview, including the site characteristics, telescope, instrumentation, and support facilities.

7733-05, Session 1

The optical performance of LAMOST Telescope

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The Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST) project has completed its engineering work, and is going to finish commissioning around the end of 2010. The LAMOST telescope is with both large aperture and wide field of view to achieve the large scale spectroscopic survey observation. It is an innovative meridian active reflecting Schmidt configuration achieved by an active deformable Schmidt plate, which could not be realized by the traditional optical system. Its primary mirror and active Schmidt plate both are segmented. The active deformable segments (sub-mirrors) are hexagonal. This paper presents the optical performance of the telescope of LAMOST. It is shown that LAMOST project successfully resolving the big technical challenges, and developed special active optics. It makes the progress in active optics.

7733-06, Session 1

The Discovery Channel Telescope: early integration

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The Discovery Channel Telescope is a 4.2m astronomical research telescope being built in northern Arizona as a partnership between Discovery Communications and Lowell Observatory. The telescope will be able to support substantial instrument payloads at Cassegrain, Nasmyth, and prime foci, and high observing cadences. The first-light configuration will be as an f/6.1 Ritchey-Chrétien at Cassegrain with a 30 arc-minute field-of-view. Major facility work is complete, and the telescope is currently in the integration phase with first-light anticipated in 2011. We present an overview of the design and progress to date, and include plans for final integration, commissioning, and early science.

7733-07, Session 1

Southern LAMOST for all sky spectroscopic survey

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The all sky survey is very important for study some subjects such as the structure and evolution of our Galaxy. The Large-Sky-Area Multi-object Fiber Spectroscopic Telescope (LAMOST) has successfully completed its engineering work and inaugurated in October of 2008. Now it is in the commissioning stage. In pursuit of the all sky spectroscopic survey, a southern LAMOST is proposed. The Southern LAMOST will be mainly a copy of present LAMOST in Xinglong, China, which is located in the northern. Some modification for much better image quality and thinner optical fibers are required because its site should be with the better seeing condition. There will be 6000 or 8000 optical fibers used on the focal surface to get the highest spectrum acquiring rate, and about 12 to 16 spectrographs with 24 to 32 CCD cameras. Southern LAMOST is going to be built by international collaboration. In this paper, some preliminary scientific results obtained in the commissioning, and the preliminary parameters of the southern LAMOST are presented.

7733-08, Session 1

The Large Binocular Telescope

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The Large Binocular Telescope (LBT) Observatory is a collaboration between institutions in Arizona, Germany, Italy, Indiana, Minnesota, Ohio and Virginia. The telescope on Mt. Graham in Arizona uses two 8.4-meter diameter primary mirrors mounted side-by-side to produce a collecting area equivalent to an 11.8-meter circular aperture. A unique feature of LBT is that the light from the two primary mirrors can be combined to produce phased-array imaging of an extended field.

This coherent imaging along with adaptive optics gives the telescope the diffraction-limited resolution of a 22.65-meter telescope.

Binocular imaging with two co-pointed prime focus cameras began in Fall 2007, and science observing continues routinely. We will describe the scientific results and technical challenges of monocular Gregorian focus observations starting in Spring 2008. Commissioning of the first Gregorian spectrometer (LUCIFER) has been completed with a rigid secondary mirror, and science observations have begun in December 2009. The telescope uses two F/15 adaptive secondaries to correct atmospheric turbulence. The first of these adaptive mirrors has been tested in Italy with the adaptive loop closed, and is planned to be at the telescope in Spring 2010. The Direct Gregorian focus has been prepared for the arrival of the second Gregorian spectrometer (MODS).

7733-09, Session 2

The Large Synoptic Survey Telescope preliminary design overview

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The Large Synoptic Survey Telescope (LSST) Project is a public-private partnership that is well into the design and development of the complete observatory system to conduct a wide fast deep survey and to process and serve the data. The telescope has a 3-mirror wide field optical system with an 8.4 meter primary, 3.4 meter secondary, and 5 meter tertiary mirror. The reflective optics feed three refractive elements and a 64 cm 3.2 gigapixel camera. The LSST data management system will reduce, transport, alert, archive the roughly 15 terabytes of data produced nightly, and will serve the raw and catalog data accumulating at an average of 7 petabytes per year to the community without any proprietary period. The project has completed several data challenges designed to prototype and test the data management system to significant pre-construction levels. The project continues to attract institutional partners and has acquired non-federal funding sufficient to construct the primary mirror, already in progress at the University of Arizona, build the secondary mirror substrate, completed by Corning, and fund detector prototype efforts, several that have been tested on the sky. A focus of the project is system engineering, risk reduction through prototyping and major efforts in image simulation and operation simulations. The project has submitted a proposal for construction to the National Science Foundation Major Research Equipment and Facilities Construction (MREFC) program and has prepared project advocacy papers for the National Research Council's Astronomy 2010 Decadal Survey. The Project is preparing for a 2012 construction funding authorization.

7733-10, Session 2

The Pan-STARRS wide-field optical/NIR imaging survey

N. Kaiser, Univ. of Hawai'i (United States)

Pan-STARRS is a highly cost-effective, modular and scalable approach to wide-field optical/NIR imaging. It uses 1.8m telescopes with very large (7 square degree) field of view and revolutionary 1.4 billion pixel CCD cameras with low noise and rapid read-out to provide broad band imaging from 400-1000nm wavelength. A first, single telescope system, PS1 has been deployed on Haleakala on Maui, and is now collecting survey data. PS1 will be joined by a second telescope PS2 in approximately 18 months.

A four aperture system PS4 is planned to replace the UH 88" telescope on Mauna Kea and to become operational following the end of the PS1 mission.

PS4 will be able to scan the entire visible sky to approximately 24th magnitude in less than a week, thereby meeting the goals set out by the NAS decadal review for a "Large Synoptic Sky Telescope". In this talk I will review the technical design, and give an update on the progress that has been made in commissioning the first telescope system.

7733-11, Session 2

LSST telescope mount and pier design overview

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The Large Synoptic Survey Telescope (LSST) is a large (8.4 meter) wide-field (3.5 degree) survey telescope, which will be located on the summit of Cerro Pachón in Chile. The survey mission requires a short slew and settling time of 5 seconds for a 3.5 degree slew. This is significantly faster than similar aperture telescopes. Since the optical system does not include a fast steering mirror the telescope has stringent vibration limitations during observation. Meeting these requirements is facilitated by the compact mount riding on a robust pier which produces high natural frequencies, an advanced control system to minimize vibration excitation and reaction mass dampers. The telescope mount design is an altitude over azimuth welded and bolted assembly fabricated from mild steel. It supports the primary / tertiary mirror cell assembly, the secondary mirror cell assembly and the camera assembly. The mount design enables the removal of these optical assemblies for servicing and recoating. Retractable / deployable platforms have also been provided for accessing the camera on telescope. As a result of the wide field of view, the optical system is unusually susceptible to stray light consequently the mount must incorporate substantial light baffling. The dynamic characteristics of the steel reinforced concrete pier were enhanced by utilizing two different wall thicknesses, an unusually large diameter of 16 meter and anchoring the foundation in unweathered bedrock. The entire pier and mount assembly has been designed to be invariant with azimuth and elevation angle to enhance the effectiveness of the advanced control system.

7733-12, Session 3

Advanced Technology Solar Telescope: beginning construction of the world's largest solar telescope

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The 4m Advance Technology Solar Telescope (ATST) will be the most powerful solar telescope and the world's leading ground-based resource for studying solar magnetism that controls the solar wind, flares, coronal mass ejections and variability in the Sun's output. The project has successfully passed its final design review and the Environmental Impact Study for construction of ATST on Haleakala, Maui, HI has been concluded in December of 2009. The project is now entering its construction phase.

As its highest priority science driver ATST shall provide high resolution and high sensitivity observations of the dynamic solar magnetic fields throughout the solar atmosphere, including the corona at infrared wavelengths. With its 4 m aperture, ATST will resolve features at 0."03 at visible wavelengths and obtain 0."1 resolution at the magnetically highly sensitive near infrared wavelengths. A high order adaptive optics system delivers a corrected beam to the initial set of state-of-the-art, facility class instrumentation located in the coude laboratory facility. The initial set of first generation instruments consists of five facility class instruments, including imagers and spectro-polarimeters. The high polarimetric sensitivity and accuracy required for measurements of the illusive solar magnetic fields place strong constraints on the polarization analysis and calibration.

Development and construction of a four-meter solar telescope presents many technical challenges, including thermal control of the enclosure, telescope structure and optics and wavefront control. A brief overview of the science goals and observational requirements of the ATST will be given, followed by a summary of the design status of the telescope and its instrumentation, including design status of major subsystems, such as the telescope mount assembly, enclosure, mirror assemblies, and wavefront correction

7733-13, Session 3

European Solar Telescope: project status

M. Collados Vera, Instituto de Astrofísica de Canarias (Spain); F. C. M. Bettonvil, Utrecht Univ. (Netherlands); L. Cavaller-Marquéz, Grantecan, S.A. (Spain); I. Ermolli, Osservatorio Astronomico di Roma (Italy); B. F. Gelly, Themis S.L. (Spain); C. Grivel-Gelly, R. Á. M. Pérez de Taoro, H. Socas-Navarro, Instituto de Astrofísica de Canarias (Spain); D. Soltau, R. Volkmer, Albert-Ludwigs-Univ. Freiburg (Germany)

EST (European Solar Telescope) is a project for a 4-meter class telescope to be located in the Canary Islands. EST is promoted by the European Association for Solar Telescopes (EAST). This is a consortium formed by a number of research organizations from fifteen European countries (Austria, Croatia, Czech Republic, France, Germany, Hungary, Italy, the Netherlands, Norway, Poland, Slovak Republic, Spain, Sweden, Switzerland, and United Kingdom). EST will specialize in high spatial and temporal resolution using diverse instruments that can efficiently produce two-dimensional spectropolarimetric information of the thermal, dynamic and magnetic properties of the plasma over many scale heights. In this contribution, the status of the development of the Design Study of EST will be presented, emphasizing the most important aspects of the mechanical structure, optical design, AO and MCAO mirrors for wavefront correction, instruments and polarization analysis.

7733-14, Session 3

NLST: the Indian National Large Solar Telescope

S. Hasan, Indian Institute of Astrophysics (India); D. Soltau, Albert-Ludwigs-Univ. Freiburg (Germany); H. J. Kärcher, M. Süss, MT Mechatronics GmbH (Germany); T. Berkefeld, Albert-Ludwigs-Univ. Freiburg (Germany)

India is planning a new solar telescope with an aperture of 2 m for carrying out high resolution studies of the Sun. Site characterization is underway at high altitude locations in the Himalayan mountains. A detailed concept design for NLST (National Large Solar Telescope) has

been completed. The optical design of the telescope is optimized for high optical throughput and uses a minimum number of optical elements. A high order AO system is integrated part of the design that works with a modest Fried's parameter of 7-cm to give diffraction limited performance. The telescope will be equipped with a suite of post-focus instruments including a high resolution spectrograph and a polarimeter. NLST will also be used for carrying out stellar observations during the night. The mechanical design of the telescope, building, and the innovative dome is optimized to take advantage of the natural air flush which will help to keep the open telescope in temperature equilibrium. After its completion (planned for 2014), NLST will fill a gap in longitude between the major solar facilities in USA and Europe, and it will be for years the largest solar telescope in the world.

7733-15, Session 3

Mechanical design of a completely open-foldable dome for EST in the range of 20- to 30m diameter with optional an effective semitransparent windscreen for telescope protection

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In the context of the EST design study for a 4m class solar telescope and a study for large open-foldable domes of the Dutch Technology Foundation STW, a design is made for the 20 to 30m diameter range. Detailed designs are made for three specific sizes: 23, 28 and 33m diameter.

Smaller size open-foldable domes based on tensioned cloth have proven to be very effective for good seeing conditions for solar telescopes. The 7m dome for the Dutch Open Telescope (DOT) and the 9m dome for the GREGOR telescope have proven this. In addition, these domes have proven to be excellent stable against storms and insensitive to ice grow, hence all weather stable. The cloth has shown no degradation over the past 13 (DOT) resp. 5 (GREGOR) years of experience and no permanent elongation with the frequent de-tensioning and tensioning with opening and closing. The application of cloth permits a design of a dome which leaves, when opened, the telescope completely free without any structure left over the telescope and no massive structures besides or under the telescope.

Basis for the design is the available pre-stretched stable cloth, which is nowadays produced in much stronger qualities than used for the DOT and GREGOR. Larger curvature radius requires larger tension in the cloth. The combination of larger dome radius and the stronger cloth fits for the up scaling. Calculations showed that the steel construction geometries of the GREGOR dome can be up scaled with some adjustments. Bearings and drives remain inside normal sizes. Cost calculations show that open-foldable domes in this size range are remarkable lower in price than closed domes.

We will show an interesting option for a semi transparent windshield of which the position can be adapted to the wind direction. This shield will give an effective wind protection of the region around the primary mirror without disturbing the wind flows above the shield and without stagnant air or big eddies behind the shield. This shield is storm safe and the costs are only a fraction of the open foldable dome costs, hence insignificant.

7733-16, Session 3

GREGOR Telescope: start of commissioning

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With the integration of a 1m primary Cesic-mirror the GREGOR telescope commissioning started. This is the first time, that the entire light path sees sunlight.

This phase includes testing of the main optics, adaptive optics, cooling system and pointing system. Also the first light post focus instrument will be tested. In summer 2010 this phase will be completed with the integration of the 1.5m primary Zerodur-mirror. An additional short commissioning will be added to allow as soon as possible scientific observations.

After inauguration GREGOR will provide with its combination of multi-conjugate adaptive optics and the top-performance post focus instruments high quality scientific results.

7733-17, Session 3

The multi-application solar telescope of the Udaipur Solar Observatory

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The Multi Application Solar Telescope (MAST) is an off-axis 9 mirror coude system with a 50 cm aperture Zerodur primary mirror and an agile hexapod mounted 10 cm aperture SiC secondary mirror. The telescope will have complete thermal control to maintain the mirror surfaces within a degree from the ambient temperature. The telescope, which is being manufactured by the Advanced Mechanical and Optical Systems (AMOS) in Belgium, will feed an adaptive optics (AO) system developed by the Udaipur Solar Observatory. The AO will feed a suite of back-end instruments which include a polarimeter, a Lithium Niobate fabry-perot based imager and a high resolution spectrograph. The various steps for planning and implementation of the telescope project will be described. The telescope is expected to see first light in mid 2010. A brief description of the science goals planned for MAST will be presented.

7733-101, Poster Session

The Robotic Earthshine Telescope

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Exact knowledge of the Earth's albedo is of fundamental importance for climate research and modeling. Lund Observatory is presently designing and constructing a robotic telescope dedicated to studies of the Earth's albedo by measuring the ratio between the intensity of the bright and dark sides of the Moon. The telescope will operate both in broadband and narrow-band modes over the entire visible wavelength range and will transmit observation results back to the operation team over the Internet. Design challenges, in particular related to choice of CCD and stray light suppression, are described, together with the design of the optics,

control system, and enclosure. Finally we present results from tests in Sweden and characterize the site and its infrastructure. The telescope will go into operation in the first half of 2011.

7733-102, Poster Session

Update and image quality error budget for the LSST camera optical design

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The Large Synoptic Survey Telescope (LSST) uses a novel, three-mirror, modified Paul-Baker design, with an 8.4-meter primary mirror, a 3.4-m secondary, and a 5.0-m tertiary feeding a camera system that includes a set of broad-band filters and refractive corrector lenses to produce a flat focal plane with a field of view of 9.6 square degrees. Optical design of the camera lenses and filters is integrated with optical design of telescope mirrors to optimize performance, resulting in excellent image quality over the entire field from ultra-violet to near infra-red wavelengths. The LSST camera optics design consists of three refractive lenses with clear aperture diameters of 1.55 m, 1.10 m and 0.69 m and six interchangeable, broad-band, filters with clear aperture diameters of 0.75 m. We describe the image quality error budget analysis methodology which includes effects from optical and optomechanical considerations such as index inhomogeneity, fabrication and null-testing error, temperature gradients, gravity, pressure, stress, birefringence, and vibration.

7733-103, Poster Session

LCOGT Telescope network capabilities

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Las Cumbres Observatory Global Telescope, based in Goleta, California, own the two robotic 2-m Faulkes Telescopes operating at Haleakala, Maui (FTN) and Siding Spring, Australia (FTS).

LCOGT are currently building and deploying a world-wide network of twelve 1-meter and thirty 0.4-meter telescopes to 3 sites in each hemisphere, to enable extended, redundant and optimally continuous coverage of time variable or transient sources.

Each f/8 1-m telescope provides a corrected, unvignetted, flat field of view of 110mm or 0.8 degrees, with image quality limited by site seeing. The 1m telescopes utilize lightweight Hextek mirrors polished at LZOS, and mechanical components designed, fabricated and assembled in California. Each 1m will be equipped with a LCOGT controlled, back-illuminated Fairchild 4Kx4K CCD486, with 15um pixels providing a pixel scale of 0.4as and 27-arcmin field of view. The instrumentation includes two off-axis SBIG guiders and one independently guided fiber feed to a cross-dispersed bench echelle spectrograph (one per site) providing full coverage from 380-950nm at R=30,000. A fourth off-axis port can be used for small-field fast-frame imaging.

Each f/8 0.4m telescope utilizes Meade RCX optics mounted on LCOGT drive hardware. Each is equipped with an SBIG 2Kx3K imager with 9um pixels providing a pixel scale of 0.6as and 20x30 arcmin Field of View, with internal off-axis guider. All telescopes provide a full range of optical narrow-band and broad-band UBVRI and ugriZY imaging filters. They are all being equipped with a moving LED light-bar flat-fielding system called Lambert.

Targets accepted by the TACs, including targets of opportunity, will be automatically scheduled on the most appropriate site, telescope and aperture, but can be automatically and rapidly re-scheduled in the event of technical or weather issues.

The 1m network is intended primarily for science observing while the 0.4m network additionally provides educational opportunities to participating schools and institutes. The global network is designed to accommodate multiple science, educational and rapid response capabilities.

7733-104, Poster Session

Mirror seeing control of large infrared solar telescope

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To obtain high resolution infrared image, both low photon efficiency and long wavelength of infrared light requires enough large aperture telescope, but large aperture vacuum windows can hardly achieve high optical quality, so open structure becomes the only viable choice for large infrared solar telescope. In addition to the effects of atmospheric turbulence, open solar telescopes suffer from the heating of the optics by sunlight, especially primary mirror heating. These factors can cause the image to shiver and become blurred, and increase infrared observing noise. Since blowing air across the front surface of the primary mirror doesn't have the necessary heat transfer coefficient to remove the absorbed heat load, it must be cooled down to maintained at a temperature between 0K and 2K below ambient air temperature to reduce the effects of turbulence. This paper will introduce some cooling methods and simulation results of primary mirror in large infrared solar telescope. On the other hand, mirror material with nice thermal conductivity can reduce the temperature difference between mirror surface and air, and mirror surface polishing at infrared wavelength can be comparatively easier than at visible wavelength, so it is possible to select low cost metal mirror as primary mirror of infrared solar telescope. To analyze the technical feasibility of metal mirror serving as primary mirror, this paper also give some polishing results of aluminum mirror with electroless nickel coating.

7733-105, Poster Session

The heat stop for the 4-m European Solar Telescope EST

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A consortium of 24 European solar physics institution from 14 different countries is conducting a design study for a 4 m class solar telescope which shall be situated at the Canary Islands.

We illustrate the study of the heat stop for EST telescope's primary focus. The heat stop is a diaphragm with a small hole to select the appropriate field of view. In a solar telescope the heat stop is illuminated by the full image of the Sun. In our study case the image of the Sun is a circle of about 60 millimeters of diameter carrying a power of about 13 kW. In order to remove the heat two devices have been considered. The first is a cooled flat mirror inclined at 45 degrees which deflects away from the optical axis of the telescope most of the unwanted incident power redirecting it either on the outside or on a liquid cooled heat absorber. The second is a 45 degree cooled conical mirror coaxial to the optical axis of the telescope deflecting the heat flux on a cylindrical trap. Both

devices include an air removal system to avoid the formation of thermal plumes. The results of the study will be presented and a comparison made between the performances of the two devices.

7733-106, Poster Session

First light of the 1.6 meter off-axis New Solar Telescope at Big Bear Solar Observatory

W. Cao, P. R. Goode, R. Coulter, N. Gorceix, Big Bear Solar Observatory (United States)

The NST (New Solar Telescope), 1.6-meter clear aperture, off-axis telescope, has been installed and operated in its commissioning phase at Big Bear Solar Observatory (BBSO). It will be the most capable, largest aperture solar telescope in the US until the 4-meter ATST (Advanced Technology Solar Telescope) comes on-line in the middle of the next decade. The NST is configured as an off-axis Gregorian system consisting of a parabolic primary, prime focus field stop and heat reflector (heat-stop), elliptical secondary and diagonal flats. The PM is made of Zerodur from Schott and figured with a final figure residual error of 16 nm rms by Steward Observatory Mirror Lab. The focal ratio of the PM is f/2.4, and the final ratio is f/50. The 120” circular opening in the field stop defines an 80” by 80” maximal square field-of-view. The working wavelength range will cover 0.4 to 1.7 micron in the Coudé Laboratory one floor beneath the telescope, and all wavelengths including far infrared at the Nasmyth focus on an optical bench attached to the side of the telescope structure. The NST will be outfitted with state-of-the-art post-focus instrumentations, which currently include Adaptive Optics system (AO), InfraRed Imaging Magnetograph (IRIM), Visible Imaging Magnetograph (VIM), Real-time Image Reconstruction System (RIRS), and Fast Imaging Solar Spectrograph (FISS). First-light scientific observations have been attained at the Nasmyth focus. In this paper, we present an up-to-data progress of the project, a detailed description of installation and alignment, and some first-light scientific results.

7733-107, Poster Session

European Solar Telescope (EST) transfer optics

R. Sanquirce, A. Gomez, G. Murga Llano, B. Etxeita, IDOM (Spain)

The European Solar Telescope (EST) is a European collaborative project to build a 4m class solar telescope in the Canary Islands, which is now in its design study phase supported by the seventh framework programme of the European Commission. The telescope will provide diffraction limited performance for several instruments observing simultaneously at the Coudé focus at different wavelengths.

This paper summarizes the work performed by IDOM, in the concept design of Transfer Optic system comprising the optomechanics and seeing control of the optical train and surrounding area. Additionally, the possibility of using the Transfer Optics system to compensate the field rotation is currently under study.

In order to duly minimize the seeing contribution of the system several alternatives are being explored: an air conditioning based thermal control system, an evacuated system, a helium based system, in all cases supported by an appropriate local control system for each source.

Different alternatives have also been considered and analysed for the Transfer Optics support and drive mechanism.

7733-108, Poster Session

Foldable dome climate measurements and thermal properties

G. Sliepen, A. P. L. Jägers, R. H. Hammerschlag, F. C. M. Bettonvil, Utrecht Univ. (Netherlands)

As part of a larger project for measuring various aspects of foldable domes in the context of EST and with support of the Dutch Technology Foundation STW, we have collected over a year continuous temperature and humidity measurements, both inside and outside the domes of the Dutch Open Telescope (DOT) on La Palma and the GREGOR telescope on Tenerife. In addition, we have measured the wind field around each dome.

Although the structure of both domes is similar, the DOT dome has a single layer of cloth, and is situated on top of an open tower. In contrast, the GREGOR dome has a double layer of cloth, and is situated on top of a tower-shaped building. These differences result in large differences in temperature and humidity insulation when the dome is closed. We will present the changes in temperature and humidity one can expect for each dome within one day, and the statistics for the variations throughout a year.

In addition, we will show that the main advantage of a foldable dome is the near instantaneous equilibration of the air inside the volume originally enclosed by the dome and that of the environment outside the dome. This property allows one to operate a telescope without needing expensive air conditioning and dome skin temperature control in order to limit dome and shell seeing effects.

The measurements give also information about the weather fluctuations at the sites of the domes. It was observed that on small time scales the temperature fluctuations are significantly greater during the day than during the night.

7733-109, Poster Session

The enclosure for the European Solar Telescope (EST)

F. C. M. Bettonvil, Utrecht Univ. (Netherlands); R. Codina, Univ. Politècnica de Catalunya (Spain); R. H. Hammerschlag, A. P. L. Jägers, Utrecht Univ. (Netherlands); J. N. M. Kommers, Hankom Engineering (Netherlands); S. J. van Leverink, Machinefabriek P.M. Duyvis (Netherlands); G. Sliepen, Utrecht Univ. (Netherlands); S. Visser, Poly-Ned BV (Netherlands)

EST (European Solar Telescope) is a 4-m class solar telescope, which is currently in the conceptual design phase. EST will be located in the Canary Islands and will aim at high spatial and temporal resolution observations in the photosphere and chromosphere, using diverse instruments that can efficiently produce two-dimensional spectropolarimetric information of the thermal, dynamic and magnetic properties of the plasma over many scale heights.

In this contribution we will present the results of the concept study for the enclosure for EST. Two different concepts have been studied in more detail: the first being a dome concept with vent gates to enhance local flushing, the other being a retractable enclosure, with an optional windshield.

The main purpose of an enclosure is to protect the telescope and instruments from severe weather conditions. An enclosure is also often needed for reducing wind buffeting on the telescope and primary mirror cell, but on the other hand enclosures are generally considered to degrade local seeing. We will look at the aspects of seeing degradation during daytime (shell, dome and floor seeing), windshake, based on both calculations and measurements, and discuss CFD simulations that have been done to help understanding the flow pattern in- and around the enclosure. Technical measures will be discussed, and mechanical concepts presented.

7733-110, Poster Session

The pier and building of the European Solar Telescope (EST)

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EST (European Solar Telescope) is a 4-m class solar telescope, which is currently in the conceptual design phase. EST will be located in the Canary Islands and will aim at high spatial and temporal resolution observations in the photosphere and chromosphere, using a suite of instruments that can produce efficiently two-dimensional spectropolarimetric information of the thermal, dynamic and magnetic properties of the plasma over many scale heights.

This paper will deal with the concept study of the pier and the building for EST. The pier is defined as the construction that supports the telescope and the enclosure. At the bottom of the pier a large Coudé lab is located, 16-m in diameter, 10-m high. To the pier is attached a service building that accommodates all auxiliary services, possibly together with a separate building.

In this contribution we present the study of both solid concrete- and open framework piers, and discuss their advantages and disadvantages. We present how much local seeing improves as function of the height of the pier, look into thermal aspects of pier and building (size, shape and orientation), and at stability issues including the layout of the foundation. Also the difference between single tower concepts and inner/outer shell concepts, which have the potential to reduce wind buffeting on the tower, have been reviewed. We will outline how the top of the pier should look for optimal seeing conditions. FE models and CFD simulations are used to give qualitative insight in the differences between the alternatives.

7733-111, Poster Session

Multi-application Solar Telescope: assembly, integration, and testing

S. Denis, P. Coucke, E. Gabriel, C. Delrez, AMOS Ltd. (Belgium); P. Venkatakrishnan, Udaipur Solar Observatory (India)

The Multi-Application Solar Telescope (MAST) is a 50 cm diameter class telescope to be installed by AMOS on the Udaipur Solar Observatory's Island on the Lake Fatehsagar in India. Despite its limited size, the telescope is expected to be competitive with respect to worldwide large and costly projects thanks to its versatility regarding science goals and due to its demanding optomechanical and thermal specification. This paper describes the latest activities, including factory assembly, integration and testing, followed by on-site installation and commissioning activities. Emphasis is put on the highly demanding thermal control of the telescope, showing development and results for the specific techniques employed on this purpose. Other key features also depicted are the unusual tracking and alignment control solutions on such a specific science target like the Sun.

7733-112, Poster Session

Current concept for the 4m European Solar Telescope (EST) optical design

J. Sánchez Capuchino, M. Collados Vera, R. L. López, Instituto de Astrofísica de Canarias (Spain); B. F. Gelly, Themis S.L. (France)

The European Solar Telescope (EST) is a pan-european project (with 29 partners, plus 7 collaborating institutions, from 14 countries) for the conceptual design study of a 4-meter class solar telescope promoted by the European Association for Solar Telescopes (EAST), to be located in the Canary Islands. The telescope, which is now in the design study phase, provides an F/50 telecentric, diffraction-limited performance, optimized in throughput for several instruments observing simultaneously at the Coudé-focus from 0.39 μm to 2.3 μm. Its current optical concept integrates multiconjugated adaptive optics with optical field de-rotation and with a perfect balance in terms of polarization being invariant with the optics orientation.

7733-113, Poster Session

Testing the e2v CCD47-20 as the new sensor for the SOFIA target acquisition and tracking cameras

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The telescope of the Stratospheric Observatory for Infrared Astronomy (SOFIA) uses three CCD cameras for target acquisition and tracking, the Wide-Field Imager (WFI), the Fine-Field Imager (FFI) and a Focal Plane Imager (FPI). All three cameras use TH7888A CCD sensors which are quite suitable in terms of their geometry and readout speed. However, their quantum efficiency and dark current rate are not comparable to newer high-sensitivity CCD sensors now widely used in astronomy. The German SOFIA Institute (DSI) under contract of the German Aerospace Center (DLR) has therefore initiated an upgrade project of the cameras with high-sensitivity and low dark current CCD sensors, the e2v CCD47-20 BI AIMO. The back-illuminated architecture allows for high quantum efficiency, while the inverted mode operation lowers the dark current significantly. Both features enable the cameras to use fainter stars for tracking. The expected improvements in sensitivity range between 1.2 and 2.5 stellar magnitudes for the three cameras.

In this paper we present results of laboratory and on-sky tests with the new sensor, obtained with a commercial camera platform and simulation optics for the three SOFIA imagers. We also report on tests of a prototype camera that was built and tested in preparation of the future SOFIA flight hardware.

7733-114, Poster Session

SOFIA in operation: status of the telescope in-flight commissioning

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After 8 years of development, the telescope of the Stratospheric Observatory for Infrared As-tronomy, SOFIA has been integrated into the aircraft and has just started with the first observation test flights. Due to its rather unique environment in the open port of a Boeing 747SP, the telescope optics of SOFIA is exposed to extreme aero-acoustic excitations. The telescope pointing system is equipped with several design features, such as a vibration isolation system, a flexible body control system and - potentially - active mass dampers, to handle excitations in different frequency ranges. Final performance features of these systems will only be available after the first test flights, which will happen in the first half of 2010. A progress report is presented and describes the recent achievements as well as the status of the telescope, and gives an update of the SOFIA pointing system, and the planned commissioning tests.

A first reactivation flight of the aircraft (after two years of refurbishing at its new home at Dryden) was successfully executed on Dec 9th, 2009 including in-flight functional tests of the cavity door and the telescope. The paper will report the latest updates of the pointing status probably be gotten by the first flights with open door.

7733-115, Poster Session

Measuring the water vapor above the SOFIA Observatory

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The SOFIA airborne observatory flies in the lower stratosphere above more than 99.9% of the Earth's water vapor. As low as this residual water vapor is, it will still affect SOFIA's infrared and sub-millimeter astronomical observations. As a result, a heterodyne instrument operating at 183 GHz will be used to measure the integrated water vapor overburden in flight. The accuracy of the measured precipitable water vapor must be 2 microns or better, 3 sigma, and measured at least once a minute. This presentation will cover the design and the measured laboratory performance of this instrument, and will discuss other options for determining the water vapor overburden during the SOFIA Early Science shared-risk period.

7733-116, Poster Session

A model of sky brightness in the stratosphere from the Balloon Observatory for wavelength and spectral emission readings

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In the interest of supporting the feasibility of diffraction-limited, balloon-borne telescopes, students from the Colorado Space Grant Consortium at the University of Colorado developed the Balloon Observatory for Wavelength and Spectral Emission Readings (BOWSER) and launched it as part of the High Altitude Student Platform (HASP), a program run by Louisiana State University. Relying on the natural rotation of a zero pressure balloon, BOWSER analyzed sky background brightness in the stratosphere utilizing an array of diodes to sample a ninety degree field of view over the course of an eighteen hour flight. Based on the MODTRAN model of sky irradiance, it was predicted that sky brightness would vary primarily as a function of three parameters: altitude, wavelength and angle from the sun. The diode array provided empirical evidence that characterizes the influence of each of the three variables on sky background brightness. This model will enable future high altitude observatories to anticipate the optimal pointing and filtering conditions necessary for observing the cosmos.

7733-117, Poster Session

The optical design of the PIPER experiment

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The balloon-borne PIPER instrument will observe the polarization in the cosmic microwave background (CMB) at 200, 270, 350, and 600 GHz. Two co-aligned telescopes, one sensitive to Stokes Q and V the other sensitive to U and V, are placed inside a large liquid helium Dewar where all optical elements are cooled to 1.5 K. Each telescope utilizes a variable-delay polarization modulator (VPM) as its primary optical element. The fore optics consist of two off-axis mirrors and a folding flat. This configuration images the cold pupil onto the VPM. The rear optics use off-axis lenses to image each of the linear orthogonal polarization signals from an analyzer grid onto two bolometer arrays - one array for each polarization state. Both telescopes will have a 6 x 4.7 deg field-of-view.

7733-118, Poster Session

An off-axis, diffraction-limited, reflective Schmidt Telescope

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The Chinese LAMOST reflective Schmidt design shows how to build large wide-field telescopes in a simple and scalable way. However, the LAMOST design suffers from obstruction by the focal plane and its supporting column; this limits its suitability in situations where diffraction-limited performance is required. For most telescope designs, going to an unobstructed off-axis design involves great sacrifices in terms of cost, field-of-view, or aperture. We show that the reflective Schmidt concept is uniquely capable of adaptation to an off-axis design without such serious penalties. We present a design for a 4-metre, f/8 design giving diffraction-limited K-band imaging over a 1 degree field, and d80<0.4" over a 4 degree field.

7733-119, Poster Session

New approaches to the design of non-redundant aperture masks

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The spatial frequencies accessible with a non-redundant mask (NRM) are directly fixed by the positions of the sub-apertures over the telescope pupil. In this paper we present several iterative algorithms for constructing sub-aperture configurations. We use a "second order autocorrelation" (that we define by the correlation of the masked pupil and its autocorrelation) of a pre-existing set of n-1 sub-apertures in order to find if and where a supplementary nth sub-aperture can be placed. As several possible locations may then be found, we propose 3 different criteria to choose among them. Favoring the positions that are the closest to the center of the pupil ends up finding configurations already described by Golay (1971). Two other new methods aim at favoring the highest spatial frequencies in the image. The possibility of working with pupils of different radii in order to obtain a better coverage is also explored. The comparison between the configurations found with our algorithms is done by computing for each of them the radial density of the spatial frequency's coverage, the total flux collected by the sub-apertures and the diffraction patterns associated to these configurations. Several pupil masks have been manufactured and tested in the High-Contrast Imaging Laboratory at Princeton University. We present at the end of this paper the experimental results obtained with them.

7733-120, Poster Session

Light-weight telescope structure optimized by genetic algorithm

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Okayama 3.8 m telescope is the first segmented optical telescope in Japan whose primary mirror consists of 18 petal shaped segment mirrors. The whole mirror is supported by 54 actuators (3 actuators per each segment mirror). In order to realize lightweight telescope structure and high speed telescope driving, we adopted full truss structure as the optics supporting structure (OSS) of the telescope and optimized its design by a newly developed software program incorporating genetic algorithm. The program automatically generates new OSS design step-by-step by optimizing the OSS parameters for realizing both lightweight of the telescope structure and minimal deformation of the mirror

surface supported by the OSS against the telescope elevation change ("homologous deformation") simultaneously. The program successfully generated an ultra lightweight OSS design whose weight is only 8 tons including the optical elements and actuators (4 tons) with an eigen frequency of 9.5 Hz. The relative deformation between the 54 nodes of the designed OSS are suppressed to be less than 100 um in the range of elevation angle 20 - 90 degrees. The OSS is under test construction. We report the results of static test and deformation performance of this test OSS model.

7733-121, Poster Session

Technical specifications of the KMTNet observation system

S. Kim, B. Park, C. Lee, I. Yuk, Korea Astronomy and Space Science Institute (Korea, Republic of); C. Han, Chungbuk National Univ. (Korea, Republic of); T. P. O'Brien, A. Gould, The Ohio State Univ. (United States); J. W. Lee, D. Kim, Korea Astronomy and Space Science Institute (Korea, Republic of)

Korea Astronomy and Space Science Institute (KASI) has officially started a project to construct an astronomical wide-field survey system, namely KMTNet (Korea Micro-lensing Telescope Network), from January 2009. Its primary scientific goal is to discover numerous extra-solar planets, especially earth-mass planets, using the gravitational micro-lensing technique. This goal requires continuous photometric observations with high cadence of about 10 minutes for tens of millions of stars in dense fields toward the Galactic bulge. KMTNet will comprise three identical systems at southern observatories with different time zones. Each observing system consists of a 1.6m wide-field optical telescope and a 20k by 20k mosaic CCD camera, which covers a 2 by 2 degrees square field of view. We will present technical specifications, designs, and fabrication schedule of the KMTNet systems.

7733-122, Poster Session

A new optical design for dismountable and portable catadioptric telescope

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A dismountable and portable telescope with an primary mirror of 250 mm in diameter and a numerical aperture of 5.6, is presented. The telescope has a all-spheric catadioptric optical design, consisting of a spherical primary and a group of spherical lenses, where the last surface is aluminized, as a secondary mirror.

The group of lenses corrects all the optical aberrations, including the spherical introduced by the primary and the chromatic ones. The telescope has a very compact design, with a physical length of 600mm. This fact, joint with the all-spherical design, make it a ligth portable and easy to align instrument: when dismounted it can be contained in a suitcase sizing 580x440x140 mm and the spherical surface for all the mirrors and lenses makes easy the final alignment of the optical train.

We discuss here in detail the optical design and the realized prototype and will show the results, both in terms of theoretical and effective performances.

7733-123, Poster Session

Performance test of a 2.5m telescope mount in workshop

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For a astronomical telescope, performance test in workshop before delivery is very important to ensure that there is no big problem for the telescope to be erected on site and there is no large trouble during commissioning on site. A 2.5m optical/infrared telescope introduced in this paper is a cooperation project between NIAOT (Nanjing Institute of Astronomical Optics and Technology) and Sagem Défense Sécurité. Sagem is in charge of optics while NIAOT is in charge of mount, including its control system which is cooperated with Nanjing SaiGu company. The main task of this paper is to describe the performance test in workshop without optical elements, including telescope pointing and tracking performance, M2 positioner performance, M3 positioner performance, etc. Meanwhile, the method to test the performance are also introduced in this paper. The test results show that the performance of the telescope mount have met the telescope's requirements completely, and even some of the results are better than the design requirements.

7733-124, Poster Session

Optomechanical design aspects of the 2m Wendelstein Fraunhofer Telescope

P. Aniol, ASTELCO Systems GmbH (Germany); H. Thiele, Kayser-Threde GmbH (Germany); M. Schmidt, Schmidt Instruments (Germany); D. Kampf, R. Schöggl, M. Hartl, Kayser-Threde GmbH (Germany); M. Dietzel, ASTELCO Systems GmbH (Germany); M. Ruder, tau-tec GmbH (Germany); J. Klammer, K. Haertel, A. Gresik, K. Zuknik, Kayser-Threde GmbH (Germany)

The new 2m "Fraunhofer" telescope, a project of the Ludwig-Maximilians-Universitaet Muenchen, and operated on top the excellent site of Mt. Wendelstein will be built by the companies Kayser-Threde GmbH, Munich/Germany (optical design of the 3-mirror f/7.4 RC and field corrector, mirror cells and FEM analysis), and Astelco Systems GmbH/Martinsried, Germany (design, manufacturing, assembly of the telescope, control system and software). The 2m "Fraunhofer" is a very compact alt-az mounted telescope with two Nasmyth ports and state of the art subsystems. The optical design and field corrector are an example for future wide-field telescope systems in the 2-4m class with super compact designs. A large hexapod will be responsible for all M2 movements needed for focusing and alignment. An effective and accurate M3 switching unit will feed both optical ports. Three high-torque direct drive motors coupled with precision encoders are responsible for a fast slewing, precise pointing and tracking. Two elevation motors are foreseen to work at high wind speeds and a rigid mechanical design together with the strong motors allow fast to ultrafast slewing speeds, when needed. A large direct driven derotator will support and move the LMU instrumentation. The modular structured software package allows a modern remote or robotic telescope and instrument operation. Here are presented various design aspects of the telescope and related issues like transportation, assembly and installation on a difficultly accessible mountain site.

7733-125, Poster Session

DEMONEX: the dedicated monitor of exotransits

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The DEdicated MONitor of EXotransits (DEMONEX) is a low-cost, 0.5 meter, robotic telescope assembled mostly from commercially available parts dedicated to obtaining precise photometry of bright stars hosting transiting planets. This photometry provides a homogeneous data set

for all transits visible from its location at Winer Observatory in Sonoita, Arizona. We are also searching for additional planets via transit timing variations, placing limits on the albedos from secondary eclipses, systematically searching known radial velocity planets for those that transit, and will follow up promising transiting planet candidates from the Kilo-degree Extremely Little Telescope (KELT). Despite its modest size, the signal-to-noise ratio per transit is comparable to that obtained with larger, 1m-class telescopes because of its short readout time and high z-band quantum efficiency. However, its main strength is that it is used every night for transit follow-up and gathers an unprecedented data set on transiting planets. With the 32 known transiting planets visible from Winer Observatory, over 90% of all nights have at least one full event to observe.

We describe the science drivers; hardware; scheduling, observing, and data reduction software; as well as our results from the first two years of operation.

While our system is dedicated to transiting planets, the outline followed and lessons learned from this project are broadly applicable to time domain astronomy. Synoptic surveys coming online will undoubtedly uncover a plethora of variable objects which will require inexpensive, robotic, dedicated telescopes like DEMONEX to adequately characterize.

7733-127, Poster Session

A scalable, cost-effective, radio telescope drive and axis system

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The scale of the upcoming radio aperture synthesis telescope arrays, such as the Frequency Agile Solar Radio telescope (FASR) and the Square Kilometer Array (SKA) are so large that they individually involve hundreds or thousands of small or medium size antennas. To successfully construct these future giant arrays, significant structure and drive system design and manufacturing improvements are urgently required. The antennas designed for these arrays should be well optimized, dimensionally scalable, easy in mass production, and most importantly, the lowest in manufactured cost. The antenna should use as much as possible the off-the-shelf commercially available parts. Ideally a well-designed solution of the antenna structure would allow their use in both the FASR and SKA arrays in order to share designs as much as possible further reducing costs.

An antenna structure includes two major components: the dish and the drive and axis system. The antenna dish design has been discussed in another paper of this conference. The drive and axis system is the major topic of this paper. A good drive and axis system is of vital importance to the antenna performance. It is directly related to the antenna pointing and tracking accuracy. The major requirement of this drive and axis part is to perform 90 deg of smooth elevation motion (0-90 deg) and 540 deg of smooth azimuth motion (+/- 270 deg). The accuracy of these pointing motions should be well within 1 arc minute. To mass produce these drive and axis systems, use of off-the shelf components and making the design scalable, standard, and compact is of significant importance. To sustain continuous, long term, and remote observation requirements with very large number of antennas, high reliability, low maintenance, robustness, and cost effectiveness are also major considerations. As an antenna has two axes, a combined elevation and azimuth drive and axis unit would be of great help in the project management as well as future maintenance. Another design consideration is the design unit should be easily adapted to various dish designs without significant design changes.

In this paper, the performances of various different drive systems have been thoroughly investigated. These systems include standard twin motor gear drive, harmonic actuator-type drive, single lead screw elevation drive, twin screw drive system, single gear and motor drive, and sprocket and chain motor drive system. Advantages and disadvantages of these systems are listed and discussed. Finally we present a compact, scalable, combined elevation and azimuth drive and axis unit design. In this design, the elevation drive and axis component shares many parts with the azimuth drive and axis component. The off-the-shelf commercial parts are used for both axis and drive chains. The design can also assure required pointing and tracking accuracy. Since it is a self contained unit, the assembly, installation, and maintenance are further simplified, resulting in overall low cost.

7733-128, Poster Session

Modeling and control study of cable-driven parallel manipulator for FAST

L. Huang, National Astronomical Observatories (China)

The focus cabin of the Five-hundred-meter Aperture Spherical Telescope (FAST) is driven by 6 cables. This device can be seen as a Cable-driven Parallel Manipulator (CPM). The authors apply the exact expression of catenary to build the non-linear static model of the CPM to get the cable tension and length for the control of the focus cabin. A linear simplified model, the Pseudo-curve Model, is presented. While ensuring the precision, the Pseudo-curve Model increases efficiency, making real-time control and massive calculation possible. Using the Pseudo-curve Model, the authors search the attitude angle to get the angle set under constraints of cable tension. An optimization schema is proposed to ensure cables a well-proportioned tension and avoid slack. A numerical instance testified the accuracy and efficiency of the Pseudo-curve Model. The authors analyze the Jacobian matrix of the kinematic equation, on the basis of which the motion plan of the CPM is presented. This paper also shows the influence of the changing of the focus cabin's attitude angles on the cable's tension and length. The exact cable tension, length, attitude angles and cable velocity are given finally.

7733-129, Poster Session

A new efficient laser scanning sensing method for the phasing and maintaining the Large Radio Telescope active reflecting antenna

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Radio telescopes with much more larger aperture collect much more signals and therefore sought after by astronomers. The primary reflecting antenna is traditionally segmented and perfectly optically aligned at the central altitude among the whole observation sky area for minimizing the gravitational deformation during operation and passively open-loop maintained at any other altitude. A new laser scanning segmentation sensing method is proposed in this paper. After the introduction of the theory, the method is tested on a special prototype of radio panel segmentation system. It provides real-time monitoring and measurement of the global segmentation status of all panels and is proved to be a high accurate, high efficient and low cost method. Finally several conclusions are reached.

7733-130, Poster Session

MicroCLINE: an innovative tiltmeter concept and its application the ALMA-EU antennas' dynamic metrology

R. Biasi, D. Pescoller, Microgate S.r.l. (Italy); F. Rampini, European Industrial Engineering s.r.l. (Italy)

Large radio-telescopes requiring accurate 'blind' pointing accuracy are often equipped with dedicated metrology systems in order to correct for structural deformations. We present here a novel tiltmeter concept conceived specifically to compensate for the fast, wind-induced deformations occurring on such large structures. This instrument combines the typical accuracy and resolution of geodetic devices with an unique capability of recovering quickly from large saturations: this condition often occurs during fast slewing of the antenna. Moreover, the device features a reduced sensitivity to in-plane accelerations. All this allows its installation in favorable positions concerning the observability of the structural deformations to be detected and corrected, thus simplifying the processing from raw instrument data to the pointing correction to be applied. The instrument has been subjected to a thorough characterization and qualification process, by means of extensive tests both in the lab, using a dedicated testbench, and on the ALMA-EU antenna prototype. This activity allowed assessing other critical aspects for the final application, in particular easiness of installation, simplicity of mechanical and electrical interfaces, robustness, reliability and very limited maintenance requirements. The device is currently installed on the ALMA-EU production antennas.

7733-131, Poster Session

The high performances of the European ALMA antenna with the innovative metrology system

F. Rampini, G. Marchiori, European Industrial Engineering s.r.l. (Italy); R. Biasi, Microgate S.r.l. (Italy); S. Stanghellini, European Organisation for Astronomical Research in the Southern Hemisphere (Germany)

The Atacama Large Millimeter Array (ALMA) consists of a large number of 12 m diameter antennas that will operate up to 950GHz. The mechanical performances in terms of surface accuracy, pointing stability and residual delay are very tight. The antennas must work at full capacity night and day in the open air, observing the sun as well. The mechanical performances are affected by all the non repeatable error sources and,in particular, by the temperature variations and wind component blowing from different directions. The design of the antennas has been done in order to have a very light and stiff structure, in particular all the elevation structure is in carbon fibre with a very low thermal expansion coefficient. In order to achieve the ALMA specifications, two different systems capable of predicting the above-mentioned error sources have been implemented so to control the antenna.

The first system is composed by a determined number of thermal sensors distributed in the alidade of the antenna (on the only steel part) that compensate the elevation axis deformation due to the temperature variation by means of a deformation matrix.

The second system is based on two high accuracy inclinometers with a very short recovery time opportunely placed on the antenna so to correct the wind induced errors.

These innovative systems and instruments have been designed and tested on the prototype antenna during production phase.

7733-132, Poster Session

DSS-28: a novel wide bandwidth radio telescope devoted to educational outreach

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We have recently equipped the 34 meter DSS-28 radio telescope at the Goldstone Deep Space Communications Complex with a novel wide bandwidth radiometer and digital signal processor as part of the Goldstone Apple Valley Radio Telescope (GAVRT) educational outreach program operated by the Jet Propulsion Laboratory and the Lewis Center for Educational Research. The system employs a cryogenically cooled wide bandwidth quad-ridge feed and InP low noise amplifiers to achieve excellent noise performance from 2.7 to 14 GHz; a fractional bandwidth better than 4:1. Four independently tuned dual-polarization receivers each down-convert a 2 GHz block to baseband, providing access to 8 GHz of instantaneous bandwidth. A flexible FPGA-based signal processor has been constructed using the CASPER FPGA hardware and tools to take advantage of this enormous bandwidth. This system demonstrates many of the enabling wide bandwidth technologies that will be crucial to maximizing the utility of future large centimeter-wavelength arrays, in particular the Square Kilometer Array.

The GAVRT program has previously used narrow bandwidth total power radiometers to study flux variability of quasars and the outer planets. The versatility of DSS-28 will enable other projects including spectroscopy and SETI. Finally, the wide instantaneous bandwidth available makes this system uniquely suited for studying transient radio pulses. A configuration of the digital signal processor has been developed which provides the capability of recording a burst of raw baseband voltage data triggered by a real-time incoherent dedispersion system which is very sensitive to pulses from a known source, such as the Crab Nebula pulsar.

7733-133, Poster Session

Optical offset pointing of radio interferometers: applications at CARMA

S. A. Corder, National Radio Astronomy Observatory (Chile); M. C. H. Wright, Univ. of California, Berkeley (United States); J. M. Carpenter, California Institute of Technology (United States)

Optical telescopes and camera systems are often used to provide an initial pointing model for many radio telescopes around the world, specifically at (sub)millimeter wavelengths where sensitivity is relatively poor and the density of radio pointing sources is low. The optical systems are usually used for initial calibration and testing of the radio antennas and radio pointing is used during the regular operation of the radio telescope. At the Combined Array for Research in Millimeter-wave Astronomy (CARMA), we have developed an approach that uses the optical systems during the course of regular radio observations.

The basic method requires no additional inputs from the user and is now the default pointing method at CARMA. The observing script adjusts the requirements for day- or night-time observing, selects an appropriate star from an optical catalog, performs an initial measurement of the optical to radio pointing offset value, measures the changes in optical pointing throughout the observation, and translates these into radio pointing offsets. The pointing errors using this system are typically reduced by factors of two to several for the CARMA antennas.

We report on the proof of concept testing, the implementation method, and the typical improvements obtained. We conclude with a brief discussion of future directions, which may offer further improved pointing at CARMA and at other facilities that require increased pointing accuracy, i.e. CCAT, ALMA, and other submillimeter wavelength facilities.

7733-134, Poster Session

Analysis of lightweight prestressed antenna back-up structure

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The planned Square Kilometer Array (SKA) includes three thousand 15m antenna dishes, to be installed in Australia or Southern Africa. The radio flux density of our sun is much stronger than other cosmic sources, so smaller aperture array, such as Frequency-Agile Solar Radiotelescope (FASR), can be used in the observation and research. FASR also includes many hundreds of antenna dishes. Therefore, lightweight low cost dish design is of vital importance for these radio astronomical array projects.

The reflecting surface supported by an antenna back-up structure,

generally, should have an RMS error less than lamda/20(lamda is the operating wavelength). For resisting gravitational, wind, and ice-snow loadings, antenna dish also requires reasonable mode frequencies. In this paper, different low cost small or medium back-up structure designs are discussed. These include double-layer truss design and prestressed dish design. In the prestressed dish design, the parabolic shape of the surface is produced by bending radial members with a tangential ring component. The curvature of beams is nearly a parabolic curve, since the deflection of a cantilever beam under bending moment follows a quadratic equation. In the detailed design, secondary reinforcement members at intermediate location and point corresponding to the hub bottom edge are added. It is also very important to keep all the structural members properly prestressed in order to store sufficient elastic energy for supporting gravitational, wind and ice-snow loadings. The secondary reinforcement members not only reduce the stress concentration on the radial members at the hub, but also improve the overall beam stiffness. This type of back-up dish structure is light in weight, easy in manufacture, simple in assembling, and low in cost. They are also very stable and reliable. In this paper, detailed finite element analysis of the prestressed structure is discussed. From the analysis, we produced a small 4.5m aperture dish design working below 3GHz. The analysis includes an initial state without prestress as well as a working state under prestress. In the paper, paraboloid surface fitting algorithm is also used to derive the surface rms error.

7733-135, Poster Session

Characterization of surface tilt of foundations for high-precision radio-astronomic antennas

B. D. Hoff, J. P. Puga, Atacama Large Millimeter Array (Chile)

The Atacama Large Millimeter/Sub-millimeter Array (ALMA) is a joint project between astronomical organizations in Europe, North America, and Japan, in collaboration with the Republic of Chile. ALMA will consist of at least 54 twelve meter antennas operating in the millimeter and sub-millimeter wavelength range. It will be located at an altitude above 5000m in the Chajnantor Plateau in northern Chile.

There are at least 172 antenna foundations under construction at ALMA's Array Operations Site (AOS). Interchangeability between foundations will permit a variety of array configurations. Foundations provide the physical interface to the bedrock, as well as to the underground signal and power cable conduits. To achieve ALMA's precision requirements, the antenna pointing angular error budget is strict with anticipated non-repeatable error on the order of a few arc seconds. This level of precision imposes rigorous requirements on antenna foundations.

The objective of this study is to demonstrate the methodology of precision tilt measurements combined with finite element simulation predictions to portray the qualitative nature of the antenna foundation surface deformation. Characteristics of foundation surface tilt have been examined in detail. Although the actual foundation has demonstrated much less resistance to tilt than the finite element representation, the simulation has predicted some key characteristics of the tilt pattern. The large deviations from the ideal have incited speculations into the compliance of materials, ambiguities in the construction, thermal effects and several other aspects described herein. This research has served as groundwork to characterize ALMA's foundation surface behavior on a micro-degree level and to identify subsequent studies to pursue. This in turn has contributed to the diagnosis of antenna pointing anomalies.

7733-136, Poster Session

Path length errors of VLBI antennas

H. J. Kärcher, E. Sust, P. Emde, MT Mechatronics GmbH (Germany)

The performance of single dish radio antennas or telescopes is depending on the surface accuracy of the reflectors in the beam path and the focus/pointing errors induced by deviations/misalignment of the reflectors from a desired direction. For multiple dish VLBI arrays an additional mechanical effect, the path length stability, is a further source of performance degradation. For application at higher frequencies environmental influences as wind and temperature have to be considered additionally to the usual required manufacturing and alignment accuracies. Active measurement ("metrology") of the antenna deformations and compensation by "active optics" (AO) respectively "flexible body compensation" (FBC) are established methods. For the path length errors AO or FBC are up to now not established methods. The paper describes how to handle the path length errors and the related metrology analogues to the established methods used for surface and focus/pointing errors.

Possible applications for ALMA (equivalent to 1000 GHz) and VLBI 2010 (equivalent to 100 GHz) will be explained. Also the use of new sensor technology as MEMS will be addressed (ongoing own F&E program).

7733-137, Poster Session

Atmospheric phase correction using the CARMA paired antennas calibration system

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High angular resolution observations at millimeter wavelengths are essential to understand a variety of astrophysical phenomena, from the solar system to high redshift galaxies. The resolution of millimeter wave interferometers is limited by large and rapid differential atmospheric delay fluctuations on long baselines. At the Combined Array for Research in Millimeter-wave Astronomy (CARMA) we have employed a paired-antenna system to calibrate the rapidly varying atmospheric delay in the extended array configurations (up to 2 km baselines, 0.15 arcsecond resolution at 1.3mm). The CARMA Paired Antenna Calibration System (C-PACS) pairs 3.5 m antennas operating at 1cm, with selected larger (6.1 and 10.4m) CARMA antennas operating in the 1 or 3 mm atmospheric bands. Two separate arrays are used: the larger diameter antennas in the "science array" observe the science target and phase calibrator, while the smaller antennas in the "calibration array" simultaneously monitor an atmospheric calibrator as close as possible to the science target. Delay correction is performed offline. We present a description of the C-PACS technique, its application to our data, and a summary analysis of the technical details of the first two seasons of operations. We also present results of successful atmospheric delay corrections applied to science observations with dramatic improvements in sensitivity and angular resolution.

7733-138, Poster Session

The Advanced Technology Solar Telescope Coudé Lab. thermal environment

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The ATST scientific instruments are located on benches installed on a large diameter rotating coudé lab floor. The light path from the telescope to the instruments is greater than 38 meters and passes from external ambient conditions to the 'shirt-sleeve' environment of the coudé lab. In order to minimize any contribution to local seeing or wavefront distortion, two strategies are implemented. First, an air curtain is installed where the beam passes from ambient conditions to the lab space and second, the coudé lab environmental conditions are tightly controlled. This paper presents the design parameters of the environmental conditions, the basis of each design parameter, an overview of the equipment and components of the system planned to control those conditions, and the thermal and computational fluid dynamic analyses that have been performed in support of the system as designed.

7733-139, Poster Session

Low-vibration high-cooling power 2-stage cryocoolers for ground-based astronomical instrumentation

G. H. Jakob, J. Lizon, European Organisation for Astronomical Research in the Southern Hemisphere (Germany)

This paper describes the outcome of a survey reviewing commercially available state-of-the-art high cooling power 2-stage cryocooler systems for a potential use in powerful scientific instruments for ground-based astronomy. Extreme resolution capabilities and increased sensitivities of modern telescopes and instrumentation implicate significant susceptibilities to mechanical disturbances. Especially for the very sensitive VLT-I experiments (the world's largest interferometer) even low level excited vibrations are very critical or unacceptable. Therefore particular emphasis was put on vibrations caused by these cryogenic refrigerators together with demanding requirements on cooling power and operation temperature range.

We present the development of a dedicated test-bed as well as vibration and performance measurements on different 2-stage refrigerator systems. As a result of this investigation program, one system was selected as ESO's new standard 20K closed cycle cooler offering substantial advantages in flexibility and orientation insensitivity along with best compromise for a low vibration device with high cooling power. The new cryocooler type was integrated with VLT instrumentation. A concept for a comprehensive vibration test program at VLT is presented in order to define admissible vibration spectra for future instrumentation.

7733-140, Poster Session

A partially foldable light weighted dome for fast pointing 3m class telescopes

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Wind is a well known performance detractor for telescope pointing. Increasing the size of the telescope increase the aeroelastic eect onto the performances of the telescope. A dome is often used for larger telescopes to minimize those interactions. Rapid pointing telescope requires rapid domes, which usually are heavy drawing their cost not negligible respect to the overall amount of budget required. For this reason fast telescope's dome are usually fully deployed leaving the telescope unprotected from the wind.

This paper want to show an improvement of the fully foldable tents in order to realize a partially foldable light-weighted tent able to follow the alt azimuthal fast movement of a large scale telescope protecting it from aeroelastic loading without interacting with the dynamic of the main system. The alt azimuthal movement of the telescope is decoupled with an azimuthal rotation of the full tent and an opposite alt motion of the two valves. In this way it is possible to work with a fully emyspherical tent leaving a window opened as large as the f.o.v. pf the telescope requires.

7733-141, Poster Session

Monitoring of the environmental conditions inside the dome of the 4m Blanco Telescope at CTIO

S. G. Els, Gaia Data Analysis and Processing Consortium (Spain); T. M. C. Abbott, A. Berdja, E. B. Bustos, J. Seguel, D. E. Walker, Cerro Tololo Inter-American Observatory (Chile); R. L. Riddle, Thirty Meter Telescope Project (United States); M. Schoeck, TMT Observatory Corp. (Canada); W. A. Skidmore, T. Travouillon, TMT Observatory Corp. (United States)

We will present the experimental setup of this measurement campaign, e.g., where the sensors were mounted and how. We will explain the data collection strategy and will show first analyses.

7733-142, Poster Session

Advances in thermal control and performance of the primary mirror, MMT Observatory, Tucson, Arizona, USA

J. D. Gibson, S. P. Callahan, B. Comisso, R. Ortiz, G. G. Williams, J. T. Williams, MMT Observatory (United States)

Strategies for thermal control of the 6.5-meter diameter borosilicate honeycomb primary (M1) mirror at the MMT Observatory have included: 1) direct control of ventilation system chiller setpoints by the telescope operator, 2) automated control of chiller setpoints, using a fixed offset from selected ambient temperatures, and 3) most recently, use of an automated proportional-integral-differential (PID) controller of temperatures for conditioned air as delivered to the M1 mirror cell. Results of these various strategies are compared and contrasted under different operational conditions. Constraints and sanity checks for thermal control are also discussed, including: 1) mirror safety, 2) aluminum coating preservation, and 3) optimization of conditions for science acquisition, including minimization of mirror seeing and glass temperature gradients. In many cases, trade-offs must be made within the control strategy between minimizing mirror seeing, which results from air turbulence at the air-glass boundary at the mirror face, and temperatures gradients within the borosilicate glass itself that can distort the mirror figure and degrade image quality. Consideration is given to special operating conditions, such as high dew or frost points, large chamber/outside air temperatures differences at sunset and under marginal observing conditions, and pre-conditioning the mirror prior to opening of the telescope chamber. The advantages of integrating multiple chillers and heat exchangers into the thermal control strategy are presented. Precise temperature control of conditioned ventilation air to the M1 mirror cell is also discussed. Finally, suggestions are made by which further refinement of the M1 mirror thermal control algorithms can be made.

7733-143, Poster Session

Wind loading analysis and strategy for deflection reduction on HET dark energy experiment upgrade

B. J. South, J. M. Good, J. A. Booth, M. S. Worthington, J. J. Zierer, Jr., I. M. Soukup, The Univ. of Texas at Austin (United States)

Wind loading can be a detrimental source of vibration and deflection for any large terrestrial optical telescope. The Hobby-Eberly Telescope (HET) in the Davis Mountains of West Texas is undergoing a Dark Energy Experiment (HETDEX) upgrade that will greatly increase the size of the instrumentation subjected to operating wind speeds of up to 45 mph. A

non-trivial consideration for this telescope (or others) is to quantify the wind loads and resulting deflections of telescope structures induced under normal operating conditions so that appropriate design changes can be made. A quasi-static computational fluid dynamics (CFD) model was generated using wind speeds collected on-site as inputs to characterize dynamic wind forces on telescope structures under various conditions. The CFD model was refined until predicted wind speed and direction inside the dome agreed with experimental data. The dynamic wind forces were then used in static loading analysis to determine maximum deflections under typical operating conditions. This approach also allows for innovative management of operating parameters without risk of damage to the telescope structure or instrumentation. With an optimum combination of parameters (i.e. dome orientation, tracker position, and louver deployment), deflections due to current wind conditions can be significantly reduced. Furthermore, the upper limit for operating wind speed could be increased, provided these parameters are monitored closely. This translates into increased seeing time for astronomers, reduced deflections, and more accurate astronomical data collection.

7733-144, Poster Session

Field stabilization (tip/tilt control) of E-ELT

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The image motion (tip/tilt) of the telescope is dominated by two types of perturbations: a) atmospheric b) wind load. The wind load effect on E-ELT can be an order of magnitude higher than the atmospheric effect. Part of the image motion due to the wind load on the telescope structure is corrected by the main axis control system (mainly large amplitude, low frequency errors). The residual tip/tilt is reduced by M5 and M4 mirror units. M5 with its large stroke and relative low bandwidth (higher than main axes) corrects for large amplitude and low frequency part of the image motion and M4 unit takes the higher frequency parts with smaller stroke availability. In this paper the two stage control strategy of the E-ELT field stabilization is introduced. The performance of the telescope due to the wind load and in the presence of the major imperfections in the control system is presented.

7733-147, Poster Session

Design and analysis of the Hobby-Eberly Telescope dark energy experiment (HETDEX) bridge

M. S. Worthington, S. P. Nichols, J. M. Good, J. J. Zierer, Jr., N. T. Mollison, I. M. Soukup, The Univ. of Texas at Austin (United States)

A large structural weldment has been designed and is undergoing fabrication to serve as the new star tracker bridge for the Dark Energy Experiment upgrade to the 9.2-meter Hobby-Eberly Telescope (HET) at McDonald Observatory in West Texas. The modeling approach, analysis techniques and design details will be of interest to designers of large structures where stiffness and mass are the primary design drivers. The 10.5-meter bridge will span the telescope's upper hexagon structure locating the science instruments with respect to the fixed primary mirror. The design and analysis is greatly influenced by the components being supported by the bridge and the kinematic constraints at the bridge to upper hexagon interface, which will be discussed. The design includes detailed structural analysis using finite element models to maximize natural frequency response and minimize deflections and light obscuration. The primary driver of the design is a minimum first mode natural frequency requirement of 9 Hz, based on experience in operating the HET tracker. While this requirement has decreased by 10% compared to the existing HET bridge, a significant challenge existed as the science payload increased in mass by a factor of seven leading to a 3.5 fold mass gain to the entire tracker. Considerable fabrication challenges were overcome to allow the integration of precision hardware required for positioning the payload to a precision of less than 5 micron along its 4-meter travel range. A detailed description of the bridge geometry, analysis results and fabrication issues will be provided.

7733-148, Poster Session

Kinematic optimization of upgrade to the Hobby-Eberly Telescope through novel use of commercially available three-dimensional CAD package

G. A. Wedeking, J. J. Zierer, Jr., J. R. Jackson, The Univ. of Texas at Austin (United States)

The University of Texas, Center for Electromechanics UT-CEM is making a major upgrade to the robotic tracking system on the Hobby Eberly Telescope (HET) as part of the Dark Energy Experiment (HETDEX). The upgrade focuses on a threefold increase in payload and necessitated a complete redesign of all tracker supporting structure and motion control systems, including the tracker bridge, ten drive systems, carriage frames, a hexapod, and many other sub-systems. The cost and sensitivity of the scientific payload, coupled with the tracker system sevenfold mass increase, necessitated major upgrades to personnel and hardware safety systems. To optimize kinematic design of the entire tracker, UT-CEM developed novel uses of constraints and drivers to interface with a commercially available CAD package (SolidWorks). For example, to optimize volume usage and minimize obscuration, the CAD software was exercised to accurately determine tracker/hexapod operational space needed to meet science requirements. To verify to hexapod controller models, actuator travel requirements were graphically measured and compared to well defined equations of motion for Stewart platforms. To ensure critical hardware safety during various failure modes, UT-CEM engineers developed Visual Basic drivers to interface with the CAD software and quickly tabulate distance measurements between critical pieces of optical hardware and adjacent components for over thousands of possible hexapod configurations. These advances and techniques, applicable to any challenging robotic system design, are documented and describe new ways to use commercially available software tools to more clearly define hardware requirements and help insure safe operation.

7733-149, Poster Session

Current status of the Hobby-Eberly Telescope wide-field upgrade

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The Hobby-Eberly Telescope (HET) is an innovative large telescope of 9.2 meter aperture, located in West Texas at the McDonald Observatory. The HET operates with a fixed segmented primary and has a tracker which moves the four-mirror corrector and prime focus instrument package to track the sidereal and non-sidereal motions of objects. A major upgrade of the HET is in progress that will substantially increase the pupil size to 10 meters and the field of view to 22 arcminutes by replacing the corrector, tracker and prime focus instrument package. In addition to supporting the existing suite of instruments, this wide field upgrade will feed a revolutionary new integral field spectrograph called VIRUS, in support of the Hobby-Eberly Telescope Dark Energy Experiment (HETDEX). This paper discusses the current status of this upgrade.

7733-150, Poster Session

Design and development of a long-travel positioning actuator and tandem constant force actuator safety system for the Hobby-Eberly Telescope wide-field upgrade

N. T. Mollison, J. R. Mock, I. M. Soukup, T. A. Beets, J. M. Good, J. H. Beno, H. J. Kriel, S. E. Hinze, D. R. Wardell, The Univ. of Texas at Austin (United States)

The Wide Field Upgrade presents a more than three-fold increase in mass for the Hobby-Eberly Telescope's tracker system. The design of the Hobby-Eberly Telescope places the Prime Focus Instrument Platform [PFIP] at a thirty-five degree angle from horizontal. The PFIP and its associated hardware have historically been positioned along this uphill axis (referred to as the telescope's Y-axis) by a single screw-type actuator. Several factors, including increased payload mass and design for minimal light obscuration, have led to the design of a new and novel configuration for the Y-axis screw drive as part of the tracker system upgrade. Typical screw drive designs in this load and travel class (approximately 50 kilonewtons traveling 4 meters) utilize a stationary screw with the payload translating with the moving nut component. The new configuration employs a stationary nut and translating roller screw affixed to the moving payload, resulting in a unique drive system design. Additionally, a second cable-actuated servo drive (adapted from a system currently in use on the Southern African Large Telescope [SALT]) will operate in tandem with the screw-drive in order to significantly improve telescope safety through the presence of redundant failsafe systems. Details of the mechanical design, analysis, and topology of each servo drive system are presented in this paper, along with discussion of the issues such a configuration presents in the areas of controls, operational and failure modes, and positioning accuracy. Findings and results from investigations of alternative safety systems, including deformable crash barriers, are also included.

7733-151, Poster Session

Improving the Blanco Telescope's delivered image quality

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The V. M. Blanco 4-m telescope at Cerro Tololo Inter-American Observatory is undergoing a number of improvements in preparation for the delivery of the Dark Energy Camera. The program includes upgrades having potential to deliver gains in image quality and stability. To this end, we have renovated the support structure of the primary mirror, incorporating innovations to improve both the radial support performance and the registration of the mirror and telescope top end. The resulting opto-mechanical condition of the telescope is described. We also describe some improvements to the environmental control. Upgrades to the telescope control system and measurements of the dome environment are described in separate papers in this conference.

7733-152, Poster Session

Tracker controls development and control architecture for the Hobby-Eberly Telescope dark energy experiment

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To enable the Hobby-Eberly Telescope Dark Energy Experiment, the University of Texas Center for Electromechanics and McDonald Observatory are developing a precision tracker system - a 15,000 kg robot to position a 3,100 kg payload within 10 microns of a desired dynamic track. Performance requirements to meet science needs and safety requirements that emerged from detailed Failure Modes and Effects Analysis resulted in a system of 13 precision controlled actuators and 100 additional analog and digital devices (primarily sensors and safety limit switches). This level of system complexity and emphasis on fail-safe operation is typical of large modern telescopes and numerous industrial applications. Due to this complexity, demanding accuracy requirements, and stringent safety requirements, a highly versatile and easily configurable centralized control system that easily links with modeling and simulation tools during the hardware and software design process was deemed essential. The Matlab-Simulink simulation environment, coupled with dSPACE controller hardware, was selected for controls development and realization. The dSPACE real-time operating system collects sensor information; motor commands are transmitted over a PROFIBUS network to servo amplifiers and drive motor status is received over the same network. Custom designed position feedback loops, supplemented by feed forward force commands for enhanced performance, and algorithms to accommodate self-locking gearboxes (for safety), reside in dSPACE. To interface the dSPACE controller directly to absolute Heidenhain sensors with EnDat 2.2 protocol, a custom communication board was developed. This paper covers details of software and hardware, design choices and analysis, and supporting simulations (primarily Simulink).

7733-153, Poster Session

Integration of VIRUS spectrographs for the HET dark energy experiment

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The Hobby-Eberly Telescope Dark Energy Experiment (HETDEX) at the University of Texas McDonald Observatory will use up to 192 Visible Integral-Field Replicable Unit Spectrographs (VIRUS) to survey large portions of the sky. Initial design studies, by General Dynamics SATCOM, established an optimal array size and an upper and lower bound on their placement relative to the existing telescope structure. Tradeoffs considering IFU (optical fiber) length, support structure mass and ease of maintenance have resulted in placement of four 3 x 8 arrays of spectrograph pairs, about mid-point in elevation relative to the fixed HET structure. Because of the desire to minimize impact on the modal performance of the HET and reduce cost, the VIRUS Support Structure (VSS) is required to be an independent, self-supporting structure and will only be coupled at the base of the telescope. Analysis shows that it is possible to utilize the existing azimuth drives of the telescope, through this coupling, which will greatly simplify the design and reduce cost. Each array is contained in an insulated enclosure that will control thermal load by means of heat exchangers and use of facility coolant supply. Access for installation and maintenance on the top, front, and rear of the enclosures must be provided. The design and analysis presented in this paper must provide an optimum balance in meeting the stringent requirements for science and facility constraints such as cost, weight, access, and safety.

7733-154, Poster Session

LSST all-sky IR camera cloud monitoring test results

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The LSST project has updated the all-sky IR camera that was installed on Cerro Pachón in Chile to continue its investigations in cloud monitoring and quantifying photometric conditions. The objective is to provide the

survey scheduler with real-time measured conditions of the sky/clouds, including high cirrus to better optimize the observing strategy. This paper describes the changes done to improve the detection performance of the first generation system and presents comparison results of visible and IR images. Contemporaneous visible measurements of extinction taken with the 1.2m Calypso Telescope on Kitt Peak are also provided.

7733-155, Poster Session

Support for site testing of the European Extremely Large Telescope: precipitable water vapor over La Silla

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The European Southern Observatory (ESO), the Institute for Space Imaging Science (ISIS) and the AstroMeteorology group at the Universidad de Valparaiso collaborated on a project to understand the precipitable water vapour (PWV) over the La Silla Paranal Observatory. Both La Silla and Paranal were studied with the goal of using them as reference sites to evaluate potential E-ELT sites. As ground-based infrared astronomy matures, our understanding of the atmospheric conditions over the observatories becomes paramount, specifically of water vapour since it is the principal source of atmospheric opacity at infrared wavelengths. Several years of archival optical spectra (FEROS) have been statistically analysed to reconstruct the PWV history above La Silla using an atmospheric radiative transfer model (BTRAM) developed by ISIS. In order to better understand the systematics involved, a dedicated campaign was conducted in May 2009 in close collaboration with Las Campanas observatory and the GMT site testing team. Several methods of determining the water column were employed, including radiosonde launches, continuous measurements by infrared radiometers (IRMA), and high-resolution optical echelle spectrographs: FEROS, HARPS and MIKE. All available observations were compared to concurrent satellite estimates of water vapour in an attempt to ground-truth the satellite data. We present a comparison of the methods used, results from the archival study and measurement campaign. Important lessons on the strengths and limitations of satellite data are presented. The value of a stand-alone high time resolution PWV monitor has been demonstrated in the context of parallel observations from Las Campanas and La Silla.

7733-156, Poster Session

Snodar: 2009 performance at Dome A, Antarctica

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Snodar is a high resolution acoustic radar designed specifically for profiling the atmospheric boundary layer on the high Antarctic plateau. Snodar profiles the atmospheric temperature structure function constant to a vertical resolution of 1 m or better with a minimum sample height of 8 m. The maximum sampling height is dependent on atmospheric conditions but is typically at least 100 m. Snodar uses a unique in-situ intensity calibration method that allows the instrument to be autonomously recalibrated throughout the year. The instrument is initially intensity calibrated against tower-mounted differential microthermal sensors. A calibration sphere is located in the near-field of the antenna to provide a fixed echo of known intensity, allowing the instrument to be continuously re-calibrated once deployed. This allows snow accumulation, transducer wear and system changes due to temperature to be monitored. Year-round power and communications are provided by the PLATO facility. This allows processed data to be downloaded every 6 hours while raw data is stored on-site for collection the following summer.

Two instruments have been synchronously profiling the atmospheric boundary layer every 5 seconds at Dome A since February 2009 as part of the PLATO facility. The instruments are separated by a distance of 20 m allowing the spatial and temporal characteristics of the atmospheric boundary layer to be investigated. Over 4 million processed samples have been downloaded through PLATO to date. We present performance data for the 2009 Antarctic summer and winter at Dome A along with calibration results.

7733-157, Poster Session

Attempt to assess the astronomical extinction over the Arab Maghreb countries

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The Arab Maghreb (Mauritania, Morocco, Algeria, Tunisia and Libya) is a substantial interval of continuous observation in longitude. These countries are either in the original absorbing dust as Mauritania or near the zone origin as other countries. An initial study showed that the transport of aerosols from the Sahara and Sahel is more towards the West but a significant portion is to the Northern direction. Our previous study comparing several sites in Morocco and the Canary Islands confirmed that transport.

In this paper, we compared, statistically, these countries levels of absorbing aerosols and make an attempt to assess the astronomical extinction coefficient over the entire region.

7733-158, Poster Session

Altitude dependence of the astronomical extinction using AERONET network and satellite data: validation for the astronomical observatories of Morocco and the Canary Islands, estimation of atmospheric extinction of Aklim Observatory in Morocco

Z. Z. Benkhaldoun, A. Bounhir, M. Sabil II, Univ. Cadi Ayyad (Morocco)

In the site selection process one key parameter is the extinction coefficient. This parameter depends on aerosol load, water vapor content and atmospheric gazes. Actually a lot of satellite products give the aerosol optical thickness over the earth with good spatial and temporal resolutions. For the astronomy community, the retrieval of the astronomical extinction coefficient at elevated places, typically where observatories are built, is very important.

In the first part of this paper we made a comparison between the extinction coefficient measured at ground level and the aerosol optical thickness measured from space at La Palma observatory in order to

study the reliability of the aerosol satellite products. We used the most popular ones: TOMS, MODIS, MISR and Envisat MERIS;

In the second part of the paper, we used three AERONET stations close to one another at the Canary Islands; Izana (latitude=28.3°, longitude=-16.5° altitude=2367m), La laguna (latitude=28.5°, longitude=-16.32°, altitude=568m) and Santa-Cruz Tenerife (latitude=28.5°, longitude=-16.25°, altitude=52m). The aerosol optical thicknesses relative to these stations were studied in order to infer the dependence of the astronomical extinction coefficient as a function of altitude.

Furthermore, we made a comparison between the aerosol optical thickness of two relatively close AERONET stations located in Morocco; one at low altitude Saada (latitude=31.63°, longitude=-8.15°, altitude=420m) and the other at Oukaimeden observatory (latitude=31.2°, longitude=-7.9°, altitude=2700m).

Based on these results we estimated from satellite measurements the extinction coefficient at Aklim observatory; one candidate to the E-ELT project (latitude=30.13°, longitude=-8.31°, altitude=2393m). This estimated extinction coefficient was compared with in-situ measurements that have been achieved with a DIMM aperture from January 2007 to September 2008.

7733-159, Poster Session

Surface layer characterization at Paranal Observatory

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In this paper the Paranal Surface Layer (SL) characterization is presented. Causes, physics and behaviour of the SL above Paranal surface are discussed. The analysis is developed using data from different turbulence profilers operated during several campaigns between 2007 and 2009. Instruments used are SL-SLODAR, DIMM, Elevated DIMM, MASS, Lunar Scintillometer and Ultrasonic Anemometers with temperature sensors positioned at different strategic heights.

7733-160, Poster Session

A dedicated tool for a full 3D Cn^2 investigation

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We present a complete mapping of the optical turbulence (OT) above astronomical sites. The mesoscale meteorological model Meso-NH was used together with the Astro-Meso-Nh package (Masciadri et al 1999a,b), and a set of diagnostic tools allowing for a full 3D investigation of the Cn^2.

In this contribution we present all the diagnostics implemented in the Astro package to fully investigate the OT structure in a volumetric space above different sites. To show the potentialities of this tool for applications in an Observatory we ran the model above sites with very different OT distributions: the antarctic plateau (Dome C, Dome A, South Pole...) and mid latitude sites.

We put particular emphasis on the 2D maps of integrated astroclimatic parameters (seeing, isoplanatic angles, wavefront coherence time...) calculated in different vertical slices at different heights in the troposphere. This is a useful tool of prediction and investigation of the turbulence structure. It can support the optimization of the AO, GLAO and MCAO systems running at the focus of the ground-based telescopes. It is, indeed, easily possible to extract vertical slices of different depths optimized for each field of view of the AO systems.

We also follow, for meteorological or astroclimatic parameters, the temporal evolution during the night and obtain their temporally averaged values on 2D surfaces around a telescope or vertical profiles extracted in precise locations.

From this study it emerges that astronomical sites clearly present different OT behaviors. Beside, our tool allows us for discriminating these sites.

7733-161, Poster Session

Optical turbulence: site selection above the internal Antarctic plateau with a mesoscale model

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Atmospherical mesoscale models can offer unique potentialities to characterize and discriminate potential astronomical sites.

Our team has recently completely validated the Meso-Nh model above Dome C (Lascaux et al. 2009, 2010). Using all the measurements of Cn2 profiles (15 nights) performed so far at Dome C during the winter time (Trinquet et al. 2008) we proved that the model can reconstruct, on rich statistical samples, reliable values of all the three most important parameters characterizing the turbulence features of an antarctic site: the surface layer thickness, the seeing in the free atmosphere and in the surface layer. Besides we proved that a horizontal resolution of 100 km, previously used by Swain & Gallee (2006) with a different model, in spite of the fact that it might in principle calculate the seeing above the whole antarctic continent with just one simulation, is too low and does not provide reliable results.

Using the same Meso-Nh model configuration validated above Dome C, an extended study is now on-going for other sites above the antarctic plateau such as South Pole and Dome A.

In this contribution we will present the most important results obtained in the model validation process and the results obtained in the comparison between different astronomical sites above the internal plateau.

We highlight that this study provides the first homogeneous estimate, done with comparable statistics, of the optical turbulence developed in the whole 20-22 km above the ground at Dome C, South Pole and Dome A.

7733-162, Poster Session

New dust measurements at ORM, and comparison with Paranal Observatory

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The performances of a modern telescope and its safety are dependent on the presence of atmospheric dust. The TNG telescope at ORM (Canary Islands) was one of the first sites monitored on a continuous basis by an automatic dust monitor. This paper presents the analysis of about 10 years of atmospheric dust content collected at the ORM using the TNG facilities. We have detected particles of 0.3, 0.5, 1.0, 3.0, 5.0 and 10.0 micron size. In this study particles of 0.5 and 5.0 micron measured at Paranal Observatory (Chile) are also compared to those similar at TNG. The seasonal behavior of the particles content in the atmosphere is compared between the two sites. The contribution of the dust emissivity

to the sky brightness in the NIR is computed for the first time. To complete this study we defined the aerosol mass critical limit to be used as a safety limit during observations. We found a limit of 12 ug per cubim metre as total mass of (0.5 + 5.0) micron particles.

7733-163, Poster Session

Comparison between astroclimatic parameters and 200 mbar wind at Aklim Observatory

A. Bounhir, Z. Z. Benkhaldoun, Cadi Ayyad Univ. (Morocco)

Aklim observatory is a candidate site to the E-ELT project. It is located in the Anti-Atlas mountains of Morocco at the geographical coordinates latitude=30.13°, longitude=-8.31° and at an elevation of 2393m. A campaign of meteorological and astroclimatic parameters have been achieved with a meteorological station and a MASS-DIMM apertures for more than a year.

In this paper we make a comparison between the wind at ground level and the seeing of six atmospheric layers, the free atmosphere seeing, the wavefront coherence time and the isoplanatic angle provided by the MASS.

In a previous paper published in the Monthly Notices of the Royal Astronomical Society we made a comparison between astroclimatic parameters provided by the MASS and the 200 mbar wind at Paranal observatory. In this paper we follow the same procedure concerning the data of Aklim observatory.

7733-164, Poster Session

Site-seeing measurements for the European Solar Telescope

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Seeing measurements are crucial for the optimum design of (multi-conjugate) adaptive optics systems operating at telescopes. For the design study of the 4-meter European Solar Telescope, to be located in the Canary Islands, several instruments have been constructed and operated, at the Observatorio del Roque de los Muchachos (La Palma) and at the Observatorio del Teide (Tenerife), to measure the properties of the ground layer and high altitude turbulence. Several units of short (~50 cm) and two long (~3.2 m) scintillometer bars are installed at both observatories. In addition to them, two wide-field wavefront sensors are attached to the optical beams of the Swedish tower, on La Palma, and of the German VTT, on Tenerife, simultaneously used with the normal operation of the telescopes. These wavefront sensors are of Shack-Hartmann type with ~1 arcminute field of view. In this contribution, the instruments setup and their performance are described.

7733-165, Poster Session

Monitoring of the atmospheric turbulence profiles for the ELTs adaptive optics systems specification

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The futures large telescopes at Dome C will be certainly equipped with Multi-Conjugate Adaptive Optics systems. The optimization of the performances of these techniques requires a precise specification of the different components of these systems. Major of these technical specifications are related to the atmospheric turbulence particularly the structure constante of the refractive index C_n^2 and the outer scale L_0. New techniques for the monitoring of the Cn2 and L_0 profiles with high vertical resolution will be presented.

7733-166, Poster Session

Measuring and forecasting of PWV above Paranal, La Silla, and APEX Observatories

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The content of precipitable water vapor (PWV) in the atmosphere is very important for astronomy in infrared and radio (sub-millimeter). Therefore the astrometeorology group has developed different methods to derive this value from measurements and making forecast using a meteorological model. The goal is use that model to know the atmosphere conditions and support thw scheduling of astronomical observations.

At ESO several means to determine PWV over the observatories are used, such as IR-radiometers (IRMA), optical and infrared spectrographs as well satellite data from GOES-12.

With all these remote sending data a study was perform about the accuracy of PWV measuments in camparison with simultaneous in-situ measuments using radiosondes. Three dedicated campaigns were conducted during the months of May. July and November of 2009 at the La Silla, APEX and Paranal observatories.

In addition the astrometeorological group is employing a WRF meteorological model with the aim of being able to simulate the state of the atmosphere (every 6 hours) and forecast the value of PWV. With these simulations, plus satellite images, radiosonde campaign data can be classified synoptically and at the same time the model can be validated with respect to PWV.

7733-167, Poster Session

Seeing measurements with autonomous, short-baseline shadow band rangers

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There is growing interest in measuring seeing at existing and prospective telescope sites. Several methods exist to quantify seeing, one among them is by measuring the scintillation of solar or lunar light using a photodiode. A shadow band ranger (SHABAR) analyses the covariance of the signals from an array of such photodiodes, which allows for the spatial resolution of the index of refraction above the SHABAR device. This allows one to estimate the index of refraction structure parameter as a function of height, $C_n^2(h)$.

Although a SHABAR has a limited height range compared to a differential image motion monitor (DIMM) or the latest wavefront sensors, the advantage is that it does not need telescope optics to work. In the context of EST and with support of the Dutch Technology Foundation STW a very compact and autonomous operating SHABAR device was developed. We describe the design of this SHABAR device with six photodiodes that can operate virtually indefinitely without requiring human intervention.

An inversion algorithm is used to convert the raw scintillation signals of the photodiodes to the desired $C_n^2(h)$ profile and a value for the Fried parameter r_0 at height zero. We show that it is possible to perform inversions of 10 second periods in real time on relatively low-end hardware, such as an Intel Atom based computer, which allows the results to be presented live to astronomers, who can use this information to help make decisions about their observation schedule.

The automatic seeing measurements of the SHABARs together with weather measurements like temperature and wind fluctuations will give more insight to the correlation between seeing and weather.

7733-168, Poster Session

Optical sky brightness at Dome A, Antarctica from the Nigel experiment

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Nigel is a fibre-fed UV/visible grating spectrograph with a thermoelectrically-cooled 256 x 1024 pixel CCD camera, designed to measure the twilight and night sky brightness from 300 nm to 850 nm. The instrument was deployed at Dome A, Antarctica in January 2009 as part of the PLATO robotic observatory. Nigel made approximately six months of continuous observations of the sky during 2009, with typically 10% deadtime between exposures. The resulting spectra provide quantitative information on the sky brightness, the auroral contribution, and the water vapour content of the atmosphere.

7733-169, Poster Session

Giant Magellan Telescope site testing PWV statistics and calibration

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Cerro Las Campanas located at Las Campanas Observatory (LCO) in Chile has been selected as the site for the Giant Magellan Telescope. We report results obtained since the commencement, in 2005, of a systematic site testing survey of potential GMT sites at LCO. Atmospheric precipitable water vapor (PWV) adversely impacts mid-IR astronomy through reduced transparency and increased background. Prior to the GMT site testing effort, little was known regarding the PWV characteristics at LCO and therefore, a multi-pronged approach was used to ensure the determination of the fraction of the time suitable for mid-IR observations. High time resolution monitoring was achieved with an Infrared Radiometer for Millimeter Astronomy (IRMA) from the University of Lethbridge deployed at LCO since September of 2007. Absolute calibrations via the robust Brault method (described in Thomas-Osip et al 2007) are provided by the Magellan Inamori Kyocera Echelle (MIKE), mounted on the Clay 6.5-m telescope on a timescale of several per month. We find that conditions suitable for mid-IR astronomy (PWV < 1.5 mm) are concentrated in the southern winter and spring months. Nearly 40% of clear time during these seasons have PWV < 1.5mm. Approximately 10% of these nights meet our PWV requirement for the entire night.

7733-170, Poster Session

Giant Magellan Telescope site testing seeing and turbulence statistics

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Cerro Las Campanas located at Las Campanas Observatory (LCO) in Chile has been selected as the site for the Giant Magellan Telescope. We report results obtained since the commencement, in 2005, of a systematic site testing survey of potential GMT sites at LCO. DIMM seeing data have been obtained at three potential sites, and are compared with identical data taken at the site of the twin Magellan 6.5m telescopes. In addition, measurements of the turbulence profile of the free-atmosphere above LCO have been collected with a MASS/DIMM. We also examine the contribution to the seeing arising from turbulence in the ground layer (defined here as below an altitude of 500 m) through the difference between the turbulence integrals in the full atmosphere (as measured by DIMM) and in the free atmosphere (as measured by MASS). Three of the four sites that have been characterized, Cos. Manqui, Alcaino and Las Campanas have excellent and very similar properties. Co. Las Camapanas and the Magellan site (Co. Manqui) are nearly identical in their seeing statistics (with a median near 0.6”), and apparently their average ground-layer characteristics.

7733-171, Poster Session

Forecasting precipitable water vapour at the Roque de los Muchachos Observatory

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Operation of modern optical and infrared (IR) astronomical sites are getting used to a flexible way of operation, namely queue modes, allowing astronomical observations in the most appropriated weather conditions for each specific observing scientific program. The forecast of weather conditions is then a mandatory issue to plan in advance the queue observations for each night in order to exploit

efficiently the astronomical facilities with the largest high quality data output for scientific exploitation. The precipitable water vapour is the parameter accounting for the IR quality of an astronomical site. The temporal fluctuation of this parameter drastically affects the quality of the IR data recorded at ground telescopes. An optical/IR telescope needs the forecasting of the precipitable water vapour for a proper queue scheduling of IR observations. The Roque de los Muchachos Observatory (ORM) on the island of La Palma (Spain) presents an abrupt topography which difficult the forecasting at this astronomical site. We discuss the performance of a mesoscale numerical weather prediction system tuned to the orographycally complex ORM region, including the comparison with local precipitable water vapour estimations from GPS(Global Positioning System).

7733-172, Poster Session

E-ELT meteorological and seeing comparison of the Aklim site and El Roque de Los Muchachos Observatory

M. Sabil II, Z. Z. Benkhaldoun, A. Habib, Y. Hach, A. M. Benhida, M. Lazrek, Y. El Azhari, Univ. Cadi Ayyad (Morocco)

The new extremely large telescope projects need accurate evaluation of the candidate sites. In this work we present the astronomical and Seeing comparison between Aklim site located in Moroccan Anti-Atlas at the geographic coordinates 30°7’39” N, 08°18’39” W, and the Observatorio del Roque de Los Muchachos (ORM), located in La Palma, Canary Islands, at 28°45’00” N, 17°53’10” W, the both sites are pre-selected to house the E-ELT.

In the first part we present the meteorological statistics, the data collected from the Automatic Weather Station WS2-550 at Aklim, the ORM host other AWS which operated by the different user’s institutions. We apply the same method to compare the daily, monthly and seasonal averages of the main parameters recorded site since the 19 previous months.

In the second part we present the seeing statistics of seeing and the free seeing measurements at each site, statistics of the mentioned parameters are obtained from the whole data recorded from the 09 May 2008 to 09 September 2009 using the Mass-Dimm system, compare the common data between the tow sites we show the stability of the various integrated parameters with time, the more representative results are shown hereafter.

7733-173, Poster Session

Meteorological parameters analysis at Oukaimeden Observatory using NCEP/NCAR data

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We present a characterization of meteorological parameters: Wind and direction speed, temperature, relative humidity and pressure. Data set is provided by the system of NCEP/NCAR re-analysis. The statistical treatment of data will cover the years between 2003 and 2006 for the Observatory Oukaimeden. An analysis of monthly, seasonal and annual results is presented. We calculated the Richardson number and the vertical gradient of refractive index potential for each month. In addition, this paper describes a comparison between balloon-sounding made at different stations and coincident model-based meteorological analyses. The comparison allows the assessment reliability of the analyses in studied period.

7733-174, Poster Session

Isopistonic and isoplanatic angles comparison of the E-ELT candidate sites

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In the frame work of the E-ELT project, many prospection campaigns were held in four sites: Aklim (Morocco), Orm (Canary Islands), Vantaroness (Chili) and Macon (Argentina).

To qualify and compare theses sites some astronomical parameters were measured such as the seeing, the isoplanatic angle and the coherence time of wave-front. From these data we have deduced the isopistonic angle which is an interferometric parameter, by using a formula given by Elhalkouj et al. (2008). In this paper we present a comparison of these parameters for the four sites.

7733-175, Poster Session

ASTEP 400: a telescope designed for exoplanets’ transits detection from Dome C, Antarctica

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We present the technical development of ASTEP 400, a 40cm telescope dedicated to exoplanets’ transits detection, which has been recently set up at Dome C, Antarctica, in December 2009.

ASTEP 400 is a Newtonian telescope with a 1° x 1° field of view. The photometric sensitivity specification is 3E-3, the goal is 1E-3, during one hour for at least 1,000 stars. The optical design of the field corrector using 5 lenses guarantees a high homogeneity of the PSF sizes from the center to the edge of the FoV, which improves the efficiency of differential photometry in the data reduction process. The mechanical structure of the telescope is based on a Serrurier design. The use of carbon fibers in the Serrurier’s bars minimizes the thermal distance variations between the primary and secondary mirrors, as well as it gives the structure a high rigidity. To achieve the required guiding accuracy, a dichroic beam-splitter sends the blue part of the beam to a guiding camera. The focal optics, the science camera and its autofocus device, and the guiding camera are enclosed in a thermally regulated box to withstand extremely low temperatures. A software controls the science and guiding acquisition, the data transmission and storage, the autofocus device, and the equatorial mount alpha and delta servomotors.

The telescope has been set up at the French-Italian base Concordia, located at Dome C, Antarctica, during the southern summer 2009-2010. It will start observing in March 2010.

7733-176, Poster Session

Opto-mechanical design of the Antarctic Telescope ICE-T

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ICE-T, the International Concordia Explorer Telescope, is a 60cm double wide-field Schmidt telescope optimized for high-precision photometry in two separate bandpasses. The project is under final design by an international consortium led by the Astrophysical Institute Potsdam AIP, Germany, and is intended to be placed at the French-Italian Concordia Station on Dome C in Antarctica. We present the optical, the mechanical, and the electronic design of the telescope and lay out the operational constraints for its search for extrasolar planets and magnetic stellar activity.

Special features of the opto-mechanical design are a light-weighted Zerodur primary mirror mainly chosen under thermal and logistic aspects, and a mirror cell and metering structure made from carbonfiber composites, chosen in regard of the temperature differences between the integration site at AIP and the operational site in Antarctica. (A second submitted paper describes the thermal layout and de-icing system).

7733-177, Poster Session

1m Kunlun Pathfinder Telescope (KPT) for Dome A

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The preliminary site testing carried out since the beginning of 2008 shows that the highest antarctic inland plateau Dome A is very likely to be the best astronomical site on earth. In early 2009, China built the first inland station named Kunlun Station. According to the roadmap of Chinese Center for Antarctic Astronomy(CCAA), we will build the 4m Kunlun Dark Universe Survey Telescope(KDUST) in the near future. And before the KDUST, 1m Kunlun Pathfinder Telescope(KPT) will be built first. Primary instrument includes an integral field spectrograph in the optical wavelength and an near-IR camera allowing for photometric observations in the wavelength range from 1 to 3.4 micron. The telescope will be elevated to a tower of 15 meter high. The objectives of this telescope include technical verification of construction of a fully functional telescope at Dome A, site property quantification, and several key scientific programs. The primary task for KPT is to followup transients discovered by Antarctic Schmidt Telescopes (AST3). The key scientific program includes: Observations of 1000 nearby SNIa with nightly photometry and spectral coverage, exoplanet search, and transient categorization.

7733-178, Poster Session

Development of automated small telescopes as Dome A site testing DIMM

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The extreme environment of Antarctic greatly benefits astronomical observations. Site testing works already show the excellent seeing and transmission on Dome C. And the higher, colder inland plateau Dome A is widely predicted as even better astronomical site than Dome C. Preliminary site testing carried out since the beginning of 2008 shows that Dome A has lower boundary layer and lower precipitable water vapour. Now the automated seeing monitor is urgently needed to quantify the site's optical character which is necessary for the telescope design and deployment. We will modify the newly bought commercial telescope with diameter of 35cm to function as site testing DIMM and make it monitor both seeing and isoplanatic angle at the same time automatically on Dome A at different height. Part of the processed datum will be transfered back by Iridium satellite network each day. The first DIMM will be deployed on Dome A in early 2011.

7733-179, Poster Session

The AST Project: preliminary study of a Dome C radioantenna

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As science makes progress, proposing new discoveries every day, it is more and more interesting for the astronomical world to perform sub-millimeter observations from very suitable terrestrial sites, due to the purity of the air, as well as to other environmental factors. A site with these characteristics has been identified in the area of Dome C in the South Pole. The problems, both technical and logistic, that the installation of a radioantenna in the South Pole imposes, are easily understandable. Proceeding at the same rate as the progress of science, also the technological and industrial capacities improve, so that it is possible to overcome all the problems that the realization of a sub-millimeter Observatory in the South Pole implies. This paper aims at summarizing the Preliminary Feasibility Study of the AST (Antarctic Sub-millimeter Telescope) Radioantenna that is intended to be installed at Dome C.

7733-180, Poster Session

CCAT optics

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CCAT is a 25 m diameter submillimeter-wave telescope that will be located on Cerro Chajnantor in the Atacama Desert. The telescope is an on-axis Ritchey-Chretien design with an f/0.4 primary and an f/6 Naysmith focus. The primary mirror has 162 segments with active control to compensate gravitational deformations. Each segment has ~0.5 m reflecting tiles (probably machined aluminum) on a ~2 m, insulated, carbon-fiber frame. A similar construction is used for the secondary mirror and for the flat fold mirror that feeds the Naysmith focus.

CCAT's field of view (FoV) ranges from 1° at =1 mm (limited by curvature of field) to 35' at =350 μm. At the shorter wavelengths, it is possible to increase the FoV to ~ 1° by adding a refractive corrector plate just before the Naysmith focus. A submillimeter camera with this FoV is impractical today, but should be possible during CCAT's lifetime. The transmission of the atmosphere at short submillimeter wavelengths is only ~0.5, so a few percent loss in a refractive corrector is tolerable. High resistivity Si is a good option for the corrector material, but some development will be required for a large corrector with broad-band, anti-reflection coatings. At Naysmith focus, the plate scale is 2.6 m/deg, so wide-field CCAT instruments will require large relay optics. A reflective relay is too large to be practical, but a refractive relay is viable if the field is broken up into small sub-fields, each with its own camera.

7733-182, Poster Session

The Giant Magellan Telescope (GMT): hydrostatic constraints

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The Giant Magellan Telescope (GMT) is an optical-infrared 25 Meter ELT to be located in Chile. It is being designed and constructed by a group of U.S. and international universities and research institutions.

Structural performance of large telescopes can be enhanced significantly with the added stiffness that results from distributing loads to many points in the structure. In defining the two rotating assemblies in an altitude-over-azimuth mount more than a kinematic set of constraints can lead to hydrostatic bearing oil film failure due to unintended forces that result from runner bearing irregularities. High Frequency Over Constraint

(HFOC) increases stiffness without risk of oil film failure. It was used successfully on the Magellan 6.5 Meter Telescopes.

GMT will employ this and two additional methods to enhance stiffness at frequencies from DC wind up through the telescope primary mode frequencies of ~11 Hz. This will be achieved without excessive hydrostatic bearing pad forces.

Detailed discussion of GMT's hydrostatic constraints, azimuth track and OSS runner bearing illustrations, and performance criteria are provided for the design.

7733-183, Poster Session

Environmental measurements at Keck to support the Thirty Meter Telescope design work

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In order to validate various assumptions about the operating environment of the Thirty Meter Telescope (TMT) and to validate the modeling packages being used to guide the design work for the TMT we have embarked on an extensive campaign of environmental measurements at the Keck telescopes. We have measured and characterized the vibration environment around the observatory floor and at certain locations on the telescope over a range of operating conditions. Similarly the acoustic environment around the telescope and primary mirror has been characterized for frequencies above 2 Hz. The internal and external wind and temperature fields are being measured using combined sonic anemometer and PRT sensors. We are measuring the telescope position error and drive torque signals in order to investigate the wind induced telescope motions. A scintillometer mounted on the telescope is measuring the optical turbulence inside the telescope tube. This experimental work is supplemented by an extensive analysis of telescope and engineering sensor log files and measurements, primarily those of accelerometers located on the main telescope optics and the telescope status information.

7733-184, Poster Session

Telling planets from speckles created by ELT segmentation

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The segmentation of ELTs creates quasi-static speckles in the image. These speckles are the main impediment for the detection of faint structures around stars, e. g. exoplanets. An elaborated post-processing method is required to improve the detection level.

The Stochastic Speckle Discrimination (SSD) method developed for this purpose uses intensity variability as a measure to distinguish between planet and speckle. Assuming that the fluctuations of the planet's intensity follow the fluctuations of the on-axis point of the PSF, SSD utilizes the fact that for the adaptive-optics-corrected images on-axis variations are smaller than off-axis ones. It has been shown on the images taken with 3 to 10-m class telescopes that SSD can significantly increase the achievable contrast.

We apply the SSD method on the images created by highly-segmented pupils. We study the efficiency of the method exploiting the first order statistics of on- and off- axis intensities of the PSF. Based on the Neumann's series approach we derive the analytical expressions for the statistical moments. Afterwards, we calculate the efficiency of SSD method for two different variability metrics. We discuss the abilities and limitations of SSD for different levels of the primary mirror co-phasing.

7733-185, Poster Session

An indoor three-mirror phasing experiment system based on a dispersed Hartmann type sensor

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Telescope with much larger primary can collect much more light and it is always pursued by the astronomers. Instead of the using a monolithic primary, more and more large telescopes, which are now planed or in construction, invariably adopted segmented primary mirror. Therefore, how to sensing and phasing the primary mirror is the key technology. Unlike edge sensors, which need careful calibrations, dispersed Hartmann sensor (DHS) is non-contact method using broadband point light sources, and it can estimate piston by the two-direction spectrum formed by the tranmissive grating's dispersion and lenslet array. Thus it can realize the combination of co-focusing and co-phasing. In this paper, we introduce the design of our dispersed Hartmann sensor together with its principle. We also manufacture a DHS sensor and do real tests on our existing segmented mirror optics platform. Finally some conclusions are given based on the test results.

7733-187, Poster Session

On-sky results of the ZEUS phasing sensor, closed-loop measurement precision in the context of multi-wavelength measurements

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The Active Phasing Experiment (APE) was designed to test four different phasing techniques and to validate wavefront control concepts for Extremely Large Telescopes. One of the sensors is the ZErnike Unit for Segment phasing (ZEUS), which was successfully tested on-sky along with the rest of the APE experiment at one of the Nasmyth platforms of the Very Large Telescope (VLT) in 2009. During the four observing campaigns, multiple results were obtained in open-loop and in closed-loop at different wavelengths. We present in this paper an analysis of the multi-wavelength data in terms of piston measurement precision at the edges of the segments and on the reconstructed wavefront, and an analysis of the evolution of these errors in successive closed-loop runs at different wavelengths. This work demonstrates how the applied multi-wavelength algorithm leads to convergence, allowing phasing of segments with piston errors of several microns.

7733-188, Poster Session

Design of a prototype position actuator for the primary mirror segments of the European Extremely Large Telescope

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European Extremely Large Telescope (E-ELT) based in 984 primary mirror segments achieving required optical performance; they must position relatively to adjacent segments with relative nanometer accuracy. CESA designs M1 Position Actuators (PACT) to comply with demanding performance requirements of E-ELT.

Three PACT are located under each segment controlling three out of the plane degrees of freedom (tip, tilt, piston). To achieve a high linear accuracy in long operational displacements, PACT uses two stages in series. First stage based on Voice Coil Actuator to achieve high accuracies in very short travel ranges, while second stage based on BLDC motor provides large stroke ranges and allows positioning the first stage closer to the demanded position.

A BLDC motor is used achieving a continuous smoothly movement compared to sudden jumps of a stepper. A gear box attached to motor allows a high reduction of power consumption and provides a great challenge for sizing. PACT space envelope was reduced by means of two flat springs fixed to VCA. Its main characteristic is a low linear axial stiffness.

To achieve best performance for PACT, sensors have been included in both stages. A rotary encoder is included in BLDC stage to close position/velocity control loop. An incremental optical encoder measures PACT travel range with relative nanometer accuracy and used to close the position loop of the whole actuator movement. For this purpose, four different optical sensors with different gratings will be evaluated.

Control strategy show different internal closed loops that work together to achieve required performance.

7733-190, Poster Session

The Discovery Channel Telescope optical coating system

H. K. Marshall, National Solar Observatory (United States) and Lowell Observatory (United States); G. S. Ash, W. F. Parsley, DynaVac (United States)

The Discovery Channel Telescope (DCT) is a project of Lowell Observatory, undertaken with support from Discovery Communications, Inc., to design and construct a 4-meter class telescope and support facility on a site approximately 40 miles southeast of Flagstaff, AZ. Lowell Observatory contracted with DynaVac of Hingham, MA to design and build an optical coating system for the DCT Optics. The DCT Optical Coating System includes a mechanical roughing pump, two high-vacuum cryogenic pumps, a Meissner trap, evaporative filament aluminum deposition system, LabView software and PLC-based control system, and all ancillary support equipment. The system was installed at the site and acceptance testing was completed in October 2009. The Optical Coating System achieved near perfect reflectivity performance, thickness uniformity of 1000 angstroms ±10%, and adhesion conforming to MIL-F-48616, Section 4.6.8.1. This paper discusses the design and analysis of the coating system, the process of transportation and assembly as well as testing results.

7733-191, Poster Session

The University of Tokyo Atacama 1.0-m Telescope

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We present the current status of the University of Tokyo Atacama 1.0m telescope constructed at the summit of Co. Chajnantor (5,640m) in Atacama, Chile, which is an optical/infrared telescope at the world's highest site. The telescope is an f/12 Ritchey-Chretien type with a field of view of 10 arcmin. The ANIR near-infrared camera (see Motohara et al.) and the MAX38 mid-infrared instrument (see Nakamura et al.) are equipped on the Cassegrain focus. The telescope is installed in a 6-m dome and is controlled from an operation room in a container separated from the dome. The engineering first light was carried out in 2009 March, and the astronomical first lights with ANIR and MAX38 were carried out in 2009 June and November, respectively. The telescope pointing is as accurate as 2.0 arcsec (RMS), and it provides good tracking performance without guiding.

The Hartmann constant is about 0.19 arcsec and the image quality of the telescope is sufficient for the attached instruments. The best PSF obtained is 0.5 arcsec (FWHM) in optical, which demonstrates that the summit of Co. Chajnantor is one of the best seeing site in the world. Also the excellent atmospheric transmission from near- to mid-infrared wavelengths at the site is proved by successful observations of ANIR and MAX38. In the near future, the operation room will be directly connected to a base support facility at San Pedro de Atacama by a wireless LAN, and the remote observation from the base facility is planned.

7733-192, Poster Session

The opto-mechanical alignment procedure of the VLT Survey Telescope

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The Vlt Survey Telescope is a f/5.5 modified Ritchey-Chretien imaging telescope to be installed at the ESO-Paranal Observatory.

It will provide a one square degree corrected field of view to perform survey-projects in the wavelength range from UV to I band.

In this paper we describe the opto-mechanical alignment procedure of the 2.61m primary mirror, the secondary and correctors lenses onto the mechanical structure of the telescope. The alignment procedure does not rely on the mechanical precision of the mirrors. It will be achieved using ad-hoc alignment tools, described in the paper, which allow the spatial determination of optical axes (and focuses where necessary) of the optical components with respect to the axis defined by the rotation of a laser beam mounted on the instrument bearing.

We placed special attention to the order of the steps to be followed in order to assure that each one is actually realizable. For each step we describe the configuration and capabilities of the telescope needed.

We verified that the achievable precision meets the telescope specifications through Zemax ray-tracing simulations and thanks to the measurements performed on the primary mirror cell of the telescope done before the shipment to the Paranal Observatory.

7733-193, Poster Session

Performance of the Large Binocular Telescope's hydrostatic bearing system

J. Howard, D. S. Ashby, Large Binocular Telescope Observatory (United States); J. Kern, Giant Magellan Telescope Organisation (United States)

The Large Binocular Telescope's hydrostatic bearing system is operational, and tuning for optimal performance is currently underway. This system allows for the precise control of the 500 ton telescope at temperatures ranging from -20°C to +25°C. It was a challenge to meet the performance requirements on such a massive telescope with a wide range of operating temperatures. This required changes to the original design, including significantly improving oil temperature control, and adding variable capillary resistors to allow for precise flow control to each pocket on each bearing. We will present a system description and report on lessons learned.

7733-194, Poster Session

The VST auxiliary units: a status report before their commissioning in Paranal

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The VST telescope is going to be commissioned in Paranal, together with its main sub-systems, such as the Image Analysis and Auto-Guiding system.

A preliminary work of fine tuning of each sub-system has been performed in Italy before their shipping to Paranal, where they are waiting for the telescope AIV to be completed in a way to start the final commissioning of the overall system.

Each unit has been extensively characterised and tested, with particular care to the Active Optics Shack-Hartmann sensor and to the Auto-Guiding arm.

We describe here the phases concerning the assembly and the integration of all the VST Auxiliary Units, and the results of the test performed on them.

7733-195, Poster Session

Performance and results from the commissioning of the first acquisition, guiding, and wavefront sensing units for the Large Binocular Telescope

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We present the results from the commissioning of the first three off-axis Acquisition, Guiding and Wavefront Sensing Units on the Large Binocular Telescope. The first unit was mounted on the telescope in April of 2008 and has been used for commissioning of the bent gregorian focal station. Two more units have been installed since then and they have been used for the commissioning of the direct gregorian focal station as well as another bent gregorian focal station. The first unit is now in use with the near-IR imager and spectrograoh LUCIFER.

The off-axis guideprobe uses a dichroic mirror to split the light between the Shack-Hartmann sensor and guider. It covers a patrol field to one side of the science field ranging from being on-axis to being off-axis by 5.5 arcminutes using a linear stage mounted on a rotational stage.

We present the procedure for calibrating the stage coordinate system astrometrically to the focal plane coordinates of the telescope as well as the positional performance of the system. We also report on the performance of the units with respect to image quality, optical efficiency and scattered light.

7733-196, Poster Session

Engineering within the assembly, verification, and integration process in ALMA

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The Atacama Large Millimeter/submillimeter Array (ALMA) is a joint project between astronomical organizations in Europe, North America, and Japan. ALMA will consist of at least 54 twelve meter antennas and 12 seven meter antennas operating as an interferometer in the millimeter and sub-millimeter wavelength range. It will be located at an altitude above 5000m in the Chilean Atacama desert. As part of the ALMA construction phase the Assembly, Verification and Integration (AIV) team receives antennas and instrumentation from vendors and Integrated Product Teams (IPTs), verifies that the sub-systems perform as expected, performs the assembly and integration of the scientific instrumentation and verifies that functional and performance requirements are met. This paper aims to describe those aspects related to the AIV Engineering team, its role within the 4-station AIV process, the different phases the group underwent, lessons learned and potential space for improvement.

AIV Engineering initially focused on the preparation of the necessary site infrastructure for AIV activities, on the purchase of tools and equipment and on the first ALMA system installations. With the first antennas arriving on site the team started to gather experience with AIV Station 1 beacon holography measurements for the assessment of the overall antenna surface quality, and with optical pointing to confirm the antenna pointing and tracking capabilities. With the arrival of the first receiver AIV Station 2 was developed which focuses on the installation of electrical and cryogenic systems and incrementally establishes the full connectivity of the antenna as an observing platform. Further antenna deliveries then allowed to refine the related procedures, develop staff expertise and to transition towards a more routine production process. Stations 3 and 4 deal with verification of the antenna with integrated electronics by the AIV Science Team and is not covered directly in this paper. It is believed that both continuous improvement and the clear definition of the AIV 4-station model were key factors in achieving the goal of bringing the antennas into a state that is well enough characterized in order to smoothly start commissioning activities.

7733-98, Poster Session

Design and construction of the Discovery Channel Telescope enclosure

H. K. Marshall, National Solar Observatory (United States) and Lowell Observatory (United States); K. Bond, BEC Southwest Inc. (United States); J. U. Teran, M3 Engineering & Technology Corp. (United States)

The Discovery Channel Telescope (DCT) is a project of Lowell Observatory, undertaken with support from Discovery Communications, Inc., to design and construct a 4-meter class telescope and support facility on a site approximately 40 miles southeast of Flagstaff, AZ. The Discovery Channel Telescope Enclosure was completed in November, 2009. The DCT Enclosure is an octagonal steel structure with insulated composite panel skin. The structure rotates on sixteen compliant bogie assemblies attached to the stationary facility. The shutter is composed of two independently actuated, bi-parting structures that provide a viewing aperture. To improve seeing, the skin is covered with adhesive aluminum foil tape and the enclosed observing area is passively ventilated via rollup doors. The observing area can also be actively ventilated using a downdraft fan, and there are provisions for upgrades to active air conditioning. The enclosure also includes operational equipment such as a bridge crane, personnel lift, and access platforms.

This paper discusses some of the design trades as well as the construction challenges and lessons learned by the DCT Project, its designer M3 Engineering and Technology Corporation (M3), and its general contractor, Building and Engineering Contractors, Southwest (BEC Southwest).

7733-198, Poster Session

Control strategies and algorithms for large astronomical optical telescope

S. Yang, Nanjing Institute of Astronomical Optics & Technology (China)

This paper gives a summary on control strategies and algorithms for contemporary large astronomical optical telescopes. The study lays emphasis on high precision tracking for large astronomical optical telescopes with large inertia,ultra-low speed and muti-disturbance. The control strategies and algorithms of some telescopes based on direct drive or friction drive are analyzed carefully. Finally, the future development in this field is presented.

7733-199, Poster Session

The UCAM CCD system for LAMOST

J. Lei, National Astronomical Observatories (China); M. Wei, Univ. of California, Santa Cruz (United States); S. Zou, Y. Luo, National Astronomical Observatories (China)

This paper is intended primarily for the LAMOST UCAM CCD systems. The illustrations given here show the prototype LAMOST UCAM systems. Designed as a universal CCD controller, the UCAM system has variety options of readout modes, sampling speeds, binning options and charge clean. Its main components, architecture and technical design are introduced here. Some important performance characteristics about the UCAM controller and the e2v-203-82 CCD (4K by 4K, blue CCD) are tested under laboratory conditions, such as readout noise and gain at different sampling modes and readout speeds, CTE, dark current, QE, and fringing. Perfect CTE and less than 3 electrons / pixel system readout noise prove that the UCAM CCD controller system meets the requirement of the LAMOST telescope.

7733-200, Poster Session

Review and new thinking on LAMOST focal plate support structure

G. Wang, K. Zhang, Nanjing Institute of Astronomical Optics & Technology (China)

LAMOST is a kind of special reflecting Schmidt telescope which solved the problem to achieve both wide FOV and large aperture on one Schmidt telescope. It is composed of Schmidt corrector, primary mirror and focal plane. The focal plane is a 1.75m diameter spherical cap formed by 4,000 fibers which are accommodated on the focal plate and linked to sixteen spectrographs simultaneously. The weight of focal plate, including fibers and its corresponding positioners, is about 2 tons and the height above base ground is 6200mm. In June of 2009, LAMOST project passed the FAT held by Chinese government. The on-site test results show that the performance of focal plate supporting system has met the design requirements. Some of them are several times higher than the design specifications. The main task of this paper is to review the design considerations of focal plate supporting structure, including lessons learned from the design and construction. Based on these review, a kind of new supporting structure is proposed in the second part of this paper. The calculation and simulation results show that the new kind of supporting structure can meet the system requirements.

7733-201, Poster Session

Design and development of a high-precision, high-payload telescope dual-drive system

M. S. Worthington, T. A. Beets, J. M. Good, B. T. Murphy, B. J. South, J. H. Beno, The Univ. of Texas at Austin (United States)

A high precision, dual drive system has been designed and developed as part of the Dark Energy Experiment upgrade to the Hobby-Eberly Telescope (HET) at McDonald Observatory in West Texas. The analysis techniques, design and controls details will be of interest to designers of large scale, high precision robotic motion devices. The drive system is required to position the 20-ton star tracker to a precision of less than 5 microns anywhere along its 4-meter travel. While positioning requirements remain essentially equal to that of the existing HET, the tracker increased in mass by a factor greater than 3.5. The 10.5-meter long tracker is driven at each end by planetary roller screws and translates along profiled rail linear bearings. Each roller screw has two distinct drive sources dictated by the desired operation: one which slowly rotates the screw when tracking a celestial object and the second which rotates the nut for more rapid movements. A rotordynamics analysis was performed for the roller screws and results are presented. A unique bearing arrangement is deployed to provide additional degrees of freedom to accommodate skew conditions created by the dual drive. The impact of a detailed Failure Modes and Effects Analysis is presented which addresses necessary safety systems required for limiting motion. Finite element analysis results are also presented showing how the use of mechanical springs increased the telescope's first mode natural frequency by 22 percent by creating load share across the telescope structure The critical analysis and the resulting design are provided.

7733-202, Poster Session

Super hardpoints for the Large Binocular Telescope

R. L. Meeks, D. S. Ashby, C. Biddick, Large Binocular Telescope Observatory (United States); J. R. De Vries, Large Synoptic Survey Telescope (United States); M. Gusick, Large Binocular Telescope Observatory (United States); J. Kern, Giant Magellan Telescope Organisation (United States)

We describe the design and performance of an improved hardpoint design for the LBT. The hardpoints define the position and orientation of the primary mirror and are key elements of the active optics system. After several years of operation various undesirable characteristics of the original hardpoints were identified.

A new design was developed that eliminates these characteristics and provides higher stiffness, greater repeatability, and better overall performance. We describe the design features and present performance data from lab testing and operation in the telescope.

7733-205, Poster Session

The finite element modeling and thermal analysis of the special focal plane of The LAMOST

H. Zuo, D. Yang, G. Li, Nanjing Institute of Astronomical Optics & Technology (China)

The Large Area Multi-Object Spectroscopic Telescope (LAMOST) is a meridian reflecting Schmidt telescope with a 40-m optical axis between the reflecting Schmidt plate and the spherical primary mirror. In the middle is located the spherical focal plane, which will focus and derotate to track/stabilize the image with collaboration of the reflecting Schmidt plate, thus a special mounting and tracking system is formed. The spherical focal plane is a spherical cap derived from a parent sphere with nominal diameter of 19.88 m. In order to accommodate 4000+ optical fibers within its aperture of 1.75-m, the focal plane is a lightweight honey-comb type structure of 120 mm thick, through which there are corresponding 4000+ unit mounting holes for the fibers, and on its back, there attached a support truss adapted from Serrurier concept.. The mechanical stabilization of the focal plane system naturally has magnificent impact on the observation efficiency of the LAMOST. A comprehensive Finite Element Model of the focal plane system has been built to evaluate thermally induced degradation of its mechanical accuracy. A normal projection of the focal plane is firstly laid out with CAD software and exported to FEM software ANSY to be meshed with plane-type element. Afterwards, using the nodal modification technique within ANSYS, the flat protection is shaped in sphere and extruded to fulfill the focal plane. By comparison, this modeling procedure benefits great save of time and computing resource. Diverse temperature load cases have been considered on the Finite Element model and related thermal analyses has been carried out to investigated thermal deformation of the focal plane. Subsequently the calculated deflection of the working surface has been extracted and reconstructed with least square fitting in MATLAB The results show that temperature change around the telescope has little effect on the performance of the focal plane within temperature variation requirements of the LAMOST. The methods of modeling and analyzing used in this research are informative for future large telescope projects.

7733-203, Poster Session

Field of view of an off-axis two-mirror system

J. Cheng, National Radio Astronomy Observatory (United States)

Most lens or mirror based optical systems are axial symmetrical. For this system, if all angles involved are so small that sin x=x and cos x=1, the approximation is paraxial optics or Gaussian optics. If third order terms of sine function are included so that sin x=x+x3/3! And cos x=1-x2/2!, then five aberrations of spherical aberration, coma, astigmatism, field curvature, and distortion exist. The image is no longer a point one. The spherical aberration is on-axis aberration. Coma is linear one with the field angle and astigmatism is quadratic one. Any surface has fixed third order aberrations with its aperture plane. When a system involves more surfaces, we have to transfer some of aberrations to the system pupil plane. By transferring pupil position, spherical aberration produces coma and coma produces astigmatism.

7733-204, Poster Session

Alignment of LBT optics using a laser tracker

A. Rakich, The Univ. of Arizona (United States)

The laser tracker allows the precise determination of positions of surfaces in three dimensions over volumes exceeding 30 m radius from the tracker head. At the Large Binocular Telescope a laser tracker has recently been employed for the initial alignment of all telescope optics in the right hand side (DX) bent Gregorian optical train. In this paper the particular approach to alignment of optical elements employed during this campaign is discussed in detail, together with results and expected accuracies. Subsequent to this “mechanical alignment” the telescope was taken “on-sky” and a subsequent “optical alignment” using a Shack-Hartman wavefront sensor with stellar sources took place. The results of this alignment are compared to the initial alignment achieved with the laser tracker. This paper will be expounding the view that the use of the laser tracker for first alignment of optical components represents a great advance over traditional methods, leading to accuracies and efficiencies not previously enjoyed in this area of activity.

7733-18, Session 4

SOFIA progress to initial science flights

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SOFIA, the Stratospheric Observatory for Infrared Astronomy, is a specially modified Boeing 747SP aircraft with a 2.7-m telescope. Flying above more than 99% of the water vapor in the Earth’s atmosphere, SOFIA will enable observations at large regions of the infrared and submillimeter that are opaque to terrestrial observatories. A joint project of NASA and DLR, SOFIA has completed a series of major flight tests leading to the Initial Science Flights this year. The first major test was the 100% open door flight where the telescope cavity was fully exposed during flight. The initial series of envelope expansion flights is described. The first series of observations will involve the FORCAST instrument, a mid-infrared imager developed by Terry Herter of Cornell, and GREAT, a heterodyne instrument led by Rolf Gusten of the Max Planck Institut fur Radioastronomie. Initial science flights will begin in 2010. This paper reports on the recent progress in the development of this major astronomical facility.

7733-19, Session 4

The Stratospheric THz Observatory (STO)

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The Stratospheric TeraHertz Observatory (STO) is a NASA funded, Long Duration Balloon (LDB) experiment designed to address a key problem in modern astrophysics: understanding the Life Cycle of the Interstellar Medium (ISM). STO will survey a section of the Galactic plane in the dominant interstellar cooling line [C II] (1.9 THz) and the important star formation tracer [N II] (1.46 THz) at ~1 arc minute angular resolution, sufficient to spatially resolve atomic, ionic and molecular clouds at 10 kpc. STO itself has three main components; 1) an 80 cm optical telescope, 2) a THz instrument package, and 3) a gondola. Both the telescope and gondola have flown on previous experiments. They have been re-optimized for the current mission. The science flight receiver package will contain four [CII] and four [NII] mixers, each with its own digital spectrometer. The first engineering test flight of STO was from Ft. Sumner, NM on October 15, 2009. In our talk we will discuss the STO test flight and the upcoming, long duration (> 14 day) Antarctic science flight, including the instrument package, telescope, and gondola.

7733-20, Session 4

Successful flight of the Sunrise Balloon-borne Solar Observatory

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Sunrise is a balloon-borne solar observatory whose aim is to investigateat high resolution the interaction of magnetic fields with convection on the solar surface. It was developed by MPS, KIS, HAO, a spanish consortium led by IAC, and LMSAL. The mission consists of a telescope with a 1m primary mirror, and two science instruments, a near UV filter imager, and a vector magnetograph, as well as an image stabilization system with a correlation tracker steering an agile mirror.

The whole system is mounted into a gondola that does the rough pointing and hangs from a stratospheric balloon.

Sunrise had its successful first science flight in June 2009. Starting from ESRANGE in northern Sweden it crossed the Atlantik and landed safely, afetr a flight of almost 6 days, on inhospitable Somerset Island in northern Canada.

The scientific data, which were stored on board, and the equipment were successfully recovered.

7733-21, Session 4

A fast EM-CCD camera as performance monitor for the SOFIA Telescope with science capabilities

J. Wolf, NASA Ames Research Ctr. (United States); H. Roeser, A. Krabbe, Univ. Stuttgart (Germany); E. H. Pfüller, NASA Ames Research Ctr. (United States)

One of the most challenging requirements for the Stratospheric Observatory for Infrared Astronomy (SOFIA) is the pointing stability of 0.2 arcseconds (rms) of its 2.7 m telescope onboard a Boeing 747SP. In its initial flights starting 2010, the pointing stability is expected to be a few arcseconds according to model calculations. Subsequently, the pointing shall be improved by carefully analyzing the disturbances experienced in flight and by fine tuning the telescope's attitude control system accordingly.

To support the analysis of pointing disturbances, an EM-CCD camera (Fast Diagnostic Camera, FDC) has been prepared that can replace the telescope's standard tracking camera and measure star positions in the focal plane at speeds up to ~ 400 fps. Currently, the FDC is planned to be mounted for special engineering flights, a procedure that requires overhead for mechanical work and optical alignment, including star tests on the night sky from the ground. In this paper we explore the possibility to mount the FDC permanently to the SOFIA telescope. Activated by means of a flip-mirror it can continuously monitor the telescopes performance with a standardized system and a standard test procedure. It would be available at any time to check on unexpected pointing or chopper effects. Finally, such a fast camera could be applied to science observations at short notice and without the overhead of mounting a special science instrument or spending a full-length flight, e.g. for photometry of stellar occultations and of transiting of extra-solar planets.

7733-22, Session 4

Improvement of the SOFIA secondary mirror controller

A. Reinacher, H. Roeser, Univ. Stuttgart (Germany)

The Stratospheric Observatory for Infrared Astronomy (SOFIA) is a 2.5m infrared telescope build into a Boeing 747SP. During observations the telescope will not only be subject to aircraft vibrations and maneuver loads - by opening a large door to give the observatory an unhindered view of the sky, there will also be aerodynamic and aeroacoustic disturbances.

A critical factor in the overall telescope performance is the SOFIA Secondary Mirror Assembly (SMA). The 35cm silicon carbide mirror is mounted on the Secondary Mirror Mechanism (SMM), which has six degrees-of-freedom and consists of two parts: The slow moving base for focusing and centering, and on top of that the Tilt Chop Mechanism (TCM) for chopping with a frequency of up to 20Hz and a chop throw of up to 10arcmin.

A new controller for the TCM is introduced in this paper in order to meet the stringent performance requirements for the chopper. A state space controller is chosen that combines a feedback path for steady state behavior with a model-based feed-forward controller for increased settling time performance.

The paper explains the modeling of the TCM via a grey-box model approach optimized with system identification data and compares simulated with measured data. Then the structure of the controller is explained and Matlab/Simulink simulations are presented. The controller performance is compared to the formerly implemented PID controller, both with simulated and measured data. Finally results are presented of the in-flight performance of the TCM, both with open and closed door.

7733-23, Session 5

Design and simulation of a sub-arcsecond high-altitude balloon pointing system for astrophysics missions

J. T. Booth, J. B. Aldrich, J. W. Alexander, A. R. Abramovici, P. B. Brugarolas, Jet Propulsion Lab. (United States)

Precision pointing control for high altitude scientific ballooning would open up ambitious new areas for astrophysics for significantly lower cost than space missions. Near-space quality data without atmospheric seeing is most useful for optical telescopes only if the gondola-telescope-instrument platform can be stabilized to the sub-arcsecond level for many applications. We present the architecture of a multiple-layer pointing control system: de-coupling from the balloon, a coarse gondola-telescope stage, and fine control at the instrument using a corrective fast steering mirror (FSM) to null both low and high frequency disturbances. We present simulations showing that the control system can reduce jitter for typical astronomical instruments to well below 50 mas. We have identified that the sensing architecture that provides the signal for the FSM to correct is clearly a key component of the system, and may offer the most challenges for an efficient, affordable design. The recent heliophysics flight of the Sunrise mission has demonstrated excellent balloon stability and control using the sun as the correction signal. We present a comparison of three nominal case studies for sensing and precision control for wide field imaging, transit spectroscopy, and direct exoplanet imaging.

The research described in this talk was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

7733-24, Session 5

Preparation of the pointing and control system of the SOFIA Airborne Telescope for early science missions

U. Lampater, H. Roeser, Univ. Stuttgart (Germany)

During observation flights the telescope structure of the Stratospheric Observatory for Infrared Astronomy (SOFIA) is subject to disturbance excitations over a wide frequency band. The sources can be separated into two groups: inertial excitation caused by vibration of the airborne platform, a highly modified Boeing 747SP, and aerodynamic excitation that acts on the telescope assembly (TA) through an open port cavity. These disturbance sources constitute a major difference of SOFIA to other ground based and space observatories, and achieving the required pointing accuracy of 1 arcsecond cumulative rms or better below 70 Hz in this environment is driving the design of the TA pointing and control system. In the current design it consists of two parts, the rigid body attitude control system and a feed forward based compensator of flexible TA deformation. Simulations were performed in the past during the design phase of the TA to predict the expected image motion, and a number of publications were released. This paper discusses the characterization and control system tuning of the as-built system. It is a process that integrates the study of the structural dynamic behavior of the TA, the resulting image motion in the focal plane, and the design and implementation of active control systems. Ground tests, which are performed under controlled experimental conditions, and in-flight characterization tests, both leading up to the early science performance capabilities of the observatory, are discussed.

7733-25, Session 5

Optical measurement of the pointing stability of the SOFIA Telescope using a fast EM-CCD camera

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The goal of the Stratospheric Observatory for Infrared Astronomy (SOFIA) is to point its airborne 2.7 meter telescope at astronomical targets stable within 0.2 arcseconds (rms). The pointing stability will be affected in flight by aircraft vibrations and movements and constantly changing aerodynamic conditions within the open telescope compartment. It is planed to analyse and characterize all disturbances and then fine tune the telescope's attitude control system to improve the pointing stability. To optically measure how star images change their position in the focal plane, an Andor DU-888 electron-multiplying (EM) CCD camera will be mounted to the telescope. The new camera, dubbed Fast Diagnostic Camera (FDC) has been characterized in the laboratory and on ground based telescopes. In ground tests on the SOFIA telescope system it proofed its capabilities by sampling star images with frame rates up to 400 frames per second. From this data the star's location (centroid) in the focal plane can be calculated and by means of a Fourier transformation, the star's movement power spectrum can be derived.

With known disturbances introduced to the telescope's fine drive system, the FDC data can be used to determine the system's transfer function. These data, when measured in flight will be critical for the refinement of the attitude control system. This paper will describe the EM-CCD camera and its characteristics and will report on the tests that lead up to its first use in a SOFIA flight.

7733-26, Session 6

Opening a new window for ground-based astrophysics: the Cherenkov Telescope Array (CTA) Observatory

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The Cherenkov Telescope Array (CTA) observatory, currently planned by a global consortium of 500 physicists and engineers shall open the third window of groundbased astrophysics, VHE gamma-ray astronomy to the whole community.

Motivated by the success of current experiments HESS, MAGIC, and VERITAS, the CTA intends to provide much improved sensitivity and energy coverage with an array of up to 100 telescopes of three different sizes, segmented mirror diameters ranging from 6 to 24m, equipped with high-performance wide-field imaging cameras. Array operation will ensure high flexibility and optimum sensitivity for a broad range of research projects in high-energy astrophysics and particle-astrophysics.

The project is about to complete the Design Study phase and will enter the Preparatory Phase in 2010. Extensive Monte-Carlo simulations and critical review of scalability of current arrays provide the basis of the plan to set up one site in each hemisphere. The concept of the arrays, the studies of telescope-, and camera-design, the layout of electronics, the status of the site selections studies as well as the plans for data handling, archiving, observatory access and operation as well as governance will be briefly reviewed. Design specifications in terms of astrophysical aims and 0requirements as well as technical goals and challenges will be described.

7733-27, Session 6

Multi-objective transforming telescope for wide-field optical monitoring of the sky with high-temporal resolution

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We present the design of a MegaTORTORA telescope - modular, multi-purpose, scalable grid of optical cameras based on commercially available objectives and fast CCDs, able to operate with sub-second temporal resolution in both wide-field monitoring regime with all objectives observing different regions of the sky as well as in narrow-field follow-up mode with co-aligned channels and installed color and polarimetric filters for detailed investigation of selected objects, and to change the regime of operation on a sub-second time scale. Prototype system, the mini-MegaTORTORA, is currently in construction at Special Astrophysical Observatory of Russian Academy of Sciences, and consists of 9 f/1.2 Canon objectives with 85mm focal length, an image intensifiers to overcome the CCD read-oou noise, and fast CCDs based on Sony ICX285AL chip operating at 7.5 Hz frame rate. The field of view of prototype is from 900 square degrees in wide-field monitoring mode to 100 square degrees in follow-up regime, constantly being imaged with 0.13 seconds temporal resolution and analyzed on the fly to automatically detect, classify and investigate the fast optical transients of various kinds.

7733-28, Session 6

Path to the stars: the evolution of the species in the hunting to the GRBs

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During the last years, a number of telescopes have been dedicated to the follow-up of GRBs: recent studies of the prompt emission and of the afterglows, evidenced a series of phenomena that do not fit very well within the standard fireball model. In those cases optical observations were fundamental to distinguish among different emission mechanisms: simultaneous observation in various optical filters became essential to understand the physics, and we discovered the need to have a detailed high time resolution follow up. But, after the Swift launch, the average observed intensity of GRB afterglows showed to be lower than thought before. Our experience with the robotic 60cm REM telescope confirmed this evidence with a large number of lost GRBs, showing at the same time that fast pointing is the winning strategy. To tackle these problems and track down a realistic model, we started the conceptual design and phase A study of a 3 (Three) meter class, fast-pointing telescope (40 sec on target), equipped with multichannel imagers, from Visible to Near Infrared (Pathos). In the study we explored all the different parts of the project, from the telescope to the instrumental suite to data managing and analysis, to the dome and site issue. Contacts with industry have been fruitful in understanding the actual feasibility of such a complex machine and no show stoppers have been identified, even if some critical points should be better addressed in the Phase B study. In this paper, we present the main results of this feasibility study.

7733-29, Session 7

Mechanical design considerations for a 3m class fast pointing telescope

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Robotic, fast pointing Telescopes in the medium class have been increasingly discussed in the last ten years. Science cases concerned with this systems, a typical example is gamma ray burst follow-up, have been progressively increased and even more demanding in terms of performance and telescope size. However Telescope size increase, for the examined class, could imply some limitations in terms of operability and technological trouble.

In order to select the best system it is necessary to take into account mechanical set up, pointing strategy, wind effects and the resulting effective costs. This paper will investigate and compare the drawbacks of traditional alt-az and alt-alt telescope configurations proposing an innovative alt-alt set up to be developed as an interesting alternative in respect to the mainstream layout of present large telescopes. The system combines a primary rail based elevation sistem with a secondary pin based alt movement

7733-30, Session 7

Future ground-based telescopes design requirements

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Current trends in astronomical research necessitate a large number of small to medium sized telescopes be commissioned to support and augment the science goals of larger ground based observatories and space observatories. The science mission requirements for these telescopes vary widely, yet the critical design requirements for the telescopes are largely consistent across many missions. This paper clarifies the critical functional and performance parameters of a gimbaled telescope system as dictated by three significant classes of telescope missions: directed energy, synoptic surveys and pointed surveys. Within these classifications several specific example science missions are considered from which specific telescope functional requirements are derived. Detailed telescope performance requirements are then evaluated from a systems engineering perspective, highlighting typical performance that may be expected from a modern telescope. Additional commentary is provided on the probable feasibility of upgrading older facilities in contrast to commissioning new telescopes systems.

Based on the predictions of the NSF / NOAO sponsored ReSTAR report, it is assumed that the demand for high observation volume pointed surveys will increase rapidly within the next ten years. A case is made for the high science value of high gimbal slew rates on the basis of effective throughput in pointed survey applications.

7733-31, Session 7

QUIJOTE telescope opto-mechanics design and manufacturing

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The QUIJOTE CMB experiment aims to characterize the polarization of the CMB and other processes of galactic and extragalactic emission in the frequency range 10-30 GHz. Inside this project IDOM has collaborated with IAC in the integrated design, development and/or manufacturing of several sub-systems such as the enclosure, the telescope and the instrumentation. The main features of the telescope opto-mechanics included an offset Dragonian optical layout and an alt-azimuth mount with continuous azimuth rotation at 15 rpm for the typical scanning mode. The concept design of the telescope started in May 2007, whilst the detail design was closed in February 2008 with the delivery of a full dossier of manufacturing drawings. Lightweight cast aluminum mirrors with CNC machined and polished optical surfaces were designed and a fork and cradle configuration was chosen to support the mirrors and provide the alt-azimuth pointing capabilities. Azimuth and elevation angles were actuated by AC frameless motors and a slip-ring provided data, electrical power and hydraulic connection between the fixed base and the azimuth continuously rotating fork. Following a fast-track construction scheme, the design of the long terms delivery

components (aluminum cast, azimuth moment bearing, AC motors...) was frozen in an early stage and the purchase orders delivered, whilst the rest of the telescope detail design was being closed. Hence, all the required components were ready to begin the workshop assembly in June 2008, ending in October 2008 and the telescope was delivered to IAC for final integration and start up in December 2008.

7733-32, Session 7

The science and design of the AGIS Observatory

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The Advanced Gamma-ray Imaging System (AGIS), a next-generation array of imaging atmospheric Cherenkov telescopes for gamma-ray astronomy, would provide unprecedented sensitivity and resolution in the energy range between 50 GeV and 100 TeV, allowing great advances in the understanding of the populations and physics of sources of high-energy gamma rays in the universe.

The baseline AGIS observatory will employ an array of 36 Schwarzschild-Couder (SC) telescopes in combination with a highly pixelated (0.05 degrees diameter) camera. The SC optics provide wide unvignetted, 8 degree field-of-view, unprecedented for IACTs, and small plate scale of ~2 mm per arcminute. It results in large cost reduction in focal plane instruments by allowing use of small-sized, integrated photo-sensors, such as Multi Anode PMTs (MAPMTs) and Silicon PMs (SiPMs) coupled with low cost electronics realized by multi-channel waveform sampling ASICs (Application Specific Integrated Circuits).

The instrument is designed to provide millicrab sensitivity allowing both deep studies of faint point sources as well as efficient mapping of the Galactic plane and extended sources. AGIS will complement and extend results now being obtained in the GeV range with the Fermi mission, by providing superior angular resolution and sensitivity to variability on short time scales, and of course by probing energies that Fermi cannot reach.

In this talk I will describe science drivers behind the AGIS observatory and the design and status of the project.

7733-33, Session 7

Optical design of the CCD/Transit Instrument with Innovative Instrumentation (CTI-II) Telescope

M. R. Ackermann, Sandia National Labs. (United States); J. T. McGraw, M. J. McFarlane, T. Williams, P. C. Zimmer, W. H. Gerstle, F. Roybal, The Univ. of New Mexico (United States)

We describe an optical system that creates a 1.42° FOV with near diffraction limited images from 400nm to 1100nm with full-field distortion less than 0.01%. The astronomical application for this optical system is the CCD/Transit Instrument with Innovative Instrumentation (CTI-II), designed to produce a highly precise photometric and astrometric survey of a complete strip of the northern hemisphere sky. We describe the CTI-II and its scientific programs which drive the optical design of this unique telescope. The optical design that achieves these scientific goals is described in detail. We describe, as well, the comparative design tests that assure the required performance for CTI-II. The all-spherical five lens ULE corrector works well with most astronomically useful fore-optics for other telescopes, existing or under design. Evaluated with the published prescriptions for SDSS, Pan-STARRS, SkyMapper, ESO's VST, the WIYN ODI, the MMT WFC and other optical systems, the five element corrector met or exceeded - in some cases spectacularly - the optical performance of these systems. Conversely, these and other optical concepts compromised the performance of the CTI-II design. The CTI-II design is similar to many other wide-field telescope and imaging camera designs, thus the design is of potential general use in astronomy.

7733-34, Session 8

The Large Millimeter Telescope

D. H. Hughes, Instituto Nacional de Astrofísica, Óptica y Electrónica (Mexico)

The Large Millimeter Telescope (LMT) is a bi-national project between Mexico and the United States of America, led the Instituto Nacional de Astrofisica, Optica y Electronica (INAOE) and

the University of Massachusetts, Amherst, respectively. The LMT is a 50-m diameter, single-dish telescope optimised for millimeter-wavelength astronomy that is situated on the summit of Volcan Sierra Negra in the Mexican state of Puebla, at an altitude of 4600m. Following the completion of the telescope construction, the LMT is now beginning the initial phase of commissioning the facility and characterizing the telescope performance, before conducting the first-light scientific observations. We will present the current status of the LMT project,

including a description of the suite of first-generation instrumentation. A summary will be made of the first scientific results from these instruments, following their earlier installation and commissioning on other submillimeter telescopes. Finally we will provide examples of the main scientific goals that take advantage of the high spatial resolution and sensitivity of the LMT, and hence the LMT will be discussed in the context of other large future facilities (EELT/GMT/TMT, JWST, ALMA, SKA etc).

7733-35, Session 8

Experimental study on the damping of FAST cabin suspension

H. Li, National Astronomical Observatories (China)

The focus cabin suspension of the FAST telescope has structurally weak-stiffness dynamics with low damping performance, which makes it quite sensitive to disturbance-induced vibrations. Moreover, low damping limits work space and band width of control frequency of the suspended Stewart platform, the secondary fine compensator in the cabin, or even causes its control instability.

A reasonable estimation about the damping is very important for the control performance evaluation of the prototype. It is a quite difficult task as the telescope is not available yet. In the paper, a series of similar experimental models are used for the estimations of the damping. The dimensions of these models range from 5m to 50m in diameter, so that the law might be found about the variation tendency of the damping as the dimension of model increases or about the influence of some main factors. The Ibrahim time domain (ITD) method is employed to estimate the damping via measuring the response of freely decaying vibration. Four influence factors are specially studied, such as internal friction of suspension cable, cabin-cable friction, aerodynamical resistance, and pulley-cable friction. Furthermore, several design concepts to improve the damping performance are also tried experimentally and compared together with the previous data. Finally based on the experimental data, an anticipated damping value is suggested for the prototype.

7733-36, Session 8

The European ALMA Project: manufacturing, on-site assembly, and performances

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The Atacama Large Millimeter Array (ALMA) is now in its manufacturing phase in Northern Chile. The array consists of up to 64 12m-diameter antennas, and a number of smaller ones, to be operated on the Chajnantor plateau at an altitude of 5000 m. The antennas will operate up to 950 GHz so that their mechanical performances, in terms of surface accuracy, pointing precision and dimensional stability, are very tight. The fact that they need to be transported and relocated on the 200 or more antenna stations on the site has caused a number of mechanical and operational constraints. Since its very beginning, the first prototype phase, up to the serial production phase, the ALMA Project has stimulated the development of concepts of innovative engineering, as well as manufacturing design. The technologies adopted, such as the large use of composite materials, motorizations without contact (Direct Drive) etc..., have allowed to obtain extreme performances with reference to the scientific/environmental context. Among them, the use of a metrology instrument able to correct the non-repeatable errors induced by the wind or temperature variation inside the structure, is a very important one. This paper aims at presenting the design features of the European ALMA antennas, with respect to manufacturing, assembly and integration in Europe and on site.

7733-37, Session 8

High-precision pointing with the Sardinia Radio Telescope

S. Poppi, C. Pernechele, T. Pisanu, M. Morsiani, Osservatorio Astronomico di Cagliari (Italy)

We present here the systems aimed to measure and minimize the pointing errors for the Sardinia Radio Telescope: they consist of an optical telescope to measure errors due to the mechanical structure deformations and a lasers system for the errors due to the subreflector displacement.

The Sardinia Radio Telescope has a main mirror of 64 m in diameter and it will operate from 0.3 to 116 GHz; at its highest frequency the beam width (FWHM) will be ~10 arcseconds, requiring thus a accuracy of about 1 arcsec, for the pointing and also for the tracking. The methods based mainly on least-square fitting models, which are adopted in radio telescopes having a larger beam-size, are insufficient, because they keep under control only the repeatable pointing errors.

We show here the results of the tests that we have done on the Medicina 32 meters VLBI radio telescope. The measurements demonstrate we can measure the pointing errors of the mechanical structure, with an accuracy of about ~1 arcsec. Moreover, we show the technique to measure the displacement of the subreflector, placed in the SRT at 22 meters from the main mirror, within +/- 0.1 mm from its optimal position.

These measurements show that we can obtain the needed accuracy to correct also the non repeatable pointing errors, which arise on time scale varying from seconds to minutes.

7733-38, Session 9

ALMA: status report on construction and early results from commissioning

R. E. Hills, R. J. Kurz, A. B. Peck, Atacama Large Millimeter Array (Chile)

The Atacama Large Millimeter/submillimeter Array (ALMA) is an international facility now at an advanced stage of construction in the Atacama region of northern Chile. ALMA will consist of two arrays of high-precision antennas: one made up of twelve 7-meter diameter antennas operating in closely-packed configurations of about 50m in diameter, and the other consisting of up to sixty-four 12-meter antennas which can be arranged in configurations with diameters ranging from about 150 meters to over 15 km. There will be four additional 12-meter antennas to provide the “zero-spacing” information, which is critical for making accurate images of extended objects. The antennas will be equipped with sensitive millimeter-wave receivers covering most of the frequency range 84 to 950 GHz. State-of-the-art microwave, digital, photonic and software systems will be used to capture the signals, transfer them to the central laboratory and to correlate them, as well as keeping everything accurately synchronized. ALMA will provide images of a wide range of astronomical objects with great sensitivity and (where needed) very high spectral resolution. The images will also have much higher “fidelity” than those from existing mm/submm telescopes. This paper will provide an update on the status of construction and it will report on progress with the testing and scientific commissioning of ALMA.

7733-39, Session 9

The square kilometre array

R. T. Schilizzi, The Univ. of Manchester (United Kingdom); T. J. W. Lazio, U.S. Naval Research Lab. (United States); P. E. Dewdney, National Research Council Canada (Canada)

The Square Kilometre Array (SKA) will be the premier instrument to study the thermal and non-thermal radiation at centimetre and metre wavelengths from the cosmos, in particular from the most abundant element in the universe, neutral hydrogen. Its science impact will be widely felt in astro-particle physics and cosmology, fundamental physics, galactic and extragalactic astronomy, solar system science and astrobiology. The SKA will have a collecting area of up to one million square metres spread over at least 3000 km, providing a sensitivity 40 times higher than the Expanded Very Large Array. Its instantaneous reception pattern on the sky will be several tens of square degrees, many times that of existing instruments, with potentially several large (100 square degree), independent fields-of-view for multiple simultaneous users. The SKA will be an extremely powerful survey telescope with the capability to follow up individual objects with high angular and time resolution. The SKA design involves parabolic dishes with innovative feeds to maximize a combination of spatial and frequency coverage; at the lower frequencies, phased arrays become cost-effective and offer new operational capabilities. Much of the required technology is currently being developed in the course of specific design studies and the construction of several SKA Pathfinder instruments around the world.

The talk will cover the science case for the SKA, and provide an update on the design, prototyping, and site development activities.

7733-40, Session 9

Combined array for research in millimeter-wave astronomy: capabilities for the future

L. G. Mundy, Univ. of Maryland, College Park (United States)

The Combined Array for Research in Millimeter-wave Astronomy (CARMA) is a 23-element interferometer operating in the 26-34 GHz, 80-115 GHz and 210-250 GHz radio bands.CARMA is just completing the implementation of a new correlator and a frequency and antenna switchyard which will enable various combinations of the existing telescopes to be used on the observatory's 15-element and 8-element correlators, and to select between a combination of IF bands and polarizations. This new flexibility creates a new set of observing modes and new science capabilities. The flexibility and developments being implemented are along CARMA's development path toward broader instantaneous frequency coverage, boarder-bandwidth, flexible correlators, and interferometry with array receivers.

7733-41, Session 9

The expanded very large array

M. M. McKinnon, R. A. Perley, J. M. Jackson, B. J. Butler, M. P. Rupen, B. Clark, National Radio Astronomy Observatory (United States)

The Expanded Very Large Array (EVLA) is an international project to improve the scientific capabilities of the Very Large Array (VLA), an aperture synthesis radio telescope consisting of 27, 25-meter diameter antennas distributed in a Y-shaped configuration on the Plains of San Augustin in west-central New Mexico. The EVLA's major science themes include measuring the strength and topology of magnetic fields, enabling unbiased surveys and imaging of dust-shrouded objects that are obscured at other wavelengths, enabling rapid response to and imaging of rapidly evolving transient sources, and tracking the formation and evolution of objects in the universe. The EVLA's primary technical elements include new or upgraded receivers for continuous frequency coverage from 1 to 50 GHz, new local oscillator, intermediate frequency, and wide bandwidth data transmission systems to carry signals with 16 GHz total bandwidth from each antenna, and a new digital correlator with the capability to process this bandwidth with an unprecedented number of frequency channels for an imaging array. The project also includes a new monitor and control system and new software that will provide telescope ease of use. The project was started in 2001 and is on schedule and within budget. Scientific observations with the new correlator will commence in March 2010. The structural modifications that convert the VLA antennas to the EVLA design will be complete by July 2010. The project will be complete in December 2012 when the last receiver will be installed on an antenna.

7733-42, Session 9

LOFAR: the low-frequency array

M. P. van Haarlem, ASTRON (Netherlands)

The Low Frequency Array (LOFAR) is a new radio telescope, operating in the 10-240 MHz frequency range, that makes use of phased array antenna technology and aperture synthesis techniques to open up a high sensitivity and high resolution window on the Universe. Further key elements of the LOFAR system include early digitization, followed by extensive and flexible digital signal processing (already at the level of the stations). Pointing and beamforming are achieved at this stage. This approach leads to greater operational flexibility and improved functionality. For example, independent digital beams can be created within the field of view of the antennas, enabling simultaneous observations in different directions on the sky. Rapid switching of the observation beam(s) on timescales of seconds is also possible, which allows the telescope to react quickly to incoming as well as self-generated triggers.

The design and construction of LOFAR has been guided by a number of key projects that the telescope will address. They include the Epoch of Reionization, detection of Transient Source and the study of Pulsars, the radio signature of Cosmic Ray Air Showers, deep extragalactic surveys, Cosmic Magnetism and studies of the Sun.

Construction of the array is well underway. When completed in 2010, it will consist of 36 stations located in the North-East of the Netherlands and a total of at least 8 stations in Germany (5), France (1), the United Kingdom (1) and Sweden (1). The elementary building blocks are relatively simple (omnidirectional) antennas, with no moving parts, which are combined to form stations that replace the individual (unit) telescopes found in many interferometric arrays. The signals from all stations are sent to a central processing facility at the University of Groningen's Centre for Information Technology. The entire array will be controlled from an operations centre at ASTRON's headquarters in Dwingeloo.

LOFAR is one of the pathfinders of the Square Kilometer Array. Many of the techniques developed for LOFAR will be directly applicable in the design of the SKA.

7733-43, Session 9

Heterogeneous array imaging with the CARMA Telescope

M. C. H. Wright, Univ. of California, Berkeley (United States)

The 23-antenna CARMA array is comprised of six 10.4m, nine 6.1m, and eight 3.5m antennas from the merger of the facilities of the OVRO, BIMA and SZA telescopes on a site in the Inyo mountains at 2700m. This heterogeneous millimeter wavelength aperture synthesis telescope enables high spatial dynamic range imaging with antenna spacings from 3.5m to 2km providing resolutions from 10 arcmin to 0.15 arcsec over a wide field of view. The array is instrumented with receivers in three bands at 26-36 GHz, 80-115 GHz, and 215-270 GHz. Hybrid digital correlators provide up to 8 GHz bandwidth in multiple subarrays.

Antennas are moved at intervals of 1-3 months into multiple antenna configurations. In the most compact configuration the 3.5m antennas at 26-36 GHz are used for mapping the SZA effect in clusters of galaxies, with the 10.4m antennas on longer spacings used for compact source subtraction.

In the more extended configurations, the antennas can be paired, with the 6.1m and 10.4m antennas making science observations in the 3mm and 1mm bands, while the 3.5m antennas are simultaneously observing calibration sources within a few degrees in the 1 cm band. This unique Paired Antenna Calibration System allows us to to correct for atmospheric phase fluctuations and make images at 0.15 arcec resolution in a wide range of atmospheric seeing conditions. In this paper we discuss in more detail the results and lessons learned with these observing techniques.

7733-44, Session 10

Thermal imaging of the Large Millimeter Telescope structure

D. R. Smith, MERLAB, P.C. (United States)

A dominant problem for large, high precision telescopes is the deformation due to temperature changes in the structure. Even for active surface designs such as the Large Millimeter Telescope/Gran Telescopio Milimetrico (LMT), accurate knowledge of the temperature distribution in the structure is necessary in order to adjust the primary reflector panels and make pointing corrections.

The design of thermal management system of the LMT consists of a fully-cladded structure, a forced ventilation system, and a collection of temperature sensors distributed throughout the telescope. During the design, both steady-state and dynamic thermal models were developed to predict the thermal behavior. Additionally, some thermal measurements were taken during construction, before the cladding was installed. Since the structure is now completely enclosed with insulating cladding, it is an excellent candidate for thermal imaging at this stage of the commissioning. Thermal images of the structure are presented, showing the actual temperature distribution of the LMT alidade structure and reflector. The images are taken from a consistent set of positions to show the how the structural temperature distribution evolves over day and night conditions.

7733-45, Session 10

Wind-induced pointing errors and surface deformation of a 10-m submillimeter antenna

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Large antennas exposed in the open air are deformed due to wind loading, which causes antenna pointing errors and gain losses. We have measured pointing errors and large-scale surface deformation of the Atacama Submillimeter Telescope Experiment (ASTE) 10-m radio telescope with four accelerometers on the main-dish, three on the subreflector, one near the elevation axis, and two angle encoders under a strong wind gust (velocities of 15-25 m s-1). The measurements have been made at six attack angles. Power spectrum densities of rotational acceleration obtained with the two instruments showed good correlations in a frequency range from 1 - 10 Hz, suggesting that the major source of pointing errors is drive controllers rather than the antenna structure in this frequency range. The side-wind loading (EL=89deg) made an astigmatic deformation of about 1 micron rms. The front wind caused typical amplitude of the vertical displacement variation of about 4 micron rms. On the other hand, all-sky pointing and continuous tracking measurements have been made with an optical pointing telescope mounted on the reflector central hub to study pointing errors induced by static/quasi-static wind loadings. The side- and tail-wind loadings of 10 m s-1 caused pointing errors of about 2 arcseconds in the azimuth and elevation directions, respectively. Pointing offset profiles suggest that deformation of a yoke structure be the major source.

7733-46, Session 10

LSST primary/tertiary mirror thermal control system

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The LSST primary and tertiary mirrors optical surfaces will be both be fabricated into a single monolithic cast borosilicate substrate. As a result of the relatively large coefficient of thermal expansion (CTE) of borosilicate glass, mirrors fabricated from this material require extensive thermal control. The thermal differences throughout the mirror must be held below 0.1C. A modified version of the thermal control system utilized on the Magellan telescope primary mirror will provide adequate cooling. This type of system supplies coolant to multiple onboard blowers in the mirror cell. Each blower contains both a fan and a heat exchanger. The blower units supply conditioned and mildly pressurized air to the mirror cell. The mirror cell then acts as an air plenum which distributes the air through individual nozzles to each honeycomb cell of the mirror. Unlike previous systems, each LSST blower assembly will incorporate individual air temperature and air flow control systems. Since air can be more accurately heated than cooled, the air will be initially overcooled by ~1C and then reheated electrically to match the ambient air temperature. Based on thermal sensors in the mirror, the optimum cooling air flow rate to balance mirror thermal distortion and mirror seeing will be determined and enforced by the variable speed fans on the blower assemblies.
To further equalize the cooling throughout the mirror, the coolant flow system has also been designed to provide inherently equal coolant flow to each blower assembly.

7733-48, Session 10

Main axes control of E-ELT

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Associated to tracking capabilities, the main axes control system of the E-ELT is the first correcting system in the chain of control loops for reducing the image motion (tip/tilt) caused by perturbations on the telescope. The main objective of the closed-loop performance analysis of the axes is to evaluate the trade offs for the choice of control system hardware, i.e. specification and location of the motors and sensors (encoders/tachometers). In addition, it defines the design constraints and requirements (actuator stroke and bandwidth) of other correcting systems in the chain: the field stabilization (M5 unit) and adaptive deformable mirror (M4 unit).

In this paper the main axes control analysis of E-ELT is presented and the performance of telescope in face of external perturbations such as wind and imperfections of the drive (cogging/ripple) and sensing (noise) systems is evaluated. The performance metric is the wavefront error at the focal plane which is derived from the mechanical motion of the telescope's optical elements together with their respective optical sensitivities.

7733-146, Session 10

Vibration suppression for the Gemini Planet Imager

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The Gemini Planet Imager (GPI) is an instrument that will mount to either of two nominally identical telescopes, Gemini North in Hawaii and Gemini South in Chile. This 2,000-kg instrument has stringent mass, center-of-gravity, flexure, and power constraints. The Flexure Sensitive Structure (FSS) supports the main opto-mechanical sub-systems of the GPI which work in series to process and analyse the telescope optical beam.

The opto-mechanical sub-systems within the FSS are sensitive to mechanical vibrations, and several passive vibration mitigation strategies were considered. An array of small tuned mass dampers (TMDs) was identified as an efficient approach to mitigate each of the first two FSS flexural modes, the main sources of image jitter. It is estimated that 5% of critical damping can be added to each of these modes with the addition of 16 kg and 7 kg of TMD mass, respectively. This estimate was based on installing TMD units on the FSS external structure. TMD mass could be reduced by nearly 50% if the units can be installed on component structures within the FSS with the highest modal displacements.

For the GPI FSS, it will be possible to tune the TMDs after the structure is built and tested. TMDs with a frequency adjustment feature will be designed based on the structure finite element model, and tuning will be performed after the instrument is assembled. The paper describes the structural design and vibration response of the FSS, modal test results, the damping design process, and plans for implementation.

7733-49, Session 11

The development of high-precision hexapod actuators for the Hobby-Eberly Telescope dark energy experiment (HETDEX)

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Hexapods are finding increased use in telescope applications for

positioning large payloads. Engineers from The University of Texas at Austin (Center for Electromechanics and McDonald Observatory) have been working with engineers from ADS International (Valmadrera, Italy) to develop large, high force, highly precise and controllable actuators for use on the Wide Field Corrector (WFC) Upgrade as part of the upgrade to the Hobby Eberly Telescope for a sky survey for the Dark Energy Experiment. These actuators are installed in a hexapod arrangement, supporting the 3150 kg scientific payload which includes the WFC, support structure, and other optical/electronic components. In addition to force capability, the actuators need to meet the tracking speed (pointing) requirements for accuracy and the slewing speed (rewind) requirements, allowing as many precision viewings in one night as possible. The hexapod actuator stroke (retraction and extension) was very closely monitored during the design phase to make sure all of the science requirements could be met, while minimizing the risk of damaging the WFC optical hardware in the unlikely event of a hexapod actuator controller failure.

This paper discusses supporting analysis and design trade-offs between stiffness, safety, backdrivability, accuracy, and mass leading to selection of motor, high ratio worm gear, roller screw, coupling, end mounts, and other key components. The paper includes data from prototype actuator testing which provides insight into actuator positioning and controllability, particularly during direction changes which was a major concern during the design selection phase.

7733-50, Session 11

The Magellan Telescopes: a performance update

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The Magellan Baade and Clay telescopes regularly produce images of 0.5" in natural seeing. We review efforts to improve collimation, active optics response, and telescope guiding and pointing to optimize the performance of the telescopes. Procedures have been developed to monitor and archive image quality delivered by the imaging science instruments. Improved models have been developed to correct for flexure of telescope and primary mirror under gravity loading.

Collimation has been improve using a "two-probe" Shack-Hartman technique to measure field aberrations.Telescope pointing has been improved by regular monitoring to improve acquisition times.

7733-51, Session 11

Development of a wide-field spherical aberration corrector for the Hobby Eberly Telescope

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A 4-mirror prime focus corrector is under development to provide seeing-limited images for the 10-m aperture Hobby-Eberly Telescope (HET) over a 22 arcminute field of view. The HET uses a fixed elevation segmented spherical primary mirror. The imaging system is pointed and the aberrations from the primary mirror are corrected by a 4-mirror spherical aberration corrector at prime focus. The optical system, which uses aspheric mirrors up to 1 meter in diameter, is currently being produced at the University of Arizona.

This paper provides a summary of the following for the optical system:

- system engineering and performance analysis
- optomechanical design
- fabrication and alignment plan
- status and lessons learned

7733-52, Session 11

New phase compensating secondary mirrors or the NASA Infrared Telescope

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As the overall image quality at the NASA Infrared Telescope Facility (IRTF) improves with better environmental control of the observatory and telescope, the static aberration in the telescope have become a dominate source of image degradation. Moreover, these aberrations, primarily 3rd order spherical aberration, zonal polishing rings, and support-pad print-through on the primary mirror, are also severely limiting the the AO system, which has not been able to acheive the expected design Strehl ratios. To continue to improve the overall image quality of the IRTF, two new secondary mirrors have been fabricated with custom phase compensating surface applied to their base optical prescriptions to correct of the wavefront errors. To determine this custom corrective surface, a special purpose instrument was fabricated to fully characterize the optics and wavefront error at both the prime and Cassegrain foci. The instrument contained an image plane imager, a knife-edge tester, a pupil plane imager, a Hartmann wavefront sensor, and a guide camera. With a fully characterized telescope and wavefront error, an optimized custom surface was designed that corrected the above aberrations plus other smaller errors. Ion Beam Polishing techniques were used to apply the final custom, phase correcting surface figure.

7733-53, Session 12

Giant Magellan Telescope site testing summary

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Cerro Las Campanas located at Las Campanas Observatory (LCO) in Chile has been selected as the site for the Giant Magellan Telescope. We report results obtained since the commencement, in 2005, of a systematic site testing survey of potential GMT sites at LCO. Meteorological (cloud cover, temperature, pressure, wind, and humidity) and DIMM seeing data have been obtained at three potential sites, and are compared with identical data taken at the site of the twin Magellan 6.5m telescopes. In addition, measurements of the turbulence profile of the free-atmosphere above LCO have been collected with a MASS/DIMM. Furthermore, we consider photometric quality, light pollution, and precipitable water vapor (PWV). LCO, and Co. Las Campanas in particular, have dark skies, little or no risk of future light pollution, excellent seeing, moderate winds, PWV adequate for mid-IR astronomy during a reasonable fraction of nights, and a high fraction of clear nights overall.

7733-54, Session 12

Support for site testing of the European Extremely Large Telescope: precipitable water vapor over Paranal

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The European Southern Observatory (ESO), the Institute for Space Imaging Science (ISIS) and the Astro-meteorological group of the Universidad Valparaiso have entered into a collaboration for the purpose of gaining a better understanding of the precipitable water vapour (PWV) above the La Silla Paranal Observatory. Both La Silla and Paranal have been studied with the goal to use them as reference sites for evaluation of potential E-ELT sites. In a first step, 8 years worth of high resolution near-IR spectra taken with VLT-UVES have been statistically analysed to reconstruct the PWV history above Paranal. To this end a radiative transfer model of Earth's atmosphere (BTRAM) developed by ISIS has been used. In order to better understand the systematics involved two dedicated campaigns were then conducted in August and November 2009. Several methods for the determination of the water column were employed, including radiosonde launches, continuous measurements by infrared radiometer, and VLT instruments operating at various wavelengths: UVES, X-shooter, CRIRES and VISIR. All available observations were compared to satellite estimates of water vapour above the observatory in an attempt to ground-truth the satellite data. Excellent agreement between methods has been found and we conclude that due to stable atmospheric conditions Paranal can serve as a reference site for other sites in Northern Chile. In order to facilitate scaling with altitude additional measurements have been taken with an IR radiometer co-located with the 183 GHz radiometer at the APEX site (5000m). Furthermore important lessons for the operational use of PWV information at an observatory such as Paranal have been learned. For the E-ELT we find that a stand-alone high time resolution PWV monitor will be essential for optimizing the scientific output.

7733-55, Session 12

Where is the surface-layer turbulence?

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Remote turbulence sensing in the first 100m above ground using lunar scintillation has revealed that the seeing measured by regular site monitors can be over-estimated. This explains the well-known discrepancy between the VLT image quality and the seeing measured by the DIMM at Paranal. The concept of "site seeing" needs to be critically reviewed, considering strong dependence of this parameter on the height of site monitors and on the local turbulence in their immediate vicinity. Higher resolution of ground-based telescopes can be reached if we accept that the natural seeing can be better than shown by the DIMMs and that the contribution of telescope and its environment to the seeing can be significant on nights with superb conditions. This is particularly relevant to the wide-angle optical and IR telescopes which do not rely on adaptive optics.

7733-56, Session 12

Site testing at Jbel Aklim in Moroccan Anti-Atlas as a potential site for the E-ELT

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In the framework of the E-ELT project a prospecting campaign was launched by the ESO to select the site that will host the next generation of optical telescopes of 42 m diameter. Moroccan Anti-Atlas (Jbel Aklim) was selected as well as other sites (ORM, Ventarrones and Macon) to be a possible potential location that will house the E-ELT.

In this paper we first present the reasons for the choice of Jbel Aklim as a E-ELT candidate through various exploration campaigns that we have achieved.

The second part concerns the ground climatology, geological and atmospheric properties.

Finally we will present the preliminary data obtained by the local DIMM monitor during 105 nights. The median and mean values of the seeing for the entire period of observation are 0:72"and 0:79 ", respectively, with a standard deviation 0:31 ". The best seeing measured was 0:20".

7733-57, Session 12

Mt. Graham: optical turbulence vertical distribution with standard and high resolution

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A characterization of the optical turbulence vertical distribution and all the main integrated astroclimatic parameters derived from the Cn2 and the wind speed profiles above Mt. Graham is presented. The statistic includes measurements related to 43 nights done with a Generalized Scidar (GS) used in standard configuration with a vertical resolution of ~ 1 km on the whole 20-22 km and with the new technique (HVR-GS) in the first kilometer. The latter achieves a resolution of ~ 20-30 m in this region of the atmosphere. Measurements done in different periods of the year permit us to provide a seasonal variation analysis of the Cn2. A discretized distribution of Cn2 useful for the Ground Layer Adaptive Optics (GLAO) simulations is provided and a specific analysis for the LBT Laser Guide Star system ARGOS case is done including the calculation of the 'gray zones' for J, H and K bands. Mt. Graham confirms to be an excellent site with median values of the seeing without dome contribution equal to 0.72", the isoplanatic angle equal to 2.5" and the wavefront coherence time equal to 4.8 msec. We provide a cumulative distribution of the percentage of turbulence developed below H* where H* is included in the (0,1km) range. We find that 50% of the whole turbulence develops in the first 80 m from the ground. The turbulence decreasing rate is very similar to what has been observed above Mauna Kea.

7733-58, Session 13

Optical turbulence above mountains seen in 3D

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Using MASS data collected by the TMT site testing campaign and the Tololo site monitoring, we constructed 3D maps of the average optical turbulence distribution above several sites. We will show a comparison with CFD models, demonstrating the use of such tomography and also describe the possible layout of a dedicated 3D optical turbulence tomography facility instrument, based on the MASS concept.

7733-59, Session 13

Boundary layer seeing measurements in the Canadian High Arctic

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The Earth's polar regions offer important advantages for ground-based optical/infrared astronomy. These include cold, dry conditions, long periods of darkness, and the potential for unsurpassed seeing. Observations from the Antarctic glacial plateau indicate that above a strong boundary layer at the ice surface there is little high-altitude turbulence inside the polar vortex. The Canadian High Arctic offers comparable climatic conditions, with some attributes more akin to the best mid-latitude sites: coastal mountain peaks where the boundary layer may be locally weak.

As part of a program to measure and evaluate atmospheric turbulence on mountains at the most northerly tip of North America, we have deployed two SODARs and a lunar scintillometer at the Polar Environment Atmospheric Research Lab (PEARL) located on a 600m-high ridge near Eureka on Ellesmere Island, at 80 degrees latitude. This paper discusses the program and presents a summary of ground-layer turbulence and seeing measurements from the 2009-10 observing season.

7733-60, Session 13

The Gattini Antarctic cameras

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The high altitude Antarctic sites of Dome C, Dome A and the South Pole offer intriguing locations for future large scale optical astronomical Observatories. The Gattini project was created to measure the optical sky brightness, large area cloud cover and aurora of the winter-time sky above each of these sites. The staged project commenced with the deployment of 2 cameras to Dome C site, home of the French-Italian Concordia station. The Gattini-DomeC project, part of the IRAIT site testing campaign and ongoing since January 2006, consists of two automated transit cameras that are virtually identical except for the nature of the lenses. The wide field cameras take images of the sky every 5 minutes. The cameras have operated throughout the past three Antarctic winter seasons.

Moving to the higher and more remote location of Dome A, the Gattini-DomeA camera was installed on the PLATO instrument module as part of the Chinese-led traverse to the highest point on the Antarctic plateau in January 2008. This single automated wide field camera contains a suite of Bessel photometric filters and a long-pass red filter for the detection and monitoring of OH emission. We have one complete winter-time dataset from the camera.

The Gattini-South Pole UV camera is a wide-field optical camera that in 2010 will measure the UV properties of the winter-time sky above the South Pole dark sector. This unique dataset will consist of frequent images taken in both broadband U and B filters in addition to narrow-band imaging at wavelengths corresponding to known bright aurora and OH lines in the 320nm-450nm region. The camera is a proof of concept for the 2m-class Antarctic Cosmic Web Imager telescope, a dedicated experiment to directly detect and map the redshifted lyman alpha fluorescence or Cosmic Web emission we believe possible due to the unique geographical qualities of the site.

We present results for the Gattini camera network and a comparison of the sites tested so far.

7733-61, Session 14

Performance of the autonomous PLATO Antarctic Observatory over two full years

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For continuous observations at locations that are inhospitable for humans, the desirability of autonomous observatories is self evident. PLATO, the 'PLAteau Observatory' was designed to support an easily configurable instrument suite in the extremely cold conditions of the Antarctic plateau, supporting up to 1 kW of instrument power consumption. Powered by jet fuel and the sun, PLATO and its instruments have been taking nearly uninterrupted astronomical science and site-testing data at Dome A, the coldest, highest and driest location on the Antarctic Plateau, since their deployment by the 24th Chinese expedition team in January 2008. At the time of writing, PLATO has delivered a total uptime of 541 days. Following a servicing mission by the 25th Chinese expedition team in 2008-9, PLATO has achieved 100% up-time (337 days) and has been in continuous contact with the rest of the world via its Iridium satellite modem. This paper discusses the performance of the observatory itself, assesses the sources of energy and dissects how the energy is used by the core observatory functions of instrument power, heating, control and communication.

7733-62, Session 14

Antarctic Infra-Red Telescope with a 40cm primary mirror (AIRT40): development and improvement

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Dome Fuji on the Antarctic plateau is expected to be one of the best sites for infra-red astronomy. In Antarctica, the coldest and the driest air on the Earth provides the deepest detection limit. Furthermore, weak atmospheric turbulence above the boundary layer (just 18m) allows for high spatial resolution. So we plan to perform site-testing at Dome Fuji during the Australian summer of 2010-2011. This will be the first observation to use an optical/infra-red telescope at Dome Fuji. This paper introduces the Antarctic Infra-Red Telescope with a 40cm primary mirror (AIRT40) which will be used in this campaign; it is an infra-red Cassegrain telescope with a fork equatorial mount. AIRT40 will be used for not only site testing (measurement of seeing and sky background) during the summer, but also for remote scientific observations during winter. For this purpose, AIRT40 has to work well even at -80 degree Celsius. Therefore we accounted for the thermal contraction of the materials while designing it, and made it with special parts which were tested in a freezer. Moreover, for easy operation, a polar alignment stage and many handles for transportation were installed. From these

approaches, AIRT40 is suited to observe at Dome Fuji. We also report the test observations (pointing accuracy and tracking error analysis) carried out at Sendai, Japan.

7733-63, Session 14

Progress of Antarctic Schmidt Telescopes (AST3) for Dome A

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The highest antarctic inland plateau Dome A has been widely predicted as the best astronomical site on earth. The preliminary site testing carried out since the beginning of 2008 shows the great advantage of Dome A as the astronomical site. Chinese first antarctic telescope CSTAR has been automatically observed for 2 years and many exciting results are obtained. AST3 is our second project for Dome A which is composed of 3 modified Schmidt telescopes with 50cm entrance diameter. Besides the function of site testing, the main sciences of AST3 are studying the dark universe and searching for exextrasolar planets. G, R, I filters are used for each telescope. Foldable dome and adjustable base are designed to keep the snow and icing off the telescope. Remote control for the tracking and auto-focusing is also designed for reliable automatic observations. The first AST telescope will be mounted on Dome A in early 2011. Now we are at the end of the manufacturing of the first one and the alignment and on-site testing observation at west China Plateau will be started at the beginning of 2010.

7733-64, Session 14

Thermal design and de-icing system for the Antarctic Telescope ICE-T

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ICE-T, the International Concordia Explorer Telescope, is under final design by an international consortium led by the Astrophysical Institute Potsdam AIP, Germany, and is intended to be placed at the French-Italian Concordia Station on Dome C in Antarctica. Experience with smaller telescopes at Concordia has shown that under the weather conditions at this site - with mean outside temperatures of -60° to -80° C and temperature changes of 20° in short time intervals - the ice-accumulation on the optical components during observation is a major problem. Also, energy consumption at this site should be minimized because fuel transport to the site is very costly.

The paper describes the thermal concept for the telescope where the waste energy of the instrument electronics is used for heating the front surfaces of the Schmidt optics. All other parts of the telescope are protected by an insulated smooth cladding against the harsh outside environment. The effectiveness of the thermal concept is verified by CFD (Computer Fluid Dynamics) calculations.

7733-65, Session 15

The Cornell Caltech Atacama Telescope: progress and plans 2010

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The Cornell Caltech Atacama Telescope (CCAT) Project is an effort to construct a 25 meter aperture telescope above 5600 meters altitude operating down to wavelengths as short as 200 µ. CCAT has developed some new and innovative approaches to telescope and optics design, added new partners to the project, and has plans for substantially increased activities over the next two years.

Begun by Cornell University and the California Institute of Technology, CCAT currently has six national and university partners. Funding has been increased and significant technical activities are underway to investigate the key enabling technologies. Areas of development include telescope optical design, mount design, application of CFRP materials to the telescope, sensing and control of primary mirror segments, and control system architecture.

Schedules and budgets for the Project have been updated and an overall approach leading to first light in 2016-2017 has been developed. CCAT promises to have a significant scientific impact on submillimeter astronomy and the prospects for success have never looked better.

7733-66, Session 15

GMT overview

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The 25 meter Giant Magellan Telescope (GMT) is one of the next generation of extremely large ground-based telescopes. When it goes into operation, GMT will conduct basic astronomical research on a broad range of key scientific programs at visible and infrared wavelengths. A site for the GMT facility has been selected at Las Campanas Observatory, Chile. The GMTO Corporation has been formed by a consortium of major US and international university and research institutions to design, construct, and operate the telescope. Broad community involvment is expected to be part of the GMT. The Project is currently mid-way through its Design Development Phase.

GMT is designed around a primary mirror consisting of seven 8.4 meter segments on an alt-azimuth mount, in a Gregorian optical configuration. The first of these segments is nearing completion and preparations for casting the second 8.4 m mirror are underway. The segments will be mounted in the telescope on a flotation support with pneumatic actuators which are currently under development. GMT will be equipped with both adaptive and non-adaptive segmented secondary mirrors. Preliminary designs for these are well advanced. An initial complement of science instruments will be provided at the start of operations. Instruments will take advantage of an adaptive optics system that is part of the GMT design. Initial instrument concepts were developed as part of the telescope conceptual design process completed in 2007. A second round of instrument design is underway which will lead to a down- select of 3-4 first generation instruments at the time of telescope prelimary design review.

This paper summarizes the organizational structure and status of the GMT Project and recent progress in the technical development of the various GMT subsystems.

7733-67, Session 15

E-ELT Telescope: the status at the end of detailed design

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The European Extremely Large telescope is a 42-m diameter adaptive telescope scheduled to start operations in 2018. The detailed design phase is scheduled to be completed at the end of 2010 and construction could start as early as 2011. The design of the E-ELT shall be presented. The output of industrial studies of the dome, main structure and various optical subsystems shall be described. The expected performance and analysis supporting this shall be discussed.

7733-68, Session 16

Pancake ELT: a practical design for an extremely large telescope

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We present the optical design for a new class of extremely large telescope, featuring both spherical primary and spherical secondary mirrors. The design makes use of an Improved Spherical Aberration Corrector (ISAC) (Reference, Improved spherical aberration corrector for fast spherical primary mirrors, Proc. SPIE. Vol. 7061 (2008)) that is adaptable to post prime focus, post Cassegrain-like focus, and post Couder/Schwarzschild-like focus applications. ISAC features three mirrors, but has a total of four reflections, with one of the mirrors being used twice.

The most unique application of ISAC is to a Couder/Schwarzschild-like configuration where one has a spherical primary mirror and a concave spherical secondary mirror, located inside the focus of the primary (i.e., not a Gregorian configuration). Curvature of the secondary mirror relative to the primary can be confocal or unconstrained. When confocal, only a single type of hexagonal segment is required for both primary and secondary. This is believed to represent a significant advancement in design for telescopes with spherical primary mirrors, and should represent a significant advantage for fabrication, testing and alignment of ELTs. With the addition of a flat mirror, it is also possible to use the primary mirror twice and avoid a powered secondary mirror altogether. This makes the telescope extremely short, being wider than it is long, giving it a pancake like configuration.

We present detailed optical designs for both the Couder/Schwarzschild-like and Pancake configurations of an ELT with spherical primary and secondary mirrors, and an ISAC-type corrector.

7733-69, Session 16

The status of the Thirty Meter Telescope Project

G. H. Sanders, Thirty Meter Telescope Project (United States); J. E. Nelson, Univ. of California, Santa Cruz (United States)

The Thirty Meter Telescope (TMT) Project has completed its design development program and is testing critical components and production processes. We will present an overview of the science requirements, and the design of the facilities, telescope, adaptive optics systems and science instruments. Mauna Kea has been selected as the preferred site for TMT. We will describe the site specific planning to initiate construction. Finally, plans for operating TMT are well advanced and these will be described.

7733-70, Session 17

Enclosure design for Thirty Meter Telescope

N. P. Loewen, Dynamic Structures Ltd. (Canada)

The enclosure design for the Thirty-Meter Telescope is now in final design phase. The focus of design activities now turns to developing details and strategies enabling efficient manufacturing, construction and operations of the enclosure on the selected Mauna Kea site. The paper will provide an overview of the enclosure design and an outline of the proposed construction plan.

7733-71, Session 17

The E-ELT Project: the Dome design status

G. Marchiori, S. de Lorenzi, A. Busatta, European Industrial Engineering s.r.l. (Italy)

Status of the Feasibility Study of E-ELT, the ESO 42 m Extreme Large Telescope, with emphasis on the Dome architecture and erection.

The Dome is a hemispherical shape concept servomechanism 86 m high, with an external diameter of 108 m and a 45 m wide Observing Slit. Such dimentions require the application of big structure technologies (like stadium, hangar etc), in order to comply with manufacturing, transport and assembly constrains. The mentioned technology must be fitted with mechanical and control system constrains required by this kind of servosystem. Mechanisms inside the Dome must be sufficiently light and stiff, and composite materials meet the above mentioned requirements. The management of the whole mass is extremely important for the services and power consumption. This paper describes how the above mentioned problems were handled during the E-ELT Dome Feed study.

7733-72, Session 17

Detail design and construction plans for a dome for the European Extremely Large Telescope (E-ELT)

G. Murga Llano, A. Bilbao, A. Vizcargüenaga, IDOM (Spain); M. W. Schneermann, European Organisation for Astronomical Research in the Southern Hemisphere (Germany)

As a continuation of the Preliminary Design for the Dome for the E-ELT Dome proposed by IDOM, a Detail Design for the E-ELT Dome is being developed with the objective of optimizing the design to minimize the manufacturing, erection and operation costs.

The concept is based on a hemispherical dome tightly fitted to the dome design volume to minimize the enclosed volume and consequently the cost.

The large observing slit, large as compared to the dome diameter, is covered by means of two horizontal biparting doors. The rest of the dome mechanisms and handling systems are solved by means of customized designs.

The design work presented in this paper has been performed under contract with the European Southern Observatory (ESO).

7733-73, Session 17

Seismic analysis of Giant Magellan Telescope (GMT)

F. W. Kan, A. T. Sarawit, Simpson Gumpertz & Heger Inc. (United States)

The Giant Magellan Telescope (GMT) is a 21.5-meter equivalent aperture optical-infrared ELT to be located at Las Campanas Observatory in Chile. It is being designed and constructed by a group of U.S. and international universities and research institutions. The Project is currently mid-way through its Design Development Phase.

This paper will discuss the seismic analysis of the GMT telescope structure. Dynamic analyses were performed to determine the response of the telescope structure to earthquake-induced ground motion for operational and survival earthquake levels. Response spectrum curves and ground motion time history data from site specific probabilistic seismic hazard study were used as inputs to modal response spectrum analysis and non-linear time history analysis. The results of the two analysis methods in the form of accelerations, displacements, and stresses were compared. The performance of the telescope structure was evaluated against the seismic design requirements. These results were used in the final design of the telescope structure and its subsystems.

7733-74, Session 18

Modeling a large submillimeter-wave observatory

J. Z. Lou, D. C. Redding, A. Kissil, S. A. Basinger, Jet Propulsion Lab. (United States)

The 25-m aperture Cornell Caltech Atacama Telescope (CCAT) will provide an enormous increase in sensitivity over the submillimeter bands compared to existing observatories, provided it can establish and maintain excellent image quality. To accomplish this at a very low cost, it is necessary to conduct accurate engineering trades to determine the best mirror materials, the best wavefront sensing approach, the best method for continuously maintaining wavefront quality in the operational environment, and many other design issues. We describe an integrated structural/optical/controls model that provides accurate performance prediction. We also detail the analysis methods used to quantify critical design trades, and simulation results of the CCAT integrated modeling will be discussed.

7733-75, Session 18

Giant Magellan Telescope primary mirror cell

C. L. Hull, J. Bagnasco, Carnegie Observatories (United States); S. M. Gunnels, Paragon Engineering (United States); J. Kern, M. W. Johns, S. A. Shectman, A. Talmor, M. Ward, Carnegie Observatories (United States)

The Giant Magellan Telescope Mirror cell provides positioning, support, with active optics compensation, and thermal control of the 8.4 meter primary mirror.

The mirror cell is a large steel welded structure, and in the case of the outer off-axis segments, is designed to be interchangeable for any one of the 6 possible mirror positions.

The mirror support and active optics compensation are provided through a series of single axis and three axis pneumatic actuators that control the force used to support the mirror at a total of 165 positions and allows for support of the mirror in any one of the six positions.

Mirror positioning is provided by a stiff hexapod actuator between the mirror and the mirror cell.

Mirror thermal control is provided by a series of fans that pressurize the mirror cell and condition the air before it is directed onto the mirror through 1700 nozzles.

This report describes the mirror cell structure, mirror support and positioning components, and mirror thermal control.

7733-76, Session 18

Tinsley progress on stress mirror polishing (SMP) for the Thirty Meter Telescope (TMT) primary mirror segments II

J. Daniel, U. Mueller, T. Peters, S. F. Sporer, J. M. Barentine, T. B. Hull, L-3 Communications Tinsley Labs. Inc. (United States)

Latest progress on Tinsley methods are described for faster stress mirror polishing of the Thirty Meter Telescope primary mirror segments. These methods are outlined, and full scale segment data results are presented. The Tinsley method complements additional processes at ITT Industries Space Systems, with the potential to effectively optically finish all TMT segments.

7733-77, Session 18

Wavefront controls for a large submillimeter-wave observatory

D. C. Redding, J. Z. Lou, A. Kissil, S. A. Basinger, Jet Propulsion Lab. (United States)

The 25-m aperture Cornell Caltech Atacama Telescope (CCAT) will provide an enormous increase in sensitivity over the submillimeter bands compared to existing observatories, provided it can establish and maintain excellent image quality. To accomplish this at a very low cost, it is necessary to conduct accurate engineering trades to determine the best mirror materials, the best wavefront sensing approach, the best method for continuously maintaining wavefront quality in the operational environment, and many other design issues. We describe an integrated structural/optical/controls model that provides accurate performance prediction. We also detail the analysis methods used to quantify critical design trades.

7733-78, Session 18

Analysis of Giant Magellan Telescope (GMT) off axis primary mirror

F. W. Kan, A. T. Sarawit, Simpson Gumpertz & Heger Inc. (United States); S. M. Gunnels, Paragon Engineering (United States)

The GMT primary mirror system consists of seven 8.4 m diameter borosilicate mirrors with an overall aperture of 25.5 meters and a filled-aperture equivalent area of 21.5 meters. The mirror support and active optics compensation are provided through a series of single-axis and three-axis pneumatic actuators at a total of 165 positions that control the force used to support each off axis mirror.

This paper will discuss the static analysis of the off axis primary mirror segments performed to evaluate the performance of the mirrors in operating conditions. A detailed finite element model of an off axis mirror segment, which includes the cast mirror blank, hardpoint wedges, and the loadspreader assemblies, was developed. The model was used to evaluate the effects of the forces applied to the GMT off axis segments by the mirror support, positioning, and active optics compensation systems. Analyses were performed for nominal actuator force sets for different gravity orientations and for actuator force errors due to misalignment of the segment on its supports. The front surface deflections and glass stresses from these analyses will be presented. The finite element model developed in this study will be used in future to optimize axial and lateral support forces, and to perform thermal analysis.

7733-79, Session 18

CFRP truss for the CCAT 25m diameter submillimeter-wave telescope

D. P. Woody, S. Padin, California Institute of Technology (United States); T. A. Sebring, Cornell Univ. (United States)

CCAT is a 25 m diameter submillimeter-wave telescope that will operate inside a dome located on Cerro Chajnantor in the Atacama Desert. The telescope must have high aperture efficiency at a wavelength of 350 microns with good performance out to 200 microns. The goal is to produce a complete passive telescope system with <10 microns ½ wave front error (WFE) using only a lookup table to correct for gravitational deformations.

A truss design for supporting the primary reflector has been developed that utilizes carbon fiber reinforced plastic (CFRP) tubes and metallic end fittings and nodes. The design exploits the very high strength to weight ratio and low coefficient of thermal expansion (CTE) of CFRP to produce a truss that is very stiff (resonant frequency ~10 Hz) and has small thermal distortions. Extensive use of “thermal homology” is invoked to distribute the CFRP to steel interface throughout the 3-D

volume between the two elevation bearings. A temperature change of 20 K for the whole telescope produces less than 0.2 micron ½ WFE despite the large differences in the CTE between steel and CFRP. The thermal performance requires not only a low average CTE, on the order of 0.2 ppm/K, but also the same effective CTE for all of the struts. A strut and end fitting design has been developed that will have a low effective CTE that can be tuned to the design value for different length struts.

7733-81, Session 19

Shack-Hartmann phasing of segmented telescopes using Fresnel diffraction

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The segments in the Keck telescopes are routinely phased using a Shack-Hartmann wavefront sensor with subapertures that span adjacent segments. However, one potential limitation to the absolute accuracy of this technique is that it relies on a lenslet array (or a single lens plus a prism array) to form the subimages. These optics have the potential to introduce wavefront errors and stray reflections at the subaperture level that will bias the phasing measurement. As part of the design of the Thirty Meter Telescope Alignment and Phasing System we investigate a lenslet-free approach that relies on Fresnel diffraction to form the subimages at the CCD. We present simulations of our results along with a comparison to experimental data.

7733-82, Session 19

Edge sensors for controlling segmented mirrors: a full industrial and turnkey product solution

B. Luong, C. Néel, A. Périn, D. Rozière, FOGALE nanotech (France)

This paper presents recent progresses in designing a nanometer-accurate inductive-type of edge sensor. A new technology of Direct Deposit on Glass (DDG) has been developed by FOGALE nanotech. The conductor coils are directly deposited on a highly mechanical stable glass substrate with micrometer accuracy and precision. The DDG sensor has a lean design, eliminating all together any intermediate material layer(s) between the coils and the substrate. The DDG technology also has high rate of reproducibility and is suitable for a manufacturing process of a large quantity of sensors. This eliminates one complex step of characterization of sensor positioning on the substrate. A lower rate of manufacturing failure is expected thus bringing a significant advantage for the mass production and still remains a very cost-effective solution.

The inductive principle having conductor coils showing to be a flexible design parameters that in turn can be optimized for specific optical needs such as different sensitivities to the focus mode. The out-of-plane piston measurement is designed so as not to be sensitive to the parasite in-plane movements of the segments. The in-plane motion can be still however measured with the coils that are sensitive to the change in gap and shear.

We discuss various electronic architectures and their impacts on the maintainability of the system when the segments are replaced taking into account the cost, power dissipation constraints; synchronization and cross-talk within the array of sensors.

We conclude by showing the experimental results for long term stability, aging tests, temperature, humidity, and dust sensitivity.

7733-83, Session 19

Dynamical aspects in control of E-ELT segmented primary mirror (M1)

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Control of primary segmented mirror of an extremely large telescope with large number of actuators and sensors and multiple control loops is a complex problem. The designer of the M1 unit is confronted to the dilemma of trade-off between the relatively though performance requirements and the robust stability of the control loops. Another difficulty arises from the contradictory requirements of the stiffness of the segment support system and position actuators for wind rejection on one hand and vibration mitigation on the other hand. The presence of low frequency mechanical modes of the back structure and possible interaction of the large number of control loops through such structure could be a limiting factor for achieving the required control bandwidths. To address these issues a better understanding of dynamical behavior of segmented mirror is necessary. This paper addresses the trade-offs on dynamical aspects of the M1 segmented mirror and the robust stability conditions of various control loops.

7733-84, Session 19

Servo design and analysis for the Thirty Meter Telescope primary mirror actuators

P. M. Thompson, Systems Technology, Inc. (United States); D. G. MacMynowski, California Institute of Technology (United States); M. M. Colavita, M. W. Regehr, Jet Propulsion Lab. (United States); M. J. Sirota, TMT Observatory Corp. (United States)

The Thirty Meter Telescope has 492 primary mirror segments, each supported by a Primary Support Assembly (PSA), each of which in turn has three actuators that control piston, tip, and tilt, for a total of 1476 actuators. Each actuator has a servo loop that controls small motions (nanometers) and large motions (5 millimeters). Candidate actuators were designed and tested that fall into the categories of “hard” and “soft,” depending on the offload spring stiffness relative to the PSA structural stiffness. Dynamics models for each type of actuator are presented, which respectively use piezo-electric transducers and voice coils. Servo design and analysis is presented that includes assessments of stability, performance, robustness, and control structure interaction. The analysis is presented for a single PSA on a rigid base and then using Zernike approximations the analysis is repeated for 492 mirror segments on a flexible mirror cell. Servo requirements include low-frequency stiffness, needed for wind rejection; reduced control structure interaction, specified by a bound on the sensitivity function; and mid-frequency damping, needed to reduce vibration transmission. The last of these requirements, vibration reduction, was found to be an important distinguishing characteristic for actuator selection. Hard actuators have little inherent damping, which is improved using PZT shunt circuits and force feedback, but still these improvements were found to result in less damping than is provided by the soft actuator. Results of the servo analysis were used for an actuator down-select study.

7733-85, Session 20

Dynamic characterization of a prototype of the Thirty Meter Telescope primary segment assembly

M. W. Regehr, Jet Propulsion Lab. (United States); P. M. Thompson, Systems Technology, Inc. (United States); M. M. Colavita, Jet Propulsion Lab. (United States)

Finite element models (FEMs) are being used extensively in the design of the Thirty Meter Telescope (TMT). One such use is in the design and analysis of the Primary Segment Assembly (PSA). Each PSA supports one primary mirror segment on the mirror cell, as well as three actuators, which are used to control three degrees of freedom - tip, tilt, and piston - of the mirror segment. The dynamic response of the PSA is important for two reasons: it affects the response of the mirror to fluctuating wind forces, and high-Q modes limit the bandwidth of the control loops which drive the actuators, and impact vibration transmissivity. We have completed a series of tests on a prototype PSA, in which the dynamic response was tested. We report on the test methods used to measure the dynamic response of the PSA alone and with candidate actuators installed, and we present comparisons between the measured response and FEM predictions. There is good agreement between FEM predictions and measured response over the frequency range within which the dynamic response is critical to control system design.

7733-87, Session 20

Meeting highest performance requirements for lowest price and mass for the M1 segment support unit for E-ELT

J. R. Nijenhuis, R. F. M. M. Hamelinck, TNO (Netherlands)

The largest telescope in the world will be the E-ELT. Its primary mirror being 42m in diameter. This mirror will consist of 984 hexagonal segments that are all individually supported. Each mirror will be controlled in six DOF while local shaping of the segments is provided by so called warping harnesses. These be able will correct for focus, astigmatism and trefoil. Hence a mirror with an extreme diameter to thickness ratio of almost 30 is obtained. Its support structure must guarantee a maximum surface form error of 30 nm rms independent of the segment attitude. Furthermore its stiffness to mass ratio must allow natural frequencies of 50Hz or higher to obtain sufficient bandwidth for the actuators that control the piston and tip/tilt of the segment.

Designing such structure is a challenge that has been successfully completed. It will be built in early 2010, hence allowing to present actual results at the conference. The lecture will concentrate on the main performance requirements and how they could be transferred into an elegant structure design. Furthermore an overview will be given about its main performance parameters to see whether present design could be further optimized.

7733-88, Session 20

Results of the wind evaluation breadboard for ELT primary mirror control

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The Wind Evaluation Breadboard (WEB) is a primary mirror and telescope formed by seven aluminium segments, including position sensors, electromechanical support systems and support structures. WEB has been developed to evaluate the performance of the control of wind buffeting disturbance on ELT segmented mirrors using an electro-mechanical set-up which simulates the real operational constrains applied to large segmented mirrors. This paper describes the close loop control design, including the dynamical characterization of the instrument and the control architecture, with the segments modal control, actuators local control, coupling treatment and feed forward. The integration of the instrument in the observatory and the results of the experiment are summarised, with different wind conditions, elevation and azimuth angles of incidence. Conclusions are extracted with respect the wind rejection performance and the control strategy for an ELT.

WEB has been designed and developed by IAC, ESO, ALTRAN and JUPASA, with the participation of FOGALE and TNO. This activity has been supported by the European Community (Framework Programme 6, ELT Design Study, contract No 011863) and the Spanish Science and Technology Ministry.

7733-189, Session 20

Robustness of Thirty Meter Telescope primary mirror control

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The primary mirror control system for the Thirty Meter Telescope (TMT) maintains the alignment of the 492 segments in the presence of both quasi-static (gravity and thermal) and dynamic disturbances due to unsteady wind loads. The latter results in a desired control bandwidth of 1 Hz at high spatial frequencies. The achievable bandwidth is limited by robustness to (i) uncertain telescope structural dynamics (control-structure interaction, or CSI) and (ii) small perturbations in the ill-conditioned influence matrix that relates segment edge sensor response to actuator commands. Both of these effects are considered herein using models of TMT. The former is explored through multi-variable sensitivity analysis on a reduced-order Zernike-basis representation of the structural dynamics. The interaction matrix ("A-matrix") uncertainty has been analyzed theoretically elsewhere, and is examined here for realistic amplitude perturbations due to segment and sensor installation errors, and sensor gap-dependence caused by gravity and thermal induced segment motion. The primary influence of A-matrix uncertainty is on the control of "focus-mode"; this is the least observable mode, measurable only through the edge-sensor sensitivity to the dihedral angle between segments. Stability will require updating the A-matrix with sensor gap-dependence. The A-matrix uncertainty also results in a higher gain-margin requirement for focus-mode, and hence the A-matrix and CSI robustness need to be understood simultaneously. Based on the robustness analysis, the desired 1 Hz bandwidth is achievable in the presence of uncertainty for all except the lowest spatial-frequency response patterns of the primary mirror; these are adequately controlled with a lower bandwidth.

7733-89, Session 21

Commissioning results from the Large Binocular Telescope

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While the ultimate proof of telescope performance is in the quality and amount of science it is able to produce, commissioning results give a good and in-depth indication of how well a telescope facility actually performs, both in terms of sub-system commissioning and on-sky commissioning. The Large Binocular Telescope has a very large number of instrument focal stations, six per side of the telescope for a total of twelve focal stations, all of which have to be commissioned to verify adequate performance. Results from those commissioning activities are presented, along with lessons learned and a discussion of the challenges for future commissioning required to prepare the LBT for true Binocular Operation and ultimately interferometric operations.

7733-90, Session 21

VISTA Telescope opto-mechanical integration

P. F. Jeffers, National Solar Observatory (United States); D. M. Henry, UK Astronomy Technology Ctr. (United Kingdom)

VISTA is a survey telescope which delivers 0.5 arc second images over a 1.65 degree diameter unvignetted field of view. The project was split into separate specific work-packages which after successful individual acceptance were integrated by the project office. The main mechanical integration is the matching up of two sides of a controlled interface and should be a very straightforward process, this covers the mounting of the M2 collimation unit (M2U), the installation of the M2 mirror assembly onto the M2U, the M1 attachment to the M1 support system components and installation of the Instrument mass simulator. The second stage of this integration is the mechanical alignment of the optical elements ie M1 & M2 to the telescope's mechanical axis. This is achieved through use of jigs and alignment equipment combined with the inbuilt adjustment in both the M2 on the M2U and the manual adjustment of the M1 through it's positional definers. This then leaves the telescope in a state ready to start optical commissioning using a Shack Hartman wavefront analyzer.

This paper deals with the mechanical integration and alignment of the telescope components up to the start of optical commissioning. There will be discussion of the build up of information through the separate component acceptance details, to the equipment methodology, preparation and actual integration of the different systems There will also be discussion of lessons learned, timeframes for different activities and how the build up to the integration was assisted by the approach adopted through the separate component builds.

7733-91, Session 21

Main axis control of the Large Millimeter Telescope

D. R. Smith, MERLAB, P.C. (United States); K. Souccar, Univ. of Massachusetts Amherst (United States)

The initial operation of the Large Millimeter Telescope/Gran Telescopio Milimetrico (LMT/GTM) main axis servo system showed promising results, with subarcsecond RMS performance even without a complete drive system. Since that time, there has been substantial progress in the commissioning of the system. For example, the alignment and grouting of the elevation axis gear rims is completed and all motors have been installed. This has allowed full-speed operation in both axes and has enabled some tuning of the servo system.

The digital control architecture of the LMT/GTM allows the rate loop and position loop to be configured either as a classical proportional-integral (PI) controller or as a model-based (e.g., LQG) state-space controller. Additionally, the architecture permits additional special-purpose control features to be implemented, including friction compensation and lookup table feedforward to reduce nonlinear effects.

With the tuning of the control system, the performance has improved. Results are presented for the LMT/GTM main axis slewing, pointing, and tracking performance with both PI-PI and LQG controllers. Additionally, the effects of nonlinear compensation systems are presented. These include lookup table feedforward to improve performance in crossing joints in the azimuth track, as well as friction compensation control to improve static positioning accuracy.

7733-92, Session 21

Friction compensation strategies in large telescopes

D. R. Smith, MERLAB, P.C. (United States); K. Souccar, Univ. of Massachusetts Amherst (United States)

For large telescopes, management of axis friction presents a significant challenge. In some cases, this is avoided or minimized in the design stage by employing hydrostatic bearings. However, the main axis servo systems of many large telescopes must cope with bearing or wheel friction. This friction affects or limits servo control performance in several ways. The most obvious is the stick-slip limit cycle that is characteristic of trying to hold position with an integrating control system in the presence of friction. If it is not taken into account, friction also introduces effects into the state estimation in model-based controllers.

There are several standard approaches to friction compensation. These include dithering (introducing a noise signal to the drive motors), direct Coulomb friction compensation (sending an additional torque based on the rate command), and adaptive techniques based on monitoring of the final drive velocities.

In this work, we experimentally compare different friction compensation approaches on the static positioning performance of the Large Millimeter Telescope/Gran Telescopio Milimetrico (LMT/GTM). Single and double integrator systems are investigated, as well as direct Coulomb friction compensation. Further, since the azimuth axis of the LMT/GTM has 16 wheels, all of which are driven, the behavior of friction compensation systems is investigated as a function of the number of drive wheels per corner.

7733-93, Session 22

Mechanical principles for large mirror supports

H. J. Kärcher, P. Eisenträger, M. Süss, MT Mechatronics GmbH (Germany)

Large thin meniscus mirrors use force controlled shape actuators to obtain the required optical performance. The shape actuators can be interpreted as an advancement of classical mirror supports as whiffle trees or iso-static levers, which worked purely mechanical. The paper develops, after a short historical overview, the theoretical background of mirror mechanics. Different combinations of force controlled shape actuators with mechanical, hydraulic or pneumatic whiffle trees or iso-static levers are analyzed in regard of their impact on optical performance, dynamic and control behavior. The investigations were the basis for the choice of the shape actuator system for the E-ELT M2, executed by MT Mechatronics under an ESO contract.

The chosen system is based on a pneumatic whiffle tree with add-on voice coil type force actuators, which allowed the reduction of waste heat production -compared with shape actuators without underlying whiffle tree system - by an order of magnitude.

7733-94, Session 22

VISTA M1 support system

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Abstract: The VISTA Telescope is obtaining superb survey images. The M1 support system is essential to image quality and uses astatic pneumatic supports to balance the M1 against the varying effects of gravity and wind, with four axes being actively controlled via software and CANbus. The system also applies externally determined active optics force patterns.

The mechanical, electronic, software and control design and as-built operation of the system are described, with the practical design points discussed.

7733-95, Session 22

LSST Telescope primary/tertiary mirror cell assembly

D. R. Neill, E. A. Hileman, National Optical Astronomy Observatory (United States)

The Large Synoptic Survey Telescope (LSST) primary/tertiary (PM/

TM) mirror cell assembly supports both on-telescope operations and off-telescope mirror coating. This assembly consists of the PM/TM monolith mirror, the mirror support systems, the thermal control system, a stray light baffle ring, a laser tracker interface and the supporting steel structure. During observing the PM/TM mirror is actively supported by figure control actuators and a hexapod. The PM/TM figure control actuators distribute the load to safely support the glass mirror and actively control its shape. The position of the mirror relative to the mirror cell is controlled by a set of six hard points (displacement controlled actuators) that form a large hexapod. When the active system is not operating the mirror is supported by a separate passive system. The center of the mirror cell supports a laser tracker which measures the relative position of the camera and secondary mirror for alignment by their hexapods. The mirror cell design height of 2 meters provides ample internal clearance for installation and maintenance of mirror support and thermal control systems. The mirror cell also functions as the bottom of the vacuum chamber during coating. Consequently, to withstand the vacuum induced stress the PM/TM mirror cell will be fabricated from high strength A572 Grade 60 steel. The vacuum induced mirror cell deformations must be isolated from the mirror support system to prevent overstressing the mirror. This is accomplished by utilizing separate truss support systems for the top deck and the vacuum boundary.

7733-96, Session 22

Six degrees of freedom, sub-micrometer positioning system for secondary mirrors

R. C. Sneed, M. F. Cash, T. S. Chambers, P. C. Janzen, CSA Engineering, Inc. (United States)

Secondary mirrors for large ground-based telescopes often require positioning systems with payload capacities on the order of 1000 kg, relative accuracies within a few micrometers, and high resonant frequencies. A suitable six-leg parallel manipulator, or hexapod, has been developed for sub-micron level positioning of large optical payloads in six degrees of freedom.

This 1000 kg class hexapod has tip/tilt rotational ranges of ±1800 arcsec and relative accuracies of ±0.020 arcsec, along with a piston translational range of ±30 mm and relative accuracy of ±125 nm for small moves. The rotational and translational rates are ≥20 arcsec/s and ≥200 μm/s, respectively. The center of rotation of the system may be placed at an arbitrary location within the range limitations of the system. The axial stiffness of each of the six actuators tested greater than 100 N/μm in order to maintain the resonant frequencies >20 Hz.

The actuators use high precision roller screws and have two degree of freedom universal joints at each end comprised of preloaded roller bearings. The preload on the joints eliminates backlash due to transitions from tension to compression and maintains friction moment of <10 Nm. An additional rotational degree of freedom is allowed in the body of the actuator to achieve the proper kinematic constraints for the motion platform. The actuators have power-off hold capability to protect against power loss and reduce heat dissipation. Overall heat dissipation has been measured and techniques have been studied to reduce its impact. The paper describes the actuator design and hexapod performance leading to its delivery and use in ground test and validation of the James Webb Space Telescope.

7733-97, Session 22

An alternative architecture and control strategy for hexapod positioning systems to simplify structural design and improve accuracy

J. H. Beno, J. A. Booth, J. R. Mock, The Univ. of Texas at Austin (United States)

Hexapod systems (6 legged Stewart Platforms), offer advantages in accuracy over other positioning systems and are finding applications in numerous telescopes. However, instruments with increased sophistication for modern telescopes continue to grow in size and required positioning accuracy. This paper details an alternative hexapod configuration and design approach, particularly focused on relatively large, high precision hexapod systems supporting high mass payloads. The new configuration improves accuracy, reduces actuator mass, simplifies design, and reduces system cost but requires modest additional control algorithm sophistication.

Conventional hexapod design focuses on optimizing design and placement of the six actuator-sensor units. Essentially, the actuator "defines" the hexapod. For high mass payloads, maximum deflections occur in and around the powerful actuators, placing high emphasis on stiffness in and around actuators and their mounts (ujoints, spherical joints, etc.) This is particularly true for actuators that employ rotary sensors on shafts of screw or worm drives, a common topology because of complications associated with integrating true linear sensors into high force linear hexapod actuators. The alternative configuration and control system described in this paper decouples the sensor from the actuator. Linear sensors are positioned independent of actuator location, allowing independent optimization of actuator design/placement and sensor design/placement. Actuators are controlled with a force control strategy to yield precise sensor lengths. Truly optimized sensor design/placement yields improved correlation between sensor readings and payload configuration for improved accuracy with less reliance on compensation tables. The sensor "defines" the hexapod, substantially alleviating actuator stiffness requirements and reducing their mass and cost.

7733-99, Session 23

Using nodal aberration theory of higher order field aberrations in the initial alignment of the Large Synoptic Survey Telescope

T. Schmid, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States); K. P. Thompson, Optical Research Associates (United States); J. P. Rolland, Univ. of Rochester (United States); D. R. Neill, J. Sebag, W. J. Gressler, Large Synoptic Survey Telescope (United States)

The classical evaluation of on-axis performance of modern telescopes produces insufficient alignment, particularly for wide-field (survey) telescopes. As the result of the secondary mirror's coma-free pivot point, tip/tilt coma can be compensated by secondary mirror decenter. Proper alignment requires the evaluation of additional aberrations (e.g. astigmatism) across the field of view. For the particular case of the Large Synoptic Survey Telescope (LSST) an approach based on third and fifth order field aberrations has been developed for the computation of misalignment parameters. To demonstrate this approach, an initial alignment plan was developed for the LSST, without the science camera. This represents a unique case since without the science camera optics, large residual wavefront aberrations remain. Since in any real application non-alignment induced aberrations will also exist, additional mirror figure errors were included in the analysis. It will be demonstrated to what extent the aberration error sources can be distinguished. It is shown how the concept of pivot points can be extended to capitalize on the nodal properties of oblique spherical aberration and third order astigmatism, de-sensitizing the alignment approach to influences from mirror figure errors. A case study for the initial alignment of the LSST is presented and misalignment parameters predicted. Correction (including mirror bending modes) based on wavefront measurements at several field-points are provided. Analytical results are compared to optical design software results. A summary technique to align the three-mirror system is described.

7733-100, Session 23

A 2-mirror unobscured wide-field telescope and autocollimator design

R. F. Horton, T. W. Peck, A. Colgate, ad hoc Optics (United States)

A family of 2 mirror wide field unobscured telescopes have been designed. An example will be described and compared to current designs. The general description will be that of an off axis Cassegrain, with aspheric surfaces and geometric adjustments. The design provides a wide diffraction limited field of view with a slightly tilted focal plane. The MTF performance of the system is that expected of a totally unobscured aperture. There are no refractive elements so the system performance is constant in wavelength with no color aberrations. The system can be fully baffled against stray light. Simple interferometric tests allow straightforward element figuring and system alignment. The system is well suited for use as a visual telescope, CCD camera or high resolution wide field collimator and IR scene projector. As a result of the tilted focal plane, a system under test can not "see" its image reflected by the opaque substrate of the projection reticle, eliminating narcissus. Instead, this reflection can be used to provide a uniform "background" irradiance field. Manufacturing, testing and mounting of the optical system will be discussed.

Conference 7734: Optical and Infrared Interferometry II

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Optical and Infrared Interferometry II

7734-01, Session 1

Recent progress at the Keck interferometer

S. Ragland, W. M. Keck Observatory (United States); R. L. Akeson, NASA Exoplanet Science Institute (United States); M. M. Colavita, Jet Propulsion Lab. (United States); R. Millan-Gabet, NASA Exoplanet Science Institute (United States); J. M. Woillez, P. L. Wizinowich, E. Appleby, B. C. Berkey, A. Cooper, W. Dahl, W. M. Keck Observatory (United States); C. Felizardo, J. Herstein, NASA Exoplanet Science Institute (United States); M. A. Hrynevych, D. W. Medeiros, D. Morrison, T. Panteleeva, J. Pott, B. Smith, K. R. Summers, K. Tsubota, C. Tyau, E. Wetherell, W. M. Keck Observatory (United States)

The Keck Interferometer (KI) combines the two 10m diameter Keck telescopes providing milliarcsecond angular resolution. KI has unique observing capabilities such as sensitive K-band V2, L-band V2 and N-band nulling operations. The instrument status of the Keck Interferometer since the last SPIE meeting in 2008 is summarized along with examples of the science enabled by KI's capabilities. We discuss performance of new visibility observing capabilities including L-band and self-phase referencing modes. A simultaneous dual beam-combiner operation in the K and L-band has been demonstrated, nearly doubling operational efficiency for bright targets. Operational improvements including simplified reliable operations with reduced personnel resources are highlighted. Statistics on lost sky time due to bad weather and telescope, adaptive optics and interferometer failures are presented. We will conclude with a brief review of the current and future developmental activities of KI. Details of ASTRA developments and nulling performance are presented elsewhere at this conference.

7734-02, Session 1

An update on the CHARA array

T. A. ten Brummelaar, H. A. McAlister, Georgia State Univ. (United States); S. T. Ridgway, National Optical Astronomy Observatory (United States); D. R. Gies, N. H. Turner, J. Sturmann, L. Sturmann, G. H. Schaefer, C. D. Farrington, L. Webster, P. J. Goldfinger, Georgia State Univ. (United States)

The CHARA Array is a six telescope optical/IR interferometer run by the Center for High Angular Resolution Astronomy of Georgia State University and is located at Mount Wilson Observatory just to the north of Los Angeles California. The CHARA Array has the largest operational baselines in the world and has been in regular use for scientific observations since 2004. In this paper we give an update of instrumentation improvements, primarily focused on the beam combiner activity. The CHARA Array supports six beam combiners: CHARA CLASSIC, a two way high sensitivity K/H/J band system; CLIMB, a three way K/H/J open air combiner, FLUOR, a two way K band high precision system; MIRC, a four/six way H/K band imaging system; CHAMP, a six way K band fringe tracker; VEGA, a 4 way visible light high spectral resolution system; and PAVO, a 3 way visible light high sensitivity system. The paper will conclude with a review of science results obtained over the last few years, including our most recent imaging results.

7734-03, Session 1

The Very Large Telescope interferometer: 2010 edition

P. Haguenauer, European Southern Observatory (Chile)

The ESO Very Large Telescope Interferometer (VLTI) offers access to the four 8-m Unit Telescopes (UT) and the four 1.8-m Auxiliary Telescopes (AT) of the Paranal Observatory located in the Atacama Desert in northern Chile. The two VLTI instruments, MIDI and AMBER deliver regular scientific results. In parallel to the operation, the instruments developments are pursued, and new modes are studied and commissioned to offer a wider range of scientific possibilities to the community. New configurations of the ATs array are discussed with the science users of the VLTI and implemented to optimize the scientific return. The monitoring and improvement of the different systems of the VLTI is a continuous work. The PRIMA instrument, bringing astrometry capability to the VLTI and phase referencing to the instruments has been successfully installed and the commissioning is ongoing. The possibility for visiting instruments has been opened to the VLTI facility.

The current status of the VLTI is described and prospects on future evolution presented.

7734-04, Session 2

Instrumental developments for the Sydney University stellar interferometer

M. J. Ireland, W. J. Tango, J. Davis, J. G. Robertson, P. G. Tuthill, A. P. Jacob, The Univ. of Sydney (Australia); T. A. ten Brummelaar, The CHARA Array (United States)

The Sydney University Stellar Interferometer (SUSI) is a long baseline optical stellar interferometer, located at latitude -30.32 deg in Australia. It has recently been enhanced by installation of the PAVO beam combiner, which uses a charge-multiplying CCD detector giving a fast, low-noise 2D readout. This allows PAVO to provide wideband wavelength-dispersed beam combination, which improves sensitivity and scientific productivity. PAVO also provides pupil segmentation which improves the instrumental fringe visibility. In preparation for large-scale scientific exploitation of the enhanced SUSI, a remote operations facility has been established, which allows the instrument to be operated from Sydney or elsewhere, with no personnel on site. Another major development is a new control system for the longitudinal dispersion corrector and siderostats. Funding has also been obtained for the development of a high-precision differential astrometry system (MUSCA) which aims to detect planets in binary star systems.

7734-05, Session 2

Magdalena Ridge Observatory interferometer: advancing to first light and new science

M. J. Creech-Eakman, V. D. Romero, C. Cormier, New Mexico Institute of Mining and Technology (United States); C. A. Haniff, D. F. Buscher, J. S. Young, Univ. of Cambridge (United Kingdom); D. J. Westpfahl, New Mexico Institute of Mining and Technology (United States)

We report on the final stages of the design and build efforts for the Magdalena Ridge Observatory Interferometer. Located at an elevation of 10,500 ft, approximately 1 hour west of Socorro, NM, the observatory is being built by the New Mexico Institute of Mining and Technology in close collaboration with scientists from the Cavendish Laboratory at the University of Cambridge. The MROI is being designed and built by a distributed team of about 25 scientists and engineers at these two universities who are actively assembling the array sub-systems including the first-light beam combiner, the fringe tracker, the delay lines and carriages, an end-to-end vacuum beam transport system, an automated alignment system and all the control software infrastructure. Additionally we are working with subcontractors on several other major sub-systems including the unit telescopes and optics, the telescope enclosures, and

the overall array infrastructure. This paper presents an overview of the design of the entire facility, discussions of innovative approaches on several subsystems, and a timeline toward first fringes and scientific commissioning of MROI. Delivery of the first telescope is anticipated in 2010, with first light anticipated in 2011.

7734-06, Session 2

Imaging beyond the fringe: an update on the LINC-NIRVANA Fizeau interferometer for the LBT

T. M. Herbst, Max-Planck-Institut für Astronomie (Germany); R. Ragazzoni, Osservatorio Astronomico di Padova (Italy); A. Eckart, Univ. zu Köln (Germany); G. P. Weigelt, Max-Planck-Institut für Radioastronomie (Germany)

We present an update on the construction and integration of LINC-NIRVANA, a Fizeau-mode imaging interferometer for the Large Binocular Telescope (LBT). The LBT is a unique platform for interferometry, since its two, co-mounted 8.4 meter primary mirrors present a view-independent entrance pupil. This allows Fizeau-mode beam combination, providing 23 meter spatial resolution and 12 meter effective collecting area for panoramic imagery

LINC-NIRVANA will sit at one of the shared, bent focal stations, receiving light from both mirrors of the LBT. The instrument uses visible wavelength radiation for wavefront control, and the near-infrared bands for science and fringe tracking. LINC-NIRVANA employs a number of innovative technologies, including multi-conjugated adaptive optics, state-of-the-art materials, low vibration mechanical coolers, active and passive control, and sophisticated software for data analysis.

The instrument is in its final construction and integration phase. This paper reports on overall progress, including insights gained on large instrument assembly, software integration, science planning, and vibration control. A number of additional contributions to this conference focus on individual subsystems and integration-related issues.

7734-07, Session 3

First results from VLTI near-infrared interferometry on high-mass protostars

S. Kraus, Univ. of Michigan (United States)

Due to the recent dramatic technological advancements, infrared interferometry can now be applied to new classes of objects, resulting in exciting new science prospects.

One of these promising new scientific areas is high-mass star formation, as I am going to highlight in this talk.

Although extensively studied at various wavelengths, the process through which massive stars form is still only poorly understood.

For instance, it has been proposed that massive stars might form like low-mass stars by mass accretion through a circumstellar disk/envelope, or otherwise by coalescence in a dense stellar cluster.

Therefore, clear observational evidence, such as the detection of disks around high-mass protostars, is urgently needed in order to unambiguously identify the formation mode of the most massive stars.

Infrared interferometry provides for the first time the opportunity to compare in detail the mass distribution in the inner-most AU around low-, intermediate-, and high-mass stars, putting the accretion-disk hypothesis for high-mass star formation to a stringent test.

After discussing the technological challenges which result from the special properties of these objects, I will present first near-infrared interferometric observations, which we obtained recently on two high-mass protostars using VLTI/AMBER.

For the interpretation of our data, we employ detailed radiative transfer simulations, finding that our observations can be reproduced with typical low-mass YSO disk models, providing new evidence for the disk-hypothesis in high-mass star formation.

7734-08, Session 3

Mid-infrared stellar interferometry with high spectral resolution

E. H. Wishnow, C. H. Townes, W. Fitelson, S. Lockwood, W. Mallard, D. Wertheimer, Univ. of California, Berkeley (United States)

The Infrared Spatial Interferometer (ISI) has been conducting mid-infrared observations for about 20 years and the instrument system and recent stellar measurements are presented. The ISI is a three telescope interferometer system that operates at 11 microns wavelength using heterodyne detection with CO2 laser local oscillators. Measurements of red giant and Mira stars have been made, using rather consistent instrumentation, over a time period that is long in comparison to stellar luminosity periods. The star Betelgeuse has been shown to vary in size by about 15% during a 16 year period of observation. A new high speed digital spectrometer system is being developed in order to obtain visibility measurements on-and-off individual spectral lines simultaneously. The spectrometer design and its proposed applications will be presented.

7734-09, Session 3

Stellar intensity interferometry: astrophysical targets for sub-milliarcsecond imaging

D. Dravins, H. Jensen, Lund Observatory (Sweden); S. L. LeBohec, The Univ. of Utah (United States)

Intensity interferometry permits very long optical baselines and the observation of sub-milliarcsecond structures. Already phase interferometers have revealed the flattened shapes of rapidly rotating stars such as Achernar or structures inside sources such as Eta Carinae. By giving access to longer baselines and shorter wavelengths, intensity interferometry may increase the spatial resolution by (at least) another order of magnitude, inviting detailed studies of B-type stars with large projected rotational velocities Vsini (Achernar or Regulus) and also rapid rotators with small Vsini (e.g., Vega). Hot O-stars include the variable and very young binary system S Mon, and the interacting Wolf-Rayet binary Gamma Vel (where already the classical intensity interferometer by Hanbury Brown & Twiss could observe how the stellar wind emission extends far beyond the stellar disk).

Signal-to-noise in intensity interferometry favors hot stars and emission-line structures, and is independent of the optical passband, be it a single spectral line or the broad spectral continuum. Some 2600 objects are hotter than 9000 K and brighter than m(v)=7, among which 34 stars are brighter than m(v)=2 or hotter than T(eff)=25,000 K. Various observations have been simulated for telescope configurations envisioned for large Cherenkov facilities (CTA, AGIS), assuming current-performance digital electronics to synthesize very many optical baselines. This enables not merely measurements of stellar diameters but also reveals the finer details of their atmospheres, disks, and circumstellar features, permitting to actually observe the stars themselves (and not merely their starlight!).

7734-10, Session 3

Adaptive optics for the CHARA array II

S. T. Ridgway, National Optical Astronomy Observatory (United States); T. A. ten Brummelaar, J. Sturmann, L. Sturmann, N. H. Turner, H. A. McAlister, Georgia State Univ. (United States); M. J. Ireland, P. G. Tuthill, The Univ. of Sydney (Australia); J. D. Monnier, Univ. of Michigan (United States); D. J. Coburn, C. J. Dainty, N. Devaney, A. V. Goncharov, National Univ. of Ireland, Galway (Ireland)

In order to implement adaptive optics for the CHARA Array we have addressed several interesting challenges. It is necessary to improve image quality both at the telescopes and in the distant beam combining laboratory, with related non-common-path concerns. The design must provide high throughput. The resulting interferometric performance must be correctly estimated. The project cost must be reasonable with respect to likely funding. The project development and additional operations load must be of appropriate scale for the facility staff. Planning for CHARA has now addressed these issues and developed a preliminary design, budget and performance analysis. The layout under development employs only two additional surfaces in the optical train, places the deformable mirror and fast wave front sensor at the telescope, and a slow wavefront sensor at the beam combining area. New technical development has been avoided, with reliance on proven technologies and available products. Expected gains in tilt tracking and interferometric efficiency open substantial new capabilities in study of fainter sources, particularly in the area of Young Stellar Objects. We will present findings, design decisions, and questions which remain open.

7734-11, Session 4

Recent science highlights from the Keck interferometer

R. L. Akeson, California Institute of Technology (United States); M. M. Colavita, Jet Propulsion Lab. (United States); R. Millan-Gabet, California Institute of Technology (United States); S. Ragland, P. L. Wizinowich, J. M. Woillez, W. M. Keck Observatory (United States)

The addition of new observational capabilities and continued sensitivity improvements have allowed observations with the Keck Interferometer to encompass new areas of astrophysics and expanded significantly the available sample size in areas which had been the focus of previous work. The technical details of the instrument techniques (including nulling, L-band and increased spectral resolution) are covered in other contributions to this conference. Here, we will highlight the astrophysics enabled by these instruments, including: a summary of the NASA Exo-zodical Dust Survey Key Project, observations across a range of dust temperatures with K and L-band measurements and faint target studies of active galactic nuclei, young stellar disks and pre-main sequence stellar masses.

The Keck Interferometer is funded by NASA and developed and operated by the Jet Propulsion Laboratory (California Institute of Technology), the W.M. Keck Observatory and the NASA Exoplanet Science Institute (California Institute of Technology).

7734-12, Session 4

Performances and first science results with the VEGA/CHARA visible instrument

D. Mourard, P. Bério, A. Blazit, D. Bonneau, M. Borges, O. Chesneau, J. Clausse, O. Delaa, Observatoire de la Côte d'Azur (France); A. Meilland, Max-Planck-Institut für Radioastronomie (Germany); N. Nardetto, Observatoire de la Côte d'Azur (France); K. Rousselet-Perraut, Lab. d'Astrophysique de l'Observatoire de Grenoble (France); A. Spang, P. Stee, Observatoire de la Côte d'Azur (France); I. Tallon-Bosc, M. Tallon, Ctr. de Recherche Astronomique de Lyon (France); H. A. McAlister, T. A. ten Brummelaar, J. Sturmann, L. Sturmann, N. H. Turner, C. D. Farrington, P. J. Goldfinger, Mount Wilson Institute (United States)

VEGA, Visible spEctroGraph and polArimeter has been installed in September 2007 at the coherent focus of the CHARA array. Science operation is in routine since summer 2008. In this paper we will present the principle and the measured performances of this instrument. With 0.3 ms of arc of spatial resolution and up to 30 000 of spectral resolution, VEGA intends to measure fundamental parameters of stars, to study stellar activities and to image and analyze circumstellar environments. We show that VEGA/CHARA is fully operational. The current limiting magnitude is nearly 7 but the results depend on the observing conditions (seeing, spectral resolution, etc). We have validated the stability of the instrumental visibility at the level of 1 to 2%

We will also present various exemples of the first science results obtained with VEGA.

7734-13, Session 4

AMBER/VLTI performances final update from experimental results

R. G. Petrov, Univ. de Nice Sophia Antipolis (France)

Five years after its first commissioning, the near infrared VLTI focal instrument AMBER has been tested and has provided astrophysical results in all spectral resolutions. Some of the limitations on the measures accuracy found in the instrument hardware have been corrected. For example, the polarizing filters with an air blade introducing Perrot-Fabry variable beatings of the visibility and phase with wavelength have been replaced. Other error sources, such as the unavoidable cross talks between photometric and interferometric beams, have been corrected by software changes. The effect of instrument concept features, such as the relatively long time needed to read multi axial interferograms of single mode beams, have been confronted with the atmospheric jitter on the differential piston. The final accuracies have been confronted with the documented limitations of the current VLTI status such as the relatively important vibrations of the UTs. The theoretical SNR computations have been confronted to experimental reality and this allows updating and validating the parameters of AMBER SNR estimations. The global picture is an update of AMBER measures accuracy, with fair absolute visibility (approaching 0.01), a good differential visibility (a few 0.001) and closure phase (a few 0.001 with specific calibration tools) and a potentially excellent differential phase (better than 0.001 radians), which remains limited by the quality of chromatic OPD corrections. The limiting magnitude is $8<K<9$ in good conditions, and would reach extragalactic values in excellent seeing conditions when the UT vibrations and other VLTI instabilities are damped.

7734-14, Session 4

Status of PRIMA for the VLTI or the quest for user-friendly fringe tracking

C. Schmid, European Organisation for Astronomical Research in the Southern Hemisphere (Germany); R. N. Abuter, European Organization for Astronomical Research in the Southern Hemisphere (Germany); S. Ménardi, L. Andolfato, F. Delplancke, F. Derie, N. Dilieto, R. Frahm, P. B. Gitton, N. Gomes, P. Haguenauer, S. A. Lévêque, S. Morel, A. Mueller, T. Phan Duc, E. Pozna, J. Sahlmann, N. Schuhler, G. T. van Belle, European Organisation for Astronomical Research in the Southern Hemisphere (Germany)

PRIMA, the Phase-Referenced Imaging and Micro-arcsecond Astrometry facility for the VLTI, is being installed and tested in the observatory of Paranal. Most of the tests have been concentrated on the characterization of the Fringe Sensor Unit (FSU) and on the automation of the fringe tracking in preparation of dual-field observations. The status of the facility, a detailed analysis of the FSU performance and the first attempts of dual-field observations will be presented in this paper.

In the FSU, the phase information is spatially encoded into four independent combined beams (ABCD) and the group delay comes from their spectral dispersion over 5 spectral channels covering the K-band. During fringe tracking the state machine of the optical path difference

controller is driven by the signal to noise ratio (SNR) derived from the 4 ABCD measurements. We will describe the strategy used to define SNR thresholds depending on the star magnitude for automatically detecting and locking the fringes.

Further, the SNR as well as the phase delay measurements are affected by differential effects occurring between the four beams. We will quantify the relative contributions of these effects (detector, readout, fiber coupling noises) on the measured phase and SNR noises. We will also assess the sensitivity of the group delay linearity to various instrumental parameters and discuss the corresponding calibration procedures and their expected/achieved accuracy.

Finally we will describe how these calibrations and detection thresholds are being automated to make PRIMA as much as possible a user-friendly and efficient facility.

7734-15, Session 4

MI-6: Michigan interferometry with six telescopes

J. D. Monnier, D. H. Berger, T. A. Eckhause, M. Anderson, X. Che, F. Baron, S. Kraus, Univ. of Michigan (United States); E. Pedretti, N. D. Thureau, Univ. of St. Andrews (United Kingdom); R. Millan-Gabet, California Institute of Technology (United States); T. A. ten Brummelaar, Georgia State Univ. (United States)

I will give a report on the efforts of the Michigan Interferometry group to utilize the six telescopes of the CHARA Array. In particular, I will detail our commissioning observations from 2009 and 2010 of the CHARA-Michigan Phasetracker (CHAMP). In addition, I will show recent imaging results using the MIRC combiner and introduce our plans to upgrade MIRC from 4- to 6-telescope operation in 2010. Progress is sorely needed in developing imaging software for real-life datasets and I will also outline some work at Michigan to advance this area.

7734-16, Session 5

The SIM-Lite astrometric observatory: progress report

J. C. Marr IV, R. Goullioud, M. Shao, Jet Propulsion Lab. (United States)

The SIM Lite Astrometric Observatory (aka SIM Lite), a micro-arcsecond astrometry space mission, has been developed in response to NASA's indefinite deferral of the SIM PlanetQuest mission. The SIM Lite mission, while significantly more affordable than the SIM PlanetQuest mission concept, still addresses the full breadth of SIM science envisioned by two previous National Research Council (NRC) Astrophysics Decadal Surveys at the most stringent "Goal" level of astrometric-measurement performance envisioned in those surveys. Over the past two years, the project has completed the conceptual design of the SIM Lite mission using only the completed SIM technology; published a 250 page book describing the science and mission design (available at the SIM website: http://sim.jpl.nasa.gov); been subject to an independent cost and technical readiness assessment by the Aerospace Corporation; and submitted a number of information responses to the NRC Astro2010 Decadal Survey. The project also conducted an exoplanet-finding capability double blind study that clearly demonstrated the ability of the mission to survey 60 to 100 nearby sun-like dwarf stars for terrestrial, habitable zone planets, even in complex planetary systems. Additionally, the project has continued Engineering Risk Reduction activities by building brassboard (form, fit & function to flight) version of key instrument elements and subjecting them to flight qualification environmental and performance testing. This paper summarizes the progress over the last two years and the current state of the SIM Lite project.

7734-17, Session 5

Potential of balloons payloads for in-flight validation of direct and nulling interferometry concepts

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While the question of low cost / low science precursors is raided to validate the concepts of direct and nulling interferometry space missions, balloons payloads offer a real opportunity thanks to their relatively low cost and reduced development plan. Taking into account the flight capabilities of various balloon types, we propose in this paper, several concepts of payload associated to their flight plan, from low mass concepts (20 kg) to heavier ones (several 100 kg). We also discuss the pros and cons of each concepts in terms of technological and science demonstration power.

7734-18, Session 5

Far-infrared interferometric telescope experiment: FITE

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FITE (Far-Infrared Interferometric Telescope Experiment) is a balloon-borne far-infrared interferometer telescope aiming at high spatial (angular) resolution in the far-infrared spectral region. The interferometer is of a two-beam Fizeau type, same as the Michelson's stellar interferometer. The aperture diameter is 40 cm for each beam, and the baseline length is 8 m for the first flight. A far-infrared linear array sensor, a mid-infrared array sensor, and two optical CCDs are mounted on each focal plane. The optical system behind the interferometer and the two infrared sensors are cooled to 2 Kelvin in a liquid-helium cryostat. The angular resolution is 4 arc-seconds for the first flight, is far better than ever achieved in the far-infrared region, such as around 30 arc-seconds by Spitzer Space Telescope and AKARI. FITE was transported to the balloon launching base in Brazil for its first flight, and will be launched in late 2010.

7734-19, Session 5

The Balloon Experimental Twin Telescope for infrared interferometry (BETTII)

S. A. Rinehart, NASA Goddard Space Flight Ctr. (United States)

Astronomical studies at infrared wavelengths have dramatically improved our understanding of the universe, and observations with Spitzer, the upcoming Herschel mission, and SOFIA will continue to provide exciting new discoveries. The relatively low angular resolution of these missions, however, is insufficient to resolve the physical scale on which mid-to far-infrared emission arises, resulting in source and structure ambiguities that limit our ability to answer key science questions. Interferometry enables high angular resolution at these wavelengths - a powerful tool for scientific discovery. We will build the Balloon Experimental Twin Telescope for Infrared Interferometry (BETTII), an eight-meter baseline Michelson stellar interferometer to fly on a high-altitude balloon. BETTII's spectral-spatial capability, provided by an instrument using double-Fourier techniques, will address key questions about the nature of disks in young star clusters and active galactic nucleiand the envelopes of

evolved stars. BETTII will also lay the technological groundwork for future space interferometers.

7734-20, Session 6

Direct imaging of Earth-like planets: why we care about exozodis

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The presence of large amounts of exozodiacal dust around nearby main sequence stars is considered as a potential show-stopper for the direct detection of Earth-like exoplanets (exoEarths) with future space-based coronagraphic and interferometric missions. In this paper, we estimate the amount of exozodiacal light that can be tolerated around various stellar types without jeopardizing the detection of exoEarths with a space-based visible coronagraph or a free-flying mid-infrared interferometer. We also address the possible effects of resonant structures in exozodiacal disks. We then review the sensitivity of current ground-based interferometric instruments to exozodiacal disks, based on classical visibility measurements and on the nulling technique. We show that the current performances are not sufficient to help prepare future exoEarth imaging missions, and discuss how new ground- or space-based instruments could improve the current sensitivity to exozodiacal disks down to a suitable level.

7734-21, Session 6

The Fourier-Kelvin stellar interferometer (FKSI): infrared detection and characterization of exozodiacal dust to super-Earths, a progress report

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The Fourier-Kelvin Stellar Interferometer (FKSI) is a structurally connected infrared space interferometer with 0.5 m diameter telescopes on a 12.5 m baseline, and is passively cooled to ~60K. The FKSI operates in the thermal infrared from 3-8 µm in a nulling (or starlight suppressing) mode for the detection and characterization of exoplanets,debris disks, extrasolar zodiacal dust levels. The FKSI will have the highest angular resolution of any infrared space instrument ever made with its nominal resolution of 40 mas at a 5 µm center wavelength. This resolution exceeds that of Spitzer by a factor of 38 and JWST by a factor of 5. The FKSI mission is conceived as a "probe class" or "mid-sized" strategic mission that utilizes technology advances from flagship projects like JWST, SIM, Spitzer, and the technology programs of TPF-I/Darwin. During the past year we began investigating an enhanced version of FKSI with 1-2 m diameter telescopes, passively cooled to 40K, on a 20-m baseline, with a sunshade giving a +/- 45 degree Field-of-Regard.

This enhanced design is capable of detecting and characterizing the atmospheres of many 2 Earth-radius super-Earths and a few Earth-twins. We will report progress on the design of the enhanced mission concept and current status of the technologies needed for this mission.

7734-22, Session 6

First results with MANIC: a monolithic nulling interferometer for characterizing extrasolar environments

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We present progress in the development of the Monolithic Achromatic Nulling Interference Coronagraph (MANIC), which is designed to enable direct detection and characterization of Jupiter-like exoplanets and debris-disks. MANIC is a fully symmetric implementation of a rotational shearing interferometer that provides access to both bright and dark outputs, consisting of fused quartz prisms and a symmetric beamsplitter optically contacted in an arrangement that geometrically flips the fields in the TR and RT arms about orthogonal axes such that upon recombination, a centro-symmetric null is produced. In addition to a small inner working angle (~0.5lambda/D), built-in alignment and stability are inherent benefits of the compact monolithic design, which make MANIC a competitive alternative to conventional multi-optic nullers proposed for imaging exoplanetary environments.

Following MANIC's initial fabrication, a multi-interferometer setup implementing a pupil-bisecting alignment cube and PZT-controlled delay line was used to measure the path error between its TR and RT arms. A calibration interferometer was used to determine the delay between the injection beams and thereby enable recovery of the path error in the monolith from the overall phase lags measured in the combined nuller and delay line half-pupil interferometer outputs. This measurement was used to determine thicknesses for compensator plates that have been bonded to the optic to reduce dispersion imbalance, which improves nulling performance. Initial benchtop laser and polychromatic nulling results will be presented along with future plans for the optic. The 180 degree field rotation ambiguity and stellar leakage attributed to MANIC's design will be addressed.

7734-23, Session 6

SIM-Lite narrow-angle modeling and processing

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The SIM-Lite observatory is a space based optical interferometer that will perform astrometric science with unprecedented accuracy. Mission goals are to perform global astrometry with 4 uas accuracy and narrow angle astrometry at a 1 uas precision level. Important topics addressed with global astrometry include galactic dynamics, improvement of basic distance yardsticks, quasar astrophysics, and others. The focus of the narrow angle observations is to detect and characterize the orbits of planets around nearby stars with special emphasis on identifying Earth-sun analog systems. This paper will address the modeling and processing of narrow angle data given realistic spacecraft constraints.

Because of the large-scale nature of the optimization problem associated with global astrometry, the initial data processing effort of reducing instrument interferometric data to astrometric science focused on global astrometry applications. But more recently the issues related to extracting narrow angle science have come to the forefront. A large effort was expended in a "double blind" test where various groups, blind to one another's activities, developed planetary models, converted the planetary models to the synthetic signals produced by the SIM-Lite instrument observations, and then the recovery of the planetary parameters from these signals. The focus of the present paper is to examine the many nuances that arise in the second step of this process. These include the validity of linearized astrometric model parameters for nearby targets with large proper motion, the effect and correction of instrument parameter errors, and the considerations and accommodations associated with realistic observation scenarios constrained by the 1-D nature of the

interferometer measurements made with large gaps due to the solar exclusion angle.

7734-24, Session 7

First Keck interferometer measurements in self-phase referencing mode: spatially resolving circum-stellar line emission of 48 Lib

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Recently, the Keck interferometer was upgraded to do self-phase-referencing (SPR) assisted K-band spectroscopy at R~1800. This means, combining a spectral resolution of 200~km/s with an angular resolution of 2.7~mas, while maintaining high sensitiviy.

This SPR mode operates two fringe trackers in parallel, and explores several infrastructural requirements for off-axis phase-referencing, as currently being implemented as the KI-ASTRA project.

The technology of self-phase-referencing opens the way to reach very high spectral resolution in near-infrared interferometry.

We present the scientific capabilities of the KI-SPR mode in detail, at the example of observations of the Be-star 48Lib. Several spectral lines of the cirumstellar disk are resolved, and the differential phase signal can be used to (i) distinguish circum-stellar line emission from the star, (ii) to directly measure line asymmetries tracing an asymetric gas density distribution, (iii) to efficiently calibrate the wavelength table on the science data, and (iv) to reach differential, astrometric precision beyond single-telescope limits.

7734-25, Session 7

Eight years of operations at the VLTI

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Since its first light in 2001, the VLT Interferometer has known many changes and extensions. The Auxiliary Telescopes entered in operations, the instruments MIDI and AMBER were offered for science to the community and in the future, PRIMA will start science operations. Facilities like the fringe tracker FINITO and the guiding camera IRIS were also added to the system. In a span of eight years, the VLTI also went from the commissioning phase using only VINCI to a full fledge science facility, which is open to the whole interferometric community both in service and visitor mode. All these developments were accompanied by a large number of necessary changes in the way the VLTI is operated. The paper will present the improvements of the observing procedures as well as the calibrations and maintenance that were required to accompany all this development. The analysis of the number of target observed by night and publications will be presented as a metric for the performance of the VLTI. The constraints that we are facing and the current results that make the VLTI one of the top Interferometric facilities in the world will also be discussed. Future perspectives and envisioned evolution of our operations will also be presented.

7734-26, Session 7

Configuration of the auxiliary telescopes at VLTI: a status report

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VLTI is the only interferometer performing routine service-mode and visitor-mode operations for an open community of users and over a wide range of scientific goals. One of the key-components are the four relocatable Auxiliary Telescopes, able to make baselines from 8m to almost 200m--although only a few are currently offered. In this paper, we describe the limitations of the currently offered configurations, the on-going efforts to improve them, and the long term work towards a general purpose imaging array. We will discuss in detail the operational and technical constraints that are driving our strategy and in particular the elements that have led us to offer the use of the four ATs in routine operations. We will also present the preliminary results of our current exchange with the community to define an optimal set of configurations to maximize the scientific return of the VLTI.

7734-27, Session 7

AMBER current performances and prospects

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AMBER (the astronomical Multi-BEam Recombiner), has been operational at the Very Large Telescope Interferometer for many years. We present here some of the constant improvements we have been providing while still operating the instrument, with a heavy load of visitor and service programs, most of the nights of the year. In particular, we will present improvements regarding the calibration and intrinsic stability of the instrument in order to bring the best possible accuracy to the astronomical observations.

7734-28, Session 7

Keck interferometer nuller instrument performance

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The Keck Interferometer combines the two 10 m Keck telescopes as a long baseline interferometer, funded by NASA, as a joint development among the Jet Propulsion Laboratory, the W. M. Keck Observatory, and the NASA Exoplanet Science Institute. In Feb 2008, the 10 um nulling mode began a 36 night observing program with three key-science teams to perform a survey of nearby stars for exozodiacal dust. This program has recently concluded, and has been followed by continued TAC-allocated nuller observing on a variety of science topics. We review the updated technical performance of the instrument based on the full data set, including sensitivity and systematic errors; the data reduction process, including the calibration approach; practical aspects of the

observing process for efficiency and data consistency; and summary data on atmospheric effects applicable to the cophasing approach.

7734-29, Session 7

Phase closure nulling: results from the 2009 observing campaign

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Phase closure nulling corresponds to interferometric observations when the system visibility amplitude is close to zero due to the large diameter of the primary star. In this case, Chelli et al. (2009) have shown that it would enhance the detection of close and faint companions. In 2009, we have conducted an campaign of observation on the VLTI/AMBER and CHARA/MIRC. This contribution will present the results of this campaign, gives the performances actually obtained on the telescopes and discuss the perspectives of such observation with new instruments.

7734-30, Session 7

Emerging capabilities of the Magdalena Ridge Observatory interferometer: commissioning and science readiness

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The Magdalena Ridge Observatory Interferometer (MROI) has been designed and is currently under construction. The first telescope will be deployed at the MRO site in 2011. The design and construction of a complete functioning telescope is split into a number of major components, each developed by a different party. At least 5 different main vendors are involved in the design and fabrication of these components and a much larger list of subcontractors.

This paper addresses progress towards first light. Why the design and developments for a unit telescope are split in different segments and the system engineering aspects that are employed. We will present lessons learned based on our experience and project this experiences on the developments of next generation large telescopes (TMT and GMT), and to a new generation of optical interferometer (KOI).

Finally we present the commissioning plan on how to bring the interferometer in operational model. For that we have developed “performance verification milestones” that successively increase the “science readiness” of the interferometer and transitions to an operational phase.

7734-31, Session 7

PACMAN: the PRIMA astrometric instrument software

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The dual feed astrometric instrument of PRIMA that is currently being integrated at the VLTI will use two spatially modulated fringe sensor units and a laser metrology system to carry out differential astrometry. Its software and hardware compromises a distributed system involving many real time computers and workstations operating in a synchronized manner. Its architecture has been designed to allow the construction of efficient and flexible calibration and observation procedures. In parallel, a novel scheme of integrating MATLAB code with standard VLT control software applications had to be devised in order to support numerically intensive operations and to have the capacity of adapting to fast varying strategies and algorithms. This paper presents the instrument software, including the current operational sequences for the laboratory calibration, sky calibration, and observation. Finally, a detailed description of the algorithms with their implementation, both under MATLAB and plain C- code, are shown together with a comparative analysis of their performance, maintainability, and robustness.

7734-32, Session 8

Signatures of strong gravity with GRAVITY

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The dynamics of stars and gas undoubtedly shows the existance of a 4 million solar mass black hole at the center of the Milky Way: Sagittarius~A* (Sgr~A*). Violent flare emission allows us to probe the immediate environment of the central mass.

Near-infrared polarimetry now shows signatures of strong gravity that are statistically significant against randomly polarized red noise allowing to derive spin and inclination information of SgrA*.

A combined synchrotron self Compton (SSC) and adiabatic expansion model with source components peaking at a few THz can fully account for the observed flare flux densities and delay times.

We discuss the centroid paths of the NIR images and shown that the geometrical structure of the emitting region (i.e. spot shape, presence of a torus or spiral-arm pattern etc.) affects the expected centroid tracks.

While all the mentioned geometries are able to fit the observed fluxes, future NIR interferometer GRAVITY on the VLT will break these degeneracies. The results of simulations propose that focusing GRAVITY observations on the polarimetry mode could reveal a clear centroid track of the spot(s). A non-detection of centroid shifts can not rule out the multi-components model or spiral arms scenarios. However, a clear position wander in the center of NIR images during the flares will support the idea of bright long-lived spots orbiting occasionally around the central black hole.

7734-33, Session 8

GRAVITY: a four telescope beam combiner instrument for the VLTI

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GRAVITY is a second generation VLTI instrument currently in its final design phase. It will combine the K-band light of the four 8m telescopes on Paranal interferometrically. Its fringe-tracking ability together with the light collecting power of the large telescopes will yield a unique sensitivity, coupled with the superb resolution and astrometric capabilities of the VLTI. GRAVITY will allow astronomers to observe faint and highly relativistic stars in the immediate vicinity of the massive black hole in the center of the Milky Way and to probe the centroid motion of near-infrared outbursts of the black hole, being dynamical probes very close to the event horizon. In order to achieve its goals, the instrument uses a near-infrared adaptive optics system to correct for the corrugations induced by Earth's atmosphere. The beam transport to the beam combiner is stabilized by means of a dedicated guiding system. The beam combiner consists of a fringe-tracking and a science channel, two fiber-fed integrated optics devices the outputs of which are spectrally dispersed before detection. The internal path lengths are monitored with a dedicated metrology system. GRAVITY is designed to deliver astrometry at the level of 10 µas within a field of 2" and interferometric imaging within 50mas. The fringe-tracker will be able to work with stars as faint as mK=10. GRAVITY is a project done jointly by groups at MPE, Paris Meudon, MPIA, University of Cologne, LAOG and SIM. This talk gives an overview of the current instrument design.

7734-34, Session 8

MATISSE: perspective of imaging in the mid-infrared at the VLTI

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MATISSE is a mid-infrared spectro-interferometer combining the beams of up to four UTs/ATs of the VLTI of the ESO. The science case study demonstrates the enormous capability of a new generation mid-infrared beam combiner.

MATISSE will constitute an evolution of the two-beam instrument MIDI. New characteristics present in MATISSE will give access to the mapping and the distribution of the material in the circumstellar environments by using a wide mid-infrared band coverage extended to L, M and N spectral bands. The four beam combination of MATISSE provides an efficient UV-coverage: 6 visibility points and 4 closure phase relations which can provide aperture synthesis images in the mid-infrared spectral regime. We will present the status of the project under development and which involves several collaborations and the following main institutes: the MPIA of Heidelberg; the MPIfR of Bonn; the ITPA of Kiel, the Univ. of Leiden and ASTRON of Dwingeloo and the OCA of Nice.

7734-35, Session 8

The potential performance of the mid-infrared second-generation VLTI instrument MATISSE

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MATISSE is a 4 beams interferometric instrument with L-M and N band spectrographs of resolution ranging from about 30 to about 1500. The sensitivity of the MATISSE coherent flux to background fluctuations will be reduced by a cascade of calibration mechanisms such as a multi axial combination of spatially filtered beams, like in AMBER, a subtraction of the two interferograms separated by a pi phase shift obtained at both outputs of a Michelson like interferometer (like in MIDI) and a temporal modulation of the OPD during the coherence time (inspired from MIDI). Combined with additional calibrations, such as beam commutation or chromatic OPD calibration, this should yield accurate closure phases and differential phases. For absolute visibility, the accuracy will be limited by this of photometry measured from chopping a background varying a little because of the atmosphere and a lot because of the pupil instability inside the VLTI. The estimation is based on a formalism validated with data from the first generation instruments MIDI and AMBER, fed with computations of the instrument contrast, transmission, beam and OPD stability specified and analyzed during the preliminary and optical design of MATISSE. The effect of the documented current VLTI features such as vibrations and pupil motion are quantified, and the gain that can be expected from infrastructure improvements is assessed. Then, it is possible to update the potential performances of image reconstruction and model fitting for different MATISSE science programs.

7734-36, Session 8

Science with the Keck interferometer ASTRA program

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ASTRA will provide phase referencing and astrometric observations at the Keck Interferometer, leading to enhanced sensitivity and the ability to monitor orbits at an accuracy level of 30-100 microarcseconds. Here we discuss recent scientific results from ASTRA, and describe new scientific programs that will begin in 2010. We begin with results from the “self phase referencing” (SPR) mode of ASTRA, which uses continuum light to correct atmospheric phase variations and produce a phase-stabilized channel for spectroscopy. We have observed a number of protoplanetary disks using SPR and a grism providing a spectral dispersion of 1800. In our data we spatially resolve emission from dust as well as hydrogen and carbon monoxide gas. Furthermore, the hydrogen line emission is spectrally resolved, allowing differential phase measurements across the emission line that constrain the relative centroids of different velocity components at the 10 microarcsecond level. In the upcoming year, we will also begin dual-field phase referencing (DFPR) measurements of the Galactic Center and a number of exoplanet systems. These observations will, in part, serve as precursors to astrometric monitoring of stellar orbits in the Galactic Center and stellar wobbles of exoplanet host stars. We describe preliminary results in these areas and discuss the design of future science programs.

7734-37, Session 9

ASTRA: the astrometric and phase-referencing astronomy upgrade for the Keck interferometer

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ASTRA, the ASTrometric and phase-Referencing Astronomy upgrade for the Keck Interferometer funded by the National Science Foundation, aims at expanding the existing capabilities of the interferometer in three incremental steps. First, a self-phase-referencing mode, based on an on-axis fringe tracker will allow longer integrations for observations with an increased spectral resolution (R~1800), aimed at benefiting YSOs observations. Second, a dual-field phase-referencing mode, based on an off-axis fringe tracker will allow observing fainter objects (K<15) with a nearby guide star. This mode will mostly benefit extra-galactic astronomy, increasing by an order of magnitude the number of observable AGN. Third, a narrow angle astrometry mode will measure relative positions with precision of ~30-100 microarcseconds for objects separated to 30 arcseconds, and further characterize known (multi-)planet systems. Ultimately, combining the upgraded capabilities of the interferometer with laser guide star adaptive optics on both telescopes will make possible the astrometric monitoring of the inner stars of the galactic center, probing general relativity in the strong field regime.

With the self-phase-referencing mode in routine operation, this contribution focuses on the status of the upcoming modes. First, we will give an overview of the three new subsystems added for the dual-field mode: a field separator, a tip/tilt metrology, and an on-axis longitudinal metrology. Then, we will present the results from the first dual-field runs. Finally, we will outline the design and implementation path chosen for the astrometric mode, based on the addition of an infrared internal longitudinal metrology system and a network of baseline metrology systems.

7734-38, Session 9

Magdalena Ridge interferometer: assembly, integration, and testing of the unit telescopes

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AMOS is in charge of the development of the unit telescopes for the MRO interferometer. This paper depicts the progress status of the project and presents the results of the factory acceptance tests that have been performed at AMOS facilities. Those tests are the earliest verifications of the telescope performance.

AMOS has now a valuable know-how in testing small and large instruments: this covers optical testing, alignment, mechanical static and dynamic measurements, system identification, etc. The strong point is the combination of various techniques of measurement that produce together accurate and reliable results.

Beyond the image quality and the tracking performance, the interferometry necessitates maintaining the optical pathlength between two telescopes sufficiently stable during observation. Another key feature is the pupil stability of each telescope of the array. A brief description of the telescope design shows how it is suitable to these requirements.

The performances are validated by test before installation on site. For each requirement to be verified, the method of test, the set-up, the data processing and the accuracy of measurement are discussed. The results obtained for the first telescope of the array are provided.

7734-39, Session 9

Magdalena Ridge Observatory interferometer automated alignment system

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Depending on the location of each of MROI’s unit telescopes (UT), light can travel distances ranging from 460 to 660 meters via several reflections that redirect the beam’s path through the beam relay trains (BR), delay lines (DL), beam reducing telescope (BCR), switchyards and finally to the beam combiners (BC). All of these sub-systems comprise three major optical axes of the MROI which must be coaligned on a nightly basis by the automated alignment system (AAS). The AAS consists of four subsystems: the primary fiducial-for beam injection, the UT tilt and shear measurement components (TASM), the BC TASM components, and the secondary fiducial-for quick alignment checks. All of these subsystems contribute to the unique design of the AAS which will allow for simultaneous measurements from the visible to the near-IR wavelengths, full automation, the capability to perform optical path difference (OPD) alignment and spectral calibration, making it cost effective and saving on realty in the beam combining area (BCA). The final design of this system has been completed and assembly of the various subsystems is expected to commence soon. Here is presented the current outline and progress of MROI’s automated alignment system design and some results of the hardware assembly experiments.

7734-40, Session 9

The GRAVITY acquisition and guiding system

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GRAVITY is a second generation VLTI instrument that will combine the K-band light of the four 8m telescopes on Paranal.

It is designed to deliver astrometry at the level of 10 μas within a field of 2" and interferometric imaging within 50mas.

In the instrument, atmosphere effects are corrected using near-infrared adaptive optics, the internal path lengths are monitored with a dedicated metrology system and the beam transport to the beam combiner is stabilized by means of a dedicated guiding system.

The beam stabilization system corrects the residual tip-tilt and pupil motion introduced by telescope and optical train vibrations, by tunnel seeing and the VLTI delay lines.

The main beam stabilization requirements result directly from the GRAVITY astrometric error goals.

The beam is monitored using an infrared acquisition camera that implements a mosaic of field, pupil and Shack-Hartmann images for each of the telescopes. The Shack-Hartmann mode is used to measure quasi-static aberrations introduced by optical train.

Star and background H-band light from the sky has been found to be able to generate images that can be used to determine the tip-tilt correction and pupil lateral position, within the GRAVITY specifications, each 10 s.

To correct the beam at higher frequencies two laser guiding beams are launched in the beam path, on field and pupil planes, and are monitored using position sensor detectors. The measurements are used to bring the beam errors within the specifications.

7734-41, Session 9

Fibered optical functions for GRAVITY

G. S. Perrin, Observatoire de Paris à Meudon (France)

The second generation VLTI instrument GRAVITY will use single-mode components to combine four beams in the K band. Beam combination will be achieved with an integrated optics chip fed by four fluoride glass single-mode standard fibers. Polarization axes will be aligned by twisting fibers. The reference source and science target interferograms will be synchronized with fibered delay lines. Prototypes have been fabricated for both of these two subsystems and performance results will be presented during this talk.

7734-42, Session 10

The Fomalhaut debris disk seen from every angle with interferometry

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In this paper, we present the results of three different studies of the Fomalhaut debris disk with infrared interferometry. First, VLTI/AMBER measurements are used to determine the position angle of the slightly oblate rapidly rotating photosphere by means of differential phase measurements across the Br-gamma photospheric line. This measurement allows us to confirm that the debris disk is located in the equatorial plane of its host star. Second, we use VLTI/VINCI to search for resolved near-infrared emission around the stellar photosphere, which would correspond to the presence of large amounts of hot dust grains located between the sublimation radius and the habitable zone. Our observations reveal a small excess of 0.88% ± 0.12% in K band relative to the photospheric flux. Finally, we use the Keck Interferometer Nuller in order to derive additional constraints on the nature of the resolved infrared emission. Our observations suggest a marginal detection of a circumstellar excess at 10 μm, which we use together with the VINCI detection to model the circumstellar emission. Preliminary results from this modeling effort are discussed.

7734-43, Session 10

Image reconstruction in optical interferometry: applications to the inner regions of protoplanetary disks

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Planets are believed to form in circumstellar disks around newly born stars at distances ranging from 0.1 to 10 AUs. This location corresponds to milli-arcsecond scales at the distance of the closest star forming regions and to temperatures ranging from a few hundred to a few thousand Kelvin. To conduct observations of close environments of such disks at the milli-arcsecond scale, infrared interferometry is a suitable tool that can be employed to observe T Tauri, FU Ori and Herbig Ae/Be stars.

However, the data obtained so far consist of a small number of measurements which can only constrain theoretical models. With the advent of recent multi-aperture interferometers, the interferometric data can be used to reconstruct images independently of any parametric model, as is routinely done in the radio frequency range. On the other hand, in the optical range, not enough measurements are available to univocally reconstruct an image and some a priori must be introduced.

In this contribution, we present systematic tests performed on the MiRA algorithm (an image reconstruction algorithm developed for optical interferometry) in order to evaluate the feasibility of the technique. The methodology allows deriving some practical rules for the user and has been applied to a variety of YSO (GW Ori, HD163296, HD45677, ZCMa and HD98922). I will present the results of the image reconstruction, providing the first images of complex YSOs. Finally, we discuss the consequences for models used so far.

7734-44, Session 10

PSF and field of view characteristics of imaging and nulling interferometers

F. Hénault, Observatoire de la Côte d'Azur (France)

In this communication are presented some complements to a recent paper entitled "Simple Fourier optics formalism for high angular resolution systems and nulling interferometry" [1], dealing with imaging and nulling capacities of a few types of multi-aperture optical systems. Herein the characteristics of such systems in terms of Point Spread Function (PSF) and Field of View (FoV) are derived from simple analytical expressions that are further evaluated numerically for various cases. We consider successively a monolithic pupil, nulling telescope, a pupil-sheared nulling telescope, a sparse aperture, axially combined interferometer, and some more general cases of Michelson and Fizeau interferometers. The analytical formalism also allows establishing the exact Object-Image relationship applicable to nulling, axially combined interferometers that are planned for future space missions searching for habitable extra-solar planets.

[1] F. Hénault, "Simple Fourier optics formalism for high angular resolution systems and nulling interferometry," JOSA A (2009).

7734-45, Session 10

Closure phase calibration studies toward detection of hot Jupiters

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Ground-based long baseline optical interferometers, such as the CHARA array, have the potential to detect thermal emission from nearby hot Jupiters using high precision closure phases. Here we report our closure phase calibration studies toward detection of hot Jupiters using CHARA-MIRC. We have found strong correlations between our closure phases and telescope azimuth & altitude, which might be due to atmosphere dispersions and/or polarization caused by the optical train of CHARA. We come up with a new calibration scheme to correct for these correlations, and test it on a high contrast binary Eps Per. We also present our preliminary upper limits of flux ratios for Ups And b after applying our new calibration scheme.

7734-46, Session 10

Speckle imaging with the SOAR and the very large telescopes

S. Rengaswamy, J. H. Girard, G. Montagnier, European Southern Observatory (Chile)

Astronomical speckle imaging is a well established technique used for obtaining images of binary and multiple stars, low contrast solar features and nearby extended objects such as comets and solar system planets. We have developed a speckle masking code to reconstruct images of such objects from the corresponding speckelgrams. This code uses speckle interferometry for estimating Fourier amplitudes and bispectrum for estimating Fourier Phases. In this paper, we discuss a few technical issues such as: What is the photometric and astrometric accuracy that can be achieved with this code? What is the closest separation between the components of a binary star that can be clearly resolved with sufficient signal to noise ratio with this code? What is the maximum dynamic range? What kind of calibration schemes can be used in the absence of a bright calibrator close to the object of interest? What is the origin of non-zero bispectrum phases for a point source and how it affects the image reconstruction and how it can be effectively used in image reconstruction? We address these questions based on computer simulations. We present a few examples from the real data obtained from the SOAR telescope. We also present the details of a technical feasibility study carried out with NACO-cubemode at the VLT.

7734-47, Session 11

Stellar intensity interferometry: imaging capabilities of air Cherenkov telescope arrays

P. D. Nunez, S. L. LeBohec, D. B. Kieda, The Univ. of Utah (United States); R. Holmes, Nutronics Inc. (United States); D. Dravins, H. Jensen, Lund Observatory (Sweden)

Many stars begin to appear as extended objects for optical baselines of hundreds of meters, while even longer ones are required for imaging stellar-disk features. Air Cherenkov telescope arrays may be used as intensity interferometers, a technique essentially insensitive to atmospheric turbulence although only the modulus of any spatial frequency component of the source image can be measured (not its phase). While this does carry information on the structure and size of the object, a full two-dimensional image reconstruction requires phase retrieval techniques, feasible if a sufficient coverage of the interferometric plane is available.

Planned large arrays of air Cherenkov telescopes will provide thousands of baselines between pairs of telescopes, ranging from tens of meters to over a kilometer, thus enabling optical imaging with unprecedented angular resolution. Numerical simulations of observations have been carried out for several types of stellar objects, assuming telescope configurations such as envisioned for the planned large arrays (e.g., CTA, AGIS).

A Cauchy-Riemann based phase recovery allows the reconstruction of images which are compared to the pristine images from which the observational data were simulated. Signal-to-noise requirements for various degrees of image complexity are illustrated by different integration times, demonstrating the potential of intensity interferometry for sub-milliarcsecond imaging.

7734-48, Session 11

Stellar intensity interferometry: experimental steps toward long-baseline observations

S. L. LeBohec, P. D. Nunez, D. B. Kieda, The Univ. of Utah (United States); D. Dravins, H. Jensen, Lund Observatory (Sweden)

Forthcoming large arrays of air Cherenkov telescopes (CTA, AGIS) will enable long-baseline optical intensity interferometry. A number of preparatory experiments are now being carried out to prepare for a digital revival of the method pioneered by Hanbury Brown and Twiss already long ago.

At the Bonneville sea base site, some 60 km west from Salt Lake City, a testbed observatory is being set up (Star Base Utah: http://www.physics.utah.edu/~lebohec/StarBaseWeb/). Two air Cherenkov telescopes of 3 m diameter with f/1 Davis-Cotton optics are placed on a 23 m baseline. Both telescopes are now operational and cameras for intensity interferometry are being constructed, together with control electronics for a continuous digitization system (100MHz) for either off- or online analysis of the data in a high-speed correlator.

At Lund Observatory and at the University of Utah, laboratory intensity interferometers simulating stellar observations have been set up and experiments are in progress, using various analog and digital correlator technologies, reaching 1.4 ns time resolution, to continuously cross correlate the stream of photon counts from pairs of laboratory telescopes.

The first full-scale experiments in digitally connecting air Cherenkov telescopes to a correlator in real time during actual stellar observations have already been carried out with pairs of 12-m telescopes at the VERITAS array in Arizona.

7734-49, Session 11

The potential of rotating-baseline nulling interferometers operating within single telescope apertures

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Classical coronagraphs are limited to searching for planets and other faint companions outside a radius of ~ 2 lambda/D of the star. In contrast, interferometry can access smaller angles, but typically at reduced contrast levels. Here we consider the advantages of single-aperture nulling interferometry for faint companion detection. In particular, a rotating nulling interferometer, such as is envisioned for space-based infrared nullers, operating within the aperture of a large telescope corrected by a next-generation extreme adaptive optics system, can reach smaller angles (sub lambda/D) than typical coronagraphs, while also providing improved interferometric contrasts. In addition, such rotating nullers also provide validation of the FKSI/TPF-I/Darwin rotating-baseline nuller approach. As practical examples we consider the Palomar fiber nuller and the Keck Observatory, as well as a small single-aperture space telescope and the thirty meter telescope.

7734-50, Session 11

Wide-field imaging interferometry image construction algorithms

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Wide-Field imaging interferometry is based on the “double-Fourier” approach whereby the two (or more) apertures and a delay line are both moved to collect a set of interferograms over a 2D wide-field detector grid simultaneously, one interferogram per detector pixel per baseline spacing. This aggregate set of interferograms is post-processed to construct a high angular/spectral resolution, wide field of view hyperspectral image cube. The spatial-spectral algorithm used to construct the “dirty” image cube and a maximum entropy approach to construct a cleaner image cube are developed and discussed. Results of using these algorithms on laboratory data from the NASA/Goddard Space Flight Center Wide-Field Imaging Interferometry Testbed (WIIT) are shown and discussed.

7734-51, Session 11

Direct imaging with a hypertelescope: array configuration versus science cases

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A hypertelescope can provide direct snapshot images of complex astrophysical objects, by using a large optical stellar interferometer, an efficient cophasing system and a pupil densifier to combine the beams. The pupil densification optimizes the imaging properties by concentrating most of the light in the focal plane in the proper field of view. The characterization of the Point Spread Function show how the imaging properties of a hypertelescope depend on the geometry of the array and on the number of sub-apertures. The choice of the array configuration is a trade-off between the spatial resolution, the useful field of view and the diffracted halo level in the image. Thus, the array configuration is directly related to the science cases. We discuss here on the links between the technical specifications of an array and the astrophysical requirements in the framework of stellar surface imaging applications.

7734-52, Session 12

Systems engineering and application of system performance modeling in SIM-Lite Mission

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The SIM-Lite Astrometric Observatory will be the first space-based Michelson interferometer operating in the visible wavelength, with the ability to perform ultra-high precision astrometric measurements on distant celestial objects. SIM-Lite data will address in a fundamental way questions such as characterization of Earth-mass planets around nearby stars, the distribution of stellar and dark matter in the Galaxy, and the relationship between accreting gas in distant quasars and the relativistic jets produced by that gas. In addition, the mission will provide the most accurate fundamental reference frame available for years to come with opportunities for addressing many other problems in astrophysics.
To accomplish these goals it is necessary to rely on a model-based systems engineering approach - much more so than most other space missions. To allocate requirements, verify the system and validate that the mission design, in fact, addresses the science objectives of the program, it is necessary to have an end-to-end performance model. Over the past several years such a model has been developed, which incorporates subsystem properties that come from several prototyping and engineering risk reduction activities. In addition, the methods of observing various types of targets, generating corresponding observing schedules, realistically reducing and combining the astrometric data over the life of mission, and subsequent comparison of these simulated mission results with the known “perfect” inputs allows characterization of mission accuracy. This paper will describe in further detail the components of this end-to-end performance model, called “SIM-sim”, and show how it has helped the systems engineering process.

7734-53, Session 12

On-orbit dynamics and controls system architecture for SIM-Lite

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The dynamic stability of white light fringes formed on the guide and science interferometers in SIM-Lite along with the pointing stability of each arm of each interferometer affect the visibility of fringes and the length of the fringe camera integration time for the observatory. Hence, tight fringe and pointing stability requirements are needed to reduce science interferometer camera integration times, which in turn help increase the all important instrument’s observing efficiency. The SIM-Lite Instrument Dynamics and Controls (D&C) System Architecture deals with such dynamic issues through a “tailored” system dynamics design complemented by a comprehensive active control system. The SIM-Lite on-orbit System architecture is described in this paper. Key roles played by the resulting D&C System are also established, while the system design is clearly linked to the four nominal phases of on-orbit operations for the observatory (Tile to Tile slew & settling, guide star acquisition, science observation, & science interferometer retargeting). Top driving requirements dictating system interferometric-baseline stability and repeatability, instrument pointing stability, and fringe stability are discussed here together with the resulting high level Error Budget. Key system sensitivities and currently known D&C related design challenges are also discussed.

7734-54, Session 12

SIM-Lite instrument calibration sensitivities and refinements

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The SIM-Lite missions will perform astrometry with microarcsecond accuracy using star light interferometry. For a typical baseline shorter than 10 meter, this requires to measure optical path differences accurate to tens of picometers calling for highly accurate calibration. A major challenge is to calibrate the star spectral dependency in fringe measurements --- the spectral calibration. Previously, we have developed a spectral calibration and estimation scheme with picometer level accuracy. In this paper, we study the sensitivities for applying this scheme and improve its performance. We first study pointing sensitivities of spectral calibration, i.e. the dependency on placement of fringes on fringe tracking camera. This sensitivity enables us to predict calibration errors due to system pointing drift. We then investigate sensitivity to the bandwidth in fringe model used by the estimation algorithm, which helps to balance an interesting trade between systematic and random errors. Finally, we show how to identify outlier strokes in a long stroke calibration experiment by analyzing the temporal variation and mitigate the effect due to system drift by interpolating and averaging instrument calibrations. We uses both simulated data and experimental data from the Spectral Calibration

Development Unit (SCDU), a test facility demonstrating the capability of accurate spectral calibration.

7734-55, Session 12

SIM-Lite: ground alignment of the instrument

F. G. Dekens, R. Goullioud, M. J. Morales, F. Nicaise, G. M. Kuan, R. O. Gappinger, Jet Propulsion Lab. (United States)

We present the current ground alignment plan for the SIM-Lite Instrument. We start with the integration and alignment of the individual benches on which all the optics are mounted. We then present the alignment plan for the benches to form the Science and Guide interferometers. The Instrument design has a guide interferometer with only a 40 arcseconds field of regard. This requires both side of the interferometer to be aligned to a fraction of that, while at the same time be orthogonal to the baseline defined by the External Metrology Truss. The baselines of the Science and Guide interferometers must also be aligned to be parallel, and finally the Guide 2 telescope must be aligned with the rest of the system.

7734-56, Session 12

SIM-Lite Guide-2 Telescope system identification, control design, and pointing performance evaluation

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The Guide-2 telescope (G2T) is an important subsystem of the new SIM Lite Astrometric Observatory. It is used to monitor inertial attitude changes of the spacecraft in two directions orthogonal to the line of sight of the science interferometer. The Guide-2 telescope hardware consists of a large aperture siderostat, compressor optics, star tracker and an angular metrology system. A rebalance loop is used to null the image of the star on the focal plane using the siderostat as the pointing actuator. The angular metrology is used to monitor the siderostat motion, which is correlated to the spacecraft attitude control system (ACS) dead bands.

In this paper we present system identification experiments, design and implementation of the G2T pointing loop that achieves milliarcsecond resolution of spacecraft attitude. The system identification experiments included determination of the optical sensitivity of the tested and the actuator dynamic response. Special emphasis was placed on characterization and modeling of PZT hysteresis since this nonlinearity plays an important part in the control loop performance. Power spectral densities of the star image centroids were use to evaluate the pointing loop performance with and with out the presence of simulated ACS disturbances injected via a fast steering mirror (FSM).

7734-57, Session 13

SIM interferometer testbed (SCDU) status and recent results

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The Spectral Calibration Development Unit (SCDU) is a picometer-class testbed for the SIM-Lite stellar interferometer. SCDU's mandate is to demonstrate that systematic errors due to spectral differences between planet-finding targets and their nearby reference stars observed by SIM Lite can be reduced to less than 1 pm over the 5 year course of the mission. This level of performance places tight requirements on the design of the interferometer, beginning with the phase dispersion in each arm of the interferometer, which has to be minimized and matched between the two arms as much as possible. In addition, there needs to be very precise control of the instrument's alignments and calibrations. The most important alignments include the placement of the starlight from the two arms onto the fringe detector, the parallelism of starlight and metrology, and the shear error between the starlight and metrology beams at each siderostat of the interferometer. The most important calibrations are the instrument dispersion calibration and the starlight spectral calibration. In this paper we summarize our new findings regarding these alignments and calibrations and their impact on overall instrument systematic error and performance. Using these techniques we have achieved an effective calibration of less than 2 pm with the SCDU testbed.

7734-58, Session 13

Flight qualification and performance testing of SIM precision optical mechanisms

R. F. Smythe, Jet Propulsion Lab. (United States)

The SIM-Lite project has designed and built PZT driven precision optical mechanisms for pointing and optical path-length phasing. This paper will discuss the designs, the flight qualification, and performance in a space representative environment of these dynamic optical devices. We will also discuss performance of the strain gauges bonded to the PZTs of the SIM Fine Steering Mirror.

7734-59, Session 13

Photonic technologies for a pupil remapping interferometer

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Interest in pupil-remapping interferometry, in which a single telescope pupil is fragmented and recombined using fiber optic technologies, has been growing among a number of groups. As a logical extrapolation from several highly successful aperture masking programs underway worldwide, pupil remapping offers the advantage of spatial filtering (with single-mode fibers) and in principle can avoid the penalty of low throughput inherent to an aperture mask. However in practice, pupil remapping presents a number of difficult technological challenges including injection into the fibers, pathlength matching of the device, and stability and reproducability of the results. Here we present new approaches based on recently-available photonic technologies in which coherent three-dimensional waveguide structures can be sculpted into bulk substrate. These advances allow us to minaturize the photonic processing into a single, robust, thermally stable element; ideal for demanding observatory or spacecraft environments. Ultimately, a wide range of optical functionality could be routinely fabricated into such structures, including beam combiners and dispersive or wavelength selective elements, bringing us closer to the vision of an interferometer on a chip.

7734-60, Session 13

Using point diffraction interferometer (PDI) for on-orbit wavefront sensing

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Future, large space telescopes will have segmented primary mirrors and/or deformable mirrors and will require sensing and control of wavefront errors to the nanometer level. In this paper we describe a simple method for measuring the telescope wavefront, independent of the sensor instrument optics, using a Point Diffraction Interferometer (PDI) and a stellar source. This approach has the advantage that non-common

path errors, plaguing other test configurations, are eliminated. A PDI experiment was designed and performed on the meter-class, 18-segment JWST Test Bed Telescope (TBT) located at Ball Aerospace. Based on resulting data, the paper answers two basic questions: (1) is the PDI capable of accurately sensing piston errors(?) and (2) what level of signal to noise ratio (SNR) is required for a given level of sensing accuracy(?) This latter question can be translated to a science requirement on the selection of stellar sources, and the specification of filter bandpass. A comparison between PDI and phase retrieval is also provided.

7734-61, Session 13

Picometer stable scan mechanism for gravitational wave detection in space

J. Pijnenburg, N. Rijnveld, TNO (Netherlands)

Detection and observation of gravitational waves requires extreme stability in the frequency range 1E-4 Hz to 1 Hz. The Laser Interferometer Space Antenna (LISA) mission will attain this by creating a giant interferometer in space, based on free floating proof masses in three spacecrafts.

Due to orbit evolution and time delay in the interferometer arms, the direction of transmitted light changes. To solve this problem, an extremely stable Point Ahead Angle Mechanism (PAAM) was designed, built and tested.

The PAAM concept is based on a rotatable mirror. The critical requirements are the contribution to the optical path difference (less than 1.4 pm / rt Hz) and the angular jitter (less than 8 nrad / rt Hz). To meet these requirements, the PAAM is designed for extreme dimensional and thermal stability. Extreme dimensional stability is achieved by manufacturing a monolithical Haberland hinge mechanism out of Ti-6Al-4V, through high precision wire erosion. Cross-talk is minimized by separation of the mirror rotation and actuation by a strut, resulting in a minimum of parasitical forces. Extreme thermal stability is realized by placing the thermal center on the surface of the mirror.

Because of piezo actuator noise and leakage, the PAAM has to be controlled in closed-loop. To meet the requirements in the low frequencies, an active target charge integration capacitance-to-digital converter is used.

Interferometric measurements with a triangular resonant cavity in vacuum proved that the PAAM meets the requirements. The critical component in the performance is the low frequency capacitive sensor noise.

7734-62, Session 13

The SIM-Lite Astrometric Observatory: engineering risk reduction activity

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The SIM Lite Astrometric Observatory is a mission concept for a space-borne instrument to perform micro-arcsecond narrow-angle astrometry to search 60 to 100 nearby stars for Earth-like planets, and to perform global astrometry for a broad astrophysics program. The main enabling technology development for the mission was completed during phases A & B. While the project is waiting for the results of the ASTRO2010 Decadal Survey to proceed into flight implementation, the instrument team is currently converting the developed technology onto flight-ready engineering models. These key engineering tasks will significantly reduce the implementation risks during the flight phases C & D of the mission. The main optical interferometer components, including the astrometric beam combiner (ABC), the fine steering mechanism (FSM), the path-length control and modulation optical mechanisms (POM & MOM), focal plane camera electronics (ATC & FTC), camera cooling cryo-heat pipe, and the siderostat mechanism are currently under development. Main assemblies are built to meet flight requirements and will be subjected to flight qualification level environmental testing (random vibration and thermal cycling) and performance testing. The Spectral Calibration Development Unit (SCDU), a white light interferometer testbed has recently demonstrated how to perform the spectral calibration of the instrument. The Guide 2 Telescope testbed (G2T) has demonstrated the 50 micro-arc-second angle monitoring capability required by SIM Lite to perform astrometry. This paper summarizes recent progress in engineering risk reduction activities, including the ABC, FSM, MOM, POM, ATC, FTC and Siderostat brass-board units and the two system testbeds, SCDU and G2T.

7734-63, Session 14

MATISSE cold optics opto-mechanical design

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MATISSE (Multi AperTure mid-Infrared SpectroScopic Experiment) will be a mid-infrared spectro-interferometer combining the beams of up to four telescopes of the European Southern Observatory Very Large Telescope Interferometer (ESO VLTI), providing phase closure and image reconstruction. Matisse will produce interferometric spectra in the LM and in the N band (2.3 to 13.5 micron). The instrument will be developed by a consortium consisting of Observatoire de la Cote d'Azur (warm optics), NOVA-ASTRON (cold optics), MPI-A (cryostats) and MPIfR (detectors).

The optical design is divided into a warm and a cold section. This paper will present the opto-mechanical design of the two cold benches containing about 300 optical components and over 50 cryogenic mechanisms. The translation of the scientific requirements into an opto-mechanical design is presented.

Key aspects will be detailed such as the highly integrated opto-mechanical approach of the design in order to guarantee the stability and accuracy specifications of the order of nanometers and arcseconds of the optical components. Further constrains are the limited volume and access in the VLTI lab and the manufacturability of the components and integration and testing aspects.

Alignment of this sensitive system requires newly developed cryogenic alignment mechanisms for Tip/Tilt, OPD (Optical path difference) and detector Tip/Tilt/Focus all using Piezo actuators. The cryostat design is presented, including the cooling concept and cooler vibration suppression.

7734-64, Session 14

Stellar intensity interferometry: optimizing air Cherenkov telescope array layouts

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Kilometric-scale optical imagers are challenging (especially at short wavelengths) but seem feasible to realize by intensity interferometry, using telescopes erected for studying Cherenkov light induced by gamma rays in air. Planned observatories (CTA, Cherenkov Telescope Array; AGIS, The Advanced Gamma-ray Imaging System) envision around 50-100 telescopes with diameters on order 10 meters, distributed over some 1-2 km, forming very powerful grids also for intensity interferometry.

Any dedicated interferometer can be optimized for the best coverage of the interferometric (u,v)-plane. However, for Cherenkov telescopes, intensity interferometry is a secondary application and telescope placements and sizes must primarily be optimized for their gamma-ray observations.

Several candidate layouts were examined for intensity interferometry to identify aspects that are neither costly nor detrimental to the gamma-ray programs, and which could realistically be incorporated. Numerically simulated observations for various stellar objects yielded signal-to-noise ratios for different Fourier components of the source images, as sampled by different baselines formed by all pairs of larger and smaller telescopes.

The exact placement of the numerous smaller telescopes appears not essential (except that an exact east-west grid should be avoided). For the fewer medium-size and the very few large telescopes a repetitive geometric pattern should be avoided to give a wider variety of baseline lengths, and permit better image reconstruction.

7734-65, Session 14

Optimal control loop design for the piston correction actuator of the LINC-NIRVANA instrument

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LINC-NIRVANA is a near-infrared image-plane beam combiner and one of the interferometric instruments for the Large Binocular Telescope (LBT). The requirements for the maximum optical path difference (OPD) are very tight (lambda/10 ~ 100nm).

A Fringe-and-Flexure-Tracking-System (FFTS) actively monitors and controls the OPD of the star light.

The Piston Mirror (PM) is the central actuator of the LN-OPD control loop, and it is designed to compensate for piston motion over a large, 2~arcmin diameter field of view, which is a unique property of the LN interferometric instrument.

We will discuss the laboratory performance of the new, flexure-minimized design of the PM-mounting, and resulting settling times of the PM. A classical proportional-integral control algorithm cannot match the requirements of a fast and precise PM motion control, due to resonance frequencies at about 100~Hz, and a (predictable) momentum-dependent flexure of the mounted PM.

Therefore, the real-time hardware of the PM control unit consists of a modern digital-signal-processor, to properly handle the final transfer function with a custom-designed optimal control algorithm.

The computer-added optimization of the linear control algorithm enables significantly faster settling times of <= 20~ms.

The presented dynamic performance of the PM is crucial to properly model the closed loop performance of the FFTS.

7734-66, Session 14

The LINC-NIRVANA fringe and flexure tracker: control design overview

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The Fringe and Flexure Tracker System (FFTS) of the LINC-NIRVANA instrument is designed to monitor and correct the atmospheric piston variations and the instrumental vibrations and flexure at the LBT during the NIR interferometric image acquisition. In this contribution, we give an overview of the current FFTS control design, the various subsystems, and their interaction details. The control algorithms are implemented on a real-time computer system with interfaces to the fringe and flexure detector read-out electronics, the OPD vibration monitoring system (OVMS) based on accelerometric sensors at the telescope structure, the piezo-electric actuator for piston compensation, and the AO systems for offloading purposes. The FFTS computer combines data from different sensors with varying sampling rate, noise and delay. This done on the basis of the vibration data and the expected power spectrum of atmospheric conditions. Flexure effects are then separated from OPD signals and the optimal correcting variables are computed and distributed to the actuators. The goal is a 120 nm precision of the correction at a bandwidth of about 50 Hz. An end-to-end simulation including models of atmospheric effects, actuator dynamics, sensor effects, and on-site vibration measurements is used to optimize controllers and filters and to pre-estimate the performance under different observation conditions.

7734-67, Session 15

Testing and alignment of the LBTI

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The Large Binocular Telescope Interferometer (LBTI) has been developed and tested and is almost ready to be installed to LBT. In preparation for installation, testing of the beam combination and phasing of the system have been developed. The testing is currently in progress.

The development of a telescope simulator for LBTI has allowed verification of phasing and alignment with a broad band source at 10 microns. Vibration tests with the LBTI mounted to the LBT were carried out in July 2008, with both seismic accelerometers and an internal optical interferometric measurement. The results have allowed identification of potential vibration sources on the telescope. Plans for a Star Simulator that illuminates each LBT aperture at the prime focus with two artificial point sources derived from a single point source via fiber optics are presented. The Star Simulator will allow testing of LBTI with the telescope, and the adaptive secondaries in particular. Testing with the Star Simulator will allow system level testing of LBTI on the telescope, without need to use on-sky time. Testing of the Star Simulator components are presented to verify readiness for use with the LBTI.

7734-68, Session 15

Fringe detection and piston variability in LINC-NIRVANA

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We present the latest status of the fringe detecting algorithms for the LINC-NIRVANA FFTS (Fringe and Flexure Tracker System) for the LBT. By considering the latest results from lab experiments, atmospheric simulations and telescope characterisation we describe the optimal fringe detecting techniques over the full range of LINC-NIRVANA's capabilities. LINC-NIRVANA presents several challenges for the FFTS, in particular the large field of view over which piston must be controlled and, in some cases, the need to track and control piston at separate wavelengths. The pistonic effects of the system from the top of the atmosphere through the telescopes and multi-conjugate AO systems to the detector are discussed and the resulting requirements for the FFTS outlined. We also present optimal fringe detection techniques for varying amounts of fringe dispersion, and its influence on instrument operations.

7734-69, Session 16

OPD models for the VLTI

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A critical requirement of optical interferometry is the accurate knowledge of the geometrical baselines linking the telescopes. As being very difficult to physically measure, it is usually statistically estimated and represented by an OPD-model.

Because the VLTI makes use of fixed as well as relocatable telescopes, a systematic approach has been developed to determine, validate and monitor the quality of these models. In this poster we describe how the OPD data are obtained on sky with the FINITO fringe-tracker, how they are fitted with the IPHASE software considering the numerous possible

configuration of the versatile VLTI array, and how OPD-models are handled for routine operations with various instruments and telescopes configurations. We also present the typical model quality, the numerous parameters that have to be taken into account and the modifications brought to some of the procedures to remove biases, the current limitation of the method and possible improvements for the future. This work is of general interest both for incoming instrumentation at the VLTI and for the next-generation of imaging interferometers.

7734-70, Session 16

GRAVITY: design and performance of the fringe tracker

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GRAVITY is a second generation instrument for the VLTI. It will combine four telescopes in the K band and perform fringe tracking on stars as faint as 10 magnitude. To achieve such a performance, new developments have to be tested. We have developed a complete simulator so as to improve algorithms and establish an efficient fringe tracking strategy. In addition, a prototype of fringe tracker for GRAVITY is being built up in order to demonstrate the results of this simulator. We present here the current status of these developments, achieved by simulating realistic tracking at VLTI.

7734-71, Session 16

Baseline definitions for the astrometric mode of the GRAVITY instrument

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Astrometry is the fundamental mode of the GRAVITY interferometric instrument. The goal is to have an astrometric precision of 10 uas over two stars separated by one arcsecond. This means 10^-5 in terms of precision. The ~100m baselines of the VLTI must therefore be known to a sub-millimeter level. This paper will review the definition of a baseline. It will highlight the fact that three different definition can exist: the wide angle astrometry baseline, the narrow angle astrometry baseline, and the interferometric baseline. This paper will then present the strategy adopted by the GRAVITY consortium to fulfill the astrometric requirements.

7734-72, Session 16

The fringe detection laser metrology for the GRAVITY interferometer at the VLTI

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Interferometric measurements of path length differences of stars over large baselines can deliver extremely accurate astrometric data. The interferometer GRAVITY will simultaneously measure two objects in the field of view of the VLTI and determine their distance to a precision of 10 µas in only 5 minutes. To perform the astrometric measurement with such a high accuracy, the differential path length through the VLTI and the instrument has to be measured (and tracked since Earth's rotation will permanently change it) by a laser metrology to an even higher level of accuracy (corresponding to 1 nm in 5 minutes).

Usually, heterodyne differential path techniques are used for nanometer precision measurements, but with these methods it is difficult to track the full beam size and to follow the light path up to the primary mirror of the telescope. Here we present the preliminary design and prototype tests of a differential path metrology system, developed within the GRAVITY project. It measures the instrumental differential path over the full pupil size and up to the entrance pupil location. The differential phase is measured by detecting the laser fringe pattern both on the telescopes' secondary mirrors as well as after reflection at the primary mirror. Based on our proposed design we evaluate the phase measurement accuracy based on a full budget of possible statistical and systematic errors. We show that this metrology design fulfills the high precision requirement of GRAVITY.

7734-73, Session 16

First results from fringe tracking with the PRIMA fringe sensor unit

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The fringe sensor unit (FSU) is the central element of the phase referenced imaging and micro-arcsecond astrometry (PRIMA) dual-feed facility for the Very Large Telescope interferometer (VLTI). It is installed since September 2008 at the Paranal observatory and undergoes commissioning and preparation for science operation.

Commissioning observations began shortly after installation at the observatory in August 2008. First results include the demonstration of spatially encoded fringe sensing and the increase in VLTI limiting magnitude for fringe tracking. However, difficulties are encountered because the FSU does not incorporate real-time photometric correction and its fringe encoding depends on polarisation. These factors affect the control signals, especially their linearity, and can disturb the tracking control loop. To account for this, additional calibration and characterisation efforts are required.

We outline the instrument concept and give an overview of the commissioning results obtained so far. We describe the effects of photometric variations and beam-train polarisation on the instrument operation and propose possible solutions. Finally, we update on the current status in view of the start of astrometric science operation with PRIMA.

7734-74, Session 17

The polarization-based collimated beam combiner and the proposed NOVA fringe tracker (NFT) for the VLTI

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A new topology for a superimposed wavefront beam combiner is presented. This concept is adopted in a proposal for an up to 6 telescope fringe-tracking instrument to be built for the VLTI, and achieves near-optimum performance in several respects while avoiding exotic or unobtainable optical components. The proposed fringe sensor operates over a 2:1 bandwidth and (low resolution) spectrally resolved detection for tracking dispersion fluctuations and resolving fringe jumps. The proposed fringe-tracker gains a two-fold sensitivity increase by using two-phase detection in fringe-locked mode, but the topology is also suited for measurement of complex visibility without requiring OPD modulation using 3 or 4 phase detection.

A key goal achieved is “Photometric Symmetry” whereby an instantaneous visibility (or phase) measurement has no first-order sensitivity to wavefront perturbations (or photometric variations following spatial filtering) which otherwise entail visibility measurements with increased error, bias, and nonlinearity in phase determination. These problems affect past instruments and grow in magnitude as the visibility magnitude decreases. Photometric Symmetry is achieved when the determinant of the kappa matrix (describing the incoherent response of the beam combiner outputs to its two inputs) is exactly zero. Rather than requiring precision in a thin-film coating to achieve 50/50 transmission and reflection (particularly difficult over a wide bandwidth), the Polarization Based Collimated Beam Combiner achieves photometric symmetry through geometrical alignment of (broadband) optical components (primarily polarizing beamsplitters).

Experimental measurements of photometric symmetry achieved using this concept will be presented. In addition to the fringe-tracker, application of the concept to visibility measurement is described.

7734-76, Session 17

The planar optics phase sensor: an answer for the VLTI second-generation fringe tracker

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In a few years, the VLTI second generation instruments (GRAVITY, MATISSE, VSI) will routinely provide interferometric observations with 4 to 6 telescopes simultaneously. To reach their ultimate performances, they will need a fringe sensor (FS) able of measuring the optical paths between the various pupils. Among several concepts we discuss here some possible designs that make use of planar optics components. We give the results of the related system studies that aim at defining the most suitable design able to achieve the best performances within the VLTI environment. First, we briefly summarize the results of a theoretical analysis of modal filtering influence on the phase measurement. The performances of the most common phase and group delay estimators are then compared, taking into account atmospheric and instrumental disturbances known to exist at the VLTI. The conceptual architectures for 4- and 6-telescope interferometer allowing the best sensitivity are then determined. The instrument conceptual design and the results of realistic simulations are finally presented.

7734-77, Session 17

Multi-axial integrated optics solution for POPS, a second-generation VLTI fringe tracker

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POPS (Planar Optical Phase Sensor) is a second-generation fringe tracker for the Very Large Telescope Interferometer (VLTI), intended to simultaneously measure the cophasing and coherencing errors of up to six Unit Telescopes (UT) or Auxiliary Telescopes (AT) in real time. The most promising concepts are probably based on the utilization of Integrated Optics (IO) components, and were the scope of a Phase A study led by Observatoire de Grenoble (LAOG). Herein is described a tentative design built around a multi-axial IO chip whose fringes are dispersed downstream on a detector array, and a Chromatic Phase Diversity algorithm presented in another paper of this conference. We depict the foreseen opto-mechanical, detection and software implementations, and provide numerical results from a realistic simulation model in terms of group and phase delay measurement accuracy and limiting magnitudes in the K band. The ultimate performance of the method is discussed.

7734-78, Session 17

Coherent integration: To real time or not to real time? That is the question

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Coherent integration is the integration of fringe visibility for periods much longer than the atmospheric coherence time. Coherent integration is crucial to advancing optical interferometry. It is the only way of obtaining high SNR measurements of small visibilities on faint targets. And making more detailed measurements of interferometric sources requires observations on longer resolving baselines where visibilities nearly always are small and where the SNR is thus small. The fact that we are always observing at the fringe-tracking SNR limit (because easy targets have already been observed) compounds the problem: small fringe visibility on faint targets. The only answer is coherent integration. Recently the push has been toward real-time coherent integration controlled by active fringe tracking. By contrast at the NPOI we are performing coherent integration in post-processing using the same data set that is used for traditional squared visibility measurements. In this paper we will discuss the advantages and limitations of each approach. In particular, real-time coherent integration requires better real-time and predictive fringe-tracking. Post-processing coherent integration does not require the same level of fringe-tracking accuracy, nor does it require predictive fringe tracking. On the other hand, it does require rapid detector readout on a time-scale shorter than the atmospheric coherence time.

7734-103, Poster Session

Review of OCA activities on nulling testbench PERSEE

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We present a review of our activities on PERSEE (Pégase Experiment for Research and Stabilization of Extreme Extinction) at Observatoire de la Côte d'Azur (OCA). PERSEE is a laboratory testbench aiming at achieving a stabilized nulling ratio better than 10-4 in the astronomical bands K and M, in presence of flight-representative spacecraft perturbations. The bench has been jointly developed by a Consortium of six French institutes and companies, among which OCA was responsible for the star simulator and of the opto-mechanical studies, procurement and manufacturing of the optical train. In this communication are presented the alignment and image quality requirements and the opto-mechanical design of the illumination module and main optical train, including a periscope Achromatic Phase Shifter (APS), tip-tilt mirrors used to introduce and then compensate for dynamic perturbations, delay lines, beam compressors and fiber injection optics. Preliminary test results of the star simulator are also provided.

7734-104, Poster Session

Upgrade of Michigan infrared combiner (MIRC)

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MIRC is a four-beam infrared image-plane combiner which uses single-mode fibers to filter out turbulence in the atmosphere. It was first commissioned on sky in September 2005 at CHARA which includes six 1-m diameter telescopes and has greatly contributed to imaging and modeling of science objects like rapid rotators since then. However, MIRC has not taken full advantage of its single mode fibers, lacking the capability to measure beam intensities at the same time as fringe amplitudes; the result has large errors (10-15%) in measured visibility^2. In this paper, we discuss our implementation of Photometric Channels in MIRC, which allow us to measure light intensity from each telescope directly and precisely in real time and thus calibrate visibility^2 down to only 2% errors.

In addition, we are planning to expand MIRC to a six-beam combiner. With the commissioning of CHAMP which is a six-beam fringe tracker, MIRC is ready to take full advantage of CHARA six telescopes. This will greatly improve imaging and modeling ability of MIRC.

7734-105, Poster Session

Measuring the effective wavelength of CHARA classic

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This poster presents an engineering project measuring the K-band effective wavelength of the CHARA Classic beam combiner on the CHARA Array. Knowing the actual wavelength of light observed is very important because that value is necessary for determining astrophysical parameters of stars, including stellar diameters. Currently, the value used for CHARA Classic data (2.15 microns) comes from a model of the system and is based on numbers published by the manufacturer of the filter; it is not derived from measurements done on the system directly. If the effective wavelength value is not accurate and precise, then it introduces systematic errors in the resulting stellar parameters. Determining the effective wavelength to a couple of tenths of a percent would allow angular diameter measurements to better than 1%.

We employ two data collection methods for our observations: using the Optical Path Length Equalizer (OPLE) cart to scan through the interference fringes and using the dither mirror to scan through the fringes. The position of the OPLE cart is known to a greater precision than the position of the dither mirror (nanometer versus micron). Consequently, we believed the observations collected with the OPLE cart would yield a more precise effective wavelength measurement. We find that the increased level of precision during data collection does not necessarily translate to increased precision in the measured effective wavelength. Based upon our results from both methods, we adopt 2.138 +/- 0.003 microns as the best estimate for the K-band effective wavelength of the CHARA Classic beam combiner.

7734-106, Poster Session

The LINC-NIRVANA fringe and flexure tracker: first measurements of the testbed interferometer

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LINC-NIRVANA is the near-infrared Fizeau interferometric imaging camera for the Large Binocular Telescope (LBT). For an efficient interferometric operation of LINC-NIRVANA the Fringe and Flexure Tracking System (FFTS) is mandatory: It is a real-time servo system that allows to compensate atmospheric and instrumental optical pathlength differences (OPD). The thereby produced time-stable interference pattern at the position of the science detector enables long integration times at interferometric angular resolutions.

As the development of the FFTS includes tests of control software and robustness of the fringe tracking concept in a realistic physical system, a testbed interferometer is set up as laboratory experiment.

This setup allows us to generate point-spread functions (PSF) similar to the interferometric PSF of the LBT via a monochromatic (He-Ne laser) or a polychromatic light source (halogen lamp) and to introduce well defined, fast varying phase offsets to simulate different atmospheric conditions and sources of instrumental OPD variations via dedicated actuators.

Furthermore it comprises a piston mirror as actuator to counteract the measured OPD and a CCD camera in the focal plane as sensor for fringe acquisition which both are substantial devices for a fringe tracking servo loop. The goal of the setup is to test the performance and stability of different control loop algorithms and to design and optimize the control approaches.

We present the design and the realization of the testbed interferometer and comment on its thermal sensitivity and first fringe tracking loop tests. We will pay special attention to the fringe-contrast behavior.

7734-107, Poster Session

OVMS: the optical path difference and vibration monitoring system for the LBT and its interferometers

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Characterisation, mitigation and correction of telescope vibrations

have proven to be crucial for the performance of astronomical infrared interferometers. The project teams of the interferometers for the LBT, LINC-NIRVANA and LBTI, and LBT Observatory (LBTO) have embarked on a joint effort to implement an accelerometer-based vibration

measurement system distributed over the optical elements of the LBT. OVMS, the Optical Path Difference and Vibration Monitoring System will serve to (i) ensure conditions suitable for adaptive optics (AO) and interferometric (IF) observations and (ii) utilize vibration information, converted into tip-tilt and optical path difference data, in the control strategies of the LBT adaptive secondary mirrors and the beam combining interferometers. The system hardware is mainly developed by Steward Observatory's LBTI team and its installation at the LBT is underway. The OVMS software development and associated computer infrastructure is the responsibility of the LINC-NIRVANA team at MPIA Heidelberg. Initially, the OVMS will fill a data archive provided by LBTO that will be used to study vibration data and correlate them with telescope movements and environmental parameters thereby identifiying sources of vibrations and to eliminate or mitigate them. Data display tools will help LBTO staff to keep vibrations within predefined thresholds for quiet conditions for AO and IF observations. Later-on real-time data from the OVMS will be fed into the control loops of the AO systems and IF instruments in order to permit the correction of vibration signals with frequencies up to 450 Hz.

7734-108, Poster Session

GRAVITY spectrometer: metrology laser blocking strategy at OD=12

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GRAVITY is a 2nd generation VLTI instrument that aims to perform high accuracy astrometric measurements by mean of a novel laser metrology system.

The metrology laser is fibre-fed into the science and the fringe tracking spectrometer. Its beams travel the same path backwards through the complete instrument optical train and the VLTI up to the M2 mirrors of the telescopes as the light of the celestial object comes down to the focal plane of the instrument. Inside the spectrometers the free-space metrology laser light needs to be blocked to avoid degradation of the science signal due to the higher intensity of the laser photons with respect to the science light and scattering reflections.

A two stage blocking system is implemented in the GRAVITY science and the fringe tracking spectrometer optical design. The blocking system consists of a dichroic mirror and a long wave band-pass filter with the top level requirements of high transmission of the science light in the K-Band (1.95 - 2.5 μm) region and high blocking power OD≥8 for the metrology laser wavelength at 1.908 μm. The laser metrology blocking filters have been identified as one critical optical component in the GRAVITY science and fringe tracker spectrometer design.

During the Phase-B study of GRAVITY we procured 3 blocking filter test samples for demonstration and qualification tests. We present the measurements results of an effective blocking of the metrology laser wavelength with a long wave band-pass filter at OD=12.

7734-109, Poster Session

Development of the integrated optics beam combiner assembly for GRAVITY/VLTI

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Gravity is a 2nd generation interferometric instrument for VLTI specifically designed to study general relativity effects around the Galactic Center black hole. The instrument will combine 4 telescopes in dual feed in the K band yielding a 3mas angular resolution in imaging mode (closure phase) and 10μas in astrometric mode. The concept of Gravity is based on two equivalent beam combiner instruments (see Eisenhauer et. al): one dedicated to the image of the main source, the other dedicated to the fringe traking on a secondary reference star (see Perrin et. al). An internal metrology is used to measure and control the internal OPD drifts and provide astrometric locking between science and fringe tracking instruments (see Bartko et. al). In Gravity, the beam combination instruments are based on an integrated optics (IO) component fed by a glued fluoride glass fiber array. Both beam combiners are implemented in a cryogenic vessel cooled at -70°C

This paper is dedicated to the description of the development of the integrated beam combiner cryogenic assembly i.e. the integrated optics beam combiner + its fibers. After describing the concept of the assembly we present the developments made on the integrated optics combiner to optimize its performances. Results of photometric and interferometric characterizations in lab will be presented. The design of the fluoride glass fibre array will be adressed as well as the tests made on the connectorization between fiber and IO to validate its performance and ageing at low temperature. The behavior of the assembly face to the high power laser source used for metrology will be described. Updated global performances and current development status will be presented.

7734-110, Poster Session

Prototyping a new data acquisition system for the NPOI

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We report on the prototyping of a new data acquisition system for the NPOI. The current NPOI back end uses photon-counting Avalanche Photodiodes (APDs). The fringes are detected by scanning piezo electric elements, 1, 2, or 4 microns across the fringes at 500 Hz. In the existing system the detected photons are binned in a 64 bins synchronized across an integer number of wavelengths. The older system has throughput limitations which is simply a result of it being decade-old technology. For example only two of the three spectrographs currently being used, and only half the detectors regularly being used on those two spectrographs. Further, the need for data buffering means that the system cannot integrate for more than 30 seconds at a time before pausing for a minute or longer while flushing data to disk. Allo of these limitations can be easily overcome with modern technology. We will report on the use of a Field Programmable Gate Array (FPGA) system which is able to collect all photons from all detectors and bin them according to several schemes. The data are transferred to a computer via a USB interface or a DMA interface. Rapid data transfers to a powerful computer also opens to exciting possibility of more sophisticated fringe tracking algorithms which in principle can be tailored to the target and to the atmospheric conditions, thus perhaps improving the magnitude limit of the NPOI.

7734-111, Poster Session

The GRAVITY spectrometers: optical design and principle of operation

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Operating on 6 interferometric baselines, i.e. using all 4 UTs, the 2nd generation VLTI instrument GRAVITY will deliver narrow angle astrometry

with 10μas accuracy at the infrared K-band, and will be able to detect the positional shift of the photocenter of a flare at the Galactic Center within its orbital timescale of ~20min, using the flares as dynamical probes of the gravitational field around SgrA*.

Within the international GRAVITY consortium, the Cologne institute is responsible for the development and construction of the two spectrometers: one for the science object, and one for the fringe tracking object. Both spectrometers are operated within the vacuum vessel of GRAVITY.

The optical design of the fringe tracking spectrometer is optimised for highest transmission, featuring a single spectral resolution of R=22 produced by a double prism and a Wollaston prism for polarimetric separation. The spectrometer for the science object is more flexible, allowing the observer to chose from 3 different spectral resolutions (R=22, R=440, R=4500) and to enable or disable the polarimetric splitting of the signal. While the lowest spectral resolution is again realised by a double prism, the two higher ones are produced by grisms. The optical input of each spectrometer is the output plane of its integrated optic beam-combiner device, which is positioned directly in the object plane.

In addition, the two spectrometers feed the four beams of the powerful metrology laser system of GRAVITY backwards into the beam-combiner, propagating to the M2 mirrors of the 4 UTs.

7734-112, Poster Session

The case for a 6 to 8 telescope imager at VLTI: status of the VSI instrument

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The VSI instrument has been proposed in 2006 to ESO as a VLTI 2nd generation instrument dedicated to spectro-imaging at the milli-arcsecond scale of various compact astrophysical sources. A phase A study has been conducted and the science cases as well as the general concept of the instrument have been positively reviewed by ESO but placed in a second priority recognizing that the full potential of the instrument will be reached when 6 apertures will be available on the VLT observatory. Since 2008, the situation has evolved with the study of second generation fringe trackers. A workshop on interferometric imaging has been held in 2009 that helped to understand the requirements for interferometric imaging. This contribution is aimed at summarizing these advances and proposing an evolution for the VSI instrument to fulfill its scientific objectives at best, i.e. imaging of possibly variable objects using up to 6 telescopes in the near infrared domain and with high spectral resolution.

7734-113, Poster Session

The hydrogen emission of young stellar objects: key science for next-generation instruments and facilities

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The hydrogen emission line is a defining characteristic of young stellar objects probing the planet forming regions of the disks. The limiting sensitivity of current interferometers has precluded it's detailed study. We'll review our current understanding of Hydrogen emission, recent results and project the science that can be achieved with sensitive interferometers such as the PRIMA off-axis mode or GRAVITY.

7734-114, Poster Session

PIONIER a visitor instrument for VLTI

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PIONIER is a 4-telescope visitor instrument for the VLTI, planed to see its first fringes in 2010. It combines four ATs or four UTs using a pairwise ABCD+scan integrated optics combiner. It provides low spectral resolution in H and K band. PIONIER is designed for imaging with a specific emphasis on fast fringes recording to allow for precision closure-phases and visibilities to be measured. In this work we provide the detailed description of the instrument and present its updated status.

7734-115, Poster Session

Evaluation of performance of the MACAO systems at the VLTI

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Multiple Application Curvature Adaptive Optics (MACAO) systems are used at the Coude focus of the UTs at the La-Silla Paranal Observatory, Paranal, to correct for the wave-front aberrations induced by the atmosphere. These systems are in operation since 2005 and are designed to provide beams with 10 mas rms tip-tilt error to the VLTI Laboratory. We have initiated several technical studies such as measuring the Strehl ratio of the images recorded at the guiding camera of the VLTI, establishing the optimum setup of the MACAO to get collimated and focused beam down to the VLTI lab and to the instruments, re-establishing the optimal integral loop-gain values under various seeing conditions, and ascertaining the data generated by the real time computer, all aimed at characterizing and improving the overall performance of these systems. In this paper we report current status of these studies.

7734-116, Poster Session

Status of the VLTI-UT performances with regards to vibrations

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The ESO Very Large Telescope Interferometer offers the unique access to the combination of the four 8-meter Unit Telescopes (UT) of Cerro Paranal. The quality of the scientific observations in interferometric mode is strongly related to the stability of the optical path difference (OPD) between the telescopes. Vibrations at the level of the telescopes and affecting the mirrors were shown to be an important source of perturbation for the OPD. ESO has thus started an important effort on the UTs and VLTI to tackle this effect. Active controls based on accelerometers and phase measurement have been developed to provide real-time correction of the variation of OPD introduced by vibrations. Systematic studies and measurement of the sources of vibration

(instruments, wind, telescope altitude,...) have been performed. Solutions to reduce the vibrations via design modification and/or new operation configurations are studied and implemented. To ensure good operational conditions, the levels of vibrations are regularly monitored to control any environmental change. We will describe the modifications implemented and foreseen and give a status of the VLTI-UT vibrations evolution.

7734-117, Poster Session

Comparison between closure phase and phase referenced interferometric image reconstructions

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Image reconstruction is a nowadays key problem in observational Astronomy, especially in the domain of optical interferometry, as the data is in the Fourier plane, not in the form of an image. By means of visibility and phase information, recent interferometers allow us to obtain reconstructed images independently of models.

We describe our approach to compare the quality of interferometric image reconstructions in the situations where we have square of the visibility plus closure phase information and square of the visibility plus visibility phase information.

We used the Multi-aperture image Reconstruction Algorithm (MiRA) for reconstructions of test cases. Our study takes into account noise according to the models presented by Tatulli and Chelli (2005). The final images were then compared to the original ones by means of a Fidelity Function.

We discuss the image reconstruction quality of two different cases: AMBER like (square of the visibility plus closure phase) and PRIMA+AMBER like (square of the visibility plus visibility phase).

7734-118, Poster Session

The effects of atmospheric calibration errors on source model parameters

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Optical long-baseline interferometric data is frequently calibrated with respect to an external calibrator, which is either an unresolved source or a star with a known angular diameter. A common observational strategy involves acquiring data in a sequence of calibrator-target pairs, where the observation of each source is obtained separately. Therefore, the atmospheric variations that have timescales shorter then the cadence between the target-calibrator pairs are not always fully removed from the data even after calibration. This results in calibrated observations of a target star that contain unknown quantities of residual atmospheric variations. We describe how the amount of atmospheric residuals can be estimated based on the squared visibility measurements of resolved single stars that are acquired simultaneously over many spectral channels (also known as scans). In turn, we demonstrate how Monte Carlo simulations of the scan-to-scan variations can be used to assess quantitatively the impact of these variations on fitted model parameters, such as angular diameters of uniform-disk models representing semi- and fully-resolved single stars.

7734-119, Poster Session

Dual three-way infrared beam combiner at the CHARA array

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Two identical three-way beam combiners have been installed parallel at the CHARA Array. The new setup is an extension of the two-way Michelson pupil plain combiner that has been in use thus far. We can now obtain phase closure data in H, K, or J band on two sets of three telescopes. A new optical design has been implemented to image the six outputs of the combiners onto six separate pixels in the infrared detector array. The new optical arrangement provides reduced background and spatial filtering. The magnitude limit of this beam combiner has reached 7.8 in K magnitude mainly as a result of better image quality by the new infrared camera optics.

7734-120, Poster Session

Probing Cepheid stars with AMBER: the case of X Sgr

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The very high spatial resolution of Near-Infrared (NIR) interferometric observations provide fundamental constraints on the pulsation properties of classical Cepheids. We present new and accurate NIR (JHK bands) spectro-interferometric observations of the Galactic Cepheid X Sgr. Current data were collected with AMBER available at the ESO Very Large Telescope Interferometer (VLTI) in good seeing conditions. We selected this target, since it is a nearby Cepheid (d=337 pc, Benedict et al. 2007) and also because accurate optical radial velocity measurements indicate that it might be a member of a binary system (Mathias et al. 2008).

The observations were secured during six runs over a period of 16 months, spectro-interferometric data were collected in low resolution mode (R=30) with three 1.8 m Auxiliary Telescopes (ATs) and the FINITO fringe tracker. To cover a wide region of the uv-plane, we adopted baselines with different lengths and orientations. The adopted observational strategy gives a spatial resolution of at least 4 mas in all directions, with a maximum of 2 mas. We discuss in detail the data reduction, the calibration procedures and investigate the temporal dependence of the visibility along the Cepheid pulsation cycle. This approach allows us to trace the radius variation and to apply the interferometric Baade-Wesselink method together with the radial velocity curve available in the literature, to estimate the distance.

We test the binary hypothesis on the basis of the observed absolute broad-band visibilities, of the differential visibilities, and of the closure phases, by performing several fits with simple geometrical models and different image reconstruction techniques.

7734-121, Poster Session

Detection of a geostationary satellite with the Navy prototype optical interferometer

J. T. Armstrong, R. B. Hindsley, U.S. Naval Research Lab. (United States); H. R. Schmitt, Interferometrics Inc. (United States); F. J. Vrba, J. A. Benson, D. J. Hutter, R. T. Zavala, U.S. Naval Observatory (United States)

We have detected a satellite via optical interferometry for the first time, using a 16 m baseline of the Navy Prototype Optical Interferometer

(NPOI) to observe the geostationary communications satellite DirecTV-9S during the "glint" seasons of February-March 2008 and 2009 when the sun-satellite-NPOI geometry was favorable for causing specular reflections from geosats. We used the USNO Flagstaff Station 40-inch telescope to generate accurate positions for steering the NPOI. Stars are the easiest targets for optical/infrared interferometers because of their high surface brightness. Low surface brightness targets are more difficult: if they are small enough not to be resolved out by typical baselines, they are likely to be too faint to produce detectable fringes in an atmospheric coherence time. The 16 m NPOI baseline, the shortest available at the time of our observations, resolves out structures larger than ~1.5 m at the distance of a geosat, while a typical size for the solar panel arrays is 2 m x 30 m. Our detection indicates that a small fraction of the satellite glinted, not surprising given that the solar panels are not accurately flat. It is also consistent with the brightness of the glints: a glint of magnitude ~2 from a satellite of albedo ~0.1 would be produced by a 4 m^2 area. Our fringe data are consistent with a two-component image consisting of a ~1 m higher surface brightness component and a ~3 m lower surface brightness component.

7734-122, Poster Session

Imaging simulations of selected science with the Magdalena Ridge Observatory interferometer

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We present realistic simulations of interferometric imaging for several topics of the Key Science Missions of the Magdalena Ridge Observatory Interferometer. Planning for the MROI reference science mission is being undertaken by scientific working groups who have been charged with assessing 6 key areas including Active Galactic Nuclei, Single and Multiple Stars, Mass-Loss and Mass-Transfer, and Solar System and Man-Made objects. These simulations will exploit the Cambridge BSMEM maximum entropy inversion code and aim to reveal the scientific potential of interferometric imaging using a multi-telescope, scalable array. They will provide the astronomical community with a glimpse into the advances anticipated for a wide range of science, ranging from the physics of stellar atmospheres and mass-loss to studies of the environments of black holes, and the imaging of man-made objects in Earth orbit. The MROI is expected to take optical interferometric imaging to the next level of capability over the coming decade.

7734-123, Poster Session

A survey of the NPOI data archive

T. Hall, A. M. Jorgensen, New Mexico Institute of Mining and Technology (United States); E. K. Baines, U.S. Naval Research Lab. (United States); H. R. Schmitt, U.S. Naval Research Lab. (United States) and Interferometrics, Inc. (United States); J. T. Armstrong, R. B. Hindsley, U.S. Naval Research Lab. (United States)

The NPOI has been in routine operation for more than a decade. During that time a large number of sources have been observed, and the observatory operations have changed several times. For example, in 2002, the observatory was modified to accept up to 6 simultaneous stations, but at the expense of dropping short-wavelength channels and using only two of three spectrographs. On several occasions new stations have been added, resulting in reconfiguring the array.

System alignments also take place on a regular basis. Re-coating the mirrors has also improved performance. In this paper we will take a look at the NPOI data from the point of view both of science and of engineering and operations, including throughput over time, types of sources oserved, observing efficiency, and data quality.

7734-124, Poster Session

A publication database for optical long baseline interferometry

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Optical long baseline interferometry is a technique that has generated almost 500 refereed papers to date. The targets span a large variety of objects from planetary systems to extragalactic studies and all branches of stellar physics. We have created a database hosted by the JMMC and connected to the Optical Long Baseline Interferometry Newsletter (OLBIN) web site using MySQL and a collection of XML or PHP scripts in order to store and classify these publications. Each entry is defined by its ADS bibcode, includes basic ADS informations and metadata. The metadata are specified by tags sorted in categories: interferometric facilities, instrumentation, wavelength of operation, spectral resolution, type of measurement, target type, and paper category, for example. The whole OLBIN publication list has been processed and we present how the database is organized and can be accessed. We use this tool to generate statistical plots of interest.

7734-125, Poster Session

Observations of binaries with the NPOI

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We will present the results of Navy Prototype Optical Interferometer observations of binary stars, in particular, of the system 16 Piscium (V=5.7 mag), which is close to the detection limit of the instrument. We will compare different data analysis methods (squared visibilities, coherent integration and imaging), and study their precision in determining binary separation, position angle and magnitude differences.

7734-126, Poster Session

SIM-Lite detection of habitable planets in P-type binary-planetary systems

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Close binary stars like spectroscopic binaries create completely different environment than single stars for the evolution of a protoplanetary disk. Dynamical interactions between one star and protoplanets in such systems provide more challenges for theorists to model giant planet migration and formation of multiple planets. For habitable planets the majority of host stars are in binary star systems. So far only a small amount of Jupiter size planets have been discovered in binary stars, and the minimum separations of those binary stars are 20 AU, the median value is about 1000 AU because of difficulties in radial velocity measurements. SIM-Lite mission, a space based astrometric observatory, has a unique capability to detect habitable planets in spectroscopic binary stars. This work simulates SIM-Lite observation and demonstrates data analysis and error estimates for searching terrestrial planets in P-type binary-planetary systems, where the planets move around both stars in a distant orbit.

7734-127, Poster Session

Homothetic apodization of circular aperture HACA: simulation results

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In this paper we describe an apodization technique of a circular aperture. The apodization procedure introduced here consists of splitting a PSF image into two PSF images, using optical systems, where one of them has undergone a homothety to change its radial dimensions. After a coherent recombination of these two PSFs, we obtain an apodized image. This procedure allows us to reduce the diffraction wings of the PSF with different reduction factors depending on the combination parameters. In laboratory this apodization aproach can be realized by using an interferometric assembly based on Mach-Zender interferometer. We present in this paper the simulation result and we show that the technique HACA reduce the diffraction wings. This technique can be combined with coronagraphy.

7734-128, Poster Session

Tunable spatial heterodyne spectroscopy (TSHS): a new technique for broadband visible interferometry

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In the study of faint, extended sources at high resolving power, interferometry offers significant etendue advantages relative to conventional dispersive grating spectrometers. A Spatial Heterodyne Spectrometer (SHS) is a compact format two-beam interferometer that produces wavenumber dependent 2-D Fizeau fringe pattern from which an input spectrum can be obtained via a Fourier transform. The sampled bandpass of SHS is limited by the highest spatial frequency that can be sampled by the detector, which is typically less than 10 nm. This limitation has made these instruments useful primarily for studies of single emission line features or molecular bands. To date there have been few broadband implementations. We describe here progress toward development of a broadband tunable SHS (TSHS) that is based on an all-reflective format where a single grating operates simultaneously as a beam-splitter, dispersive element, and beam combiner. The narrow spectral coverage of the TSHS is moved to different tuning wavenumbers by adjusting the angle of the pilot mirrors that guide the interfering beams through the optical path, thus slewing the acceptance band over a much broader spectral range. Our present effort involves a breadboard laboratory prototype of a second-generation TSHS in which we address several technical limitations of an earlier version. In particular the new design reduces wavefront distortions on the pilot mirrors, solves problems with magnification and focus of the fringe localization plane onto the detector, and addresses the sensitivity limitations of using a single blazed grating to cover such a large bandpass.

7734-129, Poster Session

From fringes to the USNO Navy prototype optical interferometer astrometric catalog

J. A. Benson, D. J. Hutter, R. T. Zavala, H. C. Harris, P. D. Shankland, K. J. Johnston, U.S. Naval Observatory (United States)

We report on the United States Naval Observatory, Navy Prototype Optical Interferometer, Astrometric Catalog (UNAC). This catalog uses observations from eight astrometric observation runs (Jan. 2005 - Nov. 2009) at the Navy Prototype Optical Interferometer (NPOI). The goal of the first release of the UNAC is to provide an astrometric catalog of at least 100 bright ($V < 5$) stars with positions accurate to < 16 milliarcseconds. In this paper we report on some of the data processing methods used to obtain absolute astrometric positions from optical interferometer data. We also compare our interferometrically derived absolute astrometric positions of a subset of the UNAC stars to independent astrometric positions.

7734-130, Poster Session

First results from MIDI observation with PRIMA FSU as a fringe sensor

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We report first results obtained from observations using PRIMA FSU as a fringe tracker for the mid-infrared instrument (MIDI) of the VLT interferometer (VLTI) when operating with the 1.8m Auxilliary Telescopes (AT). Interferometric observations require the correction of the disturbance in the optical path induced by atmospheric turbulence (piston). The PRIMA Fringe Sensor Unit (FSU) is able to compensate for such disturbances in real-time which makes it a suitable facility to stabilize the fringe signal for other VLTI instruments, e.g. MIDI.

Currently, the atmospheric coherence time in the N-band (8 to 13 microns) observed by MIDI, as well as the thermal background in this band, limit the minimum coherent target flux to about 20 Jy (in PRISM+HIGH_SENS mode and using the ATs) to allows self-fringe-tracking and data reduction. However, we show that if the fringes are stabilized by the FSU, e.g., coherent integration allows a reliable data reduction even for the observation of faint targets (below 20 Jy) with MIDI at standard detector exposure times.

The FSU K-band real time measurements of phase and group delay, required for piston stabilization, can be furthermore used to estimate the amount of water vapor and hence its dispersion in the mid-infrared. We conjecture that our observational tests done so far and the obtained results represent a first step towards Phase Referenced Imaging with the VLTI in the mid-infrared.

7734-131, Poster Session

Limb-darkened angular diameters of stars using infrared and optical interferometry

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We analyzed archival data from the Navy Prototype Optical Interferometer, which operates in visible wavelengths, and the Palomar Testbed Interferometer, which operated in the infrared K-band. Approximately 80 stars were observed using both instruments, and the stars range in spectral types from A to K in luminosity classes III, IV, and V. Limb-darkening corrections differ significantly between the two instruments' wavelength regimes and the combination of angular diameters determined independently will allow the testing of limb-darkening correction factors from the literature. Though we expect high-quality diameters from both instruments for only a quarter to a third of the sample, these results will help validate stellar atmosphere models that rely on these correction factors.

7734-132, Poster Session

A very wide-field wavefront sensor for a very narrow-field interferometer

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The LINC-NIRVANA wavefront sensors are in their AIT phase. The first Ground-layer Wavefront Sensor (GWS) is taking shape in the Adaptive Optics laboratory of the Astronomical Observatory of Padova, while both the Mid-High Wavefront Sensors (MHWSs) have been aligned and tested as stand-alone units in the Observatory of Bologna (MHWS#1 aligned to NIRVANA post focal relay).

LINC-NIRVANA is a Fizeau infrared interferometer equipped with advanced, MultiConjugated Adaptive Optics (MCAO) for the Large Binocular Telescope. The aim of the instrument is to allow true interferometric imagery over a 10” square Field of View (FoV), reaching the sensitivity of a 12m telescope and the spatial resolution of a 22.8m one. Thanks to the MCAO concept, NIRVANA will use up to 20 Natural Guide Stars (NGS) which are divided, according to Layer-Oriented Multiple Field of View technique, between the GWSs and the MHWSs. To find such a large number of references, the AO systems will use a wide FoV of 6’ in diameter and the light coming from the references used by each WFS will optically sum on its CCD camera.

The MHWSs will detect the deformations due to the high layers and will select up to 8 NGSs in the inner 2’ of the FoV.

The GWSs, instead, will reconstruct the deformations introduced by the lower atmosphere, which was found out to be the main source of seeing. Their peculiarity is the highest number of references (up to 12) ever used in a single instrument, selected in an annular 2’-6’ FoV.

7734-133, Poster Session

A monolithic Michelson interferometer as a wavelength reference source for high-precision RV measurements

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Ultra-stable Monolithic Michelson interferometer can be an ideal reference for high-precision applications such as RV measurements in planet detection and characterization. The advantages include wide waveband, simple sinusoidal spectral format, high optical efficiency and easy for operation and maintenance. Recently developed technologies allow fabricating stable interferometers with relatively low cost. The interferometer components are permanently bonded and the assembly is homogeneous in thermal expansion, such that the interferometers are mechanically stable. The interferometers have low sensitivities in instabilities of pressure, temperature, and light source pointing, own to the benefits of solid construction, thermal compensation and wide field angle. Using continuum white light sources, interferometer combs are generated from UV to near infrared. For typical spectral calibrations of instruments, the data processing is very simple and accurate because the spectral data is nearly sinusoidal.

Two Monolithic Michelson interferometers optimized for visible wavelength range from 380 nm to 700 nm are fabricated and the optical delays are ~5.8 mm. The in-house fabrication process is described. Each assembly including multimode fiber feeding and coupling is pressure tight sealed and individually thermally controlled. The relative phase shift between these two interferometers is monitored using a repetitively scanning white light interferometer, such that the individual stability is determined <3 m/s in RV. These two interferometer sources are tested for EXPERT and LIJET planet survey instruments, and the time bracketing calibration results show similar or higher precision than using a Thorium Lamp. The long term instrument operation and maintenance is much more convenient than other reference sources.

7734-134, Poster Session

Development of a high-dynamic range imaging instrument for a single telescope by a pupil remapping system

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We present the laboratory demonstration of a very high-dynamic range, diffraction limited imaging instrument FIRST (Fibered Imager foR Single Telescope). FIRST combines the techniques for aperture masking and a single-mode fiber interferometer. A degraded telescope pupil is divided into many sub-pupils, then they are injected into single-mode fibers. The spatially filtered beams from sub-pupils are remapped and combined on a focal plane to measure interferometric fringes without redundant baselines. The spatial filtering and pupil remapping by single-mode fibers ensure that redundant noise and wavefront errors are corrected almost perfectly, which leads to a very high-dynamic range very near the central object (down to a fraction of lambda/D) at visible to near-infrared wavelengths. Therefore this technique is very complementary to other high-dynamic range instruments using adaptive optics and coronagraph. A raw dynamic range up to 10^6 will be possible even at visible wavelengths, but differential techniques which are under study would further improve the dynamic range. Our laboratory experiments successfully demonstrated that the original image can be reconstructed with the expected dynamic range through a pupil remapping system, despite the existence of piston noises between fibers. We also describe the current status of the development of the prototype system. A first technical test will be performed at the Paris Observatory 1 m telescope. The system will be set-up a the Lick Observatory 3 m Shane telescope for operational tests in mid-2010.

7734-136, Poster Session

Three-dimensional photonic combiner for optical astro interferometry

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Integrated optics is an established technological solution to perform beam combination in modern infrared astronomical interferometers. Recently, a planar integrated chip allowing the measurement of the phase over 6 baselines among 4 telescopes has been realized and tested [M. Benisty, et al. A&A 498, 601-613 (2009)]. However, scaling of integrated devices for beam combinations of all-possible baselines in larger arrays of telescopes could become extremely difficult with the current planar waveguide technology, due to construction constraints.

An alternative for highly complex integrated beam combiners can be provided by laser writing techniques [S. Nolte, et al., Appl. Phys. A 77,

109-111 (2003), R. R. Thomson et al. Opt. Exp. 17, 1963-1969 (2009)] allowing the realization of fully three dimensional structures in various materials.

In our work, we put forward an innovative scheme allowing multiple beam combination and closure-phase retrieval by means of a three dimensional array of coupled waveguides. As in Gabor-like holograms, the operation principle of our device is based on the exploitation of diffraction for self-referencing phase metrology purposes. Light propagation in an array of evanescently coupled waveguides is similar to conventional diffraction, however it is bound to a system with finite degrees of freedom. We have demonstrated that the latter feature allows relating uniquely the intensity pattern at the end of a 3x3 waveguide array to the amplitude and relative phases of three monochromatic fields coupled to suitable input waveguides. The method is scalable to arbitrary large arrays of telescopes and baselines.

7734-137, Poster Session

Design, fabrication, and testing of a super stable monolithic interferometer for infrared exoplanet tracker

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Exoplanet searches are entering a new era when near infrared Doppler instruments are thriving. Among them, Infrared Exoplanets Tracker (IRET) is unique for its compact design and high radial velocity (RV) sensitivity. It is being developed for the Apache Point Observatory 3.5m telescope and works in wavelength range between 0.9 and 1.35 microns (Y and J bands). Simulations show that photon limited RV precision of IRET can reach sub m/s level (0.53 m/s for T=2000K and Vsini=5 km/s) for a J=6 M dwarf in less than 5 min exposure, which is a factor of 2 better than its competing instrument using a conventional echelle method with the same spectral resolution. We will present results from development and testing of a monolithic interferometer which is one of key components in IRET. The interferometer is designed to be field compensated and thermally stable to ensure long term RV stability. The measured thermal drift is 500 m/s/K. IRET will be installed in an environment in which temperature fluctuation is controlled to be ~1 mK rms, hence, thermal drift of the interferometer will not exceed a few m/s. After calibration with a reference source, it can reach sub m/s Doppler precision for very bright M dwarfs. In the absence of a stabilized laser source in the IR wavelength region, a scanning white light interferometer employing a stabilized He-Ne laser at 632.8 nm as the reference is applied to monitor the phase shift of the interferometer. Measurement results over weeks of continuous monitoring will be reported.

7734-138, Poster Session

Mid-infrared waveguides for interferometric beam combiners

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In the astrophysical context of the search for Earth-like extrasolar planets, TPF-NASA and Darwin-ESA projects have driven a lot of research on single-mode integrated optics devices for mid-infrared space-based interferometry. Although these projects are not in the frame of a short-term mission, preparatory projects like FKSI [Danchi03] will need to answer the question of modal filtering and nulling in the mid-IR band with rejection ratios better than 40dB. In this context, we will present results on modal filtering and beam combination in IR devices characterized at LAOG. We will show results on FTS measurements, allowing to determine the single mode spectral domain and nulling capabilities of the waveguides, as well as interference fringes obtained from Y-junctions realized on these materials.

[Danchi03] Danchi, W. C., Deming, Drake, Kuchner, Marc, & Seager, Sara, 2003, "Detection of Close-In Extrasolar Giant Planets with the Fourier-Kelvin Stellar Interferometer," Astrophysical Journal Letters, 597, L57

7734-139, Poster Session

Feeding the wavefront sensors of LINC-NIRVANA: the dedicated patrol camera

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LINC-NIRVANA is the IR Fizeau interferometric imager that will be installed within a couple of years on of the Large Binocular Telescope (LBT) in Arizona. Here we present a particular sub-system, the so-called Patrol Camera (PC), which has been now completed, along with the results of the laboratory tests. It images (in the range 600-900 nm) the same 2 arcmin FoV seen by the Medium- High-Wavefront Sensor (MHWS), adequately sampled to provide the MHWS star enlargers with the positions of the FoV stars with an accuracy of 0.1 arcsec. To this aim a diffraction-limited performance is not required, while a distortion free focal plane is needed to provide a suitable astrometric output. Two identical systems have been realized, one for each single arm, which corresponds to each single telescope. We give here the details concerning the optical and mechanical layout, as well as the CCD and the control system. The interfaces (mainly software procedures) with LINC-NIRVANA (L-N) are also presented.

7734-140, Poster Session

A new embedded control system for SUSI

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The original control system for the Sydney University Stellar Interferometer (SUSI) is based on a network of embedded processors (EP) that control key elements of the interferometer. Each EP consists of a single-board computer equipped with a 20 MHz 6800 CPU and a finite state machine (FSM), based on discrete TTL logic elements, that handles time-critical functions. Serial communication was used both because of the long distances (the maximum baseline is 640 m) and because the site is radio-quiet, ruling out the use of wireless communications.

As part of the upgrade of SUSI for remote operation it was decided to replace the existing EPs with new units based as much as possible on commercially available equipment. Because of the number of EPs it was also essential to keep the cost as low as possible.

The new system is based on a Linux-based computer that has no moving parts. It interfaces via USB to two LabJack U3 digital input/output (DIO) modules. Each unit has 20 configurable lines. Communication will be via TCP/IP over Ethernet or PPP.

Two key time critical aspects of the siderostat controllers are monitoring the output of the incremental shaft encoders and generating the motor drive signals. The first is handled directly by the LabJacks while the second is done by a separate thread in the control program that continuously generates the required signals.

The old EPs are being phased out and are being replaced by the new and far more reliable system.

7734-141, Poster Session

Custom beamsplitter and AR coatings for interferometry

C. A. Jurgenson, New Mexico Institute of Mining and Technology (United States); D. F. Buscher, C. A. Haniff, Univ. of Cambridge (United Kingdom); J. Lewis, R. Schmell, Optical Surface Technologies, LLC (United States)

This paper reports the final results of a custom thin film coating application for the Magdalena Ridge Observatory Interferometer (MROI) fringe tracker. The combiner architecture calls for one anti-reflection and two separate beamsplitter coatings, whose design was guided by an effort to minimize bending of the substrate during the application process, and achieve high throughput and visibilities in broadband polarized light. The coatings were designed at MRO, and applied to the combiner substrates via a sputtering process at Optical Surface Technologies. Measurements show that the substrate deformation is much less than the observation wavelengths, and the AR coating has less than 0.5% reflectance across H/K-bands. It is also concluded that the performance of the combiner is limited by its architecture, not the combined effect of the coatings.

7734-142, Poster Session

Fringe modulation for an MROI beam combiner

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Modulation in the MROI fringe tracker beam combiner will be performed via modulators introducing an optical path difference in increments of lambda/4 into the beam. Knowledge of the path difference introduced needs to be accurate to 1%. To achieve this accuracy, the modulators are characterized and the desired step waveform optimized through Fourier analysis. Control is then be implemented in an FPGA that will also monitor the performance by means of a slow loop Fourier algorithm. Details of the characterization, optimization and implementation are presented here.

7734-143, Poster Session

Fresnel diffraction in an interferometer: application to MATISSE

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While doing optical study in an instrument similar to the interferometers dedicated to VLT, we have to take care of the pupil and focus conjugations. Modules with artificial sources are designed to simulate the stellar beams, in terms of collimation and pupil location. They constitute alignment and calibration tools. In this paper, we present such a module in which the pupil mask is not located in a collimated beam introducing Fresnel diffraction. We study the global performance in terms of spatial coherence quantified by the fringe contrast, and peak of the image in the PSF plane. The considered example is MATISSE, but this study can apply to any other instrument concerned with Fresnel diffraction.

7734-144, Poster Session

Hybrid sol gel technology for fast prototyping of integrated optic devices used in astronomical interferometry

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Guided optics is expanding its role in modern astronomical interferometry. Many applications have been already demonstrated, covering nearly all blocks of an advanced instrument, these developments has led to creation of new field of astrophotonics.

In this rapidly developing field, a fast guided optics prototyping technology is of great interest for device development. This is the case of the hybrid sol-gel technology, which was used in this work for fabrication of prototypes of telescope beam combiners. These devices were designed for the astronomical J-band and have been characterized using an optical source with emission centered at 1265 nm and with a spectral FWHM of 50 nm.

Interferometric characterization of the coaxial two, three and four telescope beam combiners, showed average contrasts higher than 98%, 96% and 95% respectively.. The contrast of the normalized interferogram obtained from the integrated optic device can be degraded by several mechanisms, among them, polarization mismatch, and chromatic differential dispersion between the two interfering fields. Interferometric spectral analysis of the beam combiners revealed that the chromatic differential dispersion is the main contributor to the observed contrast decay in the latter cases. However the measured high contrast fringes confirm that the procedures used lead to performant integrated optics beam combiners. These results demonstrate the capabilities of the hybrid sol-gel technology for fast prototyping of complex chip designs for astronomical applications.

7734-145, Poster Session

MAMMUT: mirror vibration metrology for VLTI

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MAMMUT (Mirror vibrAtion Metrolology systeM for the Unit Telescope) is an ESO funded feasibility project for the development of a fiber interferometer prototype designed for optical path laser-metrology along the optical train of the Unit Telescopes (UT) of the Very Large Telescope Interferometer (VLTI). Fast mechanical vibrations originating in the VLTI cause fast variations of the optical path difference between two arms of the stellar interferometer, thus reducing the contrast of measured interference fringes. MAMMUT aims at monitoring in real time the optical path variations inside the Coudé train of the UT, for active control purposes.

MAMMUT features a 250 meter long optical fiber which can be used to deliver and inject a laser beam at 1355 nm into the UT. The injected beam can be dropped from the telescope in the Coudé room and interfered with a phase reference, provided by the second 250 meter long arm of the fiber interferometer. The optical path variations will be measured by means of an active homodyne scheme. Coherence between the beam at the injection point and the phase reference is provided by active fiber stabilization, made possible by the implementation of an internal metrology channel in MAMMUT.

Here we present the initial laboratory performance results of the MAMMUT prototype, which will be able to sense optical path variations of ±5 mm with sub-10 nm precision within a bandwidth of at least 100 Hz. Possible use of the instrument in combination with the fringe tracker FINITO will be discussed.

7734-146, Poster Session

The atmospheric piston simulator as an integral part of the calibration unit of LINC-NIRVANA

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The Atmospheric piston simulator is an integral part of the calibration unit of LINC-NIRVANA, the Fizeau interferometric imager for the Large Binocular Telescope. The calibration unit will be necessary to align and set up the different opto-mechanical subsystems of the instrument. It will assist in (1) the alignment of the optics via reference fibers; (2) establishing zero optical path difference using a balanced fiber splitter; (3) flatfielding of the detectors with an integrating sphere; (4) correction of the non-common path aberrations using a fiber-based phase diversity source; and (5) calibration of the adaptive optics with a rotating reference fiber plate. Substantial testing and verification of the fringe tracker under as realistic as possible conditions in the lab is desirable, since the performance of the fringe tracker will ultimately determine the high angular resolution imaging capability of LINC-NIRVANA as a whole. We are therefore constructing an atmospheric piston simulator working in the J and H photometric bands. As with many of the other calibration unit sub-systems, our design concept is mainly fiber based. Opto-electronic phase modulators will be used to introduce the piston sequences. The control system of the piston modulators will allow for easy implementation of different vibration power spectra. Together with the intrinsic flexibility of a fiber-based instrument, the calibration unit will enable us to test and demonstrate the capabilities of the fringe tracker under realistic conditions.

7734-147, Poster Session

A real-time signal processing concept for an accelerometer-based calculation of telescope-induced optical-path-difference vibrations at the LBT

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Adequate vibration-control of the optical path of the LINC-NIRVANA (LN) NIR-imaging interferometer at the LBT is important to enable efficient and sensitive interferometric operation. Here, we focus on the generation of the differential optical path (or OPD) information, relevant for LN-fringe measurements, out of the data stream provided by a collection of accelerometers, distributed over the telescope.

The accelerometer signals allow the estimation of the impact of the telescope vibrations on the actual OPD. We will discuss the data processing and how the OPD calculation depends on the chosen position of the accelerometers.

The performance limiting effect of the existing signal delay times will be mitigated by a prediction/phased-locked-loop.

Direct surface vibration measurements with a laser vibrometer are scheduled to verify our OPD-measurement scheme. The final system will deliver the vibration-induced OPD-variations, which will be integrated in the fringe-tracking control loop, to improve the sensitivity and bandwidth of the LN-fringe tracker.

We also re-visit the dynamic performance constraints on the OPD-control actuator, as derived from the current set of telescope vibration measurements.

7734-148, Poster Session

The LINC-NIRVANA fringe and flexure tracker: laboratory tests

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LINC-NIRVANA is the NIR homothetic imaging camera for the Large Binocular Telescope (LBT). In close cooperation with the Adaptive Optics systems of LINC-NIRVANA the Fringe and Flexure Tracking System (FFTS) is a fundamental component to ensure a complete and time-stable wavefront correction at the position of the science detector in order to allow for long integration times at interferometric angular resolutions. In this contribution, we present the design and the realization of the ongoing FFTS laboratory tests, taking into account the system requirements. We have to sample the large Field of View and to follow the reference source during science observations to an accuracy of less than 2 μm (1 detector pixel ~ 18μm). In particular, important tests such as cooling tests of cryogenic components and tip -tilt test (test the repeatability and the precision under the different inclinations) are presented. The system parameters such as internal flexure and precision are discussed. The results of the FFTS tests are discussed, as well.

7734-149, Poster Session

PhaseCam: the phase sensing facility for the LBT interferometer

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The LBT Interferometer requires phase sensing and correction to provide high spatial resolution. The phase sensing will be carried out at K band, using a pupil-plane interferometer, named Phasecam. This subsystem resides in the Nulling and Imaging Camera (NIC) for LBTI. Phasecam views the dual interferometric outputs, providing standard imaging, dispersed images with R=40, and pupil illumination modes of operation. The overlapped pupil images provide information about relative alignment and phasing. The dispersed images allow group delay tracking of the interferometer. The operational approach of Phasecam is described, and simulations of the performance and sensitivity of the subsystem are presented. Phasecam supports the scientific operation for nulling and imaging interferometry at N band with NIC, as well as 3-5 micron imaging interferometry with LMIRCam.

7734-150, Poster Session

Interferometry with a large number of apertures

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There are three objectives for this work. Firstly, this instrument is an essentially-complete aperture-masking system which can accomplish some very interesting science on existing telescopes.

Secondly, for future space missions, we need to demonstrate the correct way do beam combination with many apertures. Despite claims to the contrary, Michelson combination (MC) is simply a better solution than hyper-telescopes (HT). HT needs control at the level where MC only needs knowledge. HT designs will *never* achieve the precision of a good MC design because HT cannot make use of closure relationships and a good MC design does not suffer from complexity and poor sensitivity problems as claimed by the pro-HT advocates in the literature. This operational, 90-aperture interferometer shows feasibility; the next step, which is not yet funded, is to image complex sources in the lab in order to verify its sensitivity and imaging ability.

Finally, I see good interferometric-imaging as an enabler for telescopes in the 30 to 100 meter class. The A/O system on such a telescope still

needs to produce a fairly good wavefront (for coupling into the fibers) but after that, interferometric processing can correct for the remaining phase errors. In addition, if the A/O system Strehl is reasonable, say greater than 20 percent, the interferometry can be accomplished with long (seconds) exposures because under a fairly loose set of assumptions, the temporal phase variations produce station-based errors that can be correct using self-calibration.

7734-151, Poster Session

Mechanical design of the Magdalena Ridge Observatory interferometer

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We report on the mechanical design currently performed at the Magdalena Ridge Observatory Interferometer (MROI) and how the construction, assembly, integration and verification are planned towards commissioning. Novel features were added to the mechanical design, and high level of automation and reliability are being devised, which allows the number of reflections to be kept down to a minimum possible. This includes unit telescope, unit telescope enclosure, unit telescope transporter, fast tip-tilt system, beam relay system, delay line system, beam compressor, automated alignment system, beam turning mirror, switchyard, fringe tracker and vacuum system.

7734-152, Poster Session

Modified telescope alignment procedure improves CHARA Telescope beam quality

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Getting consistently good quality output beams from the telescopes became increasingly important since the commissioning of the visual (VEGA, PAVO) and fiber-based (FLUOR, MIRC) beam-combiners at CHARA. To address this issue, we developed and implemented a new, more precise alignment scheme. The new method was first applied on telescopes E1 and E2 with success. We outline the method and present wavefront curvature results from telescopes E1, E2, W1 and W2.

Further beam improvements can only be achieved by an adaptive optical system, planned at each telescope, or with a search algorithm because of the uncertainties associated with the telescope optics. A search algorithm could evaluate the beam quality in points of the relevant parameter space and select the lateral position and tilt of M2 and the pointing direction of the telescope where the beam quality is optimum.

7734-153, Poster Session

The MROI fringe tracker: laboratory fringes and progress toward first light

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The MROI fringe tracking beam combiner and spectrograph is scheduled to be the first fringe instrument for the interferometer. It was designed to utilize the array geometry and maximize sensitivity to drive the interferometer for faint source imaging. This paper reports on the first laboratory fringe measurements of the beam combiner and optomechanical development status. A defined set of tests has been carried out on the beam combiner to assess performance and validate the design concept. The optical design of the spectrograph is complete and fabrication of the optics and dewar components has begun. Its expected performance will be discussed as well as the overall beam combiner - spectrograph system concept.

7734-154, Poster Session

A new control architecture for multi-beam fringe tracker

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The major difficulty of optical interferometry from the ground is the random optical delay introduced by the atmospheric turbulence, which make the fringes jitter around by a quantity larger than the fringe spacing. Practically, fringe blurring is avoided, either by reducing the integration time to a few milliseconds, which prevents observations of faint targets; or by using a dedicated fringe-tracking facility, the purpose of which is to stabilize fringes by measuring and correcting the optical delay in real-time.

Promising results have been obtained with 2-telescope (or 2 times 2-telescope) trackers. The goal is now to co-phase a larger number of apertures: 4 or 6 in the case of VLTI and CHARA, or even 10 in the case of MROI. Several studies are on-going related to the optimal design of the beam-combiner itself, also very little effort is done regarding the controller architecture.

Our work aims at exploring what can be gained (or not) by building a controller that explicitly handles coupling and redundancies. This enables in particular to tune the different baselines control-related weighting coefficients according to the presence of noise and or potential loss of flux. Moreover, the unavoidable delays are explicitly taken into account in the control design while an observer is used to reconstruct the dynamic of the atmospheric OPD. The control design is based on a multi-variable state space representation making possible the use of standard Linear Quadratic design. The resulting controller can still be expressed in a transfer function form.

7734-155, Poster Session

The LINC-NIRVANA fringe and flexure tracker: an update of the opto-mechanical system

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LINC-NIRVANA (LN) is a German/Italian interferometric beam combiner camera for the Large Binocular Telescope. Due to homothetic imaging, LN will make use of an exceptionally large field-of-view. As part of LN, the Fringe-and-Flexure-Tracker system (FFTS) will provide real-time, closed-loop measurement and correction of pistonic and flexure signals induced by the atmosphere and inside the telescope-instrument system. Such compensation is essential for achieving coherent light combination over substantial time intervals (~10min.). The FFTS is composed of a dedicated near-infrared detector, which can be positioned by three linear stages within the curved focal plane of LN. The system is divided into a cryogenic (detector) and ambient (linear stages) temperature environment, which are isolated from each other by a moving baffle.

In this contribution, we give an overview of the current design and implementation stage of the FFTS opto-mechanical and electronic components. We present recent important updates of the system, including the development of separated channels for the tracking of piston and flexure. Furthermore, the inclusion of dispersive elements will allow for the correction of atmospheric differential refraction, as well as the induction of artificial dispersion to better exploit the observational-conditions parameter space (airmass, brightness).

7734-156, Poster Session

Design of the MROI delay line optical path compensator

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The delay lines for the Magdalena Ridge Observatory Interferometer in New Mexico are charged with providing up to 380m of optical path, in vacuum, in a single stroke. In order to meet demanding requirements in a cost-effective manner a unique combination of techniques is used in the design and construction of the delay line trolley which must operate continuously within 190m of evacuated pipe. Features include contactless power and control, actively controlled optics and composite materials to acheive good thermal stability. A prototype trolley has been built and fully tested and the first production trolley is under construction. Key design features and the construction and alignment of the delay line trolley are described. Results obtained with the trolley operating in an evacuated 20m stroke test rig are presented.

7734-157, Poster Session

Bias-free imaging at low light levels

J. A. Gordon, D. F. Buscher, Univ. of Cambridge (United Kingdom); F. Baron, Univ. of Michigan (United States)

Imaging with optical and infrared interferometers is critically dependent on accurate measurement of closure phases and hence the bispectrum. At low light levels estimation of the bispectrum can be compromised by biases which arise from a combination of photon noise, read noise and non-optimal sampling of the interferometric fringe pattern. We present an estimator for the bispectrum which is unbiased under a very general set of conditions and explore the benefits our estimator offers for image reconstruction under a variety of realistic imaging scenarios.

7734-158, Poster Session

The data-reduction software for micro-arcsecond astrometry with PRIMA at the VLT

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PRIMA (Phase-Referenced Imaging and Microarcsecond Astrometry) is an ESO/VLTI instrument designed for phase-referenced imaging and narrow-angle astrometry, dedicated to exoplanet detection. The astrometric data-reduction software (ADRS) is a key component of the system, calculating very precise (sim 10 muas) differential angular separations projected on the sky. For an interferometer with a baseline of 100 m, this separation corresponds to measuring the (differential) optical path difference with a precision of 5-15 nanometers. This precision can only be achieved with careful calibration of the instrument, including effects that are irrelevant for almost any other scientific application.

PRIMA is currently being commissioned on Paranal, and we expect to obtain the first astrometric data in February 2010. These data will provide a new insight into the operation and calibration of the instrument.

7734-159, Poster Session

The third version of the AMBER data reduction software

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We present the third release of the AMBER data reduction software by the JMMC. This software is based on core algorithms optimized after several years of operation. An optional graphic interface in a high level language allows the user to control the process step by step or in completely automatic manner. On going improvement is the implementation of a robust calibration scheme, making use of the full calibration sets available during the night. The software performances are illustrated on real data taken in various instrumental setup. The output products are standard OIFITS files, which can be used directly in high level softwares like LITpro or image reconstruction tools.

7734-160, Poster Session

GPU-accelerated image reconstruction for optical/infrared interferometry

F. Baron, Univ. of Michigan (United States); B. K. Kloppenborg, Univ. of Denver (United States)

The advent of GPU hardware and associated software libraries for scientific computing renders possible acceleration of parallelisable problems by a typical factor of 10-100. We present the first GPU-accelerated and open source image reconstruction software for optical/infrared interferometry, making use of the OpenCL library. Finally we evaluate how this improvement in speed may translate in terms of improvement in image reconstruction quality for currently computationnally intensive algorithms.

7734-161, Poster Session

Building the 'JMMC bright star diameter catalog' using the SearchCal VO service

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A good calibration of visibilities is paramount for optical interferometry. This calibration is performed using "calibrators", stars whose angular diameter is ascertained by direct or indirect methods. The JMMC Calibrator Workgroup has long developed methods to ascertain the angular diameter of stars, and provides this expertise in the SearchCal software, to help astronomers prepare Optical Long Baseline Interferometry observations. SearchCal dynamically finds calibrators near science objects by querying CDS catalogs on the fly according to observational parameters. Initially limited to bright (Mk<5.5) objects, it has been upgraded with a new method providing calibrators without any magnitude limit. To overcome latency and dependency on network resources for the frequently used bright star queries, JMMC introduces here a new static catalog of stellar diameters, containing ~25000 entries, obtained from SearchCal results aggregation on the whole celestial sphere, complete for all stars with Hippocras parallaxes. We detail the

methods and tools used to produce and study this catalog, and compare the static catalog approach with the dynamical querying provided by SearchCal engine. We introduce one new VO service, enabling the reporting of, and queries about, stars flagged as “bad calibrators” by astronomers, adding this evolutive database to our SearchCal service.

7734-162, Poster Session

SCDU testbed automated in-situ alignment, data acquisition, and analysis

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In the course of fulfilling its mandate, the Spectral Calibration Development Unit (SCDU) testbed for SIM-Lite produces copious amounts of raw data. To effectively spend time attempting to understand the science driving the data, the team devised computerized automations to limit the time spent bringing the testbed to a healthy state and commanding it, and instead focus on analyzing the processed results.

We developed a multi-layered scripting language that emphasized the scientific experiments we conducted, which drastically shortened our experiment scripts, improved their readability, and all-but-eliminated testbed operator errors. In addition to scientific experiment functions, we also developed a set of automated alignments that bring the testbed up to a well-aligned state with little more than the push of a button. These scripts were written in the scripting language, and in Matlab via an interface library, allowing all members of the team to augment the existing scripting language with complex analysis scripts. To keep track of these results, we created an easily-parseable state log in which we logged both the state of the testbed and relevant metadata. Finally, we designed a distributed processing system that allowed us to farm lengthy analyses to a collection of client computers which reported their results in a central log. Since these logs were parseable, we wrote query scripts that gave us an effortless way to compare results collected under different conditions. This paper serves as a case-study, detailing the motivating requirements for the decisions we made and explaining the implementation process.

7734-163, Poster Session

Development of a celestial infrared nuller experiment (CELINE) for broadband nulling and new single-mode fiber testing

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The small angular distance (<100 mas) and the huge flux ratio (10^7) between an Earth-like exoplanet in the so-called habitable zone and its host star makes it very difficult to direct image such systems. Nulling interferometry consists of a very powerful technique that combines destructively the light from two or more collectors to dim the starlight and to reveal faint companions in its vicinity. We have developed a new nulling experiment based on the fiber nuller principle (Serabyn et al. 2006, Martin et al. 2008). This fully symmetric reflective nulling bench aims at testing broadband nulling in both H and K bands as well as characterizing photonic fibers for modal filtering. We present in this paper the design, the development as well as preliminary results of the experiment.

7734-164, Poster Session

The fulfillment of two-level close-loop control in optical delay line of Michelson stellar interferometer

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Presently, the stellar interferometry has been popularly used in astronomy stellar obsevation. As optical dalay line (ODL) is the critical module of stellar interferometer, astronomy stellar interferometry lab of NIAOT has been designing and fulfilling a pratical ODL thses years for future large stellar interferometer of China. In this article, it is focused on the two-level close-loop control of ODL, which are divided into bottom layer control of linear motor and upper layer control of Piezoelectric Transducer (PZT). This ODL are designed to compensate geometrical optical path difference, which results from the earth rotation, real time and with high-accuracy. The bottom layer control is to drive the linear motor to compensate the optical path difference in lagrer range by moving in the changing velocity, with a bandwidth of about 10hz.Meanwhile, the upper layer control of PZT compensates the optical path difference in smaller range to further lessen the optical path difference within coherence length, based on the high-frequency and high-accuracy position perfermance of PZT, with the bandwidth of about 1khz. As to the input of the two control loops, the optical path difference simulation software puts the time-variation velocity and position valuses into the bottom close-loop control to command the linear motor, while in upper control loop the heterodyne laser interferometer measures the actual compensation of ODL, which is subtracted from the desired position to get the PZT input. Compared with Mark III, the three-level control loops are simplied into two-levels, and with the direct driving ability of linear motor, the effect of belt transmission is dismissed. The new features of this ODL ensure supposed control accuracy.

7734-165, Poster Session

Results of the Guide-2 Telescope testbed for the SIM-Lite Astrometric Observatory

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The SIM Lite Astrometric Observatory is to perform narrow angle astrometry to search for Earth-like planets, and global astrometry for a broad astrophysics program, for example, mapping the distribution of dark matter in the Galaxy. The new SIM Lite consists of two Michelson interferometers and one star tracking telescope. The main six-meter baseline science interferometer observes a target star and a set of reference stars. The four-meter baseline interferometer (guide-1) monitors the attitude of the instrument in the direction of a target star. The Guide-2 telescope (G2T) tracks a bright star to monitor the attitude of the instrument in the other two orthogonal directions. A testbed has been built to demonstrate star-tracking capability of the G2T concept using a new interferometric angle metrology system. In the presence of simulated 0.2 arcsec level of SIM attitude control system perturbations, the measured star-tracking capability of the G2T testbed system is less than 35 micro-arcsec during single SIM narrow angle observation.

7734-166, Poster Session

Mitigation of angle tracking errors due to color dependent centroid shifts in SIM-Lite

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The SIM-Lite astrometric interferometer is designed to measure angles between its targets at the micro-arcsecond level within each visit. The operation of the interferometer usually involves switching between various stellar targets within its 15 degree field of regard, guided by its angle tracking system to acquire each star and track it so that the combined beams are parallel and are placed at the correct point on the fringe tracking camera. The dual roles of acquisition and tracking on the angle tracking system require a compromise between tracking accuracy (favoring finer sampling of the point spread function (PSF)) and field of view (favoring fewer pixels per point spread function). This opens up the possibility that the angle tracking system will exhibit a shift in the computed centroid of a star's angular position depending on the spectrum of the star. This phenomenon, which we call a Color Dependent Centroid Shift (CDCS) arises from a coupling of the centroid algorithm's inherent non-linearity and the differing sizes of the PSF's for stars of different spectra. SIM-Lite's Spectral Calibration Development Unit (SCDU) is a testbed aimed at exploring the impact of spectral differences on SIM-Lite's astrometric accuracy. In the course of investigating the cause of a color bias in SCDU's astrometric error, we discovered that CDCS plays an important role. In this paper we describe the effect, its measured and predicted impact and characteristics, and discuss mitigation strategies for SIM-Lite.

7734-167, Poster Session

SCDU testbed narrow angle astrometric performance

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The most stringent Astrometric performance requirements on NASA's SIM-Lite mission will come from the so-called Narrow-Angle (NA) observing scenario, aimed at finding Earth-like planets, where the interferometer chops between the target star and several nearby reference stars multiple times over the course of a single visit (approximately 20 minutes). Since the astrometric signature due to an Earth orbiting a typical target star is well under 1 micro-arcsecond, the requirements on instrument systematic error in this observing scenario are very tight. Many of these requirements have already been demonstrated in previous testbeds. SIM-Lite's Spectral Calibration Development Unit (SCDU) is a testbed aimed at demonstrating that the post-calibration systematic errors arising from spectral differences between the target and reference stars can be brought down to less than 15 pm per visit. In 2007, SCDU demonstrated performance approaching this requirement, but the data showed occasional bias shifts as much as +/- 20 pm amongst groups of runs. Since then, investigation has been under way to understand the mechanisms that give rise to these shifts. In this paper we report our findings, the adopted mitigation strategies, and the resulting testbed performance. We conclude with the implications for the SIM-Lite mission.

7734-168, Poster Session

Progress on SIM-Lite brassboard interferometer integration and test

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The SIM Lite Astrometric Observatory is to perform narrow angle astrometry to search for Earth-like planets, and global astrometry for a broad astrophysics program, for example, mapping the distribution of dark matter in the Galaxy. Recently, the main brassboard Michelson interferometer components (fine steering mirror, path length modulation/cyclic averaging mechanisms and beam combiner assembly) have been developed for the future flight phase implementations. Field-independent interferometer tests will be performed in a vacuum chamber using two siderostats in retro-reflecting positions and a white light stimulus. Brightness and color dependence of the interferometer performance will be measured. Performance of flight dynamic and control algorithms will be tested in a simulated spacecraft attitude control system perturbation. To demonstrate the capability of a dim star observation, the angle and fringe tracking CCD sensors are cooled to -110 degC using a Methane heat pipe. In this paper, we will report recent progress toward the integration and preliminary test data of the brassboard interferometer.

7734-169, Poster Session

SIM brassboard astrometric beam combiner (ABC) integration and performance testing

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The Astrometric Beam Combiner (ABC) is a critical element of the Space Interferometry Mission (SIM) that performs three key functions: combination of starlight from two sidereostats, starlight detection for angle tracking, and starlight dispersion/detection for fringe tracking. The ABC also contains a stimulus, the corner cubes and shutters for in-orbit calibration, tip/tilt mirror mechanisms for in-orbit alignment, and the internal metrology beam launcher. The design of the brassboard ABC (which has the form, fit and function of the flight unit) is complete. Subassembly and bench-level integration is nearing completion, and functionality, performance, vibration and thermal tests will follow.

7734-170, Poster Session

Exoplanet detection performance of the terrestrial Planet Finder interferometer beam combiner

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The Planet Detection Testbed (PDT) was developed to demonstrate the feasibility of four-beam nulling, achievement of the required null stability and the consequent detection of faint planets using an approach contemplated for a future Terrestrial Planet Finder Interferometer space telescope mission. The most promising architectures for a flight mission employing synthesis imaging techniques (the X-Array and the Linear Dual-Chopped Bracewell) are four-beam nulling interferometers that use interferometric chopping to detect planets in the presence of a strong mid-infrared background. The PDT produces four mid-infrared beams of light from the star and another four from the planet, then combines star and planet beams in pairs to produce four star-and-planet beams as if detected by the four apertures of the space telescope. These beams are then nulled and cross-combined, reproducing the operation of the flight beam combiner. Here we demonstrate control of the nullers and the cross-combiner at levels close to those needed for flight and show detection of a realistic faint planet signal within a period of about two hours in the presence of ambient laboratory noise and optical disturbances

7734-79, Session 18

The 2008-2009 outburst of the young binary system Z CMa unraveled by interferometry with medium and high spectral resolution

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Z CMa is a young binary system consisting of an Herbig primary and a FU Ori companion. Both components seem to be surrounded by active accretion disks and a jet was associated to the Herbig B0. In Nov. 2008, K. Grankin discovered that Z CMa was exhibiting an outburst with an amplitude larger than any photometric variations recorded in the last 25 years. To study the innermost regions in which the outburst occurs and understand its origin, we have observed both binary components with AMBER/VLTI across the Brg emission line in Dec. 2009 in MR and HR mode. Our observations show that the Herbig Be, responsible for the increase of luminosity, also produces a strong Brg emission, and they allow us to disentangle from various origins by locating the emission at each velocities through the line. Considering a model of a keplerian disk alone fails at reproducing the asymmetric spectro-astrometric measurements, suggesting a major contribution from an outflow.

7734-80, Session 18

Implementation of the chromatic phase diversity method on the SIRIUS test bench: results and performances of this cophasing method

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As for large interferometers, the crucial point to solve is the cophasing issue. Indeed, the cophasing device must be both efficient and independent of the number of telescopes allowing a large capture range and accurate piston measurements while being easy to implement.

We developed such a cophasing method named the Chromatic Phase Diversity (CPD) method. Actually, using three spectral channels, the CPD method can determine the piston errors without ambiguity and on a range much larger than +/- half a wave. This method makes it possible to work whether in coherencing mode or in cophasing mode.

We designed and implemented this method on the SIRIUS test bench (Patru 2008 A&A 477, 345) at the Observatoire de la Côte d'Azur, France. We present the instrument design, the results obtained with the CPD method. The performances such as the achieved capture range, the accuracy of the piston values extraction and the attainable magnitude are described and analyzed.

7734-81, Session 18

Wavefront calibration and correction of an optical train path: a compliant static deformable mirror approach

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For ground-based optical interferometry the simple specification of high surface quality flat relay mirrors is not the end of the story for obtaining high quality fringes. The Navy Prototype Optical Interferometer array transports the stellar radiation from six primary collectors through a 9-reflection vacuum relay system, resulting in six separate combinable wavefronts. The surface error of each of the 54 mirrors is specified to be no greater than 32 nm peak-to-valley for fabrication purposes. However, once mounted in the 9-element optical train the errors from each mirror do not necessarily cancel one another, but can actually add and increase the resultant wavefront distortion for that path. This leads to fringe contrast reduction, reduced ability to fringe track, and a reduction in the limiting magnitude of observable objects. Fortunately, the total wavefront distortion can be measured, calibrated, and nullified by using a phase-shifting interferometer combined with a compliant static deformable mirror and control system. In this paper we describe a system that mitigates the resultant wavefront distortion.

7734-82, Session 18

The fiber coupler subsystem of the future VLTI instrument GRAVITY

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We present the Fiber Coupler subsystem of the future VLTI instrument GRAVITY. GRAVITY is specifically designed to deliver microarcsecond astrometry and deep interferometric imaging. The Fiber Coupler is designed to feed the light from a science and a reference object into single-mode fibers. The Fiber Coupler consists of four independent units. The units de-rotate the FoV. A motorized half-wave plate allows to rotate the liner polarization axis. Each unit provides actuators for fast piston actuation, tip-tilt correction and pupil stabilization for one of the beams from four VLT telescopes. The actuators are operated in closed-loop. Together with a dedicated Laser Guiding System, this allows to stabilize the beams and maximize the coherently coupled light. The fast piston actuator provides the crucial fringe tracking capability at a bandwidth of >220Hz. A special roof prism design allows to either split the FoV or to serve as a 50/50 beam splitter without changing the optical path. This offers the possibility of on-axis as well as off-axis fringe tracking. The optical train consists solely of mirrors which ensures an achromatic behavior and maximum throughput. The sophisticated optical design compensates for aberrations which are introduced by off-axis parabolic mirrors. This allows to achieve Strehl ratios of >95% across the FoV.

7734-83, Session 18

Reliable optical pump architecture for highly coherent lasers used in space metrology applications

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Laser-based metrology has been identified as an enabling technology in the deployment of large, space-borne observatories, where nanometer-level knowledge of fiducial displacement drives overall system performance. In particular, Nd:YAG NPRO (non-planar ring oscillator) based lasers have received considerable attention in this application because of their inherent high coherence at wavelengths of interest (1064

and 1319nm). However, decade long, NPRO based, space missions are limited by typical 800nm-band pump laser diode wear-out and random failure rates. Therefore, multi-hundred milliwatts NPRO power over prolonged mission lifetimes requires innovative pump architectures. In this paper we present a pump architecture capable of supporting continuous NPRO operation over 7.5yrs at 300mW. The proposed pump architecture relies on a robust all optical fiber coupler that executes the pump beam combining function necessary to support the stated mission power and operating conditions. This coupler has been demonstrated to withstand the exacting environmental requirements placed by a space mission, such as SIM Lite.

7734-84, Session 18

‘OHANA-Iki: a testbed for the ‘OHANA beam combiner and delay line at CFHT

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The possibility of interferometrically coupling large telescopes using single-mode (SM) fibers is a very attractive one, especially at topographically complex and culturally sensitive astronomical observing sites such as the Mauna-Kea summit in Hawaii. The ‘OHANA project (Optical Hawaiian Array for Nanoradian Astronomy) aims to link up seven of the large telescopes on Mauna-Kea using this technology. The concept of using SM fiber links for interferometry has been demonstrated using the two W. M. Keck telescopes. A beam-combiner and optical delay line has been installed at the Canada France Hawaii Telescope (CFHT) to link up Gemini North and CFHT. In order to test the CFHT beam-combiner without making use of CFHT and Gemini observing time, the idea of using two small, 20 cm aperture telescopes to inject starlight into the ‘Ohana interferometer fibers was devised. This project, dubbed ‘OHANA-Iki, is also exploring the concept of a “soft” optical interferometer, specifically one in which the telescopes are easily movable and would not require the heavy, fixed infrastructure found in conventional “free-space” interferometers such as the VLTI.

7734-85, Session 19

The wide-field imaging interferometry testbed (WIIT): recent progress

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The Wide-Field Imaging Interferometry Testbed (WIIT) at NASA’s Goddard Space Flight Center was designed to demonstrate the practicality and application of techniques for wide-field spatial-spectral (“double Fourier”) interferometry. WIIT is an automated system, and it is now producing substantial amounts of high-quality data from its state-of-the-art operating environment, Goddard’s Advanced Interferometry and Metrology Lab. In this paper, we discuss the characterization and operation of the testbed and present the most recent results. We also outline future research directions. A companion paper within this conference discusses the development of new wide-field double Fourier data analysis algorithms.

7734-86, Session 19

Recent progress on the NULLTIMATE test bench

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We report on recent progress made on the NULLTIMATE test bench for nulling interferometry. Dedicated mirror-based achromatic phase shifters have been compared in terms of their achievable rejection ratio. The influence of parameters, such as polarization, have been investigated.

7734-87, Session 20

Estimating the phase in interferomety: performances comparison between single-mode and multimode schemes and application to fringe tracking techniques

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In this presentation I compare the performances of multi and single-mode interferometry for the estimation of the phase of the complex visibility, by providing a theoretical description of the interferometric signal which enables to derive the phase error in presence of detector, photon and atmospheric noises, for both multi and single mode cases. It shows that, despite the loss of flux occurring when injecting the light in the single-mode component (i.e. single-mode fibers, integrated optics), the spatial filtering properties of such single mode devices enable better performances than multimode concepts in case of strong fluxes. In this high flux regime, single-mode interferometry can even be significantly more efficient when the correction provided by adaptive optics becomes poor, reaching a factor 2 when the Strehl ratio is lower than 10%. With low light level, the gain of multimode interferometry compared to single mode one never exceeds 20%, the percentage of photon loss due to the injection in the guides. Furthermore, I demonstrate that single mode interferometry is also more robust to the turbulence both in terms of fringe tracking and phase referencing. The conclusion is therefore that, from a theoretical point of view -- and contrarily to a widespread opinion, fringe trackers built using single mode optics should be considered as the primary solution.

7734-88, Session 20

Analysis of LBT LINC-NIRVANA simulated images with the software package AIRY-LN

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LINC-NIRVANA (LN) is a Fizeau interferometer that will provide for the first time images with a very high angular resolution (about 9,12,17 mas in J,H and K bands) combining the beams from the two Large Binocular Telescope (LBT) arms, by adopting a Multi-Conjugate Adaptive Optics system (MCAO) that allows for atmospheric turbulence compensation.

A big effort has been made by our group in the development of the LN reduction software. In particular, starting from the already existing Sofware Package AIRY, we developed an ad-hoc version for the data that will be collected with LN. This Software package (called AIRY-LN) includes quick-look methods, methods for specific classes of astronomical objects, PSF and sub-images extraction and a blind deconvolution algorithm. The main goal of AIRY-LN is to provide a flexible software to the LN community, able to solve various kinds of image reconstruction schemes by means of a collection of different algorithms, each one optimizing the restoration of a specific astronomical target.

We are using the AIRY-LN software for the simulation and analysis of different scientific cases (from nearby Young Stellar Objects to distant galaxies) in order to test the capability of LN in different astronomical contexts (high dynamical range, faint objects, etc.).

In this contribution we will present the new results and improvements obtained in the reconstruction and analysis of LN-simulated images, together with an evaluation of the best observing procedure to be adopted for the scientific cases of interest.

7734-89, Session 20

A novel imaging algorithm for broadband aperture synthesis data

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Our imaging algorithm is based on the well known CLEAN method, adding the effective temperature as an additional parameter for each image pixel. This information can be used to scale the PSF in each channel with the blackbody law and subtract it from the combined residual map. Once a cleaned map has been obtained (using regular phase self calibration techniques) and thus a set of phase corrected visibilities, individual channel maps are obtained by running the CLEAN restricted to non-zero pixels. The cleaned channel maps together with the total flux spectrum can then be used to estimate the blackbody temperature for each non-zero image pixel, and used for the next iteration of the modified CLEAN algorithm.

7734-90, Session 21

A novel image reconstruction software for optical/infrared interferometry

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Imaging large intensity gradients for rapid rotators, complicated spot patterns on rotating RS CVn binaries, and diffuse disk emission around Young Stellar Objects requires advanced imaging methods beyond the current image reconstruction paradigms in optical/infrared interferometry. This paper presents a flexible software which is ongoing development at the University of Michigan to solve these problems : capable of simultaneous model-fitting and image reconstruction, it also possesses new useful capabilities such as imaging on a spheroid. The problem of the local minimas due to the “missing phase” is treated, and the use of non-pixel-based reconstructions is discussed within the Bayesian evidence framework. Finally the current performance of the algorithm to the previous generation software MACIM and BSMEM on both simulated data and real data obtained at CHARA.

7734-91, Session 21

On the use of spectral regularization and parcimonious representation bases for improving the image reconstruction from interferometric data

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In order to improve image reconstruction from multi-wavelength interferometric measurements, we introduce some a priori knowledge on the spectral correlation between the brightness distributions at each wavelength. We formulate such regularization criteria along the spectral dimension for a few particular astrophysical cases, and some reconstruction results from simulated multi-wavelength data are shown.

The combined use of color-differential observables together with absolute ones allows a higher precision on the data used for the reconstruction, but it introduces a sensitivity to amospheric and instrumental effects such as the variable chromatic OPD and the chromatic background. They are tentatively represented through a model with a few free parameters, which can possibly be introduced and resolved in the reconstruction process.

We also show that the interferometric image reconstruction problem can benefit from being reformulated as a sparse approximation problem in redundant dictionaries. The dictionary is composed from union of representation bases, whose atoms correspond to geometric features of the image. Different bases (e.g. impulsions, wavelets, discrete cosine transform) correspond to different features. The sparse approximation approach consists in selecting the geometrical features that best explain the interferometric data, by imposing that only a few such features should be necessary to reconstruct the image. Simulations showing images reconstructed using this method are presented.

7734-92, Session 22

New concept for direct detection and spectra of exoplanets

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There are a few new innovations in this study.

1. Application of Double Fourier Interferometry to the nulling world

- Absolute phase retrieval by the chopping technique
- Spectral imaging without a spectrometer

2. Novel spectral imaging method

- Planetary systems are composed of point sources such as planets, a star, and fragments. In other words, the imaging of planetary systems is to reconstruct the positions and the intensities of the planets.

As a result, imaging of planetary systems can be reconstructed from only two complex visibilities, and the spectra of the planets are also estimated from the few visibility measurements.

7734-93, Session 22

Integrated optics for nulling interferometry in the thermal infrared: progress and recent achievements

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Supérieure d'Electronique et de Radioélectricité de Grenoble (France); G. J. Hawkins, The Univ. of Reading (United Kingdom); V. Kirschner, European Space Research and Technology Ctr. (Netherlands); S. Menard, Thales Alenia Space (France); G. Parent, Lab. d'Energétique et da Mécanique Théoriquée et Appliquée (France); A. Pradel, C. Vigreux, Univ. Montpellier 2 (France); S. Zhang, X. Zhang, Univ. de Rennes 1 (France)

Nulling interferometry in the thermal Infrared [6-20µm] range is well known to be a major candidate technology for the detection and spectrometry of extra-Solar Earth-like planets, thanks to its huge starlight rejection and angular resolution potential.

In the past years, quite remarkable achievements have been made in the development and validation of the necessary technology and specific components. Nevertheless, the issue of modal filters remains an field of active investigation, due to the very particular spectral range, transmission efficiency and guiding requirements of these components.

Modal filtering is critical for nulling interferometry. It can be implemented using single-mode waveguides by means of their capability to transmit only one complex amplitude function. Virtually any perturbation of the interfering wavefronts can thereby be eliminated, making very high rejection ratios possible. In the present paper we focus on the progress of Integrated Optics, one of the two candidate technologies for the fabrication of Modal Filters, together with fibre optics.

In the framework of the European Space Agency's "Integrated Optics" activity, we are developing modal filtering components by etching layers of chalcogenide material deposited on chalcogenide glass substrates, with the purpose of improving the technology until compliant prototypes can be manufactured and validated. The present paper aims at presenting the progress of the project over the last two years as far as components design, technology and testing are concerned.

7734-95, Session 22

PERSEE: experimental results on the cophased nulling bench

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Nulling interferometry is a promising method to characterize spectra of exoplanets. One of the main issues is to cophase at a nanometric level each arm despite satellite disturbances (drift and vibrations). The bench PERSEE aims to prove the feasibility of that technique for spaceborne missions. I will first present the results obtained in a simplified configuration: we have cophased down to 0.22 nm rms in OPD and 60 mas rms in tip/tilt, and have obtained a monochromatic null of 3.10-5 stabilized at 3.10-6. To maintain a nanometric correction in presence of additional typical satellite disturbances, an optimal control law is required. I will thus present results of a Kalman filter, based on previous work for adaptive optics. Simulations show a good rejection of disturbances, especially vibrations; experimental results are expected for the conference. Last, I will present the current status and results of the final PERSEE configuration, under integration, which includes an achromatic phase shifter, optical delay lines, beam compressors to simulate the telescopes and perturbation devices.

7734-96, Session 23

The 2010 interferometric imaging beauty contest

F. Malbet, G. Duvert, Lab. d'Astrophysique de l'Observatoire de Grenoble (France); W. D. Cotton, National Radio Astronomy Observatory (United States); P. R. Lawson, Jet Propulsion Lab. (United States); K. Hofmann, G. P. Weigelt, Max-Planck-Institut für Radioastronomie (Germany); J. Young, Mullard Radio Astronomy Observatory (United Kingdom); F. Baron, Univ. of Michigan (United States); D. F. Buscher, Mullard Radio Astronomy Observatory (United Kingdom); B. K. Kloppenborg, Univ. of Denver (United States); É. M. Thiébaut, Ctr. de Recherche Astrophysique de Lyon (France); S. Renard, Lab. d'Astrophysique de l'Observatoire de Grenoble (France); S. Rengaswamy, European Southern Observatory (Germany); M. Vannier, Univ. de Nice Sophia Antipolis (France); L. M. Mugnier, ONERA (France); J. D. Monnier, Univ. of Michigan (United States)

We present the results of the fourth Optical/IR Interferometry Imaging Beauty Contest. The contest consists of blind imaging of test data sets derived from model sources and distributed in the OI-FITS format. The test data consists of spectral data sets on two objects "observed" in the infrared with spectral resolution. There will be 6 different algorithms competing this time: Building Block method (BBM by Hofmann & Weigelt), Bispectrum Maximum Entropy Method (BSMEM by Young, Baron & Buscher), GPu Accelerated Image Reconstruction for Interferometry (GPAIR by Baron & Kloppenborg), Multi-aperture Image Reconstruction Algorithm (MIRA by Thiebaut & Renard), Recursive Phase Reconstruction (RPR by Rengaswamy), Weak-phase Interferometric Sample Alternating Reconstruction Device (WISARD by Vannier & Mugnier) and a new method proposed by Baron & Monnier. The results of the image reconstruction obtained by each method presented will be discussed. The strengths and limitations of each algorithm will also be discussed.

7734-97, Session 23

Optical long baseline interferometry news (OLBIN)

P. R. Lawson, Jet Propulsion Lab. (United States); F. Malbet, Lab. d'Astrophysique de l'Observatoire de Grenoble (France)

The Optical Long Baseline Interferometry News (OLBIN) is a website and forum for scientists, engineers, and students who share a common interest in long-baseline stellar interferometry. Through OLBIN you will find links to projects devoted to stellar interferometry, as well as news items, recent papers and preprints, notices of upcoming meetings, and resources for further research. This paper describes the history of the website, how it has evolved to serve the community, and the current plans for its future development. The website can be found at http://olbin.jpl.nasa.gov/.

7734-98, Session 23

Developing achromatic coronagraphic optics for LMIRCam and the LBT

M. A. Kenworthy, Leiden Observatory (Netherlands) and The Univ. of Arizona (United States); P. M. Hinz, J. L. Codona, The

Univ. of Arizona (United States); J. C. Wilson, M. F. Skrutskie, Univ. of Virginia (United States); E. Solheid, The Univ. of Arizona (United States)

The Apodizing Phase Plate (APP) is a simple optic that provides coronagraphic suppression of diffraction without the need for any focal plane occulters. We present the design and fabrication of an achromatized APP for LMIRCam that is optimised for the direct imaging of cool extrasolar giant planets around nearby stars at thermal infrared wavelengths. These optics have a high throughput and require no precision alignment.

A modification to the original chromatic design brings several significant advantages, including (i) simultaneous broadband performance from 4 to 8 microns, (ii) significant relaxation of manufacturing tolerance requirements and (iii) simplified characterization of non common path errors in the camera and AO system.

These coronagraphic optics can use the full 22m baseline of the Large Binocular Telescope to provide unique sensitivities for extrasolar planet detection. We cover the basic principle and manufacture of the optic, and initial results testing the achromatic concept with on-sky measurements at the MMTO 6.5m telescope.

7734-99, Session 23

Coherent integration results from the NPOI

A. M. Jorgensen, New Mexico Institute of Mining and Technology (United States); H. R. Schmitt, U.S. Naval Research Lab. (United States) and Interferometrics, Inc. (United States); J. T. Armstrong, U.S. Naval Research Lab. (United States); D. Mozurkewich, Seabrook Engineering (United States); E. K. Baines, R. B. Hindsley, U.S. Naval Research Lab. (United States); D. J. Hutter, U.S. Naval Observatory (United States); S. R. Restaino, U.S. Naval Research Lab. (United States)

Because of atmospheric turbulence, exposure times at optical interferometers have been limited to only a few milliseconds. In order to build SNR many observations are combined. However, the way in which the observations are combined is crucial to the usability of the resulting data product. The traditional squared visibility approach to coherent integration yields relatively poor SNR for targets that are either faint or have small visibilities (or more accurately have a SNR per exposure of less than one). This is the result of a noise floor introduced by the squaring of the data. Our approach to coherent integration makes use of multi-wavelength information of spectrally resolved fringes, and aligns the fringes (without squaring). There are two basic approaches to coherent integration: real-time tracking and integration, or post-processing fringe tracking. At the NPOI we are employing the latter approach. With coherent integration of fringe data, and the accurate calibration of the NPOI wavelength scale, we have been able to make high-accuracy measurements of binary stars and single stars, with minimal calibrator observations. In this talk we will show some of those results. Fringe tracking noise due to photon counting and other causes results in a reduction of the fringe visibility below the raw system visibility. To make optimal use of the data it is necessary to determine the fringe tracking noise and calibrate it out of the coherently integrated data. We will also discuss this calibration.

7734-100, Session 23

Toward the stability required for Darwin/TPF-I

O. Demangeon, P. A. Schuller, A. M. Léger, Institut d'Astrophysique Spatiale (France); B. Chazelas, Observatoire de Genève (Switzerland); M. Decaudin, P. Duret, P. Gabor, Institut d'Astrophysique Spatiale (France); J. Gay, Observatoire de la Côte d'Azur (France); A. M. Labèque, Institut d'Astrophysique Spatiale (France); Y. Rabbia, Observatoire de la Côte d'Azur (France); Z. Sodnik, European Space Research and Technology Ctr. (Netherlands)

We report on recent progress made on the NULLTIMATE test bench for nulling interferometry. We have pushed the long-term stability of the bench towards the required 3 10^-9 standard deviation of the null on times longer than 24 hours, using an interferometer with mean value of the null of 1 10^-5. We discuss the implications for the Darwin/TPF-I perspectives.

7734-101, Session 23

Improving null depth measurements with statistics: theory and first results with the Palomar fiber nuller

C. P. Hanot, Univ. de Liège (Belgium); B. P. Mennesson, E. Serabyn, S. R. Martin, K. M. Liewer, F. M. Loya, Jet Propulsion Lab. (United States); P. Riaud, O. Absil, Univ. de Liège (Belgium)

A unique statistical data analysis method has been developed for reducing nulling interferometry data. The idea is to make use of the statistical distributions of the fluctuating null depths and beam intensities to retrieve the astrophysical null depth in the presence of fluctuations. The approach yields an accuracy much better than is possible with standard data reduction methods, because the accuracy of the null depth is not limited by the sizes of the phase and intensity errors but by the uncertainties on these errors. The result is an improvement in the instrumental null depth measurement limit of roughly an order of magnitude. We show in this paper that broadband null depths of 10-4 can be measured in the lab with our infrared Fiber Nuller without achromatic phase shifters. On sky results are also dramatically improved, with measured contrasts up to 5 x 10-4 with our instrument mounted on the Hale telescope at the Palomar Observatory. This statistical analysis is not specific to our instrument and may be applicable to other interferometers.

7734-102, Session 23

Integrated optic beam combiners for stellar interferometry and nulling at near- and mid-infrared wavelengths

H. Hsiao, K. A. Winick, J. D. Monnier, Univ. of Michigan (United States)

Integrated optic, stellar interferometric two-beam and three-beam combiners have been designed and fabricated for operation in the L band (3 μm - 4 μm) for the first time. The devices have been realized in titanium-indiffused, x-cut lithium niobate substrates, and on-chip electro-optic fringe scanning has been demonstrated. White light fringes were produced in the laboratory using the two-beam combiner integrated with an on-chip Y-splitter. A new design for next-generation, broadband, achromatic, astronomical, beam combiners operating in the N band (8 μm - 12 μm) is proposed and analyzed. The design is based on adiabatic mode-evolution couplers fabricated using Ge/Si heterostructure rib waveguides.

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7735-01, Session 1

Advances in instrumentation at the W. M. Keck Observatory

S. M. Adkins, T. Armandroff, H. A. Lewis, W. M. Keck Observatory (United States); D. C. Martin, California Institute of Technology (United States); I. S. McLean, Univ. of California, Los Angeles (United States); C. M. Rockosi, Lick Observatory (United States); P. Wizinowich, W. M. Keck Observatory (United States)

In this paper we describe both recently completed instrumentation projects and our current development efforts in terms of their role in the strategic plan, the key science areas they address, and their performance as measured or predicted. Recently completed projects include the deployment of an upgrade to the red channel detector system of one of the observatory's work horse instruments, LRIS, and the deployment of a laser guide star (LGS) facility on the Keck I telescope, enabling LGS AO with both of the Keck telescopes. We have also fully deployed the software component of our new acquisition and guiding system, and we have completed the guide camera hardware upgrades on the second facility instrument, LRIS. On-going projects include MOSFIRE, a near IR multi-object spectrograph nearing completion with first light expected later in calendar 2010, and a new seeing limited integral field spectrograph for the visible wavelength range called the Keck Cosmic Web Imager (KCWI). We have also completed the preliminary design of the Keck Next Generation Adaptive Optics facility (NGAO), a new capability that will expand the range of science cases accessible to AO observations by providing high sky coverage, improved sensitivity, and wavelength coverage from the K-band (Strehl ~80%) to the I-band (Strehl ~20%).

7735-02, Session 1

ESO instrumentation for the La Silla/Paranal Observatory

M. M. Casali, European Organisation for Astronomical Research in the Southern Hemisphere (Germany)

The European Southern Observatory currently has an ambitious programme of 2nd generation instrumentation which aims to build on the success of delivered first-generation facilities for the VLT and VLT-I. The talk will give an overview of existing and planned facilities, and discuss trends in instrumentation development and construction.

7735-03, Session 1

Instrumentation at the Subaru Telescope

N. Takato, National Astronomical Observatory of Japan/Subaru Telescope (United States)

Developing new instruments and upgrading existing instruments has been an important part of the Subaru telescope's operation. Seven facility instruments and two visiting instruments are currently operational. Among them HiCIAO, a coronagraphic imager combined with adaptive optics(AO188), has started its full operation since 2nd semester of 2009, and are using for a large program to find new exo-planets and comprehensively understand the planet formation from proto-planetary disks. To archive higher contrast, a new coronagraph attachment with extreme AO (SCExAO) will be installed as a PI instrument. AO188 are also used with the IRCS in natural guide star mode. Laser guide star mode is in commissioning phase. The Fibre multi-object spectrograph (FMOS), which comprise 400 fibers placed at the prime focus and deliver 0.9-1.8um spectra, will be partly offered to open use from mid 2010. Hyper Suprime-Cam, the wide-field upgrade (1.5 deg FoV) of the Suprime-Cam, is under development for its first light in 2012. Development of an immersion grating has been taken place for upgrading the IRCS with a high-resolution infrared spectrograph.

7735-04, Session 1

Gemini Observatory instrumentation: a review of the past, present, and future on our 10th anniversary

E. V. Tollestrup, S. J. Kleinman, S. J. Goodsell, Gemini Observatory (United States); G. Arriagada, M. Lazo, R. Rogers, R. L. Galvez, Gemini Observatory (Chile); J. K. White, Gemini Observatory (United States)

As Gemini Observatory celebrates the 10th anniversary of the dedication of the two telescopes, the instrumentation program is evolving rapidly from the original suite of instruments to an exciting new suite of upgraded and new instruments that is taking us into the next decade. Our newest instrument, the Near-Infrared Coronagraph, is nearing the completion of a major 500-hour planet survey on Gemini-South and is now available for general observations. FLAMINGOS-2, a near-infrared multi-object spectrometer, is currently undergoing commissioning in the south, and the Gemini Near-Infrared Spectrograph is also being re-commisioned for use on Gemini-North after extensive repairs. Meanwhile, the Gemini Multi-Object Spectrograph - North is undergoing a major upgrade to include improved, red-sensitive CCDs and new control electronics. Looking into the future, the Gemini Planet Finder is currently in the integration and test phase, with an anticipated delivery to Gemini-South in 2011. The Gemini Multi-Congugate Adaptive Optics System, which is a key future capability for use with the Gemini South AO Imager and FLAMINGOS-2, is nearing completion this year after several key components were delivered in the past year, and is being integrated and tested with the telescope. Finally, Gemini is in the process of planning and defining the next, fourth generation of instrumentation, which should be available in the next few years.

7735-05, Session 1

An overview of instrumentation for the Large Binocular Telescope

R. M. Wagner, The Univ. of Arizona (United States)

An overview of instrumentation for the Large Binocular Telescope (LBT) is presented. The LBT will incorporate two 8.4 m primary mirrors with adaptive secondary mirrors on a common mount to achieve the collecting area of an 11.8 m telescope and the angular resolution of a 23 m telescope. Five fixed and two auxiliary bent focal station pairs are available. Optical instrumentation includes the Large Binocular Camera (LBC), a pair blue-red optimized wide-field mosaic CCD imagers at the prime foci, and the Multi-Object Double Spectrograph (MODS), a pair of double-beam, blue-red optimized, long- and multi-slit spectrographs mounted at the straight-through F/15 Gregorian foci for spectroscopy over a 6' field and spectral resolutions of 300-2000. Infrared instrumentation includes a near-infrared (0.85-2.5 microns) imager and spectrograph pair (LUCIFER) mounted at the bent-front Gregorian F/15 foci and designed for seeing-limited imaging, long-slit spectroscopy, and multi-slit spectroscopy utilizing cooled masks over a 4' field and diffraction-limited imaging and long-slit spectroscopy over a 0.5' field. Strategic instruments under development for the remaining

two combined bent focal stations and which can utilize the full 23 m baseline include a cryogenic beam combiner with mid- and thermal-infrared cameras for Fizeau imaging and nulling interferometry (LBTI) and an optical bench near-infrared beam combiner for super high-angular resolution imaging (LINC-NIRVANA). A fiber-fed bench spectrograph (PEPSI) capable of ultra high resolution optical spectroscopy and spectropolarimetry will be available as a principal investigator instrument.

7735-06, Session 1

Instrumentation suite at the MMT Observatory

M. A. Hastie, G. G. Williams, MMT Observatory (United States)

In the ten years since the converted 6.5m MMT dedication in 2000 the observatory has built up an impressive suite of instrumentation to compliment the three interchangeable secondary mirrors, including the deformable secondary for the AO system. This review paper presents an up-to-date perspective on all the capabilities of our full range of instrumentation, highlighting newly commissioned instruments (including; the MMT and Magellan InfraRed Spectrograph (MMIRS), a infrared spectrograph, the MMT Advanced Echelle Spectrograph (MAESTRO), a high resolution cross-dispersed spectrograph and MMTPol, an AO fed imaging polarimeter) and new modes or upgrades for established instruments (such as; Red Channel, the MMT's workhorse spectrograph, HECTOSPEC, an optical fiber-fed, multi-object spectrograph and the AO instruments the Arizona infraRed Imager and Echelle Spectrogrph (ARIES), an infrared imager and spectrograph & CLIO, a 5 micron camera). The MMT's pioneering adaptive secondary mirror can be used in both Natural Guide Star mode or with a Rayleigh Laser Guide Star system that is capable of both wide-field partial compensation with ground layer adaptive optics and high-order correction along a single line of sight with laser tomography for which we present progress to date. We also investigate how the instrument suite as contributed to the science productivity the MMT over the last 10 years.

7735-07, Session 2

The second-generation VLT instrument MUSE

R. M. Bacon, Observatoire de Lyon (France)

The second generation VLT instrument MUSE is approaching completion. A significant fraction of the hardware has been received and tested. I will present the assembly and test results of the first (among 24) Integral Field Unit. This IFU is based on a number of innovative components such as grade AR 4Kx4K detector, large band VPHG grating, glass slicer and high performance spectrograph.

Based on the updated performances I will review the expected science impact in the field of galaxy formation and evolution, using an end-to-end modelling of the instrument performances.

7735-08, Session 2

HERMES: revisions in the design for a high-resolution multi-element spectrograph for the AAT

S. C. Barden, Anglo-Australian Observatory (Australia); D. J. Jones, Prime Optics (Australia); S. I. Barnes, J. Heijmans, A. Heng, Anglo-Australian Observatory (Australia); G. Knight, Sinclair Knight Merz Ltd. (Australia); D. R. Orr, G. A. Smith, V. Churilov, L. G. Waller, K. Shortridge, A. J. Horton, D. Mayfield, R. Haynes, D. M. Haynes, D. Whittard, M. Goodwin, S. Smedley, I. Saunders, P. R. Gillingham, E. Penny, T. J. Farrell, M. Vuong, R. Heald, S. Lee, R. Muller, Anglo-Australian Observatory (Australia); K. Freeman, Australian National Univ. (Australia); J. Bland-Hawthorn, The Univ. of Sydney (Australia); D. F. Zucker, Anglo-Australian Observatory (Australia)

The AAO is building an optical high resolution multi-object spectrograph for the AAT with Galactic Archaeology as the primary science driver. The instrument, to be fed with the existing 2dF robotic fibre positioning system, has undergone significant design revision over that presented at the 2008 Marseilles SPIE meeting. The current design is a 4-channel VPH-grating based spectrograph providing a spectral resolving power of 28,000 standard and a resolution mode of 40,000 with a slit mask. The total spectral coverage is about 1000 Angstroms for up to 392 simultaneous targets within the 2 degree field of view.

The collimator is an f/6.32 off-axis Houghton derivative delivering a 190 mm diameter pupil on the gratings. The entrance slit is a curved array of the fibres that compensates for high order dispersion terms to straighten out the slit curvature on the detector. The output of the fibres are relayed from f/3.15 to f/6.32 with micro-optic relays.

Dichroic beam splitters are used to split the light into the four channels. Each channel utilizes fold mirrors, exchangeable VPH gratings, all transmissive camera optics, and a 4k by 4k E2V detector system optimized for the wavelength band of each channel. All surfaces are either spherical or plano except for the first surface of each camera, which is paraboloid.

Major challenges in the design include the mechanical stability, grating and dichroic efficiencies, and fibre slit relay implementation. An overview of the current design and discussion of these challenges is presented.

7735-09, Session 2

The multi-object double spectrographs for the Large Binocular Telescope

R. W. Pogge, B. Atwood, D. F. Brewer, P. L. Byard, M. A. Derwent, R. Gonzalez, P. Martini, J. A. Mason, T. P. O'Brien, P. S. Osmer, D. P. Pappalardo, D. P. Steinbrecher, E. J. Teiga, R. Zhelem, The Ohio State Univ. (United States)

The Multi-Object Double Spectrographs (MODS) are two identical high-throughput optical low- to medium-resolution CCD spectrometers being deployed at the Large Binocular Telescope (LBT). Operating in the 320-1000nm range, they use a large dichroic to split light into separately-optimized red and blue channels that feature reflective collimators and decentered Maksutov-Schmidt cameras with 8x3K CCD detectors. A parallel infrared laser closed-loop image motion compensation system nulls spectrograph flexure giving it high calibration stability. The two MODS instruments may be operated together with digital data combination as a single instrument giving the LBT an effective aperture of 11.8-meter, or separately configured to flexibly use the twin 8.4-meter apertures. This paper describes the properties and performance of the completed MODS1 instrument and presents the first on-sky results from commissioning at the LBT.

7735-10, Session 2

SITELLE: a wide-field imaging Fourier transform spectrometer for the Canada-France-Hawaii Telescope

L. Drissen, Univ. Laval (Canada); F. J. Grandmont, ABB Inc. (Canada); J. Maillard, Institut d'Astrophysique de Paris (France); C. Robert, G. Joncas, S. Thibault, Univ. Laval (Canada); L. Simard, National Research Council Canada (Canada); D. Devost, Canada-France-Hawaii Telescope (United States); D. Durand, National Research Council Canada (Canada); F. Boulanger, Institut d'Astrophysique Spatiale (France); J. Zorec, Institut d'Astrophysique de Paris (France)

This paper describes the concept of a new instrument for the CFHT, SITELLE as well as a clear science case and a technical study of its preliminary design. SITELLE will be an imaging Fourier transform spectrometer capable of obtaining the visible (350 nm - 950 nm) spectrum of every source of light in a field of view of 15 arcminutes, with 100% spatial coverage and a spectral resolution ranging from R = 1 (deep panchromatic image) to R = 104 (for gas dynamics). SITELLE will cover a field of view 100 to 1000 times larger than traditional integral field spectrographs. It is a legacy from BEAR, the first imaging FTS installed on the CFHT and the direct successor of SpIOMM, a similar instrument attached to the 1.6-m telescope of the Observatoire du Mont-Mégantic in Québec. SITELLE will be used to study the properties of comets, the structure and kinematics of HI I regions and ejecta around evolved stars in the Milky Way, emissionline stars in clusters, abundances in nearby gas-rich galaxies, and the star formation rate in distant galaxies.

7735-11, Session 2

Performance and sensitivity of low-resolution spectrographs(LRS) for LAMOST

Y. Hou, Y. Zhu, Z. Hu, L. Wang, J. Wang, Nanjing Institute of Astronomical Optics & Technology (China)

16 low resolution spectrographs (LRS) for LAMOST have been successfully commissioned. The design of LRS is dual-beamed and bench-mounted, with large-beamed, fast Schmidt cameras and VPH (Volume Phase Holographic) transmission gratings. The design wavelength range is 370-900nm, at resolutions R=1000-10000. Each spectrograph is fed by 250 fibers with 320 micron in diameter (corresponding 3.3 arcsec), consists of one Schmidt collimator with F/4, a dichroic beam-splitter, four VPH gratings, articulating Schmidt cameras with F/1.3optimized blue band (370-590 nm) and red band (570-900 nm), and field lens near the focal plane service as the vacuum window of CCD detector cryogenic head.

In this paper, some performance testing results such as image quality, spectra resolution, efficiency.etc, and observing spectra are given.

7735-12, Session 2

Status of the dark energy survey camera (DECam) project

B. L. Flaugher, Fermi National Accelerator Lab. (United States)

The Dark Energy Survey (DES) is a next generation optical survey aimed at understanding the expansion rate of the universe using four complementary methods: weak gravitational lensing, galaxy cluster counts, baryon acoustic oscillations, and Type Ia supernovae. To perform the survey, the DES Collaboration is building the Dark Energy Camera (DECam), a 3 square degree, 520 Megapixel CCD camera which will be mounted at the prime focus of the Blanco 4-meter telescope at the Cerro Tololo Inter-American Observatory. The survey will cover 5000 square-degrees of the southern galactic cap with 5 filters (g, r, i, z, Y). DECam will be comprised of 74 250 micron thick fully depleted CCDs: 62 2k x 4k CCDs for imaging and 12 2k x 2k CCDs for guiding and focus. DECam will be used to perform the Dark Energy Survey with 30% of the telescope time over a 5 year period. During the remainder of the time, and after the survey, DECam will be available as a community instrument. Construction of DECam is well underway and integration of the major system components will begin in 2010 at Fermilab. An overview of the DECam design and the status of the construction and integration tests will be presented.

7735-13, Session 2

ADFOSC: a new optical instrument for the 3.6m Devasthal Optical Telescope

S. Mondal, R. S. Yadav, M. Singh, Aryabhatta Research Institute of Observational Sciences (India)

ARIES-Devasthal Faint Object Spectrograph and Camera (ADFOSC) is the first-light Cassegrain instrument for the upcoming 3.6m, F/9 Devasthal Optical Telescope to be installed at Devasthal, Nainital, India. The science instrument has two mode of observations : direct broad- and narrow-band imaging, and low-medium resolution spectroscopy in the wavelength range 360--1000 nm. To take an advantage of the occasional best seeing (about 10% time) of 0.7 arcsec at the site, the imaging mode with a F/4 camera is being optimized to have a pixel scale of better than 0.25 arcsec over 10 X 10 arcmin field of view. The spectroscopy mode will provide low-medium spectral resolution of R = 250 — 2000 with a 1.0 arcsecond slit-width using set of single grisms, and up to about 4000 using the echelle grisms. The instrument is in its early opto-mechanical design stages. This paper presents an optical design overview of the instrument.

7735-14, Session 2

ESPRESSO: the Echelle spectrograph for rocky exoplanets and stable spectroscopic observations

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ESPRESSO, the Echelle SPectrograph for Rocky Exoplanets and Stable Spectroscopic Observations, will combine the efficiency of modern echelle spectrograph design with extreme radial-velocity precision. It will be installed on ESO's VLT in order to achieve a gain of two magnitudes with respect to its predecessor HARPS, and the radial-velocity precision will be improved to reach cm/s level.

We have constituted a Consortium of astronomical research institutes to fund, design and build ESPRESSO on behalf of and in collaboration with ESO, the European Southern Observatory. The spectrograph will be installed at the VLT and will be operated either with a single Unit Telescope (UT) or with up two 4 UTs. In exchange of the major financial and human effort the building Consortium will be awarded with

guaranteed observing time (GTO), which will be invested in a common scientific program.

Thanks to its characteristics and the ability of combing incoherently the light of 4 large telescopes, ESPRESSO will offer new possibilities in many fields of astronomy. Our main scientific objectives are, however, the search and characterization of rocky exoplanets in the habitable zone of quiet, near-by G to M-dwarfs, and the analysis of the variability of fundamental physical constants. In this paper will present the ambitious scientific objectives, the capabilities of ESPRESSO, and the technical solutions of this challenging project.

7735-15, Session 2

The WIYN one degree imager: project update 2010

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The One Degree Imager will be the future flagship instrument at the WIYN 3.5m observatory, once commissioned in 2011. With a 1 Gigapixel focal plane of Orthogonal Transfer Array CCD devices, ODI will be the most advanced optical imager with open community access in the Northern Hemisphere.

In this article we will describe the progress since the last presentation of ODI at the SPIE 2006 meeting: The fabrication and procurement of parts for ODI is complete, and the assembly of the instrument is well underway. We will report on the status of the optics, their anti-reflection coatings, and the fabrication of large (42cm) color filters. We describe the characterization of the thermal control system of the dewar and how we will guarantee the thermal stability and safety of the detector array. Furthermore, we describe the approach to thermal control of the entire instrument (e.g., removing waste heat from electronics, motors, etc). Finally, we will review the progress of assembling the 64 Orthogonal Transfer Array detectors in the focal plane and report on our first experience of operating four of these in a test dewar with a University of Hawaii Stargrasp control system.

7735-16, Session 3

Design, performance, and early results from extremely high Doppler precision instruments in a global network

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We report design, performance and early results from two of the Extremely High Precision Extrasolar Planet Tracker Instruments (EXPERT) as part of a global network for hunting for low mass planets around solar type stars in the next decade. The first EXPERT was commissioned at the Kitt Peak 2.1m in September 2009 and the second one is to be commissioned at the LiJiang 2.4m telescope in March 2010. EXPERT is a combination of a thermally compensated monolithic interferometer and a high throughput cross-dispersed echelle spectrograph for extremely high precision Doppler measurements for nearby bright stars (e.g., 1m/s for a V=8 solar type star in 30 min exposure). It has a spectral resolution of R=18,000 and a simultaneous wavelength coverage of 0.39-0.7 µm.

The early data shows that the instrument has already produced a Doppler precision of about 1 m/s for a solar type star with S/N~100 per pixel with iodine absorption calibration (0.5-0.6 µm only), consistent with our original design. The instrument has reached ~6 mK (P-V, or ~2mK rms) temperature stability, ~10 mpsi pressure stability over a week and a total detection efficiency of 18.8% at 0.55 µm. Our goal is to populate six 2 meter class telescopes with EXPERT instruments across the globe to have more than 90% duty cycle for time sensitive extremely high precision Doppler measurements such as hunting for Earth like rocky planets and studying stellar oscillations. The network will also be used for following up planet candidates from the on-going SDSS-III Multi-object APO Radial Velocity Exoplanet Large-area Survey (MARVELS) and space missions.

7735-17, Session 3

‘Imaka: a one-degree high-resolution facility for the Canada-France-Hawaii Telescope

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The `Imaka project is a high-resolution wide-field imager proposed for the Canada-France-Hawaii telescope (CFHT) on Mauna Kea. `Imaka takes advantage of two features of the optical turbulence above Mauna Kea: weak turbulence in the free-atmosphere and highly confined turbulence in the boundary layer/dome. The combination of the two allows a ground-layer adaptive optics system to routinely deliver an extremely-wide corrected field of view (FOV) at the free-atmosphere limit over one-degree at visible wavelengths. In addition, populating the focal-plane with orthogonal transfer CCDs provides a second level of image improvement on the free-atmosphere seeing. The impact of such an instrument covers a broad range of science and is a natural progression of CFHT’s wide-field expertise. In addition it has ramifications for GLAO on ELTs and future large FOV survey telescopes.

We present the science justification, results quantifying the dome/ground-layer seeing at CFHT, the instrument’s feasibility design, and performance estimates.

7735-18, Session 3

Design and development of the 3.2 gigapixel camera for the Large Synoptic Survey Telescope

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The Large Synoptic Survey Telescope (LSST) is a large aperture, wide-field facility designed to provide deep images of half the sky every few nights. There is only a single instrument on the telescope, a 9.6 square degree visible-band camera, which is mounted close to the secondary mirror, and points down toward the tertiary. The requirements of the LSST camera present substantial technical design challenges. To cover the entire 0.35 to 1 m visible band, the camera incorporates an array of 189 over-depleted bulk silicon CCDs with 10 m pixels. The CCDs are assembled into 3 x 3 “rafts”, which are then mounted to a SiC grid to achieve a total focal plane flatness of 10 m p-v. The CCDs have 16 amplifiers per chip, enabling the entire 3.2 Gigapixel image to be readout

in 2 seconds. Unlike previous astronomical cameras, a vast majority of the focal plane electronics are housed in the cryostat, which uses a mixed refrigerant Joule- Thompson system to maintain a -100ºC sensor temperature. The shutter mechanism uses a 3 blade stack design and a hall-effect sensor to achieve high resolution and uniformity. There are 5 filters stored in a carousel around the cryostat and the auto-changer requires a dual rail system to control its position due to severe space constraints. This paper presents an overview of the design and development that validates how the camera will meet these key design requirements.

7735-20, Session 3

The ESPRESSO spectrograph optical design for a very high-resolution spectrograph for the combined focus of the VLT

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The high-resolution echelle spectrograph for ESPRESSO at VLT is based onto an innovative optical design, firstly proposed by Delabre and Dekker (ESO) in 2005. To increase spectral resolution for a given telescope diameter asks for image or pupil slicing techniques. For example, UVES with its image slicer can reach the R~120'000 resolution, even if with reduced efficiency. Moreover, if we want to combine light coming from different telescopes, that solution cannot be followed any more, because of limited spatial separation between different spectral orders in the echellogram. To overcome these limitations, a new ingredient is required. Anamorphism can help to increase effective resolution without increasing the physical size of the main disperser (the echelle grating) and those ones of the collimation and camera optics. By cleverly combining pupil slicing and anamorphism, the effective spectral resolution can be enhanced by a large factor, asking for limited increase of the optical component sizes. We present a summary of the optical design of the spectrograph.

7735-21, Session 3

VIRUS: a massively replicated 33k fiber integral field spectrograph for the upgraded Hobby-Eberly Telescope

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The Visible Integral-field replicable Unit Spectrograph (VIRUS) consists of a baseline build of 150 identical spectrographs (arrayed as 75 pairs) fed by 33,600 fibers, each 1.5 arcsec diameter, at the focus of the upgraded 10 m Hobby-Eberly Telescope (HET). VIRUS has a fixed bandpass of 350-550 nm and resolving power R~700. VIRUS is the first example of industrial-scale replication applied to optical astronomy and is capable of surveying large areas of sky, spectrally. The method of industrial replication, in which a relatively simple, inexpensive, unit spectrograph is copied in large numbers, offers significant savings of engineering effort, cost, and schedule when compared to traditional instruments.

The main motivator for VIRUS is to map the evolution of dark energy for the Hobby-Eberly Telescope Dark Energy Experiment (HETDEX), using 0.8M Lyman-alpha emitting galaxies as tracers. The full VIRUS array is due to be deployed in 2011 and will provide a powerful new facility instrument for the HET, well suited to the survey niche of the telescope, and will open up surveys of the emission line universe for the first time. We will present the design, cost, and current status of VIRUS as it enters production, and will review performance results from the VIRUS prototype. We will also present lessons learned from our experience designing for volume production.

7735-22, Session 3

The Keck cosmic web imager

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The Keck Cosmic Web Imager (KCWI) is a new facility instrument for the Keck II telescope at the W. M. Keck Observatory (WMKO) with an estimated first light date of early 2013. KCWI is based on the Cosmic Web Imager (CWI), a wide-field integral-field spectrograph (IFS) adopting a unique image slicer that has recently had first light at the Hale Telescope. KCWI is optimized for precision sky limited spectroscopy of low surface brightness phenomena. KCWI will feature high throughput and flexibility in field of view (FOV), spatial sampling, bandpass, and spectral resolution. KCWI will provide full wavelength coverage (0.35 to 1.05 μm) using optimized blue and red channels that will provide a unique and complementary capability at WMKO (optical band integral field spectroscopy) that is directly connected to one of the observatory's strategic goals (faint object, high precision spectroscopy), at a modest cost and on a competitive time scale, made possible by its simple concept and the prior demonstration of CWI. Here we present the instrument and associated science as of Preliminary Design phase.

7735-23, Session 4

PIMMS: photonic integrated multimode microspectrograph

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We present the first integrated multimode photonic spectrograph, a device we call PIMMS #1. The first prototype comprises a set of multimode fibres that convert to single-mode propagation using photonic lanterns in series. These feed to a stack of cyclic array waveguides

(AWGs) that illuminate a common detector. As described in Bland-Hawthorn & Horton (2006), such a device greatly reduces the size of an astronomical instrument at a fixed spectroscopic resolution. Remarkably, the PIMMS concept is largely independent of telescope diameter, input focal ratio and entrance aperture. The instrument architecture can also exploit recent advances in astrophotonics (e.g. OH suppression fibres). We present a movie of the instrument's operation and discuss the advantages and disadvantages of this approach.

7735-24, Session 4

Hexabundles: first results

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New multi-core imaging fibre bundles (hexabundles) being developed at the University of Sydney will usher in a new era of wide-field multi-object spectroscopy. We have characterised the performance of several hexabundle devices for the first time, including full-fused and unfused fibres with a range of cladding thicknesses. The advantages of smaller interstitial holes is outweighed by the increase in FRD caused by the deformation of each fibre in a fully-fused bundle. High throughput and low cross-talk are essential for imaging faint astronomical targets with sufficient resolution to disentangle the dynamical structure. We will discuss optimum specifications for future hexabundle instruments.

7735-25, Session 4

The cosmic web imager integral field spectrograph design and first results

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The Cosmic Web Imager is a slicer based integral field spectrograph built for the Cassegrain focus of the 200" Hale Telescope at the Palomar Observatory. It is designed to detect faint emission from extended regions, especially the Intergalactic and Circumgalactic Media with redshifts $1.5 < z < 4$. Twenty-four 1 mm x 16 mm slicer mirrors yield a 60"x40" field of view. A suite of Volume Phase Holographic gratings give a resolution R~5000 and make accessible a total wavelength range from 370nm to 950nm, with instantaneous bandwidth of around 14 nm when the nod-and-shuffle technique is employed, and ~45 nm otherwise. The instrument uses the legacy Norris Spectrograph lens and the blue-enhanced E2V CCD 231-84 as its detector. The overall system throughput is 20% with a peak toward the blue edge of the wavelength range. The nominal mode of operation uses the nod-and-shuffle technique which allows for more accurate background subtraction. The instrument was commissioned in July 2009 with subsequent observation runs in November 2009, March and May 2010. We present the design of the instrument and early scientific results.

7735-26, Session 4

Engineering a highly segmented, very wide-field spectrograph

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The concept of segmenting the focal plane of an existing 8m class telescope in order to fill it with an array of several fast cameras has been developed further and in this work the status of an engineering program aimed to produce a design qualified for the contruction, and to assess its cost estimates is presented.

The original concept of just having simple cameras with all identical optical components other than a pupil plane correcto to remove the fixed aberrations at the off-axis field of a telescope has been extended to introduce a spectroscopic capability and to assess a trade-off between a very large number (of the order of thousand) of cameras with a small single Field of View with a smaller number of cameras able to compensate the aberration on a much larger Field of View with a combination of different optical elements and different ways to mount and align them.

The scientific target of a few thousands multi-slit spectra over a Field of View of a few square degress, combined with the ambition to mount this on an existing 8m class telescope makes the scientific rationale of such an instrument a very interesting one.

In the paper we describe the different options for a possible optical design, the trade off between variations on the theme of the large segmentation and we describe briefly the way this kind of instrument can handle a multi-slit configuration.

Finally, the feasibility of the components and a brief description of how the cost analysis is being performed are given. Perspectives on the construction of this spectrapgraph are given as well.

7735-27, Session 4

The low-resolution imaging spectrograph red channel CCD upgrade: fully depleted, high-resistivity CCDs for Keck

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A mosaic of two 2k x 4k fully depleted, high resistivity CCD detectors was installed in the red channel of the Low Resolution Imaging Spectrograph for the Keck telescopes in June, 2009 replacing a monolithic Tektronix/SITe 2k x 2k CCD. These CCDs were fabricated at Lawrence Berkeley National Laboratory and packaged and characterized by Lick Observatory. Major goals of the detector upgrade were increased throughput and reduced interference fringing at wavelengths beyond 800 nm, as well as improvements in the maintainability and serviceability of the instrument. We report on the main features of the design, the results of optimizing detector performance during integration and testing, as well as the throughput, sensitivity and performance of the instrument as characterized during commissioning.

7735-28, Session 4

High-resolution imaging and spectroscopy in the visible from large ground-based telescopes with natural guide stars

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Near-diffraction limited imaging and spectroscopy in the visible on large (8-10 meter) class telescopes has proved to be beyond the capabilities of current adaptive optics technologies, even when using laser guide stars. The need for high resolution visible imaging in any part of the sky suggests that a rather different approach is needed. This paper describes the results of simulations, experiments and astronomical observations that show that a combination of low order adaptive optic correction using

a 4-field curvature sensor and fast Lucky Imaging strategies with photon counting CCD camera systems should deliver 20-25 milliarcsecond resolution in the visible with reference stars as faint as 18.5 magnitude in I band on large telescopes. Such an instrument may be used to feed an integral field spectrograph efficiently using configurations that will also be described.

7735-29, Session 4

High-precision calibration of spectrographs using laser frequency combs

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We present the first stringent tests of a novel calibration system based on a Laser Frequency Comb (LFC) for radial velocity measurements. The tests were obtained with the high resolution, optical HARPS spectrograph. By using only one echelle order we obtain a calibration repeatability of 15 cm s−1 for exposures that are several hours apart. This is comparable with a simultaneous calibration using a Th-Ar lamp that makes use of all 72 echelle orders. In both cases the residuals are compatible with the computed photon noise. The fiber coupling was determined to be responsible for the largest systematic uncertainty but employing active fiber mode scrambling could reduce this effect below the statistical uncertainty. Averaging all LFC exposures, recorded over a few hours, we could obtain residuals of 2.4 m s−1. Thanks to the adjustable and optimally chosen line density of the LFC, we resolve a periodicity of 512 pixels in the calibration curve that is due to the manufacturing process of the CCD mask. Previous Th-Ar calibration was unable to resolve these systematic deviations, resulting in a deviation of up to 70 m s−1 from the true calibration curve. To obtain an even higher repeatability and lower residuals, a larger spectral bandwidth is necessary. An improved version of the LFC is currently under development and will be tested in spring 2010. The tests will again be carried out with HARPS and we will report on the latest results.

7735-30, Session 4

A new method to quantitatively compare focal ratio degradation due to different end termination techniques

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We show how the termination of multimode optical fibres can be optimised by quantifying the amount of focal ratio degradation (FRD). FRD arises in various degrees due to different end preparation techniques. We show that it is possible to quantitatively compare the various techniques using a theoretical model and compare this to our experimental data. Gloge showed that the far-field distribution represents a direct image of the modal power distribution. Carrasco and Parry then adapted this model in order to quantify the number of scattering defects within an optical fibre using a single parameter. This model then allows a number of predictions to be made regarding the dependence of a number of parameters, such as the fibre core diameter and the wavelength of the incident light, on the FRD. By adapting the single fibre model proposed by Carrasco and Parry to include a second fibre, we can quantify the amount of FRD induced by frozen-in stress at the end of the fibre. By placing limits on the end effect, the model can be used to estimate the residual length dependence in very long fibres without having to carry out costly experiments. As we move to build instruments for extremely large telescopes (ELTs) fibres will be key to the implementation of highly-multiplexed spectroscopy using the highly-efficient Diverse Field Spectroscopy (DFS) paradigm. As the number of fibres increases in these instruments it will become even more crucial that theoretical models can be used successfully.

7735-179, Session 4

SPHERE IFS: the spectro differential imager of the VLT for exoplanets search

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The SPHERE is an exo-solar planet imager, which goal is to detect giant exo-solar planets in the vicinity of bright stars and to characterize them through spectroscopic and polarimetric observations. It is an complete system with a core made of an extreme-Adaptive Optics (AO) turbulence correction, pupil tracker and interferential coronagraphs. At its back end, a differential dual imaging camera and an integral field spectrograph (IFS) work in the Near Infrared (NIR) Y, J, H and Ks bands (0.95 - 2.32µm) and a high resolution polarization camera covers the visible (0.6 - 0.9 µm). The IFS is a low resolution spectrograph (R~50) which works in the near IR (0.95-1.6 microns), an ideal wavelength range for the detection of planetary features. In our baseline design the IFU is a new philosophy microlens array of about 145x145 elements designed to reduce as low as possible the contrast. The IFU will cover a field of view of about 1.7 x 1.7 square arcsecs reaching a contrast of 10^-7, giving an high contrast and high spatial resolution "imager" able to search for planet well inside the star PSF.

7735-92, Poster Session

Converting a liquid nitrogen-cooled CCD to closed-cycle cooling

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The detector for the ESPaDOnS spectrograph at the Canada-France-Hawaii Telescope (CFHT) is an E2V CCD in a liquid nitrogen cooled GL Scientific cryostat. This paper describes the conversion of this camera to closed-cycle cooling using a Polycold cryogenic refrigeration system. Topics covered include vibration analysis, positional stability of the image plane, cool-down characteristics, PLC integration, and annual operational overheads for both systems.

7735-93, Poster Session

Integration and characterization of HAWAII-1RG detector with FORCAST fast-readout electronics for LMIRcam

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The L/M-band Infrared Camera (LMIRcam) is a first-generation imager being constructed for the Large Binocular Telescope (LBT) Interferometer, operating at 3-5 micron. Given the high sky background at these wavelengths and large collecting area of the LBT, we chose to acquire controller electronics based utilizing Field Programmable Gate Arrays (FPGAs) for high-speed, flexible data acquisition. Frame co-addition occurs in real-time within the FPGA memory, eliminating the need for transfer of large data volumes to the host computer. Originally, these electronics were conceived for FORCAST, a mid-IR camera/spectrograph built by Cornell University for SOFIA, which house two DRS Technologies' 256x256 detectors. However, LMIRcam is designed to operate with a Teledyne HAWAII-1RG 1024x1024 array with 16 output channels. Furthermore, based on the observing mode (broadband, narrowband, or grism) and wavelength coverage, the HAWAII-1RG can operate in either a slow (100 kHz pixel rate; 680 ms/frame) or fast (5 MHz; 14 ms/frame) readout speed. In order to facilitate the different operating modes and increased array size, we have developed a modified version of the FORCAST device driver running on a Linux-based host computer, reconfigured the FPGAs for more efficient memory management with the HAWAII-1RG, and implemented a window mode for rapid captures of individual frames.

7735-94, Poster Session

Readout electronics for DECam

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The goal of the Dark Energy Survey (DES) is to measure the dark energy equation of state parameter with four complementary techniques: galaxy cluster counts, weak lensing, angular power spectrum and type Ia supernovae. DES will survey a 5000 sq. degrees area of the sky in five filter bands using a new 3 deg2 mosaic camera (DECam) mounted at the prime focus of the Blanco 4-meter telescope at the Cerro-Tololo International Observatory (CTIO). DECam is a ~520 megapixel optical CCD camera that consists of 62 2k x 4k science sensors plus 4 2k x 2k sensors for guiding. The CCDs, developed at the Lawrence Berkeley National Laboratory (LBNL) and packaged and tested at Fermilab, have been selected to obtain images efficiently at long waveforms.

A front-end electronics system has been developed specifically to perform the CCD readout. The system is based in Monsoon, an open source image acquisition system designed by the National Optical Astronomy Observatory (NOAO). The electronics consists mainly of three types of modules: Control, Video and Clock boards. The system provides a total of 132 video channels, 396 bias levels and around 1000 clock channels in order to readout the full mosaic at 250 kpixel/s speed with 10 e- noise performance. System configuration and data acquisition is done by means of six 1Gbps optical links. The production of the whole system is currently underway. The contribution will focus on the testing, calibration and general performance of the full system in a realistic environment.

7735-95, Poster Session

Hyper Suprime-Cam: the development of the CCD readout electronics

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Hyper Suprime-Cam (HSC) will employ 112 of 2kx4k fully-depleted CCD (FDCCD) as science detectors and additional four of the same type CCD as guide detectors. The frontend electronics (FEE) includes all of analog circuits and the backend electronics (BEE) includes all other digital parts. The FEE is placed in the vacuumed dewar, and the BEE is mounted on the outside of the dewar. The FEE boards were designed to minimize the outgas and to maximize the heat transfer efficiency based on the readout electronics of Suprime-Cam. The BEE boards were designed to be simple and small as long as to achieve the readout time within 10 seconds. The requirements of the system have been verified with the prototype boards. We will show the result, and the current status of the development.

7735-96, Poster Session

Implementation of the control electronics for KMOS instrument

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The KMOS Instrument is built to be one of the second generation VLT instruments. It is a highly complex multi-object spectrograph for the near infrared. Nearly 60 cryogenic mechanism have to be controlled. This includes 24 deployable Pick-Off arms, three filter and grating wheels as well as three focus stages and four lamps with an attenuator wheel.

These mechanisms and a calibration unit are supervised by three control cabinets based on the VLT standards.

To follow the rotation of the Nasmyth adaptor the cabinets are mounted into a Co-rotating structure.

The presentation will highlight the requirements on the electronics control and how these are met by state of the art technologies applying a compact and reliable signal distribution. To enable high density wiring within the given space envelope flex-rigid PCB (printed circuit board) designs have been installed.

In addition an electronic system that detects collisions between the moving Pick-Off arms will be presented for safe operations.

The control system is designed to achieve two micron resolution as required by opto-mechanical and flexure constraints. Dedicated LVDT sensors are capable to identify the absolute positions of the Pick-Off arms. These contribute to a safe recovery procedure after power failure or accidental collision.

7735-97, Poster Session

An optical frequency comb for infrared spectrograph calibration

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Detection of extrasolar planets by measurement of the stellar radial velocity shift requires high resolution spectroscopy with long term stability. Presently, the primary wavelength standards in the NIR are NePt and ThAr lamps and absorption cells. These suffer from a combination of sparse spectral coverage, low intensity, and questionable long-term stability. As an alternative, we present a laser frequency comb uniformly

covering the H band and a portion of the J band, with frequency precision better than 1e-11.

The comb is generated from a 250MHz passively mode-locked erbium doped fiber laser, which is frequency stabilized to the atomic standards within the global positioning system (GPS). The laser spectrum is filtered via an etalon, amplified, filtered by a second etalon, then nonlinearly broadened. The result is a clean spectrum covering 1400-1800 nm with a mode spacing presently set to 12.5 GHz, suitable for a 50,000 resolution spectrograph.

We present measurements of the performance of the comb, including side mode suppression measured across the spectrum, spectral stability over the time scale of several days, and a comparison of the absolute frequency of comb modes to a more stable hydrogen maser referenced frequency standard.

7735-98, Poster Session

Comprehensive transient-state study for CARMENES high-thermal stability

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CARMENES has been proposed as a next-generation instrument for the 3.5m Calar Alto Telescope. Its objective is finding habitable exoplanets around M dwarfs through radial velocity measurements (m/s level) in the near-infrared. Consequently, the NIR spectrograph is highly constraint regarding thermal/mechanical requirements. Indeed, the preliminary requirements used for the present study limit the thermal stability to ±0.01K (within year period) over a working temperature of 243K. This can be achieved by implementing a solution based on several temperature-controlled rooms (TCR), whose smallest room encloses the vacuum vessel which houses the spectrograph's optomechanics.

Nevertheless, several options have been taken into account to minimise the complexity of the thermal design: 1) Large thermal inertia of the system, where, given a thermal instability of the environment (typically, ±0.1K), the opto-mechanical system remains stable within ±0.01K in the long run; 2) Environment thermal control, where thermal stability is ensured by controlling the temperature of the environment surrounding the vacuum vessel; and 3) Active thermal control by conduction, where the thermal stability of the vacuum vessel is ensured by a close-loop controller based on conductive heaters. The latter will be selected only if the others are not feasible, due to its very high level of complexity.

The present article also includes the comprehensive transient-state thermal analyses which have been implemented in order to make the best choice, as well as to give important inputs for the thermal layout of the instrument.

7735-99, Poster Session

FOROS: Fresnel optical propagation code for SPHERE

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SPHERE (Spectro-Polarimetric High-contrast Exoplanet Research) is VLT instrument for the discovery and study of new extra-solar giant planets orbiting nearby stars by direct imaging of their circumstellar environment. SPHERE is a complex instrument containing more than 50 optical surfaces. The optical imperfections of each of these surfaces might influence the final contrast. SPHERE has several observing modes in Visible and Infrared, and therefore several optical paths.

FOROS is an end-to-end optical propagation code for SPHERE, which includes almost all surfaces of the instrument. It models the instrument by the sequential blocks: VLT, Foreoptics, Corrective Optics, Coronagraph and so on, such that the beam quality can be studied at several selected locations. The Vis and IR paths are separated in the model. It incorporates the real data of surface measurement, according to the availability of this data; otherwise the surface error is simulated according to the existing specifications. Each surface error can be switched on and off; therefore the influence of each surface on the contrast can be studied independently.

FOROS is an IDL-PROPER-based code, the main power of which is Fresnel propagation. Therefore it represents a numerical tool to study the Fresnel diffraction effects in SPHERE. In the paper we describe the structure and philosophy of the code, and present some results of the end-to-end modeling.

7735-100, Poster Session

NIR polarimetry with SPHERE-IRDIS

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The 2nd generation VLT instrument SPHERE will include a Near Infrared imaging polarimetry capability allowing measurements of both Q and U signatures from 0.95 to 2.3 microns.

This instrument efficiency benefits from an extreme AO system, and a stellar coronagraph. We describe in this paper the instrumental concept, the expected performances, the calibration hardware, and the data reduction procedures that are mandatory to achieve high contrast performances for which this instrument is designed.

7735-101, Poster Session

The performance of the calibration module for SPHERE

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SPHERE is a second generation instrument for the Very Large Telescope (VLT) which will aim at directly detecting the intrinsic flux of young giant exoplanets thanks to a dedicated extreme adaptive optics system and coronagraphs. Exoplanet detection in the near-infrared will be performed in parallel with an integral field spectrograph (IFS) and a differential imager (IRDIS).

Exquisite calibration of all functional blocks in the optical train is required to obtain the contrast of >15mag targeted by an extra-solar planet imager like SPHERE.

To this purpose, an elaborate calibration module has been developed and built. It incorporates features required for the calibration of all elements of the AO system, of the non-common path aberrations, the calibration of the NIR dual band imager, the NIR integral field spectrograph, the NIR spectrograph, the visible high accuracy polarimeter and the visible imager.

This calibration module has now been built, integrated and tested. We will present its design, the testing of module's calibration procedures and show its performance.

7735-102, Poster Session

Manufacturing and integration of the IRDIS dual-imaging camera and spectrograph for SPHERE

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SPHERE is a planet hunting instrument for the VLT 8m telescope in Chile whose prime objective is the discovery and characterization of young Jupiter-sized planets outside of the solar system. It is a complex instrument, consisting of an extreme Adaptive Optics System (SAXO), various coronagraphs, an infrared differential imaging camera and spectrograph (IRDIS), an infrared integral field spectrograph (IFS) and a visible differential polarimeter (ZIMPOL). The performance of the IRDIS camera is directly related to various wavefront error budgets of the instrument, in particular the differential aberrations occurring after separation of the two image beams. We document the pre-integration measurements of the optical quality of individual components of IRDIS, indicating expected overall performance in comparison with design-level budgets. We also report on the status of the camera at a moment where it is planned to enter system performance tests.

7735-103, Poster Session

Comparison of methods for detection and characterization of exoplanets with SPHERE/ IRDIS

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SPHERE is a second generation instrument for the Very Large Telescope (VLT) which will aim at directly detecting the intrinsic flux of young giant exoplanets thanks to a dedicated extreme adaptive optics system and coronagraphs. Exoplanet detection in the near-infrared will be performed in parallel with an integral field spectrograph and a differential imager, IRDIS. IRDIS main mode for exoplanet detection will be Dual-Band Imaging (DBI) where two images are acquired simultaneously at close wavelengths around expected sharp features in cold planetary objects spectra. We present here the end-to-end simulations performed to obtain realistic data for IRDIS in DBI mode with temporal evolution of the quasi-static speckle pattern. Data cubes have been generated to represent 4 hour observations in IRDIS filter pairs for various star magnitudes and planets at angular separations from 0.2" to 2.0". Using this unique set of data, we present a comparison of various data analysis methods for high-contrast imaging in terms of detection and possible characterization of exoplanets with IRDIS in DBI mode.

7735-104, Poster Session

Halftoning for high-contrast imaging: developments for the SPHERE and EPICS instruments

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We have recently investigated a new approach for producing apodizer masks. These masks were used with several coronagraphs concepts such as the Apodized Pupil Lyot Coronagraph (APLC), the Dual Zone coronagraph, or Conventional Pupil Apodization concepts, and the technique has been extended for focal plane Band-Limited mask coronagraphs (BLC). The so-called microdot technique or halftone-dot process technique offers a high-level of control of the local transmission, and gathers several advantages: relative ease of manufacture, achromaticity, reproducibility, and ability to generate continuous transmission ranges without introducing wavefront errors. The technique and design optimization will be discussed considering microdots diffraction stray light and manufacturing details. Laboratory results in the near-IR with several coronagraph prototypes (APLC and BLC) will be presented. The microdot technique has been validated for upcoming ground-based coronagraphic planet-finder instruments (e.g. APLCs for SPHERE and GPI) and is being considered for space-based instruments such as JWST (BLC).

7735-105, Poster Session

Diffracted and scattered light on coronagraphic IFU reconstructed images: the case of FRIDA

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FRIDA Instrument will take advantage of the corrected image provided by the Gran Telescopio Canarias Adaptive optics system for both Imaging and Integral Field Spectroscopy (IFS) modes. FRIDA performs a slicer Integral Field Unit for IFS at diverse spaxel sizes and spectral resolutions. Furthermore the feasibility for high contrast imaging has been confirmed introducing Lyot and phase masks on diverse focal planes and apodizing masks on diverse pupil planes as well. In this paper we study associated problems with this instrumental approach such as the diffracted and scattered light of coronagraphic filtered images coupled to the slicer Integral Field Unit.

7735-106, Poster Session

Performance characterization of the HiCIAO instrument for the Subaru Telescope

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HiCIAO is a high contrast instrument for the Subaru next generation adaptive optics. The instrument is specifically designed for extrasolar planet search and studies of proto-planetary or debris disks. This near-infrared camera works as a backend instrument of the adaptive optics (AO) which feeds a diffraction limited PSF to HiCIAO. A coronagraph and some differential observing modes inside HiCIAO can extract faint objects from the sea of speckle around bright stars. The instrument is equipped with a 2048 x 2048 MCT detector array to cover 20” x 20” FOV with 0.01 arcsec/pix which is fine enough to resolve each speckle pattern. Since the first light observation in December 2008, a commissioning phase has been successfully finished in October 2009 with most performances satisfying the specifications. The AO, coronagraph, and differential observing modes are proven to work as designed and achieve a contrast of 10^{-4} and $10^{-5.5}$ at 0.”15 and 1.”0 separation from the central star, respectively, with Strehl ratio of 0.4 in the H-band. Readout noise with the CDS method is 12 e- using the Sidecar ASIC controller which was used for the first time on the sky with an 8 m class telescope. Science observations using HiCIAO have been started for the SEEDS project in October 2009 which is the first strategic observation program of the Subaru Telescope. The project is granted 120 nights in 5 years for the extrasolar planet search and disk sciences.

7735-107, Poster Session

Overview and performance results for the Gemini Planet Imager's opto-mechanical support structure (OMSS)

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The Gemini Planet Imager (GPI) is a facility class instrument being built for the Gemini Observatory, with initial deployment at Gemini South in the summer of 2011. In the midst of the build phase, this international collaborative effort consists of five main sub-systems: an integral field spectrograph, a real-time high-precision wavefront calibration system, an apodized Lyot coronagraph and a high-order AO system; all hosted by the Opto-Mechanical Support Structure (OMSS). Subject to stringent constraints for mass, balance, volume, power utilization and heat dissipation, the OMSS provides the primary optical, mechanical, electrical and software interfaces to the Gemini Observatory. Operating in a Cassegrain environment heightens the challenges for this structure with severe flexure and stability aspects. We will initially present an overview of the instrument, concentrating on the most challenging and demanding requirements for the OMSS. We will then present the performance results from the acceptance testing prior to delivery to the GPI integration facility. We will finish off with a status update, highlighting lessons learned.

7735-108, Poster Session

Data reduction pipeline for the Gemini Planet Imager

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The Gemini Planet Imager (GPI) high-contrast adaptive optics system, which is currently under construction for Gemini South, has an infrared Integral Field Spectrograph (IFS) as its science instrument. This paper describes the data reduction pipeline of the GPI science instrument. Written in IDL, with a modular architecture, this pipeline will be used to reduce an ensemble of raw high-contrast spectroscopic or polarimetric science images and calibration data into a final dataset ready for scientific analysis. It includes speckle suppression techniques such as angular and spectral differential imaging that are mandatory to achieve the extreme contrast performances for which the instrument is designed. This paper also presents a detailed simulator for raw IFS data that we developed to test the pipeline.

7735-109, Poster Session

An apodizing phase plate coronagraph for the VLT

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We describe a coronagraphic optic for use with CONICA at the VLT that provides suppression of diffraction from 1.8 to 7 lambda/D at 4.08 microns, an optimal wavelength for direct imaging of cool extrasolar planets. The optic is designed to provide 10 magnitudes of contrast at 0.2 arcseconds, over a ‘D’ shaped region in the image plane, without the need for any focal plane occulting mask.

It provides high contrast in complementary portions of phase space compared to other high contrast imaging techniques at shorter wavelengths, enabling searches for colder, older planets at inner working angles corresponding to the dimensions of our solar system for nearby stars in the Southern hemisphere. The theoretical expectations and measured performances of the coronagraph are described.

7735-110, Poster Session

An eight-octant phase-mask coronagraph for the Subaru coronagraphic extreme AO (SCExAO) system: system design and expected performance

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The Eight-Octant Phase-Mask (8OPM) coronagraph is among the highest performance coronagraph concepts, and combines high throughput, small inner working angle, and large discovery space.

However, its application to ground based telescope such as Subaru Telescope is challenging due to pupil geometry (thick spider vanes and large central obstruction) and residual tip-tilt errors.

We show that the Subaru Coronagraphic Extreme Adaptive Optic (SCExAO) system, scheduled to be installed on the telescope early spring 2010, includes key technologies which can solve these problems.

SCExAO uses a spider removal plate (SRP) which translates four parts of the pupil with tilted plane parallel plates.

The pupil central obstruction can be removed by a pupil remapping system similar to the PIAA optics already in the SCExAO system, which could be redesigned with no amplitude apodization.

The 8OPM is inserted in the focal plane to divide a stellar image into eight-octant regions, and introduces a pi-phase difference between adjacent octants.

This causes a self-destructive interference inside the pupil area on a following reimaged pupil plane.

By using a reflective mask instead of a conventional opaque Lyot stop, the stellar light diffracted outside the pupil can be used for a Coronagraphic Low Order Wave-Front Sensor (CLOWFS) to accurately measure and correct tip-tilt errors.

A modified inverse-PIAA system, located after the reimaged pupil plane, is used to remove off-axis aberrations and deliver a wide field of view.

We show that this 8OPM coronagraph architecture enables high contrast imaging at small working angle on the Subaru telescope.

Our approach could be generalized to other phase mask type coronagraphs and other ground based telescopes.

7735-111, Poster Session

Fabrication and testing of phase masks for optical vortex coronagraph to observe extrasolar planets

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We present the fabrication process and tests of a high-quality phase modifying device (PMD) for the applications on the optical vortex coronagraph (OVC). The OVC is an innovative instrument that can be applied both on space and ground-based telescopes for the direct imaging of planets around a bright star. OVC rejects the light of the on-axis star without altering that of off-axis sources, by a spiral phase plate (SPP) used as a PMD. It imprints a certain vorticity on the phase of the incident beam so its wavefront becomes helicoidal. As a result, the light beam contains screw dislocations and the intensity distribution of the vortex light beam is doughnut-shaped with a central dark region. The light coming from the bright star is focused on the centre of SPP, it is distributed around the central dark region and then it is blocked on exit pupil plane by a circular aperture, called the Lyot stop. The light from a nearby off-axis source is not affected by SPP, its light passes through the Lyot stop and then can be collected by CCD.

7735-112, Poster Session

A 64 M-pixel camera for the Wendelstein Fraunhofer Telescope Nasmyth wide-field port: WWFI

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Ludwig-Maximilians-Universitaet Muenchen operates an astrophysical observatory on the summit of Mt. Wendelstein which will be equipped with a modern 2m-class, robotic telescope (also presented at this conference). One Nasmyth port of the new Fraunhofer telescope is designed to deliver the excellent (< 0.7" median) seeing of the site over a FoV of 0.2 deg^2 utilizing 3-element transmissive field corrector optics for optical wavebands. It will be equipped with a camera built around a customized 64 MPixel Mosaic (Spectral Instruments, 4 x (4k)^2 15mu e2v CCDs). The camera has 2 filter wheels with 8 slots each (SDSS ugriz + 8 still free) as well as 2 off-axis guiding units (2 FLI Microline with 2k Fairchild CCDs on differential focus stages). A Bonner Shutter ensures high precision photometric exposures. An option to either insert a low dispersion grating (for field spectroscopy) or support a wave front sensor probe allows for further expansion of the camera. EMC-safe housing has to overcome the emission of a close by 0.5 MW radio station. Special care has been taken to design a very low ghost budget of the overall system to allow for low-surface brightness applications (e.g. weak lensing surveys).

7735-113, Poster Session

The PAU camera

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Determining the spectral energy distribution (SED) of astronomical object provides information about their nature and properties. For galaxies, the spectral features in their SEDs allow us to measure their redshifts and characteristic properties. Many cosmological applications require sampling large amounts of galaxies in large volumes with only modest spectral resolution. Therefore, a viable approach is to sample the galaxies SEDs using narrow band filters photometry instead of using a spectroscopic survey. This is the technique chosen for the PAU survey.

The PAU collaboration is building a large field of view (FoV) camera equipped with 40 narrow band filters 100 Å wide to sample the galaxies SED to obtain accurate photometric redshifts.

We are currently working on the design of two camera concepts. The first one of intermediate size (PAUCam-1) serves as a proof of concept but it is still designed to deliver scientific valuable data. The camera is intended for the WHT prime focus with a vignetted 60 arcmin diameter FoV. The filters need to be placed close to the detectors and therefore the camera uses an innovative system of filter trays which works in vacuum and cryogenic conditions. The second camera concept (PAUCam-2) is designed to fully exploit the capabilities of large FoV focal planes. It may be placed at either the WHT or the INT if they are equipped with new wide field optical correctors. The camera will cover a FoV of 2 or 3 degrees. PAUCam-2 adapts to a larger size the solutions developed for PAUCam-1.

7735-114, Poster Session

IMAKA: imaging from MAuna KeA optical design

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The ‘IMAKA (Imaging from MAuna KeA) instrument is a wide field visible light imager incorporating Ground Layer Adaptive Optics (GLAO) to take maximum advantage of the excellent seeing available at the Canada-France-Hawaii Telescope (CFHT). It requires better than 0.3” image quality simultaneously over a total field of view of approximately one square degree (~3 x 10-4 sr). This requirement along with other criterions and constraints raises a challenge for optical design. The advent of orthogonal transfer (OT) CCDs makes this function possible at the science detector itself. ‘IMAKA will take full advantage of the large array mosaics of OTCCDs developed and deployed in other instrumentation such as the GigaPixel Camera 1 for the Panoramic Survey Telescope.

Since the size of the adaptive mirror would drive the cost and hence implementation of the overall ‘IMAKA instrument, a review of possible optical design configurations which minimize the size (diameter) of the deformable mirror was undertaken. A promising design was obtained and developed in more detail. This all reflective system is described along with its predicted optical performance. An opto-mechanical design concept was developed around this nominal optical design which takes into account various constraints due to its required location on the top end of the Canada France Hawaii Telescope. The design concept is feasible and meets the optical performance requirements.

7735-115, Poster Session

Design of AMASING, a new aperture masking instrument for high-resolution imaging at optical wavelengths

L. M. Schmidt, C. A. Jurgenson, F. G. Santoro, S. W. Teare, New Mexico Institute of Mining and Technology (United States)

We describe the science goals, optical and mechanical design, software control, data reduction and current status of a new aperture masking instrument for meter class telescopes. AMASING (Aperture Masking And Speckle ImagiNG) was designed to be a flexible Nasmyth mounted platform for high resolution astronomy at optical wavelengths. Multiple filters and masks can be used in combination via computer control without physical access to the instrument. This allows for easy customization of the instrument for specific science targets and observing conditions. The instrument is also completely self contained. Unlike other masking experiments, the masks are internal and do not require placement over the primary aperture or secondary mirror. While designed specifically for aperture masking and speckle interferometry, using commercially available optical and opto-mechanical components allow for easy integration of future upgrades to the instrument while keeping costs low. The instrument is self guiding and includes cameras for target acquisition and guiding, masked pupil viewing and high frame rate data collection.

This work is supported by LANL-NMT MOU UCDRD funding, a College Cost Reduction and Access Act grant to Amarillo College and the New Mexico Space Grant Consortium.

7735-116, Poster Session

Image quality analysis and first laboratory results for the camera for the compact Echelle spectrograph for aeronomical research (CESAR)

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The success of the high resolution nightglow studies conducted with the Keck telescopes on Mauna Kea and the Very Large Telescopes in Chile led to the design of the Compact Echelle Spectrograph for Aeronomical Research (CESAR). This is an echelle spectrograph with grating post-dispersion that will be dedicated to nightglow studies at high spectral resolution (R ~ 20000) between 310-1040 nm, and that will be easily deployable at different sites. The development of CESAR is conducted by SRI international, and INO is involved in the optical design and integration of the spectrograph camera, whose all-spherical form is based on the camera of the HIRES spectrograph at the Keck I telescope. The detailed optical design is used to calculate the position of the spectral elements on the detector, predict their image quality, and estimate the level of stray light. This paper presents the methodology used in these analyses along with the first results obtained for the spectrograph camera without the dispersing elements in the laboratory.

7735-117, Poster Session

A new image acquisition system for the Kitt Peak National Observatory Mosaic-1 imager

D. G. Sawyer, S. Howell, M. R. Hunten, National Optical Astronomy Observatory (United States); H. Schweiker, WIYN Observatory (United States)

A project is currently underway to upgrade the KPNO Mosaic-1 Imager, an 8K x 8K pixel CCD array used on the Mayall 4-meter and WIYN 0.9-meter telescopes. Mosaic-1 has been a heavily subscribed instrument by the US astronomical community since it was commissioned more than a decade ago. In recent years, however, the reliability and efficiency of Mosaic-1 has declined due to aging and failing components. In addition, servicing has become more and more difficult as spare parts are used up, replacement parts become unavailable, and technical expertise for the out-dated controller technology diminishes. The Mosaic-1 upgrade project addresses these reliability and servicing concerns by replacing the CCDs with modern detectors and replacing the controllers with the MONSOON Torrent image acquisition system. The upgrade will also enhance the scientific performance of the instrument through reduced read times, lower read noise, and improved quantum

efficiency. We will describe the project planning and timeline, the technical requirements related to the installation of new CCD detectors and Torrent controllers, the configuration of the system, and integration of the system into the existing instrument and telescope environments.

7735-118, Poster Session

MAIA: a rapid three-channel imager for asteroseismology

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MAIA - Mercator Advanced Imager for Asteroseismology - is currently being designed for the 1.2-meter Mercator Telescope (La Palma, Spain). This instrument will allow for simultaneous and continuous imaging in three arms without time overhead. The science goals are versatile but mainly focused on asteroseismological applications requiring intensive multi-colour monitoring campaigns with fast sampling. The required field of view is large as to obtain enough reference stars for zero-point tracking in any line-of-sight. The compact optical design of MAIA makes it possible to observe the same large field (9.4 x 14 arcmin) simultaneously in three colour bands, corresponding approximately with an SDSS U, G, R+I+Z photometric system. The fully dioptric design uses a common collimator, two dichroic beam splitters (cut-offs at 390nm and 550nm) and three cameras. Each camera is equipped with a large frame-transfer CCD (2048 x 3072 imaging pixels), thermoelectrically cooled to -80 Centigrades. The detector controller offers a flexible suite of multiple windowing and binning modes to optimise observing strategies. MAIA is designed to be portable and by replacing the collimator, it can also be deployed at larger telescopes. The mechanical design of MAIA is particularly driven by constraints on flexure, size and most importantly, thermal stability of the quasi-isostatic lens mounts. In this contribution we present the optical and mechanical design of MAIA. We also report on the overall status of the project as well as on the results obtained with the MEROPE-II imager, using a similar frame-transfer detector and data-acquisition system.

7735-119, Poster Session

Design of a radiometric all-sky infrared camera (RASICAM) for DES/CTIO

R. H. Schindler, P. M. Lewis, SLAC National Accelerator Lab. (United States)

A unique radiometric all-sky infrared camera [RASICAM] has been constructed to allow real-time quantitative assessment of night sky conditions for the Dark Energy Survey camera [DECam] located on the Blanco Telescope at the Cerro Tololo Inter-American Observatory in Chile. The camera is optimized to detect the position, motion and density of thin, high (8-10 Km) cirrus clouds and contrails by measuring their apparent temperature above the night sky background. The camera system utilizes a novel wide-field equiresolution catadioptic mirror system that provides sky coverage of 2π azimuth and 14-900 from zenith. The up-looking convex primary mirror is 24” diameter and ~3.75” thick, while the down-looking concave secondary mirror is 5.2” diameter, ~0.75” thick and stands ~14” above the primary. The primary has a 38.1mm diameter diamond-like-carbon-coated Ge window (with anti-reflective coating on the back face) in the center, where it is coupled to a research-grade commercial FLIR A325 mid-IR camera based on a 240x320 pixel uncooled Si microbolometer array. The camera provides 16-bit calibrated temperature data at 60Hz with 50mK noise/pixel. The unique features of RASICAM are made possible by the newly-available radiometric high-rate output of the A325 which, coupled with the novel equiresolution optical design, provides unprecedented cloud detection and quantification. The detailed design and initial performance of the RASICAM system is presented.

The two-mirror equiresolution formalism is developed in Hicks, R.A., Millstone, M., and Daniilidis, K., “Realizing any central projection with a folded catadioptric sensor,” Applied Optics, 45:7205-7210 (2006) and was adapted to our application.

7735-120, Poster Session

QUOTA: the prototype camera for the WIYN one degree imager (ODI)

G. H. Jacoby, National Optical Astronomy Observatory (United States)

QUOTA is an 8Kx8K (16’x16’) optical imager using four 4Kx4K orthogonal transfer CCDs arrays (OTAs). Each OTA has 64 nearly independent CCDs having 480x494 12μm pixels. By reading out several of the CCDs rapidly (20 Hz), the centroids of the stars in those CCDs can be used to measure image motion due to atmospheric effects, telescope shake, and guide errors. Motions are fed back to the remaining 250 CCDs that continue to integrate normally, allowing a shift of the collecting charge packets so that they always fall under the moving star images, thereby effecting low order AO tip/tilt correction in the silicon to improve image quality. As a bonus, the stars that are read rapidly can be studied for high speed variability.

QUOTA was conceived to be a prototype for WIYN’s 32Kx32K One Degree Imager (ODI), providing a means to test the technical developments needed for ODI (e.g., detectors, controllers, optics, coatings, cooling, and software). QUOTA will have been to the WIYN 3.5-m telescope only twice in its current configuration with front-side illuminated OTAs, but has provided a wealth of information that has been useful to the engineering of ODI. We will report on the areas in which ODI has benefited from QUOTA, as well as some of the results at the telescope and the processes needed to reduce the data.

QUOTA was funded in part by NSF/ATI grant AST-0352979.

7735-121, Poster Session

FASTCAM optomechanical system design and manufacture

G. Murga Llano, R. Sanquirce, IDOM (Spain); A. Oscoz, R. L. López, Instituto de Astrofísica de Canarias (Spain); R. Campo, IDOM (Spain)

FastCam is an instrument jointly developed by the Instituto de Astrofísica de Canarias (IAC) and the Universidad Politécnica de Cartagena (UPCT), designed to obtain high spatial resolution images in the optical wavelength range from ground-based telescopes (http://www.iac.es/proyecto/fastcam). The instrument is equipped with a very low noise and very fast readout speed EMCCD camera which provides short exposure images to an FPGA-based processor which performs the selection, recentering and combination of images in real-time (applying Lucky Imaging Techniques) to provide difraction limited resolution images in 1-4 m class telescopes from 500 to 850 nm.

IDOM has contributed to this new state-of-the-art instrument with the design of an optomechanical system conceived to maximize the image scale stability of the system for astrometry. The combination of aluminum plates, carbon fiber (CFRP) rods and stainless steel mounts in the optical bench define an athermalized and stiff design to meet the requirements of thermal and mechanical stability.

7735-122, Poster Session

Hyper Suprime-Cam: camera design

Y. Komiyama, National Astronomical Observatory of Japan (Japan)

Hyper Suprime-Cam (HSC) is the next generation wide-field imager for the prime focus of Subaru Telescope, which is scheduled to receive its first light in 2011. Combined with a newly build wide-field corrector, HSC covers 1.5 degree diameter field of view with 116 fully-depleted CCDs.

In this presentation, we will summarize the details of the camera design: the prime focus structure, the wide-field corrector and the CCD dewar. The wide-field corrector consist of 5 lenses with lateral shift type doublet ADC element. The novel design guarantees the excellent image quality (D80<0".3) over the field of view. On the focal plane, 116 CCDs are tiled on the cold plate which is made by Sillicon Carbide and cooled down to -100 degrees by two pulse tube coolers. The system is supported by the prime focus structure which provides a precise movement of the system to align the wide-field corrector and the CCD dewar to the optical axis of the telescope. At last, we will briefly mention on the schedele and the mile stone for the first light of HSC.

7735-123, Poster Session

System architecture of the dark energy survey camera readout electronics

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The Dark Energy Survey makes use of a new camera, the Dark Energy Camera (DECam). DECam will be installed in the Blanco 4M telescope at CTIO. DECam is presently under construction and is expected to be ready for observations in the fall of 2011. The focal plane will make use of 62 2Kx4K CCDs and 12 2kx2k fully depleted CCDs for guiding, alignment and focus. This paper will describe design considerations of the system; including, the entire signal path used to read out the CCDs, the development of a custom crate and backplane, the overall grounding scheme and early results of system tests.

7735-124, Poster Session

The Large Binocular Telescope mid-infrared camera (LMIRcam): final design and status

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We report on the final design and the fabrication status of the mid-infrared imager/spectrograph that will operate behind the Large Binocular Telescope Interferometer (LBTI) primarily at wavelengths between 3 and 5 microns. Within LMIRcam, a pair of diamond-turned biconic mirrors reimages a ten arsecond square field onto a 1024x1024 HAWAII-1RG 5.1um cutoff array. The reimaging optics provide two pupil planes for the placement of filters and grisms. Flexible readout electronics enable operating modes ranging from high framerate broadband imaging at the longest wavelengths to low background R=400 spectroscopy at the shorter operating wavelengths. The LBTI will provide LMIRcam with a diffraction limited two-mirror PSF with first null dictated by the 14.4 meter separation of the two LBT mirror centers.

7735-125, Poster Session

Testing the dark energy camera on a telescope simulator

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The Dark Energy Camera is a new prime-focus instrument to be delivered to the Blanco 4-meter telescope at the Cerro Tololo Inter-American Observatory (CTIO) in 2011. Construction is in-progress at this time. In order to verify that the camera meets technical specifications for the Dark Energy Survey and to reduce the time required to commission the instrument while it is on the telescope, we are constructing a "Telescope Simulator" and performing full system testing prior to shipping to CTIO. This presentation will describe the Telescope Simulator and how we use it to verify some of the technical specifications.

The Telescope Simulator includes a full reproduction of the upper rings on the Blanco. It will support DECam in the same way that it will be supported at CTIO and allow us move the camera in pitch and roll just as it will experience on the telescope.

7735-126, Poster Session

The cosmic web imager: integral field unit

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The Cosmic Web Imager (CWI) is an integral field spectrograph built for the Cassegrain focus of the 200" Hale Telescope at Palomar Observatory. It is designed to detect diffuse emission from the Intergalactic and Circumgalactic media at redshifts $1.5 < z < 4$. The expected size of these emission regions and required spectral resolution ($R > 5000$) make an integral field spectrograph ideally suited to the task. The CWI integral field unit consists of an all-aluminum diamond-turned slicer mirror stack and an array of pupil mirrors made of optical glass. The slicer is composed of twenty-four 16 mm x 1mm mirrors that provide a 60"x40" field of view with ~1" seeing-limited resolution of unresolved sources and 2.5" slit-limited spatial resolution of extended sources.

The slicer mirrors fan out to redirect light cones to pupil mirrors which are mounted on custom-built flexure tip-tilt mounts. The pupil mirrors are arranged in a brickwall pattern to allow close packing of the spectra on the detector CCD. All reflective elements have a blue-enhanced protected aluminum coating. We discuss the details of the IFU design and construction and evaluate its performance during observing runs in 2009 and 2010.

7735-127, Poster Session

First Pa alpha imaging from the ground: the first light of Atacama near-infrared camera on the MiniTAO 1m Telescope

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We have developed a near infrared camera called ANIR (Atacama Near InraRed camera) for the University of Tokyo Atacama 1.0m telescope installed at the summit of Co. Chajnantor (5640m altitude) in Northern Chile.

The camera is based on a PACE-HAWAII2 array with an Offner relay optics for re-imaging, and field of view is 5.3' x 5.3' with pixel scale of 0.31"/pix.

The high altitude and extremely low water vapor (PWV=0.5mm) of the site enables us to carry out observation of hydrogen Paschen alpha emission line at 1.8751 micron.

The first light observation was carried out in June 2009, and we have successfully obtained Paschen alpha narrow-band images of the Galactic center, which is the first Paschen alpha imaging of Galactic objects from a ground based telescope.

System efficiencies for the broad-band filters are measured to be 15% at the J-band and 30% at Ks, while that of the Paschen alpha narrow-band filter varies from 8 to 15%, which may be caused by fluctuation of atmospheric water vapor.

ATRAN simulation suggests that this corresponds to the PWV of 1.5 - 0.25mm, consistent with the previous results of the site testing.

This shows the excellent infrared capability of the site.

7735-128, Poster Session

AMICA: the NIR/MIR camera for automatic astronomical observations from Dome C, Antarctica.

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AMICA (ANtarctic Multiband Infrared CAmera) is a instrument provided with two array detectors to perform NIR (2-5.5 μm) and MIR (5.5-28 μm) infrared astronomical imaging from Dome C, Antarctica. The Project, started at the end of 2004, is now completed. The camera will be installed at the Nasmyth focus of the 80-cm IRAIT telescope during the summer campaign 2010-2011. An overview of the instrument is given here, with particular attention devoted to the following features: 1) Winterization: the AMICA subsystems have been tested under Antarctic conditions, and suitable solutions have been adopted to ensure their correct operation in such a severe environment; 2) Automatic operation: the AMICA control system does not require human intervention; 3) Fast acquisition: AMICA can get long series of images with very short exposure times (down to less than 3 msec), synchronized with the IRAIT chopping secondary mirror; 4) Survey-mode observations: thanks to the low infrared background expected in Antarctica (from both the atmosphere and the telescope), the AMICA optical system can produce a pixel FOV of 0.534 arcsec on the NIR array and 1.345 arcsec on the MIR array, that corresponds to 2.29 and 2.87 arcmin FOV respectively, without saturation even with wide-band filters.

Although AMICA is essentially a pathfinder aimed to demonstrate the potential of the Antarctic sites for Infrared Astronomy, it is expected also to provide significant improvements in the knowledge of fundamental astrophysical processes, such as those related to the star formation and late-stages of stellar evolution, especially AGB and post-AGB stars.

7735-129, Poster Session

The Palomar transient factory survey camera: 1st year performance and results

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The Palomar Transient Factory (PTF) is a new fully-automated, wide-field survey conducting a systematic exploration of the optical transient sky. The transient survey is performed using a new 8.1 square degree camera installed on the 48 inch Samuel Oschin telescope at Palomar Observatory. The PTF Camera achieved first light at the end of 2008, completed commissioning in July 2009, and is now in routine science operations. The camera is based on the CFH12K camera, and was extensively modified for use on the 48-inch telescope. A field-flattening curved window was installed, the cooling system was upgraded to closed-cycle, custom shutter and filter exchanger mechanisms were added, new custom control software was written, and many other modifications were made. We here describe the performance of these new systems during the first year of Palomar Transient Factory operations, including a detailed and long term on-sky performance characterization. We describe lessons learned during the construction and commissioning of the upgraded camera, and briefly summarize the first spectacular supernova results from the PTF survey.

7735-130, Poster Session

Design overview and performance of the WIYN high-resolution infrared camera (WHIRC)

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We present the design overview and on-telescope performance of the WIYN High Resolution Infrared Camera (WHIRC), which is a general-use instrument at the WIYN telescope on Kitt Peak. WHIRC is a near-infrared (0.8 - 2.5 micron) camera with a filter complement of J, H, Ks broadband and 10 narrowband filters. WHIRC uses a 2048 × 2048 HgCdTe array from Raytheon's VIRGO line, which has been developed for the VISTA project. The compact on-axis refractive optical design makes WHIRC the smallest near-IR camera with this capability. WHIRC is installed on the WIYN Tip-Tilt Module (WTTM) port and can achieve near diffraction-

limited imaging with a FWHM of ~0.25 arcsec at Ks with active WTTM correction and routinely delivers ~0.6 arcsec FWHM images without WTTM correction. We determine a gain of 3.3±0.2 electrons ADU-1 via a photon transfer analysis and a readout noise of ~19 electrons. A measured dark current of 0.13 electrons s-1 demonstrates that the cryostat is extremely light tight. The plate scale of 0.099 x 0.100 arcsec pixel-1 yields a field of view (FOV) of 3.3 x 3.4 arcmin, which was a design compromise between the highest angular resolution achievable and the largest field of view correctable by WTTM. Measured throughput values ~0.27±0.02 in the H band are consistent with those predicted for WHIRC based on an analysis of individual optical elements and detector quantum efficiency. Imaging of standard star fields yields a demonstrated photometric quality better than ~0.02 magnitudes in all bands. During its first year of general use operation at WIYN, WHIRC has been used for high definition near-infrared imaging studies of a wide range of astronomical phenomena including star formation regions, stellar populations and interstellar medium in nearby galaxies, high-z galaxies and transient phenomena.

7735-131, Poster Session

Design, calibration, and in-flight performance of the Sunrise filter imager SuFI/ISLiD

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Sunrise is balloon-borne solar observatory, which had its successful first stratospheric science flight in June 2009. Sunrise consists of a light-weighted Gregory telescope with an aperture of 1m, which feeds two science instruments, a near UV filter imager (SuFI), and a vector magnetograph (IMaX). An Image Stabilisation and Light Distribution unit (ISLiD) ensures simultansous operation of both science instruments.

During the 6 day science flight the SuFI captured images of the solar surface in several wavelength bands between 210nm and 400nm with unprecedented angular resolution, close to the diffraction limit set by the 1m aperture of the telescope.

The design, verification approach, calibration aspects, and the in-flight performance of ISLiD and SuFI will be presented.

7735-132, Poster Session

Development of a new mid-infrared instrument for the Tokyo Atacama Observatory 6.5-m Telescope

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Mid-infrared wavelengths of 25 - 40 micron are one of the most important wavelengths for observing dusty astronomical objects such as star forming regions, mass losing stars, and planetary/debris disks. This wavelength range includes a wide variety of dust features as well as the peak of the blackbody radiation of ~100K. Observations in this wavelength range, especially with high spatial resolution, are quite important for detailed study of the circumstellar dust, but they have so far been poorly executed because of the difficulty from ground-based telescopes.

Tokyo-Atacama Observatory (TAO) project to build a 6.5-meter infrared telescope at the world's highest altitude (5,640m) at the Atacama area (P.I. Yuzuru Yoshii) makes significant improvements of the situation. Thanks to the high altitude and low water vapor, the 30-micron wavelength region can be observed from the ground.

We are now developing a new mid-infrared infrared instrument for the TAO telescope. It has imaging and spectroscopic capabilities in a wide wavelength range from 6 to 38 micron. Due to the large aperture of the TAO telescope, high spatial resolution of 1 arcsecond can be achieved in the 30-micron wavelength. The instrument also has a filed stacker unit which picks up two discrete fields (1 arcmin x 2) from the whole telescope field of view (30 arcmin) and brings them into the instrument field of view. It enables us to carry out simultaneous observations of a target and a reference star, which significantly improves the accuracy and reliability of the observations.

7735-133, Poster Session

3kk: the optical-NIR multichannel Nasmyth imager for the Wendelstein Fraunhofer Telescope

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Ludwig-Maximilians-Universitaet Muenchen operates an astrophysical observatory on the summit of Mt. Wendelstein which will be equipped with a modern 2m-class, robotic telescope (also presented at this conference). One Nasmyth port of the new Fraunhofer telescope is designed to deliver the excellent (< 0.7" median) seeing of the site for a smaller FoV of 60 arcmin^2 without any corrector optics at optical and NIR wavebands. Thus, it will be optimized for fast multi-wavelength follow-up observations of targets of opportunities (e.g. Gamma-Ray-bursts) or efficient photometric redshift determinations of huge numbers of galaxy clusters identified in optical (PanSTARRS), SZ (Planck) or X-ray (Abrixas) surveys. We present the design of a compact 3 channel camera which serves these science requirements, built partly from commercially available Fairchild-2k optical CCD cameras (Apogee), coupled with small Bonner Shutters, and mounted on commercial high precision linear stages for differential focusing. A specially designed beam-splitter system keeps the high optical quality. The NIR camera is built in cooperation with the IfA in Hawaii. The coupling of this camera together with two spectrographs has been already presented in SPIE2008.

7735-134, Poster Session

Filter tray jukebox in a cryostat camera

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The Physics of the Accelerating Universe (PAU) is a new project whose main goal is to measure the Baryon Acoustic Oscillations in the galaxy

distribution to characterize dark energy. The Spectral Energy Distribution (SED) of galaxies, measured with good spectral resolution, is normally achieved with spectrographs. The PAU collaboration is building two instruments devoted to perform a large area survey for cosmological studies. Using an alternative approach, SEDs are sampled using narrow band filter photometry. Based on the same distinctive concept, both are large field of view cameras equipped with ~40 filters ~100Å wide spanning the optical wavelength range to accurately measure photometric redshifts.

The filters have to be placed as close as possible to the CCD detector surfaces on segmented filter trays. The presented innovation lies in a set of 6 different exchangeable filter trays to support the filters with a jukebox-like changing mechanism inside the cryostat. The device operates within the range of temperatures from 170K to 300K at the absolute pressure of 10-8mbar, with a vapor pressure below 10-9torr, being class-100 compliant. Rolling Hybrid bearings technology with tungsten disulfide as solid lubricant was chosen to hold the movements inside the cryostat motioned by two independent servomotors with absolute encoders outside the cryostat through magnetic feedthroughs, with a precision of 10 micron. Also a life test is foreseen by IMAT (instrument manipulator assembling and testing device) were the instrument will be operated applying worse case conditions increased by a safety factor.

7735-135, Poster Session

Exploration of simultaneous and angular differential imaging observing techniques using Subaru/HiCIAO

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Ground based telescopes equipped with adaptive optics systems and specialized science cameras are now capable of directly detecting extrasolar planets. However, contrast at small separations (< 1") is still limited by the time varying speckle pattern of the target star PSF. Simultaneous and angular differential imaging (SDI, ADI) techniques have been successfully developed and implemented on the sky to subtract the speckle pattern in these regions, and the NICI campaign has successfully reported hybrid observations using both SDI and ADI. This paper uses observations from the new high contrast instrumentation suite at the Subaru Telescope (AO188, a classical Lyot coronagraph, and HiCIAO) to investigate several trade-offs and comparisons between the SDI and ADI modes for a sample of targets at different ages and distances. Assumptions from theoretical models and empirical evidence from CH$_{4}$ observations of young sub-stellar objects are incorporated into the discussion.

7735-136, Poster Session

Focus and alignment using out-of-focus stellar images at the dark energy survey

A. J. Roodman, SLAC National Accelerator Lab. (United States)

The focus and alignment of the prime focus Dark Energy Camera (DECam), for the Dark Energy Survey at the CTIO 4 meter telescope, is described. DECam includes eight 2K by 2K CCDs placed 1.5mm extra- and intra-focally for active control of focus and alignment, as well as for wavefront measurement. We describe an algorithm for out-of-focus star (donut) image analysis and present results on the use of donuts for focus and alignment. Results will be presented for both simulated DECam images and for images taken at the Blanco 4 meter with the current MosaicII camera.

7735-137, Poster Session

Measuring the flatness of focal plane for very large mosaic CCD camera

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DECam is an extremely red sensitive 520 Megapixel camera designed for the incoming Dark Energy Survey (DES). It is consist of sixty two 4k x 2k and twelve 2k x 2k 250-micron thick fully-depleted CCDs, with a focal plane of 44 cm in diameter and a field of view of 3 square degree. It will be attached to the Blanco 4-meter telescope at CTIO. The DES will cover 5000 square-degrees of the southern galactic cap in 5 color bands (g, r, i, z, Y) in 5 years starting from 2011.

We developed two image based techniques, in addition to a direct optical measurement technique, to measure the flatness of the focal plane of DECam. By imaging a regular pattern through a pinhole to the CCDs, we convert the CCD offset along the optical axis to the variation the patterns on the focal plane. After extracting the patterns and comparing the change in spacing across the whole focal plane, we can measure the flatness to high precision. In method 1, the regular pattern is projected by a source with highly precise patterns printed on while in Method 2, a precise x-y stage moves a fixed pattern across the whole focal plane. Simulation and real measurements show that the two methods work very well for our purpose, and are in good agreement with the direct optical measurements.

7735-138, Poster Session

Opto-mechanical design of PANIC

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PANIC, the PAnoramic Near Infrared Camera, is a new instrument for the Calar Alto Observatory. A mosaic of four Hawaii-2RG detectors results in a field of view of 0.5x0.5 degrees at a pixel

scale of 0.45arcsec/pixel at the 2.2m telescope. PANIC can also be used at the 3.5m telescope with twice the pixel scale over a still large field of view of 0.25x0.25 degrees. The spectral range extends from 0.8 to 2.5 micron, corresponding to the astronomical Z to K-bands. The optical design is a folded single optical train. The main challenges of the optical design are: to produce a well defined internal pupil which allows reducing the thermal background by a cryogenic pupil stop; the correction of off-axis aberrations due to the large field available; the correction of chromatic aberration because of the wide spectral coverage; and the capability to use narrow band filters (~1%) in the system with minimal degradation in the filter passband without a collimated stage in the camera.

The instrument's cold opto-mechanics consists of nine lenses up to 255 mm diameter and three rectangular folding mirrors. It will be operated at about 78 K, achieved by liquid nitrogen cooling. A compact filter unit can carry up to 19 filters distributed over four filter wheels. The mass limit of 400 kg at the 2.2m telescope requires a low mass design: a cryostat with dished ends, a separate small LN2 vessel for cooling of the detector only. All parts are light weighted and made of aluminum wherever possible. Currently the design is finished, the first parts are manufactured and the optical elements are ordered.

7735-139, Poster Session

Software control and characterization aspects for image derotator of the AO188 system at Subaru

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The image derotator is an integral part of the AO188 System at Subaru. Software control, characterization and integration issues of the image derotator for AO188 System at Subaru discussed.

Physical limitations of the current hardware considered and reviewed. Image derotator synchronization, tracking accuracy and problem solving strategies to achieve requirements presented. It's use in different observation modes for various instruments and interaction with the telescope control system provides status and control functionality.

We describe available observation modes along with integration issues. Technical solutions with results of the image derotator performance presented. Results are informative for analysis of factors degrading the image derotator performance and it's influence on the image and data quality for planned and currently used scientific instruments with AO188.

Further improvements and control software for on-sky observations discussed based on the results obtained during engineering observations. We also show control limitations and accepted solutions, that might be useful for development of other instruments image derotators.

7735-140, Poster Session

VIRUS optical tolerance and production

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The Visible IFU Replicable Unit Spectrograph (VIRUS) instrument is made up of 150+ individually compact and identical spectrographs, each fed by a fiber integral field unit. The instrument provides integral field spectroscopy from 350nm to 550nm of over 33,000 spatial elements per observation, each 1.8 sq. arcseconds on the sky. The instrument will be fed by a new wide-field corrector (WFC) of the Hobby-Eberly Telescope (HET) with increased science field of view as large as 22 arcminutes diameter. The construction of the large number of VIRUS units requires the individual spectrographs be interchangeable at the sub-system level and a production line assembly process be utilized, while meeting the optical performance specification. These requirements pose a strong emphasis on careful analysis of the manufacturing and alignment tolerances of the unit spectrograph design. In this paper, we detail the tolerance analysis, and discuss its implication for the optical performance and production of the VIRUS instrument.

7735-141, Poster Session

A versatile motion control system for astronomical instrumentation

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With steadily increasing telescope sizes and the growing complexity of scientific instruments, there is an ever-growing demand for improved electronics, controlling all the different optical parts on moving mechanisms.

Among competing requirements are, on one hand, the increasing number of actuators, with high-precision positioning in closed and open loop and on the other hand, smaller sizes, low power and restricted heat emission.

A specific challenge is accommodating mechanisms that operate in infrared instrumentation at cryogenic temperatures down to 60 Kelvin. In this area Piezo motors offer promising solutions.

To fulfill these different demands a competitive motion control system has been developed at MPIA. A modular chassis with standardized boards provide best solutions for extensive tasks.

High and low power DC servo motors, brushless DC servo motors, stepper motors and piezo motors with different technologies are supported. Diversity position feedback capabilities, like incremental and absolute encoders for non cryogenic and capacitive sensors and resolvers for cryogenic applications, are provided.

7735-142, Poster Session

There and back again: sharing a major instrument between hemispheres

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As astronomical instruments have increased in complexity, size, cost, and production time, sharing a major instrument between telescopes has become an attractive alternative to duplication. This requires solving technical and logistical problems of transportation, transferring operational support knowledge between on-site staffs, and developing a robust plan with shared responsibility for response to problems. The infrared camera NEWFIRM has been operated for two years on the 4-m Mayall telescope of Kitt Peak National Observatory in Arizona. We have recently moved it to the 4-m Blanco telescope of Cerro Tololo Interamerican Observatory in Chile for a limited period of operation, with the intent to move it back at the end of that time. We describe here our solutions to the challenges involved in relocating this ~two ton cryogenic instrument and bringing it on-sky for science, with an emphasis on “lessons learned” to date.

7735-143, Poster Session

Future development of the PLATO Observatory for Antarctic science

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PLATO is a self-contained robotic observatory built using two 10-foot shipping containers. It has been successfully deployed at Dome A on the Antarctic plateau since January 2008, and has accumulated over 540 days of uptime at the time of writing. PLATO provides 0.5-1kW of continuous electrical power for a year from diesel engines running on Jet-A1 and solar panels. One of the 10-foot shipping containers houses the power system and fuel, the other provides a warm environment for instruments. Two Iridium satellite modems allow 30MB/day of internet access.

Future enhancements to PLATO, currently in development, include a more modular design, using lithium iron-phosphate batteries, higher power output, and a light-weight low-power version for field deployment from a Twin Otter aircraft.

Technologies used in PLATO include a CAN (Controller Area Network) bus, high-reliability PC/104 computers, ultracapacitors for starting the engines, and fault-tolerant multiply-redundant design.

7735-144, Poster Session

Hexabundles: imaging fibre arrays for low-light astronomical applications

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We demonstrate for the first time an imaging fibre bundle ("hexabundle") that is suitable for low-light applications in astronomy. These devices have major advantages over deployable integral field units and "densepak" arrangements, as we discuss. The most successful survey instruments at optical-infrared wavelengths today have managed to obtain data on up to a million celestial sources, using hundreds of multimode fibres at a time, each targeting a single object and fed to a spectrograph. But a large fraction of these sources are spatially extended on the celestial sphere, resulting in a serious bias in the catalogued properties such as galaxy type. This problem can be solved by replacing each fibre with a hexabundle which would provide spectroscopic information at many distinct locations across each source. Our goal is to upgrade these survey instruments with multimode hexabundles in place of the existing single-aperture multimode fibres. We discuss two varieties of hexabundles: (i) closely packed circular cores allowing the filling fraction to approach the theoretical maximum of 91%; (ii) fused non-circular cores where the interstitial holes have been removed and the filling fraction approaches 100%. In both cases, we find that the cladding can be reduced to of order 1μm over the short fused length, well below the conventional ~10 thickness. We discuss the relative merits of fused/unfused hexabundles in terms of manufacture and deployment.

7735-145, Poster Session

Experimental investigation of adhesive bond strength between metal and optical glass

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Within the general astronomical community as well as at the University of California Observatories, there has been a long history of using epoxy to mount optics within instruments such as spectrometers and telescopes. The Ken & Gloria Levy Spectrometer, part of the Automated Planet Finder (APF) telescope located at Mt. Hamilton's Lick Observatory, relies on epoxy-bonded joints to attach the instrument's 23-kg prism and 56-kg echelle grating to its Invar space-frame structure. Design constraints dictated that these large optics each be attached at only three points, and that the bond areas be as small as possible while maintaining an adequate strength factor of safety. Previous UCO instruments, such as the Keck Telescopes' primary mirror segments and the ESI Spectrograph, used Hysol's 9313 epoxy product for this purpose. We empirically investigated the roles played by epoxy selection and techniques, such as the use of primers and surface preparation, in creating a robust metal-to-glass bond. Bond strength data was generated, leading us to select a previously unused epoxy and to implement particular techniques to ensure bond quality.

7735-146, Poster Session

A compact, light-weighted, and multi-purpose calibration unit for LINC-NIRVANA

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Laboratory and on-sky experience suggests that the integration of large astronomical instrumentation, specially of a complex interferometric system like LINC-NIRVANA is a challenging process. Simulating the final operating environment of every system component has shown how critical is the effect of flexures, vibrations and thermal expansion. Assembling and aligning the opto-mechanical sub-systems will require an absolute reference which is not affected by static displacements or positioning errors.

A multi-purpose calibration unit has been designed to ensure the quality of the alignment of optics and detectors and the reliability of the mechanical setup.

This new compact and light-weighted unit is characterized by sophisticated kinematics, simplified mechanical design and composite materials. In addition, the reduced number of motorized axis improves the stiffness and lowers the angular displacements due to moving parts.

The modular concept integrates several light sources to provide the proper calibration reference for the different sub-systems of LINC-NIRVANA.

For the standard alignment of the optics an absolute reference fiber will be used.

For flat-fielding of the detectors the unit provides an integrating sphere, and a special rotating multi-fiber plate (infrared and visible) is used to calibrate the advanced adaptive optics and the fringe-tracking systems. A module to control non-common path aberrations (DM flattening) is also provided.

7735-147, Poster Session

IAA-AVS fiber positioner for astronomical instrumentation

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Fiber-fed wide-field spectrographs dedicated to observing massive portions of the sky are increasingly being more demanded within the astronomical community. For all these instruments, the primordial and common problem is the positioning of the fiber ends, which must match the position of the objects of a target field on the sky. An actuator array is able to position all the fiber heads simultaneously, thus making the reconfiguration time extremely short and the instrument efficiency very high (e.g. LAMOST, Echidna, LBNL). The SIDE/MiniSIDE group at the IAA, together with the industrial company AVS and the University of Barcelona, has developed an actuator suitable for a large and scalable focal plane array. A real-scale prototype has been built and tested in order to validate its innovative design concept, as well as to verify the fulfilment of the mechanical requirements. The present contribution describes briefly both the concept design and the test procedures and conditions. In addition, results are shown and a full justification of the validity of the proposed concept is provided.

7735-148, Poster Session

Upgrade of Iqueye: a novel photon-counting photometer for the ESO new technology telescope

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Iqueye is a novel extremely high speed photon-counting photometer for the ESO New Technology Telescope in La Silla. Iqueye collects the light from the telescope through a few arcsec aperture, and splits it along four independent channels, each feeding a single photon avalanche diode. The produced count pulses are collected by a time-to-digital converter board and suitably time-tagged. Thanks to a rubidium oscillator and a GPS receiver, an absolute rms timing accuracy better than 0.5 ns during one-hour observations can be achieved by post-processing the data. The system can sustain a count rate of up to 8 MHz uninterruptedly for an entire night of observation.

After the first run in January 2009, some improvements have been evidenced and realized: a more practical mechanical structure, a better optimization of the optical design, an additional filter wheel per each channel, a fifth photon counting detector for monitoring the sky, a more interactive interface software. The updated Iqueye has been tested in December 2009, and the obtained results showed still better performance. As an example, the light curves of visible pulsars down to the 25th visible magnitude have been obtained in a few hours of observation.

7735-149, Poster Session

Introduction to MEFOS: a multiple-object, high-speed photometer

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MEFOS (Meudon ESO Fibre Optical System) is a multiple-fibre poistioner which was first designed for multi-objects spectroscopy, and was mounted on the 3.6-m ESO telescope at La Silla, Chile in the 90’. It remains in excellent shape and, recently, has been re-commisioned by LESIA, Paris Observatory to conduct high time resolution photometry. The whole instrument consists of a multi-objects fibre system and a fast EMCCD camera. It has be implemented at the cassegrain focus of the 193 cm telescope at the Observatoire de Haute-Provence (OHP), France. It is an arm positioner consisting of 29 arms in a 20 arc-minute field. Each arm is equipped with an individual viewing system for accurate setting and carries one individual fibre that intercept 15” arcsec on the sky. All the 29 fibre images are projected onto an EMCCD camera for fast photometry acquisition. The ProEM EMCCD camera, manufactured by Princeton Instruments, utilises the electron multiplying technique to enhance the performance of CCD signal-to-noise ratio, which is particular important for observing faint objects with high time resolution. The main mission of this instrument is to search for the small objects in outer region of the solar system, such as Kuiper Belt and Oort cloud. However, other astronomical observations which require fast photometry, for example, rapid variability in compact binaries, young stellar objects in star formation, and etc. are also included in our program.

7735-150, Poster Session

MooSci: a lunar scintillometer

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MooSci is a lunar scintillometer that will be used to probe atmospheric turbulence by measuring the scintillation of light reflected by the Moon. The 11-channel linear array of photoelectric diodes will measure the fluctuations in light from the Moon along a 0.8 meter baseline. By using the information from multiple pairs of diodes at various baselines a turbulence profile will be reconstructed from 600 meters down to a few meters above the instrument. A MooSci prototype is currently being designed and field tested. MooSci makes use of off-the-shelf components making the instrument very cost efficient and easily reproducible. This paper covers the design and testing of the instrument including the design of the physical structure, electrical circuits, and optical and electronic tests to insure that the data collected is of the highest quality and integrity.

7735-151, Poster Session

Experimental results from using two laminated film polarizers to make absolute measurements of polarization crosstalk in an optic

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In working with polarimeters, it is useful to be able to analyze the level of stress birefringence in the optics of the polarimeter individually. This birefringence shows up in the polarimeter as a conversion of linear polarization to circular polarization and vice versa. A method has been developed for using two, low-cost, laminated film polarizers to make measurements of linear-to-circular polarization conversion in sample optics. Measurements were made on several optical elements of the ESPaDOnS spectro-polarimeter during the effort to reduce the polarization crosstalk, as well as on a quarter-wave plate in order to calibrate the measurement.

7735-152, Poster Session

RINGO2: an EMCCD-based polarimeter for GRB followup

I. A. Steele, S. Bates, C. J. Mottram, R. J. Smith, Liverpool John Moores Univ. (United Kingdom)

We describe a novel application of Electron Multiplying CCD technology in building a fast response polarimeter for robotic Gamma Ray Burst followup. A 60 rpm spinning rotor containing a Polaroid disk modulates the incoming light. A fast sensor system detects the angle of rotation and triggers readout of the EMCCD eight times per revolution. This allows a measurement of polarization down to a timescale of 1 second (important for these rapidly varying objects), However the low read noise of the EMCCD means data can be binned on longer timescales for fainter objects post-observation with little SNR penalty. Hence the same observing sequence can be used for both bright and faint bursts without a priori knowledge of the burst nature.

The instrument was commissioned on the telescope in December 2009 and we will present full details of the data reduction procedures and instrument characterization.

7735-153, Poster Session

The polychromatic polarization modulator

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An increasing number of astronomical applications depend on the measurement of polarized radiation. For example, our knowledge of solar magnetism relies heavily on our ability to measure and interpret polarization signatures introduced by magnetic field. Many new instruments have consequently focused considerable attention on polarimetry. For solar applications, spectro-polarimeters in particular are often designed to observe the solar atmosphere in multiple spectral lines simultaneously, thus requiring that the polarization modulator employed is efficient at all wavelengths of interest.

We present designs of polarization modulators that exhibit near-optimal modulation characteristics over broad spectral ranges. Our design process employs a Monte-Carlo-like technique to optimize the efficiency of the modulator at specified wavelengths. In general, the resulting

modulator does not resemble a waveplate.

We will present several examples of modulator designs based on rotating stacks of Quartz waveplates, Ferroelectric Liquid Crystals (FLCs), and Liquid Crystal Variable Retarders (LCVRs). An FLC-based modulator of this design was recently deployed for the ProMag instrument at the Evans Solar Facility, Sacramento Peak, New Mexico. A second FLC-based modulator was constructed from surplus parts for use as a general "lab polarimeter". We will show that these modulator behave according to their designs, and, observations permitting, present the first results from the ProMag instrument.

7735-154, Poster Session

The ZIMPOL high-contrast imaging polarimeter for SPHERE: design, manufacturing, and testing

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ZIMPOL is the high contrast imaging polarimeter of the ESO SPHERE instrument. SPHERE is an instrument designed and built by a consortium consisting of LAOG, MPIA, LAM, LESIA, Fizeau, INAF, Observatoire de Genève, ETH, NOVA, ONERA and ASTRON in collaboration with ESO. ZIMPOL is dedicated to detect the very faint reflected and hence polarized visible light from extrasolar planets. In SPHERE it is located behind an Extreme AO (SAXO) and coronagraphic system. SPHERE is foreseen to have first light at the VLT in 2011. ZIMPOL is currently in the manufacturing, integration and testing phase. We describe the optical, polarimetric, mechanical, thermal and electronic design as well as the design trade offs. Specifically emphasized is the optical quality of the key performance component: the Ferro-electric Liquid Crystal (FLC). Furthermore, we describe the ZIMPOL test setup that is dedicated for high contrast polarimetric imaging and the first test results. The test results focus on the achieved polarimetric sensitivity and accuracy. These results will give first indications for the expected overall high contrast system performance.

7735-155, Poster Session

Correcting polarization crosstalk in the ESPaDOnS spectro-polarimeter

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ESPaDOnS is a high-resolution, cross-dispersed, fiber fed, echelle spectrograph in use at the Canada-France-Hawaii Telescope (CFHT). The light from the telescope passes through a polarimeter stage before being injected into the fibers that feed the spectrograph, so the instrument is capable of determining the polarization of the stellar spectra from 370 - 1000 nm in wavelength. One limit to the accuracy of the polarimetry is the inevitable polarization crosstalk added by all optics prior to polarization analysis. The main source of this crosstalk is stress birefringence in the glass of the optics; either residual from the annealing process or induced by the mounting of the optics. The process by which the crosstalk in ESPaDOnS has been reduced from 5% or more to less than 1% is discussed in this paper.

7735-156, Poster Session

Measurements and optimization of the occulting disk for the ASPIICS/PROBA-3 formation flying solar coronagraph

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The concept of solar coronagraphs in formation flying (i.e., coronagraphs with the occulter and the telescope on different spacecrafts, separated by large distances) is highly attractive because allows coronal observations very close to the limb, but introduces several mechanical and technological constraints that have to be met. One of the most critical issues is the external occulter design and its optimization. In the framework of the ASPIICS coronagraph, proposed for the PROBA-3 ESA mission, the occulting disk has a diameter of 1.5 m, while the telescope entrance pupil is at a distance of 150 m. The edge of the disk requires special attention in order to minimize the diffraction while being compatible with the constraints of handling and integrating large delicate space components. Another difficulty is that it is practically impossible to realize a full scale model for laboratory tests. We have therefore implemented a scaled-model breadboard of the edge of the disk. Several geometries, manufacturing techniques, and material of the edge will be tested using the Artificial Sun facility at Laboratoire d'Astrophysique de Marseille. This article describes this study and the results obtained so far on the performances of the occulting system.

7735-157, Poster Session

Utilization of redundant polarized solar spectra to infer the polarization properties of the new generation of large aperture solar telescopes

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Spectro-polarimetry plays an important role in the study of solar magnetism and strongly influences the design of the new generation of solar telescopes. Calibration of the polarization properties of the telescope is a critical requirement needed to use theses observations to infer solar magnetic fields. However, the large apertures of these new

telescopes make direct calibration with polarization calibration optics placed before all the telescope optical elements impractical.

It is therefore desirable to be able to infer the polarization properties of the telescope optical elements utilizing solar observations themselves. Taking advantage of the fact that the unploarized, linearly, and circularly polarized spectra originating from the Sun are uncorrelated, we have developed techniques to utilize direct observations of solar spectra with redundant combination of the polarization states and at several different telescope configurations to infer the polarization properties of the telescope as a whole and of its optical elements.

We show results of these techniques applied to spectroplarimetric data obtained at the Dunn Solar Telescope.

7735-158, Poster Session

The forthcoming SALT HRS spectrograph: instrument capabilities and operational modes

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The high-resolution échelle spectrograph, SALT HRS, is at an advanced stage of construction and will shortly become available to the user community of the Southern African Large Telescope. A previous paper described the optical design of the fibre-fed spectrograph, which was selected for its wide wavelength coverage from 370nm to 890nm (captured in two spectral images using red- and blue- optimised cameras and CCDs) and high resolution. Here we update this to give the instrument's final specification and we provide refined estimates of instrument performance based on the initial testing of the manufactured optics and the science-grade detectors. This paper also contributes a description of the tailoring of the fibre input optics to specific scientific aspirations to give four distinct operational modes. There are three image-sliced modes plus a further low-resolution mode having direct fibre injection. All are capable of capturing object and sky spectra simultaneously. The low resolution mode (R≈16,000) is uniquely capable of operating in a "nod-and-shuffle" manner for improved subtraction of the sky background. The medium and high resolution modes have resolutions of R≈37,000 and R≈67,000 respectively. The final sliced mode duplicates the high resolution feed but is optimised for high-precision radial velocity science. It has in-built fibre double mode scrambling and offers the option of an Iodine absorption cell to record temporal changes to the instrument's calibration for later use in the science data reduction. The instrument also has high intrinsic mechanical and thermal stability to support this mode of operation.

7735-159, Poster Session

Design of the CHIRON high-resolution spectrometer at CTIO

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Small telescopes coupled to high resolution spectrometers are powerful tools for doppler planet searches. They allow for high cadence observations and flexible scheduling; yet there are few such facilities. We present an innovative and inexpensive design for CHIRON, a high resolution (R~80.000) Echelle spectrometer for the 1.5m telescope at CTIO. Performance and throughput are very good over the whole spectral range from 410 to 870nm. An image slicer permits a moderate beam size. We use commercially available, high performance optical components, which is key for quick and efficient implementation. We discuss the optical design, optomechanical tolerances and resulting image quality.

7735-161, Poster Session

Overwiew of the GYES instrument: a multifibre high-resolution spectrograph for the prime focus of the Canada-France-Hawaii Telescope

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ESA's cornerstone mission Gaia will construct a billion-star catalogue down to magnitude 20 but will only provide detailed chemical information for the brighter stars and will be lacking radial velocity at the faint end due to insufficient signal-to-noise ratios (SNR). This calls for the deployment of a ground spectrograph under time scales coherent with those of Gaia for a complementary survey.

The GYES instrument is a high resolution (~20000) spectrometer proposed for installation on the Canada-France-Hawaii Telescope (CFHT) to perform this survey in the northern hemisphere. It exploits the large field of view available at the prime focus together with a high multiplex (~500 fibres) to achieve a SNR of 15 in one hour at magnitude 18 and render the survey possible on the order of 300 nights. The on-going feasibility aims at jointly optimising all components of the system: the field corrector, the positioner, the fibres and the spectrograph. The key challenges consist in accommodating the components in the highly constrained environment of the primary focus, as well as in achieving an optimised throughput thanks to high transmission and minimum reconfiguration delays. Meanwhile, for GYES to remain in phase with Gaia, it is fundamental to keep the complexity down by designing a predominantly passive instrument.

7735-162, Poster Session

The optical design of a highly segmented, very wide-field spectrograph

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In this paper we work out the optical design of, basically, a limited Field of View off-axis camera. This element is the ingredient of a much more complex very wide field of view spectrograph and it is intended to avoid technological difficulties related with huge optics by replicating such element (or family of such elements). The optical design has to deal with the large off-axis aberration at a point in the Field of View as far from the optical axis as more than one degree. This requires special tools for treating the convergence of the optical design as, for instance, vignetting on the edges can be severe because of the strong aberrations at the field lens entrance. Constraints into the optical design are particularly interesting as well: in fact the overall cross section of the design have to lie within the footprint of the entrance Field of View in order to allow for an array of such a design to be assembled together and guarantee the space for the allocation of micro-mechanisms required for movable slits and grisms in each module. Several starting points for the optical design has been considered and are briefly discussed.

7735-163, Poster Session

Production-line assembly of 150+ VIRUS spectrographs

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The Visual Integral-Field Replicable Unit Spectrograph (VIRUS) instrument is being built to support observations for the Hobby-Eberly Telescope Dark Energy Experiment (HETDEX) project. The instrument consists of 150+ identical fiber-fed integral field optical spectrographs. This instrument provides a unique challenge in astronomical instrumentation: each of the 150+ instruments must be identical and each component must be interchangeable amongst every other spectrograph in order to ease assembly and maintenance of the instrument. In this paper we describe plans for the production-line assembly of the spectrographs. In particular, we discuss the assembly procedures and design choices that will ensure uniformity of the spectrographs and support the project schedule.

7735-164, Poster Session

A radial velocity spectrometer for the Automated Planet Finder Telescope at Lick Observatory

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The Ken and Gloria Levy Spectrometer is being constructed at the Instrument Development Laboratory of UCO/ Lick Observatory for use on the 2.4 meter Automated Planet Finder Telescope at Mt. Hamilton. The mechanical design of the instrument has been optimized for precision Doppler measurements. A key component of the design is the space-frame structure that contains passive thermal compensation. Determinate hexapod structures are used to mount the collimator, prism and echelle grating. In this paper we describe the instrument design and features that will help it detect rocky planets in the habitable zone.

7735-165, Poster Session

OSMOS: The Ohio State multi-object spectrograph

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We present optical and mechanical details of OSMOS, the Ohio State Multi-Object Spectrograph, a facility instrument of the Hiltner 2.4m Telescope at MDM Observatory that will be commissioned in April 2010. OSMOS has a 20' diameter FOV with 0.3"/pixel when used with the MDM 4k detector. It can be used in imaging or spectroscopy mode, with good sensitivity from ~3500-10000 A. OSMOS allows rapid observer switching between up to five dispersors and imaging in up to ten different filters. The complement of dispersors will include a very low resolution triple prism and a low-resolution VPH grating. Five slit masks will be able to be loaded simultaneously, and they will be accessible for the observer to change during the night if more are desired. We present preliminary instrument performance details and some of the first on-sky results.

7735-166, Poster Session

NEFER: a high-resolution scanning Fabry-Perot spectrograph II; scanning Fabry-Perot testing

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NEFER (Nuevo Espectrometro Fabry-Perot de Extrema Resolucion) is high spectral resolution, scanning Fabry-Perot observing mode for the OSIRIS instrument at the GTC telescope. This 3D observing mode uses a high order scanning Fabry-Perot interferometer to obtain highly accurate kinematical information of extend cosmic sources such as galaxies or nebulae. Astronomical data obtained with this observation mode lead to a 3D spectroscopy data cubes composed of several images, each one at different gaps of the scanning Fabry-Perot Interferometer (two spatial dimension + one wavelength dimension). In this work we present laboratory testing of some characteristics of the ICOS ET100 Fabry-Perot acquired for this project such: Finnese, free spectral range and peak transmission. We also present software design and development for the 3D data reduction standalone package (CIGALE-based) of this high resolution observing mode.

7735-167, Poster Session

First light results from PARAS: the PRL echelle spectrograph

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We present the first light commissioning results from the Physical Research Laboratory optical fiber-fed high resolution cross-dispersed Echelle Spectrograph. It is capable of a single-shot spectral coverage of 3700A to 8600A at R ~ 70,000 and is under very stable conditions of temperature (0.02C at 27C), and pressure. Pressure control is achieved by enclosing the entire spectrograph in a low pressure vacuum chamber (~0.01 mbar). It is attached to a 1.2m telescope using two 50 micron core optical fibers (one for the star and another for simultaneous Th-Ar spectral calibration). This also includes F/13 to F/4 fiber transfer optics at the Cassegrain focus of the telescope, and vice-versa at the slit position of the spectrograph; an Optical Fiber Scrambler is also included in the fiber optics. The 1.2m telescope is located at Mt. Abu, India, and we are guaranteed about 80 to 100 nights a year for observations with the spectrograph. The instrument will be ultimately used for radial-velocity searches of exoplanets around 1000 dwarf stars, brighter than 10.5 magnitude, for the next 5 years with a precision of 3-5m/s using the simultaneous Th-Ar spectral lamp reference technique. PARAS thus stand for PRL Advanced Radial-velocity All-sky Search. We also present the technical details of the spectrograph and the optical scrambler. From fiber exit to the detector, the spectrograph throughput will be as high as 35% at the blaze peak, making PARAS a very efficient high resolution spectrograph capable of contributing to precision radial velocity work even on a 1m class telescope.

7735-168, Poster Session

Astro-comb calibration of an Echelle spectrograph

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We describe recent work calibrating a cross-dispersed echelle spectrograph with an astro-comb. An astro-comb is a laser calibrator composed of a high repetition rate, octave spanning femtosecond laser and a filter cavity suppressing laser modes to match the resolution of the spectrograph. Our astro-comb provides ~1500 evenly spaced (~0.6 A) calibration lines of roughly 100 nW per line between 7800 and 8800 Angstroms. The calibration lines of the laser are stabilized to atomic clocks which can be referenced to GPS providing intrinsic stability of the source laser below 1 cm/s as well as long term stability and reproducibility over years. We used the astro-comb for calibration of the TRES spectrograph at the 1.5 m telescope at the Fred L. Whipple Observatory, achieving internal precision below 1 m/s for six spectrograph orders from 7800-8800 A.

7735-169, Poster Session

Analyzing the MUSE opto-mechanics serving as an optical bench in 3D space

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MUSE as Multi Unit Spectroscopic Explorer is a second-generation VLT instrument. With the high multiplexing factor of twenty-four, it requires complex opto-mechanics to split the field of 1x1 arcminute on the sky into sub-fields and guide them along the central instrument structure to the feeding point of the spectrographs. The requirements on the underlying mechanical structure are quite demanding in terms of opto-mechanical stability under thermal loads (diurnal and seasonal variations) and thermal mismatch (between steel basement and aluminium structure), warping of its basement (from telescope's azimuth track) and excessive earthquake loads (at the telescope site). In total seven individual load cases and combinations of them have been analyzed in extensive finite-element analyses (Nastran) with subsequent optical analyses (Zemax). The FEA model and the results of those will be demonstrated and analyzed in the light of specifications. It is demonstrated by the combined analyses that all requirements are met within the specification.

7735-170, Poster Session

Fiber-stabilized PSF for sub-m/s Doppler precision at Lick Observatory

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The detection of small rocky planets requires extreme Doppler precision and long term stability in order to measure tiny reflex velocities in the host star. Our Doppler technique uses a gas cell to imprint molecular iodine lines in the stellar spectrum. The iodine lines allow us to track changes in the instrumental PSF, ensuring long term stability in our velocity measurements. The PSF from the spectrometer should be slowly varying with temperature and pressure changes. However, variations in the illumination of the slit and of the spectrograph optics occur on time scales of seconds, primarily because of guiding errors, but also on timescales of minutes, because of changes in the focus or seeing. These variations yield differences in the PSF, which are difficult to model and which are currently limiting the Doppler precision. In order to stabilize the PSF of the Hamilton spectrograph of Lick observatory, we designed a low cost fiber optic feed, FINDS. Here, we present the design of this fiber feed along with the first measurements that show dramatic improvement in the PSF stability.

7735-171, Poster Session

Manufacturing and integration of the IFS integral spectrograph for SPHERE

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Currently in the last phase of the integration, the Integral Field Spectrograph of Sphere (IFS) will see the first light at ESO Paranal as a VLT second generation instrument during 2011. In this paper we will describe the main aspects in the assembly, integration and testing phase (AIT) of the instrument at INAF-OAPD laboratories. As result of the AIT a full set of tests and qualifications of IFS will be discussed. These tests have been designed and realized with the purpose to obtain an accurate comparison between design goals and effective performances of the instrument.

7735-172, Poster Session

PUCHEROS: a low-cost fiber-fed echelle spectrograph for the visible spectral range

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PUCHEROS is a high resolution optical Echelle spectrograph designed for the ESO 50 cm telescope located at the PUC observatory of Santa Martina. With a resolution about 20.000, PUCHERO-ESO50 offers the ideal synergy for the study of bright and variables objects like Be stars. Using a fiber optic to bring the light from the telescope to the instrument, it can be located in a gravity invariant, temperature stabilized location, allowing precise long term observations. PUCHEROS will be a valuable tool both for research and didactics at the graduate and undergraduate level. In this work we present the optical and mechanical design of the spectrograph as well as the first laboratory tests.

7735-173, Poster Session

Design of Echelle spectrograph for small telescopes with commercially available components

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We present the design of an echelle spectrograph based on commercially available components. This instrument is an ideal solution to equip small telescopes with low cost but scientifically effective instrumentation. The spectrograph is fiber fed, reaches a resolution of about 8000, can be located in a gravity invariant and thermally controlled environment and can be used for the long term spectroscopic monitoring of bright objects. The optical design and performances of the instrument are analyzed using Zemax, we present options for the mechanical design too.

7735-175, Poster Session

A near-infrared spectrometer to measure zodiacal light absorption spectrum

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We are at the stage of completion and testing the high throughput cryogenic Fabry-Perot spectrometer for measuring near infrared absorption lines in the zodiacal light spectrum. We have previously developed and demonstrated the feasibility of the a cryogenic temperature tuned silicon immersion Fabry-Perot etalons. That has paved the way to developing this large format (80 mm diameter silicon etalons) high resolution (R=20,000) spectrometer. These measurements will provide the intensity of the zodiacal light in the COBE/DIRBE 1.25 micron band. The results of this project will be very important not only for the studies of zodiacal light, but for accurate subtraction of zodiacal light foreground and thus accurate measure of the remainder, the extragalactic background light (EBL). Uncertainties in the modeling of the zodiacal light contribution had been the largest obstacle in determining the extragalactic background in the near infrared. We will greatly reduce these uncertainties by measuring the zodiacal light Fraunhofer spectrum directly.

7735-177, Poster Session

Science capabilities of the Robert Stobie spectrograph on the SALT Telescope

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The Robert Stobie Spectrograph consists of a Visible Arm covering a wavelength range of 0.32-1.0 microns and a Near Infrared Arm, which will cover the 0.9 to 1.7 micron wavelength range. The visible arm has been delivered and is being commissioned at the 11-meter Southern African Large Telescope (SALT). The NIR Arm is scheduled to be commissioned on the telescope in 2012. Together they will provide high throughput, low- to medium-resolution long-slit and multi-object spectroscopy with broadband, spectropolarimetric, and Fabry-Perot imaging modes over an 8 diameter field of view. Once fully commissioned, this will be the only 10-meter-class instrument capable of simultaneous visible and NIR spectroscopy over a multi-object field. We present several of the primary science drivers along with the associated performance predictions for each mode.

7735-178, Poster Session

Production and performance of replicable integral field units for VIRUS

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Lead by the University of Texas at Austin, the AIP is involved in the development of VIRUS, a highly replicable integral field spectrograph for the Hobby-Eberly Telescope Dark Energy Experiment (HETDEX), which aims to detect up to 800,000 Lyman-alpha galaxies in a volume of 9 cubic Gpc. Within the partnership, the AIP is responsible for the development and delivery of up to 96 identical integral-field units, consisting of over 43,000 fibers in total that feed 192 spectrographs.

While a replication of units on this scale is expected to simplify R&D efforts and to save costs, it is a challenge in terms of project management and quality assurance procedures.

AIP has produced optical fiber bundle prototypes, which are in operation at both the 2.7m Harlan-Smith Telescope at McDonald Observatory and at the 9.2m HET, where VIRUS-P is used for the HETDEX pilot survey. After passing the preliminary design review, AIP engaged in technology transfer and has, together with industrial partners, built a first set of fiber bundles in a mini-series. These IFUs with altogether over 4000 fibers, which is a tenth of the foreseen entire spaxels, are currently undergoing acceptance tests.

7735-180, Poster Session

Design of the fiber optic support system and fiber bundle accelerated life test for VIRUS

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The quantity and length of optical fibers required for the Hobby-Eberly Telescope Dark Energy eXperiment [HETDEX] create unique fiber handling challenges. For HETDEX, at least 33,000 fibers will transmit light from the focal surface of the telescope to an array of spectrographs making up the Visible Integral-Field Replicable Unit Spectrograph [VIRUS]. Up to 96 Integral Field Unit [IFU] bundles, each containing 448 fibers, hang suspended from the telescope's moving tracker located more than 15 meters above the VIRUS instruments. A specialized mechanical system is being developed to support fiber optic assemblies onboard the telescope. The discrete behavior of 448 fibers within a conduit is also of primary concern. A life cycle test must be conducted to study fiber behavior and measure Focal Ration Degradation [FRD] as a function of time. This paper focuses on the technical requirements and design of the HETDEX fiber optic support system, the electro-mechanical test apparatus for accelerated life testing of optical fiber assemblies and test results. The test results will be of great interest to designers of robotic fiber handling systems for major telescopes. There is concern that friction, localized contact, entanglement, and excessive tension will be present within each IFU conduit and contribute to FRD. The life cycle test will study the behavior of the fibers and FRD as a function of time. The test apparatus design utilizes six linear actuators to replicate the movement of the telescope over 65,000 accelerated cycles, simulating five years of actual operation.

7735-181, Poster Session

A Fabry-Perot calibrator of the HARPS radial velocity spectrograph: performance report

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The radial velocity (RV) technique has pushed the planet detection limits down to super-earths. The current precision achieved by RV is around 69 cm.s-1. To reach the precision required to detect earth-like planets it is necessary to reach a precision around 1cm.s-1. This implies lifting some instrumental limitations, among them the wavelength calibration. The Observatory of Geneva has designed, built and tested in collaboration with ESO a calibrator system based on a Fabry-Perot interferometer to explore its potential to improve the wavelength calibration of RV spectrographs. Unlike the Th-Ar lamp this device allows the production of optimally and regularly spaced calibration lines covering all orders of the spectrograph. Our paper will report on the actual performance of the calibrator which has been tested on the HARPS RV spectrograph since Sept 2009.

7735-182, Poster Session

ESPRESSO: projecting a rocky exoplanet hunter for the VLT

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ESPRESSO is a high resolution, highly stable spectrograph for the VLT. It will inherit and enhance most capabilities from HARPS and UVES, combining both stability and efficiency. The main science driver will be the detection and characterization of Earth-like planets, but many additional science cases will benefit from its highly stable spectroscopic observations. The facility will be installed at the combined Coudé focus of the VLT and may be linked with any of the four UT telescopes, enabling thus a great flexibility for the efficient use of telescope time. This particularity makes the interface with the VLT more complex than for an instrument fed by a single telescope. It impacts on the complexity of the relationship between the provider for the instrument, the consortium and ESO, the customer and owner of the four telescopes. The targeted high RV accuracy requires very high performances in stability and resolution, which in turn require adequate technical solutions at several levels. The paper describes the instrument system and subsystems, enlightening the most valuable differences between ESPRESSO and it's predecessors. The paper describes also the details of the project, including the planning - the project will enter the detailed design phase in summer 2010, installation and commissioning on the VLT are foreseen by end of 2014 - and the ESPRESSO consortium - composed of Italian, Portuguese, Spanish and Swiss institutes, as well as the relationship between the consortium and ESO.

7735-183, Poster Session

KMOS pick-off arm optical alignment, calibration, and testing

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The pick-off arm is the part of the KMOS instrument which re-images a sub-field of the VLT focal plane to a position outside of the main field where it can be used for integral field spectroscopy. In this paper we describe the optical alignment and test procedure developed to meet the challenging alignment requirements of the instrument. It is important to note that although the alignment is done at ambient temperature, the alignment of the optical components must be maintained at the instruments cryogenic operational temperature.

This paper describes the methods used to achieve the absolute positioning accuracy and the test results obtained and discussed some of the practical difficulties that were encountered

7735-184, Poster Session

Development of the prototype integral field unit for prompt follow-up spectroscopy of gamma-ray bursts

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We are now prototyping an integral field unit (IFU) using micro-lenses and optical fibers for a new integral field spectrograph (IFS). The IFS is one of the primary instruments of a new 3.8m telescope which is under development. We report basic concept of the IFS and current status of the prototyping work. Main aim of the 3.8m telescope is prompt follow-up spectroscopy of rapidly variable astronomical objects such as gamma-ray bursts (GRBs). The IFS allows us to omit procedures of target identification and acquisition, and to start exposure very quickly. We are developing a prototype IFU for the IFS in order to establish the construction technologies. We have already finished basic design, and move to detailed design phase. We will install the prototype IFU into an existing optical imaging spectrograph, KOOLS, of the 188cm telescope at Okayama Astrophysical Observatory for test observations. Through the test observations, we will establish the observing procedures and the data reduction techniques. The prototype IFU has the 20 x 20 arcsec^2 field of view (FoV) and the 2 arcsec spatial sampling on the 188cm telescope. The new IFS will have the 20 x 20 arcsec^2 FoV and the 1 arcsec spatial sampling on the 3.8m telescope. The X-ray telescope of the Swift satellite distributes GRB locations with the accuracy of 3-5 arcsec after 70 sec from GRB triggers. Since the FoV of the new IFS is much wider than this positional error circle, we can make prompt spectroscopy of GRBs.

7735-185, Poster Session

KMOS: assembly, integration, and testing of three 0.8-2.5 micron spectrographs

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KMOS is a second generation instrument in construction for use at the ESO VLT. It operates in the near-infrared (0.8 to 2.5 microns) and employs 24 deployable, image slicing integral field units feeding three spectrographs. The spectrographs are designed and built by a partnership of Oxford University and Rutherford Appleton Labs. We will describe in detail the assembly, integration and alignment procedures involved in the construction. We also present the results of the cryogenic optical tests of the spectrographs. The first data taken through the full spectrograph optical train are included along with details of the test facility and procedures involved.

7735-186, Poster Session

The calibration unit and detector system tests for MUSE

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The Multi-Unit Spectroscopic Explorer (MUSE) is an integral-field spectrograph for ESO's Very Large Telescope (VLT). After completion of the Final Design Review in 2009, MUSE is now in its manufacturing, assembly and test phase. To achieve a relatively large integral-field-of-view combined with fine spatial sampling, MUSE features 24 identical spectrograph-detector units. The acceptance tests of the detector sub-systems on a reference spectrograph, the design and manufacture of the calibration unit, and the development of the Data Reduction Software for MUSE are under the responsibility of the Astrophysical Institute Potsdam. The optical design of the spectrograph implies strict tolerances on the alignment of the detector systems to minimize aberrations. For the acceptance testing, the detector vessels are mounted to a MUSE reference spectrograph and an illumination unit that mimics the image slicer output. Using the calibration unit and dedicated software, the image quality of the system is evaluated.

The paper describes the status of the calibration unit and the testing of the instrument detector systems in combination with the spectrograph.

7735-187, Poster Session

The Carnegie planet finder spectrograph: integration and commissioning

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The Carnegie Planet Finder Spectrograph (PFS) has been commissioned for use with the Magellan Clay telescope at Las Campanas Observatory in Chile. PFS is optimized for high precision measurement of stellar radial velocities in support of an ongoing search for extrasolar planets. PFS uses an R4 echelle grating and a prism cross-disperser in a Littrow arrangement to provide complete wavelength coverage between 388 and 668 nm distributed across 66 orders. The spectral resolution is 38,000 when using a 1 arcsec wide slit. The optional use of an iodine absorption cell allows the superimposition of well-defined absorption features on the stellar spectra, providing a fiducial wavelength reference. To improve velocity stability, the echelle grating is enclosed in a vacuum tank with the cross-dispersing prism acting as the vacuum window. The spectrograph is mounted on an optical bench that is surrounded by an insulated enclosure containing an active thermal control system that is regulated by a heated, recirculating fluid. An optional time delayed integration mode is available in which the flexure-mounted CCD is translated during each exposure at the same rate and in the opposite direction of timed charge shifts, minimizing the deleterious effects of imperfect flat fielding at the sub-pixel level. The spectrograph was commissioned at Magellan during Fall and Winter 2009 and is now being used to collect scientific data.

7735-188, Poster Session

Design of a near-IR Doppler instrument for planet searches

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Doppler searches are extending to the near infrared to detect and characterize habitable planets around low mass stars. We present optical design and performance of a near IR Doppler instrument. This instrument has two operation modes covering 0.9-1.8 microns. One mode is called IRET, which consists of a fix-delay interferometer and a cross-dispersed echelle spectrograph to simultaneously cover 0.9-1.35 microns with a spectral resolution of R=22000 on a 2kx2k H2RG IR array. The other mode is called FIRST, which uses a silicon immersion grating as the main disperser to simultaneously cover 1.4-1.8 microns with a spectral resolution of R=55000 on the same detector as IRET. The triple-pass parabola white pupil design is used to restrain background scatter radiation with stable configuration for precision radial velocity measurements. We used high index standard glasses for camera optics and VPH gratings as cross-dispersers in both modes. The FIRST mode can be switched in and out conveniently while the IRET mode keeps stable. This instrument is designed to deliver up to 1 m/s Doppler precision RV measurements of nearby bright M dwarfs at the Apache Point Observatory 3.5 meter telescope. The instrument is expected to be operational in late fall 2010.

7735-189, Poster Session

Science with GYES: a multifibre high-resolution spectrograph for the prime focus of the Canada-France Hawaii Telescope

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We present the scientific motivations for GYES: a high multiplex (of the order of several hundred), high resolution (about 20000), spectrograph to be placed at the prime focus of the CFHT. The main purpose of such an instrument is to conduct a spectroscopic survey complementary to the GAIA mission. The final GAIA catalogue (expected around 2020) will provide accurate distances, proper motions and spectrophotometry for all the stars down to a magnitude of 20. The spectroscopic instrument on board the GAIA satellite will provide intermediate resolution (R=$11,500$) spectra for stars down to 17th magnitude. For the fainter stars there will be no radial velocity information. For all the stars the chemical information will be limited to a few species. A multifibre spectrograph at the prime focus of the CFHT will be able to provide the high resolution spectra for stars fainter than 13th magnitude, needed to obtain both accurate radial velocities and detailed chemical abundances. The possible use of GYES will not be limited to GAIA complementary survey and we here describe the potentialities of such an instrument. We describe here how the scientific drivers are translated into technical requirements. The results of our on-going feasibility study are described in an accompanying poster.

7735-190, Poster Session

Application of fixed delay Michelson interferometer for radial velocity measurement

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A fixed delay Michelson interferometer (FDMI) also called wide-angle Michelson interferometer (WAMI) is different from traditional Michelson interferometer. Its fixed delay is not only useful to widen the field of view, but improve the accuracy of RV measurement. So it's widely known that works well on upper atmospheric wind study by measuring the Doppler velocity of some emission lines. Using a new technique called External Dispersed Interferometry (EDI) based on FDMI and post-disperser can efficiently overcome the fundamental limitation of narrow bandpass of interferometer techniques. The related systems have been successfully used in the field of exoplanet survey. In this paper, the FDMI concept is reviewed, the application in these two fields is described. Finally, a major astronomical project in China, which is developing a multi-object exoplanet survey system based on FDMI, is introduced.

7735-191, Poster Session

Extreme multiplex spectrograph: a high-demanding mechanical design

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XMS is a multi-channel wide-field spectrograph designed for the prime focus of the 3.5m Calar Alto telescope. The instrument segments the unvignetted 1-degree field available into four equal quadrants, each of which contains an identical spectrograph channel. Each mask covers all four channels giving spectra for up to 4000 objects in a single exposure.

An innovative mechanical design approach has been implemented to minimize the separation between the channels to allow large area sky surveys with maximal filling factor. Furthermore, very tight constraints in terms of space envelope and overall mass must be respected, which determine very compact and light-weight mechanics of the instrument. The latter has special impact on the detector dear, which must leave less than 150mm from the detector focal plane to the rearmost part of the vessel. Regarding the optomechanics, lenses must be aligned within tight position tolerances according to the requirements coming from the optical design. Moreover, in order to preserve the optical performance during operation, the optomechanical design must ensure self-centering on the position of the lenses under large temperature variations. And, last but not least, other key components of the instrument, the masks, are highly demanding since each of them must include up to 4000 slits on a 100μ-wide sheet, keeping the shape errors lower than 60μ.

An overview of this very challenging mechanical design (at concept/preliminary stage) is here presented, making more emphasis on those more critical aspects.

7735-192, Poster Session

Toward the commissioning of the GIANO-TNG spectrometer

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GIANO is a high resolution (R=50,000) IR spectrograph whigh provides a quasi-complete coverage of the 0.95-2.5 microns wavelengths range in a single shot. The instrument is designed to achieve the highest possible throughput and stability. The instrument is being integrated in Arcetri-INAF (Florence) and will be soon commisioned at the 3.58m TNG Italian telescope in La Palma.

The major scientific goals include the search for rocky planets with habitable conditions around low-mass stars, quantitative spectroscopy of brown dwarfs, accurate chemical abundances of high metallicity stars and stellar clusters.

This presentantion riviews the status of the projects and presents the crucial results obtained during the laboratory tests.

7735-193, Poster Session

The fiber positioning system of LAMOST with 4000 positioner

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Parallel controllable fiber positioning systme with 4000 psotioners was successfully used in LAMOST, this system includes 4 parts: positioner,control system,focal plate and measurement system. this paper describe the design and manufacture of 4000 positioners its precision is less than 6 micro(rms);the control system based on wireless communication network, the special design of control and communication unit is discussed in this paper; design and manufacture focal plate with 4000 high precision holes and curved surface and measurement system is also described in this paper.

7735-195, Poster Session

Time resolved astronomy with the SALT

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While time resolved astronomical observations are not new, the extension of such studies to sub-second time resolution is and has resulted in the opening of a new observational frontier, High Time Resolution Astronomy (HTRA). HTRA studies are well suited to objects like compact binary stars (CVs and X-ray binaries) and pulsars, while asteroseismology of pulsating stars, occultations, transits and the study of transients, will all benefit from such HTRA studies.

HTRA has been a SALT science driver from the outset and the first-light instruments, namely the UV-VIS imager, SALTICAM, and the multi-purpose Robert Stobie Spectrograph (RSS), both have high time resolution modes. These are described, together with some observational examples. We also discuss the commissioning observations with the photon counting Berkeley Visible Image Tube camera (BVIT) on SALT. Finally we describe the software tools, developed in Python, to reduce SALT time resolved observations.

7735-196, Poster Session

A new MOS mask cutter facility at Gemini/Cerro Tololo observatories

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The installation and commissioning of a new laser cutter facility in La Serena, Chile is a cooperative effort between Gemini Observatory and the Cerro Tololo Interamerican Observatory. This system enables the cutting of aluminum and carbon fiber slit masks for three multi-object spectrographs operating in Chile: GMOS-S, Flamingos-2, and Goodman spectrograph. Selection of the new laser cutter tool was based on slit mask specifications developed for two materials. Prior to the commissioning all slit mask production was performed at Gemini's Northern base facility with a similar laser cutter system. The new facility supports two observatories and enhances the capabilities for both. This paper will discuss that arrangement with respect to mask data tracking, operations, and maintenance. In addition the laser system and

facility will be discussed along with mask cutting performance, process development and manufacturing methods

7735-197, Poster Session

The differential tip-tilt sensor of SPHERE

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The SPHERE instrument aims at detecting giant extrasolar planets in the vicinity of bright stars. Such a challenging goal requires the use of a high performance AO system, a coronagraphic device to cancel out the flux coming from the star itself, and smart focal plane techniques to calibrate residual uncorrected turbulent and/or static wavefronts. A specific tool is developed in SPHERE to ensure that the star is always well centered on the coronagraph. This tool called Differential Tip-Tilt Sensor (DTTS) is located next to the coronagraph and measure the position of the star at the optimized scientific wavelength in order to unsure that the star is well centered on the coronagraph. After describing the DTTS, we will described the tests and results of stability measurement of the DTTS in the laboratory.

7735-311, Poster Session

Automated characterization of CCD detectors for DECam

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The Dark Energy Survey Camera (DECam) will be comprised of a mosaic of 74 charge-coupled devices (CCDs). The goal of the Dark Energy Survey (DES) is to measure the dark energy equation of state parameter, w, to a statistical precision of 5% with four complementary methods. This goal sets stringent technical requirements for the CCDs. Testing a large number of CCDs to determine which best meet the DES requirements would be a very time-consuming manual task. We have developed a system to automatically collect and analyze CCD test data. The test results are entered into an online SQL database which facilitates selection of those CCDs that best meet the technical specifications for charge transfer efficiency, linearity, full well capacity, quantum efficiency, noise, dark current, cross talk, diffusion, and cosmetics.

7735-312, Poster Session

Imaging polarimetry of circumstellar environments with the Extreme Polarimeter: results, performance analysis and data reduction techniques

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Two successful observation campaigns have been conducted with the Extreme Polarimeter, an imaging polarimeter for the study of circumstellar environments in scattered light at visible wavelengths. The design of this instrument has been presented in 2008SPIE.7014E.227R. The instrument operates at visible wavelengths without an adaptive optics system. A contrast ratio between the central star and the circumstellar source of 10-5 can be achieved with polarimetry, with a Lyot coronograph capable of increasing this contrast by another three orders of magnitude. The polarimeter uses the dual-beam exchange technique, in which the two orthogonal polarisation states are imaged simultaneously after which a polarisation modulator is used to swap the polarisation states of the two beams before the next image is taken. In ExPo, the images are taken at a frame rate of 35 fps.

Here we present the results from the first observation campaigns, highlighting observations of protoplanetary disks around several young stars. Systematic effects that limit the polarimetric sensitivity, and the strategies we employ to overcome them, are discussed in detail. In particular, the advantages of the dual-beam exchange polarimetry method are demonstrated. We also discuss the techniques used for pre-processing and combining the large amount of images needed to obtain the final results. Finally, the methods used to calibrate these results are explained.

7735-31, Session 5

CYCLOPS 'a better way to find extrasolar planets': an optical fiber system for UCLES at the AAT

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CYCLOPS is a new front end for the Anglo-Australian Telescope's UCL high-resolution Coudé spectrograph, which employs a fiber bundle to relay the light from the Telescope's Cassegrain focus to the UCLES spectrograph, in place of the Coudé mirror train. The CYCLOPS facility is a significant upgrade to the Anglo-Australian Telescope's ability to carry out the high-profile task of detecting planets orbiting other stars, as well as providing greatly enhanced capabilities for a number of other compelling astronomical programs.

The CYCLOPS fiber feed will significantly improve both the system throughput and resolution of UCLES for a majority of UCLES observing programs by using a single, spatially undifferentiated IFU which reformats a 3" aperture on-sky into a 0.6" wide and ~10" long 'slit'. In typically seeing conditions CYCLOPS will deliver approximately 50% improved throughput and almost doubled the maximum possible spectral resolution compared to the Coudé mirror system. It will make R= /Δ ≈75,000 abundance observations (which are currently almost impossible to do because of the need for a 0.6" slit) routine on the AAT. Moreover, because CYCLOPS reformats light from a larger aperture on the sky onto the UCLES slit than the current Coudé train, it make UCLES observing much more "seeing resistant" than at present.

In this paper we present the details of the CYCLOPS system design, build and on sky performance

7735-32, Session 5

High-spatial resolution and high contrast in speckle imaging for the search of nearby companions in the optical regime

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In this paper, we present an original observational approach, which combines, for the first time, traditional speckle imaging with image post-processing to obtain in the optical domain diffraction-limited images with high contrast (1e-5) within 0.5 to 2 arcseconds around a bright star. The post-processing step is based on wavelet filtering an has analogy with edge enhancement and high-pass filtering. Our I band on-sky results with the 2.5m Nordic Telescope (NOT) and the lucky imaging instrument FASTCAM show that we are able to detect L-type brown dwarf companions around a solar-type star with a contrast Delta_I~12

at 2 arcseconds and with no use of any coronographic capability, which greatly simplifies the instrumental and hardware approach. This object has been so far detected only in the near-infrared on AO-assisted 8-10 m class telescopes (Gemini, Keck). Discussing the advantage and disadvantage of the optical regime for the detection of faint intrinsic fluxes close to bright stars, we develop some perspectives for other fields, including the possible detection of the reflected light by planetary-mass companions. To the best of our knowledge this is the first time that high contrast considerations are included in a speckle imaging approach.

7735-33, Session 5

SPHERE: a planet imager for the VLT

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The prime objective of the Spectro-Polarimetric High-contrast Exoplanet Research (SPHERE) instrument for the VLT is the discovery and study of new extra-solar giant planets orbiting nearby stars by direct imaging of their circumstellar environment. The challenge consists in the very large contrast between the host star and the planet, larger than 12.5 magnitudes (or 105 in flux ratio), at very small angular separations, typically inside the seeing halo. The whole design of SPHERE is therefore optimized towards reaching the highest contrast in a limited field of view and at short distances from the central star. Both evolved and young planetary systems will be detected, respectively through their reflected light (mostly by visible differential polarimetry) and through the intrinsic planet emission (using IR differential imaging and integral field spectroscopy). Both components of the near-infrared arm of SPHERE will provide complementary detection capabilities and characterization potential, in terms of field of view, contrast, and spectral domain. SPHERE has passed its Final Design Review in December 2008 and is now in the assembly, integration and test phase. We will present the science objectives, conceptual design and expected performance of the SPHERE instrument and report on the current status of the project. First light is expected by mid of 2011.

7735-34, Session 5

In the path toward extremely precise radial velocity measurements

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In the last six years, thanks to the very high radial velocity precision of the HARPS spectrograph, it was possible to detect 21 out of the 30 "super-Earth" extrasolar planets (masses below 20 times the mass of the Earth) discovered up to date. The radial velocity precision of the instrument is estimated around 60 cm/sec on a single measurement.

The main instrumental limitations are the wavelength calibration and the stability of the light injection.

We address both factors and present the results of recent tests on the HARPS spectrograph.

The laser frequency comb is the ideal wavelength calibrator, due to the width, density and flux of the lines, and to its intrinsic stability. We will present the results from the recent tests that we performed on HARPS.

The accurate guiding of the telescope is critical to maintain a stable light distribution at the injection stage, where the light is sent into the spectrograph entrance fiber. To pursue this goal we have installed a secondary guiding system which is able to apply the guiding corrections twenty times faster than the primary guiding. We report the results from the first tests of this new system.

These achievements will be discussed in the context of the ongoing HARPS planet search programs and also in the context of future instrumentation for the VLT and the E-ELT.

7735-35, Session 5

The prototype design of most powerful exoplanet tracker based on LAMOST

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A new technique called External Dispersed Interferometer (EDI) is successfully used to enhance the accuracy of radial velocity measurement by astronomical telescopes with medium aperture. Chinese national science project-LAMOST has been commissioned successful in June, 2009. The aperture of LAMOST is 4m, its focal plane is 1.75m in diameter, corresponding to a 5° field of view, may accommodate as many as 4000 optical fiber, and feed 16 multi-object low-medium resolution spectrometers. Now, a multi-object exoplanet survey system with this advanced technique based on LAMOST is being developed by NIAOT and NAOC, and supported by National Natural Sciences Foundation of China (NSFC). This system is composed of a multi-object fixed delay Michelson interferometer (FDMI) and a multi-object medium resolution spectrometer (R=5000). In this paper, some results of the feasibility experience are shown; the prototype design of FDMI is given, including optical system and mechanical structure.

7735-36, Session 5

High-contrast imaging within the diffraction limit: an overview of the Palomar fiber nuller first astronomical results

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We report on high accuracy high resolution (< 20mas) stellar measurements obtained in the near infrared (K band) at the Palomar 200 inch telescope using two elliptical (3m x1.5m) sub-apertures located 3.5m apart. Our interferometric coronagraph, known as the "Palomar Fiber Nuller" (PFN), is located directly downstream of the Palomar AO system and recombines destructively the two separate stellar beams into a common single-mode fiber. We developed a new statistical method to analyze the resulting null sequences and were able to measure astronomical nulls largely below 1%, with 1-sigma uncertainties as low as 0.05%. Such an accuracy translates into a dynamic range greater than 1000:1 within the diffraction limit, demonstrating that the PFN bridges the traditional gap between regular coronagraphs, limited in angular resolution, and long baseline interferometers, whose dynamic range is restricted to ~100:1.

As our measurements are extremely sensitive to the brigthness distribution very close to the optical axis, we were able to constrain the limb darkening properties and amounts of circum-stellar emission around a number of bright stars. For the stars alf Boo, alf Her, and beta Peg, the derived parameters are well aligned with the latest modeling of these stars. For the supergiant alf Ori, and the semi-regular variable rho Per, sources of extra emission are clearly detected and discussed. In the case of Vega, we place a new upper limit to the amount of near infrared excess emission arising from the 0.1 to 0.5 AU central region.

With the improvement expected when the PAL3000 AO system comes on-line, the exact same instrument now equipped with a state of the art low noise fast read-out near IR camera, would yield 10000:1 contrast or better within 30 to 200 mas of stars brighter than mK=5.

7735-37, Session 5

Impact of calibration on extrasolar planets direct imaging with the infrared dual-imaging camera and spectrograph for SPHERE

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The detection and characterization of extrasolar planets by direct imaging is becoming more and more promising with the preparation of dedicated high-contrast instruments and the help of new data analysis techniques. SPHERE (Spectro-Polarimetric High-contrast imager for Exoplanets REsearch) is currently being developed as part of the second generation instruments of the ESO-VLT. IRDIS, one of the SPHERE subsystems, will provide dual-band imaging with several filter pairs covering the near-infrared from 0.95 to 2.3 microns, among with other observing modes such as long slit spectroscopy. This paper describes the impact of instrumental calibration on finding and characterizing extrasolar planets, and on observing strategies. It concludes by discussing constraints to achieve the required contrast, precision and stability.

7735-38, Session 5

CARMENES: Calar Alto high-resolution search for M dwarfs with exo-earths with a near-infrared Echelle spectrograph

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CARMENES, Calar Alto high-Resolution search for M dwarfs with Exo-earths with a Near-infrared Echelle Spectrograph, is a study for a next-generation instrument for the 3.5m Calar Alto Telescope to be designed, built, integrated, and operated by a consortium of nine German and Spanish institutions. Our main objective is finding habitable exoplanets around M dwarfs, which will be achieved by radial velocity measurements on the m/s level in the near-infrared, where low-mass stars emit the bulk of their radiation. CARMENES is expected to become operational in 2013.

CARMENES will cover the wavelength range from 500 to 1800 nm at a spectral resolution of 85,000 with two cross-dispersed echelle spectrographs, coupled to the telescope with optical fibers. The near-infrared spectrograph will be calibrated with the simultaneous ThAr method; our goal is to reach a radial velocity precision better than 3 m/s. The large wavelength range will allow us to monitor activity indicators (H alpha and the Ca triplet) simultaneously with the radial velocity, facilitating the discrimination between radial-velocity signals induced by planetary companions and by stellar activity. Using most of the bright time for a period of five years, CARMENES could search for planets in a sample of 300 M dwarfs.

7735-39, Session 6

The FIRE infrared echelle spectrometer at Magellan: construction and commissioning

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FIRE employs a pair of low-noise HAWAII-2RG SCAs controlled by SIDECAR readout electronics, to achieve the low background required for high resolution infrared spectroscopy. Its optical train begins with a pre-slit Offner Relay diamond-turned from RSA-6061 Aluminum. After the slit, the 50mm F/11 beam is collimated by an OAP, and relayed to a network of four large prisms (2 ZnSe and 2 Infrasil) used for cross dispersion. The materials and geometries of the prisms are carefully optimized to achieve uniform order spacing while providing the dispersion required to cover a full 2048 pixel chip. FIRE's camera is a 3-element refracting design, containing 2 diamond-turned and MRF-polished CaF2 aspheric surfaces. It delivers sub-pixel images across the full footprint of the Echelle format. FIRE is scheduled for installation on the Magellan Baade Telescope in January 2010.

7735-40, Session 6

Recent progress on the KMOS multi-object integral-field spectrograph for ESO VLT

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KMOS is a near-infrared multi-object integral field spectrometer which has been selected as one of a suite of second-generation instruments being constructed for the ESO VLT in Chile. The instrument is being built by a consortium of UK and German institutes working in partnership with ESO and is scheduled for commissioning at Paranal, Chile in 2011. KMOS competed the Final Design Review process in April 2008 and is currently midway through the manufacture, integration and test phase. The main cryostat assembly is now complete and extensive tests of the subsystems (pickoff arms, integral field units and spectrographs) are underway. The first end-to-end optical tests are planned for Jan 2010. This paper will present a summary of the science requirements for KMOS and the tradeoffs required to reach on the final design parameters together with the first performance results. It will be supported by a number of additional papers on specific subsystems and design approaches.

7735-41, Session 6

GNOSIS: a fully funded, photonic OH-suppression near-infrared spectrograph

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GNOSIS is an OH suppression unit to be used in conjunction with existing spectrographs. The OH suppression is achieved using fibre Bragg gratings and photonic lanterns, both developed at the University of Sydney and the Anglo-Australian Observatory. It will deliver the darkest near-infrared background of any ground-based instrument. Laboratory and on-sky tests demonstrate that FBGs can suppress OH lines by >30 dB while maintaining 90% throughput between the lines, resulting in a ~4 mag decrease in the background. In the first implementation (2010-11), GNOSIS will feed IRIS2 on the AAT. It will consist of a seven element lenslet array, covering 1.5” on the sky, and will fully suppress the wavelength region 1050-1750 nm. In 2012, GNOSIS will be upgraded to ~100 lenslet array and be installed on GNIRS at Gemini-N.

7735-42, Session 6

Spectropolarimetry with the SALT RSS

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The large (~10m) aperture of the Southern African Large Telescope (SALT) coupled with the unique capabilities of the Robert Stobie Spectrograph (RSS), promises unparalleled prospects for polarimetric observations on an 8 - 10 m class telescope. RSS is a highly versatile first-generation instrument of the SALT. RSS-VIS, the visible arm spanning 320-900 nm, employs a high UV-transmitting optical design to support UV spectroscopy down to the atmospheric cutoff at 320nm (rare on large telescopes). The RSS-NIR arm, currently under construction, will extend the wavelength coverage into the near-infrared (to 1.7 µm), allowing for simultaneous UV-VIS-NIR observations.

The instrument resides at the f/4.2 prime focus and provides operational modes including long-slit and multi-object spectroscopy as well as Fabry-Perot imaging spectroscopy and narrow band imaging. The RSS can combine linear and circular polarimetry, separately or an “all-Stokes” mode, with any of these modes, allowing a wide range of polarimetric capabilities.

Results from some of the first commissioning observations with the RSS-VIS are presented here. A method for reducing SALT RSS spectropolarimetry data is proposed and verified on observations of unpolarized and polarized standard stars. The method includes robust spectrum extraction, the use of variance and data-quality planes for error propagation and analysis techniques to estimate the Stokes parameters. The results provide estimates of telescope and instrumental polarization as well as a calibration of the instrument’s polarimetric position angle offset. The calibration results and reduction methods described here will be directly applicable to the pipeline data reduction of future RSS polarimetric data.

7735-43, Session 6

ARCHONS: a highly multiplexed superconducting optical to near-IR camera

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We report on the development of ARCHONS, the ARray Camera for High-resolution Optical to Near-IR Spectrophotometry. This photon counting integral field unit (IFU), being built at UCSB and Caltech with detectors fabricated at JPL, will use a unique, highly multiplexed low temperature detector technology known as Microwave Kinetic Inductance Detectors (MKIDs). These detectors, which operate at 100 mK, provide photon counting with energy resolution of R~20 and time resolution of a microsecond, with a quantum efficiency of around 50%. We expect to field the instrument in the fourth quarter of 2010 with an array containing 1000 pixels in a 20x50 pixel form factor to yield a field of view of approximately 6” x 15”. The bandwidth of the camera is limited by the rising sky count rate at longer wavelengths, but we anticipate a bandwidth of 0.35 to 1.0 microns will be achievable. A simple optical path and compact dewar utilizing a cryogen-free adiabatic demagnetization refridgerator (ADR) allows the camera to be deployed quickly at Naysmith or Coudé foci at a variety of telescopes. A highly expandable software defined radio (SDR) readout that can scale up to much larger arrays has been developed.

7735-44, Session 6

NESSI: the New Mexico Tech extrasolar spectroscopic survey instrument

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Less than 20 years after the discovery of the first extrasolar planet, exoplanetology is rapidly growing with more than one discovery every week on average since 2007. An important step in exoplanetology is the chemical characterization of exoplanet atmospheres. It has recently been shown that molecular signatures of transiting exoplanets can be studied. To advance this idea and prepare more ambitious projects such as THESIS, a dedicated spectrometer named New Mexico Tech Extrasolar Spectroscopic Survey Instrument (NESSI) is being built at New Mexico Tech in collaboration with the NASA Jet Propulsion Lab. This paper focuses on the NESSI optical design. This is a purpose-built multi-object spectrograph that operates in the J, H and K-bands with a resolution of R=1000 in each, as well as a lower resolution of R=250 across the entire J/H/K region.

7735-45, Session 6

Commissioning of the infrared imaging survey (IRIS) system

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The Infrared Imaging System (IRIS) is a 0.8m telescope and a 1024 1024 pixels camera with a HAWAII-1 detector array. IRIS will be located at the Cerro Armazones Observatory in Chile that is operated by the Ruhr University Bochum jointly with the Universidad Católica del Norte in Antofagasta. It will be used primarily to survey star-forming regions for variability. The goal is to discover young stellar objects undergoing accretion instabilities or rotational modulation of star spots, eclipsing binaries, and variable reflection nebulae. The telescope and the infrared camera are completed and are now being commissioned. This paper will present the optical and mechanical design of the infrared camera and the telescope, the control system, and the data reduction pipeline. We expect to report the first results from this new telescope.

7735-46, Session 6

Development of the mid-IR Echelle high-dispersion spectrograph employing the germanium immersion grating

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We have developed the IRHS (mid-InfraRed High dispersion Spectrograph), a cryogenic echelle spectrometer designed for the Nasmyth focus stage of NAOJ Subaru 8.2 m telescope, which operates at 8-13 μm in wavelength with the R ~ 50,000 at 10 μm. To reduce the thermal radiation of the instrument, all optics is arranged on the 80 cm-diameter cold optical base plate (~30 K) of the cryostat. In order to achieve the high dispersion, broad bandwidth, and high sensitivity, two key devices are adopted: a single crystal germanium immersion echelle grating (30×30×72 mm) and a Si:As IBC (Impurity Band Conductor) focal plane array (FPA) detector (412×512 pixels, unit pixel size 30 μm) operated at 5 K. The most important key device, germanium immersion echelle grating for collimated beam size of 28 mm was fabricated by utilizing ultra precision micro-grinding method coupled with the ELID (ELectrolytic In-process Dressing) technique. By using IRHS, we observed 2 emission spectra of NH3 (~2 Torr) in laoratory, and found the currently derived resolving power, R = 20,000 ~ 30,000, and about 100 times more sensitive than those derived by using commercial FT-IR with same condition, showing the high performance of IRHS.

7735-47, Session 6

The Apache Point Observatory galactic evolution experiment (APOGEE) high-resolution near-infrared multi-object fiber spectrograph

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The Apache Point Observatory Galactic Evolution Experiment (APOGEE) will use a dedicated 300-fiber narrow-band (1.5-1.7 micron), high resolution (R~30,000) near-infrared spectrograph to survey approx. 100,000 giant stars in the Milky Way. This survey will revolutionize our understanding of kinematic and chemical enrichment histories of all galactic populations conducted as part of the Sloan Digital Sky Survey III (SDSS III). The instrument, currently in fabrication, will be housed in a separate building adjacent to the 2.5 m SDSS telescope and fed light via 50-meter fiber runs from the telescope. The instrument design includes numerous technological challenges and innovations including a gang connector that allows simultaneous connection of all fibers with a single plug to the telescope cartridge which positions the fibers on the sky, numerous places in the fiber train in which focal ratio degradation must be minimized, a large (290 mm x 475 mm elliptically shaped recorded area) mosaic-VPH, an f/1.4 six-element refractive camera featuring Silicon and Fused Silica elements with diameters as large as 393 mm, three JWST NIRCam-style H2RG detectors mounted in a 1 x 3 mosaic with sub-pixel translation capability, all housed within a custom LN2 cooled stainless steel vacuum cryostat with dimensions 1.4 m x 2.3 m x 1.3 m.

7735-48, Session 6

On-sky performance of FLAMINGOS-2: the facility wide-field near-infrared imager and multi-object spectrograph for Gemini

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We report on the performance of FLAMINGOS-2 as measured during on-sky acceptance testing and scientific commissioning in 2009 and 2010. FLAMINGOS-2 covers the 0.9-2.5-micron bandpass and provides a 6.2-arcmin imaging field of view, as well as lonsglit and multi-object spectroscopy over a 6x2-arcmin field at resolutions of R ~1200 and R ~3300. It also works with the F2T2 tunable filter module and with the Gemini MCAO system. We report on measured FLAMINGOS-2 performance parameters, including image quality, throughput, detector noise, and on-sky sensitivity.

7735-49, Session 7

Design and development of MOSFIRE: the multi-object spectrometer for infrared exploration at the Keck Observatory

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MOSFIRE is a unique multi-object spectrometer and imager for the Cassegrain focus of the 10-m Keck 1 telescope. A refractive optical design provides near IR (0.97-2.45 m) multi-object spectroscopy over a 6.14 x 6.14 field of view with a resolving power of R~3,270 for a 0.7 slit width (2.9 pixels in the dispersion direction), or imaging over a field of view of 6.8 diameter with 0.18 per pixel sampling. A single diffraction grating can be set at two fixed angles, and order-sorting filters provide spectra that cover the K, H, J or Y bands by selecting 3rd, 4th, 5th or 6th order respectively. A folding flat following the field lens is equipped with piezo transducers to provide tip/tilt control for flexure compensation at the 0.1 pixel level. A special feature of MOSFIRE is that its multiplex advantage of up to 46 slits is achieved using a cryogenic Configurable Slit Unit or CSU developed in collaboration with the Swiss Centre for Electronics and Micro Technology (CSEM). The CSU is reconfigurable under remote control in less than 5 minutes without any thermal cycling of the instrument. Slits are formed by moving opposable bars from both sides of the focal plane. An individual slit has a length of 7.1 but bar positions can be aligned to make longer slits. When masking bars are removed to their full extent and the grating is changed to a mirror,

MOSFIRE becomes a wide-field imager. Using a single, ASIC-driven, 2K x 2K H2-RG HgCdTe array from Teledyne Imaging Sensors with exceptionally low dark current and low noise, MOSFIRE will be extremely sensitive and ideal for a wide range of science applications. This paper describes the design and testing of the instrument prior to delivery later in 2010.

7735-50, Session 7

OCTOCAM: a fast multi-channel imager and spectrograph for the 10.4m GTC

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OCTOCAM is a multi-channel instrument that will perform simultaneous observations in 8 bands, covering the complete spectrum from the ultraviolet (u-band) to the near infrared (K-band) in a single exposure. It will have an imaging mode with a field of view of 3' x 3' and a long slit spectroscopic mode with full wavelength coverage from 0.33 to 2.5 µm at a resolution of ~ 1000 - 2000 (depending on the slit width). It will be based on the use of electron multiplying CCD (EMCCD) detectors (with fast readout and negligible noise) in the optical, and new technology HAWAII-2RG detectors in the near-infrared (nIR) to achieve time resolutions of down to 0.01 seconds. In this way, OCTOCAM will be occupying a region of the time resolution - spectral resolution - spectral coverage diagram that is not covered by a single instrument in any other observatory, with an exceptional sensitivity.

OCTOCAM is being designed for one of the folded Cassegrain foci of the 10.4m Gran Telescopio Canarias telescope. It will be using readily existing technology, both in optics and detectors, hence implying a low overall risk. The design will be kept simple to make the instrument stable and reliable. Our preliminary estimates indicate that the instrument should have a cost below 4 Meur, with an expected delivery time of 3 years.

7735-51, Session 7

First end-end performance testing and results for KMOS

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KMOS is a modular design consisting of three identical parallel segments which in turn contain eight integral field channels. The assembly and integration plan is to build up the instrument step by step and test performance at each stage. In order for the end to end verification process to be de-bugged and problems with the build found in enough time to be corrected with minimum impact, a single end-end chain was assembled as early as possible.

The first end to end chain was complete at the end of 2009 and testing commenced. This paper describes the philosophy and management of the test programme, the testing procedures used to study the instrument performance as the light path was built and the results obtained. A number of issues were found and resolved during the testing and these are described. An assessment of how well the planning and systems engineering methods have helped to minimise problems is made.

7735-52, Session 7

Early Linc-Nirvana science: a bridge between current AO- and future ELT-imaging

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LINC-NIRVANA (LN), the LBT near-infrared imaging interferometer, is entering the final integration and test phase.

Early scientific measurements are envisioned to start two years from now.

In this contribution, we allude to the LN science by summarizing the early scientific capabilites of the instrument (astronomical bands, filters, observing modes, expected efficiencies, etc.), and by presenting the unique particularities and advantages of Fizeau-type imaging interferometry. LN will deliver images with an angular resolution of a 22~m filled aperture.

Therefore, the typical LN science case, examples of which are presented in this article, will explore an astronomical parameter space inaccessible to the existing adaptive-optics assisted 8-10~m class facilities.

While other LN-contributions to this conference rather concentrate on individual aspects of the hard- and software-developments of LN, here the consortium shows how the complex machinery, acting in concert, defines the eventual observing sequence, efficiences, and possible data calibration schemes, as a basis for preparing scientific observing programs.

The remainder of the contribution deals with the rich, mutual interaction between astronomical requirements, derived from the science cases, and general capabilities of modern telescope sub-systems (sensitivities and field-of-views, optical path and wavefront control, etc.). We will present how LN design strategies aim at mediating between between both sides, as examples for future ELT instrumentation.

7735-53, Session 7

Performance of X-shooter: the new wide-band intermediate resolution spectrograph at the VLT

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X-shooter is the first second-generation instrument newly commissioned at the VLT. It is a high efficiency single target intermediate resolution spectrograph covering the range 300 - 2500 nm in a single shot. We will present performances as measured during commissioning and the first months of science operations.

7735-54, Session 7

Comissioning the VISTA infrared camera

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We will present a summary of the commissioning campaign for the VISTA IR Camera which took place during 2008/2009, starting from the first mounting of the camera on the completed telescope, early imaging results and a description of the path to a fully functioning system. The talk will aim to include details of some interesting insights into the functioning of a fully integrated system where the instrument and telescope function together to produce optimal images at the instrument focal plane.

7735-55, Session 7

FMOS the fibre multiple-object spectrograph, part VIII: current performances and results of the engineering observations

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The Fibre Multi-Object Spectrograph for Subaru Telescope (FMOS) is a near-infrared instrument with a large multiplicity in a 30' field of view at F/2 prime focus. To observe 400 objects at the same time, we have developed a fibre positioner called “Echidna” using tube piezo actuators. We have also developed two OH-airglow suppressed and refrigerated spectrographs. Each spectrograph has two spectral resolution modes; the low-resolution mode covers the complete wavelength range of 0.9 - 1.8 um with one exposure, while the high-resolution mode requires four exposures at different camera positions to cover the full wavelength range.

The conceptual design started in 1998, and all optical/mechanical components were assembled, mounted and calibrated on the Subaru telescope at the end of 2007. Engineering observations with FMOS have been carried out since December 2007.

This paper reports on FMOS’s observation efficiency from the based on the results of these observations. It also describes specifications of the optical image quality on the focal plane, including auto guide and the detector readout, noise and sensitivity, etc.

The common-use observations with FMOS begin in February 2010.

7735-56, Session 7

LUCIFER1 commissioning at the LBT

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LUCIFER is a NIR camera and spectrograph installed at the Large Binocular Telescope. Working in the wavelength range of 0.9-2.5micron, the instrument is designed for direct imaging and spectroscopy with 2 different cameras. A set of longslit masks as well as up to 22 user defined (MOS) masks are available.

The set of user defined masks can be exchanged while the instrument is at operating temperature.

Two identical instruments are build by a consortium of 5 German institutes.

LUCIFER has just passed the commissioning phase and will enter regular science operation as of January 2010. The second instrument is presently being integrated in the lab in Europe.

The main results gained during the commissioning runs will be presented and the instrument performance compared to the specifications.

7735-68, Session 7

Preliminary design of IGRINS (immersion grating infrared spectrometer)

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The Korea Astronomy and Space Science Institute (KASI) and Department of Astronomy at the University of Texas at Austin are developing near infrared wide-band high resolution spectrograph, IGRINS. IGRINS can observe all of the H- and K-band spectra with resolving power of 40,000 in a single exposure. The spectrograph uses a white pupil cross-dispersed layout and includes a dichroic to divide the light between separate H and K cameras, each provided with a 2kx2k HgCdTe detector. A silicon immersion grating serves as the primary disperser and a pair of volume phased holographic gratings serve as cross dispersers, allowing the high resolution echelle spectrograph to be very compact. IGRINS is designed to be compatible with telescopes ranging in diameter from 2.7m (the Harlan J. Smith telescope) to 8 or 10m. Commissioning and initial operation will be on the 2.7m telescope at McDonald Observatory from 2013.

7735-198, Poster Session

Science requirements and performances for EAGLE for the E-ELT

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EAGLE is a Phase A instrument study for a multi-IFU, near-infrared spectrometer for the European Extremely Large Telescope (E-ELT). EAGLE will deliver AO-corrected spectroscopy across a large (38.5 sq. arcmin) field. When combined with its multiplex capability and the unprecedented light-gathering power of the E-ELT, EAGLE will enable efficient and unique observations of targets that range from stellar populations at Mpc distances, out to observations of `first light' galaxies at the largest redshifts. We give an overview of the science case, summarise the instrument requirements that flow-down from it, and provide illustrative performances from simulated observations.

7735-199, Poster Session

EAGLE ISS: a modular twin-channel integral-field near-IR spectrograph

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The ISS (Integral-field Spectrograph System) has been designed as part of the EAGLE instrument Phase A Study for the E-ELT. EAGLE incorporates ten ISSs to obtain spectra from twenty individual scientific targets. An ISS consists of two independent input channels of 1.65x1.65 arcsec field-of-view, reconfigured spatially by an image-slicing integral-field unit to feed a near-IR spectrograph using cryogenic volume-phase-holographic gratings to disperse the image spectrally. A single 4k x 4k array detects the dispersed image.

The optical design incorporates anamorphic magnification, cryogenic Volume-Phase Holographic gratings scanned in a novel manner and a three-lens camera corrected mechanically for the effects of achromatism. The mechanical implementation features IFU optics in Zerodur, a modular bench structure and a number of high-precision cryo-mechanisms. The packaging of the instrument has to meet strict limits on mass and volume.

7735-200, Poster Session

METIS (cryogenic) optomechanical design and packaging study

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METIS (Mid-infrared E-ELT Imager and Spectrometer) is a mid-infrared instrument proposed for the European Extremely Large Telescope (E-ELT). It is designed to provide imaging and spectroscopic capabilities in the 3μm to 14μm region up to a spectral resolution of 100.000.

The recently finished Phase-A study carried out within the framework of the ESO sponsored E-ELT instrumentation studies has been performed by an international consortium with institutes from Germany, Netherlands, France, United Kingdom and Belgium. The overall instrument concept and the elaborate science case are presented elsewhere in this conference.

This paper describes the design constraints and key issues regarding the packaging of the five main modules of METIS: Fore-Optics, L/M and N band Imager, L/M band Spectrometer, the Wave Front Sensor and Calibration Units. This will focus on the design solutions in order to create a light, small and fully accessible instrument that can be built concurrently at various different institutes around Europe.

In addition the paper covers the design and development studies for the special, challenging units such as the large optical cryogenic image de-rotator, the cryogenic (2D) chopper mechanism and the special cryogenic drives.

7735-201, Poster Session

Mid-infrared astronomy with the E-ELT: performance of METIS

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We present results of performance modelling for METIS, the Mid-infrared European Extremely Large Telescope Imager and Spectrograph. Designed by a consortium of NOVA (NL), UK Astronomy Technology Centre (UK), MPIA Heidelberg (Germany), CEA Saclay (France) and KU Leuven (Belgium), METIS will cover the atmospheric windows in L, M and N-band and offers imaging, medium-resolution slit spectroscopy (R~1000-3000) and high-resolution integral field spectroscopy (R~100,000). Our model uses a detailed set of input parameters for site characteristics and atmospheric profiles, optical design, thermal background and the most up-to-date IR detector specifications. We show that METIS will bring an orders-of-magnitude level improvement in sensitivity and resolution over current ground-based IR facilities, bringing mid-IR sensitivities from the ground to the micro-Jansky regime. As the only proposed E-ELT instrument for this spectral region, and the only mid-IR high-resolution integral field unit planned on the ground or in space, METIS will open up a huge discovery space in IR astronomy in the next decade.

7735-202, Poster Session

MICADO: optical configuration, performance, and folding

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MICADO is the first-light IR imaging camera for the E-ELT. It has been designed to work in conjunction with both SCAO and LGS-MCAO (MAORY) modules and delivers diffraction limited quality over about 1 arcmin field of view covering the wavelength range from 0.8 to 2.5 micron. In this paper, we will describe the optical configurations with observing modes, for both the main and the auxiliary arms, of the current baseline with the expected performances and how the optical path can be folded to fit the available limited space in the cryo-chamber.

7735-203, Poster Session

Expected performance and simulated observations of the instrument HARMONI at the European Extremely Large Telescope (E-ELT)

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HARMONI has been conceived as a workhorse visible and near-infrared

(0.6-2.5 microns) integral field spectrograph for the European Extremely Large Telescope (E-ELT). It provides both seeing and diffraction limited observations at several spectral resolutions (R= 4000, 10000, 20000). HARMONI can operate with almost any flavor of AO

(e.g. GLAO, LTAO, SCAO), and it is equipped with four spaxel scales (4, 10, 20 and 40 mas) thanks to which it can be optimally configured for a wide variety of science programs, from ultra-sensitive observations of point sources to high-angular resolution spatially resolved studies of extended objects.

In this paper we compare the expected performance of HARMONI with respect to other ground and space based instruments, commenting on their synergies and complementarities. We further illustrate the scientific potential of HARMONI with simulated observations of selected astronomical objects.

7735-204, Poster Session

The cryo-mechanical system of SIMPLE E-ELT

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We present and discuss the design of the cryo-mechanical system of SIMPLE, the high resolution near-infrared spectrometer for the E-ELT covering the wavelengths range 0.84-2.5 micron.

The main features of the design are the low-stress mechanical interface with the optical bench, the long-term stability and reliability for automatic, unattended operations.

7735-205, Poster Session

CODEX optics

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CODEX is a high resolution spectrograph for the ESO E-ELT. A classical spectrograph can only achieve a resolution over 100.000 on a 42 m telescope with extremely large echelle gratings and cameras. This paper describes in detail the new optical concept of CODEX, which uses only optical elements of similar size of current high resolution spectrographs. This design is based on slicers, anamorphic beams and slanted VPH as cross dispersers. In this new version of the CODEX design, no special expensive materials as Calcium fluoride or abnormal dispersion glasses are needed. The optical quality is excellent and compatible with 10K x 10K detectors with 9 µm pixels.

7735-206, Poster Session

Web-based scientific simulation tools for E-ELT instruments

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In the frame of the EAGLE phase A study, we have developed a scientific simulator which has been used to constrain the instrument high level specifications. This simulator was coupled to a web interface to allow an easier access by the EAGLE science team, and run specific simulations covering the EAGLE scientific objectives. We will give a functional description of this simulator, and illustrate how it was used in practice to derive a specification on the Ensquared Energy of EAGLE. The success of the EAGLE simulator was used as a basis to develop other telescope/instrument simulator, including a general image/datacube simulator which is now freely accessible on the web.

7735-207, Poster Session

OPTIMOS-EVE design tradeoff analysis

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OPTIMOS-EVE (OPTical Infrared Multi Object Spectrograph - Extreme Visual Explorer) is the fiber fed multi object spectrograph proposed for the European Extremely Large Telescope (E-ELT). It is designed to provide a spectral resolution ranging from 5000 to 30.000, at wavelengths from 0.37 µm to 1.70 µm, combined with a high multiplex (>200) and a large spectral coverage. The system consists of three main modules: a fiber positioning system, fibers and a spectrograph.

The recently finished OPTIMOS-EVE Phase-A study, carried out within the framework of the ESO E-ELT instrumentation studies, has been performed by an international consortium consisting of institutes from France, Netherlands, United Kingdom and Italy.

This paper describes the design tradeoff study and the key issues determining the price and performances of the instrument. Additionally the design tradeoff is elaborated for various sub-structures (such as the fiber positioning system, the Atmospheric Dispersion Corrector and the Spectrograph, including grating type, camera performance and detector parameters).

7735-208, Poster Session

The infrared imaging spectrograph (IRIS) for TMT: the science case

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The InfraRed Imaging Spectrograph (IRIS) is a first-light instrument being designed for the Thirty Meter Telescope (TMT). IRIS is a combination of an imager that will cover a 17” field of view at the diffraction limit of TMT (4 mas sampling), and an integral field unit spectrograph that will sample objects at 4-50 mas scales. IRIS will open up new areas of observational parameter space, allowing major progress in diverse fields of astronomy. We present the science case and resulting requirements for the performance of IRIS. Ultimately, the spectrograph will enable very well-resolved and sensitive kinematics and internal chemical abundances of high-redshift galaxies, shedding light on many scenarios for the evolution of galaxies at early times. With unprecedented imaging and spectroscopy of exoplanets, IRIS will allow detailed exploration of a range of planetary systems that are inaccessible with current technology. By revealing details about resolved stellar populations in nearby galaxies, it will directly probe the formation of our on Milky Way.

Because it will be possible to directly characterize the stellar initial mass function in many environments and in galaxies outside of the the Milky Way, IRIS will enable a greater understanding of whether stars form differently in different conditions. IRIS will reveal detailed kinematics in the centers of low-mass galaxies, allowing a test of black hole formation scenarios. Finally, it will revolutionize the characterization of reionization and the first galaxies to form in the universe.

7735-209, Poster Session

The science calibration system for the TMT NFIRAOS and client instruments: requirements and design studies

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We present basic requirements and current results of design studies of the science calibration system for the NFIRAOS adaptive optics system and its client infrared instruments of the Thirty Meter Telescope. The two major requirements of the science calibration system are to provide pupil-simulated telescope beams to the adaptive optics system for telescope pupil calibration and to provide flat-fielding and wavelength-calibration illumination to client infrared instruments. We describe the details of these requirements and relevant analyses, together with our current opto-mechanical designs of the science calibration system.

7735-210, Poster Session

The science drivers for a mid-infrared instrument for the TMT

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A mid-infrared (MIR) imager and spectrometer is under consideration for construction in the first decade of the Thirty Meter Telescope (TMT) operation. Combined with adaptive optics for the MIR, it realizes 15 times higher sensitivity (0.1mJy) and 4 times better spatial resolution (0.08") at 10 microns compared to 8m-class telescopes. In addition, its large light-gathering power allows high-dispersion spectroscopy in the MIR that will be unmatched by any other facility.

We, a collaborating team of Japanese and US MIR astronomers, studied science drivers for the TMT MIR instrument. Furthering the science cases for the MIRES (Elias et al. 2006), where high-dispersion spectroscopy is emphasized, we discuss additional requirements for the instrument. The science cases include broader areas of astronomical fields: star and planet formation, solar system bodies, evolved stars, interstellar medium (ISM), extragalaxies, and cosmology. For example, the low- and high-dispersion spectroscopic capabilities enable detailed investigations of dust and gas in planet forming/formed circumstellar disks. They are also powerful to reveal the material cycle in universe: molecule and dust formation around evolved stars and evolution in the ISM. In the field of cosmology, high-sensitivity imaging with the sub-arcsecond resolution enables detecting flux anomalies of lensed galaxies, which gives us information on the substructure of dark matter distribution.

Based on these science drivers, essential and optional instrument capabilities are discussed (see the companion paper by Alan Tokunaga): imaging, low- and high-spectral resolution modes, integral field spectroscopy, and polarimetry.

7735-211, Poster Session

An infrared multi-object spectrograph (IRMS) with adaptive optics for TMT: the science case

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IRMS, a Near-Infrared Multi-object Spectrograph, was selected by the TMT Scientific Advisory Committee as one of the first light instruments for the Thirty Meter Telescope.

IRMS will be a clone of the MOSFIRE instrument on the Keck telescope, with the significant difference that it will be fed by an adaptive optics system. As a result, we use the already available MOSFIRE design and expertise, significantly reducing the total cost and development time. IRMS will be a quasi diffraction limited imager and multi-slit spectrograph with moderate resolution (R~4000) that takes advantage of the full 2 arcmin field delivered by Narrow-Field Infrared Adaptive Optics System (NFIRAOS).

There are a number of exceedingly important scientific questions, waiting to be addressed by the TMT/IRMS combination. Given the much sharper images, it is less affected by the sky background, which is a limiting factor in ground-based observations at near-IR wavelengths. IRMS will be the ideal instrument for studying spectroscopic properties of galaxies at the re-ionization epoch ($z > 7$), where the Lyman alpha line shifts to the near-IR wavelengths. It can be used to measure rotation curves of spiral galaxies and velocity dispersions of elliptical galaxies at z~2-3 and hence, their dynamical mass. It can be used to search for population III stars and to perform measurement of spectroscopic lines at high redshifts, diagnostic of metallicity. Finally, IRMS allows measurement of the gradient of spectroscopic lines across single galaxies, fainter than L* and at high redshifts.

7735-212, Poster Session

The infrared imaging spectrograph (IRIS) for TMT: the atmospheric dispersion corrector

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We present a conceptual design for the atmospheric dispersion corrector (ADC) for TMT's Infrared Imaging Spectrograph (IRIS). The severe requirements of this ADC are reviewed, as are limitations to observing caused by uncorrectable atmospheric effects. The requirement of residual dispersion less than 1 milliarcsecond can be met with certain glass combinations. The design decisions are discussed and the performance of the design ADC is described. Alternative options and their performance tradeoffs are also presented.

7735-213, Poster Session

Science flow down for the Thirty Meter Telescope

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How do we know that the current technical requirements and architecture for the TMT observatory will indeed allow TMT to tackle the broad range science within the reach of a large optical/IR telescope and fully realize its scientific potential? The path from science to observatory design is frequently not linear, and often involves multiple iterations. Ideally, the final design will meet as many science requirements as possible within the constraints imposed by technological readiness, schedule and cost. A properly established science flowdown plays an invaluable role in estimating the impact of various design decisions (including instrument selection) on science returns. In this paper, we describe the flowdown of scientific and observatory requirements from the TMT science cases in terms of the following key elements: the science programs themselves, the science flowdown matrix, the Science-based Requirements Documents (SRD), the Observatory Requirements, the Observatory Architecture and the Operations Concepts Documents (ORD, OAD and OCD).

7735-214, Poster Session

The infrared imaging spectrograph (IRIS) for TMT: imager design

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We describe an optical design of an imaging mode of the IRIS instrument for the Thirty Meter Telescope. IRIS is a fully-cryogenic diffraction-limited infrared camera and integral-field spectrograph working in the wavelength coverage from 0.85 to 2.5 microns. The instrument is placed after the adaptive optics system (NFIRAOS) at the Nasmyth platform. The imaging mode covers 17 arcsec x 17 arcsec FOV with a 4096 x 4096 detector array with sampling 4 milliarcsec/pix. One of the challenges which science cases require in the imaging mode is that rms wavefront error should be less than 30 nanometers. Among possible optical configurations which we have tried with lenses and mirrors, a refracting solution with apochromatic triplets best meets the requirements. The optical system has four lenses each in a collimator and a camera section. The focal length is 750 mm and 1290 mm, respectively with pupil diameter of 50 mm. Both sections have BaF2-Fused Silica-ZnSe apochromatic triplets plus a single lens near the focus. The rms wavefront error of the system including the telescope, the adaptive optics, and the instrument is less than 25 nanometers with ideal optical parameters. A Monte Carlo simulation shows that reasonable amount of errors in fabrication and alignment will give the rms wavefront error of less than 30 nanometers in 90% of all cases.

7735-215, Poster Session

Conceptual design phase stray light analysis of the MOBIE imaging spectrograph for TMT

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The Multi-Object Broadband Imaging Echellette (MOBIE) is the seeing-limited, optical spectrograph planned for the first generation of TMT instruments. An end-to-end stray light analysis of full optical path (telescope to detector array) has been undertaken as a first step towards validating the design concept with regard to stray light requirements. The geometric, stray-light model includes the TMT Calotte-style dome structure, telescope optics, telescope support structures, and the MOBIE instrument itself. The stray light calculations, including assumptions, methodology, and conclusions, are described. Particular emphasis is placed on the stray light contributions from the telescope, atmospheric dispersion corrector, and spectrograph optics. Recommendations for stray light controls internal to the MOBIE instrument are discussed.

7735-216, Poster Session

Instrumentation at Paranal Observatory

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This presentation provides miscellaneous information on instrumentation activities at Paranal Observatory. It introduces the set of 20 instruments which are under the responsibility of the Paranal Instrumentation group, information on the type of instruments, their usage and downtime statistics. The data is based on the comprehensive data recorded in the Paranal Night Log System and the Paranal Problem Reporting System whose principles are explained as well. The work organization of the 15 team members around the high number of instruments is laid out, which includes: (i) maintaining ancient instruments with partially obsolete components, (ii) receiving new instruments and supporting their integration and commissioning (iii) contributing to future instruments in their developing phase.

The assignments of the Instrumentation staff to the actual instruments as well as auxiliary equipment (Laser Guide Star Facility, Mask Manufacturing Unit, Cloud Observation Tool) are explained with respect to responsibility and scheduling issues. The essential activities around hardware & software are presented, as well as the technical and organizational developments within the groups towards its challenges of the present and the future.

7735-217, Poster Session

Nasmyth focus instrumentation of the New Solar Telescope at Big Bear Solar Observatory

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The largest solar telescope, the 1.6 meter New Solar Telescope (NST) has been installed and is being operated in its commissioning at Big Bear Solar Observatory (BBSO). It has an off-axis Gregorian configuration with a focal ratio of F/50. Early in 2009, first light scientific observations were successfully made at the Nasmyth prime focus, which is located on the east side of the telescope structure. As the only available scientific instruments for present routine observation, Nasmyth focus instrumentation (NFI) consists of several filtergraphs to offer high spatial resolution photometry in G-band 430 nm, Ha 656 nm, TiO 705 nm and near infrared 1083 nm, 1.6 micron, 2.2 micron as well. With the assistance of a local correlation tracker system, diffraction limited images were obtained frequently in a field-of-view of 70" by 70" after being performed speckle reconstruction algorithm. These data sets not only serve as scientific analysis with an unprecedented spatial resolution, but also provide engineering feedback to the NST operation, maintenance and optimization. In this paper, the design and the implementation of NFI will be described in detail. First observational results will be shown and discussed.

7735-218, Poster Session

Instrumentation at the Magellan Telescopes

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The Magellan Telescopes at Las Campanas Observatory operate a diverse and expanding suite of instrumentation. IMACS, MagIC, PANIC, MIKE (and a wide field fiber interface, MIKE-Fibers), LDSS3, and MagE are simultaneously deployed at the four Nasmyth and two auxiliary folded ports of the Baade and Clay telescopes for routine observations using the facility f/11 secondary mirrors. Commissioning of a new f/5 secondary and a pair of new Cassegrain facility instruments, Megacam and MMIRS, was initiated at the Clay telescope in 2009. In addition, two new f/11 facility instruments, FIRE and FourStar, are being completed for the Baade telescope with commissioning efforts tentatively scheduled for the first half of 2010. Finally, late 2009 also saw the addition of a new f/11 PI instrument, the Planet Finding Spectrograph (PFS) to the Clay telescope. We present up to date status of the capabilites and performance for the full Magellan instrumentation complement with a focus on the new instruments and upgrades to the existing instruments.

7735-219, Poster Session

SOFIA image motion compensation

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We describe a laboratory simulation of an image motion compensation system for SOFIA that uses high-speed image acquisition from the science instrument HIPO as the sensing element of the system and the SOFIA telescope's secondary mirror assembly (SMA) as the correcting actuator. For this work the SMA is simulated by means of a Newport voice-coil actuated fast steering mirror. The performance of the Newport mirror is comparable to the SMA and is tuned to improve the simulation's fidelity. The system is described and the observed performance is presented together with expectations for applicability in flight with SOFIA.

7735-220, Poster Session

Infrared imaging magnetograph of the New Solar Telescope at Big Bear Solar Observatory

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Infrared Imaging Magnetogram (IRIM) is one of the first imaging solar spectro-polarimeters working in the IR, which will be installed at the Gregorian focus of the 1.6-meter New Solar Telescope (NST) in 2010 spring at Big Bear Solar Observatory (BBSO). This innovative system, which includes a 2.5-nm interference filter, a unique 0.25-nm birefringent Lyot filter, and a Fabry-Pérot etalon, is capable of providing a bandpass as low as 0.01-nm over a field-of-view of 50" in a telecentric configuration. An IR achromatic waveplate rotates ahead of M3 of the NST as polarimeter modulator to reduce polarization cross-talk induced by subsequent oblique reflective mirrors. Dual-beam differential polarimetry is employed to minimize seeing-caused spurious polarization. Based on the unique advantages in IR window, the most capable NST with AO, IRIM will provide unprecedented solar spectro-polarimetry with high Zeeman sensitivity, high spatial resolution (0.2"), and high cadence (1-min). In this paper, we present the design, fabrication, and calibration of IRIM, as well as the results of the first scientific observations.

7735-221, Poster Session

Data reduction strategies for lucky imaging

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Lucky Imaging is a proven technique for near diffraction limited imaging in the visible; however, data reduction and analysis techniques are relatively unexplored in the literature. We review the processes that create the rapidly varying, multiply stochastic PSF in short exposures, and use both simulated and real data to test and calibrate improved guide star registration methods including using multiple guide stars. Last, we present some results on the spatial variability of the PSF in reduced images over wide fields of view, and describe a PSF fitting package developed specifically for extracting science data from such images.

7735-222, Poster Session

A broadband imager for the European Solar Telescope

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The European Solar Telescope (EST) is a joint project of several European research institutes to design and realize a 4-m class solar telescope.

The EST broad band imager is an imaging instrument whose function is to obtain diffraction limited images over the full field of view of EST at multiple wavelengths and high frame rate. Its scientific objective is the study of fundamental astrophysical processes at their intrinsic scales in the Sun's atmosphere.

The current layout foresee two observation modes: a maximum field of view mode and a high resolution mode. The imager will have a 2'x2' corrected field of view in the first mode and an angular resolution better than 0.04" at 500nm in the latter mode. The imager will cover a wavelength range spanning from 390nm to 900nm through a number of filters with bandpasses between 0.05nm and 0.5nm. To optimize optical performances and throughput there will be two arms working simultaneously: a blue arm (covering the 380nm — 500nm range) and a red arm (600nm — 900nm). The blue arm will have two channels while the red arm only one. Each channel will be divided in three subchannels: one will host narrow band filters for chromospheric observations, another one, in focus wide band filters used as reference for speckle reconstruction and photospheric observations, and the last one, out of focus wide band filters for phase diversity reconstruction of photospheric observations.

Different optical designs (dioptric and catadioptric) satisfying these requirements are currently being evaluated.

7735-223, Poster Session

MiniTAO/MAX38 first light: 30-micron band observations from the ground-based telescope

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We have developed a new infrared camera MAX38 (Mid-infrared Astronomical eXplorer) for imaging and spectroscopy in the wavelength of 8 to 38 micron. It is mounted on the University of Tokyo Atacama 1.0-

m telescope (miniTAO telescope), which is the world's highest infrared telescope at 5,640m altitude. Thanks to the high altitude and dry weather condition of the Atacama site, we can access the 30-micron wavelength region from a ground-based telescope for the first time.

For the 30-micron region observations, many characteristic devices are employed in MAX38. First, a Si:Sb 128x128 array detector is installed which can detect long mid-infrared light up to 38-micron. Second, we developed metal mesh filters for 30-micron region band-pass filter, which are composed of several gold thin-films with cross-shaped holes. Third, a cold chopper, a 6-cm square plane mirror controlled by a piezoelectric actuator, is built into the MAX38 optics to cancel out the atmospheric turbulence noise. It enables chopping with a 50-arcsecound throw at a frequency higher than 5-Hz. Finally, a low-dispersion grism (R=50) will provide information on the transmission spectrum of the terrestrial atmosphere in 20 to 40 micron.

In November 2009, we mounted MAX38 on the miniTAO telescope and achieved the first-light observation. In this observation, we successfully obtained the 38-micron images for the first time from ground-based telescopes. These results clearly demonstrates that the atmospheric windows around 30-micron can be used for astronomical observations at the miniTAO site. We present an overview of MAX38 and the first-light observation results.

7735-224, Poster Session

Fast photometry mode possibilities for the Canarias infrared camera experiment (CIRCE)

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In this paper we analyze different solutions to implement a fast photometry mode in the Canarias InfraRed Camera Experiment (CIRCE), a visitor-class near-IR imager, spectrograph, and polarimeter for the 10.4 meter Gran Telescopio Canarias (GTC). The fast photometry mode will be one of the enhanced capabilities of CIRCE that will differentiate our instrument from similar instruments. The fast photometry capability, along with the polarimetric and spectroscopic capabilities of the instrument will provide a unique instrument for the study of rapidly-varying objects. We combine the different output modes of the HAWAII-2 2048x2048 detector, with very simple modifications in our already built Array Controller Subsystem (MCE-3), and with modifications in the firmware of the readout control electronics to provide the instrument with this powerful capability. We expect to increase the frame capture rate on the order of 5 to 14 times faster depending on the frame size and the final solutions chosen.

7735-225, Poster Session

A new two-degree FOV prime focus corrector and ADC concept for the 4.2m WHT

T. Agocs, M. Balcells, C. R. Benn, D. C. Abrams, D. Cano Infantes, Isaac Newton Group of Telescopes (Spain)

We present a conceptual design for a new refractive corrector for the prime focus of the 4.2m William Herschel Telescope, optimised to allow multi-object spectroscopy over a two degree field of view. The proposed design satisfies the demanding requirement that the PSF be smaller than 0.5 arcsec (80% encircled energy) over a two degree FOV and a wavelength range of 380nm - 1000nm. Using materials which transmit well in the UV this wavelength range could be extended down to 340nm, with only minor degradation in polychromatic image quality.

Correcting such a large field of view for a 4.2m telescope requires the use of large optics (up to 1 metre in diameter), therefore it is essential to take into account the manufacturing limitations at an early stage in the design process. We discuss the specifications and describe the design process for the corrector, which also acts as an atmospheric dispersion corrector (ADC). The design that we present contains only one aspherical surface and, in addition to satisfying the science requirements, forms the basis of a realistic manufacturable system.

7735-226, Poster Session

Spectrophotometric calibration system for DECam

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We present a spectrophotometric calibration system that will be implemented as part of the DES DECam project at the Blanco 4 meter at CTIO. Our calibration system uses a 2nm wide tunable source to measure the instrumental response function of the telescope from 300nm up to 2500nm. The system consists of a monochromator based tunable light source that is projected uniformly on a Lambertian screen using a broadband "line to spot" fiber bundle and an engineered diffuser. Several calibrated photodiodes strategically positioned along the beam path will allow us to measure the throughput as a function of wavelength. Our system has an output power of 0.25 mW, equivalent to a flux of approximately 100 photons/s/pixel on DECam. We will also present results from the deployment of a prototype of this system at the Swope 1m at Las Campanas Observatory for the calibration of the photometric equipment used in the Carnegie Supernova Project.

7735-227, Poster Session

Improved REM telescope interface with a new simultaneous multiband visible camera

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A new mechanical interface between the telescope Nasmyth derotator and the focal plane instrumentation has been developed and built for the robotic REM telescope in La Silla. A light-weighted flange will substitute the existing one in order to improve performances in term of mechanical flexures. A new ghost-free, high performances, dichroic has been designed and installed inside the new mechanical flange, improving the efficiency of the wavelength splitting between the visible and the near-infrared channels. The visible camera has been completely redesigned in order to get simultaneous multi-band coverage within the existing 10'x10' field of view. Four bands will be observed onto the same 2kx2k, 13.5 micron pixel, detector. Band splitting is obtained with plate dichroics, working at 45 deg of incidence angle. It will allow to fast observe gamma-ray burst afterglow from the 400 nm up to 2.5 micron, to better characterize spectral features of these fastly evolving sources.

7735-228, Poster Session

Self-coherent camera: first results of a high-contrast imaging bench in visible light

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Direct detections of Earths require high contrast and high angular resolution. In the framework of the future European Extremely Large Telescope (E-ELT), new instrumental concepts are necessary to improve the sensitivity of the telescope down to rocky planets.

Extreme adaptive optics (AO) and coronagraphy are mandatory to detect such faint objects. However, AO residual and quasi-static aberrations limit the instrument performance producing speckle noise in the focal

plane. We propose a self-coherent camera (SCC) to overcome this problem using the sole science image. The principle is based on the lack of coherence between stellar and companion lights. We create a reference beam to spatially modulate the coronagraphic speckle pattern with Fizeau fringes. In a first step, we are then able to extract wavefront aberrations from the science image and correct for them using a deformable mirror. In a second step, we apply a post-processing algorithm to discriminate the companion image from the speckle field.

To validate the instrumental concept, we are developing a high contrast imaging bench in visible light at Paris Observatory. We first associated a SCC to a four quadrant phase mask coronagraph and a deformable mirror with a high number of actuators (32x32 Boston Michromachines MEMS). We will present this bench and show first experimental results of focal plane wavefront sensing and high contrast imaging. These performances will be compared to our numerical simulations.

7735-229, Poster Session

A high-efficiency fibre double-scrambler prototype

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Results for a high efficiency fibre double scrambler are reported. The scrambler is based on the concept first presented by Casse and Vieira (1997) but with substantial improvement in performance. The design uses a simple finite conjugate relay with large magnification followed by a combined scrambler/focal reducer singlet. This approach allows flexibility in the coupling of fibres with various focal ratios and diameters, and can be used to minimize loss of throughput due to focal ratio degradation. A prototype has been constructed using simple off-the-shelf optics which is shown to be capable of coupling a 300 micron fibre to a 320 micron fibre with an efficiency of 85%. The combined FRD is zero when operated at f/3.65. A fully optimized version is intended to be deployed as part of the Hobby Eberly Telescope HRS upgrade (MacQueen and Barnes, these proceedings).

7735-230, Poster Session

MANIFEST: a many instrument fiber positioning system for GMT

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MANIFEST is a proposed fibre positioning concept for the Giant Magellan Telescope. It is designed to work over 320nm-1810nm, feeding the GMACS, NIRMOS and either QSPEC or G-Clef spectrographs, simultaneously if wanted. The challenges are the large (1.2m diameter), strongly curved (3.25m RoC) and gravity-varying focal plane, and the very large numbers of apertures (2000+) that can be accommodated by the various spectrographs. Two technological solutions have been identified: a commercial H-frame robot, modified only as needed to allow pick-and-place operation, and a radical new 'hanging starbugs' design, described in a separate paper by Goodwin et al. Hexabundles and fibre tapers will be used extensively, creating a very efficient, 'throughput neutral' design. Commercial telecommunication fibre technologies will be used extensively, allowing a highly flexible and modular system.

MANIFEST allows all the spectrographs to make full use of the GMT's 20' field of view. It also allows for convenient image-slicing, both to provide a multiplexed deployable IFU capability, and to increase spectral resolution without any penalty in spectral coverage. These attributes make MANIFEST ideal for carrying out a large Lyman-alpha tomography survey, to determine the structure of the IGM at redshifts 2-3. It is also intended that OH-suppression be included into the fibre feed for NIRMOS, increasing the J and H band sensitivities by 1-2 orders of magnitude.

7735-231, Poster Session

APOGEE cryostat design

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The Apache Point Observatory Galactic Evolution Experiment (APOGEE) is a survey of all galactic stellar populations that will employ an R=30,000 spectrograph in the near-infrared (1.5-1.7μm) wavelength range. The fiber-fed spectrograph is housed in a large (1.4m x 2.3m x 1.3m) stainless steel cryostat that is LN2 cooled and located in a building near the 2.5m Sloan Digital Sky Survey (SDSS) telescope. The choice of shell material and configuration was an optimization among optics packaging, weight, strength, external dimensions, rigging and transportation, the available integration and testing room, and the ultimate instrument room at APO. Internals are fabricated of more traditional 6061-T6 aluminum which is well proven in cryogenic applications. An active thermal shield with MLI blanketing yields an extremely low thermal load of 45-50 watts for this ~3000 liter Dewar. Cryostat design details are discussed with applicable constraints and trade decisions.

7735-232, Poster Session

APOGEE fiber-feed prototype testing

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Development of the Apache Point Observatory Galactic Evolution Experiment (APOGEE) near-infrared spectrograph has motivated thorough investigation into the properties and performance of optical fibers. The fiber selected for APOGEE is a PolyMicro step index, multi-mode fiber, with a 120μm low OH, fused silica core, 25μm cladding, and 10μm buffer. The instrument design includes a 50 meter fiber run, connecting the spectrograph to the 2.5m Sloan Digital Sky Survey (SDSS) telescope, and an additional fiber segment located within the instrument Dewar, a vacuum-sealed, cryogenic environment. This light path is convoluted and includes many transitions and connections where the beam is susceptible to losses, especially from focal ratio degradation (FRD). The focus of this research has been to identify potential sources of loss and where applicable, select material components to minimize this effect. There is little previous documented work concerning the performance of optical fibers within this wavelength band (1.5-1.7μm). Consequently, the following includes comprehensive explanations of the APOGEE fiber system components, our experimental design and optical test bed set-up, beam alignment procedures, fiber terminating and polishing techniques, and results from our examination of FRD as correlated with source wavelength, fiber length and termination, and environmental conditions.

7735-233, Poster Session

Nulling interferometry for lateral shearing by use of double Fresnel rhombs

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Nulling interferometer for directly imaging exoplanets with a segmented-mirror telescope is investigated. Lateral shearing interferometry is useful for a segmented-mirror telescope such as the Thirty Meter Telescope

(TMT). We propose to use double Fresnel rhombs for achieving achromatic nulling and lateral shearing simultaneously. Double Fresnel rhombs are inserted into both arms in Mach-Zehnder interferometer. ZnSe is chosen for the material of Fresnel rhomb in near IR region. The computer simulations show high performance of our proposed method in broad wavelength region, J-K.

7735-234, Poster Session

Multiband filters for near-infrared astronomical applications

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We are developing multiband filters for practical application in astronomical observations, primarily in the near-infrared. A multiband filter is one whose bandpass consists of multiple transmissive segments, separated by gaps where the transmission drops to near zero. We foresee several applications.

First, in the near infrared, OH emission lines from the atmosphere hinder sensitive observations from the ground. Because these lines are unevenly distributed in wavelength, a filter that selectively transmits in low-OH regions can be up to five times more efficient for observations of faint continuum sources than a conventional 1.25 micron J band filter.

Second, multiband filters can be used to increase the choice of bandpasses, by placing multiple bandpasses on each physical filter, and then selecting the desired bandpass with a blocking filter in series. This can dramatically increase the number of bandpasses available for a fixed number of filter slots, and is valuable when physical filter changes are difficult- as when the filters are at cryogenic temperature, or in space.

Third, matched multiband filters could be used in imaging searches for objects with highly structured and characteristic spectra, such as spectral type T brown dwarfs. These objects would stand out prominently from general continuum emission sources in a filter whose transmission bands are matched to the peaks in the dwarf's spectrum.

While such filters have been discussed before in the literature, the technology to build them has matured only recently. We will present example filter designs, predictions for performance, and a status report on filter acquisition.

7735-235, Poster Session

Chilled water glycol system for CANOPUS at Gemini South

G. Gausachs, R. L. Galvez, M. Bec, Gemini Observatory (Chile)

CANOPUS is the facility instrument for the Gemini Multi Conjugate Adaptive Optics System (GeMS) wherein all the adaptive optics mechanisms and associated electronic are tightly packed. At an early stage in the pre-commissioning phase Gemini undertook the redesign and implementation of its chilled Ethylene Glycol Water (EGW) cooling system to remove the heat generated by the electronic hardware. The electronic boards associated with the deformable mirrors (DM) represent the highest density heat yielding components in CANOPUS being also quite sensitive to overheating. The limited size of the two electronic thermal enclosures (TE) requires the use of highly efficient heat exchangers (HX) coupled with powerful yet compact DC fans.

A systematic approach to comply with all the various design requirements brought about a thorough and robust solution that, in addition to the core elements (HXs and fan), makes use of high performance vacuum insulated panels, vibration mitigation elements and several environment sensors for example. This paper describes the design and implementation of the solution in the lab prior to delivering CANOPUS for commissioning.

7735-236, Poster Session

DMD-based MOS demonstrator on Galileo Telescope

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Multi-Object Spectrographs (MOS) are the major instruments for studying primary galaxies and remote and faint objects. Current object selection systems are limited and/or difficult to implement in next generation MOS for space and ground-based telescopes. A promising solution is the use of MOEMS devices such as micromirror arrays which allow the remote control of the multi-slit configuration in real time.

We are developing a Digital Micromirror Device (DMD) - based spectrograph demonstrator. We want to access the largest FOV with the highest contrast. The selected component is a DMD chip from Texas Instruments in 2048 x 1080 mirrors format, with a pitch of 13.68µm. Such component is also currently under study by our team for application in EUCLID-NIS. Our optical design is an all-reflective spectrograph design with F/3 on the DMD component.

This demonstrator permits the study of key parameters such as throughput, contrast and ability to remove unwanted sources in the FOV (background, spoiler sources), PSF effect, spectrum stability on the detector. This study will be conducted in the visible with possible extension in the IR. A breadboard on an optical bench is currently under way for a preliminary determination of these parameters.

The demonstrator on the sky is then of prime importance for characterizing the actual performances of this new family of instrument, as well as investigating the operational procedures on astronomical objects. This demonstrator will be studied in order to be placed on the Galileo telescope in the coming year.

7735-237, Poster Session

The solar seeing monitor MISOLFA: presentation and first results

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PICARD is a space mission developed to observe the Sun at high angular resolution. One of the main space objectives of PICARD is to measure the solar diameter with few milli arc-seconds accuracy. A replica of the space instrument will be installed at Calern Observatory for the same goal. High angular resolution observations with ground-based instrument are however limited by atmospheric turbulence. The seeing monitor MISOLFA is developed to give all observation conditions at the same moments when solar images will be recorded with the twin PICARD instruments. They will be used to link ground and space measurements.

An overview of the PICARD mission and the solar ground-based experiments will be first given. Optical properties of MOSOLFA will be after presented. The basic principles to measure atmospheric parameters and the methods used to obtain then from solar images will be given. Finally, some recent results obtained at Calern Observatory will be presented and discussed.

7735-239, Poster Session

EPOL: the exoplanet polarimeter for EPICS at the E-ELT

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EPOL is the imaging polarimeter in EPICS (Exoplanet Imaging Camera and Spectrograph) for the 42-m E-ELT. It uses sensitive imaging polarimetry to differentiate between unpolarized, direct starlight, and linearly polarized starlight that has been reflected by exoplanets, and to characterize properties of exoplanet atmospheres that cannot be determined from intensity alone. EPOL consists of a coronagraph and a dual-beam polarimeter with a liquid-crystal retarder to exchange the polarization of the two beams. The polarimetry thereby increases the contrast between star and exoplanet by 3 to 5 orders of magnitude over what the extreme adaptive optics and the coronagraph alone can achieve. EPOL operates between 600 and 900 nm, can select more specific wavelength bands with filters and aims at having an integral field unit to obtain linearly polarized spectra of known exoplanets.

We will present the conceptual design of EPOL along with an analysis of its performance.

7735-240, Poster Session

HAWCPol: a first-generation far-infrared polarimeter for SOFIA

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We describe our ongoing project to build a far-infrared polarimeter for the HAWC instrument on SOFIA. Far-IR polarimetry reveals unique information about magnetic fields in dusty molecular clouds and is an important tool for understanding star formation and cloud evolution. SOFIA provides flexible access to the infrared as well as good sensitivity to and angular resolution of continuum emission from molecular clouds. We are making progress toward outfitting HAWC, a first-generation SOFIA camera, with a four-band polarimeter covering 50 to 220 microns wavelength. We have chosen a conservative design which uses quartz half-wave plates continuously rotating at ~0.5 Hz, ball bearing suspensions, fixed wire-grid polarizers, and cryogenic motors. Design challenges are to fit the polarimeter into a volume that did not originally envision one, to minimize the heating of the cryogenic optics, and to produce negligible interference in the detector system. Here we describe the performance of the polarimeter measured at cryogenic temperature as well as the basic method we intend for data analysis. We are on track for delivering this instrument early in the operating lifetime of SOFIA.

7735-241, Poster Session

The polarization optics for the European Solar Telescope (EST)

F. C. M. Bettonvil, Utrecht Univ. (Netherlands); A. Feller, Max-Planck-Institut für Sonnensystemforschung (Germany); B. F. Gelly, Themis S.L. (Spain); C. U. Keller, Utrecht Univ. (Netherlands); T. J. Kentischer, Albert-Ludwigs-Univ. Freiburg (Germany); A. López Ariste, Themis S.L. (Spain); O. Pleier, Max-Planck-Institut für Sonnensystemforschung (Germany); H. Socas-Navarro, Instituto de Astrofisica de Canarias (Spain)

EST (European Solar Telescope) is a 4-m class solar telescope, which is currently in the conceptual design phase. EST will be located at the Canary Islands and will aim at high spatial and temporal resolution observations in the photosphere and chromosphere, using diverse instruments that can efficiently produce two-dimensional spectropolarimetric information of the thermal, dynamic and magnetic properties of the plasma over many scale heights.

Since the very beginning the polarimetric properties of the telescope have been included in the project, both in terms of optical design and place of the calibrators/modulators, as well as in terms of detectors and calibration strategies. It is unique for such a big project but also needed in order to be able to meet the challenging science requirements. Main point in the study is that the whole system should be flexible, allowing for different setups, optimally tuned for different programs.

One of the possibilities for EST will be an optical system that is compensated for instrumental polarization in it self, incorporating a compensated field rotator. EST will be an on-axis optical system and at F2, in the very front of the telescope, before any oblique reflection, a large volume is reserved for installation of calibration and modulator packages. Under consideration is a concept using both a slow and a fast modulator.

In this contribution we will report about the status of the EST polarization optics, discuss the concepts and look at the next steps to be done.

7735-242, Poster Session

Progress on MMT-POL: a 1-5µm adaptive optics optimized polarimeter for the MMT

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We report on progress toward regular operation of MMT-POL, including laboratory calibration and optimization. Characterization of the 1-5µm Virgo array and supporting electronics is included, as are the polarimetry optics at the heart of this instrument. MMT-POL is an adaptive optics optimized imaging polarimeter for use at the 6.5m MMT. By taking full advantage of the adaptive optics secondary mirror of the MMT, this polarimeter will offer diffraction-limited polarimetry with very low instrumental polarization. The instrument will permit observations as diverse as protoplanetary discs, comets, red giant winds, galaxies and AGN.

7735-243, Poster Session

Laboratory performance of a lenslet-based dual-beam imaging polarimeter

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The science instrument of the Gemini Planet Imager (GPI) is a lenslet-based integral field spectrograph featuring also a polarimetry mode. Combined with a modulator upstream, this instrument is designed to detect faint polarized signal buried in the bright and unpolarized point spread function halo whose signal is dominated by speckle noise. This paper presents the laboratory performance results obtained with a GPI-like differential polarimeter prototype.

7735-244, Poster Session

A method to subtract the skylight for the multi-fiber instrument E-ELT/OPTIMOS-EVE

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OPTIMOS-EVE is a multi-fiber instrument proposed for the E-ELT, which will be able to observe at optical and infrared wavelengths simultaneously. Sky light is an important source of noise during observations. One major issue during the observation of faint objects is the subtraction of the sky background, especially for a fiber-fed instrument, because it restricts the depth of multi-object fiber spectroscopic observations. This issue arises in fiber instruments because it is extremely difficult to sample the sky light near the object. In the frame of the phase A study of the fiber instrument E-ELT OPTIMOS-EVE, our team has developed a new technique that combines a surface reconstruction and a PCA analysis to extract both the sky background and OH emission lines. It allows us to subtract the sky contribution in a 5 arcmin FoV within an accuracy of 1%, or 0.3-0.4% for integral field unit observations.

7735-245, Poster Session

The GREGOR Fabry-Perot interferometer: a new instrument for high-resolution solar observations

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The GREGOR Fabry-Perot Interferometer (GFPI) is one of the first-light instruments of the 1.5-meter solar telescope GREGOR currently being commissioned at Observatorio del Teide (ODT), Tenerife. A spectral resolution of about 250,000 over the wavelength range from 530 nm to 860 nm can be achieved using a tunable dual etalon system. A high spectral resolving power is needed to extract physical parameters (e.g., temperature, plasma velocity and the magnetic field vector) from inversions of photospheric and chromospheric spectral lines. The GFPI is outfitted with a polarimeter, which allows to accurately measure the full Stokes vector. Precision polarimetry is enabled using a calibration unit immediately following GREGOR's secondary mirror. The GFPI operates close to the diffraction limit of GREGOR, thus providing access to fine structures as small as 60 km on the solar surface. The field-of-view of 50" x 40" is sufficiently large to cover significant portions of active regions. Large-format, high-cadence CCD detectors are an integral part of the GFPI to ensure that scans of spectral lines can be obtained in time spans corresponding to the evolution time scale of solar phenomena such as granulation, evolving magnetic fields or dynamic features of the chromosphere. Besides describing the technical features of the GFPI and providing a status report on commissioning the instrument, we will use data obtained with the Vacuum Tower Telescope at (ODT) to illustrate its science capabilities.

7735-246, Poster Session

Progress report on FORCAST grism spectroscopy as a future general observer instrument mode on SOFIA

L. D. Keller, Ithaca College (United States); C. P. Deen, The Univ. of Texas at Austin (United States); K. A. Ennico, NASA Ames Research Ctr. (United States); D. T. Jaffe, The Univ. of Texas at Austin (United States); T. P. Greene, NASA Ames Research Ctr. (United States); J. D. Adams, T. L. Herter, G. C. Sloan, Cornell Univ. (United States)

We have implemented and tested a suite of grisms that will enable a moderate-resolution mid-infrared spectroscopic mode in FORCAST, the facility mid-infrared camera on SOFIA. We have tested the hardware for the spectral modes extensively in the laboratory with grisms installed in the FORCAST filter wheels. The grisms perform as designed, consistently producing spectra at resolving powers in the 200-1200 range at wavelengths from 5 to 38 microns. In anticipation of offering this capability as a SOFIA general observer mode, we are developing software for reduction and analysis of FORCAST spectra, a spectrophotometric calibration plan, and detailed plans for in-flight tests prior to commissioning the modes.

We present a brief summary of the FORCAST grism spectroscopic system and a status report.

7735-247, Poster Session

E-ELT instrument study for first light, OPTIMOS-DIORAMAS: mechanical concept study for slit masks system

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The Seeing-limited, large multiplex, optical/near-IR spectrograph, Optimos-Dioramas, currently under study by a Consortium of Institutes from France, Italy, and Switzerland, is one of the possible candidates for first light on the E-ELT Telescope. The spectograph is designed to maximize the field of view and cover in one-shot the spectral range (0.37micron - 1.4micron). This paper describes the studies performed to establish a base-line conceptual design of the Slit Masks System for the Optimos-Dioramas spectrograph. This unit has been designed in order to better satisfy the limits of the allowed volume on the Nasmyth E-ELT platform, and it is also able to guarantee all the optical specifications needed to cover the overall field of view (7x7arcmin). In order to take and position the masks in the focal plane, the performed system is fully robotic and able to load/unload the masks in the proper quadrant. A central cross structure, about 8.33arcsec wide, is needed. Each mask will necessarily be larger than 786x786mm, i.e. 800x800mm. The system based on four 0.6 mm thick (black painted steel) masks is fully feasible and complies with all specifications. Vignetting due to the focal plane curvature is minimized and the slits (cut via a stencil-laser machine) can have all shapes and sizes. The loss in the useful field of view is ~4%.

7735-248, Poster Session

OPTIMOS-EVE optical design of a very efficient, high-multiplex, large spectral coverage, fiber-fed spectrograph at EELT

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OPTIMOS-EVE is a fiber-fed, high-multiplex, high-efficiency, large spectral coverage, spectrograph for EELT covering visible and near-infrared simultaneously. More than 200 seeing-limited objects will be observed at the same time over the full 7 arcmin field of view of the telescope, feeding the spectrograph, asking for very large multiplexing at the spectrograph side. The spectrograph consists of two identical units. Each unit will have two optimized channels to observe both visible and near-infrared wavelengths at the same time, covering from 0.37 to 1.7 micron. To maximize the scientific return, a large simultaneous spectral coverage per exposure was required, up to 1/3 of the central wavelength. Moreover, different spectral resolution modes, spanning from 5'000 to 30'000, were defined to match very different sky targets. Many different optical solutions were generated during the initial study phase in order to select that one that will maximize performances within given constraints (mass, space, cost). Here we present the results of this study, with special attention to the baseline design. Efforts were done to keep size of the optical components well within present state-of-the-art technologies. For example, large glass blank sizes were limited to ~35 cm maximum diameter. VPH gratings were selected as dispersers, to improve efficiency, following their superblaze curve. This led to scanning gratings and cameras. Optical design will be described, together with expected performances.

7735-249, Poster Session

Status of the echelon-cross-echelle spectrograph for SOFIA

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The Echelon-cross-Echelle Spectrograph (EXES) is one of the first generation instruments for the Stratospheric Observatory for Infrared Astronomy (SOFIA). It operates at high, medium, and low spectral resolution in the wavelength region 4.5 to 28.3 microns using a 1024x1024 Si:As detector array. From SOFIA, the high spectral resolution mode (R=100,000) will provide truly unique data given the improved atmospheric transmission. We are currently involved with system testing in preparation for our first ground-based telescope run, hopefully to occur in 2010B. At the conference, we will present the current status of EXES including detailed lab results in our high and medium resolution modes, our plans for ground-based observing, and our expectations for operations on SOFIA.

7735-250, Poster Session

Mechanical design of (SIFS) SOAR integral field unit spectrograph

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The SOAR Integral Field Unit Spectrograph (SIFS) is fed by an integral field unit composed of a bi-dimensional arrangement of 1300 optical fibers. It has been developed in Brazil by a team of scientists and engineers led by the National Laboratory of Astrophysics (MCT/LNA) and the Department of Astronomy of the Institute of Astronomy, Geophysics and Atmospheric Sciences of the University of São Paulo (IAG/USP). It comprises three major subsystems; a fore-optics installed on the Nasmyth port of the telescope or the SOAR Adaptive Optics Module, a 14-m optical fiber IFU, and a bench-mounted spectrograph installed on the telescope fork. SIFS is successfully assembled and tested on the SOAR Telescope in Chile and has now moved to the commissioning phase. This paper reports on technical characteristics of the mechanical design and the assembly, integration and technical activities.

7735-251, Poster Session

The optical design of wide integral field infrared spectrograph

C. Chou, D. Moon, Univ. of Toronto (Canada); S. S. Eikenberry, Univ. of Florida (United States)

We introduce a basic optical design of an integral-field spectrograph named Wide Integral-Field Infrared Spectrograph (WIFIS). WIFIS is designed to provide a spectral resolution R ~ 5000 spectra for each J, H and Ks band in a single exposure with a field of view of 6" x 10" on a 10-m telescope. The entire design is composed of three major components: a Offner relay, an integral field unit (IFU) and a spectrograph. The light from the telescope focal plane will go through the Offner relay which replays the focal plane deeper into the Dewar to reduce the thermal noise and provide a position for the cold stop. The 22-slicer IFU called Florida Image Slicer for Infrared Cosmology and Astrophysics (FISICA) slices the image from the relay and reform it into a pseudo long-slit. Meanwhile, the FISICA reduces the focal ratio of the pseudo long-slit by a half. The grating-based spectrograph followed by the FISICA is used to obtain the spectra of the pseudo long-slit. The processed light from the FISICA will be collimated by the collimator system composed of an odd-polynomil aspherical collimator mirror and a correction lens. The collimated beam will be dispersed by three different planar gratings for J, H and Ks bands. The six-lens spectrograph camera is used to focus the dispersed light onto the HAWAII-II 2k detector array. The spectrograph camera is composed of all spherical lenses except one surface is described by an odd aspherical polynomial. WIFIS is designed to study the kinematics, chemistry and the physical conditions of an extended source. Therefore, WIFIS can provide good approaches to scientific topics such as the gas feeding mechanism in the galactic center of nearby active galaxies, interaction histories of high-z galaxy mergers and the derivation of physical conditions of supernova remnants.

7735-252, Poster Session

Design and status of a near-infrared multi-object spectrograph for the TAO 6.5-m Telescope

M. Konishi, K. Motohara, M. Doi, S. Sako, K. Toshikawa, N. Mitani, T. Aoki, T. Handa, The Univ. of Tokyo (Japan); Y. Ita, National Astronomical Observatory of Japan (Japan); D. Kato, K. Kawara, K. Kohno, S. Koshida, T. Minezaki, T. Miyata, T. Soyano, T. Tanabe, M. Tanaka, K. Tarusawa, Y. Yoshii, The Univ. of Tokyo (Japan)

We describe the design and current status of a near-infrared multi-object spectrograph for the University of Tokyo Atacama Observatory (TAO) project (P.I.: Prof. Y.Yoshii), which constructs a 6.5-meter infrared telescope on the summit of Co. Chajnantor (an altitude of 5,640m) in the northern Chile.

The instrument is covering a wavelength range from 0.9 to 2.5 microns with a field of view of 9.6 arcmin in diameter using 4096 x 4096 pixels with a pixel scale of 0.12 arcsec/pixel. It has two observation modes: a wide-field imaging and a multi-object spectroscopy (MOS). The MOS mode uses cooled multi-slit masks with approximately 30 objects, and achieves a spectral resolution of R ~ 500-1000. In both modes, two wavelength ranges of 0.9-1.4 microns and 1.4-2.5 microns are observed simultaneously with a dichroic mirror placed in the collimated beam. As well as increasing the efficiency of observations, simultaneous observations in those two bands can also provide us data covering the wide spectral range under same conditions such as weather, telescope pointing, and so on. Such data are highly efficient for not only galaxies at various redshifts but also rapidly time-variable events such as Gamma-

ray Bursts.

As the instrument is expected to be completed before the construction of the 6.5m telescope, we plan to carry out performance verification and initial scientific observation on the Subaru Telescope at Hawaii.

7735-253, Poster Session

Design inputs for a high-performance high-resolution near-infrared spectrograph

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The combination of immersion grating and infrared array detector technologies allows the construction of high-resolution spectrographs in the near-infrared that have capabilities approaching those of optical spectrographs. It is possible, for instance, to design spectrographs with very large wavelength coverage and high throughput. We explored the scientific and functional drivers for spectrograph designs. The science community and scientific goals for the spectrograph are reviewed. Several key inputs into the design are reviewed including risk, mechanical-optical trades, and operations.

We discuss a design for a no moving parts spectrograph with either 1.1-2.5 or 3-5 micron simultaneous wavelength coverage.

7735-254, Poster Session

KMOS data flow: reconstructing data cubes in a single step

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KMOS is a multi-object near-infrared integral field spectrometer with 24 deployable pick-off arms. Data processing is inevitably complex. We discuss specific issues that must be addressed in the data reduction pipeline, and outline the requirements that have arisen on the raw data format as well as on simulated data. We discuss the pipeline architecture. We focus on its modular style and show how these modules can be used to build a classical pipeline, as well as a more advanced pipeline that can account for both spectral and spatial flexure as well as variations in the OH background. A novel aspect of the pipeline is that the raw data are reconstructed into a cube in a single step. We discuss the advantages of this, outline the way in which we have implemented it, and show how it performs.

7735-255, Poster Session

MIRADAS: a proposal for an intermediate dispersion NIR spectrograph for the GTC

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As a response for the GTC call for proposals for second generation instrument, teams from the University of Florida and the Instituto de Astrofísica de Canarias has joined effort to submit an instrument concept for an intermediate to high dispersion NIR spectrometer. Our baseline instrument concept is a seeing, limited spectrometer operating over the 1, 2.5 µm bandpass at spectral resolutions R~10,000 and R~20,000 with some multiplex capability. There is a rather large range of parameter space which falls within this general description, and defining the requirements for an optimal instrument will require careful analysis of trades between scientific performance, cost, and technical risk. The instrument science team is currently exploring and refining the science cases, with particular emphasis on analyzing the dependence of scientific performance on key instrument parameters such as wavelength coverage and spectral resolution, throughput, multiplex gain, etc. With this information, the CALIFA system engineering group is carrying out technical trade studies of the instrument parameters. The results of these will be presented in this contribution as the final concept which will be submitted to the GTC Project Office.

7735-256, Poster Session

The habitable zone planet finder: a proposed high-resolution NIR spectrograph for the HET to discover low-mass exoplanets around M stars

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The Habitable Zone Planet Finder (HZPF) is a proposed instrument for the 9m Hobby Eberly telescope that will be capable of discovering low mass planets around M dwarfs. HZPF will be fiber-fed, provide a spectral resolution R~ 50,000 and cover the wavelength range 0.9-1.65 m, the Y, J and H NIR bands where most of the flux is emitted by late type M stars, and where most of the radial velocity information is concentrated. Enclosed in a chilled vacuum vessel with active temperature control, fiber scrambling and mechanical agitation, HZPF is designed to achieve a radial velocity precision < 3m/s, with a desire to achieve 1m/s for the brightest targets. This instrument will enable a study of the properties of low mass planets around M dwarfs; discover planets in the habitable zones around these stars, as well serve as an essential radial velocity confirmation tool for astrometric and transit detections around late M dwarfs. Radial velocity observation the NIR will also enable a search for close in planets around young active stars, complementing the search space enabled by upcoming high-contrast imaging instruments like GPI, SPHERE and PALM3K. Tests with a laboratory prototype Pathfinder have already demonstrated the ability to recover radial velocities at 7-10 m/s precision from integrated sunlight. We will discuss lessons learned about calibration and performance from our tests and how they impact the overall design of the HZPF.

7735-257, Poster Session

Characterizing the Robert Stobie spectrograph's near-infrared detector

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The near infrared (NIR) upgrade to the Robert Stobie Spectrograph (RSS) will be commissioned on the 11-meter Southern African Large Telescope (SALT) in 2012.

The instrument provides high throughput, low- to medium-resolution long-slit and multi-object spectroscopy with broadband, spectropolarimetric, and Fabry-Perot imaging modes over an 8 × 8 field of view. The RSS-NIR utilizes a single HAWAII-2RG HgCdTe array with a 1.7 µm cut-off wavelength controlled by a SIDECAR ASIC. The detector and SIDECAR electronics are housed in a dewar cryogenically cooled to approximately 120 K. We present the results from our detector characterization effort, including readout noise, dark current, quantum efficiency, and persistence measurements.

7735-258, Poster Session

Fourier transform spectroscopy on very large telescopes

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Observatory (United States)

While a premier technique for laboratory spectroscopy, Fourier transform spectroscopy (FTS) has fallen into disuse in astronomical applications. The speed of a FTS can be dramatically less than that of a dispersive spectrograph with an array detector due to multiplex disadvantage. However, there are a number of advantages of the FTS technique that can be exploited to offer spectroscopic capabilities that would otherwise not be available. These include spectral resolutions significantly in excess of 100000 for very large telescopes. We explore the possibilities of using pre-existing FTS equipment upgraded with modern detectors on next generation telescopes. Some observing applications are described.

7735-259, Poster Session

Quick-look reduction software for FORCAST Grism mode on SOFIA

C. P. Deen, The Univ. of Texas at Austin (United States); L. D. Keller, Ithaca College (United States); D. T. Jaffe, The Univ. of Texas at Austin (United States); K. A. Ennico, T. P. Greene, NASA Ames Research Ctr. (United States); J. D. Adams, T. L. Herter, G. C. Sloan, Cornell Univ. (United States)

We have designed and fabricated a suite of grisms for use in FORCAST, a mid-infrared camera scheduled as a first-light instrument on SOFIA. The grism suite gives SOFIA a new capability: low resolution spectroscopy from 5 to 38 microns at resolving powers from R=200 to R=1200, without the addition of a new instrument. We have developed an IDL based spectral data reduction and quick-look software package, in anticipation of FORCAST grism spectroscopy becoming a facility observing mode on the SOFIA telescope. The package allows users to quickly view their data by extracting single-order and cross-dispersed spectra immediately after acquiring them in flight. We have optimized the quick-look software to reduce the number of steps required to turn a set of observations into a fully reduced extracted spectrum. We present a description of the philosophy of the data reduction software, supplemented with screen shots and examples in hopes of garnering feedback and critiques from potential end users, software developers, and instrument builders.

7735-260, Poster Session

The Pathfinder testbed: exploring techniques for achieving precision radial velocities in the near infrared

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The Penn State Pathfinder is a prototype warm fiber-fed Echelle spectrograph with a Hawaii-1 NIR detector that has already demonstrated 7-10 m/s radial velocity precision on integrated sunlight. The Pathfinder testbed was initially setup for the Gemini PRVS design study to enable a systematic exploration of the challenges of achieving high radial velocity precision in the near-infrared, as well as to test possible solutions to these calibration challenges. The current version of the Pathfinder has an R3 echelle grating, and delivers a resolution of R~50,000 in the Y, J or H bands of the spectrum. We will discuss the on sky-performance of the Pathfinder during an engineering test run at the Hobby Eberly Telescope as well the results of velocity observations of M dwarfs. We will also discuss the unique calibration techniques we have explored, like Uranium-Neon hollow cathode lamps, notch filter, and modal noise mitigation to enable high precision radial velocity observation in the NIR. The Pathfinder is a prototype testbed precursor of a cooled high-resolution NIR spectrograph capable of high radial velocity precision and of finding low mass planets around mid-late M dwarfs.

7735-261, Poster Session

Spectral resolution and scattered light properties for high-resolution and high signal-to-noise ratio spectroscopy in the infrared

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In recent years various 8m class telescopes have been equipped with high resolution infrared spectrographs. As one is exploring a completely new field of science while using the largest optical telescopes available in many cases quite high signal to noise ratios are achieved and the final S/N-ratio is no longer governed by photon statistics or detector noise but by systematics such as residual detector cosmetics or stray light induced by the object itself.

In the course of studying the Martian atmosphere - not really a faint object - it became obvious, that the signal levels of the recorded spectra, in the cores of fully saturated telluric absorption lines, do not come down to zero but would stay at a level of 10^-2 to 10^-3. On the other hand, when using proper modeling for instrumental effects and telluric absorption, spectral features as faint as 10^-3 of the continuum could unambiguously be detected and attributed to molecular transitions. Still it is unsatisfactory, especially when unknown features are detected, that the nature of the obvious in-dispersion stray light could not be explained.

Using CRIRES, the ESO-VLT adaptive optics fed spectrograph, in conjunction with an infrared HeNe laser and noble gas discharge lamps very high (S/N)-ratio spectra have been taken. These spectra achieve a contrast of 10^5. For frequencies less than 100000GHz the residual line profiles can readily be fitted with a Voigt profile for the entire set of data.

When convolving theoretical telluric spectra with the resulting Voigt profiles, taking typically +/-100 pixel around the core of the lines, the observed straylight level in the cores of saturated telluric lines can be fully explained. This opens the possibility to analyze extremely high quality spectra in an un-ambiguous way.

7735-262, Poster Session

Pressure and temperature stabilization of an existing Echelle spectrograph

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The Echelle spectrograph FOCES, that was operated at the 2.2m Calar Alto telescope between 1995 and 2009 will be used as a test bed for stabilization, fiber scrambling and illumination stability tests.

The layout of this laboratory experiment will be presented in this paper together with the required spectrograph stability, technical concepts and first results from the stabilization efforts and the Munich fiber test set-up.

7735-263, Poster Session

Development of VIRUS alignment and assembly fixtures

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The Visible Integral-Field Replicable Unit Spectrograph (VIRUS) Instrument is a set of 150+ optical spectrographs to support observations for the Hobby-Eberly Telescope Dark Energy Experiment (HETDEX). We plan to use a production line assembly process to construct the large number of VIRUS units. This allows each sub-assembly of a VIRUS unit to be interchangeable amongst all other VIRUS units. A production line manufacturing procedure will enable various sub-assemblies to be built and test in parallel. Examples of alignment and assembly fixtures required for the VIRUS manufacturing process include a camera mirror alignment system, a collimator structure assembly device, a collimator mirror mounting tool, and a grating alignment system. In this paper we describe the design of these fixtures and their importance in the VIRUS assembly process.

7735-264, Poster Session

Mechanical design evolution of the VIRUS instrument for volume production and deployment

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The Visible Integral-Field Replicable Unit Spectrograph (VIRUS) is an integral field spectrograph to support observations for the Hobby-Eberly Telescope Dark Energy Experiment (HETDEX). The VIRUS instrument is fed by more than 33,000 fiber optics and consists of 150 spectrograph in 75 individual, identical units. This paper discusses the evolution in mechanical design of the VIRUS unit spectrographs to maximize the cost benefit from volume production. Design features which enable volume manufacture and assembly are discussed. Strategies for reducing part count while enabling precision alignment are detailed. Design considerations for deployment, operation, and maintenance en masse at the Hobby-Eberly Telescope are also made. In addition, several enabling technologies are described including the use of cast aluminum in vacuum housings, use of cast Invar, and processing cast parts for precision tolerances.

7735-265, Poster Session

Development of a cryogenic system for the VIRUS array of 150 spectrographs for the Hobby-Eberly Telescope

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The upcoming Hobby-Eberly Telescope Dark Energy Experiment (HETDEX) has provided motivation for upgrading the Hobby-Eberly Telescope (HET) at the McDonald Observatory. This upgrade includes an increase in the field-of-view to accommodate the new and revolutionary Visible Integral-Field Replicable Unit Spectrograph (VIRUS). VIRUS is the instrument designed to conduct the HETDEX survey and consists of 150 individual integral-field spectrographs fed by 33,600 total optical fibers covering a 22 arc-minute field-of-view of the upgraded HET. The spectrographs are mounted in four enclosures, each 4.5 x 2.5 x 1.5 meters in size. Each spectrograph contains a CCD detector that must be cryogenically cooled, presenting an interesting cryogenic and vacuum challenge within the distribution system. In this paper, we review the proposed vacuum jacketed, thermal siphon, liquid nitrogen distribution system used to cool the array of detectors and discuss recent developments. We focus on the design, prototyping, and testing of a novel “make-break” thermal connector, built from a modified cryogenic bayonet that is used to quickly detach a single spectrograph pair from the system.

7735-266, Poster Session

iSHELL: a 1-5 micron cross-dispersed R=70,000 immersion grating Echelle spectrograph for IRTF

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iSHELL is 1-5 micron high spectral resolution spectrograph being built for the NASA Infrared Telescope Facility (IRTF) on Mauna Kea, Hawaii. Dispersion is accomplished with silicon immersion gratings in order to keep the instrument small enough to be mounted at the cassegrain focus of the telescope. The white pupil spectrograph is designed to produce resolving powers of up to R=70,000. Cross-dispersing gratings mounted in a tiltable mechanism at the second pupil allow observers to select slit lengths ranging from 5 to 25 arcseconds, as is required by the wide-ranging science case. One 2048x2048 H2RG array is used in the spectrograph and one 512x512 Aladdin 2 array is used in the slit viewer for object acquisition and guiding. About $4 million in funding has been provided by NSF and NASA. First light is expected in 2014. In this paper we discuss the science drivers, instrument modeling, the optical design, and present an overview of the overall instrument design.

7735-267, Poster Session

The Hobby Eberly Telescope high-resolution spectrograph upgrade

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The Hobby Eberly Telescope (HET)High Resolution Spectrograph (HRS) has been inefficiently coupled to the HET since commissioning in 2001, leading to low throughput performance. A significant upgrade has been designed and is being implemented during 2010. The surface-relief cross dispersers will be replaced with VPHGs for a wavelength dependent gains between 1.6 and 3. The VPHG cross dispersers give greater inter-order separation (IOS) to support object-fiber plus sky-fiber image slicers for gains of 1.7x, 3x, and 5x at resolving powers 30,000, 60,000, and 110,000, respectively. To maintain spectral coverage with the increased IOS, HRS will become a double spectrograph with the addition of a blue arm and the reconfiguration of the current arm as the red arm. The

blue arm extends the blue spectral coverage from ~410 nm to 365 nm to broaden the scientific capabilities of HRS, particularly for metal poor star science. Additionally, improved optical fibers are being implemented along with new auxiliary instrumentation including a fiber double scrambler, exposure meter, fast x-y movement of the fiber inputs to track image motion, and enhanced temperature stabilization of the instrument.

This paper gives the design of the HRS upgrade, the new instrument configurations, and a performance analysis of the upgraded HRS design relative to the current HRS. The implementation phases will be described as HRS is used every clear night requiring downtime to be minimized.

7735-268, Poster Session

The LUCIFER MOS: a full cryogenic mask handling unit for a near-infrared multi-object spectrograph

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The LUCIFER-MOS is the full cryogenic mask-exchange unit for the near-infrared multi object spectrograph LUCIFER at the large binocular telescope.

In this paper we present the design and functionality of this device. Unlike with other NIR Multi-Object spectrographs, in LUCIFER the masks are stored, handled and placed in the focal plane in cryogenic conditions at all times, resulting in very low thermal background emission from the masks during observations.

The manipulation of the masks is done by a novel cryogenic mask handling robot that can address up to 33 fixed and user-provided masks and place them in the focal plane with high accuracy in every instrument orientation.

Exchange of old and new MOS masks is likewise done in cryogenic conditions through the use of auxiliary cryostats which attach to the very instrument using a unique exchange drive mechanism.

Masks are laser cut from a specially designed coated stainless steel, optimized for NIR cryogenic applicaations.

7735-269, Poster Session

Correcting METIS spectra for telluric absorption lines: maximising spectral fidelity

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METIS (Mid-infrared E-ELT Imager and Spectrometer) is a mid-infrared instrument proposed for the European Extremely Large Telescope (E-ELT). It is designed to provide imaging and spectroscopic capabilities in the 3 to 14 micron region up to a spectral resolution of 100000. One of the novel concepts of METIS is that of a high-resolution integral field spectrograph (IFS) for a diffraction limited mid-IR instrument. While this concept has many scientific and operational advantages over a long-slit spectrograph, one drawback is that the spectral resolution changes over the field of view. This has an impact on the procedures to maximise spectral fidelity, the ability to distinguish a weak spectral feature from the continuum. One obstacle in achieving the highest spectral fidelities is the correction of telluric line absorption. The classical technique of division by a standard star spectrum, observed in a single IFS spaxel, cannot simply be applied to all spaxels, because the spectral resolution changes from spaxel to spaxel. In this contribution we present and discuss possible techniques of telluric line correction of METIS IFS spectra, including the application of synthetic model spectra of telluric transmission, to maximise spectral fidelity. We conclude that, with the help of model spectra, the spectral fidelity will reach the values to fulfill all METIS science cases.

7735-270, Poster Session

Design study of an image slicer-based integral-field spectrograph for EPICS

M. Tecza, N. A. Thatte, F. Clarke, G. S. Salter, Univ. of Oxford (United Kingdom)

We present the results of a design study carried out in the context of the EPICS Phase A study. EPICS is the planet finder imager and spectrograph for the E-ELT. In our study we investigated the feasibility of an image slicer based integral field spectrograph and developed an optical design for both the image slicer and the necessary pre-optics, as well as the spectrograph optics. We present a detailed analysis of the optical performance of the design and a conceptual mechanical design.

7735-271, Poster Session

Using the X-shooter physical model to understand instrument flexure

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We have developed a physical model of the VLT 2nd generation instrument X-shooter. The parameters of this model, that describe the positions, orientations and other physical properties of the optical components in the spectrograph, are continually updated by an optimisation process that ensures the best possible fit to arc lamp line positions in calibration exposures. Besides its use in driving the wavelength calibration in the data reduction pipeline, the physical model provides us with an insight into physical changes in the optical components and the possibility to correlate these with changing environmental conditions and instrument orientation. By utilising a continually growing database of automatic flexure compensation exposures that cover a wide range of instrument orientations, we are able to investigate flexure in terms of physical model parameters.

7735-272, Poster Session

The upgraded WIYN bench spectrograph

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Jacoby, National Optical Astronomy Observatory (United States)

We present the as-built design overview and post-installation performance of the upgraded WIYN Bench Spectrograph. This Bench currently feeds two general-use multi-fiber instruments at the WIYN 3.5m telescope on Kitt Peak, the Hydra multi-object spectrograph, and the SparsePak integral field unit (IFU). It is very versatile, and can be configured to accommodate low-order, echelle, and volume phase holographic gratings. The overarching goal of the upgrade was to increase the average spectrograph throughput by ~60% while minimizing resolution loss (< 20%). In order to accomplish these goals, the project has had three major thrusts: (1) a new CCD was provided with a nearly constant 30% increase is throughput over 320-1000 nm; (2) two Volume Phase Holographic (VPH) gratings were delivered, a 740 l/mm grating that is 1.5-2 times more efficient than comparable single rules gratings, and a 3300 l/mm grating that is ~2 times more efficient than the available echelle grating; and (3) installed a new all-refractive collimator that properly matches the output fiber irradiance (EE90) and optimizes pupil placement. Initial analysis of commissioning data indicates that the total throughput of the system has increased 50-70% using the 600 l/mm single ruled grating, indicating that the upgrade has achieved its goal. The 600 l/mm grating is a very efficient grating, and higher gains are expected in other configurations. Furthermore, it has been demonstrated that overall image resolution meets the requirement of <20% loss.

7735-273, Poster Session

Gemini multi-object spectrograph focal plane CCD upgrade

K. Szeto, R. G. Murowinski, A. Anthony, J. Dunn, D. A. Erickson, J. M. Fletcher, T. Hardy, National Research Council Canada (Canada)

The Herzberg Institute of Astrophysics has been commissioned by the Gemini Observatory to develop and implement a new focal plane assembly, with an array of three Hamamatsu CCDs, for the Gemini Multi-Object Spectrographs. This paper describes the overall design of the new focal plane system with respect to the existing interfaces required and outlines the test methodology to validate the new system against its performance requirements.

7735-274, Poster Session

Mechanical design of the near-infrared arm of the Robert Stobie spectrograph for SALT

M. P. Smith, Univ. of Wisconsin-Madison (United States); J. P. Wong, Paradigm Design Inc. (United States); W. P. Mason, D. P. Adler, A. R. Rogers, A. I. Sheinis, M. J. Wolf, D. J. Thielman, M. P. Mulligan, J. W. Percival, Univ. of Wisconsin-Madison (United States)

The near infrared upgrade to the Robert Stobie Spectrograph (RSS/NIR) for the Southern African Large Telescope (SALT) extends the capabilities of the visible arm RSS into the NIR. The RSS/NIR instrument is at the prime focus of SALT. It is a versatile spectrograph with broadband imaging, spectropolarimetric, and Fabry-Perot imaging capabilities. The multiple modes and prime focus location introduce interesting engineering considerations. The spectrograph has an ambient temperature collimator, cooled (-40C) dispersers and camera and a cryogenic detector. Many of the mechanisms are required to operate within the cooled and cryogenic environments. The RSS/ NIR upgrade includes the following mechanisms; an active, flexure compensating fold mirror, a filter exchange mechanism, a VPG grating exchange and rotation mechanism, an etalon inserter, a beam splitter inserter, an articulating camera, internal camera focus and a cutoff filter exchange wheel. Structural, mechanical and thermal aspects of the design are addressed in this paper

7735-275, Poster Session

Design drivers for a wide-field multi-object spectrograph for the WHT

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Wide-field multi-object spectroscopy is a high priority for European astronomy over the next decade. Most 8-m - 10-m telescopes have a small field of view, making 4-m class telescopes a particularly attractive option for wide-field instruments. We present a science case and design study for a wide-field multi-object spectrograph (MOS) for the 4.2-m WHT on La Palma.

The science cases for wide-field MOS fall into 3 groups with different requirements in spectroscopic resolution R: (1) cosmological redshift surveys (R ~ 1,000); (2) high-precision radial-velocity studies, and galaxy evolution (R = 5,000-10,000), and (3) high-precision stellar element abundances for Milky-Way archaeology (R ~ 30,000).

The study presented here focuses on intermediate-resolution designs. A new prime-focus corrector and atmospheric-dispersion corrector (Agocs et al, this conf.) will deliver a field of view 2 deg in diameter, with good throughput from 380 to 1,000 nm. The multiplex factor will be set by the science requirements and by the fibre-positioning technology, and is likely to be ~ 500 - 1000. Several options are discussed, building in part on published design studies for E-ELT spectrographs. Indeed, a WHT MOS will not only efficiently deliver data for exploitation of important imaging surveys planned for the coming decade, but will also serve as an essential test-bed to optimize the design, construction and exploitation of MOS instruments for the future E-ELT.

7735-276, Poster Session

LRS2: a new low-resolution spectrograph for the Hobby-Eberly Telescope and its application to scalable spectrographs for the future extremely large telescopes

H. Lee, T. S. Chonis, G. J. Hill, The Univ. of Texas at Austin (United States); D. L. DePoy, J. L. Marshall, Texas A&M Univ. (United States); B. L. Vattiat, The Univ. of Texas at Austin (United States)

With the deployment of the Hobby-Eberly Telescope (HET) Wide-Field Upgrade (WFU), the current Marcario LRS will be replaced with a fiber-fed broad band instrument, called LRS2. LRS2 will be based on the VIRUS unit spectrograph that was designed to be easily adapted to a wide range of spectral resolutions, and wavelength ranges. The current snapshot of LRS2, fed by a 7x12 sq. arcsec lenselet-coupled fiber integral-field unit (IFU), covers 350-1100 nm, simultaneously at a fixed resolving power R~1800, with the wavelength range split into two pairs of spectrographs, one for the blue and red wavelength range (350-630nm) and the other for the red and far-red range (630-1100 nm). Only minimal modification in gratings (for both pairs) and in the detector (for the red pair only) is required. In addition to this flexibility, the generic nature and massively replicable characteristic of the instrument allows LRS2 to be adapted to a wide range of not only telescope diameters (1 m ~ 40 m), but also observing modes (single to multiple objects). We discuss the current LRS2 design and its implication in the era of the future Extremely Large Telescopes (ELT).

7735-277, Poster Session

High-stability light injection in optical fibers for ultra-high stability spectrographs: the pilot case of CODEX

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In order to achieve ultra-high radial velocity accuracies such as those required in ultra-stable spectrographs as ESPRESSO@VLT or CODEX@EELT the image centroid stability at the level of fiber injection is crucial. The required 2 cm/s accuracy of CODEX implies to control the position of the injected PSF to few milliarcseconds. Such an accuracy needs to be achieved at the expense of a very limited number of photons, because faint objects are among the targets of CODEX. This requires a new concept of Front/End unit based on fine real-time controls and mechanical positions reading. We present in this paper the Front/End of CODEX as a template for innovative high accuracy injection in fiber.

7735-278, Poster Session

Diverse field spectroscopy: instrument concepts

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We are currently developing a range of instrument concepts which combine the advantages of integral field and multi-object systems. They are modular, arbitrarily scalable, and will be capable of addressing large fields with extremely high efficiency. We have coined the phrase 'Diverse Field Spectroscopy' to describe this paradigm shift in instrument versatility. Whereas other existing and proposed instruments (multiplex, multiple-field) use deployable fibres, IFUs or field pickoff mechanisms, the focus in Durham has been on implementing the downselection by means of advanced optical switches. Several of our most promising concepts will be presented in this paper.

The emergence of adaptive optics systems in recent years has enabled current spectroscopic instruments to access very large numbers of spatial sampling elements (spaxels). For current eight-metre class telescopes the total available data in a given field at the highest resolutions already exceeds the detection capabilities of any realistic instrument. With the spatial resolution of AO corrected ELTs the situation will however be unprecedented. An efficient downselection must therefore be applied so that only regions of interest are delivered to the detectors. Integral field and multi-object field selection using optical fibres are both proven techniques for achieving this, however the greatest efficiency will be realised only with hybrid instruments. These must exhibit true flexibility when addressing the focal plane, down-selecting using adaptive sampling strategies. We envision systems which will operate over a continuum of regimes; assigning fibres to any object or combination of objects within the field regardless of size, shape or distribution.

7735-279, Poster Session

High-contrast observations with slicer-based integral field spectrographs (simulations)

G. S. Salter, N. A. Thatte, M. Tecza, F. Clarke, Univ. of Oxford (United Kingdom); C. Verinaud, Lab. d'Astrophysique de l'Observatoire de Grenoble (France); M. E. Kasper, European Organisation for Astronomical Research in the Southern Hemisphere (Germany)

Instruments are now being built to obtain direct images and spectra of extrasolar planets. This means achieving contrasts of >10^6 at separations of few tenths of an arcsecond. All new instruments incorporate an Integral Field Spectrograph, due to their unique ability to both detect and characterise in a single observation, thus obviating the need for expensive follow-ups.

A design study for EPICS on the E-ELT is already underway and is hoping to detect exo-Earths which means contrasts of around 10^9. Promising research is being done into using an IFS and a method called spectral deconvolution to eliminate quasi-static speckles by using their chromatic behaviour to surpass the speckle noise limit to achieve the required contrasts.

As part of the EPICS design study, an investigation has been made into whether there are fundamental limits to the contrast achievable with slicer based integral field spectrographs and if so why and by how much.

We are simulating the effect an image slicer IFS has on the speckle pattern of a high contrast observation by taking simulated complex amplitudes of a datacube, slicing it up in the spatial direction and adding appropriate wave front error (WFE) in the pupil plane.

Simulations are made adding in both WFE due to manufacturing errors (random 1/f^2 profile) and ZEMAX generated design errors.

The analysis of the contrast limitations introduced by the modification of the speckle pattern in these simulations will be presented.

7735-280, Poster Session

High-contrast observations with slicer-based integral field spectrographs (experimental tests)

G. S. Salter, N. A. Thatte, M. Tecza, Univ. of Oxford (United Kingdom); F. Clarke, Oxford Univ. (United Kingdom); C. Verinaud, Lab. d'Astrophysique de l'Observatoire de Grenoble (France); M. E. Kasper, European Organisation for Astronomical Research in the Southern Hemisphere (Germany)

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Simulations can only tell us the effect of adding wave front error (WFE) in the pupil plane. An experimental test bed including a slicer based IFS has been set up for comparison to the simulations and to analyze effects that cannot be well simulated, such as Fresnel effects, scattered light, real manufacturing errors and non-pupil-plane WFE.

Results from these experimental tests will be presented.

7735-281, Poster Session

The design of dispersing elements for a highly segmented, very wide-field spectrograph

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Wide field spectrographs at the largest optical telescopes will be decisive to address the main open questions in modern astrophysics. This project is aimed at building a very wide field optical spectrograph for a 10-m class telescope. The key feature of this instrument is the modular concept: the spectrograph is the combination of about one thousand identical small cameras, each carrying a few slits and operating at low to moderate spectral resolution, to be illuminated at the Cassegrain focus of an existing 8m class telescope.

The dispersing element to be used in these small cameras has to satisfy some requirements in term of efficiency, resolution, size, small series production. Moreover the cameras have to work both in imaging and spectroscopy modes, therefore a GRISM configuration of the dispersing element is suitable.

Based on these considerations, we have focused our attention to Volume Phase Holographic Gratings (VPHGs) since they show large peak efficiency in the target spectral range (400-800 nm), they can be arranged in a GRISM configuration reaching large resolution.

The main constrains concern the available room for the dispersing element, indeed the camera design is very compact. As a consequence, slanted VPHGs are studied and optimized in combination with normal and Fresnel prisms.

7735-282, Poster Session

New generation multichannel subtractive double pass for EST imaging spectropolarimetry

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A new generation MSDP is proposed for spectropolarimetry with the EST grating spectrograph.

It provides simultaneous 2D images in a number of wavelengths covering several line profiles. The aim is to hold simultaneously spectrograph advantages (dispersion, number of lines) and possibilities of imaging devices in terms of spatial resolution (possible image restoration) and high observing speed (large data cubes). We present the general layout, and a functional diagram with different observing modes. Spot diagrams show the image quality close to the diffraction limit.

Previous MSDPs operated at several large telescopes (Meudon Solar Tower, German VTT and THEMIS for example) use slicers made of prisms. New generation slicers are proposed for EST. They are made of mirrors to increase the photon fluxes, as well as the number of channels (field of view and line profile coverage).

7735-283, Poster Session

METIS: system engineering and optical design of the mid-infrared E-ELT instrument

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METIS is a mid-infrared instrument proposed for the European Extremely Large Telescope (E-ELT). It is designed to provide imaging and spectroscopic capabilities in the 3µm to 14µm region up to a spectral resolution of 100.000. Here the technical concept of METIS is described which has been developed based on an elaborated science case which is presented elsewhere in this conference.

There are five main opto-mechanical modules all integrated into a common cryostat: The fore-optics is re-imaging the telescope focal plane into the cryostat, including a chopper, an optical de-rotator and an un-dispersed pupil stop. The imager module provides diffraction limited direct imaging, low-resolution grism spectroscopy, polarimetry and coronography. The high resolution IFU spectrograph offers a spectral resolution of 100.000 for L- and M-band and optional 50.000 for the N-band. In addition to the WFS integrated into the E-ELT, there is a METIS internal on-axis WFS operating at visual wavelengths. Finally, a cold (and an external warm) calibration unit is providing all kinds of spatial and spectral calibrations capabilities. METIS is planned to be used at one of the direct Nasmyth foci available at the E-ELT.

This recently finished Phase-A study, carried out within the framework of the ESO sponsored E-ELT instrumentation studies, has been performed by an international consortium with institutes from Germany, Netherlands, France, United Kingdom and Belgium.

7735-284, Poster Session

The infrared imaging spectrograph (IRIS) for TMT: sensitivities and simulations

S. A. Wright, Univ. of California, Berkeley (United States); E. J. Barton, Univ. of California, Irvine (United States); J. E. Larkin, Univ. of California, Los Angeles (United States); A. M. Moore, California Institute of Technology (United States); D. Crampton, L. Simard, National Research Council Canada (Canada)

IRIS (InfraRed Imaging Spectrograph) is currently being designed to be the first light instrument package to take advantage of the diffraction-limit of the future Thirty Meter Telescope (TMT). IRIS will house a near-infrared (850 - 2400 nm) imaging camera (0.004” per pixel) and integral field spectrograph (0.004” - 0.05” per element) to spatially sample the high angular resolution achieved with TMT's multi- conjugate adaptive optics system. Science goals for the instrument package have been under development across the breadth of astronomical research to yield system requirements. We present sensitivity calculations for point and resolved sources that the imager and integral field spectrograph will be able to achieve. IRIS, with TMT's adaptive optics system, will achieve unprecedented point source sensitivities compared to current 8-10m ground-based integral field spectrograph systems. We also present integral field spectrograph simulated data cubes illustrating the extraordinary potential of IRIS on range of science cases.

7735-285, Poster Session

TMT infrared imaging spectrograph (IRIS): wavefront sensing and AO interface

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The InfraRed Imaging Spectrograph (IRIS) is a first light client science instrument of the facility multi-conjugate adaptive optics system, NFIRAOS, of the Thirty Meter Telescope (TMT). The IRIS science instrument is comprised of the IRIS-NFIRAOS interface, the on-instrument wavefront sensors (OIWFS), and the science dewar containing

an imager and a lenslet and slicer spectrograph. This paper reports on the concept study of the IRIS-NFIRAOS interface and OIWFS subsystems.

The IRIS-NFIRAOS interface includes the instrument rotator and macro structure that supports the OIWFS and the science dewar. The IRIS OIWFS includes three low order natural guide star wavefront sensors; two tip/tilt sensors for fast guiding, and one tip/tilt/focus sensor for focus correction. The images of natural guide stars are sharpened to compensate for atmospheric turbulence by the adaptive optics system over a 2 arcmin field of view to improve the sky coverage for tip/tilt sensing in the infrared with the OIWFS.

In this paper, we report on the concept study and baseline concept design of the IRIS-NFIRAOS interface and OIWFS subsystems, a collaborative effort by NRC-HIA, Caltech, and TMT AO and Instrument teams. This includes work on system engineering, structural and thermal design, sky coverage modeling, patrol geometry, probe optics and mechanics design, detector design, and controls design.

7735-286, Poster Session

A proposal for an upgrade of the VISIR mid-IR instrument at the VLT

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The European Southern Observatory (ESO) is studying a proposal to perform an upgrade of the mid-IR image and spectrograph VISIR at the VLT. The study team is comprised of ESO staff and members of the original consortium that built VISIR: CEA Saclay, ASTRON. The goal is to enhance the scientific performance of VISIR by installing improved hardware as well as by optimising the operations of the instrument. In order to fully capture the needs of the ESO user community we collected input from the users by means of a web-based questionnaire. The limitations of the current detector (sensitivity, cosmetics, artefacts) have been known for some time and a new 1k x 1k Si:As Aquarius array (Raytheon) will be the cornerstone of the VISIR upgrade project. A modified spectroscopic mode will allow covering the N-band in a single observation. In addition concepts for several new modes (polarimetry, coronography) have been studied and are being evaluated. In addition we anticipate enhancing the operational scheme to ensure that optimal use of the observing conditions (e.g. low precipitable water vapour) will be made. The plan also calls for full support by ESO pipelines which will deliver data products using physical units and from which all instrumental signatures have been removed.

7735-287, Poster Session

A high-performance imager and integral field spectrograph for the W. M. Keck Observatory's next-generation adaptive optics facility

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We report on the preliminary design of the first light science instrument for the W. M. Keck Observatory's next generation adaptive optics facility. The instrument will provide imaging at the diffraction limit from ~0.7 microns to 2.4 microns over a field of ~30", and integral field spectroscopy with a field of over 4" x 4" with 0.05" pixels. The instrument features a common set of fore optics for both imaging and spectroscopy, and includes a coronagraph. The design aims at high throughput and low wavefront error while addressing a broad range of wavelengths. The challenges of designing the instrument to address a wide range of science cases while maintaining a strict limit on overall cost will be discussed and the current predictions of performance will be presented along with details of the optical, mechanical, electronic, and software designs.

7735-289, Poster Session

The error analysis and improvement scheme of large scale CCD measuring system in LAMOST field environment

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The whole LAMOST project achieved successfully last year and has observed properly. In the focal plane system, there are the four thousand fiber positioning units on the plane which receive the galaxy spectrum. The precision of the fiber positioning unit will directly effect on the final efficiency of the telescope. The whole positioning system has now been driven by the step motor with open-loop control system and used CCD measurement system to calibrate the precision of the fiber positioning unit. But in the field environment there are many issues such as long distance and large scale decreasing the precision of CCD measurement system. The air disturbance will be the main factors much large than in the lab condition which effect on the measurement system. The cause of the influence factors in the CCD measurement system will be mainly discussed in this paper, and tries to find the scheme to diminish influence, increases the system measuring accuracy, meet the requirement for calibration of the fiber positioning unit. Furthermore, the scheme will be the important foundation to build the closed-loop system in the future.

7735-290, Poster Session

Data simulator for the HERMES instrument

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The HERMES instrument is a high-resolution fiber fed spectrograph (R~30,000) in development for the Australian-Anglo Telescope (AAT), covering the wavelength range (370-1000nm). Given the sophistication of HERMES we have developed an end-to-end data simulator that accurately models the predicted detector images. The data simulator encompasses all aspects of the transmission and optical aberrations of the light path: from the science object, through the atmosphere, telescope, fibers, spectrograph and finally the camera detectors. The simulator uses optical information derived from ZEMAX software that has been processed and verified using MATLAB software. The simulator is sufficiently flexible to model other fiber spectrographs. In addition to helping validate the instrument design, the resulting simulated images will used to develop the required data reduction software. In this paper

we present the aspects of the model, software, example simulations and verification.

7735-291, Poster Session

Performance predictions for the Robert Stobie spectrograph near-infrared arm on SALT

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The Robert Stobie Spectrograph Near Infrared Arm (RSS-NIR) will provide high throughput, low- to medium-resolution long-slit and multi-object spectroscopy with broadband, spectropolarimetric, and Fabry-Perot imaging modes over an 8' x 8' field of view. The wavelength range of the instrument is 0.9-1.7 microns, and can be operated simultaneously with the visible arm to extend the short wavelength limit to 0.32 microns. Once fielded, RSS-NIR will be the only facility instrument on an 8-10 meter class telescope with multi-object spectroscopy capability covering this spectral range simultaneously. RSS-NIR is scheduled to be commissioned on the 11-meter Southern African Large Telescope (SALT) in 2012. This is an upgrade to the existing visible instrument, with which it shares the slit plane and an ambient temperature collimator. Beyond the collimator, the NIR arm is cooled to -40 C, with a cryogenic dewar containing the detector, long wavelength blocking filters, and final camera optics. This semi-warm configuration has required extensive upfront analysis of the instrumental thermal background levels. These analyses have been incorporated into instrument performance simulators for spectroscopic, Fabry-Perot imaging, and spectropolarimetric modes. We present the performance predictions for each of these modes of RSS-NIR and the analyses leading up to these performance estimates.

7735-292, Poster Session

Results of LUCIFER1 commissioning

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LUCIFER is a NIR camera and spectrograph installed at the Large Binocular Telescope. Working in the wavelength range of 0.9-2.5micron, the instrument is designed for direct imaging and spectroscopy with 2 different cameras. A set of longslit masks as well as up to 22 user defined (MOS) masks are available.

The set of user defined masks can be exchanged while the instrument is at operating temperature.

Extensive tests have been done on the electro-mechanical functions, image motion due to flexure, optical quality, instrument software, calibration and especially on the multi-object spectroscopy. Also a detailed characterization of the instrument's properties in the different observing modes has been carried out. Technical results will be presented and compared to the specifications.

7735-293, Poster Session

Precise infrared radial velocimetry with the triplespec exoplanet discovery instrument: current performance and results

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The TripleSpec Exoplanet Discovery Instrument (TEDI) is optimized to detect extrasolar planets orbiting mid-to-late M dwarfs using the Doppler technique at infrared wavelengths. TEDI is the combination of a Michelson interferometer and a moderate-resolution near-infrared spectrograph, TripleSpec, mounted on the Cassegrain focus of the Palomar 200-inch Hale Telescope. The interferometer multiplies the stellar spectrum by a sinusoidal transmission comb, which both provides a reference and preserves the Doppler content otherwise lost to the instrumental profile of the spectrograph. The combination provides large simultaneous bandwidth and shifts systematic errors from pixel-to-pixel wavelength calibration to knowledge of the interferometer cavity distance, which is calibrated simultaneously with a ThAr lamp. Here we present results from observations of Doppler-velocity standard stars and laboratory sources over the past year. Our results indicate that dispersion effects within the interferometer, combined with non-common-path errors between the ThAr calibration source and starlight, limit our performance to approximately 100 m/s. An upgraded version of TEDI, TEDI 2.0, will eliminate this behavior by mixing ThAr with starlight in a scrambled fiber before the interferometer.

7735-294, Poster Session

The Oxford SWIFT spectrograph: first commissioning and on-sky results

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The Oxford SWIFT spectrograph is an I & z band integral field spectrography, commissioned at the 200 inch Hale Telescope at Palomar Observatory in October 2008. SWIFT provides integral field spectroscopy of ~4000 spaxels arranged in a 2:1 aspect ratio contiguous field. It provides spectral resolving power of R~4000 over the wavelength range 6500 to 10500 Angstroms. SWIFT works in conjunction with the Palomar adaptive optics system PALMAO, which is soon to be upgraded to a ~2700 actuator high order AO system PALM3K. SWIFT uses two 4k x 2k thick, fully depleted, LBNL CCD detectors, with high QE up to 1000 nm.

We present the commissioning data from SWIFT, and the results of the first on-sky observations. Diagnosing of problems and fixes will also be described.

7735-295, Poster Session

Mechanical configuration of the re-ionization and transients infrared camera (RATIR)

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RATIR (Re-ionization And Trainsients InfraRed camera) involves manufacturing and implementation of an optical infrared camera in the

1.5m telescope in the Mexican National Astronomical Observatory in San Pedro Martir, Baja California. The primary goal of the RATIR project is to remotely observe Gamma Ray Bursts as detected by the SWIFT satellite. This document describes the problem definition, the mechanical calculations, the conceptual design, the finite element analysis, the final concept configuration and the mechanical performance of the main Support Structure and Dichroic Mounts for the RATIR Instrument.

7735-296, Poster Session

Schedule and commissioning plans for the upgraded GMOS-N science detectors

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We present plans for the commissioning and integration of the new Gemini Multi-Object Spectrograph North (GMOS-N) red-sensitive science detectors. Gemini has purchased three science grade detectors from Hamamatsu Photonics and these are being integrated into a new GMOS-N focal plane assembly at the NRC Hertzberg Institute of Astrophysics. These deep depletion CCDs provide comparable or significantly improved quantum efficiency (QE) across the entire optical range (including blue wavelengths) and into the near infrared, retaining > 80% QE at 1 micron and ~20% QE at 1.1 micron.

These new detectors will not only significantly improve observations currently obtained with GMOS-N, but will open new spectral ranges and observing modes potentially including imaging, longslit and IFU operations with Altair, the Gemini North adaptive optics module. Particular care has been taken to ensure that the popular Nod & Shuffle observing mode will be supported, especially since accurate sky subtraction is of increasing importance at longer wavelengths due to the increased density of strong sky emission lines. The commissioning plan focuses on demonstrating the improvement in all currently available observing modes while minimizing the period of time that GMOS-N is not available to the community for science observing.

The current schedule for delivery of the new focal plane to Gemini North has science commissioning occurring in the first half of August 2010, with GMOS-N semester 2010B queue and classical observing commencing as soon as possible thereafter.

7735-297, Poster Session

Experimental results of multi four-quadrant phase mask

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In the framework of direct detection of exoplanets, a large number of coronagraphs have been proposed to overcome the large ratio that exists between the star and its planet. We propose to use a combination of chromatic Four Quadrant Phase Mask coronagraph to achromatize the dephasing of the coronagraph. After describing the coronagraph principle, we will show preliminary results for large chromatic bandwidth in the visible. Contrast larger than 10000 are reached with more than 250nm of spectral bandwidth.

7735-298, Poster Session

Ultraviolet compatibility tests of lens coupling fluids used in astronomical instrumentation

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We report on extensive laboratory testing of the optical compatibility of immersion fluids often used in ground-based astronomical instrumentation. A strong near-ultraviolet absorption feature is seen after incubating several fluids with polyurethane often used in expansion bladders, and a lesser absorption in the deeper UV with Viton O-Ring material. Substitute materials were tested, many of which show no such absorption. This program was started in response to a strong UV feature which developed over time in the Robert Stobie Spectrograph of the Southern African Large Telescope. A repair strategy was successfully implemented.

7735-299, Poster Session

Infrared radial velocimetry with TEDI: performance development

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The TripleSpec - Exoplanet Discovery Instrument (TEDI) is a device to use interferometric spectroscopy for the radial-velocity detection of extrasolar planets at infrared wavelengths (0.9 - 2.4 µm). The instrument is a hybrid of an interferometer and a moderate resolution echelle spectrograph (TripleSpec, R=2,700,) at the Cassegrain focus of the Palomar 200" telescope. We describe our experimental diagnostic program using laboratory sources and standard stars in different optical configurations, along with performance analysis and results. We explain our instrumental upgrade development to achieve a long-term performance that can utilize our demonstrated, < 10 m/s, short-term velocity precision.

7735-300, Poster Session

Second-earth imager for TMT: SEIT

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The goal of SEIT is to directly detect and characterize Earth-like planets in habitable zone around M stars. The scientific goal is different from that of already proposed Planet Formation Imager (PFI) that aims at reflected-light Jovian planets; our purpose is to detect Earth-like planets but with different atmospheric features. Technically SEIT has a system for sky background and speckle suppressions. The system could be the first instrument to directly detect and characterize such "Earth-like" planets.

7735-301, Poster Session

The Irkutsk Barium filter at the Dutch Open Telescope for narrow-band wide-field high-resolution solar images

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A wide field birefringent filter for the Barium line of 455.4nm is developed in Irkutsk. The Barium line is excellent for Doppler-shift measurements because of low thermal line broadening and steep flanks of the line profile. The filter width is 0.008nm and the filter is tunable over 0.4nm through the whole line and far enough in the neighboring regions. At the Dutch Open Telescope (DOT) is developed a fast tuning system with servomotor. Observations are done in speckle mode with 10 images per second and Keller-VonDerLühe reconstruction with synchronous images of a nearby blue continuum channel at 450.5nm. Reconstruction of only a low number narrow band images is executed with the many high intensity not changing continuum images. Simultaneous observation of several line positions, typically 3 or 5, are made by this combination of fast tuning and speckle. The filter was originally made for hand tuning. Mechanical improvements were made to the filter for the fast and continually motor tuning for making movies. Other improvements are replacing the oil in which the birefringent crystal plates rotate for tuning and a safety system for keeping the tuning within the permitted limits. The refraction index of this oil has to be very nearby that of the crystal plates for reducing the light loss in the many surfaces and has to be stable. All polarizers are birefringent prisms which reduced largely the light loss compared to polarizing sheets. The advantage of this filter over Fabry-Perot filters is the wide field because of large permitted entrance angle and no need of polishing extreme precise surfaces which is difficult for the blue spectral region. The observations at the DOT are done simultaneously with a fast tunable birefringent H-alpha filter also with Keller-VonDerLühe speckle reconstruction. Both filters together give the unique possibility of simultaneous observation of velocities in Photosphere with Barium and Chromosphere in H-alpha.

7735-302, Poster Session

Gemini planet imager coronagraph testbed results

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The Gemini Planet Imager (GPI) is an extreme AO coronagraphic integral field unit YJHK spectrograph destined for first light on the 8m Gemini South telescope in early 2011. GPI fields a 1500 channel AO system feeding an apodized pupil Lyot coronagraph, and a nIR non-common-path slow wavefront sensor. It targets detection and characterizion of relatively young (<2GYr), self luminous planets up to 10 million times as faint as their primary star. We present the coronagraph subsystem's in-lab performance, and describe the studies required to specify and fabricate the coronagraph. Coronagraphic pupil apodization is implemented with metallic half-tone screens on glass, and the focal plane occulters are deep reactive ion etched hole in optically polished silicon mirrors. Our JH testbed achieves H-band contrast below a million at separations above 5 resolution elements, without using an AO system. We present data and numerical Fresnel modeling of the system, and a procedure for calibrating our measured contrast. We also demonstrate the performance of an astrometric and photometric grid that enables coronagraphic astrometry relative to the primary star in every exposure, with a one to a few milliarseconds' precision.

7735-303, Poster Session

The experimental results of APIC: absolute position interfero-coronagraph for direct exoplanet detection

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For the detection and direct imaging of exoplanets, when the intensity ratio between a star and its orbiting planet can be as large as 10^6, coronagraphic methods are mandatory. In 1996, a concept of achromatic interfero-coronagraph (AIC) was presented by J. Gay and Y. Rabbia for the detection of very faint stellar companions, such as exoplanets.We present a modified version of the AIC permitting not only to detect these faint companions but also to determine their relative position with respect to the parent star, a problem that was not solved in the original design of the AIC. In our modified design, two cylindrical lens doublets are used in order to destroy the axis of symmetry induced by the AIC's original design. Our theoretical study, along with the numerical computations and the experimental results show that the axis of symmetry is destroyed when one of the cylindrical doublets is rotated around the optic axis.

7735-304, Poster Session

Results on fibre scrambling for high accuracy radial velocity measurements

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Experience accumulated with the HARPS in La Silla Observatory shows that one of the limitations in the accuracy of radial velocity measurements is the stability of the point spread function (PSF) on the detector caused by the position variations of the star in front of the optical fibre. We use optical and mechanical fibre scramblers to reduce the "fibre memory" of the position of the star with respect to the fibre. We analyze its impact on both,the near and far fields. Theoretical simulations shows big improvements in scrambling gains by using square or octagonal fibres. In this paper we present the results with these fibres including the focal ratio degradation. The scramblers reduce the throughput of the fibre. The scrambling gain - efficiency trade off is discussed.

We present experimental scrambling gain results with mainly mechanical scramblers. Scrambling gains beyond 1000 have been reached. These figures are inside the specifications of ESO high accuracy spectrographs such as ESPRESSO (for the VLT) and for CODEX (for the E-ELT) at expenses of transmission loses. We discuss future tests to improve the scrambling gain optimizing the efficiency.

7735-305, Poster Session

Coronagraphic capability for HARMONI at the E-ELT

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HARMONI is a visible and near-infrared (0.48 to 2.45 micron) integral field spectrograph, capable of providing the E-ELT's core spectroscopic capability, over a range of resolving powers from R ~ 4000 to R ~ 20000. The IFU provides simultaneous spectra of ~32000 (8000) spaxels in the near-IR (visible) arranged in a 2:1 aspect ratio contiguous field.

HARMONI provides a range of spatial pixel (spaxel) scales, which permit the user to optimally configure the instrument for a wide range of science programs. The coarsest scale is well suited to seeing limited observations, and the finest scale provides Nyquist-sampled observations at near-infrared wavelengths, and diffraction-limited images.

We will explore the merits of adding a coronagraphic capability to HARMONI, specifically targeted at enabling observations of faint, nearby companions that require high contrast. The instrument design provides the capability to insert masks at both focal and pupil planes within the instrument. Although the peak Strehl ratio is only ~70%, we show that substantial contrasts can be achieved by post-processing the IFS data cube using spectral deconvolution. We make predictions of achievable contrast as a function of angular distance, based on semi-analytic computations and full Monte-Carlo simulations. We explore various designs of coronagraphs (e.g Lyot, APLC, FQPM), and test the impact of the E-ELT mirrors' aberrations, as well as instrumental aberrations before and after the coronagraph. The optimal choice of elements for the coronagraphic mode of HARMONI is presented. We also investigate the precision with which spectral deconvolution can recover synthetic planetary spectra.

7735-306, Poster Session

Oukaimeden Observatory: detection of exoplanets by the transit method

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About 400 exoplanets have been detected since 1995; at Oukaimeden Observatory we have launched the exoplanets detection by the transit method.

In this paper we present the progress work and the results obtained for the HD 209458b and Corot-2b transit, the instruments used is C14 Telescope, AP900GTO Mount, and CCD SBIG-ST7XME Camera.

The awaited results will allow us to be known by an international network that gathers the professional astronomers (transitsearch.org).

7735-307, Poster Session

Direct imaging of exo-planets and zodiacal disks in the thermal regime with the E-ELT/METIS instrument

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The detection and the characterization of exoplanets will be one of the major topic for the astrophysical sciences in the next decade.

In the context of the upcoming giant (30-42 m) ground-based telescopes (ELTs), it is important to assess the scientific perspectives for mid-infrared instruments observing in the L' (3.5 um) to the N (8-13.5 um) bands.

I will first show that to achieve the challenging goal of the direct imaging of the exoplanets in the thermal regime we will need to develop some new observing modes inherited from the high angular resolution techniques currently or soon used in the near-infrared range.

Besides the characterization of self-luminous giant exoplanets by direct imaging, we identify three important niches for the upcoming thermal infrared instruments on ELTs:

- the direct observations of warm (irradiated) giant exoplanets placed on relatively close orbits (0.2-1 AU)

- direct imaging of melted proto Earth-like planets at the young stages of the planets formation(10-100 Myr)

- the detection of exo-zodiacal disks down to a limit of 10 times our zodiacal disk

7735-308, Poster Session

The visible spectro-polarimeter for the ATST

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We present a conceptual design for the Visible Spectro-Polarimeter (ViSP), which will be one of the post-focus instruments of the 4-m Advanced Technology Solar Telescope (ATST). ViSP is a spectrograph designed to work simultaneously at up to three wavelengths, with a spectral resolution of 170,000 and a spatial resolution of two times the diffraction limit of the telescope (0.08 arcsec at 630.2 nm).

The design is optimized for a spectral range between 380 and 1100 nm, but with the possibility of extending up to 1.6 microns. The instrument implements a versatile, easily reconfigurable layout with the ability to use multiple gratings. The gratings are optimized for the observation of different combinations of solar spectral lines of relevance for magnetic diagnostics. Three wavelengths are selected using independently automated fold mirrors that direct the spectra towards separate camera lenses. At each prime spectral focus a beam splitter creates two spectral images for 'dual beam' polarimetry, which are re-imaged onto 4Kx4K detectors. The instrument is provided with a library of fixed photo-etched slits on optical quality substrates. Light reflected from the slit is used for context imaging. We illustrate the specifications and expected performance of the instrument, and examples of configurations for typical solar observations.

7735-309, Poster Session

Space-based photometric precision from ground-based telescopes

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Ground-based telescopes supported by lidar and spectrophotometric auxiliary instrumentation can attain space-based precision for all-sky photometry, with uncertainties dominated by fundamental photon counting statistics. Earth's atmosphere is a wavelength-, directionally- and time-dependent turbid refractive element for every ground-based telescope, and is the primary factor limiting photometric measurement precision. To correct accurately for the transmission of the atmosphere requires direct measurements of the wavelength-dependent transmission in the direction and at the time that the supported photometric telescope is acquiring its data. While considerable resources have been devoted to correcting the effects of the atmosphere on resolution, the effects on precision photometry have largely been ignored.

We describe the facility-class lidar that observes the stable stratosphere, and a spectrophotometer that observes NIST absolutely calibrated standard stars, the combination of which enables fundamentally statistically limited photometric precision. This inexpensive and replicable instrument suite provides the lidar-determined monochromatic absolute transmission of Earth's atmosphere at visible and near-infrared wavelengths to 0.25% per airmass and the wavelength-dependent transparency to less than 1% uncertainty per minute. The atmospheric data are merged to create a metadata stream that allows throughput corrections from data acquired at the time of the scientific observations to be applied to broadband and spectrophotometric scientific data. This new technique replaces the classical use of nightly mean atmospheric extinction coefficients, which invoke a stationary and plane-parallel atmosphere. We demonstrate application of this instrument suite to stellar photometry, and discuss the enhanced value of routinely provably precise photometry obtained with existing and future ground-based telescopes.

7735-310, Poster Session

Testing of a transmission-filter coronagraph for ground-based imaging of exoplanets

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We present the first laboratory test of a new coronagraph using one transmission filter at the visible wavelength. The primary goal of this work is to test the feasibility of the coronagraph, which is specially designed for ground-based telescope with a central obstruction and spider structures. The transmission filter is circular symmetrically coated with inconel film on one surface and manufactured with a precisely position-controlled physical mask during the coating procedure. At first, the transmission tolerance of the filter is controlled within 5% for each circular step. The target contrast of the coronagraph is set to be 10-5~10-6 at an inner working angle around 5 /D. Based on the high-precision testbed in the laboratory, we obtained the first PSF image of the coronagraph with central obstruction and spider structures on its pupil. As a follow-up effort, the transmission error should be controlled in 2% and the transmission for such filter will be optimized in the near infrared wavelength, which should deliver better performances. Finally, it is shown that the transmission-filter coronagraph has a potentiality to be used for ground-based direct imaging of exoplanets.

7735-57, Session 8

GPI: cryogenic spectrograph optics performances

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The Gemini Planet Imager (GPI), currently under construction as a facility instrument for the 8-m Gemini South telescope. The science instrument for GPI is a cryogenic integral field spectrograph based on a lenslet array. The integral field nature of the instrument allows for a full mapping of the focal plane at coarse spectral resolution. With such a data cube, artifacts within the PSF such as residual speckles can be suppressed. Additionally, the initial detection of any candidate planet will include spectral information that can be used to distinguish it from a background object: candidates can be followed up with detailed spectroscopic observations. The optics between the lenslet array and the detector are essentially a standard spectrograph with a collimating set of lenses, a dispersive prism and a camera set of lenses in a folded assembly. We generally refer to this optical set as the spectrograph optics. This paper describes the spectrograph optical and mechanical design, the assembly procedure (room temperature vs cryogenic compensation), the test support equipments and finally the laboratory optical performances over the field of view. The test procedure includes the imaging performances in both non dispersive and dispersive mode. The test support equipments include a test cryostat, an illumination module with monochromatic fibre laser and waveband light sources and a test detector module.

7735-58, Session 8

Sparse aperture masking (SAM) at NAOS/ CONICA on the VLT

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The new operational mode of aperture masking interferometery has been added to the CONICA camera which lies downstream of the Adaptive Optics corrected focus provided by NAOS on the VLT-UT4 telescope of ESO. Masking has been shown to deliver superior PSF calibration, rejection of atmospheric noise and robust recovery of phase information through the use of closure phases. Over the resolution range from about half to several resolution elements, masking interferometry is presently unsurpassed in delivering high fidelity imaging and direct detection of faint companions. In order to commission this mode, new observing techniques, such as telescope pupil tracking and detector cube mode, have been developed and further enhancements such as “star-hopping” have been proposed for future implementation. These new techniques have also proven to be of interest for many classical modes of NAOS/ CONICA, and are now also offered in combination with classical imaging and coronagraphy in a variety of instrumental configurations.
In this paper we describe the technical steps which were required to commission this powerful new operational mode and we discuss the utility for masking in a variety of scientific contexts. Of particular interest is the combination of the CONICA polarimetry capabilities together with SAM mode operation, which has revealed structures never seen before in the immediate circumstellar environments of dusty evolved stars.

7735-59, Session 8

The first VisAO-fed integral field spectrograph: MagAO IFS

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We present the optomechanical design of the Magellan-AO Integral Field Spectrograph (MagAO IFS), designed to take advantage of Magellan’s commissioned and soon-to-be-integrated 85.1cm concave ellipsoidal Adaptive Secondary Mirror (ASM). With 585 actuators and an equal number of actively-controlled modes, this revolutionary ASM will be the first to achieve moderate Strehls into the visible wavelength regime.
We have designed the MagAO IFS to be coupled to Magellan’s LDSS-3 spectrograph and to optimize VisAO science. Designed for narrow FOV, high spatial resolution science, this lenslet-coupled fiber-fed IFS will offer exciting opportunities for scientific advancement in a variety of fields, including protoplanetary disk morphology and chemistry, resolution and spectral classification of tight astrometric binaries, seasonal changes in the upper atmosphere of Titan, and a better understanding of the black hole M-sigma relation.

7735-60, Session 8

XMS: the extreme multiplex spectrograph for wide-field multi-object spectroscopy

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Two feasibility studies for spectrographs that can deliver at least 4000 MOS slits over a 1° field at the prime focuses of the Anglo-Australian and Calar Alto Observatories have been completed. We describe the design and science case of the Calar Alto eXtreme Multiplex Spectrograph (XMS) for which an extended study, half way between feasibility study and phase-A, was made. The conclusions are quite similar to the AAO study. In a single night, 25000 galaxy redshifts can be measured to z~0.7 and beyond for measuring the Baryon Acoustic Oscillation (BAO) scale and many other science goals. This may provide a low-cost alternative to large fibre systems in projects. The design features four cloned spectrographs which gives a smaller total weight and length than a monolithic spectrograph and make it able to be mounted at prime focus. The clones use a transparent design including a grism in which all optics are about the size or smaller than the clone rectangular subfield so that they can be tightly packed with little gaps between subfields. Only low cost glasses are used; the variations in chromatic aberrations between bands are compensated by changing a box containing the grism and two adjacent lenses. Three bands cover the 420nm to 920nm wavelength range at 10A resolution while another covers the Calcium triplet at 3A. An optional box does imaging. We however also studied different innovative methods for acquisition without imaging. Conceptual designs for larger projects (AAT 2° field, CFHT, VISTA) have also been done.

7735-61, Session 8

Focal plane detectors for the dark energy survey

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The Dark Energy Camera (DECam) is the new wide field prime-focus imager for the Blanco 4m telescope at CTIO. This instrument was developed for the Dark Energy Survey that will start operations at CTIO during 2011. The DEcam focal plane will use 250um thick fully-depleted CCDs designed at LBNL. We have finished packaging and testing of the 62 science grade detectors to be installed in this focal plane. This presentation will describe the performance of the DECam science detectors and the procedures implemented to test them.

7735-62, Session 8

On-sky demonstration of optical speckle stabilization using the SPIFS prototype

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We present on-sky performance results of a new technique, speckle stabilization, with the Stabilized sPeckle Integral Field Spectrograph (SPIFS) prototype. The SPIFS prototype is an optical-imaging instrument capable of diffraction-limited spatial resolutions. It achieves this aim by measuring speckle patterns in real time (through the use of an L3CCD), finding the highest quality speckle, and stabilizing it onto a traditional, low readout speed science camera through the use of a fast steering mirror. This process is repeated at ~100 Hz over the course of long exposures resulting in a diffraction-limited core surrounded by a diffuse halo. We show in the first on-sky tests (in the Sloan i’ and z’ bands) that SPIFS produces spatial resolutions much better than the seeing limit, even approaching the diffraction limit.

7735-63, Session 9

FIFI LS getting ready to fly aboard SOFIA

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FIFI LS is the German far-infrared integral field spectrometer for the SOFIA airborne observatory. The instrument consists of two independent integral field spectrometers for two different wavelength bands (45-110um and 100-200um). A dichroic filter enables simultaneous observation of two different spectral lines in the same field-of view. This allows very efficient mapping of extended regions with FIFI LS in many important far-infrared cooling lines with line ratios sensitive to temperature and density.

In this paper, we present the latest laboratory test results on both spectrometers within FIFI LS with a focus on the new results on the short wavelength spectrometer. We discuss the science potential of FIFI LS as it will become available to the general community within the NASA sponsored Extended Observing Opportunity Program. The instrument will be user-friendly through the same framework and interfaces as other SOFIA instruments, while FIFI LS stays also a Principal Investigator instrument operated by the FIFI LS team and it will be maintained at UC Berkeley.

7735-64, Session 9

FORCAST: a ‘first light’ facility instrument for SOFIA

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FORCAST has been selected to be the “first light” U. S. science instrument aboard SOFIA.

FORCAST will offer dual channel imaging in discrete filters at 5 - 25 microns and 30 - 40 microns, with diffraction-limited imaging at wavelengths > 15 microns.

FORCAST will have a plate scale of 0.75 arcsec per pixel, giving it a 3.2 arcmin x 3.2 arcmin FOV on SOFIA. We give a status update on FORCAST development, including commissioning plans; design and performance of the calibration box; flux calibration in the laboratory; performance of new metal mesh filters; and performance of a new Si:Sb detector.

7735-65, Session 9

CASIMIR: a FIR/sub-mm heterodyne spectrometer for SOFIA

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CASIMIR, the Caltech Airborne Submillimeter Interstellar Medium Investigations Receiver, is a far-infrared and submillimeter heterodyne spectrometer, being developed for the Stratospheric Observatory For Infrared Astronomy, SOFIA. CASIMIR will use newly developed superconducting-insulating-superconducting (SIS) mixers. Combined

with the 2.5 m mirror of SOFIA, these detectors will allow observations of unprecedented sensitivity to be made in the frequency range from 500 GHz up to 1.4 THz. Initially, at least 5 frequency bands in this range are planned, each with a 4-8 GHz IF passband. Up to 4 frequency bands will be available on each flight and bands may be swapped readily between flights. The local oscillators for all bands are synthesized and tuner-less, using solid state multipliers. CASIMIR also uses a novel, commercial, field-programmable gate array (FPGA) based, fast Fourier transform spectrometer, with extremely high resolution, 22000 (268 kHz at 6 GHz), yielding a system resolution greater than 1 million. CASIMIR is extremely well suited to observe the warm, 100 K, interstellar medium, particularly hydrides and water lines, in both galactic and extragalactic sources.
We present an overview of the instrument, its capabilities, systems and expected performance. We also describe recent progress in development of the local oscillators and present the first astronomical observations obtained with the new type of spectrometer.

7735-66, Session 9

The cosmic infrared background experiment (CIBER): instrumentation and first results

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Ultraviolet emission from the first generation of stars in the Universe ionized the intergalactic medium in a process which was completed by z~6; the wavelength of these photons has been redshifted by (1+z) into the near infrared today and can be measured using instruments situated above the Earth's atmosphere. First flying in February 2009, the Cosmic Infrared Background ExpeRiment (CIBER) comprises four instruments housed in a single reusable sounding rocket borne payload. CIBER will measure spatial anisotropies in the extragalactic IR background caused by cosmological structure from the epoch of reionization using two broadband imaging instruments, make a detailed characterization of the spectral shape of the IR background using a low resolution spectrometer, and measure the absolute brightness of the Zodical light foreground with a high resolution spectrometer in each of our six science fields. In this presentation, the scientific motivation for CIBER and details of its first and second flight instrumentation will be discussed. First flight results on the color of the zodiacal light around 1 microns and plans for the future will also be presented.

7735-67, Session 10

Feasibility study of high-resolution integral-field spectrographs for EST with multislit and multiwavelength capabilities

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This communication presents the feasibility study for the four-meter European Solar Telescope of two integral-field spectrographs, one for visible wavelengths (390-1100 nm) and the other for the NIR (700-2300 nm). Both spectrographs are conceptually identical with a field of view of 9x9 squared arcseconds, spectral resolution of 300,000 and spatial resolution of 0.1 arcseconds. The input field of view is reorganized into 8 long slits using an integral field unit. Several wavelengths may be observed simultaneously with each spectrograph (five for the visible range and four for the infrared one). One detector per wavelength is used, in which the wavelength is replicated as many times as the number of entrance slits. Each spectrograph is preceded by a predisperser, with a mask located in its focal plane to generate the spectrograph entrance slits.

7735-69, Session 10

Auxiliary full-disc telescope for the European Solar Telescope

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The Auxiliary Full-Disc Telescope (AFDT) will be used for the orientation of the observer on the solar disc and in its surroundings, for an easy guidance of the EST main telescope to a selected target, and for precise coordinate measurements. AFDT can also be used as an autonomous robotic telescope for synoptic observations and records of solar activity when no observations are carried out at the EST main telescope.
The principal functions of AFDT and the related requirements are summarized. The specific axial mechanical structure accommodating the refractor optical system is outlined. The optical system and its components are described. Two alternatives of the control system - the guiding control system and the positional control system - are described and their functionality is analyzed.

7735-70, Session 10

Spectrograph capabilities of the European Solar Telescope

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EST is a project for a 4-meter class telescope to be located in the Canary Islands. EST will be optimized for studies of the magnetic coupling between the photosphere and the chromosphere. This requires high spatial and temporal resolution diagnostics tools of properties of the plasma, by using multiple wavelength spectropolarimetry. To achieve these goals, visible and near-IR multi-purpose spectrographs are being designed to be compatible with different modes of use: LsSS (Long-slit Standard Spectrograph), multi-slit multi-wavelength spectrograph with an integral field unit, TUNIS (Tunable Universal Narrow-band Imaging Spectrograph), and new generation MSDP (Multi-channel Subtractive Double-pass Spectrograph). In this contribution, these different instrumental configurations will be described, with the necessary modules that need to be inserted in the optical path that make them compatible with the main spectrograph and allow for simultaneous measurements of several spectral lines.

7735-71, Session 10

The ATST visible broadband imager: a case study for real-time image reconstruction and optimal data handling

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The Visible Broadband Imager (VBI) is the highest priority, first-light instrument of the Advanced Technology Solar Telescope (ATST). VBI will deliver high cadence, diffraction limited images in a number of spectral regimes ranging from UV to NIR wavelengths and with a spectral resolution between 0.05 nm to 1nm. In order to achieve diffraction-limited resolution over an extended field-of-view as well as accurate photometry, additional processing of the adaptive optics (AO) corrected images is essential. This is true in particular at UV wavelengths where the Strehl delivered by the AO is relatively low. The VBI data pipeline therefore incorporates near real-time image reconstruction using speckle interferometry algorithms. These algorithms have been refined to make use of the information about residual wavefront errors contained in the telemetry data delivered by the ATST adaptive optics system. The acquisition and reconstruction process requires the use of the high-speed data handling infrastructure of the ATST to retrieve the necessary data from both AO system and instrument cameras. In addition to the VBI delivering science ready data this approach has the added benefit of reducing the data volume to be transferred from the telescope to the ATST data center by a factor of about 100. Near real-time visualization of speckle reconstructed images at the telescope and, at a reduced cadence, for remote observers will aide in monitoring observations and adjusting of observational parameters based on events on the Sun. We present the current design of this infrastructure together with a feasibility analysis of the underlying algorithms.

7735-72, Session 10

The diffraction-limited near-IR spectropolarimeter of the Advanced Technology Solar Telescope

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Solar Magnetic fields shape the appearance of the outer solar atmosphere. Their evolution and interactions with the solar plasma generate energetic solar phenomena. Understanding of these phenomena requires observations that recrod the spectra polarized by the presence of magnetic fields in the solar atmosphere with critical spatial, spectral, and temporal resolutions and field of view coverage. The Diffraction-Limited Near-IR Spectropolarimeter (DL-NIRSP) for the Advanced Technology Solar Telescope (ATST) is specifically designed for this task. It incorporates a novel multiple-slit spectrograph design to greatly enhance the scanning speed of the instrument. It is capable of simultaneous observation of up to four spectral lines in the visible and near-IR (400 nm to 2500 nm) wavelengths. It also supports a large-format fiber-optic array for high speed true-imaging spectropolarimetry of extended 2D fields to study triggering and acceleration mechanisms of the energetic solar events. This paper describes the design and expected performance of the instrument.

7735-238, Session 10

ZIMPOL-3: a powerful solar polarimeter

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The area of high precision solar spectropolarimetry has made great advances in recent years and the Zurich IMaging POlarimeter (ZIMPOL) systems have played a major role in that.

ZIMPOL reaches a polarimetric accuracy of 10^{-5} by using fast (kHz) polarization modulation/demodulation of the light beam in combination with large-area array detectors.

A new generation of improved cameras (ZIMPOL-3) are being implemented for the scientific observations at the solar observatory at Istituto Ricerche Solari Locarno, Switzerland. The new system is based on a flexible and compact modular design, which easily adapts to new applications. A faster electronics and new sensors with higher quantum efficency compared to the previous ZIMPOL versions, allow to achieve a better overall efficency.

Future plans include observing campaigns at foremost large telescopes and the exploration of new technologies (e.g. CMOS).

7735-73, Session 11

The TMT instrumentation program

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An overview of the current status of the Thirty Meter Telescope (TMT) instrumentation program is presented. Conceptual designs for the three first light instruments (IRIS, WFOS and IRMS) are in progress, as well as feasibility studies of MIRES. Considerable effort is underway to understand the end-to-end performance of the complete telescope-adaptive optics-instrument system under realistic conditions on Mauna Kea. Highly efficient operation is being designed into the TMT system, based on a detailed investigation of the observation work flow to ensure very fast target acquisition and set up of all subsystems.

Future TMT instruments will almost certainly involve contributions from institutions in many different locations in North America and partner nations. Coordinating and optimizing the design and construction of the instruments to ensure delivery of the best possible scientific capabilities is an interesting challenge. TMT welcomes involvement from all interested instrument teams.

7735-74, Session 11

An overview of the European ELT instrumentation programme

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In this paper we present a brief status report on the conceptual designs of the instruments and adaptive optics modules that have been studied for the European Extremely Large Telescope (E-ELT). In parallel with the design study for the 42-m telescope, ESO launched 8 studies devoted to the proposed instruments and 2 for post-focal adaptive optics systems. The majority of the studies have been carried out by consortia of institutes outside ESO and will be completed by the time of the meeting. The result promises to be a scientifically powerful set of facility instruments.

The aims of the individual studies are broad: to explore the instrumental capabilities required to meet the E-ELT science goals, to examine the

technical feasibility of the instrument, to understand the requirements placed on the telescope design and to develop a delivery plan. From the perspective of the observatory, this is a key input to the development of the proposal for the first generation E-ELT instrument suite together with science goals of highest priority and the budgetary and technical constraints. We will discuss the lessons learned and some of the key results of the process.

7735-75, Session 11

Science instrument development for the Giant Magellan Telescope

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The Giant Magellan Telescope (GMT) is a 25m diameter optical/infrared telescope. Its seven 8.2m primary mirrors give it a collecting area equivalent to a 22m filled aperture. The nine GMT partners are constructing the telescope at the Las Campanas Observatory in Chile with first light planned for the end of 2018. In this paper, we describe the plans for the first-light focal plane instrumentation for the telescope. The GMTO Corporation has solicited studies for instruments capable of carrying out the broad range of objectives outlined in the GMT Science Case. At the time of the SPIE meeting, with advice from a panel including members from the GMT partners and the US science community, the GMTO board will have selected six instruments for 14 month long Phase A studies. The study group will include instruments that exploit the natural seeing, ground layer adaptive optics, and adaptive optics modes of the GMT. We will describe the features of these instruments, their expected performance, and the major science programs that they enable. The presentation will include both technical details of the individual designs and a discussion of how the instruments fit into the overall design of the telescope system.

7735-76, Session 11

PixelOne: a proposed novel technology to mosaic ELT focal planes

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The early future of astronomy will be dominated by Extremely Large Telescopes where the focal lengths will be of the order of several hundred meters. This yields focal plane sizes of roughly one square meter to obtain a field of view of about 5 x 5 arcmin. When operated in seeing limited mode this field is correctly sampled with 1x1mm pixels. This can be accomplished using a peculiar array of tiny cmos active photodiodes illuminated through microlenses. If the photodiode is small enough and utilizes the 5T pixel technology, its dark current could be well below the sky background photocurrent avoiding the use of cumbersome cryogenics systems. An active smart electronics will manage each pixel up to the A/D conversion and data transfer. This modular block is the PixelOne. 50 x 50 mm tiles filled with 2500 PixelOnes could be the basic unit to mosaic very large focal planes. By inserting dispersion elements inside the optical path of the lenslet we could produce a low dispersed spectrum of each focal plane subaperture and by using an array of few smart photodiodes we can get multiwavelength information in the optical band for each equivalent focal plane pixel. An application to the E-ELT is detailed described.

7735-77, Session 11

Progress of the conceptual design for the MOBIE imaging spectrograph for TMT

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The Multi-Object Broadband Imaging Echellette (MOBIE) is the seeing-limited, multi-object optical spectrograph planned for the first generation of TMT instruments. Following the successful completion of a feasibility study and review in December 2008, the MOBIE instrument project, based at the UC Observatories on the UC Santa Cruz campus, entered a two-year conceptual design phase. We report here on the conceptual design developments to date, including the instrument optical system, opto-mechanics, science detector systems, instrument structures, slit mask fabrication and selection, shutters, filter-changing systems, and motion-controlled subsystems.

7735-78, Session 11

DIORAMAS: a wide-field visible and near-infrared imaging multi-slit spectrograph for the EELT

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Under contract with ESO, we have conducted a Phase A study for DIORAMAS a visible and near-infrared imaging and multi-slit spectrograph for the European ELT. The instrument has a wide field and can work under atmospheric seeing, or under GLAO corrected PSF. Spectral resolution varies from 300 to 3000. More than 300 slits cut by laser in a slit-mask can be observed simultaneously, with an instantaneous wavelength coverage from 0.37 to 1.4 microns. This instrument has outstanding performances in terms of throughput and image quality. It will enable extremely deep imaging to magnitude AB~30, and MOS to AB~27. This simple yet efficient instrument will enable to address some of the main science goals of the EELT, like the discovery and study of the first population of galaxies in the early Universe.

7735-79, Session 11

The infrared imaging spectrograph (IRIS) for TMT: instrument overview

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We present an overview of the design of IRIS, an infrared (0.85 - 2.5 micron) integral field spectrograph and imaging camera for the Thirty Meter Telescope (TMT). It has extremely low wavefront error (<30 nm) and on-board wavefront sensors to take advantage of the high angular resolution of the narrow field infrared adaptive optics system (NFIRAOS) to dissect the sky at the diffraction limit of the 30-meter aperture. With a primary spectral resolution of 4000 and spatial sampling starting at

4 milliarcseconds, the instrument will create an unparalleled ability to explore high redshift galaxies, the Galactic center, star forming regions and virtually any astrophysical object. This paper summarizes the entire design and basic capabilities. Among the design innovations is the combination of lenslet and slicer integral field units, new 4Kx4k detectors, extremely precise atmospheric dispersion correction, infrared wavefront sensors, and a very large vacuum cryogenic system.

7735-80, Session 11

MICADO: the adaptive optics imaging camera for the E-ELT

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MICADO is the adaptive optics imaging camera for the E-ELT. It has been designed and optimised to be mounted to the LGS-MCAO system MAORY, and will provide diffraction limited imaging over a wide (1arcmin) field of view. For initial operations at first light, it could also be used with its own simpler AO module that provides on-axis diffraction limited performance using natural guide stars. I will describe the instrument's key capabilities and expected performance, outline the science drivers, and show how these have shaped its design. In particular I will focus on the issues of astrometry and photometry, discuss the level of accuracy that can be expected, and describe what measures are required to achieve this high precision.

7735-81, Session 12

SIMPLE: a high-resolution near-infrared spectrometer for the E-ELT

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SIMPLE is the Phase A study of a high resolution near-infrared spectrometer for the E-ELT.
In this contribution we present the system-overview, design and main scientific goals of the project.

7735-82, Session 12

The design of a mid-infrared instrument for the Thirty Meter Telescope

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A mid-infrared (MIR) imager and spectrometer is under consideration for construction in the first decade of the Thirty Meter Telescope (TMT) operation. MIRES, a MIR high-spectral resolution optimized instrument, was proposed to afford these capabilities to the TMT community. Working with our Japanese colleagues, we have updated and enhanced the science drivers for the MIR instrument (see the companion paper by Yoshiko K. Okamoto), with a view to increasing the capabilities of the imaging and low-spectral resolution modes, as well as offering an improved optical design for the high-spectral resolution mode with R=100,000. In this paper we describe the technical drivers and the flow down into the design of the instrument, especially the optical design.

7735-83, Session 12

EAGLE: the multi-IFU, AO assisted, near-IR spectrograph for the EELT: a status report

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EAGLE is an instrument for the European Extremely Large Telescope (E-ELT). It is designed for highly efficient spectroscopic observations (assisted by Adaptive Optics) of high redshift galaxies and stellar populations at Mpc distances. It strongly complements the scientific capabilities of JWST and ALMA. The 2-yr ESO funded phase A study was completed in autumn 2009 by a consortium of UK and French institutes. The instrument, as designed, can be built with existing technologies at an affordable cost and manageable risks. We provide a status report of the instrument design and system, and provide performance estimates comparing EAGLE with other space and ground based facilities.

7735-84, Session 12

EPICS: direct imaging of exoplanets with the EELT

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Presently, dedicated instruments at large telescopes (SPHERE for the VLT, GPI for Gemini) are about to discover and explore self-luminous giant planets by direct imaging and spectroscopy. The next generation of 30m-40m ground-based telescopes, the Extremely Large Telescopes (ELTs), has the potential to dramatically enlarge the discovery space towards older giant planets seen in reflected light and ultimately even a small number of rocky planets. EPICS is a proposed instrument for the European ELT, dedicated to the detection and characterization of expolanets by direct imaging and spectroscopy. ESO completed a phase-A study for EPICS with a large European consortium which - by simulations and demonstration experiments - investigated state-of-the-art diffraction and speckle suppression techniques to deliver highest contrasts. The paper presents the instrument concept and analysis as well as its main innovations and science capabilities. EPICS is capable of

discovering hundreds of giant planets, and dozens of lower mass planets down to the rocky planets domain.

7735-85, Session 12

CODEX

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CODEX is the High Resolution, Super Stable optical spectrograph for the E-ELT. Starting from outstanding scientific projects (direct measurement of the dynamics of the universe, finding earth-like twins, determine stellar ages with nucleo-chronometers, the chemical evolution of the intergalactic medium and discover whether physical constants varied in the past) we derived top level requirements and we have carried out a Phase A study for CODEX at the E-ELT. Thanks to a novel design and careful implementation, it is possible to fulfill all the requirements of an exceptionally precise, high resolution, efficient spectrograph with contained costs and in time for the planned first light of the E-ELT. The phase A study includes all aspects of the instrument. In order to prove the feasibility of the most critical items a number of CODEX-related R&D activities have been conducted (Laser Comb Calibration, Fibre Scrambling, slanted VPH gratings, super stable cryostats), which have proven the feasibility of these components within the required specifications.

7735-86, Session 12

Instrument concept and science case for the mid-infrared E-ELT imager and spectrograph METIS

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METIS is the concept for a Mid-infrared E-ELT Imager and Spectrograph, which has just completed the phase-A study. It is the only instrument concept at wavelengths longward of 3 microns for the E-ELT. The METIS baseline includes an imager (incl. coronagraph and polarimeter) and a high resolution (R~100,000) IFU spectrograph, both working at the diffraction limit.

In this presentation we summarize the science case for METIS, which consists of five main science drivers: proto-planetary disks and the formation of planets, physical and chemical properties of exoplanets, the formation history of the Solar system, the growth of supermassive black holes, and the Dynamics of High-z Galaxies. We derive the science requirements, and describe the instrument baseline. We discuss what observing modes are the most promising for such an instrument and predict its performance. We also give an overview of the instrument cost and the particular challenges for this instrument.

This presentation provides the basis for more detailed METIS papers on specific subsystems.

7735-87, Session 13

The infrared imaging spectrograph (IRIS) for TMT: spectrograph design

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The Infra-Red Imaging Spectrograph (IRIS) is one of the three first light instruments for the Thirty Meter Telescope (TMT) and is the only one to directly sample the diffraction limit. The instrument consists of a parallel imager and off-axis Integral Field Spectrograph (IFS) for optimum use of the Near Infra-Red (0.8um-2.4um) Adaptive Optics corrected focal surface. We present an overview of the IRIS spectrograph module that is designed to probe a range of scientific targets from the dynamics and morphology of high-z galaxies to the dynamics of compact Active Galactic Nuceli (AGN), the latter requiring a narrow field and high Strehl performance. To optimally address the science case the IRIS spectrograph combines two technologies into one single camera optical design. A high-Strehl, low wavefront lenslet IFS samples the finest plate scales of 8mas and 12mas at a spectral resolution of R~4000. The lenslet IFS can be operated in a smaller bandpass mode for maximum field of view. Larger plate scales (25mas and 50mas) are delivered by an image slicer IFS that produces fields up to 4.5arcec x 2.25arcsec. This channel offers complete band (z, Y, J, H, K) integral field spectroscopy at a spectral resolution of R~4000. The lenslet and image slicer Integral Field channels are combined at the grating, such that both grating set and Infra-red detector are shared. Thus, the IRIS spectrograph adopts two different multiplexing techniques that enables low wavefront error, diffraction limited 2D spectroscopy at the finest scales as well as high efficiency 2D spectroscopy with large wavelength coverage on more modest spatial scales. We present a layout of the combined system with performance goals.

7735-88, Session 13

HARMONI: a single-field, wide-band, integral-field spectrograph for the E-ELT

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HARMONI is a visible and near-infrared (0.48 to 2.45 μm) integral field spectrograph, providing the E-ELT's core spectroscopic capability, over a range of resolving powers from R (/Δ) ~ 4000 to R~20000. The IFU provides simultaneous spectra of ~32000 (8000) spaxels in the near-IR (visible) arranged in a 2:1 aspect ratio contiguous field.

HARMONI provides a range of spatial pixel (spaxel) scales, which permit the user to optimally configure the instrument for a wide range of science programs, from ultra-sensitive to diffraction limited spatially resolved physical, chemical and kinematic studies of astrophysical sources. The coarsest scale (with spaxels of 0.04") provides a 5" x 10" FoV, well suited to seeing limited observations, and the finest scale a factor of 10 finer, Nyquist sampling the diffraction limit of the E-ELT at near-infrared wavelengths. With its large range of spaxel scales, HARMONI can easily adapt to any flavour of adaptive optics -- indeed it is designed to work with GLAO, LTAO and SCAO, or even with no AO at all!

HARMONI is conceived as a workhorse instrument that will exploit the E-ELT's scientific niche in its early years, starting at first light. At close-to-diffraction limited scales, it will capitalise on the D4 sensitivity gains of the E-ELT, providing unprecedented gains in sensitivity and spatial resolution, which when put together, will transform the landscape in observational visible and near-infrared astronomy.

We present the design of the instrument developed during the Phase A study, including optics, mechanics, cryogenics, electronics and software aspects.

7735-89, Session 13

The EAGLE pick-off system

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The EAGLE instrument requires multiple science targets to be acquired over a large focal plane within a specific space and mass budget. This paper describes the investigation into suitable methods for picking-off the science targets, the limiting factors and the associated trade-offs involved in reaching a design ready for the detail design phase of the project. The novel solutions selected uses free standing pick off mirrors and 3 axis beam-steering mirrors to direct the filed further into the instrument. The additional functions needed for telescope guidance are also described.

7735-90, Session 13

GMTNIRS (Giant Magellan Telescope near-infrared spectrograph): design concept

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We are proposing a sensitive high resolution (R=60,000-100,000) spectrograph to the Giant Magellan Telescope (GMTNIRS, the GMT Near-Infrared Spectrograph). Using large-format IR arrays and silicon immersion gratings, this instrument will cover all of the JHK atmospheric windows (longer than 1.15 microns) or all of the LM windows in a single exposure. GMTNIRS makes use of the GMT adaptive optics system for all bands. The slit dimension of approximately 43 x 500 mas for JHK and 80 x 1000 mas for LM will offer the possibility of spatially resolved spectroscopy as well as the superior sensitivity and wavelength coverage. The GMTNIRS team, composed of scientists and engineers at the University of Texas, the Korea Astronomy and Space Science Institute, and Kyung Hee University in Korea, will carry out conceptual design study to solidify the instrument design. In this paper, we describe the optical and mechanical design of the instrument. The principal innovative feature of the design is the use of silicon immersion gratings which are now being produced by our team with sufficient quality to permit designs with high resolving power and broad instantaneous wavelength coverage across the near-IR.

7735-91, Session 13

Project overview of OPTIMOS-EVE: the fiber-fed multi-object spectrograph for the E-ELT

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OPTIMOS-EVE (OPTical Infrared Multi Object Spectrograph - Extreme Visual Explorer) is the fiber fed multi object spectrograph proposed for the European Extremely Large Telescope (E-ELT). It is designed to provide a spectral resolution ranging from 5000 to 30.000, at wavelengths from 370nm to 1.7µm, combined with a high multiplex (>200) and a large spectral coverage. Additionally medium and large IFUs are available. The system consists of three main modules: a fiber positioning system, fibers and a spectrograph.

The recently finished OPTIMOS-EVE Phase-A study, carried out within the framework of the ESO E-ELT instrumentation studies, has been performed by an international consortium consisting of institutes from France, Netherlands, United Kingdom and Italy. All three main science themes of the E-ELT are covered by this instrument: Planets and Stars; Stars and Galaxies; Galaxies and Cosmology.

This paper gives an overview of the OPTIMOS-EVE project, describing the science cases, top level requirements, the overall technical concept and the project management approach.

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SPIE Astronomical Instrumentation

7736-01, Session 1

The scientific impact of reaching the diffraction limit with ELTs

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The new generation of extremely large telescopes (ELTs) will have key advantages over today's 8-10m telescopes. They will collect more light due to their larger area: light-gathering power scales as the telescope diameter D2, so gains of a factor of ~10 or more are expected. Further, with adaptive optics performing at close to the diffraction limit, ELTs will have much higher point-source sensitivity. This is because for observations limited by background light from the sky, there will be less background included within a diffraction-limited area. Point-source sensitivity will improve at least as fast as D4, permitting gains of a factor of 70 - 100. We describe a few of the areas of astronomical science which stand to benefit from these huge performance improvements: 1) Resolved stellar populations in crowded fields will be used to study the initial mass function of stars, and to map the orbits of stars near the black hole in the center of the Milky Way galaxy for tests of General Relativity. 2) The high-contrast capabilities of ELTs will allow direct imaging and spectroscopy of giant extrasolar planets, and of protoplanetary disks. 3) Near-infrared spatially resolved spectroscopy of galaxies at redshifts ranging from 1.5 to 7 will shed new light on the processes of galaxy assembly and evolution. 4) Diffraction-limited ELTs will allow us to probe the physical properties of the first luminous galaxies in the universe. These and other new science capabilities will enable ELTs to produce dramatic advances in astrophysical understanding.

7736-02, Session 1

ESO adaptive optics program and status

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We will present the status and program of Adaptive Optics at the European Southern Observatory for both the Very Large Telescope and the 42 m European Extremely Large Telescope. A short review of progresses made in the area of key AO technologies and concepts will be provided as well as the path forward for the coming years.

7736-03, Session 1

First light adaptive optics systems and components for the Thirty Meter Telescope

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Atmospheric turbulence compensation via adaptive optics (AO) will be essential for achieving most objectives of the TMT science case. The performance requirements for the initial version of the observatory's facility AO system include diffraction-limited performance in the near IR with 50 per cent sky coverage at the galactic pole. High point spread function uniformity and stability over a 30 arc sec field-of-view are also required for precision photometry and astrometry. These capabilities will be achieved via an order 60x60 multi-conjugate AO system (NFIRAOS) with two deformable mirrors optically conjugate to ranges of 0 and 11.2 km, six high-order wavefront sensors observing laser guide stars in the mesospheric sodium layer, and up to three low-order, IR, natural guide star wavefront sensors located within each client instrument. The associated laser guide star facility (LGSF) will employ 150W of laser power at a wavelength of 589 nm to generate the six laser guide stars.

In this paper, we provide an update on the progress in designing, modeling, and validating these systems and their components over the last two years. This includes work on the overall layout and detailed opto-mechanical designs of NFIRAOS and the LGSF; fabrication and test of a full-scale prototype tip/tilt stage (TTS), which will serve as the mount for the ground-conjugate deformable mirror; conceptual designs studies for the real time controller (RTC) hardware and processing algorithms; fabrication and initials tests of the detectors to be used in the laser- and natural-guide star wavefront sensors; detailed AO system modeling and performance optimization; lab tests of adaptive wavefront sensor centroiding algorithms for use with elongated, time-varying laser guide stars; and high resolution LIDAR measurements of the mesospheric sodium layer. Further details may be found in more specialized papers on each of the above topics.

7736-04, Session 1

An update on the Magellan adaptive secondary AO system

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We present an update to the Magellan adaptive optics system (MagAO). The MagAO system utilizes a 2nd generation 585 element adaptive secondary mirror. The system should be able to achieve both very high strehl Mid-IR AO imaging and very high angular resolution (20 mas) imaging in the visible. 20 mas optical imaging from the ground is not trivial. We have identified a number of necessary non-traditional "VisAO" components and design choices: including: 1) new high-performance atmospheric dispersion compensators (such ADCs are critical for the WFS and VisAO camera); 2) Kalman filtering of the AO loop to minimize the effect of fast/large telescope vibrations; 3) non-common path error/vibration minimization with an ultra-compact piggybacked science package inside the WFS itself; 4) a "smart" predictive shutter to block short periods of poor correction during deep exposures. We expect to be commissioning at Magellan by the end of 2011.

MagAO should bring a gain of 200-300% higher spatial resolutions for deep imaging and spectra than previously possible (from the ground or in space). Our instruments will map out the Halpha, [OI], and [SII] emission from the surfaces of planet-forming circumstellar disks, jets, planetary nebulae, and compact HII regions at scales never before possible. We will make the highest resolution deep spectral maps of the surfaces of asteroids and moons like Titan and Io. We will gain the highest resolution probes of the stellar populations and Ca Triplet kinematics of bright AGN and globular cluster cores. Significant astrophysical insights will be obtained in many fields of astrophysics, planetary science and adaptive optics.

7736-05, Session 1

GeMS: ultimate calibrations and laboratory results

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The Gemini MCAO system, GeMS, is the first instrument of its kind: a Multi-Conjugate adaptive optics system using Laser Guide Stars. It is currently undergoing the last phases of Integration and Test (I&T) at the Gemini South base facility and finally reaching a state in which all the subsystems have been received, integrated and almost all tested. This paper aims to summarize all the key steps of the I&T we have been through, the technical choices we have made, as well as the first full characterization of the performance in the lab.

Particular emphasis will be given to following points: NGS/LGS WFS subaperture (quadcell) centroid gains estimation strategy, flexures calibrations and LUT, optimal extrapolator issues, transfer function/bandwidth characterization, static performance and tomographic NCPA, dynamic performance and reconstructor comparison.

7736-06, Session 1

Latest achievements of the MCAO testbed of the Gregor Solar Telescope

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The testbed of the MCAO for the new 1.5 meter Solar telescope Gregor is now operational. Most of the components will be moved to the telescope after commissioning. The testbed features 4 adaptive mirrors (1 tip-tilt, and 3 DMs), and two Hartmann-Shack sensor units for wavefront tomography in a guide-region oriented approach. We will present the latest performance data, and results of testing various wavefront reconstruction and control schemes, as well as wavefront sensor positions. We will also comment on the effect of the number and positions of guide regions, which can by easily modified in our approach.

The MCAO system of Gregor and the testbed were described in SPIE paper 7439B-33 lately. In this paper we present the results of the experiments performed with the testbed.

7736-07, Session 1

The adaptive optics and wavefront correction systems for the Advanced Technology Solar Telescope

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The high order adaptive optics system is the centerpiece of the 4m aperture ATST wavefront correction system. The ATST wavefront correction system is required to achieve a Strehl of S = 0.6 or better at visible wavelength. The system design closely follows the successful AO implementation at the Dunn Solar Telescope and is based on the correlating Shack-Hartmann wavefront sensor and requires a minimum of 1313 actuators and 1236 subapertures. In addition to AO the ATST will utilize wavefront sensors to implement active optics and Quasi Static Alignment (QSA) of the telescope optics, which includes several off-axis elements. Non-common path wavefront errors are a concern because of the ATST's large instrument setups and associated long optical path distances. Provisions for implementation of multi-conjugate adaptive optics have been made with the design of the optical path that feeds the instrumentation at the coude station. We will give an overview of the design of individual subsystems of the ATST wavefront correction system, discuss performance analysis and describe some of the unique features of the ATST wavefront correction system, such as the need for thermally controlled corrective elements.

7736-12, Session 1

First light AO (FLAO) system for LBT: final integration and acceptance test results in Europe

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The paper describes the NGS adaptive optics system of the LBT telescope called FLAO (First Light Adaptive Optics system). The system uses an adaptive secondary mirror with 672 actuatuators and a pyramid wavefront sensor with adjustable sampling from 30x30 down to 4x4 subapertures. The system was fully assembled in the Arcetri Observatory solar tower together with the LBT infrared test camera. The system passed the acceptance test in early December 2009. The performance measured during the test were closed to goal specifications for all star magnitudes. In particular in the bright end (8,5 magnitude star in R band) the SR in H band correcting 495 modes with 30x30 subapertures was measured to be 81%. In the faint end (16.5 magnitude) the SR correcting 36 modes with 7x7 subapertures was measured to be 4.6%. The seeing conditions for this test were 0.8 arsecond seeing (r0=0.14m@550nm) and an average wind speed of 15m/s. Other seeing conditions up to 1.5 arcsecond seeing has been tested successfully. After acceptance completion the system will be packed and shipped to Mount Graham and should arrive at the LBT telescope in February 2010. The first AO observation is scheduled for May-June 2010 and the commissioning campaign should be completed by the end of 2010.

7736-08, Session 2

The scientific potential of ground layer AO on large telescopes

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Recent technical demonstrations on 8-10m class telescopes suggest that the promise of significant gains in image quality from ground-layer AO can be realized in practice. I will discuss the potential scientific impact of GLAO systems that produce factors of 2 - 4 improvements in encircled energy for both imaging and spectroscopic instruments. Simulations of spectroscopic surveys of high redshift galaxies, photometric studies of resolved stellar populations and astrometric surveys will be used to quantify the scientific gains enabled by GLAO. Case studies will be developed to illustrate how representative observing programs can be made more efficient and more effective with the use of GLAO. Lastly I will consider how GLAO may be coupled to other emerging technologies, such as OH suppression, to further enhance the power of large telescopes on the ground.

SPIE Astronomical Instrumentation

7736-09, Session 2

NFIRAOS: facility adaptive optics system for the TMT

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NFIRAOS, the TMT Observatory's initial facility AO system is a multi-conjugate AO system feeding science light from 0.8 to 2.5 microns wavelength to several near-IR client instruments. NFIRAOS has two deformable mirrors optically conjugated to 0 and 11.2 km, and will correct atmospheric turbulence with 50 per cent sky coverage at the galactic pole. An important requirement is to have very low background: the plan is to cool the optics; and one DM is on a tip/tilt stage to reduce surface count. NFIRAOS' real time control uses multiple sodium laser wavefront sensors and up to three IR natural guide star tip/tilt and/or tip/tilt/focus sensors located within each client instrument. Extremely large telescopes are sensitive to errors due to the variability of the sodium layer. To reduce this sensitivity, NFIRAOS uses innovative algorithms coupled with Truth wavefront sensors to monitor a natural star at low bandwidth. It also includes an IR acquisition camera, and a high speed NGS WFS for operation without lasers. For calibration, NFIRAOS includes simulators of both natural stars at infinity and laser guide stars at varying range distance. Because astrometry is an important science programme for NFIRAOS, there is a precision pinhole mask deployable at the input focal plane. This mask is illuminated by a science wavelength and flat-field calibrator that shines light into NFIRAOS' entrance window. We report on recent effort especially including trade studies to reduce field distortion in the science path.

7736-10, Session 2

The GMT adaptive optics system

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The adaptive optics (AO) system for the GMT is currently under design development. The baseline system is planned around a segmented adaptive secondary mirror (ASM), with elements similar in size to current ASMs for 8 m telescopes. A facility wavefront sensing system is planned to provide AO correction at several science instrument ports. The AO system will contain a subsystem dedicated to controlling the relative phases between the seven segments of the GMT aperture. The anticipated modes include natural guide star, laser tomography, and ground layer adaptive optics. A cooled optical relay is planned to provide baffling and reimaging of the focal plane to the various science ports. The laser projection system will use six beacons on an adjustable radius to support both diffraction-limited and ground layer correction modes. A dedicated test setup is planned to provide off-sky, system-level verification of the AO facility.

7736-11, Session 2

ATLAS: the LTAO system for the E-ELT: design, performance, and sky coverage

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ATLAS (Advanced Tomography with Laser for AO system) is the LTAO module of the E-ELT. It aims at providing a diffraction limited PSF (SR around 50% in K band) in a small scientific FoV for a very significant part of the sky (more than 60% of the whole sky). 6 Laser Guide Stars (located on a 4.3 arcmin ring) will be used together with 2 Natural Guide Stars to be picked off in a 2 arcmin FoV. A MMSE-based RTC algorithm will be considered to obtain an optimal tomographic reconstruction of the turbulent volume and correct for Laser defects (cone effects). A first concept of the module combined with opto-mechanical implementation and associated performance is presented. The main ATLAS components are described and their specificities and innovation highlighted. In particular, a new concept for the natural guide star wavefront sensor (based on a focal plane measurement scheme) is proposed allowing reaching extremely good sky coverage. In addition, the impact of Cn^2 mis-calibrations is analysed and solutions to mitigate this error are proposed.

Results show the feasibility of the concept, its versatility and a relative simplicity which is a good first step toward a potential implementation in the early time of the telescope.

7736-13, Session 2

ARGOS the laser guide star system for LBT

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ARGOS is the Laser Guide Star and Wavefront sensing facility for the large binocular telescope. In this paper we will present the overall design of ARGOS that aims for a wide field adaptive optics correction, available for large image fields and multi-object spectroscopy. ARGOS will deploy multiple laser beacons above each of LBT's binocular mirrors, allowing both sides and a wide field of view to benefit from laser guided adaptive

optics correction. With powerful green pulsed lasers creating laser beacons of more than sufficient brightness, a wavefront sensor with range gated light detection and the use of LBT's adaptive secondary mirror, we expect the ground layer adaptive optics system to enhance the image quality in almost every atmospheric condition. The gain in image quality with ARGOS GLAO implementation at LBT will allow a wide range of science cases to benefit from adaptive optics. Apart from the wide field correction ARGOS delivers in its ground layer mode, we already foresee the implementation of a hybrid Sodium with Rayleigh beacon combination for a diffraction limited AO performance.

7736-14, Session 2

First laboratory results of the SPHERE eXtreme AO system: SAXO

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The direct imaging of exoplanet is a challenging goal of today's astronomy. The light transmitted by exoplanet atmosphere is of a great interest as it may witness for life sign. SPHERE is a second generation instrument for the VLT, dedicated to exoplanet imaging, detection, and characterisation. SPHERE is a global project of a European consortium of 11 institutes from 5 countries. We present here results of the integration phase of the Extrem AO part of SPHERE (a.k.a. SAXO). A full calibration of the individual AO key componants is first described (the high order CILAS DM with 41x41 actuators, the ultra-sensitive EMCCD with less than 1e- RON for a 1.2 kHz frame rate and the ESO-SPARTA RTC). First closed loop results are also presented and actual SAXO performance is discussed and compared to simulation results.

7736-16, Session 3

Impact of laser guide fratricide on TMT MCAO system

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In sodium Laser guide star (LGS) multi-conjugate or multi-object AO systems, a fraction of the outgoing laser light for one LGS may be scattered by the atmosphere, and then be collected by a second LGS WFS where it creates a bright background in the affected subapertures. This effect is referred to as fratricide, which is particularly important for Laser beacons launched from the center of the telescope pupil. There are four major contributions to fratricide caused by 1) Rayleigh, 2) Aerosol, 3) Cirrus, and 4) ozone Chappius band scatter. The Rayleigh scatter has been studied extensively, but the ozone Chappius band scatter has never been discussed in this community to the best of our knowledge. We find that the ozone Chappius band scatter contributes more to fratricide than the Rayleigh scatter due to its higher altitude. On the other hand, the aerosol and cirrus scatter affect the throughput more than back-scatter, due to their almost negligible back-scatter phase function. In this paper, we will discuss all these four effects, quantify the resulting performance degradation for TMT MCAO system, and discuss methods to mitigate these effects.

7736-17, Session 3

Monte-Carlo simulation of ELT scale multi-conjugate and multi-object AO systems

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The use of software based simulation packages is essential for the design of adaptive optics systems on next generation ELT scale telescopes. We present Monte-Carlo AO simulation results for an E-ELT multi-IFU spectrograph instrument comprising multiple laser and natural guide stars with wavefront correction along multiple lines of sight, including performance estimates and simulation calculation times. We discuss the techniques used to perform these simulations, including the use of multi-core processors, GPUs, FPGAs, memory resource sharing and algorithm optimisation. Considerations are also given to compressed reconstructor representations which can greatly simplify the design of real-time control systems. Results for least-square and minimum variance wavefront reconstruction are presented, and the method used to produce these controllers. We also detail algorithms developed specifically for open-loop wavefront control, including slope linearisation, and discuss the benefits that these algorithms have.

We also present simulation results for a proposed technology demonstrator instrument which is designed for 4m class telescope operation, and include results for novel techniques such as the Apply and Learn, using on-sky measurements to build up a control algorithm.

The simulations have been performed using the Durham AO simulation platform, a Monte-Carlo code developed in Durham, and cross-checked with other analytical and Monte-Carlo codes.

7736-18, Session 3

Wide-field AO systems on Extremely Large Telescope: analysis of tomographic reconstruction based on rescaled end-to-end simulation tools

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We investigate in this article tomographic reconstruction using both LGS and NGS, and address related issues such as cone effect and tip-tilt indetermination. To support our analysis, various simulation codes have been developed. Indeed, due to the huge complexity of the E-ELT, fast simulation tools or simulation of downscaled systems must be considered to explore quickly the tomographic issues. We describe the various simulation tools used including Fourier codes and end-to-end (Monte Carlo) codes and discuss relevant scaling laws. First results on Tomography for E-ELT WFAO systems are then presented and discussed. Performance of WFAO systems on the E-ELT is evaluated and control procedures for LGS/NGS based tomography are derived.

7736-30, Session 3

Impact of Cn2 profile on ELT wide-field AO performance

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WFAO system are in their design phase for the ELTs. MCAO (MAORY), LTAO (ATLAS) and MOAO (EAGLE) approaches have been analyzed for the E-ELT. All these approaches require a precise tomographic reconstruction of the turbulent volume. Cn2 profiles come up at two levels: the input "true" profile, and the prior profile used as a regularization in the tomographic reconstruction.

True profile of course impacts on performance, and we show that with E-ELT conditions performance is very sensitive to this input. We therefore address the issue of what is a good true profile, what is a good vertical sampling... We also show that isoplanatic angle is not sufficient to characterize profiles in WFAO. We then derive a practical criterion accounting for the WFS geometry and allows to compare profiles with respect to expected performance.

We then address the issue of the impact of profile uncertainties on tomographic reconstruction. We evaluate the number of layers to be reconstructed, the acceptable precision on the profile. We then discuss the implications in terms of control and strategies that could allow to infer this information from multi-guide-star WFS data.

We believe that these elements are key aspects for the design of future ELT WFAO systems.

7736-19, Session 4

W. M. Keck Observatory's next-generation adaptive optics facility

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We will report on the preliminary design of W.M. Keck Observatory's Next Generation Adaptive Optics (NGAO) facility. This facility is being designed to address a number of key science questions including understanding the formation and evolution of today's galaxies, measuring dark matter in our galaxy and beyond, testing the theory of general relativity in the Galactic Center, understanding the formation of planetary systems around nearby stars, and exploring the origins of our own solar system. The requirements derived from these science questions have resulted in NGAO being designed to have near diffraction-limited performance in the near-IR (K-Strehl ~ 80%) over narrow fields (< 30" diameter) with modest correction down to visible wavelengths (I-Strehl ~ 20%), high sky coverage, improved sensitivity and contrast and improved photometric and astrometric accuracy. The resultant design incorporates laser tomography to measure the wavefront and correct for the cone effect. Open loop AO-corrected near-IR tip-tilt sensors, with MEMS deformable mirrors, will be used to provide high sky coverage. The required high Strehls and companion sensitivity (DJ > 11 magnitudes at 0.2 arcsec with high sky coverage) are supported by a high order deformable mirror that corrects both atmospheric and telescope static errors. PSF stability and calibration will be critical to providing the required photometric and astrometric accuracy (e.g., < 100 micro-arcsecond Galactic Center astrometry). To achieve the required extragalactic sensitivity the science path will be cooled to -15°C. Both imaging and integral field spectroscopy capabilities will be provided by the NGAO science instrument.

7736-20, Session 4

Manufacturing of the ESO adaptive optics facility

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The ESO Adaptive Optics Facility (AOF) consists in an upgrade of one of the ESO VLT unit telescope to an adaptive telescope with a deformable mirror in its optical train, in this case the secondary 1.1 m mirror. This upgrade implements many challenging technologies like: thin shell mirror (1m diam. 2mm thick), high power Na lasers (22W), low RON wavefront sensor cameras (< 1e-), new generation of Real Time Computer (SPARTA) for adaptive control. It also faces many problematic similar to an ELT and as such, will validate many technologies and solutions needed for the E-ELT 42m telescope. The AOF will offer a very large FOV (7 arcmin) GLAO correction in J,H and K bands (GRAAL+Hawk-I), a visible integral field spectrograph with 1 arcmin GLAO corrected FOV (GALACSI-MUSE WFM) and finally a LTAO 7 arcsec FOV (GALACSI-MUSE NFM). Most systems of the AOF have completed final design and are in manufacturing phase. Specific activities are linked to the modification of the 8 m telescope in order to accomodate the volume of electronics, increased power and cooling requirement with respect to the actual state. A one year test period in Europe is planned to test and validate all modes and their performance followed by a commissioning phase in Paranal scheduled for 2013-14.

7736-21, Session 4

E-ELT M5 field stabilisation unit scale 1 demonstrator design and performances evaluation

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The M5 Field Stabilization Unit (M5FU) for European Extremely Large Telescope (E-ELT) is a fast correcting optical system that shall provide tip-tilt corrections for the telescope dynamic pointing errors and for the effect of atmospheric tip-tilt and wind disturbances.

NTE-SENER (S) is in charge of building a M5FU Scale 1 Demonstrator (M5FU1D) and developing the conceptual design of the final unit, under ESO contract and supported by CSEM and SAGEM as subcontractors.

The M5FU1D is being built to assess the feasibility of the key elements (actuators, sensors, mirror, mirror interfaces) and the real-time control algorithm. The strict constraints (e.g. Tip-tilt bandwidth 100Hz, 3 meter ellipse mirror size, Mirror first Eigen frequency 300Hz, maximum range ± 150 µrad, maximum tip-tilt error < 200 nrad) have been a big challenge for developing the M5FU Conceptual Design and its demonstrator.

The paper summarises the proposed design for the demonstrator and the early measured performances compared to the applicable specifications.

7736-22, Session 4

Commissioning status of Subaru laser guide star adaptive optics system

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The laser guide star adaptive optics system at Subaru Telescope is under commissioning mainly for the laser guide star mode. We use curvature wavefront sensor and bimorph deformable mirror with 188 sub apertures. The natural guide star mode is opened to all observers since the fall of 2008. We successfully achieved the Strehl ratio at K-band around 0.6 to 0.7 using the guide stars brighter than 10 magnitude in R-band.

While we serve the natural guide star mode, the engineering observations have been conducted for characterizing the laser guide star itself, and building a control method of focusing and steering for laser guide star on the sky. The FWHM size of the laser guide star is estimated by the obtained image, whose exposure time is 10 to 20 second, about 1.2 to 1.6 arcsecond under the averaged seeing condition.

On the other hand, we have been fabricating the tip-tilt and focus wavefront sensor, the tip-tilt and focus guide star acquisition system, wavefront control software for hybrid wavefront sensors, remote switching system for beam splitters, which are mandatory for the laser guide star mode.

The tip-tilt jitter and focus drift of the laser guide star are compensated by the tip-tilt mirror located at the pupil plane inside the higher order wavefront sensor and the focus adjustment function of the guide star acquisition system in front of the higher order wavefront sensor.

We are planning to start the on-sky test for the laser guide star mode from January 2010.

7736-23, Session 4

Status of the 6.5m MMT Telescope laser adaptive optics system

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The Laser Adaptive Optics system of the 6.5 m MMT telescope has now commissioned Ground Layer Adaptive Optics operations as a tool for astronomical science. In this mode the wavefronts sampled by each of five laser beacons are averaged leading to an estimate of the aberration in the ground layer which is compensated by the deformable secondary mirror at 400 Hz. Image quality of 0.2-0.3 arc sec is delivered in the near infrared bands from 1.2-2.5 µm over a field of view of 2 arc min. Tomographic wavefront sensing tests are scheduled for April 2010 paving the road to close the AO loop in this mode and enabling image correction to the near IR diffraction limit. We expect a moderate Strehl ratio (30% at K band) almost anywhere in the sky. A novel approach will be used to compute the tomographic wavefront reconstructor, which will be built on the fly as conditions evolve, relying on closed-loop system telemetry. In this way, the system will be continuously optimized for changing conditions in the turbulence layer profile and the optical train caused by flexure or temperature drifts. This capability offers a major advantage for any kind of adaptive optics system. Also, we describe the addition of ARIES to the system, the primary instrument for AO at the MMT, which has up to now only been used with NGS. ARIES offers both imaging and echelle spectroscopy in separate optical channels, operating in JHK bands. ARIES can also be loaded with up to six slit masks simultaneously for MOS, offering spectral resolution ~3000. Finally, we will also describe a number of system upgrades now being carried out.

7736-24, Session 4

Laboratory results from the CANARY on-sky MOAO demonstrator

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The CANARY on-sky Multiple Object Adaptive Optics (MOAO) demonstrator will be commissioned on-sky at the 4.2m William Herschel Telescope during July 2010. This initial phase of the experiment will demonstrate open-loop tomographic Adaptive Optics (AO) correction of a single on-axis science target. Here we present the results of the assembly, integration and testing phase of CANARY, including performance of individual subsystems, such as the tomographic wavefront sensors and real-time control system. The performance of the system as a whole in both open and closed-loop configurations has been measured in the laboratory while running on multi-layered emulated turbulence. We present an early analysis of the sensitivity of open-loop AO to changes in turbulence profile as well as the alignment and calibration of the system. We then discuss the remaining work to be undertaken for the NGS-only tomography phase of CANARY and the upgrade path to performing multi-LGS tomography.

7736-25, Session 5

Progress and prospects for high-contrast adaptive optics

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So-called “Extreme” adaptive optics systems, designed specifically for high-contrast / high-Strehl imaging of extrasolar planets, have been proposed for more than a decade. Over the past ten years, the field of high-contrast imaging has advanced significantly, particularly the recognition of the importance of systematic error terms, and the lessons learned applied to the design of new systems. Using new instruments and processing techniques the first images and spectra of extrasolar planets have now been produced by existing AO systems. In 2011, the first systems designed from the beginning solely for planet imaging will become operational, an order of magnitude more powerful than their predecessors. I will review the evolution of the field and the possibilities for the future.

7736-26, Session 5

Conceptual design of the multi-conjugate adaptive optics module for the European Extremely Large Telescope

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The Multi-conjugate Adaptive Optics RelaY (MAORY) for the European Extremely Large Telescope (E-ELT) provides a corrected field of view of up to 2 arcmin diameter over the wavelength range 0.8-2.4 micron. It is expected to achieve a correction of high quality and uniformity with high sky coverage: with a seeing of 0.8 arcsec in the visible, the expected Strehl Ratio averaged over a 1 arcmin field is approximately 50% at 2.16 micron wavelength over 50% of the sky at the Galactic Pole. Wavefront correction is obtained by means of the E-ELT adaptive mirrors M4/M5 and of two post-focal deformable mirrors conjugated at 4km and 12.7km from the telescope pupil. Wavefront sensing is performed by 6 Sodium laser guide stars and by 3 natural guide stars, used to measure atmospheric and windshake tilt and to provide a reference for the focus and for the low-order aberrations affected by the Sodium layer variability. MAORY is located on the E-ELT Nasmyth platform and has a gravity invariant port with mechanical field derotation, feeding the high angular resolution camera MICADO, and a vertical port without field derotation for a detached instrument. A conceptual design study has been carried out by a consortium formed by the Italian National Institute for Astrophysics (INAF) and by Office National d’Etudes et de Recherches Aerospatiales (ONERA), in the framework of the phase A studies for the E-ELT instrumentation sponsored by the European Southern Observatory. This paper presents the conceptual design and the estimated performance of the module.

7736-27, Session 5

EAGLE MOAO system conceptual design and related technologies

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This work is part of the Phase A study of EAGLE, one of the potential E-ELT instruments. It is a wide field, multi Integral Field Unit (IFU) near IR spectrograph covering a 10 arcmin patrol field and also consists of a fully integrated AO system for enhanced performance. One of its main scientific drivers is the analysis of the physics and evolution of high-redshift galaxies. The AO system is used to increase the spatial resolution performance: Ensquared Energy (EE) > 30% for 75x75 mas^2 spatial resolution to ensure a high SNR. It is a Multi Object AO system, delivering the full AO correction for small field areas centered on the selected galaxies. It combines 6 LGS and 6 NGS for the wavefront sensing distributed over the whole patrol field. It provides open-loop compensation for the atmospheric turbulence on each target using tomographic reconstruction. Numerical simulations, key-concept laboratory validations and an on-sky demonstration are conducted to ensure a well design the system, to demonstrate the feasibility of the concept and to reduce the risks. We will present the design, the selected key technologies and the results obtained for the concept validations.

7736-28, Session 5

Raven: a harbinger of multi-object adaptive optics based instruments at the Subaru Telescope

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In the context of instrumentation for Extremely Large Telescopes (ELTs), an Integral Field Units (IFU) spectrograph, fed with a Multi--Object Adaptive Optics (MOAO) system, has many scientific and technical advantages.

Integrated with an ELT, a MOAO system will allow the simultaneous observation of up to 20 targets in a several arc--minute field--of--view, each target being viewed with unprecedented sensitivity and resolution.

However, before building a MOAO instrument for an ELT, several critical issues, such as open--loop control and calibration, must be solved.

The Adaptive Optics Laboratory of the University of Victoria, in collaboration with the Herzberg Institute of Astrophysics, the Subaru telescope and two industrial partners, is starting the construction of a MOAO pathfinder, called Raven.

The goal of Raven is two--fold:

First, Raven has to demonstrate that MOAO technical challenges can be solved and implemented reliably for routine on--sky observations.

Secondly, Raven must demonstrate that reliable science can be delivered with multiplexed AO systems.

In order to achieve these goals, the Raven science channels will be coupled to the Subaru's spectrograph (IRCS) on the infrared Nasmyth platform.

This paper will present the status of the project, including the conceptual instrument design and a discussion of the science program.

7736-29, Session 5

Adaptive optics and MCAO for the 4-m European Solar Telescope EST

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A consortium of 29 European solar physics institution from 9 different countries is conducting a design study for a 4 m class solar telescope which shall be situated at the Canary Islands. In this paper we introduce the AO and MCAO design concept for EST. A ground layer deformable mirror is combined with an arrangement of four deformable layer mirrors. A combination of Shack-Hartmann wave front sensors with wide and narrow fields of view is used to control the system and to achieve a corrected field of view of one arcmin. Simulations show the expected performance.

7736-15, Session 6

Laser guide star return flux simulations based on observed sodium density profiles

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The upcoming generation of 30+m telescopes will rely crucially on sodium laser guide star (LGS) assisted adaptive optics. Because powerful lasers at 589 nm are still under development and will be expensive, the required laser power to achieve the return flux specifications must be accurately modeled. Previous simulations describe the efficiency of cw LGS lasers [1], but are based on numerous assumptions and simplifications, regarding specifically the mesospheric sodium distribution, temperature, and gas densities.

In this work, we employ high-resolution lidar sodium density profiles that have recently become available [2]. Moreover, we simulate the laser mesospheric irradiance distribution using physical optics [3], depending on beam quality, laser projection equipment, and the atmospheric turbulence. Finally, we compute the return flux efficiency depending on all of these inputs using optical Bloch equations [1] and integrate along the laser beam in the mesosphere. We are thus able to produce accurate sky maps of photon return, governed by airmass and angle to the geomagnetic field. We can show that the return flux from modern LGS lasers a) is biased towards the sodium in the lower parts of the mesosphere, and b) decays with increasing zenith angle more strongly than the inverse airmass. We compare different laser types and geographic telescope locations.

[1] R. Holzlöhner et al, A&A 13108-09, in print (2009), http://dx.doi.org/10.1051/0004-6361/200913108

[2] T. Pfrommer et al., Geophys. Res. Lett. 36, L15831, doi:10.1029/2009GL038802

[3] R. Holzlöhner et al., Proc. SPIE 7015, pp. 701521-701521-11 (2008)

7736-31, Session 6

Modeling update for the Thirty Meter Telescope laser guide star dual-conjugate adaptive optics system

L. Gilles, L. Wang, B. L. Ellerbroek, Thirty Meter Telescope Project (United States)

This paper presents three areas of modeling work in progress for the Thirty Meter Telescope (TMT) Narrow Field Infrared Adaptive Optics System (NFIRAOS), which is the observatory's facility laser guide star (LGS) dual-conjugate adaptive optics system. Topics discussed are: (1) a novel minimum variance split tomography reconstruction scheme for optimal blending of laser and natural guide star wavefront sensor (WFS) measurements, fully applicable to all laser tomography systems (multi-conjugate and multi-object), (2) a noise propagation analysis for elongated sodium laser guide stars for various laser launch telescope configurations, and (3) an algorithm for real-time turbulence profile estimation from closed loop laser guide star measurements.

7736-32, Session 6

Fractal iterative method for fast atmospheric tomography on Extremely Large Telescopes

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A challenge of adaptive optics (AO) on Extremely Large Telescopes (ELTs) is to overcome the difficulty of solving a huge number of equations in real time, especially when atmospheric tomography is involved. This is particularly the case for multi-conjugate or multi-objects AO systems. In addition, the quality of the wavefront estimation is crucial to optimize the performances of the future systems in a situation where measurements are missing and noises are correlated.

The Fractal Iterative Method has been introduced as a fast iterative algorithm for minimum variance wavefront reconstruction and control on ELTs. This method has been successfully tested on Classical Single Conjugate AO systems on Octopus numerical simulator at ESO. But the minimum variance approach is expected to be mostly useful with atmospheric tomography.

We present the first results obtained with FrIM in the context of atmospheric tomography. We recall the principle of the algorithm and we summarize the formalism used for modeling the measurements obtained from laser guide stars that entail spot elongation and tip/tilt indetermination, mixed with low order measurements from natural guide stars. We show the respective effects of tip/tilt indetermination, spot elongation, unseen modes on various configurations, as well as the usefulness of priors and correct noise models in the reconstruction.

This analysis is essential for balancing the various errors that combine in a quite complex way and to optimize the configuration of the future AO systems for specific science cases and instrument requirements.

7736-33, Session 6

Sky coverage assessment strategy for wide-field AO systems: application to ALTAS, the LTAO system of the E-ELT

S. Meimon, T. Fusco, J. Conan, ONERA (France); F. Assémat, Observatoire de Paris à Meudon (France)

Tomographic AO (or Wide Filed AO) systems use laser guide stars to build a 3D model of turbulence. However, they rely on natural guide stars for low order sensing. They are led to use sophisticated control laws for low order sensing, mixing temporal and spatial models of the turbulence, in order to maximize the NGS limit magnitude, and hence the sky coverage. A correct estimation of the sky coverage in this context is therefore a key issue. In the case of the E-ELT laser tomographic system ATLAS, we have developped a sky coverage estimation strategy suited to the Kalman filter low order control law. This strategy relies on a Besançon model starfield generation, a star couple (or triplet) selection tool, and a careful estimation of the residual tilt and focus anisoplanatism (after reconstruction process between the NGSs), noise and temporal error contributors. In this paper, we describe the details of the procedure, and we derive the ATLAS expected performance, showing that this system should be able to reach a extremely high sky coverage with good (near IR) performance both in terms of Encircled energy and Strehl Ratio. Finally, we show that it is applicable to a wide range of tomographic systems (MOAO, MCAO or GLAO like) both on the Very and the future Extremely Large telescopes.

7736-90, Poster Session

Setting up ELP-OA: the polychromatic laser guide star demonstrator

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No abstract available

7736-91, Poster Session

Maintenance and operation of the adaptive optics module for NICI, the high-contrast coronagraphic imager of GEMINI Observatory

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NICI, the high-contrast coronagraphic imager of Gemini observatory, primarily dedicated to planet hunting has been offered to the astronomical community since end of 2008. We will present our

experiences in operating and maintaining NICI's 85 element curvature adaptive optics system.

We will summarize the behavior of interaction matrices, control matrices and error transfer functions under different operational conditions (e.g. repeatability, impact of tilt or focus offsets).

Furthermore, we describe tuning (membrane mirror stroke/extra focal distance) for non-optimal seeing conditions as well as for niche applications of NICI such as observing small moons and asteroids. According on-sky performances are compared to theory or simulation.

7736-92, Poster Session

MOAO activities in Tohoku University

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We started adaptive optics development activities in Tohoku university in Japan targetting Multi-Object Adaptive Optics system for the next generation ground-based large telescope. Currently three researches are underway. First one is the development of a large stroke (20micron) MEMS deformable mirror with large number of elements (64x64) which is required for AO systems on 30m class telescopes. Based on our original design to achive the requirements, prototyping of the device is currently underway using the MEMS development facility in Tohoku university. Prototype driver electronics for the DM is also under fabrication in collaboration with Subaru telescope. Second one is a consideration of tomographic algorithm for the wavefront estimation required for the MOAO system. The last one is the development of the MOAO test bench in the lab. The test bench will have 3 and one light paths representing three laser/natural guide star and a science target. Concept design of the test bench system will be shown.

7736-93, Poster Session

A focal plane sensor for low-order sensing on laser tomographic systems

S. C. Meimon, T. Fusco, J. Sauvage, S. Dandy, L. Mugnier, F. Cassaing, ONERA (France)

Laser Tomographic systems, such as ATLAS, will rely on natural guide stars (NGS) to sense low order perturbation. This low order perturbation contains low order turbulence and Telescope Windshake, which strength lead to NGS wave front sensor (WFS) frame rate of several hundred Hertz. Therefore, the ability of the NGS WFS to deliver precise low order measurements in low signal to noise conditions will drive the limit magnitude of the NGS, hence the sky coverage. We have investigated the use of a focal plane sensor for this purpose, and consider it as the most efficient sensor in this context. We compare it to classical sensors, such as Pyramid WFS and Shack-Hartmann WFS. We derive an analytic model of the noise propagation law, which we validate on End-to-End diffractive simulations, based on realistic phase screens.

7736-94, Poster Session

A compact design of a wfs for a natural guide star-based ELT adaptive optics system

J. Farinato, R. Ragazzoni, C. Arcidiacono, A. Baruffolo, M. Dima, G. Gentile, D. Magrin, V. Viotto, Osservatorio Astronomico di Padova (Italy)

We describe the opto-mechanical implementation of a group of WaveFront sensors able to drive an MCAO system in order to cover a Field of View of the order of 1-2 arcmin, but getting advantages from the starlight coming from a Field of View as large as 10 arcmin in diameter.

This involves a number of arms with a miniaturized, very small Field of View, single reference Adaptive Optics systems. A pyramid wavefront sensor working in close loop is fed through a small Deformable Mirror that is continuously monitored by an extremely high dynamic range wavefront sensor, whose signal has similar modality than the Pyramid one.

In this way, a very compact wavefront sensor with a dynamic range limited by the stroke of the Deformable Mirror is achieved. Such a sensor is characterized by a limiting magnitude performances typical of a closed loop coherent wavefront sensor. This concept, in addition with an architecture of a Wavefront Computer that allows the implementation of a number of virtual Deformable Mirrors, allows for the development of an NGS based concept described elsewhere.

Emphasis is given in this talk to the practical implementation and to the opto-mechanical details, including an overview of the required components, especially the detectors and the deformable mirrors; we also show that the goal is attainable with today existing components.

7736-95, Poster Session

Status and new operation modes of the irreplaceable and versatile VLT/NaCo

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This paper aims at giving an update on the most versatile Adaptive Optics fed instrument to date, the well known and successful NaCo (for the Nasmyth Adaptive Optics System NAOS and the Near-Infrared Imager and Spectrograph). Although NaCo is only scheduled for two more years at the Very Large Telescope (VLT), it keeps on evolving with many more operation modes. The high contrast imaging community uses it creatively as a test-bench for SPHERE and other second generation planet imagers. A new visible wavefront sensor (WFS) optimized for Laser Guide Star (LGS) operations has been installed and tested, the cube mode is more and more required for frame selection on bright sources, a seeing enhancer mode (no tip/tilt correction) is now offered to provide full sky coverage and welcome all kind of extragalactic applications, etc. The Instrument Operations Team (IOT) is currently working hard on calibrating non-common path aberrations, flexures, and many other infamous NaCo issues to provide the community with a well tuned and original instrument for the remaining two years. In the present contribution we are also reporting performances and capabilities (especially for the new modes), some results from original experiments that have been carried out in the past months, and we attempt to quantify and evaluate the science return NaCo is having in today's context.

7736-96, Poster Session

Fast, autonomous holographic adaptive optics

G. P. Andersen, U.S. Air Force Academy (United States)

We have created a new adaptive optics system using a holographic modal wavefront sensing method with the autonomous (computer-free) closed-loop control of a MEMS deformable mirror. A multiplexed hologram is recorded using the maximum and minimum actuator positions on the deformable mirror as the "modes". On reconstruction, an input beam will be diffracted into pairs of focal spots - the ratio of particular pairs determines the absolute wavefront phase at a particular actuator location. The wavefront measurement is made using a fast, sensitive photo-detector array such as a multi-pixel photon counters.

This information is then used to directly control each actuator in the MEMS DM without the need for any computer in the loop.

We present results of a 32-actuator prototype device with a footprint the size of a sheet of paper operating at kHz rates. We further demonstrate that being an all-optical, parallel processing scheme, the speed is independent of the number of actuators. In fact, the limitations on speed are ultimately determined by the maximum driving speed of the DM actuators themselves. Finally, being modal in nature, the system is largely insensitive to both obscuration and scintillation. This should make it ideal for laser beam transmission or imaging under highly turbulent conditions.

7736-97, Poster Session

Feasibility study of wavefront sensing with a Mach-Zehnder for extreme adaptive optics with very large telescopes

M. P. Langlois, Ctr. de Recherche Astrophysique de Lyon (France); M. Tallon, Ctr. de Recherche Astronomique de Lyon (France); G. Moretto, Lab. de Physique Corpusculaire Clermont-Ferrand (France)

Direct detection of exo-planets from the ground will become a reality with the advance of a new class of extreme-adaptive optics instruments that will come on-line within the next few years on 8-10 meters class telescopes. One major technical challenge in reaching the requisite high contrast at small angles is the sensing and control of wave front errors, which becomes even more challenging in the case of the extremely large telescopes.

This paper investigates the feasibility of a single stage extreme adaptive optics (XAO) system using a Mach-Zehnder wavefront sensor. Such WFS is particularly well adapted to XAO because of its near optimal, very high sensitivity and smaller computing requirements allowing to control very accurately a high number of degrees of freedom. The main limitation to its use is a small dynamical range. We propose to overcome this constraint with polychromatic operation and new phase unwrapping techniques adapted to non-linearity. We validate this concept by numerical simulations for the future ELTs extreme adaptive optics systems.

7736-98, Poster Session

Residual tip-tilt motion of LGS in monostatic scheme

V. P. Lukin, V. V. Nosov, L. A. Bolbasova, Institute of Atmospheric Optics (Russian Federation)

There is analyzed the possibility to correcting the general tilt of the wave front on base of the signal from laser guide star (LGS). The calculation of the image motion of the spherical wave is conducted with random center. It is offered the exact formula for random vector, defining the position of the image of the spherical wave in focus of the telescope provided that position the source of radiation also fluctuated.

The calculated dispersion these residual fluctuations. The analysed dependency the variance of this residual motion from parameter, describing optical experiment. The analysis of the similar problem interesting for decision of the row of the practical problems, including, and for analysis of the possibility to correction “global” tilt of the wave front when use the LGS.

It is analyzed in addition quality of the image extraterrestrial object, formed by astronomical optical system through turbulent atmosphere. Relative increase the parameter Strehl is calculated under adaptive correction on base of the using the technology of the laser guide stars. It is compared efficiency of adaptive correction the distortions for different type of the guide sources. The calculations are executed for different models of the high-altitude evolution of the structure parameter of the refractive index of turbulent atmosphere.

7736-99, Poster Session

High-precision fast photometry from ground-based observatories

J. Osborn, R. W. Wilson, Durham Univ. (United Kingdom); V. Dhillon, The Univ. of Sheffield (United Kingdom); R. Avila, Univ. Nacional Autónoma de México (Mexico); G. D. Love, Durham Univ. (United Kingdom)

High precision fast photometry from ground based observatories is a challenge due to intensity fluctuations induced by the Earth’s atmosphere. Here we describe a method to reduce this noise source by conjugating the pupil to the altitude of a high dominant turbulent layer. We reduce the scintillation from this layer by apodising the pupil to block the diffraction rings and normalise with a comparison star to remove the scintillation we now obtain from the lower layers. We find by simulation that given a simple atmosphere with a single high altitude turbulent layer and a strong surface layer a reduction in the intensity variance by a factor of 30 is possible. Given a more realistic atmosphere as measured by SCIDAR at San Pedro Mártir we find that on a night with a strong high altitude layer we can expect the median variance to be reduced by a factor of 6.5. By reducing the scintillation noise we will be able to detect much smaller changes in brightness. If we assume a 2 m telescope and an exposure time of 60 seconds a reduction in the scintillation noise by a factor of 6.5 would reduce the photometric errors from 1 mmag to 0.35 mmag which will enable the routine detection of, for example, the secondary transits of extrasolar planets from the ground.

7736-100, Poster Session

Online wind estimation and prediction for a two-layer frozen flow atmosphere

L. C. Johnson, D. T. Gavel, D. M. Wiberg, Univ. of California Observatories (United States)

We present a method for online estimation and prediction of wavefront distortions caused by two independent layers of frozen flow turbulence. The key to this algorithm is a fast, gradient-based estimator that uses optical flow techniques to extract the bulk velocity vectors of the two wind layers from three consecutive measurements of their combined wavefront. Once these velocity vectors are known, the phase aberrations associated with each layer can be found by de-shifting and averaging a sequence of past wavefront measurements. Each wind layer is then shifted by the appropriate amount and the layers are recombined to calculate a deformable mirror correction that compensates for the time delay errors in the control loop.

Previous results have shown that predictive control can significantly improve the Strehl performance of adaptive optics systems and that this performance improvement becomes more dramatic as the actuator density of the deformable mirror increases. Predictive control will be especially beneficial for visible light and high-contrast adaptive optics. A multi-layer approach to predictive control is necessary since most observing sites have multi-layer atmospheres. The spatial domain method that we present is attractive because it uses all spatial frequency components of the wavefront simultaneously to find a global wind model. It also does online estimation of the wind vectors and their corresponding phase aberrations so it is sensitive to changes in the wind on the order of tens of milliseconds.

7736-101, Poster Session

Implementation and characterization of a phase apodization coronagraph using a focal plane interferometer

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Arizona (United States)

A phase apodization coronograph (PAC, Codona & Angel, ApJ, 604, L117-L120, 2004) is implemented using a single MEMS deformable mirror (DM) at the pupil plane. The MEMS PAC method does not require the use of a Lyot stop, and can provide halo suppression for complex pupils to the control radius of the DM, 6 lambda/D for the fully illuminated 12x12 actuator DM. While computing the required actuator displacements is theoretically possible, it is unlikely to achieve high performance without adaptive tuning. We use a focal plane interferometer (Roger Angel, ASP, 294, 543-556, 2003) which uses a focal plane mask to divert the bright starlight for use as a reference with sequential phase shifts introduced using a piezo-controlled mirror. The halo and any residual aberration speckles are suppressed over the region of interest using oppositely-phased speckles scattered from ripples applied to the DM (Codona and Angel, ApJ 604, 2004). The resulting DM settings can be used without the interferometer as a stand-alone phase apodization coronagraph. By including a Lyot stop, the focal plane interferometer becomes a conventional Lyot coronagraph with the DM used to correct flaws in the halo suppression. The performance of the two techniques are reported and compared.

7736-102, Poster Session

Reducing PSF halo with adaptive pupil masking

J. Osborn, R. M. Myers, G. D. Love, Durham Univ. (United Kingdom)

We describe a method to reduce the halo and increase the peak intensity of a point spread function (PSF) using an adaptive pupil mask. Areas of the pupil where the residual wavefront aberrations are large are selected and masked using a spatial light modulator. The technique can be used as a standalone system on a smaller telescope without adaptive optics or in conjunction with an adaptive optics system to further improve the PSF. We find by simulation that for a 1 m telescope and using an 8x8 system we can increase the peak intensity by 40 % and reduce the FWHM by 76 % to near the diffraction limit. For an 8 m class telescope with a 16x16 pupil mask and adaptive optics the intensity was found to increase by 23 % and the FWHM reduced from 0.022 to 0.018 .

7736-103, Poster Session

Adaptive optics using a linear response 91-actuator magnetic liquid deformable mirror

D. Brousseau, E. F. Borra, M. Rochette, D. Bouffard Landry, Univ. Laval (Canada)

Building deformable mirrors having large number of actuators is very expensive. Although MEMS deformable mirrors have demonstrated potential for low-cost and high number of actuators, they still are limited to strokes of a few microns. Also, MEMS deformable mirrors are not appropriate for optical testing applications where large mirror diameters are often required. A new promising technology to build deformable mirrors having a high number of actuators, large stroke and low-cost has been suggested by Borra et al. in 2004. These new deformable mirrors use magnetic liquids (ferrofluids) whose surface is deformed by arrays of small electrical coils. Many technical improvements have been made by Borra et al. since 2004 but there remained major inconveniences with these early-generation FDMs (e.g. non-linearity and no push-pull response). We present the experimental performance of a new 91-actuator magnetic liquid deformable mirror that uses a novel technique that linearizes the response of the mirror by superposing a uniform magnetic field to the one produced by the actuators. We demonstrate linear driving of the mirror using influence functions measured using a Shack-Hartmann wavefront sensor. Wavefront PV amplitudes greater than 50 um as well as the correction of turbulent wavefronts are also demonstrated.

7736-105, Poster Session

The Magellan adaptive secondary VisAO Camera: diffraction-limited broadband visible imaging and 20mas fiber array IFU

D. A. Kopon, L. M. Close, J. R. Males, V. Gasho, K. Brutlag, Steward Observatory, The Univ. of Arizona (United States)

The Magellan Adaptive Secondary AO system, scheduled for first light in the fall of 2011, will be able to simultaneously perform diffraction limited AO science in both the mid-IR, using the BLINC/MIRAC4 10µm camera, and in the visible using our novel VisAO camera. The VisAO camera will be able to operate as either an imager, using a CCD47 with 8.5 mas pixels, or as an IFU, using a custom fiber array at the focal plane with 20 mas elements in its highest resolution mode. In imaging mode, the VisAO camera will have a full suite of filters, coronagraphic focal plane occulting spots, a grism for low-resolution spectra, and SDI prisms. The imaging mode should provide 15-20% mean Strehl diffraction-limited images over the band 0.5-1.0 µm. In IFU mode, the VisAO instrument will provide R~1,800 spectra over the band 0.6-1.05 µm. Our unprecedented 20 mas spatially resolved visible spectra would be the highest spatial resolution achieved to date, either from the ground or in space. We also present lab results from our recently fabricated advanced triplet Atmospheric Dispersion Corrector. This advanced ADC is designed to perform 58% better than conventional doublet ADCs and is one of the enabling technologies that will allow us to achieve broadband (0.5-1.0 µm) diffraction limited imaging and wavefront sensing in the visible.

7736-106, Poster Session

Diffraction limited operation with ARGOS: an hybrid AO system

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ARGOS is the Laser Guide Star facility of the Large Binocular Telescope. In its first-light mode, ARGOS will implement a Ground Layer AO system, using 3 low-altitude Rayleigh lasers, that will improve the resolution of a factor 2-3 in almost every seeing condition over the wide 4x4 arcmin seeing-limited FoV of the LUCIFER instrument, capable of NIR imaging and multi-object spectrography.

In this paper we describe the simulated performance of the foreseen upgrade of ARGOS required to exploit the performance of LUCIFER in the diffraction limited mode having a 30x30 arcsec FoV.

We discuss the performances and the reconstruction scheme of an hybrid AO system that uses the ARGOS Rayleigh beacons to sense the strong ground-layer turbulence complemented with one faint high-altitude star (NGS or sodium beacon) to sense the weaker turbulence of upper atmospheric layers.

After commissioning of the ARGOS system, the NGS-upgrade can be immediately implemented at LBT using the already existing Pyramid WFS: this hybrid scheme will offer performance similar to the NGS AO system with the advantage of a larger sky coverage.

Preliminary numerical simulation will be presented; in particular, for the sodium beacon case, a Strehl ratio up to 50% in K-band over a 30x30" FoV can be obtained with a single tip-tilt star and a few watt sodium laser sensed with a 5x5 SH-WFS.

7736-107, Poster Session

Extremly large telescopes MCAO with a single NGS

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MCAO systems plan to use laser beacon to create star constellation for tomographic reconstruction over a wide field of view. LGS tip tilts indetermination prevents correct estimation of low order Zernike modes over the whole tomographic volume.

Thus, for extremely large telescopes, several NGSs are needed in order to reconstruct low order modes.

We propose a technique that estimates low order modes from the LGS constellation and a single NGS, associated to the High order modes estimation achieved from LGSs.

This technique requires the launch of LGS beams from the top of the secondary mirror. The upward LGS beam is then included inside the tomographic volume but a part of this beam is propagating through a shadow zone, unseen from any star. Even though this helps for estimate the LGS tip/tilt, and as a consequence improves LGS low order modes reconstruction. In such a way, only one NGS is needed for the isoplanatic tip tilt and second radial order modes measurements.

Reducing the number of required NGS down to one, significantly improves the MCAO system sky coverage.

We present in this paper MCAO star oriented performances for a 42 m diameter telescope, over a two arcmin field of view, using two deformable mirrors.

Simulation are achieved using numerical computations of a thousand Zernike modes, considering the central obscuration for the estimation of the shadow zone effect.

7736-108, Poster Session

New method of fabricating phase screens for simulated atmospheric turbulence

R. Rampy, D. Dillon, Univ. of California, Santa Cruz (United States); D. T. Gavel, S. J. Thomas, Univ. of California Observatories (United States)

A crucial part of enabling adaptive optics technology to function is the ability to simulate atmospheric turbulence in the lab. We report a new technique of creating phase plates developed at the Laboratory for Adaptive Optics (LAO) which involves the application of clear acrylic paint onto a clear substrate. Results of interferometric characterization of these plates is described and compared with Kolmolgorov statistics. These plates have been used in the Multi-Conjugate Adaptive Optics (MCAO) testbed and as part of the Villages (Visible Light Laser Guidestar Experiments) calibration system. The result of these applications is also presented.

7736-109, Poster Session

System overview of the multiconjugated adaptive optics RelaY for the E-ELT

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MAORY, the multi-conjugate adaptive optics module for the European Extremely Large Telescope, will be located on one of the Nasmyth platforms of the telescope to provide Multi Conjugated Adaptive Optics correction of the wavefront. The scientific instruments fed by the module will benefit from a very uniformly corrected field of view of 2 arcmin diameter. The two post-focal deformable mirrors of the module are projected at high altitude by the optical system based on 5 mirrors and one dichroic which is used to split the laser light of the artificial reference stars from the science channel. The third deformable mirror, conjugated to the ground, is integrated into the telescope. Six laser guide stars are foreseen in order to measure wavefront distortion and three natural guide stars are used to solve the tip-tilt indetermination problem. The natural guide stars wavefront sensors are located close to the output focal plane in order to minimize non common path aberrations. Two output ports are foreseen: one gravity invariant located below the optical bench, well suited for high accuracy astrometry measurement, and one on one side of the bench to feed heavy and large instrument placed on the Nasmyth platform and detached from MAORY. A mechanical derotator is foreseen on the gravity invariant port to provide derotation to the client instrument.

The current operational concept and design of the module are presented together with the thermal analysis.

7736-110, Poster Session

Calibration strategy and optics for ARGOS at the LBT

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Effective calibration procedures play an important role for the efficieny and perfomance of astronomical instrumentation. We report on the calibration scheme for ARGOS, the Laser Guide Star (LGS) facility at the LBT. An artifical light source is used to feign the real laser beacons and perform extensive testing of the system, independent of the time of day and weather conditions, thereby greatly enhancing the time available for engineering. Fibre optics and computer generated holograms (CGHs) are used to generate the necessary wavefront. We present the optomechanical design, and discuss the expected accuracy, as well as tolerances in assembly and alignment.

7736-111, Poster Session

Multi-conjugate adaptive optics at the Dunn Solar Telescope

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Solar observations are performed over an extended field of view and the isoplanatic patch over which conventional adaptive optics (AO) provides diffraction limited resolution is a severe limitation. The development of multi-conjugate adaptive optics (MCAO) for the next generation large aperture solar telescopes is thus a top priority. The Sun is an ideal object for the development of MCAO since solar structure provides multiple guide stars" in any desired configuration. At the Dunn Solar Telescope (DST) we implemented a dedicated MCAO bench with the goal of developing well-characterized, operational MCAO. The MCAO system uses two deformable mirrors conjugated to the telescope entrance pupil and a layer in the upper atmosphere, respectively. The high altitude deformable mirror can be placed at conjugates ranging from 2km to 10km altitude. We have successfully and stably locked the MCAO system on solar granulation and demonstrated the MCAO system's ability to significantly extend the corrected field of view. We present results derived from analysis of imagery taken simultaneously with conventional AO and MCAO and discuss future plans for MCAO development, with the ultimate goal to implement MCAO at the ATST.

7736-112, Poster Session

The optical tests for the E-ELT adaptive mirror demonstration prototype

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In the framework toward the E-ELT realization a Demonstration

Prototype (DP) of the M4 adaptive mirror (M4AM) has been realized by our consortium using voice coil controlled 2mm thick Zerodur mirror shell. The DP is a cut of the final, proposed M4AM and its segmented structure will test the possibility to replicate the same co-phasing technology for the larger unit.

The DP has two 1 m long segments with 111 actuators each manufactured using the "brick" modular structure linearly scalable to the whole M4AM. The DP optical control bench must implement three different measures:

i) the entire mirror shape and its low spatial frequency deformations;

ii) the higher frequency in a higher resolution, stitching mode and

iii) the cophasing between the two adjacent segments.

We present the complex machine which has performed all the required optical measures by means of a structured interferometric cavity located in our laboratory in INAF-OAB, Merate.

The optical characterization of the DP is reported.

7736-113, Poster Session

Adaptive optics systems for HARMONI: a visible and near-infrared integral field spectrograph for the E-ELT

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HARMONI is a visible and near-infrared (0.48 to 2.45 μm) integral field spectrograph, capable of providing the E-ELT's core spectroscopic capability, over a range of resolving powers from R~ 4000 to R~20000. HARMONI is conceived as a workhorse instrument that will exploit the E-ELT's scientific niche in its early years, starting at first light. In order to capitalise on the D4 sensitivity gains of the E-ELT and thus providing unprecedented gains in sensitivity and spatial resolution, HARMONI need to work at close-to -diffraction limited scales. This will be possible thanks to two adaptive optics systems, complementary to each other. Both systems will make use of the telescope's adaptive M4 and M5 mirrors. The first one is a simple but efficient Single Conjugate AO system, fully integrated in HARMONI itself. Working with a single natural guide

star, at visual wavelengths, it should provide a very good correction (up to 70 % of SR) at near infrared wavelengths (2.2 microns) but with very limited sky coverage. The second one is a Laser Tomographic AO system which will use the 6 Laser Guide Stars of the telescope in order to provide a good correction (typically 50 % of SR) but for more than 60 % of the whole sky. In this paper, we present the overall design of HARMONI SCAO system, specifications and performance and we discuss the complementaries of SCAO and LTAO systems for HARMONI science cases.

7736-114, Poster Session

Diffraction-limited upgrade to ARGO: the LBT's ground-layer adaptive optics system

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The LBT is now operating with the first permanently installed adaptive secondary mirror, and the first of two complementary near-IR instruments called LUCIFER is operational as well. The ARGOS laser guided ground-layer adaptive optics (GLAO) system, described elsewhere at this conference by Rabien et al., is designed to deliver the highest resolution over the 4 arc min wide-field imaging and multi-object spectroscopic modes of LUCIFER. In this paper, we describe a planned upgrade to ARGOS which will supplement the Rayleigh-based GLAO system with sodium laser guide stars (LGS) to fulfill the telescope's diffraction-limited potential. With a field of 30 arc sec, LUCIFER will deliver imaging at the Nyquist limit of the individual 8.4 m apertures down to J band and long-slit spectroscopy with resolution up to 40,000. In addition, the LBT Interferometer will cophase the two apertures, offering imaging at the diffraction limit of the 22.8 m baseline at wavelengths from 1.2 to 20 microns. In the first phase of the upgrade, a 10 W sodium LGS will be added to each half of the LBT, using the same launch telescopes mounted behind the two secondary mirrors as the Rayleigh LGS. The upgrade will rely on other components of the ARGOS infrastructure such as acquisition and guiding, and fast tip-tilt cameras. New wavefront sensors will be added to LUCIFER and LBTI. In the upgrade's second phase, the sodium and Rayleigh LGS will be used together in a hybrid tomographic sensing system. This configuration will offer the advantage that a single tip-tilt star will continue to be sufficient even for MCAO operation, as is planned with LBT's LINC-NIRVANA instrument.

7736-115, Poster Session

Is ESO's adaptive optics facility suited for MCAO?

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As of 2013, the ESO's VLT will be equipped with the Adaptive Optics Facility for Ground Layer and Laser Tomography adaptive optics assisted imaging and spectroscopy, using a Deformable Secondary Mirror and four Laser Guide Stars.

Following the successful experience of the MAD demonstrator, we initiated a speculative study to evaluate the performance gain obtained by implementing a type of MCAO correction that benefits from the unique features provided by the AOF. In this paper we present the basic concept and provide a first estimation of the correction performance obtained in the near infrared.

7736-116, Poster Session

Implementation and results of an optimal wavefront controller for the MMT NGS adaptive optics system

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The MMT observatory recently implemented and tested an optimal wavefront controller for the NGS adaptive optics system. Open loop atmospheric data collected near real-time is used as the input to a MATLAB based analytical model of the closed loop adaptive optics system. The controller is then optimized using methods of nonlinear constrained minimization to select gains which minimize the residual RMS wavefront computed from the analytical model. This technique of simulation based design requires an accurate analytical model of the adaptive optics closed loop system to obtain the best performance. The real-time controller that performs the adaptive optics close loop

operation is implemented on a dedicated PC. To test controller, we injected a swept sine wave to deform the adaptive secondary mirror. Using the real time telemetry data stream, we validated the analytical hardware models. Tests at the MMT confirmed the optimal controller significantly reduced the residual RMS wavefront compared with the previous controller. Significant reductions in image FWHM and increased peak intensities were obtained, particularly at shorter wavelengths in J, H and K-bands. For poor seeing conditions (1.2” in the visible) the optimal controller increased the peak intensity by a factor of 2.5 in K-band and by a factor of 5 in H-band over the previous controller. Image FWHM was effectively reduced by a factor of two over the previous controller in H and K bands and good image quality was obtained in J-band.

7736-117, Poster Session

Closed-loop tomographic control on HOMER wide-field AO bench: experimental results and identification issues

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Adaptive Optics (AO) is a proven technique that allows ground-based telescopes to improve their angular resolution by correcting the effects of atmospheric turbulence. However these systems have a limited corrected field of view because of the anisoplanatism effect. Wide Field AO (WFAO) concepts, such as Multi-Conjugate AO (MCAO), have been developed to overcome this limitation. These complex WFAO systems raise critical challenges such as tomographic control and calibrations.

We present new results obtained in closed-loop configuration with the recent laboratory bench HOMER which is devoted to implementation and validation of these WFAO concepts in the perspective of future VLT/ELT AO systems. Turbulence is generated with several rotating phase screens and multi-directional analysis is performed. Tomographic control relies on Linear Quadratic Gaussian control law. The correction can then be applied thanks to one or two Deformable Mirrors (DM).

We also focus on calibration issues and models identification. We investigate in particular identification of relative geometry of the wave front sensors, DM altitude and asterism and its impact on performance.

7736-119, Poster Session

Development and performance of the EAGLE active optics LGS WFS refocusing system

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The EAGLE instrument for the E-ELT is a multi-object adaptive optics IFU spectrograph. The wavefront sensing of the AO system is performed on Laser Guide Stars (LGS) and Natural Guide Stars. As the distance to the LGS is finite and varies between 80 and 200 km, it is required to track the optical path to the LGS in order to maintain the focus on the LGS Wavefront Sensors (WFS).

The Laboratoire d’Astrophysique de Marseille (LAM) has a strong expertise in active optics, and proposed, then developed and tested a Variable Curvature Mirror (VCM) as an active refocusing system for the LGS WS. The EAGLE VCM design uses a convex mirror with a curvature radius going from 3000mm to 1200mm on a clear aperture of 120mm. The VCM is actuated by air-pressure and the pressure is regulated by a in-house-developed servo-loop system. A displacement sensor within the VCM measures the mirror sag and feeds the information to the servo loop.

This paper is the second of two from the LAM team for the VCM project within the FP7 ELT Prep framework,. Hugot et al. (AS10-AS109-9) present the mirror design and performance simulations. In this second paper, we first report on the VCM system development integration and test setup. Then we present actual VCM performance results and analysis for the mirror optical quality along the deformation range and VCM system robustness. We conclude by discussing the overall performance (design, cost, etc) and compare it to other LGS refocusing optical systems.

7736-120, Poster Session

FFREE: a Fresnel-FRee experiment for EPICS, the EELT exoplanets imager

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The main purpose of FFREE - the new optical bench devoted to experiments on high-contrast imaging at LAOG - consists in the validation algorithms based on phase-diversity and speckles nulling for the wavefront measurement. The aim is the rejection by AO of the static speckles pattern arising in a focal plane after a diffraction suppression system (based on apodization or coronagraphy). The bench has been optimized to minimize Fresnel propagation on a large IR bandwidth in a way allowing efficient rejection up to the AO control radius.

7736-121, Poster Session

Designing and prototyping VRALA: a novel, high-efficiency actuator for large adaptive mirrors

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The next-generation Extremely Large Telescopes adaptive optics systems require high-order, long-stroke, quite large deformable mirrors.

Higher forces and greater actuator densities than the ones provided by the current technology are needed, still maintaining its requests in terms of accuracy and bandwidth. The electromagnetic “Vrala” actuator can accomplish this very demanding goal. Based on a very simple magnetic circuit, providing a compact device, it allows to deliver a large force with very low power dissipations. With a typical efficiency of about 7 N/W and an overall radius that allows actuator separations as low as 25 mm, the deformable mirror can be actuated on small spatial scales, and/or its thickness can be increased, in order to simplify the manufacturing, with a little thermal impact. This paper will mainly discuss the magnetic design of the proposed actuator, its effects on the thermal response of the device as well as its behavior in a closed loop control system - from the geometrical optimization process to the dynamic performances. A prototype built accordingly to the proposed design has been tested. The test set-up, as well as the first set of the measured data, well matching the results of the numerical simulations, will also be shown.

7736-122, Poster Session

Simulations for diffraction limited near-infrared adaptive optics systems on the AOF

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In this paper, we describe the simulations done to explore concepts for new AO systems for the Very Large Telescope Adaptive Optics Facility. These systems are aimed to work in the near infrared and should provide

diffraction limited capabilities, using at least the existing AOF capabilities (4 Laser guide stars, one high order deformable mirror integrated in the telescope). Concepts simulated include Ground-Layer AO, Laser Tomography AO and Multi-Conjugate AO. We explore the benefits of adding deformable mirror(s) and wavefront sensor(s) to the existing infrastructure.

7736-123, Poster Session

Optical designs with wide field-of-view adaptive optics for IMAKA of CFHT

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A ground-layer adaptive optics system is usually a simple and cost-effective solution for turbulence correction to get high resolution under large field of view for ground-based telescopes. In this project we have designed a relay optics which includes a deformable mirror to get an excellent image quality over wide field of view for the Canada-France-Hawaii- Telescope. The goal is to achieve a PSF with Full Width at Half Maximum of less than 0.15" over a 1- degree field for extended broadbands within the spectral waveband of 470 nm - 900 nm.

Based on our preliminary optical design and performance analysis with the 4 optical design approaches, it seems possible to achieve most of the IMAKA requirements. The science camera and adaptive mirror in the proposed designs are located below the Cassegrain environment for three of the proposed configurations and between the primary mirror and the top ring for the fourth design. The 4 proposed approaches can fully cover a FOV as large as 1-degree for any 150 nm wide wavebands within the 470-900 nm spectral domains. In all cases, the effective focal length of the telescope with the added correction relay is about 20.63 m for a working focal ratio of about 5.74. The design configurations included in this paper have achieved nearly diffraction limited performances either with a flat or with a mild curvature adaptive mirror having a diameter inferior to 0.3 m for most configurations. The adaptive-mirror conjugation achieved with the most designs is few meters around the primary mirror of the telescope.

7736-124, Poster Session

An update of the on-sky performance of the layer-oriented wave-front sensor for MAD

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The Multi-conjugate Adaptive optics Demonstrator (MAD) is an experiment devoted to demonstrate the Multiconjugate Adaptive Optics concept in the framework of the ESO European Extremely Large Telescope project. Aboard MAD two different Multiconjugate Adaptive Optics techniques have been implemented: Star Oriented multi-Shack-Hartmann and Layer Oriented (LO) multi pyramids. MAD has been designed to retrieve partially corrected adaptive optics image on a 2x2 arcmin field of view re-imaged by the CAMCAO infrared camera. The PSF uniformity and performance are strongly depending on the guide stars brightness, atmospheric conditions and adaptive optics control loop setup. In this paper we present the performance as they have been measured on data taken during the Guaranteed time observation nights. The Multi-Conjugate Adaptive Optics technique in its Layer Oriented realization have been successfully demonstrated, retrieving diffraction limited resolution point source images largely uniform on the Field of View. We will present the instrumentation issues and technical aspects which stay behind this success, especially taking care of the limiting magnitude achieved with respect to other techniques. We take the opportunity to discuss the lesson learnt using the instrument.

7736-125, Poster Session

Analysis of adaptive optics control for the Advanced Technology Solar Telescope

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Large aperture solar telescopes, like the 4 meter aperture Advanced Technology Solar Telescope (ATST), depend on a high order adaptive optics (AO) system to achieve the telescope's diffraction limit resolution. The AO system not only corrects incoming distortions introduced by atmospheric turbulence, its performance also plays a critical role for the operation of other subsystems and affects the results obtained by downstream scientific instrumentation. For this reason, robust and optimal operation of the AO system is vital to maximize the scientific output of ATST.

To understand and address possible performance issues, we have evaluated different strategies to obtain and optimize the control matrix of the AO system. The dependency of AO performance on various control parameters, such as different system calibration and reconstruction schemes, was analyzed using an AO simulation tool. The simulation tool implements a layered atmosphere and takes into account the field of view dependency of cross-correlating wavefront sensors. This approach provides a realistic solar AO simulation and allows a detailed evaluation of the residual corrected phase along various field directions.AO corrected point spread functions and Strehl ratios can be computed for different points in the field.

The results of this study are necessary to understand and properly operate the AO system of the ATST.

7736-126, Poster Session

First-generation adaptive optics system of the New Solar Telescope at Big Bear Solar Observatory

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Big Bear Solar Observatory (BBSO), in collaboration with the National Solar Observatory (NSO), has successfully developed the 1st generation adaptive optics (AO) system for the largest solar telescope, the 1.6-meter New Solar Telescope (NST). Most of hardware takes over from the "AO-76" system which was used for now-retired 65-cm telescope. It employs a Shack-Hartmann wave front sensor with 76 sub-apertures. High speed Baja camera with a frame rate of 2500-frame/s and off-the-shelf digital signal processors are responsible for wave front data acquisition, computation and reconstruction. Deformable mirror has a diameter of 7 cm with 97 actuators. Closed-loop bandwidth of the whole system can reach 135-Hz. Detailed and realistic error budget analyses that include AO residuals, as well as telescope and instrument error budgets, show that the Strehl ratio of AO-corrected image is about 80% in the near infrared under nominal median BBSO seeing. This AO system will be installed on the vertical optical bench in Coude Lab of the NST building this coming February, with subsequent system testing and optimization. In this presentation, we describe the optical design and implementation, demonstrate the open- and close-loop AO performance.

7736-127, Poster Session

The METIS AO system: bringing extreme adaptive optics to the mid IR

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METIS (Mid-infrared E-ELT Imager and Spectrometer) is the mid-infrared instrument proposed for the European Extremely Large Telescope (E-ELT). METIS will be the first instrument in the mid-IR that will actually require an Adaptive Optics system in order to reach a performance close to the diffraction limit. Extending Adaptive Optics for the mid-IR from the current generation of telescopes to 30-42 meter telescopes is technically challenging, but appears at first sight significantly easier than at visible and near infrared wavelengths.

Adaptive Optics has been demonstrated to deliver Strehl Ratios exceeding 95% on 6-8 meter class telescopes at 10 microns, but achieving this performance on E-ELTs under normal observation conditions, requires that several higher order effects are taken into account. The performance of a mid-IR AO system drops significantly if refractivity effects and atmospheric composition variations are not compensated. Reaching Strehl Ratios of over 90% in the L, M and N band will require special considerations and will impact the system design and control scheme of AO systems for mid-IR on ELTs.

The METIS instrument has finalized its preliminary design phase and in this paper we present the results of our performance estimates of the METIS AO system. We have included the effects of refractivity and composition fluctuations on the performance of the AO system and we have investigated how these effects impact the science cases for mid-IR instrumentation on an ELT.

7736-128, Poster Session

First light AO (FLAO) system for LBT: system characterization and performance optimization

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The First Light AO (FLAO) system of the LBT comprises an adaptive secondary mirror (ASM) with 672 actuators and a pyramid wavefront sensor (PWFS) with adjustable sampling. The FLAO system has been integrated in the Arcetri Solar Tower Laboratory and thoroughly tested during 2009. We will focus in this paper on the system characterization, modal control analysis and optimization. The procedure to acquire a modal interaction matrix in the laboratory was optimized in order to maximize the signal-to-noise ratio of each modal measurement without saturating the pyramid sensor. The system parameters (number of controlled modes, number of subapertures, integration time, pyramid's modulation amplitude, controller parameters, etc.) were optimized as a function of the observing conditions (star magnitude, seeing, and wind speed). At the telescope, look-up tables will allow the system to be configured with the optimized parameters at the beginning of an observation run. We have also investigated automatic gain control techniques in order to cope with changes in the turbulence conditions once an observation is taken place. Finally, we have investigated and tested in the laboratory an optimal controller based on the Kalman filter in order to compensate for telescope vibrations on a selected number of modes. The system passed the acceptance test in early December 2009 and will be shipped to the LBT in January 2010.

7736-129, Poster Session

Demonstration of a robust curved carbon fiber reinforced polymer deformable mirror with low-surface error

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Carbon fiber reinforced polymer (CFRP) composites provide several advantages as a substrate for thin-shell adaptive secondary mirrors, including high stiffness-to-weight ratio and low coefficient of thermal expansion (CTE). New manufacturing capabilities pioneered by Composite Mirror Applications (CMA, Tucson, AZ) yield CFRP substrates that preserve the precision optical surface of its mandrel optic, eliminating core print-through issues caused by the fiber strands. Additionally, multiple high-fidelity mirrors can be replicated inexpensively from the same mandrel.

The utility of CFRP as a substrate for deformable secondary mirrors in astronomical adaptive optics depends on its maintenance of good figure quality in a mountaintop environment. Specifically, the surface error must remain suitable for near-infrared (IR) wavelengths (< 100 nm RMS) under temperature drifts of 30 degrees C and large fluctuations in humidity. The actuator forces required to correct these errors must lie within the dynamic range of magnetic voice coil actuators used for deformable secondaries today.

We have addressed some of these concerns with a test-bed consisting of an actuator assembly and a prototype 3 inch convex, spherical CFRP mirror. We present measurements of surface error as a function of temperature and humidity. Under actuator relaxation, its surface error is low (~80 nm RMS) and dominated by edge curvature. This error is reduced further under best actuator correction to 40 nm RMS, placing it into consideration for use in near-IR astronomy. Furthermore, the actuator forces required to correct the figure are small compared to the dynamic range of voice coil actuators (<< 0.1 N).

7736-130, Poster Session

Real-time control for Keck Observatory next-generation adaptive optics

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The next generation adaptive optics systems for large telescopes will be complex systems far larger and more complex with higher performance requirements than any currently installed. This increased complexity, size and performance has led to the need to adopt new algorithms, new technologies, and new architectures to implement them. The Keck Next Generation Adaptive Optics (KNGAO) system requires real-time wavefront reconstruction and tomography given input from 4 laser guidestars and 3 natural tip/tilt stars. System bandwidth requirements will demand that we sample the atmospheric turbulence 2,000 times a second, produce a tomographic estimate of the atmosphere from them, and use this estimate to control deformable mirrors to correct the effect of the turbulence. To implement the algorithm we take advantage of the massive parallelism inherent in the algorithm and realize it on a massive array of processors, including FPGAs, GPUs, and multi-core CPUs. In this paper, we present the design of the overall real-time control system and describe how it achieves the KNGAO needs.

7736-131, Poster Session

Adaptive optics system for the IRSOL Solar Observatory

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We present a low cost adaptive optics system developed for the solar observatory at the Istituto Ricerche Solari Locarno (IRSOL), Switzerland. The Shack Hartmann Wavefront Sensor is based on a Dalsa CCD camera with 256 pixels x 256 pixels working at 1kHz.

The correction is obtained by a deformable mirror with 37 actuators and a tip-tilt mirror. A real time control software has been developed on a dedicated PC running the Linux RTAI OS. Special tools for the online analysis of the system behavior have been programmed in Scicos/Scilab. The software is completely open source.

7736-132, Poster Session

SAM sees the light

A. A. Tokovinin, R. Tighe, P. Schurter, R. Cantarutti, N. S. van der Bliek, M. Martinez, E. Mondaca, W. Naudy, National Optical Astronomy Observatory (United States)

We present a progress report on the SOAR Adaptive Module, SAM, including some results of tests of the Natural Guide Star mode, such as corrected images in the visible, performance estimates and experiments with lucky imaging. We have tested methods to measure the seeing and the AO time constant from the loop data and compared the results to those of the the stand-alone site monitor. Measurements of the instrument throughput, telescope vibrations, and non-common-path aberrations are given. We report progress on the Laser Guide Star system implementation, including tests of the UV laser, test of the beam transfer optics with polarization control and the design of the laser launch telescope.

7736-133, Poster Session

Testing the VLT AO facility with ASSIST

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The testing and verification of ESO Very Large Telescope Adaptive Optics Facility (VLT-AOF) requires new and innovative techniques to deal with the absence of an intermediate focus on the telescope. ASSIST, The Adaptive Secondary Setup and Instrument STimulator, was developed to provide a testing facility for the ESO AOF and will allow off-telescope testing of three elements of the VLT Adaptive Optics Facility; the Deformable Secondary Mirror (DSM) and the AO systems for MUSE and HAWK-I (GALACSI and GRAAL).

ASSIST will provide a full testing environment which includes an interferometric testing mode for the DSM, an on-axis testing mode with a single wavefront sensor and full operation testing modes for both the AO systems. Both natural as well as laser guide stars will be simulated under various asterisms and a realistic atmosphere will be provided for varying atmospheric conditions.

ASSIST passed its final design review and is now being manufactured, integrated and tested and will be operational in mid 2011, in time for first testing with the DSM.

7736-134, Poster Session

Performance of Subaru adaptive optics system AO188

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The Subaru adaptive optics system (AO188) is a 188-element curvature sensor adaptive optics system that is operated in both natural and laser guide star modes. AO188 was installed at Nasmyth platform of the Subaru telescope and it has been successfully operating in the natural guide star mode since October 2008. We will start a commissioning of the laser guide star mode on January 2010. The performance of AO188 in the natural guide star mode has been well verified from on-sky data obtained with the infrared camera and spectrograph (IRCS). Under normal seeing condition, AO188 achieves K-band Strehl ratio between 60% and 70% using R=9.0 magnitude natural guide stars and it works well with faint guide stars down to R=16.5 magnitude. We measured the FWHM and Strehl ratio of stellar images in globular clusters and found that the isoplanatic angle is approximately 30 arcsec. We present performance of AO188 such as angular resolution, Strehl ratio, and sensitivity gain for detecting faint objects, together with actually achieved scientific results. We also show the expected performance of AO188 in laser guide star mode based on the data obtained in the commissioning observations.

7736-135, Poster Session

GMT adaptive secondary design

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The GMT adaptive secondary mirror (ASM) is based on a “segmented” concept following the primary segment layout: seven 1.05m diameter circular, independent adaptive mirrors are fed by the primaries and focus to the main telescope focal stations. The adaptive unit’s design is based on the consolidated thin mirror, contactless technology already employed in several units (MMT, LBT, Magellan, VLT and one of the proposed E-ELT M4 designs), but nevertheless the mirror’s topology reveals several design challenges. In particular, the off-axis units are strongly aspheric and therefore they require aspheric shaping of both thin mirror surfaces and of the thick reference body. The strong tilt of the off-axis units forced us to consider a peculiar fine positioning hexapod design, maximizing its stiffness and also implementing a special design of the last three rings of actuators to remain within the prescribed obstruction. From the control point of view, the actuator density of the adaptive mirrors is remarkably lower than in all previous units: 672 actuators with 36mm spacing compared to 30mm typical separation adopted so far. This choice is validated by static and dynamic performance computation though a sophisticated numerical simulator based on a full state space model incorporating mechanics, control and fluid dynamics. The control system fulfills the dimensional constraints of the unit. The design has completed the feasibility phase, including the cost estimate. The choice of making the GMT adaptive secondary mirrors similar to the already existing ones strongly reduces the implementation risks and allows shortening the remaining design path.

7736-136, Poster Session

A portable solar adaptive optics system: software and laboratory developments

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We discuss a solar adaptive optics system that features small physical size, high-performance and a moderate cost. The adaptive optics is optimized for diffraction-limited imaging in the 1.0 ~ 5.0 µm infrared wavelength range for 1.5-m class solar telescopes. Our software is developed in the high-level computer language LabVIEW, which is different from other adaptive optics systems that use low-level languages such as C++. Furthermore, we use a multi-core commercial personal computer for real-time image and signal processing. We show how to develop a system that is able to deliver high-performance at a moderate cost. We present our recent software development, as well as a laboratory test and characterization of the adaptive optics. The small physical size should make the system a popular visiting instrument that can be brought to any major solar observatory to perform high-resolution imaging with an existing solar telescope.

7736-137, Poster Session

SAMI: the SCAO module for the E-ELT adaptive optics imaging camera MICADO

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We present the results of the study made in the framework of the MICADO phase A to design and estimate the performance of this SCAO module: mechanical design, optical design, thermal analysis, real-time computer, performances, calibrations

7736-138, Poster Session

Gemini NICI planet-finding campaign: combining angular and spectral difference imaging

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The Gemini NICI Planet-Finding Campaign, a 500 hour program to directly image planets around ~ 300 nearby stars, is currently underway on the 8-m Gemini South Telescope.

The NICI(Near Infrared Coronagraphic Imager) instrument was specially designed for direct imaging of planets.

It is equipped with an 85 element adaptive optics system, a Lyot coronagraph, and a dual channel camera capable of simultaneous spectral difference imaging (SDI) on and off the 1.6um methane feature of cool (T < 1400 K) planets and brown dwarfs. It also allows angular difference imaging (ADI) where the telescope image rotator is turned off, so that the sky rotates on the detector, while instrument and telescope PSF artifacts remain fixed.

We demonstrate how SDI and ADI techniques are combined to obtain unprecendented contrasts at separations greater than 0.5" from bright stars. Speckles with long correlation times are removed by subtracting a static PSF constructed from the ADI process. Short-lived speckles are removed by the subtracting the simultaneously imaged off-methane channel, where the companion flux is relatively smaller. For the 120 stars observed so far in the campaign, we achieved a median contrast of 14.8 magnitudes at 1.0".

7736-139, Poster Session

Visible and infrared multi-spectral illumination concept based on GALILEAN collimation systems: IACATS illumination source

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A LED based illumination system in which five galilean collimation systems have been used is reported on. It is a part of a turbulence simulator for the evaluation of on ground telescopes instrumentation developed by INTA (optics) and LIDAX (opto-mechanics) for the IAC called IACATS. The illumination requirements (some visible and infrared lines) allow the use of five different LEDs (red, green, blue and two infrareds). In order to optimize the illumination level of each wavelength, a galilean collimating optical configuration was constructed for each wavelength channel.

The IACATS instrument simulates a scene consisting of a set of different binary stars simulating the required separation between them, ant its spectral characteristics. As a result, a visible and infrared multi-spectral illumination system has been integrated as a part of the turbulence simulator, and the features (opto-mechanical) and illumination characteristics are described in the following lines.

7736-140, Poster Session

IACATS AIV: AIV process for a versatile turbulence simulator

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IACATS is an atmosphere and telescope simulator for the evaluation of on ground telescopes instrumentation developed by INTA (optics) and LIDAX (opto-mechanics) for the IAC.

Three telescopes have been simulated, matching the f number, focal plane, and optical interface of the actual telescopes. An optical breadboard was designed and built containing the required opto-mechanics for simulating the telescopes, and various levels of turbulence required.

In addition to the telescope simulator optics, a set of three phase plates have been procured and conveniently combined in order to reproduce the turbulence required by the IAC. A wave front sensor has been also included in order to evaluate the deformation that the phase plates, or the simulated turbulence, produce in the wave front coming from the illumination system and star simulator. Finally, a specific illumination system was developed including different working wavelengths in order to fulfil the requirements. The description of the illumination system itself has been done in a separate publication.. In the following lines, the characteristics of the IACATS instrument as well as the results obtained from the AIV (Assembly and Integration Verification) process are reported on.

7736-141, Poster Session

Tip/tilt offload of Subaru AO188 by telescope secondary mirror

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In an actual adaptive optics system, a separate tip/tilt compensator is required in addition to a deformable mirror. Not only large amount of atmospheric tip/tilt components, but also tracking error of the telescope must be canceled by compensator. In the case of, Subaru LGSAO188 system the deformable mirror of is mounted on a tip/tilt mount and used for usual loop operation.

However, at thermal infrared wavelengths (e.g., L- and M-band), offset of tip/tilt mount generates strong background pattern due to the change of beam path before the mirror. Especially, dusts on the three mirrors in the image rotator generate strong ring-shape pattern because the mirrors are close to the entrance focus point which is inside the image rotator to reduce the size of the mirrors.

An idea is to use tip/tilt function of the telescope secondary mirror located at the entrance pupil. Even tip/tilt axes of the secondary mirror move, background pattern little changes because sky background is uniform and dust pattern on the telescope primary and secondary mirrors are defocused enough.

Recently, a tip/tilt off-load function from AO188 deformable mirror mount to Subaru telescope infrared secondary mirror has implemented and tested. In this paper, we report the effect of reducting thermal background pattern by off-loading tip/tilt components by the telescope secondary mirror.

7736-142, Poster Session

Design and expected performances of the SCAO-WFS module of SIMPLE: the high-resolution near-infrared spectrometer for the E-ELT

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We present and discuss the design and expected performances of the SCAO-WFS module of SIMPLE, the high resolution near-infrared spectrometer for the E-ELT which is designed to operate in the wavelengths range 0.84-2.5 micron with an entrance slit width of 27mas.

We analyze the design and performances of pyramid and SH near-infrared wavefront sensors. We find in particular that remarkably high values of light-concentration in the slit can be obtained even at the shortest wavelengths. The importance of this result for first-light scientific observations is discussed.

7736-144, Poster Session

Experimental validation of a numerical modeling for noncontact, massively actuated, deformable adaptive mirrors

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Design and analysis of non contact, voice coil motor massively actuated deformable adaptive mirrors requires a multidisciplinary approach encompassing: deformable structures, fluid dynamics and control systems. Such a task can be pursued by using sufficiently detailed numerical models, which should be usable, in a sufficiently comprehensive and thoroughly manner, for all of the design, installation and operational phases. Within such a framework experimental validations are often required to achieve full confidence in the tools at hand. This work presents the results obtained in a specific instance of such a validation process, entailing an adaptive specimen with 45 actuation points (dubbed P45, developed as an engineering prototype for the LBT adaptive secondary mirrors). This is far from the many thousands to be used in actual applications, e.g. in the E-ELT adaptive M4 or GMT adaptive secondary. It is nonetheless adequate to pin point all of their critical design and operational points. A description of the multi physics model is presented, followed by the results obtained by simulating actual tests on the specimen and their correlation with true measurements. The significance of various modeling details and their effect on the correlation is discussed. Among them, imprecise co-location, different fluid dynamic approximation schemes, sensor-actuation noises and quantization effect, compensation filters and computational delays, saturations, feed forward control identification are considered. The remarkable match between numerical and experimental results allows a confident use of the available simulation tools within medium-high fidelity design simulations of any actual adaptive mirror based on the modeled technology.

7736-145, Poster Session

Lucky imaging and adaptive optics on 10-m class telescopes: a real promise for diffraction limited imaging in the visible?

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Lucky imaging (LI) has been considered for a very long time as a cheap and/or competing alternative to adaptive optics (AO) systems. Very recent results in 4-5 m class telescopes indicate the potential benefits of having both techniques working together. In this paper we investigate from numerical simulations the potential benefits of extending such collaboration between both techniques to the domain of the 10-m class telescopes where already existing AO systems exist having been designed and optimized for operation in the NIR wavelength range. The combination of LI plus AO results not only on a better level of correction in the wavelength domain in the NIR, but also allows to extend the domain of AO correction to shorter wavelengths where AO is expected to deliver poor corrections. As a particular science case, we will show how the combination of AO+LI results in achieving a higher contrast ratio which is further enhanced when combined with a novel post-processing approach. This post-processing technique has achieved contrast ratio of up to 12 magnitudes in I-band at 2 arcsec when applied to traditional lucky imaging at 2-m class telescopes without AO. Hopes are high that significant gains in contrast ratio and angular resolution will result when applied to AO+LI systems in 10-class telescopes.

7736-146, Poster Session

Adaptive optics simulation with mechanically motivated basis functions

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For high accuracy simulation of Adaptive Optics (AO), multi-conjugate AO (MCAO), and ground layer AO (GLAO) analytic models have proven to be of significant importance. Usually, analytical models employ a finite set of Zernike basis functions that allow to replace point-by-point computation of phase maps by algebraic manipulation of basis function coefficients.

For closed loop simulation of AO systems it is essential to consider the spatial and temporal dynamics of deformable mirrors and wavefront sensors. In this case, simulations with Zernike basis functions have several drawbacks. First of all, they become computationally intractable when high order and high frequency behavior is analyzed. Additionally, the spatial dynamics of deformable mirrors cannot be approximated well by Zernike functions when mechanical constraints are considered.

In this paper, a set of orthogonal basis functions formed by spatial eigenmodes of deformable mirrors is proposed for simulation of large scale AO systems. It is shown that an analytic approximation of deformable mirror bending modes can be derived by solving a partial differential equation (PDE) and an inclusion of appropriate boundary conditions. Three sets of basis functions from different boundary conditions are studied in detail: the cases of a clamped edge, free edge, and flexible support of a circular plate at the inner radius. The basis functions are compared to the Zernike functions and their mathematical properties are discussed.

7736-147, Poster Session

Multilayered temporally evolving phase screens based on statistical interpolation

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Simulation of the dynamic effects of atmospheric turbulence assists in understanding, testing and effective implementation of adaptive optics systems. Most commonly used model involves a simple temporal superposition of phase screens at layers of different altitudes. This kind of modeling is unrealistic and does not present a close illustration of atmospheric turbulence. This is due to the fact that atmospheric wind velocity is a function of altitude from the surface of the Earth. Using finite number of grid points, it is difficult to accurately superpose phase screens moving at different velocities since it may require movement of the phase screens by non integral multiples of grid spacing. This simple multilayered model can be revised by suitably applying linear or statistical interpolation (Han-Ling Wu, et. al., 2009) over each layer and then adding them individually. Statistical method has an edge over linear interpolation since it allows us to retain the spatial statistics of atmospheric turbulence even after interpolation. A method of simulating evolving phase screens using the fast Fourier transform technique is illustrated using the existing wind profile measurements. We applied statistical interpolation in the simulation of temporally evolving phase screens using the multilayer model of atmospheric turbulence. A comparison of the statistical method with bilinear interpolator and random midpoint displacement method is presented. It is shown that underestimating Fried's parameter (r0) in the interpolation leads to large errors and hence it is appropriate to choose a little larger value of r0 than estimated from the phase screens. The method is also applied on phase screens simulated using Zernike covariance matrix and the covariance matrix of von Karman spectrum.

7736-148, Poster Session

Optimizing the modal index of Zernike polynomials for regulated phase screen simulation

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Simulation of phase screens is essential for evaluating the performance of adaptive optics systems. Many techniques exist to generate dynamic atmospheric phase screens. Atmospheric metrics are temporal variables and randomly fluctuate about a mean value. Hence, simulating the propagation of light through the atmosphere involves imitating randomly fluctuating spatial and temporal coherence properties. Knowing the temporal evolution of spatial coherence length of atmospheric turbulence, it is possible to simulate atmosphere like phase screens in a controlled fashion. Here, we calibrate the index of Zernike polynomials to control the spatial coherence of the generated phase screens. Phase screens following Kolmogorov statistics were simulated using Zernike polynomials through the Zernike moment covariance relation derived by Noll. Here, we make use of the fact that the spatial frequency increases with the radial index (n) of Zernike polynomials. To simulate phase screens with smaller Fried parameter (r0), the lower order Zernike polynomials are omitted. The resultant phase screens also followed Kolmogorov statistics. Each of the generated phase screens is normalized between 0 and 1. We report some interesting patterns observed in the relationship between the Zernike orders used and the obtained Fried parameter. As the number of lower orders omitted is increased, there is power law fall in the normalized Fried parameter (r0 ~ A n^{-0.3083} + B; where A and B are constants). Also, within a Zernike order, the dependence of r0 on 'n' is not uniform. At large value of 'n', there is saturation in the minimum achievable r0 value. Wavefront stitching methods can be used for effective simulation of large wavefronts along with the proposed methodology.

7736-149, Poster Session

Multi-conjugate adaptive optics with plenoptic cameras and the Fourier transform reconstructor

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Multi-Conjugate Adaptive Optics (MCAO) will play a key role in future astronomy. Every Extremely Large Telescope (ELT) is being designed with its MCAO module, and most of their instruments will rely on that kind of correction for their optimum performance.

Many technical challenges have to be solved in order to develop MCAO systems.

One of them, related to its use on ELT's, is to find fast algorithms to perform the reconstruction at the required speed. For that reason we have been studying the application of the Fourier Transform Reconstructor (FTR) to MCAO. We use the Fourier Slice Theorem in order to reconstruct the atmospheric volume. The process consists on reconstructing 'slices' of atmosphere, taking 1D-FFT's of the different projections to build a 2D Fourier space that is inverse-transformed to build the reconstructed slice. The advantage of using the FTR is that this algorithm gives us directly the Fourier Transform of the projections, speeding up the process.

To do a good reconstruction it is necessary to know the height at which the laser guide star is focused, and we propose to use a plenoptic camera to get this information, that we use together with the available information relative to the atmosphere we are reconstructing, Cn2, to weight the inverse-transforms and obtain a better estimate. The height is obtained in real-time, a very important advantage for the reconstruction.

We present the preliminary results of our MCAO simulations and the configuration of the plenoptic camera that could be applied to an ELT.

7736-150, Poster Session

Modeling the adaptive optics systems on the Giant Magellan Telescope

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Modeling adaptive optics systems is crucial to understanding their performance limitations and a key aid in their design. This paper describes an effort to model the different modes of the Giant Magellan Telescope's adaptive optics systems using end-to-end simulation methods and semi-analytic methods. Emphasis is placed on validating simulation results and showing how simulations can be used to drive design decisions.

7736-151, Poster Session

Simulations of the extreme adaptive optics system for EPICS

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We show end-to-end adaptive optics simulation results detailing the performance of EPICS, the first extreme adaptive optics system designed for the European ELT. The simulation software, Parallel EPICS Simulation Code and Applications (PESCA), is developed to perform efficiently on a cluster containing 4-500 computing units. The parallelization enables realistic modeling of error sources like wavefront sensor non-linearity effects, spider diffraction, segment mis-figure, pupil rotation and WFS mis-registration for telescopes having a size of an ELT. In addition, PESCA can simulate several wavelengths to model chromaticity impacts. We study the baseline of EPICS, a cascaded system of two independent AO loops, and characterize the AO system performance in terms of instantaneous contrast. The results show that a contrast of 10^-5-10^-6 can be achieved with a magnitude 4 star, and the performance gradually decreases when dimmer sources are used (factor of 10 in contrast with magnitude 10 stars). In addition, we see that at high fluxes, temporal error and WFS effects are the dominant error sources. The main challenges for EPICS AO system include the development of fast wavefront reconstruction algorithms for sensors with strong diffraction properties.

7736-152, Poster Session

The CAOS problem-solving environment: recent developments

M. Carbillet, Univ. de Nice Sophia Antipolis (France)

We present recent developments of the CAOS problem-solving environment (PSE), an IDL-based software tool whose original aim was to define and simulate as realistically as possible the behavior of a generic adaptive optics (AO) system, from the atmospheric propagation of light, to the sensing of the wave-front aberrations and the correction through a deformable mirror. The different developments made through the last years result in a very versatile numerical tool complete of a global graphical interface (the CAOS Application Builder), a general utilities library (the CAOS Library) and different specialized scientific packages: the original one designed for end-to-end AO system simulations (the Software Package CAOS), an image reconstruction package with interferometric capabilities (the Software Package AIRY), an extension of the latter specialized for the LBT instrument LINC NIRVANA (the Software Package AIRY-LN), an ad hoc package dedicated to the VLT instrument SPHERE (the Software Package SPHERE), and an embedment of the analytical AO simulation code PAOLA (the Software Package PAOLAC).

We present the status of the whole CAOS PSE, together with the most recent developments, and plans for the future of the overall tool.

7736-153, Poster Session

Modeling adaptive optics for the segmented aperture of the GMT

R. P. Knox, P. M. Hinz, J. L. Codona, Steward Observatory, The Univ. of Arizona (United States)

We present expected performance for the Giant Magellan Telescope (GMT) adaptive optics system. Using a custom adaptive optics modeling code developed at the University of Arizona, we are able to simulate the various aspects of atmospheric turbulence, wavefront sensing, and adaptive correction for the specific geometry of the GMT AO system. This allows us to explore the design space of the GMT and determine the performance of the system for various adaptive optics modes, including Laser Tomography AO and Ground-Layer AO. We present results showing the effect of the segmented aperture on AO performance, and discuss strategies for sensing and correction with the GMT aperture.

7736-154, Poster Session

An atmospheric turbulence generator for dynamic tests with LINC-NIRVANA's adaptive optics system

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LINC-NIRVANA (LN) is an instrument for the Large Binocular Telescope (LBT). Its purpose is to combine the light coming from the two primary mirrors in a Fizeau-type interferometer. In order to compensate turbulence-induced dynamic abberrations, the layer oriented adaptive optics system of LN consists of two major subsystems for each side: the Ground-Layer-Wavefront sensor (GLWS) and the Mid- and High-Layer Wavefront sensor (MHLWS). The MHLWS is currently set up in a laboratory at the Max-Planck-Institute for Astronomy in Heidelberg. To test the multi-conjugate AO with multiple simulated stars in the laboratory and to develop the necessary control software, a dedicated light source is needed. For this reason, we designed an optical system, operating in visible as well as in infrared light, which imitates the telescope's optical train (f-ratio, pupil curvature). By inserting rotating surface etched glass phase screens, artificial abberrations corresponding to the atmospheric turbulence are introduced. In addition, different turbulence altitudes can be simulated depending on the position of these screens along the optical axis. In this way, it is possible to comprehensively test the complete system, including electronics and software, in the laboratory before integration into the final LINC-NIRVANA setup. Combined with an atmospheric piston simulator, also this effect can be taken into account. Since we are building two identical sets, it is possible to feed the complete instrument with light for the interferometric combination during the assembly phase in the integration laboratory.

7736-155, Poster Session

Simulation of low-order AO performance on LAMOST

H. Bai, X. Yuan, Nanjing Institute of Astronomical Optics & Technology (China)

Large Sky Area Multi-Object Fibre Spectroscopic Telescope(LAMOST) is a large aperture and wide field telescope whose image quality requirement at Xinglong station is 80% light energy within 2 arcsecond. In fact, the designed image quality of the central field of view is diffraction

limited under optical wavelength. Due to the 60m long light path and poor natural seeing, dome seeing and other errors, the image quality is averaged about 0.5arcsecond to 1 arcsecond. We consider to deploy a low-order adaptive optics system on LAMOST to improve seeing conditions and the corresponding image quality. Based on the sounding balloon results on Xinglong Station, we make the numerical simulation of the AO performance and get Fried parameter, the final point spread function (PSF) characteristics of LAMOST including Strehl ratio, full width at half- maximum (FWHM), encircled energy, and the isoplanatic angle gain.

7736-156, Poster Session

Performance evaluation of a SCAO system for a 42-m telescope using the pyramid wavefront sensor

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We perform simulations of a SCAO system for an ELT-like telescope using a pyramid wavefront sensor (hereafter PYRWFS) and an on-axis NGS. The advantage of this WFS has already been demonstrated, being currently preferred in many AO systems where low signal sensitivity is critical. The main objective of this work is to evaluate the performance of such SCAO system under different control parameters (loop gain, modulation, SVD truncation mode), sensing wavelengths, atmospheric coherence scales and NGS magnitudes. Always adopting K as the science band, we have verified that the overall performance tends to be poorer as the sensing wavelength becomes shorter. The loop gain optimal range is dependent on the singular-value decomposition truncation threshold used to build the command matrix, and a zero modulation for the PYRWFS produces in general poorer results when compared to modulated cases, being this especially true for the R-sensing band. The default atmospheric model adopted was a von Karman with r0=0.13m (500nm) and outer scale of 25m, but poorer and better seeings have also been tested, being the long-exposure Strehls better for larger modulations. The telescope pupil had a central obstruction of 28% and spiders are now being introduced in the simulations. We intend to present in this conference results for guide stars dimmer than mV=5, verifying the range where the pyramid sensitivity gain outperforms other sensors.

7736-157, Poster Session

Modeling the spatial PSF at the VLT focal plane for MUSE data deconvolution purpose

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MUSE is the Multi Unit Spectroscopic Explorer, an AO-assisted integral field spectrograph for visible and near-IR wavelengths which is planned to be commissioned at the UT4 of the Very Large Telescope in 2012. We present the status on the modeling of the spatial PSF at the UT focus and its field-of-view and spectral variations. Modeling these variations and studying their implications is a cornerstone for deconvolution of MUSE datacubes.

By using the adaptive optics simulation tool PAOLA, we model the spatial PSFs as a function of atmospheric turbulence parameters, observed wavelengths, Adaptive Optics (AO) mode and position in the field of view. In Wide Field Mode (1 square arc-minute Field of View (FoV), 0.2 arcsec spatial sampling), MUSE can operate without AO correction or with a Ground Layer Adaptive Optics (GLAO) facility aimed at providing a uniform correction over a large field of view. In Narrow Field Mode (7.5 square arcseconds FoV, 0.025 arcsec spatial sampling) MUSE will make use of a Laser Tomography AO (LTAO) reconstruction, implying stronger variations. We also discuss the possible deconvolution methods to be employed for such varying PSFs and their robustness to the PSF estimation errors, and some issues concerning the estimation of the PSF itself. Finally, we present some results and characterize the estimated improvements.

7736-158, Poster Session

Dimensioning and localising the Gravity AO WFS

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We present the sudy made to dimension and localise the Gravity WFS. We first study the optimal bandpass given the AO TLR and then perform AO simulations with YAO (end-to-end AO simulation tool written in Yorick by F. Rigaut) for different WFS parameters/locations. We study also the optimal detector readout and mirror command modes taking into account the dectector characteristics and MACAO DM constraints

7736-159, Poster Session

Atmosphere and telescope simulator for new adaptive optics methods development

J. Moreno Raso, J. Serrano, H. Arguelaguet Vilaseca, LIDAX (Spain)

The IACAT Simulator is an Optical Ground Support Equipment which simulates atmospheric turbulence and reproduces the performance of three very different telescopes: GTC and WHT, located in Observatorio Roque de los Muchachos in La Palma (Canarias), and OGS which is located in Observatorio del Teide in Tenerife (Canarias). Its mission is to provide the Scientists with the same measurement conditions as the real telescopes but in a friendly laboratory environment, to assist the development of new adaptive optics methods based in FPGAs.

Most important telescopes' characteristics are simulated such as f number, pupils' size and position, magnification, central obscuration, etc. Up to 13 stellar objects can be created, individually or as binary stars with specific angular separations down to miliarcseconds.

For the atmosphere simulation, it allows creating three different turbulence layers at the same time within different altitude and wind speed ranges.

7736-160, Poster Session

Adaptive optics for satellite-to-ground laser communication at the 1m Telescope of the ESA Optical Ground Station, Tenerife, Spain

T. Berkefeld, D. Soltau, Kiepenheuer Institut für Sonnenphysik (Germany); R. Czichy, E. Fischer, B. Wandernoth, Synopta GmbH (Switzerland); Z. Sodnik, European Space Research and Technology Ctr. (Netherlands)

We present the optical setup, reconstruction scheme and observational results of an Adaptive Optics (AO) system implemented at the 1m telescope of the ESA Optical Ground Station, Observatorio del Teide, Tenerife.

The system is used to improve the signal-to-noise ratio of satellite to ground laser communications. It operates with coherent laser communication systems at 1064nm. The wavefront sensor is an 88-element Shack-Hartmann-sensor (11 subapertures across the pupil), matched to a 12x12 actuator “Multi-DM” membrane DM.

The system is able to correct 102 degrees of freedom, using a modal approach based on the double diagonalization scheme that produces statistically uncorrelated and orthogonal modes in the DM vector space.

Due to a special high speed infrared camera, the control loop can run at speeds up to 20 kHz, achieving a 0db bandwidth of well above 300Hz, depending on the received laser power.

7736-161, Poster Session

ARGOS: a laser constellation for adaptive optics at the LBT

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ARGOS is an innovative multi-star adaptive optics system being built for use with LUCIFER on the Large Binocular Telescope (LBT). LUCIFER is a wide field imager and multi-object spectrograph. Using a constellation of laser guide stars permits psf correction over a wide field in exchange for a relatively small sacrifice in achievable correction. The laser constellation consists of three stars per each of the two eyes of the LBT. The stars are nominally positioned on a circle 2 arcminutes in radius, but each star can be moved by upto 0.5 arcminutes in any direction.

Nd:YAG lasers are used in their second harmonic generation configuration to create the green (532nm) laser stars, and have an output above 18 W each at the planned pulsing frequency of 10kHz. The lasers are launched using a 40cm telescope and focused at a height of 12 km. We describe the characteristics of the laser system and its role in the adaptive optics setup for use with LUCIFER on LBT.

7736-34, Session 7

OCam and CCD220: world’s fastest and most sensitive camera system for advanced AO wavefront sensing

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For the first time, sub-electron noise has been demonstrated at 1300 Hz frame rate and 240x240-pixel frame size.

ESO and JRA2 OPTICON have jointly funded e2v technologies to develop a custom CCD for AO wavefront sensing applications. The device, called CCD220, is a compact Peltier-cooled 240x240 pixel frame-transfer 8-output back-illuminated sensor. Using the electron-multiplying technology of L3Vision detectors, the device is designed to achieve sub-electron read noise at frame rates from 25 Hz to 1,500 Hz and dark current lower than 0.01 e-/pixel/frame. This presentation describes the design of the device, the technology trade-offs and the test camera OCam that has been built for testing the devices. OCam includes a low noise preamplifier stage, a digital board to generate the clocks and a microcontroller. The data acquisition system includes a user friendly timer file editor to generate any type of clocking scheme. We confirmed the specifications of the detector with measurements in the laboratory. A second version of OCam, called OCam II, is currently under design offering enhanced performances, a completely sealed camera package and an additional Peltier stage to facilitate operation on a telescope. OCam II will offer two types of built-in data link to the Real Time Computer: the CameraLink industry standard interface and various fiber link options like the sFPDP interface. OCam II will also have a mechanical design allowing to integrate any type of microlens array for use of this camera in a wavefront sensing system.

A new OPTICON project started in June 2009 with the aim of developing a detector and camera dedicated to the artificial laser guide star.

7736-35, Session 7

Adaptive optics wavefront sensors based on photon-counting detector arrays

B. F. Aull, D. R. Schuette, R. K. Reich, Lincoln Lab. (United States); R. L. Johnson, Air Force Research Lab. (United States)

MIT Lincoln Laboratory has a long and continuing history of developing high-performance wavefront sensing charge-coupled device imagers for DoD and astronomy applications. These devices have tens of thousands of pixels and operate at several thousand frames per second with readout noise of a few electrons rms. For adaptive optics systems being planned, there is a growing demand for wavefront sensors that operate at higher frame rates and with more pixels while maintaining low readout noise. Lincoln Laboratory has been investigating Geiger-mode avalanche photodiode (GMAPD) arrays integrated with CMOS readout circuits as a potential solution. This type of sensor counts photons digitally within the pixel, enabling data to be read out at high rates without the penalty of readout noise. After a brief overview of adaptive optics sensor development at Lincoln Laboratory, we will present the status of the GM-APD technology along with future plans to improve performance.

7736-36, Session 7

NIR low-order wavefront sensor for TMT IRIS

D. D. S. Hale, R. M. Smith, G. Rahmer, California Institute of Technology (United States); D. Loop, National Research Council Canada (Canada); B. L. Ellerbroek, L. Wang, Thirty Meter Telescope Project (United States)

The Thirty-Meter Telescope (TMT) InfraRed Imaging Spectrograph (IRIS) is a first light science instrument, currently in its conceptual design phase. As a client of NFIRAOS, the facility multi-conjugate adaptive optics system, IRIS includes a sophisticated on-instrument wavefront sensor (OIWFS). In this paper we describe the IRIS OIWFS requirements and design choices, including our study of a conventional Teledyne HxRG detector with windowed readout for each of the three J-H band sensor channels. We have verified noise versus frame rate during capture and guide modes through laboratory tests of a recent 2.5μm-cutoff Teledyne detector. Optimization of the pixel timing and readout waveforms and the origin of the ultimate noise floor are discussed, together with practical matters such as the thermo-mechanical design. Based on these initial results, we describe predicted OIWFS performance and the resulting sky coverage predictions.

7736-37, Session 7

The Subaru coronographic extreme adaptive optic (SCExAO) system: implementation and performances of the coronographic low-order wave-front sensor

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In order to achieve high-contrast imaging at small working angles using the HICiAO camera on the Subaru telescope, a Phase Induced Amplitude Apodization (PIAA) Coronograph system is currently being assembled. The Subaru Coronographic Extreme Adaptative Optic (SCExAO) system, scheduled to be installed on the telescope early spring 2010, is located between the Subaru Adaptive Optic system (AO-188) and the recently commissioned HICiAO camera. It is designed to achieve a 1e-6 contrast at separations <0.5”. This high contrast coronographic imaging requires an accurate control of low order wave-front aberrations, such as tip-tilt and focus errors. Simulations and laboratory prototyping have shown that a Coronographic Low Order Wave-Front Sensor (CLOWFS), which uses a single defocused image of a reflective focal plane ring, can measure tip-tilt to an accuracy of 1e-3 lambda/D. We report the implementation and performances of the CLOWFS on the SCExAO system. Using both the CLOWFS camera as well as the science camera in the system, we quantify the accuracy of this system and its ability to successfully remove tip-tilt errors from the science image. We show that CLOWFS measurements can be used in post-processing to accurately remove coronographic leaks due to residual tip-tilt errors. We finally deduce the maximum contrast to be reached using the SCExAO system alongside the HICiAO camera and the AO-188 on the Subaru telescope.

7736-38, Session 8

Introduction to advanced real-time control algorithms

R. Conan, Univ. of Victoria (Canada); J. Veran, National Research Council Canada (Canada)

Since the early days, many aspects of Adaptive Optics (AO) have seen tremendous changes. From the early experimental systems providing low order correction in a tiny patch of sky to today’s fully automated specialized system offering correction in a much wider field and/or a much higher degree of correction, the evolution has been remarkable. For example, deformable mirror (DM) technology and wavefront sensing methods have been constantly improved. As well, real-time control algorithms have been greatly refined. This paper will review the different real-time control strategies that have been used with astronomical adaptive optics. They all have in common the same objective, that is the derivation of an “optimal” command for the deformable mirror(s) in order to get the least amount of residual optical aberrations in the science path. We will show that, most of the time, the real-time control algorithm is split in two independent components, the first part performing the wavefront (spatial) reconstruction, the second part performing the temporal control. With the advent of the extremely large telescopes (ELTs), as well as new AO modalities requiring several DMs and wavefront sensors, performing both these tasks in an ever shrinking glimpse of time is even more challenging. We will describe advanced fast and iterative reconstruction methods recently proposed for next generation AO systems.We will underline the importance of the trade-off in the choice of the priors, between accurate priors that would lead to optimal performance versus approximate priors that reduce the computational complexity. We will review the recently proposed Kalman based algorithms, which combine in an unique formalism wavefront reconstruction and temporal control.

7736-39, Session 8

Optimal AO control with NGS/LGS wave-front sensors: the multirate case

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Adaptive optics (AO) systems, which are now present on all large telescopes, use deformable mirrors (DMs) to compensate in real time wave-front aberrations caused by atmospheric turbulence, using measurements provided by a wave-front sensor (WFS).

In Multi-Conjugate AO (MCAO) systems, several DMs and WFSs are used to overcome anisoplanatism and make possible a high performance correction over an extended Field of Interest (FoI). This performance requirement can be expressed as maximizing the Strehl Ratio (SR), or equivalently as minimizing the residual phase variance. In a Minimum-Variance approach, this naturally translates into minimizing the average variance in the FoI.

However, this often results in non-homogenous performance. Yet for high precision photometry and astrometry, uniformity may be an advantage that could simplify calibration and post-processing accuracy.

A trade-off peak performance versus uniformity is therefore to be implemented in the control law.

In this contribution, this problem is addressed within the general framework of Linear Quadratic Gaussian (LQG) control, where the performance-uniformity trade-off can be encapsulated in a modified quadratic cost function. The resulting controller exhibits the same real-time structure and complexity as the original LQG MV solution.

Extension to Ground-Layer AO is also investigated. Results are illustrated for VLT-like MCAO systems, with a discussion on the impact on photo/astro-metric precision. Prospective applications include Gemini South MCAO, ESO VLT MCAO and the MAORY E-ELT MCAO system.

7736-40, Session 8

An optimized controller for ARGOS: using multiple wavefront sensor signals for homogeneous correction over the field

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ARGOS is the ground layer adaptive optics system planned for the LBT. The goal of such a ground layer adaptive optics system is to provide a maximum homogeneity of the point spread function over the full field of view.

Controllers for optimized correction with an adaptive optics system with guide star and science target at different field angles are well known in the case of a single guide star. As ARGOS uses three laser guide stars and one auxiliary natural guide star a weighting scheme is required to optimize the homogeneity using all available information. Especially the single off axis guide star provides only poor tip and tilt estimation over the full field. Therefore, the measurement from the laser guide star sensor is used to improve the tip and tilt estimation.

I will present the full scheme for an optimized controller for the ARGOS system. This controller uses the wavefront signals of the three lasers to additionally reconstruct the lower atmosphere. Information on the higher atmosphere will be provided by a DIMM-MASS instrument. The improvement in the homogeneity over the field gained by this approach is compared to the homogeneity gained by a system using a conventional controller.

7736-41, Session 8

Wavefront control algorithms for the Keck next-generation adaptive optics system

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The Keck Next Generation Adaptive Optics (KNGAO) system promises to yield high-Strehl observations over a wide range of science wavelengths from the optical through the infrared. The demands of the system have led to a multiple laser guidestar design where the real-time controller (RTC) must process wavefront input data from multiple directions and perform a tomographic estimate of the volume of turbulence-induced index of refraction changes above the telescope. We describe the set of algorithms we propose to use within a massively parallel processor environment in order to achieve the exacting wavefront accuracy needs of NGAO. The algorithms take advantage of the Fourier domain to speed up processing and ensure minimum variance control that incorporates prior as well as current data. We present the unique approach to the design that enables such a complex tomography processor to scale more favorably with telescope aperture size than the more traditional RTC approaches.

7736-162, Session 8

Modeling of turbulence-induced wavefront distortions and the effects on optimal AO control

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In recent years various researchers have proposed an optimal control approach for the rejection of turbulence-induced wavefront distortions in an adaptive optics system. An optimal controller renders the best possible performance -in a least squares sense- given a model of the deformable mirror, the wavefront sensor and the dynamics of the wavefront distortion. This also holds for multi-conjugate AO systems with multiple deformable mirrors and multiple wavefront sensors.

The essential element in the design of an optimal controller is the model for the turbulence-induced wavefront distortion. The choice for the turbulence model has direct consequences for the optimal control solution and its performance.

In this paper various models as proposed in literature are considered; ranging from first order auto-regressive temporal models to high-order full spatial-temporal models. The various models are analyzed and the resulting optimal control solutions are derived.

The performance of the optimal control solutions are compared for a von Karman type of turbulence under the frozen flow assumption. Here, the focus is on wavefront reconstruction and prediction which is the essence of the optimal AO control approach.

7736-43, Session 9

Progress and prospects in adaptive optics simulation capabilities

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In this paper, we discuss the current trends in simulating and modeling adaptive optics systems. We address the developments in analytical as well as end to end numerical simulation tools, especially in the context of the next generation of extremely large telescopes. We address also the hardware developments which could improve the performance of current and future AO simulations.

7736-44, Session 9

Identification of system misregistrations during observations corrected by adaptive optics

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The adaptive optics facility (AOF) designed for the Very Large Telescope (VLT) in Chile will be equipped with a deformable secondary mirror (DSM). The calibration procedure of the interaction matrix, which characterizes the system and the relationship between the DSM commands and the wavefront sensors (WFS) slopes, will be more complex than for the previous systems at the VLT since it will have to be measured on sky and for a much larger number of degrees of freedom (1170 actuators).

In addition, gravity or temperature variations for instance are likely to introduce slow evolution of the matching between the DSM and the WFS geometry. This can occur during observations and therefore degrade the adaptive optics (AO) correction. To relax the need of frequent painful calibrations and to prevent a loss of performance due to misregistrations, we investigate how to track the evolution of the interaction matrix errors in closed-loop without introducing any degradation in the observations. This is done thanks to identification methods and optimization theory.

First, we formally describe the closed-loop problem and its specificities. Then, we present a solution, based on the optimization of the error of predictions of the WFS slopes, at the output of the closed-loop AO. The performance of this method and its limitations are analyzed formally and thanks to numerical simulations of an AO system somehow characteristic of the ones expected in the AOF.

7736-45, Session 9

Comparing centroiding methods for Shack-Hartmann wavefront sensing with laser guide stars on an ELT

D. Gratadour, Univ. Paris-Diderot (France) and LESIA, Observatoire de Paris (France); É. Gendron, Observatoire de Paris à Meudon (France); T. Fusco, ONERA (France); G. C. Rousset, Observatoire de Paris à Meudon (France); V. Michaud, S. Meimon, ONERA (France)

Adaptive optics (AO) is a key component in the development of the future E-ELT and several concepts of instrument under study envision the use of laser guide stars (LGS). While LGS-AO has already been implemented on several 8m-class telescopes upscaling it to the 40m case is particularly challenging, starting with wavefront sensing aspects. In this paper, we present the results of a study comparing the performance of various centroiding methods on an extended spot. Various spot shapes, in good agreement with measurements of the Sodium layer density profile, are investigated. We compare the performance of center-of-gravity (COG) based and cross-correlation (CC) based methods and the matched filter (MF) algorithm. These methods all require an estimate of the profile shape. While their performance are comparable in the case of a Gaussian Sodium profile, we show that, above 15 to 20 m off-axis, substantial differences appear in the case of a known non-Gaussian Sodium density profile. CC based and MF methods seem to have comparable or better performance with various spot shapes while non-Gaussian shapes have a dramatic impact on COG based methods. Additionally, MF performance depend strongly on the spot shape which is not the case with CC based methods. We also investigate the impact of model errors on each of these methods and show that, in the case of a non-Gaussian Sodium profile, an accurate estimate of the spot shape is mandatory in each case to reach acceptable performance.

7736-46, Session 9

Dynamic behaviour of a large deformable mirror for future E-ELT

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Increasing dimensions of ground based telescopes and adaptive optics needs for these instruments to correct the turbulent wave fronts require increasing diameters of deformable mirrors (DM) and increasing number of actuators. These new sizes and characteristics of these structures incite to focus on their dynamic behaviour and the way to control the spurious vibrations due to their eigenmodes.

The aim of this paper is the study of the dynamic behaviour of a 1-meter prototype of E-ELT's DM. We first present the first eigenmodes of the prototype determined by both finite element analysis and experimental modal analysis. Then a state space model and corresponding frequency responses are described. Some solutions to control these spurious modes are finally suggested.

7736-47, Session 9

Deformable mirror models for open-loop adaptive optics using non-parametric estimation techniques

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Open-loop adaptive optics is a technique in which the turbulent wavefront is measured before it hits the deformable mirror for correction, therefore the correct control of the mirror in open-loop is key to achieving the expected level of correction. In this paper, we present non-parametric estimation techniques to model deformable mirrors working in open-loop. We have results with mirrors characterized by non-linear behavior: a Xinetics electrostrictive mirror and a Boston Micromachines MEMS mirror. The inputs for these models are the wavefront corrections to apply to the mirror and the outputs are the set of voltages to shape the mirror. We have performed experiments on both mirrors, achieving Go-To errors of the order of 1 % RMS of the peak-to-peak wavefront excursion. These techniques are trained with interferometric data from the mirror under control, therefore they do not depend on the physical parameters of the device.

7736-48, Session 9

‘Imaka: a Lagrangian invariant of ELTs

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The `Imaka project is a ground layer corrected wide field imager proposed for CFHT. It consists of three processes or components: The dome and local turbulence will be controlled by ventilation; the remaining ground layer turbulence will be corrected by a GLAO system and the free atmosphere seeing will be locally reduced by using an Orthogonal Transfer CCD to correct for tip-tilt within the isokinetic angle of field stars.

In designing the AO system, wether based on an adaptive secondary mirror or using pupil relay optics, it becomes apparent that the conjugation of the deformable mirror is a difficult constraint to achieve given the large field. It turns out this problem is not isolated to `Imaka, because the Lagrange Invariant for our project is in the same range as that of EAGLE for example. The effects of tilting the deformable mirror with respect to the pupil or compensating for misconjugation of an adaptive secondary mirror using a tomographic reconstructor have been investigated using Monte Carlo simulation codes, including our code developed specifically for GLAO simulations.

We report on quantitative results of performance of `Imaka for a variety of realistic turbulence conditions for each topical scheme, and allude to how these results are applicable to ELTs' adaptive optics designs.

7736-49, Session 9

Optimal method for exoplanet detection by spectral and angular differential imaging

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In the context of the SPHERE planet finder project, we characterize and further develop a recently proposed method for the efficient detection of planets using spectral and angular differential imaging, based on a Maximum-Likelihood approach. The method uses the fact that with the SPHERE instrument, when the pupil is stabilized, the field rotates during the night; furthermore, at each acquisition time, two images are recorded by the IRDIS instrument in two different spectral channels. The method starts with appropriate subtractions between AO-corrected, coronagraphic images recorded at different times and wavelengths. An optimization of the subtractions is performed to take into account the flux variation during the night due to the evolution of the quality of AO correction. These images differences constitute the so-called pseudo-data, which are the input for the algorithm to detect the position and estimate the amplitude of potential companions of the observed star. A statistically sound detection criterion is also proposed; it is based on the computation of the noise propagation from the images to the estimated flux. The robustness of the method versus various factors which can degrade the precision of the flux estimation (smearing of the planet signal due to the rotation of the field within one frame, error of the image centering, etc.) has been tested. Finally, the method has been validated on data simulating realistic conditions, performed by the SPHERE consortium.

7736-50, Session 9

Point-spread function reconstruction for Altair, Gemini North adaptive optics system: first on-sky results

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A few years ago, we adapted the Véran et al. point spread function reconstruction (PSF-R) method originally developed for curvature systems to Shack-Hartmann-based systems. The algorithm was tested with Altair (the Gemini North AO system) pre-commisioning data. The preliminary results were encouraging and we are implementing the algorithm to Altair 0n-sky data with the ultimate goal of providing a regular PSF-R service to the observer.

We will present results for a variety of optical turbulence and NGS brightness conditions which will allow us to estimate the sensitivity of the PSF-R process accuracy to the two major sources of uncertainty. These are (1) the fidelity of the noise propagation model and (2) the determination of the WFS centroid gain. The impact of other sources of errors (such as non common-path aberrations and vibrations) are also evaluated and discussed. Plans for future developments are briefly described at the end of the paper.

7736-51, Session 10

Dissecting galaxies with adaptive optics

R. Davies, Max-Planck-Institut für extraterrestrische Physik (Germany)

We describe several projects addressing the structure and evolution of galaxies for which adaptive optics is mandatory to reach high spatial resolution but is also a challenge due to the lack of guide stars and long integrations. In the nearest galaxies we wish to measure the black hole mass by spatially resolving its sphere of influence and to understand how star formation regulates the inflow of gas to fuel it. For major mergers, the aim is to understand what physical processes are important at different stages. At high redshift, we need to resolve the structure of galaxies to assess their dynamical state. In each case kinematics of the stars and gas, derived from integral field spectroscopy, plays a key role. We explain why deconvolution is not an option, and that instead the PSF is used to convolve a physical model to the required resolution. We discuss the level of detail with which the PSF needs to be known, and the ways available to derive it. We explain how signal-to-noise can limit the resolution achievable and show there are many science cases that require high, but not necessarily diffraction limited, resolution.

7736-52, Session 10

Novel, multi-frame approach to photometry of exoplanets

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Adaptive Optics (AO) imaging of exoplanets is very difficult due to the glare of their nearby, much brighter parent stars. Although many methods have been proposed for the detection of faint companions among residual speckles, the problem of measuring their brightness is relatively neglected. The problem is important because, in principle, differential photometry can be used to derive the planetary mass.

Traditional methods such as aperture photometry or PSF-fitting are not best-suited for the task. The former integrates the stellar light surrounding the companion, and has a tendency to overestimate its flux while the latter, PSF-fitting, relies on an extremely accurate estimate of the PSF. This is difficult to obtain because the AO PSF undergoes significant changes, even on short time-scales.

Recently, we showed that the probability density function (PDF) of intensity of the core of the AO PSF differs from the PDF of off-axis intensity. The two shapes are almost reverse versions of each other and we propose to use this morphological difference in the flux estimation process. In this technique, which we call “PDF deconvolution”, the traditional 2-D image deconvolution is replaced by a 1-D time-series deconvolution. The intensity distributions at the location of the star and its companion are scaled and shifted versions of the same peak intensity PDF. This fact is exploited in a 1-D, “blind,” iterative deconvolution scheme with the speckle PDF as the blurring kernel. We present results of its accuracy from AO images obtained from 3-8m apertures, as well as on simulated observations with VLT/SPHERE and also the proposed 42m European Extremely Large Telescope.

7736-53, Session 10

Recent results and perspectives for precision astrometry and photometry with adaptive optics

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Large ground-based telescopes equipped with adaptive optics (AO) systems have ushered in a new era of high-resolution infrared imaging and astrometry. Relative astrometric accuracies of ~0.1 mas have already been demonstrated from infrared images with spatial resolutions of 55-95 mas resolution over 10-20” fields of view. Relative photometric accuracies of 3% and absolute photometric accuracies of 5%-20% are also possible. I will hilight our improvements and current limitations in astrometry and photometry of crowded stellar fields. These capabilities enable unique experiments such as measuring orbits for brown dwarfs and exoplanets, studying the supermassive black hole in our Galactic center, and testing the universality of the initial mass function within our Galaxy.

7736-54, Session 10

Accurate photometry and astrometry of exoplanets after ADI processing

C. Marois, National Research Council Canada (Canada); B. A. Macintosh, Lawrence Livermore National Lab. (United States)

Ground-based exoplanet imaging with adaptive optics is severely limited by quasi-static speckle noise originating from optical defects on the telescope mirrors and instrument optics. The invention of angular differential imaging (ADI) for speckle subtraction has significantly lifted this limitation by allowing the subtraction of speckles by up to two orders of magnitude for hour-long exposure sequences, making it possible to search for exoplanets at very small angular separations (ADI uses the intrinsic field-of-view rotation generated by Earth rotation when observing with an alt-azimuthal telescope to decouple the planet flux from speckle noise). Although it is easy to implement this algorithm to detect planets, the inherent variable-speed field-of-view rotation induces several important complications when trying to derive accurate exoplanet photometry and astrometry, especially if the system transits close to the local zenith. Since ADI is being used for ongoing surveys and is considered for next generation surveys with the Gemini Planet Imager (GPI), having a robust technique to obtain an accurate position and flux of exoplanets is critical; it will enable better orbital determination of the decade-long orbits and will improve the characterization while possibly allowing for the detection of variability of an exoplanet’s atmosphere.

I will go over the challenges that we have discovered when trying to analyze the HR 8799 three planets system that transits 1.3 degrees from Zenith at Mauna Kea and the solutions that we have implemented to overcome them.

7736-55, Session 11

The Gemini NICI planet-finding campaign

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Our team is currently carrying out a 50-night observing campaign to directly image and characterize young (<~1 Gyr) extrasolar planets using

the Near-Infrared Coronagraphic Imager (NICI) on the Gemini-South 8.1-meter telescope. NICI is the first instrument on a large telescope designed from the outset for high-contrast imaging, comprising a high-performance adaptive optics (AO) system with a simultaneous dual-channel coronagraphic imager. In combination with state-of-the-art AO observing and data analysis methods, NICI typically achieves about 1-2 magnitudes better contrast compared to previous ground-based or space-based planet-finding efforts, at separations inside of ~2 arcseconds. We have also carried out complementary efforts to identify previously unrecognized young stars as targets, to develop a rigorous quantitative methodology for constructing the observing strategy, and to optimize the combination of the angular differential imaging (ADI) and spectral differential imaging (SDI) observing techniques. The Planet-Finding Campaign will have completed its second year of observing by summer 2010, with deep imaging of ~150 stars already obtained. We describe the Campaign's goals, design, target selection, on-sky performance, and results. The NICI Planet-Finding Campaign represents the largest and most sensitive imaging survey to date for massive (~1 Mjup) planets around other stars.

7736-56, Session 11

XAO coronagraphy with the high-order testbench in the light of the SPHERE instrument

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The high-contrast instrument SPHERE, dedicated to the search for extrasolar planets, is currently being integrated with first light in early 2011.

It combines an extremely high performance adaptive optics system correcting for atmospheric turbulence, with a coronagraph to reduce starlight, and speckle calibration techniques to push the contrast further down. The paper presents recent laboratory experiment with the High-Order Testbench (HOT) which is a high-contrast imaging adaptive optics bench developed at the European Southern Observatory. The experiment makes use of a turbulence generator with a real-time XAO-system correction, and an Apodized Pupil Lyot Coronagraph (APLC) in the near-infrared. Laboratory results are compared with simulation of the near-IR camera of SPHERE, and demonstrate that contrast reached after the coronagraph is in good agreement with expectation.

These first images enable probing limitations occurring in realistic conditions at high-AO correction after the coronagraph (e.g. pinned speckles and quasi-static speckle limitation).

Additionally, results obtained with a new algorithm developed to discriminate planets from speckles in AO-corrected coronagraphic images, and applied on HOT images, will be presented.

7736-57, Session 11

The Gemini planet imager: status and integration

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The Gemini Planet Imager is a dedicated high-contrast instrument, combining an advanced 1800-actuator AO system, a high-performance coronagraph, a precision infrared interferometric wavefront sensor, and an integral field spectrograph. Assembly and testing of GPI and its subsystems has now begun, and I will present a design overview (showing how the design has evolved), status, subsystem and component testing results, and plans for completion and comissioning.

7736-58, Session 11

System study of EPICS: the exoplanets imager for the EELT

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ESO and a large European consortium completed the phase-A study of EPICS, an instrument dedicated to exoplanets direct imaging for the EELT. The very ambitious science goals of EPICS, the imaging of reflected light of mature gas giant exoplanets around bright stars, sets extremely strong requirements in terms of instrumental contrast achievable. The segmented nature of an ELT appears as a very large source of quasi-static high order speckles that can impair the detection of faint sources with small brightness contrast with respect to their parent star. The paper shows how the overall system has been designed in order to maximize the efficiency of quasi-static speckles rejection by calibration and post-processing using the spectral and polarization dependency of light waves. The trade-offs that led to the choice of the concepts for common path and diffraction suppression system is presented. The performance of the instrument is predicted using simulations of the extreme Adaptive Optics system and polychromatic wave-front propagation through the various optical elements.

7736-163, Poster Session

Noise reduction in the centroiding of laser guide star spot pattern using thresholded Zernike reconstructor

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Errors in wavefront reconstruction are largely determined by the accuracy of centroiding in Shack Hartmann Sensor (SHS) based adaptive optics systems. These centroid estimation errors primarily occur due to the presence of photon noise, readout noise, finite background and strong scintillations. Elongation of the spots in the case of large telescopes while using Laser Guide Star (LGS) as reference makes the situation further worse. In this paper, we suggest an efficient noise reduction algorithm based on thresholded Zernike reconstructor (not to be confused with modal reconstruction) and pattern matching to largely overcome these problems. The method is validated using numerical experiments. von Karman and Kolmogorov phase screens simulated using FFT method and Zernike covariance method respectively are used in Monte Carlo simulations for algorithm testing. LGS spot pattern is simulated by assuming that the launch point is at the center of the telescope aperture and adopting single as well as bimodal vertical profile of sodium layer. Different noise terms are added appropriately to the spot pattern. Complex Zernike coefficients corresponding to the spots of individual subapertures are calculated by a fast and accurate method. The high frequency components representing strong background and scintillations are removed by discarding the higher order Zernike moments during reconstruction of the spots. Thresholding which is an important step in many existing centroiding techniques is applied on the spot images. For improved accuracy in the cases of low signal to noise ratio, the centroid is estimated by matching the shape of the Zernike reconstructed spot with an expected ideal elongated spot pattern. These resultant spots are used for wavefront reconstruction through Fourier technique. It is

observed that this method is sensitive to the number of Zernike modes used for image reconstruction.

7736-164, Poster Session

Classic adaptive optics: disturbance rejection control

A. Abelli, Observatoire de la Côte d'Azur (France); J. Folcher, Univ. de Nice Sophia-Antipolis (France); A. Ferrari, M. Carbillet, Univ. de Nice Sophia Antipolis (France)

This paper addresses the residual wavefront variance minimization by means of a linear optimal stochastic control methodology.

The proposed approach emphasizes the ability of the LQG controller loop to reject the atmospheric aberration, in this work modelled as simple yet effective autoregressive model. We derive a diagonal state space system which clearly separates the dynamics of the plant (DM & WFS) from the disturbance dynamics (atmospheric model). This representation facilitates the numerical resolution of the problem. The effectiveness of the approach is demonstrated through numerical experiments using wavefront screens generated with the software package {tt CAOS}.

7736-165, Poster Session

An optimal control law for wide-field AO on ELTs

M. Chebbo, B. Le Roux, Observatoire Astronomique de Marseille-Provence (France)

The control of AO systems dedicated to ELT is a difficult problem related to the large number of degrees of freedom. The standard and most used adaptive optics AO control starting from the integrator to the LQG are not useful in such a case. In fact, for future Extremely Large Telescope (ELT's) the number of degrees of freedom is very large related to the large diameter of the ELT's and the emergence of new architectures for the AO systems. So that the necessary computational power for real time computing RTC on such systems is currently unattainable when using these control methods.

Thus, more efficient algorithms are required. We present simulation results of a tomographic AO system in the configuration of EAGLE instrument (multi-object adaptive optics). We explore theoretical developments to define an optimized control law.

7736-166, Poster Session

Multiple field-of-view MCAO for a Large Solar Telescope: LOST simulations

M. Stangalini, F. Berrilli, D. Del Moro, R. Piazzesi, Univ. degli Studi di Roma Tor Vergata (Italy)

We have implemented into LOST (Layer Oriented Simulation Tool) Simulation Package new algorithms specifically developed for a Solar Telescope MCAO (Multi Conjugated Adaptive Optics), to evaluate the performance of a solar MCAO system for the next generation 4m class telescopes.

We are particularly interested in methods to reduce the time delay error which is critical in solar adaptive optics, by optimizing the wavefront reconstruction procedures.

In this work we present two methods to achieve this goal:

a) the reordering of the modal base to decompose the incoming wavefront phase, by applying the Mutual Information Entropy concept.

b) the forecasting of the wavefront correction through ARMA (Auto-Regressive Moving Average) stationary processes or Neural Networks.

We evaluate these techniques underlining pros and cons of their usage in different control conditions (closed loop and open loop) by analyzing the results of the LOST simulations.

7736-167, Poster Session

Implementation of type-II tip-tilt control in NFIRAOS, with woofer-tweeter and vibration cancellation

J. Véran, National Research Council Canada (Canada); C. Irvin, Univ. of Victoria (Canada); G. Herriot, National Research Council Canada (Canada)

In a previous paper, we have proposed to implement a type-II controller in NFIRAOS, the Narrow Field Infra Red Adaptive Optics System for the Thirty Meter Telescope. Type-II control enables increased tip-tilt rejection, which, for a given error budget, translates into increased sky-coverage. Our proposed type-II controller is a cascade of two integrators, a gain and a lead filter. The correction is then split between the tweeter (the deformable mirror surface) and the woofer (a tip-tilt stage that holds the deformable mirror) using high and low pass filters. So far, we had only characterized this controller in the continuous domain, where the discrete nature of the real-time computer part is approximated by continuous functions (Laplace analysis). In this paper, we discuss the discrete implementation, with particular focus on a) anti-windup, to robustly deal with temporary saturations, and b) low sampling rates, where frequency warping may occur in the discretization process. The implementation is tested in a hybrid Simulink model, where continuous and discrete processes are properly implemented using continuous or discrete blocks, respectively, and the performance is compared with the performance predicted by the continuous domain analysis. Finally, we analyze the implication of the implementation of an additional notch filter to further attenuate a potential vibration at a known frequency.

7736-168, Poster Session

Numerical control matrix rotation for the LINC-NIRVANA multiconjugate adaptive optics system

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escope (LBT). A double channel Layer Oriented multi-pyramids multi-conjugate adaptive optics system assists the two arms of the interferometer, supplying high order wave-front correction. In order to counterbalance the field rotation, mechanical derotation for the two ground wave-front sensors, and optical derotators for the mid-high layers sensors fix the positions of the focal planes with respect to the pyramids aboard the wave-front sensors. But the derotation introduces a rotation of the pupil images analyzed by the wavefront sensors: in this way the projection of the influence functions of the deformable mirrors on the sensor consequently change. The proper adjustment of the control matrix will be applied real-time through numerical computation of the new matrix. In this paper we investigate the temporal and computational aspects related to the pupils rotation, explicitly computing the wave-front errors that may be generated. Wherever possible we measure the effect of an improper derotation by the means of one of two secondary mirrors of the LBT currently in testing phase in Italy and of the pyramid wave-front sensor which controls it. We crosscheck and explore different cases and matrix computation procedures using End-to-End numerical simulations.

7736-169, Poster Session

Experimental validation of type-II tip-tilt control in a woofer-tweeter adaptive optics system

R. Conan, Univ. of Victoria (Canada); J. Veran, National Research Council Canada (Canada); K. J. Jackson, Univ. of Victoria (Canada)

Woofer--Tweeter Adaptive Optics (AO) systems use two Deformable Mirrors (DM) with a single wavefront sensor (WFS) to correct for optical aberrations.

The splitting of the DM commands derived from the WFS measurements must accommodate both the spatial and temporal bandwidth of the DMs.

This paper reports on a woofer--tweeter experiment developed at the AO laboratory of the University of Victoria.

This experiment uses a tip--tilt mirror as a woofer and a 9X9 CILAS PZT DM as a tweeter.

The response of the woofer is slowed down in order to reproduce the behavior of the tip--tilt platform supporting the DM of the TMT/NFIRAOS system.

For this experiment, only the tip--tilt mode is considered, especially the off-loading of the low temporal frequencies of the tip--tilt mode from the DM to the slow tip--tilt mount is investigated.

The closed--loop controller is a type II controller with a cascade of two integrators and a lead filter.

The performance of this Woofer--Tweeter scheme as measured in the experiment is presented, and compared with the performance predicted by a hybrid Simulink model. The increased rejection achieved by the type II controller compared to a classical controller is quantified, as well as the increase in the associated noise propagation.

7736-170, Poster Session

Real-time open-loop control of a 1024-actuator MEMS deformable mirror

C. Blain, R. Conan, C. Bradley, Univ. of Victoria (Canada); O. Guyon, National Astronomical Observatory of Japan/Subaru Telescope (United States); D. Gamroth, R. Nash, D. Roberts, Univ. of Victoria (Canada)

Many of the next generation Adaptive Optics (AO) systems are planning to use micro-electro-mechanical-system (MEMS) Deformable Mirrors (DM), due to their advantages of high actuator count and small size of the DM package. Specific AO architectures, such as Multi-Object AO, will also require open-loop control of the DM.

Recently, progress has been made in developing accurate models of MEMS DMs, particularly for application in open-loop control systems. In parallel with the refinement of these models, it is critical to demonstrate successful integration of the DM and model into a Real-Time Control (RTC) architecture. The University of Victoria Adaptive Optics Laboratory (UVicAOLab) has developed an empirical DM model, based on the calibration of both the actuator influence function and the actuator stroke-voltage relationship. This model is used as a framework to investigate the feasibility of developing an open-loop RTC.

The wavefront sensor path of an existing woofer-tweeter adaptive optics test bench was modified to accommodate the inclusion of a 1024-actuator Boston Micromachines MEMS DM (as a tweeter DM) in an open-loop control configuration. The open-loop experiment is presented in this report, including the details of the optical design, the real-time computer system and the open-loop control algorithm. The performance of the open loop RTC system is presented.

7736-171, Poster Session

Recent development in real-time control system of Subaru adaptive optics including laser guide star mode

M. Hattori, Y. Minowa, S. Colley, V. Garrel, S. E. Egner, T. I. Golota, O. Guyon, M. Ito, S. Oya, M. Watanabe, Y. Hayano, H. Takami, M. Iye, Y. Saito, National Astronomical Observatory of Japan/Subaru Telescope (Japan)

We report recent development in real time control system of Subaru laser guide star adaptive optics system. The main topic is modification of the real time control system for laser guide star operation. The primary change is adding lower order wavefront sensor. And also, an auxiliary tip tilt and focus control are appended before higher order wavefront sensor to absorb the perturbation of the laser beam and height of sodium layer. Our implementation will be introduced throughly from the basis of the system design and down to the details. That includes, not only the design of the real-time system itself, but also how to handle then to let entire system efficiently work in laser guide star mode, from testing to the commissioning in our actual case. Also, our presentation will include other newly developed functions, such as monitoring system with cascaded integration system or external Tip-tilt control. There are some modifications in real-time controlling with prospects for enhancing the performance of the Subaru's adaptive optics as a curvature AO system, with or without laser guide star.

7736-172, Poster Session

A COTS high-performance real-time control system for adaptive optics

A. G. Basden, R. M. Myers, S. Dimoudi, T. J. Morris, E. J. Younger, N. E. Looker, D. Geng, N. A. Dipper, Durham Univ. (United Kingdom)

The advent of high performance multi-core processors in desktop computers has opened the door for high performance, yet easy to maintain and upgrade, adaptive optics real-time control systems. We describe the Durham Adaptive Optics Real-time Controller, and give details of performance, including latency and jitter, and maximum frame rates as well as scalability with adaptive optics system size.

These results include laboratory test results. This system is to be used as a laboratory test bench in Durham with low and high order (up to 32x32 actuators) systems, and also on-sky as a control system for CANARY.

This system has abstracted input and output interfaces, meaning that libraries can be written (compatible with an existing header file) to allow the control system to be used with any camera and mirror configuration without altering (or even restarting) the core system, and we discuss the benefits that this has.

It can also be used as figure sensor and DM controller, accepting mirror demands from an open-loop AO system controller, and rapidly adjusting the values actually sent to the mirror in closed-loop until it matches the required shape.

We discuss the concepts behind the real-time controller and the algorithms implemented, including several slope measurement algorithms, and linearisation algorithms for open-loop operation. We also describe the telemetry stream concept that the system uses.

Hardware acceleration techniques including FPGAs and GPUs can be used with the real-time controller, and these are discussed.

7736-173, Poster Session

SPARTA roadmap and future challenges

E. Fedrigo, B. Bauvir, R. Donaldson, European Organisation for Astronomical Research in the Southern Hemisphere (Germany)

SPARTA, the ESO Standard Platform for Adaptive optics Real Time Applications, provides a pretty generic decomposition in functional blocks that can be appliead, unchanged, to a variety of different AO systems, ranging from very small single conjugate AO with less than 100 actuators to much bigger and faster systems.

For AO systems under development, SPARTA provides an implementation for all those functional blocks that are mapped to currently available technologies. The E-ELT with its instruments poses new challenges in terms of cost and computational complexity. Simply scaling the current SPARTA implementation to the size of E-ELT AO system would be unnecessary expensive and in some cases not even feasible. So, even if the general architecture is still valid, some degree of re-implementation and use of new technologies will be needed.

This paper analyses the new general requirements that the E-ELT and its instruments will pose, without directly referencing actual instrument studies, and promising technology and solutions that could replace the current ones and show how the SPARTA architecture could evolve to address those new requirements.

7736-174, Poster Session

The real-time control system for the CANARY multi-object adaptive optics on-sky demonstrator

N. A. Dipper, N. Looker, D. Geng, E. J. Younger, R. M. Myers, A. G. Basden, Durham Univ. (United Kingdom); G. C. Rousset, E. Gendron, Z. Hubert, Observatoire de Paris à Meudon (France)

CANARY is a Multi-Object Adaptive Optics (MOAO) system designed to demonstrate the AO aspects of the proposed E-ELT multi-object spectrograph EAGLE. The first phase of Canary will be executed on the 4.2m William Herschel Telescope in mid 2010. We describe here the AO Real-time Control System (RTCS) for Canary. This is based on a distributed architecture of components interconnected by a fast serial fabric (sFPDP). The hardware used is a hybrid of FPGA and CPU technology. The middleware used for system data telemetry and control is based on CORBA and the publish/subscribe pattern. The system is designed to be easily modified and extended for the later, higher order, phases of Canary. In order to provide the increase in computational power required in higher order systems, the current CPU technology can be readily replaced by acceleration hardware based on FPGA or GPU technologies. The Canary RTCS thus provides a test-bed for these new technologies that will be required for EAGLE. In order to efficiently handle the larger data telemetry requirements of higher order systems, we intend to introduce the Data Distribution Service (DDS) in parallel with CORBA. These design concepts can be developed to provide the RTCS for EAGLE and are in line with those under consideration by ESO for the E-ELT AO systems to which the EAGLE RTCS will be required to interface.

7736-176, Poster Session

Control system of a dispersed fringe type sensing system of active optics

Y. Zhang, Z. Zhang, Nanjing Institute of Astronomical Optics & Technology (China)

Active optics is play an important part in segmented mirrors of astronomy telescopes. A dispersed fringe sensor(DFS) using a broadband point source is an efficient method for cophasing and is also highly automated and robust. DFS can estimate the piston between segments by only using the spectrum formed by the transmissive grating's dispersion and therefore can replace the edge sensors. So we build an system in our lab to experiment the DFS method. The whole control system of DFS system is put forward, including control of displacement actuators and control of shifting the optical fiber. Control of displacement actuators consists in industry computer, HY-6120 I/O card, six stepper motor and other parts. Some theoretical analysis and experiment tests reveal that the actuator could be control to 5nm and without backlash by this control strategy.

The optical fiber could be shifted out of optical path or shifted in part and whole of optical path so that the spectrum formed by the transmissive grating's dispersion could alter. When six actuators are moving, the piston is changing, and the spectrum is also moving and altering. And the whole control of DFS system is constructed now and seems well. Further test and experiment will be carry out.

7736-177, Poster Session

Point-spread function reconstruction for the ground layer adaptive optics system ARGOS

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ARGOS is the ground layer adaptive optics system planned for the LBT.

The system uses three Rayleigh laser guide stars and one natural tip and tilt star for atmospheric measurements and provides a relatively homogeneous point spread function over the full field of view. However, there will be still variations of the order of more than 10%.

These are mostly due to the fact that only one auxiliary guide star is used.

Astrometry and photometry on adaptive optics corrected images are effected by these variations in the shape of the point spread function with field angle. To reduce this effect for the ARGOS system a scheme for point spread function reconstruction from wavefront sensor data is developed. The scheme uses the wavefront sensor data twofold: To reconstruct the wavefront and to measure the atmospheric profile via SLODAR technique.

I investigate in the accuracy of the reconstruction scheme of the full system for various seeing conditions and guide star angles. This accuracy of the reconstruction is tested in two ways: The difference in the residual RMS wavefront error and the resulting astrometric accuracy in the image.

7736-178, Poster Session

Transients in the sodium layer: assessment and mitigation for TMT

G. Herriot, National Research Council Canada (Canada); R. Conan, Univ. of Victoria (Canada); P. Hickson, The Univ. of British Columbia (Canada); K. J. Jackson, O. Lardière, Univ. of Victoria (Canada); T. Pfrommer, The Univ. of British Columbia (Canada)

Sporadic events such as micrometeors or gravity waves can disturb the structure and height of the sodium layer. On time scales of a second, the mean altitude can change by 100 m - 1000 m, which, if uncompensated, would introduce Laser Guide Star AO focus errors of at least 400 nm for the Thirty Meter Telescope. Interestingly, these Na transients not only impact the mean altitude, but also the skewness (3rd central moment) of the profiles. We found out recently that there is a very good correlation between the residual RMS wavefront error and the skewness of the Na profile. These transient events typically last 1-2 seconds, and occur once or twice per hour and sometimes every ten minutes. We evaluate the response to these transients by the DM control system interacting with the natural star focus WFS and the LGS refocussing optics in NFIRAOS together with the the LGS WFS matched filter (centroider) background update process. Strategies to reduce the impact on the delivered science images are investigated.

7736-179, Poster Session

Anisoplanatism across wide fields at high-frame rates

T. D. Staley, C. D. Mackay, Univ. of Cambridge (United Kingdom)

In this paper we investigate the variation of the isoplanatic patch size and other turbulent effects over short timescales and wide angular separations.

We tested a visible band photon counting camera running with four 1k squared detectors to provide a contiguous field of view of 1000*4000 pixels. Resolution was 35-100 mas per pixel at frame rates from 20-111hz, providing data on wide angle atmospheric turbulence. We discuss the potential of such cameras to perform high resolution optical surveys using developments of standard “lucky imaging” techniques, and the implications of our results for adaptive optics systems design.

7736-180, Poster Session

Making a robust, reliable, and a highly available DIMM seeing monitor

J. M. Delgado Hernandez, L. F. Rodriguez Ramos, H. Vazquez Ramio, D. Jimenez Mejias, Instituto de Astrofisica de Canarias (Spain)

During the last 20 years, many DIMM instruments have been developed to measure astronomical seeing. IAC has been involved in several projects to run different campaigns to characterize its observatories. However, the cost in manpower to maintain and operate these instruments has been too high and it is mandatory to minimize this effort by constructing a well reliable, robust and high available seeing monitor.

A review of all sources of errors has been done for fitting with the best reliable measurement: Acquisition parameters as box size, signal threshold, SNR threshold, flux, deformations and vibrations for centroid calculations, best pixel scale, jitter in the images sampling, light bandwidth, CCD noise, as well as the centroid calculation algorithm. Experimental measurements about the influence of exposure time, number of images for seeing computing or defocus have been carried out to identify the practical limits of the instrument.

The IAC automatic DIMM design has been reviewed to improve its robustness and its availability to guarantee the maximal time of working and to maximize the time between failures. The new design will be showed as part of this work.

7736-181, Poster Session

Atmospheric dispersion correction for the Subaru AO system

S. E. Egner, National Astronomical Observatory of Japan/Subaru Telescope (United States); Y. Ikeda, Photocoding (Japan); M. Watanabe, Hokkaido Univ. (Japan); Y. Hayano, T. I. Golota, M. Hattori, M. Ito, Y. Minowa, S. Oya, Y. Saito, H. Takami, National Astronomical Observatory of Japan/Subaru Telescope (United States); M. Iye, National Astronomical Observatory of Japan (Japan)

In this paper, we present the science path ADC unit (atmosperic dispersion corrector) for the AO188 Adaptive Optics System of the Subaru Telescope. The AO188 instrument is a curvature-based Adaptive Optics system with 188 subapertures and achieves good correction down to shorter wavelengths like J-band. At these wavelengths, the atmospheric dispersion within the band becomes significant and thus a good correction of the atmospheric dispersion is essential to reach diffraction-limited image quality. We give an overview of the requirements, the final optical & mechanical design of the ADC unit, as well as the structure of its control software. We conclude the paper with the results of the on-sky performance evaluation.

7736-182, Poster Session

The physics of the mesospheric sodium layer

E. J. Kibblewhite, The Univ. of Chicago (United States)

In this talk I will review the physics of the mesospheric sodium layer. I will first describe the chemistry and environment of the mesosphere and how it affects the abundance of sodium. I will then discuss the various interactions between the atom and the radiation field and collisions with other molecules. It is usual to discuss collision lifetimes in terms of hard sphere (“billiard ball”) interactions, we will show that long range inter-atomic forces have a significant effect on the collision lifetime. I will show how atomic physics and the effects of radiation pressure and the earth’s magnetic field can explain the difference in photon return from the sodium layer as a function of laser spectral and temporal format of different types of laser. Lastly I will show how a number of different techniques can improve the photon return for some classes of laser and will describe the results of experiments in chirping and backpumping carried out at Palomar Observatory.

7736-183, Poster Session

Laser guide star facility at La Silla Paranal Observatory: latest upgrades, operation, and performance

J. L. Alvarez, European Southern Observatory (Chile)

At Paranal Observatory in the YEPUN (UT4) telescope, two instruments are installed and equipped with adaptive optics systems: an infrared spectro imager (CONICA) below the adaptive optics module NAOS; and an integral field spectrograph (SINFONI). In the same telescope, the Laser Guide Star Facility (LGSF) is installed to provide a reference star to the adaptive optics systems. The LGSF is tuned to the sodium D2 line to use the resonance fluorescence of atomic sodium in the mesospheric layer at an altitude of 90 Km.

The LGSF system has been fully operational for several years now. During this time, important modifications have been made to the system to increase its availability, simplify its remote operation and improve its performance.

In this contribution, we report on the latest upgrades in hardware as well as the software of the system. Some upgrades like the exchange of the cooling system of the VERDI lasers, as well as the exchange of motors in the PARSEC laser system, have been critical to improve the performance of the system. We also describe the improvements in the maintenance and operation procedures and operational constraints we have faced so far. Finally, we present and analyze the latest technical performance achieved by the LGSF in operational conditions.

7736-185, Poster Session

Gemini North laser guide star system: operations, maintenance, and science observations review

V. Fesquet, R. Oram, Gemini Observatory (United States)

The Gemini North telescope has been providing Laser Guide Star Adaptive Optics (LGS AO) regular science queue observations for worldwide astronomers since February 2007. In this paper we comment on the reliability of the Laser Guide Star Facility high-power solid-state laser during normal operations, and discuss progress made on various issues that will enable a “turn-key” operation mode for the laser system. In the effort to obtain stable laser parameters (brightness, spot size), we have been working on improving both laser wavelength and output power stabilization. We will discuss our findings on opto-mechanical design issues in laser resonators, and laser enclosure thermal and gravity environment effects. We will present our failure mode effect analysis of the laser system and sub systems and present the routine maintenance operations that are ongoing as a result, including pump laser diode replacements and wavelength tuning practice, as well as Sum Frequency Generation (SFG) crystal degradation along with our detailed plans to improve overall laser reliability, and availability. Finally, we provide an overview of normal operation procedures during LGS runs and present a snapshot of data accumulated over several years that describes the overall LGS AO observing efficiency at the Gemini North telescope.

7736-186, Poster Session

A pulsed guide star laser can be the brightest

N. Simakov, M. Hamilton, P. Veitch, J. Munch, The Univ. of Adelaide (Australia)

We have developed a new, pulsed Na guide star laser suitable for use in very large telescopes with adaptive optics systems requiring dynamic refocusing to avoid guide star elongation. It makes use of sum frequency generation (SFG) of two, Q-switched, injection mode-locked Nd:YAG lasers. The output is a micro-macropulse with a macro-pulse length less than 3μs as required for dynamic refocusing. When operating at the required pulse repetition frequency of 800Hz, the resulting average duty cycle is 0.24%. This may appear insufficient for an adaptive optical system, but this conclusion is based on results from cw or quasi-cw guide star laser systems, where the low peak power is modeled using rate equations and optical pumping to predict the fluorescence brightness. We have developed a numerical model appropriate for our pulse format, supported by experimental results. Our model is similar to previously published theoretical investigations of high peak power, short pulse pumping.* We report results from experiments on fluorescence from alkali atoms illuminated with variable pulse length and peak power, and compare our results with predictions from our numerical model using coherent pumping by short, high peak power pulses or π-pulse pumping. The model is then used to predict very bright Na guide stars, using short pulses to excite most of the Na atoms available followed by sufficient time to let them decay. Details of our experiments and calculations will be presented together with the latest experimental results on Na fluorescence using our new laser.

*eg L.Bradley, JOSA-B, 1931-44, 1992

7736-187, Poster Session

Characterizing site specific considerations for protecting aircraft during LGS operations at W. M. Keck Observatory

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W. M. Keck Observatory (WMKO) routinely operates laser guide star (LGS) AO systems at the telescope facility on the Big Island of Hawaii. One of the operational requirements for the LGS system is that it must include a safety system to prevent nearby aircraft from being adversely affected by the laser. We will support operations in the near term with human aircraft spotters until we can successfully develop and get the appropriate approvals needed for an Automated, Integrated and Reliable System for an Aircraft Friendly Environment (AIRSAFE).

This report describes some of the preliminary requirements development work at WMKO in support of the future development of AIRSAFE. We discuss the results of recent work to characterize site specific considerations that impact requirements development. The site specific considerations include the proximity of WMKO laser operations to nearby commercial airports, the implications of military operations in the area and the character of the air traffic volume and flight patterns over the telescope facility. Finally, we discuss how the design and implementation of AIRSAFE will be impacted by these site specific considerations.

7736-188, Poster Session

The characteristics of laser-transmission and guide star's brightness for Subaru LGS/AO188 system

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We are developing the Laser Guide Star Adaptive Optics (LGS/AO188) system for Subaru Telescope at Hawaii, Mauna Kea. This system utilizes a combination of an all-solid-state mode-locked sum-frequency generation (SFG) laser (1.7GHz-bandwidth, 0.7ns-pulse width) as a light source and single-mode optical fiber for beam transference. However, optical fibers induce nonlinear scattering effects, such as stimulated Raman scattering (SRS) and stimulated Brillouin scattering (SBS), beyond certain threshold levels in high-power lasers. We measured the laser transmission characteristics of a photonic crystal fiber (PCF) whose mode field diameter (MFD) was 11μm, and a step index fiber (SIF) cable whose MFD was 4.2μm to evaluate the threshold levels for non-linear effects. We observed SRS in the 200-m-long SIF when we input 1.3W. The material losses of them were 10db/km and 6.4dB/km, respectively. However, SRS and SBS were not induced in the 200-m-long PCF, even for an input power of 5.3W. As a result, we estimated the threshold of SRS to be 33W for the 35-m-long PCF designed for the Subaru LGSAO system.

We also measured the brightness of the LGS and evaluated its relationship with the factors, such as elevation of the telescope and wavelength of the laser. The LGS's brightness showed a peculiar tendency that did not be extinguish even though the wavelength has varied about 2pm. The tendency was not shown with the experiment using sodium gas cell. Therefore, it may be concerned the environment of the sodium layer in the mesosphere.

7736-189, Poster Session

Gemini North r' band imaging of the Keck II Laser

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The Gemini Multi-Object Spectrographs (GMOS), with a field of view of over 5.5 X 5.5 arc minutes, was used to obtain r' band imaging of the Raleigh scattered Keck II laser beam. We also present some off-band images to confirm the laser beam is not visible outside of the r-band.

The data samples the laser beam at several elevations when the Keck II laser is propagating toward the zenith. The beam is large at low elevation, nearly filling the GMOS-N field of view, with low surface brightness. At higher elevations the surface brightness increases substantially and the size of the beam correspondingly decreases.

Near the top of the Rayleigh beam however the brightness decreases markedly as seen by Gemini. In addition we present some GMOS spectra of the laser beam. These data allow us to characterize the effect lasers from other telescope have on GMOS-N science data useful for both investigators and queue observers. In addition, we have collected pertinent information on how lasers impact the performance of the GMOS-N on-instrument wavefront sensor which operates at optical wavelengths 495 nm using a 495 nm longpass filter, encompassing the Na laser feature at 589 nm.

7736-190, Poster Session

The performance of the laser guide star system for the Subaru Telescope

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We are developing a laser guide star (LGS) system in Subaru 188-elements Adaptive Optics system (AO188) of the Subaru telescope.

We describe results of performance tests of the LGS system.

The beam that excites sodium atoms at 90 km altitude for the LGS is generated by the following sequence.

The source of the beam is a quasi-CW mode locked sum-frequency generating 589 nm laser. This laser beam propagates in a diagnostics system for measuring the wavelength and the beam quality. This beam couples with a solid-core photonic crystal fiber cable for transmitting the beam to a telescope for launching the beam (LLT: Laser Launching Telescope). The output beam from this fiber cable is collimated by the optics mounted on LLT. This collimated beam is expanded by LLT and launched on the sky.

We executed several engineering observations of the LGS system from 2009 for confirming the performance of subcomponents of which this sequence consist. We also report the quality of the LGS.

7736-191, Poster Session

Optical setup and wavefront sensor for solar adaptive optics at the Domeless Solar Telescope, Hida Observatory

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We develop a solar adaptive optics system at the 60 cm domeless solar telescope in the Hida Observatory, Japan. Our system is designed for compensating low-order wavefront errors, and currently uses a deformable mirror with 52 electromagnetic actuators, a Shack-Hartmann wavefront sensor with a 6x6 microlens array and standard personal computers. It worked so as to suppress image variation in our solar observations even when solar granulation was used as a target for wavefront sensing, only under relatively good seeing conditions. In not good seeing conditions, the system was useful when small sunspots were available for wavefront sensing.

To improve the wavefront sensor, we are replacing the 6x6 microlens array by a 10x10 one. While the use of the 10x10 array will enable more precise measurement, it requires a better detector. We are going to introduce a new CMOS camera with more pixels and a faster frame rate than a CCD camera used in the present system. The frame rate of the CCD camera is now a bottleneck in the dynamic behavior of our system. We predict that the use of the new camera will raise the 0dB error cutoff frequency by more than 10 Hz and the -3dB cutoff frequency by more than 20 dB.

We will present the details of our system and results of solar observations.

7736-192, Poster Session

Installation and observation of correlation tracker for New Solar Telescope

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The 1.6 m off-axis New Solar Telescope is being developed by New Jersey Institute of Technology, University of Hawaii, and Korea Astronomy and Space Science Institute. There are several instruments which will be installed separately at Coude room and Nasmyth bench. The correlation tracker (CT) is for the Nasmyth bench, which is the simplest form of adaptive optics. It consists of three sub-systems: a tip-tilt mirror unit, a camera unit, and a control unit. Its software has been developed via Microsoft Visual C++, which is to take images from the CMOS camera in order to measure the image motions by using sum of absolute differences (SAD) algorithm, and to control the Piezo tip-tilt mirror. We adopted parallel programming technology without any additional processing system (FPGA or DSP) for high-speed performance. We installed the CT system at Big Bear Solar Observatory. By using real solar image, we can make a tip-tilt correction up to about 700 Hz with 64 × 64 pixels.

7736-193, Poster Session

Symmetrically weighted center of gravity for Shack-Hartmann wavefront sensing on a laser guide star

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Phase local gradient measurements in a Shack-Hartmann (SH) wavefront sensor (WFS) is achieved by tracking the displacements of a spot in each sub-aperture. This can be done by comparing the position of its center-of-gravity (COG) to a reference position. A commonly used method for position tracking is the weighted (W) COG in which the original image is multiplied by a weighting function, before centroiding, in order to reduce the impact of noise in the estimation process. A gaussian slightly larger than the spot or an estimate of the spot itself are usually used as weighting functions. However, it can be shown that, if the spot centered on its COG is not even, the WCOG estimator is biased. When dealing with laser guide stars (LGS), the shape of the spot will depend on the Sodium layer density profile which is not likely to be either purely Gaussian nor even. We propose a new method for spot centroiding with a direct application to wavefront sensing on a LGS: the symmetrically weighted (SW) COG, in which the weighting function is taken as the symmetrical of the spot with respect to its COG. We show that the SWCOG estimator is not biased in the case of a non-Gaussian spot and we demonstrate, using numerical simulations, that SWCOG provides comparable performance than correlation based methods or matched filtering, even for large off-axis distances, at a much more reasonable computing price than the latter.

7736-194, Poster Session

Full end-to-end simulation of a pyramid wave front sensor with a laser guide star

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Pyramid wave front sensor is one of the most sensitive WFS. Its behaviour when it is used with a laser guide star is nevertheless not fully studied.

We present both analytical simulations and full end to end simulations of the performance of an AO system on an ELT class telescope using a pyramid wave front sensor and a laser guide star. We show that the major impact of the laser guide star is to been seen by the pyramid not only as a x-y extended objet but as a x-y-z extended object, due to the width of the sodium layer. The x-y extension can be, to some extended, compared to the effect of the modulation of the pyramid and therefore, if taken into account, is not critical. The z-extension can have more dramatic effects and imply a significant loss of performance if it is not taken into account. We nevertheless show that we can reduce a lot this effect on the performance by using an adapted optical system and a control law for the AO system that includes a full model of the pyramid wave front sensor.

The global performace of the system is deduced of a full end to end simulation, taking also into account the x-y-z extension and the cone effect.

7736-195, Poster Session

Advanced curvature-sensing techniques

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Curvature sensors do have substantial advantages over the most generally used Shack-Hartmann sensors, such as an adjustable dynamic range and direct correspondence between sensor measurements and mirror commands. And, de facto, existing curvature-based systems were shown to be more efficient than their Shack-Hartmann counterparts.

But as the adaptive optics technique tends towards increasing actuator numbers, it is a widely accepted - though not positively demonstrated - fact, that curvature sensors are incompatible with high-order corrections.

From a theoretic point of view and through simulations, we show that the performance of curvature sensors comes close to optimal Karhunen-Loève correctors, and this up to several hundred actuators.

We further argue that the bi-morph mirrors built at our institute have resonant frequencies suitable for high order curvature systems.

7736-196, Poster Session

Wavefront sensors and algorithms for adaptive optical systems

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The results of recent works related to techniques and algorithms for wave-front (WF) measurement using Shack-Hartmann sensors show their high efficiency in solution of very different problems of applied optics. The goal of this paper was to develop a sensitive Shack-Hartmann sensor with high precision WF measurement capability on the base of modern technology of optical elements making and new efficient methods and computational algorithms of WF reconstruction. The Shack-Hartmann sensors sensitive to small WF aberrations are used for adaptive optical systems, compensating the wave distortions caused by atmospheric turbulence.

A high precision Shack-Hartmann WF sensor has been developed on the basis of a low-aperture off-axis diffraction lens array. The device is capable of measuring WF slopes at array sub-apertures of size 640õ640 mkm with an error not exceeding 4.80 arcsec (0.15 pixel), which corresponds to the standard deviation of the reconstructed WF equal to 0.017 of wavelength. Also the modification of this sensor for adaptive system of solar telescope using extended scenes as tracking objects, such as sunspot, pores, solar granulation and limb, is presented. The software package developed for the proposed WF sensors includes three algorithms of local WF slopes estimation (modified centroids, normalized cross-correlation and fast Fourier-demodulation), as well as three methods of WF reconstruction (modal Zernike polynomials expansion, deformable mirror response functions expansion and phase unwrapping), that can be selected during operation with accordance to the application.

7736-197, Poster Session

A new optical differentiation wavefront sensor

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We present a new concept for an optical differentiation wavefront sensor, featuring a high number of phase measurements across the pupil, with a linear response versus the phase gradient. We show measurements with this sensor, obtained though turbulence on a elongated laser spot.

7736-198, Poster Session

Prototype of a laser guide stars wavefront sensor for E-ELT: test results

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The current baseline for the multi-conjugate adaptive optics module (MAORY) for the E-ELT is based on the Sodium Laser Guide Stars approach, in order to ensure correction uniformity and sky coverage. However, since the Sodium layer is approximately 10 km thick, the artificial reference source looks elongated, especially when observed from the edge of a large aperture, with elongation depending on the actual telescope diameter, on the Sodium layer properties and on the laser launcher position. We studied numerically, by means of simulations, the performance of three different algorithms for the instantaneous LGS image position measurement in presence of elongated spots: the Weighted Center of Gravity, the Correlation and the Quad-cell. Since all the three considered algorithms require some sort of 'reference', the problem of the temporal variation of the Sodium Layer properties has to be addressed. Another important aspect that has be addressed in the analysis is the impact of the low-order aberrations introduced by the MCAO module re-imaging optics, by the Sodium Density profile shape and by its projection in the LGSs image plane. An LGS WFS laboratory prototype was designed to reproduce the relevant aspects of an LGS WFS Shack-Hartmann for the E-ELT and, through laboratory tests, to evaluate the performance of different centroid algorithms in presence of elongated spots, with realistic Sodium profiles, as previously investigated numerically and analytically, analyzing the impact of the low-order aberrations and of relevant WFS parameters, like SNR, sampling and subaperture size. This paper shows the results of the tests performed with this prototype.

7736-199, Poster Session

Wide-field AO correction: the large wavefront sensor detector of ARGOS

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Wide field correction allowing large field to benefit from adaptive optics (AO) is challenging in more than one aspect. We address here the wavefront sensor (WFS) detector side where, in addition to high sensitivity and low noise, the simultaneous detection of multiple laser beacons and the large number of subapertures in a Shack-Hartmann WFS require a detector to have a large imaging area while preserving a very high readout frame rate. The detector considered has a frame

area of 264x264 pixels with a pixel size of 48 microns. By splitting the image into two framestore areas during readout, repetition rates of more than 1000 frames per second can be achieved. The electronic noise contribution is approximately 3 electrons at the operating temperature. We therefore analyze its performances, showing it fulfills the requirements, in a wavefront sensing application: the measurement of centroids in the case of a Shack-Hartmann WFS for the ARGOS AO project.

7736-200, Poster Session

The Gemini planet imager calibration wavefront sensor instrument

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The Gemini Planet Imager will employ an apodized-pupil coronagraph to make direct detections of faint companions of nearby stars to a contrast level of the 10-7 within a few lambda/D of the parent star. Such high contrasts from the ground require exquisite wavefront sensing and control both for the AO system as well as for the coronagraph. Un-sensed non-common path phase and amplitude errors after the wavefront sensor dichroic but before the coronagraph would lead to speckles which would ultimately limit the contrast. The calibration wavefront system for GPI will measure the complex wavefront at the system pupil before the apodizer and provide slow phase corrections to the AO system to mitigate errors that would cause a loss in contrast.

This talk will describe the low-order and high-order wavefront sensors that compose the calibration wavefront sensor, how they operate, and how their information is combined to form the wavefront estimate before the coronagraph. Our instrument is now fully assembled, and is undergoing acceptance testing before integration with the other GPI subsystems. We will describe performance of the cal system as measured against the acceptance test criteria.

7736-201, Poster Session

Results from the laboratory demonstration of the nonlinear curvature wavefront sensor

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We present results from the laboratory demonstration of the non-linear curvature wavefront sensor (nlCWFS). The non-linear approach builds on the successful curvature wavefront sensing concept but uses more than two image planes and a non-linear phase retrieval wavefront reconstruction scheme. The wavefront is reconstructed from the defocused pupil images using the Gerchberg-Saxton (GS) phase diversity algorithm. This scheme is ideally suited for wavefront sensing on bright (mV<15) natural guide stars, where it operates at the sensitivity limit imposed by the telescope's diffraction limit (instead of the seeing limit for more conventional WFSs). Simulations show that a nlCWFS-based extreme-AO system can reduce residual diffracted light by two orders of magnitude compared to what can be achieved with the Shack-Hartmann (SH) WFS. We explore the ideal number of defocused planes and defocus distances that allow sampling of all spatial frequencies within the AO system control range. On sky, the control loop must operate at about 1 kHz. With the algorithm running on a single CPU, the nlCWFS can operate at ~ 100 Hz. A 1 ms timescale can be achieved in a cost-effective way by using a machine built from 10 to 12 GPUs. To overcome non-linearity issues (limited speed and risk of falling into a local minimum), we propose to combine a SHWFS with a nlCWFS and use both non-linear and linear phase retrieval. We discuss the challenge of using two WFSs in the same spatio-temporal control regime and the implementation of the nlCWFS on the 6.5 m MMT.

7736-202, Poster Session

Prototype of a laser guide stars wavefront sensor for E-ELT: design and integration

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In the framework of the studies related to the European Extremely Large Telescope (E-ELT) a great importance must be given to Laser Guide Stars (LGSs) Wavefront Sensing which is essential to permit wide correction uniformity and a relevant sky coverage. The finite distance of the sodium layer where the LGSs form, its width and density time variability require detailed studies in order to better perform the wavefront measurement. Many LGS peculiar problems such as perspective elongation, focus uncertainty and launching angle, that can be neglected or more easily managed for 8m class telescopes, become fundamental issues in the design of future LGS Wave Front Sensors (WFSs) for the E-ELT. In this paper we present the LGS WFS prototype built at Bologna Observatory reproducing the expected conditions of a E-ELT like LGS Shack-Hartmann WFS. The main scope of the prototype is to cross check the simulations concerning the centroiding algorithms in the case of elongated spots using different light intensities, pixel scales, spot offsets, sub-aperture field of views and elongated source intensity profiles. Starting from the conceptual idea we show the system design and the integration in the lab. Finally the prototype optical quality and its capability to perform the required tests are presented.

7736-203, Poster Session

Performance of a Shack-Hartmann wavefront sensor using real sodium laser data

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The future of adaptive optics includes laser guide stars. While they are a great solution to sky coverage, they do introduce additional errors in the adaptive optics system. In particular, because of the finite thickness of the sodium layer, there is reduced centroiding accuracy due to elongated spots in the wavefront sensor. These become ever more pronounced on large telescope apertures. In this paper we focus on the performance of a Shack-Hartmann wavefront sensor for 30m-plus large aperture telescopes studying the consequences of both the decrease in signal to noise ratio due to the spot elongation and the variations of the sodium atoms density variations in the mesosphere. We incorporate real on-sky measurements of the return from the sodium layer using images of the laser guide star taken at Lick Observatory and simulate the expected wavefront reconstruction performance in the case of a Thirty Meter Telescope. Over this ensemble of data, we compare performance for various Hartmann centroiding methods, including correlation and weighted least square algorithms.

7736-204, Poster Session

Characterization of the wavefront sensor unit for LBTI

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We present progress and results for the Wavefront sensor unit for the Large Binocular Telescope's Interferometer (WLBTI). The system is a clone of the pyramid sensor (PS) unit developed at Arcetri Observatory for the LUCIFER instrument. We detail a flexible laboratory calibration method employing a small deformable mirror as the aberration and correction source. This approach will allow system-level testing of the unit prior to integration with the adaptive secondaries of the LBT.

We explore both synthetic reconstructors, generated via a simulation of the system, and reconstructors obtained through a lab-generated interaction matrix. In lab testing, a 52-actuator deformable mirror (DM) applies aberrations to the wavefront. The PS response to each mode is recorded and a reconstructor created. The accurate representation of the modes by the DM is independently verified by an interferometric comparison of the DM to a reference surface prior to PS calibration.

We present progress toward testing the WLBTI with the AO system on the MMT, with the goal of comparing PS performance to that of the Shack-Hartmann system currently used on the MMT. Finally, we present a plan to achieve PS integration with the LBT adaptive optics system.

7736-205, Poster Session

Visible low-order wavefront sensor for the Subaru LGSAO system

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The Subaru laser guide star adaptive optics system (AO188) was installed at the Nasmyth focus of the Subaru Telescope on Octorber 2006 and it is in operation with the natual guide star (NGS) mode. The operation of the laser guide star (LGS) mode will start on January 2010. A visible low-order wavefront sensor (LOWFS) was built to measure tip-tilt and defocus terms of wavefront by using a single NGS within a 2.7 arcmin diameter field when an LGS is used for high-order wavefront sensing with the 188-element curvature based wavefront sensor. This LOWFS is a 2 x 2 sub-aperture Shack-Hartmann sensor with 16 photon-counting avalanche photodiode (APD) modules. A 4 x 4 lenslet array is located after the 2 x 2 Shack-Hartmann lenslet array and it is coupled with the APD modules through optical fibers. The field of view of the LOWFS is 4 arcsec in diameter. It has own guide star acquisition unit, acquisition and pupil cameras, and atmospheric dispersion corrector.

We describe the design, construction, and integration of this low-order wavefront sensor.

7736-206, Poster Session

Handling complex adaptive optics concepts including the third and fourth dimension

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Adaptive Optics (AO) concepts involves sometimes very complex behaviours of rays, waves and optical elements. Just think, to be convinced, as the way multiple probes aim to correct for a large field of view Multi Conjugated AO, and as these deploys onto a dynamic turbulent atmosphere. In order to explain the behaviour of novel concepts we developed visualization techniques that involves the display of three dimensional images and the creation of movies to explain how the concept deals with an evolving situation, or, in other words, adding the fourth dimension of time. We produce solid models of the optical concepts we are developing, including the evolving temporal behaviour of the turbulence, and these can be manipulated in a virtual manner in order to allow for the production of different means of visualization. These ranges from so called "static movies" where a three dimensional concept is just explored in three dimension by handling it around the observer, to the creation of three dimensional anagliphs or anagliphs movies. While the paper is mainly focussed onto the ways these techniques are exploited in order to produce satisfactory results, the poster allow the visito to experience some of these images and movies. The aim of this work is not only of a sort of high level didactical purpose, but we think it would be useful into scientific discussion and during meeting to develop engineering concepts of several AO concepts.

7736-207, Poster Session

Integration and alignment of adaptive optics systems: 10 years experience at the VLT

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The number and importance of the adaptive optics instruments has grown in the world through the last two decade. Such systems are becoming key elements for large telescopes, with increasing types and complexity. The Very Large Telescope is now hosting many instruments using adaptive optics with Shack-Hartmann, curvature or pyramid wave front sensors. In this framework ESO has collected a large expertise in the field of instrument integration and in particular the integration of adaptive optics systems. The purpose of this article is to share this expertise with the astronomical community.

All instruments are different and there are multiples ways of performing a successful integration of an AO system. The integration phase is often critical and requires specific care. These issues have first to be addressed at system design level choosing a good tolerance strategy and analysis. The quality of the opto-mechanics and the design of integration tools are of great importance. In general a good preparation work will boost the work efficiency and lead to the best alignment and system performances.

We describe here the gained experience in the integration of such instruments at the VLT. We will remind some important rules and practical hints in instrument alignment. For instance the use of dedicated tools like sighting telescopes, microscopes and autocollimators will be discussed. Here we want to give clues about the specificity of adaptive optics integration, answering the following question: what should one do to manage successfully the integration of an AO system?

7736-208, Poster Session

Final design of the wavefront sensor unit for ARGOS, the LBT's LGS facility

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In this paper we present the final design of the Wavefront Sensor unit of ARGOS, the Laser Guide Star facility for the Large Binocular Telescope.

ARGOS will implement a GLAO system using 3 Rayleigh pulsed beacons and the ground-conjugated LBT's adaptive secondary mirror.

The ARGOS WFS is composed of two subunits: a SH-WFS and a large dichroic window that deflects the laser beam toward the WFS while transmitting the R/IR light to the LUCIFER instrument and to the autoguider and tip-tilt units.

The SH-WFS is designed to fit the three 15 subapertures spot patterns on a single lenslet array and a single detector. Range gating of the laser beams is accomplished through Pockel cells units. Field and pupil stabilizers allow to compensate for the fast jitter of the laser beams and

for optical flexures. Three patrol cameras with a large field of view permit to acquire and repoint the laser beams into the 5” WFS field stop.

The WFS includes a calibration unit to check the internal alignment; this unit will be also used for closed-loop laboratory tests using a MEMS DM.

7736-210, Poster Session

Wavefront corrector for solar telescopes based on variable reluctance actuators

R. F. M. M. Hamelinck, N. J. Doelman, TNO (Netherlands)

As in other areas of ground-based astronomy, larger telescope apertures are needed to advance in solar physics. As a result, the technological challenge for the Multi Conjugate Adaptive Optics system and in particular for the wavefront corrector expands. The corresponding number of degrees of freedom and the actuator density increases. Deformable mirrors up to 1k actuators on a typical pitch of 3mm, combined with heat loads in the order of 1-2 kW/m2 make wavefront correctors for solar astronomy in particular challenging. Proper heat transfer should avoid the temperature of the DMs surface to rise with respect to its environment and avoid detrimental air flow in the path of light. Active cooling systems are often needed with the risk of introduced vibrations on the nm level. TNO presents a 3mm actuator pitch DM, based on variable reluctance actuators, specially designed for solar AO systems. The absorbed heat is transferred by conduction to a heat sink. Since no liquid is used, the risk of leakage and vibrations is avoided. All advantages that accompany the use of variable reluctance actuators such as high efficiency and low voltages drivers are exploited. Its actuator stiffness is controlled by design and allows for an optimal combination of actuator coupling, mirror resonance frequency and optical impact at failure.

7736-211, Poster Session

Laboratory test of application of electric-field conjugation image-sharpening to ground-based adaptive optics

S. J. Thomas, Univ. of California Observatories (United States); A. Give’on, Jet Propulsion Lab. (United States); D. Dillon, Univ. of California Observatories (United States); B. A. Macintosh, Lawrence Livermore National Lab. (United States); D. T. Gavel, Univ. of California Observatories (United States); R. Soummer, Space Telescope Science Institute (United States)

High contrast imaging is an ongoing theme in the domain of astronomy, both for ground-based and space-based telescopes. Achieving 10^6-10^7 expected with GPI and SPHERE or 10^10 for space projects, requires extreme wavefront correction as well as good coronagraphic systems. With the testbed located at the Laboratory of Adaptive Optics in Santa Cruz, we statically correct the wavefront to 0.5 nm in band and reach contrast of a few 10^7 with an Apodized Lyot Coronagraph (APLC).

The Electric Field Conjugation (EFC) allows us to further improve on this performance. EFC is a formalism of the correction problem that computes the actuator commands for the deformable mirror (DM) to correct for both amplitude and phase in a pre-defined region of a plane of interest. To take into account non-common-path errors and potential amplitude aberrations, we consider the final image plane. The proper actuator commands are computed using an image plane-based DM diversity to reconstruct the complex electric field.

Already successfully tested for space-based telescopes, we here attempt to adapt this method to ground-based observations, using the EFC high contrast solution to record new reference centroids for a Shack-Hartmann wavefront sensor, which in turn can be used to recreate the far-field image.

This paper shows results of this first use of the EFC method with an APLC. We achieved 4.10^8 contrast on a [4-9] lambda/d square region. We also show that it can be applied to ground based adaptive optics, using Shack-Hartmann wavefront sensors.

7736-212, Poster Session

Integrated dual-stage deformable mirrors

M. S. Griffith, BAE Systems (United Kingdom); R. M. Myers, Durham Univ. (United Kingdom); P. Doel, Univ. College London (United Kingdom); L. Laycock, N. Archer, I. Sardharwalla, BAE Systems (United Kingdom); A. K. Kirby, Durham Univ. (United Kingdom); D. Brooks, Univ. College London (United Kingdom)

We present the results of a study on Dual-Stage Deformable Mirrors using Zonal Bimorph Deformable Mirror (ZBDM) technology. A high density ‘tweeter’ DM is assembled onto a lower density, high dynamic range ‘woofer’ DM to generate an integrated mirror which offers both high resolution and high dynamic range simultaneously. Such a device has the potential to significantly simplify the design of astronomical AO systems. Recent developments are presented, including the fabrication of a small scale demonstrator.

7736-213, Poster Session

Progress of development of a large, low-cost deformable mirror

R. Heimsten, T. E. Andersen, Lund Observatory (Sweden); D. G. MacMynowski, California Institute of Technology (United States)

Large (>1m) deformable mirrors with hundreds or thousands of actuators are attractive for extremely large telescopes. Use of force actuators coupled to the mirror via suction cups, and electret microphones for position sensing, has the potential of substantially reducing cost. However, a mirror controlled with force actuators will have many structural resonances within the desired system bandwidth, shifting the emphasis somewhat on to control aspects. Local velocity and position control loops for each actuator can add significant damping but gives poor performance at high spatial frequencies. We therefore introduce a novel control strategy with many parallel “actuator families”, each controlled by single-input-single-output controllers. This family approach provides performance close to that of global feedback, but without the accompanying robustness challenges. Using a complete simulation model of a representative large deformable mirror, we demonstrate feasibility of the approach. We also show performance of an upgraded force actuator prototype using a voice coil with internal position feedback from an LVDT position sensor. Finally, we present recent plans and progress on a prototype experiment of a 1-m deformable mirror.

7736-214, Poster Session

High-power visible-laser effect on a Boston Micromachines’ MEMS deformable mirror

A. P. Norton, Univ. of California, Santa Cruz (United States); D. T. Gavel, Univ. of California Observatories (United States); D. Dillon, Univ. of California, Santa Cruz (United States); S. Cornelissen, Boston Micromachines Corp. (United States)

The Laboratory for Adaptive Optics (LAO) is exploring the use of Boston Micromachines Corporation’s micro-electrical mechanical system (MEMS) deformable mirror (DM) for laser uplink correction in Phase II of the Visible light laser guidestar experimental system (Villages). A MEMS DM will be used to correct the Laser GuideStar (LGS), as it is projected from the 40” Nickel telescope, to a diffraction limited spot on the mesosphere. This will reduce the power needed for the LGS while simultaneously increasing the efficiency of wavefront sensing. However, the response of MEMS DMs to high-power incident light, such as the 10

watts required for uplink correction, is not well understood. In an effort to measure and characterize the response of MEMS DMs, the LAO has designed tests to qualify the use of the continuous face-sheet DM for uplink laser correction.

7736-215, Poster Session

Demonstration prototype and breadboards of the piezo stack M4 adaptive unit of the E-ELT

B. Crépy, CILAS (France); S. Chaillot, BOOSTEC S.A. (France); M. Cola, AMOS Ltd. (Belgium); R. Cousty, CILAS (France); M. Dimmler, European Organisation for Astronomical Research in the Southern Hemisphere (Germany); E. Gabriel, AMOS Ltd. (Belgium); R. Gasmi, Observatoire de Paris à Meudon (France); R. Grasser, CILAS (France); N. Hubin, L. Jochum, European Organisation for Astronomical Research in the Southern Hemisphere (Germany); F. Locre, CILAS (France); P. Madec, European Organisation for Astronomical Research in the Southern Hemisphere (Germany); P. Morin, CILAS (France); M. Müller, European Organisation for Astronomical Research in the Southern Hemisphere (Germany); D. Petitgas, J. Roland, J. Sinquin, CILAS (France); E. Vernet, European Organisation for Astronomical Research in the Southern Hemisphere (Germany)

Demonstration prototype :

We intend to present the manufacturing step of the E-ELT M4 demonstration prototype, the dynamical test such as the experimental modal analysis and the global thermal behaviour checking.

Breadboards :

The most important breadboard is a mirror that represents the local behaviour of the final mirror with 37 actuators. With this Breadboard the IF, the hysteresis, the creep, the print through effect are analyzed.

7736-216, Poster Session

The Subaru coronagraphic extreme AO (SCExAO) system: progress report

F. Martinache, O. Guyon, F. Vogt, V. Garrel, K. Yokochi, T. Yoshikawa, National Astronomical Observatory of Japan/Subaru Telescope (Japan)

In 2009 our group started the integration of the SCExAO project, a highly flexible, open platform for high contrast imaging at the highest angular resolution, to be inserted between the coronagraphic imaging camera HiCIAO and the 188-actuator AO system of Subaru.

In its first version, SCExAO combines a MEMS-based wavefront control system feeding a high performance PIAA-based coronagraph, that suppresses the central obscuration and the thick spider vanes while preserving throughput and angular resolution.

It also includes a coronagraphic low-order wavefront sensor, a non-redundant aperture mask and a visible imaging mode, all of them designed to take full advantage of the angular resolution (40 mas in the H-band) that an 8-meter telescope has to offer.

7736-217, Poster Session

Polarization properties of the vector vortex coronagraph with image plane wavefront control

D. C. Moody, L. A. Pueyo, D. P. Mawet, Jet Propulsion Lab. (United States)

The Vector Vortex Coronagraph, the most recent member of the phase-mask coronagraph family, is generated by a rotationally symmetric halfwave plate creating two conjugated phase ramps embedded in the orthogonal circular polarization states of light. Using the liquid crystal polymer technology, a prototype of topological charge 4 has been tested on the high contrast imaging testbed, demonstrating the potential of this coronagraph for high contrasts when coupled to high precision wavefront control. New generation devices are currently being manufactured, and promise improved performance. However, focal plane wavefront sensing based on phase diversity must take the particular polarization properties of the VVC into account. Here we describe experimental and modeling results assessing the optimal hardware and software configurations to deal with that peculiarity, down to its fundamental limitation.

7736-218, Poster Session

Polarimetry with the Gemini planet imager

M. D. Perrin, Univ. of California, Los Angeles (United States); J. R. Graham, Univ. of California, Berkeley (United States); J. E. Larkin, Univ. of California, Los Angeles (United States); S. Wiktorowicz, Univ. of California, Berkeley (United States); J. Maire, Univ. de Montréal (Canada); S. Thibault, ImmerVision (Canada); R. Doyon, Univ. de Montréal (Canada); B. A. Macintosh, Lawrence Livermore National Lab. (United States); D. T. Gavel, Univ. of California Observatories (United States); B. R. Oppenheimer, American Museum of Natural History (United States); D. W. Palmer, Lawrence Livermore National Lab. (United States); L. Saddlemeyer, National Research Council Canada (Canada); J. K. Wallace, Jet Propulsion Lab. (United States); M. P. Fitzgerald, Lawrence Livermore National Lab. (United States)

The Gemini Planet Imager (GPI), currently under construction as a facility instrument for the 8-m Gemini South telescope, will study circumstellar disks using the polarization of scattered starlight. GPI will obtain these observations using a novel ‘integral field polarimetry’ mode, in which the dispersing prism of the integral field spectrograph is replaced by a Wollaston prism, providing simultaneous dual polarimetry for each lenslet in the field of view. By splitting the polarizations only after the lenslet array, this design minimizes any wavefront differences or misalignments between the polarization channels, providing optimal contrast for circumstellar dust in the difference images. Furthermore, unlike previous AO polarimeters, no reduction in field of view is required. A rotating achromatic waveplate provides modulation. End-to-end numerical performance modeling indicates that GPI will be sensitive to scattered light from debris disks significantly fainter than can currently be imaged. We discuss the tradeoffs and design decisions for GPI polarimetry, describe the required calibration and reduction procedures, and present the current status of integration and testing.

7736-219, Poster Session

Focal plane wavefront sensor sensitivity for ELT planet finder

P. Baudoz, M. Mas, R. Galicher, G. C. Rousset, Observatoire de Paris à Meudon (France)

In the framework of Extremely Large Telescope, several instruments are considered for the characterization of extrasolar planets. Since the performance of such an instrument is limited by wavefront errors, the use of extreme Adaptive Optic (AO) systems is mandatory. Studies for future planet finder instruments such as SPHERE/VLT or GPI/GEMINI show that a strong limitation of the performance of a planet finder is the differential aberrations that are not measured by the wavefront sensor, which is physically separated from the common optics by a beam splitter. We propose here to efficiently estimate these aberrations by directly measuring the wavefront errors in the final science image. To do so, we propose to couple the foreseen extreme AO system at high speed of an

ELT planet Finder with a low speed Self-Coherent Camera (SCC) which can measure directly the differential aberrations at the final science focal plane. The SCC which is based on the principle of light coherence estimates the wavefront errors by spatially encoding the speckles with fringes in the final image. After recalling the principle of the SCC, we will present simulation results of the SCC performance in the context of ELTs.

7736-220, Poster Session

PSF reconstruction for NICI: the high-contrast coronagraphic imager of GEMINI Observatory

M. Hartung, Gemini Observatory (Chile); D. Gratadour, Observatoire de Paris à Meudon (France); M. R. Chun, Univ. of Hawai'i (United States); T. L. Hayward, Gemini Observatory (Chile); J. C. Christou, Gemini Observatory (United States)

It is 12 years ago that PSF reconstruction from wavefront sensor (WFS) data has been described by Veran et al. (JOSA A, 1997) and successfully demonstrated at CFHT/PUEO. Nevertheless, even though adaptive optics (AO) has evolved into a mature technology, no breakthrough has been reached yet in terms of a broad use of WFS estimated PSFs in astronomical image data reduction. Reasons for this are certainly the lack of easy access to the needed AO data as well as the automatic supply of reconstructed PSFs along with the science exposures to eventually give the astronomical community a chance to exploit its potential. The key information are the covariance matrices of the WFS signal and the DM voltages in sync with the science exposures. Without active interaction from the user side with the observatory, we intend to automatically provide the user with these AO data together with the retrieved PSF for every taken science exposure.

Typical applications for a WFS retrieved PSF are photometry and image sharpening by deconvolution. For the high-contrast imager NICI, the reconstructed PSF will be of particular use providing a fixed reference point to derive planet detection contrast curves completely in sync with the science exposure. We will compare how well the WFS estimated PSF matches the science image PSF at various AO guide stars, and will study the impact of system modeling errors.

7736-221, Poster Session

Application of wavelength diversity for astronomical adaptive optics imaging

D. Burke, N. Devaney, National Univ. of Ireland, Galway (Ireland); J. C. Christou, M. Hartung, Gemini Observatory (United States)

Wavelength diversity uses multi-wavelength data to simultaneously estimate the point spread function (PSF) of an imaging system as well as the astronomical object of interest e.g. a binary star with a faint companion. For AO applications, the technique requires the PSF to be stable so that a series of multiple exposures are taken taken simultaneously.

The algorithm presented does not recover the PSFs directly but estimates the Zernike coefficients of the residual wavefront phase aberration in the pupil of the telescope. For dual channel point source imaging, the common wavefront is estimated and the residuals between the measured and estimated PSFs correspond to non common path aberrations in each of the imaging paths. We note that although wavelength diversity is insensitive to the sign of the even radial order Zernike coefficients, the corresponding estimate of the PSF is still valid for deconvolution or as part of the Hotelling observer. The Hotelling observer is a prewhitening matched filter. In the process of prewhitening, the data are divided by the data covariance matrix to produce spatially stationary, uncorrelated noise. The data covariance model requires a good PSF estimate; the PSF estimate is used to subtract the signal of the bright star from the image (PSF subtraction), flatten the residuals (prewhitening), and estimate the companion signal via matched filtering.

This algorithm is well suited for application to data from the dual-channel Near-Infrared Coronagraphic Imager (NICI) at Gemini South and results from both real observations and simulations will be presented.

7736-222, Poster Session

The Subaru coronagraphic extreme AO (SCExAO) system: visible imaging mode

V. Garrel, National Astronomical Observatory of Japan/Subaru Telescope (United States) and LESIA, Observatoire de Paris (France); O. Guyon, National Astronomical Observatory of Japan/Subaru Telescope (United States); P. Baudoz, LESIA, Observatoire de Paris à Meudon (France); F. Martinache, F. Vogt, T. Yoshikawa, K. Yokochi, National Astronomical Observatory of Japan/Subaru Telescope (United States)

The Subaru Coronagraphic Extreme Adaptive Optics (SCExAO) system is an instrument designed to be inserted between the Subaru AO188 system and the infrared HiCIAO camera in order to greatly improve the contrast in the very close (<0.5") neighbourhood of stars.

Next to the infrared coronagraphic path, a visible scientific path, based on a EMCCD camera, has been implemented. Benefiting from both AO correction and new data processing techniques, it is a powerful tool for high angular resolution imaging and opens numerous new science opportunities. A factor 2 to 3 in Strehl ratio is obtained compared to the AO long exposure time: up to 25% Strehl in the 650nm wavelength, depending on the image processing algorithm used and the seeing conditions. The system is able to deliver diffraction limited images at 650 nm (17 mas FWHM). Our baseline image processing algorithm is based on the selection of the best signal for each spatial frequency. We demonstrate that this approach offers significantly better results than the classical select, shift and add approach (lucky imaging). We report on the first on-sky visible imaging results.

We also describe how the SCExAO visible channel will also later host a high performance optical wavefront sensor based on a nonlinear curvature scheme.

7736-223, Poster Session

Weighing black holes using open-loop focus corrections for LGS-AO observations of galaxy nuclei at Gemini Observatory

R. M. McDermid, Gemini Observatory (United States); D. Krajnovic, European Organisation for Astronomical Research in the Southern Hemisphere (Germany); M. Cappellari, Univ. of Oxford (United Kingdom); C. Trujillo, Gemini Observatory (United States); R. L. Davies, Univ. of Oxford (United Kingdom)

We present observations of early-type galaxies with laser guide star adaptive optics (LGS AO) obtained at Gemini North telescope using the NIFS integral field unit (IFU). We employ an innovative technique where the focus compensation due to the changing distance to the sodium layer is made 'open loop', allowing the extended galaxy nucleus to be used only for tip-tilt correction. The targeted galaxies were chosen to have central light profiles showing both core and cusp profiles, to probe the feasibility of using the galaxy centre as the natural guide source required for LGS AO. The purpose of these observations is to determine high spatial resolution stellar kinematics within the nuclei of these galaxies and, in combination with previously obtained large scale observations with the SAURON IFU, to determine the masses (M) of the supermassive black holes. Although high Strehl ratios are not obtained, the resulting data have spatial resolution of 0.2" FWHM or better. This is sufficient to positively constrain the presence of the central black hole in even low-mass early-type galaxies, suggesting that larger samples of such objects could be observed with this technique in the future. The open-loop focus correction technique is a supported queue observing mode at Gemini, significantly extending the sky coverage in particular for faint, extended guide sources.

7736-224, Poster Session

Demonstration of on sky contrast improvement using the modified Gerchberg-Saxton algorithm at the Palomar Observatory

R. S. Burruss, E. Serabyn, D. P. Mawet, Jet Propulsion Lab. (United States); J. P. Hickey, K. Rykoski, California Institute of Technology (United States); S. Bikkannavar, Jet Propulsion Lab. (United States)

We have successfully demonstrated dramatic improvements in the high contrast detection limit of the Well Corrected Subaperture (WCS) on the Palomar Hale telescope using automated Modified Gerchberg-Saxton (MGS) phase retrieval calibration methods. The MGS routines reduce the non-common-path quasi-static wave front errors not measured by the Palomar Adaptive Optics (PALAO) system from 120 nm (rms) to 30 nm. This error reduction has led to the suppression of scattered starlight speckle noise in the science detector coronagraphic image plane, thus enabling high contrast observations very close to stars. The MGS routines require only two equidistant defocused images, one on either side of the science camera focal plane. Using an image of the camera pupil as the pupil amplitude constraint, the wave front error at the exit pupil plane is estimated by the MGS routines. This wave front error is then fit to the commands sent to the PALAO deformable mirror, and the process is repeated until the wave front error noise floor is reached (30 nm rms). The entire process typically requires three five-minute iterations during the day, in addition to a single iteration on sky at each starting telescope position taken just before observing a target.

We describe the MGS method, the excellent results produced both in the lab and on the sky, and show how these methods helped in the detection of the three exoplanets orbiting the star HR8799 using only a 1.5 meter unobscured subaperture relay of the 5 meter Hale primary mirror.

7736-225, Poster Session

FARIES: medium-field Arizona infrared imager and echelle spectrograph

S. M. Ammons, D. W. McCarthy, Jr., C. Kulesa, M. Hart, M. Rademacher, E. A. Bendek Selman, N. M. Milton, K. B. Powell, V. Vaitheeswaran, The Univ. of Arizona (United States)

We describe inexpensive modifications to the MMT Arizona Infrared Imager and Echelle Spectrograph (ARIES) that will permit multi-object near-infrared spectroscopy using Laser Guide Star Ground-Layer Adaptive Optics (GLAO) correction. MMT GLAO system currently delivers 0.15” - 0.25” image quality in K over a 1.8 x 1.8 arcminute field with five Rayleigh beacons gated at 23 km altitude.

Spectral resolution of R = 3000-4000 will be achieved in H- or K-band with small slit widths (0.2”), enabling operation in-between OH lines. Sensitivity is further enhanced by the use of interchangable, cooled slit masks. The number of objects is limited by the slit length necessary to capture the sky spectrum and can be as high as 50 for bright stellar sources (K < 16) and 10-25 for extended sources. We use a pinhole mask to map focal plane distortion in ARIES and machine specialized slit masks with a Kern MMP Micromilling machine in preparation for several test exposures on-sky in late 2010. We report expected point and extended source sensitivities.

FARIES will address a wide range of unique science cases. Sensitive spectroscopy in young, super-stellar clusters will reveal masses of stars and constrain the massive end of the IMF. FARIES will also permit the measurement of rotation curves of distant galaxies using Halpha with a strong multiplexing advantage. The high spatial resolution will enable more precise measurements of the dynamical masses of galaxies, providing increased constraint of mass assembly and bulge formation models at high redshift.

7736-226, Poster Session

Computed PSF subtraction for high-contrast imaging

J. L. Codona, M. A. Kenworthy, The Univ. of Arizona (United States)

Subtraction of a reference PSF should allow better detection thresholds to be set very near stars. In practice however, the reference PSF estimate and the science images include variance from both low-order aberrations and residual speckle noise that spoil the subtraction, limiting effectiveness. We explore a new method, Computed PSF Subtraction, that uses adaptive optics WFS measurements, combined with fast science camera images to derive a reconstructor for the optical transfer function (OTF). The WFS-to-OTF relationship is nonlinear, but in a diffraction-limited AO system can be made nearly linear by subtracting the mean OTF and explicitly handling the tip-tilt which causes phase wrapping. The Fourier-transformed science camera data are combined with the pupil WFS data (in this case a Shack-Hartmann) using SVD to find an OTF reconstructor. The speckles and low-order aberrations in the science camera images can thus be estimated directly from the WFS data, and subtracted frame-by-frame from the OTF estimates. Upon integration, a faint companion will appear as a residual ripple in the differential OTF, which will Fourier-transform back into a PSF-subtracted image of the companion. The technique includes non-common path differences since it is calibrated using the science camera also used to collect the final data. Although we calibrate this technique using narrowband science images, it can be used to compute more broadband speckle images. This should allow PSF subtraction with larger bandwidth images. The technique will work equally well with coronagraphic images, with the added benefits of reduced speckle and photon noise.

7736-227, Poster Session

Frame selection techniques for the Magellan adaptive optics VisAO camera

J. R. Males, L. M. Close, D. A. Kopon, V. Gasho, K. Brutlag, The Univ. of Arizona (United States)

The Magellan AO system will begin commissioning in late 2011. Its VisAO camera will provide 20 mas FWHM images with mean Strehl ratios of ~0.2 in R band on a 6.5m telescope. Depending on seeing conditions, Strehl ratio may reach temporary peaks as high as 0.5 at these wavelengths. To take advantage of these brief periods of high performance, we plan to adopt “Lucky Imaging” style data taking and reduction techniques. As part of this effort we have developed a novel real-time frame selection technique, which will use AO system telemetry and a fast shutter to limit CCD exposure to these very brief moments of higher Strehl. Here we describe the expected benefits of our frame selection techniques in various operating modes. We also present the results of laboratory characterization of the shutter, and describe the performance of predictive algorithms used to control it.

7736-228, Poster Session

Novel technology for small deformable mirrors

M. Strachan, UK Astronomy Technology Ctr. (United Kingdom); K. Cooke, J. Hampshire, Teer Coatings Ltd. (United Kingdom); J. Hough, Univ. of Glasgow (United Kingdom); D. Hutson, S. Kim, K. Kirk, Univ. of the West of Scotland (United Kingdom); R. M. Myers, Durham Univ. (United Kingdom); S. Rowan, Univ. of Glasgow (United Kingdom); E. Uzgur, Univ. of the West of Scotland (United Kingdom); M. van Veggel, Univ. of Glasgow (United Kingdom)

We have been developing a series of novel technological solutions to address the challenges posed by the adaptive optic requirements for extremely large telescopes. Our deformable mirror surface material, a compliant from of silicon carbide, offers a Young's Modulus comparable to glass but with greater, non-catastrophic, resistance to fracture. In combination with the extraordinary new material we have been working on a new low power actuator with a deflection capability of tens of microns. We have considered the systems requirements for our deformable mirror and developed both a coating technology and a unique use of hydroxide catalysis bonding.

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Our work has consisted of developing and testing the new mirror surface material and the associated polishing processes. We have tested a novel actuator suited to our application and believe that the combination of technologies is both scalable and will lead to cost effective large adaptive optics. We will report the results of the material testing and deflection testing of the mirror surface. We will report on the results on the actuator deflection together with results on hydroxide catalysis bonding of the actuators to the mirror surface. We will also present the work carried out on a 300mm diameter prototype DM.

7736-229, Poster Session

The LSST camera corner raft conceptual design: a front-end for guiding and wavefront correction

V. J. Riot, Lawrence Livermore National Lab. (United States); K. Arndt, E. Alagoz, A. Biccum, A. Bohn, J. Clampit, T. Coiro, W. Cui, A. Lichti, D. Skaggs, M. J. Triano, B. Xin, K. Ziegler, Purdue Univ. (United States); J. Oliver, Harvard Univ. (United States); R. Van Berg, Univ. of Pennsylvania (United States); G. M. Haller, L. Sapozhnikov, SLAC National Accelerator Lab. (United States); I. Shipsey, Purdue Univ. (United States); S. S. Olivier, Lawrence Livermore National Lab. (United States)

The Large Synoptic Survey Telescope (LSST) is a proposed ground based telescope that will perform a comprehensive astronomical survey by imaging the entire visible sky in a continuous series of short exposures. Four special purpose rafts, mounted at the corners of the LSST science camera, contain wavefront sensors and guide sensors. Wavefront measurements are accomplished using curvature sensing, in which the spatial intensity distribution of stars is measured at equal distances on either side of focus by CCD detectors. The four Corner Rafts also each hold two guide sensors. The guide sensors monitor the locations of bright stars to provide feedback that controls and maintains the tracking of the telescope during an exposure. The baseline sensor for the guider is a Hybrid Visible Silicon hybrid-CMOS detector. We present here a conceptual mechanical and electrical design for the LSST Corner Rafts that meets the requirements imposed by the camera structure, and the precision of both the wavefront reconstruction and the tracking. We find that a single design can accommodate two guide sensors and one split-plane wavefront sensor integrated into the four corner locations in the camera.

7736-230, Poster Session

New techniques for the live update of gain tables in NGS and LGS WFS operation

M. D. Oliker, D. Roskey, SAIC (United States)

No abstract available

7736-231, Poster Session

Novel technologies for large deformable mirrors

M. Strachan, UK Astronomy Technology Ctr. (United Kingdom); M. Strangwood, The Univ. of Birmingham (United Kingdom); M. R. Krödel, ECM GmbH (Germany); K. Cooke, J. Hampshire, Teer Coatings Ltd. (United Kingdom); R. M. Myers, Durham Univ. (United Kingdom); D. Hutson, Univ. of the West of Scotland (United Kingdom); M. van Veggel, S. Rowan, J. Hough, Univ. of Glasgow (United Kingdom); K. Kirk, Univ. of the West of Scotland (United Kingdom); E. Uzgur, Anadolu Univ. (Turkey); S. Kim, Univ. of the West of Scotland (United Kingdom)

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7736-59, Session 12

Performance of MEMS-based visible-light adaptive optics at Lick Observatory

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At the University of California's Lick Observatory, we have implemented an on-sky testbed for next-generation adaptive optics (AO) technologies. The Visible-Light Laser Guidestar Experiments instrument (ViLLaGEs) includes visible-light AO, a micro-electro-mechanical-systems (MEMS) deformable mirror, and open-loop control of said MEMS on the 1-meter

Nickel telescope at Mt. Hamilton. (Open-loop in this sense refers to the MEMS being separated optically from the wavefront sensing path; the MEMS is still included in the control loop.) Future upgrades include an up-link corrected laser guide star and pyramid wavefront sensing. Our unique optical layout allows the wavefronts along the open and closed loop paths to be measured simultaneously, facilitating comparison between the two control methods. In this paper we evaluate the performance of ViLLaGEs in open and closed loop control, working toward a full analysis of the error budget of the system.

7736-60, Session 12

GRAAL: a seeing enhancer for the NIR wide-field imager Hawk-I

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GRAAL is an adaptive optics module of the Adaptive optics facility (AOF) feeding Hawk-I, a wide-field, NIR imager with a 7.5 arcmin square field of view and a pixel size on sky of 0.1”. GRAAL will be the first of the AOF systems installed in 2013 in the Paranal observatory.

The adaptive optics averages the 4 Laser guide-star references provided by the 4LGS facility (4LGSF) to estimate the ground layer turbulence. A standard RTC platform (SPARTA) provides the real-time calculations to control the wave-front correction to be brought by the DSM.

The LGSs are located on a 12 arcmin diameter, outside the scientific FoV to prevent vignetting during observations. Only the first kilometre of turbulence can be significantly corrected by the module. Given the atmospheric profile of turbulence in Paranal, GRAAL provides a K-band typical seeing of 0.4”, doubling the occurrence of exceptional seeing better than 0.3”.

In addition, a classical NGS mode is included for commissioning and maintenance (MCM), with K-band Strehl ratio higher than 70%.

GRAAL is currently in manufacture and assembly, the opto-mechanics being close to completion. An industrial supplier -NTE- assembles most of the mechanical structure of GRAAL; the electronics and final opto-mechanical assemblies will be integrated by an ESO team.

This paper presents the rationales for the project, the performance expected from extended simulations including representative Cn2 profiles, the main design choices, the status of manufacture, assembly and integration, and the plan for installation in Chile.

A prospective study for an upgrade of GRAAL with higher performance on a limited FoV concludes this paper.

7736-61, Session 12

Status of the PALM-3000 adaptive optics system

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The PALM-3000 upgrade to the Palomar Adaptive Optics system on the 5.1 meter Hale telescope will deliver extreme AO correction in the near-infrared, and diffraction-limited images down to visible wavelengths. PALM-3000 will utilize 3388-actuator tweeter and 241-actuator woofer deformable mirrors, a Shack-Hartmann wavefront sensor with selectable pupil sampling, and an innovative wavefront control computer based on a cluster of 16 graphics processing units to correct wavefront aberrations at scales as fine as 8.1 cm at the telescope pupil using natural guidestars. The system is currently undergoing integration, with deployment at Palomar Observatory planned in early 2011. We will present updates on deformable mirror characterization, real-time control system and wavefront sensor performance, and testbed activities.

7736-62, Session 12

ALTAIR NGS/LGS performance at Gemini North

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We will present up-to-date performance characteristics for both natural guide star (NGS) and laser guide star (LGS) operation of the ALTAIR adaptive optics system at the Gemini N. 8m telescope.

Using consistent (exposure time and wavelength) nightly monitoring of the delivered point spread function (PSF), we have been able to characterise the performance, as measured by Strehl ratio and full width at half-maximum (FWHM) under a wide range of seeing conditions. These measurements show that for K-band imaging the FWHM does not approach the diffraction-limit even under the best conditions. We have also looked at power spectral density measurements from circular buffer wavefront sensor (WFS) measurements for both daytime calibrations and the nightly monitoring. These demonstrate that system vibrations, corresponding to an rms of ~10-15mas, are the primary source of degraded performance in the focal plane and the dominant frequencies have been confirmed by measurements from individual optical elements on the ALTAIR bench. Non-common path aberration calibration also show the effect of these vibrations. The source of these vibrations and their mitigation is currently being investigated. Taking into account these measurements we will present the ALTAIR performance with respect to the atmospheric turbulence.

In addition to the NGS measurements we will also present performance metric for LGS operation. It has now been in routine and stable operation for the last two years and we will present measurements of its routine performance in terms of delivered image quality as well as flux return from the sodium layer.

7736-63, Session 12

The MCAO systems within LINC-NIRVANA: functions, procedures, and control strategies

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LINC-NIRVANA is the near-infrared homothetic imaging camera for the Large Binocular Telescope. Once operational, it will provide an unprecedented combination of angular resolution, sensitivity and field of view. Its layer-oriented MCAO systems (one for each arm of the interferometer) are conjugated to the ground layer and an additional layer in the upper atmosphere. In this contribution we describe the role of the MCAO systems within and the interaction with the instrument. The procedures that are foreseen to close and maintain the loop are outlined as well as key functionality beyond wavefront control that has to be implemented in the systems’ software.

In addition to the core functionality of any AO system (wavefront correction) the MCAO systems of LINC-NIRVANA have to fulfill a set

additional tasks: Independent from the science field, they have to derotate its own fields of view. The sensor optics (pyramids) have to be accurately positioned at the natural guide star images in the focal plane. Any wavefront information obtained by the sensors has to be matched to the time invariant modes of the deformable mirrors in the system. The tip/tilt control scheme is outlined, in which atmospheric, but also instrumental tip-tilt corrections are sensed with the high layer wavefront sensor and corrected by the adaptive secondary mirror of the LBT. Slow image motion effects on the science detector have to be considered, which are caused by flexure in the non-common path between AO and the science camera, atmospheric differential refraction, and alignment tolerances of the derotators.

7736-64, Session 13

Laser systems for laser guide star adaptive optics: status and perspectives

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The success of laser guide star adaptive optics (LGS AO) over the past 5 years has led to a number of new LGS AO facilities either proposed or currently in development. This progress has been accompanied by improved technologies and systems for the production of the required ~598 nm wavelength laser light needed for such systems. In addition to the development of laser technologies, important work has been done on understanding the physics of the mesosphere and how the laser light interacts with the rarefied sodium atoms within it. This paper will provide an overview of current developments in laser technologies, and how those developments relate to our current best understanding of the physics involved in the production of the LGS return flux. The paper will also consider the deployment of such systems on a wider scale which is driven by operational factors such as cost, reliability and ease of use. The paper will conclude by discussing how our current understanding of the factors related to LGS return efficiency and system level concerns such as spot elongation on extremely large telescopes might best drive the development of future laser technologies.

7736-65, Session 13

PM fiber lasers at 589nm: a 30W prototype and a portable laser system for LGS return flux studies

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The work on fiber lasers at ESO has been done also in collaboration with industry with the goal of developing compact, ruggedized fiber lasers for field operation at astronomical telescopes, which can be integrated directly in the laser launch telescopes, in what we call ‘a laser guide star unit’.

In this paper we first present the concept of LGSU and illustrate the LGS return flux field experiments which we intend to setup.

We then present the laser design, analysis and experimental results for two laser units: one which has delivered 30W CW at 589nm, built for demonstration purposes, and another delivering 20W CW at 589nm, built to be mounted directly on a 30cm laser-launch telescope for the field experiments on the return flux.

The lasers use polarization maintaining fiber amplifiers at 1178nm, to deliver a diffraction limited beam at the laser head unit located at the launch telescope. The laser head unit has a compact frequency doubling unit which transforms the 1178nm photons into 589nm photons, with efficiencies >80%. The use of such lasers in LGS-AO systems will also discussed.

7736-66, Session 13

Keck I laser guide star AO system integration

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With the much anticipated delivery of the Lockheed Martin Coherent Technology Quasi-CW laser, the W. M. Keck Observatory was able to complete the installation and integration of the Laser Guide Star Adaptive Optics System on the Keck I telescope. The Keck I LGSAO system was developed to provide redundancy for the Keck II system as well as balancing the instrumentation load between the two telescopes and interferometers. With the improved sodium coupling efficiency of the laser and a center launching system, the Keck I laser performance is expected to exceed those on the Keck II system.

We present the challenges of integrating the Keck I Laser Guide Star Adaptive Optics System on an operational telescope. We will present issues and performance data related to the primary subsystem components such as the laser itself, the Selex Galileo Avionica launch telescope, the Mitsubishi fiber transport, and the Adaptive Optics System. The paper will also focus on the integration and testing performed at the W. M. Keck headquarters as well as the summit of Mauna Kea. We will present initial first light performance of the Keck I LGSAO System and compare those to the existing Keck II LGSAO System.

7736-67, Session 13

Air Force Research Laboratory: testing and validation of a 50-watt facility class sodium guidestar pump laser

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The development of a reliable and effective laser source for pumping mesospheric sodium to generate an artificial guidestar has been well documented and a number of industry, academic, and military efforts to this end are ongoing. Beginning in the fall of 2008, the Air Force Research Laboratory’s Advanced Electric Lasers Branch began a project to build, test, verify and deliver a facility-class high power 589nm source for use at the AF Maui Optical Station (AMOS) in the summer of 2010. This artificial guidestar will be similar in design to the groundbreaking prototype still in use at the Starfire Optical Range (SOR) and will produce 50W of diffraction limited, linearly polarized narrow linewidth 589nm light by combining the output of two injection-locked Nd:YAG ring lasers (operating at 1064nm and 1319nm) using resonant sum-frequency generation in a lithium triborate crystal (LBO). The AMOS system will include upgraded features such as modularized sub-components, embedded control electronics, digitally controlled Pound-Drever-Hall locking loops, and a simplified cooling system.

The first portion of this upgrade project is to reconstruct the current SOR components and include improved methods of regulating the gain modules of the two injection lasers. In parallel with this effort, the technical plans for the modularization and re-packaging of the guidestar will be finalized. This presentation will summarize the result of these efforts to date to include verification of the 50W 589nm output. Additionally, plans for next-generation guidestar upgrades for both SOR and AMOS will also be discussed.

7736-68, Session 13

A bright, pulsed, guide star laser for very large telescopes

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We describe significant progress on our new, improved approach for a bright, pulsed sodium guide-star laser for the correction of atmospheric aberrations in astronomical telescopes. We believe that this laser is the only known design that simultaneously satisfies all requirements for advanced pulse burst waveforms, including the high average brightness required for adaptive optics, and the waveform required for dynamic refocusing in Na. The approach satisfies all current requirements for Multi Conjugate Adaptive Optics (MCAO) for existing and future telescopes, including extremely large ground telescopes (ELTs). It makes use of sum frequency generation (SFG) of two, Q-switched, injection mode-locked Nd:YAG lasers, resulting in a macro-micro pulse-burst output, optimized in power and bandwidth to maximize the fluorescence from the high altitude sodium layer. Here we describe the performance of SFG at the Na wavelength using two injection mode-locked lasers operating at 1.06μm and at 1.3μm, including the latest experimental results on the characterization of the laser in the laboratory. We also describe the detailed design and performance specifications of a deployable laser using this technology, and how it can be optimized to generate a guide star laser operating at the low duty cycle necessary for dynamic refocusing, yet simultaneously exceeding the average fluorescence brightness of a cw guide star laser operating at the same average power output. In a companion paper we describe the physics behind this improvement.

7736-69, Session 13

System overview of a 30 W and 60 W 589 nm guidestar laser systems

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Lockheed Martin Coherent Technologies (LMCT) reports on the successful delivery of a 30 W solid-state sodium beacon Guidestar Laser System (GLS) to the W. M. Keck Observatory, and the demonstration of a 60 W GLS to be delivered to the Gemini South Observatory in 2010. This paper describes the GLS performance results of both the Keck I and Gemini South GLSs with an emphasis on the system design, desired performance specifications, and delivered performance. The 589 nm output was generated via sum frequency mixing (SFM) of 1064 nm and 1319 nm Nd:YAG lasers in a single LBO crystal. The Keck I GLS underwent extensive testing at our facility and has demonstrated consistent performance with a CW mode-locked output of > 30 W and measured M2 < 1.2 while locked to the sodium D2a nominal line center. The Keck I GLS was installed on the telescope in late 2009 and first light on the sky is expected in early 2010. Initial testing of the Gemini South GLS shows a CW mode-locked output of > 60 W and measured M2 ~1.2 while locked to the sodium D2a nominal line center. The Gemini South GLS has produced a maximum power of 76 W of 589 nm light with 85 W of 1319 nm and 110 W of 1064 nm as inputs to the SFM, representing a single-pass conversion efficiency of 39%.

7736-70, Session 14

Open questions in site characterization and turbulence parameter measurements

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With the development of increasingly larger and more complex telescopes and instrumentation, site testing and characterization efforts also increase in both magnitude and complexity. This happens not only because the investment into these larger systems is higher and therefore warrants a more extensive site characterization effort, but also because parameters that did not use to matter previously suddenly become important. An example of such parameters is the vertical distribution of turbulence, which has no effect on seeing-limited observations (only the integrated seeing matters in this case), but matters for single-conjugate adaptive optics systems, and becomes even more important for multi-conjugate AO systems.

We present some of the advancements that have been achieved in site testing and characterization over the last decades and describe remaining questions which, to date, are not generally addressed by "standard" site characterization efforts, either because they are technically not (yet) feasible or because they are impractical. We center our observations around the experience gained during the Thirty Meter Telescope (TMT) site testing effort with an emphasis on turbulence measurements, but our findings are applicable in general to other current and future projects as well.

7736-71, Session 14

High-resolution mesospheric sodium observations for extremely large telescopes

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Variations in density structure and altitude of mesospheric sodium impact the performance of adaptive optics systems employing sodium laser guide stars. The associated wave-front errors grow as the square of the telescope aperture and will be very significant for the next generation of large-aperture ground-based optical/infrared telescopes. To support the adaptive optics program for the Thirty Meter Telescope and European Extremely Large Telescope, we are conducting a program of sodium monitoring using a high-resolution sodium lidar system on the 6-meter Large Zenith Telescope. Located at +49 degrees latitude, the LZT lidar system provides density profiles with spatial and temporal resolution sampling of 4.8 m and 20 ms. In this paper we report highlights of results obtained over two years of observations.

7736-72, Session 15

Recent progress and perspectives for GLAO and MOAO

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Ground Layer Adaptive Optics (GLAO) is a relatively novel form of AO designed to provide image improvements over fields of view of ~10' or larger. GLAO systems are under design or consideration for several 8m, and some 4m, class telescopes, and GLAO is also an important component of some ELT plans. Typically a rather low level of correction is acceptable in GLAO designs, but the availability of this correction with respect to variations in seeing conditions, the use of natural guide stars, and the observational wavelength range is predicted to be exceptionally high. GLAO is therefore often conceived as something like

a “universal seeing improver” for a telescope. A representative range of GLAO instrumentation projects and examples of target science areas are summarised. GLAO designs are often associated with large adaptive mirrors implemented in the main telescope optics, where the correction can be enjoyed by all downstream instrumentation, and where a large field of view is easily conveyed.

A related novel form of very wide field AO is Multi-Object Adaptive Optics (MOAO). In this case, however, much higher orders of correction are typically required and the guide star constellation must be used to conduct high accuracy tomography of the illuminated turbulent volume. Correction is, however, only required for sparsely distributed “islands” (such as individual galaxies) within this large field, and can be applied by multiple miniature deformable mirrors: one per target. The correction must however be applied in open-loop fashion. This unusual requirement and the high accuracy, wide field tomography aspects mean that MOAO involves considerable technological development before its full deployment, and a number of lab experiments and telescope demonstrator projects have been constructed and more are underway. These pathfinders, as well as actual MOAO facility projects and their scientific potential, are surveyed here.

7736-73, Session 15

Adaptive optics with solely natural guide stars at an Extremely Large Telescope

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In the past decade the ingredients for making real an Extremely Large Telescope with an Adaptive Optics system driven solely by Natural Guide Stars has been conceived, developed, built and proven on the sky. Still, the straightforward merging of these concepts is not enough to fullfill such an ambitious goal. We show here that a combination of the layer-oriented approach, the virtual deformable mirrors concept, the use of wavefront sensors that takes advantage of working in closed loop, and the extremely high dynamic range usage of a combination of different kind of wavefront sensors makes the goal a reachable one. It is remarkable that such an approach requires, on a telescope of ELT class, including a common Deformable Mirror conjugated to the entrance pupil or close-by, a minimum impact on the guide probe units. The last involves the adoption of small closed loop AO system with an extremely high dynamic range wavefront sensor looking at the detailed shape of a small Deformable Mirror that allows the use of sensors taking advantage of the closed loop conditions. A pyramid wavefront sensor feeded by the Natural Guide Stars light and the YAW looking at the mirror allows for a natural and efficent combination of the datas. The limits in the Field of View covered by such an approach are given by pure metapupil superpositions rather than to the spatial frequency of the achievable correction, breaking the limits previously thought for this kind of systems. The overall combination leads to a significant sky coverage with performances comparable to the ones under discussion for some Laser Guide Stars approaches, without the related hurdle. The small technical impact on the telescopes makes this approach not directly in-conflict with a Laser Guide Stars one allowing the designer with the degree of freedom to keep all the options on the table up to a very late stage.

7736-74, Session 15

The Subaru coronagraphic extreme AO (SCExAO) system: wavefront control and detection of exoplanets with coherent light modulation in the focal plane

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The SCExAO system is designed to enable high contrast imaging at small angular separation (<0.5”) in the near-IR. It receives light from Subaru Telescope’s AO system and includes a second step of wavefront control and a high performance PIAA coronagraph. Light is then sent to the HiCIAO camera. For wavefront sensing, SCExAO uses a MEMS type deformable mirror to introduce known diversity in the pupil phase. The corresponding modulation is detected in the science focal plane, and leads to a measurement of the residual wavefront aberrations. The same modulation is also simultaneously used to differentiate residual scattered starlight (which is coherent with the light introduced in the focal plane by the modulation) from actual sources (planets, disks).

This combined wavefront control and coherent detection scheme is ideally suited for detection of faint companions at small angular separation. Detailed numerical simulations and recent laboratory results show that this techniques can calibrate and remove static and slow speckles which traditionally limit high contrast detections. A visible light lab prototype system at Subaru Telescope recently demonstrated speckle halo reduction to 2e-7 contrast within 2 lambda/D, and removal of static coherent speckles to 3e-9 contrast.

7736-75, Session 15

A comparison of tip-tilt star sharpening techniques for precision laser guide star adaptive optics systems

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As adaptive optics system mature to enable diffraction-limited visible-light imaging science, objectionable tip-tilt errors will becoming increasing difficult to suppress. Future LGS AO systems will seek to sharpen multiple field NGS to the diffraction-limit in order to minimize residual tip-tilt error. We present a comparison of science target performance for different NGS sharpening strategies including SCAO, MCAO, and MOAO. By careful balancing of high-order on-axis errors with those induced by anisoplanatism, generalized anisoplanatism, and anisokineticism, we can optimize science target correction. For an MOAO sharpening implementation, we also describe the appropriate division of available laser power to balance wavefront sensing in the science target and field NGS directions.

7736-76, Session 15

Experimental demonstration of laser tomographic adaptive optics on a 30-meter telescope at 850 nm

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A critical goal for instrumentalists in the next decade will be to extend Adaptive Optics correction to visible wavelengths on large telescopes. Due to a darker sky background and a sharper diffraction limit in the optical, AO systems will be an order of magnitude more sensitive to faint astronomical objects at visible wavelengths compared to the near-IR.

We demonstrate in the laboratory the highly accurate atmospheric tomography necessary to defeat the cone effect on ELTs, an essential milestone on the path to this capability. We simulate a high-order Laser Tomographic AO (LTAO) System for a 30-meter telescope at a science wavelength of 850 nm with the LTAO/MOAO testbed at the Laboratory for Adaptive Optics (LAO). Eight sodium laser guide stars are sensed by 100x100 subaperture Shack-Hartmann wavefront sensors over a field of regard of 80” diameter. A split-tomography approach (L. Gilles et al. 2009) is used to simultaneously analyze high-order LGS wavefronts and tip/tilt information from 3 natural guide stars. Tip/tilt correction is separately performed for each science star with a New Focus picomotor-actuated fold mirror. A phase modulator with the equivalent of 9500 degrees of freedom is used as a high-order deformable mirror. Using a 3D Mauna Kea-type atmosphere with r_0 = 16 cm, the AO system

achieves the diffraction limit at a simulated science wavelength of 850 nm (S = 10-15%) over a narrow, central field of regard of 15" diameter.

7736-77, Session 16

Compared performance of different centroiding algorithms for high-pass filtered laser guide star Shack-Hartmann wavefront sensors

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Sodium laser guide stars (LGS) increase the sky coverage of adaptive optics (AO) systems. However, the finite height, the double pass through the atmosphere and the elongated size of the LGS, still limit the extent of the sky coverage. For Shack-Hartmann wavefront sensors (WFS), the slow variations of the sodium layer altitude and atom density profile induce changing errors on centroid measurements, especially for extremely large telescopes (ELTs) as the spot elongation increases with the telescope diameter. These LGS--induced aberrations are propagated on the science path and must be filtered out by (i), optimizing the LGS WFS and the centroiding algorithm, and (ii), by adding a high-pass filter on the LGS path and a low-bandwidth (LB) natural-guide-star (NGS) WFS. In the context of the ESO E-ELT project, four different centroiding algorithms, namely the center-of-gravity, the weighted center-of-gravity (WCoG), the matched filter and the quad-cell, have been evaluated in closed-loop on the University of Victoria LGS wavefront sensing test bed. This optical bench reproduces, in the laboratory, both NGS spots and LGS elongated spots with changing sodium profiles and turbulence. Each centroiding algorithm performance is compared for a central-launch versus side-launch laser; different fields of view; pixel sampling; and, signal-to-noise ratios. WCoG and quad-cell stability issues when combined with a LB NGS-WFS are also presented and discussed.

7736-78, Session 16

Anisoplanatism effects in wave-front sensing with laser guide stars on the ELTs

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Adaptive Optics (AO) relies on a Wave Front Sensor (WFS) to measure properly the perturbations induced by the turbulence on the wave front. Yet, source extension may limit its performance: waves coming from different points of an extended source are not identically distorted by the turbulence, depending on the atmospheric volume seen through the propagation. This effect called anisoplanatism affects the accuracy of the wave front measurements when AO systems are used with extended objects, such as Laser Guide Stars (LGS). This may be an issue for the next generation of 40 m telescopes, called Extremely Large Telescopes (ELTs), since the field angle with which the LGS is seen from the edge of the telescope increases with the diameter of the primary mirror.

The present study is aimed at estimating the wave front measurement error induced by anisoplanatism, in case of LGS for the ELTs.

Considering firstly a Shack-Hartmann WFS, our approach is to evaluate the slope measurement error with a numerical end-to-end model, and then to use this measurement error in a wave front reconstruction process. We consider first a single LGS case, and study the propagation of the error in a 6 LGS launching scheme, performing tomography to reconstruct the whole volume of turbulence.

Secondly, we perform a comparative study of various WFS used for this purpose.

7736-79, Session 16

Optimized phase diversity sensor for wideband analysis on long-exposure AO corrected images: theory, simulations, and experimental validations

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Exoplanet direct imaging is a challenging goal of today's astronomy. The small angular separation, as well as the high contrast between the star and the planet require the use of dedicated extreme adaptive optics systems. In order to achieve the required performance, all the static aberrations down to the imaging camera have to be measured in the camera focal plane, and compensated. Phase diversity is an accurate focal plane sensor, widely used for NCPA analysis and compensation. Its application to exoplanets direct imaging involves on-line calibration (that is calibration data obtained during the scientif exposure), and therefore the presence of residual turbulence, and the need for wide-band imaging (typically R< 10). We present here an optimized phase diversity sensor for wide band analysis on long-exposure AO corrected images. Both theory and simulations results are proposed. The performance and the potentiallity of this approach is illustrated in the case of SPHERE (the Planet Finder instrument of the VLT) and EPICS (the planet finder instrument of the E-ELT). In addition, experimental results, obtained on the ONERA AO bench, are presented.

7736-80, Session 16

Advanced static speckle calibration for exoplanet imaging

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The Gemini Planet Imager will be equipped with a post coronagraphic calibration interferometer that estimates the amplitude and the phase of non-common path errors in a pupil relocated before the science detector. When operating in a closed loop, this device will deliver a 1 nm rms residual wavefront. In this paper we present novel algorithms that allow such a reconstruction in the presence of differential phase errors and absolute phasing uncertainties within the calibration interferometer, as well as operations in the sub-optimal coronagraphic regime. These algorithmic developments are illustrated using experimental result obtained during the tests of the actual instrument.

7736-81, Session 17

Contactless thin adaptive mirror technology: past, present and future.

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The contactless, voice coil motor adaptive mirror technology starts from an idea by Piero Salinari in 1993. This idea has progressively evolved to real systems thanks to a fruitful collaboration involving Italian research institutes (INAF - Osservatorio Astrofisico di Arcetri and Aerospace Department of Politecnico di Milano) and small Italian enterprises (Microgate and ADS). Collaboration between research institutions and industry is still very effectively in place, but nowadays the technology has left the initial R&D phase reaching a stage in which the whole projects are managed by the industrial entities. In this paper we present the baseline concept and its evolution, describing the main progress milestones. These are paced by the actual implementation of this idea

into real systems, from MMT, to LBT, Magellan, VLT, GMT and E-ELT. The fundamental concept and layout has remained unchanged through this evolution, maintaining its intrinsic advantages: tolerance to actuators' failures, mechanical de-coupling and relaxed tolerances between correcting mirror and reference structure, large stroke, hysteresis-free behavior. Moreover, this concept has proved its expandability to very large systems with thousands of controlled d.o.f. Notwithstanding the solidity of the fundamentals, the implementation has strongly evolved from the beginning, in order to deal with the dimensional, power, maintainability and reliability constraints imposed by the increased size of the targeted systems.

7736-82, Session 17

The adaptive secondary mirror for the Large Binocular Telescope: result of the optical acceptance test

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The Large Binocular Telescope has two 911mm-diameter adaptive secondary mirrors based on 672 voice-coil force actuators. The shape of the mirror is controlled using internal metrology based on co-located capacitive sensors. During springtime 2009 the optical acceptance test was successfully performed using the 14-m optical test tower in Osservatorio Astrofisico di Arcetri showing the capability of flattening the shell at the level of 14nm rms surface error with forces in the specified limits (<0.2N). The paper reports the optical layout, calibration procedures and results of the optical acceptance test.

7736-83, Session 17

MEMS deformable mirrors for astronomical adaptive optics

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We report on the development of high actuator count, micro-electromechanical (MEMS) deformable mirrors designed for high order wavefront correction in ground and space-based astronomical adaptive optics instruments. The design of these polysilicon, surface-micromachined MEMS deformable mirrors builds on technology that has been used extensively to correct for ocular aberrations in retinal imaging systems and for compensation of atmospheric turbulence in free-space laser communication. These light-weight, low power deformable mirrors have an active aperture of up to 25.2mm consisting of a thin silicon membrane mirror supported by an array of 140 to 4092 electrostatic actuators which exhibit no hysteresis and have sub-nanometer repeatability making them well suited for open-loop control applications such as Multi-Object Adaptive Optics (MOAO). The continuous membrane deformable mirrors, coated with a highly reflective metal film, are capable of up to 6µm of stroke, have a surface finish of <10nm RMS with a fill factor of 99.8%. Presented in this paper are device characteristics and performance test results, as well as reliability test data and device lifetime predictions that show that trillions of actuator cycles can be achieved without failures.

7736-84, Session 17

Characterization of the PALM-3000 3388-actuator deformable mirror

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We describe the lab characterization of the new 3388-actuator deformable mirror for PALM-3000. This 66 by 66 actuator Xinetics mirror has the largest number of actuators of any deformable mirror currently available and will enable high-contrast imaging with the PALM-3000 adaptive optics system on the Palomar Hale 200" telescope. We present optical measurements of the powered and unpowered mirror surface, influence functions, linearity of the actuators, hysteresis and creep. We also quantify the effect of environmental changes such as temperature and humidity.

7736-85, Session 17

Last progress concerning the design of the piezo stack M4 adaptive unit of the E-ELT

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Cilas proposes a M4 adaptive mirror (M4AM) that corrects the atmospheric turbulence at high frequencies and residual tip-tilt and defocus due to telescope vibrations by using piezostack actuators. The design presents a matrix of 7217 actuators (hexagonal geometry, spacing equal to 29 mm) leading to a fitting error reaching the goal. The mirror is held by a positioning system which ensures all movements of the mirror at low frequency and selects the focus (Nasmyth A or B) using a hexapod concept. This subsystem is fixed rigidly to the mounting system and permits mirror displacements. The M4 control system (M4CS) ensures the connection between the telescope control/monitoring system and the M4 unit - positioning system (M4PS) and piezostack actuators in particular. This subsystem is composed of electronic boards, mechanical support fixed to the mounting structure and the thermal hardware.
With piezostack actuators, most of the thermal load is minimized and dissipated in the electronic boards and not in the adaptive mirror. The mounting structure (M4MS) is the mechanical interface with the telescope (and the ARU in particular) and ensures the integrity and stability of M4 unit subsystems. M4 positioning system and mounting structure are subcontracted to Amos company

7736-86, Session 18

Laboratory performance of the Gemini planet imager's adaptive optics wavefront reconstruction and control system

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The Adaptive Optics control system of the Gemini Planet Imager instrument features several new technologies and algorithms, including Fourier Transform wavefront reconstruction, the spatially filtered wavefront sensor, and optimized-gain Fourier control. Use of Predictive Fourier Control is a goal for the instrument. We report on the experimental performance of these new methods in the instrument's integration and test phase.

The GPI AOC testing consists of four phases. In the first, stand-in hardware (i.e. an engienering grade 32 x 32 MEMS instead of a science grade 64 x 64 MEMS) and non-realtime IDL implementations of the algorithms were used to allow in-depth exploration of the algorithms and methods in a non-dynamic environment.

Specific examples include: development of precise alignment and calibration techniques, verification of Fourier-domain influence function compensation, verification of FTR with Woofer-Tweeter control and handling of misbehaving actuators with clipping.

In the second phase, the same hardware was controlled with the real-time controller (RTC).

This allowed both verification of the implementations of the algorithms, as well as studying the dynamic performance. In particular, optimized-gain Fourier control was verified with spinning phase plates providing the dynamic aberations.

In the third phase, final and engineering-grade GPI hardware is used. This allows repetition of all previous tests, but with the real instrument hardware.

In the final phase, which we may or may not be able to report on given scheduling and progress, the AOC is integrated with the rest of the final instrument and re-tested.

7736-87, Session 18

MYST: a comprehensive high-level control tool for GeMS

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Myst is the Gemini MCAO System (GeMS) high level control GUI. It is written in yorick, python and C. In the first part of this paper, we describe MYST's architecture, followed by its purpose, which is multifold: (a) MYST is used as a real time display for basic data (slopes, actuator commands) and more elaborate information (modal decomposition, r0, Cn2 profile, etc); (b) it is also used to carry out daily/weekly system calibrations, generate control matrices, NCPA sets (and more) and finally (c) it is used as a server to coordinate high level actions as closing the loop (in a MCAO system that includes a number of individual steps and checks), dithering, etc...

7736-88, Session 18

SPARTA for the VLT: status and plans

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SPARTA, the ESO Standard Platform for Adaptive optics Real Time Applications, is the real time computing platform serving 3 major 2nd generation instruments at the VLT (SPHERE, GALACSI and GRAAL) with plans to serve more, smaller, instruments in the near future.

SPARTA offers a very modular and fine-grained architecture which is generic enough to serve a variety of AO systems. SPARTA includes the definitions of all the interfaces between those modules and provides libraries and tools to implement and test the various modules as well as a map to technologies capable to deliver the required performance, most of them innovative with respect to ESO standards in use.

For the above mentioned instruments, SPARTA provides also a complete implementation of the AO application, with features customised for each of the 3 instruments.

This paper presents the architecture of SPARTA, its technologies, functions, performance and test tools as well as the plans to increase the reach of the platform to smaller system with what we call SPARTA Light.

7736-89, Session 18

Wavefront sensing and wavefront reconstruction for the 4m European Solar Telescope EST

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We give an overview of the wavefront sensing and wavefront reconstruction for the Adaptive Optics (AO) and Multi-conjugate Adaptive Optics (MCAO) system of the planned 4m European Solar Telescope (EST).

EST will include a high order AO capable of achieving a Strehl of 0.4 at r0=7cm (500nm) and of 0.6 at r0=10cm by correcting 2000 degrees of freedom.

Furthermore, it is planned to feature an MCAO correcting a field of view of one arcminuteusing four additional layer DMs at 5,9,15,30 km conjugate heights.

The optimization process of the AO / MCAO parameters is shown, including the parameters and layout of the Shack-Hartmann wavefront sensor setup, the DMs and the various possibilities of the wavefront reconstruction schemes presently being considered.

First estimates of the overall performance of AO and MCAO are presented.

Conference 7737: Observatory Operations: Strategies, Processes, and Systems III

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7737-01, Session 1

10 years of VLT end-to-end operations

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Ten years after the start of Science Operations with its first 8.2-m telescope 'Antu' and the scientific instruments ISAAC and FORS1, the ESO Very Large Telescope (VLT) operates today with four 8.2-m Unit Telescopes (UTs) and a suite of 11 scientific instruments including the first instrument of the second generation, i.e., X-SHOOTER. The Laser Guide Star Facility (LGSF) provides two of the three adaptive optics supported instruments of the VLT with an artificial reference star. The VLT Interferometer (VLTI) combines the light of either the Unit Telesopes or the 1.8-m Auxiliary Telescopes (ATs) to feed one of the two interferometric first generation instruments with a coherent wavefront further stabilized by the VLTI fringe tracker. The 4-m near infrared survey telescope VISTA has been the latest addition to the observatory and starts its full science operations in early 2010.

The on-site operation of the telescopes and instruments at the Paranal Observatory is embedded into the VLT end-to-end operations model with 'front' and 'back' end operations being hosted at ESO Garching, while the facilities and the observations are managed from Chile. Garching operations handles the 'front' and 'back' ends of the process through user support, medium-term scheduling, data processing, quality control and archiving while Paranal operations handles the short-term scheduling, the successful execution of the approved programmes in Service Mode and the on-site support of visiting astronomers.

In this paper we will review the end-to-end operations model and present the lessons learned over the past decade. Based on this experience we will discuss possible implications for the future operation of the European Extremely Large Telescope E-ELT.

7737-02, Session 1

The MMT Observatory: operations 10 years after conversion

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In 2000, the MMT Observatory replaced its ground-breaking cluster of six 1.8-m primary mirrors with one 6.5-m mirror, increasing the light-gathering power of the telescope by a factor of 2.5, and its available field of view by a factor of about 15. Utilizing the existing chamber structure provided distinct advantages in cost and capability to create the new telescope, however, it has also presented many challenges to the efficient operations of the observatory. We use three secondary mirrors, ranging from the wide-field f/5 secondary to the deformable f/15 secondary as part of the adaptive optics system. The suite of available instrumentation ranges from visible multi-object fiber spectrographs to near- and mid-infrared imagers and spectrographs. We have addressed problems ranging from thermal control of the chamber and primary mirror of the telescope to storage and mounting of instrumentation, and cleaning and aluminizing the primary mirror in situ: unique problems have spawned creative technical solutions. The status of the successful conversion after 10 years will be reviewed.

7737-03, Session 1

The IRAM Plateau de Bure interferometer: current status, upgrades, and future

P. H. Cox, R. Neri, Instituto de RadioAstronomía Milimétrica (France)

The current status of the IRAM Plateau de Bure Interferometer will be presented in this paper with an emphasis on its operations. Recent upgrades will be described and their implementation will be reviewed. The impact of these strategic upgrades upon the science that can be addressed will be discussed. Finally, future upgrades of the IRAM Interferometer that are currently under discussion, known as the NOEMA project (for NOrthern Extended Millimeter Array), will presented

7737-04, Session 1

Constructing the EVLA while operating the VLA

R. L. Dickman, National Radio Astronomy Observatory (United States)

Begun in 2001 with a total budget of around $100M dollars, the Expanded Very Large Array (EVLA) project is the only major upgrade to the VLA undertaken since the interferometer was completed in 1980. The goal of this 11-year long project is to improve all the observational capabilities of the original VLA - except for collecting area and spatial resolution - by at least an order of magnitude.

The extremely long duration of the EVLA construction project and the need to maintain the scientific productivity of the telescope precluded shutting down the old array while new infrastructure was built and commissioned. The construction plan was therefore based on the assumption that the old VLA would continue to operate as new EVLA capabilities gradually came online. Current commissioning plans attempt to strike a balance between making new EVLA capabilities available to the user community as soon as they have been installed and verified, and maintaining a stable and robust end-to-end data acquisition and delivery process.

In this talk I review the relationship between EVLA construction planning and VLA operations. I summarize the current status of array commissioning and the operational status of the telescope, with particular focus on the watershed transition to the new WIDAR correlator that began in January 2010.

7737-05, Session 1

Mixing completion, commissioning, and operations at the LBT

R. F. Green, J. M. Hill, The Univ. of Arizona (United States) and Large Binocular Telescope Observatory (United States); J. G. Brynnel, The Univ. of Arizona (United States); J. H. Slagle, D. S. Ashby, N. J. Cushing, J. Little, R. M. Wagner, M. Pedani, The Univ. of Arizona (United States) and Large Binocular Telescope Observatory (United States)

By June 2010, the Large Binocular Telescope Observatory will have supported six semesters of observing with prime focus imaging, with the addition of IR imaging and spectroscopy in the most recent. Interspersed in the last year were installation and commissioning of one direct and one bent Gregorian focal station and extended commissioning of the

first bent Gregorian focal station. We examine the lost time statistics and distribution of issues that reduced on-sky access in the context of the limited technical support provided for observing. We also note some of the restrictions imposed by the alternation of engineering and commissioning activities with scheduled observing time. The goal is to apply the lessons learned to the continuing period of observation plus commissioning anticipated as new spectroscopic, adaptive optics, and interferometric capabilities are added through 2012.

7737-06, Session 1

A new La Silla site operations paradigm

G. J. F. Ihle, A. Kaufer, I. Saviane, M. F. Sterzik, B. Ahumada, J. Duk, J. C. Fluxa, A. Gonzalez, I. Kastinen, E. Matamoros, M. Pavez, J. C. Pineda, A. Pizarro, P. Sinclaire, European Southern Observatory (Chile)

In 2007 ESO Council endorsed a concept to maintain the La Silla Site within the context of a streamlined operational and support scenario.

La Silla remains part of the La Silla Paranal Observatory Division, and supports science projects of the ESO community using the 2.2m, NTT and 3.6m telescope. Infrastructure to host externally funded projects at national telescopes is provided.

A detailed Site Operations Plan for La Silla 2010+ had been developed, and is been implemented since October 2009. We describe its implications on staffing, infrastructure, and science operations. We report our first experience gathered under this new operations paradigm.

An analysis to determine the feasibility to apply such working model is done based on the stability of the existing equipment in La Silla and the capability to continue providing good science to the community.

The selection of the core positions in the site, done by a working group, and its implications in the manpower reduction is also analysed together with the first results.

A new operations model that considers the remote support to visiting astronomers by ESO staff astronomers and the role of the system engineers in the success of the model and the external support provided by other sites of the organization is also mentioned.

Routine maintenance procedures to keep the observatory operations with the minimum downtime are followed according to a established plan.

Changes in the logistics as well as in the infrastructure use are presented together with the benefits that are expected in the observatory run.

7737-08, Session 1

APEX: first five years of operations

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The Atacama Pathfinder Experiment (APEX) is a modified ALMA prototype antenna and it is located at the Chajnantor plateau in Chile. It is designed to work at sub-millimeter wavelengths, and it is equipped with receivers for observations between 1.5THz and 200 GHz (0.2 to 1.5 mm) - both spectral line and bolometer receivers. The main dish has a diameter of 12 meters and consists of 264 aluminum panels with an average surface accuracy of 15 micrometers (r.m.s.).

APEX is a collaboration between the Max Planck Institute for Radio Astronomy (MPIfR) at 50%, the European Organisation for Astronomical Research in the Southern Hemisphere (ESO) at 27%, and Onsala Space Observatory (OSO) at 23%. The telescope was designed and constructed by VERTEX Antennentechnik GmbH (Germany), under contract by MPIfR, it is based on a prototype antenna constructed for the ALMA project, and it is operated by ESO.

I will present the telescope and its instrumentation and I will talk about the challenges we face operating a telescope 12m class telescope at 5000m 24h per day for most part of the year. APEX can be remotely controlled from any part of the world, although it is normally operated from the Chajnantor control room during daytime, and from the base station (Sequitor, 2500m), which lies 50km from the APEX site.

Finally I will show some science highlights from the first five years of APEX operations and if the circumstances allow I will perform a quick observation from the meeting room.

7737-09, Session 1

Laser guide star operations at the Gemini North Observatory

T. C. Matulonis, Gemini Observatory (United States)

The Laser Guide Star (LGS) operations at the Gemini North (GN) Observatory have greatly improved the sky coverage, far beyond using a Natural Guide Star (NGS), for the high angular resolution Adaptive Optics (AO) science demanded by our astronomical community. An understanding of the current LGS logistics from an operational standpoint is imperative for any facility planning to incorporate the LGS approach. The details of LGS operations will be highlighted, in particular the role of the Systems Support Associate (SSA) who is responsible for the safe and efficient operation of the complex GN AO system, Altair. An overview of the LGS related monitoring tools that measure the sodium layer distance, laser power, as well as the magnitude and focus of a tip-tilt NGS will be presented. The Laser Traffic Control System (LTCS) that supports the first-on-target concept to minimize the impact on the science of non-lasing neighboring observatories will also be discussed. Requirement parameters for LGS science will be summarized to include image quality, NGS magnitude, weather, laser power, elevation, and off-axis distance. A summary of safety protocols will include Space Command authorization for propagation windows, FAA approval, and aircraft spotter communication necessary for the safety of aircraft pilots and satellites will be introduced. Additional highlights include the streamlining of staff support, required for the success of LGS runs, leading to the SSA inheriting the major responsibilities of the laser operator and the All Sky Camera (ASCAM) assuming the role of the aircraft spotters.

7737-10, Session 1

Laser operations the 8-10m class telescopes Gemini, Keck, and the VLT: lessons learned, old and new challenges

P. Amico, European Organisation for Astronomical Research in the Southern Hemisphere (Germany); R. D. Campbell, W. M. Keck Observatory (United States); J. C. Christou, Gemini Observatory (United States)

Laser Guide Star (LGS) assisted Adaptive Optics operations have commenced at three of the major astronomical observatories, in 2000 (Keck), 2006 (VLT) and 2007 (Gemini) respectively. Subaru is also on the verge of putting its LGS facility into operations. In this paper we concentrate on the operational aspect of the laser facilities: we discuss common problems such as weather constraints, beam collisions, aircraft avoidance and optimal telescope scheduling. We highlight important differences between the observatories, especially in view of the valuable lessons learnt. While it is true that the three observatories have made quick progress and achieved important scientific results during the first years of operations, there is much room left for improvement in terms of the efficiency that can be obtained on sky. We discuss the challenges ahead and the possible solutions.

7737-11, Session 2

The ALMA maintenance plan

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The Atacama Large Millimeter Array is a major new astronomical facility currently under construction at 5000m on the Chajnantor Plateau in northern Chile. The current version of the ALMA Operations Plan was developed in 2007. In late 2009 / early 2010, the Joint ALMA Observatory (JAO) undertook a major revision of the Operations Plan, to reflect the current status and understanding of the project. This included a complete bottoms-up review of the ALMA Maintenance Plan. This paper describes the process employed, and the results of that review of the Maintenance Plan.

7737-12, Session 2

Operational model for the Magdalena Ridge Observatory interferometer

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The Magdalena Ridge Observatory (MRO) interferometer is designed to be a 10 element interferometer operating in the visible and the near-infrared bands. Initial funding has been provided by the Navy through congressional appropriations. As such the interferometer will have a dual purpose, to serve astronomers to collect unique high-spatial resolution observations, and to provide a tool for space situational awareness. MRO is hosted by the New Mexico Institute of Mining, New Mexico. The MRO interferometer is expected to see first light in 2011 and enter the commissioning phase later that year once two telescopes are available on the site and a fringe can be detected.

This dual purpose model (astronomy and space situational awareness), and the mix of available funding stream for a private observatory, leads to a unique operational model for the MRO interferometer.

This paper presents the operational model that the MRO interferometer is working towards. It describes how open access could become available through a peer reviewed process. MRO is designed to be a facility class observatory and we will elaborate on what this implies for the operational model. Finally and overview will be provided of the estimated cost to operate MRO and how this relates to other observatories for which data is available.

7737-13, Session 2

Testing and validation of orbital operations plans for the MESSENGER Mission

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Launched in 2004, the MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) spacecraft continues on its journey to become, in 2011, the first spacecraft to orbit the planet Mercury. The goal of MESSENGER's one-year orbital mission is to answer several key questions about the structure and history of Mercury and its surrounding environment. The science and mission operations teams are testing a concept of operations to use the instrument payload most efficiently and to ensure full mission success. To ensure all essential observations are obtained and to allow for contingencies, an advance science planning (ASP) effort is used to develop a full yearlong mission baseline plan far in advance. To ensure the plan can be adapted in response to unexpected events over time, an adjusted baseline plan will be regenerated in the ASP process every five weeks during the actual orbital mission. The near-term science planning (NTSP) activity converts weeklong portions of the baseline plan into executable commands to conduct the orchestrated observations. A feedback process from NTSP to ASP will be used to ensure that the baseline observing plan accounts for and reschedules any observations that were not successful. In this paper, we describe the MESSENGER payload orbital concept of operations and how it will be executed by the science and mission operations teams. We describe the software and processes to be used for both advance science planning and near-term science planning. We also describe the testing and validation strategies for both the processes and tools.

7737-14, Session 2

Using the Baldrige criteria for observatory strategic and operations planning

N. M. Radziwill, James Madison Univ. (United States); L. Mitchell, National Radio Astronomy Observatory (United States)

In 1987, the U.S. Congress created the Malcolm Baldrige National Quality Award (MBNQA), a competition that rewards businesses and nonprofits that demonstrate effective, efficient operations. Underlying the MBNQA are criteria to help organizations integrate seven key areas of operations, including: leadership, strategic planning, customer focus, information management, workforce planning, process management, and results. Independent of the award process, the Baldrige Criteria can be used to guide strategic and operations planning. This presentation includes an example of how the Baldrige Criteria were used to develop a Workforce Management Plan for NRAO in just weeks, responding to funding agency demands. As part of the example, we will outline the process that was used to create the plan so quickly.

7737-15, Session 3

Scientific productivity and impact of large telescopes

D. R. Crabtree, National Research Council Canada (Canada)

The primary scientific output from an astronomical telescope is the collection of refereed papers based on data from that telescope. A telescope's productivity is measured by the number of papers published which are based upon data taken with the telescope. The scientific impact of a paper can be measured quantitatively by the number of citations that the paper receives. In this paper I will examine the productivity and impact of the major optical telscopes and compare their productivity and impact.

7737-16, Session 3

ALMA science operations

L. Nyman, European Southern Observatory (Chile)

ALMA Early Science Operations is expected to start in the second half of 2011, and the preparations are well under way. ALMA science operations include activities at the Operations Support Facility (OSF) near San Pedro de Atacama, the Santiago Central Office (SCO) in Santiago de Chile, and the ALMA Regional Centers (ARCs) in each ALMA region - Europe, North America and East Asia.

ALMA observations will take place 24h/day, interrupted by maintenance periods, and will be done in service observing mode with flexible (dynamic) scheduling. The observations are executed in the form of scheduling blocks (SBs), each of which contains all information necessary to schedule and execute the observations. The default output to the astronomer will be pipeline-reduced images, calibrated according to the calibration plan. The Joint ALMA Observatory (JAO) is responsible for the data product quality. All science and calibration raw data are captured and archived in the ALMA archive, a distributed system with nodes at the OSF, SCO and ARCs.

Observation preparation will follow a Phase 1/Phase 2 process. During Phase 1, observation proposals will be created using software tools provided by the JAO and submitted for scientific and technical review.

Approved Phase 1 proposals will be admitted to Phase 2 where all observations will be specified as SBs using software tools provided by the JAO.

User support will be done at the ARCs through a helpdesk system as well as face-to-face support.

7737-17, Session 3

Kepler science operations processes, procedures, and tools

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The Kepler Science Operations Center (SOC) is responsible for the configuration and management of the science pipeline, processing of the science data, distributing data and reports to the Science Office and Team, exporting calibrated pixel data and other products for archival at the Data Management Center at the Space Telescope Science Institute, and generation and management of the target and aperture definitions.

We present an overview of the SOC processes, procedures, and workflows for the data types managed and processed by the SOC, which require differing levels of reviews, approvals, and processing activities. To accomplish the SOC goals we describe the process flow from data receipt through data generation, export, and delivery; the procedures in place for interactions between different elements in the Kepler Ground Segment; and the associated tools -- in-house developed command line utilities and Graphical User Interfaces as well as comercial-off-the-shelf products -- which provide a wide range of functionality for the SOC including pipeline operation, configuration management, and process workflow implementation. As a demonstration, we present the life of a quarter's worth of data, from target and aperture table generation through archival of the data collected with those tables, covering both the planned and actual implementation timelines, and highlighting the successes and lessons learned.

7737-18, Session 3

The care and feeding of the JWST on-board event-driven system

V. A. Balzano, D. Zak, W. Whitman, Space Telescope Science Institute (United States)

The software architecture of the James Webb Space Telescope (JWST) includes an operational layer implemented by on-board JavaScripts that orchestrate event-driven Observatory operations. Request files, which together specify up to ten days of high-level science and engineering tasks, along with a time-ordered execution list are uploaded periodically to the on-board event-driven system. Processing of these files by the JavaScripts is dictated by on-board events. The tasks execute within their specified windows or could be skipped due to an isolated anomaly, such as a failure to locate a suitable guide star. For each high-level task, the necessary flight software commands are constructed according to operational rules and positive completion confirmation is required before proceeding on with the next flight software command.

The event-driven nature of JWST on-board operations both at the task and command level presents challenges to the JWST Science and Operations Center currently being constructed at the Space Telescope Science Institute. This paper will outline the design implications on science and engineering operations planning, flight real-time operations, and post-observation data management. Included will be descriptions of how the Operations Center will handle planning time-windowed tasks to ensure that the event-driven system will remain scientifically productive even when anomalies occur, how to interface with and monitor JWST event-driven operations, and how to record related Observatory status information for each science image. The strong foundation and heritage of Hubble operations is being built upon to create a robust Operations Center for the James Webb Space Telescope.

7737-19, Session 3

Gemini Observatory: five years of multi-instrument queue operations

I. Jorgensen, Gemini Observatory (United States); B. Rodgers, D. R. Crabtree, Gemini Observatory (Chile)

Gemini Observatory has operated Gemini North and South in multi-instrument queue mode since early 2005. Each telescope has about 85% of the time scheduled for science, of which 90% are in queue mode. More than one instrument is used 75-80% of all science nights. We present on-sky performance data from the last five years: Completion rates for queue programs, open-shutter performance, and acquisition times. Open-shutter performance and acquisition times are highly competitive with other 8-10 meter-class telescopes for which data are available. We give an overview over queue planning and integration of engineering and commissioning observations into the queue execution.

7737-20, Session 3

GALEX extended mission operations

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The Galaxy Evolution Explorer is a NASA Small Explorer mission that has been surveying the ultraviolet sky for seven years. Mission operations were originally designed to support a 28 month science survey. The longevity and success of GALEX has been due in part to the continual development of mission planning and the automated data processing pipeline. The project is now planning to exploit the unique capabilities of the GALEX instruments to extend surveys into the next decade. This will involve implementing a new and more cost effective mission operations system as well as a new mode of observing science targets.

In this paper we will present the options that have been investigated for streamlined operations as well as the development of the mission planning system that will support the new observation mode.

7737-21, Session 3

Downsizing a great observatory: the story of warm Spitzer

L. J. Storrie-Lombardi, S. R. Dodd, California Institute of Technology (United States)

The Spitzer Space Telescope transitioned from the cryogen mission to the IRAC warm mission during 2009. This transition involved changing several areas of operations in ordered to cut the mission operation's costs to 1/3 of the cryogen mission. In spite of this substantial cut back, Spitzer continues to have one of the highest science return per dollar ratio of any of NASA's extended missions. This paper will describe the major operational changes made for the warm mission and how they affect the science return. The paper will give several measures showing that warm Spitzer continues as one of the most scientifically productive mission in NASA's portfolio. This work was performed at the California Institute of Technology under contract to the National Aeronautics and Space Administration.

7737-59, Poster Session

Interfaces between science and engineering operations for the WISE Telescope

B. E. Fabinsky, Jet Propulsion Lab. (United States); T. Conrow, California Institute of Technology (United States)

WISE is an earth-orbiting spacecraft carrying an infrared telescope cooled by means of a cryostat filled with solid hydrogen. The purpose of the mission is to conduct an all-sky survey at infrared wavelengths of 3.3, 4.7, 12 and 23 microns. The 10-month mission, launched December 14th from Vandenberg Air Force Base, has completed one month of in-orbit checkout (IOC) and is beginning 9 months of Survey Operations.

Data collected during the WISE survey will be delivered in a photometrically and astrometrically calibrated image atlas and source catalog by the WISE Science Data Center at Caltech's Infrared Processing and Analysis Center 17 months after the end of on-orbit operations. In order to produce this catalog, image data and ancillary information must be delivered by the Engineering Operations element of the mission to their Science Operations partners.

Prior to launch, WISE exercised interfaces between science and engineering operations for both the calibration and characterization activities of In-Orbit Checkout and the Survey itself via ground testing and operations rehearsals. Much was learned from ground testing. Immediately following launch, engineering and science interfaces were incrementally exercised, and some minor problems were uncovered during this high activity post-launch period. These were resolved without impacting the successful implementation of the mission and its timeline.

In this discussion, we provide a description of the plans that were made for information exchange between the engineering and science data processing teams; how these plans were tested prior to launch; and, what lessons were learned following launch. The testing of engineering and science interfaces proved to be of great value in uncovering incompletely or incorrectly defined processes and data formats, and in large part contributed to the efficient completion of checkout activities and smooth transition to Survey Operations. The few oversights made in the definition and testing of these interfaces are noted.

7737-60, Poster Session

Preventive maintenance optimization at Paranal Observatory

E. F. Bugueno, European Southern Observatory (Chile)

Step for a PMO

Prepare PMO

Collect information of the different system existing at the Observatory

Define System or Equipment according to Reliability Requirements

The selection of the PM to be optimize when thru different stages

- Make a list prioritization, base on reliability, availability and efficiency.
- Once the system was choose
- The information collected from two sources is analyzed
- Obtain statistics of the different failure mode of the system
- Evaluation of the failure mode

Review Existing PM

- Check everyone of the task of the actual PM
- Analyze each one of the activities

Screen Task for Removal

- Removed unnecessary activities

Optimize Remaining Tasks

- Add activities if necessary

Fill Gaps on PM

Review Manufacture Recommendations

Optimize PM Work Order

Implement Change

Evaluate Improvement.

7737-61, Poster Session

Reliability as culture at the La Silla Paranal Observatory

S. E. Gonzalez, European Organisation for Astronomical Research in the Southern Hemisphere (Chile)

The Maintenance Department at the La Silla - Paranal Observatory has been an important base to keep the operations of the observatory in a good level of reliability and availability.

Several strategies have been implemented and improved in order to cover these requirements and keep the system and equipment working properly when it is required.

For that reason, one of the latest improvements has been the introduction of the concept of reliability.

Basically, this means that we don't just speak about reliability concepts. It involves much more than that — It involves the use of technologies, data collecting, analysis of data, taking decisions to improve, committees concentrated in analysis of failure modes and how they can be eliminated, aligning the results with the requirements of our internal partners and establishing steps to get success.

Some of these steps have already been implemented: data collection, use of technologies, analysis of data, development of priority tools, committees dedicated to analyze data and people dedicated to reliability analysis. This has permitted us to optimize our process, analyze where we can improve, avoid functional failures, reduce the failures range in several systems and subsystems, All this has had a positive impact in terms of results for our Observatory.

All these tools are part of the reliability culture, which allows our system to operate with a high level of reliability and availability.

7737-62, Poster Session

Data management subsystem software architecture for JWST

D. A. Swade, Space Telescope Science Institute (United States)

At the Space Telescope Science Institute, the Data Management Subsystem (DMS) is responsible for data reformatting from telemetry to FITS, pipeline calibration, and providing the data archive. A DMS has been previously developed for two astronomical telescopes in space, the Hubble Space Telescope and the Kepler Mission. DMS software analysis and design has begun for the James Webb Space Telescope (JWST), which is scheduled for launch in 2014 by the National Aeronautics and Space Administration. Although there will be a great deal of software reuse from the previous missions, differences in the operations concept for JWST will have implications for the DMS software system architecture.

A number of the design challenges for the DMS software system architecture that result from the JWST operations concept will be considered. Event-driven operations, which mean the detailed observation schedule cannot be predicted ahead of execution time, will require extensive changes to the data flow at the beginning of DMS science data processing. A scheme for priority processing of exposures must be implemented to insure rapid turn around on time critical wave front sensing data. JWST science data product design will reflect infrared detectors utilizing up-the-ramp processing. The concept of an observation in program planning will result in a new model to associate exposures and form higher level data products. In addition, the JWST DMS will introduce a new paradigm for reprocessing to meet data user demands and be compatible with the Virtual Observatory protocols.

7737-63, Poster Session

Queue observing as a student training tool

E. Artigau, R. Doyon, R. A. Lamontagne, Univ. de Montréal (Canada)

Queue planning of observation and service observing are generally seen as specific to large, world-class, astronomical observatories that draw proposal from a large community. One of the common grievance, justified or not, against queue planning and service observing is the fear of training a generation of astronomers without hands-on observing experience. At the Observatoire du Mont-Mégantic (OMM) 1.6-m telescope, we are developing a student-run service observing program. Queue planning and service observing are used as training tools to expose students to a variety of scientific project and instruments beyond what they would normally use for their own research project. The queue mode at the OMM specifically targets relatively shallow observations that can be completed in less than a few hours and are too short to justify a multi-night classical observing run.

7737-64, Poster Session

Fermi Large Area Telescope operations: from pre-launch challenges to mission success

R. A. Cameron, SLAC National Accelerator Lab. (United States)

The Fermi Gamma-ray Space Telescope was launched into orbit in June 2008, and is conducting a multi-year gamma-ray all-sky survey, using the main instrument on Fermi, the Large Area Telescope (LAT). Sub-systems of the the LAT were constructed at several institutions around the world and integrated into the full LAT at the SLAC National Accelerator Laboratory, and SLAC hosts the LAT Instrument Science Operations Center (ISOC). The ISOC supports Fermi mission operations in cooperation with other mission ground system elements, and supports the activities of the LAT Science Collaboration.

LAT configuration, control and data processing are managed at the ISOC, with routing of commanding to the LAT and the return of science and engineering data from the LAT both passing through the Fermi Mission Operations Center at NASA's Goddard Space Flight Center. The LAT has an average output data rate of about 130 Gbits/day. Several hundred computers in SLAC's computer farm are used to process raw LAT data, to reconstruct information about the gamma-ray photons and charged particle background events detected by LAT.

The post-launch on-orbit activation and commissioning of the LAT, and the transition to routine science operations, have proceeded very smoothly. The success of LAT operations owes much to pre-launch testing, which combined rigorous engineering testing as typical of a space mission with large-scale collaboration-wide data challenges typical of a ground-based particle physics experiment. We describe the pre-launch testing performed with the LAT as a example to operations readiness testing for future science missions.

7737-65, Poster Session

Shootout: the performance of dual-image cosmic-ray detection algorithms

R. R. Laher, N. Hamam, F. J. Masci, S. Monkewitz, C. J. Grillmair, S. R. Dodd, S. Mattingly, California Institute of Technology (United States); S. Krughoff, A. Connolly, Univ. of Washington (United States); D. R. Kirkby, Univ. of California, Irvine (United States); P. Kendall, Northrop Grumman Corp. (United States); S. Asato, Defense Group Inc. (United States)

This paper is relevant to optical surveys that acquire pairs of images to improve the rejection of cosmic rays, such as is planned for the Large Synoptic Survey Telescope. We test two different algorithms for cosmic-ray detection: that which is implemented in the Hubble-Space-Telescope cosmic-ray-split software vs. a new method based on artificial neural networks (ANNs). The quantitative performance of each algorithm is scored on the same set of blind-test data using completeness and reliability analysis. The paper compares and discusses the results. The input data sets, separate for ANN training and algorithm testing, consist of simulated images with cosmic-rays injected via the GEANT4 model. In the ANN method, the images are pre-filtered with a novel sigmoidal-squashing stage, which we have found to be effective for conditioning the inputs and enhancing the success of ANN training. The ANNs allow for inputs from the two same-sky-footprint images simultaneously, and are trained to have rotational invariance in the four cardinal directions of the image-pixel coordinate system. ANNs with both single and double hidden layers are tested, in order to find the best architecture.

7737-66, Poster Session

Recent developments on the SINFONI pipeline

K. Mirny, Radius ZUG (Germany); A. Modigliani, M. Neeser, European Organisation for Astronomical Research in the Southern Hemisphere (Germany); D. Nuernberger, European Southern Observatory (Chile)

The SINFONI data reduction pipeline, as part of the ESO-VLT Data Flow System, provides recipes for Paranal Science Operations, and for Data Flow Operations at Garching headquarters. At Paranal, it is used for the quick-look data evaluation.

The pipeline is available to the science community for reprocessing data with personalised reduction strategies and parameters. The recipes are implemented with the ESO Common Pipeline Library (CPL). SINFONI is the Spectrograph for INtegral Field Observations in the Near Infrared (1.1-2.45 um) at the ESO-VLT. SINFONI was developed and build by ESO and MPE in collaboration with NOVA. It consists of the SPIFFI integral field spectrograph and an adaptive optics module which allows diffraction limited and seeing limited observations. The image slicer of SPIFFI chops the SINFONI field of view on the sky in 32 slices which are re-arranged to a pseudo slit. The latter is dispersed by one of the four possible gratings (J, H, K, H+K). The detector thus sees a spatial dimension (along the pseudo-slit) and a spectral dimension.

In the present poster we describe two major improvements to the SINFONI pipeline. The first is a development to monitor instrument efficiency and stellar zeropoints using telluric standard stars. The second involves the implementation of a semi-empirical algorithm to calibrate and remove the effects of atmospheric dispersion, sometimes visible in the 3D cube reconstruction. The latter improves the positional offsets through the wavelength cube to an r.m.s. shift of better than 0.25 pixels.

7737-67, Poster Session

The GPS water vapor monitor and thermal astronomy at Gemini South

J. T. Radomski, G. Trancho, L. Fuhrman, P. Gigoux, V. Montes, F. Daruich, Gemini Observatory (Chile); M. Falvey, Univ. de Chile (Chile); M. Lazo, Gemini Observatory (Chile)

We will discuss the implementation and calibration of a new GPS based water vapor monitor installed at Cerro Pachon for the Gemini Observatory in Chile. The primary goal of this system is the use of GPS signals to monitor the Precipitable Water Vapor (PWV) in the atmosphere in near-realtime. This is vital in maximizing the efficiency of queue observations in the thermal infrared in which atmospheric transmission and sensitivity is highly dependent on PWV. The GPS WV system was calibrated using near-IR spectroscopy of known water lines based on atmosphere models and imaging the thermal mid-IR background.

Observations were conducted using the near-IR imager/spectrometer PHOENIX for K, L, and M-band spectroscopy (2.2um, 3.5um, 4.5um)

and the mid-infrared imager/spectrometer T-ReCS imaging between 8-20microns.

7737-68, Poster Session

DTS: the NOAO data transport system

M. J. Fitzpatrick, National Optical Astronomy Observatory (United States)

The Data Transport System (DTS) provides automated, reliable, high-throughput data transport between the telescopes, archives and pipeline processing systems used by NOAO centers in the Northern and Southern hemispheres. DTS uses an XML-RPC architecture to eliminate the need for persistent connections between the sites, allowing each site to provide or consume services within the DTS network only as needed.

The RPC architecture permits remote control and monitoring of the system or an individual site (e.g. to enable a new data queue, manually transfer a file, or collect logging information at a central operations point).

Client applications are language-independent, permitting web interfaces for monitoring as well as compiled tasks queue/manage data that may be more tightly coupled with the instrument acquisition system, archive or pipeline system.

The DTS service daemon is highly multi-threaded and capable of managing many different data paths and scheduling priorities, each of which can be easily configured or extended as needed. Bulk data transport is independent of the primary command-and-control methods; a variety of transfer protocols are supported to take best advantage of the bandwidth or properties of the data being moved (e.g. single large image versus many small files).

The default transport method uses parallel TCP/IP sockets to "stripe" the data to a remote machine, providing a significant improvement in throughput over slow or busy networks. Additional transport protocols will be added in the future. Arbitrary execution of ingest and delivery applications further separate transport from its boundary uses.

7737-69, Poster Session

The Gemini recipe system: a dynamic workflow for automated data reduction

K. Labrie, C. Allen, P. Hirst, Gemini Observatory (United States); J. Holt, Univ. of California, Santa Cruz (United States); R. Allen, D. K. Dement, Gemini Observatory (United States)

Gemini's next generation data reduction software suite aims to offer greater automation of the data processing without compromising flexibility that some science programs require. The ultimate goal is to simplify the path to high quality ready-for-science products.

Central to the new data reduction software suite is the Recipe System. The system, developed in Python, aims at near-real time processing for data quality assessment and science quality processing, both on-line and off-line. The Recipe System can be run as a standalone application or as part of a pipeline system where it forms the data processing unit. The data reduction steps, called "primitives", are defined in "recipes" in a scientifically meaningful language rather than a programming language. For users requiring more hands on optimization, the data processing routines wrapped by the "primitives" can also be launched individually from the PyRAF user interface.

Most importantly, the Recipe System offers dynamic flow control. It allows for decisions regarding processing and calibration of the data to be made automatically, in real-time, based on the pixel data and the meta-data properties of the data at the stage in processing where the decision is being made, and the context in which the processing is being carried out.

Processing history and provenance recording is provided natively by the AstroData middleware. AstroData also offers header abstraction and data type recognition to facilitate the development of instrument-agnostic processing routines.

7737-70, Poster Session

The Spitzer bibliography database: bibliographic statistics

E. Scire, B. H. Chan, N. Silbermann, California Institute of Technology (United States); A. Shields, Univ. of Washington (United States)

The Spitzer Science Center maintains a database of peer refereed publications utilizing observations made by the Spitzer Space Telescope. Originally intended as a way to easily track these publications with limited resources, the database has grown in scope to provide more than just a bibcode reference for investigators. The design and population of the system and some interesting insights into the use of Spitzer data are presented.

7737-71, Poster Session

Spitzer warm mission transition and operations

W. A. Mahoney, L. J. Garcia, California Institute of Technology (United States); J. C. Hunt, Jr., Jet Propulsion Lab. (United States); D. B. McElroy, V. G. Mannings, California Institute of Technology (United States); D. S. Mittman, Jet Propulsion Lab. (United States); J. C. O'Linger, California Institute of Technology (United States); M. A. Sarrel, Jet Propulsion Lab. (United States); E. Scire, California Institute of Technology (United States)

Following the successful dynamic planning and implementation of IRAC Warm Instrument Characterization activities, transition to Spitzer Warm Mission operations has gone smoothly. Operation team procedures and processes required minimal adaptation and the overall composition of the Mission Operations System retained the same functionality it had during the Cryogenic Mission. While the warm mission scheduling has been simplified because all observations are now being made with a single instrument, several other differences have increased the complexity. The bulk of the observations executed to date have been from ten large Exploration Science programs that typically have more complex constraints, more observing requests, and more exo-planet observations with durations of up to 145 hours. Communication with the observatory is also becoming more challenging as the Spitzer DSN allocations have been reduced from two tracking passes per day to a single pass impacting both uplink and downlink activities. While IRAC is now operating with only two channels, the data collection rate is roughly 60% of the four-channel rate leaving a somewhat higher average volume collected between the less frequent passes. Also, the maximum downlink data rate is decreasing as the distance to Spitzer increases requiring longer passes. Nevertheless, at well over 90%, efficiency has equaled or exceeded that achieved during the cryogenic mission.

7737-72, Poster Session

Post-cryogenic reanalysis of the absolute calibration of the infrared array camera on the Spitzer Space Telescope

D. M. Cole, Spitzer Science Ctr. (United States); S. J. Carey, J. A. Surace, W. J. Glaccum, J. Ingalls, J. Krick, California Institute of Technology (United States); M. D. Lacy, National Radio Astronomy Observatory (United States); P. J. Lowrance, S. J. Laine, J. C. O'Linger, California Institute of Technology (United States); J. L. Hora, Harvard-Smithsonian Ctr. for Astrophysics (United States); W. F. Hoffmann, The Univ. of Arizona (United States); G. G. Fazio, Harvard-Smithsonian Ctr. for Astrophysics (United States)

We are conducting a reanalysis of the primary photometric calibration of the Infrared Array Camera (IRAC) during the cryogenic phase of the Spitzer Space Telescope mission, in order to improve on the absolute calibration reported in Reach et al. (2005, PASP, 117, 978). Making use of the complete 5-year long data set will enable us to update the array-location dependent photometric correction, as well as map out for the first time the 2-dimensional intra-pixel response variation. We are also applying the KIII spectral templates from Engelke et al. (2006, AJ, 132, 1445) to add K giants back into our calibrator database. Our expectation is that the absolute value of the calibration factor will change by less than 1%, but that the uncertainty in it will decrease from 3% to 1-2%. This should make possible the use of Spitzer archival data for addressing a new set of scientific questions, i.e. searching through the database for exoplanet transits.

Support for this research was provided by NASA.

7737-73, Poster Session

Toward a 'green' observatory

U. Weilenmann, C. Ramirez, P. Vanderheyden, European Southern Observatory (Chile)

Many of the modern Observatories are located at remote sites, far from larger cities and away from infrastructure like power grids, water supplies and roads. On-site power generation in island mode is often the only choice to provide electricity to an observatory.

During the 2008 petrol price rally, conventional power generation has received special attention and alternatives are being studied now in many organisations to keep energy prices at bay.

This paper shall outline the power generation at the ESO VLT/VLTI Observatory at Paranal as it is now and a plan for a possible way out of the dependency on fossil fuels in the near future.

A discussion of several alternatives including wind energy, solar energy and heat recovery from a conventional power plant shall be analysed and compared.

Finally, a project is being proposed to equip the VLT/VLTI with a modern alternative energy supply, based on a novel concept: Solar cooling.

7737-74, Poster Session

First year of ALMA site software deployment: where everything comes together

V. Gonzalez, M. Mora, R. Araya, D. Arredondo, M. Bartsch, P. Burgos, Atacama Large Millimeter Array (Chile); J. Ibsen, European Southern Observatory (Chile); J. Reveco, N. Saez, A. Schemrl, J. Sepulveda, T. Shen, R. Soto, N. Troncoso, M. Zambrano, Atacama Large Millimeter Array (Chile); B. Glendenning, National Radio Astronomy Observatory (United States); G. Raffi, European Organisation for Astronomical Research in the Southern Hemisphere (Germany); J. S. Kern, National Radio Astronomy Observatory (United States)

Starting 2009, the ALMA project initiated one of its most exciting phases within construction: the first antenna from one of the vendors was delivered to the Assembly, Integration and Verification team. With this milestone and the closure of the ALMA Test Facility in New Mexico, the JAO Computing Group in Chile found itself in the front line of the project's software deployment and integration effort. Along the group's main responsibilities are the deployment, configuration and support of the observation systems, besides infrastructure administration, all of which needs to be done in close coordination with the development groups in Europe, North America and Japan. Software support has been the primary interaction key with the current users (mainly scientists, operators and electronics engineers), as the software is normally the most visible part of the system.

During this first year of work with the production hardware, three consecutive software releases have been deployed and commissioned. Also, the first three antennas have been moved to the Array Operations Site, at 5.000 meters elevation, and the complete end-to-end system has been successfully tested. This paper shares the experience of this 15-people group as part of the construction team at the ALMA site, and working together with Computing IPT, on the achievements and problems overcome during this period. It explores the excellent results of teamwork, but also the infinite troubles which such a complex and geographically distributed project can run into. Finally, it approaches the challenges to come, with the transition to the ALMA operations plan.

7737-75, Poster Session

Software operations support at Gemini Observatory

A. W. Ebbers, Gemini Observatory (United States); C. Urrutia, Gemini Observatory (Chile); T. Cumming, Gemini Observatory (United States); P. Gigoux, Gemini Observatory (Chile)

Operating a modern telescope requires many software systems working together to maintain/monitor the optical-mechanical positions, sequence and control individual instruments and wave-front sensors and control the data transfer and quality monitoring. Supporting these complex interconnected systems can be a daunting task, especially when any single failure can cause a cascade effect which tends to hide the original problem.

At Gemini, we have several indispensable tools which allow us to track the behavior and performance of all running systems and enable us to accurately investigate and isolate any problems which occur at night. These tools include: The Gemini Engineering Archive (GEA), VME console logs, operational software logging, circular buffers and high level tools like the observation logs. We'll go into some detail about each of these tools and how they enable us to accurately investigate problems and performance issues.

Finally, the most important ingredient for successful operations support is the dedicated people from electronics, systems, mechanical, optical and software specializations who work together, sharing their varied expertise, utilizing the tools and data collected in order to solve issues as they occur.

7737-77, Poster Session

Process-oriented modeling method for sensors resources management under sensor web

J. Chen, N. Chen, Wuhan Univ. (China)

Various types of sensors lead to complex and diverse data sources. Current methods cannot support a unified sensor modeling and resource managing approach for diverse sensors. Although there are many sensor modeling standards now, the existing standards are based on the sensor modeling at physical level, and do not form user-oriented applications directly, furthermore, there is no better sensor modeling tool. Sensor Model Language (Sensor ML) is a process oriented modeling standard. This paper studies the structure of Sensor ML, and establishes the process oriented modeling flow on the basis of this study, then designs the sensor modeling tool. According to a large number of instances based on Sensor ML, it picks up key information of sensors and uses Lucene.NET to establish index Library. Meanwhile, it manages sensor resources, clips of sensor examples, and interacts with the modeling tools to provide editing function with sensor resources. For the dynamic information, in another word, sensor processing results, it uses a dynamic way to call process with the purpose of handling real-time access to sensor processing output data, this paper just shows an example on sensor spatial and temporal location queries based on dynamic call resource management. By sensor modeling and sensor resource management, it proved that process oriented recursive-based modeling method for sensors had good flexibility and reusability.

7737-78, Poster Session

The ESO Extremely Large Telescope dome: system engineering strategies for elecrical power management

G. Marchiori, L. Giacomel, European Industrial Engineering s.r.l. (Italy)

The isolated location and the electrical power demanded by EELT Dome operations put several engineering challenges from a system point of view: the power generation and distribution (Medium and Low Voltage-MV and LV), the required Electromagnetic Compatibility (EMC) between different users connected to the same network, the management of the dome mass accelerations associated to other electrical power peaks. Moreover, initial costs and life-cycle costs shall also be considered for the electrical network configuration and for the final trade-offs. The systemic approach is presented with the strategies proposed for generation, distribution and users connection, in order to optimise the configuration and assure the required Dome performances.

7737-79, Poster Session

A portable observatory for persistent monitoring of the night sky

J. A. Wren, W. T. Vestrand, P. Wozniak, H. R. Davis, Los Alamos National Lab. (United States)

We describe the design and operation of a small, transportable, robotic observatory that has been developed at Los Alamos National Laboratory. This small observatory, called RQD2 (Raptor-Q Design 2), is the prototype for nodes in a global network capable of continuous persistent monitoring of the night sky. The observatory employs five wide-field imagers that altogether view about 90% of the sky above 12 degrees elevation with a sensitivity of R=10 magnitude in 10 seconds. Operating robotically, the RQD2 system acquires a nearly full-sky image every 20 seconds, taking more than 10,000 individual images per night. It also runs real-time astrometric and photometric pipelines that provide both a capability to autonomously search for bright astronomical transients and monitor the variability of optical extinction across the full sky. The first RQD2 observatory is currently operating at the Fenton Hill site located near Los Alamos, NM. We present a detailed description of the RQD2 system and the data taken during the first several months of operation.

7737-80, Poster Session

SMARTS revealed

J. P. Subasavage, Jr., Cerro Tololo Inter-American Observatory (Chile); C. D. Bailyn, Yale Univ. (United States); R. C. Smith, Cerro Tololo Inter-American Observatory (Chile); T. J. Henry, Georgia State Univ. (United States); F. M. Walter, Stony Brook Univ. (United States); M. M. Buxton, Yale Univ. (United States)

The Small and Moderate Aperture Research Telescope System (SMARTS) is comprised of four telescopes atop Cerro Tololo Inter-American Observatory: the 0.9m, 1.0m, 1.3m, and 1.5m. A consortium of twelve institutions and universities began funding operations in February 2003. Time allocation for these facilities is as follows: 65% to consortium members, 25% to the general community via NOAO, and 10% to Chilean researchers. Thus, resources remain available to the community while providing a unique opportunity for consortium members; the possibility of high temporal cadence monitoring coupled with long time baseline monitoring. Indeed, a number of member programs have benefited from such a schema.

Furthermore, two of the four telescopes are scheduled in a queue mode in which observations are collected by service observers. Queue mode investigators have access to spectroscopic observations (both RC and echelle) as well as direct imaging (both optical and near-IR simultaneously). Of the remaining two telescopes, the 1.0m is almost exclusively operated in user mode and contains a 20 arcmin FOV optical imager, and the 0.9m is operated both in user and service mode in equal allotments and also has a dedicated optical imager. The latter facilities are frequently used for hands-on student training under the superb sky conditions afforded at CTIO.

Currently, three of the partner universities are responsible for managing telescope scheduling and data handling, while one additional university is responsible for some of the instruments. In return, these universities receive additional telescope time. Operations are largely run by a handful of people, with six personnel from the four support universities and six dedicated personnel in Chile (five observers and one postdoctoral appointee). Thus far, this model has proven to be both an efficient and an effective method for operating the small telescopes at CTIO.

7737-81, Poster Session

From Chile to Europe in minutes: handling the data stream from ESO's Paranal Observatory

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The ESO telescopes in Chile are operated in a geographically distributed scheme, in which some of the essential steps in the observing chain take place in Europe. This scheme strongly depends on the speed with which the data stream produced by the telescopes can be sent to Europe. The main challenge to achieve a fast intercontinental data transfer is the data volume itself, which currently reaches an average 25 GB/night (compressed) for the four VLT Unit Telescopes. Since late 2008, this stream is transferred through the internet via a 4.56 Mbit/s bandwidth assured via a Quality of Service policy, which suffices to transfer an average night of data within a few hours. Ultimately, the average data volume produced on Paranal once the survey telescopes and all second-generation VLT instruments become available will exceed 200 GB/night. Transferring it over the internet will require a new fiber-based infrastructure currently under construction, as well as the use of additional high bandwidth channels. This infrastructure, provided by the European Union co-funded project EVALSO, will provide a data transfer capacity exceeding 1 Gbit/s that will allow the transfer to Europe of the entire Paranal data stream, as well as that of the nearby Observatory of Cerro Armazones, in minutes at most since the data were taken.

7737-82, Poster Session

PySALT: the SALT science pipeline

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PySALT is the python/pyraf-based data reduction and analysis pipeline for the Southern African Large Telescope (SALT), a modern 10m class telescope with a large user community consisting of 13 partner institutions. The two first generation instruments on SALT are SALTICAM, a wide-field imager, and the Robert Stobie Spectrograph (RSS). These instruments provide a wide range of observing modes, including Fabry-Perot imaging, polarimetric observations, and high-speed observations. Due to the large user community, resources available, and unique observational modes of SALT, the development of reduction and analysis software is key to maximizing the scientific return of the telescope. PySALT is developed in the Python/PyRAF environment and takes advantage of a large library of open-source astronomical software. The goals in the development of PySALT are: (1) Provide science quality reductions for the major operational modes of SALT, (2) Create analysis tools for the unique modes of SALT, and (3) Create a framework for the archiving and distribution of SALT data. The data reduction software currently provides support for the reduction and analysis of regular imaging, high-speed imaging, and long slit spectroscopy with planned support for multi-object spectroscopy, high-speed spectroscopy, Fabry-Perot imaging, and polarimetric data sets. We will describe the development and current status of PySALT and highlight its benefits through early scientific results from SALT.

7737-83, Poster Session

Autonomous observations in extreme environments: the AMICA case

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The AMICA project takes up the great challenge of the development of a high reliable instrumentation to characterize and exploit the excellent atmospheric properties of Dome C for infrared observations. For this reason a fully autonomous observatory is being installed. It will be constituted by the IRAIT telescope and the scientific equipment of AMICA. IRAIT is a 0.8 m, F/22 Cassegrain with two Nasmyth foci. AMICA is a dual channel camera operating in the near- and mid-infrared bands (1-27µm) and the integration with the telescope has recently started. The robotisation of the whole system is a necessary condition due to the extreme climate conditions, as a result of which human activities are reduced and essentially stopped during the winter. Moreover, the instrumentation needs fail-safe solutions to deal with such peculiar environment and to avoid its damaging. The AMICA Control Software (ACSW) is an agent-based cooperative system, modeled under the principles of the OO Programming (C++, Java). Its architecture descends directly from the underlying modular hardware, resulting in a multiprocess system that allows to execute scheduled observations under the supervision of a high confidence thermal control. The management of all subsystems activity is organized in a multilevel application domain, that provides decisional and real-time control redundancy. Finally, the system will be endowed with a remote monitoring package showing detailed information on the past and on-going activities, thus providing statistics that will be used to detect anomalies from the expected behavior and to prevent malfunctions.

7737-84, Poster Session

PACS scan mapping mode optimization with the Herschel Space Observatory

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The ESA Herschel Space Observatory was launched successfully on May 14th 2009.

In the Herschel Key Programs, observations in scan mapping using the PACS bolometer detector represent more than 60% of the allocated time, to map the far-IR Universe in the wavelength range 60-200 microns.

Great attention has been put in optimizing this observing mode in early science operations.

The following aspects are discussed that let to changes/optimization of the uplink system and data processing system :

- The observation overheads optimization

- Definition of a new 'mini scan map' mode as a successful alternative to the chop/nod point-source mode.

- The on-board compression was adjusted to maximize sensitivity - The observing mode was tuned to achieve homogeneous coverage for various scan configurations.

- The relative timing of the instrument frames with ACMS attitude data was calibrated to the best accuracy.

- Several methods are being developed to improve the pointing accuracy.

7737-85, Poster Session

The X-Shooter pipeline

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The X-Shooter data reduction pipeline, as part of the ESO-VLT Data Flow System, provides recipes for Paranal Science Operations, and for Data Product and Quality Control Operations at Garching headquarters. At Paranal, it is used for the quick-look data evaluation.

The pipeline recipes can be executed either with EsoRex at the command line level or through the Gasgano graphical user interface. The recipes are implemented with the ESO Common Pipeline Library (CPL).

X-Shooter is the first of the second generation of VLT instruments.

It allows to collect in one shot the full spectrum of the target from 300 to 2500 nm, subdivided in three arms optimized for UVB, VIS and NIR ranges, with an efficiency between 15% and 35% including the telescope and the atmosphere, and a spectral resolution varying between 3000 and 17,000. It allows observations in stare, offset, using the slit or an IFU, and observing sequences nodding the target along the slit.

Data reduction can be performed either with a classical approach, by determining the spectral format via 2D-polynomial transformations, or with the help of a dedicated instrument physical model to gain insight on the instrument and allowing a constrained more robust solution that depends on a few parameters with a physical meaning.

In the present talk we describe the steps of data reduction necessary to fully reduce science observations in the different modes with examples on typical data calibrations and observations sequences.

7737-86, Poster Session

The new FORS pipeline

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Over the last decade of successful science operations with the VLT at Paranal, the instrument pipelines have played a critical role in ensuring the quality control of the instruments. During the last few years, instrument pipelines have gradually evolved into a tool suite capable of providing science grade data products for all modes available for each instrument. In this paper we present the major enhancements that have been recently brought into the body of the FORS pipeline. The algorithms applied for wavelength and photometric calibrations have been deeply revised and improved by implementing innovative ideas, and the FORS instrument is now almost fully supported in all of its modes: spectroscopy, imaging and spectro-polarimetry. Furthermore, the satisfactory results obtained with the FORS pipeline have prompted synergies with other instrument pipelines. EFOSC at the NTT of the La Silla Observatory already shares with the FORS pipeline the imaging and spectroscopic data reduction code, and the spectroscopic part of the VIMOS pipeline is being reengineered along the same lines.

7737-87, Poster Session

Spectroradiometric calibration of telescopes using laser illumination of flat field screens

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It is standard practice at many telescopes to take a series of flat field images prior to an observation run. Typically the flat field consists of a screen mounted inside the telescope dome that is uniformly illuminated with a broadband light source. These flat field images are useful for characterizing the relative response CCD pixels to light passing through the telescope optics and filters, but carry limited spectral information and are not calibrated for absolute flux.

We present the results of performing in situ, spectroradiometric calibrations of the 1.2 meter telescope at the Fred Lawrence Whipple Observatory, Mt. Hopkins, AZ. To perform a spectroradiometric calibration, a laser, tunable through the visible to near infrared, was coupled into an optical fiber and used to illuminate the flat field screen in situ at the telescope facility. A NIST traceable, calibrated photodiode was mounted on the telescope to measure the spectral flux reaching the aperture. For a particular filter, images of the screen were then captured for each laser wavelength as the wavelength was tuned over the filter bandpass. Knowledge of the incident flux then allows the relative responsivity of each CCD pixel at each wavelength to be calculated.

7737-88, Poster Session

Changes and improvements to the Gemini North aircraft avoidance program at the Gemini North laser guide star facility on Mauna Kea

J. P. Archambeau, R. Oram, M. Sheehan, Gemini Observatory (United States)

Since March 2005 Gemini North Observatory routinely propagates a 12W solid state sodium laser into the night sky as part of Adaptive Optics imaging on dimmer portions of the celestial sphere. Gemini along with Keck and Subaru telescopes have created aircraft spotting programs to meet The FAA's rules for aircraft avoidance for outdoor laser propagation.

This paper reviews the GN laser safety protocol for the outdoor use of lasers and assessment of the risks considered as part of outdoor laser propagation. We will show the results of Gemini's Aircraft Spotter program, and its continuous development over the past 5 years.

As part of a continuous improvement activity Gemini in conjunction with the other laser equipped MK Observatories, Keck and Subaru, is currently testing the use of an all sky camera (ASCAM) to monitor the night sky and shutter the laser for air traffic over the Mauna Kea summit, HI. Use of the ASCAM is expected to increase the efficiency and accuracy of the aircraft spotting program. Gemini not only complies with, but strives to exceed the strict FAA rules for aircraft avoidance for outdoor laser propagation. The creation and implementation of the ASCAM is reviewed in this paper.

7737-89, Poster Session

Washing very large mirrors, in-situ: extending the life of astronomical coatings

J. T. Williams, R. Ortiz, MMT Observatory (United States)

Periodic water, soap, cotton swab dabbing of standard aluminum coatings on glass mirrors has dramatically reduced optical scattering, and maintain high reflectance on the 6.5m primary mirror at the converted MMT Telescope, without detectable scratching of the bare aluminum surface. Manual in-situ dabbing on the unprotected aluminum surface with a generous wet foam of mild soapy suds imparts the modest mechanical action of crushing soap foam, sufficient to loosen most attached debris and hydrated dust residue, not otherwise removed by CO2 snow sweeping.

This wet soapy wash, followed by extensive rinsing with de-mineralized water, applied to the zenith pointing mirror at 9 month intervals(average) has extended the life of high quality coatings to 4 years with minimum degradation to telescope imaging and throughput. More frequent washing, especially following dust storms and local contamination incidents, would further reduce the surface "graying" and loss of specular reflectance.

Based on MMTO results, high quality well adhered bare aluminum coatings on primary mirrors (91% reflectance and <0.5% scattering, measured 400nm - 700nm) can be maintained (>89% reflectance and <1.5% scattering)for up to 4 years periods. Regular CO2 cleaning, especially before accumulated dust is hydrated, together with timely wet soapy foam washes, yield considerably better results than CO2 cleaning only.

7737-90, Poster Session

High-precision near-infrared differential photometry using WirCam on the Canada-France-Hawaii Telescope

D. Devost, D. Teeple, L. Albert, T. A. Vermeulen, Canada-France-Hawaii Telescope (United States)

A new mode of observations has been implemented in Queue Scheduled Observing at the Canada-France-Hawaii Telescope. This new mode, called staring mode, offers continuous, guided, observing sequences of up to 6 hours. It use the full mosaic of WIRCam H2RG detectors for science and has the ability to defocus by up to 2mm while guiding and taking short exposures (>3sec). The target is positioned to a 1-pixel accuracy in a repeatable fashion. The high accuracy is obtained by 1) spreading flux on more pixels thus limiting each pixel's flat field error 2)centering the PSF on the same pixel without dithering to prevent introducing systematic errors and 3) by tracking the defocus so it stays constant and no PSF change occurs.

This new mode of observations offers accuracy on the order of 0.1%. This allows detection and characterization of exoplanets and detection of Brown Dwarf variability. Early results showing a 7 sigma detection at 0.1% will be presented.

7737-91, Poster Session

Effect seasonal of optical seeing above Oukaimeden Observatory in the Morocco High Atlas mountains: dependence of results on the exposure time

Y. Hach, M. Sabil II, A. Abahamid, Z. Z. Benkhaldoun, A. Jabiri, Y. Elazhari, Univ. Cadi Ayyad (Morocco)

In this paper, we presents a study of daily, monthly and seasonal variations of seeing value above the site Oukaimeden. The used data are made by the differential method (DIMM) during the period spanning between July 2003 and March 2006. Throughout the measurements period, the average and median values of seeing are respectively 0”.85 and 0”.92. The best seasonal and monthly values are observed for the summer season and September month 2003. As other sites, we have conducted, during the period between March 2005 and March 2006, a series of experiments by implementing the interlaced-exposure technique. We give a comparison of the two data set (10 and 20 ms) and presents the estimated seeing at null exposure time.

7737-92, Poster Session

Characterization of the mid-IR image quality at Gemini South

D. Li, C. M. Telesco, F. Varosi, Univ. of Florida (United States)

To help the prospective observer take the full advantage of the mid-IR capability of Gemini, we carried out a project to characterize a key aspect of the mid-IR performance of the 8-meter telescope at Gemini-S, namely, the appearance and stability of its delivered mid-IR image profiles. Our goal was to assess the potential for using these profiles to extract astronomical information with angular distributions on scales close to the diffraction limit. About 2000 images obtained with T-ReCS (the facility mid-IR camera at Gemini-S) between late 2003 and early 2009 were available for our image-quality analysis. All targets were flux standards imaged through one or more of the following four bands: Si-2 (8.74 μm), N (10.36 μm), Si-5 (11.66 μm), and Qa (18.3 μm). A non-linear least squares fitting of three PSF models (Lorentzian, Gaussian, and Moffat) was performed on each image, and the key parameters FWHM, ellipticity, position angle (PA) and Strehl ratio were measured from the fitted PSF. Properties of the low-intensity PSF wings were also characterized. We found that the long time-scale image quality was quite stable in terms of FWHM or ellipticity, though short time-scale variations are obvious. We also examined the correlation between the image quality and several ambient parameters, and we confirmed the interdependence between the image quality in the Qa band and the ambient humidity. We comment on several other aspects of the project, including characterization of the PSF ellipticity in each filter and the average profiles, which may prove useful as references in the future when the high-quality PSF reference is not available during the observation. This research was supported by NSF grant AST-0738883 to CMT.

7737-93, Poster Session

Mopra remote observing: a story of innovation and success

B. T. Indermuehle, P. G. Edwards, Commonwealth Scientific and Industrial Research Organisation (Australia)

The Mopra Radio Telescope is a 22m single-dish radio telescope located near Siding Spring Observatory in New South Wales, Australia. Its receiver systems cover the 3mm, 7mm and 12mm bands for normal observing, as well as the 6/3cm and 20/13cm bands used for VLBI. The remote location of the telescope, a good day’s drive from Sydney, made it a good candidate to implement remote observing capabilities which would no longer require observers to travel to the telescope, but bring the telescope to them. In a first step this was implemented in a controlled environment three years ago. It enabled remote observing from a dedicated workstation at the Australia Telescope Compact Array (ATCA) control building some 160km away from the observatory. In a second step two years ago, remote observing was extended to allow observing from any location in the world for qualifying observers. There were a number of challenges that needed addressed, from telescope safety to internet and data link reliability, computer security, and providing the observers with adequate situation awareness tools. The uptake by observers has been very good with over 40% of the observing in 2009 having been executed remotely. Further, many small and unallocated time slices were able to be productively used as they would not have warranted a trip to the observatory in their own merit but were usable thanks to remote observing. This helped push the productivity of the Mopra telescope in 2009 to the highest figure in its 17 year history.

7737-22, Session 4

The VLT rapid-response mode: implementation and scientific results

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The Rapid-Response Mode (RRM) at ESO’s Very Large Telescope allows for rapid automatic observations of any highly variable target such as Gamma-Ray Burst (GRB) afterglows. The mode has been available for various instruments at the VLT since a few years, and can be easily implemented for any new instrumentation. The RRM can be activated by a user with an approved program, by ftp-ing the coordinates of the target and the name of a pre-defined observation template. Software at the telescope picks up these coordinates, and after running several checks (e.g. observability, target-moon distance), it ends the on-going observation and starts executing the RRM-requested one. The delay time between user activation and start of the observations is of the order of 5-10 minutes.

The RRM has been most successfully applied for Ultraviolet and Visual Echelle Spectrograph (UVES) observations of GRB afterglows, where in several cases the delay time between the start of the burst and the start of the observations was less than 10 minutes. Due to the power law decay nature of the brightness of GRB afterglows, it is crucial to start observing these targets as early as possible. Apart from discussing the RRM in more detail, we will also present some examples of UVES afteglow spectra where clear variation of absorption lines is observed, made possible thanks to the RRM. Using photo-excitation modelling, we show that this variation is due to the afterglow flux exciting a gas cloud at a distance of about a kiloparsec away from the GRB.

7737-23, Session 4

Managing target of opportunity (ToO) observations in queue mode at Gemini Observatory

K. C. Roth, Gemini Observatory (United States); R. Carrasco, B. Miller, Gemini Observatory (Chile); A. Stephens, I. Jorgensen, Gemini Observatory (United States); B. Rodgers, Gemini Observatory (Chile)

Target of Opportunity (ToO) observations come in several flavors, and generally involve objects or events of particular scientific interest whose position or timing are not known in advance. Rapid ToOs are the most traditional type, and they are typically transient objects discovered by dedicated survey telescopes which must be observed with short notice before the brightness of the targets fades and the object is no longer observable. Standard ToOs (aka slow ToOs) are known objects which undergo irregular episodic events (eg. flares, storms or pulsations) or targets from a certain class of object (eg. high redshift galaxies, brown dwarfs, extra solar planets) which are statistically expected to be discovered during the course of on-going surveys at other telescopes.

The Gemini Observatory has traditionally supported ToO observations of all types with the fraction of queue observations dedicated to ToOs currently around 15-20% (>25% in the highest ranking band). With the advent of new, large telescopes dedicated to all-sky surveys (eg. Pan-STARRS, LSST) that fraction is expected to increase significantly in the coming years. Gemini Observatory is particularly well suited to support ToOs with its flexible queue dominated operations mode and quick switching between three active instruments mounted at the Cassegrain focus, and ideally Gemini will continue to support both rapid and standard ToO operations with no limit on the fraction of observing time dedicated to ToOs. But there are many factors to consider when faced with the prospect that the majority of the science programs awarded time in a given semester have no targets with associated coordinates and/or preferred observing date. Further complicating matters, different ToO programs possibly target overlapping classes of science targets.

We discuss possible solutions to several of these issues, including duplication checking (within and between the two Gemini telescopes), target prioritization (within and across scientific ranking bands) and scheduling (including automated on-the-fly queue schedule generation).

7737-24, Session 4

LCOGT sites and site operations plan

J. Martinez, T. M. Brown, P. Conway, M. Elphick, M. Falarski, E. Hawkins, W. Rosing, J. Shobbrook, Las Cumbres Observatory Global Telescope Network (United States)

LCOGT is currently building and deploying a world-wide network of at least twelve 1-meter and twenty-four 0.4-meter telescopes to 3 sites in the Southern hemisphere (Chile, S. Africa, Australia) and 3 in the Northern hemisphere (Hawaii, Western North America, Canary Islands, Asia TBD), to enable extended, redundant and optimally continuous coverage of mainly variable or transient sources. Each site will support two or three 1m telescopes and four or more 0.4m telescopes. Both 1m and 0.4m telescope classes are equatorial, C-ring mounts with rapid slew and settle times and good tracking and guiding. The 1m telescopes will be housed in 18.5-foot Ash domes atop custom built modularized wall systems, and the 0.4m telescopes in LCOGT designed “Aqawan” clamshells and the existing Faulkes Clamshell enclosures. Central services for each site will be housed in a Site Services Building that is housed in a modified shipping container. This unit will contain computing and communication resources, chilled glycol, power conditioning, and a fiber-fed spectrograph, all of which will be shared among the site’s telescopes.

Our deployment and operations model emphasizes modularity and interchangeability of major components, maintenance and troubleshooting personnel who are local to the site, and autonomy of operation. We plan to ship, install, and spare large units (in many cases entire telescopes), with minimal assembly on site. We also expect to perform much preliminary data reduction on site, so that bandwidth demands between sites and headquarters in Santa Barbara can be kept as small as possible.

7737-25, Session 4

Scheduling observations on the LCOGT network

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LCOGT is building and deploying a world-wide network of telescopes to enable extended, redundant and optimally continuous coverage of mainly variable or transient sources. We desire that all of the telescopes in this network be scheduled so as to maximize its efficiency with respect to a declared and coherent set of science goals. In addition, various considerations demand that the scheduling process following from TAC decisions should be automated and transparent in operation.

To achieve these goals, we are developing a unified software structure to carry observing programs from the initial proposal stage through time allocation, scheduling, telescope control, data acquisition, quality assurance, and feedback to the schedule. Key elements in this structure are a central database of observation requests, requirements, and status, a protocol to describe observations and the constraints they must meet, and a set of planners that work at successively finer levels of detail. Although ultimate control is to be centralized, almost all of the small-level decision-making is delegated to site-level processes that are able to respond in real time to local conditions. We expect the modules within this structure to evolve dramatically as we gain experience with the system’s actual performance.

7737-26, Session 4

The Gamma-ray Coordinates Network (GCN): real-time events to the world

S. D. Barthelmy, NASA Goddard Space Flight Ctr. (United States)

The Gamma-ray Coordinates Network (GCN) has been collecting and distributing in real-time the coordinates of Gamma-Ray Bursts (GRB) and other transients since 1993. The methods of collecting and distributing the information will be reviewed. Depending on the distribution method, the time delays range from 0.1 sec to about 1 minute. Many of the space-based missions that contribute these transients have their information available to GCN within 5 to 20 sec.

This provides a convenient one-stop source of transient coordinates so they can make follow-up observations. The new VOEvent capabilities will be described.

7737-27, Session 4

VOEvent as a framework for autonomous observatory operations

R. D. Williams, California Institute of Technology (United States); R. L. Seaman, National Optical Astronomy Observatory (United States)

The study of things that go bump in the night is a growth industry. Ground-based and space observatories at all wavelengths and apertures, and with diverse operating paradigms will encounter more and more time domain related observing proposals in future years. The efficient handling of time domain observing programs - from synoptic investigations to target-of-opportunity observing modes - will require a standard celestial transient event format and transport protocol. VOEvent is such a standard from the International Virtual Observatory Alliance. We discuss the ins-and-outs of the who, what, where, when, why and how of publishing such alerts from the grand time domain surveys of the next decade, as well as new technologies that permit quick, flexible and ubiquitous subscription to such event streams.

7737-28, Session 5

The Catalina real-time transient survey

A. J. Drake, G. Djorgovski, A. A. Mahabal, R. D. Williams, M. J. Graham, C. Donalek, California Institute of Technology (United States); E. Beshore, The Univ. of Arizona (United States)

The Catalina Real-time Transient Survey (CRTS) is an open collaborative project which utilizes data from three dedicated telescopes administered by the Catalina Sky Survey (CSS). This survey covers the sky at declinations between -80 and 70 with 10 degree avoidance of the Galactic plane. Observations cover 2000 square degrees per night on the sky for the 21 darkest nights per lunation and typically reaching objects with magnitudes as faint as 21.5 (depending on telescope).

Survey observations have been taken in sequences of four images separated by 10 minutes over past five years, thus CRTS sensitive to transient phenomena and variability with timescales from minutes to years.

More than 1200 optical transients have been discovered by the CRTS project during the first two years of operation.

These transients include more than 500 newly discovered supernovae and dwarf novae. Among the initial discoveries are many extremely energetic and luminous supernova residing in faint host galaxies. Other populations of optical transients discovered include Blazars, AGN and flare stars.

All CRTS discoveries are processed and distributed openly within minutes of observation using SkyAlert and VOEvent technologies as well as html tables, RSS and Twitter feeds. Further transient classification is performed using follow up imaging and spectroscopy with Palomar, Keck, Gemini and SMARTs telescopes in combination with VO-enabled archival analysis of the CSS and Palomar Quest synoptic datasets along with DSS, 2MASS, SDSS, GALEX and UKIDSS data. Additional rapid classification efforts are also being undertaken to utilize collaborative Citizen science based on human computing via the AstroCollation and SkyAlert projects.

7737-30, Session 5

AstroCollation: building knowledge communities in transient astronomy

M. J. Graham, G. Djorgovski, A. J. Drake, C. Donalek, A. A. Mahabal, R. D. Williams, California Institute of Technology (United States)

First-generation citizen science projects (such as Galaxy Zoo) have proven very successful at utilizing the efforts of volunteers (human computation) to attack specific problem areas, such as certain types of image analysis, where machines are not currently especially effective. However, there has been little or no attempt in these to capture or transfer the domain knowledge from carbon-based to silicon-based systems.

AstroCollation is a next generation collaborative science venture that aims to foster a more synergistic relationship between humans and machines around transient astronomy. Data mining algorithms will be applied to transient event data to produce conceptual models describing them. These models will then be presented to citizen scientists for value judgments, deciding which of a set of models provides the best description, as well as providing contextual information to aid the classification process. Finally decisions and information are factored back into the system and consolidated to produce a consensus description of an event.

The project is predicated upon semantic technologies - allowing the formal representation of conceptual relations within a particular domain - and will leverage data and infrastructure from the Catalina Real-time Transient Survey and SkyAlert system. It will address such issues as the formal treatment of uncertainty in data, how to map a multistage computational process to a simple and minimal interface or set of interfaces, and how to fold human computation into a workflow process where time criticality can be important.

7737-31, Session 5

Transient events on mobile devices: astronomers as consumers

A. Allan, The Univ. of Exeter (United Kingdom)

The arrival of the next generation of mobile devices; with large screens, relatively fast processors, and an almost ubiquitous connection to the Internet has changed the way we interact with the world. Tasks that previously tied us to our desks can now be accomplished indiependant of location.

Increasingly the prospect of real-time notification of transient events, and even the analysis of data on mobile platforms, will allow astronomers to interact with their observing programmes in real time. Cutting the time between important and interesting events and ground-based follow-up.

Utilising a combination of a peer-to-peer architecture, intelligent agents, and a software as a service delivery model, we have built a closed loop autonomous network for observing transient events. We discuss the impact of the next generation of mobile devices on our work and how these devices are making their way into the conservative world of big science.

7737-32, Session 5

Transient alert operations for the Large Synoptic Survey Telescope

R. C. Smith, R. L. Seaman, National Optical Astronomy Observatory (United States); T. Axelrod, J. Kantor, LSST Corp. (United States)

The astronomical time domain is entering an era of unprecedented growth. LSST will join current and future surveys at diverse wavelengths in exploring variable and transient celestial phenomena characterizing astrophysical domains from the solar system to the edge of the universe. Adding to the large but relatively familiar operational load of a project of the scale of the Large Synoptic Survey Telescope will be many challenging issues of handling the dynamic empirical interplay between LSST and contingent follow-up facilities. We discuss concerns unique to this telescope, while exploring consequences common to emerging observational time domain paradigms.

7737-33, Session 6

New observing concepts for ESO Survey Telescopes

T. Bierwirth, K. Baugh, D. Dorigo, M. S. Klein Gebbinck, A. Manning, D. Muravov, P. Nunes, M. Rejkuba, European Organisation for Astronomical Research in the Southern Hemisphere (Germany); T. Szeifert, European Southern Observatory (Chile); I. Vera Sequeiros, European Organisation for Astronomical Research in the Southern Hemisphere (Germany)

The start of operations of the VISTA survey telescope will not only offer a new facility to the ESO community, but also a new way of observing. Survey observation programs typically observe large areas of the sky and might span several years, corresponding to the execution of hundreds of observations blocks (OBs) in service mode. However, the execution time of an individual survey OB will often be rather short. We expect up to twelve OBs to be scheduled per hour, as opposed to about one OB per hour on the VLT. OBs of different programs are competing for observation time and must be executed with adequate priority. For these reasons, the scheduling of survey OBs requires a high level of automation. Two new key concepts are introduced to address these challenges: ESO's phase 2 preparation tool P2PP allows PIs of survey programs to express advanced mid-term observing strategies using scheduling containers of OBs (groups, timelinks, concatenations). Telescope operators are provided with effective short-term decision support based on ranking observable OBs. The ranking takes into account both empirical probability distributions of various constraints and the observing strategy described by the scheduling containers. We introduce the three scheduling container types and describe how survey OBs are ranked. We demonstrate how the new concepts are implemented in the preparation and observing tools and give an overview of the end-to-end workflow.

7737-34, Session 6

Dynamic scheduling at the submillimeter array

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The Submillimeter Array (SMA) is an 8-element radio interferometer located atop Mauna Kea in Hawaii operating at frequencies from 180 GHz to 700 GHz. It shares its observing time between the two funding partners (Smithsonian Astrophysical Observatory and the Academia Sinica Institute of Astronomy and Astrophysics) and the University of Hawaii. The observing time share is split 72%:15%:13% between SAO, ASIAA, and UH respectively. The array has 4 configurations (subcompact, compact, extended, and very extended) and the dates of these configurations is determined entirely by the proposals we accept twice a year. The nightly observations at the SMA are scheduled on a day-to-day basis based on the weather and the current array configuration. Maintaining telescope time shares among the partner affiliations can be challenging in light of these additional parameters.

In this talk I will discuss the challenges of dynamic scheduling with added complexity of maintaining observing time shares among the three affiliations as well as the proposal-driven array configuration schedule. I will also briefly discuss some of the software tools that were devised to keep these issues manageable. Since the SMA has been operating in this mode for several years, it is possible that the techniques and tools we have devised may act as a template for future large, multi-national projects such as ALMA.

7737-35, Session 6

JWST planning and scheduling operations and concepts

W. M. Kinzel, Space Telescope Science Institute (United States)

The James Webb Space Telescope (JWST) will be a large infrared space observatory in orbit about the Sun-Earth second Lagrange Point. This paper provides an overview of the expected operational requirements imposed by the observatory's basic science activities (imaging, spectroscopy, coronography) and the operational issues associated with interleaving periodic engineering activities (Wave Front Sensing & Control activities, Momentum Unloads, and orbit Station Keeping) with the science observations. The planning and scheduling operations must maximize the overall science integration time while meeting the mission and observer specified constraints. The "Observation," "Visit," and Observation Template constructs are explained in the context of providing an interface to the Observer that provides the ability to specify complex observations, such as mosaics and cluster targets, while also minimizing specification errors and allowing planning and scheduling flexibility of the observations. The expected nominal planning and scheduling process including the creation and maintenance of the Long Range Plan (~1.25 year duration), the Short Term Schedules (~three weeks), and the on-board Observation Plan (<10 days) is described. The event-driven on-board operations of JWST and how the planning and scheduling process monitors and reacts to the onboard execution of the Observation Plan are described. Finally, the methods employed to allow for robust interfacing of scheduled real-time operations (for example, Station Keeping) with the Observation Plan and unplanned, but expected, modifications to the Observation Plan (for example, Target of Opportunity) are described.

7737-36, Session 6

Simulation of autonomous observing with a ground-based telescope: the LSST Experience

S. T. Ridgway, National Optical Astronomy Observatory (United States); K. H. Cook, Lawrence Livermore National Lab. (United States); R. Allsman, LSST Corp. (United States); T. Axelrod, The Univ. of Arizona (United States); S. Chandrasekharan, C. F. Claver, F. Delgado, National Optical Astronomy Observatory (United States); Z. Ivezic, R. L. Jones, S. Krughoff, Univ. of Washington (United States); M. Miller, National Optical Astronomy Observatory (United States); C. Petry, The Univ. of Arizona (United States); F. Pierfederici, Harvard-Smithsonian Ctr. for Astrophysics (United States); P. Pinto, The Univ. of Arizona (United States); A. Saha, National Optical Astronomy Observatory (United States)

A survey program with multiple science goals will be driven by multiple technical requirements. On a ground-based telescope, the variability of conditions introduces yet greater complexity. For a program that must be largely autonomous with minimal dwell time for efficiency it may be quite difficult to foresee the achievable performance. Furthermore, scheduling will likely involve self-referential constraints and appropriate optimization tools may not be available. The LSST project faces these issues, and has designed and implemented an approach to performance analysis in its Operations Simulator and associated post-processing packages. The Simulator has allowed the project to present detailed performance predictions with a strong basis from the engineering design and measured site conditions. At present, the Simulator is in regular use for engineering studies and science evaluation, and planning is underway for evolution to an operations scheduling tool. We will describe the LSST experience, emphasizing the requirements, the approach, and the lessons learned.

7737-37, Session 6

Implementation of the LSST operations simulator for testing observatory design, operations, observing cadences, and delivery of LSST science

K. H. Cook, Lawrence Livermore National Lab. (United States); R. Allsman, LSST Corp. (United States); S. Chandrasekharan, National Optical Astronomy Observatory (United States); F. Delgado, Cerro Tololo Inter-American Observatory (Chile); R. L. Jones, S. Krughoff, Univ. of Washington (United States); M. Miller, National Optical Astronomy Observatory (United States); C. Petry, The Univ. of Arizona (United States); F. Pierfederici, Harvard-Smithsonian Ctr. for Astrophysics (United States); P. Pinto, The Univ. of Airzona (United States); S. T. Ridgway, A. Saha, National Optical Astronomy Observatory (United States)

We have developed an operations simulator for the Large Synoptic Survey Telescope (LSST) which is used to explore the design and operations parameter space for its ten year mission of performing a single survey to address multiple scientific objectives. The design is modular, allowing the main science program to be supplemented by other science programs, described in separate modules with different scheduling algorithms, strategies and priorities. The simulator includes sophisticated models of the telescope facility, including the camera and dome. All important parameters for the telescope, the site and the science programs are easily accessible in configuration files. We use seeing data from the chosen LSST site, Cerro Pachon, and cloud data from the neighboring mountain, Cerro Tololo.

The Operations Simulator has supported engineering investigations to determine survey performance sensitivity to telescope parameters. It is being used to specifically address optimal approaches to recovering transients and variable star characteristics as well as looking at the effect of dithering each visit on co-added image depth. There are ongoing refinements to the Operations Simulator to enhance it's fidelity. A survey simulation with results that meet basic science requirements of the LSST is designated the 'reference survey.' This survey is used by the LSST collaboration to explore the full range of potential science enabled by the survey and identify potential enhancements of survey cadences and strategies. The Operations Simulator is helping LSST determine a cadence that achieves a broad range of science within its main science program--a single wide-fast-deep survey

7737-38, Session 7

Switching the Liverpool Telescope from a 'full service' operating model to 'self service'

R. J. Smith, N. R. Clay, S. N. Fraser, C. M. Moss, I. A. Steele, J. Marchant, Liverpool John Moores Univ. (United Kingdom)

The Liverpool Telescope has recently undergone a major revision of its operations model, intended to improve the facility's flexibility and rapid response to targets of opportunity. We have moved from a "full service" model where observation requests were vetted by a support astronomer to a direct access model where approved observers can personally load sequences directly into the telescope scheduler database at any time.

The Liverpool Telescope is a fully robotic 2m optical telescope, operated on La Palma by Liverpool John Moores University (UK). The observatory runs autonomously without direct human control either on site or remotely and is distinct from most other robotic telescopes in being a common-user facility, time allocated by an open, peer-review process and conducting a variety of optical and IR imaging, spectroscopic and polarimetric programmes.

Observers provide fully specified observation sequences to the Robotic Control System (RCS) which dynamically schedules the disparate programs in response to changing observing conditions. Until recently observers have submitted requests to the Support Astronomer for interpretation, checking and uploading into the scheduler database. Now however all observers have direct access to the scheduler database, allowing them to modify or add their observations at any time, including during the night.

We will discuss our experiences of this major shift in operating model, looking at the process of developing the new observer user interface, the change to the user experience, protecting the equipment from damage and efficacy of the telescope in obtaining the data required by the observer.

7737-39, Session 7

A shared approach to supporting remote observing for multiple observatories

R. I. Kibrick, Lick Observatory (United States); G. D. Wirth, W. M. Keck Observatory (United States); E. L. Gates, B. J. Grigsby, W. T. S. Deich, K. Lanclos, S. L. Allen, Lick Observatory (United States)

The University of California (UC) has operated the Lick Observatory on Mount Hamilton, California since 1888. Nearly a century later, UC became a founding partner in the establishment of the W. M. Keck Observatory in Hawaii, and it is now a founding partner in the Thirty Meter Telescope (TMT) project. Currently, most UC-affiliated observers conduct the majority of their ground-based observations using either the Keck 10-meter Telescopes on Mauna Kea or one or more of the six Lick Telescopes now in operation on Mt. Hamilton; some observers use both the Keck and Lick Telescopes. Within the next decade, these observers should also have the option of observing with the TMT.

During the current decade, a growing fraction of the observations on the Keck and Lick Telescopes have been conducted from remote observing facilities located at the observer's home institution; we anticipate that TMT observers will expect the same. Such facilities are now operational at 8 of the 10 campuses of UC and at one of the UC-operated national laboratories; similar facilities are are also operational at several other Keck-affiliated institutions. All of the UC-operated remote observing facilities are dual-use, and currently support remote observations with the Keck or Lick Telescopes.

We report on our first two years of operating such dual-use facilities and describe the similarities and differences between the Keck and Lick remote observing procedures. We also examine scheduling issues and explore the possibility of extending these facilities to support TMT observations.

7737-40, Session 7

VISTA: survey area definition tool

J. P. Emerson, Queen Mary, Univ. of London (United Kingdom)

VISTA, the Visible and Infrared Survey Telescope for Astronomy, was accepted as a part of ESO's Cerro Paranal Observatory on 10 December 2009. VISTA is a 4-m class wide field survey telescope equipped with the world's largest near-IR camera, with 1.65-degree diameter field of view 67Mpixel camera with 0.34arcsec pixels and seven near-infrared filter trays covering Z-Ks (0.88-2.15 micron). The telescope's fast f/1 primary mirror gives an f/3.25 focus to the near-IR camera at Cassegrain. The near-IR camera includes a wide-field corrector lens system (3 infrasil lenses), autoguider and active optics sensors.

VISTA is operated in queue-scheduled mode and to maximise observing efficiency stars for use with the autoguider and active optics sensors in the near-IR camera are pre selected by a Survey Area Definition Tool. This tool also allocates the positions of the individual pointings that make up any particular area being surveyed with VISTA (or VST).

We report on the design, capabilities and performance of the Tool.

7737-41, Session 7

Support of remote and robotic observations by the MONET Telescope network

F. V. Hessman, Georg-August-Univ. Göttingen (Germany)

The MONET project is a small network of two 1.2m telescopes used for research, university, and high school education operated by Goettingen, McDonald Observatory, and SAAO. The telescopes are operated primarily remotely by a range of different users scattered all over the globe and with a wide range in previous astronomical experience and training. In my talk, I will describe the different hardware, software, didactic and management strategies used to support both research and educational programs with a minimum of effort and personnel. The challenges of enabling and supporting both remote and robotic observations, particularly for time- and phase-critical projects are discussed.

7737-42, Session 7

Data compression for optimizing observatory workflows

R. L. Seaman, National Optical Astronomy Observatory (United States)

Data and metadata are the lifeblood of an observatory. Telescopes and instrumentation exist to produce a stream of observations in service of scientific investigations. The format and representation of those observations is critical to their efficient capture, transport, processing, archiving, analysis, interpretation and publication. The "compression" of data is really just another name for the proper handling of the information entropy inherent in a sequence of data products. A framework such as FITS tile-compression (http://heasarc.nasa.gov/fitsio/fpack) can formalize the logistics of data handling in addition to providing easy management of a toolkit of task-specific compression algorithms.

Observatory workflows begin when a science program is proposed and extend in a rich fashion through many contingent steps of proposal preparation, the planning of observations, scheduling of telescope access and the actual collection of data. Observing modes may be classical or queue or target-of-opportunity. Science data are transported through many network links and saved to many temporary or permanent storage devices. Future operations modes will place a premium on the coordination of activities both within and between observatories at remote locations. The efficient representation of data and metadata, in particular through a nuanced application of modern compression techniques, will become more and more clearly evident as a key issue to maximize the science returned from ground and space-based facilities.

7737-43, Session 8

Spitzer heritage archive

X. Wu, T. Roby, L. M. Rebull, H. I. Teplitz, L. Ly, California Institute of Technology (United States)

he Spitzer Heritage Archive will host all the raw and final reprocessed science and calibration data products from the observations made by Spitzer Space Telescopes. We decided on using Google Web Toolkit to deliver an AJAX based web interface, which is powerful and easy-to-use. It will give users the tools to search the database, explore their search results interactively. The meta data will be presented in an easy to read table format. Users can page through their data results, perform sorting, filtering on any column. They can also view the FITS images and spectrum plots before they decide to download them. We also try to reuse the existing software and services, pay close attention to the re-usability of the newly developed system, make it easy to expand, to adopt new technology in the future.

This talk will discuss our design principles, system architecture, reuse of the existing software, and reusable components of the system.

7737-44, Session 8

STARS 2: implementation issues for 2nd-generation archiving and query software

T. Winegar, National Astronomical Observatory of Japan/Subaru Telescope (United States)

STARS 2 is 2nd-generation archiving and query software for the Subaru Telescope. STARS 2 is currently completing beta-test by internal staff, and should be released for use by observers in early 2010. However, implementation issues present some considerable hurdles - especially in applying modern software utilities and 'cloud' resources. The primary implementation issues, and software utilities we are testing to overcome these issues, are:

Documentation - Bilingual Online Text-Based Help (English and Japanese)

Training - Online Training Videos, User Comments and Responses

User Experience - Automatic Daily Data Provide to Observers

Data Provide - Compressed Files, Mirrored Archives and Outsourced Storage

Archive Permanence - Online Backup and Optical Libraries

Our experience is that implementation issues are important to success - especially with users around the world. We are re-examining our requirements and continuing to develop the software to meet the needs of our user community.

7737-45, Session 9

ESO's strategy, plans, and lessons learned on science data production

M. Romaniello, W. Freudling, European Organisation for Astronomical Research in the Southern Hemisphere (Germany); A. Smette, C. Dumas, European Southern Observatory (Chile); P. Ballester, European Organisation for Astronomical Research in the Southern Hemisphere (Germany)

ESO aims at supporting the production of science grade data products for all of its Paranal instruments. This serves the double purpose of facilitating the immediate exploitation of the data by the respective PIs, as well the longer term one by the community at large through the ESO Science Archive Facility.

The production of science grade data products requires an integrated approach to science and calibration observations and the development of software to process and calibrate the raw data.

In this talk, we will present ESO's strategy to complement the in-house generation of data products with contributions returned by our users. The most relevant lessons we have learned in the process will be discussed, as well.

7737-48, Session 10

User support: new ways forward after 10 years of successful VLT operations

F. Primas, European Organisation for Astronomical Research in the Southern Hemisphere (Germany)

User support and operations of a large observatory rely on a well defined infrastructure, which is based on different policies, procedures, and tools. If successful, there may be not much stimulus to review and improve such schema.

April 1, 2009 marked the 10th anniversary of VLT operations. Our VLT operations and data-flow schemas have proven to be reliable and efficient and users feedback continues to be positive. However, eleven years of user support has offered us a detailed view of what works very well and what still works very well but with some extra effort. Thanks to our day-to-day experience and to our users feedback, we have evaluated new possible ways forward to make operations even smoother and more efficient. Here, I will review recent developments and new services offered to our VLT users community.

7737-49, Session 10

ALMA science operations and user support (software)

M. G. Rawlings, Atacama Large Millimeter Array (Chile)

An overview will be presented of the various software subsystems currently in development for the support of ALMA Early and Full Science Operations. This will include a description of the software subsystems currently being devised to address the following:

- Proposal preparation and submission system (ObsPrep)
- Software systems for tracking the proposal review process, post-acceptance project tracking, plus other miscellaneous components (ObOps)
- Observation Scheduling (Scheduler)
- Data Archive (Archive)
- Data Reduction Pipelines (QuickLook, Pipeline)
- Quality Assurance and Trend Analysis (AQUA, Trendanalysis)

Additional user support systems (Science Operations Web Pages, User

Portal, etc.) will be outlined.

The functional role of each of the above and their interactions will be summarized, and the testing and planned deployment strategies will be outlined.

7737-50, Session 10

Handling observation proposals for SALT

C. Hettlage, D. A. H. Buckley, A. C. Charles, South African Astronomical Observatory (South Africa); M. Cordiner, NASA Goddard Space Flight Ctr. (United States); D. R. Harbeck, National Optical Astronomy Observatory (United States); K. H. Nordsieck, J. W. Percival, Univ. of Wisconsin-Madison (United States); E. Romero Colmenero, South African Astronomical Observatory (South Africa); M. D. Still, NASA Ames Research Ctr. (United States)

While the complexity of the Southern African Large Telescope (SALT) and its instrumentation require that observation proposals are submitted in a specific XML format, the telescope users shouldn't have to worry about this. At the same time, the users must be prevented from requesting non-feasible observations.

In order to meet these requirements, SALT uses the Principal Investigator Proposal Tool (PIPT). This is a GUI based application for generating, checking, submitting and editing proposals, which runs under all major operating systems. It is explained how the PIPT maps XML into Java classes which allow error and consistency checking on the fly. It is shown how these are created from a schema, and how this implies that the PIPT is extensible in an easy and transparent way when new instruments become available and that the class generation mechanism can be used for other projects.

Various tools allowing the user to simulate observations with the available instruments are included with the PIPT. While these come with a variety of standard source spectra (e.g. black body, power law, Kurucz model atmospheres), they also allow users to add their own library spectra. Again it is pointed out how these tools could be customized for other projects.

The PIPT is complemented by the SALT Web Manager, a web-based tool for the administration of submitted proposals, including time allocation as well as data downloading by the observers. This tool is introduced with a view to how the Science Database structure is mapped to a set of PHP classes.

7737-51, Session 10

Science peer review: Is it time to end the face-to-face meetings?

B. S. Blacker, D. S. Adler, D. A. Golombek, A. J. Roman, Space Telescope Science Institute (United States)

In some eyes, the Phase I proposal selection process is the most important activity handled by the Space Telescope Science Institute (STScI). Proposing for HST and other missions, consists of requesting observing time and/or archival research funding. This step is called Phase I, where the scientific merit of a proposal is considered by a community based peer-review process. Accepted proposals then proceed thru Phase II, where the observations are specified in sufficient detail to enable scheduling on the telescope.

Each cycle the Hubble Space Telescope (HST) Telescope Allocation Committee (TAC) reviews proposals and awards observing time that is valued at $0.5B, when the total expenditures for HST over it's lifetime are figured on an annual basis. This is in fact a very important endeavor, that we continue to fine-tune and tweak. This process is open to the science community and we constantly receive comments and praise for this process and other Observatories use our system as a basis for their reviews. However, has the time come to change the way we do HST Science Peer Review and do away with the face to face meetings?

This paper will outline how the current HST science peer review process occurs. We will discuss the state of the art technologies that now exist that might enable the end of the face to face meetings and will provide cases of other Peer Review processes that are entirely electronic. We will also discuss the pros and cons for implementing such a system for the HST review.

7737-52, Session 11

Calibration of the LSST instrumental and atmospheric photometric passbands

D. L. Burke, SLAC National Accelerator Lab. (United States); T. Axelrod, National Optical Astronomy Observatory (United States); S. Blondin, European Organisation for Astronomical Research in the Southern Hemisphere (Germany) and Ctr. de Physique des Particules de Marseille (France); C. F. Claver, V. L. Krabbendam, M. Liang, A. Saha, National Optical Astronomy Observatory (United States); R. C. Smith, CTIO, National Optical Astronomy Observatory (United States); C. W. Stubbs, Harvard-Smithsonian Ctr. for Astrophysics (United States)

The Large Synoptic Survey Telescope (LSST) will continuously image the entire sky visible from Cerro Pachon in northern Chile every 3-4 nights throughout the year. The LSST will provide data for a broad range of science investigations that require better than 1% photometric precision across the sky (repeatability and uniformity) and a similar accuracy of measured broadband colors. The fast and persistent cadence of the LSST survey will significantly improve the temporal sampling rate with which celestial events and motions are tracked. To achieve these goals, and to optimally utilize the observing calendar, it will be necessary to obtain excellent photometric calibration of data taken over a wide range of observing conditions - even those not normally considered "photometric". To achieve this it will be necessary to routinely and accurately measure the full optical passband that includes the atmosphere as well as the instrumental telescope and camera system. The LSST mountain facility will include a new monochromatic dome illumination projector system to measure the detailed wavelength dependence of the instrumental passband for each channel in the system. The facility will also include an auxiliary spectroscopic telescope dedicated to measurement of atmospheric transparency at all locations in the sky during LSST observing. In this paper, we describe these systems and present laboratory and observational data that illustrate their performance.

7737-53, Session 11

Absolute spectroradiometry of standard stars

J. T. Woodward, S. W. Brown, K. R. Lykke, A. W. Smith, National Institute of Standards and Technology (United States); J. T. McGraw, P. C. Zimmer, The Univ. of New Mexico (United States); C. E. Cramer, Harvard Univ. (United States); E. E. Falco, Harvard-Smithsonian Ctr. for Astrophysics (United States); C. W. Stubbs, Harvard Univ. (United States)

The SI traceability of astronomical measurements depends on measurements of Vega made at Mount Hopkins in the 1970's. More recent observations of Vega have shown it is oriented pole on, rapidly rotating, and surrounded by a debris disk. This leads to questions about its suitability as a standard star. Additionally, advances in both radiometry and measurements and modeling of the atmosphere over the past 30 years lead us to conclude that a new campaign to make SI traceable measurements of absolute stellar spectroradiometry is in order.

There are two primary challenges facing such a campaign: making low-uncertainty, traceable radiometric measurements in the field as opposed to a laboratory setting, and accounting for atmospheric absorption. A

new Telescope Calibration Facility (TCF) has been created at NIST to aid in the development of radiometrically characterized transfer telescopes and sources to be used in field campaigns. This includes a laboratory with an 80 meter optical range and a field site with a 0.5 km range. A LIDAR system, based on the Astronomical LIDAR for Extinction (ALE) system, in conjunction with atmospheric modeling is being developed to correct for atmospheric extinction. Methodologies and results from a preliminary campaign at Mount Hopkins will be presented.

7737-54, Session 11

Solving the global photometric self-calibration problem

R. L. Jones, Univ. of Washington (United States); N. Padmanabhan, Yale Univ. (United States); Z. Ivezic, Univ. of Washington (United States); T. Axelrod, The Univ. of Arizona (United States); D. L. Burke, SLAC National Accelerator Lab. (United States); A. Saha, National Optical Astronomy Observatory (United States)

We present an innovative method for photometric calibration of massive survey data that will be applied to the Large Synoptic Survey Telescope (LSST). LSST will be a wide-field ground-based system designed to obtain imaging data in six broad photometric bands (ugrizy, 320-1050 nm). Each sky position will be observed multiple times, with about a hundred or more observations per band collected over the main survey area (20,000 sq.deg.) during the anticipated 10 years of operations. Photometric zeropoints are required to be stable in time to 0.5% (rms), and uniform across the survey area to better than 1% (rms). The large number of measurements of each object taken during the survey allows identification of isolated variable sources, and forms the basis for LSST's global self-calibration method. Inspired by SDSS's uber-calibration procedure, the self-calibration requires that repeated measurements of non-variable stars must be self-consistent when corrected for variations in atmospheric and instrumental bandpass shapes. This requirement constrains both the instrument throughput and atmospheric extinction. The atmospheric and instrumental bandpass shapes will be explicitly measured using auxiliary instrumentation. We describe the algorithm used, with special emphasis both on the challenges of controlling systematic errors and how such an approach interacts with the design of the survey, and discuss ongoing simulations of its performance.

7737-55, Session 11

Quality control and data flow operations of the survey instrument VIRCAM

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VIRCAM is the Visible and Infrared Camera of the survey telescope VISTA on Paranal and is dedicated to large programs. VIRCAM has sixteen detectors and duplicates the data volume generated by the VLT/I. Several challenging issues have been solved and have been put into operation.

For the required high performance data processing via a data reduction pipeline a dedicated compute cluster is provided. For the management and certification of complex quality control data extracted from individual detectors a scoring system has been implemented and aggregate quality characteristics are monitored. Finally the advantages of survey operations like continuous data rates and low data complexity have been taken into account to improve efficiency of QC operations.

7737-56, Session 11

The physical model in action: quality control for XSHOOTER

S. Moehler, P. Bristow, F. Kerber, A. Modigliani, J. Vernet, European Organisation for Astronomical Research in the Southern Hemisphere (Germany)

The data reduction pipeline for the VLT 2nd generation instrument XSHOOTER uses a physical model to determine the distortion and derive the wavelength calibration. The parameters of this model describe the positions, orientations, and other physical properties of the optical components in the spectrograph. They are continually updated by an optimisation process that ensures the best possible fit to arc lamp line positions in calibration exposures. ESO Quality Control monitors these parameters along with all of the usual diagnostics describing the conditions of any given observation. This enables us to look for correlations between inferred physical changes in the instrument and, for example, instrument temperature sensor readings. We present here the results of this analysis.

7737-57, Session 11

Handling heterogeneous arrays: calibrations and data reduction

S. A. Corder, National Radio Astronomy Observatory (Chile); M. C. H. Wright, Univ. of California, Berkeley (United States)

Despite opposing opinions on their benefits and disadvantages, heterogeneous interferometers are a reality. The Combined Array for Research in Millimeter-wave Astronomy (CARMA) was the first array that tried to take advantage of its heterogeneous nature to improve mosaicked images. The Atacama Large Millimeter-submillimeter Array (ALMA), which is already the most powerful submillimeter interferometer in the world, is also a heterogeneous interferometer. The greatest benefit of such arrays is the ability to recover all spatial scales simultaneously. While CARMA is still working to make such observing modes a reality, ALMA plans to push this advantage from the beginning.

The heterogeneous nature allows the gains of all the antennas to be cross-calibrated at the same time on the same source, removing one of the largest uncertainties in the joint imaging process. There are, however, additional difficulties including different primary beam shapes, mismatched IF responses, and differential thermal effects from the telescope types, including baseline changes and other issues associated with different mount styles. We present results from work to handle these issues as apriori calibration and in data reduction. We outline the approaches needed to track relevant parameters over time from an operational prospective. We also present an overview of different methods used to combine the heterogeneous interferometric visibilities and the single dish data collected with the same system, potentially at the same time.

SPIE Astronomical Instrumentation

7737-58, Session 11

The APEX calibration plan: goals, implementation, and achievements

M. Dumke, F. Mac-Auliffe, European Southern Observatory (Chile)

For the vast majority of astrophysical projects, the quality and therefore the usability of the science product (i.e. final scientific data) depends on the quality of the absolute intensity calibration of these data. Because of various challenges on instrumental and environmental side, this absolute intensity calibration is especially difficult in mm- and sub-mm astronomy.

At the Atacama Pathfinder Experiment (APEX), a single-dish radio telescope operating between 200um and 2mm wavelength (150 to 1500 GHz), we invest a significant fraction of technical time for various efforts to ensure a proper absolute calibration of the final science product. These range from real-time efforts (pointing and focus models) over target-associated measurements (e.g. hot-cold calibrations), to measurements whose results are applied afterwards (during data reduction) to the uncalibrated science product, like opacity, efficiencies, or calibration factors.

In this presentation we will summarize the main challenges for science data calibration in the sub-mm regime, and will give an overview over the various steps taken at APEX in order to overcome these challenges. Main emphasis will be put on calibration data which are observed to ensure a post-observation absolute calibration of the science product. We will explain the implementation of these calibration observations in form of a calibration plan for bolometer and heterodyne data, and will outline their application to the scientific data. Further, we will present a statistical analysis of the calibration data taken during the last years at APEX, and will discuss the results in view of the reliability of the absolute calibration of the released science product.

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7738-01, Session 1

System safety and hazard analysis for the Advanced Technology Solar Telescope

R. P. Hubbard, National Solar Observatory (United States)

The Advanced Technology Solar Telescope (ATST) is a four-meter class instrument being built to perform diffraction-limited observations of the sun. This paper describes how ATST has dealt with system safety and in particular hazard analysis during the design and development phase. For ATST the development of a system safety plan and the oversight of the hazard analysis fell, appropriately, to systems engineering. We have adopted the methodology described in MIL-STD-882E, "Standard Practice for System Safety." While these methods were developed for use by the U.S. Department of Defense, they are readily applicable to the safety needs of telescope projects.

MIL-STD-882 precisely defines the relevant terminology it applies to hazard analysis. It defines a hazard to be a condition that could cause injury to personnel, damage to equipment, or damage to the environment. The hazard analysis process begins with identification of hazards in a design. Consideration must be given to all phases of the project from design and development through fabrication, construction, integration, operations, and maintenance. This must be performed in a systematic and disciplined way. The next step is to estimate the severity and likelihood of the hazard. The last step is to propose a means of mitigating the hazard.

We describe the details of our process, how it was implemented by the ATST design team, and some useful lessons learned. We conclude with a discussion of our safety related plans during the construction phase of ATST and beyond.

7738-02, Session 1

Optical and system engineering in the development of a high-quality student telescope kit

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The GalileoscopeTM student telescope kit was developed by a professional, but largely volunteer team of astronomers, science education experts, and optical engineers, in conjunction with the International Year of Astronomy 2009. The telescope is in production, with over 110,000 units purchased worldwide and an additional 70,000 units in production. The telescope was designed to be able to resolve the rings of Saturn and to be used in urban areas.

This talk will describe the process by which the telescope system requirements, performance metrics, and architecture were set, based on an analysis of current inexpensive telescopes. Several of the optical design approaches used in the various prototypes and system trade-offs will be described, including the use of diffractive optics. As in any manufacturing program, risk analysis and risk management were critical as was cost management since the final product was a $15 telescope that had to perform as well as $100 telescopes. Change-management issues were especially critical for the project since low-cost was a key project goal. In the system engineering of the GalileoscopeTM a variety of analysis and testing approaches were used, including stray light design and analysis using FREDTM. This talk will be a frank assessment of the many design challenges, technology choices, and system trades, and the management process used to make these decisions.

7738-03, Session 1

MUSE instrument global performance analysis

M. Loupias, Observatoire de Lyon (France)

MUSE (Multi Unit Spectroscopic Explorer) is a second generation instrument developed for ESO (European Southern Observatory) and will be assembled to the VLT (Very Large Telescope) in 2012. MUSE spectrograph operates in the visible wavelength range (465-930nm), and makes a 3D image of a 1*1arcmin² field of view, thanks to 24 identical Integral Field Units (IFU). A collaboration of 7 institutes has successfully passed the Final Design Review and is currently working on the first sub-assemblies. The sharing of performances has been based on 4 main functional subsystems. The Fore Optics sub-system derotates and anamorphoses the VLT Nasmyth focal plane, the Splitting and Relay Optics associated to the Main Structure are feeding each IFU with 1/24th of the field of view. Each IFU is composed of a 3D function insured by an image slicer system and a spectrograph, and a detection function by a 4k*4k CCD cooled down to 163°K. This article depicts the sharing of performances between these 4 sub-systems (throughput, image quality...), and underlines the constraining parameters of the interfaces either internal or with the VLT. The validation of all these requirements is a critical task started a few month ago which requires a clear traceability and performances analysis.

7738-04, Session 1

Delivered image quality budget for the Discovery Channel Telescope

B. W. Smith, Lowell Observatory (United States); S. M. Manuel, College of Optical Sciences, The Univ. of Arizona (United States)

The Discovery Channel Telescope is a 4.2m telescope designed for dual optical configurations, featuring an f/6.1, 0.5° FoV, Ritchey-Chretien prescription, and a corrected f/2.3, 2° FoV, prime focus. The DCT is expected to typically deliver sub-arcsecond images, with a telescope and local seeing contribution of <0.28" FWHM at the R-C focus and <0.38" FWHM at the prime focus. The DIQ budget considers errors from design residuals, manufacturing, environmental effects, and control system limitations. We present an overview of the analytical methods used, including sensitivity analysis for determining collimation effects, and a summary of contributors to the overall system performance.

7738-05, Session 2

A method for studying the effects of thermal deformations on optical system for space application

E. Segato, Univ. degli Studi di Padova (Italy); V. Da Deppo, Consiglio Nazionale delle Ricerche (Italy); S. Debei, Univ. degli Studi di Padova (Italy); G. Cremonese, Osservatorio Astronomico di Padova (Italy)

Optical instruments for space missions works in hostile ambient, it's thus necessary to accurately study the effects of ambient parameters variations on the equipment.

In particular optical instruments are very sensitive to ambient conditions, especially temperature. This variable can cause dilatation and misalignment of the optical elements, and can also led to rise of dangerous stresses in the optics. Their displacements degrade the

quality of the sampled images.

In this work the optics and mountings of a stereo-camera for the BepiColombo mission are modelled and processed by a thermo-mechanical FEM analysis, reproducing expected operative conditions. The output is elaborated into a MATLAB optimisation code, based on non-linear least square algorithm to determine the equation of the best fitting nth polynomial or spherical surfaces of the deformed lenses and mirrors; model accuracy is 10-8m.

The obtained mathematical surface representations are then directly imported into ZEMAX for sequential raytrace analysis. The results are spot diagrams, chief ray coordinates on the detector, MTF curves and Diffraction Encircled Energy variations due to simulated thermal loads.

This helps also to design and compare different optical housing systems for a feasible solution. Different types of lenses and prisms constraints have been designed and analysed. The results shows the preferable use of kinematic constraints instead of glue to make use of the optical instrument in orbit around Mercury considering an operative temperature between -20°C and +30°C.

7738-06, Session 2

Investigation of disturbance effects on space-based weak lensing measurements with an integrated model

M. D. Lieber, M. L. Kaplan, Ball Aerospace & Technologies Corp. (United States); M. J. Sholl, Univ. of California, Berkeley (United States); G. M. Bernstein, Univ. of Pennsylvania (United States)

Many astrophysicist consider the uncovering the mystery of accelerated expansion of the universe by a field called dark energy as the greatest challenge to solve in the field of cosmology. Gravitational weak lensing has been identified as one of the best methods to provide constraints on dark energy model parameters. Weak lensing introduces image shear which can be measured statistically from a large sample of galaxies by determining the ellipticity parameters. Several papers have suggested that a goal in the ability to measure shape biases should be <0.1% - this goal and flowdowns will be reviewed in terms of the observatory “transfer function”. Time-varying instrument effects introduced by thermoelastic deformations and vibration add bias and noise to the shape measurements. This is compounded by the wide field-of-view required for the weak lensing science which leads to a spatially varying PSF (point spread function). To fully understand these effects, a detailed integrated model was constructed starting with a coupled structure/ optics/ detector/ disturbance model. Because of the complicated processing required to extract shape parameters an integrated model can help in maximizing science return while iterating the telescope/ instrument design against mission cost constraints. This model can be used to explore the effectiveness of shape extraction algorithms, instrument calibration processes and ways to desensitize the measurement from these effects. Furthermore it provides a basis for cradle-to-grave support of the JDEM program. Finally, we will briefly discuss scene models and the need for iteration between algorithm / calibration teams and integrated observatory models.

7738-08, Session 2

The Kepler end-to-end model: creating high-fidelity simulations to test Kepler ground processing

S. T. Bryson, J. Jon, NASA Ames Research Ctr. (United States); D. J. Peters, Ball Aerospace & Technologies Corp. (United States); P. Tenenbaum, NASA Ames Research Ctr. (United States) and SETI Institute (United States); T. C. Klaus, NASA Ames Research Ctr. (United States) and Orbital Sciences Corp. (United States); J. P. Gunter, Orbital Sciences Corp. (United States); M. T. Cote, NASA Ames Research Ctr. (United States)

The Kepler mission Is designed to detect the transit of Earth-like planets around Sun-like stars by observing 100,000 stellar targets. Such transits produce a reduction of starlight on the order of 100 parts per million, lasting 10-15 hours and occuring once every year or so. The Kepler data analysis pipeline is designed to detect these small signals automatically. Developing and testing the Kepler ground-segment processing system, in particular the data analysis pipeline, requires high-fidelity simulated data. This simulated data is provided by the Kepler End-to-End Model (ETEM). ETEM simulates 1) the astrophysics of planetary transits, including Sun-like stellar variability, for a range of star and planet sizes and planet orbits, as well as eclipsing binaries; 2) properties of the Kepler spacecraft, including pointing jitter, CCD properties and electronic systems including measured noise sources; 3) the format of the data as delivered in a Kepler downlink and 4) the selection of the specific pixels actually downlinked. Major challenges addressed by ETEM include the production of large amounts of simulation data in a reasonable time and building in extensibility and maintainability, which allow the addition of new simulated phenomena. This paper describes the ETEM framework, the most significant phenomena that are simulated, and how ETEM fits into the larger Kepler ground segment testing environment.

7738-09, Session 3

Comparing numerical simulation of the VLT/ MUSE instrument with the first real data

A. Jarno, R. M. Bacon, A. Pécontal-Rousset, P. Ferruit, Observatoire de Lyon (France) and Univ. de Lyon (France)

The Multi Unit Spectroscopic Explorer (MUSE) instrument is a second-generation integral-field spectrograph in development for the Very Large Telescope (VLT), operating in the visible and near IR wavelength range (465-930 nm). Given the complexity of MUSE we have developed a numerical model of the instrument, which includes the whole chain of acquisition from the atmosphere down to the telescope and including the detectors, and taking into account both optical aberrations and diffraction effects, by propagating a wavefront through the instrument, according to the Fourier optics concept.

This simulator has been, among other things, used to produce simulated exposures of the test setup (focus exposures, calibration exposures, etc.), in order to develop and validate the test procedures, and later to develop the softwares used for the tests phase. The VLT/MUSE instrument has currently reached the Assembly Integration and Tests (AIT) phase, and the first spectrograph has been characterized. This paper compares and analyses the differences between the real data and the numerical simulations, and describes the techniques used to improve the numerical model in order to match the real instrument.

7738-10, Session 3

Introducing atmosphere effects in the numerical simulation of the VLT/MUSE instrument

A. Jarno, R. M. Bacon, A. Pécontal-Rousset, P. Ferruit, Observatoire de Lyon (France) and Ctr. de Recherche Astrophysique de Lyon (France)

The Multi Unit Spectroscopic Explorer (MUSE) instrument is a second-generation integral-field spectrograph in development for the Very Large Telescope (VLT), operating in the visible and near IR wavelength range (465-930 nm). Given the complexity of MUSE we have developed a numerical model of the instrument, which includes the whole chain of acquisition from the atmosphere down to the telescope and including the detectors, and taking into account both optical aberrations and diffraction effects, by propagating a wavefront through the instrument, according to the Fourier optics concept.

Simulating atmosphere effects such as turbulence, refraction or sky background is complex and computation intensive. When coupled direc tly to an instrument simulator, it leads to huge computation times, that are not compatible with the use of an instrument simulator in the context of software development or scientific exposure preparation. In addition, the simulation of these effects is usually out of scope of an instrument simulator, and is often done by different people in dedicated simulations, from which only the final results are available. This paper describes how these effects have been introduced in the VLT/MUSE numerical simulator, using the results from dedicated simulations, with the simplifications used to achieve a reasonable computation time, as well as the assumptions leading to these simplifications and their limits.

7738-11, Session 3

Thermal modeling environment for TMT

K. Vogiatzis, Thirty Meter Telescope (United States)

In a previous study we had presented a summary of the TMT Aero-Thermal modeling effort to support thermal seeing and dynamic loading estimates. In this paper a summary of the current status of Computational Fluid Dynamics (CFD) simulations for TMT is presented, with the focus shifted in particular towards the synergy between CFD and the TMT Finite Element Analysis (FEA) structural and optical models, so that the thermal and consequent optical deformations of the telescope can be calculated.

To minimize thermal deformations and mirror seeing the TMT enclosure will be air conditioned during day-time to the expected night-time ambient temperature. Transient simulations with closed shutter were performed to investigate the optimum cooling configuration and power requirements for the standard telescope parking position.

A complete model of the observatory on Mauna Kea was used to calculate night-time air temperature inside the enclosure (along with velocity and pressure) for a matrix of given telescope orientations and enclosure configurations. Generated records of temperature variations inside the air volume of the optical paths are also fed into the TMT thermal seeing model.

The temperature and heat transfer coefficient outputs from both models are used as input surface boundary conditions in the telescope structure and optics FEA models. The results are parameterized so that sequential records several days long can be generated and used by the FEA model to estimate the observing spatial and temporal temperature range of the structure and optics.

7738-12, Session 3

Thermal analysis of the TMT telescope structure

M. K. Cho, National Optical Astronomy Observatory (United States); A. Corredor, The Univ. of Arizona (United States); K. Vogiatzis, G. Z. Angeli, California Institute of Technology (United States)

Thermal performances of the Thirty Meter Telescope (TMT) structure were evaluated by finite element thermal models. Temporal and special temperature distributions of the optical assembly systems and the telescope structure were calculated under various thermal conditions including air convections, conductions, heat flux loadings, and radiations. In order to capture thermal responses faithfully, a three-consecutive-day thermal environment data was implemented. This thermal boundary condition was created by CFD based on the environment conditions of the TMT site at Mauna Kea. The thermo-elastic analysis was made to predict thermal deformations of the telescope structure at every hour for three days. The goal of this thermal analysis is to establish creditable thermal models by finite element analysis to simulate the thermal effects with the TMT site environment data. These thermal models can be utilized for estimating the thermal responses of the TMT structure. Thermal performance prediction of the TMT structure will guide us to access the thermal impacts, and which enables us to establish a thermal control strategy to control and maintain the system from the “seeing” effects.

7738-13, Session 3

LSST camera heat requirements using CFD and thermal seeing modeling

J. Sebag, National Optical Astronomy Observatory (United States); K. Vogiatzis, Thirty Meter Telescope (United States)

The LSST camera is located above the LSST primary/tertiary mirror and in front of the secondary mirror in the shadow of its central obscuration. Due to this position within the optical path, heat released from the camera has a potential impact on the seeing degradation that is larger than traditionally estimated for Cassegrain or Nasmyth telescope configurations. This paper will present the results of thermal seeing modeling combined with Computational Fluid Dynamics (CFD) analyses to define the thermal requirements on the LSST camera.

Camera power output fluxes are applied to the CFD model as boundary conditions to calculate the steady-state temperature distribution on the camera and the air inside the enclosure. Using a previously presented post-processing analysis to calculate the optical seeing based on the mechanical turbulence and temperature variations along the optical path, the optical performance resulting from the seeing is determined. The CFD simulations are repeated for different wind speeds and orientations to identify the worst case scenario and generate an estimate of seeing contribution as a function of camera-air temperature difference. Finally, after comparing with the corresponding error budget term, a maximum allowable temperature for the camera is selected.

7738-14, Session 3

Primary mirror dynamic disturbance models for TMT: vibration and wind

D. G. MacMynowski, California Institute of Technology (United States); M. M. Colavita, Jet Propulsion Lab. (United States); W. A. Skidmore, K. Vogiatzis, Thirty Meter Telescope (United States)

The principal dynamic disturbances acting on a telescope segmented primary mirror are unsteady wind pressure (turbulence) and narrowband vibration from rotating equipment. Understanding these disturbances is essential for the design of the segment support assembly, segment actuators, and primary mirror control. The wind disturbance is relatively low frequency, and can be at least partially compensated for with the primary mirror control system; the response depends on the control bandwidth and the quasi-static stiffness of the actuator and support assembly. Equipment vibration is at frequencies higher than the control system bandwidth; the response depends on segment damping, and the proximity of segment support resonances to dominant vibration tones. We present here both disturbance models and parametric response. Wind modeling is informed by CFD (presented elsewhere) and based on propagation of a von Karman pressure screen. The vibration model is informed by analysis of accelerometer and adaptive optics data from Keck. This information is then extrapolated to TMT and applied to the telescope structural model to understand the response dependence on actuator design parameters in particular. Whether the vibration response or the wind response is larger depends on design choices such as actuator technology; “soft” (e.g. voice-coil) actuators provide better vibration reduction but require high servo bandwidth for wind rejection, while “hard” (e.g. piezo-electric) actuators provide good wind rejection but require damping to avoid excessive vibration transmission to the primary mirror segments. The results for both nominal and worst-case disturbances and design parameters are then incorporated into the TMT actuator performance assessment.

7738-15, Session 4

Modeling of the European Extremely Large Telescope for high-contrast imaging tasks

S. Gladysz, European Organisation for Astronomical Research in the Southern Hemisphere (Germany); L. Jolissaint, aquilAOptics (Switzerland)

We study the capability of the European Extremely Large Telescope (E-ELT) to image exoplanets. For this task we have developed a simulation which models the telescope, adaptive-optics (AO) systems, coronagraphs, science instrument and image post-processing.

At the telescope level we simulate aberrations on the M1 segments due to wind buffeting, gravity, and thermal effects. In our simulations these aberrations are then partially corrected using E-ELT's single-conjugate AO, or extreme AO provided by the planet-finder instrument.

We model AO as a high-pass filter acting on the atmospheric spatial power spectrum. The wavefronts containing residual aberrations from the primary mirror and from the atmosphere are then propagated through a coronagraph. We model "perfect" and more realistic coronagraphs (classical Lyot setup, or apodized pupil Lyot coronagraph). The science instrument is a near-infrared, low-resolution integral field spectrograph. At the level of the instrument we obtain contrasts in the range 10^6 - 10^7 relative to the un-obscured star.

For the model of the integral field spectrograph we have implemented polychromatic far-field propagation for one hundred channels. With the resulting data cube of long exposures we perform "spectral deconvolution" which is a speckle-suppression technique yielding a gain of two orders of magnitude in contrast. We translate the final contrast curve at the level of 10^8 - 10^9 to the detectability of various classes of exoplanets.

7738-16, Session 4

Normalized point source sensitivity for off-axis optical performance evaluation of the Thirty Meter Telescope

B. Seo, C. R. Nissly, M. Troy, Jet Propulsion Lab. (United States); G. Z. Angeli, California Institute of Technology (United States)

The Normalized Point Source Sensitivity (PSSN) has previously been defined and analyzed as a On-Axis seeing-limited telescope performance metric. In this paper, we expand the scope of the PSSN definition to include Off-Axis field of view (FoV) pints and apply this generalized metric for performance evaluation of the Thirty Meter Telescope (TMT). We first propose various possible choices for the PSSN definition and select one as our baseline. We show that our baseline metric has useful properties including the multiplicative feature even when considering Off-Axis FoV points, which has proven to be useful for optimizing the telescope error budget. Various TMT optical errors are considered for the performance evaluation including segment alignment and phasing, segment surface figures, temperature, and gravity, whose On-Axis PSSN values have previously been published by our group.

7738-17, Session 4

Investigation of Thirty Meter Telescope wavefront maintenance using low-order Shack-Hartmann wavefront sensors to correct for thermally induced misalignment

C. R. Nissly, B. Seo, M. Troy, Jet Propulsion Lab. (United States); G. Z. Angeli, M. K. Cho, Thirty Meter Telescope (United States); L. C. Roberts, Jr., J. C. Shelton, N. Sigrist, Jet Propulsion Lab. (United States); M. J. Sirota, L. M. Stepp, Thirty Meter Telescope (United States)

We evaluate how well the performance of the Thirty Meter Telescope (TMT) can be maintained against thermally induced errors during a night of observation. We first demonstrate that using look-up-table style correction for TMT thermal errors is unlikely to meet the required optical performance specifications. Therefore, we primarily investigate the use of a Shack-Hartmann Wavefront Sensor (SH WFS) to sense and correct the low spatial frequency errors induced by the dynamic thermal environment. Given a basic SH WFS design, we position single or multiple sensors within the telescope field of view and assess telescope performance using the JPL optical ray tracing tool MACOS for wavefront simulation. Performance for each error source, wavefront sensing configuration, and control scheme is evaluated using wavefront error, plate scale, pupil motion, pointing error, and the Point Source Sensitivity (PSSN) as metrics. This study provides insight into optimizing the active optics control methodology for TMT in conjunction with the Alignment and Phasing System (APS) and primary mirror control system (M1CS).

7738-18, Session 4

Analysis of active alignment control of the Hobby-Eberly Telescope wide-field corrector using Shack-Hartmann wavefront sensors

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One of the key aspects of the Wide-Field Upgrade (WFU) for the 10m Hobby-Eberly Telescope (HET) is the use of wavefront sensing (WFS) in active alignment control of the new four-mirror Wide-Field Corrector (WFC), as it tracks sidereal motion, with respect to the fixed spherical segmented primary mirror. This creates a unique problem of dynamically changing pupil illumination, in addition to various problems including seeing, primary segment errors, and dynamic deflection of the internal optical components of the WFC. We conducted extensive simulations to understand the robustness of the WFS in the face of these errors and the results of these analyses are discussed in this paper.

7738-19, Session 4

Integrated finite element analysis and raytracing, oriented to structural optimization, for astronomical instrument design

M. Riva, V. De Caprio, S. Paolo, Osservatorio Astronomico di Brera (Italy)

The design of astronomical instrument is growing in dimension and complexity, following the new requirements imposed by ELT class telescopes. The availability of new structural material like composite ones is asking for more robust and reliable designing numerical tools.

This paper wants to show a possible integrated design framework. The procedure starts from the developing of a raw structure consisting in an assembly of plates and beams directly from the optical design. The basic Finite Element Model is then prepared joining together plate and beam elements for the structure and mass and semirigid element for the the opto-mechanical subsystems.

The technique developed is based onto Matlab commands and run the FEA, extrapolate the optical displacements, implement them into the optical design and evaluates the image quality in terms of displacement and spot size. Thanks to a simplified procedure the routine is able to derive the full field of displacements from a reduced sequence of three different load sets.

The automatic optimization routine modifies the properties of plates and beams considering also different materials and, in case of composites different lamination sequences. The algorithm is oriented to find the best compromise in terms of overall weights w.r.t. eigenfrequencies, image

stability and quality.

As an example it will be shown the results of this procedure onto the design of the optical bench of a multi purpose instrument that includes a multi-wavelength high-speed photometer, a high-speed spectrograph and a polarimeter.

7738-20, Session 4

SOFIA Telescope modal survey test and test-model correlation

P. J. Keas, CSA Engineering, Inc. (United States); R. Brewster, Orbital Sciences Corp. (United States); H. J. Kärcher, MT Aerospace AG (Germany); U. Lampater, S. Teufel, J. Wagner, Univ. Stuttgart (Germany)

The NASA/DLR Stratospheric Observatory for Infrared Astronomy (SOFIA) employs a 2.5-meter reflector telescope in a Boeing 747SP. The telescope is housed in an open cavity and will be subjected to aeroacoustic and inertial disturbances. The image stability goal for SOFIA is 0.2 arc-seconds (RMS). Throughout the development phase of the project, analytical models were employed to predict the image stability performance of the telescope, and to evaluate pointing performance improvement measures. These analyses clearly demonstrated that key aspects which determined performance were:

1) Disturbance environment and relevant load-paths

2) Telescope modal behavior

3) Sensor and actuator placement

4) Control algorithm design

The SOFIA program is now entering an exciting phase in which the characteristics of the telescope and the cavity environment are being verified through ground and airborne testing. A modal survey test (MST) was conducted in early 2008 to quantify the telescope modal behavior. This paper will describe the analytical and test methods used to validate the finite element model (FEM) of the telescope for the purpose of image stability performance predictions. We will give a brief overview of methods that have been employed in the end-to-end modeling of the SOFIA telescope and its pointing control systems. In this context, we will describe the motivation for the MST and the pre-test analysis which determined the MST sensor/shaker placement. A summary will then be given of the FEM-test correlation effort and updated end-to-end simulation results.

7738-22, Session 5

Evolution of system modeling as a management tool for the Hubble Space Telescope Astrophysics Observatory

T. J. Griffin, NASA Goddard Space Flight Ctr. (United States)

Operating for over 20 years, the Hubble Space Telescope continues to be a world class space astrophysics Observatory. This remarkable achievement has been made possible through five successful Space Shuttle-based servicing missions. For each of these missions, engineering and management challenges were encountered and managed through a variety approaches, including training, testing and analytical modeling. Unique in the civilian spacecraft industry, Hubble engineers were required to design new components and systems for a vehicle already on orbit. The approach to meeting the engineering challenge has evolved since the first servicing mission; but, has always addressed minimizing the “analytical” bridge to fill the gap left when ground testing cannot completely emulate the on orbit environment and interfaces. By nature of the nearly 100% success rate experienced during the five servicing missions, the processed worked for over 50 spacecraft components and Scientific Instruments. This report will examine management techniques employed to define the servicing mission programs where training, testing and system modeling were used to minimize the risk of failure. Three critical spacecraft systems, each essential to the Observatory science operations, will be used as examples of how the engineering challenges were successfully managed. Using the Solar Array III, the Scientific Instrument Data Handler-2 and the Soft Capture Mechanism, this report will present how the challenge was addressed through design, test, training and modeling.

7738-23, Session 5

Managing complex space missions like the James Webb Space Telescope

P. A. Sabelhaus, NASA Goddard Space Flight Ctr. (United States)

Mr. Sabelhaus has been a project manager for several NASA space projects since the early 1990’s. He is currently the JWST project manager. He will provide an overview and assessment of NASA project management practices and tools. Based on his JWST experience, he will discuss what he believes is working well for managing space projects and what can or should be improved. He will also provide a JWST project overview and discuss the specific management structure and some of the challenges on the JWST project.

7738-24, Session 5

Management and systems engineering of the Kepler mission

J. L. Fanson, L. L. Livesay, M. A. Frerking, B. C. Cooke, R. M. Duren, Jet Propulsion Lab. (United States)

Kepler is NASA’s first mission capable of detecting Earth-size planets orbiting in the habitable zones around other stars in the galaxy. Selected for implementation in 2001 and launched into space in 2009, Kepler seeks to determine whether Earth-like planets are common or rare in the galaxy. The investigation requires a large space-based photometer capable of simultaneously measuring the brightness of 100,000 stars at part-per-million level of precision. This paper traces the development of the mission from the perspective of project management and systems engineering, and describes various methodologies and tools that were found to be effective. The experience of the Kepler development is used to illuminate lessons that can be applied to future missions.

7738-25, Session 5

Managing the development of the Wide-field Infrared Survey Explorer Mission

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The Wide-field Infrared Survey Explorer (WISE), a NASA MIDEX mission, is surveying the entire sky in four bands from 3.4 to 22 microns with a sensitivity 1000 times greater than the IRAS in the common bands. The single WISE instrument consists of a 40 cm three mirror anastigmatic telescope, a two-stage solid hydrogen cryostat, a scan mirror mechanism, and reimaging optics giving 5” resolution (full-width-half-maximum). WISE was placed into a Sun-synchronous polar orbit on a Delta 7920 launch vehicle on December 14, 2009. WISE was selected by NASA as a Medium cost Explorer mission (MIDEX) in 2002 following a rigorous competitive selection process. To gain further confidence in WISE, NASA extended the development period one year with an option

to cancel the mission if certain criteria were not met. MIDEX missions are led by the Principal Investigator who delegated day-to-day management to the Project Manager. With a cost cap and relatively short development schedule, it was essential for all WISE partners to work seamlessly together. This was accomplished with an integrated management team representing all key partners and disciplines. The project was developed on budget and on schedule in spite of the need to surmount significant technical challenges. This paper describes our management approach, key challenges, and critical decisions made. Results are described from a programmatic, technical and scientific point of view. Lessons learned are offered for projects of this type.

7738-26, Session 6

Management evolution of the LSST project

D. W. Sweeney, LSST Corp. (United States); C. F. Claver, LSST Corp. (United States) and National Optical Astronomy Observatory (United States); S. Jacoby, J. Kantor, LSST Corp. (United States); V. Krabbendam, National Optical Astronomy Observatory (United States); N. Kurita, SLAC National Accelerator Lab. (United States)

The Large Synoptic Survey Telescope (LSST) project has evolved from just a few staff members in 2003 to about 100 in 2010; the affiliation of four founding institutions has grown to 30 universities, government laboratories, and industry. The public private collaboration aims to complete the estimated $400 M observatory in the 2017 timeframe. During the design phase of the project from 2003 to the present the management structure has been remarkably stable. At the same time, the funding levels, staffing levels and scientific community participation have grown dramatically. The LSSTC has introduced project controls and tools required to manage the LSST's complex funding model, technical structure and distributed work force. Project controls have been configured to comply with the requirements of federal funding agencies. Some of these tools for risk management, configuration control and resource-loaded schedule have been effective and others have not. Technical tasks associated with building the LSST are distributed into three subsystems: Telescope & Site, Camera, and Data Management. Each sub-system has its own experienced Project Manager and System Scientist. Delegation of authority is enabling and effective; it encourages a strong sense of ownership within the project. At the project level, subsystem management follows the principle that there is one Board of Directors, Director, and Project Manager who have overall authority.

7738-27, Session 6

Advanced Technology Solar Telescope project management

J. J. Wagner, National Optical Astronomy Observatory (United States)

The Advanced Technology Solar Telescope (ATST) has recently received National Science Foundation (NSF) approval to begin the construction process. ATST will be the most powerful solar telescope and the world's leading resource for studying solar magnetism that controls the solar wind, flares, coronal mass ejections and variability in the Sun's output.

This paper gives an overview of the project, and describes the project management principles and practices that have been developed to optimize both the project's success as well as meeting requirements of the project's funding agency.

7738-28, Session 6

The poacher turned gamekeeper: or getting the most out of the design review process

S. C. Craig, Joint Astronomy Ctr. (United States)

This paper presents an accumulation of knowledge from both side of the design review table. Using experienced gained over many reviews and post mortems, some painful, some less painful; examining stake-holder's viewpoints and expectations; challenging aspects of accepted wisdom and posing awkward questions, the author brings out what he considers to be key criteria for a constructive design review. While this is not a guarantee to a successful outcome, it may nudge the balance from the reviews being an obligatory milestone (millstone?) towards them being a beneficial mechanism for project development.

7738-29, Session 6

The MUSE project from the dream toward reality

P. Callier, Ctr. de Recherche Astrophysique de Lyon (France) and Ctr. National de la Recherche Scientique (France) and Univ. Claude Bernard - Lyon 1 (France)

MUSE (Multi Unit Spectroscopic Explorer) is a second generation instrument developed for ESO (European Southern Observatory) to be installed on the VLT (Very Large Telescope) in year 2012. The MUSE project is supported by a European consortium of 7 institutes.

After a successful Final Design Review the project is now facing a turning point which consist in shifting from design to manufacturing, from calculation to test,... from dream to reality.

At the start, many technical and management challenges were there as well as unknowns. They could all be derived from the same simple question: How to deal with complexity? The complexity of the instrument, of the work to de done, of the organization, of the interfaces, of financial and procurement rules, etc.

This particular moment in the project life cycle is the opportunity to look back and evaluate the management methods implemented during the design phase regarding this original question. What are the lessons learn? What has been successful? What could have been done differently?

Finally, we will look forward and review the main challenges of the MAIT (Manufacturing Assembly Integration and Test) phase which has just started as well as the associated new processes and evolutions needed.

7738-30, Session 7

Management of the Herschel/Planck Programme

T. Passvogel, European Space Agency (Netherlands)

The development of the Herschel and Planck Programme, the largest scientific space programme of the European Space Agency (ESA), has culminated in May 2009 with the successful launch of the Herschel and Planck satellites onboard an Ariane 5 from the European Spaceport in Kourou. Both satellites are operating flawlessly since then and the scientific payload instruments provide world-class science.

The Herschel/Planck Programme is a multi national cooperation with the managerial lead by the European Space Agency and with the major contributions from European industry for the spacecraft development and from scientific institutes organised in international consortia for the payload instruments. The overall project complexity called for various, adapted, management approaches to resolve technical and programmatic difficulties. Some of the management experiences of the decade of realisation of the satellite program will be presented with the lessons learnt for future programmes with the similar complexities.

7738-31, Session 7

EAGLE: A successful instrument phase A study for the E-ELT

J. Cuby, Observatoire Astronomique de Marseille-Provence (France)

EAGLE is a multi-IFU, AO assisted, near IR spectrograph for the E-ELT. The two-year, ESO funded phase A study was completed in autumn 2009 by a consortium of UK and French institutes.

Originally perceived as a potentially complicated E-ELT instrument, the phase A study has demonstrated instead that the instrument, as designed, can be built with existing technologies, at an affordable cost and with manageable risks.

We describe in this paper the project methodology, management style and system engineering methods that were used during phase A, and the anticipated benefit of this strong foundation as the project progresses to the next phase.

7738-32, Session 7

The Javalambre Astrophysical Observatory project

J. Cenarro, M. Moles, S. F. Sanchez, D. Cristobal, Centro de Estudios de Fisica del Cosmos de Aragon (Spain)

The Centro de Estudios de Fisica del Cosmos de Aragon (CEFCA) is a new Institute for Astrophysics and Cosmology in Spain which is in charge of building up the Javalambre Astrophysical Observatory, at the Sierra de Javalambre (Teruel, Spain), 1957m above the sea. The observatory, which is thought and defined for carrying out large all-sky surveys, will be operated in robotic mode. It will primarily consist of two telescopes:

T250, a very large etendue telescope of 2.5m aperture and 3 deg diameter FoV, and T80, a 0.8m auxiliary telescope with a FoV of up to 2 deg.

By February 2010, the bidding process for the construction of the whole observatory was closed. The first light of T250 is scheduled for the first half of 2012, about 105 weeks after signing up the contract. The auxiliary T80, however, is planed to be operative up in the mountain during the spring of 2011.

The immediate objective of the T250 is a photometric survey of 8000 square degrees projected on the sky, using narrow-band filters in the whole optical range (~100 angstroms width, from 3500 to 8500 angstroms), following the specifications defined in Benitez et al. (2009) for the measurement of baryon acoustic oscillations along the line of sight with photometric red shifts. To do this, T250 will hold a panoramic camera of 14 10Kx10K CCDs covering the entire focal plane.

The present paper describes the overall project conceived to comply with the scientific and technical requirements and the managerial approach considered. Other aspects such as the operation of the observatory, the software/hardware specifications, and the data handling will be also outlined.

7738-33, Session 7

Using value-based total cost of ownership (TCO) measures to inform subsystem trade offs

N. M. Radziwill, James Madison Univ. (United States); R. F. DuPlain, National Radio Astronomy Observatory (United States)

Total Cost of Ownership (TCO) is a metric from management accounting that helps expose both the direct and indirect costs of a business decision. However, TCO can sometimes be too simplistic for “make vs. buy” decisions when value and extensibility are more critical than total cost (e.g. choosing between competing design alternatives, or choosing between open source and commercial software). A three-dimensional value-based TCO, which was developed to clarify product decisions for an observatory prior to Final Design Review (FDR), will be presented in this session. This value-based approach incorporates priority of requirements, satisfiability of requirements, and cost, and can be easily applied in any environment. The approach was derived from research in cost accounting and project management dating back to the early 1990’s, and was piloted in 2009 on several subsystem selections for a cyberinfrastructure implementation. Attendees of this talk will be shown a step by step approach for understanding and applying this value-based TCO, which can help them justify product decisions to their managers and funding agencies.

7738-56, Poster Session

Modeling of control system for LAMOST based on Petri net workflow

L. Xu, X. Xu, Nanjing Institute of Astronomical Optics & Technology (China)

The Chinese ever-ambitious project LAMOST (Large sky Area Multi-Object fibre Spectroscopic Telescope) has now come to its final completion of R&D stage. Major functions of the telescope have successfully passed a serial of pilot observation recently, and various kinds of applications integrated into the automation of the telescope chamber are being under vigorous site tests too. The TCS (Telescope Control System) is built on multi-layer distributed network platform with many sub-systems at different levels. How to efficiently process the enormous amount of message with particular implications running in and out the TCS is one of the major issues of the TCS software package. The paper focuses on the modelling of control system for LAMOST based on Petri net workflow. The model is also analyzed and verified with the matrix equation.

7738-57, Poster Session

LAMOST control system: past and future

X. Xu, L. Xu, Nanjing Institute of Astronomical Optics & Technology (China)

The project of much-anticipated LAMOST (Large sky Area Multi-Object fibre Spectroscopic Telescope) has successfully been inspected and accepted at national-level evaluation. It will become the world’s most powerful meter-class level ground astronomical optical survey telescope. The ever-ambitious project throughout the development history of Chinese astronomical optics telescopes has brought an extraordinary challenge to its control system from all-round aspects. Painstaking effort has been made to the R&D of the control system from its design strategy, functionality analyses to most subtle technical solutions, and of course efficient engineering management is also included. A number of papers highlighting the anticipated LAMOST control system have previously been published during the course of the project evolving. However, much lesson and experience have been learned since 10 years ago. Now the telescope with all its facilities and observation chamber has been put into trial observation. This is the time to review the past and ponder over the future of the control system as a whole against the functional telescope in current reality. Lesson and experience are discussed. Some considerations for improving the system efficiency and the accessibility are presented too in this paper.

7738-58, Poster Session

Surface figure measurement of the Hobby-Eberly Telescope primary mirror segments via phase retrieval and its implication for the wavefront sensing in the new wide-field upgrade

H. Lee, The Univ. of Texas at Austin (United States); M. Hart, Hart Scientific Consulting International L.L.C. (United States); G. J. Hill, M. D. Rafal, The Univ. of Texas at Austin (United States)

Mirror segment figure error is potentially deleterious to the wavefront sensing in the new Hobby-Eberly Telescope (HET) Wide-Field Upgrade (WFU). Previous measurements indicated the presence of figure errors including surface astigmatism on the segments, but need a systematic analysis to quantify the amounts. We developed a Phase Retrieval procedure that estimates the surface figure map by applying the iterative transform method to a set of focus-diversed images of a point source formed by the 91 segments of the 11m HET primary mirror. In this paper, we discuss this analysis and the implication of the analysis results for wavefront sensing in the WFU.

7738-59, Poster Session

Orthonormal aberration polynomials over arbitrarily obscured pupil geometries for wavefront sensing in the Hobby-Eberly Telescope

H. Lee, The Univ. of Texas at Austin (United States); M. Hart, Hart Scientific Consulting International L.L.C. (United States); G. J. Hill, M. D. Rafal, The Univ. of Texas at Austin (United States)

Wavefront sensing (WFS) is one of the key elements for active alignment of the new Wide-Field Corrector (WFC), as it tracks sidereal motion, with respect to the fixed Hobby-Eberly Telescope (HET) primary mirror. During a track, part of the 10m-pupil of the WFC can lie outside the primary periphery and be clipped off. An additional field-dependent central obscuration by the holes and baffles of the WFC leads to complex pupil geometries. This unique problem to the WFS needs to be dealt with by choosing an appropriate set of orthonormal aberration polynomials during wavefront reconstruction. We have developed a numerical method that generates a new set of orthonormal polynomials over arbitrarily obscured pupil geometries and discuss its details here.

7738-60, Poster Session

Computational fluid dynamic modeling of the summit of Mt. Hopkins for the MMT Observatory

S. P. Callahan, MMT Observatory (United States)

Over the past three decades, the staff of the MMT observatory used a variety of techniques to predict the summit wind characteristics including wind tunnel modeling and the release of smoke bombs. With the planned addition of a new instrument repair facility to be constructed on the summit of Mt. Hopkins, new computational fluid dynamic (CFD) models were made to determine the building's influence on the thermal environment around the telescope. The models compared the wind profiles and density contours above the telescope enclosure with and without the new building. The results show the steeply-sided Mount Hopkins dominates the summit wind profiles. In typical winds, the height of the telescope remains above the ground layer and is sufficiently separated from the new facility to insure the heat from the new building does not interfere with the telescope. The results also confirmed the observatories waste heat exhaust duct location needs to be relocated to prevent heat from being trapped in the wind shadow of the new building and lofting above the telescope.These useful models provide many insights into understanding the thermal environment of the summit.

7738-61, Poster Session

Unsteady aerodynamic simulations for TMT primary mirror segment wind loading

K. Vogiatzis, Thirty Meter Telescope (United States); D. G. Macmynowski, California Institute of Technology (United States)

Segmented mirror telescopes are more susceptible to wind disturbances than their monolithic ancestors. The need for venting in order to flush the primary mirror and exchange the enclosure air volume competes with the desire for minimizing segment discontinuities due to wind unsteady wind forces. Hence the optimal venting and primary mirror control strategies require an understanding of the nature of the wind loads on the primary mirror.

Initial simulations of segment wind loading for TMT have been based on propagating a von Karman pressure phase screen across M1 at a uniform velocity, with the mean velocity and rms pressure derived from an estimate of the expected differential pressure rms map based on steady Computational Fluid Dynamic (CFD) simulations. However, the actual flow field is more complex, since the turbulence is not fully developed. We therefore present a new approach, using a direct pressure record from unsteady CFD Large Eddy Simulations (LES). This new approach required a new CFD grid methodology to be developed. The use of “honeycomb” vent screens to mitigate wind loading is also investigated.

Comparisons between the two methods are made in order to understand the relevant physics and validate assumptions.

7738-62, Poster Session

Simulating the LSST system

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The LSST is one of the most ambitious astronomical surveys of the coming decade. Extracting science from the resulting data stream will require a detailed knowledge of the expected performance of the LSST, and the properties of the images and derived source catalogs (including the limits to which we detect sources and how well we measure their shapes and properties). The measured attributes will depend on many different aspects of the LSST including the design of the telescope and camera, the conditions under which the data are taken, the survey strategy employed and the processes used to analyze and reduce the data. To prepare for the LSST data stream the LSST Simulation

group is, therefore, developing a framework to model and simulate the LSST system as a whole. This includes catalogs for the cosmology, Galactic structure and Solar System (to r=28), and high fidelity image simulations that trace photons through the atmosphere and telescope to the detector. We describe here the progress towards implementing this system for modeling the LSST and how it might be used as an end-to-end simulation for validating the LSST and to enable the development of science analyzes prior to the LSST coming on line.

7738-63, Poster Session

High-speed data acquisition system to measure telescope response to earthquake-induced ground motion

M. Sheehan, Gemini Observatory (United States)

The Gemini Observatory operates two telescopes, both in geographical areas that pose a significant risk of damage due to earthquakes. To assess the potential of damage due to earthquake induced ground motion, a system of accelerometers, data acquisition and analysis hardware has recently been installed on each telescope. Information from these sensors will be used to evaluate the response at various locations on the telescope including the primary and secondary mirrors and support structures, instruments, mount, pier and adjacent ground. A detailed discussion of the design of this sensor system will be presented. Future upgrades are also discussed, including provisions for automatic subsystem parking and shutdown, laser safety and alarms.

7738-64, Poster Session

Kinematic analysis of a hexapod telescope mount

Y. Huang, Institute of Astronomy and Astrophysics (Taiwan)

This paper reports a kinematic study on the hexapod mount for the Array for Microwave Background Anisotropy (AMiBA). The AMiBA is currently the only telescope utilizing a hexapod as the pointing mount. To facilitate our understanding on this novel telescope mount, we have simulated the hexapod through mathematically modeling its actuators' motion. This kinematic results are then compared with a finite element analysis (FEA) model. Our methodology will provide the first attempt of behavior analysis on the hexapod used for astronomical or communication purposes.

7738-65, Poster Session

Stray light analysis of the Thirty Meter Telescope

J. S. Pazder, National Research Council Canada (Canada)

The stray light analysis of the Thirty Meter Telescope (TMT) is discussed. Analysis has been done via non-sequential ray tracing and analytical methods. The TMT has minimal baffling to reduce cost, wind loading, and dome seeing. The result is a requirement for instrumentation to provide internal baffling to preserve performance. Key to the analysis is a quantification of telescope mirror BRDF's at the Mauna Kea summit environment due to dust contamination. A base line stray light performance is derived based on the mirror scattering. Scatter from the mechanical structures is managed to not significantly degrade this baseline. The predicted scattered light levels and the impact on observational efficiency for the telescope are reported for a variety of observing scenarios.

7738-66, Poster Session

Optical mount optimization through the integration of ANSYS and GNU octave

J. T. Fitzsimmons, National Research Council Canada (Canada)

The development of the next generation, precision instruments for the existing 8m- and 10m-class ground-based telescopes and the future 30m-class ground-based telescopes are driving the opto-mechanical precision and stability requirements to new levels. This study examines the challenges associated with designing mount configurations for precision optical mirrors (~5nm RMS WFE) and details the numerical technique developed to address these challenges. Many of these mirrors will need to be supported under all gravity vector orientations, for 60ºC temperature fluctuations and for vibration conditions typical of a cassegrain-mounted instrument. By way of developing a general technique to address this class of problem, a numerical technique was developed to integrate the ANSYS Parametric Design Language (APDL), for completing structural finite element analyses, with the GNU Octave high-level computational language, for implementing the optimization routines. The integration of these software tools allows for semi-automated optimization routines, specifically tailored to designing optical mounts, which could not be easily completed with ANSYS alone. Additional Zernike decomposition tools are also implemented through GNU Octave to evaluate the nature of the front surface deflections and facilitate the definition of meaningful merit functions.

7738-67, Poster Session

Active dynamic isolation and pointing control system design and analysis for the ACCESS TPF mission concept

P. Vallone, R. M. Egerman, J. Elias, ITT Corp. (United States)

Current concepts for some future space based astronomical observatories require extraordinary stability with respect to pointing and jitter disturbances. Exoplanet finding missions with internal coronagraphs require pointing stability of <10nanorad-rms, 3 sigma. Closed-loop active dynamic isolation at the interface between a telescope and the spacecraft (where reaction wheels are the primary jitter source) can attain this stability when incorporated with a robust overall pointing control system architecture which utilizes information from IRUs, star-trackers, and steering mirrors. ITT has developed a high TRL Active Isolation Mount System (AIMS) and through analyses and hardware test-bed work demonstrated that these stringent pointing and dynamic stability requirements can be met for the ACCESS Terrestrial Planet Observatory.

7738-69, Poster Session

LSST Telescope guider loop requirements analysis and predicted performance

M. Warner, Cerro Tololo Inter-American Observatory (Chile); V. J. Riot, Lawrence Livermore National Lab. (United States); J. Sebag, National Optical Astronomy Observatory (United States)

The LSST Telescope has critical requirements on tracking error to meet image quality specifications, and will require closing a guiding loop, with the telescope servo control, to meet its mission. The guider subsystem consists of eight guiding sensors located inside the science focal plane at the edge of the 3.5deg field of view. All eight sensors will be read simultaneously at a high rate, and a centroid average will be fed to the telescope and rotator servo controls, for tracking error correction.

A detailed model was developed to estimate the sensors centroid noise and the resulting telescope tracking error for a given frame rate and telescope servo control system. The centroid noise depends on the photo-electron flux, seeing conditions, and guide sensor specifications. The model for the photo-electron flux takes into consideration the guide

star availability at different galactic latitudes, the atmospheric extinction, the optical losses at different filter bands, the detector quantum efficiency, the integration time and the number of stars sampled.

A 7-layer atmospheric model was also developed to estimate the atmospheric decorrelation between the different guide sensors due to the 3.5deg field of view, to predict both correlated and decorrelated atmospheric tip/tilt components, and to determine the trade-offs of the guider servo loop.

7738-71, Poster Session

A formal risk management process for instrumentation projects at the Anglo-Australian Observatory

D. R. Orr, A. Heng, Anglo-Australian Observatory (Australia)

Risk management is a dynamic activity that takes place throughout the development process from the concept phase to the retirement phase of the project.

The successful management of risk is a critical part of the instrumentation development process at the AAO. The AAO has a risk management process based on the AS/ISO standard for risk management.

Brainstorming sessions are conducted with the project team. Potential project risks are identified by the team and grouped into the categories of technical, political, operational, logistical, environmental, and safety. A risk matrix is populated with details of each risk. The risk is then ranked based on the consequence and likelihood according to the scale of Low, Moderate, Significant, and High. The level of risk is evaluated; mitigation control mechanisms are identified, and assigned to a specific team member for resolution.

Risk management is used as a management tool for the HERMES project. The top 5 risks are identified, and management efforts are then concentrating on reducing these risks. Risk management is also used during the development process as a trade study tool to evaluate different design options and assist senior management to make informed decisions.

7738-72, Poster Session

PORÍS: practical-oriented representation for instrument systems

J. J. Vaz-Cedillo, J. C. Lopez-Ruiz, J. Marco de la Rosa, Instituto de Astrofísica de Canarias (Spain)

This article presents a toolkit for defining simple but powerful systems. PORIS toolkit is an open and extensible source collaborative project that allow describing system graph-based systems and their behavior in a snapshot. It provides a web editor for a domain visual specific language and transformation tools to generate software prototypes, system configurations, specific user interfaces and documentation. Different kind of instruments, like the astronomical ones,can be described and represented using PORIS specifications and models. A significant advantage of using PORIS toolkit is that it makes easy and lighter providing instant feedback to domain experts in the dynamic process of defining new instruments.

7738-73, Poster Session

Role and uses of uncertainty in integrated modeling of telescope and instrumentation systems

L. Zago, HEIG-VD (Switzerland)

Integrated (end-to-end) modeling has become in past years a standard component of the development process of high-precision opto-mechatronic systems. In particular, complex models are used to formulate and evaluate all aspects and performances of telescope and instrumentation systems. They also constitute the main tool for preparing the error budget tables which have been used for a still longer time in the design of these systems, in particular to derive subsystem and component requirements.

Curiously enough, uncertainty is not often considered rigorously in these models: engineers still tend in many cases to take conservative (“wrong-side”) assumptions for critical parameters instead of fully including a rigorous assessment of all uncertainty aspects in the modeling.

In this paper we first summarize the modern approach to uncertainty in metrology, in particular the GUM (Guide to the expression of Uncertainty in Measurement) ISO standard, as well as some of its still controversial aspects.

We then proceed to illustrate how such methods can be usefully implemented in integrated models, in particular to derive design parameters and error budgets that are more precisely quantified in statistical terms and less biased to overconservative assumptions.

With the advent of much greater complexity in the concept of ELT’s and next generation instruments, the cost of “prudent” overspecification of components becomes unbearable. Integrated models capable of producing figures with uncertainties that are rigorously assessed and therefore uncontroversial become then necessary and significant to the development process.

7738-74, Poster Session

VISTA, a success story: from conceptual design to operation

A. J. Born, UK Astronomy Technology Ctr. (United Kingdom)

This paper considers the development and progression of the VISTA telescope, from conception to the point where it is now being operated by the scientific community (end user). It analyses and evaluates the value of effective Project Management and Systems Engineering practices with practical examples.

The practical application of Systems Engineering is addressed throughout the Requirement Capturing, Requirements Management, Design, Manufacture, Assembly, Integration, Commissioning, Verification and Acceptance phases, highlighting the value gained by appropriate application of step-by-step procedures and tools. Special emphasis on the importance of effective Systems Engineering during on-site installation, verification and validation will be illustrated.

Project Management aspects are covered from Tendering and Procurement through Contractor Management processes to final integration and commissioning, with great emphasis placed on the importance of a “win-win” approach and the benefits of effective, constructive Customer/Contractor liaison. Consideration is given to the details and practicalities of day-to-day Site Management, safety, housekeeping, and the management and support of site personnel and services.

Recommendations are made to improve the UK ATC System Engineering process so that future projects can benefit from the lessons learned on VISTA

7738-75, Poster Session

Integrating AO in a performance budget: toward a global system engineering vision

P. Laporte, Observatoire de Paris à Meudon (France); H. Schnetler, UK Astronomy Technology Ctr. (United Kingdom)

EAGLE (Extremely large Adaptive telescope for GaLaxy Evolution) is one of the eight E-ELT instruments concepts that was developed as part of the Phase A E-ELT instrument studies. EAGLE is a near-infrared wide field multi object spectrograph. It includes its own multi-object adaptive optics system (MOAO) and its subsystems are cooled down so as to ensure that the instrument can both achieve the desired spatial resolution in the K-band and to ensure that the instrument is background limited, as required in the primary science case. To ensure that the instrument can deliver the performance in the K-band,. In this paper we discuss the performance matrix developed to allow us to partition and allocate the important performance characteristics to the various subsystems as well as to describe the process to verify that the current concept design will deliver the required performance. Due to the integrated nature of the instrument, a large number of AO parameters have to be controlled. The performance matrix also has to deal with the added complexity of active optical elements such as the science channel deformable mirrors (DMs). This paper also defines a method of how to convert the ensquared energy (EE) and signal-to-noise ratio (SNR) required by the primary science case into the "as designed" wavefront error and the overall residue wavefront error. To ensure successful integration and verification of the next generation instruments for ELT it is of the utmost importance to have method to control and managed the instrument's critical performance characteristics.

7738-78, Poster Session

Image quality verification analysis of the JWST

S. Knight, Ball Aerospace & Technologies Corp. (United States)

The JWST optical performance verification poses challenges not yet encountered in space based telescopes. The deployable, segmented Primary Mirror and Secondary Mirror require re-alignment after launch rendering ground alignment states unusable. The architecture of JWST was designed to accommodate these difficulties by including active positioning of the Secondary Mirror and the Primary Mirror Segments. In fact, the requirements are written such that the active control system shall be used to meet the requirements. Therefore many of the optical requirements are necessarily based on modeling and simulations of the active re-alignment of the telescope. This paper provide an overview of a process of computer simulation using an end-to-end integrated model that is used to statistically evaluate the on-orbit, re-alignment performance based on the uncertainties in the integration and test program and deployments.

7738-80, Poster Session

The VST telescope primary mirror safety system: simulation model and mechanical implementation

F. Perrotta, P. Schipani, D. Fierro, Osservatorio Astronomico di Capodimonte (Italy)

The VST telescope is a wide field survey telescope partially installed at Cerro Paranal (Chile). Due to the geological nature of the area, telescopes in Chile are always submitted to unpredictable and sometimes severe earthquake conditions. The common way to investigate earthquake-related stress and deformation conditions on a structure is to perform a Response Spectrum Analysis. In order to clarify some aspects of VST telescope peculiar dynamics during an earthquake, that are not well represented by a linear procedure like RSA, a transient nonlinear analysis of the whole telescope has been foreseen. A mixed approach FE- Matlab-Simulink has been introduced and a linear FE model of the telescope has been developed, with all the nonlinearity sources represented by linear elements whose stiffness is the initial stiffness of the nonlinear force-displacement curve. This model has been then transported, using a space state model representation, into Simulink, where all nonlinearities are then appropriately built and a transient analysis is run. The transient analysis will be performed applying to the model a base excitement corresponding to accelerograms compliant with Paranal MLE Response Spectrum, following the provisions of EUROCODE 8. The paper describes both model and results, giving also a brief overview of the actual safety system mechanical implementation, based on analysis results.

7738-81, Poster Session

The Baldrige criteria for performance excellence for quality management in observatories

N. M. Radziwill, James Madison Univ. (United States)

The criteria are used by the Malcolm Baldrige National Quality Award (MBNQA), administered by the National Institute of Standards and Technology (NIST). The framework has been developed by over 2,000 professionals in technical management and quality management since 1987. This presentation will introduce the Baldrige Criteria.

7738-82, Poster Session

Virtual reality and project management for astronomy

L. A. Martinez, F. Angeles, R. A. Flores, J. L. Villarreal, E. Bribiesca, Univ. Nacional Autónoma de México (Mexico)

In every project, communication plays a fundamental role to achieve success. Over the years astronomical instrumentation projects are becoming increasingly complex making necessary to find efficient ways for project communication management. While all projects share the need to communicate project information, the information needs and the methods of distribution widely vary between projects and project staff. A particular problem experienced on many projects regardless of their size, is related to the amount of design, planning information and how that is distributed among the project stakeholders. One way to improve project communications management is to use a workflow that offers a predefined way to share information in a project. Virtual Reality (VR) offers the possibility to get a visualization of designed components without the costs of building prototypes, giving an experience that mimics real life situations using a computer. This work explores VR as a communication technology that helps to manage instrumentation projects by means of a workflow designed at Universidad Nacional Automa de Mexico (UNAM). Considering the fact that most of the engineering designs are modeled through computer-aided design (CAD) software, the workflow can integrate VR environments generated from CAD models.

7738-84, Poster Session

Collaborative engineering and design management for the Hobby-Eberly Telescope tracker upgrade

N. T. Mollison, R. J. Hayes, J. R. Jackson, R. D. Savage, M. D. Rafal, J. H. Beno, The Univ. of Texas at Austin (United States)

The engineering and design of systems as complex as the Hobby-Eberly Telescope's tracker require that multiple tasks be executed in parallel and overlapping efforts. When the design of individual subsystems is distributed among multiple organizations, teams, and individuals, challenges can arise with respect to managing design productivity and coordinating successful collaborative exchanges. This paper focuses on design management issues and current practices for the tracker design portion of the Hobby Eberly Telescope Wide Field Upgrade project. The scope of the tracker upgrade requires engineering contributions and input from numerous fields including optics, instrumentation, electro-mechanics, software controls engineering, and site-operations. Successful system-level integration of tracker subsystems and interfaces is critical to the telescope's ultimate performance in astronomical observation. Software and process controls for design information and workflow management have been implemented to assist the collaborative transfer of tracker design data. The tracker system architecture and selection of subsystem interfaces has also proven to be a determining factor in design task formulation and team communication needs. Interface controls and requirements change controls will be discussed, and critical team interactions are recounted (a group-participation Failure Modes and Effects Analysis [FMEA] is one of special interest). This paper will be of interest to engineers, designers, and managers engaging in multi-disciplinary and parallel engineering projects that require coordination among multiple individuals, teams, and organizations.

7738-86, Poster Session

A paradigm shift to enable more cost effective space science telescope missions in the upcoming decades

G. Matthews, R. M. Egerman, K. A. Havey, Jr., ITT Corp. (United States)

Modern astronomy currently is dealing with a exciting but challenging dichotomy. On one hand, there has been and will continue to be countless advances in scientific discovery, but on the other the astronomical community is faced with what unfortunately is considered by many to be an insurmountable budgetary impasse for the foreseeable future. The National Academy of Sciences' Astro2010: Decadal Survey has been faced with the difficult challenge of prioritizing sciences and missions for the upcoming decade while still allowing room for new, yet to be discovered opportunities to receive funding. To this end, we propose the consideration of a paradigm shift to the astronomical community that may enable more cost efficient space-based telescope missions to be funded and still provide a high science return per dollar invested. The proposed paradigm shift has several aspects make it worthy of consideration: 1) Telescopes would leverage existing Commercial Remote Sensing Satellite (CRSS) Architecture such as the1.1m NextView systems 2) Through the use of large EELV class fairings multiple telescopes with different science missions could be flown on one spacecraft bus sharing common features such as communications and telemetry (Current Earth Science Missions in early development phases are considering this approach) 3) Multiple 1.1m observatories could be flown in a single launch vehicle for instances where the different science payloads had incompatible requirements and 4) by leveraging CRSS architectures, vendors could supply the telescopes at a fixed price. Here we discuss the implications and risks that the proposed paradigm shift would carry.

7738-34, Session 8

Systems engineering on the James Webb Space Telescope

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The James Web Space Telescope (JWST) is a large, infrared-optimized space telescope scheduled for launch in 2014. JWST is an international collaboration between NASA, the European Space Agency (ESA), and the Canadian Space Agency (CSA). The NASA Goddard Space Flight Center is managing the development effort. The prime contractor is Northrop Grumman; the Space Telescope Science Institute is responsible for JWST science operations after launch. The imaging performance of the telescope will be diffraction limited at 2μm, defined as having a Strehl ratio >0.8. System-level verification of critical performance requirements will rely on integrated observatory models that predict the wavefront error accurately enough to verify that allocated top-level wavefront error of 150 nm root-mean-squared (rms) through to the wave-front sensor focal plane is met. An end-to-end optical test at operating temperatures and environments following a standard "test as you fly" approach is not practical with available ground thermal vacuum chambers. The systems engineering approach for such a large cryogenic telescope while rooted in traditional systems engineering practices must therefore be augmented for the James Webb Space Telescope throughout its life cycle to enable the telescope to be verified by analysis. This paper describes the systems engineering used on the JWST through the detailed design phase with an eye to the verification phase of the project.

7738-35, Session 8

10 years of Chandra: reflecting back on engineering lessons learned during the design, fabrication, integration, test, and verification of NASA's Great X-ray Observatory

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Chandra was designed for a five year life, and in September of 2009 NASA and the astronomical community proudly celebrated its 10 year anniversary on-orbit taking breathtaking images and collecting critical science data that has been used to further our understanding of the cosmos. This paper will emphasize how the Chandra telescope hardware was designed, tested, and most importantly verified and accepted for flight for the benefit of all future missions that must find efficient ways to drive out cost and schedule while still maintaining an acceptable level of risk. Examples of how the verification methodology mitigated risk will be provided along with actual flight telemetry which confirms the robustness of the Chandra Telescope design and its verification methodology.

7738-36, Session 8

NuSTAR: system engineering and modeling challenges in pointing reconstruction for a deployable X-ray telescope

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The Nuclear Spectroscopic Telescope Array (NuSTAR) is a NASA Small Explorer mission that will make the first sensitive images of the sky in the high energy X-ray band (6 - 80 keV). The NuSTAR observatory consists of two co-aligned grazing incidence hard X-ray telescopes with an ~10 meter focal length, achieved by the on-orbit extension of a deployable mast.

A principal science objective of the mission is to locate previously unknown high-energy X-ray sources to an accuracy of 10 arcseconds (3-sigma), sufficient to uniquely identify counterparts at other wavelengths. In order to achieve this, a star tracker and laser metrology system are built into the instrument; in conjunction, they will determine the orientation of the optics bench in celestial coordinates and also measure the flexures in the deployable mast as it responds to the varying on-orbit thermal environment. The architecture of the NuSTAR system for solving the attitude and aspect problems differs from that of previous X-ray telescopes, which did not require ex post facto reconstruction of the instantaneous observatory alignment on-orbit.

In this paper we describe the NuSTAR instrument metrology system architecture and implementation, focusing on the systems engineering challenges associated with validating the instantaneous transformations between focal plane and celestial coordinates to within the required accuracy. We present the mathematical solution to photon source reconstruction, along with a detailed budget that relates component errors to science performance. We also describe the architecture of the instrument simulation software being used to validate the end-to-end performance model.

7738-37, Session 8

The project office of the Gaia data processing and analysis consortium

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This paper will describe the approach with which the software development for the Gaia data processing is managed. The development of the data reduction and analysis software for the Gaia instruments - astrometry, photometry and spectroscopy - and the subsequent scientific analysis, is done independent from each other. So the DPAC Project Office is developing the methods to monitor and guide the different developer groups towards the final data product.

7738-38, Session 8

The role of stray light modeling and analysis in telescope system engineering, performance assessment, and risk abatement

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Stray light modeling and analysis play a key role in new technology assessment, system engineering, and the overall performance assessment of telescope/instrument systems under real use conditions. It also is a key tool in risk reduction as stray light problems that appear late in the program are usually severe, expensive to fix, and often compromise final system performance. This paper will review the current stray light software and testing tools of value to the astronomical community and their capabilities/ limitations for general and specialized telescope systems. We will describe the role of stray light analysis in end-to-end modeling and integrated modeling for a number of systems we have analyzed and discuss in detail the stray light modeling and analysis cycle for different types of programs. A key issue is how managers might deal with the issues revealed by an analysis as well as the risks of an incomplete or improperly-timed analysis. The importance of stray light analysis for end-to-end performance assessment and whether such an analysis can reduce life-cycle costs will also be discussed. The paper will use examples from ground and space-based astronomical telescope/ instrument systems.

7738-40, Session 9

Confronting the NIRSpec instrument performance simulator outputs with results of the NIRSpec demonstration model calibration campaign

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The James Webb Space Telescope (JWST) is the successor mission to the Hubble Space Telescope and will operate in the near- and mid-infrared wavelength ranges. One of the four science instruments on board the spacecraft is the multi-object spectrograph NIRSpec, currently developed by the European Space Agency (ESA) with EADS Astrium Germany GmbH as the prime contractor. NIRSpec will be able to measure the spectra of more than 100 objects simultaneously and will cover the near infrared 0.6-5.0μm wavelength range at various spectral resolutions. To verify the performance of NIRSpec and simulate future on-ground and in-orbit observations with this instrument, the Instrument Performance Simulator (IPS) software is developed at Centre de Recherche Astrophysique de Lyon (CRAL) as subcontractor to Astrium.

In early and mid-2009, the NIRSpec Demonstration Model (DM), fully representative up to the slit plane where the detector was located, underwent cryogenic tests and calibration runs. A simpler version of the IPS was prepared, matching the DM configuration (IPS1) and also serving as a testbed for the final software for the flight model. In this paper, we first present the simulation approach used in the IPS, followed by results of the DM calibration campaign. Then, for the first time, simulation outputs are confronted with the measured data to verify their validity.

7738-41, Session 9

The JWST/NIRSpec instrument performance simulator software

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The spectrograph NIRSpec is one of the four instruments present on the future James Webb Space telescope (JWST). NIRSpec is a multi-object spectrograph that will be capable of low (100) to medium (1000-2700) resolution spectroscopy through a fully-addressable array of micro-shutters. NIRSpec will also have an integral-field spectrograph mode, a classical slit spectrograph mode and an imaging mode for target acquisition. It is being built by EADS Astrium for ESA. The Centre de Recherche Astrophysique de Lyon (CRAL) is responsible of the development of a dedicated software for the modeling of NIRSpec's performances and to simulate raw exposures.

In this paper, we describe the latest version of this instrument performance simulator (IPS) software. We first present the key simulation modules of the software as well as as its user interface. We then discuss "benchmark" test results outlining its intrinsic accuracy. Last we show the first results of the simulation of calibration exposures for the various modes of NIRSpec as they will be obtained during the NIRSpec on-ground calibration campaign.

7738-42, Session 9

An update on the role of system modeling in the design and verification of the James Webb Space Telescope

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The James Web Space Telescope (JWST) is a large, infrared-optimized space telescope scheduled for launch in 2014. JWST is an international collaboration between NASA, the European Space Agency (ESA), and the Canadian Space Agency (CSA). The NASA Goddard Space Flight Center is managing the development effort. The prime contractor is Northrop Grumman; the Space Telescope Science Institute is responsible for JWST science operations after launch. The imaging performance of the telescope will be diffraction limited at 2µm, defined as having a Strehl ratio >0.8. System-level verification of critical performance requirements will rely on integrated observatory models that predict the wavefront error accurately enough to verify that allocated top-level wavefront error of 150 nm root-mean-squared (rms) through to the wave-front sensor focal plane is met. Furthermore, responses in several key disciplines are strongly cross-coupled. The size of the lightweight observatory structure, coupled with the need to test at cryogenic temperatures, effectively precludes validation of the models and verification of optical performance with a single test in 1-g. Rather, a complex series of incremental tests and measurements are used to anchor components of the end-to-end models at various levels of subassembly, with the ultimate verification of optical performance is by analysis using the assembled models. The assembled models themselves are complex and require the insight of technical experts to assess their ability to meet their objectives. This paper describes the systems engineering and modeling approach used on the JWST through the detailed design phase.

7738-43, Session 9

Verification of the observatory integrated model for the JWST

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A modular, interactive system model tool is developed for JWST to serve as “Virtual Observatory”. This tool serves as system simulation environment, analysis toolkit, and software test bed. The system model is designed to represent a high fidelity model of the optical system and those subsystems whose performance affects the optical performance of the Observatory. As input to the optical performance, there is a combination of data derived from the Integrated Modeling and various optical tests. These inputs are aggregated in the Integrated Telescope Model and analyzed in conjunction with the WFS&C system to produce data to verify the optical requirements. This paper describes the validation of the system models. The validation is important since the mission level pre-flight optical requirements are verified by analysis.

7738-44, Session 10

Application of systems engineering concepts in the Canada-France-Hawaii Telescope Observatory automation project

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In 2007, the Canada-France-Hawaii Telescope (CFHT) undertook a project to augment the efficiency of the observatory by implementing remote control and observing capabilities. Instead of having the current Observing Assistant and Service Observer operating the telescope and performing the observations from the summit, this project will allow one Remote Observer to remotely control the observatory for the night from the headquarters building in Waimea with no staff at the summit.

This paper will describe how systems engineering concepts have shaped the design of the project structure and execution. Requirements analysis and management, systems architecture, project planning, interface management, systems test and integration, and risk management are some of the systems engineering tools that have formed the foundation of this project.

The paper will also discuss the status of the integration and installation of the upgrades that the CFHT is undergoing to facilitate the remote operation of the observatory on a regular basis by the end of 2010. This constitutes major changes for a facility that was never designed for remote operation, and systems engineering practices are enabling the modification of legacy equipment and the smooth integration of new control and monitoring instrumentation throughout the observatory. The system design and planning for the upgrades ensures implementation can be completed without downtime or loss of observing time, and without compromising the reliability of summit operations or safety.

7738-45, Session 10

Systems engineering for the Thirty Meter Telescope

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This paper will provide a critical overview of the systems engineering processes implemented in the TMT project. Major components of these processes are configuration management, requirements engineering, system verification, system trades, and performance estimates. As the details of some of these areas are covered in other publications, we mostly focus on performance allocation and estimates, as well as a stochastic approach to defining the environmental conditions for the observatory. The science capabilities of the observatory crucially depend on concurrently maintaining good image quality in the entire FoV, acceptable pupil alignment, as well as uniform and stable plate scale. While these characteristics are obviously highly relevant to seeing limited observations, they also form the basis of the adaptive optics performance. The paper explains the control architecture capable of achieving these simultaneous objectives, as well as the resulting requirements and tolerances for the participating subsystems. The simulations validating the architecture are also summarized. The environmental conditions at the site of the observatory are significant design drivers, so it is essential to understand them both from performance and cost viewpoint. The probabilities for the observatory of not meeting performance, not being able to properly functioning, or suffering excessive damage are included in the cost/performance trade. The selected design requirements for temperature, humidity, wind speed, and precipitation are reported.

7738-46, Session 10

Systems engineering of the Thirty Meter Telescope through integrated opto-mechanical analysis

S. Roberts, National Research Council Canada (Canada)

The merit function routine (MFR), implemented in the MATLAB numerical computing environment, links ANSYS finite element modeling and ZEMAX optical design software to provide a powerful opto-mechanical engineering tool. The MFR is utilized by the Thirty Meter Telescope Project to assess the telescope active optics system requirements and performance. The input data are structural system finite element model displacements based on elevation angle gravitional changes and thermal loads. The results calculated include the rigid body motion of the primary mirror segments, the secondary, tertiary mirrors, and the science instruments; the resultant optical axis of the telescope after active optics correction; the required actuator strokes to phase the 492 primary mirror segments; primary mirror segment lateral motion and the resulting

gap change between segments; plate scale variation, and pupil shifts. This information is used to define and evaluate telescope alignment tolerances, error budgets, and to assess and optimize the telescope structural performance relative to requirements. This paper describes the MFR tool, including the interfaces to Ansys, Zemax, the method of calculation of the results, and the internal data structures used. A summary of the required performance of the Thirty Meter Telescope, and the MFR results for the telescope system design are presented.

7738-47, Session 10

Use of requirements engineering to maintain traceability and consistency between high-level science requirements and the detailed requirements applicable to individual subsystems of the Thirty Meter Telescope

J. Rogers, TMT Observatory Corp. (Canada)

The Thirty Meter Telescope is comprised of thirty six individual sub-systems which include optical systems, instruments, adaptive optics systems, controls, mechanical systems, supporting software and hardware and the infrastructure required to support their operation. These thirty six sub-systems must operate together as a system to enable the telescope to meet the science cases for which it is being developed. These science cases are formalized and expressed as science requirements by the project's Science Advisory Committee. From these, a top down requirements engineering approach is used within the project to derive consistent operational, architectural and ultimately detailed design requirements for the sub-systems. The various layers of requirements are stored within a DOORS requirements database that also records the links between requirements, requirement rationale and requirement history. This paper describes the development of the design requirements from science cases, the reasons for recording the links between requirements and the benefits that documenting this traceability will yield during the design and verification of the telescope. Examples are given of particular science cases, the resulting operational and engineering requirements on the telescope system and how individual sub-systems will contribute to these being met.

7738-48, Session 10

Building confidence early and often: a systematic approach to requirement verification for a large telescope project

H. A. Thompson, TMT Observatory Corp. (Canada)

Hundreds of requirements have been written for the Thirty Meter Telescope at both the system level and at the level of the thirty-six defined subsystems. These statements about future performance are only meaningful if something is done to verify that each one is met. This paper presents a systematic approach to selecting verification methods that build confidence in the system as early as possible and limit verification using expensive end-to-end system tests to a minimum. Understanding how requirements will be verified enables the impact of verification activities on integration and test schedules to be assessed. The TMT verification framework ensures that tests and verifcation activities are planned, recorded and traceable. The set of documents that are used to capture this information are described and examples from the TMT verification matrix are provided. Ultimately this documentation improves the capability of operations teams to trace the causes of future anomalies by providing an archive of the procedures and results that were used to establish the initial system performance with respect to the written requirements.

7738-79, Session 10

The large observatories maintenance management: tools and strategies for maintenance manuals preparation

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New large Observatories, like E-ELT and ALMA, require enormous efforts in preparing and maintaining the Maintenance Manuals. The possibility to adopt a standardised system, associated to centralized data base and software tools is investigated to evaluate the initial efforts w.r.t. to the final benefits, both for the tools preparation and for the end-users operation. The adoption of this relatively new strategy implies a small revolution of Maintenance Manuals: from a descriptive collection of information(mainly paper-based), to a modular approach where data module is defined as "the smallest self-contained information unit within a technical publication". The initial efforts associated to the data module preparation and organization is compensated by several benefits like time savings for technicians and other end-users of this technical data; training requirements are also reduced because information can be accessed more rapidly, reducing down-time for equipment. Moreover, cost savings in the preparation process performed in a manner that will be repeatable across multiple publications, even for different equipment, is possible. Finally, this standardised strategy will assure interoperability across different partners as it normally happens for Large Astronomical Projects. The possibility to migrate from existing manuals data to the new ones by making the complete computerization and the subdivision of the contents in Data Module (DM), is also recalled.

7738-50, Session 11

Using SysML for MBSE analysis of the LSST system

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The Large Synoptic Survey Telescope is a complex hardware - software system of systems, making up a highly automated observatory in the form of an 8.4m wide-field telescope, 3.2 billion pixel camera, and a peta-scale data processing and archiving system. As a project, the LSST is using model based systems engineering (MBSE) methodology for developing the overall system architecture coded with the Systems Modeling Language (SysML). With SysML we use a recursive process to establish three-fold relationships between requirements, logical & physical structural component definitions, and overall behavior (activities and sequences) at successively deeper levels of abstraction and detail. Using this process we have analyzed and refined the LSST system design, ensuring the consistency and completeness of the full set of requirements and their match to associated system structure and behavior. As the recursion process proceeds to deeper levels we derive more detailed requirements and specifications, and ensure their traceability. We also expose, define, and specify critical system interfaces, physical and information flows, and clarify the logic and control flows governing system behavior. The resulting integrated model database is used to generate documentation and specifications and will evolve to support activities from construction through final integration, test, and commissioning, serving as a living representation of the LSST as designed and built. We discuss the methodology and present several examples of its application to specific systems engineering challenges in the LSST design.

7738-51, Session 11

The Large Synoptic Survey Telescope OCS and TCS models

G. Schumacher, F. Delgado, Cerro Tololo Inter-American Observatory (Chile)

The Large Synoptic Survey Telescope (LSST) is a project envisioned as a system of systems with demanding science, technical, and operational requirements, that must perform as a fully integrated unit. The design and implementation of such a system poses big engineering challenges when performing requirements analysis, detailed interface definitions, operational modes and control strategy studies. The OMG System Modeling Language (SysML) has been selected as the framework for the systems engineering analysis and documentation for the LSST. Models for the overall system architecture and different observatory subsystems have been built describing requirements, structure, interfaces and behavior. In this paper we show the models for the Observatory Control System (OCS) and the Telescope Control System (TCS), and how this methodology has helped in the clarification of the design and requirements. In one common language, the relationships of the OCS, TCS, Camera and Data management subsystems is captured with models of the structure, behavior, requirements and the traceability between them.

7738-52, Session 11

Conquering complexity with systems engineering, as illustrated by EAGLE (a multi-object adaptive optics IFU spectrograph)

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This paper illustrates how the design of an instrument such as the Extremely Large Adaptive Telescope for GaLaxy Evolution (EAGLE) instrument can be simplified. EAGLE is a Wide Field Multi Object Integral Field Unit Spectrometer aimed as a cornerstone instrument for the European Extremely Large Telescope (E-ELT). The instrument is rich in capabilities and will require Adaptive Optics to ensure that the expected spatial resolution (typically 15 times higher than that of a seeing limited instrument) can be met. The complexities introduced by inclusion of Multi-Object Adaptive Optics (MOAO) can be effectively managed by using well defined systems engineering processes. These processes include the capturing, analysis and flow down of requirements, functional and performance analysis and an integrated system design approach. In this paper we will also show by example why the discipline imposed by the UK ATC formal systems engineering process is necessary, especially given that projects such as EAGLE also have to deal with the complexities of international collaborations. Finally we show that the process promotes innovation and creativity.

7738-53, Session 11

E-ELT phase-A instrument studies: a system engineering view

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During the last two and half years ten phase-A instrument studies for the E-ELT have been launched by ESO and carried out by consortia of institutes in the ESO member states. These studies have been undertaken in parallel with the phase B of the E-ELT telescope. This effort has pursued two main goals: to prove the feasibility and performance of a set of instruments to meet the project science goals and to identify and incorporate in the telescope design those aspects that satisfy best the needs of the future hosts, ie, the science instruments. To succeed on this goal it is crucial to identify such needs as early as possible in the design process.

This concurrent approach definitively benefits both the instruments concept design and the telescope development, but implies as well a number of difficult tasks. This paper compiles, from a system-engineering point of view, the benefits and difficulties as well as the lesson learned during this concurrent process. In addition, the main outcomes of the process, in terms of telescope-instruments interfaces definition and requirements from the instruments to the telescope and vice-versa, are reported.

7738-54, Session 11

Error budgets definition for the European Solar Telescope (EST)

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The European Solar Telescope (EST) is a European collaborative project to build a 4m class solar telescope in the Canary Islands, which is now in its design study phase. The telescope will provide diffraction limited performance for several instruments observing simultaneously at the Coudé focus at different wavelengths.

In order to guarantee the achievement of the demanding scientific requirements, error budgets of main performance have been defined from the early design study phase in top-down fashion. During the design study, analyses are being performed in order to update the defined error budgets in bottom-up fashion. Error budget management is proposed from the design study phase to be used during the complete project life cycle.

Conference 7739: Modern Technologies in Space- and Ground-based Telescopes and Instrumentation

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7739-02, Session 1

Fabrication technologies for large optical components at Carl Zeiss Jena GmbH

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Optic for telescope use - on ground and in space - is getting more and more into complex geometries. Weight reduction and new materials together with aspherical shape and off-axis set-ups increases the need for fabrication approaches with a high number of implemented and interconnected steps. With the advent of free-form surfaces having no symmetries at all, a new chapter for fabrication issues is opened.

This paper describes our current achievements to combine different fabrication and measurement technologies to cope with the increasing demand in precision and complexity. We will explain our fabrication approach covering the full range from the raw material down to the coated and measured component. From classical robot polishing systems which are often used for large optics to ion beam figuring techniques, we will also look further into off-axis aspheres and shed some light into recent developments on fabrication and metrology of free-form surfaces.

7739-03, Session 1

How fast is too fast: manufacturing limitations of aspheric optics at Tinsley

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Recent results on optics that exhibit very fast f/# and high aspheric departure suggest that modern designers can reach for the performance of more extreme designs than previously available. We will describe the manufacturing limitations on f/#, aperture, aspheric departure, surface irregularity, and surface roughness currently achievable. Using older methods, when aspheric departure becomes large, optics exhibit zone artifacts.

We will demonstrate with PSD curves that our modern methods produce remarkably smooth behavior over all spatial frequencies, even for optics with aspheric departures far beyond the manufacturing capabilities of currently available OEM equipment. Smoothness of surface at mid-spatial frequencies may have a significant effect on the performance metrics contrast and ensquared energy. We will talk about several specific cases, including constraints imposed by testing these optics.

7739-04, Session 1

Precision grinding for rapid fabrication of segments for extreme large telescopes using the Cranfield BoX®

X. P. Tonnellier, P. M. Morantz, P. R. Shore, A. Baldwin, Cranfield Univ. (United Kingdom)

A new ultra precision large optics grinding machine, BoX®, was developed and commissioned at Cranfield University. BoX® offers a rapid and economic solution for grinding large off-axis aspherical and free-form optical components [1]. The efficient grinding process stage is provided in order to reduce necessary polishing stages through achievement of high surface form accuracy, good surface quality and low subsurface damage [2].

This paper provides data to re-enforce the claim the BoX® machine offers a rapid grinding capability for producing ELT mirror segments [3]. A production grinding capability of 1 mirror segment of 1.46m per day is achievable using BoX®.

Two Zerodur hexagonal mirrors of 1m and 1.46m across corners were machined. The grinding experiments have been conducted using diamond resin bond wheels with grits sizes of 76µm, 46µm and 25µm. The highest material removal rate used (187.5mm3/s) ensures that a 1m diameter optic can be ground in less than 10 hours. The surface roughness and surface profile were measured using a Form Talysurf on small representative parts. The subsurface damages were revealed using a sub-aperture polishing process [4] in combination with an etching technique.

These experiments point out the scalability of the rapid grinding process developed on large optics up to 1.5m. The use of an in-situ measurement technique and error correction procedure permitted to improve initial ground form [5] achieving a form accuracy of 1µm p-v over 1 metre. The results highlighted the effect of grinding parameters and machines dynamics on form accuracy and induced levels of subsurface damage.

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7739-05, Session 1

M2: the most difficult mirror in many telescope systems

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When telescopes become large, fields wide, unobscured designs required and f/numbers aggressive, the secondary mirror (M2) rapidly becomes the most difficult mirror in the telescope system to fabricate. This is largely due to the difficulty of accurately measuring convex mirrors during optical process convergence, and having optical finishing methods available that can achieve a smooth PSD over all relevant spatial frequencies and over the entire surface. Similar problems associate with convex mandrel fabrication, and similar methods may be used. We will discuss results at L-3 Tinsley (and Brashear) suggesting the realm of paradigms that are available to telescope architects and optical designers for new generations of telescopes and beam expanders. Actual cases will be described, and relevant functional parameters discussed. Emerging instruments may assist in simplifying test equipment for future systems.

7739-06, Session 1

M1 and M2 mirror manufacturing for ARIES project: current status

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JSC LZOS under the contract with firm AMOS is carrying out the manufacturing works of Primary and Secondary Mirrors of Devasthal Optical Telescope (DOT) for Aryabhatta Research Institute of Observational Sciences (ARIES). Primary mirror specifications: diameter 3700 mm, vertex radius 14639 mm (F/1.96), conical constant -1.03296, asphericity 111 microns. Secondary mirror specifications: diameter 980 mm, vertex radius 4675 mm (F/1.78), conical constant -2.79561, asphericity 47 microns. The current progress status under this project is presented here in the manuscript.

7739-07, Session 1

Ultra-precisely manufactured mirror assemblies with well-defined reference structures

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Aspherical surfaces for imaging, spectroscopy or beam shaping are a centerpiece of today's high-performance mirror optics. The growing design freedom is accompanied by new challenges regarding the manufacturing and assembly of optical components. Only mirrors that are manufactured ultra-precisely, characterized and assembled into the optical path with micrometer accuracy can tap their full potential for the application. References and interfaces with a tight geometrical relation to the mirror are equally important as the high quality of the optical surface itself. The time consuming assembly of optical instruments like mirror telescopes can be considerably reduced by adjusting the position of more than one mirror surface during the manufacturing process. Hence the alignment of mirrors on a common substrate is fixed in highest precision using this manufacturing approach.

The diamond tool offers outstanding properties for the ultra precise cutting of a variety of non ferrous metals. The reduction of the form deviation to the sub-micrometer level over the optical surface is achieved by correcting the measured systematic errors, with a modified tool path during the cutting process. A newly developed manufacturing approach, which accounts for the shape and also for the position of functional elements, allows controlling and precisely correcting not only the form, but also the alignment of reference marks, assembly surfaces or even other mirror faces in the sub-assembly. The approach is based on the manufacturing of the mirror surface, references, interfaces and other optical mirrors in only one machine setup. All mentioned elements are machined in a conjoint coordinate system, which is available to additional linked processes like the measurement, using the in-process reference marks.

The acquisition of form and position errors is now based on a fixed relation to the optical coordinate system of the mirror surface. Hence the targeted correction of form and position of all elements relative to the reference marks can be achieved in an additional manufacturing step on the ultra precision machine.

Taking advantage of the rotational symmetry of system designs like the Korsch-telescope or Three Mirror Anastigmats (TMA), it is also possible to diamond turn whole mirror assemblies containing two or more mirrors with different aspheric shapes on a common breadboard with a relative position of both surfaces in highest machine precision. After machining the first surface, the blank for the second mirror is mounted reproducible onto the breadboard in the turning setup and is diamond turned. Additional reference marks allow the correction of the shape of each mirror, their relative position and the position of interfaces for the system integration. The completed mirror module as presented in the talk contains a secondary and tertiary mirror of a Korsch-telescope. The form error of M2 is 280 nm (p-v); M3 deviates 350 nm (p-v) from the ideal aspheric shape. The vertex positions of both mirrors are aligned within a distance of only 200 nm. Both mirrors are positioned within 500 nm to the plane through the in-process manufactured mounting interfaces for the system assembly. The tilt of the mirrors vs. the mounting plane is less than 5 arcsec. The shown method opens up a novel manufacturing strategy with the potential to enhance the relative positioning accuracy of mirrors in an assembly in the order of one magnitude.

7739-08, Session 1

Emerging results for producing low-scatter EN clad and bare Al mirrors: enabling technology for new astronomical instruments

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Processes have been developed at L-3 IOS Tinsley and are now producing mirrors that exhibit very low microroughness surfaces on bare electroless nickel (EN); three to as much as ten times better than prior industry practice. Coupled with Tinsley's single point diamond turning methods, designers may now consider metal substrate approaches leading to high-performing, low-scatter mirrors. Advantages include aggressive optical forms, excellent thermal continuity (important for cooled systems), and potentially significant cost savings from traditional glass fabrications used to reach these scatter levels. Parameters will be presented. Also emerging results on unclad post polishing of bare aluminum will be presented.

7739-32, Session 1

Measurement of aspheric mirror segments using Fizeau interferometry with CGH correction

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Large aspheric primary mirrors are proposed that use hundreds segments, aligned and phased, to approximate the desired continuous mirror. We present a method of measuring these concave segments with a Fizeau interferometer where a spherical convex reference surface is held a few millimeters from the aspheric segment. The aspheric shape is accommodated by a small computer generated hologram CGH. Different segments are measured by replacing the CGH. As a Fizeau test, nearly all of the opticas are common path, so the tolerances are not tight. Also, since the reference sphere is common to all tests, this system achieves excellent control for the radius of curvature variation from one part to another. This paper describes the test system design and analysis for such a test, and presents data from a similar 1.4-m test performed at the University of Arizona.

7739-09, Session 2

Fabrication and testing of the first 8.4 m off-axis segment for the Giant Magellan Telescope

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The primary mirror of the Giant Magellan Telescope consists of seven 8.4 m segments which are borosilicate honeycomb sandwich mirrors. Fabrication and testing of the off-axis segments is challenging and has led to a number of innovations in manufacturing technology. The polishing system includes an actively stressed lap that follows the shape of the aspheric surface, used for large-scale figuring and smoothing, and a passive "rigid conformal lap" for small-scale figuring and smoothing. Three independent measurement systems support all stages of fabrication and provide redundant measurements of all critical parameters including mirror figure, radius of curvature, off-axis distance and clocking. The first measurement uses a laser tracker to scan the surface, with external references to compensate for rigid body displacements and refractive index variations. The main optical test is a standard full-aperture interferometric measurement, but it requires an asymmetric null corrector with three elements including a 3.75 m mirror and a computer-generated hologram to compensate for the surface's 14 mm departure from the best-fit sphere. The third independent measurement is a scanning pentaprism system that measures slope errors in linear scans across multiple diameters of the segment. Together these measurement provide high confidence that the segments will meet all requirements. In particular, the low-order aberrations that are the most difficult to measure will be controlled to an accuracy that will allow easy correction with the segments' active supports. In this paper we describe the fabrication process and results of the three measurements.

7739-10, Session 2

Narrow ion-beam figuring: a new tool to address extreme slopes on small surfaces located near telescope pupils

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Advanced shapes can now be produced for the corrective optics placed near a reimaged pupil, or even a deformable mirror surface. These surfaces can be improved, and even apodization added to improve contrast. The Hubble Co-Star corrective optics produced at Tinsley by a prior method is one example of the power of using corrective optics at a reimaged pupil for systemic telescope performance improvement. The surface figure of such an off-axis optic is an extremely challenging asphere, with large radius of curvature changes over small distances, going from significantly concave to convex in a radial distance of only a few mm. Small tool polishing cannot adequately address these regions with adequate resolution. In this paper, we describe a special form of Narrow Ion Beam Figuring (NIBF) developed at L-3 Tinsley. In contrast to existing Ion Beam Figuring (IBF) machining schemes the FWHM beam width is controlled in a much narrower band while still providing high beam currents. This paper provides preliminary results both on test samples, and on improvement of the Olivier Guyon's PIAA approach to exoplanet coronography, being worked under contract to NASA Ames.

7739-11, Session 2

A novel technique for the mass production of segmented primary mirrors for optical telescopes

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The large optical telescopes of the next generation require very large mirrors. As example, the giant primary mirrors of the ELTs will consist of up to thousand segments with about 1.5 meter in size. Despite the sizes of each segment are not particularly demanding to be manufactured with traditional optical figuring techniques, the production of very large amount of them is challenging. On the other hand, also telescopes with smaller optics may benefit from the use of segmented mirrors. This requires the development of new technologies able to deliver mirror segments with tight optical requirements within industrial mass production.

The Astronomical Observatory of Brera (INAF-OAB) is investigating a technique for the manufacturing of stiff and lightweight optical mirror segments; each one having a composite sandwich-like structure with two glass skins on both sides of a core's material. The reflecting side is a thin glass sheet thermally conformed to the desired optical shape using a high quality ceramic mold. The core's material is a high performance foam with good mechanical properties. The shell is then glued to the core material and to a second sheet of glass to form a sandwich structure. This procedure combines the good optical performances achievable by means of the hot slumping technique with the lightweight and stiffness of the foamed material and, finally, the good structural properties achievable in sandwich-like structures. This paper describes the process of production; we also present and discuss some results obtained from test panel realized.

7739-12, Session 2

Fast and agile 3D error correction and figuring of large optical surface using RAP

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A unique combination of machine tool expertise and rapid atomic plasma (RAP) technology is bringing surface figuring of large optical components to the high level required for the next generation of photonic surface. This paper focuses on key achievements in terms of integration of process control by the correlation of two prediction techniques: heat transfer modelling using finite element analysis and surface figuring using de-convolution methods. This analysis highlights the critical process parameters with regard to material, process parameter range and final surface figure requirements. Based on this output, the optimum strategy for the tool path algorithm is chosen. Both figure error correction and surface figuring are implemented through an iterative process. After assessing the action and interaction of the main process parameters through a design of experiments the process parameters are tuned to shorten the processing time. Also in this paper, a cost-effective surface figuring technique for large optical components using a plasma plume is presented which has the great advantage of being a contact-less machining process and also of offering a high material removal rate. Finally the authors detail how, with extended understanding of heat transfer and of its control benefits, it can be used to advantage with this advanced figuring technique in order to widen the range of processed materials. The processed surfaces are analyzed using phase-shifting interferometery for 3D surface deformation. We report surface profiles produced by reactive atomic processing are in the +/-5 nm range for both 500 nanometres deep neutral removal and surface error correction over 100 mm in diameter processed area.

7739-13, Session 2

On the super polishing under stress of aspherical surfaces for exoplanet detection and solar instruments

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The stress polishing method is well suited for the superpolishing of aspheric components for astronomy. The principle of this figuring technique is the following: a warped substrate is spherically polished using a full size tool, in order to become aspherical once unwarped. The main advantage of this technique is the very high optical quality obtained either on form or on high spatial frequency errors. Furthermore, the roughness can be decreased down to a few Ångström, thanks the

classical polishing with a large pitch tool. We describe here the results obtained on the three toric mirrors for the VLT-SPHERE instrument, dedicated to exoplanet direct imaging. Now applied for the production of off-axis parabolas, this technique will drastically reduce the cost of such expensive aspherical mirrors, with a super-polished finition. Result from the first prototype will be presented and applications for Exoplanet detection and solar observations are discussed.

7739-14, Session 2

Low-cost, low-cycle time, replicated glass mirrors

R. M. Egerman, S. De Smitt, D. N. Strafford, ITT Corp. (United States)

ITT has been patented and continues to develop processes to fabricate low cost borosilicate mirrors that can be used for both ground and space-based optical telescopes. Borosilicate glass is a commodity and is the material of choice for today's flat-panel televisions and monitors. Supply and demand has kept its cost low compared to mirror substrate materials typically found in telescopes. The current technology development is on the path to having the ability to deliver imaging quality optics of up to 1m (scalable to 2m) in diameter in few weeks. For those applications that can accommodate the material properties of borosilicate glasses, this technology has the potential to revolutionize ground and space based astronomy. ITT has already demonstrated finishing a planar 0.6m borosilicate optic to 50 nm-rms. This paper will discuss the current and future state of this technology, including extending the manufacturing process to Corning ULE® glass.

7739-15, Session 3

Composite panels for optical mirrors for Cherenkov Telescopes: development of the cold glass slumping technology

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In the last decade a new window for ground-based high energy astrophysics has been opened. It explores the energy band from about 100 GeV to 10 TeV making use of Imaging Atmospheric Cherenkov Telescopes (IACTs). Research in Very High Energy (VHE) gamma-ray astronomy is improving rapidly and thanks to the newest facilities as MAGIC, HESS and VERITAS astronomers and particle physicists are obtaining surprising implications in the theoretical models.

New projects have been started as the European Cherenkov Telescope Array (CTA) and the U.S. Advanced Gamma-ray Imaging System (AGIS). The aim is to enhance both the sensitivity and the energy band coverage to perform imaging, photometry and spectroscopy of sources. In this framework, tens of thousands of optical mirror panels have to be manufactured, tested and mounted into the telescopes. Because of the this high number of mirrors it is mandatory to develop a technique easily transferable to industrial mass production, but keeping the technical and cost-effectiveness requirements of the next generation of TeV telescopes.

In this context the Astronomical Observatory of Brera (INAF-OAB) is investigating a technique for the manufacturing of stiff and lightweight glass mirror panels with moderated angular resolution. These panels have a composite sandwich-like structure with two thin glass skins on both sides of a core material; the reflecting one is optically shaped using an ad-hoc slumping procedure. The technology here presented is particularly attractive for the mass production of cost-effective mirror segments with long radius of curvature like those required in the primary mirrors of the next generation of Cherenkov telescopes. In this paper we present and discuss some relevant results we have obtained from the latest panels realized.

7739-16, Session 3

Modeling of the thermal expansion behaviour of ZERODUR® at arbitrary temperature profiles

R. Jedamzik, T. Johansson, T. Westerhoff, SCHOTT AG (Germany)

The thermal expansion of glass ceramics is not only a function of temperature, but also a function of time, due to the structural relaxation behaviour of the materials. The application temperature range of the upcoming ELT projects varies depending on the chosen construction site between -13°C to +27°C. Typical temperature change rates during the night are in the range between 0.1°C/h and 0.3°C/h. The material behaviour under observation conditions can not be measured directly because the application temperature rates are much smaller than the typical rates achieved in laboratory measurements. SCHOTT developed a model approach to describe the structural relaxation behaviour of ZERODUR®. With this model it is possible to precisely predict the thermal expansion behaviour of the individual ZERODUR® material batches at arbitrary application temperature profiles T(t).

This paper presents results of the modelling, showing ZERODUR® material behaviour at typical temperature profiles of different applications.

7739-17, Session 3

Optimized, ultra-light-weighted mirror structures made of Cesic® for space applications

P. Hofbauer, M. R. Krödel, ECM GmbH (Germany)

Today's space applications increasingly utilize light-weighted construction concepts, motivated by economics and the demands of construction and functionality. Particularly for space optics, mirror stability and stiffness need to be maximized, while mass needs to be minimized. Therefore, mirror materials must possess, besides high material strength and manufacturing versatility, high thermal conductivity, low heat capacity, and long-term. Additionally, one must consider the interplay between material properties and mirror design on one hand, and budgetary constraints on the other. In this paper, we address these issues by presenting an FEM design study of closed-back mirror structures with extremely thin reinforcing ribs, with the goal of obtaining optimal physical characteristics. Furthermore, we show that ECM's carbon-fiber reinforced SiC composite, Cesic®, with its low CTE and a density near 2.7 g/cm3, is not only an excellent mirror material, but allows the rapid manufacturing of closed-back, monolithic mirror structures at reasonable cost.

7739-19, Session 3

The center of curvature optical assembly (and null lens) for the JWST primary mirror cryogenic optical test

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The JWST Optical Telescope Element (OTE) consists of a 6.6 m clear aperture, all-reflective, three-mirror anastigmat. The 18-segment primary mirror (PM) presents unique and challenging alignment, integration and testing requirements. A full aperture center of curvature optical null test is performed at the integrated observatory level to verify PM optical performance requirements. The center of curvature optical assembly (CoCOA), designed and being built by ITT Space Systems Division is used to align and test the JWST primary mirror in Chamber A at Johnson Space Center. The CoCOA contains a multi wave interferometer, patented null lens, actuation for alignment to the OTE, full in situ calibration capability, coarse and fine alignment sensing systems, as well as a system for monitoring changes in the PM to CoCOA distance. This

paper will introduce the systems-level architecture of the CoCOA and its main subsystems.

7739-20, Session 3

Manufacturing of the ZERODUR 1.5m primary mirror blank for the solar telescope GREGOR as preparation of for light weighting of blanks up to 4m diameter

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The 1.5m primary ZERODUR mirror blank of the Solar Telescope GREGOR incorporates 420 pockets at the backside for active cooling to avoid the thermal load impact of the sun to deteriorate the observation. This design is also under discussion for the 2 m Indian Solar Telscope and also for the 4.2m European Solar Telescope (EST).

The tip and tilt M5 mirror of the European Extremly Large Telescope (E-ELT) requires an even more demanding approach in light weighting. The approximately 3 m x 2.5 m elliptical plano mirror is specified to a weight of less than 500 kg.

During the successful manufacturing of the GREGOR light weighted mirror blank, SCHOTT developed a systemtic approach for processing such complex and long lead items which is capable for upscaling to 4 m dimension. In parallel SCHOTT tested machining of challenging aspect ratios in rib thickness and pocket height to prove the machinability of the E-ELT M5 design suggestions.

7739-111, Session 3

Material characteristics of CLEARCERAM-Z HS from OHARA

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There is growing interest within the Astronomical community in the design, development and use of very large aperture telescopes which make use of tremendous light gathering capability and also incorporate the latest advancements in optical materials and fabrication. Two of the most notable of these large size telescope projects being developed are the Thirty Meter Telescope (TMT) and European Extremely Large Telescope (E-ELT). The TMT will use 492 low expansion mirror segments in the actively controlled 30 meter diameter primary mirror and the E-ELT 42 meter diameter aperture will also be comprised of segmented mirrors. CLEARCERAM-Z HS, a glass ceramic material produced by Ohara Inc., has a Coefficient of Thermal Expansion near zero, low residual stress, and is a candidate material for use in large diameter mirrors, including the M1 segment blanks for TMT.

In this paper we present the results of a material characteristics study on CLEARCERAM-Z HS large diameter blanks which includes data on the Coefficient of Thermal Expansion (CTE), CTE uniformity, residual stress and internal quality targeting potential use in the TMT M1 segment blanks.

7739-21, Session 4

Alignment and use of the optical test for the 8.4m off-axis primary mirrors of the Giant Magellan Telescope

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The Giant Magellan Telescope has a 25 meter f/0.7 near-parabolic primary mirror constructed from seven 8.4 meter diameter segments. Several aspects of the interferometric optical test used to guide polishing of the six off-axis segments go beyond the demonstrated state of the art in optical testing. The null corrector is created from two obliquely-illuminated spherical mirrors combined with a computer-generated hologram (the measurement hologram). The larger mirror is 3.75 m in diameter and is supported at the top of a test tower, 23.5 m above the GMT segment. Its size rules out a direct validation of the wavefront produced by the null corrector. We can, however, use a reference hologram placed at an intermediate focus between the two spherical mirrors to measure the wavefront produced by the measurement hologram and the first mirror. This reference hologram is aligned to match the wavefront and thereby becomes the alignment reference for the rest of the system. The position and orientation of the reference hologram, the 3.75 m mirror and the GMT segment are measured with a dedicated laser tracker, leading to an alignment accuracy of about 100 microns over the 24 m dimensions of the test. In addition to the interferometer that measures the GMT segment, a separate interferometer at the center of curvature of the 3.75 m sphere monitors its figure simultaneously with the GMT measurement, allowing active correction and compensation for residual errors. We describe the details of the design, alignment, and use of this unique off-axis optical test.

7739-22, Session 4

Automated metrology simulator for multi-objects instruments

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The most challenging of the metrology needs of multi-objects instruments is the registration of the pupil on the deformable mirror which corrects the wavefront errors. Pick-off mirrors in multi-objects instruments and specially spectrographs (MOS) require accurate positioning and simultaneous viewing of the pupil on the deformable mirror (DM) and the focal plane image on the image slicer at the sub-micron level. A laboratory test prototype simulating the telescope (E-ELT), the beam steering mirror (BSM) and the pupil imaging mirror (PIM), is presented to confirm the correct positioning of the pupil on the DM and to provide the movements of the moveable optical elements to achieve it. The opto-mechanical design and testing of this prototype is shown. The BSM stages (Goniometric cradle, Rotation, & Linear) provide the key mechanical system elements, with precision alignment, resolution, and repeatability.

The design and behaviour of the control system is discussed; the ultimate aim of which is to adjust the BSM and PIM to correct for any slight mis-positioning of the pick-off mirror and any temporal drift of all the components to achieve the required alignment. The control system can also cope with flexure effects when required.

7739-23, Session 4

Interference testing methods of large astronomical mirrors base on lenses and CGH wavefront correctors

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Since last years and at present days LZOS, JSC has been producing a range of primary mirrors of astronomical telescopes with diameter more than 1m under contracts with foreign companies. Simultaneous testing of an aspherical surface figure by means of a lens corrector and CGH (computer generated hologram) corrector, testing of the corrector using

the CGH allow challenging the task of definite testing of the mirrors surfaces figure. The results of successful figuring of the mirrors with diameter up to 4m like VISTA Project (Sothern European Observatory), TNT (Tai National telescope, Australia - Thailand), LCO telescopes (Las Cumbres Observatory, USA) and Russian national projects and meeting these mirrors specifications' requirements are all considered as the sufficient evidence.

7739-24, Session 4

Saving SALT: repairs to the spherical aberration corrector of the Southern African Large Telescope

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The performance of the Southern African Large Telescope (SALT) has been hobbled by poor image quality. The chief problems have been a focus gradient and astigmatism across the 8 arcmin science field of view. At the last conference in the series, it was shown that the 4-mirror spherical aberration corrector (SAC) was responsible for the poor imaging performance. This paper describes the design and execution of repairs to the SAC. During the latter part of 2008, a new interface to the telescope was designed to isolate the SAC from the deleterious effects of the interface. The SAC was removed from the telescope in April 2009 and the new interface installed. The alignment of the 4 strongly aspheric mirrors had been destroyed by the previous problems, so a complete re-alignment of the SAC was required. Details of this will be presented. By the time of the conference the re-alignment should be complete, the SAC re-installed on the telescope, the telescope brought back into operation and on-sky tests carried out to determine whether or not the repair program has succeeded and rendered the telescope capable of performing to its original specification.

7739-25, Session 4

Metrology of complex astigmatic surfaces for astronomical optics

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This paper will focus on the metrology of multiple complex surfaces that are to be integrated into the KBand Multi-Object Spectrograph (KMOS). KMOS is a multi-field astronomical spectrograph designed for integration with the 8.2m diameter European Southern Observatory Very Large Telescope (VLT) and capable of surveying 24 independent fields. There are no less than 1080 separate optical surfaces in the design, many of them being complex freeform surfaces.

Optical surfaces are manufactured in aluminium using a precision freeform diamond machine. In principle, any surface that can be mathematically defined can be replicated using this technique. This flexibility, combined with the ability to achieve form accuracies of better than 15 nm RMS over a 20 mm aperture, gives the designer great freedom in generating powerful and unorthodox optical designs. However, the complexity of these freeform surfaces poses a significant challenge in their accurate characterisation, particularly in the close monitoring of form deviation.

This paper will discuss in detail the metrology of a specific freeform component in the KMOS instrument. The form of these complex astigmatic surfaces is measured using a tilted Twyman-Green Interferometer arrangement to enable accurate characterisation using a spherical wave. There are eight separate designs for this type of component, each with a different degree of astigmatism and with a different orientation of the astigmatic axis with respect to the component co-ordinate frame. This requires careful mechanical fixturing to align the astigmatic axis to the test set up. The impact of mechanical tolerances on measurement uncertainty will be discussed in detail.

7739-26, Session 4

Accuracy of laser tracker measurements of the GMT 8.4 m off-axis mirror segments

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We have developed a metrology system that is capable of measuring rough ground and polished surfaces alike, has limited sensitivity to the nominal surface shape, and can accommodate surfaces up to 8.4 m in diameter. This system was built to guide loose abrasive grinding and initial polishing of the off-axis primary mirror segments for the Giant Magellan Telescope (GMT), and will also be used to guide the fabrication of the Large Synoptic Survey Telescope primary and tertiary mirrors. In addition to guiding fabrication, the system also works as a verification test for the GMT principal optical interferometric test of the polished mirror segment to corroborate the measurement in several low-order aberrations. The system couples a commercial laser tracker with an advanced calibration technique and a system of external references to mitigate numerous error sources. A quantitative assessment of the system accuracy is presented, along with measurement results for GMT, including a comparison to the optical interferometric test of the polished surface.

7739-27, Session 5

Imaging issues for interferometry with CGH null correctors

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Aspheric surfaces are accurately interferometrically measured using computer generated holograms that compensate the aspheric departure of the part under test. The CGH is generally optimized to correct the wavefront, but it can also introduce problems in the imaging that limit the performance of the test. The common effects of imaging distortion, retrace error, and low pass filtering are familiar to test engineers. This paper describes and defines these issues, provides parametric relationships for determining the effects on the measurements, and provides techniques for mitigating the problems.

7739-28, Session 5

Metrology systems for active alignment control of the Hobby-Eberly Telescope wide-field upgrade

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The Hobby-Eberly Telescope (HET) Wide-Field Upgrade (WFU) will be equipped with new metrology systems to actively control the optical alignment of the new four-mirror Wide-Field Corrector (WFC) as it tracks sidereal motion with respect to the fixed primary mirror. These systems include a tip/tilt sensor (TTS), distance measuring interferometers (DMI), guide probes (GP), and wavefront sensors (WFS). While the TTS and DMIs are to monitor the mechanical alignment of the WFC, the WFSs and GPs will produce direct measurement of the optical alignment of the WFC

with respect to the HET primary mirror. Together, these systems provide fully redundant alignment and pointing information for the telescope, thereby keeping the WFC in focus and suppressing alignment-driven field aberrations. We describe the current snapshot of these systems and discuss their expected performance, production and operation plans.

7739-29, Session 5

Optical testing of aspheres based on photochromic computer-generated holograms

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Aspherical optics are widely used in modern optical telescopes and instrumentation because of their ability to reduce aberrations with a simpler optical system. Testing their optical quality through null interferometry is not trivial because of the lack of the reference optics. Computer-Generated Holograms (CGHs) are effective devices that allow to generate a well defined optical wavefront just by designing a specific binary pattern on a glass substrate and they are used to mimic the reference optic. Usually the realization of these CGHs is complex and expensive.

In this background, we developed rewritable CGHs for the interferometric test of aspheres whose operation is based on the large transmission change of photochromic substrate in the visible region upon photoirradiation. These photochromic holograms are cheaper and easy to obtain since they do not need any post exposure process.

CGHs simulating spherical lenses with different focal length were obtained by using a custom-made laser plotter and interferometric tests were performed. Fringes patterns were recorded and a complete interferometric analysis was carried out. These first results are promising for the use of our photochromic CGH for testing of optical surfaces.

7739-30, Session 5

Image improvement using phase diversity for sparse apertures

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Sparse-aperture telescopes have several design advantages while retaining high spatial resolution. However, subaperture misalignment and other optical aberrations in the system can dramatically degrade image quality. Phase diversity is an image-based wavefront sensing technique that jointly estimates the aberrations and the observed object, potentially delivering high image quality for minimal system cost. We present image restoration results obtained using phase diversity to post-process degraded images of extended objects observed with a surrogate sparse-aperture telescope in a laboratory setting. We also discuss the effects on performance of noise, object spectral content and scene complexity, and the choice of phase diversity.

7739-31, Session 5

Interferometric test method for testing convex aspheric mirror surfaces

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An interferometric null test method is described for testing convex aspheric surfaces, such as found in secondary mirrors of Cassegrain telescopes or variations thereof such as Mersenne or Ritchey-Chrétien. A family of test designs is described covering a wide range of mirror diameters, radii of curvature, and aspheric shapes as described by conic constants and/or polynomials. The test method has been used successfully for testing the convex hyperboloid surface of the 244-mm diameter secondary mirror of the NASA 3-meter IRTF telescope. It is currently being used to test the 120-mm diameter, convex paraboloid secondary mirrors of the Magdalena Ridge Observatory Interferometer (MROI). Test designs exist on paper for both Keck secondary mirrors (0.53 m and 1.4 m diameter) and for secondary mirrors of some of the extremely large telescopes of the future, such as the TMT secondary (3.2-m diameter). In typical test embodiments, the simplicity of the test enables rapid implementation at a fraction of the cost of comparable Hindle-Sphere or Hindle-Simpson tests.

7739-01, Session 6

ELT primary mirror prototype segment manufacturing and testing

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Sagem - Reosc has been awarded by ESO a contract for the manufacturing and testing of seven prototype segments of the E-ELT primary mirror. The prototypes are fully representative of the future E-ELT primary mirror segments: they have an hexagonal outer shape of about 1,5 meter across, 80 meters radius of curvature and a quasi parabolic shape.

These prototypes have been made in various low coefficient of thermal expansion materials and have been produced according to various grinding and polishing processes. The main purpose of the development efforts are to assess the segment feasibility and define a baseline process for the serial production of more then one thousand of these segments. The optical requirements are very stringent and cover various domain of spatial frequencies which have been tested on the prototypes by dedicated metrology test benches.

The paper will present the results obtained so far on the different prototypes segments and compared them to the requirement of the future E-ELT segments.

We will also address the future plans for the manufacturing of the E-ELT segments.

7739-33, Session 6

Liquid deformable mirror for advanced sub-optical system testing

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Test and characterization of the optical performance for advanced sub-optical-systems, as designed for large ground based astronomical telescopes or space based optical system, often need to be carried out in the labs before working in the field. New giant telescope can be compared to space project and will require ground based test support equipment to fully characterize the optical sub-system functionalities and performances before costly commissioning on the telescope. Those support equipment must be designed to reproduce the telescope or the front optical systems aberrated wavefront. Optical refractive or reflective system and computer generated hologram (CGH) are the most commonly used equipment to produce the aberrated wavefront but these solutions is costly and limited in field or in waveband. We show that the aberrated wavefront can be generated at low cost by a magnetic liquid deformable mirror. The deformable mirror uses magnetic liquids (ferrofluids) surface activated by an array of small electrical coils. A prototype 91-actuators liquid deformable mirror having a diameter of 33 mm has been built and used to simulate the off-axis aberrated CFHT primary mirror up to 0.5 degrees FOV. We show that we can add the mirror error map to the wavefront to be more realistic. This new experimental tool is compared experimentally to CGH and other complex reflective approaches.

7739-34, Session 6

Scanning pentaprism test for the GMT 8.4 m off-axis segments

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The University of Arizona has developed several independent methods of measuring the figure of the 8.4 m off-axis segments for the Giant Magellan Telescope. In addition to the standard interferometric optical test, two verification tests have been developed. These tests are accurate enough to measure low-order aberrations (including power or radius of curvature) at a level that could easily be corrected at the telescope with the segment's active support system. In one verification test, a laser tracker is used to scan the surface with a resolution of 10-50 cm and an accuracy of around 0.5 micron rms, adequate to guide loose-abrasive grinding and initial polishing. The second verification test is done with a scanning pentaprism system that can measure slope errors down to 0.5 microrad rms. The pentaprism test system illuminates the off-axis segment with a 50 mm collimated beam of light that parallels the optical axis of the parent mirror. Displacements of the spot image at prime focus are used to measure slope errors. The system includes a 9 m rail on a rotating bearing that can scan the pentaprism across any diameter of the segment, and a second, stationary pentaprism that creates a reference beam that is used to compensate for misalignments in the system. Pentaprism test results for the first GMT segment, including comparisons with the interferometric test, will be presented.

7739-36, Session 6

Development of a large mosaic volume phase holographic (VPH) grating for APOGEE

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Volume Phase Holographic (VPH) gratings are increasingly used as diffractive elements in astronomical instruments due to their potential for very high peak diffraction efficiencies and the possibility of a compact instrument design when the gratings are used in transmission. Historically, VPH sizes have been limited by the size of manufacturer's holographic recording optics. We report on the design, specification and fabrication of a large, 290 mm x 475 mm elliptically shaped, mosaic VPH grating for the Apache Point Observatory Galactic Evolution Experiment (APOGEE) spectrograph. This high-resolution near-infrared multi-object spectrograph is in construction for the Sloan Digital Sky Survey III (SDSS III). The 1008.6 lines/mm VPH grating was designed for optimized performance over a wavelength range from 1.5 to 1.7 micron. A step-and-repeat exposure method was chosen to fabricate a three-segment mosaic on a 305 mm x 508 mm monolithic fused-silica substrate. Specification considerations imposed on the VPH to assure the mosaic construction will satisfy the end use requirements are discussed. Production topics and test results of the mosaic VPH grating are given.

7739-37, Session 6

The vector vortex coronagraph: analysis of sensitivity to low-order aberrations, central obscuration and chromatism

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The Vector Vortex Coronagraph is one of the most efficient coronagraphs in terms of inner working angle, throughput and contrast capabilities. Using liquid-crystal polymer technology, this new type of coronagraph has recently been the subject of extensive lab demonstration in the near-infrared and visible, and was also deployed at the Palomar Hale telescope in the H and K bands (1.65 and 2.2 microns, respectively), to good effect. However, as for any other coronagraph, this type of coronagraph has a sensitivity to low-order aberrations (tip-tilt, focus,...) and to the central obscuration and secondary support structures, as well as a bandwidth limitation. Here, we review in details these sensitivities as a function of the topological charge of the vortex, and show that in practice all of them can be properly mitigated.

7739-128, Session 6

A novel optical sensor for mirror edge sensing

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The Southern African Large Telescope (SALT) recently (2007) abandoned attempts at using capacitive mirror edge sensors, mainly due to poor performance at a relative humidity above ~60%, a not infrequent occurrence. Different technologies are now being explored for alternative sensors on SALT. In this paper we describe the design and development of a novel prototype optical edge sensor, based on the application of the interferential scanning principle, as used in optical encoders. These prototype sensors were subsequently tested at SAAO and ESO, for potential application on SALT and E-ELT.

Environmental tests, conducted at SALT in climatic control chambers, looked at temperature and relative humidity sensitivity, long term stability and sensor noise. The temperature sensitivity for height and gap were, respectively, 10nm/°C and 44nm/°C, while for relative humidity they were 4nm/10% and 50nm/10%, respectively. These either met, or were close to, the SALT specification. While there were significant lags in response, this was due to the sensor's relatively large mass (~200 gm per sensor half), which was not optimized. This is likely to improve, should a revised design be developed in future. Impressively the sensor noise was <0.015 nm RMS, over three orders of magnitude better than the specification. Our conclusions are that optical edge sensing is a viable technique for use on segmented mirror telescopes.

7739-40, Session 7

Flight model performance of the integral field unit for the James Webb Space Telescope's near-infrared spectrograph

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The James Webb Space Telescope (JWST) is a collaborative project between the National Aeronautics and Space Administration (NASA), the European Space Agency (ESA) and the Canadian Space Agency (CSA).

On board JWST, the NIRSpec instrument developed by EADS Astrium for ESA is a near-infrared spectrograph covering the 0.6-5.0 µm domain at spectral resolutions of 100, 1000 and 2700.

NIRSpec will be primarily operated as a multi-object spectrograph (MOS) but it also includes an integral field unit (IFU) allowing a 3"x3" field of view to be sampled continuously with 0.1" spatial resolution. This IFU, based on the "advanced" image slicer concept, is a very compact athermal unit made of aluminium. The slicer, pupil and slit mirrors are 30-element arrays machined from monolithic blocks using 5-axis diamond-machining techniques. The single-surface image relay and plane fold mirrors are also diamond-machined. Many of the mirrors have complex surfaces like toric sections with 3rd-order corrections. The mechanical design is complicated by the need to accommodate the differential expansion between the aluminium unit and the titanium assembly in which it is mounted across a 250K drop from assembly temperature, necessitating rigorous design and testing of the isostatic mounting system.

After a brief explanation of the integral-field spectroscopy mode of NIRSpec, this paper presents the development of the IFU from the design and the diamond machining techniques applied for manufacturing the mirrors, to the optical and cryogenic testing of the assembled flight model unit. The final performance parameters of the IFU will be described.

7739-41, Session 7

High-precision cryogenic wheel mechanisms of the JWST/MIRI instrument: performance of the flight models

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The Max-Planck-Institute for Astronomy, Heidelberg (MPIA) has developed a number of optical cryomechanisms for the ISO and HERSCHEL infrared space observatories and is currently engaged in the development of the MIRI and NIRSPEC instruments to be flown on the James Webb Space Telescope. This paper reports on technological innovations in these mechanisms such as drives, bearings, flexural pivots which are of potential interest for other applications in the field of cryogenic space instrumentation and will present lessons-learnt from the extensive acceptance test program of the flight models and qualification tests.

Following a warm launch in 2014, NASA's astrophysics flagship mission JWST will be operated for a lifetime of 5-10 years in an L2-orbit. Its four cryogenic instruments will be cooled to the temperature range 7 - 35 K. Within the European contribution to JWST, the Max-Planck-Institute for Astronomy, Heidelberg is responsible for the development of cryo-optical wheel mechanisms for the mid-infrared instrument MIRI. To provide JWST with powerful astrophysical observing such as broad/narrow-band imaging, coronagraphy and low/medium resolution spectroscopy in the thermal infrared, MIRI is equipped with one filter wheel and two dichroic-grating wheel mechanisms. They enable to re-configure the instrument between the different observing modes and wavelength ranges. Key requirements for the three mechanisms with up to 18 positions on the wheel include: (1) reliable operation at T = 7 K, (2) positional accuracy of 4 arcsec, (3) low power dissipation, (4) high vibration capability of 40G, (5) functionality at 7 K < T < 300 K and (6) long lifetime (5-10 years) corresponding to more than 30,000 full rotations. To meet these requirements a space-proven wheel concept consisting of a central MoS2-lubricated integrated ball bearing, a central torque motor for actuation, a ratchet system with monolithic CuBe flexural pivots for precise and powerless positioning and a magnetoresistive position sensor has been implemented.

In our paper we will present final results from the acceptance test program of the wheel mechanisms which are currently integrated into the MIRI flight model. These tests include functional and performance tests, vibration tests and thermal vacuum cycling. Critical components have also been subjected to high loads in various bread-board qualification tests such as cryo-radiation testing.

7739-42, Session 7

Accurate blackbodies

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Infrared radiometers and spectrometers generally use blackbodies for calibration. There has been an increasing need for high accuracy, for example the NASA climate science mission CLARREO, which is to measure Earth's emitted spectral radiance from orbit, has an absolute accuracy requirement of 0.1 K (3) at 220 K over most of the thermal infrared. Space Dynamics Laboratory has a blackbody design capable of meeting strict modern accuracy requirements. This design is relatively simple to build, was developed for use on the ground or on-orbit, and is readily scalable for aperture size and required performance, with lower performance allowing a smaller blackbody. Blackbodies of this design are currently in use as a ground calibration unit and with a high-altitude balloon instrument. We are currently building a prototype to demonstrate ability to achieve very high accuracy, and we expect it to have emissivity of ~0.9999 from 1.5 to 50 µm, temperature uncertainties of ~25 mK, and radiance uncertainties of ~7 mK due to temperature gradients. The high emissivity and low thermal gradient uncertainties are achieved through cavity design, while the temperature uncertainty is reached by including phase change materials such as Mercury, Gallium, and water in the blackbody. Blackbody temperature sensors are calibrated at the melt points of these materials, which are determined by heating through their melt point. This allows absolute temperature calibration traceable to the SI temperature scale.

7739-43, Session 7

The filter wheel mechanism for the Euclid near-infrared imaging photometer

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The Euclid dark energy mission is currently competing in ESA's Cosmic Vision program. Its ambitious science requirements are driving significant technical developments in Europe. The imaging and spectroscopic instruments are difficult to implement both optically and mechanically. The 5 year mission will survey the entire extragalactic sky, in both the visible and near-infrared, and will be used to determine some of the most fundamental physical parameters in the Universe.

The near-infrared imaging photometer (NIP) is a key component of the Euclid mission. The large survey area and the need to not only image each patch of sky in multiple bands, but also in multiple dithers, requires over 350 000 operations of the NIP instrument's filter wheel mechanism. At 127 mm (5 in) in diameter, the brittle infrared filters dictate highly demanding requirements on this single-point-failure mechanism. To accommodate the large filters the filter wheel must have an outer diameter of 425 mm, which will result in significant loads being applied to the bearing assembly during launch.

The centrally driven titanium filter wheel will house the infrared filters in specially designed mounts. Both stepper motor and brushless DC drive systems have been considered and tested for this mechanism. This paper presents the design considerations and results from the first prototype of this challenging mechanism. The design, finite element analysis and prototyping of the filter mounting concept are also presented.

7739-44, Session 7

Cryogenic magnetic bearing scanning mechanism design for the SPICA/SAFARI Fourier transform spectrometer

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TNO, together with its partners, has designed a cryogenic scanning mechanism for use in the SAFARI Fourier Transform Spectrometer (FTS) on board of the SPICA mission. SPICA is one of the missions competing to be launched in ESA's Cosmic Vision programme in 2017 or 2018. It is developed in collaboration with JAXA.

The optics of the FTS scanning mechanism (FTSM) consists of two back-to-back cat's-eyes. The optics are mounted on a central "back-bone" tube which houses all the important mechanical parts: the magnetic bearing linear guiding system, a magnetic linear motor serving as the OPD actuator, internal metrology with nanometer resolution, and a launch lock.

A magnetic bearing is employed to enable a large scanning stroke in a small volume. It supports the optics in a free-floating way with no friction, or other non-linearities, enabling sub-nanometer accuracy within a single stage with a stroke of -4 mm to +31.5 mm. This technique is based on the design of the breadboard ODL (Optical Delay Line) developed for Darwin by the same consortium, which was based on the MABE mechanism developed by Micromega Dynamics.

Because the FTSM will be used at cryogenic temperatures of 4 Kelvin, the main structure and optics are all constructed from 6061 Aluminium. The overall outside dimensions of the FTSM are: 393 x 130 x 125 mm, and the mass is 2.2 kg.

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7739-165, Session 7

The thermal architecture of the Clover cryostats

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Clover is a ground based CMB polarization instrument, intended to measure the primordial B-mode power spectrum to a limit of r=0.03, using 592 TES detectors at three frequencies; 97, 150 and 220 GHz.

All the detectors need to operate from a base temperature of 100mK. In order to achieve the science goals of the instrument, two large aperture (30 cm diameter) cryostats with novel cryogenic systems have been developed. Both are required to achieve a base temperature of 100mK, a hold time of 14 hours whilst allowing the system to be tilted by 45 degrees. The cryogenic system consists of a pulse tube cooler, a two-stage helium sorption fridges and a novel dilution refrigerator. The designed cooling power at 100mK is 5 microW, and required temperature stability is 4 microK on long timescales and 60 nK/sqrt(Hz). The entire system is liquid cryogen free and is able to maintain cooling at various tilt angles. We report on the performance of the system, including details of thermal isolation and thermal filtering along the optical path.

7739-167, Session 7

The innovative MAIT plan for the MATISSE cold optics, comprising an unprecedented 300 cryogenic optical components

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MATISSE (Multi AperTure mid-Infrared SpectroScopic Experiment) will be a mid-infrared spectro-interferometer combining the beams of up to four telescopes of the European Southern Observatory Very Large Telescope Interferometer (ESO VLTI), providing phase closure and image reconstruction. Matisse will produce interferometric spectra in the LM and in the N band (2.3 to 13.5 micron) and is as such a successor of MIDI. The instrument will be developed by a consortium consisting of Observatoire de Nice (warm optics), NOVA-ASTRON (cold optics), MPI-A (cryostats) and MPIfR (detectors).

Beams of up to four Unit Telescopes or Auxiliary Telescopes (UT - AT) pass the warm pre-optics and in the cold optics the each beam is split in 3 beams and combined in all possible combinations with the remaining 3 telescopes. These beam-pairs have to be aligned in position, parallelism and optical path difference with respect to each other. All beam pairs recombine on the detector where they create a spectral interference pattern.

An innovative MAIT plan drastically shortens the MAIT phase and therefore reduces cost. The MAIT plan comprises the assembly and alignment procedure of about 300 cryogenic optical components for which a mirror mount clip has been developed. Alignment accuracy and stability specifications are of the order of nanometers and arcsec, which requires nearly 50 cryogenic alignment mechanisms for Tip/Tilt, OPD (Optical path difference) and detector Tip/Tilt/Focus. The design, realization and test results of these mechanisms are presented. A cryogenic electrical switch significantly reduces the complexity of the electronic cabling and improves reliability.

7739-46, Session 8

A control loop closure system for the Sardinia Radio Telescope active surface

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The Sardinia Radio Telescope (SRT) is a single dish radioantenna of 64 meter in diameter which is in the building phase in Italy. One of the most challenging properties of SRT is his capability to work up to a frequency of 100 GHz thanks to its main reflector active surface. The active surface is composed by 1008 mechanical actuators which may modify the shape of the main reflector surface making possible to correct for wavefront distortions due to gravitational and thermal deformations.

In order to observe at a frequency of 100 GHz the surface shape must be accurate within a value of 150 m r.m.s. This value may be obtained during the initial alignement phase by means of microwave holography but it cannot be maintained during the scientific operations because of the (dynamical) deformations. In order to permit the observations at any time a system able to measure the surface shape with the necessary accuracy and time-response of few minutes (the time-scale of the deformations) must be operative.

We propose here a simple and robust method for measure the relative deformations of the panels with respect to an initial aligned surface. The method make use of a bidimensional sensor placed close to the reflector vertex and a series of laser diodes placed on a corner of each panel. The tilt of a single panel is measured by the tilt of the diode beam as recorded by the sensor. In such a sense the system is based on the same concept of the Hartmann test largerly used in the visible range. A prototype of the system has been realized and successfully tested on the active optics radiotelescope of Noto (Italy).

7739-48, Session 8

A prototype micro-autonomous positioning system for mirror deployment within multi-object instruments

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The complexity and size of instruments for next generation telescopes demands innovative approaches to existing problems. Within this framework, we present MAPS; a Micro Autonomous Positioning System for mirror deployment in an E-ELT instrument such as EAGLE. The micro-robots have a 30mmx30mm footprint and utilise RF communications and small rechargeable batteries to be completely wireless. Coarse positioning and fine alignment is achieved through the use of miniature stepper motors and gearheads. Positional information is determined externally and relayed to the robots. This paper reports on the challenges which such a system presents, current developments, and areas of expected future research.

7739-49, Session 8

Starbugs: focal plane fiber positioning technology

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We report on the technological achievements of our latest Starbug prototypes and their implications for smart focal plane fiber positioning applications for wide-field astronomy. The Starbugs are innovative self motile miniature robotic devices that can simultaneously and independently position fibers or payloads over a field plate located at the telescope's focal plane. The Starbugs concept overcomes the limitations associated with the traditional 'pick and place' methods where a robot places fixed buttons onto the field plate. The new Starbug prototypes use piezo-electric actuators and have the following improvements: (i) new 'lift-and-step' method (discrete step) for accurate positioning over different surfaces; and (ii) operate in an inverted hanging position underneath a transparent field plate, removing the need for fibercable retractors. In this paper, we present aspects of the Starbug prototypes, including the theoretical model; mechanical design; control electronics, control software, metrology, performance results and applications for astronomical instrumentation.

7739-50, Session 8

Vibration damping system for ALMA antenna transporters

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ESO is responsible for the two antenna transporters of the ALMA Observatory. They are used to relocate the 12-meter antennas and to move them between the low site at 3000m and the high altitude site at 5000m altitude. The transport is carried out on unpaved roads, which are regularly maintained. After final design in 2007, when analyzing the dynamic response of the ALMA transporters to road ripple of critical height and inter-distance, it was found that transporter accelerations exceeding the seismic accelerations (used as critical design parameters) cannot be excluded. This is considered as a remote risk however with possibly catastrophic consequences for the equipped antennas. The problem was analyzed by ESO experts for dynamic simulations and a solution was found to limit the loads to acceptable values. For this purpose both transporters are equipped with an additional damping system designed by ESO consisting of nitrogen charged accumulators and throttle valves for each wheel pair as well as an automatic emergency brake system that brings the vehicle to a safe stop in critical situations independent of the driver. End of May 2009 both safety systems where successfully adjusted and tested at ALMA OSF in Chile. For the tests the vehicles were equipped with additional sensors. Loaded with a dummy mass they were excited in their critical resonance mode with increasing excitation amplitude. The measurements were completed by drive and brake tests.

This paper describes the design of the additional damping system including its concept, the model-based design using dynamic simulations and verification tests. The damping concept is applicable to other heavy load damping applications.

7739-51, Session 8

Friction drive characterization breadboard: test results

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The drive and bearing technologies have a major impact on the static and dynamic performance of steerable structures such as telescope and dome. Merging drive and bearing system into friction drive mechanical devices (bogie) can reduce the complexity and cost of the design. In the framework of ELT design study (European FP6) a breadboard test setup was realized to test and evaluate the static and dynamic behavior of such bogies. In this paper some of the characterization test results are presented. Characterization of the bogies and the setup structure in the frequency domain, quantification and measure of the most important parameters of the friction forces, the control of the bogies and the tracking performance of the test setup are among the main results discussed in this paper.

7739-52, Session 8

Study on a novel panel support mechanism of a radio telescope

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Traditionally, panels of radio telescopes are shaped in trapezoid and each of the panels is supported and positioned by four adjustors beneath its four vertexes. Such configuration of panel supporting system is essentially hyper-static, which means the panel is over-constrained from kinematical point of view. When the panel is to be installed and/or adjusted, it will suffer stress from its adjusters and hence its shape is to be distorted within elastic limit. This reality is not preferable for high precision panels especially for millimeter and shorter wavelength observation. This paper puts forward a novel panel support design deriving from the support mechanism of optical mirrors. The support system is a novel swing-arm-based mechanism. With its three swinging jibs, the novel support mechanism is characterized by straightforward structure, orientation-independently constant stiffness and free of thermal stress. The principle and performance of the support system are elaborated before a practical example is presented with comprehensive finite element analysis and simulation.

7739-53, Session 8

EST main telescope structure: concepts and trade-offs of the main structure for the European Solar Telescope

M. Süss, MT Mechatronics GmbH (Germany); F. C. M. Bettonvil, Utrecht Univ. (Netherlands); R. Volkmer, Albert-Ludwigs-Univ. Freiburg (Germany); H. J. Kärcher, P. Eisenträger, D. Fischer, MT Mechatronics GmbH (Germany)

EST (European Solar Telescope) is a 4-m class solar telescope, to be located at the Canary Islands, which is currently in the conceptual design phase. EST will specialize in high spatial and temporal resolution observations of the deep photosphere and upper chromosphere, using instruments that can efficiently produce two-dimensional spectropolarimetric information of the thermal, dynamic and magnetic properties of the plasma over many scale heights.

The Main Telescope Structure of this telescope is being analyzed, starting from the principle layout of the optical system, basic number and configuration of the mirrors. Different concepts for the main (steel-) structure in combination with different techniques for bearing and drive systems are compared with special focus on the EST application. The trade off is being supported by extensive structural analysis as well as historical and recent developments in the field of bearing and drive systems for optical telescopes. Control simulations are supporting the trade-offs of the main axis drive systems. In the upcoming month the selected design will be further detailed, leading to a preliminary reference design, which can be presented by summer 2010.

7739-54, Session 8

GREGOR M1 mirror and cell design: effects of different mirror substrates on the telescope design

M. Süss, MT Mechatronics GmbH (Germany); R. Volkmer, Albert-Ludwigs-Univ. Freiburg (Germany); P. Eisenträger, MT Mechatronics GmbH (Germany)

After suffering from serious problems in the course of the SiC 1.5m M1 manufacturing, the existing design of the M1, it's cell and the associated mirror cooling system was investigated in terms of modification efforts to be compatible for a different M1 substrate (Zerodur). The analysis included the system requirements, the M1 design, the M1 support system, the M1 cooling system as well as the M1 cell.

The investigations resulting in a modified design of the above mentioned system. Driven by the choice of material, different requirements became design driving factors. The conse-quences on the detail design of the M1 Mirror as well as on the support system and the cool-ing system are presented.

The Zerodur M1 is currently in manufacturing. The manufacturing of the other components will begin early 2010, with the goal of completion in April 2010.

7739-142, Session 8

LSST telescope primary/tertiary mirror hardpoints

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The Large Synoptic Survey Telescope (LSST) utilizes an 8.4-meter cast borosilicate primary/tertiary mirror. Since the telescope's optical system does not include a fast steering mirror and the mission requires a short slew and settling time, the telescope has stringent vibration requirements during observation. The position stability of the primary/tertiary mirror relative to the mirror cell is controlled by six hardpoints (displacement controlled actuators) that form a large hexapod. The design is based largely on previous hardpoints implemented for borosilicate mirror positioning. All dynamic forces applied to the mirror are reacted through these hardpoints. Consequently, the characteristics of these hardpoints critically affect the ability of the telescope to meet the stringent dynamic requirements without overstressing the mirror. The hardpoints must have a high stiffness of 120 N/um in the axial direction, while protecting the mirror by limiting the loads in all six degrees of freedom. The non-axial direction loads are limited by flexures. The axial load is limited by a pneumatic breakaway mechanism. Since the hardpoints apply the dynamic loads to the mirror, the axial breakaway force directly limits the telescope's slewing accelerations. The travel of the breakaway mechanism must be sufficient to accommodate the transfer of the primary mirror from its active supports to its static supports. The hardpoint positioning mechanism must have sufficient travel and resolution to properly position the mirror relative to the mirror cell. Fulfilling these functions also requires numerous sensors, including a precision axial load cell which is paramount in determining the figure control actuator forces.

7739-144, Session 8

Innovative enclosure design for the MROI array telescopes

I. Payne, New Mexico Institute of Mining and Technology (United States); G. Marchiori, A. Busatta, European Industrial Engineering s.r.l. (Italy)

The close-pack array of the MROI necessitated an original design for the Unit Telescope Enclosure (UTE) at Magdalena Ridge Observatory. The Magdalena Ridge Interferometer (MROI) is a project which comprises an optical array of up to ten relocatable (10) 1.4m telescopes arranged in a "Y" configuration. Each of these telescopes will be housed inside a Unit Telescope Enclosure (UTE) which can be lifted and moved onto any of 28 stations. The most compact configuration includes all ten telescopes, several of which are at a relative distance of as little as 7.8m center to center from each other. Since the minimum angle of the field of regard is 30° with respect to the horizon, there was also the necessity to prevent optical blockage caused by adjacent UTEs in this compact array.

This paper presents a description of how the constraints imposed by the requirements for the close-pack configuration and relocatability led to the design of an innovative, compact and light-weight enclosure of small diameter and high structural strength.

Finally, we describe how the unique internal lay-out gives sufficient space inside to house, not only to house the telescope mount, but also associated electronics, nasmyth table opto-mechanical equipment and beam relay system.

7739-56, Session 9

Smart structures for deformable mirrors actuated by shape memory alloy

M. Riva, Osservatorio Astronomico di Brera (Italy); P. Bettini, G. Sala, Politecnico di Milano (Italy); F. M. Zerbi, Osservatorio Astronomico di Brera (Italy)

Deformable mirrors actuated by smart structures are promising devices for next generation astronomical instrumentation.

Thermal activated Shape Memory Alloys are materials able to recover their original shape, after an external deformation, if heated above a characteristic temperature. If the recovery of the shape is completely or partially prevented by the presence of constraints, the material can generate recovery stress. Thanks to this feature, these materials can be positively exploited in Smart Structures if properly embedded into host materials.

This paper will show the technological processes developed for an efficient use of SMA-based actuators embedded in smart structures tailored to astronomical instrumentation. In particular the analysis of the interface with the host material.

Some possible modeling approaches to the actuators behavior will be addressed taking into account trade-offs between detailed analysis and overall performance prediction as a function of the computational time.

We developed a combined Finite Element and Raytracing analysis devoted to a parametric performance predictions of a SMA based substrate applicable to deformable mirrors. We took in detail into account the possibility to change the focal length of the mirror keeping a satisfactory image quality.

Finally a possible approach with some preliminary results for an efficient control system for the strongly non-linear SMA actuators will be presented.

7739-57, Session 9

Smart structures for deformable mirrors actuated by piezocomposites

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Deformable mirrors actuated by smart structures are promising devices for next generation astronomical instrumentation.

The piezo technology and in particular piezoceramics is currently among the most investigated structural ma- terials. Fragility makes Ceramic materials extremely vulnerable to accidental breakage during bonding and embedding processes and limits the ability to comply to curved surfaces (typical of mirrors). Moreover lead-based piezoceramics typically have relevant additional masses.

To overcome these limitations, we studied the applicability of composites piezoceramics actuators to smart structures with these purposes.

We developed a combined Finite Element and Raytracing analysis devoted to a parametric performance predictions of a smart Piezocomposites based substrate applicable to deformable mirrors. We took in detail into account the possibility to change the focal length of the mirror keeping a satisfactory image quality.

In this paper we present a specific type of Piezocomposite actuators and numerical/experimental techniques purposely developed to integrate them into smart structures. We evaluated numerical and experimental results comparing bonding and embedding of these devices.

7739-58, Session 9

EST Telescope: primary mirror, support, and cooling system

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The solar telescope EST is currently in the conceptual design phase. It is planned to be build on the Canary Islands until end of the decade. It is specialized on polarimetric observations and will provide high spatial and spectral observations of the different solar atmospheric layers.

For EST a primary mirror with illuminated diameter of about 4.1 m is planned. Different types of mirror shapes were investigated with respect to thermal and mechanical characteristics.

To remove the absorbed heat an air cooling system from the back side will be applied. Additional an air flushing system will remove remaining warm air from the front side.

To achieve optimal optical performance an active support system is planned. The primary mirror cell needs to be stiff enough to support the primary mirror without deformation at strong wind in case of the open telescope option, but sufficient room for the active support system and cooling system below the backside of the mirror is also required. Preliminary designs and analysis results will be presented.

7739-59, Session 9

Calibration dome screen for the Large Synoptic Survey Telescope

W. J. Gressler, V. L. Krabbendam, M. Liang, A. Saha, National Optical Astronomy Observatory (United States); C. W. Stubbs, Harvard Univ. (United States)

The Large Synoptic Survey Telescope (LSST) flat-fields must repeatedly trace not only the spatial response variations, but also the chromatic response through the entire optical system, with an accuracy driven by the photometric requirements for the LSST survey data. This places challenging requirements on the LSST Calibration Dome Screen, which must uniformly illuminate the 8.4-meter diameter telescope pupil over its 3.5-degree field of view at desired monochromatic wavelengths in a way that allows the measurement of the total system throughput from entrance pupil to the digitization of charge in the camera electronics. This includes the reflectivity of the mirrors, transmission of the refractive optics and filters, the quantum efficiency of the sensors in the camera, and the gain and linearity of the sensor read-out electronics. The baseline design uses a single tunable laser and includes an array of discrete projectors. The projected flux of light produced by the screen must fill the entire telescope pupil and provide uniform illumination to 1% at the focal plane and to within 0.25% over any optical trajectory within 0.5 degrees of each other. The wavelength of light is tunable across the LSST bandpass from 320 nm to 1080 nm. The screen also includes a broad-band (“white”) light source with known Spectral Energy Density (SED) that spans the same range of wavelengths.

7739-60, Session 9

New paradigms for producing high-performing meter class ground-based telescopes

R. L. Hedrick, A. Keller, J. Haberman, PlaneWave Instruments (United States); T. B. Hull, L-3 Communications Tinsley Labs. Inc. (United States); A. R. Clarkson, L-3 Brashear (United States)

Design-to-cost exercises and innovative design have resulted in remarkably high performing half-meter class wide field astronomical telescopes. This approach is being extended to meter+ class telescopes, with further innovation on mounts and optics. Custom motors, drives and bearings have been developed to keep performance up and cost down. We will also report on a concurrent engineering campaign with Brashear Optics to ensure optical performance while maintaining highest value for the primary mirrors of our line of meter (and larger) astronomical telescopes.

7739-61, Session 9

High-precision robotic equatorial C-ring telescope mounts: design, fabrication, and performance

M. A. Dubberley, Las Cumbres Observatory Global Telescope Network (United States)

The performance of the C-Ring Telescope mount rivals other designs in stiffness, tracking, simplicity, lack of field rotation, mechanical size and operating envelope. Issues relating to cost, fabrication, and complexity have suppressed the prevalence of the c-ring mount. The LCOGT robotic C-ring telescope mounts, built for its network of 1.0m and 0.4m telescopes, include solutions for these issues. The design yields a scalable mount with performance capabilities well suited for telescopes located at the best astronomical sites in the world at a low cost. Pointing has been demonstrated to be under 7 arc-sec RMS. Unguided tracking performance is 0.6 arc-sec for 1 minute and 2 arc-sec for 15 minutes. Slew speeds of 20deg/sec are reliably used with sub-second settling times. The mount coupled with the 0.4 meter LCOGT telescope yields a well damped 22 Hz system. Axis are driven with zero backlash direct drive motors with a 0.01 arc-sec resolution. High system bandwidth yields superb disturbance rejection making it ideal for open air operation. Drive and bearings are maintenance free and feature a novel "bug cover" to seal them from wear and damage. Very competitive cost are achieved with the drive/feedback configuration, structure design, and fabrication techniques, as well minimizing operating and maintenance. Discussed here are design features at a level of detail important for replicating and scaling the mount for broad application. Included are friction drive material selection, drive calculations, novel design feature details, as well as the design, fabrication, and concept advancements made by the LCOGT C-ring mount.

7739-62, Session 9

Design and performance characterization of the LCOGTN One-Meter Telescope optical tube assembly

B. J. Haldeman, R. M. Haynes, V. Posner, J. R. Tufts, A. J. Pickles, M. A. Dubberley, Las Cumbres Observatory Global Telescope Network (United States)

The LCOGT network will include 12 or more robotic 1-m telescopes at 6 sites around the globe. Scientific performance specifications, a necessity for ease of commissioning and maintenance, and a desire for automated sensing and remote collimation have led to novel designs and features in the Optical Tube Assembly (OTA). We describe the telescope mirrors, passive and active support systems, and their monitoring sensors. Integrated subsystems for cleaning of the optics, and an air-knife for condensation abatement and improved seeing are provided. We discuss the design of a carbon fiber/epoxy composite truss with unique spherical node connections to offset invar vanes. We present thermal effects on focus shifts and vane preload. A novel Hartman mask is integrated into the mirror cover and enables remote collimation feedback. A flexure based, closed loop, 3-DOF secondary mirror mechanism is used for tip/tilt collimation and features an independent focus axis with minimal parasitic motions. The telescope is designed for a 70 kg instrument at a 0.5 lever arm. The optics and deflections of the OTA components were iteratively designed for passive collimation with a changing gravity vector. We present the FEA predictions, measured deflections, and measured hysteresis for each of the components. Vibration modes, amplitudes, and damping of the system are presented with an FFT frequency analysis. We present on sky results of the OTA and discuss the scientific capabilities.

7739-63, Session 9

The active optics system for the Discovery Channel Telescope

B. W. Smith, T. Chylek, Lowell Observatory (United States); B. Cuerden, The Univ. of Arizona (United States); B. DeGroff, P. J. Lotz, A. Venetiou, Lowell Observatory (United States)

The Discovery Channel Telescope (DCT) is a 4.2m telescope designed for dual optical configurations, featuring an f/6.1 Ritchey-Chretien prescription with a 0.5° field-of-view, and a corrected f/2.3 prime focus with a 2° field-of-view. The DCT Active Optics System maintains collimation and mirror figure to provide seeing limited images across the focal planes and rapid settling times to minimize observing overhead, using a combination of feed-forward and low-bandwidth feedback control via wavefront sensing. Collimation is maintained by tip-tilt-piston control of the M2 assembly and articulating M1 within its cell, taking advantage of the 120 degree-of-freedom support used for figure control. We present an overview of the AOS design and principles of operation, and a summary of progress and results to date.

7739-64, Session 9

Challenges of extreme load hexapod design and modularization for large ground-based telescopes

R. Gloess, Physik Instrumente (PI) GmbH & Co. KG (Germany); B. Lula, PI (Physik Instrumente) L.P. (United States)

Next generation large aperture telescope projects like the 8.4-meter LSST and the 21.5 meter GMT are employing sophisticated and innovative optical designs requiring very precise active collimation of large secondary mirrors and heavy instrumentation packages.

This paper describes the modularizing of a hexapod positioning system using compact hexapod design proposals for the very high loads required by the next generation of large ground based telescopes. Actuator construction providing up to 90,000N of independent load capability will be detailed including discussion on the design choices for the electromechanical and metrology components while optimizing the actuator design for low power dissipation to minimize thermal effects. The metrology discussion will center on an innovative laser gravure encoder direct written onto internal components of the hexapod actuator to obtain more than 100,000 increments per revolution while a second absolute encoder is implemented to provide the necessary redundancy against any position error in closed loop operation. Open loop transfer functions and system stability phase margin will be described in time domain and with Nyquist criteria.

Cardan joints have been chosen for the actuator to provide high structural stiffness with axis offsets. FEM calculations will show the advantage in stiffness for cardan joints with axis offset. The paper also describes the hexapod controller concept when integrating individual actuator/cardanic joint mechanical subsystems. This allows the integration of individual hexapod actuators into the main telescope structure without the previous need for integral top and base rings thereby reducing mass and providing a higher degree of design flexibility for the telescope's designers. Advances in collision avoidance control to enhance operational safety will also be discussed along with the adaptive control system required for this modular mechanical approach.

7739-65, Session 9

Innovative enclosure dome/observing aperture system design for the MROI Array Telescopes

G. Marchiori, A. Busatta, European Industrial Engineering s.r.l. (Italy); I. Payne, New Mexico Institute of Mining and Technology (United States)

The close-pack array of the MROI necessitated an original design for the Unit Telescope Enclosure (UTE) at Magdalena Ridge Observatory. The Magdalena Ridge Interferometer (MROI) is a project which comprises an array of up to ten (10) 1.4m diameter mirror telescopes arranged in a "Y" configuration. Each of these telescopes will be housed inside a Unit Telescope Enclosure (UTE) which are relocatable onto any of 28 stations. The most compact configuration includes all ten telescopes, several of which are at a relative distance of less than 8m center to center from each other. Since the minimum angle of the field of regard is 30° with respect to the horizon, it is difficult to prevent optical blockage caused by adjacent UTEs in this compact array.

This paper presents the design constraints inherent in meeting the requirement for the close-pack array. An innovative design enclosure was created which incorporates an unique dome/observing aperture system. The description of this system focuses on how the field of regard requirement led to an unique and highly innovative concept that had to be able to operate in the harsh environmental conditions encountered at an altitude of 10,460ft (3,188m).

Finally, we describe the wide use of composites materials and structures (e.g. glass/carbon fibres, sandwich panels etc.) on the aperture system which represents the only way to guarantee adequate thermal and

environmental protection, compactness, structural stability and limited power consumption due to reduced mass.

7739-66, Session 10

Are opthalmic hydrophobic coatings useful for astronomical optics?

C. Schwab, Landessternwarte Heidelberg (Germany); A. C. Phillips, Univ. of California Observatories (United States)

Astronomical optics are often exposed to moisture and dust in observatory environments, which frequently compromises their high-performance coatings. Suitable protective layers to resist dust and moisture accumulation would be extremely advantageous, but have received scant attention thus far. Hydrophobic and scratch-resistant coatings, developed primarily for opthalmic use, exhibit several attractive properties for astronomical optics. We examine the properties of one such coating and its applicability to astronomical mirrors and lenses. This includes efficiency of dust removal, abrasion resistance, moisture resistance, ease of stripping, and transmission across a wide wavelength range.

7739-67, Session 10

Design and manufacturing of high-performance notch filters

U. B. Schallenberg, B. Ploss, M. Lappschies, S. Jakobs, mso jena Mikroschichtoptik GmbH (Germany)

Notch filters are characterized by blocking a narrow spectral range and providing high transmission outside the blocking range. For manufacturing of notch filters, rugate designs with small refractive index contrast and apodisation features are well known but the deposition of the required gradient index layers is very complicated. In our approach we apply the equivalent index theory to replace the gradient index profile of a notch filter design by layers of high-index and low-index materials with high index contrast. This leads to a combination of thick (>100 nm) and thin (<10 nm) layers and apodisation is the result of thickness optimization. Stable coating processes with dense layers are strict requirements. Another challenge is the accurate thickness control of very thin layers in the nanometer range. We produce single and multiple notch filters with plasma ion assisted deposition and broad-band optical monitoring. As applications in astronomical instrumentation a 500nm-notch-filter as beam-splitter for the multi-instrument configuration of the GREGOR telescope and a 589nm-notch-filter for the separation of the Na-line in the GALACSI instrument of the VLT are discussed in detail as examples. Additionally, a multiple notch filter with four lines and a 216nm-notch-filter both made for fluorescence spectroscopy applications are presented as further examples of the state-of-the-art for notch filters.

7739-68, Session 10

Dual-achromatic mask for nulling: experimental demonstrator

D. Pickel, F. Chemla, M. Cohen, O. Dupuis, D. Pelat, J. Réess, D. Rouan, Observatoire de Paris à Meudon (France)

A way to detect directly exoplanets is to use nulling interferometry in Fizeau configuration. In order to detect bio-tracers simultaneously, we have to create an achromatic phase shift of pi between the arms of the interferometer. We test a new achromatic phase shifter, which achieves theoretically these requirements. This phase shifter is a mask containing two cellular subpupils, each composed of several cells with different thicknesses introducing phase shifts that are respectively odd and even multiples of half of the central wavelength. This mask is currently used on the bench DAMNED (Dual Achromatic Mask for Nulling Experimental Demonstrator) in order to confront theoretical prediction with experimental results and we present here the first results.

7739-69, Session 10

Experimantal advances in phase mask coronagraphy

M. N'Diaye, Univ. Nacional Autónoma de México (Mexico); K. Dohlen, Observatoire Astronomique de Marseille-Provence (France); S. Cuevas, Univ. Nacional Autónoma de México (Mexico)

Stellar coronagraphy is a key technology for current and future planet search and characterization instruments, both on the ground and in space. We persue the research on coronagraphs based on cylindrical phase-masks and report in this paper on recent advances in terms of the trade between spectral bandwidth and achievable contrast. We also consider some interesting options concerning focal-plane wavefront sensing in such coronagraph systems.

7739-70, Session 10

Verification of the controllability of refractive index by subwavelength structure fabricated by photolithography: toward single-material mid- and far-infrared multilayer filters

H. Makitsubo, Japan Aerospace Exploration Agency (Japan) and The Univ. of Tokyo (Japan); T. Wada, M. Mita, Japan Aerospace Exploration Agency (Japan)

We are developing high performance mid- and far-infrared (MIR/FIR) multilayer filters with robustness for thermal cycling. Multilayer interference filters enable us to design a wide variety of spectral response by controlling refractive index and thickness of each layer. However, in MIR/FIR region, there are a few optical materials so that we can only use limited refractive index values to design filters. Consequently, optimization of refractive index required for designing high performance filters becomes difficult. Furthermore, it is difficult to deposit thick layers required for MIR/FIR multilayer filters. Deposition of two materials, which have different coefficients of thermal expansion, makes filters fragile for thermal cycling. To clear these problems, we introduce sub-wavelength structure (SWS) for controlling the refractive index. Then, only one material is necessary for fabricating filters, which enables us to design high performance filters with robustness for thermal cycling. According to the effective medium approximation (EMA) theory, the refractive index of randomly mixing materials in sub-wavelength scale is controllable by changing the ratio of mixing materials. However, it is not clear that the EMA can be applied to simple SWS, such as periodic cylindrical holes on bulk material, which is easily fabricated by photolithography. In order to verify the controllability of refractive index by simple SWS, we fabricate one-layer silicon SWS on silicon substrate by dry etching and measure its transmittance. Comparing measured transmittance with theoretical transmittance calculated by the EMA, we confirm that the EMA can be applied to simple SWS fabricated by photolithography.

7739-71, Session 10

Assessment of black and spectrally selective surfaces for stray light reduction in telescope systems

S. M. Pompea, National Optical Astronomy Observatory (United States)

This talk gives an update on practical considerations in choosing spectrally selective and tailored emissivity surfaces for a wide range of ultraviolet/optical/infrared telescopes and instruments. Although there is a wide range of types of surfaces that can be used; BRDF data is lacking in many cases as is a frank assessment of their durability and practical use. The author has tracked many of these surfaces, including black felts/flocks and the latest set of "nano-fibre" materials in reviews such as the chapter on "Characterization and Use of Black Surfaces" for the Handbook of Optics. The talk will also describe the context for use of black surfaces for stray light control and fundamental rules for effective selection and use of these surfaces.

7739-72, Session 11

The OPTICON technology roadmap for optical and infrared astronomy

C. R. Cunningham, D. Melotte, UK Astronomy Technology Ctr. (United Kingdom); F. Molster, Netherlands Research School for Astronomy, NOVA (Netherlands)

The Key Technology Network (KTN) within the OPTICON Framework Programme 6 and 7 (FP6 and FP7) has been developing a roadmap for the technology development needed to meet the challenges of optical and infrared astronomy over the next few years, with particular emphasis on the requirements of Extremely Large Telescopes. Through a series of workshops, we identified critical areas for support such as Astrophotonics, infrared detectors and adaptive optics on-sky demonstrator facilities. We facilitated consortium building and development of proposals, resulting in new joint research activities in OPTICON FP7. The KTN is now revising the roadmap and running a series of workshops on topics including position sensing and metrology, polarimetry techniques and devices, deformable mirrors and real-time computing. We believe it is particularly important to look for connections between developments needed for ground and space-based astronomy, and to encourage joint proposals to develop new technologies which can have significant impact in both fields. We are also encouraging knowledge exchange activities with industry and other research sectors.

7739-73, Session 11

Direct laser written multimode waveguides for astronomical applications

N. Jovanovic, S. Gross, C. Miese, A. Fuerbach, J. S. Lawrence, M. J. Withford, Macquarie Univ. (Australia)

The direct write technique entails focusing a femtosecond laser pulse into a dielectric material (such as a block of glass) thereby modifying the index of refraction within the focal volume of the objective lens. By translating the focal point through the material it is possible to create tracks of modified index. If the index change is positive, then waveguiding regions are formed and these can be used to guide and manipulate light within the block of glass. By using this technique it is possible to realize complex integrated photonic devices in a miniaturized and inherently stable platform.

To date, research in direct write technology has been primarily focused on single-mode waveguide structures. However, multimode fibres are currently extensively used in astronomical instruments, for example to transport light from the focal plane of a telescope to a spectrometer; and therefore integrated multimode waveguides are of key interest. With this in mind, we investigate multimode waveguide structures created by using the direct write technique.

In particular we characterize parameters such as waveguide dimensions, refractive index profile, numerical aperture, coupling losses, transmission losses, and focal ratio degradation, in order to optimize the waveguide properties. We discuss the suitability and potential of such easily produced waveguides to astronomical applications.

7739-75, Session 11

Defining requirements and identifying relevant technologies in astrophotonics

J. R. Allington-Smith, Durham Univ. (United Kingdom); T. A. Birks, Univ. of Bath (United Kingdom); J. Bland-Hawthorn, The Univ. of Sydney (Australia); C. R. Cunningham, UK Astronomy Technology Ctr. (United Kingdom); S. Dagupta, Univ. of Southampton (United Kingdom); R. Haynes, Anglo-Australian Observatory (Australia); P. J. V. Garcia, Univ. do Porto (Portugal); A. K. Kar, Heriot-Watt Univ. (United Kingdom); A. Kelz, Astrophysikalisches Institut Potsdam (Germany); P. Y. Kern, Lab. d'Astrophysique de l'Observatoire de Grenoble (France); L. Labadie, Instituto de Astrofísica de Canarias (Spain); J. S. Lawrence, Macquarie Univ. (Australia); E. P. Le Coarer, Lab. d'Astrophysique de l'Observatoire de Grenoble (France); M. M. Roth, Astrophysikalisches Institut Potsdam (Germany); R. M. Sharples, Durham Univ. (United Kingdom); R. R. Thomson, Heriot-Watt Univ. (United Kingdom)

Astrophotonics offers the potential to avoid some of the problems of building instruments for the next generation of telescopes though the use of photonic devices to miniaturise and simplify instruments. It has already proved its worth in interferometry over the last decade and in fibre-based OH-suppression. This may allow radically different approaches to highly-multiplexed spectroscopy and turn-key systems for interferometry leading to major benefits to important studies such as the determination of the cosmic equation of state and identification of terrestrial planets. The Astrophotonica Europa partnership comprises a number of astronomical and photonics institutes throughout Europe and Australia. Granted funds from the European Union via the FP7 programme through OPTICON, It acts as a means of coordinating work in this region. A critical function is to define the scientific and technical requirements for the investigation and to quantify the advantage of the photonics approach over traditional techniques by simulation and technical evaluation of related telecommunication devices. We report the outcome of the definition of the these requirements and the identification of the most relevant photonics devices for the next phase of the programme.

7739-76, Session 11

Supercontinuum light sources for use in astronomical instrumentation: a test with PMAS, the Potsdam multi-aperture spectrophotometer

M. M. Roth, Astrophysikalisches Institut Potsdam (Germany); H. Löhmannsröben, O. Reich, C. Dosche, Univ. Potsdam (Germany); R. Haynes, Astrophysikalisches Institut Potsdam (Germany); L. Leick, NKT Photonics A/S (Denmark)

Innovative photonic devices have recently arrived in astronomical instrumentation, and hold the promise for remarkable advances. Supercontinuum white light is spectrally broadened laser light that is generated in photonic crystal fibers through non-linear effects of ultra-short pulsed lasers. Supercontinuum sources are now available as fibercoupled turn-key systems off-the-shelf, and they are used as convenient light sources, mostly in laboratory applications. Continuum calibration light sources in astronomy so far have been dominated by tungsten filament lamps for reasons of high radiative power, easy control, and low cost. However, modern instrumentation requirements are now more often not compatible with the heat generation and high temperature of such lamps in the immediate vicinity of optical systems. Instruments like e.g. the PMAS integral field spectrophotometer at Calar Alto, or MUSE, a 2nd generation instrument for the ESO VLT, employ a remote optical feeding scheme with waveguides. We report on test results of supercontinuum white laser light which was used for flatfield illumination of the PMAS IFUs at the Calar Alto 3.5m telescope in Spain.

7739-78, Session 11

Dither-based sensor for improved consistency of adaptive optics system

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Consistent and high wavefront reconstruction accuracy is necessary to maintain good quality imaging in adaptive optics systems. Most commonly used wavefront sensor is the Shack Hartmann sensor where the accuracy of wavefront reconstruction depends on how precisely the local centroids are determined to estimate local slopes and the method that is used for wavefront reconstruction from slope measurements. By applying Monte Carlo simulations on vector matrix multiply methods and Fourier reconstructor it is shown that the wavefront reconstruction error is not constant but fluctuates rapidly about a mean value irrespective of the sensing geometry at place. In this paper, a possible solution to this problem is addressed. The wavefront reconstruction accuracy in Shack Hartmann sensor depends strongly on the way wavefront distortion points match with the points of phase estimation. A small dither signal which acts like a translating operator on the wavefront sensor with respect to the phase screen is applied. For randomly generated Kolmogorov phase screens, the wavefront reconstruction accuracy is calculated by applying dither such that the sensor shifts in all directions and by different magnitudes. Probabilistically the point of best wavefront reconstruction is near the center of the phase screen. We show through numerical simulations that the consistency and the accuracy of wavefront reconstruction can be significantly improved using this technique. In real time system, the dither signal to be applied can be obtained from the wavefront sensor data of the immediate past within the wavefront decorrelation time. The practicality of building such a sensor is also discussed.

7739-79, Session 11

Ground-based observatory operations optimized and enhanced by direct atmospheric measurements

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Earth's atmosphere represents a turbulent, turbid refractive element for every ground-based telescope. We describe the significantly enhanced and optimized operation of observatories supported by the combination of a lidar and spectrophotometer that allows accurate, provable measurement of and correction for direction-, wavelength- and time-dependent astronomical extinction. The data provided by this instrument suite enables atmospheric extinction correction leading to "sub-1%" imaging photometric precision, and attaining the fundamental photon noise limit. In addition, this facility-class instrument suite provides quantitative atmospheric data over the dome of the sky that allows robust real-time decision-making about the photometric quality of a night, enabling better use of queue-based, service, and observer-determined telescope utilization. With operational certainty, marginal photometric time can be redirected to other programs, allowing useful data to be acquired. Significantly enhanced utility and efficiency in the operation of telescopes result in improved benefit-to-cost for ground-based observatories.

We propose that this level of decision-making will make large-area imaging photometric surveys, such as Pan-STARRS and the future LSST both more effective in terms of photometry and in the use of the telescopes. The atmospheric data will indicate when angular or temporal changes in atmospheric transmission could have significant effect across the rather wide fields-of-view of these telescopes.

We further propose that implementation of this type of instrument suite for direct measurement of Earth's atmosphere will enable observing programs complementary to those currently requiring space-based observations to achieve the required measurement precision, such as ground-based versions of the Kepler Survey or the Joint Dark Energy Mission.

7739-80, Session 11

Flexure mount for a MEMS deformable mirror for the GPI planet imager

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Small deformable mirrors (DMs) produced using microelectromechanical systems (MEMS) techniques have been used in thermally stable, bench-top laboratory environments. With advances in MEMS DM technology, a variety of field applications are becoming more common, such as the Gemini Planet Imager's (GPI) adaptive optics system. Instruments at the Gemini Observatory operate in conditions where fluctuating ambient temperature, varying gravity orientations and humidity and dust can have a significant affect on DM performance. As such, it is crucial that the mechanical design of the MEMS DM mount be tailored to the environment. GPI's approach has been to mount a 4096 actuator MEMS DM, developed by Boston Micromachines Corporation, using high performance optical mounting techniques rather than a typical laboratory set-up. Flexures are incorporated into the DM mount to reduce deformations on the optical surface due to thermal fluctuations. These flexures have also been sized to maintain alignment under varying gravity vector orientations. This paper is a follow-up to a previous paper which presented the preliminary design. The completed design of the opto-mechanical mounting scheme is discussed and results from finite element analysis are presented, including predicting the stability of the mirror surface in varying gravity vectors and thermal conditions. As well, the adhesive joint is analyzed. Test results for the finished design are included.

7739-81, Session 11

Fibre Bragg gratings for temporal spectral astronomy

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Many astronomical objects exhibit Doppler or photometric spectral variability. To be able to observe these phenomena in detail and on much smaller time-scales than are currently possible, instruments with very high spectral resolution and fast read-out speeds are required. Astrophotonic devices such as fibre Bragg gratings (FBGs) offer potential advantages for such applications. The use of fibre Bragg gratings allows for very high spectral resolutions and the stability and precision needed in the observation of the fast variation of a particular spectral line. FBGs, with band-edge gradients as steep as 0.28 to 0.725 dB/pm, have already been proven to detect spectral shifts as small as 10 pm (resolution of /Δ ~155000). The use of these gratings will lead to an instrument that is light weight, small, robust, and low cost. This break-through should allow us to significantly improve our knowledge of time varying astrophysical events, looking into very fast variations that haven't been measured before, with a possibility to observe multiple spectral lines simultaneously.

We will discuss the main science requirements and present the proof-

of-concept for a fibre Bragg grating based instrument specifically for temporal spectral astronomy.

7739-177, Session 11

Optical design of optical switches for diverse field spectroscopy

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Diverse field spectroscopy is a new concept in which any part of a field can be optically captured and send to the entrance slit of a spectrograph. It is more general than integral field spectroscopy, multi-object spectroscopy and even multi-integral-field spectroscopy which combine the two as in the KMOS instrument. In diverse field spectroscopy, point sources and extended sources are simultaneously optically captured in an optimal way that fully use the spectrograph for only the regions of interest; as opposed to multi-integral-field spectroscopy where rectangular or square fields are fully captured, the capturing mechanism will follow the complex shapes of the sources removing any useless field which can then be use for other sources instead or permit to observe larger sources. Optical switches can be programmed to transmit any subset of the spatial elements of a field to the spectrograph. We will present the different optical designs of switches that we made, some using micromirrors arrays, others not. A critical aspect of the designs is to minimize the cost so that the switches can be mass-produced while maintaining high optical performances. A general discussion will be made of the relation between the total cost of the switch system plus spectrograph and the multiplex advantage with respect to a spectrograph alone giving the same performances for different spectrograph characteristics.

7739-194, Session 11

Characterising modal noise in fibre-coupled spectrographs for astronomy

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Fibre modal noise occurs in high spectral resolution, high signal to noise applications. It imposes fundamental limits upon the photometric accuracy of state-of-the-art fibre-spectrograph systems. In order to maximize the performance of current and future instruments it is therefore essential to be able to predict and characterize fibre modal noise. Explicitly theoretical approaches are often limited to special cases, so this paper presents a phenomenological approach to describe modal noise in fibre spectrographs. At the beginning of the paper the theoretical background is established with a focus on requirements for astronomy, to give a framework for the subsequent research. Experimental investigations are then described which have been undertaken in Durham to explore the fibre and spectrograph dependency of modal noise. The goal of this work is to derive a reliable model which can be used for the optimization of future spectrograph designs. PEPSI-LBT (commissioning planned for 2011) is a prime example of an instrument which will be working in resolution and SNR regimes where the impact of modal noise becomes significant. Although PEPSI will ultimately be equipped with fibre actuators in order to minimize modal noise, initial measurements will be conducted to supplement our experiments with valuable data to verify the phenomenological approach.

7739-104, Poster Session

Fabrication of 4-meter class astronomical optics

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The 8-meter mirror production capacity at the University of Arizona is well known. As the Arizona Stadium facility is occupied with giant mirrors, we have developed capability for grinding, polishing, and testing 4-m mirrors in the large optics shop in the Meinel building housing the College of Optical Sciences. Several outstanding capabilities for optics up to 4.3 meters in diameter are now in place:

- A 4.3-m computer controlled grinding and polishing machine allows efficient figuring of steeply aspheric and non-axisymmetric surfaces.
- Interferometry using infrared and visible wavelengths and surface profilometry with a laser tracker allows quick, accurate in-process measurements from a movable platform on a 30-m vertical tower.
- 2-meter class flats are measured with a 1-m vibration insensitive Fizeau interferometer and scanning pentaprism system; stitching of 1-m sub-apertures provides complete surface data.

These methods were proven with successful completion of several optics including the 4.3-m primary mirror for the Discovery Channel Telescope. The 10 cm thick ULE substrate, supported with 120 actuators, was ground and polished to16 nm rms accuracy, corresponding to 80% encircled energy in 0.073 arc-second, after removing low order bending modes. The successful completion of the DCT mirror demonstrates the engineering and performance of the support system, ability to finish large aspheric surfaces using computer controlled polishing, and accuracy verification of surface measurements. In addition to the DCT mirror, a 2-meter class flat was recently produced to an unprecedented accuracy of <10 nm-rms, demonstrating the combined 1-m Fizeau interferometer and scanning pentaprism measurement technique.

7739-105, Poster Session

Studies on evaluating and removing subsurface damage on the ground surface of CLEARCERAM-Z HS

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In manufacturing segmented mirrors of extremely large telescopes, such as the Thirty Meter telescope(TMT), the surface of a glass mirror blank is ground first.

Grinding causes subsurface damage(SSD), which has to be finally removed because it affects the performance of the mirror.

We evaluated the depth of SSD on the ground surface of the ultra low expansion glass-ceramics CLEARCERAM-Z(R) HS (CC-Z HS) by Ohara Inc., which is one of the candidates for material for the TMT segmented mirrors. We made a polishing spot of Magnethorheological Finishing on the ground surface and measured exposed SSD features on the spot surface using an optical microscope. Large cracks with a diameter of a few microns reached about 7.5 μm depth for semi finish grinding and less than 1.5 μm depth for finish grinding. Smaller cracks have to be investigated after slight etching to expose them in the next stage.

We are also studying removal of SSD by acid etching, which is expected to be an effective method to remove an SSD layer than usually used time-consuming polishing if its uniformity is acceptable. We etched the 50 mm per side area of the ground surface of CC-Z HS by 20 μm depth, and evaluated its uniformity. The overall figure deviation was less than about 1 μm. However, scare deep valleys or bumps with about several microns depth emerged from place to place. Reducing these deep features remains to be solved.

7739-106, Poster Session

Diamond machining of multifaceted and freeform components for astronomical optics

D. J. Robertson, D. A. Ryder, K. Parkin, Durham Univ. (United Kingdom)

In this paper we outline the processes for the machining of multiple complex surfaces that are to be integrated into the NirSpec Instrument and the K-Band Multi-Object Spectrograph (KMOS). NirSpec is a multi-object spectrograph designed for the JWST and KMOS is a multi-field astronomical spectrograph designed for integration with the 8.2m diameter European Southern Observatory Very Large Telescope (VLT) and capable of surveying 24 independent fields. Both of these instruments employ Integral Field Units which are constructed using diamond machining techniques developed by the authors. In the K-mos instrument there are 1080 separate optical surfaces making up the 24 IFUs, many of them being complex freeform surfaces. This puts significant onus on the process development which will be outlined.

The optical surfaces are manufactured in aluminium using a combination of 5-axis (raster flycutting) and 3-axis (fast tool servo) precision diamond machines. The ability to generate any surface that can be mathematically defined combined with accuracies of better than 15 nm RMS over a 20 mm aperture allows an optical designer greater flexibility in generating powerful and unorthodox optical designs. This paper will outline the techniques used to machine these challenging optical surfaces using components from both the NirSpec and K-mos instruments as specific examples. Areas such as material choice and processing, tool design and component fixtures all have an effect on the final performance of each individual component and are discussed in detail.

7739-107, Poster Session

Investigation of sub-aperture polish techniques for manufacturing astronomical mirror

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Nanjing Institute of Astronomical Optics & Technology (NIAOT) is investigating two types of sub-aperture polish technique for manufacturing aspheric components in large astronomical telescopes. One technique is computer controlled optical surfacing (CCOS). It removes material by a small polish tool through traditional mechanical and chemical process. The other is ion beam figuring (IBF) technique. It employs a neutralized ion beam to physically sputter material form optical surface. Although the basic mechanism of the two techniques is different, they true share the same mathematical architecture which will be put forward firstly in this paper. Then tool design and material removal function in CCOS will be studied following by a fabrication instance using CCOS. After that some recent progresses achieved in IBF is presented. The last part will focus on the complementary relationship of CCOS and IBF. By using them alternatively optimal combination of surface precision, efficiency and edge control could be obtained. Simulation is provided to support this view and experiment will be done in near future.

7739-120, Poster Session

An improved method of the spatial point's position detection

W. Li, Univ. of Science and Technology of China (China); L. Zhu, National Astronomical Observatories (China)

During the experimental process of the spatial point's position detection, the advantages and disadvantages of the method that used on position detection of spatial point is analyzed, such as the method of edge detection, Gravity Method and so on. Based on accuracy analysis, an improved method on sub-pixel level is proposed with high-accuracy detection. Experimental results show that, the proposed detection method could improve the accuracy of the spatial point of position detection.

7739-121, Poster Session

A method of attitude measurement of the spatial target

W. Li, Univ. of Science and Technology of China (China); L. Zhu, National Astronomical Observatories (China)

A new method of attitude measurement of the target based on machine vision is proposed in this paper. Firstly, the intrinsic parameters and extrinsic parameters of the CCD camera are calibrated by using the feature points on the calibration target. Secondly, the calibration target in certain position is measured with the CCD camera. Through the 3D reconstructing method, the calibration target's attitude is acquired. Experimental results show that: the proposed method is simple, flexible and effective.

7739-122, Poster Session

A method of 3D reconstruction based on single camera

W. Li, X. Li, Univ. of Science and Technology of China (China)

This paper presents a method of 3D reconstruction based on single camera. Using the uncalibrated camera to take pictures of the planar pattern from a different angle and precisely calculated the internal and external parameters of the camera with Two-stages camera calibration method. Standard stereo steps such as sign matching and reconstruction. Experimental results show that: the position error of sign is about 20 micron. The proposed method is high-accuracy, simple, flexible and effective.

7739-123, Poster Session

Use of a Faro Arm for optical alignment

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Faro Arms are used in verification in component manufacture, as well as reverse engineering. We used a 6-axis Platinum Faro Arm for re-alignment of the spherical aberration corrector of the Southern African Large Telescope. We describe our experience with using this inexpensive portable co-ordinate measuring machine, emphasizing how it must be used in order to achieve accuracies required in optical alignment. In particular, the suppliers advertise an accuracy of 20 microns. Yet, errors a factor of 2 to 3 larger than this can occur, unless the user understands how these may be circumvented. All in all, this is a valuable and inexpensive tool for aligning expensive and complex optical assemblies.

7739-124, Poster Session

Surface measurements of radio antenna panels with white-light interferometry

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Typical radio telescopes have the primary reflector surface which is composed of single panels that have dimensions of a few tenths of meter a side. The manufacturing of these radio panels yield a precision of 1:1E-5 over the volume on the single panel, hence the surface roughness of the panels can be measured with very high accuracy by means of the low coherence interferometry (LCI) technique which reaches micrometric spatial and depth resolution and has the advantage of being contact-less.

We have developed a multi-channel partially coherent light interferometer

to realize non contact 3D surface topography with millimetric depth range and micrometric resolutions both in the spatial and depth axes. The technique is based on the LCI principle, for which a bi-dimensional sensor - a CMOS - has been developed to directly acquire images. 3D measures are recovered with a single scanning along the depth direction, and every single pixel of the bi-dimensional sensor measures a point on the object, this allows a fast analysis in real time on square centimeter areas.

In this paper we show the results obtained by applying the LCI technique method to analyze the surface roughness of the panels of a large radio antenna of 64 m of width and used for astronomical observations at 100 GHz; by measuring their 3D structure at micrometric resolution it is possible to verify their fabrication errors.

7739-125, Poster Session

Lens curvature measurements with contact-less LCI technique

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We present the development of a 3D measuring system for non-contact topography of reflective and diffuse surfaces with millimetric depth range and micrometric resolutions both in the spatial and depth axes. Based on the low coherence interferometry (LCI) technique, the novel concept implies the use of a bi-dimensional CMOS sensor where every pixel measures a point on the object thus permitting a fast analysis on square centimeter areas. LCI is able to analyze surface roughness with sub-micrometric depth resolution and has the advantage, in contrast to the classical interferometry, to resolve phase ambiguity, thus making it possible to measure surface topography up to the millimetric scale range.

Used for fast and precise alignment of optical instrumentation, the LCI technique allows to analyze the surface topography of lenses. For a semitransparent sample with several reflective surfaces, interference is capable of detecting all of the surfaces. We present results for an achromatic doublet which is composed of two lenses of different glasses, in particular the curvature and 3D surface of the central lens is recovered, a measure that cannot be analyzed by any contact instrument, and the thicknesses of the two lenses that compose the doublet are measured as well.

7739-126, Poster Session

Optical testing of the LSST combined primary/tertiary mirror

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The Large Synoptic Survey Telescope (LSST) utilizes a three-mirror design in which the primary (M1) and tertiary (M3) mirrors are two concentric aspheric surfaces on one monolithic substrate. The substrate material is Ohara E6 borosilicate glass, in a honeycomb sandwich configuration, currently in production at The University of Arizona's Steward Observatory Mirror Lab. In addition to the normal requirements for smooth surfaces of the appropriate prescriptions, the alignment of the two surfaces must be accurately measured and controlled in the production lab. The pointing, centration and spacing of the two surfaces are important parameters. This paper describes the basic metrology systems for each surface, but focuses on the alignment of the two surfaces. These surfaces are aspheric enough to require null correctors for each wavefront. Both M1 and M3 are concave surfaces with both non-zero conic constants and higher-order terms (6th order for M1 and both 6th and 8th orders for M3). M1 is hyperboloidal and can utilize a standard Offner null corrector. M3 is an oblate ellipsoid, so it has positive spherical aberration and requires a diffractive null corrector (a phase-etched computer-generated hologram (CGH)). Additional validation CGHs, which are chrome-on-glass, used in reflection, provide independent verification of wavefronts (which is then backed-out of the data) and optical axis reference. One relatively new metrology tool is the laser tracker, which is relied upon to measure the alignment and spacings. A separate laser tracker system will be used to measure both surfaces during loose abrasive grinding and initial polishing.

7739-130, Poster Session

Advanced wavefront sensing and control testbed (A-WCT)

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The Advanced Wavefront Sensing and Control Testbed (A-WCT) is built as a versatile facility for developing and demonstrating, in hardware, future technologies for wavefront sensing and control algorithms for active optical systems. The testbed includes a source projector for a broadband point-source and a suite of extended scene targets, a dispersed fringe sensor, a Shack-Hartmann camera and a large format imaging camera capable of phase retrieval wavefront sensing. The testbed also provides two accessible conjugated pupil planes which can accommodate active optical devices such as deformable mirror and segmented mirrors. In this paper, we describe the testbed optical design, testbed configurations and capabilities, as well as the results from the testbed hardware integrations and tests.

7739-131, Poster Session

Wavefront sensing using phase retrieval methods

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Phase retrieval is an image-based wavefront sensing process, used to recover phase information from defocused stellar images. Phase retrieval has proven useful for diagnosis of optical aberrations from space telescopes, calibration of adaptive optics systems, and is intended for use in aligning and phasing the James Webb Space Telescope. This paper describes a robust and accurate phase retrieval algorithm for wavefront sensing, which has been successfully demonstrated on a variety of testbeds and telescopes. Key features, such as image pre-processing, diversity adaptation, and prior phase nulling, are described and compared to other methods. Results demonstrate high accuracy and high dynamic range wavefront sensing.

7739-132, Poster Session

SALT segmented primary mirror: laboratory test results for Fogale inductive edge sensors

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At the Southern African Large Telescope (SALT), in collaboration with Fogale Nanotech, we have been testing the recently-developed new generation inductive edge sensors. The Fogale inductive sensor is one technology being evaluated as a possible replacement for the now defunct capacitance-based edge sensing system.

We present the results of exhaustive environmental testing of two variants of the inductive sensor. In addition to the environmental testing including RH and temperature cycles, the sensor was tested for sensitivity to dust and metals. We also consider long-term sensor stability, as well as that of the electronics and of the glue used to bond the sensor to its supporting structure. A prototype design for an adjustable mount is presented which will allow for in-plane gap and shear variations present in the

primary mirror configuration without adversely disturbing the figure of the individual mirror segments or the measurement accuracy.

7739-135, Poster Session

First cophasing of a segmented mirror with a tunable filter and the pyramid wavefront sensor

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Optical cophasing has a key role in ensuring that segmented mirror telescopes will reach their best performaces. To measure and correct segments misalignment it is necessary to have a wavefront sensor in the telescope optical path. All the cophasing wfs suffer the phase ambiguity problem that limits the piston error measurements to a unit of wavelength. To overcome this problem we have developed a new cophasing technique based on the wavelength sweep.

In this paper we will present the results of laboratory and on-sky tests of this technique, comparing them with the expected performance obtained through numerical simulations. The first tests were carried out on the Active Phasing Experiment bench at ESO premises in Garching. We measured piston errors up to 15um with an accuracy better than 0.1um on a pupil conjugate segmented mirror using the Pyramid Phasing Sensor and a commercial Tunable Filter. We tested the possibility to propagate the differential piston measurements over the mirror to cophase it, getting a residuals rms of 0.1um. The on-sky test of the technique was made at William Hershel Telescope exploiting the NAOMI deformable mirror. We checked here the effects of atmospheric turbulence on the measurements of large piston errors and we got a level of accuracy of 0.25um, in agreement with the expected value.

7739-55, Poster Session

Deformable active optics test of the submirrors of the LAMOST reflecting Schmidt plate

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The reflecting Schmidt plate of the LAMOST implements both segmented mirror active optics and deformable mirror active optics on its 24 hexagonal sub-mirrors. Each of the 1100 mm sub-mirrors assembly has to pass comprehensive conventional test of the both active optics at laboratory before delivery. A dedicated testing setup with a paraboloidal primary mirror of 910 mm was established. In order to cover the larger to-be-tested hexagonal sub-mirror with the smaller testing setup, we turned to figure out the full aperture with the measured central wave-front information by various extrapolation techniques. The deformable active correction is a force-method-based procedure aided with finite element analysis (FEA). A flexibility matrix was calculated by FEA software and stored in computer beforehand, afterwards, least square fitting technique is used to find correction forces corresponding to the wavefront compensation. Different methods were studied for mapping the measured wavefront data to the meshed FEA model grid of the sub-mirror. Besides the analytical extrapolation mapping methods with typical Zernike polynomials and power series, we found that the discrete technique based on either free vibration mode shapes or the calculated flexibility matrix is prevailing. Additionally, the bi-linear interpolation technique derived from shape function in finite element theory was directly used for the mapping to keep the raw data with as high fidelity as possible. The same procedure has been also successfully implemented in a full-aperture Ritchey-Common test for the segments to verify the active optics correction.

7739-136, Poster Session

An innovative low-cost antenna dish built with commercial off-the-shelf (COTS) components

J. Cheng, National Radio Astronomy Observatory (United States)

The Frequency Agile Solar Radiotelescope (FASR) and the Square Kilometer Array (SKA) are very important multi-wavelength imaging instruments. These aperture synthesis arrays cover wide wavelength range, including low, middle and high frequency sub-arrays. In the middle frequency range, the antennas are working between 250 MHz to 3 GHz in frequency. Antennas working in this range are relaxed in their surface shape tolerance. Our innovative antenna dish structure design effort will start from this relatively lower frequency end.

Reflector antenna dishes usually involve a double-layer truss backup structure. The central part of the bottom layer is connected to supporting structure and the top layer supports the reflecting panels. Radiation is reflected by the surface panels and focuses to a feed horn in the apex. The reflecting panels are metal plates or wire meshes for wavelengths longer than a few centimeters. One obvious advantage of using wire mesh panels is its reduced wind resistance which influences the dish structure rigidity as well as the drive system power. With a double-layer truss structure, the backup stiffness is assured through the height between the top and bottom layer members. The deeper the backup structure, the stiffer it is. However, the double-layer truss involves members with various lengths and joints with different orientations. All these increase the dish structure cost.

Single-layer truss usually has less stiffness so that special design is needed to increase its stiffness. One way is to prestress the radial beams through bending them. The dish using this method is light in weight. Full FEA (finite element analysis) of this prestressed dish structure also shows that the dish has small displacement under gravity loading. However, the inner part of the radial beam may have local buckling when the survival wind loading is applied. Besides that, the prestressing process is also labor intensive which results in high cost even though the material cost is lower. Another way is to use high bending moment commercial off-the-shelf (COTS) struts and fixtures to make a simple cone shaped dish backup structure. The surface curved shape is maintained by adjusting the panel adjusters' height. This type of dish involves minimum special parts and minimum manpower in its manufacture and assembly, so that a big cost saving in dish structure is guaranteed.

7739-137, Poster Session

The VST active primary mirror support system

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The 2.6-m primary mirror of the VST telescope is equipped with an active optics system in order to correct low-order aberrations, constantly monitoring the optical quality of the image and controlling the relative position and the shape of the optical elements. Periodically an image analyser calculates the deviation of the image from the best quality. VST is equipped with both a Shack-Hartmann in the probe system and a curvature sensor embedded in the OmegaCam instrument. The telescope control software decomposes the deviation into single optical contributions and calculates the force correction that each active element has to perform to achieve the optimal quality. The set of correction forces, one for each axial actuator, is computed by the telescope central computer and transmitted to the local control unit of the primary mirror system for execution. The most important element of the VST active optics is the primary mirror, with its active support system located within the primary mirror cell structure. The primary mirror support system is composed by an axial and a lateral independent systems and includes an earthquake safety system. The system is described and the results of the qualification test campaign are discussed.

7739-138, Poster Session

Performance of the VST secondary mirror support system

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The VST telescope is equipped with an active optics system based on a wavefront sensor, a set of axial actuators to change the primary mirror shape and a secondary mirror positioner stage. The secondary mirror positioning capability allows the correction of defocus and coma optical aberrations, caused by incorrect relative positions of the two mirrors arising from the deformation of the telescope tube and of the optical train under the effect of gravity and thermal espansion. Periodically the image analyser calculates the deviation of the image from the best quality and the telescope control software decomposes the deviation into the single optical contributions. The new position and orientation of the secondary mirror is computed by the telescope control software and transmitted to the secondary mirror support system for execution. The secondary mirror positioner is a hexapod, i.e. a parallel robot with a mobile platform moved by six linear actuators acting simultaneously. This paper describes the secondary mirror support system and the qualification test campaign performed both in laboratory and at the telescope.

7739-139, Poster Session

The axial actuators for the VST primary mirror

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The VST primary mirror is a 2.6-m meniscus made of Astro-Sitall. An active optics system is implemented to correct surface errors due to manufacturing or induced by gravity and temperature changes. The primary mirror is axially supported by 84 supports disposed in four concentric rings. Three of the supports, symmetrically placed and much stiffer than the other ones, define the axial plane of the primary mirror acting as fixed points. The remaining 81 supports are force controlled actuators, used to change the shape of the mirror according to wavefront measurements in closed loop operation, or to a look-up table in open loop. This paper describes the solutions adopted for the axial actuator, as well as the test campaign to assess their performance and degree of reliability.

7739-140, Poster Session

Research on signal cable entering cabin

G. Pan, National Astronomical Observatories (China)

The focus cabin of FAST telescope was suspended by six wire ropes, which moves in a large area by controlling windlass to roll the wire ropes. The supporting structure that keeps the focus cabin of FAST telescope airborne is highly flexible, the signals need to be transmitted between the focus cabin and control room. Based on the special structure of the focus cabin suspension, using special optical fiber cable, the scheme of passive entering cabin is proposed to transmit signal, In order to reduce signal loss, particular mechanical structure limit-place is ensured the minimum bending radius of optical fiber cable. The bending fatigue life is 66000 cycles and the single attenuation is less than 2dB under dynamic test.

7739-141, Poster Session

Thermal behavior of the Medicina 32 Meter Radio Telescope

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We measured the thermal effects on the 32 m diameter radiotelescope of the Institute of Radio Astronomy (IRA), Medicina, Bologna, Italy. The results clearly show that the thermal gradients affect and deteriorate the pointing performance of the antenna.

Data were collected using: a): one inclinometer mounted near the elevation axis on the alidade structure that supports the primary reflector; b): an optical system to measure the secondary mirror position; c) few tens of thermal sensors mounted on the alidade trusses. We made two series of measurements during a sunny day: one with the antenna in stow position (looking at the horizon), the other while tracking a circumpolar astronomical source (antenna dish facing north, opposite to the Sun). With the antenna in stow position we observed a straight correlation between the inclinometer measurement and the differential temperature measured from the sensors located on the South and North sides of the alidade. The results indicate that the inclinometers track well the thermal deformation of the alidade.

With the antenna pointing at the source we measured both the pointing errors and the inclination of the alidade. We found that the pointing errors measured on-source were 20-30 arcseconds larger than those measured with the inclinometer. This discrepancy is explained by taking into account the deformations of other parts of the antenna structure not measured by the inclinometers; for instance, the thermal deformation of the quadrupod structure determines a shift of the sub-reflector optimal position that can be measured using the optical system.

7739-143, Poster Session

Fast force actuators for LSST primary/tertiary mirror

E. A. Hileman, National Optical Astronomy Observatory (United States); M. Warner, Cerro Tololo Inter-American Observatory (Chile); O. Wiecha, National Optical Astronomy Observatory (United States)

The very short slew times and resulting high inertial loads imposed upon the Large Synoptic Survey Telescope (LSST) create new challenges to the primary mirror support actuators. Traditionally large borosilicate mirrors are supported by pneumatic systems, which is also the case for the LSST. These force based actuators bear the weight of the mirror and provide active figure correction, but do not define the mirror position. A set of six locating actuators (hardpoints) arranged in a hexapod fashion serve to locate the mirror. The stringent dynamic requirements demand that the force actuators must be able to counteract in real time for dynamic forces on the hardpoints during slewing to prevent excessive hardpoint loads. The support actuators must also maintain the prescribed forces accurately during tracking to maintain acceptable mirror figure. To meet these requirements, candidate pneumatic cylinders incorporating force feedback control and high speed servo valves are being tested using custom instrumentation with automatic data recording. Comparative charts are produced showing details of friction, hysteresis cycles, operating bandwidth, and temperature dependency. Extremely low power actuator controllers are being developed to avoid heat dissipation in critical portions of the mirror and also to allow for increased control capabilities at the actuator level, thus improving safety, performance, and the flexibility of the support system.

7739-145, Poster Session

Innovative relocation system for enclosures for MROI array telescopes

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Magdalena Ridge Observatory Interferometer (MROI) comprises an array of up to 10 1.4m-diameter mirror telescopes. Each of these 10 telescopes will be housed inside a Unit Telescope Enclosure (UTE) which can be relocated, with the telescope inside to any of 28 stations arranged in a "Y" configuration. these stations comprise fixed foundations with utility and data connections. There are four standard array configurations, the most compact of each one has less than 350mm of space between the enclosures. This paper describes the relocation system that were evaluated, including a rail-based system, wheels or trolley fixed to the bottom of the enclosure, and various lifting mechanisms. Eventually a relocation system utilizing a modified reachstaker (a transporter used to handle freight containers) has been selected. The reachstaker is capable of manoeuvring between and around the enclosures, is capable of lifting the combined weight of the enclosures with the teelscope (40 tons), and can manoeuvre the enclosure with minimum vibrations. A rigorous testing procedure has been performed to determine the vibrations induced in a dummy load in order to guarantee the safety of optics that must remain on the nasmyth table during the relocation. Finally, we describe the lifting system, constituted by hydraulic jacks and locating pins, designed to lift and lower the enclosure and telescope during the precise positioning of the telescopes in the various stations.

7739-147, Poster Session

Design and simulation of the direct-drive system

C. Ren, Tsinghua Univ. (China)

As direct drive technology is finding their way into telescope drive designs for its many advantages, it would push to more reliable and cheaper solutions for future telescope complex motion system. However, the telescope drive system based on the direct drive technology is one high integrated electromechanical system, which one complex electromechanical design method is adopted to improve the efficiency, reliability and quality of the system during the design and manufacture circle. The telescope is one ultra-exact, ultra-speed, high precision and huge inertial instrument, which the direct torque motor adopted by the telescope drive system is different from traditional motor. This paper explores the design process and some simulation results are discussed

7739-148, Poster Session

Toward high-dynamic active mirrors for LGS refocusing systems

E. Hugot, F. Madec, M. Ferrari, D. Le Mignant, J. Cuby, Observatoire Astronomique de Marseille-Provence (France)

Specific astronomical applications may require high dynamic active mirrors, meaning the variable asphericity range can grow up to more than one millimetre. We propose high dynamic variable curvature mirrors (VCM) for a laser guide star (LGS) refocusing system, in the frame of the EAGLE instrument for the E-ELT. We designed a convex VCM able to provide a large sag variation on a spherical surface with a 120mm clear aperture, with an optical quality better than lambda/4 RMS up to 1000µm of sag. The mirror is made of a thin meniscus linked to an outer thick ring via a very thin collar. Finite element analysis (FEA) showed that geometrical and material non linearity may introduce a variation in the global shape of the deflection. In order to compensate for that, a variable thickness distribution is machined on the meniscus mirror, equilibrating the RMS surface error over the full range of deflection. A preliminary study of the pre-stressing has also been performed by FEA, showing that a permanent deformation remains after removal of the loads. Results of analytical theory and simulations are presented. A specific article on experimental results is also presented in this conference (Madec et al), based on this design.

7739-149, Poster Session

In-flight aberrations corrections for large space telescopes using active optics

M. Laslandes, M. Ferrari, E. Hugot, Observatoire Astronomique de Marseille-Provence (France)

The need for both high quality images and light structures is a constant concern in the conception of space telescopes. The goal here is to determine how an active optics system could be embarked on a satellite in order to correct the wave front deformations of the optical train. The optical aberrations appearing in a space environment are due to mirrors' deformations, with three main origins: the thermal variations, the weightlessness conditions and the use of large weightlighted primary mirrors.

We are developing a model of deformable mirror as minimalist as possible, especially in term of number of actuators, which is able to correct the first Zernike polynomials in the specified range of amplitude and precision. Flight constraints as weight, volume and power consumption are considered. Firstly, such a system is designed according to the equations from the elasticity theory: we determine the geometrical and mechanical characteristics of the mirror, the location of the forces to be applied and the way to apply them. Then the concept is validated with a Finite Element Analysis, allowing to optimize the system by taking into account parameters absent from the theory. At the end, the mirror will be realized and characterized in a representative optical configuration.

7739-151, Poster Session

The calibration and evaluation for laser tracker apply in LAMOST field environment

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The whole LAMOST project achieved successfully last year and has observed properly. As the high precision and large scale modern measuring instrument, laser tracker is widely used in various field environment. But in the process of LAMOST building, the measurement requires high precision in most cases especially for focal plane system measuring. This paper mainly focuses on the focal plane measurement, to testify the feasibility for using laser tracker to measure the focal plane plate. And a lot of experiment results and analysis will be mentioned in the paper. There are three laser tracker producers in the world and the main models with the three producers have all compared in detail. Furthermore, the special calibration scheme for the laser tracker will be discussed, and tries to improve the precision and stability of the laser tracker measuring system in the LAMOST field environment.

7739-152, Poster Session

Design of performance verification testing for HET wide-field upgrade tracker in the laboratory

J. M. Good, R. J. Hayes, J. R. Mock, I. M. Soukup, J. H. Beno, R. D. Savage, J. A. Booth, G. J. Hill, H. Lee, M. E. Cornell, M. D. Rafal, The Univ. of Texas at Austin (United States)

In support of the Hobby-Eberly Dark Energy Experiment (HETDEX),

McDonald Observatory (MDO) and the Center for Electromechanics (CEM) at the University of Texas at Austin are developing an upgrade to the current HET tracker in support of the Wide-Field Upgrade (WFU) and the Visible Integral-Field Replicable Unit Spectrograph (VIRUS) program. The precision tracker is required to be capable of maintaining the position of a 3,100 kg payload within ten microns of its desired position relative to the telescope's primary mirror. The system to accomplish this has ten precision controlled actuators. Prior to installation on the telescope full performance verification is required of the completed tracker, with a test mass representative of the payload, in CEM's lab without a primary mirror or the telescope's final instrument package. To accomplish this requires the development of a laboratory test stand capable of supporting the completed tracker over its full range of motion and an instrumentation suite and methodology that can verify the accuracy of the tracker motion over full travel (4m diameter circle, 400 mm deep, with 9 degrees of tip and tilt) at a cost and schedule in keeping with the HET WFU requirements. Several systems have been evaluated to complete this series of tests including: photogrammetry, laser tracker, autocollimator, and distance measuring interferometer. The design of the proposed system and its implementation in the lab is presented along with the test processes, predicted accuracy, and the analysis supporting the decision to use the chosen method.

7739-153, Poster Session

Upgrading the controller of the fast tip-tilt tertiary mirror for the SOAR telescope

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The SOAR telescope fast tip-tilt tertiary mirror, was delivered by the Goodrich Optical and Space Systems Division, Danbury, CT, and integrated into the SOAR optical system in 2004, it consist of a flat, light weighted 600 mm mirror, controllable over a range of ±1 mrad, in two axes, with a required position loop bandwidth of 50Hz, it operates using the guider probe signal for position command, in an outer loop fashion.

The original tertiary mirror controller consisted of several analog circuit boards, incorporating the position control loop compensation, and power amplifiers, the system was limited by the difficulty of any modifications, to optimize the control loop, and meet the required bandwidth. The analog controller was replaced with a digital controller based on a National Instruments Compact RIO/FPGA device, this allows the full optimization of the control system, and also allows closing the torque loop using the optical feedback of the guide signal alone, which should result in even higher performance.

This paper will describe the models, design, and performance tests, of the new digital control system.

7739-154, Poster Session

LN2 continuous-flow cryostats, compact vibration free cooling system for single to multiple detector systems

J. Lizon, M. Accardo, European Organisation for Astronomical Research in the Southern Hemisphere (Germany)

In comparison with mechanical cryo-coolers, liquid nitrogen cooling has the double advantage to be free of vibration and to remain not affected by power failure. Unfortunately the most common practice is to bolt the experiment directly onto the bottom plate of a LN2 bath. This method suffers from the disadvantage of having the holding time directly dependant from the size of the cryostat it-self and then lead to large and heavy cryostat in order to increase the holding time.

The paper reports about cryostat using a continuous circulation of liquid nitrogen which is provided from an external storage tank. Since years, this compact cryostat is intensively used on the ESO VLT to cool either optical or Infra Red detectors. Actually more than 12 of this cryostat is already in operation.

After an introduction presenting the principle, the paper reports the performance of the cryostat recoded over many years of utilization. The cryostat was originally designed for a simple application on a static instrument. We also present a few additional developments which allowed the use of the cryostat for more exotic applications such that Nasmyth rotating instruments or extremely stable radial velocity spectrograph.

With the construction of MUSE we enter in a new era for this cryostat. The large multi IFU instrument requires 24 cryostats. The last chapter of the paper describes this futurist system which is already close to completion.

7739-155, Poster Session

Liquid nitrogen pre-cooling of large infrared instrument at ESO

J. Lizon, European Organisation for Astronomical Research in the Southern Hemisphere (Germany)

Since the last decade, most of the large Infrared instruments are kept at operating cryogenic temperature using mechanical cryo-coolers. Generally Gifford MacMahon Closed Cycle Coolers or Pulsed Tubes are doing this duty.

These coolers are well dimensioned to keep the instrument and the detector at a sufficiently low operating temperature. Using the only cooling power provided by the steady state mechanical cryo-coolers would lead to several days for the initial cooling down. Therefore an additional cooling has to be used to allow a reasonable cooling time.

The present paper describes the liquid nitrogen continuous flow cooling system developed at ESO for ISAAC. During the past years, this system has also been used successfully for a number of VLT instruments (CRIRES, HAWK-I..). We will clearly outline the advantage of this system which allows extracting the heat exactly where it is necessary. We will present the design of the various components (heat exchangers, manifolds, connections..) which have been developed to get this system safe, reliable and efficient.

In a last part of the paper we report about some development work which has been done to push this technique toward temperatures lower than normal LN2 boiling temperature. Using well designed heat exchangers, temperature lower than 68 K has been reached by decreasing the operating pressure.

7739-156, Poster Session

A very accurate filter wheel for a large-field IR imager

J. Lizon, European Organisation for Astronomical Research in the Southern Hemisphere (Germany)

HAWK-I is a near-infrared imager with a relatively large field of view. Two filter wheels of 6 positions each offer a choice of 10 filters. The filters are directly in front of the detector, a mosaic of 2 x 2HAWAII 2RG 2048x2048 pixels detectors. A rather high positioning reproducibility (< 6 arc sec) is required in order to avoid any disagreement caused by subtraction of eventual fix pattern on the filters.

The document describes various drive systems which have been tested in order to reach the specified positioning reproducibility. This includes an interesting dissipation free locking system combining electro magnet and permanent magnet. The paper gives the extremely high reproducibility (< 2 arc sec) which has been reached with this system, but it also report on a few unespected problem meet with rare earth magnet at cryogenic temperature. Every solution is discussed and the performances measured in the laboratory during a long campaign of test are exposed. We also address the choice of other critical components like the ball bearings, mounting of the filters and cooling of the wheels.

7739-157, Poster Session

A hybrid liquid nitrogen system for the cooling of ESO OmegaCAM detector

J. Lizon, A. Silber, G. H. Jakob, European Organisation for Astronomical Research in the Southern Hemisphere (Germany)

For the optimal trade-off between dark current, sensitivity, and cosmetics, these detectors need to be operated at a temperature of about 155 K. The detectors mosaic (32 E2V 2Kx 4K) with a total area of 630 cm2 directly facing the Dewar entrance window, is exposed to a considerable radiation heat load. This can only be achieved with a very performing cooling system.

The paper describes the cooling system, which is build such that it makes the most efficient use of the cooling power of the liquid nitrogen. This is obtained by forcing the nitrogen through a series of well designed and strategically distributed heat exchangers. We give a detail description of the design and of the arrangement of the 3 main heat exchangers used to extract the heat of the focal plane. We explain also most of the choices with direct link with the various aspect of the requirements (Holding time, reliability, flexures...)

Results and performance of the system recorded during the laboratory system testing are reported as well. In addition to the cryogenic performance, the document reports also about the overall performance of the instrument including long term vacuum behavior.

7739-158, Poster Session

Advanced high-cooling power 2-stage Gifford-McMahon refrigerator systems

G. H. Jakob, J. Lizon, European Organisation for Astronomical Research in the Southern Hemisphere (Germany)

Powerful cryogenic instruments for ground-based astronomy require very high cooling power. Standard industrial type 2-stage Gifford-McMahon (GM) refrigerators were selected to serve as reliable cooling devices, known to implement proven technology, low vibrations and practicable mean-time-between-failure (MTBF) respectively service intervals. Although well-engineered and optimized, due to physical limitations their Carnot efficiencies are reaching just a few percent. Therefore one cannot expect much more than typically 100 W of cooling power at 80 K for a single system, already demanding several kW of compressor input power.

Our paper describes the development of ultra-high cooling power systems by making use of multiple cold head operation with a minimized number of compressor units. These advanced cooling systems were investigated for optimization and their Carnot efficiencies were analyzed. Test series were performed to monitor and rank some of their very critical operation parameters. Operating envelopes for different cold head / compressor configurations were defined for applications in various VLT instruments. This new concept of providing high pressure helium as a service point for a large number of detached cold heads is a first step towards a new cryogenic facility concept for the E-ELT.

7739-159, Poster Session

First concept for the E-ELT cryogenic infrastructure

J. Lizon, European Organisation for Astronomical Research in the Southern Hemisphere (Germany); I. R. Bryson, D. Montgomery, UK Astronomy Technology Ctr. (United Kingdom); C. Monroe, Monroe Brothers Ltd. (United Kingdom)

The start of the new generation of giant telescope opens a good opportunity to re-assess the cryogenic cooling of the instruments and detectors. An analysis has been carried out comparing three different technologies: Mechanical cryo-coolers, helium forced flow and open liquid nitrogen cooling. The most different aspects from the running cost to the reliability and technology readiness have been compared in order to establish a fair ranking. The first part of the paper will present in detail the result of this analysis.

Based on this study and the various experiences collected over more than 25 years and a large number of cryogenic instruments, a strategy is elaborated for the cryogenic cooling of the E-ELT instrument suite. A discussion presents the advantages of the selected solution.

Finally, the last part of the document sketches a first concept for the cryogenic infrastructure of the E-ELT. We will also point out the various points where some experience and reliable technology is still missing. We will also draft a possible strategy to be implemented in order to harmonize the expertise within the various instrument teams.

7739-161, Poster Session

An optical shutter for the Euclid imager

A. M. Glauser, ETH Zürich (Switzerland) and UK Astronomy Technology Ctr. (United Kingdom); J. Amiaux, J. Augueères, Commissariat à l'Énergie Atomique (France); S. J. Lilly, ETH Zürich (Switzerland); A. Refregier, Commissariat à l'Énergie Atomique (France)

We present a first design study of a shutter mechanism for the visible channel of the Euclid Imager. The main functionality of the shutter is to obscure the light during the CCD detector read-out and flat field calibration. Hence, the major design drivers are the requirements for a high number of open/close cycles (160,000), an opening/closing time of 5 sec, and the minimization of uncompensated momentum disturbances. The current design utilizes two fully redundant actuators, which drive the shutter via a lever system. In case of a single actuator failure, the failed actuator can be disengaged via a fail-safe system.

7739-162, Poster Session

Large format filter changer mechanism and shutter for the dark energy survey

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The Dark Energy Survey is a Stage III Dark Energy Experiment that will obtain cosmological parameters by combining four techniques; Galaxy Clusters, Weak Lensing, Type Ia Supernovae and Baryon Acoustic Oscillations. A new wide field camera (DECam) will be placed on the Blanco 4 m telescope at CTIO. We describe a large format (clear aperture 600 mm) Filter Changer Mechanism (FCM) and Shutter for the Dark Energy Survey Camera (DECam). The FCM, based on the Pan-STARRS design, has been constructed and tested under realistic conditions. The shutter, constructed at Bonn, has been put through a series of qualification tests. Both the FCM and Shutter are the largest ever constructed.

7739-163, Poster Session

Assembly of the dark energy survey CCD imager

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The Dark Energy Camera (DECam) is the new wide field prime-focus imager for the Blanco 4m telescope at CTIO. This instrument is a 3 sq. deg. camera with a 45cm diameter focal plane consisting of 62 2kx4k CCDs and 12 2kx2k CCDs and was developed for the Dark Energy Survey that will start operations at CTIO in 2011. DECam includes

the vessel shell, the optical window cell, the CCDs with their readout electronics and vacuum interface, the focal plane support plate and its mounts, and the cooling system and thermal controls. Assembly of the imager, alignment of the focal plane and installation of the CCDs are described. During DECam development a full scale prototype was used for multi-CCD readout tests. This test vessel went through several stages as the CCDs and related hardware progressed from early prototypes to final production designs. Testing results for the final hardware configuration are described.

7739-164, Poster Session

Cooling the dark energy camera CCD array using a closed-loop two-phase liquid nitrogen system

H. P. Cease, Fermi National Accelerator Lab. (United States)

The Dark Energy Camera (DECam) is the new wide field prime-focus imager for the Blanco 4m telescope at CTIO. This instrument was developed for the Dark Energy Survey that will start operations at CTIO during 2011. DECam is a ~520 megapixel optical CCD camera consisting of 62 2kx4k CCDs and 12 2kx2k CCDs. The sensors are supported by an aluminum focal plate operating at 173K. The focal plate is cooled using a pumped, closed loop, two-phase, circulating nitrogen system. The cooling system has been operating since late 2008 on a full scale prototype camera. This paper will describe the cooling system engineering basis including the thermal model and the two-phase flow model. Operating results showing cool down time, temperature stability of the focal plate, low induced vibrations, and a breakdown of the measured system thermal loads is presented. The operating range of the two-phase flow during telescope motions, and electrically isolating the cooling system from the instrument is also described.

7739-166, Poster Session

A precision lens cell for large temperature excursions

S. A. Smee, The Johns Hopkins Univ. (United States)

Details of a novel lens cell design are described. The design makes use of existing concepts in design and manufacturing to produce an elegant method for establishing and maintaining accurate lens placement over a broad range of temperature. Here lenses are centered by multiple roll-pin shaped flexures precisely machined into the cell. Like other flexure cells, the roll-pin flexures provide radial compliance to accommodate the difference in radial expansion between the lens and cell. However, the cylindrical flexure geometry is easily multiplexed and allows reference features for axial placement, centration in a barrel, and cell-to-cell stacking to be more easily integrated in a single mechanical component. This eases manufacture and improves accuracy. In this paper, the concept, detailed design, and analysis for the roll-pin flexure cell are presented, along with examples of their use with a variety of lens materials, diameters (25 mm to 375 mm) and temperatures (ambient to cryogenic).

7739-169, Poster Session

GRAVITY spectrometer: mechanical design

S. Fischer, M. Wiest, C. Straubmeier, C. Araujo-Hauck, Univ. zu Köln (Germany); F. Eisenhauer, Max-Planck-Institut für extraterrestrische Physik (Germany); G. S. Perrin, Observatoire de Paris à Meudon (France); W. Brandner, Max-Planck-Institut für Astronomie (Germany); A. Eckart, Univ. zu Köln (Germany)

Operating on 6 interferometric baselines, i.e. using all 4 UTs, the 2nd generation VLTI instrument GRAVITY will deliver narrow angle astrometry with 10µas accuracy at the infrared K-band.

Within the international GRAVITY consortium, the Cologne institute is responsible for the development and construction of the two spectrometers: one for the science object, and one for the fringe tracking object.

Optically two individual components, both spectrometers are two separate units with their own housing and interfaces inside the vacuum vessel of GRAVITY. The general design of the spectrometers, however, is similar. The optical layout is separated into beam collimator (with integrated optics and metrology laser injection) and camera system (with detector, dispersive element, & Wollaston filter wheel). Mechanically, this transfers to two regions which are separated by a solid baffle wall incorporating the blocking filter for the metrology Laser wavelength. The optical subunits are mounted in individual rigid tubes which pay respect to the individual shape, size and thermal expansion of the lenses.

For a minimized thermal background, the spectrometers are actively cooled down to an operating temperature of 80K in the warm environment of the GRAVITY vacuum dewar. The integrated optics beam combiner and the metrology Laser injection are mounted thermally isolated to the cold housing of the spectrometers.

The optical design has shown that the alignment of the detector is crucial to the performance of the spectrometers. Therefore, in addition to four wheel mechanisms, six cryogenic positioning mechanisms are included in the mechanical design of the detector mount.

7739-170, Poster Session

GRAVITY spectrometer: cryo-mechanism commissioning testbed

M. Wiest, C. Straubmeier, S. Fischer, C. Araujo-Hauck, Univ. zu Köln (Germany); F. Eisenhauer, Max-Planck-Institut für extraterrestrische Physik (Germany); G. S. Perrin, Observatoire de Paris à Meudon (France); W. Brandner, Max-Planck-Institut für Astronomie (Germany); A. Eckart, Univ. zu Köln (Germany)

GRAVITY is a 2nd generation VLTI Instrument which operates on 6 interferometric baselines by using all 4 UTs. It will offer narrow angle astrometry in the infrared K-band with an accuracy of 10µas.

The University of Cologne is part of the international GRAVITY consortium and responsible for the design and manufacturing of the two spectrometers. One is optimized for observing the science object, providing three different spectral resolutions and optional polarimetry, the other is optimized for a fast fringe tracking at a spectral resolution of R=22 with optional polarimetry. In order to achieve the necessary image quality, the mechanical design foresees, in addition to the three filter wheels, 8 cryogenic positioning mechanisms.

Both spectrometers require precise linear and rotational movements on micrometer or arcsecond scales. These movements will be realized using custom linear stages and compliant joints. The concept of our actuators is based on a Phytron/Harmonic Drive combination. For dimensioning and in order to qualify the reliability of these mechanisms, it is necessary to evaluate the mechanisms on the base of several prototypes. In this contribution, we will present our cryogenic laboratory test facility which we are going to use to qualify the accuracy, repeatability, and lifetime tests for our mechanisms. One important measurement for example will be the delivered force of our self-assembled actuators when used in a cryogenic environment.

The presentation will include first results of our measurements.

7739-171, Poster Session

HARPS secondary guiding

G. J. F. Ihle, European Southern Observatory (Chile); G. Avila, European Organisation for Astronomical Research in the Southern Hemisphere (Germany); I. Kastinen, European Southern

Observatory (Chile); G. Lo Curto, European Organisation for Astronomical Research in the Southern Hemisphere (Germany); A. Segovia, P. Sinclaire, European Southern Observatory (Chile); R. Tomelleri, Tomelleri s.r.l. (Italy)

The HARPS spectrograph, after its first six years of operations has established itself as the worldwide reference for accurate Doppler measurements.

The radial velocity precision of the instrument on a single measurement is estimated around 60 cm/sec.

One of the main limitations to the radial velocity precision is the variation of the injection illumination function due to tracking errors.

A light and fast guiding system has been recently developed for HARPS. In this way we increase the guiding closed loop bandwidth by a factor of 10 with respect to the standard guiding performed with the telescope.

The system is composed by a refractive glass placed along the light beam near the fiber entrance, and it is supported by a tip-tilt table.

A tilt of the glass displaces the star's image in the focal plane, where the fiber entrance is located, and allows guiding.

We discuss here the hardware and software implementation of this new guiding system, and report the first results after tests at the telescope.

7739-172, Poster Session

Manufacturing of silicon immersion grating for infrared spectrometer

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Silicon immersion gratings have been a promising future technology for high resolution infrared spectroscopy for over 15 years. Finally, the future has arrived. We report here on our current immersion grating research, including extensive measurements of the performance of micromachined silicon devices. We are currently producing gratings for two high resolution spectrometers: ISHELL at the University of Hawaii and IGRINS at the University of Texas and the Korea Astronomy and Space Science Institute. The gratings are R3 devices with total lengths of ~100mm. The use of a high index material like silicon permits the spectrometers to have high resolving powers (40,000-75,000) at decent slit sizes with very small (25mm) collimated beams. The lithographic production of coarse grooves allows for instrument designs with continuous wavelength coverage over broad spectral ranges. We will discuss the science requirements for grating quality and efficiency and the measurements we have made to verify that the gratings meet these requirements. The measurements include optical interferometry, measurements of the monochromatic point spread function with high dynamic range, and measurements of efficiency as a function of wavelength.

7739-173, Poster Session

High-performance silicon grisms for 1.2-8.0 µm: detailed results from the JWST-NIRCam devices

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Anti-reflection coated silicon grisms have high throughput and clean spectral characteristics that should make them an attractive dispersive element for moderate resolution IR spectroscopy in both ground and space based instruments throughout the 1.2-8 µm spectral region. We have recently completed a set of silicon grisms for JWST-NIRCam. These devices have exquisite optical performance: phase surfaces flat to /55 peak to valley at the blaze wavelength, diffraction-limited PSF's down to at least 10-5 of the peak, low scattered light levels, and large resolving-power slit-width products for their width and thickness. The production technique employs photolithography and anisotropic etching of Si. Our group has demonstrated the favorable surface properties of these techniques in both grisms and immersion gratings. The one possible drawback to these devices is the large Fresnel loss caused by the large refractive index of Si. We report here on throughput and phase-surface measurements for a sample grating with a high performance antireflection coating on both the flat and grooved surfaces. These results indicate that we can achieve very high on-blaze efficiencies. We have demonstrated the thermal survivability of the gratings, and they are now space ready.

7739-174, Poster Session

Optomechanical system of AIT tools to perform tests and integrations of 24 IFU

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The second generation instrument MUSE (Multi Unit Spectroscopic Explorer) developed for the VLT (Very Large Telescope) for ESO (European Southern Observatory) is composed of 24 identical Integral Field Unit. To perform the tests and the integration in a shorter time, we have developed an opto-mechanical system of AIT Tools (Assembly-Integration-Test) referenced to a unique simulator of IFU. Each IFU sub system and its test bench (sources, image slicer, spectrograph, IFU) are checked with respect to the same opto-mechanical reference. These references are also used to align all the 24 IFU onto the MUSE main structure. The system allows a better homogeneity between IFU in term of performances and a better traceability between its sub-systems. This article present the different AIT tools developed at CRAL (Centre de Recherche Astrophysique de Lyon) to reach the specified performances for the serial phase of AIT of 24 IFU.

7739-175, Poster Session

Improvements in diamond machining applied to the fabrication of a large ZnSe immersion grating

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LLNL has fabricated small (~1 cm2) germanium immersion gratings for a number of years (Kuzmenko et al. 2006) Recent improvements in the thermal stability of the machine environment and in fixturing of the workpiece have led to a several fold reduction in the diffracted wavefront error (as low as 0.011 wave rms in reflection at 633 nm).

We have applied these improvements toward the fabrication of a large (17 x 44 mm entrance aperture) ZnSe immersion grating for the WINERED spectrograph (Yasui et al. 2008). The first two tries at cutting the grating yielded unsatisfactory results (poor wavefront error and chipping of the grooves) due to failure of machine subsystems during the machining process. These subsystems have been repaired and the grating is being recut. Results of an optical inspection of the finished grating and an interferometric measurement of wavefront error will be reported.

A detailed discussion of the optical performance will be provided in an accompanying paper (Ikeda et al. 2010).

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7739-176, Poster Session

HERMES: VPH grating design issues with polarization

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The AAO is building an optical high resolution multi-object spectrograph, called HERMES, for the AAT with Galactic Archaeology as the primary science driver. The design is a 4-channel VPH-grating based spectrograph providing a spectral resolving power of 28,000 standard and a resolution mode of 40,000 with a slit mask. The total spectral coverage is about 1000 Angstroms for up to 392 simultaneous targets within the 2 degree field of view.

The gratings work at an external Bragg angle of 67.2 degrees. Significant polarization effects at this angle exist with limited bandwidth performance if the gratings are optimized for unpolarized light. There are also difficulties in getting good AR coating performance for the substrates at such angles.

A design trade is explored and presented to on how best to optimize the design parameters for the gratings and AR coatings. We explore polarization design options and their impact on efficiency and bandwidth.

7739-178, Poster Session

ESPRESSO: design and analysis of Coudé-Train concepts for stable and efficient optical feeding

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The first purpose of ESPRESSO is to develop a competitive, innovative high-resolution spectrograph to fully exploit the potentiality of the Very Large Telescope (VLT) of the European Southern Observatory and to allow new science. It is thus important to develop the VLT array concept bearing in mind the need to obtain the highest stability, while preserving an excellent efficiency. This high-resolution ultra-stable spectrograph will be installed at the VLT Combined Coudé Laboratory. A Coudé Train carries the light from the Nasmyth platforms to the Combined Coudé Laboratory, where it feeds the spectrograph. Several concepts can be envisaged for the Coudé Train depending on the use of mirrors, prisms and lenses or fibres or any of the possible combinations of these elements. Three concepts were selected for analysis, one based on purely optical components and two other using fibres (with different lengths). These concepts have different characteristics in terms of efficiency, stability, complexity, and cost. The selection must take into account all these issues. In this paper, we present for each concept the optical setups, detail their opto-mechanical implementation and analyse the expected throughput efficiency budget.

7739-195, Poster Session

Scattered light analysis of a DMD slit mask

Zoran Ninkov, Kenneth Fourspring, Rochester Institute of Technology

The DMD (Digital Micromirror Device) has an important future in both ground and space based multi-object spectrometers. A series of laboratory measurements have been performed to determine the sub-pixel scatter function of a DMD. The DMD under test had a 17 micron pitch and 1 micron gap between adjacent mirrors. Prior characterization of this device has been focused on its use in DLP (TI Digital Light Processing) projector applications in which a whole pixel is illumined by a uniform collimated source. The purpose of performing these measurements is to determine the limiting signal to noise ratio for utilizing the DMD as a slit mask. A detailed software model has been created to examine the effects of material surface roughness and BRDF scatter function. The DMD pixel was determined to scatter more around the pixel edges and central via, indicating that it is important to design a set of fore-optics for the DMD spectrometer that sample it appropriately. The trends derived from the DMD scatter measurements can be simplified to a characteristic function to describe the sub-pixel scatter. Further measurements are underway on a newer DMD device, which has a smaller mirror pitch and likely different scatter characteristics. Also an instrument previously constructed at RIT (the RITMOS RIT-multi-object spectrometer) will be used to validate these scatter models and signal to noise ratio predications through imaging a star field on a telescope.

7739-180, Poster Session

Progress toward high-performance astronomical coatings

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We present an update on efforts at University of California Observatories to develop improved optical coatings for astronomical telescopes and instruments. The main thrust has been in the areas of protected silver mirror coatings and sol-gel based anti-reflection coatings. Some silver coatings have been in use in Keck and Lick instruments for several years, and the Lick 1-m telescope has been silver-coated for the past two years, and we report on their performance. We discuss process improvements, including use of ion-assisted deposition and reactively-deposited oxides. Sol-gel based AR coatings have been exposed to cryogenic environments to test their suitability for IR instruments, with encouraging results. Finally, we describe our plans for future work.

7739-182, Poster Session

Cleaning the Southern African Large Telescope’s M5 mirror

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The M5 mirror of the spherical aberration corrector (SAC) of the Southern African Large Telescope (SALT) is a 410 mm diameter conic asphere with a 375 mm vertex radius of curvature. It is coated with multilayer coatings from the Lawrence Livermore National Laboratory (LLNL). The SAC was recently taken off the telescope for repairs and re-alignment and this offered the opportunity to investigate the state of cleanliness of this obviously very dirty mirror: it had been on the telescope for 5 years with no cleaning possible and layers of dust were very obvious along with 4 or 5 glycol blotches from an accidential glycol spill. Two cleaning strategies were attempted: use of First Contact, and washing with Sodium Lauryl Sulphate soap. The first led to evidence for coating separation at the edges where the coating is admittedly very thin. Water rinsing followed by two wipes of cotton wool saturated in Sodium Lauryl Sulphate essentially removed all the dust and the coating was restored to as near pristine as possible, albeit with some pinholing left over from the coating process and which was present prior to the cleaning beginning. This paper describes these strategies and shows the results achieved.

7739-184, Poster Session

Blocking filters with enhanced throughput for x-ray microcalorimetry

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NASA will fly x-ray microcalorimeters on several mission payloads scheduled within the next 5 years. New and improved blocking filters are urgently needed to realize the full potential and throughput of these missions. High transmission polyimide support mesh is being developed to replace the nickel mesh used in previous blocking filter flight designs. Polyimide's composition affords high transparency to x-rays, especially above 3 keV. Prototypes have 93-96% transmittance in the UV-visible range. A new filter fabrication technique that simplifies assembly, eliminates adhesives from the filter field, and creates a stronger foil/mesh bond than epoxy, has also been demonstrated. In addition to support mesh, embedded resistive traces are also being developed to provide deicing capability to actively restore filter performance in orbit. This report details the progress of this research to date.

7739-185, Poster Session

Stray light calculation of complex telescope systems: efficiency and accuracy

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Most of the stray light calculations for telescopes nowadays are by codes, based on Monte Carlo ray tracing. When the 1-M optical telescope of NAOC CAS is with a re-image optic after its focal plane, the system becomes complex in the aspect of stray light calculation comparing to the original two mirror systems. The third and fourth order scattering light will be the leading stray light energy. Monte Carlo ray tracing, with high efficiency and accuracy in this system, need tracing numerous rays and importance sampling at large. This means several days to arrange the sampling and then waiting the tracing results, otherwise insufficient input rays and importance sampling generate a "better" PST (Point source transmittance) data. Several operational methods to accelerate this procedure, including multi-core CPU tracing simultaneously, are estimated comparatively. The results Indicated that time can be saved distinctly. Potential methods for accuracy estimation of the Monte-Carlo ray tracing are also discussed.

7739-186, Poster Session

Pass-band filter performance for space-flight dark energy missions

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The nature of Dark Energy can by constrained by the precise determination of super-novae distance moduli in visible and near IR pass-bands. Space-based observations are required for these moduli to be measured with the scientifically required photometric accuracies. Consequently, robust pass-band filters operable at cryogenic temperatures (120-140K) are needed with demanding performance attributes that include high in-band transmission, low ripple, good out-of-band rejection, and moderate band-edge slope. We describe the requirements and performance of robust dielectric multi-layer filters with spectral profiles that are suitable for both achieving the science and for being accurately calibrated using plausible on-orbit measurement systems.

7739-187, Poster Session

Large Synoptic Survey Telescope filter design and fabrication

D. K. Gilmore, SLAC National Accelerator Lab. (United States)

The current LSST filter complement (u, g, r, i, z, y) is modeled on the system used for the SDSS (Fukugita et al. 1996), which covers the available wavelength range with roughly logarithmic spacing while avoiding the strongest telluric emission features and sampling the Balmer break.

Extension of the SDSS system to longer wavelengths (y-band) is possible because the deep depletion CCDs have high sensitivity to 1 um. The u-band improves the robustness of photometric redshifts of galaxies, stellar population separation, and quasar color selection, and will provide signicant additional sensitivity to star formation histories of detected galaxies.

The current LSST baseline design has a goal of 1% relative photometric calibration which drives the requirements on the filter set.

The filter set wavelength design parameters, the FWHM transmission points for each filter, out of band rejection results for the initial design study, and the overall performance characteristics to meet the LSST science goals will be presented.

7739-188, Poster Session

Development of five multifiber links for the OPTIMOS-EVE study for the E-ELT

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The OPTIMOS-EVE concept provides optical to near-infrared (370-1700 nm) spectroscopy, with three spectral resolution (5000, 15000 and 30000), with high simultaneous multiplex (at least 200). The optical fiber links are distributed in five kinds of bundles: several hundreds of mono-object systems with three types of bundles, fibre size being used to adapt spectral resolution, 30 deployable medium IFUs (about 2"x3") and one large IFU (about 6"x12").

This paper gives an overview of the design of each mode and describes the specific developments required to optimise the performances of the fiber system.

7739-189, Poster Session

Optical fiber tapers for applications in astronomy

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The field of astrophotonics (the application of photonic technologies to astronomy) has emerged in response to the increasing demands of astronomical instrumentation for both current generation large telescopes and next generation extremely large telescopes. The size of astronomical instruments scales with telescope aperture and therefore conventional technologies are no longer efficient or cost effective. Fiber tapers are important for future astronomical instrumentation as they will facilitate the use of alternative photonic technologies.

Optical fibre tapers show great promise as a simple and highly effective means of efficiently coupling broadband light into astronomical instruments. Fibre tapers can replace bulk optics systems such as focal plane reduction and magnification optics by controlling and manipulating image scale and beam angle in a small, robust and cost effective device. In addition, fibre tapers are expected to benefit astrophotonic developments such as planar waveguide combiners, frequency combs,

and integrated photonic spectrographs in a similar way.

Like any new photonic device fiber tapers must be thoroughly modelled and characterized before they can be applied to astronomy. The specific characteristics of importance are the device's ability to maintain the etendue of the system and to transmit light over a broad wavelength range with minimal loss. In this paper we present fibre taper modelling and preliminary characterization results for beam angle, focal ratio degradation and throughput.

7739-190, Poster Session

Multi-way optical fiber connectors for astronomy

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Instrumentation concepts with many thousands of multi-mode optical fibers are now being proposed in response to the science community's request for highly multiplexed instruments which will require a fiber connector system that can deliver excellent optical performance and reliability.

Over the past two decades, different fiber connector systems have been investigated and implemented, with limited success in multi-mode optical fiber based instruments. Because of the complexity of current and future fiber based astronomical instruments, there is an increasing demand for modularity and operational simplicity, providing the drive to find a cost effective, high performance, robust optical fiber connector technology.

The telecommunications and defence industry have been using multi-fiber connectors for years with great success. This industry has had the finances and facilities to prove multi-fiber connector technology delivering reliable, robust and cost effective devices that can be purchased off the shelf.

In this paper we report on the viability of commercially available fiber connectors for use in current and future multi-mode optical fiber based astronomical instrumentation. A down select of two multi-way fiber connectors were investigated and their optical performance characterized in detail. We outline the two fibre connector technologies and report on the characterization of their focal ratio degradation, throughput and wavelength fringing performance.

7739-191, Poster Session

Study of optical fibers scrambling to improve radial velocity measurements

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The detection of extrasolar planets has been possible first thanks to the use of radial velocity (RV) measurements. This technique has accomplished extraordinary achievements and pushed the planet detection limits down to super-earth regime. The current precision achieved by RV is around 30 cm/s. To reach the required precision to detect earth-like planets it is necessary to reach precision of the 1 cm/s. To reach these precisions, it is necessary to address astrophysical issues like intrinsic radial velocity noise due to stellar activity but it is also necessary to address some instrumental challenges. This poster shows possible improvements in the image scrambling performed by optical fiber necessary to mitigate the effects of atmospheric turbulence and telescope guiding errors. Current state of the art instrument still suffer from residual fluctuations in their illumination : either in the "slit" space or in the pupil space. These results in direct shifts or in chromatic deformations of the spectrum that results in systematic errors on the RV measurement. We will present an analysis of present performances of circular step index fibers and the properties of square and octogonal optical fibers, through simulations and lab experiments, that could improve significantly the scrambling performances of RV instruments.

7739-192, Poster Session

Fiber positioning revisited: the use of an off-the-shelf assembly robot for OPTIMOS-EVE

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PTIMOS EVE calls for rapid fiber positioning over a physical field of more than 2m diameter, but with a relatively benign plate scale of ~3mm/arcsec. We present the results of an investigation of whether or not this regime lends itself to the use of COTS manufacturing robots for the positioner system, together with a description of how such a system will be used in practice for the OPTIMOS-EVE instrument of the E-ELT.

7739-193, Poster Session

The ADC for the VST Telescope: theory and preliminary test of the electromechanical system

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The VST telescope is equipped with an Atmospheric Dispersion Corrector (ADC) to counterbalance the spectral dispersion introduced by the atmosphere. The well known effect of atmospheric refraction is the bending of incoming light due to variable atmospheric density along the light path. This effect depends on the tangent of the zenith angle and also varies with altitude, humidity and wavelength. Since the magnitude of refraction depends on the wavelength, the resulting effect is not only a deviation of the light beam from its original direction but also a spectral dispersion of the beam. This effect can be corrected by introducing a dispersing element in the instrument. In the VST case the device that compensates for this effect is based on a set of four prisms in two cemented doublet pairs. The system provides an adjustable counter dispersion by counter-rotating the two pairs of prisms. The counter-rotating angle depends on the atmospheric dispersion, which is computed with an atmospheric model using both environmental data (temperature, pressure, humidity) and the telescope position. Two different approaches have been compared for the computations to cross-check the results. The electromechanical system has been assembled, tested and debugged prior the shipping to Chile. This paper describes the atmospheric models used in the VST case, the solutions adopted for the electromechanical system and the status of work.

7739-82, Session 12

Cryogenic submicron linear actuator (CSA)

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The CSA (Cryogenic Submicron Linear Actuator) is a high range (±5 mm) high resolution (<20 nm) linear actuator suitable to be used at cryogenic temperature (10-70K). The unit has been developed to be used for fine positioning.

Main CTU characteristics are as follows:

Type: push & pull

Motion range: ±5 mm

Mechanical resolution: < 50 nm

Speed: 0.01 to 0.1 mm/s

Load Capability: 20 N

Operating temperature range: 10K to 300K

Vacuum: 10-7 mbar

Power Dissipation (average): <200 mW

Size: Ø25 x 150 mm

The CSA unit is based on classic motor-gear concept with nut and spindle; different material and lubrications have been tested for the same design configuration to compare performances.

This paper describes mean design features, results of different lubrications tested, tested performances, and main lesson learned during the development.

7739-83, Session 12

Design and qualification of an innovative cryogenic tip-tilt mirror

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Cryogenic mechanisms are needed for the alignment plan of MATISSE, a mid-infrared spectro-interferometer for the European Southern Observatory Very Large Telescope Interferometer (ESO VLTI) that combines up to four Unit Telescopes or Auxiliary Telescopes.

Telescope beams are split into 24 beams that need to be aligned on the detector and corrected for OPD (Optical path difference) in order to create an interference pattern.

Alignment accuracy and stability specifications are of the order of nanometers and arcsec. These specifications cannot be met by warm alignment or manufacturing tolerances, therefore nearly 50 motorized tip-tilt units are needed that operate in a vacuum cryogenic environment.

Key aspects of the mechanisms are that the optical element and mechanism are combined in a compact single component, driven by self braking piezo actuators in order to hold position without power. The design, realization and test results of these mechanisms are presented.

7739-84, Session 12

Different ways of reducing vibrations induced by cryogenic instruments

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The infrared instruments and most of the detectors have to be operated at cryogenics temperatures. Today, this is generally achieved using mechanical coolers. Compared to traditional nitrogen systems, these coolers, which large implementation started 15 years ago, have the advantage of reducing considerably the operation effort at the observatories.

Depending of the technology, these coolers are all generating a level of vibration which in most of the cases is not compatible with the extremely high stability requirement of the large size telescope.

This paper described different ways which have been used at ESO to reduce the vibration caused by the large IR instruments. With the start of the regular operation of the VLT interferomtre it has been necessary to make significant efforts to reduce the vibration caused by the actual IR instruments. While we exchanged the CCC system cooling our high resolution IR spectrograph (CRIRES), HAWK-I the K large field imager has been modified in order to be kept cold with LN2. In parallel a system producing counter vibration was developed. The paper reports about these three different approaches to reach a common low vibration level on the VLT.

7739-85, Session 12

Ultra-stable operation of detectors for high-resolution spectrographs

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High resolution spectroscopy demands detector operation in an extremely stable mechanical and thermal environment; any tiny perturbation may affect the location of the spectral lines affecting the instrument global performance. A test campaign was proposed and executed on HARPS to determine the overall internal stability of the spectrograph's detector array. Under a number of controlled conditions, which allow disentangling the origin and effect of potential instabilities in the measurements, the program was executed. The analysis of the results obtained so far and the current activity to improve further the detectors cryostat performances is presented.

7739-86, Session 12

Cryogenic Fourier transform infrared spectrometer from 4 to 20 micrometers

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We describe the design and performance of a cryogenic Fourier transform spectrometer (Cryo-FTS) operating at a temperature of approximately 15 K. The instrument is based on a porch-swing scanning mirror design with active alignment stabilization using a fiber-optic coupled diode laser and voice-coil actuator mechanism. It has a KBr beamsplitter and has been integrated into an infrared radiometer containing a calibrated Si:As blocked impurity band (BIB) detector. Because of its low operating temperature, the spectrometer exhibits very small thermal background signal and low drift. Data from tests of basic spectrometer function, such as modulation efficiency, scan jitter, spectral range, and spectral resolution are presented. We also present results from measurements of faint point-like sources in a low background environment, including background, signal offset and gain, and spectral noise equivalent power, and discuss the possible use of the instrument for spectral characterization of ground-based infrared astronomy calibration sources. The Cryo-FTS is presently limited to wavelengths below 25 micrometers but can be in principle extended to longer wavelengths with changes in beamsplitter and detector.

7739-87, Session 12

A novel athermal approach for high-performance cryogenic metal optics

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This paper describes a new athermal approach for high performance metal optics, particularly with regard to extreme environmental conditions

as they usually may occur in terrestrial as well as in space applications. Whereas for infrared applications on diamond turning of spherical and aspherical surfaces the shape deviation fulfils a criterion of less than 200 nm peak-to-valley (100 mm diameter), it is insufficient for those at wavelengths less than 5 µm. Especially for applications at near infrared wavelengths (0.8 µm - 2.4 µm) on cryogenic temperature (-200°C) requirements exist, which are only partially met for diamond turned substrates. Here are athermal concepts of enormous interest such as optical surfaces with high shape accuracy and small surface micro-roughness without diffraction effect and marginal loss of stray light.

Metal optics made of Aluminium 6061 have been widely used to fulfil the demands of an athermal instrument design. However, surface roughness, scattering behaviour and form accuracy of aluminium mirrors are limited due to the crystallographic and mechanical properties of the substrate material. On aluminium substrates with an amorphous electroless nickel (NiP) layer, various polishing techniques may be applied to overcome the performance limitation. Nevertheless, the significant mismatch in the Coefficient of Thermal Expansion (CTE) prohibits the cryogenic use of this composite.

The novel, patented material combination matches the CTE of an aluminium alloy with a high silicon content (> 40 %) as mirror substrate with the CTE of the electroless nickel plating. Besides the harmonization of the CTE (~ 13 * 10-6 K-1), considerable advantages are achieved due to the materials high specific stiffness. Hence this alloy also fulfils an additional requirement: it is ideal for the manufacturing of very stable light weight metal mirrors.

To achieve minimal form deviations, occurring due to the bimetallic effect, a detailed knowledge of the thermal expansion behaviour of both, the substrate and the NiP layer is essential. The paper describes the reduction of the bimetallic bending by the use of expansion controlled aluminium - silicon alloys and electroless nickel as a polishing layer. The acquisition of CTE-measurement data, the finite elements simulations of light weight mirrors as well as interferometrical experiments under cryogenic conditions are pointed out. The use of the new athermal approach is described exemplary.

7739-88, Session 13

MATIOMA: a project for an enhanced optical contact technology offering repositioning possibility and a precise structural model

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MATIOMA comes from the joint interest of several partners. Recent and future optical applications point out the need of integrated optics. The technical requirements of these equipments can only be achieved with optical contact technic. The need of well qualified optical contact technics for space application leads us to go ahead.

MATIOMA will improve precise structural modellisation and industrial manufacturing process with a comprehensive physics; all collaborators bring their experience to develop the most efficient procedure with a structural model of bonding.

The general physics of optical bonding technics based on interfaces physico-chemical studies permit to understand the process of the optical contacting. We will show an improvement of the classical technics. This improvement let the possibility to correct any misalignment before the definitive bonding.

A huge development is also done for the structural modelization. The main difficulty here is the large scale between the nano structure to the macro component.

A complete mechanical characterisation will be done including, traction, shear,cleaving, fatigue and shock hardiness.

7739-90, Session 13

Optical performance of a large diamond-machined ZnSe immersion grating

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ZnSe immersion gratings provide the possibility of high resolution spectroscopy in a wide infrared wavelength region from the NIR (Near Infrared) to the MIR (Mid Infrared), because ZnSe has a high refractive index (n~ 2.45) and a low internal extinction in these wavelength regions.

We are developing ZnSe immersion gratings for the ground-based NIR high-resolution spectrograph, WINERED (see Yasui et al. 2008), and the space MIR high-resolution spectrograph mounted on the infrared space telescope (SPICA), MIRHES (see Kobayashi et al. 2008 and Sarugaku et al. 2010). We already have produced fine grooves on the ZnSe substrate with a small pitch (~30 um) by nano precision fly-cutting technique at the Lawrence Livermore National Laboratory (see Kuzmenko et al. 2008), and we concluded that it has achieved the good surface irregularity (< lambda/8), the small surface roughness (< 5 nm), and the small random pitch error (< 3 nm), which adequately satisfy our requirements for the short NIR application (see Ikeda et al. 2008).

We finally produced a large prism-shaped ZnSe immersion grating using this technology. This grating has an entrance clear aperture of 17mm x 44mm, a groove pitch of 30 um, and a blaze angle of 70 degrees. The theoretical spectral resolution, lambda/delta_lambda, exceeds 200,000. We carefully examine the optical performances of this grating using a laser source. In this paper, we will report the results and discuss the feasibility as a optical device.

7739-91, Session 13

Miniature spectrograph: characterization of arrayed waveguide gratings for astronomy

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The increased physical scale of astronomical instrumentation has led to rising costs in terms of both implementation and operation. This is particularly true for the next generation of large and extremely large ground-based telescopes and a major cost contributor to any space based mission. Miniaturized spectrographs are currently one of a number of cutting-edge astrophotonic technologies being developed around the world that offer the potential to revolutionize the nature of telescope instrumentation. These devices perform complex manipulation of photons on microscopic scales, which will enable mass produced and complex suppression filters, line filters, and miniaturized spectrographs to be implemented on telescopes.

The integrated photonic spectrograph is a miniature integrated photonic circuit with an Array Waveguide Grating structure, allowing incoming light from a standard optical fiber to be output as a spectrum on the focal plane of the device. Building on our previous on-sky demonstration of a prototype device, we present results from a detailed experimental characterization of the spectral and spatial properties of the output of these devices. Additionally, we explore the use of off-axis input waveguides to enhance the multiplexing capability. Lastly, we discuss further modifications to the traditional Array Waveguide Grating design structure to meet the needs of astronomy.

7739-92, Session 13

Miniature astronomical spectrograph using array waveguide gratings: capabilities and limitations

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The size of the optical elements (gratings, mirrors, lenses) in traditional astronomical spectrographs scales with telescope diameter (unless the telescope is operating at the diffraction limit). For large telescopes, this leads to spectrographs of enormous size and implied cost. The integrated photonic spectrograph offers the potential to break this scaling law and allow massively multiplexed instruments. One proposed format for such a spectrograph recently demonstrated on-sky employs the arrayed-waveguide grating, which creates dispersion using interference between a series of waveguides with precisely defined length increments. Arrayed-waveguide gratings fabricated via planar techniques are used extensively in the telecommunications industry as optical (de) multiplexers. Current commercial devices are not directly applicable for astronomical use, and several design modifications are thus required.

Here we investigate the potential capabilities and limitations of arrayed-waveguide grating technology to provide massively multiplexed spectroscopy for astronomy. In particular, we examine the dependence of the arrayed-waveguide grating design parameters (such as focal length, device order, array spacing, array length increment, refractive index contrast, chip size, number and structure of input modes, and configuration of output cross-dispersive optics) on the characteristics of the device output (spectral and spatial point spread functions, free spectral range, resolution, number of required detector pixels, and multiplexing capacity).

7739-93, Session 14

Optical fiber spectroscopy and sensing innovation at innoFSPEC

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InnoFSPEC Potsdam, an internationally visible Center for Innovational Competence, was launched in 2009. The centre's mission is to study, develop and apply innovative fiber-based technologies for spectroscopy and optical sensing. InnoFSPEC Potsdam is focusing on the challenging demands of multichannel spectroscopy and sensor technology, developing applications and instrument concepts using these technologies, and striving for new solutions where existing technologies have reached their limits. Flagship projects include the development of: integrated photonics spectrographs, optical fiber tapers, and fiber sensors. The center has an interdisciplinary approach, combining the astrophysical and chemical know-how of the supporting institutes, the Astrophysical Institut Potsdam and the University of Potsdam. Priority will be given to the following aspects of optical systems; high spatial, spectral and temporal resolution; modularity and miniaturization; efficiency and effectiveness. InnoFSPEC will provide the link between research and industry in areas including: optical fiber spectroscopy, laser sensors, 3D measuring, and astrophotonics.

In this paper we present the astrophotonics research and development program for the recently launched innoFSPEC innovation center.

7739-94, Session 14

Design, modeling, and tests for space environment qualification of an image slicer using optical contact technology

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From several years, R&D activities are in progress at LAM for the spatial qualification of Image Slicers using optical contact technology. During the last two years, we have been more focused on the thermal cycles, vibration and shock qualification of such fragile components.

In this context, an opto-mechanical concept of an image slicer prototype using the optical contact technology, supported by three bipods and mounted on a spectrograph simulator has been designed, realized and tested at the laboratory.

This paper presents the mechanical design of the invar mount equipped with three bipods and supporting an assembly of 40 thin zerodur slices tied together thanks to optical contact, and mounted on a bracket fixed on a spectrograph simulator.

We document the design and we describe all the tests conducted: optical contact break limit characterization by traction tests, vibrations, shocks and thermal tests. Thanks to detailed FEM analysis, we correlate simulations and tests.

7739-95, Session 14

MUSE integral field unit: test results on the first out of 24

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MUSE (Multi Unit Spectroscopic Explorer) is a second generation VLT panoramic integral field spectrograph developed for the European Southern Observatory (ESO), operating in the visible wavelength range (0.465-0.93 µm). It is composed of 24 identical Integral Field Units (IFU); each one incorporates an advanced image slicer associated with a classical spectrograph and a detector vessel. The Image Slicer subsystem -ISS- is composed of two mirror arrays of 48 spherical elements each. It is made of Zerodur and uses an innovative polishing approach where all individual components are polished together by classical method. The MUSE Spectrograph -SPS- with fast output focal ratio of f/1.95 implements a Volume Phase Holographic Grating - VPHG. The last subsystem, the Detector Vessel -DV- includes a chip of 4k by 4k pixels of 15µm each fed by a vacuum and cryogenic system provided by ESO.

The first out of 24 IFUs for MUSE instrument has been manufactured, aligned and tested last months. First, this talk describes the optical design, the manufacturing and test results (image quality, pupil and field of view positioning) of each subsystem independently. Second, we will focus on overall system performances (image quality and positioning) of the spectrograph associated with the detector vessel. At the end, the test results (image quality, positioning, throughput, mechanical interfaces) onto the first IFU for MUSE instrument will be reported.

Most of them are compliant with requirements that it demonstrates that the manufacturing, integration and alignment processes are mature and gives good confidence for series production by 24 times applied to MUSE instrument.

7739-96, Session 14

ERASMUS-F: pathfinder for an E-ELT 3D instrumentation

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ERASMUS-F is a pathfinder study for a possible E-ELT 3D-instrumentation, funded by the German Ministry for Education and Research (BMBF). The study investigates the feasibility to combine a broadband optical spectrograph with a new generation of multi-object deployable fiber bundles. The baseline approach is to modify the spectrograph of the Multi-Unit Spectroscopic Explorer (MUSE), which is an integral-field instrument using slicers, with a fiber-fed input. Including developments in astrophotonics, it is planned to equip such a spectrograph with fused fiber bundles (hexabundles) that offer larger filling factors than dense-packed classical fibers.

The overall project involves an optical and mechanical design study, the development of a software package for 3D-spectrophotometry, based upon the experiences with the P3d Data Reduction Software and the investigation of a science case for such an instrument. A proof-of-concept within a VLT pathfinder instrument is an important step before any possible implementation at a future E-ELT.

The paper describes the status of the opto-mechanical design study of ERASMUS-F and presents the first concept realization of components using an adopted fiber-fed spectrograph prototype.

7739-97, Session 14

Volume phase holographic echelle grating: a theoretical study

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Volume Phase Holographic Gratings have found in the last ten years a large interest in the astronomical community for some interesting features, such as the high peak efficiency (larger than 90%), the tunability of the efficiency according to the wavelength, the possibility to reach very large size and large line density. Up to know, these dispersing elements have been used only without a slanting angle in the first/second order, but there is not any application as echelle grating. This is due to the lack of efficiency at high orders of normal VPHGs based on sinusoidal refractive index profile. Here we want to probe into the possibility to increase the efficiency of VPHGs at high orders to pave the way to other applications in astronomical spectroscopic instrumentation. A theoretical study has been carried out based on RCWA (Rigorous Couple Wave Analysis): the profile of the refractive index and the thickness of the grating have been changed according to the possibility of common sensitive materials (dichromated gelatines, photopolymers) used to make astronomical VPHGs. The efficiency results are reported for different diffraction orders with a detailed analysis on the possible scenarios.

7739-98, Session 14

Photochromic polymers for making volume phase holographic gratings: between theory and practical

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Volume Phase Holographic Gratings (VPHGs) are becoming widespread dispersing elements in modern optical instrumentations also in the astronomical field. Indeed these gratings show large peak efficiency (larger than 90%) and they can reach large size (40 x 40 cm and more), matching the requirements of new generation instrumentation. Photochromic materials show a large change in the refractive index upon photoirradiation, therefore they can be suitable substrate for holographic devices in the near-IR region.

Diarylethene-based photochromic films have been realized and fully characterized in order to determine the important properties for making the devices. A holographic set-up based on a Lloyd's mirror configuration and a 532 nm DPSS laser has been designed and built for writing the VPHGs on the photochromic substrates. Samples have been realized and efficiencies measured showing interesting results.

Since these materials strongly absorb light during the exposure process, the writing step is more complex compared to standard holographic materials. Therefore, we have developed a theoretical model to predict the refractive index pattern as function of the substrate features. Finally, the efficiencies calculated by using the RCWA approach have been compared with the experimental values.

7739-99, Session 14

Development of MEMS-based programmable slit mask for multi-object spectroscopy

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We are developing MEMS-based programmable reflective slit masks for future generation infrared multi-object spectroscopy (MOS) for space and ground-based telescopes. These devices are composed of single-crystalline silicon micromirrors of size 200x100 um2 which can be tilted by electrostatic actuation yielding a tilt-angle of 20°. An electromechanical clamping mechanism has been demonstrated that provides uniform tilt-angle within one arc minute precision over the whole array (5x5 micromirrors). Slit masks of different sizes have been produced; the largest one measures 25x22 mm2 and is composed of 20'000 micromirrors. Thanks to the architecture and the fabrication process of these slit masks; the micromirror peak-to-valley deformation (PTV) is uniform over the device and was measured being below 10 nm for uncoated micromirror. A slit mask of size 5x5 micromirrors was successfully tested in cryogenic conditions at 92 K; the micromirrors were actuated before, during and after the cryogenic experiment. For the large arrays to achieve a better fabrication yield and higher reliability, the architecture, the process flow, the assembly and the electronics is being optimized.

For this application, the micromirrors have to be individually actuated therefore a line - column actuation scheme based on the electrostatic hysteresis of the actuator was developed. Full optical characterizations as well as experiments of the large devices are underway. In order to cover the large surface of the telescope focal plan, these MEMS-based programmable slit masks could be placed in a mosaic pattern.

7739-100, Session 14

Efficiency measurements performed on the MUSE VPHG

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Volume Phase Holographic Gratings (VPHG) are key elements for the second generation instrument MUSE(Multi Unit Spectroscopic Explorer) developed for the VLT (Very Large Telescope) for ESO (European Southern Observatory). MUSE operates in the visible wavelength range (465-930nm) and is composed of 24 spectrographs including one VPHG each. This article briefly describes the design of the grating

realised by Kaiser Optics, to reach the MUSE spectral resolution and efficiency. On the other hand the set up developed in CRAL (Centre de Recherche Astronomique de Lyon) to test the VPHG final performance is deeply discussed. This set up uses a broadband source coupled to a monochromator, and a compensation arm to remove the source intensity fluctuations. The source is amplitude modulated by a chopper, and a lock-in amplifier extracts the modulated signal from the photodiodes. The measurement arm scans the 0, 1rst and 2nd diffraction orders of the grating and allows to test different areas over its whole surface of 120mm*60mm. The accuracy reached below the percent in efficiency, allows us to validate the performance and its uniformity over the surface of the gratings.

7739-101, Session 14

The SOAR integral field unit spectrograph optical design and IFU implementation

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SIFS is a lenslet/fiber Integral Field Unit Spectrograph which has just been delivered to the SOAR 4.1m telescope in Chile. The instrument was designed and constructed by the National Laboratory of Astrophysics (MCT/LNA) in collaboration with the Department of Astronomy of the Institute of Astronomy, Geophysics and Atmospheric Sciences of the University of Sao Paulo (IAG/USP). It is designed to operate at both the raw Nasmyth and the SAM (the SOAR Adaptive Optics Module) which delivers GLAO-corrected images in optical wave-bands longward of 500nm. The lenslets have a 1mm pitch feeding a set of 1,300 fibres in a 26-by-50 format. Sets of deployable fore-optics convert the f/16.5 input beam to give samplings between ~0.1 and 0.3 arcsec. The fiber output is in the form of a curved, pupil-centric, long-slit which is fed into a bench-mounted spectrograph. An off-axis Maksutov collimates the beam onto a set of VPH gratings and thence imaged by an f/3 refractive camera onto a 2-by-1 mosaic of 2k-by-4k E2V CCDs. The camera is articulated over a >90 deg. angle to allow the grating/camera combination to operate in a transmission Littrow configuration. The wavelength range is limited by the CCDs to the 350 to 1000nm range with spectral resolution maxima of ~20,000. The paper will review the optical design of the spectrograph and the methods used to fabricate the lenslet/fiber IFU.

7739-102, Session 14

Combining laser frequency combs and iodine cell calibration techniques for Doppler detection of exoplanets

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Exoplanets can be detected from a time series of stellar spectra by looking for small, periodic shifts in the absorption features that are consistent with Doppler shifts caused by the presence of an exoplanet, or multiple exoplanets, in the system. While hundreds of large exoplanets have already been discovered with the Doppler technique (also called radial velocity), our goal is to improve the measurement precision so that many Earth-like planets can be detected. The smaller mass and longer period of true Earth analogues require the ability to detect a reflex velocity of ~10 cm/s over long time periods. Currently, typical astronomical spectrographs calibrate using either Iodine absorptive cells or Thorium Argon lamps and achieve ~10 m/s precision, with the most stable spectrographs pushing down to ~2 m/s. High velocity precision is currently achieved at HARPS by controlling the thermal and pressure environment of the spectrograph. These environmental controls increase the cost of the spectrograph, and it is not feasible to simply retrofit existing spectrometers.

We propose a fiber-fed high precision spectrograph design that combines the existing ~5000-6000 A Iodine calibration system with a high-precision Laser Frequency Comb (LFC) system from ~6000-7000 A that just meets the redward side of the Iodine lines. The scientific motivation for such a system includes: a 1000 A span in the red is currently achievable with LFC systems, combining the two calibration methods increases the wavelength range by a factor of two, and moving redward with the LFC decreases the “noise” from starspots. The proposed LFC system design employs a fiber laser, tunable serial Fabry-Perot cavity filters to match the resolution of the LFC system to that of standard astronomical spectrographs, and terminal ultrasonic vibration of the multimode fiber for a stable point spread function.

7739-103, Session 14

The Brazilian tunable filter imager for SOAR

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A scientific and engineering team led by the USP’s IAG is engaged in the development of a highly versatile, new technology, optical imaging interferometer to be used both in seeing-limited mode and at high spatial resolution using the SAM GLAO facility on the SOAR telescope. Such an instrument opens up important new science capabilities for the SOAR astronomical community from studies of nearby galaxies and the ISM to statistical cosmological investigations. The Brazilian Tunable Filter Imager (BTFI) system uses EMCCDs to enable rapid-scanned data-cubes over a field size of 3 arcmin. with pixel sampling of 0.12 arcsec.

The BTFI concept takes advantage of two new technologies that have been successfully demonstrated in the laboratory environment but have yet to be deployed in astronomical instrumentation. The iBTF (imaging Bragg Tunable Filter) concept utilizes volume phase holographic grating in a double-pass configuration while the new Fabry-Perot concept involves the use of commercially available technology allowing a single etalon to act over a very large range of interference orders. The combination allows for highly versatile capabilities. Spectral resolutions spanning the full range between 5 and 35,000 can be achieved in the same instrument through the use of the iBTF at ultra-low resolution and scanning Fabry-Perots beyond R ~1,000.

Conference 7740: Software and Cyberinfrastructure for Astronomy

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7740-01, Session 1

Control software and electronics architecture design in the framework of the E-ELT instrumentation

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During the last years the European Southern Observatory (ESO), in collaboration with European astronomical institutes, has started several feasibility studies for the E-ELT (the European-Extremely

Large Telescope) instrumentation and post-focal adaptive optics. The goal is to create a flexible suite of instruments to deal with the wide variety of scientific questions astronomers would like to see solved in the coming decades. In this framework the INAF-Astronomical Observatory of Trieste is currently responsible of carrying out the analysis and the preliminary study of the architecture of the electronics and control software of three instruments: CODEX (control software and electronics) and OPTIMOS-EVE/OPTIMOS-DIORAMAS (control software only). To cope with the increased complexity and new requirements in terms of stability, precision, real-time latency and communications among sub-systems imposed by these instruments, new solutions has been investigated by our group. In this paper we present the proposed software and electronics architecture based on a distributed common framework that uses OPC Unified Architecture as a standard layer to communicate with COTS components of three different vendors. We will describe three working prototypes that has been setup in our laboratory and discuss their performance, integration complexity and ease of deployment.

7740-02, Session 1

Flight control software for the wave-front sensor of Sunrise 1m Balloon Telescope

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This paper describes the flight control software of the wave-front correction system that flew on the 2009 science flight from Kiruna (Sweden) to northern Canada of the 1m Sunrise balloon telescope. The software discussed here allowed fully automated operations of the wave-front sensor, communications with the adaptive optics sub-system, the pointing system, the instrument control unit and the main telescope controller. During flight autonomous as well as ground controlled operation was done, both modes are described in detail. A short overview of the used hardware will be given as well. The software was developed using modern object oriented analysis and design techniques. Various prominent design patterns were identified and implemented to achieve a maximum of robustness and reusability of the code. It consists of roughly 13.000 lines of C++ code not counting code written for the on-board communication layer and the actual adaptive optics code. The software operated error free during the 5.5 day flight, achieving good image quality and stability (0.04 arcs, RMS) during 33 hours, containing 45 sequences between 10 and 45 minutes.

7740-03, Session 1

The LUCIFER control software

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The LUCIFER NIR spectrograph and imager with MOS, one of the first light instruments of the LBT, is in science operation since December 2009. The operation of this complex instrument has to accomplish different software requirements with respect to different types of users. For prototype and lab testing as well as the commissioning of the instrument direct control mechanism of the different instrument units are available. They are normally used by experienced engineers. In the commissioning phase and the following science operations the main user group shifts toward astronomers who are focused on quite different operational aspects. Now complex observation programs have to be executed efficiently to maximize scientific output. The software needs the flexibility to provide adequate functionality for both types of users for the lifetime of the instrument.

Here we present our solution to these issues and the things learned during the instrument commissioning and first science operations.

7740-04, Session 1

The LBT AO diagnostic software

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The Adaptive Optics system for LBT is close to became fully operative: its capabilities and performances are described elsewhere in this same conference.

The capability to diagnose the behavior of the AO system during operations is a key feature which affects crucial aspects such as system performances and safety. The AO system overall status depends on a number of operating and environmental parameters, not to say of the 672 force control loops which control the mirror actuators.

The design and implementation of a good diagnostics system involves the solution of various engineering problems such as data gathering (with or without decimation), data analysis, both to derive quality parameters and to detect possibly dangerous events, system control, to react properly to changing conditions. All of these within a hard real-time scenario.

In this paper we discuss the approach adopted in the development of the LBT Adaptive Optics system to the design of an efficient and reliable diagnostic system and we describe the resulting software architecture providing also some details derived from actual operation of the system during the test activity in the laboratory.

7740-05, Session 2

Control software architecture for the SALT Robert Stobie Spectrograph

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Of the two first-light instruments commissioned for the Southern African Large Telescope (SALT) the Robert Stobie Spectrograph (RSS) represents the most intricate hardware system to control. As such the RSS control software (RCON) called for a design that would handle the necessary elaborate configuration commands required to coordinate various hardware mechanisms of RSS.

The RCON software forms a layer between the Telescope Control System (TCS) and the RSS hardware mechanisms. The TCS sends a desired configuration to RCON, which interprets the required changes in order to move RSS from the current configuration to the new desired one.

The RSS hardware has nine mechanisms some of which require specific hardware states from other mechanisms before they can be safely moved. Although a purely sequential command system could be used to avoid all hardware conflicts a scheme to minimize the configuration overhead time had to be devised. For a queue-scheduled telescope with a restricted observing window, like SALT, this is essential to maximize observing efficiency. The RSS control system which is able to send both sequential and parallel commands to each mechanism at the appropriate times, which dramatically reduces the RSS configuration time.

In this paper we describe in detail the LabVIEW software architecture used to control the RSS hardware mechanisms, A command id based array system was developed to allow the multi-faceted commands to execute, while facilitating the shortest configuration times and managing all of the hardware interdependencies.

7740-06, Session 2

Software systems for operation, control, and monitoring of the EBEX instrument

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We present the hardware and software systems implementing autonomous operation, distributed real-time monitoring, and control for the EBEX instrument. EBEX is a NASA-funded balloon-borne microwave polarimeter designed for a 14 day Antarctic flight that circumnavigates the pole.

To meet its science goals the EBEX instrument autonomously executes several tasks in parallel: it collects attitude data and maintains pointing control in order to adhere to an observing schedule; tunes and operates up to 1920 TES bolometers and 120 SQUID amplifiers controlled by as many as 30 embedded computers; coordinates and dispatches jobs across an onboard computer network to manage this detector readout system; logs over 3 GiB/hour of science and housekeeping data to an onboard disk storage array; responds to a variety of commands and exogenous events; and downlinks multiple heterogeneous data streams representing a selected subset of the total logged data. Most of the systems implementing these functions have been tested during a recent engineering flight of the payload, and have proven to meet the target requirements.

The EBEX ground segment couples uplink and downlink hardware to a client-server software stack, enabling real-time monitoring and command responsibility to be distributed across the public internet or other standard computer networks. Using the emerging dirfile standard as a uniform intermediate data format, a variety of front end programs provide access to different components and views of the downlinked data products. This distributed architecture was demonstrated operating across multiple widely dispersed sites prior to and during the EBEX engineering flight.

7740-07, Session 2

Faking it for pleasure and profit: the use of hardware simulation at AAO

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Traditionally, AAO tasks controlling hardware were able to operate in a simulation mode. They could ignore the actual hardware and simply respond as if the hardware were connected and working properly. However, this did not allow a rigourous testing of the low-level details of the hardware control software. For recent projects, particularly the replacement of the control system for the 3.9m AAT, we have introduced detailed software simulators that mimic the hardware and its interactions down to the individual bit level in the interfaces. By having one single simulator task representing the whole of the hardware, we get a realistic simulation of the whole system - an encoder read by one task will change realistically as a motor voltage is changed by another task, for example. Communications with the simulator task are introduced just above the driver calls that would normally communicate with the real hardware, allowing all of the hardware control software to be tested. Simulation can be partial, only simulating those bits of the hardware not yet available. This approach allows incremental software releases that can demonstrate full functioning of complete aspects of the final system even before any hardware is available. This allows a rigourous 'value-added' approach to measuring the progress of the software under development. This was particularly successful for the telescope control system, and has been used since for other projects including the new HERMES spectrograph, which has added support for CANopen hardware, simulated accurately at the level of individual CANbus frames.

7740-08, Session 2

OAdM Robotic Observatory: openROCS and dome control

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The Montsec Astronomical Observatory (OAdM) is a small-class observatory working on a completely unattended control. There are key problems to solve when a robotic control is envisaged, both on hardware and software issues. We present the openROCS (ROCS stands for Robotic Observatory Control System), an open source platform developed for the robotic control of the OAdM and similar astronomical observatories. It is a complex software architecture, composed with several applications for hardware control, event handling, environment monitoring, targets scheduling, image reduction pipeline, etc., developed in Java, C++, Python and Perl. The software infrastructure used is based on the Internet Communications Engine (Ice), an object-oriented middleware that provides object-oriented remote procedure call, grid computing, and publish/subscribe functionality. We also describe the subsystem in charge of the dome control: several hardware and software elements developed to specially protect the system at this identified single point of failure. It integrates a redundant control and a rain detector signal for alarm triggering and it responds autonomously in case communication with any of the control elements is lost (watchdog functionality). This self developed dome control system has proven to be highly reliable.

7740-09, Session 3

Heterogeneous real-time computing in radio astronomy

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Modern Computer architectures suited for general purpose computing are often not the best choice for I/O or compute bound problems. Sometimes the best choice is to not choose, but to take advantage of the best characteristics of different computer architectures to solve your problems. This paper examines the tradeoffs between using computer systems based on the ubiquitous X86 Central Processing Units (CPU's), Field Programmable Gate Array (FPGA's) based signal processors, and Graphical Processing Units (GPU's). We will show how a heterogeneous system can be produced that blends the best of each of these technologies into a real-time signal processing system. FPGA's tightly coupled to analog-to-digital converters couple the instrument to the telescope and supply the first level of computing to the system. These FPGA's are coupled to other FPGA's to continue to provide highly efficient processing power. Data is then packaged up and shipped over fast networks to a cluster of general purpose computers equipped with GPU's, which are used for floating-point intensive computation. Finally, the data is handled by the CPU and written to disk, or further processed. Each of the elements in the system has been chosen for its specific characteristics, and the role it can play in creating a system that does the most for the least, in terms of power, space, and money.

7740-10, Session 3

Astronomers as mechanical turks: distributing decision making in real time

A. Allan, The Univ. of Exeter (United Kingdom)

The ubiquitous availability of high bandwidth networks changed the way professional astronomers work, and how both robotic and non-robotic telescopes operate. Single isolated telescopes are increasingly being integrated into the expanding smart telescope networks, spanning continents and responding to transient events in seconds.

Utilising a combination of a peer-to-peer architecture, intelligent agents, and a software as a services delivery model, we have built a closed loop autonomous network for observing transient events; such as gamma-ray bursts or microlensing anomalies that might hint at the presence of an extra-solar planets.

However while day-to-day management of the observing programmes on these continent-spanning networks are still in the hands of autonomous systems, human input for crucial real-time decision making is being sought using mobile devices. Increasing the astronomer can be used as a Mechanical Turk by their own agent software, making decisions that the autonomously operating agent has decided are beyond its capabilities.

We talk about how the new technologies of ubiquitous computing and distributed software are making their way into the conservative world of big science and how we're pushing forward towards software systems designed for survivability and self-healing.

7740-11, Session 3

Skyalert: a platform for event understanding and dissemination

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Skyalert.org is an event repository, web interface, and event-oriented workflow architecture that can be used in many different ways for handling astronomical events that are encoded as VOEvent. It can be used as a remote application (events in the cloud) or installed locally. Some applications are: Dissemination of events with sophisticated discrimination (trigger), using email, instant message, RSS, twitter, etc; Authoring interface for survey-generated events, follow-up observations, and other event types; event streams can be put into the skyalert.org repository, either public or private, or into a local installation of Skyalert; Event-driven software components to fetch archival data, for data-mining and classification of events; human interface to events though wiki, comments, and circulars; use of the "notices and circulars" model, where machines make the notices in real time and people write the interpretation later; Building trusted, automated decisions for automated follow-up observation, and the information infrastructure for automated follow-up with DC3 and HTN telescope schedulers; Citizen science projects such as artifact detection and classification; Query capability for past events, including correlations between different streams and correlations with existing source catalogs; Event metadata structures and connection to the global registry of the virtual observatory.

7740-12, Session 3

Transiting planet search in the Kepler pipeline

J. M. Jenkins, H. Chandrasekaran, S. D. McCauliff, D. A. Caldwell, P. Tenenbaum, J. Li, T. C. Klaus, M. T. Cote, C. Middour, NASA Ames Research Ctr. (United States)

The Kepler Mission simultaneously measures the brightness of more than 150,000 stars every 30 minutes over a 3.5-year mission to search for transiting planets. Kepler collects photoelectrons from ~30 pixels per star and stores the pixel data on-board. At the Science Operations Center, the raw pixels are processed, calibrated, and summed to yield a flux time series for each star from which the systematic effects are removed. Detecting transits can be cast as a signal-detection problem where the signal of interest is a periodic pulse train and the predominant noise source is non-white, non-stationary (1/f) type process of stellar variability. A significant number of stars also exhibit (quasi) coherent oscillations. The noise characterization inherent to the transit detection algorithm must then account for colored broadband noise with potential coherent structures in the frequency domain. Our detection algorithm operates in four stages: 1) identifying and removing strong astrophysical oscillations, 2) filling inter-quarter gaps and removing edge effects, 3) detecting deep

eclipsing binaries with a simple matched filter, and 4) transforming the stellar flux time series into the wavelet domain (a joint time-frequency decomposition) in order to characterize the properties of the noise as a function of time. An adaptive matched filter is formulated in the wavelet domain enabling creation of a super resolution detection statistic time series for detecting orbital periods and epochs at a resolution significantly better than 30 minutes. We discuss the effectiveness of TPS using the flight data.

7740-13, Session 3

Adapting a publish-subscribe (DDS) middleware to a RPC style command response pattern

D. Morrison, J. M. Johnson, W. M. Keck Observatory (United States)

As part of the System Design for the TCS Upgrade project at W.M.K.O. we examined and prototyped what it would take to adapt publish-subscribe middleware, namely Data Distribution Service (DDS), to an RPC style command response pattern. The design and prototype was based on the middleware neutral Common Services Framework (CSF) in use by NSO for the Advanced Technology Solar Telescope (ATST). CSF has been shown to work with CORBA and ATST is currently using ICE as the chosen communication middleware for both the connection and event services.

Using the connection service interfaces and proxy-stub pattern of CSF we introduced DDS as the middleware and we were easily able to transparently integrate DSS into the CSF. We also updated the CSF event service to use DDS as the communication middleware. This was a much more natural fit for DDS and is not discussed in the paper. The paper describes the command response pattern used to adapt DDS for RPC style commands. It highlights the differences encountered between the RTI and PrismTech implementations and contrasts the ICE based connection service in CSF to a DDS based one.

7740-15, Session 4

The Data Processing Centre for the Planck low-frequency instrument: design strategies and operational experience

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Planck is an ESA mission, launched in May 2009, aimed at mapping the microwave sky in nine frequencies with the purpose of accurately measuring the anisotropies of the Cosmic Microwave Background (CMB) with its complement of two instruments.

The Data Processing Centre for the Low-Frequency Instrument has been designed to allow distributed development and centralized operations, in a funding scenario based on multiple funding agencies and, in most cases, on fixed budget in the presence of launch delays. The DPC needs to support both a day-by-day quasi-real-time workflow and high-throughput pipelines for high-volume data flow.

A strategy for managing effectively the geographically distributed and collaborative software development and maintenance has been developed, based on the use of open source and COTS software, and on the reuse of systems developed ad-hoc for other missions.

Product and quality assurance has been supported throughout development, integration and testing.

The effectiveness of the design choices has been proven by the readiness of the system and the smooth operations phase. Some lessons learned will be discussed.

7740-16, Session 4

Lessons learned deploying a second-generation observation control system for Subaru Telescope

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Subaru Telescope is deploying and commissioning a second-generation Observation Control System (OCS), building upon a 10 hear history of using the first generation OCS, and seeking to improve several key aspects of managing and using it. Replacing an extensive, functional, mission-critical software at the core of the telescope is an ambitious undertaking. In this paper we present some important and sometimes surprising lessons learned during the build out and commissioning phase of the Generation 2 OCS at Subaru Telescope. We present our experience with the rewrite vs. refactor decision, aspects of testing including unit and functional tests, compatibility decisions regarding legacy systems, and managing telescope priorities vs. developer priorities.

7740-17, Session 4

Control and data handling for the EST European Solar Telescope

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We introduce the concepts for the control and data handling systems of the European Solar Telescope (EST), the main functional and technical requirements for the definition of these systems, and the outcomes from the trade-off analysis to date.

Concerning the telescope control, EST will have performance requirements similar to those of current medium-sized night-time telescopes. On the other hand, the science goals of EST require the simultaneous operation of a large number of instruments. This leads to a projected data flux that will be technologically challenging and exceeds that of most other astronomical projects.

We give an overview of the reference design of the control and data handling systems for the EST to date, focusing on the more critical and innovative aspects resulting from the overall design of the telescope.

7740-18, Session 4

Science data quality assessment for the Large Synoptic Survey Telescope

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LSST will have a Science Data Quality Analysis (SDQA) subsystem to support the assessment of the data products that will be produced during the course of a 10 yr survey. The LSST will produce unprecedented volumes of astronomical data as it surveys the visible sky every few nights. The SDQA subsystem will enable comparisons of the science data with expectations from prior experience and models, and with established requirements for the survey. While analogous systems have been built for previous large astronomical surveys, SDQA for LSST must meet a unique combination of challenges. Chief among them will be the extraordinary data rate and volume, which restricts the bulk of the quality computations to the automated processing stages, as revisiting the pixels for a post-facto evaluation is prohibitively expensive. The identification of appropriate scientific metrics is driven by the breadth of the expected science, the scope of the time-domain survey, the need to tap the widest possible pool of scientific expertise, and the historical tendency of new quality metrics to be crafted and refined as experience grows. Prior experience suggests that contemplative, off-line quality analyses are essential to distilling new automated quality metrics. Thus, the SDQA architecture must support integrability with a variety of custom and community-based tools, and be flexible to embrace evolving QA demands. Finally, the time-domain nature of LSST means every exposure may be useful for some scientific purpose, so that the model of quality thresholds must be sufficiently rich to reflect the quality demands of diverse science aims.

7740-19, Session 4

LBT data mining leads to increased open shutter time

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The software group at the Large Binocular Telescope Observatory (LBTO) used logs and telemetry related to telescope control system behavior to investigate improving the operation of the telescope. Our investigation unearthed several surprises of unexpected, unknown, and undesired system behavior. What had actually been implemented was not always the same as what we thought had been implemented. A bit of rework using minimal resources would provide an inexpensive and immediate benefit leading directly to a more efficient operation. Also noted were software resource usage anomalies that had gone unnoticed and areas where logging and telemetry data were inadequate to answer fundamental questions. We considered trade-offs regarding what and when to modify both hardware and software to provide a more efficient telescope system, and configuration parameters that when changed would increase efficiency. In this paper we statistically examine the raw data and model system efficiency improvements for different implementations when viewed as a system. We also compare the overall system performance before and after the modifications we have implemented.

7740-20, Session 4

An algorithm for fitting of planet models to Kepler light curves

P. Tenenbaum, J. M. Jenkins, H. Chandrasekaran, J. Li, E. V. Quintana, J. D. Twicken, NASA Ames Research Ctr. (United States)

We describe an algorithm which fits model planetary system parameters to light curves from Kepler Mission target stars. The algorithm begins by producing an initial model of the system which is used to seed the fit, with particular emphasis on obtaining good transit timing parameters. An attempt is then made to determine whether the observed transits are more likely due to a planet or an eclipsing binary. In the event that the transits are consistent with a transiting planet, an iterative fitting process is initiated: a wavelet-based whitening filter is used to eliminate stellar variations on timescales long compared to a transit; a robust nonlinear fitter operating on the whitened light curve produces a new model of the system; and the procedure iterates until convergence upon a self-consistent whitening filter and planet model. The fitted transits are removed from the light curve and a search for additional planet candidates is performed upon the residual light curve. The fitted models are used in additional tests which identify false positive planet detections: multiple planet candidates with near-identical fitted periods are far more likely to be an eclipsing binary, for example, while target stars in which the model light curve is correlated with the star centroid position indicates a likely background eclipsing binary, and subtraction of all model planet candidates yields a light curve of pure noise and stellar variability, which can be used to study the probability that the fitted model planets result from statistical fluctuations in the data.

7740-62, Poster Session

Development of an analysis framework for HSC and Belle II

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A 2000-square-degree survey in 150 nights is being planned with the next-generation prime-focus camera, Hyper Suprime-Cam (HSC), of the Subaru Telescope.

In order for that wide survey in the reasonable time, HSC will have a wide, 1.5-square-degree field of view.

Accordingly, there are 116 CCDs laid out on the focal plane, which will produce 2 GBytes of data per exposure.

An efficient analysis system to process that large data is thus one of the important subjects in the development of HSC.

We developed a new application framework to help the implementation of analysis pipelines for fast data processing, in collaboration with the Belle II group in KEK.

The framework has a mechanism to process images in parallel on multiple computers. It utilizes the standard Message Passing Interface (MPI).

Users can write parallel analysis modules with MPI, and the framework assists users in the construction of parallel pipelines with the modules.

Another feature of the framework is that users can write modules in Python scripts as well as in C++. It will raise the efficiency of software development.

Pipelines all modules of which are in C++ are still not intervened by Python, decrease in execution efficiency thus avoided.

We have ported onto the framework a simple data analysis pipeline for the current wide-field camera, Suprime-Cam.

This system is under testing for the future application to observations with HSC.

We will report on details of design and implementation of the framework, and on results of performance tests with the ported pipeline prototype.

7740-63, Poster Session

The MOSFIRE desktop: a highly customizable, GUI-building user interface for the MOSFIRE instrument

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At an observatory like the W. M. Keck Observatory, there are many users of an instrument, including the astronomers, the support astronomers, and the engineers, each with their own idea of how the user interface should look. With the MOSFIRE Desktop, the instrument interface can be easily tailored to the needs of the specific user, and GUIs specific to that user can be rapidly created simply by editing XML GUI specification files without any coding or rebuilding necessary. Built around the flexibility of MVC and the extensibility of Java, the MOSFIRE Desktop links the standard Keck KTL keyword layer to customizable widgets that can display and modify keyword values in a number of ways. Widgets can be arranged in custom dialogs, and dialogs can be arranged in custom desktops, all encapsulated in XML definition files for preservation. Due to abstraction, the Desktop system could be modified to work with any number of data models or instrument and observatory architectures. This paper describes the system, and explores how the Desktop could be extended for use beyond the Keck paradigm.

7740-64, Poster Session

Experience with a new approach for instrument software at Gemini

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Gemini Observatory is using a new approach with instrument software that takes advantage of the strengths of our instrument builders and at the same time better meets our own operational needs. A lightweight software library in conjunction with modern agile software development methodologies is being used to ameliorate the problems encountered with the development of the first and second generation Gemini instruments.

Over the last two years, Gemini and the team constructing the software for the Gemini Planet Imager (GPI) at HIA have been using an agile development process to implement the Gemini Instrument Application Interface (GIAPI) and the high-level control software for the GPI instrument. The GPI is being tested and exercised with the GIAPI, and this has allowed us to perform early end-to-end testing of the instrument software. Early in 2009 for the first time in our development history, we were able to move instrument mechanisms with Gemini software during early instrument construction. As a result of this approach, we discovered and fixed software interface issues between Gemini and GPI. Resolving these problems at this stage is simpler and less expensive than when the full instrument is completed.

GPI is currently approaching its integration and testing phase, which will occur in 2010. We expect that utilizing this new approach will yield a more robust software implementation resulting in smoother instrument integration, testing, and commissioning phases. In this paper we describe the key points of our approach and results of applying the new instrument API approach together with agile development methodologies. Lessons have been learned, and the paper concludes with suggestions for adapting agile approaches in other astronomy development projects.

7740-65, Poster Session

New architectures support for ALMA common software: lessons learned and taught

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The ALMA Common Software (ACS) is a distributed control framework based on the CORBA specification that provides communication between distributed pieces of software. Because its size and complexity, it provides its own compilation system, a mix of several technologies. The current ACS compilation process is a complex system, because it depends on specific tools, compilers, code generation and a strict dependency model induced by the large amount of software components. This document presents a summary of several porting and compatibility attempts of ACS over platforms other than the officially supported. A porting of ACS to the Microsoft Windows Platform and to the ARM Processor architecture were done, with different grades of success. Also, support for LINUX-PREEMPT using a new design for a real-time service was implemented. These efforts were integrated with the ACS building and compilation system, while other were included in its design. From all this efforts, different lessons, learned and taught, are presented, and a general approach is extracted from them.

7740-66, Poster Session

Photometer performance assessment in Kepler science data processing

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This paper describes the algorithms of the Photometer Performance Assessment (PPA) software component in the science data processing of the Kepler mission. One task of PPA is to analyze the health and performance of the Kepler instrument based on the science data of 150,000+ target stars, ~275,000 collateral pixels and ~375,000 background pixels at each 30-minute long cadence, which are down-linked via Ka band approximately every 30 days. For each of 84 module/outputs, the metric of Combined Differential Photometric Precision (CDPP) is determined for a series of target magnitude bins and integration times. This metric is the fundamental measure of the Kepler's detection ability. In addition to CDPP, the instrument metrics, e.g. encircled energy, plate scale, background level, are analyzed as well with a tracking algorithm where the mean and uncertainty are determined, out-of-bound values are identified and the trend is predicted. PPA also determines the attitude of the Kepler spacecraft from the measured centroid position of the images of 16,000+ bright target stars at each long cadence. To compress the data to be processed, two-dimensional polynomials are built in the Photometric Analysis (PA) software component to map the right ascension and declination of a target star to the row and column of the centroid of the star image for each module/output. Provided the polynomials for all module/outputs, PPA is able to determine the attitude of the Kepler spacecraft with high precision. The PPA algorithms are demonstrated to work effectively with the Kepler flight data.

7740-67, Poster Session

Presearch data conditioning in the Kepler Science Operations Center pipeline

J. D. Twicken, H. Chandrasekaran, J. M. Jenkins, J. P. Gunter, F. R. Girouard, T. C. Klaus, NASA Ames Research Ctr. (United States)

We describe the Presearch Data Conditioning (PDC) software component and its context in the Kepler Science Operations Center (SOC) pipeline. The primary tasks of this component are to correct systematic errors and condition the raw flux light curves for over 150,000 long cadence (thirty minute) and 512 short cadence (one minute) targets across the focal plane array. The long cadence corrected flux light curves are subject to

a transiting planet search in a subsequent pipeline module. We discuss the types of data anomalies and systematic errors present in the Kepler flight data. We describe in detail the science algorithms for long and short cadence PDC: ancillary data conditioning; identification and correction of unexplained (i.e. unrelated to known anomalies) discontinuities; identification of phase shifting harmonics for variable targets; cotrending against conditioned ancillary data to correct systematic errors; coarse systematic error correction for targets where cotrending does not perform well; removal of excess flux due to aperture crowding; identification and removal of flux outliers; filling of short and long data gaps. We discuss the propagation of uncertainties from raw to corrected flux. Finally, we present examples of raw and corrected flux time series for flight data to illustrate PDC performance. PDC light curves are exported to the Multi-mission Archive at Space Telescope [Science Institute] (MAST) and will be made available to the general public in accordance with the NASA Kepler data release policy.

7740-68, Poster Session

Design of modular C++ observatory control system: from observatories to laboratories and back

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We present design of a system operating various observatory and laboratory setups. Lessons learned during RTS2 development are summarized. Our experiences on object oriented design of the observatory control system are summarized. The system currently support a wide range of devices, which are provided as plug-and-play modules. Also our experiences on observatory scheduling, integration of image processing, GRB reaction modes are presented. The system is described on http://rts2.org, with list of supported devices presented on http://rts2.org/wiki/hw:start. Emphasis is put on new developments happened during recent years and our experiences building a community of users and developers of the package. System use at the laboratory for CCD testing, as well as the ease of quick transition from previously unsupported observatory hardware to fully automated operation is explained. We discuss how this change affected code design, and present unexpected benefits its introduction provides.

7740-69, Poster Session

Collaborative use of the common services framework at ATST and Keck Observatories

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The Common Services Framework (CSF) is a software architecture developed at the National Solar Observatory for control of the Advanced Technology Solar Telescope. The framework was designed with the intent to make it independent of the ATST application and freely available to other projects. As part of the System Design phase for the Telescope Control System upgrade and Next Generation Adaptive Optics projects at the W.M. Keck Observatory a number of software frameworks and middlewares were evaluated. Of those evaluated, CSF was selected as the primary choice for the software architecture and will be pursued further in the next design phases.

This paper discusses the collaboration between the two observatories on the software framework and the effort involved in creating and maintaining shared software. Collaborations are difficult to coordinate and execute, due mostly to differing organizational priorities and goals, and often do not fully succeed. Prior papers presented at SPIE and ICALEPCS have discussed and proposed several strategies to software sharing in astronomy. We discuss the efforts of the two observatories in the collaboration, what strategies are useful, and how to support philosophical differences in planning and mission. In this paper we also discuss what the ATST has done to make CSF portable, why Keck has extended and modified the framework, and how the two groups will support the two forks through the lifetime of the projects.

7740-70, Poster Session

Pixel-level calibration in the Kepler Science Operations Center pipeline

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We present an overview of the pixel-level corrections developed for the Calibration (CAL) software component, which is the first stage in the Kepler Science Operations Center (SOC) data processing pipeline. The SOC receives raw pixel data from each Kepler CCD, including collateral pixel data that is collected primarily for calibration. These collateral pixels include serial register elements used to estimate the black level (voltage bias), and masked and over-clocked rows used to measure the dark current and estimate the smear that results from the lack of a shutter on the spacecraft. Detailed models of each CCD have been developed from pre-flight hardware tests, along with full-frame images (FFIs) taken during commissioning prior to the dust cover ejection. We discuss how these models are applied within CAL to correct for 2D bias structure, gain and nonlinearity of the ADU-to-photoelectron conversion, local detector electronics effects (such as undershoot/overshoot), and flat field (variations in pixel sensitivity to uniform light).

We also discuss our algorithms that address blooming charge from saturated stars into the masked/virtual regions, cosmic ray events, and other necessary corrections. Other CAL components include artifact mitigation issues and the propagation of uncertainties though the entire CAL chain. CAL operates on long (30 min) and short (1 min) cadence data, as well as FFIs. We present results for each of these data types, and discuss future plans to further improve the quality of Kepler data. The calibrated target pixel data can be retrieved from the Multi-mission Archive at Space Telescope (MAST).

7740-71, Poster Session

New direction in the development of the observation software framework (BOSS)

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The Observation Software (OS) of astronomical instruments, which lie directly beneath the instructions of astronomers, carrying out exposures and calibrations is the supervisor of the multi-process and multi-layer instrument software package. The main responsibility of the OS is the synchronization of the subsystems (detectors and groups of mechanical devices) and the telescope during exposures. At ESO a software framework Base Observation Software Stub (BOSS) takes care of the common functionalities of all OS of various instruments at the various sites VLT, VLTI, La Silla and Vista since 10 years.

The ever increasing pressure on high resolution detectors imposes also an increasing complexity on the top level control software, which is now becoming a critical component in the instrument design as the latest BOSS application indicates.

In case of the ESO-VLT instrument CRIRES in order to achieve the accuracy required - i.e. to maintain the image of the target within its 0.2 arcsec entrance slit- the OS had to manage four internal loops accounting for various optical phenomena (e.g. differential atmospheric refraction, distortion, etc.), differential tracking, auto-guiding, and AO handling. These internal loops have to be carried out behind the scenes, i.e. without interrupting the commanded exposure sequence or the operator's interventions.

This paper introduces the generic requirements of CRIRES which are incorporated into the BOSS framework, using a solution which resolves problems of event queues, interdependent functionalities, parallel commands and asynchronous messages using OO technologies.

7740-72, Poster Session

JCMT telescope control system upgrades for SCUBA-2

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The JCMT Telescope Control System (TCS) received significant upgrades to provide new observing capabilities to support the requirements of the SCUBA-2 instrument. The core of the TCS is the Portable Telescope Control System (PTCS), which was developed through a collaboration between the Joint Astronomy Centre and the Anglo-Australian Observatory. The PTCS provides a well-designed virtual telescope function library that simplifies these sorts of upgrades. The TCS was previously upgraded to provide the required scanning modes for the JCMT heterodyne instruments. The heterodyne instruments required only relatively simple raster or boustrophedon patterns, which are basically composed of multiple straight-line scans to cover a rectangular area. The most recent upgrades built upon those heterodyne scanning modes to satisfy the SCUBA-2 requirements. With the upgrades, the TCS can scan the telescope in any pattern that can be described as a continuous function of time. This new capability has been utilized during the current SCUBA-2 on-sky commissioning

phase to scan the telescope in a Lissajous pattern on the sky. In addition, another scanning mode was added that moves the telescope in a pattern reminiscent of the 1970's "Pong" video game. This paper will give a brief description of the PTCS, provide information on the selection of the SCUBA-2 scanning modes, describe the changes to the TCS that were necessary to implement the new scanning modes, and show the performance of the telescope during SCUBA-2 commissioning.

7740-73, Poster Session

The LBT real-time based control software to mitigate and compensate vibrations

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The Large Binocular Telescope (LBT) uses two 8.4 meters active primary mirrors on the same mounting to take advantage of its interferometer capabilities. The secondary mirrors are adaptive. Both applications, interferometry and AO, are vibration sensitive. Several vibration measurement campaigns have been carried out at the LBT, and their results strongly indicate that a vibration monitoring system is required to improve the performance of LINC-NIRVANA, LBTI, and ARGOS - a laser guided ground layer adaptive optic system.

Currently, a control software for mitigation and compensation of the vibrations is being designed. A complex set of algorithms will collect real-time vibration data, archiving it for further analysis, and in parallel, generating the tip-tilt and optical path difference (OPD) data for the control loop of the instruments.

Due to its flexibility and performance, UEI data acquisition devices equipped with embedded real-time Linux will be used in our systems.

A set of quick-look tools will be also developed in order to make available the accelerometers signals and to verify if the conditions are suitable for interferometric/adaptive observations.

7740-74, Poster Session

A framework for propagation of uncertainties in the Kepler data analysis pipeline

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The Kepler mission is designed to detect transits of Earth-like planets around Sun-like stars by simultaneously observing 100,000 stellar targets nearly continuously over a three and a half year period. The 96-megapixel focal plane consists of 42 charge-coupled devices (CCD) each containing two 1070x1132 pixel arrays. Cross-correlations between calibrated pixels are potentially introduced by common calibrations performed on each CCD requiring downstream data products access to the covariance matrix in order to properly estimate uncertainties. The prohibitively large covariance matrices corresponding to the ~75,000 calibrated pixels per CCD preclude calculating and storing the covariance in standard fashion. We present a novel framework used to implement standard propagation of uncertainties (POU) in the Kepler Science Operations Center (SOC) data processing pipeline. The POU framework captures the variance of the raw pixel data and the kernel of each subsequent calibration transformation. This allows the full covariance matrix of any subset of calibrated pixels to be recalled on-the-fly at any step in the calibration process. Singular value decomposition (SVD) is used to compress and low-pass filter the raw uncertainty data as well as any data dependent kernels. The combination of POU framework and SVD compression provide downstream consumers of the calibrated pixel data access to the full covariance matrix of any subset of the calibrated pixels traceable to pixel level measurement uncertainties without having to store, retrieve and operate on prohibitively large covariance matrices. We describe the POU Framework and SVD compression scheme and its implementation in the Kepler SOC pipeline.

7740-75, Poster Session

Using ICE to provide a multi-platform interface to the Teledyne SIDECAR ASIC

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The MOSFIRE and GPI projects are among the first instruments that will be using the SIDECAR ASIC, a new single-chip, cryogenic, focal plane array control device developed by Teledyne Imaging Sensors. The API to the SIDECAR provided by Teledyne is a Windows-specific COM object. Observatory mandates of Solaris-based (Keck) and Linux-based (GEMINI) servers have prompted the use of a middleware layer. We have thus developed a software package that allows complete control of the SIDECAR across the Internet on multiple platforms and in potentially a myriad of programming languages by using the Internet Communication Engine (ICE) toolkit by ZeroC, Inc. In this paper, we describe our system and our experiences as some of the first developers to provide control software to this exciting device.

7740-76, Poster Session

SPHERE data reduction software: first insights into data reduction software development for next-generation instruments

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The Spectro-Polarimetric High-contrast Exoplanet Research (SPHERE) instrument for the VLT is designed for discovering and studying new extra-solar giant planets orbiting nearby stars by direct imaging. The accuracy demands on this complex instrument are high and this is reflected in demanding requirements on the data reduction handling. Another novelty of the SPHERE data processing software is that complex scientific data analysis routines that go beyond pure data reduction are part of the pipeline.

In this paper, we briefly outline the design of the data reduction software for SPHERE and describe recent progress in its development. We then argue that SPHERE can be seen as one of the first of a new generation of instruments and discuss what can already now be learned from SPHERE about new challenges in data reduction software design, management and development processes. Along with the key issues, we formulate some general principles that would help in overcoming these challenges.

7740-77, Poster Session

Photometric analysis in the Kepler Science Operations Center pipeline

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We describe the Photometric Analysis (PA) software component and its context in the Kepler Science Operations Center (SOC) pipeline. The primary tasks of this module are to compute the photometric flux and photocenters (centroids) for over 150,000 long cadence (thirty minute) and 512 short cadence (one minute) targets across the focal plane array from the calibrated pixels in their respective apertures, and to compute barycentric corrected timestamps per target and cadence. We describe in detail the science algorithms for long and short cadence PA: identification of Argabrightening events; cosmic ray cleaning; background polynomial fitting and background removal; aperture photometry; centroiding based on Pixel Response Function (PRF) fitting and flux weighting; motion polynomial fitting; computation of brightness and encircled energy metrics; computation of barycentric corrections to cadence timestamps. We discuss the end to end propagation of uncertainties for the science algorithms. Finally, we present examples of photometric apertures, raw flux light curves, and centroid time series for Kepler flight data. PA light curves, centroid time series, and barycentric corrected timestamps are exported to the Multi-mission Archive at Space Telescope [Science Institute] (MAST) and will be made available to the general public in accordance with the NASA Kepler data release policy.

7740-78, Poster Session

High-performance graphical data trending in a distributed system

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Trending near real-time data is a complex task, specially in distributed environments. This problem was typically tackled in financial and transaction systems, but now it applies to its out-most in hardware monitoring of radio-antenna arrays. Data handling requires subscription to specific data feeds that needs to be implemented avoiding replication, and data rate of transmission has to be assured. On the side of the graphical client, rendering needs to be fast enough so it may be perceived as real-time processing and display.

In this context the ALMA Common Software (ACS) provides a software infrastructure for distributed projects, which may require trending large volumes of data. For this requirements, ACS offers a Sampling System, which allows sampling selected data feed in different frequencies, reason to develop an application with good trending performance.

Currently there are many graphical libraries available for data trending. This imposes a problem when trying to choose a library: it is necessary to know which one has the best performance, and which combination with a programming language is the best decision.

This work presents a performance study of different graphical libraries and languages in order to present the optimal environment when writing or re-factoring an application using trending technologies in distributed systems. To properly address the complexity at hand, a specific set of alternative was pre-selected, including libraries in Java and Python, languages which are part of ACS. The stress benchmark will be developed in a simulated distributed environment using ACS in order to test the trending libraries.

7740-79, Poster Session

A simple way to build from scratch an ANSI-C like compiler and embed it on the instruments software

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The principal reason to have a compiler embedded into the instrument software is to have a tool that can access during run time to any resources of the instrument, without compiling the whole system and without a software engineer reviewing the process. So, with this tool it is possible to change the instrument behaviour without stopping it, in an easy way without a software expert. This is an invaluable tool in the integration, validation and operation phases of an instrument. Starting from scratch and step by step, all the compiler stages of an ANSI-C like language are analysed, simplified and implemented. The runner performances are tested in three operating systems in order to provide advice on which solution is advisable. Usually other language embedding solutions need to add big libraries (hundreds of KBytes) to the executable file and use an interface to access to/from script. With the simplifications and the assumptions made is it possible to have a compiler and a runner both with only 64 KBytes that can be easily transferred to other architectures in a transparent way. Finally it is explained the experience of embedding a language on the magnetograph IMaX and the expected use in the future spectrograph CARMENES.

7740-80, Poster Session

Science Analysis Portal for the Dark Energy Survey Collaboration

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Modern astronomical surveys involving large collaborations and

generating large volumes of data require new software tools for efficient and well-documented scientific exploration of the resulting data sets. To this end we are developing a user-friendly web-based science portal which provides an integrated environment with easy access to data, a variety of services and analysis algorithms. The portal is being developed using the Python language and following the Model-View-Controller design pattern. The system is highly modular and all of its structures, such as module and workflow descriptions, are encoded in XML files. One of its strengths is the ability to incorporate legacy codes by wrapping them as Python modules. An organized sequence of inter-dependent modules is called a pipeline, which constitutes the fundamental element of the portal. Data selection and inspection is handled via a search engine tool, which requires no previous knowledge about the data structure and organization (yet, it drives the user through a particular hierarchy). The search engine is open-ended, thus allowing integration of different data sources under the same interface. The portal is designed to operate in a distributed environment (clusters and grids), being able to aggregate computing resources from geographically distant sites for scalability, which is fundamental to avoid large data transfers. This portal is being developed for the Dark Energy Survey collaboration and will allow its scientific working groups to validate science codes, comparing results from different algorithms applied to mock catalogs with different cosmologies as well as simulated data.

7740-81, Poster Session

A methodological proposal for the development of an HPC-based antenna array scheduler

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As new astronomy projects choose interferometry to improve angular resolution and to minimize costs, preparing and optimizing schedules for an antenna array becomes an increasingly critical task. This problem shares similarities with the job-shop problem, which is known to be a NP-hard problem, making a complete approach unfeasible. In the case of ALMA, 7000 projects per season are expected, and the best schedule must be found in the order of minutes.

The problem imposes severe difficulties: the large domain of observation projects to be taken into account; a complex objective function, composed of several abstract, environmental, and hardware constraints; the number of restrictions imposed and the dynamic nature of the problem, as weather is an ever-changing variable. A solution can benefit from the use of High-Performance Computing for the final implementation to be deployed, but also for the development process.

Our research group proposes the use of both metaheuristic search and statistical learning algorithms, in order to create schedules in a reasonable time. How these techniques will be applied is yet to be determined as part of the ongoing research. Several algorithms need to be implemented, tested and evaluated by the team.

This work presents the methodology proposed to lead the development of the scheduler. The basic functionality is encapsulated into software components implemented on parallel architectures. A scripting layer integrates these components, exposing a domain-level interface to the researchers, enabling then to develop early prototypes for evaluating their proposed techniques.

7740-82, Poster Session

Choosing a control system for CCAT

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The Cerro Chajnantor Atacama Telescope is a 25m aperture sub-millimeter wavelength telescope to be built in northern Chile at an altitude of 5600m. Like any modern telescope, CCAT will require a powerful and comprehensive control system; writing one from scratch is not affordable, so the CCAT TCS must be based, at least in part, on existing software. This paper describes how the search for a suitable system (or systems) was carried out, looks at the criteria used to judge the feasibility of various approaches to developing the new system, and suggests the further studies needed to validate the choices.

Although the purpose of the study was to find a control system for a specific telescope, with its own particular technical requirements, many of the factors considered, such as maintainability, the ability to adapt to new requirements in the future, and so on, are of concern to all telescopes. Consequently, the processes used to select the system for CCAT are relevant to other projects faced with the same decision, even if the conclusions turn out to be different.

7740-84, Poster Session

Progress in cancellable, multi-threaded, control software

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The AAO's DRAMA data acquisition environment provides a very successful flexible model for instrument control tasks based on the concept of named 'actions'. A task can execute a number of these actions simultaneously, and - something we have found to be of paramount importance in control systems - they can be cancelled cleanly if necessary. However, this flexibility has been achieved by use of what is essentially a collaborative multi-threading system, each action running in short 'stages' in a single-threaded task. The original DRAMA design pre-dated the general availability of multi-threading systems, but until now we have been reluctant to move to a multi-threading model because of the difficulties associated with attempting to cleanly cancel a thread stuck in a blocking operation. We now believe we have an acceptable solution to this problem, and are modifying the internals of DRAMA to produce an approach - compatible with the existing system - that will allow individual actions to execute in separate threads. It will be able to carry out dialogues with hardware in a much simpler manner than has been allowed so far, and this should simplify the coding of DRAMA tasks enormously.

7740-85, Poster Session

A solution for remote-upgrading field controllers based on FPGA Cyclone 2C35

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Modern telescopes usually have more controlled nodes than classical ones. Those nodes are separately distributed at various locations of the instrument and not easy to access. While in adjustment, it always requires to modify the control software, or sometimes to reform the hardware structure and to upgrade the related programs. To solve the problems of renewing the numbers of field controllers, we introduce a FPGA based telescope controller system and a scheme for remote-upgrading it via Ethernet.

This paper mainly describes the structure of the field controller,the requirements for remote-upgrading and system composition. Also discussed is the protocol applications and extensions, the processing methods as well as the ideal of software design. The scheme has been in trial run for a large telescope with 16 field controllers sub-system and excellent results were obtained. It may effectively solve the remote-upgrading problems for multiple field controllers of large telescopes. Besides the scheme can be used in other multi-nodes industrial control systems too, which is of high value in applications.

7740-86, Poster Session

A virtual reality environment for telescope operation

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Astronomical observatories and telescopes are becoming increasingly large and complex systems, thus demanding from the users a greater amount of information to operate them. At present, the most common way to deal with this information is through graphical user interfaces and more computer monitors to have a larger display area.

Tonantzintla Observatory has a 1-m telescope with a remote observing system. As a step forward in the improvement of the telescope software, a Virtual Reality (VR) environment was developed that works as an extension of the remote system and allows the users to operate the telescope using virtual controls. In this work we explore the use of this kind of technology that is being suggested as an experimental software platform for the operation of the 1-m telescope.

7740-87, Poster Session

Middleware design and implementation for LSST

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The LSST middleware design is based on a set of software abstractions; which provide standard interfaces for common communications services. The observatory requires communication between many subsystems, and comprehensive archiving of subsystem status data. Control commands as well as health and status data from across the observatory must be stored to support both the science data analysis, and trending analysis for the early detection of hardware anomalies.

The Software Abstraction Layer (SAL) is implemented using open source packages that implement open standards of DDS (Data Distribution Service) for data communication and SQL for storage.

Designs for the automatic generation of code, documentation, and subsystem simulation, are being developed. Abstractions for the Telemetry datastreams, each with customized data structures, Command/Response, and the Logging and Alert messages are described.

The definition of instances of these abstractions is tightly controlled by reference to a system dictionary. All code referencing them is automatically generated and includes real-time consistency checking on a per-transaction basis.

All command transactions, telemetry, and messages, are automatically stored in a system wide “Facility Database” system.

Virtual Machine technology is used to provide an easily replicated and consistent developer toolset for generating middleware interfaces on a per subsystem basis.

7740-88, Poster Session

The research on direct-drives control system in the large-aperture telescope

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A 30m giant telescope project, Chinese Future Giant Telescope (CFGT), has been proposed by Chinese astronomers. At present, a series of key techniques are being developed. This paper explores a direct drive servo motor control method in giant telescope application, which is based on a segmented Permanent Magnet Synchronous Motor (PMSM). The platform of the experiment is a 2.5-meter diameter precision drive rotating turret, designed with a control method combined modern control theory and PWM vector control theory. The feedback circuit for rotor position and rotating speed signal, choosing the incremental and absolute photo-electricity coder, is designed for commutation of the motor and the detection of rotor position & rotating speed signal. The core of the main drive circuit uses three-phase voltage source inverting circuit. It’s the point to minimize the current harmonic output from drive circuit and harmonic loss of the motor and to reduce the effect of pulsating torque such as cogging torque by the methods of software design and hardware design. The reasonable design can make the drive control system suitable to the requirements of giant telescope, including low speed, high precision, wide speed regulation and so on.

7740-89, Poster Session

The PANIC software system

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PANIC is the Panoramic Near Infrared Camera for the 2.2m and 3.5m telescopes at Calar Alto observatory. The project started in September 2006 and is a joint project between MPIA (Max-Planck-Institut für Astronomie) and IAA-CSIC (Instituto de Astrofísica de Andalucia). The aim of the project is to build a wide-field general purpose NIR camera. With its focal plane array of 2x2 HAWAII2-RG detectors it covers a 30x30 arcmin field-of-view and it has a pixel scale of 0.45 arcsec/pixel in the 2.2m, very well suited for surveys, and 0.23 arcsec/pixel in the 3.5m telescope, for higher resolution observations. The first light is foreseen for mid of 2011.

In this paper we describe the software sytem of the instrument, which comprises four main packages: GEIRS for the instrument control and the data acquisition; the Observation Tool (OT), the software used for detailed definition and pre-planning the observations, developed in Java; the Quick Look tool (PQL) for easy inspection of the data in real-time and a scientific pipeline (PAPI), both based on the Python programming language. We summarize the structure and status of the control software and the data processing system for the PANIC instrument, describing the individual processing steps, calibration plan and data products.

7740-90, Poster Session

Practical considerations for pointing a binocular telescope

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The Large Binocular Telescope (LBT) consists of two 8.4-meter primary mirrors on

a common mount. When the telescope is complete, to complement the two primaries there will be two 0.9-meter adaptive secondaries and two tertiary mirror flats which all work to support a variety of Gregorian focal stations, as well as prime focus.

A fundamental goal of the telescope is to perform interferometric observations, and therefore, there is a critical need for the ability to co-point both sides of the telescope to high precision. Further, a unique aspect of the LBT is the comparatively large range over which the optics can be adjusted which enables the capability of high precision co-pointing.

In the most general case, an observer could be performing a mis-aligned observation using different instruments on the two telescope sides, with different observing duty cycles.

As a consequence of the binocular nature of the telescope and the number of possible observing combinations, there are unique requirements imposed on the Telescope Control System (TCS), and in particular, on the Pointing Control Subsystem (PCS). It is the responsibility of the PCS to arbitrate the pointing requests made on the two sides of the telescope by the observers (as well as incorporate guide updates), generate tracking trajectories for the mount and the rotators, in conjunction with providing tip/tilt demands on the subsystem controlling the optical elements, and ensure each target remains on the specified location (i.e., pointing origin) in the focal plane during an active observation. This paper describes the current design/implementation of the LBT PCS.

7740-91, Poster Session

A high-efficient and fast KNN algorithm based on CUDA

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K-Nearest Neighbor (kNN) algorithm is an effective classification approach in the statistical methods of pattern recognition. But its speed is rather slow when applied for massive data, especially facing large survey projects in astronomy. NVIDIA® CUDA is a general purpose parallel computing architecture that leverages the parallel compute engine in NVIDIA graphics processing units (GPUs) to solve many complex computational problems in a fraction of the time required on a CPU. In this paper, we implement a CUDA-based kNN algorithm, and compare its performance in celestial object classification with that of CPU-based kNN algorithm. The result demonstrates that CUDA is very effective and useful to speedup KNN when selecting quasar candidates.

7740-92, Poster Session

The Blanco Telescope TCS upgrade

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The Blanco 4-meter telescope has been in operation for over 30 years and is now subject to an extensive upgrade of its control system, both of the hardware and software. The motivation for the upgrade, besides the normal replacement of obsolete components, is the preparation of the telescope for the installation of the DECAM instrument, which makes greater operational demands than can't be met by the current system. The architecture of the new system is in line with the designs developed for modern telescopes like the Large Synoptic Survey Telescope (LSST), and its implementation utilizes similar technologies as proposed for that project. In this paper we present a detailed description of the upgraded system, including tape encoders, control algorithms, the use of trajectories to optimize motions, communications middleware, and its performance as a whole.

7740-93, Poster Session

A prototype of Hyper Suprime-Cam data analysis system

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We report status of a prototype of the data analysis system for the next-generation wide-field camera Hyper Suprime-Cam (HSC) at Subaru Telescope. The present prototype is optimized for data of Suprime-Cam, which is a precursor instrument of HSC, operating for general observations.

The main goals of this prototype are to construct and to evaluate a quick analysis system for assisting observations and survey data management at the observing site.

The system is designed to perform quality assessment of the data, by quick analysis for every frame and obtaining statistical information including seeing, sky-background level, astrometric solution, and photometric zeropoint when available.

The time variation in the derived values are shown in a web-based status monitor. Observers can request the system to make a flat frame or mosaic-stacked images by combining a particular set of reduced images through a web browser. Frame search is performed using the statistical values derived by the quick analysis.

This system consists of analysis pipelines responsible for data processing and a middleware part for controlling data flow to the pipelines and execution of the pipelines.

The middleware allows to efficiently use databases to register all the analysis results and operation histories associated with data analysis. Distributed data processing on multiple nodes is also realized by the middleware.

We will present the design and implementation of the system, and explain how this system assists actual observations with Suprime-Cam. The future prospect to extend this system for HSC data analysis will be discussed.

7740-94, Poster Session

Dedicated versus realtime Linux-based adaptive optics systems for LINC-NIRVANA

F. R. Briegel, J. Berwein, T. Bertram, W. Gaessler, Max-Planck-Institut für Astronomie (Germany); A. T. Puglisi, L. Busoni, Osservatorio Astrofisico di Arcetri (Italy); F. Kittmann, Univ. zu Koln (Germany)

The MPIA is leading an international consortium of institutes in building an instrument called LINC-NIRVANA, the LBT INterferometric Camera and Near-IR Visible Adaptive INterferometer for Astronomy.

LINC-NIRVANA is a Fizeau interferometer for the Large Binocular Telescope doing imaging in the near infrared (J, H, K - band). Multi-conjugated adaptive objects (MCAO) is used to increase sky coverage and to get diffraction limited images over a 2 arcminute field of view.

The distributed control system has to manage four independent adaptive optics loops, these ao loops are grouped in two pairs.

The first pair of the ao loops are for correcting the ground layer wavefront, for every side of the telescope a seperate control loop. These are based on a dedicated slope computer provided by the Large Binocular Telescope (LBT) infrastruture, developed by the AO group at Arcetri in Florenz and Microgate in Bolzano.

The second pair of AO loops for the high layer wavefront are designed using a realtime linux based system running on off-the-shelf hardware components using Wavefront Sensor Cameras from SciMeasure? and a deformable mirror from Microgate.

In this presentation we compare both approaches regarding design, computing performance and integration into our distributed control system based on a service oriented architecture (SOA).

7740-95, Poster Session

Instrument-specific features within the observation preparation software for LINC-NIRVANA

A. I. Pavlov, J. Trowitzsch, Max-Planck-Institut für Astronomie (Germany)

The LINC-NIRVANA(LN) Observation Preparation Software (LOPS) supports an observer during the complex process of preparing the observations for LINC-NIRVANA (LN). LN is a German-Italian beam combiner for the Larger Binocular Telescope. The instrument exploits its full capability by means of Multi-Conjugate Adaptive Optics and an IR Fringe and Flexure Tracker.

These sub-systems of the LN instrument and the fixed geometry of the telescope put specific constraints on the observation and scheduling process. LOPS is committed to the generic approach which allows to easily include new features on the so called procedure-plug-in level (low level).

Considering specific aspects of the LN instrument the implementation on the generic procedure level is not adequate enough, because an user/observer needs to deal with a lot of instrument-specific parameters when preparing an observation program (OP).

For this reason, LOPS provides a high-level application plug-in system which allows to maintain the features of an OP also as separate application in order to benefit from the more advanced GUI.

In this paper we present the Guide Star Buffer concept as an exemplary feature-specific application in the framework of LOPS. It is dedicated to search, select and organize guide stars in the corresponding groups needed for LN observations.

7740-97, Poster Session

Research of remote control for Chinese Antarctica Telescope based on iridium satellite communication

L. Xu, X. Xu, S. Yang, Nanjing Institute of Astronomical Optics & Technology (China)

Astronomers are ever dreaming of sites with best seeing on the Earth surface for celestial observation, and the Antarctica is one of a few such sites only left owing to the global air pollution. However, Antarctica region is largely unaccessible for human being due to lacking of fundamental living conditions, travel facilities and effective ways of communication. Worst of all, the popular internet source as a general way of communication scarcely exists there. Facing such a dilemma and as a solution remote control and data transmission for telescopes through iridium satellite communication has been put forward for the Chinese network Antarctic Schmidt Telescopes 3 (AST3), which is currently under all round research and development. This paper presents iridium satellite-based remote control application adapted to telescope control. The pioneer work in China involves hardware and software configuration utilizing techniques for reliable and secure communication, which is outlined in the paper too.

7740-98, Poster Session

Comparison of several algorithms for celestial object classification

N. Peng, Y. Zhang, Y. Zhao, National Astronomical Observatories (China)

We present a comparative study of implementation of supervised classification algorithms on classification of celestial objects. Four different algorithms including Linear Discriminant Analysis (LDA), Fisher Discriminant Analysis(FDA), K-Dimensional Tree (KD-tree), Support Vector Machines (SVM) are used for classification of pointed sources from the Sloan Digital Sky Survey (SDSS) data release 7. All of them have been applied and tested on the SDSS photometric data. On the one hand, we study the performances of these methods in this issue. On the other hand, we compare the computing times of them from the view of efficiency. Moreover the advantages and disadvantages of the methods are examined. In addition, we also discuss about which input pattern is the best combination of different colors for the effectiveness of these methods, respectively.

7740-99, Poster Session

Design and realization of the IP control core in field controllers for LAMOST spectroscopes

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The China-made telescope, LAMOST, consists of 16 spectroscopes to detect stellar spectra via 4000 optical fibers. In each spectroscope, many movable parts work in phase. Those parts are real-time controlled and managed by field controllers based on FPGA.

This paper mainly introduces how to use DSP Builder module library in MATLAB / Simulink to construct the IP control core on FPGA chip. This method can also be used to design the control core of PID arithmetic, to carry out arithmetic simulation emulation and generate VHDL language file, as well as to integrate it into SOPC developing environment so as to repeatedly use. In this way, the design period of the control system may be shortened and design process simplified. Finally due to the reversibility and programmability of the IP control core, an on-chip system for field controllers of spectroscope is realized, which meets astronomical control requirements, providing an effective scheme for embedded system in astronomical instrument applications.

7740-100, Poster Session

Approaches for photometric redshift estimation of quasars from SDSS and UKIDSS

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We investigate two methods: kernel regression and nearest neighbor for photometric redshift estimation with the quasar samples from SDSS and UKIDSS. Both nearest neighbor and kernel regression belong to the family of instance-based learning algorithms, which store all the training examples and "delay learning" until prediction time. The major difference between these two algorithms is that kernel regression is a weighted average of spectral redshifts of the neighbors. However, nearest neighbor utilizes the spectral redshift of the nearest neighbor for a query point. Each algorithm has its own advantage and disadvantage. According to these two datasets, nearest neighbor algorithm obtains more accurate predicting results, and shows its superiority.

7740-101, Poster Session

Clock synchronization of motor control systems and PC system time

F. Kittmann, Max-Planck-Institut für Astronomie (Germany) and Univ. zu Köln (Germany); T. Bertram, F. Briegel, J. Berwein, Max-Planck-Institut für Astronomie (Germany)

The power of the Large Binocular Telescope (LBT) with the two 8.4m primary mirrors based on one mount will unfold its full potential with the LINC-NIRVANA (LN) instrument. LINC-NIRVANA is a German-Italian beam combiner for the LBT and will interfere the light from the two 8.4m mirrors of the LBT in Fizeau mode. More than 140 motors have to be handled by custom developed motor controllers (MoCons). One important feature of the MoCon is the support of externally computed trajectories. Motion profiles provide information on the movement of the motor along a defined path over a certain period of time. Such profiles can be uploaded to the MoCon over Ethernet and can be started at a specific time. For field derotation it is critical that the derotation trajectories are executed with a very precise relative and absolute timing. This raises the problem of the synchronization of the MoCon internal clock with the system time of the servers that are hosting LINC-NIRVANA's Instrument Control Software. The MoCon time should be known by the servers with an uncertainty of few milliseconds in order to match the start time of the motion profile and the field rotation trajectory. Another aspect is the correction of precalculated profiles during execution. Such a correction again requires a precise timing and a prediction of calculation and upload time. In this paper we will discuss the challenge how to synchronize the MoCon internal time and the PC system time.

7740-102, Poster Session

Producing an LSST data release

T. Axelrod, The Univ. of Arizona (United States); J. Kantor, LSST Corp. (United States)

During LSST survey operations, the Data Management System creates and archives a new Data Release (DR) at least once per year.

A DR is a static self-consistent collection of data products generated from all survey data taken from the date of survey initiation to the cutoff date for the DR. The data products include optimal measurements of the properties (shapes, positions, fluxes, motions) of all objects, including those below the single visit sensitivity limit, astrometric and photometric calibration of the full survey object catalog, and limited classification of objects based on both their static properties and time-dependent behavior. Deep coadded images of the full survey area are produced as well.

This paper discusses the processing flow used to produce a DR, which occurs in several phases: 1) all individual exposures are run through an image processing pipeline, which removes the instrumental signature, and characterizes each image with a PSF, WCS, and rough photometric zeropoint. 2) the processed exposures are projected onto a Healpix grid, and coadded to produce deep images for object detection and for image differencing. 3) difference images are produced and processed to detected variable and moving objects. 4) the rapidly moving objects are processed to determine their orbits. 5) objects are detected and measured by simultaneously processing all exposures that overlap each patch of sky with the multifit algorithm. This yields astrophysical models for each object. 6) the photometry of the full survey is globally tied together and referred to a common photometric standard.

7740-103, Poster Session

The ATST base: command-action-response in action

J. R. Hubbard, B. D. Goodrich, S. Wampler, National Solar Observatory (United States)

The ATST Common Services Framework (CSF) provides the technical framework necessary to quickly and easily develop applications implementing the command-action-response model. The ATST Base builds on top of CSF and provides applications that, with few modifications, can be dropped into a telescope control system or an instrument control system. This is done by extending the CSF Controller and writing applications that perform one of the common tasks needed by telescope and instrument control systems. This paper includes a general look at the hardware controller and an in-depth look at the management and motion controllers.

Telescope and instrument control systems typically have multiple axes of motion that need to be coordinated. Management controllers allow a simple command to be given to a single controller and then aggregated to multiple worker controllers who can perform multiple actions. Management controllers aggregate the state and status of their workers. The workers can be of the same type (e.g. multiple servo control systems) or of different types (e.g. two different servo controllers, a hexapod controller, digital I/O controller and a camera controller).

Most users of turnkey motion control solutions primarily use only a few of the commands that the motion control system provides. The ATST Base motion controller abstracts the hardware, and provides a simple interface (focusing on the few common instructions) to use in controlling different types of motion stages.

7740-104, Poster Session

Automated classification of pointed sources

Y. Zhang, Y. Zhao, National Astronomical Observatories (China); H. Zheng, North China Electric Power Univ. (China)

Adopting survey data from optical bands (SDSS, USNO-B1.0) and radio band (FIRST), we investigate feature weighting and feature selection by means of random forest algorithm. Then we employ k-nearest neighbor method to discriminate quasars from stars. Then the performance of this approach based on all features, weighted features and selected features are compared. The experimental result shows that the accuracy improves and adds up to more than 93% when using weighted features or selected features. K-nearest neighbor algorithm is a quite easy and efficient approach to nonparametric classification. Obviously k-nearest neighbor approach combined with random forests is more effective to separate quasars from stars with multi-wavelength data.

7740-105, Poster Session

Support vector machines for quasar selection

N. Peng, Y. Zhang, Y. Zhao, National Astronomical Observatories (China)

We introduced an automated method called Support Vector Machines (SVM) for quasar candidate selection in order to construct an input catalogue for The Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST) and improve the efficiency of its 4000 fibers. The data were adopted from UKIDSS data release 3 which is the latest world release now. We then studied the discrimination of quasars from stars by finding the classification hyperplane in high-dimensional space of colors. Furthermore, we discussed the performances based on different input parameters of SVM and investigated the estimation of the photometric redshifts of quasars for the sake of selecting high-Z quasar candidates. Finally, the experiment results showed that the precision and the recall of SVM for separating quasars from stars can be both over 95%. Obviously, this approach is effective and applicable for this problem.

7740-106, Poster Session

The design of LBT's telemetry source registration

T. Edgin, N. J. Cushing, The Univ. of Arizona (United States)

The LBT Observatory (LBTO) is developing a telemetry logging system for the Large Binocular Telescope (LBT). The telemetry logging system, called telemetry, has three responsibilities. It will provide system data to LBTO personnel during engineering activities such as commissioning, failure diagnosis and system repair. In order to catch failures as they occur, telemetry will provide the personnel with the capability of monitoring the status of key telescope systems. Finally, in order to help personnel understand how the LBT operating characteristics evolve with time, telemetry will provide access to historical telescope system data.

One of the key requirements captured during the inception of telemetry

was that it must be able to easily adapt to new sources of data. To minimize the changes required to telemetry, telemetry has no foreknowledge about the structure of the data it will collect. Instead, it requires the data source to describe the structure of the data it will send as part of the source's registration process. Furthermore, the data description requires no external data files to be maintained since the description is built up by a sequence of function calls to the C++ library. This strategy has proven successful, since only a few minor modifications have been made to accommodate the nearly 400 sources of data that have started using it over the past year. This paper describes the design of telemetry's source registration.

7740-107, Poster Session

Design considerations for LBTI observer interface

V. Vaitheeswaran, P. M. Hinz, C. O'Connell, J. Kraus, Steward Observatory, The Univ. of Arizona (United States)

We outline the design considerations and principles for developing a graphical user interface for configuring and operating Large Binocular Telescope Interferometer(LBTI) on sky and examine the "weblication" methodology to deliver this astronomical software over the web. LBTI is an instrument to be installed at the Large Binocular Telescope to search for exoplanets. The instrument consists of an universal beam combiner to combine the light from both arms of the LBT, a L and M band science camera, a K band nulling channel along with wavefront sensor unit for adaptive optics correction. Additionally, the application will have an interface to the telescope control system and XML based telescope telemetry data flow.

7740-108, Poster Session

A multistrategy control system for field controllers of astronomical instruments

D. Zhu, Y. Zhu, Nanjing Univ. of Posts and Telecommunications (China)

As well-known, system on a programmable chip (SOPC) is widely used in a variety of field control systems, due to their flexible configurations and intelligent stand-alone characteristics. They are also increasingly used in astronomical instrument control nowadays. For those complex and diverse systems, a number of different control strategies are stored in FLASH, but the controller of on-chip determines which one to load. At the same time, it can be switched intelligently and remotely to form a multi-strategy control system, so as to extend the control functions and achieve system on-line reconfiguration quickly.

In this paper we describe a design concept and realization method of a multi-strategy control system on the basis of FPGA-based system on a chip. Its hardware core is Altera's Cyclone series EP3C25 chip. In SOPC BUILDER development environment, a control system is constructed, which consists of NIOS II soft core as CPU, REMOTE_UPDATE IP core and control algorithms as well.

The concept and design has been verified in the field controllers for various astronomical applications. Satisfactory results have been obtained.

7740-109, Poster Session

A simple and effective algorithm for quasar candidate selection

T. Pei, Y. Zhang, Y. Zhao, National Astronomical Observatories (China)

K-Nearest Neighbor (kNN) algorithm is one of the simplest and most flexible and effective classification algorithms, which has been widely used in many fields. Based on data from large survey projects of SDSS and UKIDSS, we try selecting quasar candidates from a sample which consists of 8996 stars and 8496 quasars with kNN method. The different input patterns are considered and compared. Additionally, we introduce principal component analysis (PCA) to reduce the dimension of high dimensional space. When applying PCA to data preparation, the effectiveness and efficiency of classification both increase. The experimental results show that the classification accuracy can add up to 98%, which suggests that it's applicable and effective to use PCA kNN method to select quasar candidates.

7740-110, Poster Session

An automated algorithm for determining photometric redshifts of quasars

D. Wang, Y. Zhang, Y. Zhao, National Astronomical Observatories (China)

We employ nearest neighbor algorithm for photometric redshift measurement of quasars with the Fifth Data Release (DR5) of the Sloan Digital Sky Survey (SDSS). Nearest neighbor is an instance learning algorithm where the result of new instance query is predicted based on the nearest neighbor category of training samples. The regressor do not use any model to fit and only based on memory. Given a query quasar, we find the quasar or (training point) closest to the query point, whose redshift value as the prediction value of this query instance. Four different magnitudes (Petro, PSF, Model or Fiber) and spectral redshifts are used as input parameters, separately. The experimental results achieved are satisfied. For example, when model magnitudes as the input, 58.3%, 76.4% and 83.8% of photometric redshifts are even obtained within $\Delta z < 0.1$, 0.2 and 0.3, respectively. Compared to other methods (e.g. color-redshift relation), nearest neighbor avoid catastrophic photometric failures.

7740-111, Poster Session

Separating quasars from stars by support vector machines

Y. Zhang, National Astronomical Observatories (China); H. Zheng, North China Electric Power Univ. (China); Y. Zhao, National Astronomical Observatories (China)

Based on survey databases from different bands, we firstly employed random forest approach for feature selection and feature weighting, and investigated support vector machines (SVMs) to classify quasars from stars. Two sets of data were used, one from SDSS, USNO-B1.0 and FIRST (short for FIRST sample), and another from SDSS, USNO-B1.0 and ROSAT (short for ROSAT sample). The classification result with different data was compared. Moreover the SVM performance with different features was presented. The experimental result showed that the accuracy with FIRST sample was superior to that with ROSAT sample, in addition, when compared to the result with original features, the performance using selected features improved and that using weighted features decreased. Therefore we consider that while SVMs is applied for classification, feature selection is necessary since this not only improves the performance, but also reduces the dimensionalities. The good performance of SVMs indicates that SVMs is an effective method to preselect quasar candidates from multiwavelength data.

7740-112, Poster Session

Development of an automatic program to count the number of sunspots using Visual C++

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The sunspot is an important object because it represents solar activity which significantly affects satellites and communication systems. The number of sunspots has been counted by human inspection for several hundred years, which is likely to affected by human subjectivity. To overcome this, we have developed a program to detect sunspots and count their numbers using visual C++ software. For this work, we used white light full disk images from Big Bear Solar Observatory. We applied an iterative threshold method to separate solar full-disk image from background. By using an edge-detection method and a filling-algorithm, we could distinguish penumbra from the image as well as umbra from the penumbra image. For each sunspot, we could obtain its size, its location, and its mean intensity. We applied this method to twenty data sets. The sunspot numbers from this method was compared with those by human inspection, which is an average made by two authors according to the same criteria. The comparison shows that they have a very high correlation (r=92%). Therefor we expect that this program would be applied to count the number of sunspots in real observational systems.

7740-113, Poster Session

Calibration of LAMOST spectral analysis

F. Wang, A. Luo, National Astronomical Observatories (China)

LAMOST started its test observation in the past year. 2D pipeline and 1D pipeline are applied as data reduction and analysis software respectively, and the analysis results show some system errors that need to be calibrated. We will present many calibrations in this paper. Comparing with known objects, we can calibrate the result of our pipeline. Different spectral analysis software, such as SSPP, will be applied to LAMOST data for calibration.

7740-114, Poster Session

Control, acquisition, and reduction software for infrared spectrometers

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Modern IR spectrometers must be equipped with well suited software for the low level controls, acquisition, handling and fast pre-reduction of data.

Such a complex software structure can be conveniently managed by means of dedicated GUIs which allow one to access the system at differente levels: from the lowest (cryogenic controls) to the highest (data pre-reduction).

We will be briefly describe the structure and the performances of this software, that has already been tested on GIANO spectrometer.

7740-115, Poster Session

Robustness of LAMOST networked control system

A. Luo, K. Wu, National Astronomical Observatories (China)

Observation process using LAMOST is executed by a networked control system, named OCS. The robustness of OCS depends on reliability of network, bandwidth allocation, communication protocol etc., which will be discussed respectively in this paper. A simulated software NS2 was used to analyze the complex of the system. Experiments were designed to verify time delay effect and package loss, which could degrade the performance of the system.

7740-116, Poster Session

Research of large telescope control system

S. X. Ying, Chizhou College (China); Z. Zhang, Nanjing Institute of Astronomical Optics & Technology (China)

This paper research advanced control technique of TCS, presents the topology structure of wireless local area networks control, remote control based on satellites and wireless mobile control and expatiates the software design of those means.

Wireless Networks Telescope Control System (WTCS) is a wireless local area network control systems, including main controller, wireless communication system and local control unit (LCU). WTCS can provide added flexibility, reduced infrastructure costs, and greater convenience. Modified standard IEEE 802.11 DCF and PCF to reduce the delay of wireless stations, ensure bounded delays, enhance the performance and real-time.

The Antarctica Plateau has recently turned out to be the best place on the Earth to perform astronomical observations. We are going to devise telescope to build in the Antarctica. Remote control center transmits commands to local control units through satellites. LCUs connect the local server with wireless channel. To improve the communication performance, the special exchange format of data between remote control center and local control units must be designed.

To achieve the control of telescope at “Any Time, Any Where, Any Body”, proposed a telescope mobile control system based on Java. The system adopted the J2ME-J2EE frame so that client can control the telescope in time through mobile terminal.

7740-117, Poster Session

Position measurement of the direct-drive motor of large-aperture telescope

Y. Li, D. Wang, Z. Zhang, Nanjing Institute of Astronomical Optics & Technology (China)

Along with the development of space and astronomy science, production of large aperture telescope and super large aperture telescope will definitely become the trend. It’s one of methods to solve precise drive of large aperture telescope using direct drive technology unified designed of electricity and magnetism structure. A direct drive precise rotary table with diameter of 2.5 meters researched and produced by us is a typical mechanical & electrical integration design.

This paper mainly introduces position measurement control system of direct drive motor. In design of this motor, position measurement control system requires having high resolution, and precisely aligning the position of rotor shaft and making measurement, meanwhile transferring position information to position reversing information corresponding to needed motor pole number. This system has choose high precision metal band coder and absolute photo-electricity coder, processing information of coders, and has sent single chip LPC2119 making software processing, and gained high resolution composite coder. The paper gives relevant laboratory test results at the end, indicating the position measurement can apply to large aperture telescope control system.

7740-118, Poster Session

Design and implementation of LAMOST CCD cameras' master control

X. Deng, J. Ge, J. Wang, Univ. of Science and Technology of China (China)

The Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST) uses 32 scientific CCD cameras on 16 low-dispersion spectrographs for object spectrum. This paper introduced the CCD Master system; based on LAMOST system and UCAM controller, we gave a design; the interfaces to OCS and UCAM are given and the management of commands and statuses are discussed.

7740-119, Poster Session

The primary mirror system control software for the VST

P. Schipani, L. Marty, Osservatorio Astronomico di Capodimonte (Italy)

The most important element of the VST active optics is the primary mirror, with its active support system located within the primary mirror cell structure. The primary mirror support system is composed by an axial and a lateral independent systems and includes an earthquake safety system. The primary mirror system software has been designed with a system engineering approach. Actually the software has to change the mirror shape during observations, but in addition shall allow the user to perform many other activities. The primary mirror software has to support also the periodic maintenance operations like the alignment, the mirror removal and installation for recoating, the functional tests of the system, the engineering operations, the recalibration of parameters. This paper describes how the primary mirror system software has been designed at a system engineering level to support both the observations and the maintenance activities.

7740-120, Poster Session

Telescope information service system of LAMOST

S. Sun, National Astronomical Observatories (China)

The Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST) had been finished. It's beginning to developing Telescope information service system(TISS) of LAMOST now.In this paper, the maintenance extent of softwares and hardwares are presented, and the standard of interface is introduced. The driving of the model and the communication between TISS and different subsystems are also analyzed.Otherwise,the methods of collection,storage and display of data are showed.The system improves efficiency of LAMOST.

7740-121, Poster Session

A code generation framework for ALMA common software

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Code generation helps in smoothing the learning curve of a complex application framework and in reducing the number of Lines Of Code (LOC) that a developer needs to craft. The ALMA Common Software (ACS) has adopted code generation in specific areas, but we are now exploiting the more comprehensive approach of Model Driven code generation to transform directly an UML Model into a full implementation in the ACS framework.

This approach makes it easier for newcomers to grasp the principles of the framework. Moreover, a lower handcrafted LOC reduces the error rate. Additional benefits achieved by model driven code generation are: software reuse, implicit application of design patterns and automatic tests generation. A model driven approach to design makes it also possible using the same model with different frameworks, by generating for different targets.

The generation framework presented in this paper uses Open Architectureware as the model to text translator. Open Architectureware provides a powerful functional language that makes this easier to implement the correct mapping of data types, the main difficulty encountered in the translation process. The output is an ACS application readily usable by the developer, including the necessary deployment configuration, thus minimizing any configuration burden during testing. The specific application code is implemented by extending generated classes. Therefore, generated and manually crafted code are kept apart, simplifying the code generation process and aiding the developers by keeping a clean logical separation between the two.

Our first results show that code generation improves dramatically the code productivity.

7740-122, Poster Session

The interaction between pointing and active optics on the VISTA Telescope

D. L. Terrett, Rutherford Appleton Lab. (United Kingdom); W. J. Sutherland, Queen Mary, Univ. of London (United Kingdom)

The VISTA telescope has a field of view of 45 arc minutes radius and an F1 primary mirror and so, in order to meet the image quality requirements at the edge of the field, the position of M2 has to be actively controlled in all 5 axes (focus, centring and tilt). Tilting M2 not only affects the image quality, it also shifts the image in the focal plane which introduces an interaction between the active optics and the telescope pointing. The design of the VLT control system and the M2 hexapod does not allow movements of M2 and the telescope to be coordinated well enough for M2 to be tilted while a science exposure is in progress without introducing unacceptable image motion. Therefore, application of tilts requested by the active optics system have to be coordinated with the activity of the infra-red camera.

This paper describes how the active optics system measures M2 tilt corrections and how the application of these tilts to the mirror and the compensating adjustments the telescope pointing are integrated with the operation of the telescope and camera in order to deliver the best possible image quality without reducing the survey efficiency.

7740-123, Poster Session

MOCS: a new control system for the Mercator Telescope

W. Pessemier, G. Raskin, S. Prins, F. Merges, J. P. Padilla, H. Van Winckel, C. Waelkens, Katholieke Univ. Leuven (Belgium)

A new control system is currently being developed for the 1.2-meter Mercator Telescope at the Roque de Los Muchachos Observatory (La Palma, Spain). Formerly based on transputers, the new Mercator Observatory Control System (MOCS) consists of a small network of Linux computers complemented with a central industrial controller. Python is chosen as the high-level language to develop flexible yet powerful supervisory control and data acquisition (SCADA) software for

the Linux computers. Specialized applications such as detector control, autoguiding and middleware management are also integrated in the same Python software package. The industrial controller, on the other hand, is connected to the majority of field devices and is targeted to run various control loops, some of which are real-time critical. Independently of the Linux distributed control system (DCS), this controller makes sure that high priority tasks such as the telescope motion, mirror support and hydrostatic bearing control are carried out in a reliable and safe way. In addition to the software, obsolete hardware of the current Mercator telescope control is gradually being replaced by standard industrial alternatives with ethernet-based fieldbus communication. The use of Python as a scripting language allows a smooth migration to the final MOCS: finished parts of the new control system can readily be commissioned to replace the corresponding transputer units of the old control system with minimal downtime. In this contribution, we give an overview of the systems design, implementation details and the current status of the project.

7740-124, Poster Session

A high-availability, distributed hardware control system using Java

A. Niessner, Jet Propulsion Lab. (United States)

Two independent coronagraph experiments that require 24/7 availability with different optical layouts and different motion control requirements are commanded and controlled with the same Java software system executing on many geographically scattered computer systems interconnected via TCP/IP. High availability of a distributed system requires the computers have a robust communication messaging system making the mix of TCP/IP, a robust transport, and XML, a robust message, a natural choice. XML also adds the configuration flexibility. Java then adds object-oriented paradigms, exception handling, heavily tested libraries, and many third party tools for implementation robustness. The result is a software system that provides users 24/7 access to two diverse experiments with XML files defining the differences.

7740-125, Poster Session

Zigbee networking technology and its application in Lamost optical fiber positioning and control system

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4,000 fiber positioning units need to be positioned precisely in LAMOST(Large Sky Area Multi-object Optical Spectroscopic Telescope) optical fiber positioning & control system, and every fiber positioning unit needs two stepper motors for its driven, so 8,000 stepper motors need to be controlled in the entire system. Wireless communication mode was adopted to save the installing space on the back of the focal panel, and can save more than 95% external wires compared to the traditional cable control mode. This paper studies how to use the ZigBee technology to group these 8000 nodes, explores the pros and cons of star network and tree network in order to search the stars quickly and efficiently. ZigBee technology is a short distance, low-complexity, low power, low data rate, low-cost two-way wireless communication technology based on the IEEE 802.15.4 protocol. It based on standard Open Systems Interconnection (OSI): The 802.15.4 standard specifies the lower protocol layers-the physical layer (PHY), and the media access control (MAC). ZigBee Alliance defined on this basis, the rest layers such as the network layer and application layer, and is responsible for high-level applications, testing and marketing. The network layer used here, based on ad hoc network protocols, includes the following functions: construction and maintenance of the topological structure, nomenclature and associated businesses which involves addressing, routing and security and a self-organizing-self-maintenance functions which will minimize consumer spending and maintenance costs. In this paper, freescale's 802.15.4 protocol was used to configure the network layer. A star network and a tree network topology was realized, whom can build network, maintenance network and create a routing function automatically. A concise tree network address allocate algorithm was present to assign the network ID automatically.

7740-126, Poster Session

Realizing software longevity over a system's lifetime

K. Lanclos, W. T. S. Deich, R. I. Kibrick, S. L. Allen, J. Gates, Lick Observatory (United States)

A successful instrument or telescope will measure its productive lifetime in decades; over that period, the technology behind the control hardware and software will evolve, and be replaced on a per-component basis. These new components must successfully integrate with the old, and the difficulty of that integration depends strongly on the design decisions made over the course of the facility's history. The same decisions impact the ultimate success of each upgrade, as measured in terms of observing efficiency and maintenance cost.

We offer a case study of these critical design decisions, analyzing the layers of software deployed for instruments under the care of UCO/Lick Observatory, including recent upgrades to the Low Resolution Imaging Spectrometer (LRIS) at Keck Observatory in Hawaii, as well as the Kast spectrograph, Lick Adaptive Optics system, and Hamilton spectrograph, all at Mt. Hamilton's Share 3-meter Telescope.

These issues play directly into design considerations for the software intended for use at the next generation of telescopes, such as the Thirty Meter Telescope. We conduct our analysis with the future of observational astronomy infrastructure firmly in mind.

7740-127, Poster Session

Instrument control software requirement specification for Extreme Large Telescopes

M. J. Kiekebusch, G. Chiozzi, European Organisation for Astronomical Research in the Southern Hemisphere (Germany); P. Young, The Australian National Univ. (Australia)

Engineers in several observatories are now designing the next generation of optical telescopes, the Extremely Large Telescopes (ELTs), with apertures over 20 meters. These are very complex machines that will host sophisticated astronomical instruments to be used for a wide range of scientific studies such as the search for exoplanets, the detection and characterization of first light galaxies and the physics and evolution of distant galaxies among others.

In order to carry out scientific observations, a software infrastructure is required to orchestrate the control of the multiple subsystems and functions which are part of an instrument. With respect to the previous generation of telescopes and instruments, there are new strong requirements for the software infrastructure that are dictated by the need to keep end to end control of the wavefront through the optical path, by the high data rates imposed by the high resolution detectors and by the complex adaptive optics modes of the instruments. This paper will focus on describing the considerations, strategies and main issues related to the definition and analysis of the software requirements for the Instrument Control System of the European-ELT and of other ELTs using modern development processes and modelling tools like SysML.

7740-128, Poster Session

Introducing high-performance distributed logging service for ACS

J. Avarias, National Radio Astronomy Observatory (United States); J. S. López, C. D. Maureira, Univ. Tecnica Federico Santa Maria (Chile); H. Sommer, G. Chiozzi, European Organisation for Astronomical Research in the Southern Hemisphere (Germany)

The ALMA Common Software (ACS) provides the infrastructure for the Atacama Large Millimeter Array and other projects. ACS, based on CORBA, offers basic services and common design patterns for distributed software.

Every properly built system needs to be able to log status and error information. Logging in a single computer scenario can be as easy as using fprintf statements. However, in a distributed system it must provide a way to centralize all logging data in a single place without overloading the network nor complicating the applications.

ACS provides a complete logging service infrastructure in which every log has an associated priority and timestamp, allowing filtering at different levels of the system (application, service and clients). Currently the ACS logging service uses an implementation of the CORBA Telecom Log Service in a customized way, using only a minimal subset of the features provided by the standard.

The most relevant feature used by ACS is the ability to treat the logs as event data that gets distributed over the network in a publisher-subscriber paradigm. For this purpose the CORBA Notification Service, which is resource intensive is used.

The Data Distribution Service (DDS) provides an alternative standard for publisher-subscriber communication for real-time systems, offering better performance and featuring decentralized message processing.

We describe how the new high performance logging service of ACS has been modeled and developed using DDS, replacing the Telecom Log Service. Benefits and drawbacks are analyzed. A benchmark is presented comparing the differences between the implementations.

7740-129, Poster Session

A new control system hardware architecture for the Hobby-Eberly Telescope prime focus instrument package

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The Hobby-Eberly Telescope (HET) will be undergoing a major upgrade as a precursor to the HET Dark Energy Experiment (HETDEX). As part of this upgrade, the Prime Focus Instrument Package (PFIP) will be replaced with a new design that supports the HETDEX requirements along with the existing suite of instruments and anticipated future additions. This paper describes the new PFIP control system hardware plus the physical constraints and other considerations driving its design.

Because of its location at the top end of the telescope, the new PFIP is essentially a stand-alone remote automation island containing over a dozen subsystems. Within the PFIP, motion controllers and modular IO systems are interconnected using a local Controller Area Network (CAN) bus and the CANOpen messaging protocol. CCD cameras that are equipped only with USB 2.0 interfaces are connected to a local Ethernet network via small microcontroller boards running embedded Linux. Links to ground-level systems pass through a 100 m cable bundle and use Ethernet over fiber optic cable exclusively - communications are either direct or through Ethernet/CAN gateways that pass CANOpen messages transparently. All of the control system hardware components are commercially available, designed for rugged industrial applications, and rated for extended temperature operation down to -10 °C.

7740-130, Poster Session

Integrating a university team in the ALMA software development process: a successful model for distributed collaborations

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Observatories are not all about exciting new technologies and scientific progress. Some time has to be dedicated to the future engineers' generations who are going to be on the front line in a few years from now. Over the past six years, ALMA Computing has been helping to build up and collaborating with a well-organized engineering students' group at Universidad Técnica Federico Santa María in Chile. The Computer Systems Research Group (CSRG) currently has wide collaborations with national and international organizations, mainly in the astronomical observations field. The overall coordination and technical work is done primarily by students, working side-by-side with professional engineers. This implies not only using high engineering standards, but also advanced organization techniques.

This paper aims to present the way this collaboration has built up an own identity, independently of individuals, starting from its origins: summer internships at international observatories, the open-source community, and the short and busy student's life. The organizational model and collaboration approaches are presented, which have been evolving along with the years and the growth of the group. This model is being adopted by other university groups, and is also catching the attention of other areas inside the ALMA project, as it has produced an interesting training process for astronomical facilities. Many lessons have been learned by all participants in this initiative. The results that have been achieved at this point include a large number of projects, funds sources, publications, collaboration agreements, and a growing history of new engineers, educated under this model.

7740-131, Poster Session

SPHERE instrumentation software in the construction and integration phases

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SPHERE is a second generation instrument for the VLT whose prime objective is the discovery and study of new extrasolar giant planets orbiting nearby stars. It is a complex instrument, consisting in an extreme Adaptive Optics System (SAXO), various coronagraphs, an infrared differential imaging camera (IRDIS), an infrared integral field spectrograph (IFS) and a visible differential polarimeter (ZIMPOL).

SPHERE INS is the software devoted to the control of all instrument functions; it implements all the observation, calibration and maintenance procedures, the interactive GUIs and manages the software interfaces with the observation handling system and the data flow management system. Development of the SPHERE INS has been conducted by a team distributed over four nations. The SPHERE subsystems are nearing completion and the integration of the whole instrument will start soon. In this paper we report on the current status of the software and on the activities concerning both its construction and integration with the SPHERE subsystems. In particular, we will discuss how we managed development and integration within our distributed team, including the tools that we employed to support our work.

7740-132, Poster Session

The OAdM Robotic Observatory: the scheduler

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The Montsec Astronomical Observatory (OAdM) is a small-class observatory working on a completely unattended control, due to the isolation of the site. Robotic operation is mandatory for its routine use. The level of robotization of an observatory is given by its reliability in responding to environment changes and by the required human interaction due to possible alarms. These two points establish a level of human attendance to ensure low risk at any time. But there is another key point when deciding how the system performs as a robot: the capability to adapt the scheduled observation to current conditions. The scheduler represents a fundamental element to fully achieve an intelligent response at any time. Its main task is the time optimization and it has a direct effect on the scientific return achieved by the observatory. We present a detailed description of the scheduler developed for the OAdM, which is separated in two parts. Firstly, a pre-scheduler that makes a temporary selection of objects from the available projects according to their possibility of observation. This process is carried out before the beginning of the night following different selection criteria. Secondly, a dispatch-scheduler that is executed any time a target observation is over and a new one must be scheduled. This is based on a figure-of-merit calculation and enables the selection of the best target in real time according to current environment conditions and the set of priorities.

7740-133, Poster Session

UCam: universal camera controller and data acquisition system

S. A. McLay, UK Astronomy Technology Ctr. (United Kingdom); D. J. Ives, European Organisation for Astronomical Research in the Southern Hemisphere (Germany)

This paper describes the software architecture and design concepts used in the UKATC's generic camera control and data acquisition software system (UCam) which was originally developed for use with the ARC controller hardware. The ARC detector control electronics are developed by Astronomical Research Cameras (ARC), of San Diego, USA. UCam provides an alternative software solution programmed in C/C++ and python that runs on a real-time Linux operating system to achieve critical speed performance for high time resolution instrumentation. UCam is a server based application that can be accessed remotely and easily integrated as part of a larger instrument control system. It comes with a user friendly client application interface that has several features including a FITS header editor and support for interfacing with network devices. Support is also provided for writing automated scripts in python or as text files. UCam has an application centric design where custom applications for different types of detectors and read out modes can be developed, downloaded and executed on the ARC controller. The built-in demultiplexor can be easily reconfigured to readout any number of channels for almost any type of detector. It also provides support for numerous sampling modes such as CDS, FOWLER, NDR and threshold limited NDR. UCam has been developed over several years for use on many instruments such as the Wide Field Infra Red Camera (WFCAM) at UKIRT in Hawaii, the mid-IR imager/spectrometer UIST and is also used on instruments at SUBARU, Gemini and Palomar.

7740-134, Poster Session

An object-oriented software framework for telemetry and data logging at the MMT Observatory, Tucson, Arizona, USA

J. D. Gibson, T. Trebisky, D. Porter, S. Schaller, MMT Observatory (United States)

An object-oriented software approach to acquisition and logging of telemetry data has been implemented at the MMT Observatory (MMTO). This approach includes: 1) a uniform interface to RS-232 serial and TCP/UDP network-enabled hardware devices, 2) a multiplexed socket server able to handle multiple simultaneous connections, 3) standardized ASCII network protocols, 4) uniform relational database interfaces for data logging, and 5) centralized configuration files. An abstract "MMTserver" class has been written in Perl because of the robustness of that scripting language and the widespread Perl legacy code at the MMTO. Over 20 miniservers, each of which typically corresponds to a single hardware device, inherit from the MMTserver class and implement the hardware-specific protocol for communication with the hardware device. The miniserver collects data from the device and allows access to the dataset for that device via a uniform ASCII protocol. Each miniserver also periodically logs data to MySQL relational databases. Attributes within the MMTserver class monitor telemetry data staleness, hardware status, and server status. Over 29 gigabytes of logged telemetry data, representing over 1500 distinct parameters and 120,000,000 MySQL records, are currently available for the past 4-5 years through this software framework. Use of a uniform ASCII-based network protocol and MySQL relational databases makes it easy to write desktop- and web-based clients in essentially any common programming language. This object-oriented approach to telemetry provides a framework into which new hardware devices can easily be added and leverages existing data acquisition, analysis, and visualization tools.

7740-135, Poster Session

Software for automated CCD testing and characterization for Large Synoptic Survey Telescope

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We present description of control system for CCD testing and characterization laboratory. The system modularity allows us to quickly integrate new devices, and get the proper values recorded on proper place. We also unveil a bit a tests done with the CCDs, which are used to calculate and verify various CCD parameters. We discuss the differences between modified package and RTS2 standard version, the features designed specifically for our laboratory setups, and planned future improvements.

7740-136, Poster Session

Software for automated run-time determination of calibration values and hardware capabilities in torrent detector control systems

N. C. Buchholz, P. N. Daly, National Optical Astronomy Observatory (United States)

The Torrent detector control system being developed at NOAO is a follow-on to the MONSOON systems being successfully used for instruments at several institutions. The unique features of Torrent are low-power, detector limited performance, multi-controller synchronization, multiple communications path options and small size.

A collective of python software has been written that extracts information from the firmware VHDL source code and is used to determine the register address for all functions, read/write method, and the format of the eeprom data to be stored in the DHE. During the board test procedure the extracted information is used to determine test ranges and to write into the eeprom the conversion slope and offset and minimum and maximum values attained by each function during testing.

At the time the Torrent system is to be integrated with a Dewar/Detector the software allows the detector engineer to reliably determine the correct connections and to set valid, warning and alarm operation levels for an attached detector/Dewar. At run time the information stored in the EEPROMS is used to create the Attribute-Value database used by the standard MONSOON PAN processes to determine how the DHE functions are to be accessed. In addition the Torrent Transition Module that is permanently connected to the Dewar/Detector contains the information that allows the software to identify the detector being controlled and prevent the user from setting DHE functions to invalid or dangerous values. This means that any DHE of the proper type (IR or CCD) can be used to replace a defective DHE of the same type. The IR and CCS systems use different analog front end signal chains and therefore have different register requirements.

7740-137, Poster Session

World coordinate system keywords for FITS files from Lick Observatory

S. L. Allen, J. Gates, R. I. Kibrick, Lick Observatory (United States)

Every bit of metadata added at the time of acquisition increases the value of image data, facilitates automated processing of those data,and decreases the effort required during subsequent data curation activities.

In 2002 the FITS community completed a standard for World Coordinate System (WCS) information which describes the celestial coordinates of pixels in astronomical image data.

Most of the instruments in use at Lick Observatory predate this standard.

None of them were designed to produce FITS files with WCS information.

We report on the design and implementation of the WCS server, a new component of the data acquisition systems at Lick Observatory.

This server combines the information from three sources: 1) the telescope pointing system, 2) a description of the pixel layout of the detector, and 3) the mapping between the telescope focal surface and the detector focal surface.

The outputs from the WCS server are sets of FITS keywords that describe various coordinate systems.

These include coordinates which refer to the detector structure itself (for locating defects and artifacts), coordinates referred to the telescope structure, and celestial coordinates.

7740-138, Poster Session

Re-using the NOCS as a common instrument interface

P. N. Daly, National Optical Astronomy Observatory (United States)

The NEWFIRM Observation Control System (NOCS) was developed to provide high-level access to a wide-field IR imager on the KPNO Mayall 4m telescope. This system uses a (NOAO-developed) MONSOON controller and achieved first light in February 2007. Since then, NEWFIRM has been a regularly scheduled instrument and has proven popular with observers. In 2010, it is scheduled to be commissioned on the CTIO Blanco 4m telescope.

The successor to MONSOON is Torrent - cheaper, faster, better - and is fully backwards compatible with the earlier controller. New funds have identified 2 projects to modernize the 4m instrumentation suite: an upgrade to the current MOSAIC camera and a new spectrograph.

Both intend to use Torrent controllers and both have rapid development timescales.

Since the NOCS works so well in the 4m environment and already schedules observations by communicating with the telescope and MONSOON, we have started to look at re-using the NOCS as a common interface to these 3 different instruments. Initial analysis looks promising.

7740-139, Poster Session

Upgrading the Gemini secondary mirror micro-controller

M. J. Rippa, Gemini Observatory (United States)

This paper describes the preliminary re-design of the M2TS and discusses the proposed alternative solutions to classic VME type controllers. Of particular interest to developers of new systems is the use of RTEMS as the operating system of choice and a commercial off the self (COTS) EPICS IOC solution. I'll briefly describe the original DOS based controller and show how the proposed replacement system can meet the design requirements.

7740-140, Poster Session

Effect of noise in image restoration of Multi-aperture Telescope

Z. Zhou, D. Wang, Y. Wang, Y. Wan, Beijing Univ. of Technology (China)

Multi-aperture telescope is proposed to achieve high angular resolution without fabricating a large diameter monolithic primary mirror. Due to the array structure, the multi-aperture telescope has almost the same cut-off frequency as an equivalent diameter telescope, but the area of collecting light decrease which is the reason that the direct output image of multi-aperture telescope is blurred and low contrast. To obtain a clear picture, image restoration method is applied, however, the existence of noise will lead to a contrary result. We investigate the relationship between the noise and image quality of restored image and analysis the noise limitation for several image restoration method.

7740-141, Poster Session

Programmable workflow control with rule check on LAMOST

G. Liu, J. Wang, X. Deng, J. Ge, Univ. of Science and Technology of China (China)

A programmable workflow environment grants more flexibility to conduct an observation. This paper provides an easy way to develop visual workflow control. Staffs can drag and drop command elements to make up a workflow. The workflow supports sequence and parallel patterns. When a workflow starts to run automatically, a full set of manual interventions is supplied, which enable staffs to cope with unpredictable online situation. Beside this, rule check is implemented to workflows, which ensures there is no incorrect operation sequence in a user-defined workflows. Rules are not permanent. They can be modified or added if necessary.

7740-21, Session 5

Building archives in the virtual observatory era

R. L. Plante, Univ. of Illinois at Urbana-Champaign (United States); G. Greene, R. J. Hanisch, Space Telescope Science Institute (United States); T. A. McGlynn, NASA Goddard Space Flight Ctr. (United States); C. J. Miller, National Optical Astronomy Observatory (United States); D. Tody, National Radio Astronomy Observatory (United States); R. L. White, Space Telescope Science Institute (United States)

In this presentation, we consider how the Virtual Observatory is influencing the development of modern astronomical archives. Broad support for VO standards by archives has been critical for the success of the VO as a research platform as shown by the many effective data discovery, visualization, and integration tools that have been created which rely on them. We are now seeing a growing trend among archive developers toward leveraging VO standards and technologies not just to provide interoperability with other archives, but also to support an archive's internal needs and the needs of the archive's primary user base. We examine the motivation for choosing VO technologies for implementing an archive's functionality as well as the lessons learned from several current archive efforts, including by the Hubble Legacy Archive, NASA HEASARC, NOAO, and NRAO. We also discuss the expected implications for some of the ambitious observatory projects planned for the near future.

7740-22, Session 5

Complex/large data sets: information representation and processing on manifolds and graphs

M. Z. Pesenson, California Institute of Technology (United States); I. Z. Pesenson, Temple Univ. (United States); B. McCollum, California Institute of Technology (United States)

Modern science and technology are undergoing a rapid, unprecedented and accelerating growth in both the amount and the complexity of data. An effective data exploration and knowledge discovery from such highly complex and massive sets poses significant challenges. There are complex interdependencies between a very high number of dimensions within the data, which are not parallelizable, so the problem can not be simply solved by increasing the computational power. It is essential to develop new mathematical approaches for organization, scientific visualization (as opposed to mere illustrative visualization) and analysis of heterogeneous, multiresolution data across application domains. We present novel methods for data compression, dimensionality reduction and denoising based on our innovative developments of sampling and variational splines. We describe sampling on infinite graphs as a more adequate approach to modeling petascale data sets. We also describe a novel method for pattern recognition and data visualization based on nonlinear dynamics. The methods are tested on space-based infrared data from the Spitzer Space Telescope.

7740-23, Session 5

The Kepler DB: a database management system for arrays, sparse arrays, and binary objects

S. D. McCauliff, T. C. Klaus, F. R. Girouard, B. Wohler, C. Middour, M. T. Cote, NASA Ames Research Ctr. (United States)

The Kepler Science Operations Center needs to store pixel information on six million pixels collected every 30 minutes as well as data products that are generated as a result of running the Kepler science processing pipeline. The Kepler Database (Kepler DB) management system was created to act as the repository of this information. After nine months of flight usage Kepler DB is managing several terabytes of data and is expected to grow to over 10 TiBytes over the course of the mission. Kepler DB is a non-relational, transactional database where data are represented as one dimensional arrays, sparse arrays or binary large objects. It participates in distributed transactions with third party products that support XA transactions. Kepler DB is implemented in Java, so is platform independent. We will discuss Kepler DB's APIs, implementation, usage and deployment at the Kepler Science Operations Center.

7740-24, Session 5

An open source, service-oriented architecture for the WIYN one degree imager software system

A. Yeatts, J. W. Ivens, D. R. Harbeck, WIYN Observatory (United States); J. Cavin, Univ. of Wisconsin-Madison (United States)

The One Degree Imager (ODI) is a new era of instrument for the WIYN 3.5m telescope. The ODI camera provides a one degree field of view populated with 64 orthogonal transfer array (OTA) CCDs that provide tip-tilt atmospheric compensation based on hundreds of video stream from multiple readouts on each CCD. The amount of data, the complexity of the imaging system, and the degree of automatic control required for surveys, queues, and online image process monitoring have necessitated new approaches to the software architecture.

Challenges for ODI include massive reconfigurations in rapid sequences, new video streaming and on-line analysis, coupled with legacy integration. Existing command and control systems must interoperate with new devices and new software. The existing telescope and CCD controller systems provide similar, but incompatible network event systems. A new cluster based image processing system must be rapidly sequenceable to provide dither and survey support, where any of 3000 or more settings for CCD biases, guide star positions, etc. may be required to change between exposures.

By using Java application server technology, we are able to minimize custom code and take advantage of extensive open source libraries. The ODI system is organized as a set of services, hosted in JBoss. It can be reconfigured at each exposure through the use of XML configurations that are rewritten with the use of XSL transformations describing compute resources, CCD settings, and telescope motion. Requests and telemetry are communicated throughout the cluster by means of a distributed XML based event system.

7740-25, Session 5

Discovery Channel Telescope software key technologies

P. J. Lotz, Lowell Observatory (United States)

The Discovery Channel Telescope is a 4.2m astronomical research telescope being built in northern Arizona as a partnership between Discovery Communications and Lowell Observatory. The project software

team has designed and partially implemented a component-based system. We describe here the key features of that design (state-based components that respond to signals) and detail specific implementation technologies we expect to be of most interest: examples of the Command Pattern, State Pattern, and XML-based configuration file handling using LabVIEW classes and shared variables with logging and alarming features.

7740-26, Session 5

Future management needs of a 'software-driven' science community

O. Moeller-Nilsson, Max-Planck-Institut für Astronomie (Germany); K. Nilsson, European Organisation for Astronomical Research in the Southern Hemisphere (Germany)

The work of any natural scientist in general, and astronomer in particular, is getting more complex and advanced as the progress of computer development occurs. With improved computing capabilities and increased data flow, more sophisticated software is required in order to interpret, and fully exploit, this data. However, it is not possible for every astronomer to also be a software specialist, nor to have a perfect overview of what software already exists for particular applications. As history has shown, the work of scientists always becomes increasingly specialised, from all-studying scientists such as Galileo or da Vinci in the early human history, to the current split into chemists, physicists, astronomers (or even further splits into theoretical or observational astronomer, cosmologists or planetologists etc.). Time is now ripe for another, at least partial, split between "programmers" and "interpreters". Such a split would strongly facilitate progress in astronomical data analysis and computational methods. In this presentation we describe the problems that currently exist at the interface between scientific and computational work in astronomical research and outline our vision for a more fruitful symbiosis between software specialists and scientists. We describe what new managerial processes and changes would be necessary.

7740-27, Session 6

An observation execution system for next-generation large telescopes

K. K. Gillies, Space Telescope Science Institute (United States); S. Walker, Gemini Observatory (Chile)

The telescope development projects of the 1990's produced a set of capable 8-10m telescopes that are now in operations across the northern and southern hemispheres. This was the first generation of telescopes to benefit from carefully engineered software systems, yet several years of 8m operations have revealed weaknesses in a common architecture employed by many of them. Today engineers are working on the next generation of telescopes, the extremely large telescopes (ELTs), along with their software systems. It is our view that many of the fundamental assumptions about how software systems for 8-m class large telescopes should be constructed are not optimal for the next generation of extremely large telescopes. In fact, these ideas may constrain the solution space and result in overly complex software and increased development costs. This paper points out issues with current architecture solutions and how they they impact the software needed for extremely large telescopes. It then provides the outline of a new approach for the design of the software running at the telescope that is targeted towards the development issues of ELTs and large telescope operations.

7740-28, Session 6

Software architecture of the Magdalena Ridge Observatory interferometer

A. R. Farris, D. A. Klinglesmith III, J. Seamons, N. Torres, New Mexico Institute of Mining and Technology (United States); D. F. Buscher, J. Young, Univ. of Cambridge (United Kingdom)

How do you merge systems developed from 36 independent work packages into a single coherent, unified software system to support an observatory with a 20 year lifespan while using limited resources? The Magdalena Ridge Observatory Interferometer (MROI) solves this problem by using standardized interface software automatically generated from simple high-level descriptions of these systems.

The MROI software system is a collection of hierarchically structured distributed systems, corresponding to the major functional divisions of the interferometer (Unit Telescope, Delay Line System, Automated Alignment System, etc.) managed by a centralized Supervisory System. All hard real-time control modules lie at low levels within these systems. Each system defines a set of high-level interface commands using simple spreadsheets that are designed to completely manage that system, including collecting monitor (engineering) and science data. Generic interface software, in Java or C using gigabit Ethernet with a TCP/IP protocol, is automatically generated from these spreadsheets using a code generation framework. The Supervisory System itself is a collection of systems containing an Executive, Operator Interface, Database Manager, one or more Data Collectors, and one or more Supervisors each with its own Fault Manager, to manage the collection of distributed systems using only their generic interfaces.

This approach provides the flexibility to integrate systems as diverse as HVAC systems using BACNET, LabView-based systems managing hardware modules, real-time systems using Linux/Xenomai, or FPGA-based systems. All of these are controlled using only standard Linux/GNU/POSIX software without relying on complex middle-ware systems such as CORBA.

7740-29, Session 6

Designing a high-availability cluster for the Subaru Telescope second-generation observation control system

E. Jeschke, T. Inagaki, National Astronomical Observatory of Japan/Subaru Telescope (Japan)

Subaru Telescope is commissioning a second-generation Observation Control System (OCS), building upon a 10 hear history of using the first generation OCS. One of the primary lessons learned about maintaining a distributed OCS system is that the idea of individual computer nodes specialized for specific functions greatly complicates troubleshooting and failover, even with a dedicated "hot spare" for each specialized node.

In contrast, the Generation 2 (Gen2) system was designed from the ground up around the principle of a High-Availability (HA) cluster, commonly used for high-traffic, mission-critical web sites. In such a cluster, nodes are not specialized, and any node can perform any function of the OCS. We describe the problems encountered in trying to troubleshoot and manage failure on the legacy OCS system and describe the architectural design of the HA cluster for the new system, including special characteristics designed for the high-altitude, remote environment of the summit of Mauna Kea, where there is a greatly increased probability of such failures. Although the focus is primarily on the hardware, we touch upon the software architecture written to take advantage of the features of the HA cluster design. Finally, we outline the advantages of the new system and show how the design greatly facilitates troubleshooting, robustness and ease of failure management. The results may be of interest to anyone designing a distributed system using COTS hardware and open-source software to withstand failure and improve manageability in a remote environment.

7740-30, Session 6

Evolution of the VLT instrument control system toward industry standards

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The VLT control system is a large distributed system consisting of Linux Workstations providing the high level coordination and interfaces to the users, and VME-based Local Control Units (LCU's) running the VxWorks real-time operating system with commercial and proprietary boards acting as the interface to the instrument functions. After more than 10 years of VLT operations, some of the applied technologies used by the astronomical instruments are being discontinued making it difficult to find adequate hardware for future projects. In order to deal with this obsolescence, the VLT Instrumentation Framework is being extended to adopt well established Commercial Of The Shelf (COTS) components connected through industry standard field buses. This ensures a flexible state of the art hardware configuration for the next generation VLT instruments allowing the access to instrument devices via more compact and simpler control units like PC-based Programmable Logical Controllers (PLC's). It also makes it possible to control devices directly from the Instrument Workstation through a normal Ethernet connection. This paper outlines the requirements that motivated this work, as well as the architecture and the design of the framework extension. In addition, it describes the preliminary results on a use case which is a VLTI visitor instrument used as a pilot project to validate the concepts and the suitability of some COTS products like a Soft-PLC, EtherCAT and OPC UA as solutions for instrument control.

7740-31, Session 6

Operating global network of autonomous observatories

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We present the experiences gained during design, development, commission and use of the heterogenous network of autonomous observatories. We particularly focus on our experiences in its use for target of opportunity gamma ray burst observations. Various management issues are presented. The network nodes are listed on http://rts2.org/wiki/obs:start.

7740-32, Session 7

Achieving reusability in KMOS instrument software through design patterns

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KMOS is a near-infrared multi-object spectrometer, which is currently being built by a British-German consortium for the ESO VLT. As for any other VLT instrument, the design of the KMOS instrument software is based on and follows the guidelines given by the VLT Common Software framework, the latter one providing the basis of the main components Instrument Control, Observation, and Maintenance Software. However, due to the complexity of KMOS with its 24 robotic pick-off arms for target selection, some additional design issues have to be addressed. Since both the allocation of targets, performed by the dedicated preparation tool KARMA, and the actual device control through the instrument workstation require a similar functionality with respect to several necessary permissibility checks, user interface and configuration control, a relatively large number of tasks have to be implemented twice and slightly differently. A closer inspection of these specific requirements now shows that many of the well-known object-oriented design patterns like, for instance, Singleton, Observer, Visitor, Memento, State, or Strategy, having proven their usefulness in software engineering for many years, are not only a suitable solution also to our design issues, but turn out as such in a quite natural way. We show that the application of patterns indeed facilitates reuse, thereby improving also the overall design of the KMOS instrument software. For this purpose we present a selected set of sample design problems along with their particular pattern solution.

7740-33, Session 7

Re-using the VLT control system on the VISTA Telescope

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Once it was decided that the VISTA infra-red survey telescope would be built on Paranal and operated by ESO it was inevitable that the control system would be based on that of the VLTs. Benefits over developing a new system such as lower development costs or disadvantages such as constraints on the design were not relevant to the decision but now that the telescope is complete the pros and cons of re-using and existing system can be evaluated.

This paper reviews the lessons learned during construction and commissioning and attempts to show where reusing an existing system was a help and where it was a hindrance. It highlights those things that could have been done differently to better exploit the fact the we were using a system that was already proven to work and where, with hindsight, we would have been better to re-implement components from scratch rather than modifying an existing one. It also discusses which characteristics of the VLT control system helped its use on another telescope and which inhibited it, and suggest, based on the experience of implementing the VISTA control system, ways in which future systems can be made more suitable for reuse.

7740-34, Session 7

Evaluating and evolving common services framework for use at W.M.K.O

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As part of the System Design for the Telescope Control System (TCS) upgrade and Preliminary Design for the Next Generation Adaptive Optics (NGAO) projects at the W.M. Keck Observatory we have been working with the National Solar Observatory to evaluate the Common Services Framework (CSF) under development for the Advanced Technology Solar Telescope. A decision was made to proceed with CSF at W.M.K.O with some modifications for the next stages of the projects, the adaptation becoming KCSF. This co-authored paper describes the collaboration effort to date. The paper focuses on the technical differences between the two variations and the reasons for them. It highlights the many commonalities and explores the usage and extensions that will be specific to each site. Some changes are site specific extensions such as providing interoperability between CSF and EPICS via Channel Access. Some changes are more collaborative and may result in new features that are usable at both observatories. Other changes are more fundamental and may have a bigger impact on our ability to directly share the framework.

7740-35, Session 7

Integration of SCUBA-2 within the JCMT Observatory control system

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The high data rates and unique operation modes of the SCUBA-2 instrument made for an especially challenging effort to get it working with the existing JCMT Observatory Control System (OCS). Due to some forethought by the original designers of the OCS, who had envisioned a SCUBA-2 like instrument years before it was reality, the JCMT was already being coordinated by a versatile Real Time Sequencer (RTS). The timing pulses from the RTS are fanned out to all of the SCUBA-2 Multi Channel Electronics (MCE) boxes allowing for precision timing of each data sample. The SCUBA-2 data handing and OCS communications are broken into two tasks, one doing the actual data acquisition and file writing, the other communicates with the OCS through DRAMA. These two tasks talk to each other via shared memory and semaphores. Many of the OCS programs that were developed for heterodyne observing are the same, or nearly identical, to those used with SCUBA-2 and it is possible to swap back and forth between heterodyne and SCUBA-2 observing simply by selecting an observation for a particular instrument. A JCMT Observation Sequencer (JOS) was written for SCUBA-2 but it uses all of the primitives that were developed for heterodyne observing. All of the hard work from the team lead to a very seamless integration of SCUBA-2 within the JCMT OCS.

7740-36, Session 7

Commensal observing with the Allen Telescope array: software command and control

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The Allen Telescope Array is a Large-Number-Small-Diameter radio telescope array currently with 42 individual antennas and 5 independent back-end science systems (2 imaging FX correlators and 3 time domain beam formers). The goal of the ATA is to run multiple back-ends simultaneously, supporting multiple science projects commensally. The primary software control systems are based on a combination of Java, JRuby and Ruby on Rails. The primary control API is simplified to provide easy integration with new back-end systems while the lower layers of the software stack are integrated into a resource locking system to ensure that science projects do not interfere destructively with each other. The complexity of the ATA lead to the design of an alarm system based on traversing a directed-acyclic graph, representing dependencies between components. This allows a small group of workers to identify and trouble-shoot issues with the running system, as well as allowing the system to potentially “self-heal”. Scheduling observations for the ATA is based on finding a union between science needs of multiple projects and automatically determining an efficient path to operating the various sub-components to meet those needs. When completed, the ATA is expected to be a world-class radio telescope, combining dedicated SETI projects with numerous radio astronomy science projects.

7740-37, Session 8

Writing Web 2.0 applications for science archives

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Users expect more and are drawn to more interactive and intuitive web sites.

Writing these sort of science archive web applications is now possible because of some significant breakthroughs in web technology over the last four years. The Web browser is no longer a glorified batch processing terminal, but an interactive environment that allows the user to have a similar experience as one might expect with an installed desktop application.

Taking advantage to this technology requires a significant amount of UI design and advanced interactions with the web server. There is a new levels of sophistication required to effectively develop this sort of web application.

The IRSA group (NASA/IPAC Infrared Science Archive) is developing web based software that both takes advantage of modern technology and is designed in such a way to easily be reused. This way we can add new missions and data sets without a large programming effort while keeping the advanced interface.

We can now provide true web based FITS viewing, data overlays, and interaction without any plugins. Our tabular display allows us to filter, sort and interact with large amounts data in ways that takes advantage of the browser’s power.

This talk will show how we can us AJAX technology, the Google Web Toolkit (GWT), and Java to develop a data archive that is both well designed and creates a truly interactive experience.

7740-38, Session 8

Build great web-based search applications quickly with Solr and Blacklight

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The NRAO faced performance and usability issues after releasing a single-search-box (“Google-like”) web application to query data across all NRAO telescope archives. Running queries with several relations across multiple databases proved to be very expensive in compute resources. An investigation for a better platform led to Solr and Blacklight, a solution stack which allows in-house development to focus on in-house problems. Solr is an Apache project built on Lucene to provide a modern search server with a rich set of features and impressive performance. Blacklight is a web user interface (UI) for Solr primarily developed by libraries at the University of Virginia and Stanford University. Though Blacklight is developed for libraries, it is highly adaptable for many types of search applications which benefit from the faceted searching and browsing, minimal configuration, and flexible query parsing of Solr and Lucene. The result: one highly reused codebase provides for millisecond response times and a flexible UI. Not just for observational data, NRAO is rolling out Solr and Blacklight across domains of library databases, telescope proposals, and more -- in addition to telescope data products, where integration with the Virtual Observatory is on-going.

7740-39, Session 8

HTML 5, Websockets, and Sproutcore: a web-based user interface for the dark energy camera (DECam)

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Over the past year the web browser technology has made significant leaps in speed and functionality. These advances have made the web browsers a viable platform for a desktop like, interactive, graphical user interface (GUI). One of the most important advances is the inclusion of WebSockets.

Until now, the only method of pulling information into a web browser was via a discrete, browser initiated, HTTP request.

With WebSockets, a browser can initiate Unix socket type connections which can be used to 'push' data, asynchronously, to the browser. WebSockets are part of the emerging HTML 5 standard. In addition, modern browsers, such Apple's Safari and Google's Chrome, have dramatically increased the speed in which Javascript, the code behind almost every dynamic web page, can be parsed and executed allowing much more complex pages to be rendered sufficiently fast. Once thought of as static documents, web pages can now support the full range of functionality expected in a graphical user interface. To taking advantage of the new capabilities of modern browsers, SproutCore is an open source framework that strives to implement a full functional application framework, similar to. Net or Cocoa, in the browser context. SproutCore further abstracts the browser away as simply a drawing and operating context, removing the requirement for direct manipulation of the browser allowing the programmer to focus on the application. We will report on the use of these new technologies in the development of the graphical user interface system for the Dark Energy Camera, the new instrument for the Dark Energy Survey.

7740-40, Session 8

User interface software development for the WIYN one degree imager (ODI)

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Developing user interfaces (UIs) is a necessity for almost any data acquisition system. The development team for ODI chose to develop a user interface that allows access to most of the instrument control for both scientists and engineers through the World Wide Web, because of the web's ease of use and accessibility around the world. Having a web based UI will allow for ODI to grow from a visitor-mode instrument to a queue-managed instrument and also facilitate remote servicing and troubleshooting. The challenges of developing such a system involve the difficulties of browser inter-operability, speed, presentation, and the choices involved with integrating front and back end technologies. To this end, the team has chosen a combination of Java, JBOSS, AJAX technologies, XML data descriptions, Oracle XML databases, and an emerging technology called the Google Web Toolkit (GWT) that compiles Java into Javascript for presentation in a browser. Advantages of using GWT include developing the front end browser code in Java, GWT's native support for AJAX, the use of XML to describe the user interface, the ability to profile code speed and bottlenecks, the ability to efficiently communicate with application servers such as JBOSS, and the ability to optimize and test code for multiple browsers. We will discuss the inter-operation of all of these technologies to create fast, flexible, and robust user interfaces that are scalable, manageable, separable, and as much as possible allow the developer to maintain all code in Java.

7740-41, Session 8

The use of Flex as a viable toolkit for astronomy software applications

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The challenges facing the developers of user interfaces for astronomy applications has never been greater. Astronomers and engineers often use well designed commercial and web applications outside work and consequently they expect similar user experiences with applications developed for their work tasks. The connectivity provided by the Internet and the ability to work from anywhere can improve user productivity, but it has been always been a challenge to provide the kind of interactivity and responsiveness needed for astronomical applications to web based projects. It is fair to say that browser-based applications have not been adequate for many kinds of workhorse astronomy applications. The Flex/Actionscript framework from Adobe has been used successfully at Space Telescope Science Institute in a variety of situations that were not possible with other technologies. In this paper, the framework and technology is briefly introduced followed by a discussion of its advantages and disadvantages and how it addresses user expectations. A variety of astronomy applications will be presented demonstrating the technology capabilities with useful performance data. Flex/Actionscript is not well known within the astronomy development community, and our goal is to demonstrate that it can be the right choice for many astronomy applications.

7740-42, Session 10

An open source application framework for astronomical imaging pipelines

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The LSST Data Management System is built on an open source software framework that has middleware and application layers. The middleware layer provides capabilities to construct, configure, and manage pipelines on clusters of processing nodes, and to manage the data the pipelines consume and produce. It is not in any way specific to astronomical applications. The complementary application layer provides the building blocks for constructing pipelines that process astronomical data, both in image and catalog forms. The application layer does not directly depend upon the LSST middleware, and can readily be used with other middleware implementations. Both layers have object oriented designs that make the creation of more specialized capabilities relatively easy through class inheritance.

This paper outlines the structure of the LSST application framework and explores its usefulness for constructing pipelines outside of the LSST context, two examples of which are discussed. The classes that the framework provides are related within a domain model that is applicable to any astronomical pipeline that processes imaging data.

Specifically modeled are mosaic imaging sensors; the images from these sensors and the transformations that result as they are processed from raw sensor readouts to final calibrated science products; and the wide variety of catalogs that are produced by detecting and measuring astronomical objects in a stream of such images. The classes are implemented in C++ with Python bindings provided so that pipelines can be constructed in any desired mixture of C++ and Python.

7740-43, Session 10

Automated calibration and imaging on the Allen Telescope array

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Planned instruments such as the Atacama Large Millimeter Array (ALMA), the Large Synoptic Survey Telescope (LSST) and the Square Kilometer Array (SKA) will measure their data in petabytes. Innovative approaches in signal proccessing, computing hardware, algorithms, and data handling are necessary. The Allen Telescope Array (ATA) is a 42-antenna aperture synthesis array equipped with broadband, dual polarization receivers from 0.5 to 11 GHz. Four independent IF bands feed 4 spectral cross correlators and 3 beamformers. In this paper we describe the automated data processing to handle the high data rate and RFI in close to real time at the ATA.

Automated data quality control, monitor and editing are essentialfor real time data processing. Three subsystems: RFI excision, calibration, and imaging, function with limited or no a-priori information about the sky

or telescope system, using a-priori calibrations, iteratively flagging data and imaging the sky to build a model for the calibrator field and self-calibrating to that model.

Automated instrument-health diagnostics, RFI identification and excision, and calibration, routinely produce high dynamic range images with absolute positions within a hundredth of a synthetic beam. This level of calibration accuracy is not constrained to bands protected for radio astronomy, and is even obtained in bands that are very polluted by RFI, and enables imaging bright targets (such as the sun or moon) that are many orders of magnitude brighter than the calibration sources.

7740-44, Session 10

The Kepler Science Operations Center pipeline framework

T. C. Klaus, S. D. McCauliff, M. T. Cote, F. R. Girouard, B. Wohler, C. Allen, C. Middour, D. A. Caldwell, J. M. Jenkins, NASA Ames Research Ctr. (United States)

The Kepler mission is designed to continuously monitor 100,000 stars at a 30 minute cadence for 3.5 years searching for Earth-size planets. The data are processed at the Science Operations Center at NASA Ames Research Center. Because of the large volume of data and the memory and CPU-intensive nature of the analysis, significant computing hardware is required. We have developed pipeline infrastructure software that is used to distribute and synchronize the processing across a cluster of 128 processors and to manage the resulting products. The infrastructure software is Java-based and therefore platform-independent, and scales from a single, standalone workstation (for development and research on small data sets) to a full cluster of homogeneous or heterogeneous hardware with minimal configuration changes. A plug-in architecture provides customized control of the unit of work without the need to modify the infrastructure software itself. Distributed transaction services provide for atomic storage of pipeline products for a unit of work across a relational database and the custom Kepler File Store. Generic parameter management and data accountability services are provided to record the parameter values, software versions, and other meta data used for each pipeline execution. A graphical console allows for the configuration, execution, and monitoring of pipelines. An alert and metrics subsystem is used to monitor the health and performance of the pipeline. While developed for Kepler, none of this infrastructure software is Kepler-specific and could be used for other applications where these services are needed.

7740-45, Session 10

The Kepler Science Operations Center pipeline framework extensions

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The Kepler Science Operations Center (SOC) is responsible for several aspects of the Kepler Mission, including managing targets, generating on-board data compression tables, monitoring photometer health and status, processing the science data, and exporting the pipeline products to the mission archive. We describe how the generic pipeline infrastructure software developed for Kepler is used to achieve these goals, including pipeline configurations, custom unit of work generators that control how the Kepler data are broken up and distributed across the computing cluster, and management of the hundreds of parameters. We describe the interface between the Java software that manages the retrieval and storage of the data for a given unit of work and the MATLAB algorithms that process these data. The data for each unit of work are packaged into a single file that contains everything needed by the science algorithms, allowing these files to be used to debug and evolve the algorithms offline. The challenge of transforming the over 100,000 individual FITS files received by the SOC every month (organized by time slice) into pixel time series suitable for storage in the custom Kepler File Store and processing by the various Kepler pipelines required several innovations, including the development of the LazyFITS library, which takes advantage of the homogeneous nature of the Kepler FITS files to process the large number of files in an efficient way. Finally, we describe how we created pipelines to automate generation of simulated data and to test the science pipelines.

7740-46, Session 10

Data validation in the Kepler Science Operations Center pipeline

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We present an overview of the Data Validation (DV) software component and its context within the Kepler Science Operations Center (SOC) pipeline and overall Kepler Science mission. The SOC pipeline performs a transiting planet search on the corrected light curves for over 150,000 targets across the focal plane array. We discuss the DV strategy for automated validation of Threshold Crossing Events (TCE's) generated in the transiting planet search. For each TCE, a transiting planet model is fit to the target light curve. A multiple planet search is conducted by repeating the transiting planet search on the residual light curve after the model flux has been removed; if an additional detection occurs, a planet model is fitted to the new TCE. A suite of automated tests are performed after all planet candidates have been identified. We describe a centroid motion test to determine the significance of the motion of the target photocenter during transit and to estimate the coordinates of the transit source within the photometric aperture; a series of eclipsing binary discrimination tests on the parameters of the planet model fits to all transits and the sequences of odd and even transits; and a statistical bootstrap to assess the likelihood that a TCE would have been generated purely by chance given the target light curve with all transits removed. We also briefly discuss planned DV enhancements.

7740-47, Session 11

Kepler Science Operations Center architecture

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We give an overview of the operational concepts and architecture for an element of the Kepler Ground Data System, the Science Operation Center (SOC). The department's charter is to analyze stellar photometric data from the Kepler spacecraft, and report results to the project for further analysis. We describe how this is accomplished via the science data pipeline, the hardware infrastructure, the scientific algorithms, and the operational procedures. The SOC consists of an office at Ames Research Center, with software development and operations

departments, plus a data center which hosts the many computers required for data analysis.

We discuss the high-performance, parallel computing software which performs transit photometry, pixel-level calibration, systematic error correction, attitude determination, stellar target management, and instrument characterization. We explain how data processing environments are divided to support operational processing and test needs. We explain the operational timelines for data processing, and the data constructs which flow into the SOC.

7740-48, Session 11

Semi-weekly monitoring of the performance and attitude of Kepler using a sparse set of targets

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To meet its goal of detecting Earth-size planets, the Kepler spacecraft is in a heliocentric Earth-trailing orbit, continuously observing ~170,000 select stars over a ~105 deg2 of sky using its photometer of 42 highly sensitive CCDs. The science data from these stars, consisting of ~6 million pixels at 30-minute intervals, is downlinked only every ~30 days to minimize interruptions to science data collection, using NASA's Deep Space Network via a high-rate Ka-band communications link. Additional low-rate X-band communications contacts are conducted with the spacecraft twice a week to downlink a small subset of the science data -- known as reference pixels -- in order to assess and monitor the performance of the photometer and the pointing stability of the spacecraft. Comprised of a sparse set of carefully chosen stars distributed over the entire focal plane, the reference pixels include stars, background, and so-called collateral data.

This paper describes the Photometer Data Quality (PDQ) pipeline software that calibrates the raw reference pixels, computes the centroids of the stars, and tracks and trends numerous performance metrics for each of the CCD modules; these metrics include black, smear, background, and brightness levels, encircled energy, platescale, row/column centroids, and the dynamic range of the onboard local detector electronics. In addition, PDQ also provides a high-fidelity calculation of spacecraft attitude to monitor pointing stability and, particularly after a quarterly roll, to produce a delta-quaternion for executing a small attitude tweak maneuver on-board for precise science target alignment.

7740-49, Session 11

Focal plane geometry characterization of the Kepler Mission

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The Kepler Mission focal plane contains 42 charge coupled device (CCD) photodetectors, with each CCD composed of 2.2 million square pixels 27 micrometers on a side arranged in 2,200 columns of 1,044 rows each. The science goals of the Kepler Mission require that the position of each CCD be determined with an accuracy of 0.1 pixels, corresponding to 2.7 micrometers or 0.4 seconds of arc, a level which is not achievable through pre-flight metrology. We describe a technique for determining the CCD positioning using images of the Kepler field of view (FOV) obtained in flight. The technique uses the fitted centroid row and column positions of 400 pre-selected stars on each CCD to obtain emprical polynomials which relate sky coordinates (Right Ascension and Declination) to chip coordinates (row and column). The polynomials are in turn evaluated to produce constraints for a nonlinear model fit which directly determines the model parameters which describe the location and orientation of each CCD. The focal plane geometry characterization algorithm is itself embedded in an iterative process which determines the focal plane geometry and the Pixel Response Function for each CCD in a self-consistent manner. In addition to the fully-automated calculation, a person-in-the-loop implementation was developed to allow an initial determination of the geometry in the event of large misalignments, achieving a much looser capture tolerance for more modest accuracy and reduced automation.

7740-50, Session 11

Selecting pixels for Kepler downlink

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The Kepler mission, designed to detect the transits of Earth-size planets around Sun-like stars, is monitoring more than 100,000 stellar targets in a 100-square-degree field of view using 42 2200 x 2048 pixel CCDs. Bandwidth constraints prevent the downlink of all 96 million pixels at the nominal 30-minute cadence, so the Kepler spacecraft downlinks a specified collection of pixels for each target object. These pixels are selected by considering the object brightness, background and the signal-to-noise of each pixel, and are optimized to maximize the signal-to-noise ratio of the target. The pixels associated with each object are assigned to a relatively small number of apertures stored on the spacecraft, and it is these apertures that are downlinked. This paper describes pixel selection, creation of a set of spacecraft apertures that efficiently captures selected pixels, and the assignment of an aperture to each target. Special cases such as diagnostic apertures, short-cadence targets and custom specified shapes are discussed in detail.

7740-51, Session 11

Kepler Mission's focal plane characterization models implementation

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The Kepler Mission photometer is an unusually complex array of CCDs. There are a large number of time-varying instrumental and systematic effects which must be modeled and removed from the Kepler pixel data to produce light curves of sufficiently high quality for the mission to be successful in its planet-finding objective. After the launch of the spacecraft, many of these effects are difficult to remeasure frequently, and various interpolations over a small number of sample measurements must be used to determine the correct value of a given effect at the necessary points in time. A library of software modules, called Focal Plane Characterization Models (FC) is the element of the SOC pipeline that handles this. FC or products generated by FC are used by nearly every element of the SOC processing chain. FC includes Java components: database persistence classes, operations classes, model classes, and data importers, and MATLAB code: model classes, interpolation methods, and wrapper functions. These classes, their interactions, and the database tables they represent, are discussed. This paper describes how these data and software work together to provide the SOC pipeline with the correct values to remove non-photometric effects caused by the photometer and its electronics on the Kepler lightcurves. The interpolation mathematics is discussed, as well as the special case of the sky-to-pixel/pixel-to-sky coordinate transformation code, which incorporates a compound model which is unique in the SOC software.

7740-52, Session 12

The application of cloud computing to the creation of image mosaics and management of their provenance

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Cloud computing offers many potential benefits to end-users, such as on-demand provisioning and usage-based pricing. Should cloud computing prove effective in astronomical computing and data storage, it may well enable the creation of many new data products from the vast quantities of public data. As recognized by a recent National Academies of Science (NAS) committee (*), these products should be accompanied by records of their provenance; that is, records of the data and processes used in the their creation. We have used the Montage image mosaic engine to investigate the computational, I/O and processing cost and performance of image processing on the Amazon EC2 cloud, and to inform the requirements that higher-level products impose on provenance management technologies. Comparison of the performance of Montage, an I/O intensive application, on Amazon EC2 and on the Abe High Performance Cluster (HPC) at NASA Ames shows that Abe provides better performance because it offers faster networks and parallel file systems. The performance on Amazon EC2 is certainly adequate, and storing the mosaic in the cloud can control transfer costs. We will present a detailed comparison of the performance of Montage on the cloud and on the HPC. Because Montage necessarily generates many intermediate products, we have used it to understand the science requirements that higher-level products impose on provenance management technologies. We describe experiments with provenance management technologies such as the “Provenance Aware Service Oriented Architecture” (PASOA).

(*) “Ensuring The Integrity, Accessibility, and Stewardship of Research Data in the Digital Age.” (2009)

7740-53, Session 12

EVALSO: a high-bandwidth communication infrastructure to efficiently connect the ESO Paranal and the Cerro Armazones Observatories to Europe

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Within the EC-FP7 initiative, the EVALSO (Enabling Virtual Access to Latin-America Southern Observatories) project aims to create a physical infrastructure (and the tools to exploit it) to efficiently connect the ESO Paranal and the Cerro Armazones Observatories to Europe.

This paper describes the technical choices and the solutions adopted to create high bandwidth (>1Gbps) communication links to both the ESO Paranal and the Cerro Armazones Observatories located in the Atacama desert, in the Northern region of Chile. Such infrastructure includes the construction of new fiber paths, the use of existing fibers/LAMBDA form the existing commercial provider, the interface to the academic networks, at both national and continental level, the needed equipment. The complete system is planned to be fully operational in place by mid-2010.

This paper will focus on the technical aspects related to the creation of the infrastructure, while the planned use (data transfer, etc) is covered on other papers.

The EVALSO project is a consortium of 9 members and co-founded by the EC (European Commission) within the frame of the FP7-INFRASTRUCTURES-2007-1.2-02. More on the project is available at www.evalso.eu.

7740-54, Session 12

File-storage cyberinfrastructure for large projects years before first-light

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Large ground-based and space-based telescopes are expected to make exciting discoveries in the upcoming decade. These large projects start years before first-light and continue to operate for many years. The file-storage cyberinfrastructure of large-scale projects has to evolve over a decade from a conceptual prototype before commissioning of the telescope to a highly flexible data distribution network, incorporating any new hardware components, software algorithms and new international partners of the project. We use two simple abstraction concepts, “logical data namespace” and “logical storage namespace” in the distributed file-storage architecture. Logical data namespace provides virtualization of data across distributed storage resources, including the ability to manage multiple physical replicas of the same file. Logical storage namespace provides storage virtualization at a very high level, allowing storage resource from any international partner to be used and to grow the data distribution across the world. These two simple concepts together create a logical data-storage namespace, which makes the project highly flexible for technology migration and updating the international data centers involved in the project. In addition to these direct benefits, the logical data storage namespace allows deployment of hierarchical data storage management policies such as mandatory project-wide policies and autonomous local policies at each international partner location. An architecture using these concepts is being prototyped for LSST, and will evolve during LSST’s lifetime. This effort was a finalist at the storage challenge in the Supercomputing Conference last year (SC08). We will provide technical details of this effort in the proposed talk/paper.

7740-55, Session 12

CANFAR: the Canadian advanced network for astronomical research

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The Canadian Advanced Network For Astronomical Research (CANFAR) is a 2½-year project that will deliver a network-enabled platform for the accessing, processing, storage, analysis, and distribution of very large astronomical datasets. The goal of CANFAR is to support collaboration and scientific discovery by members of major Canadian astronomical survey teams. CANFAR is currently working with six specific teams as prototypes to be used to develop the necessary services and infrastructure. Ultimately the system will become a community resource, supporting an even broader range of users in Canada and internationally.

The CANFAR infrastructure is being implemented as an International Virtual Observatory Alliance (IVOA) compliant web service infrastructure such that front-facing services will make use of IVOA protocols whenever possible. A challenging feature of the project is to channel all survey data through Canadian research cyberinfrastructure (components of CANARIE and Compute Canada). Sitting behind the portal service, the internal architecture makes use of high-speed networking, cloud computing, cloud storage, meta-scheduling, provisioning and virtualisation. The talk

will describe the context in which this project took shape, the high-level architecture of the infrastructure and current state of the project at its halfway point.

7740-56, Session 13

The Australian SKA Pathfinder (ASKAP) software architecture

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The Australian SKA Pathfinder (ASKAP) is a 1% Square Kilometre Array (SKA) pathfinder radio telescope, comprising of 36 12-metre diameter reflector antennas, each with a Focal Plane Array consisting of approximately 100 dual-polarised elements operating at centimetre wavelengths and yielding a wide field-of-view (FOV) on the sky of about 30 square degrees. ASKAP is currently under construction and will be located in the remote radio-quiet desert Midwest region of Western Australia. It is expected to be fully operational in 2013. Key challenges include near real-time processing of large amount of data (~ 5 GB/s), control and monitoring of widely distributed devices (approx. 150,000 monitoring I/O points) and remote semi-automated operations. After evaluating several software technologies we have decided to use the EPICS framework for the Telescope Operating System and the Internet Communications Engine (ICE) middleware for the high-level control message bus. This paper presents the overall ASKAP software architecture, as well as describing how EPICS and ICE technologies fit in the control software design.

7740-57, Session 13

The DECam data acquisition and control system

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The DES mountain top software is called the Survey Image System Process Integration (SISPI). Implemented as a distributed multi-processor system, SISPI consists of a set of processes that will coordinate and perform image acquisition and deliver images to the data management system for processing. Separate processes for instrument control, image building and analysis, image acquisition and observatory control are built on top of an infrastructure layer that provides message passing and communications. Additional system components include a flexible configuration system and the facility database. The command protocol is implemented in Python using a client-server design pattern derived from the SML and SCLN communications software developed at CTIO. A publish-subscribe model has been added to support the distribution of telemetry data and alarm messages. The design of the graphical user interfaces follows the Model-View-Controller approach to distinguish between the actual information and the graphical representation of the data.

We will discuss the software architecture of the DES readout and control system and report on the current status of the project. Particular emphasis will be given to the novel design features and our experience developing a large data acquisition system for an astronomical instrument.

7740-58, Session 13

ALMA software management and deployment

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The Atacama Large Millimeter/Submillimeter Array (ALMA) is the largest radio telescope currently under construction by a world-wide collaboration. The first antennas (the total will be 54x12m and 12x7m antennas) are being commissioned and a few are already installed as part of the ALMA interferometric array at a high site (5000m) in Chile. The ALMA Software (~ 80% completed) is in daily use at the ALMA Observatory and has been developed as an end-to-end system including proposal preparation, dynamic scheduling, instrument control, data handling and formatting, data archiving and retrieval, automatic and manual data processing, and support for observatory operations. Meanwhile development continues incrementally via new releases.

This presentation will expand on some software management aspects, procedures for releases, integrated system testing and deployment in Chile. Software development is based from the beginning on a common software infrastructure (ALMA Common Software - ACS) to achieve a homogeneous and maintainable overall system. End-to-end testing is done routinely on computer models during development and before new releases. With the availability of the first antennas at the high site interferometry with more than two antennas has been achieved. The availability of a two antenna test interferometer at the observatory site (3000m) will make future testing and validation easier, in parallel to ALMA commissioning and science verification (CSV) activities at the high site. The balance between incremental development and the stability of software is a challenge we have at the moment, while managing a large team distributed over four continents has been successfully achieved.

7740-59, Session 13

Discovery Channel Telescope software development overview

P. J. Lotz, Lowell Observatory (United States)

The Discovery Channel Telescope is a 4.2m astronomical research telescope being built in northern Arizona as a partnership between Discovery Communications and Lowell Observatory. We present an overview of the current status of the project software effort, including the iterative development process (including planning, requirements management and traceability, design, code, test, issue tracking, and version control), our experience with management and real-time and object-oriented design techniques and tools (including DOORS, Requirements Gateway, Enterprise Architect UML modeling tool, Enterprise Tester, JIRA) the team uses that support the effort, key features of the component-based architectural design, and implementation examples that leverage new LabVIEW-based technologies, including native LabVIEW objects and shared variable publish-subscribe communication incorporating datalogging and alarming.

7740-60, Session 13

An overview of the LSST data management system

J. P. Kantor, T. Axelrod, LSST Corp. (United States)

The LSST Data Management System (DMS) processes the incoming stream of images that the camera system generates to produce transient alerts and to archive the raw images, periodically creates new calibration data products that other processing functions will use, creates and archives an annual Data Release (a static self-consistent collection of data products generated from all survey data taken from the date of survey initiation to the cutoff date for the Data Release), and makes all LSST data available through an interface that uses community-based standards and facilitates user data analysis and production of user-defined data products with supercomputing-scale resources.

This paper discusses DMS distributed processing and data, and DMS architecture and design, with an emphasis on the particular technical challenges that must be met. The DMS publishes transient alerts in community-standard formats (e.g. VOEvent) within 60 seconds of detection. The DMS processes and archives over 50 petabytes of exposures (over the 10-year survey). Data Releases, include catalogs of tens of trillions of detected sources and tens of billions of astronomical objects, 2000-deep co-added exposures, and calibration products accurate to standards not achieved in wide-field survey instruments to date. These Data Releases grow in size to tens of petabytes over the survey period. The expected data access patterns drive the design of the database and data access services. Finally, the DMS permits interactive analysis and provides nightly summary statistics describing DMS output quality and performance.

7740-61, Session 13

LSST data challenges

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The LSST Data Management system will have to perform near-real-time calibration and analysis of acquired images, particularly for transient detection and alert generation; annual processing of the entire dataset for precision calibration, object detection and characterization, and catalog generation; and support of user data access and analysis. Images will be acquired at roughly a 17-second cadence, with alerts generated within one minute. The ten-year survey will result in tens of petabytes of image and catalog data and will require ~250 teraflops of processing to reduce.

The LSST project is carrying out a series of Data Challenges (DC) to refine the design, evaluate the scientific and computational performance of candidate algorithms, and address the challenging scaling issues that the LSST dataset will present. This paper discusses the progress of the DCs to date and plans for future DCs.

Algorithm development must address dual requirements for the efficient use of computational resources and the accurate, reliable processing of the deep and broad survey data. The DCs incorporate both existing astronomical images and image data resulting from detailed photon-level simulations. The data is used to ensure that the system can scale to the LSST field of view and 3.2 gigapixel camera scale and meet the scientific data quality requirements. Future DCs, carried out in conjunction with the LSST Science Collaborations, are planned to deliver data products verified by computer-aided analysis and actual applications as suitable for high-quality science.

Conference 7741: Millimeter, Submillimeter, and Far-Infrared Detectors and Instrumentation for Astronomy V

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Millimeter, Submillimeter, and Far-Infrared Detectors and Instrumentation for Astronomy V

7741-01, Session 1

CEA bolometer arrays: the first year in space

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The CEA/LETI and CEA/SAp started the development of far-infrared filled bolometer arrays for space applications over a decade ago. The unique design of these detectors makes possible the assembling of large focal planes comprising thousands of bolometers running at 300 mK with very low power dissipation.

Ten arrays of 16x16 pixels were thoroughly tested on the ground, and integrated in the Herschel/PACS instrument before launch in May 2009. These detectors have been successfully commissioned and are now operating in their nominal environment at the second Lagrangian point of the Earth-Sun system.

In this paper we briefly explain the functioning of CEA bolometer arrays, and we present the properties of the detectors focusing on their noise characteristics, the effect of cosmic rays on the signal, the repeatability of the measurements, and the stability of the system. We especially concentrate on the lessons we learnt after one year of operation in space, and we compare our findings with previous studies from ground-testing.

7741-02, Session 1

Performance of the Herschel/SPIRE bolometer arrays

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The SPIRE instrument (Spectral and Photometric Imaging Receiver) on the Herschel Space Observatory exemplifies the state-of-the-art in germanium semiconducting bolometric detectors. The bolometers (and readout circuitry) are among the best understood and well characterised of any sub-mm astronomy instrument to date. SPIRE contains five arrays of NTD (neutron transmutation doped) germanium spiderweb bolometers with up to 139 pixels per array. Repeated measurements in the years prior to launch have shown that their behaviour is extremely stable and can also be described extremely well by a simple physical model (the ideal bolometer model). Furthermore, and more importantly, the detectors meet the requirements for the mission.

Herschel was launched in May 2009 and the SPIRE detectors have performed excellently since then. Here we discuss in detail the on-orbit performance of the detectors.

7741-03, Session 1

Latest results from GISMO: a 2-mm bolometer camera for the IRAM 30-m Telescope

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In April 2010, we demonstrated for the third time our 2 mm bolometer camera GISMO (the Goddard IRAM Superconducting 2 Millimeter Observer) for astronomical 8observations at the IRAM 30 m Telescope. GISMO uses a monolithic 8 by 16 Backshort Under Grid (BUG) array with superconducting Transition Edge Sensors (TES). Illustrated by astronomical observations we obtained, we demonstrate the scientific potential of the camera, followed by a discussion of the achieved performance.

7741-04, Session 1

SCUBA-2: first results and on-sky performance

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SCUBA-2 is a 10,000 pixel camera operating at submillimeter wavelengths on the JCMT. This paper will give an update on the project including the first astronomical results. As of mid-Dec 2009 the instrument will be released to the community for the first time. The current on-sky performance will be presented highlighting the operational modes and array characteristics. An array upgrade (planned for March/April 2010) will allow the SCUBA-2 part of the JCMT Legacy Surveys to begin. These six surveys will cover aspects of astronomy ranging from the earliest galaxies, through star formation in our Galaxy to debris disks around the nearest stars.

7741-05, Session 1

Characterising the SCUBA-2 superconducting bolometer arrays

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SCUBA-2 is a state of the art 10,000 pixel submillimeter camera installed and being commissioned at the James Clerk Maxwell Telescope (JCMT) providing wide-field simultaneous imaging at wavelengths of 450 and 850 microns. At each wavelength there are four 32 by 40 sub-arrays of superconducting Transition Edge Sensor (TES) bolometers, each packaged with inline SQUID multiplexed readout and amplifier. In this paper we present the results of characterising individual 1280 bolometer science grade sub-arrays, both in a dedicated 50mk dilution refrigerator test facility and in the instrument installed at the JCMT.

7741-06, Session 1

Multiband millmeter-wave polarimetry with BICEP

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BICEP is a millimeter-wave bolometric polarimeter that observed from March 2006 to November 2008 at the geographic South Pole through atmospheric transmission windows at 100 GHz, 150 GHz, and 220 GHz. Approximately one-fifth of BICEP's observing time was dedicated to mapping and characterizing the Galaxy's emission on large scales. From these observations, high signal-to-noise temperature and polarization maps, within several degrees of the Galactic plane, have been produced. Instrument design, calibration, data filtering, statistical and systematic errors, and maps will be discussed.

7741-07, Session 2

Beginning of operation on APEX of the polarimeter for the Large APEX Bolometer Camera (LABOCA)

G. Siringo, European Southern Observatory (Chile)

An enhanced version of the "Polarimeter fuer bolometer Kameras" (PolKa) has been installed on the APEX telescope (Atacama Pathfinder EXperiment) in October 2009, to work in combination with LABOCA (the Large APEX Bolometer Camera).

This polarimeter was included in the design of LABOCA's optics from the beginning and it is now going through a commissioning phase.

Preliminary tests on sky have confirmed that the combination of PolKa, LABOCA and APEX provides unprecedented capabilities in mapping the polarization of the continuum emission at submillimeter wavelengths.

Beginning of science operations is planned for the second half of 2010.

7741-08, Session 2

MKID multicolor array status and results from DemoCam

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We present the results of the latest multicolor MKID focal plane arrays. The new detectors on the arrays are superconducting resonators with interdigitated capacitors (IDCs). To avoid out-of-band pickup by the capacitor, a stepped-impedance filter is used to prevent radiation from reaching the absorptive Aluminum section of the resonator. These arrays are tested in the preliminary demonstration instrument, DemoCam, a precursor to the Multicolor Submillimeter Inductance Camera (MuSIC). We present laboratory results of the responsivity to light and noise performance compared to resonators of the previous design on the same device. We assess the performance of the detectors in filtering out-of-band radiation, and find the level of excess load and its effect on detector performance. Finally, we look at the sensitivity performance at the Caltech Submillimeter Observatory, which will predict well the sensitivities expected by MuSIC.

7741-09, Session 3

Latest progress in developing large-format Ge arrays for far-IR astronomy

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Development of large format, far infrared focal-plane arrays has been identified as a pressing need for future astronomical instruments. In particular, array sizes as large as 128x128 with sensitivities better than 10E-18 W/√Hz are the goals to be achieved within the next ten years. Our initial effort produced a 2x16 Ge:Sb array with an NEP in the low 10E-18 W/√Hz range, rivaling the best far IR arrays currently available. Further work has resulted in design and fabrication of a low noise, 2-side buttable 32x32 (64x64 mosaic) CTIA readout, the first 1k-pixel Ge:Sb fully assembled FPA, a new hybrid design better suited for far IR arrays, and the preliminary design of a 2-side buttable 64x64 (128x128 mosaic)

readout. Our developmental work continues and we believe that NEP levels below 10E-18 W/√Hz are within reach. This paper presents an overview of our progress so far and outlines our road map for further work.

7741-10, Session 3

Development of a far-infrared Ge:Ga monolithic array for a possible application to SPICA

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We present the current status of the development of a far-infrared monolithic Ge:Ga photoconductor array proposed for the SAFARI instrument onboard SPICA, which is a future infrared space mission. SPICA has a large (3-m class) cooled (<6K) telescope, which enables us to make astronomical observations with high spatial resolution and unprecedented sensitivity in the mid- and far-infrared wavelength. As a candidate detector to cover the 50--110um bands of a far-infrared focal plan instrument of the SAFARI, we are developing a large format monolithic Ge:Ga array. The monolithic Ge:Ga array is directly connected to cryogenic readout electronics (CRE) using the Au-Indium bumping technology. Our goal is to develop a 64x64 Ge:Ga array, on the basis of existing technologies and experience in making the 3x20 Ge:Ga monolithic arrays for AKARI. In order to realize a larger format array with better sensitivity than that of the AKARI array, we have been making some technical improvements; (1) the optimization of the fabrication for the transparent electrode, (2) Anti-reflection coating to avoid the interference fringe between the Ge substrate, (3) Au-In bump technology to realize the large format array, (4) Use the low-noise cryogenic readout electronics with low power consumption for space application. Initial testing of the prototype 5x5 Ge:Ga arrays has shown that it works well as expected; the detector responsivity is ~10 A/W and the pixel-to-pixel variation is ~20% r.m.s.. We demonstrate experimentally the feasibility of these elemental technologies, and also show the results of performance measurements for the prototype Ge:Ga arrays.

7741-11, Session 3

Development of a large-scale stressed Ge:Ga detector array for SAFARI

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e report on the development of a large format stressed gallium doped germanium (Ge:Ge) array for the SAFARI instrument planned for the Japanese infrared satellite SPICA. Building on flight proven PACS heritage, the goal of our development is a 32 pixel stressed Ge:Ga module enabling a 32 x 32 pixel photoconductor array for the wavelength range between 110 and 210 microns. The unprecedented size of this array would allow the use of almost all of the 3.8 x 3.8 arcmin field of view provided for SAFARI in the SPICA focal plane. Our 32 pixel prototype module features three selectable read out architectures enabling the evaluation and optimization of the detector performance as well as a two stage multiplexer to distribute the dissipative heat load on the temperature levels provided by the satellite. Thermal modeling has shown that the heat loads are in compliance with the thermal budgets of the SPICA cryogenic system. The ultimate development goal with optimized read out circuits is an NEP of 10E-18 W/sqrt(Hz), which presents a factor of 8 improvement in the noise performance compared to the PACS stressed Ge:Ga array.

7741-12, Session 4

Status of the ArTeMiS camera to be installed on APEX

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The ArTeMiS submillimetric camera will observe simultaneously the sky at 450, 350 and 200 µm using 3 different focal planes made of 2304, 2304 and 1152 bolometric pixels respectively. This camera will be mounted in the Cassegrain cabin of APEX, a 12 m antenna located on the Chajnantor plateau, Chile.

To realize the bolometric arrays, we have adapted the Silicon processing technology used for the Herschel-PACS photometer to account for higher incident fluxes and longer wavelengths from the ground. In addition, an autonomous cryogenic system has been designed to cool the 3 focal planes down to 300 mK. Preliminary performances obtained in laboratory with the first of 3 focal planes will be presented.

Latest results obtained in 2009 with the P-ArTeMiS prototype camera will also be discussed, including massive protostellar cores and several star forming regions that have been clearly identified and mapped.

7741-13, Session 4

The balloon-borne large-aperture submillimeter telescope and polarimeter: BLAST-pol

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The Balloon-borne Large Aperture Submillimeter Telescope and Polarimeter (BLAST-pol) is a suborbital mapping experiment designed to

study the role played by magnetic fields in the star formation process. BLAST-pol is the reconstructed BLAST telescope, with added sensitivity to linear polarization. Using a 1.8m Cassegrain telescope, BLAST-pol images the sky onto a focal plane that consists of 270 bolometric detectors in three arrays, observing simultaneously at 250, 350, and 500 µm. The diffraction-limited optical system provides a resolution of 30” at 250 µm. The polarimeter consists of photolithographic polarizing grids mounted in front of each bolometer/detector array. A rotating 4 K achromatic half-wave plate provides additional polarization modulation. With its unprecedented mapping speed and resolution, BLAST-pol will produce three-color polarization maps for a large number of molecular clouds. The instrument provides a much needed bridge in spatial coverage between larger-scale, coarse resolution surveys and narrow field of view, high resolution observations of substructure within molecular cloud cores. Our first science flight will be from McMurdo Station, Antarctica in December 2010.

7741-14, Session 4

A next-generation bolometer camera for the Green Bank Telescope

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With an 8” FWHM beam and a surface RMS across the primary mirror better than 250um, the 100m diameter Green Bank Telescope (GBT) is the most sensitive single dish telescope operating at 90 GHz. Currently its only 90 GHz instrument is MUSTANG, a 64 element array of TES bolometers. Regular proposals for the use of MUSTANG have been accepted from the scientific community and over 100 hours of observing time has been scheduled in the last year. The combination of MUSTANG and the GBT has produced great results including the highest resolution map of the Sunyaev-Zel’dovich effect made to date. However more remains to be done. In this presentation we will outline a development path based on MUSTANG’s successes which will result in more than an order of magnitude increase in the GBT’s 90 GHz sensitivity.

7741-15, Session 4

MUSIC for sub/millimeter astrophysics

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MUSIC (the Multiwavelength Submillimeter kinetic Inductance Camera, formerly known as the MKID Camera) is an instrument being developed for the Caltech Submillimeter Observatory as a collaborative effort of Caltech, JPL, the University of Colorado, and UC Santa Barbara. MUSIC uses microwave kinetic inductance detectors (MKIDs) as photon detectors. MKIDs are superconducting micro-resonators fabricated from thin aluminum and niobium films. We measure the change in the surface impedance of antenna-coupled MKIDs produced by photon-induced breaking of Cooper pairs. The bandpasses are defined using superconducting, lumped-element on-chip filters. The readout is almost entirely at room temperature and is highly multiplexed; tiles of 288 resonators are read out concurrently on a single feedline, requiring only 1 cryogenic HEMT amplifier and a pair of coaxial cables for each tile. MUSIC will have 576 spatial pixels that image simultaneously in four bands at 850, 1100, 1300 and 2000 microns. The bandpasses have been chosen to be well-matched to the atmospheric transmission windows; performance at or near BLIP is anticipated. MUSIC is scheduled for deployment at the Caltech Submillimeter Observatory in the fall of 2010. We will present an overview of the camera design and readout and describe the current status of testing and fabrication.

7741-16, Session 4

BASIC: a high-sensitivity all silicon bolometer focal plane for the SAFARI instrument aboard the SPICA Observatory

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The 6 K cooled primary mirror of the SPICA observatory, to be launched in 2017, allows an imaging photometry gain in sensitivity in the far infrared of two orders of magnitude when compared with current instrumentation in space. All the proposed detector solutions will have to deploy radically different solutions from previous developments to cope with the extremely low background and very low power budgets available at the lowest temperature stages. We present the current design of very large “all Silicon” filled Bolometer Arrays cooled below 100 mK, and the solutions we develop for the BASIC (Bolometer Arrays for the All Silicon SAFARI Imaging Camera) focal planes of SAFARI. They will cover simultaneously three wavelength bands between 30 and 210 µm. Prototype Array measurements are presented here.

7741-17, Session 5

Antenna-coupled TES bolometer arrays for BICEP2/Keck and SPIDER

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The Cosmic Microwave Background experiments BICEP2/Keck and SPIDER will be using planar arrays of polarization sensitive antenna-coupled TES bolometers, operating at frequencies between 96GHz and 220GHz.

At 145GHz each array consists of 64 polarimeters (128 TES sensors) and four of these arrays are assembled together to make a focal plane. The detector arrays are integrated with a time-domain SQUID multiplexer developed at NIST and read out using the Multi-Channel Electronics (MCE) developed at University of British Columbia.

At the LTD13 conference we reported on our progress in characterizing focal plane arrays using the time-domain SQUID multiplexed readout and improving detector parameters uniformity across the arrays. Since then our main effort has focused on improving detector arrays optical performances and noise performances in order to achieve science target sensitivities and produce science grade focal planes.

The main problems we have been trying to solve are:

1) direct coupling of out-of-band radiation to the TES island;

2) reduction of detectors aliased noise in our science band.

We report on changes in detector design implemented to optimize optical performances and noise performances and following focal plane arrays test results. BICEP2 has deployed a first 145GHz science grade focal plane to the South Pole in December 2009.

7741-18, Session 5

Feedhorn-coupled TES polarimeters for next-generation CMB instruments

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The next generation of cosmic microwave background (CMB) polarization experiments targeting the signatures of inflation will require orders-of-magnitude greater sensitivities in addition to careful control of systematics. With existing detector technologies approaching the photon noise limit, improvements in system sensitivities must come from ever-larger focal plane arrays of millimeter-wave detectors. We report on the design and performance of microfabricated planar orthomode transducer (OMT) coupled TES polarimeters and silicon micromachined platelet feedhorns for 150 GHz operation. We have achieved accurate spectral band definition using planar microstrip filters, dark detector noise consistent with phonon contribution, and end-to-end optical efficiencies of 60-70%. Individual pixel polarimeters will be deployed in ABS, and monolithic arrays under development are targeted for deployment in ACTpol and SPTpol.

7741-19, Session 5

Dual-polarized-multifrequency-channel-antenna-coupled TES bolometers for the Polarbear CMB experiment

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We have designed a new antenna-coupled TES bolometer architecture based around the sinuous antenna that is both dual polarized and sufficiently broad-band to support multiple frequency channels. We will show optical data from prototype sinuous pixels that have two and three channels per polarization that demonstrate high optical throughput, gaussian beam shapes with high gain, and strong cross-pol rejection. We will also report on a trial run of a single pixel in the PolarBear telescope in Cedar Flats that used only the 150GHz channel of a sinuous coupled detector. The Polarbear2 camera will have a focal plane of detectors with 90 and 150GHz channels on each polarization within each detector. This design will boost the telescope's mapping speed over what it currently has with single color detectors.

7741-20, Session 5

Background-limited transition-edge sensors for far-IR/sub-mm spaceborne spectroscopy

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We have used advanced surface and bulk micromachining techniques to build membrane-isolated transition-edge sensor (TES) arrays suitable for far-IR/submm spectroscopy from space. Each TES consists of a metallized SiN absorber, a Mo/Au bilayer thermistor, and four SiN support beams. The support beams have dimensions of 1mm long by 0.4um wide by 0.25 thick to make the thermal conductance of the TES very low. By tuning the transition temperature of the Mo/Au bilayer below 100mK, the effective noise equivalent power (NEP)of our TESs is below 1x10^-19 W/Hz^1/2, making them sensitive enough for future astrophysics missions including the Background-Limited far-IR/Submm Spectrograph (BLISS).

7741-21, Session 5

Low-noise transition edge sensor (TES) for SAFARI instrument on SPICA

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Transition edge sensor (TES) is one of the detector options for SAFARI FIR Imaging Spectrometer (wavelength 30-210 um) on the SPICA telescope. Since the telescope is cooled down to below 7 K, the instrument sensitivity is limited by the detector noise. Therefore the required NEP is 2E-19 W/Hz^0.5 at base temperature of >50 mK.

We develop TiAu TES bolometers on a Si3N4 membrane, where narrow, 1 um thick Si3N4 membrane legs act as thermal links between TES and the bath. We discuss two type of devices:

The first one with a Tc of 110 mK has 4 long (1.8 mm) straight supporting legs. The thermal conductance (G) is measured 3.2E-13 W/K. The electrical NEP is about 3E-19 W/Hz^0.5 based on the measured G, taking only the phonon noise into account.

The second type of device with a Tc of 155 mK has a spider-web like Si3N4 supporting structure. This novel design allows for a very low G but keeps detector size smaller, as required for the focal plane array for SAFARI. The Measured G is 2E-12 W/K, and the NEP based on phonon noise is 1E-18 W/Hz^0.5.

TES arrays of 5x5 pixels based on both designs have been fabricated. The variation of Tc within an array is less than 3%, indicating a good uniformity.

We will present the device design and the outcome of latest dark tests, including IVs, noise, complex impedance data, and analysis.

7741-22, Session 6

A review of the lumped element kinetic inductance detector

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The Lumped Element Kinetic Inductance Detector (LEKID) was first proposed in 2007 as a solution for using kinetic inductance type detectors for sub-mm astronomy (450 - 200um). Since then the LEKID has shown its potential across a much wider band. Examples of this have been 200um detection of a cold blackbody and successful testing of a demonstration array operating at 2mm on the IRAM telescope in October 2009. Due to its combined absorbing and detecting elements the LEKID is an extremely simple detector to fabricate requiring only one deposition and etch step to produce an array of up to 1000 pixels being multiplexed onto a single feedline. The LEKID is also a very compact detector making it ideal for producing arrays with high filling factors. The suitability of the LEKID for use in large arrays has prompted a return visit to the IRAM telescope with a dual band instrument in the spring of 2010. This presentation will review the progress to date of the LEKID's development and outline design considerations for producing large arrays of LEKIDs for future astronomical experiments. Also reviewed will be possible applications for the LEKID outside sub-mm and mm astronomy.

7741-23, Session 6

Characterization of lumped element kinetic inductance detectors for mm-wave detection

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Lumped-element kinetic inductance detectors (LEKIDs) have recently shown considerable promise as direct-absorption mm-wavelength detectors for astronomical applications. One major research thrust within the Néel Iram Kids Array (NIKA) collaboration has been to investigate the suitability of these detectors for deployment at the 30-meter IRAM telescope located on Pico Veleta in Spain.

Compared to MKIDs, using quarter wavelength resonators, the resonant circuit of a LEKID consists of a discrete inductance and capacitance coupled to a feedline. A very high and constant current density distribution in the inductive part of these resonators makes them very sensitive [1]. Due to only one metal layer on a silicon substrate, the fabrication is relatively easy.

In order to optimize the LEKIDs for this application, we have recently probed a wide variety of individual resonator and array parameters through simulation and physical testing. This included determining the optimal feed-line coupling, pixel geometry, resonator distribution within an array (in order to minimize pixel cross-talk), and resonator frequency spacing. Based on these results, a several Aluminum arrays were fabricated and tested in a dilution fridge with optical access.

7741-24, Session 6

Advanced resonator designs for far-infrared astrophysics with MKIDs

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We have investigated detector designs suitable for direct absorption of far-infrared photons using Microwave Kinetic Inductance Detector (MKID) technology. MKIDs are superconducting thin-film microresonators that respond to light when photons break Cooper pairs inside the film and change its surface inductance and resistance, which results in a frequency and dissipation signal. The lumped-element resonators are made from a superconducting layer of TiNx on a silicon substrate fabricated at JPL. The Tc of the TiNx layer can be tuned in the range of 0-4.5 K by varying its stoichiometry, and the material exhibits very high surface inductance and very low microwave loss. The resonators use interdigitated capacitors (IDCs) or crystalline-silicon parallel-plate capacitors, which allow significant reduction or near elimination of two-level system (TLS) noise in each case respectively. The predicted NEPs of these devices is ~ 10^(-20) W/sqrt(Hz), suitable for spectroscopy with highly multiplexed arrays in space. We will present resonator design details and challenges like microwave inter-resonator coupling in highly packed arrays, and measurement results including dark and optical responsivity, noise performance, quasi-particle lifetimes, and very impressive resonator internal quality factors as high as Qi ~ 30x10^6.

7741-25, Session 6

Fabrication of an absorber-coupled MKID detector and readout for sub-millimeter and far-infrared astronomy

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We have fabricated absorber-coupled microwave kinetic inductance detector (MKID) arrays for sub-millimeter and far-infrared astronomy. Each detector array is comprised of /2 stepped impedance resonators, a 1.5μm thick silicon membrane, and 380μm thick silicon walls. The resonators consist of parallel plate aluminum transmission lines capacitively coupled to low impedance Nb microstrip traces of variable length, which set the resonant frequency of each resonator. This allows for multiplexed microwave readout and, consequently, good spatial discrimination between pixels in the array. The Al transmission lines simultaneously act to absorb optical power and are designed to have a surface impedance and filling fraction so as to match the impedance of free space. Here we discuss some novel techniques that were employed to fabricate MKID arrays upon large silicon membranes, in which the circuit is built on both sides of the single crystal silicon membranes using single crystal silicon as the dielectric and the silicon walls form a structural frame to support the thin membranes as well as the resonators.

7741-26, Session 6

Optimization of MKID noise performance via readout technique for astronomical applications

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Detectors employing superconducting microresonators (MKIDs) can be read out by measuring changes in either the resonator frequency or dissipation. We will discuss the pros and cons of both methods, in particular, the readout method strategies being explored for the Multiwavelength Sub/millimeter Inductance Camera (MuSIC). As predicted theoretically and observed experimentally, the frequency responsivity is larger than the dissipation responsivity, by a factor of 2-4 under typical conditions. Thus, it should be easier to overcome amplifier noise using frequency readout. However, the resonators exhibit excess frequency noise that has been ascribed to a surface distribution of two-level fluctuators and is sensitive to specific device geometries and fabrication techniques. Impressive dark noise performance has been achieved using modified resonator geometries employing interdigitated capacitors (IDCs), but recent optical measurements suggest broadband low-level sub/millimeter pickup by the IDCs. While reverting to standard resonator geometries and using dissipation readout would avoid these complications, model predictions indicate that the resulting amplifier-limited NEP would be at least a factor of 2 above BLIP. To date, our noise measurement and modeling efforts have assumed an on-resonance readout, with the carrier power set well below the nonlinear regime. Several experimental indicators suggested to us that the optimal readout technique may in fact require a higher readout power, with the carrier tuned somewhat off resonance, and that a careful systematic study of the optimal readout conditions was needed. We will present the results of such a study, and discuss the optimum readout conditions that can be achieved relative to BLIP.

7741-27, Session 7

Efficient optical modeling for far-infrared astronomical instrumentation

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Efficient optical modelling in the far infrared is challenging because of the dominance of diffraction effects in typical astronomical instruments. With the development of the next generation of array imagers and multi-moded feed systems the necessity for computationally efficiency has become critical to ensure an optimised design, comprehensive system and telescope analysis and image deconvolution. A multi-technique capability is necessary to simulate both efficiently and accurately the propagation of the signal collected by the telescope through the quasi-optical beam guide and feed structures using an appropriate combination of modelling tools, seamlessly passing from one regime to the next from detector to sky. Physical optics for example, although computationally intensive, is useful tool when detailed telescope beam analysis is required, particularly for providing cross polarisation information. Modal analysis is often appropriate for modelling beam guide structures while analysing the detector feed coupling may rely on a more complete electromagnetic analysis because of the small sizes involved and the use of waveguide and planar structures. Image recovery ideally requires a decovolution technique based on a modal approach and precise knowledge of the beams on the sky. In this paper we report on our work on the continued development of such appropriate techniques with the particular goal of prototyping powerful efficient computational tools for imaging arrays and partially coherent systems. In the presentation, we will discuss these issues and present examples from real instrumentation.

7741-28, Session 7

Anti-reflection coating of large-format lenses for sub-mm applications

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Small anti-reflection-coated plastic lenses have been produced and qualified for flight on board Herschel-SPIRE and Planck-HFI. We have now developed and extended the applicability this coating technique to much larger lenses, with very high degrees of curvature. This coating technology is suitable for applications in the frequency range 60GHz to around 10THz, and we are currently working on extending this frequency range.

We have just delivered coated lenses for the Polarbear and EBEX CMB experiments. These lenses have diameters up to 380mm, and in some cases are very highly curved. The coating has been successfully applied to all lenses, including concave surfaces and meniscus lenses. Coatings can be varied to optimise pass-band characteristics, and may be asymmetric (different coating thickness to each lens surface) to maximise the width of the optimal transmission band.

We present details of the coating technique, spectroscopic test results from samples, and comparisons with theoretical predictions.

This is a crucial technology development area for future CMB polarization experiments, where refractive telescopes will be necessary for the control of systematics and minimization of instrumental polarization effects. We discuss the technology readiness level of this technology, and the technology roadmap for incorporation in a future satellite mission such as B-Pol.

7741-29, Session 7

Corrugated feed horn arrays in silicon

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Next generation cosmic microwave background (CMB) polarization anisotropy measurements will feature millimeter-wave focal-plane array detectors with thousands of pixels. At present, efficient polarization-maintaining, free-space coupling to individual pixels using metal-platelet corrugated feedhorns is routine. We exploit the availability of high resolution photolithography and wafer-scale etch tools to build monolithic arrays of corrugated platelet feed horns made with Silicon. The thermal expansion of Si horn arrays is conveniently matched to Si detectors. In circular, corrugated waveguide structures we observe 0.15 dB/cm loss from 80 to 110 GHz at room temperature. Preliminary measurements of a single corrugated Si horn from 140 to 200 GHz shows performance equivalent to electroformed horns: low insertion loss (<1 dB), wide bandwidth (~40%), minimal side lobes (<-30 dB) and low cross-correlation (<-20 dB). We present progress on a prototype 75 mm diameter horn array. We aspire to build devices with >1000 horns using 150 mm diameter Si wafers and expect that our techniques could be applied to fabricate horn arrays at frequencies up to 1 THz.

7741-30, Session 7

Submillimeter pupil plane wavefront sensing

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The goal of high aperture efficiencies at frequencies up to 1 THz for a telescope as large as the CCAT's design diameter of 25 m calls for a re-examination of potentially applicable wavefront sensing techniques. In particular, the availability of large-format submm detector arrays suggests that appropriate variants of optical pupil-plane wavefront sensing techniques can now be profitably applied to the submm. Here we examine the performance of a particularly simple common-path pupil-plane interferometric wavefront sensor, a scanning version of the Zernicke/Dicke phase contrast interferometer, which should be able to reach theoretical performance limits.

7741-31, Session 7

Optical performance of the BICEP2 Telescope at the South Pole

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BICEP2 deployed to the South Pole during the 2009-2010 austral summer, and is now mapping the polarization of the Cosmic Microwave Background (CMB), searching for evidence of inflationary cosmology. BICEP2 belongs to a new class of telescopes including Keck (ground-based) and Spider (balloon-borne) that follow on BICEPs strategy of employing small, cold, on-axis refracting optics. This design provides key advantages for BICEP2, ideal for targeting the polarization signature from Inflation, including: (i) A large field of view, allowing substantial light collecting power despite the small aperture, while still resolving the degree-scale polarization of the CMB, (ii) liquid helium-cooled optics and cold stop, allowing for low, stable instrument loading, (iii) the ability to rotate the entire telescope about the boresight, (iv) a baffled primary aperture, reducing sidelobe pickup, and (v) the ability to characterize the optical performance of the telescope from the ground. We describe the last of these advantages in detail, including our efforts to measure the main beam shape, beam-match between orthogonally-polarized pairs, polarization efficiency and response angle, sidelobe pickup, and ghost imaging. We do so with ground-based polarized microwave sources mounted in the far field as well as with astronomical calibrators. Ultimately, BICEP2's sensitivity to CMB polarization from inflation will rely on precise calibration of these beam features.

7741-32, Session 7

Optics for MUSIC: a new (sub)millimeter camera for the Caltech Submillimeter Observatory

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We will present the design and implementation, along with calculations and some measurements of the performance, of the room-temperature and cryogenic optics for MUSIC, a new (sub)millimeter camera for the Caltech Submm Observatory (CSO) scheduled to be deployed in late 2010. The design consists of two focusing elements in addition to the CSO primary and secondary mirrors: a warm off-axis elliptical mirror and a cryogenic (4K) lens. These optics will provide a 14 arcmin field of view that is diffraction limited in all four of the MUSIC observing bands (0.85, 1.0, 1.3, and 2.0 mm). A series of dielectric and metal-mesh low pass filters have been implemented to reduce the optical power load on the MUSIC cryogenic stages to a quasi-negligible level while maintaining good transmission in-band. A cold (4K) Lyot stop will be used to define the primary mirror illumination, which will be maximized while keeping spillover at the sub 1% level. The MUSIC focal plane will be populated with broadband phased antenna arrays that efficiently couple to a factor of ~3 in fractional bandwidth, and each pixel on the focal plane will be read out using a set of four lumped element filters that define the MUSIC observing bands (i.e., each pixel on the focal plane simultaneously observes in four different bands).

7741-68, Poster Session

A new generation of receivers on the Atacama Pathfinder EXperiment (APEX)

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The Atacama Pathfinder EXperiment is the most powerful radio telescope for millimeter and submillimeter astronomy in the Southern Hemisphere. The great value of this facility is due to the combination of several factors as the location on the 5100 m high Chajnantor plateau, the good surface accuracy over the large 12 meter diameter but also the suite of state-of-the-art receivers commissioned during the last few years: the two bolometer cameras LABOCA (Large APEX Bolometer Camera) and SABOCA (Submillimeter Bolometer Camera) for observations of the continuum emission at 345 and 850 GHz, the two CHAMP+ (the Carbon Heterodyne Array of the MPIfR) arrays of 7 heterodyne receivers at 660 and 860 GHz and the SHFI (Swedish Heterodyne Facility Instrument) single-beam spectrometers at 230, 345, 460 and 1300 GHz.

Starting from 2010, APEX will be upgraded with new receivers. LABOCA will be replaced by LABOCA-2, having the same field of view and operation frequency of LABOCA but using superconducting technology (TES bolometers, SQUIDs readout) and a dry, close-cycle cryostat, with improved sensitivity and operability. SABOCA will be replaced by SABOCA+, a 1000+ beams array for the same 850 GHz atmospheric window of SABOCA, also operated on a close-cycle cryostat for improved operability. Additionally, new frequency bands (660 GHz and 1.5 THz) will be available for mapping of the continuum when the new Artemis receiver will be installed.

7741-69, Poster Session

Extinction correction and on-sky calibration of SCUBA-2

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Commissioning of SCUBA-2 included a program of skydips and observations of calibration sources intended to be folded into regular observing as standard methods of source flux calibration and to monitor the atmospheric opacity and stability. During commissioning, it was found that these methods could also be utilised to characterise the fundamental instrument response to sky noise and astronomical signals. Novel techniques for analysing on-sky performance and atmospheric conditions are presented, along with results from the calibration observations and skydips.

7741-70, Poster Session

Development of compact far-infrared array sensor with high efficiency

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We have developed a far-infrared array sensor for astronomical observation with high efficiency and compactness, and have applied to the main sensor of a balloon-borne telescope, FITE (Far-Infrared

Interferometric Telescope Experiment). The array sensor is a stressed Ge:Ga photoconductor, and it covers the wavelength range of 100 - 200 micrometer. By optimizing the cavity and beam collector with electromagnetic wave analysis, the efficiency has been significantly improved by reducing the cavity size. We have found the previous design of the cavities. e. g., the AKARI LW array, the Spitzer MIPS 160 array, etc. We found the smaller cavity is generally better; the efficiency can be improved significantly from the previous designs. We also developed a compact stressing mechanism so as to realize a compact two dimensional array. The pixel pitch can be reduced to be only 1.5 mm in both directions of the focal plane, which allows us to reduce the size of the camera optics as well as the total volume and weight of space-borne instrument. The measured responsivity of the developed array is more than 100 A/W at 150 micrometer. The format of the present work is one-dimensional array of 15 pixels so as to optimize it for FITE, and it can be stacked in the other direction to be a two-dimensional array.

7741-71, Poster Session

Far-infrared extended blocked impurity band (FIREBIB) detectors

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A variant of conventional arsenic doped silicon (Si:As) blocked impurity band (BIB) detector technology has been demonstrated to extend cutoff wavelength to at least 50 µm, almost double its nominal cut-off wavelength. Further wavelength extension to at least 100 µm is anticipated. This Far-Infrared Extended BIB (FIREBIB) innovation was motivated by the need for high detectivity, highly stable detection systems for characterization and monitoring of the Earth's emission spectrum from orbit. The Climate Absolute Radiance and Refractivity Observatory (CLARREO) currently being developed by NASA may need such high performance detectors in its Far-IR Fourier Transform Spectrometer system to meet stringent measurement accuracies. Because FIREBIB detectors are derived from the same Si:As BIB that currently provides megapixel format arrays for space, airborne, and ground-based applications, it will be a small step to similar FPA formats for Far-IR astronomy applications. This paper reports the progress of the FIREBIB detector/FPA development efforts.

7741-72, Poster Session

Development of superconducting transition edge sensors based on electron-phonon decoupling

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We have successfully fabricated the superconducting transition edge sensor (TES), bolometer technology that centers on the use of electron-phonon decoupling (EPD) to thermally isolate the bolometer. Along with material characterization for large format antenna coupled bolometer arrays, we will present the initial test results of bolometer based on EPD designed for THz detection. We have selected a design approach that separates the two functions of photon absorption and temperature measurement, allowing separate optimization of the performance of each element. We have integrated Molybdenum/Gold (Mo/Au) bilayer TES and ion assisted thermally evaporated (IAE) Bismuth (Bi) films as radiation absorber coupled to a low-loss microstripline from Niobium (Nb) ground plane to a twin-slot antenna structure. The thermal conductance and the time constant of these devices have been measured, and are consistent with our calculations. The device exhibits a single time constant at 0.1 K of ~160 µs, which is compatible with readout by a high-bandwidth single SQUID or a time domain SQUID multiplexer. The effects of thermal conductance and electrothermal feedback are major determinants of the time constant, but the electronic heat capacity also plays a major role. The NEP achieved in the device described above is 2.5×10-17 W/√Hz. Our plan is to demonstrate a reduction of the volume in the superconducting element to 5 µm × 5 µm in films of half the thickness at Te=60mK. By calculation, this new geometry corresponds to an NEP reduction of two orders of magnitude to 2.5×10-19 W/√Hz, with a time constant of ~130µs.

7741-73, Poster Session

Characterizing SixNy absorbers and support beams for far-IR/sub-mm transition-edge sensor bolometers

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We report on the characterization of SixNy optical absorbers and support beams for transition-edge sensor (TES) bolometers that are suitable to meet ultra-sensitive noise equivalent power (NEP≤10-19W/√Hz) and effective response time ( ) requirements (≤150ms) for space-borne far-IR/sub-mm spectrometers, such as the BLISS and SAFARI instruments for SPICA. The thermal response time (0) of an absorber suspended by support beams from a low-temperature substrate depends on the heat capacity (C) of the absorber and the thermal conductance (G) of the support beams (0=C/G). The effective response time, , may be a factor of 100 smaller than 0 for voltage-biased TESs. To guarantee that our fabricated SixNy absorbers and support beams meet the specifications for ultra-sensitive space-borne spectrometers, we measured G and 0 for two architectures under different fabrication processes: (1) a solid membrane SixNy absorber suspended by thin and long SixNy support beams and (2) a wire-mesh SixNy absorber suspended by long, and even thinner, SixNy support beams. The first architecture is suitable for a spectrometer such as SAFARI, with G~100fW/K, 0~10ms, and expected NEP~10-19W/√Hz at 50mK. The second architecture is appropriate for BLISS, with G~10fW/K, 0~180ms, and expected NEP<10-19W/√Hz at 50mK. The heat capacity may be reduced to the order of 1fJ/K at 50mK. However, C may be 5-10 times larger for different fabrication processes, and we discuss this finding in more detail.

7741-74, Poster Session

Optical and polarization efficiencies of feedhorn-coupled TES polarimeters for next-generation CMB instruments

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The next generation of Cosmic Microwave Background (CMB) experiments probing for signals of inflation and small angular scale polarization anisotropies require higher sensitivity and better control of systematics. We are developing monolithic arrays of orthomode transducer (OMT) coupled TES polarimeters designed for operation at 150 GHz to address these requirements. OMT coupling allows for simultaneous and independent detection of two orthogonal linear polarization states incident on a single pixel. We present measurements of optical and polarization efficiencies of single pixels and of a ten-pixel test array. Single pixels exhibit 55% optical efficiency and polarization efficiencies greater than 90% (cross-polar leakage less than 5%). These monolithic polarimeter arrays still under development are slated for use in the ACTpol and SPTpol experiments, while single-pixel polarimeters are to be deployed in ABS.

7741-75, Poster Session

Component development for ALMA Band 1 (31-45 GHz)

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ALMA Band 1, covering 31-45 GHz, is the lowest signal frequency band of the ALMA telescope and development of the technology to be used for the front-end cartridge is currently in a research phase. We have made progress on various key components designed for use in the ALMA Band 1 cartridge, including the orthomode transducer (OMT), low-noise amplifier (LNA), lens, and down-converting mixer. Since the layout of the ALMA cartridges within the antenna is not optimised for the lowest band, a dielectric lens is required to avoid blocking other bands. Using a lens necessitates careful characterization of the dielectric properties controlling focal length and dielectric loss. It is also important to match the index of refraction of the lens to minimize reflection while still providing equal performance for both linear polarizations and not introducing any cross-polarization effects. Different anti-reflection techniques will be shown; for example, a hole array, as an anti-reflection layer, has been used for a vacuum window and measured results are compared with simulation. A test cryostat has been constructed by adding an extension to a commercial liquid helium cryostat. Initial sensitivity measurements of a simplified prototype receiver will be given, incorporating an HDPE window, commercial conical feedhorn, 3-stage LNA, and warm amplification stage. An overview of the system losses, receiver noise budget, and system alignment tolerances will also be shown. Furthermore, there is interest in either extending or shifting the existing frequency towards 50 GHz, and the impact on each component will be considered.

7741-76, Poster Session

A compact L-band ortho mode transducer

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We describe the design, construction and performance of a compact, wideband, Ortho Mode Transducer for the L-P dual-band receiver of the new 64 meter SRT (Sardinia Radio Telescope), which is being built in Sardinia, Italy. The OMT consists of four probes arranged in symmetrical configuration across a 172 mm diameter circular waveguide. A shaped tuning stub with cylindrical profile is placed a quarter wavelength away from the probes to guarantee broadband operation with low reflection coefficient across the frequency band 1300-1800 MHz (L-band). The device separates the two linear polarizations associated with the TE11 modes propagating in circular waveguide and couple them, through the probes, to coaxial outputs. The four identical probes have a cylindrical structure, each consisting of three concentric cylinders that attach to the central pin of standard 7/16 connectors.

The OMT is placed in a cryogenic environment inside a Dewar and is cooled at 80 K. The L-band feed, located outside the Dewar, couples directly into the cryogenic Dewar interface through a circular waveguide vacuum window with diameter 190 mm. The window is connected to the OMT circular waveguide input through a conical transition (length 85 mm) filled with a styrodur foam that provides mechanical support for a 0.125 mm thick Mylar vacuum barrier.

The geometry of the OMT was optimized with a commercial electromagnetic simulator, and provides return losses larger than 25 dB across the full band.

7741-77, Poster Session

Selective spectral detection of continuum terahertz radiation

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The knowledge of THz continuum spectra is essential to investigate the emission mechanisms by high energy particle acceleration processes. Technical challenges appear for obtaining selective spectral sensing in the far infrared range to diagnose radiation produced by solar flare burst emissions measured from space as well as radiation produced by high energy electrons in laboratory accelerators. Efforts are been carried out intended for the development of solar flare high cadence radiometers at two THz frequencies to operate outside the terrestrial atmosphere (i.e. at 3 and 7 THz). One essential requirement is the efficient suppression of radiation in the visible and near infrared. Experimental setups have been assembled for testing (a) THz transmission of “low-pass” filters: rough surface mirrors; membranes Zitex G110G and TydexBlack; (b) radiation response from distinct detectors: adapted commercial microbolometer array using HRFZ-Si window, pyroelectric module and Golay cell; (c) a fabricated 2.4 THz resonant grid band-pass filter transmission response for polarization and angle of incidence. Qualitative detection of solar radiation at a sub-THz frequency has been tested with a microbolometer array placed at the focus of the 1.5 m reflector for submillimeter waves (SST) at El Leoncito, Argentina Andes.

7741-79, Poster Session

The dual-band L-P feed system for the Sardinia Radio Telescope prime focus

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We present the design of the passive feed system of the dual-band receiver for the prime focus of the Sardinia Radio Telescope (SRT), a new 64 m diameter radio telescope which is being built in Sardinia, Italy. The feed system operates simultaneously in P-band (305-410 MHz) and L-band (1300 - 1800 MHz). The room temperature illuminators are arranged in coaxial configuration with an inner circular waveguide for L-band (diameter of 19 cm) and an outer coaxial waveguide for P-band (diameter of 65 cm). Choke flanges are used outside the coaxial section to improve the cross-polarization performance and the back scattering of the P-band feed. The geometry was optimized for compactness and high antenna efficiency in both bands using commercial electromagnetic simulators.

Four probes arranged in symmetrical configuration are used in both the P- and the L-band feeds to extract dual-linearly polarized signals and to combine them, through phased-matched coaxial cables, into 180 deg hybrid couplers. A vacuum vessel encloses the two P-band hybrids and the two L-band hybrids which are cooled, respectively at 15 K and 77 K. For the P-Band, four low loss coaxial feedthroughs are used to cross the vacuum vessel, while for the L-Band a very low loss large window is employed. The P-band hybrids are based on a microstrip rat-race design with fractal geometry. The L-band hybrids are based on an innovative double-ridged waveguide design that also integrates a band-pass filter for Radio Frequency Interference (RFI) mitigation.

7741-80, Poster Session

A slot array antenna for a millimeter/submillimeter-wave focal plane

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Planar slot array antennas consisting of multiple slot elements fed by a microstrip network are being developed for use in millimeter and submillimeter wavelength astronomical instruments. As these antennas are fabricated photolithographically and do not require individual feedhorns or lenses, they significantly simplify construction of a focal plane. We present details of the design of a wide-bandwidth slot array antenna to be used in the Multiwavelength Submillimeter Kinetic Inductance Camera (MUSIC). The antenna has over an octave of bandwidth, allowing for simultaneous imaging in four bands at 0.85, 1.1, 1.3 and 2.0mm, and can be closely packed to efficiently use the available area on the focal plane. The impedance characteristics, gain, and surface wave coupling of the antenna are calculated using a method-of-moments approach in combination with a circuit model of the microstrip feed network.

7741-81, Poster Session

Optical properties of astronomical silicates with infrared techniques

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Astronomical dust is observed in a variety of astrophysical environments and plays an important role in radiative processes and chemical evolution in the galaxy. Depending upon the environment, dust can be either carbon-rich or oxygen-rich (silicate grains). Both astronomical observations and ground-based data show that the optical properties of silicates can change dramatically with the crystallinity of the material, and recent laboratory research provides evidence that the optical properties of silicate dust vary as a function of temperature as well. Therefore, correct interpretation of a vast array of astronomical data relies on the understanding of the properties of silicate dust as functions of wavelength, temperature, and crystallinity. The OPASI-T (Optical Properties of Astronomical Silicates with Infrared Techniques) project addresses the need for high quality optical characterization of metal-enriched silicate condensates using a variety of techniques. A combination of both new and established experiments are used to measure the extinction, reflection, and emission properties of amorphous silicates across the infrared (near infrared to millimeter wavelengths), providing a comprehensive data set characterizing the optical parameters of dust samples. We present room temperature measurements and the experimental apparatus to be used to investigate and characterize additional metal-silicate materials.

7741-82, Poster Session

A wideband smooth-walled feed horn with low cross-polarization for millimeter astronomy

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We present a smooth-walled feedhorn with cross polarization and reflected power lower than -30dB across the entire 30% bandwidth.

A prototype feedhorn has been fabricated, and the wide-band, low-cross polarization performance has been demonstrated.The feedhorn has a circular aperture and monotonically narrows towards an input waveguide interface. This allows it to be manufactured by progressively milling the profile using a set of custom tools. This is especially useful in applications where a large number of feeds are desired in a planar array format. Such applications include astronomical cameras in millimeter waveband that require large arrays of detectors for future increases in mapping speed and sensitivity. Specifically, large arrays of feedhorns are well-matched to the problem of measuring the polarization of the cosmic microwave background to search for the faint signature of inflation, as they provide good beam control, provide the requisite sensitivity, and are possible to couple to low-noise bolometric detectors.

7741-83, Poster Session

High-efficiency anti-reflection-coated cryogenic silicon lenses for millimeter wavelengths

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The increasing scale of cryogenic detector arrays for millimeter-wavelength astrophysics has led to the need for large, high-efficiency, cryogenic optics. The large throughput and cold stop requirements of upcoming receivers motivates the use of lenses with a high-index of refraction. Silicon, a high-index material (n = 3.42) with a relatively high thermal conductivity, can now be grown as large as 395 mm in diameter with resistivity > 500 Ohm-cm. We have used a vector-network analyzer to measure the loss of different resistivities of silicon between 130 GHz and 220 GHz at ambient and cryogenic temperatures to understand the resistivity requirements for low-loss lenses operated near 4 K. We are also developing techniques to produce large-area gradient-index anti-reflection coatings for these lenses by removing silicon from the lens surfaces. We present the results of our simulations and measurements.

7741-84, Poster Session

Modeling and characterization of the SPIDER half-wave plate

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SPIDER is a balloon-borne array of six telescopes operating at 90, 145, 220, and 275 GHz to observe the Cosmic Microwave Background. Over a 4-day first flight, and a 21-day long-duration flight, the 2624 antenna-coupled bolometers in the instrument will make a half-sky polarization map of the CMB at ~degree resolution. Polarization modulation is achieved via a cryogenic AR-coated sapphire half-wave plate (HWP) in front of the primary optic. The HWP will be stepped to several angles during each flight. We have developed an optical model for the HWP that accounts for frequency-dependent non-idealities at normal incidence. This model will guide characterization of the integrated instrument, and allow us to improve the quality of post-flight polarization maps. We will also present preliminary results of lab testing of the 145 GHz HWP.

7741-85, Poster Session

Compact radiative control structures for millimeter astronomy

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We have designed, fabricated, and tested compact radiative control structures, including antireflection coatings and resonant absorbers, for far infrared through millimeter wavelength astronomy. The antireflection coatings consist of micromachined single crystal silicon dielectric subwavelength honeycombs. The effective dielectric constant of the structures is set via honeycomb pitch and wall thickness. We measured a power reflection coefficient of ~ 0.05 for a 300 micron thick dielectric honeycomb, which possesses a dielectric constant of 2.15, at 1 THz. The resonant absorbers consist of pieces of solid single crystal silicon, which serve as stepped impedance antireflection coatings, and thin phosphorus implanted regions, which serve as the absorbers. The sheet resistance of the implanted region is set so as to maximize power absorption. We present an implantation model that can be used to predict the ion energy and dose required for obtaining a target implant layer sheet resistance. Resonant absorber fabrication is discussed, and the measured values of absorption coefficients for these absorbers exceeds 0.8 at 31 + 4.7n cm-1; here n is an integer. A hybrid radiative control structure, which consists of a silicon dielectric honeycomb with an implanted region, has also been fabricated and is found to act as a neutral density filter. These radiative control structures are scalable, which makes them compatible with large focal plane detector arrays.

7741-86, Poster Session

A waveguide orthomode transducer for 385-500 GHz

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We describe the design, construction, and performance of a waveguide Orthomode Transducer (OMT) for the 385-500 GHz band. The OMT is based on a symmetric backward coupling structure and has a square waveguide input port (0.56x0.56 mm2) and two single-mode waveguide outputs: a standard WR2.2 waveguide (0.56x0.28 mm2) and an oval waveguide with full-radius corners. The OMT design is rescaled from the 84-116 GHz device described in [1]; it was optimized using a commercial 3D electromagnetic simulator. The prototype device employs standard UG387 flanges at all ports and consists of two mechanical blocks fabricated in split-block configuration using conventional CNC milling machine. The OMT was tested at JPL using a 325-500 GHz Vector Network Analyzer equipped with OML millimeter-wave extender.

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7741-89, Poster Session

Testing results and current status of FTS-2: an imaging Fourier transform spectrometer for SCUBA-2

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The SCUBA-2 imaging Fourier Transform Spectrometer (FTS-2) is a dual-band Mach-Zehnder imaging spectrometer, built for use with the SCUBA-2 camera on the James Clerk Maxwell Telescope (JCMT). FTS-2 will provide resolving powers of R ~ 10 to 5000 across the 450 and 850 μm bands, with a FOV up to 5 square arcmin. The instrument has been built and tested, with first light on the telescope planned for mid-2010. We present the alignment process, lab testing and early commissioning results, and discuss the first science targets in the context of other similar space and ground-based instruments.

7741-90, Poster Session

A novel 180° hybrid power combiner

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We describe the design, construction and performance of a novel 1800 hybrid power combiner for L-band (1.3-1.8 GHz). The hybrid is based on a double ridge waveguide cavity that also integrates a band pass filter. The device will operate at 77 K inside a cryogenically cooled receiver to be installed at the primary focus of the Sardinia Radio Telescope.

The hybrid has three ports consisting of N-type coaxial connectors whose central pins are attached to launching probes located inside the double ridge waveguide structure. The two input ports, to be excited by out-of-phase signals, are arranged in balanced configuration with the two axially symmetric probes aligned along the same axis and the connectors on opposite sides of the double ridge waveguide structure. The signal is extracted from an output probe located on the opposite end of the cavity. Both input and output probes are located in front of shaped tunerless backshorts that provide broad band responses with low reflection coefficients. The band pass filter is located in the middle of the structure, between the two input and output transitions. The dimensions of the device (excluding connectors) are 70 x 57.2 x 254.4 mm . The design was optimized using a commercial electromagnetic simulator.

At cryogenic temperature the measured output reflection coefficient was less than -17 dB, the coupling and the phase difference between inputs and output was respectively, 3.15±0.1dB and 180.50±0.10 over the full band.. The amplitude and phase balance is much superior to that of commercially available devices.

7741-91, Poster Session

Analysis of the amplification system of ALMA band 1

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The Atacama Large Millimeter Array (ALMA) is currently being built at the northern Chilean altiplanos. Every one of its constituent antennas will cover the spectroscopic window allowed by the atmospheric transmission at the construction site with ten different bands. Eight of those receivers are, currently, at different stages of construction. From the remaining two, despite being declared as a high scientific priority by the ALMA Scientific Advisory Committee, band 1 (31 - 45 GHz) was not selected for construction during the initial phase of the project. However, Universidad de Chile has started a program for the construction of a prototype receiver for band 1 that meets the stringent specifications required by ALMA.

In short, the receiver has been designed as follows. The incoming signal is brought to an optimized spline-profile corrugated horn via a lens. After the horn, the signal is divided in its linear polarization components using an orthomode transducer (OMT). Each polarization branch is first amplified and then down-converted independently. For amplification, we will use high electron mobility transistors (HEMT). Given the frequency coverage of this band and the availability of the LO signal, an upper sideband mixing scheme has been selected. A high pass-band filter that cancels out the lower sideband is, therefore, needed. Finally, the down-conversion and amplification of the intermediate signal is planned to be done with commercial components. In this paper we present the design of the proposed receiver and the results of the performance of several constructed parts.

7741-92, Poster Session

Coherent polarimeter modules for the QUIET experiment

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The Q/U Imaging Experiment (QUIET) is a five year program to make very sensitive measurements of the CMB polarization from the ground. The ultimate target of CMB polarization experiments is the B-mode polarization predicted from primordial gravitational waves. This signal is expected to be orders of magnitude weaker than the CMB temperature fluctuations and successful experiments will require exquisite sensitivity and freedom from systematics.

High electron-mobility transistors (HEMTs) are coherent amplifiers which have been developed for frequencies above 1 GHz. They have been used in a variety of ground-based CMB experiments as well as WMAP and Planck. The sensitivity of individual HEMT amplifiers is approaching fundamental limits and, although further improvement is expected, this alone will not provide the sensitivity required for B-mode detection. Instead, the number of detectors must be dramatically increased. Until recently, this has been prohibitively expensive and time-consuming.

However, exploiting a breakthrough in mm-wave packaging at JPL, the QUIET experiment has developed a polarimeter-on-a-chip which lends itself to the mass-production techniques used in the semiconductor industry. A total of 19 polarimeter modules were built for the 40 GHz receiver and 91 for the 90 GHz receiver, using a combination of automated and manual assembly. Future phases of the experiment will involve ~1500 such modules across multiple telescopes.

We describe the design, implementation and performance of these polarimeter modules.

7741-93, Poster Session

Development of MMIC receivers for cosmic microwave background interferometry

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Next generation Cosmic Microwave Background (CMB) experiments will search for the signature of inflation and other fundamental physics processes in the curl modes (B-modes) of the polarization signal. Such instruments will require excellent sensitivity, dynamic range, and field of view. Interferometers are well suited for CMB polarization measurements because they naturally reject many instrumental effects that can otherwise dominate the faint signal of interest. We report on the development of some of the key technologies that will be needed for a large-format interferometer with many hundreds of wideband W-band (75-110 GHz) receivers. We are developing a scalable three-baseline prototype interferometer (one dual-polarization and two single-polarization heterodyne detectors) as a technology demonstration for a much larger ground- or space-based instrument. Each prototype receiver integrates two InP Monolithic Microwave Integrated Circuit (MMIC) low-noise amplifiers, a coupled-line bandpass filter, a second harmonic balanced diode mixer, and a 90° local oscillator phase switch into a single compact module that is suitable for mass production. Incoming radiation is coupled into the MMIC modules through mass-producible smooth-walled feedhorns and waveguide polarizers, which separate incoming signals into circular polarization components. The prototype receivers have demonstrated band-averaged cryogenic noise temperatures better than 50 K from 84-94 GHz and 63 K from 82-100 GHz. We expect this performance to improve based on recent measurements of packaged amplifiers, which show noise temperatures as low as 30 K. These MMIC receivers can also be directly used for other applications such as spectroscopy, earth-sensing, and investigating the Sunyaev-Zel'dovich effect.

7741-94, Poster Session

Development of a 150 GHz MMIC module prototype for large-scale CMB radiation experiments

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We have designed and tested a prototype heterodyne amplifier module developed to operate from 140 to 170 GHz using Monolithic Millimeter-Wave Integrated Circuit (MMIC) low noise InP High Electron Mobility Transistor (HEMT) amplifiers. In the last few decades, astronomical instruments have made state-of-the-art measurements operating over the frequency range of 5-100 GHz, using HEMT amplifiers that offer low noise, low power dissipation, high reliability, and inherently wide bandwidths. Recent advances in low-noise MMIC amplifiers, coupled with industry-driven advances in high frequency signal interconnects and in the miniaturization and integration of many standard components, have improved the frequency range and scalability of receiver modules that are sensitive to a wide (20-25%) simultaneous bandwidth. HEMT-based receiver arrays with excellent noise and scalability are already starting to be manufactured at 100 GHz, but the advances in technology should make it possible to develop receiver modules with even greater operation frequency - up to 200 GHz. The purpose of this project was to deliver a compact, scalable module centered on the 150 GHz atmospheric window with demonstrated good noise performance and wide bandwith at cryogenic temperatures. Arrays equipped with hundreds of these modules can be optimized for many different astrophysical measurement techniques, including spectroscopy and interferometry.

7741-96, Poster Session

ALMA front-end verification unsing a dry cold load

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Noise temperature is one of the crucial parameters that describe the performance of a high sensitivity cooled receiver. The noise performance of a receiver can be characterised by performing a relative measurement using thermal calibration loads with the radiated noise power or radiometric temperature known a priori. For a reference radiometric temperature, thermal calibration loads commonly use high emissivity absorbing materials immersed in liquid cryogen (wet load), which provides stable radiometric temperatures at stationary state. However, due to the difficulties in handling of the wet load, the measurement could be cumbersome when the receiver under test needs to be measured repeatedly at different orientation. The verification of the Atacama Large Millimeter/submillimeter Array (ALMA) front-end requires such a task, for which use of a closed cycle refrigerator cooled load inside a vacuum container, i.e., a dry cold load is proposed. This will reduce the need for a liquid Nitrogen (LN2) load and will ensure the stable load temperature during the measurement. Key requirements of the dry cold load include a constant stable brightness temperature over a wide bandwidth up to 1 THz, polarisation insensitiveness, high emissivity, mechanical stability, etc. Owing to the presence of the window and metallic surroundings in the dry cold load, the accurate estimation of the load brightness is challenging. In this paper, we present the design and construction of the dry cold load for ALMA front-end verification and several techniques for estimating the brightness of the load.

7741-97, Poster Session

Vertically illuminated TW UTC photodiodes for terahertz generation

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More efficient continuous-wave photonic near-infrared mixers as terahertz sources are investigated with the motivation to develop a universal photonic local oscillator for astronomical submillimeter/terahertz receiver systems. For this, we develop new concepts for vertically illuminated traveling-wave (TW) photomixers, on the basis of TW Uni-Travelling Carrier (UTC) photodiode structures. Device simulation/modeling and optical/terahertz testing is being done in the new terahertz photonics laboratory at the Electrical Engineering Department of the University of Chile, whereas device fabrication is performed at the MC2 cleanroom facility at Chalmers Technical University. We will report on the concept, simulations and first results of fabrication and THz-testing.
We acknowledge support from the ALMA-Conicyt fund Nº 31080020 for Chilean Astronomy, and the Chilean Fondecyt fund Nº 1090306.

7741-98, Poster Session

Beam characterization for the QUIET antenna arrays using polarized and unpolarized astronomical sources

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Beam characterization is of great importance for analyzing and interpreting data from CMB experiments. In this poster we present scanning strategies, data analysis methods and important results of the main-beam characterization for the 19- and 91-element QUIET telescope antenna arrays, using the Crab nebula and Jupiter/Venus as polarized and unpolarized point sources respectively, at 40 and 90 GHz. Even though it is traditional to parametrize beams in one- or two-dimensional gaussian form, this alternative is not appropriate for QUIET since at the desired levels, of less that -20dB, the beams are systematically non-gaussian. The beam profiles are therefore modelled as a sum of gaussian terms multiplied by orthogonal polynomials after symmetrizing them using observations taken at different polarization angles. Obtained profiles are shown along with the theoretical expectations, final expanded models and fitted parameters. The l-space window function calculation procedure is graphically explained including parameter uncertainty propagation. These “window” or “filter” functions describe the response of the experiment to power in a particular mode of the fluctuation spectrum, thus serving as input in the CMB analysis pipeline. The data presented in this work have been collected during the phase I of the experiment, starting in September 2008.

7741-99, Poster Session

Calibration of the QUIET telescope

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The QU Imaging ExperimenT (QUIET) is a telescope that collects cosmic microwave background (CMB) data in the Q (40 GHz) and W (90 GHz) frequency bands. CMB is a polarized signal containing a wealth of information and is composed of two components: E-modes and B-modes. Details of E-modes have provided increasingly tight constraints on cosmological parameters. Detection of B-modes could lead to confirmation of inflation, or to ruling out a large class of inflationary models. QUIET’s primary goals are to measure the E-mode spectrum to unprecedented accuracy, and to detect or significantly improve constraints on the B-mode spectrum.

The 40/90 GHz receivers of the QUIET instrument contain polarization and total power pixels. Total power gain calibration is derived from a

combination of Jupiter and skydip measurements. Jupiter measurements provide an absolute calibration every week; and skydip measurements made every ~1 hour provide a more frequent relative gain measurement. Polarized gains are obtained in a similar manner, except that this calibration is also performed with respect to pixel orientation. The absolute value of the polarized gain relies on measurements of TauA. Relative gain measurements are made for all pixels scanning across the Moon and using a polarized wiregrid for a careful relative measurement of all horns at the same time once during the season. We find that the relative values of the total power and polarized gains track together throughout the season so skydip measurements are used as a proxy to track short-timescale variations of the polarized gain as well.

7741-100, Poster Session

BICEP: measurement of galactic plane polarization as a calibration source

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We present the use of the polarized millimeter-wave Galactic emission observed by BICEP as a calibration source on the sky. BICEP is a ground-based cosmic microwave background experiment that observed from the South Pole at three frequency bands, 100, 150 and 220 GHz.

In the three years of observations (2006 through 2008) BICEP spent about 20 % of the observation time mapping the Galactic plane at degree angular scales. The BICEP bolometric polarimeter is characterized with high precision. Thus, BICEP's high signal-to-noise Galactic polarization maps, which have low systematic uncertainties, are a potential calibration source for future polarization experiments. In this presentation, we describe the BICEP Galactic maps, a detailed breakdown of the statistical and systematic uncertainties, and a method for using the BICEP maps as a polarization calibration source.

7741-101, Poster Session

A fast superconducting nanoswitch for cosmology instruments

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Phase modulation of electromagnetic signals at millimetre wavelength is a key process in polarimeters of modern focal plane arrays aiming to measure the polarization of the cosmic microwave background. This is because phase modulation reduces readout noise and allows the measurement of Stokes Parameters U and Q without rotating the polarimeter components.

We have already reported the successful operation of superconducting nanoswitches in the frequency range 200-260 [1,2]. The switch comprises a Niobium nano-strip of approximately 20 nm thickness and 0.5 μm wide, deposited across the electrodes of a NBN unilateral finline. A current source was then connected across the nano-strip and the current was switched periodically from zero to above the critical current value. In this way the impedance of the transmission line was varied between two extreme values, corresponding to superconducting and normal impedances of the nanostrip. As expected however, the dynamic range of the switch was limited by the inductive value of the strip in the superconducting state.

We have already shown [1] that using capacitive coupling can achieve far better performance than direct DC coupling between the phase switch device and the finline elctrodes. In that case, the switch behaves as an RLC circuit, resulting in a much larger dynamic range between the normal and the superconducting states at resonance. We have therefore developed a technology for fabricating a new generation of phase switch devices with capacitive coupling, using e-beam lithography. In this new approach, a capacitive layer is deposited between the finlines and the switch forming a capacitance and allowing DC biasing of the switch without DC connection to the fins. In this paper we shall present measured results of the new switch performance as a function of frequency in the range of 200-260 GHz and compare the experimental values with simulations.

1. Yassin, G., Kuzmin, L. S., Grimes, P., Tarasov, M., Otto, E. and Mauskopf, P. D. (2007) "An Integrated Superconducting Phase Switch for Cosmology Instruments" Physica C: Applied Superconductivity and Application, vol. 466 (issue 2) pp. 115-123.

2. Kuzmin,L.S., Tarasov, M., Otto, E., Yassin, G., Grimes, P. K., and Mauskopf, P. D.(2007): "Superconductive sub-Terahertz nanoswitch," JETP Letters, vol. 86 no. 4 pp. 275-277.

7741-102, Poster Session

Calibration sources for the Polarbear Telescope

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The Polarbear experiment is a 3.5 meter Gregorian Dragone telescope with a millimeter-wave polarization sensitive bolometric receiver. The receiver consists of seven wafers with a total of 672 polarization sensitive dual slot crossed dipole antennas, each coupled by means of a superconducting stripline to a TES bolometer. The bolometer outputs are frequency multiplexed into groups of eight for readout. Polarbear will be deployed in Fall 2010 to the Chilean Atacama desert where it will observe at 90, 150, and 220 GHz with a goal of detecting the Cosmic Microwave Background (CMB) tensor-to-scalar ratio down to a limit of r=0.01. This level of sensitivity requires unprecedented control over systematic errors. We will discuss the techniques used to reduce systematic uncertainties in the measurements. These techniques include the use of a dielectric sheet calibrator to determine the polarization orientation of the detectors, mm-wave sources for beam characterization, as well as planet scans.

Preliminary results will be presented from the initial deployment of the calibration devices showing measured properties of the Polarbear instrument.

7741-103, Poster Session

Thermal and mechanical architecture for the SAFARI focal plane assembly

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The very challenging SPICA/SAFARI scientific goals imply to cool most detector solutions below 100 mK. This implies to find reliable solutions providing very efficient thermal insulation between the different temperature stages. The main constraints are the available power budget (1-2µW) including electrical power and parasitic loads, keeping the stray light level well below the foreseen astronomical background (20 aW/pixel !).

This poster describes how the PACS Bolometer Focal Plane thermo-mechanical design can be adapted to the new thermal and optical needs, while keeping a sufficiently stiff structure to withstand launch vibrations.

We give the first results on the thermal and mechanical behaviour obtained with a prototype.

7741-104, Poster Session

On-orbit performance of a cryogen-free 4K system for JEM/SMILES

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SMILES is a mission for sounding sub-millimeter wave limb emission with superconducting mixers on board JEM/ISS. SMILES has cryogenic receiver system consisting of two superconducting mixers and two cryogenic amplifiers which are cooled by a 4He JT cooler without liquid helium. Two mixers are cooled to 4K and two amplifiers are cooled to 20K and 100K respectively. SMILES was launched by H-IIB rocket on September 11, 2009. The cryogenic system started cooling down on September 25 and the temperature reached to 4.1K on September 28. The initial check out of SMILES has been successfully completed and normal operation is now underway.

7741-105, Poster Session

SCUBA-2: engineering and commissioning challenges of the world largest sub-mm instrument at the JCMT

S. C. Craig, Joint Astronomy Ctr. (United States); H. M. McGregor, E. Atad-Ettedgui, D. Montgomery, UK Astronomy Technology Ctr. (United Kingdom); D. Bintley, T. C. Chuter, Joint Astronomy Ctr. (United States); W. S. Holland, D. W. Lunney, M. J. MacIntosh, UK Astronomy Technology Ctr. (United Kingdom); E. Starman, Joint Astronomy Ctr. (United States)

Over preceding conferences, the design and implementation of the SCUBA-2 (Submillimetre Common-User Bolometric Array 2) instrument hardware has been described in detail. SCUBA-2 has been installed on the James Clerk Maxwell Telescope (JCMT) for over two years and its hardware has been successfully commissioned. This paper describes the culmination of this process and compares the optical/mechanical design and test expectations of the instrument hardware against the performance achieved in the field.

7741-106, Poster Session

Real-time Tbps digital correlator in NTU-array

S. K. Wong, National Taiwan Univ. (Taiwan)

NTU-Array is a W-band, dual-polarization, 6-receiver interferometer telescope aiming to detect the cross-over of CMB primary and secondary anisotropies. The telescope has 34Ghz instantaneous bandwidth for the continuum observation. The ultra-wide bandwidth is down-converted to four IF bands of 0-8.7Ghz for the ensuing digital correlation. We have completed the development of an FX digital correlator system for NTU-Array, which ultilizes 18Ghz, 1-bit samplers for digitization and Virtex-4 FPGAs for subsequent digital processing of Fourier transformation and cross-correlation. This new digital correlator has 275Mhz frequency resolution and is processing in real time the 850 Gbps input data at power consumption about 1 KW. We stress that our present setup substantially under-rates this FPGA computing machine, as it is designed to process 2.5 Tbps input data in real time from 18Ghz, 3-bit ADCs

7741-107, Poster Session

Detection and repair of readout FPGA corruption in a space-based TES bolometer array

G. Smecher, F. Aubin, McGill Univ. (Canada); D. Chen, COM DEV International Ltd. (Canada); O. Djazovski, Canadian Space Agency (Canada); M. Dobbs, McGill Univ. (Canada); G. Faulkner, F. Gulino, COM DEV International Ltd. (Canada); P. O. Hyland, K. Macdermid, McGill Univ. (Canada); N. Rowlands, COM DEV International Ltd. (Canada)

Frequency-domain multiplexed readout systems for large arrays of TES bolometers are used in, for example, the ground-based South Pole Telescope, APEX-SZ, and Polarbear Telescope as well as the EBEX balloon-borne telescope. To reduce these systems' size and power requirements, FPGAs have recently replaced mixed-signal designs that perform signal-processing and control algorithms. We anticipate that future satellite instruments will likely use similar technology. We describe the unique challenges of operating FPGAs in an orbital radiation environment. To mitigate corruption in an FPGA's configuration memory, we introduce a novel neighbour-neighbour monitoring scheme, where each FPGA in the system monitors its neighbor's configuration memory and can detect and correct a subset of errors due to radiation events. We evaluate the configuration logic within Xilinx' Virtex-4 FPGA, and describe how critical portions of our firmware can be re-architected to provide better radiation immunity without a prohibitive increase in design time or FPGA logic. We describe radiation events that cannot be corrected in this manner, and explore other ways to mitigate them. Overall, this approach reduces the system's susceptibility to crippling events without relying on triple redundancy or radiation-hardened FPGAs, which raise the cost, power budget, and design complexity of the project.

7741-108, Poster Session

SISCAM 32-ch readout module with GaAs-JFET ASICs

H. Matsuo, Y. Hibi, National Astronomical Observatory of Japan (Japan); H. Nagata, H. Ikeda, Japan Aerospace Exploration Agency (Japan); M. Fujiwara, National Institute of Information and Communications Technology (Japan)

We discuss on the development of 32 channel cryogenic readout module for superconductive imaging submillimeter-wave camera (SISCAM). The readout module is composed of GaAs-JFET integrated circuits such as 16-ch capacitive trans-impedance amplifiers (CTIAs), 32-ch multiplexer with sample-and-holds and 32-ch shift-registers.

We use SIS photon detector array at 650 GHz for the SISCAM. The detector works as superconducting photoconductors and the CTIA amplifiers integrate photo current from the detectors. For ground-based observation, atmospheric emission of about 100 pW creates photo-current of about 10 nA. With integration capacitor of 3 pF, reset frequency of an order of kHz is required which also avoids relatively large 1/f noise of GaAs-JFETs. Power dissipation of the 32-ch readout module is currently dominated by output buffer of each ASICs and is 400 uW, which can be reduced down to 100 uW.

Operation temperature of the GaAs-JFET readout module can be less than 1 K. Since the operation temperature of SIS photon detectors for ground-base observation is about 1 K, we can operate the readout electronics at the same temperature for arrays up to 1000 pixels. For larger format arrays and lower temperature operation for space applications, we need a design to operate the detector and readout electronics at different temperatures, which can be adjusted to the cryogenic requirement of the system.

7741-33, Session 8

First results from Supercam: a 64-pixel array receiver for the 350 GHz atmospheric window

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We report on both laboratory and telescope commissioning results from SuperCam, a 64 pixel imaging spectrometer designed for operation in the astrophysically important 870 micron atmospheric window. SuperCam will be used to answer fundamental questions about the physics and chemistry of molecular clouds in the Galaxy and their direct relation to star and planet formation. The Supercam key project is a fully sampled Galactic plane survey covering over 500 square degrees of the Galaxy in 12CO(3-2) and 13CO(3-2) with 0.3 km/s velocity resolution

In the past, all heterodyne focal plane arrays have been constructed using discrete mixers, arrayed in the focal plane. SuperCam reduces cryogenic and mechanical complexity by integrating multiple mixers and amplifiers into a single array module with a single set of DC and IF connectors. These modules are housed in a closed-cycle cryostat with a 1.5W capacity 4K cooler. The Supercam instrument is currently undergoing laboratory testing with four of the eight mixer array modules installed in the cryostat (32 pixels). Work is now underway to perform the necessary modifications at the 10m Heinrich Hertz Telescope to accept the Supercam system. Supercam will be installed in the cassegrain cabin of the HHT, including the optical system, IF processing, spectrometers and control electronics. Supercam will be integrated with the HHT during the 2009-2010 observing season with 32 pixels installed. The system will be upgraded to 64 pixels during the summer of 2010 after assembly of the four additional mixer modules is completed.

7741-34, Session 8

ZEUS-2: a second generation submillimeter grating spectrometer for exploring distant galaxies

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ZEUS-2, the second generation (z)Redshift and Early Universe Spectrometer, like its predecessor is a moderate resolution (R~1000) long-slit, echelle grating spectrometer optimized for the detection of faint, broad lines from distant galaxies. ZEUS-2 employs three TES bolometer arrays (555 pixels total) to deliver simultaneous, multi-beam spectra in up to 4 submillimeter windows. The NIST Boulder-built arrays operate at ~100mK and are readout via SQUID multiplexers and the Multi-Channel Electronics from the University of British Columbia. The instrument is cooled via a pulse-tube cooler and two-stage ADR. Various filter configurations give ZEUS-2 access to 7 different telluric windows from 200 to 850 micron enabling the simultaneous mapping of the [NII] 205 micron, CO(7-6), [CI] 370 and 609 micron, and 13CO(6-5) lines from extended sources or the simultaneous detection of the 158 micron [CII] line and the [NII] 122 or 205 micron lines from z = 1-2 galaxies. ZEUS-2 is designed for use on the CSO, APEX and possibly JCMT. Using ZEUS-2 we will: (1) Probe star formation in the early Universe by detecting redshifted far-IR fine-structure gblines from distant (z ~0.21 to 5) galaxies. (2) Investigate star formation in nearby galaxies through simultaneously mapping up to five submillimeter lines that trace the physical conditions and the cooling of the major phases of the ISM. (3) Observe high-J CO and 13CO emission of nearby IR-bright galaxies to determine the dominate source of heating in the molecular ISM.

7741-35, Session 8

Large-format heterodyne arrays for observing far-infrared lines with SOFIA

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In the wavelength regime between 300 and 60 microns there are a number of atomic and molecular emission lines that are key diagnostic probes of the interstellar medium. These include transitions of [CII], [NII], [OI], HD, H2D+, OH, CO, and H2O. In Giant Molecular Clouds (GMCs), evolved star envelopes, and planetary nebulae, these emission lines can be extended over many arc minutes and possess complicated line profiles that can only be disentangled using high resolution (R> 10^6) spectroscopy. Observations of these lines are crucial to understanding the delicate interplay between the interstellar medium and the stars that form from it. This feedback is central to all theories of galactic evolution. Large format heterodyne array receivers can provide the spectral resolution and spatial coverage required for this work.

The advent of large format (~100 pixel) spectroscopic imaging cameras in the far-infrared (FIR) will fundamentally change the way astronomy is performed in this important wavelength regime. While the possibility of such instruments has been discussed for more than two decades, only recently have advances in mixer and local oscillator technology, device fabrication, micromachining, and digital signal processing made the construction of such instruments tractable. In our talk we will discuss how recent advances in these technologies can be implemented to construct large format, far-infrared heterodyne array instruments for SOFIA.

7741-36, Session 9

A THz unilateral finline SIS mixers on 15-μm silicon substrate

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We report the design and performance of two single-ended 700 GHz SIS finline mixers. A key feature of our design is the utilization of a new type of waveguide-to-planar circuit transition comprising a unilateral finline

taper deposited on a 15 μm thick silicon substrate [1]. This transition is markedly easier to design and simulate than the antipodal finline we have employed previously [2], and is also simpler to fabricate since the fins do not overlap at any stage. The employment of the very thin substrate is achieved using Silicon-On-Insulator technology which makes it easy to match the incoming signal to loaded waveguide. The mixer chip is held in the E-plane of the waveguide using gold beam leads, avoiding the need for a deep groove in the waveguide wall. This new design yields a significantly shorter chip, free of serrations and wider RF bandwidth since excitation of higher order modes in the groove is no longer a problem.

Coupling of RF power from the finline to microstrip can be done either directly from slotline to microstrip, or more elegantly via a coplanar waveguide (CPW). HFSS simulations of the transition show that a bandwidth well over 100 GHz can easily be achieved. Since tuning and all other circuits are integrated on the mixer chip, the mixer block is extremely simple, comprising a smooth-walled horn and a waveguide section without any complicated mechanical features. The tuning circuit comprises a two sections microstrip and a radial stub, and includes a transformer to match the impedance of the junction to the source.

A well known advantage of finline mixer is that they offer a large substrate area where miniature superconducting circuits can be fabricated on the mixer chip. The present design can therefore be extended to include balanced and sideband separating circuits that can elegantly be integrated in microstrip. A back-to-back finline taper can be used to couple the signal from one end and the LO from the other, eliminating the use of a beam splitter and requiring only a small fraction of the LO power.

In this paper, we shall present detailed design of the mixer chip including electromagnetic simulations, and the implementation of the Silicon-On-Insulator technology to fabricate the mixer on very thin silicon substrate. The mixer performance will be presented and compared with SuperMix simulations.

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7741-37, Session 9

Towards a compact THz local oscillator based on a quantum-cascade laser

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Heterodyne spectroscopy of molecular rotational lines and atomic fine-structure lines is a powerful tool in astronomy and planetary research. One example is the OI fine-structure line at 4.7 THz. This is a main target to be observed with GREAT, the German Receiver for Astronomy at Terahertz Frequencies, which will be operated on board of SOFIA.

We report on the development of a compact, easy-to-use source, which combines a quantum-cascade laser (QCL) operating at 3.1 THz with a compact, low-input-power Stirling cooler. This work is part of the local-oscillator development for GREAT/SOFIA. The QCL, which is based on a two-miniband design, has been developed for high output and low electrical pump power. Efficient carrier injection is achieved by resonant longitudinal-optical phonon scattering. The amount of generated heat complies with the cooling capacity of the Stirling cooler. The whole system weighs less than 15 kg including cooler, power supplies etc. The output power is well above 1 mW at 3.1 THz. With an appropriate optical beam shaping, the emission profile of the laser becomes a fundamental Gaussian one. Sub-MHz frequency accuracy can be achieved by locking the emission of the QCL to a molecular resonance. We will present the performance of the QCL-based source along with some application examples in high-resolution molecular spectroscopy.

7741-38, Session 10

High-power local oscillator sources for 1-2 THz

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Successful implementation of tunable frequency-multiplied sources for the 1 2 THz regime was an enabling feature of the HIFI instrument onboard the Herschel Space Observatory. Since then, a number of technological advances have been made that have resulted in a substantial increase in the available output power from Schottky diode frequency-multiplier-based sources. The advent of GaN-based amplifiers along with power combining technologies have substantially increased the power available to first-stage frequency multipliers. Transistor amplifiers with power levels ranging from hundreds of milliwatts to nearly a watt are becoming routinely available around 100 GHz. To take advantage of these increases in available input power, frequency multipliers using high thermal conductivity substrates (such as diamond) have been demonstrated that achieve high conversion efficiency and show that chip thermal design is extremely important for optimizing performance.

Recently demonstrated chains to 900 GHz have shown output powers in the milliwatt range, which is needed to drive higher frequency multiplier stages. Newly developed chains to 1400 GHz have also shown marked improvements over performance obtained for the HIFI hardware. This paper will discuss the current state-of-the-art for multiplier-based sources in the 1-2 THz range and discuss the potential and capabilities of this technology for far infrared astrophysics.

7741-39, Session 10

An SIS finline mixer with an ultra-wide IF bandwidth

Y. Zhou, G. Yassin, P. K. Grimes, J. Leech, Univ. of Oxford (United Kingdom)

We present a design for a 230 GHz finline SIS mixer with an extremely large IF bandwidth (2-20 GHz). This high instantaneous IF bandwidth will give a brightness sensitivity comparable to bolometers, while maintaining the advantages inherent in the phase sensitivity offered by coherent detection. We intend to demonstrate this mixer technology in a prototype interferometer, GUBBINS, designed to observe the frequency null in the S-Z effect near 217 GHz.

Our mixer design features a unilateral finline transition fabricated on Si substrate to couple the incoming RF waveguide mode to slotline and then to microstrip via a broadband slotline-to-microstrip transition. The unilateral finline is not only easier to fabricate than a more traditional antipodal finline, it is also well suited to wide IF bandwidth operation as its cutoff frequency is well above the high end of the IF band. The capacitance of the SIS tunnel junction is tuned out by a three-stage microstrip Chebyshev transformer with a relatively narrow microstrip width (2 $mu rm{m}$). Our transformer design exhibits very low parasitic reactance over an exceptionally large IF and RF bandwidth. The preliminary design is finished now and it is expected to have the first batch of this mixer chip in the early stage of 2010.

7741-40, Session 10

Development of a 1.4THz SIS mixer for radio astronomy

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Institute of Technology (United States)

The 1.4 THz SIS mixer is prepared for a heterodyne spectrometer CASIMIR aimed for the stratospheric observatory SOFIA. One of goals of this work is to supply a low noise spectrometer for the studies of the H2D+ 101 - 000 line around 1370 GHz.

We report on the development of a new version of a THz band SIS mixer. In order to reduce the loss in the matching circuit of the mixer we are using Nb/Al microstrip circuit with the Silicon dioxide dielectric layer. The low loss in the circuit using SiO2 dielectric layer should provide a significant improvement compared to the previously used mixer circuits with SiO dielectric. The mixer is using a quasi optical design in order to couple the SIS junctions with the telescope beam. The mixer chip with a planar double-slot antenna is mounted at the back side of a Silicon lens. The SIS junction normal resistance to the area product RNA is about 6 Ohm per micron square. At the target frequency of about 1.4 THz the on-chip coupling is expected to be better than 70%. With this level of the circuit loss the expected receiver noise may be close to 4-5 hv/k. The receiver design bandwidth is 1300 - 1500 GHz, about 200 GHz wide.

The mixer test with SiO and SiO2 dielectric in the circuit will be reported.

7741-41, Session 10

Terahertz traveling wave tube amplifiers as high-power local oscillators for large heterodyne receiver arrays

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The size of existing and projected submillimeter heterodyne receiver arrays is rapidly increasing. As the number of pixels in astronomical receiver arrays grows ever larger, the local oscillator power required increases as well. Over the past three years, our collaboration (TeraVision, Steward Observatory, AFRL) has worked on the development of low-noise THz Traveling Wave Tube (TWT) amplifiers that promise to provide more than enough power to pump the largest arrays being planned for submillimeter telescopes. The Traveling Wave Tube amplifier technology we have developed combines revolutionary carbon nanotube cathodes and a very low noise electron gun design with unique software modeling and micro-fabrication capabilities. Prototype circuits have been fabricated up to 350 GHz and detailed numerical simulations indicate that the technology is scalable to at least 750 GHz.

After a brief overview of existing technologies we review key enabling technologies that make this breakthrough possible, We will show the design of our carbon nanotube cathode based THz TWT. We will also discuss design trades and predicted performance at several frequencies of interest to the astronomical community and present preliminary results from devices fabricated at 220 and 350 GHz.

7741-42, Session 10

Ultra-broadband IF/LO system of NTU W-band interferometer array

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NTU-Array is designed for W-band (78-113Ghz) observation through SZ-effects. The first-phase operation of the telescope with 6 eceivers had its first light in 2008 with single-polarization and half the

full bandwidth. The second-phase operation of NTU-Array in Nevada will begin the dual-polarization, full-band observation in 2010. One-bit sampling at 18Ghz and digital correlation are in use in this telescope.

Due to the ultra broadband coverage, the IF system divides the 35GHz full-band into four 8.7GHz sub-bands. The first stage of IF module containing a 35GHz broadband amplifier with fairly flat-gain performance over 25db gain divides the first-stage IF into two outputs. The 2nd-stage IF module further divides the two input IF signals and down-converts them to four basebands of DC-8.7Ghz.

An LO module with 8.7Ghz input is to generate outputs with x2, x3 and x9 harmonics for the down-conversion. The Walsh function is injected into the x9 LO through up-conversion with an IQ mixer.

Each IF baseband is transmitted through an optical fiber to the 18Ghz, 1-bit sampling ADC located in the control room. The analog optical link contains a driver and equalizer to compensate for the path loss.

Considering the limited size of the telescope mount, the entire IF/LO system of each receiver has a compact size about 20cm cubed. This physical size can be further reduced to fit the future 19-pixel-receiver upgrade of NTU-Array.

7741-43, Session 10

Smithsonian Astrophysical Observatory SMA SIS device tuning and optimizing techniques

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The Submillimeter Array is an 8-element interferometer operating in the atmospheric windows from 180 to 700 GHz on the summit of Mauna Kea, Hawaii. Its 6-meter dishes can be arranged into baseline configurations ranging from 9 to 509 meters. The cryostats can hold up to eight SIS DSB receiver inserts and at present the cryostats are populated with four of these inserts, an A band, 180 to 240 GHz, a B band 250-350 GHz, a C band 320-440 GHz and a E band 600-700 GHz. In producing the highest quality submillimeter data possible, considerable effort has gone into optimizing and monitoring the heterodyne SIS detectors and receivers. This paper will explain the procedures and tools the SMA uses to measure the devices in the antennas and how the receivers are optimized before science observations begin. How they are monitored throughout the observation and after, a data "quick look" summary has been developed to analyze the data visually. This gives the observatory a tool to quickly check the quality of the data and to help identify any problems that have occurred during the science track. The paper will also explain a recent upgrade to the instrument, an increase of its IF bandwidth from 2 GHz to 4 GHz. This increase of the IF to 8 GHz DSB has increased the sensitivity of the instrument by root 2.

7741-44, Session 11

Heterodyne gas cell measurements at 2.9 THz using a quantum cascade laser as local oscillator

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High-resolution heterodyne spectrometers operating at above 2 THz are crucial for detecting, e.g., the HD line at 2.7 THz and oxygen OI line at 4.7 THz in astronomy. The potential receiver technology is a combination of a hot electron bolometer (HEB) mixer and a THz quantum cascade laser (QCL) local oscillator (LO).

Here we report the first high-resolution heterodyne spectroscopy measurement of a gas cell using such a HEB-QCL receiver. The receiver employs a 2.9 THz free-running QCL as local oscillator and a NbN HEB as a mixer. By using methanol (CH3OH) gas as a signal source, we successfully recorded the methanol emission line at 2.92195 THz. Spectral lines at IF frequency at different pressures were measured using a FFTS and well fitted with a Lorentzian profile.

Our gas cell measurement is a crucial demonstration of the QCL as LO for practical heterodyne instruments. Together with our other experimental demonstrations, such as using a QCL at 70 K to operate a HEB mixer and the phase locking of a QCL (P. Khosropanah et al, Opt. Lett, 34, 2958 (2009)) such a receiver is in principle ready for a next step, which is to build a real instrument for any balloon-, air-, and space-borne observatory.

7741-45, Session 11

Development of the nano-HEB array for low-background FIR applications

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Recently, we have achieved the extremely low thermal conductance in Ti hot-electron nanobolometers (nano-HEB) with Nb Andreev contacts (~ 100 fW/K at 300 mK and ~ 0.1 fW/K at 40 mK). This thermal conductance translates into the phonon-noise NEP ≈ 3x10^-21 W/Hz^1/2 at 40 mK and NEP ≈ 10^-18 W/Hz^1/2 at 300 mK that meets the requirements of the future most sensitive space FIR applications (SAFIR, SPICA, Millimetron, CALISTO).

Here we studied the electrical noise, the signal and noise bandwidth, and the response time in somewhat larger devices (6μm x 0.4μm x 56nm, T_c = 300-350 mK). The output electrical noise was measured down to 50 mK by a dc SQUID and was in the range of 50-100 pA/Hz^1/2 (phonon noise dominated). The corresponding electrical NEP is ~ 6x10^-18 W/Hz^1/2 at 320 mK and 1.5x10^-20 W/Hz^1/2 at 50 mK.

The small heat capacity in nano-HEBs may enable infrared calorimetry in space. We obtained data on the counting statistics using 20-GHz pulses imitating IR photons and found the minimum detectable FWHM energy of h×24THz at 300 mK. This energy is expected to decrease by a factor of 15 at 50 mK so the detection of 3-THz photons should become possible.

We also demonstrated the integration of the GHz FDM readout using dc SQUIDs coupled to microresonators with the nano-HEBs. The readout noise ~ 2 pA/Hz^1/2 and the MHz bandwidth are suitable for these detectors. This MUX scheme allows for 100s of detectors to be read using a few wires.

7741-46, Session 11

Filine integrated cold electron bolometer

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Cold-Electron Bolometers (CEB) [1, 2] are expected to have several advantages over the commonly used TES detectors. In particular, they have higher sensitivity, higher saturation power, much faster response and easier to integrate in planar circuits.

We have designed, fabricated and tested a Cold-Electron Bolometer (CEB) integrated in a finline antenna. Bolometers were fabricated using e-beam direct-write technology and tests were performed at 110 GHz. The bolometer was cooled to 270-300 mK and preliminary DC tests yielded an estimated NEP of ~ 5*10-16 W/Hz1/2. These estimates were done without power loading, and dominated by electron-phonon noise at bath temperature. For simplicity, we have chosen a fabrication technology that tends to produce an absorber volume larger than required for significant thermal feedback cooling and optimum operation of the CEB. This will however allow us to investigate basic properties of the detector such as optical coupling efficiency and basic properties of the device using simple tests and analysis tools.

The design of the bolometer chip comprises a CEB fabricated across the slot of a unilateral finline. The samples were fabricated using e-beam lithography in direct-write mode using the trilayer fabrication technology of tunnel junctions [3]. Gold contact pads and wires are first patterned using e-beam exposure and thermal evaporation. The finline electrodes are then patterned in the same way, and finally the Cold-Electron Bolometer structures are fabricated across the finline using trilayer process. The Cu-Au layer is removed by Ion-Beam Etching on the top of the trilayer structure.

The CEB performance was tested by mounting samples in a He3 sorption cryostat HELIOX-AC-V at a bath temperature of 270 mK. Optical window in the cryostat was equipped with two low-pass filters with cut-off frequency 33 cm-1 and 2 neutral density filters with 10 db attenuation each, to reduce the background power radiation overheating. DC IV curves were first measured in a current bias mode, then samples were irradiated with a microwave signal from IMPATT diode at 110 GHz modulated at 127 Hz. The signal response was measured using a lock-in amplifier. These preliminary tests were conducted by coupling power directly into the finline chip. We are now planning more careful tests by coupling the power through a horn into the detector block where the finline chip is mounted. In this paper we shall provide detailed design of the CEB detector and report the recent sensitivity measurements.

References:

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7741-47, Session 11

Noise temperatures and beam patterns of a NbN hot electron bolometer mixer at 5.25 THz

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We report the measured sensitivities of a superconducting NbN hot electron bolometer (HEB) heterodyne receiver at 5.25 THz. The terahertz (THz) radiation is quasi-optically coupled to the HEB mixer with a lens and a spiral antenna. Using a measurement setup with black body radiation sources and a beam splitter in vacuum, and an antireflection coated Si lens, we obtained a double sideband receiver noise temperature of 1150 K, the half of which is contributed by the quantum noise. The optimal LO power required by the HEB itself is 130 nW, which was in this experiment provided by an optical pumped gas laser. In addition, the measured far field beam patterns of the integrated lens antenna from 2.5 THz to 5.3 THz shows a collimated beam, making it reliable to measure using the vacuum setup. Our experimental results in combination with an antenna-to-bolometer coupling simulation suggest that the HEB mixer can work well at least up to 6 THz, suitable for next generation of high-resolution spectroscopic space telescopes, and, in particular, for the detection of the neutral atomic oxygen (OI) line at 4.7 THz.

7741-48, Session 12

EBEX: a balloon-borne CMB polarization experiment

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The E and B Experiment (EBEX) is a NASA-funded balloon-borne telescope designed to measure the polarization of the cosmic microwave background (CMB). The experiment will use 1432 transition edge sensor (TES) bolometric detectors read out with a frequency multiplexed SQUID readout. EBEX will observe in three frequency bands centered at 150, 250, and 410 GHz, with 768, 384, and 280 detectors in each band, respectively.

This broad frequency coverage will provide valuable information about foreground emission from thermal dust.

The polarimetry and signal modulation are achieved using an achromatic half wave plate (AHWP) rotating on a superconducting magnetic bearing and a xed wire grid polarizer. The 420 square degree observing area and 8' resolution provide sensitivity to an angular power spectrum from 0.2 deg to 5 deg. This will allow EBEX to observe the primordial B-mode signal predicted by ination on scales of about 0.5 deg and the anticipated lensing B-mode signal at smaller angular scales. Simulations show that EBEX will detect the primordial B-mode signal if the tensor to scalar ratio, r, is 0.1, or it will reduce the current upper limit to 0.05. This limit assumes that errors due to foreground subtraction are below detector noise, and it does not include systematic uncertainties.

The test ight took place in June, 2009, from Ft. Sumner, NM, and the science ight will occur over Antarctica.

I will discuss the EBEX instrument and the North American engineering ight.

7741-49, Session 12

QUIET: a ground-based probe of cosmic microwave background polarization

I. Buder, for the QUIET Collaboration (United States)

QUIET is a ground-based experiment that measures the polarization of the Cosmic Microwave Background (CMB) radiation. Previous CMB polarization data have been used to constrain the cosmological parameters that model the history of our universe. The exciting target for current and future experiments is detecting and measuring the faint polarization signals caused by gravity waves from the inflationary epoch in the first second after the Big Bang. QUIET finished an observing season at 40 GHz (Q-Band) in June 2009; observing at 90 GHz (W-Band) is ongoing. The instrument incorporates several technologies and approaches novel to CMB experiments. The telescope is a 1.4m crossed-Dragone design, chosen to limit spurious optics-induced polarization. Instead of individually electroformed feedhorns, an array of horns is constructed as a single piece "platelet". All optical elements are enclosed by a co-moving, absorbing ground shield. The detectors are sensitive High Electron Mobility Transistor based coherent polarimeters. These are read out with 800 kHz ADCs, allowing for diagnosis and understanding of problems which appear at high frequency. Observations are performed from the Chajnantor Plateau in Chile, one of the best sites for microwave astronomy in the world. The observing strategy is designed to reduce systematic errors and allows for calibration as frequently as once every hour. These systems combine to produce a polarization sensitivity of 70 (60) micro-Kelvin for a 1 second exposure of the Q (W) Band array. I will describe the QUIET instrument and explain how systematic errors are reduced.

7741-50, Session 12

PolarBear-II experiment

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PolarBear-II (PB-II) is a second phase experiment of the PolarBear (PB-I), which is a telescope to measure B-mode polarization of CMB at 150GHz and 220GHz. The goal of PB-II is a simultaneous observation at two bands of 90GHz and 150GHz over PB-I sensitivity, and a well study of B-mode physics due to gravity lensing and primitive gravitational wave. Especially, same sky and band (90GHz) observation with the QUIET will give us valuable information. To reach this goal, two advanced technologies will be introduced; multichroic antenna-coupled TES bolometer and 0.1K cooling system.

Multichroic antenna has sinusoidal antenna pattern with four TES bolometers (two colors and two polarizations). PB-II will equip 1280 pixels and 5120 bolometers, which are twice and four times than that of PB-I, respectively. Frequency multiplexing of 16 will be introduced as TES readout. Multichroic optics is also important, so broadband AR coating is under testing now.

The increase of pixel number requires twice focal plane size than PB-I, so new larger cryostat is under designing. An easy solution to reach 0.1K is to use dilution cryocooler, however, we decided to use ADR to combine PB-II development with R&D for our future satellite project. The ADR will be attached on 0.3K sorption cooler, pre-cooled by 4K pulse-tube cryocooler. Estimated cooling power of the ARD is about 0.5 μm at 0.1K. Magnetic leakage and shielding from the ADR to the SQUID will be studied in this development.

Overview and whole design of the PB-II will be presented.

7741-51, Session 12

The Atacama B-mode search: a microwave background polarimeter

J. W. Fowler, Princeton Univ. (United States)

The Atacama B-mode Search (ABS) is a compact receiver for measuring the polarization of the cosmic microwave background (CMB) at degree angular scales. At these scales, B modes of CMB polarization are expected to arise from gravitational waves in the early universe.

Their observation would be a strong confirmation of cosmic inflation.

ABS will observe at 150 GHz with a 25 cm aperture and 0.6 degree beams. It contains a two-mirror Gregorian telescope inside a cryostat, imaging the sky onto an array of 240 corrugated feed horns.

The horns couple radiation into a new focal plane array of polarimeters under development at NIST. The polarimeters consist of planar superconducting ortho-mode transducers, microstrip lines with bandpass filters, and a pair of bolometers (transition edge sensors) to measure the power in each polarization. A continuously spinning sapphire half-wave plate outside the cryostat will modulate the polarized component of the signal at several hertz. We will describe our science objectives, the instrument, the planned observations from the Chilean Atacama Desert, and the sensitivity and systematic error requirements for a measurement of CMB B-modes.

7741-52, Session 12

The BICEP2 microwave polarimeter

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BICEP2 is a microwave telescope designed to measure the polarization of the cosmic microwave background on angular scales near one degree, with the goal of detecting the B-mode polarization that would be induced by primordial gravitational waves produced during inflation. BICEP2 follows the success of Bicep 1, which has set the most sensitive current limits on B-modes in multipoles of 30-300. By adopting TES detectors coupled to beam-defining slot antennas photolithographically patterned in the same silicon wafer, with SQUID-multiplexed readout, BICEP2 is able to achieve a higher detector count, and improve on the mapping speed of BICEP1 by a factor of 10. BICEP2 has deployed to the South Pole in November 2009 with 512 detectors at 150 GHz, and will observe through 2011. The first data from BICEP2 demonstrate the performance of the Caltech/JPL antenna-coupled TES arrays, and our two years of observation will achieve unprecedented sensitivity to B-modes on degree angular scales.

7741-53, Session 13

Initial performance of the BICEP2 antenna-coupled superconducting bolometers at the South Pole

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We report on the preliminary detector performance of the BICEP2 mm-wave polarimeter, deployed in 2009 to the South Pole. BICEP2 is currently imaging the polarization of the cosmic microwave background at 150GHz, using an array of 512 antenna-coupled superconducting bolometers. The antennas, band-defining filters and transition edge sensor (TES) bolometers are photolithographically fabricated on 4 silicon tiles. Each tile consists of an 8x8 grid of ~7mm pixels, for a total of 256 spatial pixels. A pixel contains 2 sets of orthogonal antenna slots summed in-phase, with each set coupled to a TES by a filtered microstrip. The detectors are read out using time-domain multiplexed SQUIDs. The detector pair of each pixel is differenced to yield a measurement of net polarization. We report on the performance of the BICEP2 detectors in the field, including the focal plane yield, detector and multiplexer optimization, detector noise and stability, and optical efficiency. The measured single-detector and instrument sensitivities are reported, as well as the implications for the mapping speed of the BICEP2 instrument in its search for the B-mode polarization signal from inflation.

7741-54, Session 13

The C-band all-sky survey: instrument design, status, and first-look data

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The C-Band All-Sky Survey (C-BASS) is a project that aims to produce sensitive, all-sky maps of Galactic synchrotron emission at 5 GHz in total intensity and linear polarization. These measurements will be used primarily in the subtraction of foregrounds from measurements of the polarized Cosmic Microwave Background. Secondary scientific goals include studying the nature of the Galactic magnetic field, constraining the Galactic cosmic ray energy spectrum, and constraining the so-called “anomalous” microwave emission. Measurements will be performed using a 6.1 m dish at the Owens Valley Radio Observatory (OVRO) in California, and a 7.6 m dish in the new Radio Astronomy Park near Carnarvon, South Africa. The telescope optics employs several novel aspects to reduce systematics, including a foam-supported secondary mirror and absorbing baffles around the mirrors. We describe the design of the analog instrument currently deployed on the OVRO dish, the status of observations, and first-look data. A second version of the receiver using a modified, digital, design is being built. We describe the design and status of construction of the second C-BASS receiver, and a timeline for the project.

The C-BASS project is a collaboration between Caltech/JPL in the US, Oxford and Manchester Universities in the UK, and Rhodes University and the Hartebeesthoek Radio Astronomy Observatory in South Africa. It is funded by the NSF (AST-0607857) and the participating institutions. http://www.astro.caltech.edu/cbass/

7741-55, Session 14

SCUBA-2: mechanical overview and lessons learned

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Scuba2, Sub-millimetre Common User Bolometer Array 2, as now been commissioned to the James Clerk Maxwell Telescope in Hawaii. This paper is an overview of the final mechanical design of the instrument and will cover the design challenges involved in developing a sub millimetre camera with a very large field of view and novel detectors operating below 100mk. It will also cover the lessons learned from the success and failures of the design, handling and integration.

7741-56, Session 14

The cryomechanical design of MUSIC: a novel imaging instrument for millimeter-wave astrophysics at the Caltech Submillimeter Observatory

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MUSIC (Multiwavelength Submillimeter kinetic Inductance Camera) is a new facility instrument for the Caltech Submillimeter Observatory (Mauna Kea, Hawaii) developed as a collaborative effect of Caltech, JPL, the University of Colorado and UC Santa Barbara, and is due for initial commissioning in late 2010. MUSIC utilizes a new class of superconducting photon detectors known as microwave kinetic inductance detectors (MKIDs), an emergent technology that offers considerable advantages over current types of detectors for submillimeter and millimeter direct detection. MUSIC will operate a focal plane of 576 spatial pixels, where each pixel is a slot line antenna coupled to multiple detectors through on-chip, lumped-element filters, allowing simultaneously imaging in four bands at 0.85, 1.1, 1.3 and 2.0 mm.

The MUSIC instrument is designed for closed-cycle operation, combining a pulse tube cooler with a two-stage helium-3 adsorption refrigerator, providing a focal plane temperature of 0.3 K with intermediate temperature stages at approximately 50, 4 and 0.4 K for buffering heat loads and heat sinking of optical filters. Detector readout is achieved using semi-rigid coaxial cables from room temperature to the focal plane, with cryogenic HEMT amplifiers operating at 4 K. Several hundred detectors may be multiplexed in frequency space through one signal line and amplifier.

This paper discusses the design of the instrument cryogenic hardware, including a number of features unique to the implementation of superconducting detectors. Experimental data on the performance of the instrument system will also be presented and discussed.

7741-57, Session 14

Thermal architecture for SPIDER long-duration cryostat

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We describe the cryogenic system for Spider, a balloon-borne microwave polarimeter that will map a large fraction of the sky with degree-scale resolution. The system consists of a ~1000-liter liquid helium cryostat and a 14-liter capillary filled superfluid helium tank, which provide base operating temperatures of 4 K and 1.5 K, respectively. Closed-cycle helium-3 adsorption refrigerators supply sub-Kelvin cooling power to multiple focal planes, which are housed in monochromatic telescope inserts. The cryostat is suspended from a vacuum vessel with thermally-insulating fiberglass flexures, and shielded from thermal radiation by a combination of two vapor cooled shields and superinsulation. This system allows for an extremely low instrumental background and a hold time in excess of 20 days. The relatively lightweight cryogenic system enables conventional long duration balloon flights. We will discuss the design, thermal analysis, and qualification of the cryogenic system.

7741-58, Session 15

SPIDER: a balloon-borne CMB polarimeter for large angular scales

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SPIDER is a balloon-borne instrument that will measure the polarization of the millimeter-wave sky at large angular scales with ~1° resolution. The flight cryostat has provision for six monochromatic refracting telescopes, each observing at a frequency of 96, 145, 220, or 275 GHz. Each focal plane consists of an array of several hundred transition-edge sensors, coupled to beam-defining slot antennas patterned on the same piece of silicon and read out using a time-domain SQUID multiplexer. A rotating sapphire half-wave plate modulates the polarization of the incoming light to mitigate systematics, while the instrument's simultaneous multi-wavelength coverage will allow the characterization and removal of galactic foregrounds. An initial 2-6 day flight from Alice Springs, Australia will take advantage of large sky coverage to measure the polarization signature of the epoch of reionization. A later, long-duration flight will probe the imprint of cosmological inflation on the polarization of the cosmic microwave background.

7741-59, Session 15

Design and performance of the SPIDER instrument

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The Spider project aims to measure the polarization of the Cosmic Microwave Background at multiple millimeter wavelengths from a stratospheric balloon platform. The cryostat has provision for six monochromatic, axially-symmetric, refracting telescope inserts at frequencies of 96, 145, and 220 GHz. Each insert's focal plane consists of an array of hundreds of antenna-coupled transition-edge superconducting detectors cooled to 300mK. Polarization modulation is achieved via a rotating, AR-coated, sapphire half-wave plate. We greatly reduce magnetic field pickup through the use of both superconducting and high permeability shields. We will discuss the instrument design and performance in preparation for Spider's first flight.

7741-60, Session 15

The Primordial Inflation Polarization Explorer (PIPER)

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The Primordial Inflation Polarization Explorer (PIPER) is a balloon-borne instrument designed to search for the faint signature of inflation in the polarized component of the cosmic microwave background (CMB). Each flight will be configured for a single frequency, but in order to aid in the removal of the polarized foreground signal due to Galactic dust, the filters will be changed between flights. In this way, the CMB polarization at a total of four different frequencies (200, 270, 350, and 600 GHz) will be measured on large angular scales. PIPER consists of a pair of cryogenic telescopes, one for measuring each of Stokes Q and U in the instrument frame. Each telescope receives both linear orthogonal polarizations in two 32 by 40 element planar arrays that utilize Transition-Edge Sensors (TES). The first element in each telescope is a variable-delay polarization modulator (VPM) that fully modulates the Stokes parameter to which the telescope is sensitive. The advantages of this architecture are threefold.

First, by modulating at the front of the optics, polarized instrumental effects are unmodulated and therefore are cleanly separated from source polarization. Second, by implementing this system with the appropriate symmetry, systematic effects can be further mitigated. In the PIPER design, many of the systematics are manifest in the unmeasured linear Stokes parameter for each telescope and thus can be separated from the desired signal. Finally, the modulation cycle never mixes the Q and U linear Stokes parameters, and thus residuals in the modulation do not twist the observed polarization vector. This is advantageous because measuring the angle of linear polarization is critical for separating the inflationary signal from other polarized components.

7741-61, Session 15

5,120 superconducting bolometers for the PIPER balloon-borne CMB polarization experiment

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We are constructing the Primordial Inflation Polarization Explorer (PIPER) to measure the polarization of the cosmic microwave background (CMB) and search for the imprint of gravity waves produced during an inflationary epoch in the early universe. The signal is faint and lies behind confusing foregrounds, both astrophysical and cosmological, and so many detectors are required to complete the measurement in a limited time. We will use four of our matured 1,280 pixel, high-filling-factor backshort-under-grid bolometer arrays for efficient operation at the PIPER CMB wavelengths. All four arrays observe at a common wavelength set by passband filters in the optical path. PIPER will fly four times to observe at wavelengths of 1500, 1100, 850, and 500 µm in order to separate CMB from foreground emission. The arrays employ leg-isolated superconducting transition edge sensor bolometers operated at 145 mK; tuned resonant backshorts for efficient optical coupling; and a second-generation superconducting quantum interference device multiplexer readout. We describe the design, development, and performance of PIPER bolometer array technology to achieve background-limited sensitivity for a cryogenic balloon-borne telescope.

7741-62, Session 15

The Keck array: a pulse-tube-cooled CMB polarimeter

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The Keck array, scheduled to begin observing from the South Pole in early 2011, is a ground-based, bolometric polarimeter targeting the polarization of the cosmic microwave background radiation (CMB). It is optimized to detect the faint cosmological B-mode component of the CMB polarization that is a generic prediction of inflationary models. The initial deployment will consist of 3 monochromatic copies of the BICEP2 experiment, operating at 150 GHz in compact, pulse tube cooled cryostats. A future upgrade to Keck will add additional receivers at 100 and 220 GHz. In this presentation we discuss the novel cryostat design as well as the performance of the phased-array bolometers when operating in the presence of a pulse tube cooler, specifically how this performance compares to that in a liquid cryogen dewar. We will also discuss the prospects for Keck to detect inflationary B-modes.

7741-63, Session 15

ACTPol: a polarization-sensitive receiver for the Atacama Cosmology Telescope

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The Atacama Cosmology Telescope (ACT) is a six-meter telescope on the Atacama plateau, Chile that was built to characterize the cosmic microwave background (CMB) at arcminute angular scales. Since 2008 ACT has been used to measure the temperature anisotropies in the CMB. We present a new receiver for ACT that will add polarization sensitivity to the telescope (ACTPol), while improving the temperature sensitivity by roughly a factor of five at 150 GHz. The combined polarization and temperature measurements will characterize the gravitational lensing of the CMB, improve constraints on the dark energy equation-of-state by calibrating galaxy bias, and constrain the sum of the neutrino masses with ~0.05 eV precision. Our observing fields have been selected to overlap with the upcoming baryon oscillation spectroscopic survey by the SDSS collaboration, enabling a variety of cross-correlation science, including growth of structure measurements from Sunyaev-Zel'dovich galaxy clusters and additional independent constraints on the sum of the neutrino masses. The ACTPol receiver design includes new optics to couple to three polarization sensitive focal planes under development at NIST that comprise large arrays of feedhorn-coupled polarimeters. The polarimeters are planar-superconducting ortho-mode transducers coupled to on-chip stub bandpass filters with a bolometric transition-edge sensor to measure each polarization. Helium-3 backed adiabatic-demagnetization refrigerators will be used to cool the detector arrays to 100 mK. We describe the ACTPol receiver design and science objectives.

7741-64, Session 16

SQUID-based multiplexed readout electronics and TES bolometer array during an engineering flight of the EBEX stratospheric balloon

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EBEX (the E and B EXperiment) is a balloon-borne telescope designed to measure the polarisation of the cosmic microwave background radiation. During the science flight, EBEX will operate 768, 384 and 280 spider-web transition edge sensor (TES) bolometers at 150, 250 and 410 GHz, respectively. The flight will circumnavigate Antarctica for about two weeks. The 10-hour EBEX engineering flight took place in June 2009 over New Mexico and Arizona. This is the first time a large array of TES bolometers was operated in a space-like environment. The successful implementation increases the technology readiness level of the bolometers and the associated readout system for future space missions. A total of 82, 49 and 82 TES detectors were operated during the engineering flight at 150, 250 and 410 GHz. They were read out with a new SQUID-based digital frequency domain multiplexed readout system that was designed for low power consumption. We describe the system, its software and the remote, automated tuning of the bolometers and SQUIDs. We compare results from tuning at float to ground, and discuss bolometer performance during flight.

7741-66, Session 16

Baseband feedback for SAFARI-SPICA TES using frequency-domain multiplexing

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We report on the performance of the digital baseband feedback circuit developed to readout and process signals from 5x5 transition edge sensors (TES) for SPICA-SAFARI in frequency domain multiplexing (FDM). It is shown that the gain bandwidth of any flux locked loop (FFL) is limited by the effective loop delay td. Baseband feedback corrects for the phase for each carrier frequency and increases the achievable FLL bandwidth. Our electronic is under integration and test with the TES sensors developed by SRON and Cardiff University to provide the SAFARI demonstrator for the ESA Cosmic Vision selection.

7741-67, Session 16

An open-source software-defined radio readout for MKIDs

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We will present the design, implementation and performance analysis of a software defined radio (SDR) readout system for arrays of microwave kinetic inductance detectors (MKID) for mm/submm astronomy. The SDR system will perform frequency domain multiplexed real-time complex microwave transmission measurements in order to monitor the instantaneous resonance frequency and dissipation of superconducting microresonators. Each SDR unit will be able to cover up to 550 MHz bandwidth and readout 256 complex frequency channels simultaneously with frequency resolution up to 1 Hz. The digital electronics include the customized DAC, ADC, IF system and the FPGA based signal processing hardware developed by CASPER group in Berkeley. The entire system is open sourced, and can be customized to meet challenging requirement in many applications: e.g. MKID, MSQUID etc.

Conference 7742: High Energy, Optical, and Infrared Detectors for Astronomy IV

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7742-01, Session 1

High-speed photon-counting CCD cameras for astronomy

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The design of electron multiplying CCD cameras require a very different approach from that appropriate for slow scan CCD operation. This paper describes the main problems in using electron multiplying CCDs for high-speed, photon counting applications in astronomy and how these may be substantially overcome. With careful design it is possible to operate the E2V Technologies L3CCDs at rates well in excess of that claimed by the manufacturer, and that levels of clock induced charge dramatically lower than those experienced with commercial cameras that need to operate at unity gain. Measurements of the performance of the E2V Technologies CCD201 operating at 26 MHz will be presented together with a guide to the effective reduction of clock induced charge levels. Examples of astronomical results obtained with our cameras will be presented.

7742-02, Session 1

EMCCD cryogenic cameras for the Brazilian tunable filter imager

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We present the cryogenic camera for the Brazilian Tunable Filter Imager, which is a new instrument proposed for the SOAR 4 meter telescope. The camera uses the latest electro-multiplication charge-coupled (EMCCD) detector developed by E2V, a 1600 x 1600 pixels full-frame device. We installed the device in a compact chamber, cooled to cryogenic temperatures using a Cryotiger. The detector is readout using the new CCCP - CCD Controller for Counting Photons, achieving single photon counting performance with negligible clock-induced charge (CIC) noise. We present the design of the camera and the first laboratory results.

7742-03, Session 1

The darkest EMCCD ever

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EMCCDs are devices capable of sub-electron read-out noise at high pixel rate, together with a high quantum efficiency (QE). However, they are plagued by an excess noise factor (ENF) which has the same effect on photometric measurement as if the QE would be halved. In order to get rid of the ENF, the photon counting (PC) operation is mandatory, with the drawback of counting only one photon per pixel per frame. The high frame rate capability of the EMCCDs comes to the rescue, at the price of increased clock induced charges (CIC), which dominates the noise budget of the EMCCD. The CIC can be greatly reduced with an appropriate clocking, which renders the PC operation of the EMCCD very efficient for faint flux photometry or spectroscopy, adaptive optics, ultrafast imaging and Lucky Imaging. This clocking is achievable with a new EMCCD controller: CCCP, the CCD Controller for Counting Photons. CIC levels measured with the controller are in the range of 0.001 - 0.002 electron/pixel/image, which is about an order of magnitude lower than what is commercially available. This new controller was integrated into an EMCCD camera and tested at the observatoire du Mont-Mégantic. The results are presented in this paper.

7742-04, Session 1

Adaptive optics wavefront sensing detector developments at ESO

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The detector is a critical component of any Adaptive Optics WaveFront Sensing (AO WFS) system. The required combination of fast frame rate, high quantum efficiency, low noise, large number and size of pixels, and low image lag can often only be met by specialized custom developments.

ESO's very active WFS detector development program will be described.

Key test results will be presented for newly developed detectors: a) the e2v L3Vision CCD220 (the fastest/lowest noise AO detector to date) to be deployed soon on 2nd Generation VLT instruments, and b) the MPI-HLL pnCCD with its superb high "red" response.

The development of still more advanced laser/natural guide-star WFS detectors is critical for the feasibility of ESO's E-ELT. The paper will outline: a) the multi-phased development plan that will ensure detectors are available on-time for E-ELT first-light AO systems, b) results of design studies performed by industry during 2007 including a comparison of the most promising technologies, c) results from CMOS technology demonstrators that were built and tested over the past two years to assess and validate various technologies at the pixel level, their fulfillment of critical requirements (especially read noise and speed), and scalability to full-size. The next step will be towards Scaled-Down Demonstrators (SDD) to retire architecture and process risks. The SDD will be large enough to be used for E-ELT first-light AO WFS systems. For full operability, 30-50 full-scale devices will be needed.

7742-06, Session 2

Study of pixel area variations in prototype LSST CCDs

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Future wide field astronomical surveys, like Large Synoptic Survey Telescope (LSST), require photometric precision on the percent level.

The accuracy of sensor calibration procedures should match these requirements.

Pixel size variations found (Roger Smith and G.Rahmer) in CCDs from different manufacturers are the source of systematic errors in the flat field calibration procedure.

To achieve the calibration accuracy required to meet the most demanding science goals this effect should be taken into account.

The study of pixel area variations was performed on fully depleted, thick CCDs produced in a technology study for LSST.

These are n-channel, 100 micron thick devices with pixel size 13.5 microns.

Data were taken in the laboratory at 830nm wavelength at bias voltages between -5 and -40V. To increase statistical accuracy, images taken in identical conditions were co-added after base line subtraction and

master files were produced. Flat field image simulator was developed for statistical comparison of simulated and measured images.

Similar to the results of earlier studies (Roger Smith and G.Rahmer), we find short range spatial correlations between pixels that can be attributed to pixel area variations.

These correlations are present in both row and column direction.

In addition, diffusion is found to smooth short range correlations by redistributing charge between neighboring pixels.

It is shown that the characteristic diffusion width can be extracted from the flat field data.

Results on pixel area variations and diffusion, data features, analysis technique and modeling technique are presented and discussed.

7742-07, Session 2

PSF and MTF measurement methods for thick CCD sensor characterization

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Knowledge of the point spread function (PSF) of the sensors to be used in the Large Synoptic Survey Telescope (LSST) camera is essential for optimal extraction of subtle galaxy shape distortions caused by weak lensing. We have developed a number of techniques for measuring the PSF of candidate CCD sensors to be used in the LSST camera, each with its own strengths and weaknesses. The two main PSF measurement techniques that we use are the direct Virtual Knife Edge (VKE) scan developed by Karcher, et al.[1], and the indirect interference fringe method of Andersen and Sorensen[2] that measures the modulation transfer function (MTF) directly. The PSF is derived from the MTF by Fourier transform. Other PSF measurement techniques that we employ include 55Fe x-ray cluster image size measurements and statistical distribution analysis, and cosmic ray muon track size measurements.

The VKE technique utilizes a diffraction-limited spot produced by a Point-Projection Microscope that is scanned across the sensor with sub-pixel resolution. This technique closely simulates the actual operating condition of the sensor in the telescope with the source spot size having an f/# close to the actual telescope design value. The interference fringe method uses a novel equal-optical-path Michelson-type interferometer with a single-mode fiber source that produces interference fringes with 100% contrast over a wide spatial frequency range sufficient to measure the MTF of the sensor directly. The merits of each measurement technique and results from the various measurement techniques on prototype LSST sensors are presented and compared.

[1] A. Karcher, et al., "Measurement of lateral charge diffusion in thick, fully depleted, back-illuminated CCDs," IEEE Trans. Nucl. Sci., vol. 51, no. 5, pp. 2231-2237, 2004

[2] M. Andersen and A.N. Sorensen, "An Interferometric Method for Measurement of the Detector MTF," Expt. Astron. 8, pp. 9-12, 1998

7742-08, Session 2

Ultra-high sensitivity APD-based 3D ladar sensors

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Raytheon is developing NIR sensor chip assemblies (SCAs) for scanning and staring 3D LADAR systems. High sensitivity is obtained by integrating high performance detectors with gain i.e. APDs with very low noise Readout Integrated Circuits. Unique aspects of these designs include: independent acquisition (non-gated) of pulse returns, multiple pulse returns with both time and intensity reported to enable full 3D reconstruction of the image. Recent breakthrough in device design has resulted in HgCdTe APDs operating at 300K with essentially no excess noise to gains in excess of 100, low NEP <1nW and GHz bandwidths and have demonstrated linear mode photon counting. SCAs utilizing these high peformance APDs have been integrated and demonstrated excellent spatial and range resolution and 3D imagery both at short range and long ranges. In this presentation we will review progress in high resolution scanning, staring and ultra-high sensitivity photon counting LADAR sensors.

7742-33, Session 2

The use of EM-CCDs on the proposed International X-ray Observatory

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The use of Electron Multiplying Charge-Coupled Devices (EM-CCDs) in scientific applications is increasing due to their ability to detect incoming photons that are few in number and low in energy. EM-CCDs are used to amplify low energy signals above the readout noise of the device allowing these events to be easily seen after they are read out. This is done through the use of a gain amplifier after the serial output register of the EM-CCD and before the amplification electronics at the output node.

The X-ray Grating Spectrometer (XGS) on board the International X-ray Observatory (IXO) has a goal of operating over the 300-1000 eV range. The lower energy limit is largely determined by that energy which back-illuminated CCDs with conventional read noise can still usefully detect X-rays. This is the lower energy limit of the highly successfully Reflection Grating Spectrometer (RGS) on board XMM-Newton. The use of EM-CCDs potentially allows this lower energy baseline to be extended down to 200 eV thereby allowing access to lower energy X-ray emission including, that from carbon.

This paper evaluates the potential of EM-CCDs to increase the scientific capability of the XGS by going down to these lower X-ray energies, the potential science that could be uncovered in this energy range and preliminary results showing the capability and effectiveness of these devices in detecting sub-keV X-rays.

7742-09, Session 3

Mas-PMAS: commissioning of a 4k-CCD detector for the Potsdam multi-aperture spectrophotometer

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During 2009, a new CCD detector was integrated into the existing Potsdam Multi-Aperture Spectrophotometer (PMAS), which is in operation at the Calar Alto 3.5m telescope. PMAS is a dedicated 3D-spectrograph, featuring two integral field-units and a fiber-fed spectrograph with optimized optics to cover the entire optical wavelength regime between 350 and 900 nm. The current spectrograph detector was successfully replaced with a CCD231 device produced by e2v, featuring 16 million pixels. This upgrade yielded various efficiency gains, such as a wider wavelength coverage, increased quantum efficiency, reduced noise and shorter read-out times.

The paper describes the measured characteristics of the e2v chip in the AIP laboratory and the first on-sky performance after integration into the PMAS instrument.

7742-10, Session 3

Characterization of a sigma-delta-based CMOS monolithic detector

B. J. Hanold, D. F. Figer, B. Ashe, T. Montagliano, D. Stauffer, Rochester Institute of Technology (United States); Z. Ignjatovic, D. Maricic, Univ. of Rochester (United States); S. Nikzad, Jet Propulsion Lab. (United States)

The Rochester Imaging Detector Laboratory, University of Rochester, and Jet Propulsion Laboratory are developing a monolithic silicon detector with an on-chip Δ ADC. The device generates a digital bit stream that can be transmitted to external electronics with immunity to interference. This paper reports progress in developing the device and test results, including, optimized device operation, read noise, dark current, linearity, and well depth. Test results are reported for devices with and without backside thinning and delta-doping. Current testing indicates the device has <50 uV of read noise and ~0.2 e-/s/pixel of dark current. Detector optimization through iterative testing and re-design are summarized. Lastly, future design plans and testing are discussed.

7742-11, Session 4

Fundamental performance differences between CMOS and CCD imagers: part IV

J. R. Janesick, J. H. Pinter, R. Potter, Sarnoff Corp. (United States); T. Elliott, Jet Propulsion Lab. (United States); J. T. Andrews, J. R. Tower, M. Grygon, Sarnoff Corp. (United States)

This paper is a status report on recent scientific CMOS imager developments at Sarnoff. Topics primarily include test results from custom Sandbox CMOS imagers discussed in a previous 2009 SPIE paper (i.e., Part III). Technology in the paper emphasizes - near IR / x-ray response, SOI for backside illumination, buried channel MOSFETs for low noise, 1 e- charge transfer performance for very large 5TPPD pixels, substrate bias for deep depletion, dark current sources and their control, new findings on RTS noise, etc.. Sub electron on-chip signal chain circuitry to read pixels is also reviewed. Very high speed / ultra low noise stitched imager architectures are discussed. Future developments seen on the horizon will be examined.

7742-12, Session 4

Hybridization of a sigma-delta-based CMOS hybrid detector

K. E. Kolb, C. W. Maloney, Rochester Institute of Technology (United States); N. C. Stoffel, Infotonics Technology Ctr. (United States); A. D. Raisanen, B. Ashe, D. F. Figer, Rochester Institute of Technology (United States)

The Rochester Imaging Detector Laboratory, University of Rochester, and Jet Propulsion Laboratory developed a hybrid silicon detector with an on-chip Δ ADC. This paper describes the hybridization design, process, and results, with special emphasis on the photodiode array. The design utilizes aluminum pads on both the readout circuit and the photodiode array with interconnecting indium bumps between. An overview of the photodiode function and design as well as the development of the bump-bonding process are discussed. Specific material choices, interim process structures, and final function are described. Results include measurements of bond integrity, cross-wafer uniformity of indium bumps, and overall performance of the device with an emphasis on noise characteristics of the bond structure. Future plans for improving the bump-bonding process are summarized.

7742-13, Session 4

CCD test bench for the Euclid visible channel: performances and preliminary results

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Euclid is a candidate ESA mission to map the geometry of the dark Universe using two cosmological probes, namely Weak Lensing and Baryonic Acoustic oscillations. The payload consists of a 1.2m diameter telescope with three instruments.

The visible imaging channel, VIS, will perform the measurement of the shapes of galaxies in the wavelength range 550-920 nm (R+I+Z).

In order to meet the scientific goals, a severe control of the quality of the system PSF is required. One of the potential sources of variation of the system PSF in that respect is the long term effect of proton irradiations of the CCDs.

Based on the experience of GAIA, ESA decided to start as early as possible a dedicated characterization test campaign to answer these fundamental questions. An industrial consortium was contracted for that purpose. In parallel to this campaign initiated in May 2009, a dedicated test bench was developed at ESTEC in the SRE-PA laboratory, as part of a general need to have such facility in house for future missions, Euclid being the first case.

We report on the test bench development progress and validation as well as on preliminary results obtained on the n-channel CCD-204, one of the variant of the 203-82 originally chosen as baseline for Euclid.

The bench has two main purposes:

- radiometric measurements using monochromatic light as well as reference detectors

- MTF and point source illumination (supra and sub-pixel).

We will detail the different performances achieved by the bench and compare the preliminary CCD characterization results with what has been obtained by the industrially led consortium.

7742-14, Session 4

High-performance hybrid CMOS sensors for ground-based astronomy applications

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Teledyne continues to improve the performance of sensors for ground-based astronomy, and this paper presents the advancements made since the 2008 SPIE meeting. This paper reports on large format arrays, and specialized sensors for adaptive optics, interferometry and solar astronomy.

In the area of large format arrays, the H2RG (2048×2048 pixels, 18 micron pitch) is widely used for infrared instrumentation. Already recognized to provide high quantum efficiency, the H2RG has been improved since 2008 to provide better performance in several ways: lower readout noise, lower dark current, reduced interpixel capacitance, reduced persistence and improved pixel operability. The H2RG, traditionally produced for ground-based astronomy in 2.5 micron cutoff wavelength, is now being produced in 1.7 and 5.3 micron cutoff versions, with deliveries made to ground-based observatories. In preparation for the large number of pixels required in the era of Extremely Large Telescopes, Teledyne has been funded to develop the next generation of infrared array for ground-based astronomy; the 4096×4096 pixel (15 micron pitch) H4RG-15. The first prototype H4RG-15 arrays will produced in 2011, and development completed in 2013.

This paper also provides an update on new developments for adaptive optics, interferometry and solar astronomy. The development of high speed, low noise infrared arrays is reported and the new designs proposed for ground-based solar observatories are presented.

The development of the SIDECAR ASIC focal plane electronics, hardware

and software, is presented. New silicon carbide (SiC) based packaging for image sensors is being developed and the advantages of SiC packaging will be discussed.

7742-15, Session 4

Recent advancements in high-performance CMOS image arrays for astronomical instrumentation

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This paper provides an update of Teledyne's imaging technologies, reporting on the advancements made since the last SPIE Astronomical Instrumentation Symposium was held in 2008. During the past two years, Teledyne has improved visible and infrared quantum efficiency, reduced readout noise, reduced dark current, and improved pixel operability. Teledyne has increased the Technology Readiness Level (TRL) of sensors used in space missions and has delivered sensors to several ground-based and space observatories. Since 2008, several space missions and ground-based telescope instruments have been developed and/or commissioned with Teledyne's sensors. In addition, new types of readout circuits have been developed for specialized applications, and Teledyne has advanced its SIDECAR ASIC focal plane electronics, and developed new packaging for image sensors and electronics.

This paper will report on the advancements made during the past two years for visible (silicon PIN), infrared (HgCdTe) and combined visible-infrared (substrate-removed HgCdTe) sensors.

7742-16, Session 5

High-performance infrared and visible detector arrays for astronomy applications: current state of the art and future developments at Raytheon Vision Systems

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Raytheon Vision Systems (RVS) has developed a family of high performance detector arrays for astronomy and civil space applications. RVS offers unique of-the-shelf solutions to the astronomy community. This paper describes mega-pixel arrays, based on multiple detector materials, developed for astronomy and low-background applications. Several new Astronomy focal plane arrays were developed and tested successfully in 2009.

Large Sensor Chip Assemblies (SCAs) using various detector materials like Si PIN, HgCdTe, InSb, and Si:As IBC, covering a detection range from visible to large wavelength infrared (LWIR) have been demonstrated with an excellent quantum efficiency and very good uniformity. These focal plane arrays have been assembled using state-of-the-art low noise, low power, readout integrated circuits (ROIC) designed at RVS.

Raytheon packaging addresses reliability, precision alignment and flatness requirements for ground-based and space applications. Mosaic packaging will be discussed. The VISTA telescope, for example, contains sixteen 2k × 2k infrared focal plane arrays.

RVS astronomical arrays are being deployed world-wide in ground-based and space-based applications continuing to raise the TRL and MRL ratings. A summary performance data of each of these array types from instruments in operation will be presented including the VIRGO 2K x 2K Array for large format SWIR deployed in the VISTA telescope and the Orion 2K x 2K Array for large format MWIR deployed on the GEMINI telescope.

Future developments will include Large format Arrays beyond 2K x 2K, ROIC improvements, interface control electronics, and MBE/Si progress achieving the high performance that is needed for Astronomy Applications.

7742-17, Session 5

Packaging LBNL 4-side abuttable p-channel CCDs

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Fully depleted, back-illuminated, p-channel CCDs developed at Lawrence Berkeley National Laboratory exhibit high quantum efficiency in the near-infrared (700-1050nm), low fringing effects, low lateral charge diffusion (and hence small, well-controlled point spread function), and high radiation tolerance. We have developed techniques and hardware that have produced space-qualified (TRL6) 4-side abuttable, high-precision detector packages for 10.5µm pixel, 3.5k x 3.5k p-channel LBNL CCDs. These packages are built on a silicon carbide mount, providing excellent rigidity, thermal stability, and heat transfer. Precision fixturing produces packages with detector surface flatness better than 5µm P-V, and overall height and parallelism relative to the mounting surface controlled within 10µm without shimming. These packages with active areas of 36.8mm square may be packed on a detector pitch as small as 44mm. LBNL-developed Front End Electronics packages can mount directly to the detector packages within the same footprint and detector pitch. This combination, along with identically-interfaced NIR detector/FEE packages offers excellent opportunities for high density, high pixel count focal planes for space-based, ground-based, and airborne astronomy.

7742-18, Session 5

Characterization and absolute QE measurements of delta-doped N-channel and P-channel silicon-based imaging arrays

B. C. Jacquot, S. P. Monacos, T. J. Jones, J. Blacksberg, M. E. Hoenk, S. Nikzad, Jet Propulsion Lab. (United States)

Future UV and Optical missions will require detectors with high QE, stable response, broadband response, and low noise. In our laboratory, we are developing a variety of advanced detector arrays and concepts in preparation for future missions. This paper will describe the characterization of such devices under a variety of operating conditions and covering the spectral range from Far UV to Near IR.

In this paper we present results of absolute QE testing of both n-channel and p-channel delta doped silicon arrays. Delta doping allows for low-temperature growth of a highly doped thin silicon layer on the imaging surface of a detector that does not contaminate the underlying high-purity silicon. The delta layer eliminates a dead layer near the surface allowing the near theoretical high-efficiency capture of photogenerated carriers with shallow absorption depth, such as UV photons. The delta layer also acts as an electrode that can be biased to deplete the detector resulting in high resolution back-illuminated imagers. With the addition of AR coatings, detectors can exhibit further enhanced response that expands the range of potential applications. In addition to QE, characteristics such as uniformity, stability, and noise will be discussed as a function of parameters such as temperature and illumination.

7742-19, Session 5

Improving red wavelength sensitivity of CCDs

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The aim is present results on new high-rho e2v sensors together with previous similar device types including bulk CCDs. Both use high resistivity silicon of increased thickness. Depending on available test results and time available, we will also present results on AR coating optimisation including multi-layer optimisations appropriate to the extended wavelength range. [Please read in conjunction with primary abstract].

7742-20, Session 5

Update of the STA1600 10560 x 10560 pixel high-resolution CCD

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A 10560 x 10560 pixel, 95mm x 95mm, full-frame CCD imager with 9x9 μ2 pixel size has been developed for use in professional astronomical applications. Recent results for device performance and systems incorporating the device will be described, including a camera with a 2x2 array of STA1600s. In addition we will describe status of several other large area astronomical CCD imagers.

7742-22, Session 6

Lumped element microwave kinetic inductance detectors for optical to near-IR spectrophotometry

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Microwave Kinetic Inductance Detectors (MKIDs) are a promising, highly multiplexed low temperature detector technology. We report on the development of a new type of UV to Near-IR spectrophotometer based on a lumped element MKID constructed out of a high normal state resistivity superconductor. This new optical lumped element (OLE) pixel has demonstrated the highest energy resolution yet seen in an optical MKID detector. It promises to combine extremely high energy resolution with reasonable quantum efficiency and a very wide bandwidth extending from the UV to K band. We plan to deploy these detectors in an instrument called ARCHONS for the Palomar 200" telescope in Fall 2010.

7742-23, Session 6

Cryogenic trap detector with high-quantum efficiency from 4-28 micrometers

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The Low Background Infrared (LBIR) facility has been developing a trap detector for use as a transfer standard in calibrations of infrared powers down to 1 pW, with 0.1% uncertainty. Blocked impurity band (BIB) devices provide excellent detectivity in the mid-IR but suffer from significant surface reflection and spectral inhomogeneity, drawbacks which can be overcome by a trap detector arrangement. Our BIB-trap is composed of two high-efficiency Si:As BIB detectors in a wedge geometry. Custom-fabricated BIB detectors for use in the trap were designed to maximize internal quantum efficiency and detector absorption. The backside-illuminated detectors have their backing silicon polished away to minimize loss in the substrate and a very thick IR-active layer to maximize absorption in a single detector pass. The trapping arrangement has a seven bounce minimum for incoming photons before escape, rendering total quantum efficiency greater than 98% in the range from 4-28 μm, according to computer modeling. Initial data on the BIB-trap spectral responsivity and noise will be presented, and its potential use in spectral calibrations will be discussed.

7742-24, Session 6

Imaging soft x-ray spectrometers based on superconducting tunnel junction detectors

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X-ray detectors based on superconducting tunnel junctions (STJs) have demonstrated good energy resolution in the soft X-ray energy range 0.1-6 keV. In particular DROIDS (Distributed Read Out Imaging Devices), consisting of a superconducting absorber strip with superconducting tunnel junctions as read-out devices on either end, could combine this high resolving power with a large sensitive area and good soft X-ray detection efficiency.

In this paper we present results on spectroscopic performance of Al and Ta/Al DROIDs with different absorber materials (Ta, Re). Various shapes of the readout STJs are compared with a view to optimizing the absorber fill factor while maintaining good energy resolution. Also different absorber configurations have been explored: the traditional integrated absorber is compared with an absorber deposited after definition of the read-out structure. The latter allows maximising the detection efficiency through thicker layers and different absorber materials. Finally, absorbers which are electrically coupled to the readout structure are compared to insulated absorbers which couple to the readout structure by phonon exchange across a thin dielectric layer.

7742-25, Session 6

Code-division SQUID multiplexers for transition-edge sensor arrays

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Time-division SQUID multiplexing has played an integral role in the success of the transition-edge sensor microcalorimeter arrays that hold the resolution records for non-dispersive detectors over a wide range of energies, including x-rays, gamma rays. However, present time-division and frequency-domain SQUID multiplexing technologies are limited in the number of detectors that can be multiplexed by SQUID noise aliasing and crosstalk considerations, respectively. We have developed a SQUID based code-division multiplexer (CDM) that combines many of the advantages of time-domain and frequency-domain multiplexing and enables a substantial increase in the number of detectors multiplexed for a variety of applications. In our code-division approach, the polarities of the signals coupled to a SQUID amplifier are alternated in the pattern of an NxN Walsh matrix. In this manner, a frame composed of N orthogonal samples can be used to reconstruct the detector signals. Measurements

of prototype multiplexers demonstrating the intrinsic performance advantages of this approach will be presented. In addition, results of efforts towards implementation of CDM specifically to instrument TES x-ray detector arrays will be offered.

7742-26, Session 7

In-orbit performance of avalanche photodiode as radiation detector onboard a pico-satellite Cute-1.7+APD II

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The Cute-1.7+APD II is the third pico-satellite developed by students at the Tokyo Institute of Technology. One of the primary goals of the mission is to validate the use of avalanche photodiodes (APDs) as a radiation detector for the first time in a space experiment. The satellite was successfully launched by ISRO PSLV-C9 rocket in Apr 2008, and has since been in operation for more than 20 months. The Cute-1.7+APD II carries two reverse-type APDs to monitor the distribution of low energy particles down to 9.2 keV trapped in a Low Earth Orbit (LEO), including the South Atlantic Anomaly (SAA) as well as aurora bands. We present the design parameters and various preflight tests of the APDs prior to launch, particularly, the high counting response and active gain control system for the Cute-1.7+APD II mission. Examples of electron/proton distribution, obtained in continuous 12-hour observations, will be presented to demonstrate the initial flight performance of the APDs in orbit.

7742-27, Session 7

Measurements of Si hybrid CMOS x-ray detector characteristics

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The development of Hybrid CMOS Detectors (HCDs) for X-Ray telescope focal planes will place them in contention with CCDs on future satellite missions due to their faster frame rates, flexible readout scenarios, lower power consumption, and inherent radiation hardness. CCDs have been used with great success on the current generation of X-Ray telescopes (e.g. Chandra, XMM, Suzaku, and Swift). However, their bucket-brigade readout architecture, which transfers charge across the chip with discrete component readout electronics, results in clockrate limited readout speeds that cause pileup (saturation) of bright sources and an inherent susceptibility to radiation induced displacement damage that limits mission lifetime. In contrast, HCDs read pixels through the detector substrate with low power, on-chip multiplexer electronics in a random access fashion. Faster frame rates achieved with multi-output readout design will allow the next generation's larger effective area telescopes to observe bright sources free of pileup. Radiation damaged lattice sites effect a single pixel instead of an entire row. Random access, multi-output readout will allow for novel readout modes such as simultaneous bright-source-fast/whole-chip-slow readout. The PSU X-ray group is currently testing 4 Teledyne HCDs, with low cross-talk CTIA devices in development. We will report laboratory measurements of HCD readnoise, dark current, interpixel-capacitance, and IPC's impact on event selection. Additionally, we will report device linearity and energy resolution as a function of energy.

7742-28, Session 8

The DEPFET-based focal plane detectors for MIXS on BepiColombo

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X-ray detectors based on arrays of DEPFET macropixels, which consist of a silicon drift detector with a combined detector/amplifier structure DEPFET as a readout node, provide a convenient and flexible way to adapt the pixel size of a focal plane detector to the resolving power of any given X-ray optical system. Macropixels combine the traditional benefits of an SDD, like scalability, arbitrary geometry and excellent QE even in the low energy range, with the advantages of DEPFET structures: Charge storage capability, near Fano-limited energy resolution, low power consumption and high speed readout. Being part of the scientific payload of ESA's BepiColombo mission, the MIXS instrument will be the first instrument to make using DEPFET macropixel based FPAs in space. MIXS will perform a complete planetary X-ray fluorescence analysis of Mercury's crust with high spectral and spatial resolution. MIXS will contain a focal plane detector consisting of a 64 x 64 macropixel matrix with 300 x 300 square micron pixel size. The main challenges for the instrument are the difficult radiation and thermal environment around Mercury, requiring high speed readout to reduce the impact of thermally generated leakage current within an irradiated detector. Dedicated VLSI integrated readout electronics has been developed for MIXS: a fast, radiation hard, low power, high voltage switch circuit to control the device, and a low noise, high speed amplifier/shaper IC. Detector assemblies have been built and tested both electrically and spectroscopically, screening to select detectors for the flight models is in progress. Results will be presented.

7742-29, Session 8

The IXO wide-field imager

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The Wide Field Imager (WFI) of the International X-ray Observatory (IXO) is based on a large monolithic DePFET (Depleted P-channel Field Effect Transistor) Active Pixel Sensor. With a format of 10 x 10 cm2 and 1024 x 1024 pixels it will cover a field of view of 18 arcmin. The pixel size of 100 x 100 µm2 corresponds to a fivefold oversampling of the telescope's expected point spread function of 5 arcsec. The WFI's basic DePFET structure combines the functionalities of sensor and integrated amplifier with Fano-limited energy resolution and high efficiency from 100 eV to 20 keV. The development of dedicated control and amplifier ASICs allows for high frame rates up to 1 kHz and flexible readout modes. Representative prototypes with a format of 256 x 256 pixels are already under test.

7742-30, Session 8

Quantum efficiency measurements of eROSITA pnCCDs

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For the eROSITA X-ray telescope, which will be launched in 2012, detectors were developed and fabricated at the MPI Semiconductor Laboratory. The fully depleted, backside illuminated pnCCDs have an ultrathin pn-junction as entrance window to improve low-energy X-ray response. The device thickness of 450 µm is fully sensitive to X-ray photons yielding high quantum efficiency of more than 90% at photon energies of 10 keV. An on-chip filter is deposited on top of the entrance window to suppress optical and UV radiation which would interfere with the X-ray observations.

The pnCCD type developed for the eROSITA telescope was characterized in terms of quantum efficiency and spectral response function. The described measurements were performed in 2009 at the synchrotron radiation sources BESSY II and MLS in cooperation with the Physikalisch-Technische Bundesanstalt (PTB). Quantum efficiency measurements over a wide range of photon energies from 3 eV to 20 keV as well as spectral response measurements between 100 eV and 11 keV are presented. For X-ray energies from 3 keV to 10 keV the quantum efficiency of the CCD including on-chip filter is shown to be above 90% with an attenuation of visible light of more than five orders of magnitude. A detector response model is described and compared to the measurements.

7742-31, Session 8

Development of a 3D CZT detector prototype for Laue Lens elescope

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We report on the development of a 3D position sensitive prototype suitable as focal plane detector for Laue lens telescope. The basic sensitive unit is a drift strip detector based on a CZT crystal, (19×8 mm2 area, 2.5 mm thick), irradiated transversally to the electric field direction. The anode side is segmented in 65 strips, that divide the crystal in 8 independent sensor (pixel), each composed by one collecting strip and 7 (one in common) adjacent drift strips. The drift strips are biased by a voltage divider, whereas the anode strips are held at 0 V. Furthermore, the cathode is divided in 4 horizontal strips for the reconstruction of the Z interaction position. The 3D prototype will be made by packing 8 linear modules, each composed by one basic sensitive unit, bonded on a ceramic layer. The linear modules readout is provided by a custom designed front end implementing a set of three RENA3 for a total of 128 channels (or equivalent voxels). The front-end electronics and the operating logics (in particular coincidence logics for polarisation measurements) are handled by a versatile and modular multiparametric back end electronics developed using FPGA technology.

Furthermore we intend to present first functional and performance results obtained using radioactive sources together with a simulation study of the performance achievable by this type of detector as a scattering polarimeter.

7742-32, Session 8

The silicon drift detector for the IXO high-time resolution spectrometer

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The High Time Resolution Spectrometer (HTRS) on board of the International X-ray Observatory (IXO) is a non-imaging instrument simultaneously providing timing and spectroscopic information of the X ray emission by accreting black holes and neutron stars. As the sources are the brightest in the sky and the studies require good photon statistics the instrument design is driven by the capability to operate at extremely high count rates.

HTRS is based on a monolithic multi-channel Silicon Drift Detector (SDD) with 31 cells in a circular envelope and a sensitive volume of 4.5cm2 x 450µm. The SDD concept combines a large sensitive area with a small output capacitance guaranteeing high energy resolution and high count rate capability. To obtain a uniform count rate over the array the sensor is placed out of focus and the formats and areas of the SDD cells are adapted to the telescope's radial intensity distribution. The SDD array will be read out by four dedicated 8-channel ASICs.

7742-34, Session 8

Estimating the eROSITA detector background using Monte-Carlo simulations with Geant4

C. Tenzer, G. Warth, E. Kendziorra, A. E. Santangelo, Eberhard Karls Univ. Tübingen (Germany)

The eROSITA (extended ROentgen Survey with an Imaging Telescope Array) instrument consists of seven individual co-aligned X-ray telescopes - each with its own camera and mirror module. It will be launched on board the Russian satellite Spectrum-RG at the beginning of 2014. A new type of PN-CCD detector will allow imaging with a time resolution of 50 ms in the X-ray energy band from 0.3 keV up to 10 keV.

A Monte-Carlo simulation code using the Geant4 toolkit has been created to assess the internal detector background induced by interactions of the heavy detector shielding with cosmic-ray particles. Besides a brief introduction to the features of the simulation environment created at our institute, the input particle spectrum and flux as well as the postsimulation event treatment and analysis are explained. Different material and thickness configurations for the camera shielding have been studied in their effect on the background. Latest results for the current background level and its spectral shape induced by interactions of cosmic-ray protons with the camera housing are given. In addition, we show results from a study concerning variation of the background level as a function of the CCD thickness.

7742-35, Session 8

First performance measurements with the SIMBOL-X science verification model

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The Simbol-X mission is a projected X-ray space telescope with spectro-imaging capabilities covering an energy range from 500 eV up to 80 keV.

Using a formation flight approach, a focal length between the mirror and the detector spacecraft of 20 m can be achieved, resulting in a so far unrivaled angular resolution and sensitivity in the hard X-ray band. To detect photons within this wide range of energies, a silicon-based "DEpleted P-channel Field Effect Transistor" (DEPFET)-matrix is used as a low energy detector (LED) on top of an array of CdTe-"Caliste" modules, which act as a high energy detector (HED).

A Science Verification Model (SVM) consisting of one LED quadrant in front of one Caliste module has been set up at our institute (IAAT) and is operated under laboratory conditions that approximate the future environment in space. In a first step we used the SVM to test and optimize the performance of the LED operation and data acquisition chain, consisting of a sequencer, an event-preprocessor and an interface-controller which have been developed at our institute to handle the high readout rate of approximately 8000 frames per second.

The final goal is to study the behavior and the interactions of LED and HED operating as one detector system.

We report on the development status of the SVM and its associated electronics and present first results of the currently achieved spectral and imaging performance.

7742-36, Session 8

First x-ray imaging measurements with the new SLAC free-electron laser (LCLS)

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The first light of the recently commissioned AMO beamline with the CAMP experimental beamline detector at SLAC delivered a wealth of new insights in the interactions of very intense and short X-ray beams with atomic clusters, nanocrystals and biological samples. The pulse length of the beam was as short as 3 Femtoseconds with up to 1013 photons in every individual pulse with X-ray energies between 850 eV up to 2.000 eV. We will report about the very first outstanding X-ray images with a pnCCD camera system, originally designed for the XMM Newton mission. The two camera systems installed in the CAMP chamber have a format of 1024 x 1024 pixels each, read out 120 times a second with spectroscopic quality. Single photon counting is performed in the part of the images with sparse photon population while intensity measurements are done in the diffraction peaks with up to 1.000 photons per pixel. We will report about the performance of the new system and lessons learnt for future X-ray missions.

7742-37, Session 8

Test results of the new large area PNCCD for the eROSITA X-ray Telescope

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The new X-ray telescope eROSITA (extended ROentgen Survey with an Imaging Telescope Array) is a main instrument on the Russian new Spectrum-RG satellite, scheduled for launch in 2012. The primary scientific goal of eROSITA is the detection of about 100,000 clusters of galaxies by the means of an all sky survey. This allows a systematic study on the large scale structures in the Universe and will give new information about the nature of dark energy.

The focal plane detector is a 3 cm x 3 cm framestore PNCCD, an advanced successor of the XMM-Newton PNCCD. It has 384 x 384 pixels of 75 µm x 75 µm in the image area and will provide high position, time and spectral resolution as well as a high quantum efficiency for X-ray photons in the energy range from 0.3 keV up to 10 keV. The first flight-identical CCDs have been finished in 2008. Since then, they have been under systematic, extensive study at our test facility. The aim is to optimize the performance of the detectors with regard to several aspects, like charge transfer losses, power comsumption and heat dissipation, radiation hardness, the handling of minimal ionizing particles (MIPs) and ultimately energy resolution. Those parameters can be influenced by the operating voltages, the timing, the temperature and by the electronic design. In this contribution we present test results and the conclusions which can be drawn for the eROSITA flight modules.

7742-95, Session 8

Off-plane x-ray grating spectrometer camera for IXO

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The International X-ray Observatory (IXO) is a merger of the former ESA XEUS and NASA Constellation-X missions, with additional collaboration from JAXA, proposed for launch ~2020. IXO will address the leading astrophysical questions in the 'hot universe' through its breakthrough capabilities in X-ray spectroscopy. The mission covers the 0.1 to 40 keV energy range, complementing the capabilities of the next generation observatories, such as ALMA, LSST, JWST and 30 metre ground-based telescopes. An X-ray Grating Spectrometer is baselined to provide science in the energy range 0.3 to 1 keV at a spectral resolution of / Δ > 3,000 with an effective area greater than 1,000 cm2. This will require an array of soft X-ray enhanced CCDs operating at a modest frame rate to measure the diffracted light in both position and energy. Here we describe the baseline camera for the Off-Plane XGS instrument using mature CCD technology and present on-going technological developments in collaboration with e2v technologies that could enhance the science capabilities of this instrument by extending the Bandpass of the camera down to 0.2 keV.

7742-69, Poster Session

New developments for detector controllers at NOAO

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The Torrent image acquisition system is being developed at NOAO as a follow-on to the MONSOON systems which has been successfully used for instruments at several institutions. The poster will cover the evolution of MONSOON into Torrent and will cover: Motivations, What's gained/What's lost, Major Technological Differences, Goals, plans and first users.

7742-70, Poster Session

Method to implement the CCD timing generator based on FPGA

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The timing generator is an essential module to a CCD imaging system. Many methods to implement this generator have been invented since the CCD's birth. Some old CCD timing generators made by pure digital sequential logic circuits are very complicated. Once a hardware generator has completed, the possibility to modify it is little. Nowadays with the advances in semiconductor manufacturing technology, especially the modern programming logic devices, great changes have taken place in the digital logic design methods. CCD timing generators based on FPGA have become very popular. We also develop a method to implement the CCD timing generator, which is based on the Altera's FPGA integrated development environment (Quartus II) and the VHDL programming. The method takes advantage of the FPGA, the VHDL and the altera's soft-core CPU (Nios II), thus possesses good portability. Using this method, we have built several CCD cameras for different kinds of CCD and different applications in recent years. This paper presents the philosophy and implementation skills of the method. With an instance of the RDCCD camera developed one year ago, we introduce the structure of the timing generator, input and output signals, VHDL program flowchart. We also describe implementation steps of the timing generator in Quartus II, and the interconnections between the generator and the Nios II which is the controller of this generator. Some simulation and testing results are presented and analyzed in the paper.

7742-71, Poster Session

SIDECAR ASIC focal plane electronics for astronomical instrumentation

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The SIDECAR ASIC combines all of the functionality of focal plane electronics into a small mixed signal (analog & digital) CMOS circuit, saving size, weight and power relative to conventional electronics. The low power and small size enables the SIDECAR to be placed in close proximity to a focal plane array in the cold region of an instrument, achieving lower noise and simpler system design. The SIDECAR ASIC was designed to interface directly the H2RG hybrid CMOS image array, and is being used in this configuration in the James Webb Space Telescope and in the instrumentation of several ground-based observatories, as well as being planned for several future missions / facilities.

While designed to interface directly to the H2RG, the SIDECAR has been adapted to operate arrays made by other manufacturers. For example, the SIDECAR is now operating the CCD sensors of the Hubble Space Telescope Advanced Camera for Surveys, and is being prepared to operate the thermal infrared sensor of the Landsat Data Continuity Mission.

This paper presents a summary of the most important technical data of the SIDECAR ASIC, and practical information on how to best utilize the SIDECAR ASIC in ground-based and space-based instrumentation. The paper discusses recent developments in SIDECAR ASIC packaging, electronics, assembly code, and software, and presents the applications in which the SIDECAR ASIC is being used.

7742-72, Poster Session

Characterization and performance of the 4k x 4k Hawaii-2RG Mosaic for PANIC

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The Calar Alto Observatory in Spain, Almería, has begun with its next generation of instruments, and PANIC, the PAnoramic Near-Infrared Camera, is one of them. Its revolutionary optical design and extreme light-weight cryostat allows PANIC to be used at both the 2.2 m and the 3.5 m Telescopes. These characteristics, in combination with its 4k x 4k detector mosaic, make this camera one of the most powerful systems in this observatory.

In order to cover a field of view of approximately 30 arcmin, PANIC uses a mosaic of four 2k x 2k HAWAII-2RG arrays from Teledyne. These are mounted into a molybdenum mosaic assembly plate (GL Scientific) that integrates the four chips as separate modules into one single thermal and vibration stable structure allowing precision alignment and physical flatness between all 4 detectors.

The MPIA is the responsible institute for the infrared detectors, readout electronics and software. The mosaic was delivered in December 2008 allowing a dedicated test phase for the corroboration of the basic functioning of the arrays together with the newly-developed in-house readout electronics. The characterization process is on the way, and the results of this process including, among others, system gain, readout noise, dark current and linearity will be presented. The performance of the system as a whole (readout electronics, software and detectors), as well as the in-house readout electronics capabilities will also be discussed.

7742-73, Poster Session

Repackaging and characterization of a HgCdTe CMOS infrared camera for the New Solar Telescope

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In order to satisfy more observational requirements from the new-built 1.6-meter New Solar Telescope (NST), a 1024 × 1024 HgCdTe TCM8600 CMOS camera manufactured by the Rockwell Scientific Company (now named as Teledyne Technologies Company) is being repackaged and upgraded at Infrared Laboratories, Tucson. A new ND-5 dewar is designed to house the TCM8600 with a low background filter wheel, inverted operation and at least 12 hours of hold time. The repackaged camera will be used for high-resolution IR photometry at the NST Nasmyth focus and high-precision IR spectro-polarimetry in the NST Coude room. A characteristic evaluation will be carried out at Big Bear Solar Observatory. In this paper, we describe the repacking, presents a series of measured performance parameters including linearity, readout noise, gain, full well capacity, hot pixels, dark, flat field, frame rate, vacuum, low temperature control, etc., and show some scientific observation results.

7742-74, Poster Session

Comparisons of the performances of a HAWAII2RG operated with an in-house acquisition system and a cold SIDECAR ASIC

G. Smadja, Institut de Physique Nucléaire de Lyon (France); C. Cerna, Ctr. de Physique des Particules de Marseille (France); A. Castera, Institut de Physique Nucléaire de Lyon (France); A. Ealet, Ctr. de Physique des Particules de Marseille (France)

A 1.7µm cutoff HAWAII2RG is operated with two acquisition systems: an in house acquisition system based on a mezzanine board which includes a 32 bit RISC microprocessor with a linux operating system and a Teledyne SIDECAR operating at cold temperature. The performances of the two setups in terms of gain conversion and readout noise are compared.

7742-75, Poster Session

Reciprocity failure in 1.7 µm cut-off HgCdTe detectors

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The Detector Characterization Laboratory at NASA/GSFC has investigated the reciprocity failure characteristics of 1.7µm cut-off HgCdTe devices provided by Teledyne Imaging Sensors to the Hubble Space Telescope (HST) Wide Field Camera 3 (WFC3) project. The reciprocity failure follows a power law behavior over the range of fluxes tested (0.1-10^4 photons/second). The slope of the power law varies among detectors, ranging from ~0.3-1%/dex at 1.1µm, which is much smaller than the ~6%/dex effect observed with the HST NICMOS 2.5µm cut-off detectors. Reciprocity failure is nevertheless an important effect in the calibration of WFC3 data, as well as in other applications in which there is a large difference in flux between the photometric standards and the scientific sources of interest.

7742-76, Poster Session

Characterization of multicolor Type-II InAs/GaSb strained-layer superlattice photodetectors for use in astronomical observation

A. Wong, M. J. Nelson, Univ. of Virginia (United States); E. A. Plis, The Univ. of New Mexico (United States); T. Vandervelde, Tufts Univ. (United States); M. F. Skrutskie, Univ. of Virginia (United States); S. Krishna, H. Kim, A. Khoshakhlagh, S. A. Myers, The Univ. of New Mexico (United States)

We report on the testing of a set of InAs/GaSb multicolor strained-layer superlattice photodetectors fabricated by the Center for High Technology Materials at The University of New Mexico. These photoconductors are nBn (n-type, barrier, n-type) devices sensitive to near-IR and mid-IR wavelengths. The wavelength sensitivities of these devices are a function of the applied forward and reverse bias. We present measurements of the dark current, wavelength response, and quantum efficiency of these photodetectors measured at both cryogenic and room temperatures.

7742-77, Poster Session

Testing of an extended-wavelength InGaAs array in an astronomical spectrograph

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We report on the integration of a low dark current extended wavelength (2.3um cutoff) InGaAs array into the CorMASS spectrograph. The InGaAs array was fabricated onto a SB-206 512x512 ROIC by Goodrich/Sensors Unlimited and subsequently went through a series of lab characterization tests at the University of Virginia demonstrating dark current performance of better than 10 e-/s. CorMASS is a cross-dispersed R=300 near-infrared spectrograph, originally based on a NICMOS3 HgCdTe 2.5um cutoff array. When deployed on a telescope this configuration will rigorously exercise the dark current performance and calibration stability of this device.

7742-78, Poster Session

Radiation hardness studies of InGaAs and Si photodiodes at irradiation energies of 30, 52, 98 MeV and fluences to 10^{10} protons/cm^2

B. J. Baptista, S. L. Mufson, Indiana Univ. (United States)

The Joint Dark Energy Mission (JDEM) will be using photodiodes as calibration detectors on the focal plane and for monitoring of internal calibration light sources. JDEM requires space qualified Si and InGaAs photodiodes for visible to NIR coverage. We are investigating the effects of proton radiation damage on the responsivity as a function of wavelength as well as the change in dark current at energies of 30, 52, and 98 MeV with fluences up to 10^10 protons/cm^2 at the Indiana University Cyclotron Facility. Both monochromator and narrow band filter methods are used to measure these effects to 2% precision traceable to NIST standards. Five different manufactures of 1.5-3mm diameter InGaAs photodiodes were chosen, and a single manufacturer for 3mm Si photodiodes. Three devices from each manufacture were used, one device at each energy. An extra Si and InGaAs device remains unirradiated to determine the measurement precision over the course of the experiment. All measurements of responsivity are ratios to a NIST calibrated photodiode. This ratio allows us to compute the relative change in the responsivity of the photodiodes under test.

7742-79, Poster Session

Experiment on the radiation damage evaluation for CCD7899

Q. Song, National Astronomical Observatories (China)

The E2V CCD 7899 is chosen as the image detector of the space solar telescope, an expected space astronomical project of China in near future. In order to predict the radiation damage of the CCDs in the environment of the space solar telescope's 3-years-long mission on orbit, a serials of tests are processed and the radiation hardness of the CCD is evaluated. After analysis, a 3mm thick aluminum shield is suggested.

7742-80, Poster Session

The challenge of highly curved monolithic imaging detectors

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Current assemblies of image sensors and optics rely on the optics to project a corrected image onto a flat detector. While scientific large size CCDs (49mm square) have been produced unintentionally with a spherical radius of convex curvature of around 5m, in the past most efforts have concentrated onto flattening the light sensitive detector silicon area as best as possible for both scientific state-of-the-art systems, as well as commercial low cost consumer products. In some cases curved focal planes are mosaicked out of individual flat detectors, but a standard method to derive individual spherically curved large size detectors has not been demonstrated.

In a recent optical design study of CODEX - a visible spectrograph planned for the European Extremely Large Telescope (E-ELT) - it was determined that a significant simplification of the optical design

- accompanied by an improvement of the image quality - could be achieved through the application of large format (90mm square) concave spherically curved detectors with a low radius of curvature (500 to 250mm).

This paper summarizes important developments in the area of curved detectors in the past and their different technical approaches mostly linked to specific thinning processes. ESO's specifications for an ongoing feasibility study are presented. First results of the latter are described with a link to theoretical and practical examinations of currently available technology to implement curved CCD and CMOS detectors for scientific application.

7742-81, Poster Session

Characterization of deep-depletion Hamamatsu CCDs for the Gemini multi-object spectrograph

T. Hardy, R. G. Murowinski, J. M. Fletcher, D. A. Erickson, A. Anthony, K. Szeto, J. Dunn, National Research Council Canada (Canada)

We have performed extensive characterization and performance optimization of back-illuminated deep-depletion CCDs from Hamamatsu Photonics. Three of these 2048x4096, three-side buttable devices will replace the current CCDs in the Gemini Multi-Object Spectrograph to improve the performance of the instrument in the red and near-infrared wavelengths. We describe our testing campaign and report on the results.

7742-82, Poster Session

Centroid precision as a function of total counts in a windowed CMOS image of a point source

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We performed a simple experiment to determine the precision we might expect when using a CMOS detector to provide the position error signals to a telescope's closed-loop guider system. We find that, under non-optimized operating conditions, the error in the computed centroid is dependent on the counts in the point image only when the peak counts in the image are below a certain threshold. This result suggests the required minimum brightness for acceptable guide stars using this CMOS setup.

7742-83, Poster Session

Characterization and performance of hyper suprime-cam CCD

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Hyper Suprime-Cam (HSC) is a super wide field imaging camera with the field of view about ten times larger than that of the Subaru Suprime-Cam (SC). HSC is expected to make the survey speed considerably faster than SC, while maintaining the high image quality of SC. Its field of view of 1.5 degree in diameter is covered with 116 2k x 4k fully depleted CCDs with, 15 um pixels developed by Hamamatsu Photonics K. K. (HPK) and NAOJ. The visible-enhanced type CCDs to be used for HSC have higher quantum efficiency (QE) in a wider wavelength range, especially in the blue region, than those for the SC. HPK improved the assembly process to realize better flatness. We have started acceptance tests of the CCDs being delivered to NAOJ from HPK. The charge transfer efficiency (CTE) will be measured with the X-ray source of 55Fe, and the linearity will be evaluated with an LED light source for all the delivered CCDs. We will evaluate the QE for half of the CCDs by using the NAOJ-developed QE measurement equipment. In this paper, we report the results from the acceptance tests and characterization of the CCDs.

7742-84, Poster Session

CCD imaging technique for moving objects in the field of view

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In the optical positioning observations to the near earth objects (NEO) such as artificial earth satellites, spacecraft, space debris, asteroids and so on, those relative measurement methods (i.e., the measured object relative to the calibration stars) are commonly used to improve the astrometric position accuracy of the object. However, due to the characteristics of motion of the measured object and the restrictions on current CCD imaging technology, single positioning accuracy of these relative measurement methods for the object is not high. This is because there is relative motion between the calibration stars and the measured object in the field of view of the telescope. This paper analyzes characteristics of relative movement of the objects on the GEO and the stars in the field of view of an equatorial telescope, and CCD imaging effects for these object and stars, then present a new CCD imaging technique termed as dual-speed tracking imaging on same frame for moving and still objects, short for DSTIS. That is, one half of the CCD photo-sensing area is used to image moving objects in the field of view in drift scan mode, another half to image simultaneously still objects in the field of view in stare mode. We explore the possibilities for developing this camera and it applications. A prototype camera controller has been built in our laboratory. Thus the paper also describes the the structure of the controller, the implementation method and skills, and some experimental results.

7742-85, Poster Session

Interpixel crosstalk in a 3D-integrated active pixel sensor for x-ray detection

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MIT Kavli Institute for Astrophysics and Space Research and MIT Lincoln Laboratories have developed an active pixel sensor for use as a photon counting device for imaging spectroscopy in the soft X-ray band. A silicon-on-insulator (SOI) readout circuit was integrated with a high-resistivity silicon diode detector array using a per-pixel 3D integration technique developed at Lincoln Laboratory. We have tested these devices at 5.9 keV and 1.5 keV. Here we examine the interpixel crosstalk.

7742-87, Poster Session

Mosaic packaging advancements for large-format devices: current and future capabilities at Raytheon Vision Systems

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The desire for larger and larger format arrays for astronomical observatories - both ground and space based - has fueled the development of very large focal plane array (FPA) packaging technology.

This has generated new designs and the use of new materials suitable for high reliability and long thermal cycle performance when exposed to operating temperatures from ambient to below 10 Kelvin.

We present the design and performance of a series of package designs meeting these requirements evolving from single large mega-pixel arrays through the multiple detector arrays utilizing spaced and 4-side butting. This butting arrangement permits future detector arrays of significant size of approaching a meter on a side for visible and infrared astronomy.

This packaging technology and the use of thermally compatible materials enable the large format packaging of all detector and Readout Integrated Chip (ROIC) combinations in current production.

7742-88, Poster Session

Electroplated indium bumps as thermal and electrical connection of NTD Ge sensors for the fabrication of microcalorimeter arrays

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We are developing a method to build arrays of Ge-based microcalorimeters for the detection of soft X-rays using micro-photolithographic techniques. Arrays of germanium sensors have already bean built, and we are presently working on the electrical and thermal connection between the sensors and the interconnection electrical tracks, that lay on a substrate acting as mechanical support and thermal sink. The geometry of the sensors, that have a square base truncated pyramid shape, makes feasible a connection through indium soldering. We describe a technique based on microlithography and electroplating adopted to grow Indium bumps of a few tens of square microns of area and several microns high, on top of the contact pads patterned on the substrate. The sensor array can be placed over the bumps, and a subsequent baking would melt the indium, soldering the sensors to the pads.

7742-89, Poster Session

Packaging CCD's for space applications

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Silicon Charged Coupled Devices (CCDs) have proven to be powerful optical imaging devices in a variety of space missions. The packaging and the mounting of these devices to the focal plane in a space telescope has to meet very demanding specifications. Focal planes increasingly use a mosaic of many CCD's so the packages usually have to be four side buttable. The telescope optics places stringent flatness tolerances on the focal surface, requiring that each detector package be flat relative to its mounting surface and that the overall package thickness be well controlled. The focal plane is usually cooled to below -100 C by edge contact at a few locations, requiring the focal plane and detector materials to be good thermal conductors with little temperature gradient across them and that the coefficient of thermal expansion of all materials used be well matched to prevent stresses and distortions during the cooling and heating cycles. We have developed a design for packaging Charged Coupled Devices that meet the stringent requirements of space applications, although the design is also useful for any large ground-based mosaic. We have constructed and assembled prototype packages using this design. Testing of these prototypes has demonstrated that these packaged CCDs are flight worthy. The design, construction, and testing of these prototypes are described in this paper.

7742-90, Poster Session

Utilizing a commercial cRIO FPGA platform to operate a microshutter array on a UV sounding rocket mission

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We are developing a microshutter control system using National Instruments cRIO-9074 hardware to be flown on a UV sounding rocket mission. The requires the microshutter array to block out bright sources on the sky similar to the way they are operating in the NIRSpec instrument on JWST. To accomplish this, a heritage 128x64 microshutter array left over from the JWST development program will be utilized. During the flight, the FPGA residing in the cRIO will actively control the opening and closing of the microshutter array based on data it collects from the UV detectors. The data collected from the detectors will represent a 2D histogram, where each shutter receives a bin. From this, the shutters with the highest bin values will be closed.

The NI cRIO-9074 is a 2 million gate FPGA chassis with 8 expansion ports, which can be populated with a multitude of differing I/O modules. The FPGA programming is easily accomplished utilizing Labview. The entire cRIO package, software and expansion cards had a cost of less than $10k. The benefits to this approach are two fold. Not only does this represents a dramatic cost savings to the mission had custom hardware being developed and used, but it also allowed for rapid development of the system as we are not waiting for circuit boards and associated hardware to be designed and constructed. This mission also represents a milestone as this will be the first time the microshutters, as well as, a CRIO module will be flown on a sounding rocket.

7742-91, Poster Session

Radiation testing of CCD's for space applications

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Silicon Charge Coupled Devices (CCD's) have proven to be powerful optical imaging devices in a variety of space missions. The high radiation levels in space require highly radiation resistant devices. This article reports the results of radiation resistance tests of fully depleted p-channel Charge Coupled Devices (CCDs) developed at the Lawrence Berkeley National Laboratory for imaging applications in space. Several such devices were irradiated by 12 MeV protons at the tandem accelerator at the Wright Nuclear Structure Laboratory at Yale University by doses up to 8 x 10**10 protons/cm2. The equivalent dose at an orbit near L2 for a six year mission in space was estimated to be an equivalent 1 x 10**9 12 MeV protons/cm2. The performance of the CCDs was measured both before and after irradiation. The charge transfer efficiency CTE was degraded from 0.999999 before irradiation to 0.999996 after the expected six year dose. The dark current, which was 3 electrons/pixel/hour before irradiation, is degraded to an equilibrium rate of 15 electrons/pixel/hour in orbit. We conclude that the performance of these devices is quite acceptable for high precision imaging in a space mission. The beam and instrumentation to carry out these tests at the Yale tandem

accelerator and the results of the measurements of the performance of the CCD's both before and after these irradiations will be described in this paper.

7742-92, Poster Session

New optical modalities utilizing curved focal plane imaging detector devices and large arrays for terrestrial and spaceborne telescopes

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As terrestrial and spaceborne astronomical telescopes advance in multi-functional design sophistication, incorporating greater spectral resolutions, the utilization of curved focal plane CCD and CMOS imaging detectors, contoured to match the telescope's Petzval field of curvature, provides a fundamental and novel optical simplicity facilitating new imaging frontiers in astronomical research. For space based telescopes, curved focal plane detector devices require significantly fewer optics than their flat counterparts, which require field flattening optics, in achieving maximum imaging resolutions for adjoining spectrometers or imaging cameras. Consequently, with fewer optics comes greater room to place other optics within the same space to accomplish other tasks, providing much greater diversification of observing functions and techniques reserved simultaneously for the telescope. Included within this is the operational capability of producing multi-wavelength spectrometers gathering data concurrently at a multitude of selected wavelengths, with greater sensitivity, reliability, size reduction, and operational longevity of the restructured optical system. Specialized applications involving optical interferometry are also achievable with further enhancements when the curved detectors are applied specifically to refine or maximize detection of fringes, and when employing occulting mask algorithms for existing light paths. For planetary surface mapping space probes, curved focal plane detection provides real-time 3D multi-perspective image acquisition for streaming 3D data sets, replacing onboard or remote computationally intensive 3D reconstructions used for examining terrestrial surface features performed with corresponding flat detectors. For Earth based telescopes, where mass of the telescope's optics are not so constrained, more degrees of freedom are also part of the benefits introduced by curved focal plane detector device optimization. Associated with the very large Petzval radii of curvature for very large and extreme telescopes within this class are wide field spatial distortions which are instantaneously corrected when arrays of curved CCD's or CMOS devices are joined homogeneously and precisely together along the converging field of curvature, without field flattening optics, insuring complete full field detection superior to flat facet detectors which compromise the telescope's imaging field curvature detection abilities. Also at this scale, deformable mirror segments may be linked dynamically to corresponding flexible curved detectors, or their arrays, positioned at the telescope's field of curvature focal plane, enabling an advanced method of adaptive optics which would operate significantly faster than conventional adaptive optics systems. For such large telescopes, this feature would serve as a necessary requirement in correcting major atmospheric aberrations at sufficient speeds to accommodate the telescopes' much larger apertures and fields of view.

7742-93, Poster Session

Controller and data acquisition system for SIDECAR ASIC driven HAWAII detectors

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SIDECAR is an Application Specific Integrated Circuit (ASIC), which can be used for control and data acquisition from near-IR HAWAII detectors offered by Teledyne Imaging Sensors (TIS), USA. The standard interfaces provided by Teledyne are API and socket servers running under MS Windows platform. These interfaces communicate to the ASIC (and the detector) through an intermediate card called JWST ASIC Drive Electronics (JADE2). As part of an ongoing programme of several years, for developing astronomical focal plane array (CCDs, CMOS and Hybrid) controllers and data acquisition systems (CDAQs), IUCAA is currently developing the next generation controllers employing Virtex-5 family FPGA devices. We present here the capabilities which are built into these new CDAQs for handling HAWAII detectors. In our system, the computer which hosts the application programme, user interface and device drivers runs on a Linux platform. It communicates through a hot-pluggable USB interface (with an optional optical fibre extender) to the FPGA-based card which replaces the JADE2. The FPGA board in turn, controls the SIDECAR ASIC and a HAWAII-2RG detector, both of which are located in a cryogenic test Dewar set up which is liquid nitrogen cooled. The system can acquire data over 1, 4, or 32 readout channels, with or without binning, at different speeds, can define sub-regions for readout, offers various readout schemes like Fowler sampling, up-the-ramp etc. In this paper, we present the perfromance results of our system.

7742-94, Poster Session

Gamma radiation damage study of 0.18 µm process CMOS image sensors

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A 0.18 µm process CMOS image sensor has recently been developed by e2v technologies plc. with a 0.5 megapixel imaging area consisting of 6 × 6 µm 5T pixels. The sensor is able to provide high performance in a diverse range of applications including machine vision and medical imaging, offering good low-light performance at a video rate of up to 60 fps. The CMOS sensor has desirable characteristics which make it appealing for a number of space applications. Following on from previous tests of the radiation hardness of the image sensors to proton radiation, in which the increase in dark-current and appearance of bright and RTS pixels was quantified, the sensors were then subjected to a dose of gamma radiation. Knowledge of the performance after irradiation is important to judge suitability for space applications and radiation sensitive medical imaging applications. This knowledge will also enable image correction to mitigate the effects and allow for future CMOS devices to be designed to improve upon the findings in this paper. One device was irradiated to destruction after 120 krads, and four other devices were irradiated between 5 and 20 krads. This paper explores the resulting radiation damage effects on the CMOS image sensor such as increased dark current, flat-band voltage shifts, and a central brightening effect, and discusses the implications for use of the sensor in space applications.

7742-38, Session 9

A fast model of radiation-induced electron trapping in CCDs for implementation in the Gaia data processing

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The European Space Agency's Gaia mission is scheduled for launch in 2012. It will operate at L2 for 5 years, rotating slowly so that its two optical telescopes will repeatedly observe more than one billion stars. The resulting data set will be iteratively reduced to solve for the relative position, parallax-distance and proper motion of every star, yielding a three dimensional dynamical model of our galaxy. The focal plane contains 106 large area silicon CCDs continuously operating in TDI mode

at a line rate synchronised with the satellite rotation.

One of the greatest challenges facing the mission is radiation damage in the CCDs which will cause charge loss and image distortion. This is particularly severe because the large focal plane is difficult to shield and because the launch will coincide with solar maximum. Despite steps taken to minimize the effects of radiation (e.g. regular use of charge injection), the residual distortion will need to be calibrated during the pipeline data processing. Due to the volume of data involved, this requires a trapping model which is physically realistic, yet fast enough and simple enough to implement in the pipeline. The current prototype Charge Distortion Model will be presented. This model was developed specifically for Gaia in TDI mode. However, an imaging mode version has already been applied to other missions, for example, to indicate the potential impact of radiation damage on the proposed Euclid mission.

7742-39, Session 9

Comparison of a fast analytical model of radiation damage effects in CCDs with experimental tests and detailed Monte-Carlo simulations

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ESA's mission Gaia aims to create the most complete and accurate stereoscopic map of the Milky Way by collecting parallaxes, proper motions, radial velocities, and astrophysical parameters for one billion celestial objects. The required astrometric accuracy is extreme, e.g., the end of mission parallax error is required to be 12-25 micro-arcseconds for a 15th magnitude star. The corresponding requirement on the residual centroiding error per CCD transit is ~ 0.01 pixels (~ 0.6 milli-arcseconds).

During the 5-year mission lifetime, solar protons will collide with the satellite's focal plane and create charge traps in its 106 CCDs. For all Gaia measurements this will lead to significant charge loss, which will cause a decrease in precision. For the astrometric data the distortion of the PSF will lead to biases in the image location measurement of up to 10 milli-arcseconds for a 15th magnitude star. To mitigate these effects the Gaia Data Processing and Analysis Consortium developed a scheme that necessitates simulating the stellar image distortion through a fast analytical charge transfer inefficiency model called CDM (charge distortion model).

We will discuss the performances of the current best CDM candidate. The validation procedure and results will be described with a particular focus on how we used a combination of experimental and synthetic data to elaborate and enhance the model. The experimental tests will be introduced as well as the detailed physical Monte-Carlo simulation we used to produce the synthetic data.

7742-40, Session 9

Silvaco ATLAS model of ESA's Gaia satellite e2v CCD91-72 pixels

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The Gaia satellite is a high-precision astrometry, photometry and spectroscopic ESA cornerstone mission, currently scheduled for launch in 2012. Its primary science drivers are the composition, formation and evolution of the Galaxy. Gaia will achieve its unprecedented positional accuracy requirements with detailed calibration and correction for radiation damage. At L2, protons cause displacement damage in the silicon of CCDs. The resulting traps capture and emit electrons from passing charge packets in the CCD pixel, distorting the image PSF and biasing its centroid. Microscopic models of Gaia's CCDs are being developed to simulate this effect. The key to calculating the probability of an electron being captured by a trap is the 3D electron density within each CCD pixel. However, this has not been physically modelled for the Gaia CCD pixels. In Seabroke, Holland & Cropper (2008), the first paper of this series, we motivated the need to calculate this using specialised 3D device modelling: Silvaco's physics-based, engineering software: the ATLAS device simulation framework. In Seabroke, Holland, Burt & Robbins (2009), the second paper of the series, we presented our first results using ATLAS, successfully benchmarking it against other simulations and test device measurements. In this paper, the third of the series, we present our 3D ATLAS model of the Gaia e2v CCD91-72 pixel, including buried and supplementary channels and an anti-blooming drain. We map how electron density and charge packet size varies as a function of position within the pixel and the number of electrons within the charge packet.

7742-41, Session 9

The effects of radiation damage on the spectral resolution of the Chandrayaan-1 x-ray spectrometer

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The Chandrayaan-1 X-ray Spectrometer (C1XS) was launched onboard the Indian Space Research Organisation (ISRO) Chandrayaan-1 lunar mission in October 2008. The instrument consisted of 24 swept-charge device silicon X-ray detectors providing a total collecting area of ~24 cm^2, corresponding to a 14 degree field of view (FWHM), with the ability to measure X-rays from 0.8 - 20 keV. During the 10 months the spacecraft was located in orbit around the Moon a number of solar flare X-ray events were detected, along with calibration data from X-ray sources housed inside the movable door of the instrument. This paper presents a study of the degradation in spectral resolution of the measured X-ray calibration lines, comparing those recorded at intervals during the mission lifetime with ground based calibration data collected prior to the launch of the instrument. An overview of the simulated radiation environment the detectors were expected to be subjected to is provided and discussed in light of the actual radiation damage effects on the spectral resolution observed in flight.

7742-42, Session 9

Charge trap identification for proton-irradiated p+ channel CCDs

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Charge trapping in bulk silicon lattice structures is a source of charge transfer inefficiency (CTI) in CCDs. These traps can be introduced into the lattice by low-energy proton radiation in the space environment, decreasing the performance of the CCD detectors over time. Detailed knowledge of the inherent trap properties, including energy level and cross section, is important for understanding the impact of the defects on charge transfer as a function of operating parameters such as temperature and clocking speeds. This understanding is also important for mitigation of charge transfer inefficiency through annealing, software correction, or improved device fabrication techniques. In this paper, we measure the bulk trap properties created by 12.5 MeV proton irradiation on p+ channel, full-depletion CCDs developed at LBNL. Using the pocket pumping technique, we identify the majority trap populations responsible for CTI in both the parallel and serial transfer processes. We find the dominant parallel transfer trap properties are well described by the silicon lattice divacancy trap, in agreement with other studies. While the properties of the defects responsible for CTI in the serial transfer

are more difficult to measure, we conclude that divacancy-oxygen defect centers would be efficient at our serial clocking rate and exhibit properties consistent with our serial pocket pumping data.

7742-43, Session 10

Fully digital image sensor employing sigma-delta indirect feedback ADC with high-sensitivity to low-light illuminations for astronomical imaging applications

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We describe a fully digital CMOS image sensor with column-parallel analog to digital conversion that realizes the advantages of an oversampling $\Delta\Sigma$ ADC in a 3 transistor, 36% fill-factor design. This design is suitable for high-dynamic range, low power, and excellent low-light response applications ranging from wireless surveillance imaging to astronomical imaging applications. The $\Delta\Sigma$ design places the readout transistor within the modulator loop so the noise shaping of the $\Delta\Sigma$ modulator reduces its noise contribution, and thereby improves low light response in comparison to other state-of-art designs. In addition, reset noise and offset related FPN are removed by the design without the need for traditional power demanding correlated double sampling.

Unlike previous $\Delta\Sigma$ image sensor implementations that utilize in-pixel circuits to provide feedback charge to the photodiode, this implementation utilizes column-level indirect feedback, which allows more precise control i.e., lower LSB values, and eliminates the DAC switching noise and leakage that was limiting the low-light performance of previously reported $\Delta\Sigma$ imagers.

We fabricated a prototype image sensor in 0.35µm TSMC technology. The prototype included a 128 x 128 array of conventional 3T pixels and on-chip column-level comparators. The current design utilized off-chip digital circuits including a decimation filter and feedback DAC multiplexed to each column. The sensor has a measured intra-scene DR of 91 dB and peak SNR of 54 dB. The measured readout noise of the prototype is 37.8µV achieved for an exposure time of 33ms, which is the lowest voltage noise reported for any fabrication technology.

7742-44, Session 10

ASIC chip set for control and readout of astronomical CCDs

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Two application specific integrated circuits (ASICs) have been developed to implement a complete CCD readout controller. The ASIC designs accommodate cryogenic operation so that they can be operated adjacent to the cold detectors. In addition, the designs employ techniques to allow operation in a space radiation environment. One ASIC contains four channels of correlated double sampling and 14-bit ADC. The other provides bias voltages and clocking to the CCD. Both are controlled with a simple LVDS interface. We report on the status of the implementation and packaging and operation of the ASICS with a CCD.

7742-45, Session 10

SIDECAR ASIC at ESO

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Teledyne Imaging Sensors developed a miniturized controller on chip, the SIDECAR application-specific integrated circuit (ASIC). This ASIC allows driving the HxRG family of detector with up to 32 channel per single chip. It provides all the functionality of FPA drive electronics to operate visible and infrared imaging detectors with a fully digital interface. ESO has evaluated this chip for the use in ground based Astronomy and has build its own digital interface card based on FPGA technology running under the standard ESO Linux software enviroment. We have tested this interface with a H2RG HyViSI detector in 32 channel readout mode at cryogenic temperatures. The SIDECAR has been evaluated and the performance results have been compared to those obtained with external electronics. We find that the SIDECAR ASIC provides performance equal to optimized external electronics but significant advantages to system design.

7742-46, Session 10

Description of the UCAM detector control system with particular emphasis to a development of 4K x 4K CCD camera systems

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This paper describes the features and functionality of the UCAM (UKATC Universal Camera Control and Data Acquisition) detector control system with particular emphasis on development and testing of two 4K x 4K CCD camera systems built recently at UKATC and delivered to a group of telescopes in India. These two camera systems use two variants of an e2v CCD203 device; a 4kx4k standard back-thinned device and a deep depleted silicon device. Apart from the expected differences with the spectral response of these devices, other performance differences have been observed between the two systems such as conversion gain non-linearity, electrical crosstalk between outputs, fringing etc. which are thought to be related to the silicon thickness. Both these detectors show charge trapping during device power on or when saturated. The effects of this charge trapping and a solution implemented to minimise it will be presented. The configuration of the UCAM system, custom built detector mount and fanout board and the overall performance of these camera systems will also be presented.

7742-96, Session 10

Optimization of noise performance of low-background detector arrays

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The performance of the 2k x 2k Teledyne H2RG detectors is key to the success of the JWST mission. For broad band imaging, where background limited sensitivity is quickly reached, the key parameter is the quantum efficiency of the detectors, which is, in general, very good. For near infrared spectroscopy and narrow band imaging, we cannot generally reach the background limit, so instrument sensitivity is directly dependent on the read noise of the detector. We have initiated a program to analyze the noise characteristics of the H2RG detectors, studying the correlations among the detector outputs and with the reference output, as well as the temporal correlations in a given detector section. Using the measured characteristics of the noise correlations, we can determine the optimal coefficients for the removal of correlated noise as a function of frequency. By using available reference sources and adding more frequent references, we have been able to reduce the noise by a factor of two. We find that the detectors have significantly lower noise that observed in prior tests, and can offer significant improvements in the performance of the JWST instruments. We will present the analysis and mitigation techniques, discuss prospects for further improvements with existing detectors, and describe considerations for improvements in next-generation detectors.

7742-48, Session 11

High-throughput processes for high-performance silicon imagers

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High performance imagers in the ultraviolet/optical/near infrared are required for future missions and instruments under planning. Silicon imagers achieving near ideal performance will be required. To achieve the highest performance possible, back illumination in essential. The delta-doping technique, invented and developed at JPL offers near ideal performance in this spectral range. In an era of gigapixel focal planes, the need for high performance imagers remains with the additional requirements of producing such devices with high throughput and high yield. We will report on exciting new developments in our laboratory that will take our end-to-end post fabrication processing to a new level. We present the work on high throughput, high yield processes for high performance silicon imagers including using a newly acquired and installed silicon molecular beam epitaxy (MBE) which is capable of high capacity delta doping for back illumination of scientific imagers of CMOS, CCD, or hybrid design.

7742-49, Session 11

The photometric stability of delta-doped detectors

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In this paper, we present a theoretical and experimental study of surface passivation by delta-doping to demonstrate and analyze the photometric stability of delta-doped detectors. Surface passivation of back-illuminated detectors has recently attracted considerable attention in the astronomical community because of the critical importance of photometric stability and the recent discovery of quantum efficiency hysteresis in the Wide Field Camera 3 detectors. Surface-related instabilities and noise have plagued solid-state imaging detectors since the 1970's, when NASA first invested in charge-coupled devices (CCDs) for astronomical instruments in space. Such instabilities are especially problematic in the deep ultraviolet, where photons carry sufficient energy to damage the surface. Using molecular beam epitaxy to achieve subnanometer control of the surface composition, delta-doping completely eliminates quantum efficiency hysteresis in back-illuminated CCDs and CMOS imaging arrays. Experimental data affirm the stability of delta-doped detectors, even under intense illumination by Lyman-alpha radiation at 121.6 nm. Bandstructure calculations elucidate the physics of surface passivation by delta-doping, and provide both qualitative and quantitative understanding of the mechanisms of isolation and decoupling of surface from bulk that is achieved by delta doping and other surface passivation technologies.

7742-50, Session 11

A high-performance projector for laboratory emulation of gravitational weak lensing observations from space

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Several space missions have been proposed to infer the distribution of dark matter and the nature of dark energy by measuring sub percent average elongation of the images of background galaxies due to the bending of light by the intervening matter. Since most of the Weak Lensing signal comes from the most distant galaxies, which are barely resolved, it is vitally important to develop and verify procedures to correct for systematic shape measurement errors caused by detectors, which can easily exceed the 0.1% goal for residual ellipticity. We describe the opto-mechanical design and tolerance analysis for a projector, which relays images from sub-micron resolution chrome-on-glass masks to the detector with PSF ellipticity approaching the post calibration goals. Thousands of simulated galaxies and PSF calibration stars can be measured simultaneously over the entire 40 mm by 40 mm field to obtain sufficient statistical precision to emulate the actual Weak Lensing observation, using representative PSF size and shape, intensities, observing cadence and image dithering for resolution recovery from undersampled data. Missions under consideration are being driven to coarser plate scales to maximize field of view (or minimize cost), increasing the difficulty of correction of detector induced shape errors. This experimental setup is intended to allow us to validate and refine the correction of detector artifacts, to test the impact of residual errors on PSF deconvolution, and to quantify how performance limits change as a function plate scale, so that this crucial mission design choice will be well informed.

7742-51, Session 11

Photon collider: a four-channel autoguider solution

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The "Photon Collider" uses a compact array of four off axis SBIG ST-1603ME cameras positioned with independent filtering and focus. The photon collider is two way symmetric and robustly mounted with the off axis light crossing the science field which allows the compact single frame construction to have extremely small relative deflections between guide and science CCDs. The photon collider provides four independent guiding signals with a total of 15 square arc minutes of sky coverage. These signals allow for simultaneous altitude, azimuth, field rotation and focus guiding. Guide cameras read out without exposure overhead increasing the tracking cadence. The independent focus allows the photon collider to maintain in focus guide stars when the main science camera is taking defocused exposures as well as track for telescope focus changes. Independent filters allow auto guiding in the science camera wavelength bandpass. The guide signals along with onboard temperate sensors are used to develop a more accurate mount model. The four cameras are controlled with a custom web services interface from a single Linux based industrial PC, and the autoguider mechanism and telemetry is built around a uCLinux based Analog Devices BlackFin embedded microprocessor. Off axis light is corrected with a custom compound tilt field flatterer. Guide CCDs are cooled with ethylene glycol and an advanced leak detection system. The photon collider was built for use on Las Cumbres Observatory's 2 meter Faulks telescopes and currently used to guide the alt-az mount.

7742-52, Session 11

Flagging and correction of pattern noise in the Kepler focal plane array

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In order for Kepler to achieve its required <20 PPM photometric precision for magnitude 12 and brighter stars, instrument-induced variations in the CCD readout bias pattern (our "2D black image"), which are either fixed or slowly varying in time, must be identified and the corresponding pixels either corrected or removed from further data processing. The two principle sources of these readout bias variations are crosstalk between the 84 science CCDs and the 4 fine guidance sensor (FGS) CCDs and a high frequency amplifier oscillation on <40% of the CCD readout channels. The crosstalk produces a synchronous pattern in the 2D black image with time-variation observed in <10% of individual pixel bias histories. We will describe a method of removing the crosstalk signal using continuously-collected data from masked and over-clocked image regions (our "collateral data"), and occasionally-collected full-frame images and reverse-clocked readout signals. We use this same set to detect regions affected by the oscillating amplifiers. The oscillations manifest as time-varying moiré pattern and rolling bands in the affected channels. Because this effect reduces the performance in only a small fraction of the array at any given time, we have developed an approach for flagging suspect data. The flags will provide the necessary means to resolve any potential ambiguity between instrument-induced variations and real photometric variations in a target time series. We will also evaluate the effectiveness of these techniques using flight data from background and selected target pixels.

7742-53, Session 12

First results from electrical qualification measurements on DEPFET pixel detector

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We report on the first results from a new setup for electrical qualification measurements on DEPFET pixel detector matrices. In order to measure the transistor properties of all pixels, the DEPFET device is placed into a benchtest setup and electrically contacted via a probecard. Using a switch matrix, each pixel of the detector array can be addressed individually for characterization.

These measurements allow to investigate topics like the homogeneity of transistor parameters on device, wafer and batch level in order to learn about the stability and reproducibility of the production process. Additionally, this allows a preselection of the DEPFET matrices prior to the mounting of the matrix as detector device. Especially with regard to the detector development for the IXO WFI, this yield learning will be an important tool.

The first electrical qualification measurements with this setup were done on DEPFET macropixel detector flighthardware, which will form the FPAs of the Mercury Imaging X-ray Spectrometer (MIXS) on board of the 5th ESA cornerstone mission BepiColombo. The DEPFET array consists of 64x64 macropixel for which the transfer, output and clear characteristics were measured.

Precharacterized MIXS detector matrices are already mounted as Lab Module and first spectroscopic measurements confirm the full functionality. Investigating if and how the parameter fine structure observed by electrical measurements translates into details of detector properties will be important for technology feedback.

7742-55, Session 12

Measurement results for an x-ray 3D-integrated active pixel sensor

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We have developed a hybrid Active Pixel Sensor for detecting low energy X-rays. The sensor consists of a silicon diode detector array built on a high resistivity wafer and an SOI CMOS readout circuit, connected together by means of unique 3D integration technology developed at MIT Lincoln Laboratory. In this paperwe will describe measurements of device depletion depth and dark current in a range of temperatures and bias voltages, along with corresponding simulations aimed to optimize device performance. We also describe race condition in the column decoder and identify ways to eliminate it in order to reduce fixed pattern noise.

7742-56, Session 13

Extraction of the frequency spectrum of the noise of a HAWAII2RG NIR detector and impact on low-flux measurements

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In the context of the SNAP / JDEM project, we present here a study of the noise frequency spectrum of a HAWAII2RG near-infrared detector. The variation of the noise as a function of the number of Fowler samples and their frequency is measured. The algebraic relation connecting the observed dependence to the frequency spectrum of the noise, parametrised as A + B/f^a is derived. An adjustment is done to extract the amplitudes of the white and power part of the noise spectrum. A simulation allows to compare the founded power spectrum of the noise to observations taken in different experimental conditions, with exposure times extending from 300s to 6000s.

7742-57, Session 13

Development of high-speed, low-noise NIR HgCdTe avalanche photodiode arrays for adaptive optics and interferometry

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The readout interface circuit (ROIC) of current infrared wave front sensors and fringe trackers is based on CMOS technology. However due to basic limitations of CMOS, the read noise improvements for the last two decades have been marginal and may be mainly attributed to smaller pixel sizes. The most promising way to overcome the CMOS noise

barrier is the amplification of the photoelectron signal directly at the point of absorption inside the infrared pixel by means of avalanche gain and thus to raise the signal above the noise floor of the ROIC. HgCdTe material, having a cut-off wavelength of lambda cutoff >2.3 micron is the ideal detector material since, compared to silicon, it offers noise free avalanche gain.

For almost a decade the British company SELEX-Galileo have been successfully using electron Avalanche Photo Diode (eAPD) gain in sensors for laser-gated three dimensional (3D) imaging. These sensors have a cut-off wavelength of 4.5 microns and their dark current is too high for wavefront sensors which typically require integration times of ~ 1ms. Therefore ESO contracted SELEX to develop HgCdTe eAPD arrays with cutoff wavelengths of lambda cutoff ~2.5 micron. The goal of this development was the investigation of the dark current at short cut-off wavelengths and the exploration of the gain, noise and operability parameter space. The eAPD arrays were hybridized to an existing 3D ROIC having a format of 320x256 pixels with four parallel video outputs. The evaluation of the arrays has shown a classic avalanche gain of up to 20 at a 9V bias, a readout noise of < 6e rms, even with the non-optimized ROIC and a dark current meeting the requirements of AO wavefront sensing. The further development of a specific ROIC for AO will deliver the performance goal of a readout noise less than 3e rms at a frame rates of ~ 1KHz.

7742-58, Session 14

A method for the characterization of subpixel response of near-infrared detectors

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Many future missions, including JDEM, are designed as wide-field surveys. The increased area of the survey is often achieved by increasing the plate scale of the detectors used and as a result these can be undersampled. Under these conditions response variations within an individual pixel degrade photometric and shape information of observed astronomical sources. These effects can be corrected for by mapping the subpixel response of all pixels on a detector. The previous method for measuring subpixel sensitivity by projecting a single, micron size spot, the Spot-O-Matic, while very effective, required a significant amount time making it impossible to create such a detector-wide map. The concept has been extended to design a multi-spot projector, enabling the mapping of an entire detector. This new projector has been constructed and is currently undergoing testing and calibration in order to achieve the small spot size required for pixel characterization over the field of view of the entire detector.

7742-59, Session 14

Investigating reciprocity failure in 1.7-micron cut-off HgCdTe detectors

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NIR instruments that strive for precise photometry rely on photometric calibrations over a wide range of intensities, and hence on a complete understanding of the linearity of the detectors. The Michigan NIR group has studied the count rate dependent detector nonlinearity (reciprocity failure) that has been observed for the NICMOS near infrared array on the Hubble Space Telescope. For this purpose a dedicated test set-up was designed and built. The system produces a variable but precisely determined fluence at selected wavelengths and the detector response is measured. Details of the set-up and results will be presented.

7742-60, Session 14

Advancement of large-format silicon blocked impurity band focal plane arrays

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DRS is a major developer and supplier of arsenic doped silicon (Si:As) and antimony doped silicon (Si:Sb) blocked impurity band (BIB) focal plane arrays (FPA) for ground, airborne and space-based infrared instruments. This status follows from DRS's 2001 acquisition of the team that invented and developed BIB technology at Boeing and previously at Rockwell for defense and astronomy applications. With development of the focal plane system for the Wide-field Infrared Survey Explorer (WISE) instrument in 2007 DRS advanced its low-flux Si:As BIB FPA format to 1024x1024 pixels. Si:As and Si:Sb BIB FPAs in this format have since been developed for the higher flux environments of ground and airborne applications, including JPL's MegaMIR Camera and the Cornell's FORCAST instrument for SOFIA, respectively. These high-flux FPA designs are also compatible with tiling to construct larger-format focal plane sensors. Design and pilot development are in progress at DRS on further advancements of silicon BIB technology, including gallium doped silicon (Si:Ga) BIB FPAs to achieve similar operating temperature to LWIR mercury cadmium telluride (MCT) with improved operability and stability. This paper discusses the DRS product line and the expected extensions to it.

7742-62, Session 14

Calibration of ultra-low infrared power at NIST

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The Low Background Infrared (LBIR) facility has developed and tested the components of a new detector for calibration of infrared powers down to 1 pW, with 0.1% uncertainty. Calibration of such low powers could be valuable for the quantitative study of weak astronomical sources in the infrared. The pW-ACR is an absolute cryogenic radiometer employing a high resolution transition edge sensor (TES) thermometer, ultra-weak thermal link and miniaturized receiver to achieve a noise level of around 1 fW at a temperature of 2 K. The novel thermometer employs the superconducting transition of a tin (Sn) core and has demonstrated nano-Kelvin capability. Using an applied magnetic field from an integrated solenoid to suppress the Sn transition temperature, the operating temperature of the thermometer can be tuned to any temperature below 3.6 K. The conical receiver is painted on the inside with infrared-absorbing paint and has a demonstrated absorptivity of 99.94% at 10.6 µm. The thermal link is made from thin-walled Kapton tube and has exhibited very low thermal conductance near 2x10^-7 W/K. In tests with a heater mounted on the receiver, the receiver/thermal-link assembly demonstrated a thermal time constant of about 15 s. Based on these experimental results, it is estimated that an ACR containing these components can achieve noise levels below 1 fW, and the design of a radiometer merging the new thermometer, receiver and thermal link will be discussed.

7742-63, Session 14

Noise performance in long exposures for a recent low-noise 2.5 μm Teledyne H2RG

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The very low floor in the dark current versus temperature relation achieved by Teledyne when growing HgCdTe detector material by MBE held promise of achieving very low total noise in long exposures through multiple sampling. However until recently the detector material exhibited read noise considerably in excess of the multiplexor noise. We report on laboratory tests of arecent H2RG detector manufactured using an improved recipe for 2.5μm cutoff which delivers much lower read noise, <4 e- after multiple sampling, and show that this is degraded only marginally in exposures up to three hours. We examine whether the slight increase in total noise for exposures greater than one hour is due to dark current, residual errors in the cosmic ray exclusion algorithm or very low frequency detector and multiplexor noise. A comparison is presented between the noise inferred from the same data sets using CDS, Fowler and Least Squares Fit algorithms, over a wide range of exposure times for both spatial and temporal noise metrics, and several different cosmic ray exclusion procedures. We examine the noise power spectrum, and discuss the importance of taking into account the dependence of conversion gain and effective duty cycle on the processing algorithm.

7742-64, Session 14

Performance evaluation of 5 μm cut-off Hawaii-2RG detectors using the fast readout amplifiers

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ESO has begun an ambitious mid-IR detector program with the funded development of a new Raytheon 1k x 1k Si:As detector (AQUARIUS) and the further development of instruments to use 5 μm cut-off 2k x 2k HgCdTe, Teledyne HAWAII-2RG detectors. Both these detector types are capable of high pixel readout speeds, through multiple readout ports, resulting in data rates in excess of 250 Mbytes/s. This has required further development of our new detector controller system (NGC) to allow it to operate at these high speed digitization rates. This has also entailed the development of new high speed cryogenic CMOS pre-amplifiers which are mounted close to the detector to allow us to drive long cable runs, typical of an astronomical instrument and which can operate at 60K. We report on the development and performance of our new higher speed NGC systems with particular regard to the operation of a Hawaii-2RG detector configured to use its high speed readout stages (5MHz). We will present data on the performance of such a device, configured to operate in both slow and fast readout modes, with particular regard to noise versus pixel speed, cosmetic quality and linearity.

7742-65, Session 14

Detector characterization for the JWST fine guidance sensor

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THe James Webb Space Telescope (JWST) is an international collaboration among National Aeronautics and Space Administration's (NASA), the European Space Agency (ESA), and the Canadian Space Agency (CSA) to study the first galaxies that formed in the early Universe. An Optical Telescope Element (OTE) will gather the light coming from space and provide it to four scientific instruments, including the Fine Guidance Sensor (FGS) and Tunable Filter Imager (TFI) which are being provided by the Canadian Space Agency.

The two FGS Guider channels and the TFI channel all make use 2048x2048 5 micron cutoff HAWAII-2RG HgCdTe detectors from Teledyne Imaging Systems. While the detector requirements for the TFI and Guider are somewhat different, a common procurement had some advantages in that of the detector arrays fabricated, those with high short wavelength quantum efficiency and low readout noise could be selected for the Guider channels, while those arrays with the lowest dark current and good long wavelength quantum efficiency were candidates for the TFI channel. An extensive test campaign was undertaken at Teledyne Imaging Sensors to comprehensively assess the detector performance. We report here on our efforts to optimize the performance of the FGS detector sub-system consisting of the detector arrays, the Teledyne SIDECAR ASIC, and the FGS specific SIDECAR Control Electronics. The FGS-Guider has a number of unique readout modes which are required to support observatory operations, requiring different optimizations for these readout modes compared to those required for science observations with the TFI.

7742-66, Session 14

Dark current characterization of Teledyne LWIR HgCdTe detector array for low background applications

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To meet the desire for passively cooled (operating T ~ 30K) long wave detector arrays for use in future infrared space missions, the University of Rochester has been working with Teledyne to develop >= 10 micron cutoff HgCdTe detector arrays specifically designed for low background astronomical applications. In 2003 and 2004, three detector arrays with cutoff wavelengths ~ 9.0 microns were delivered and characterized in order to ascertain the limitations of then current technology in producing scientific grade low background 10 micron cutoff HgCdTe detector arrays. These three detector arrays have been reported on in SPIE Proceedings Volume 5167, 5563 and 5902 by Bacon et al. A fourth array with a 10.3 micron cutoff was delivered in 2006 and is characterized in this paper. This characterization includes an analysis of the dark current mechanisms at applied reverse biases ranging from 0 mV to 200 mV at 30 K and over a temperature range of 31 - 37 K at 50 mV applied reverse bias. Among the dark current mechanisms discussed here are dislocation-induced trap-to-band tunneling, surface current and dislocation-enhanced surface current. The best of these pixels are limited by surface current, while most pixels with higher dark current exhibit some form of dislocation-related current. A discussion of these mechanisms and characterization of the pixels that exhibit them is illustrated in this paper, indicating the need for improved manufacturing and processing techniques to reduce the density of these dislocations. Newer techniques are already implemented by Teledyne, making future deliveries even more promising.

SPIE Astronomical Instrumentation

7742-67, Session 14

Curved infrared detectors: applications to spectrometry and astronomy

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The traditional design of optical systems is severely complicated by the curved shape of the image surface which has to be recorded on a planar retina. This constraint decreases the image quality; optical elements are then added to avoid aberrations and lead to increase the dimensions of the system. However, miniaturization could be achieved, without decreasing resolution and sensibility, by recording the image surface on a curved retina. The optical advantages of curved sensors have been demonstrated; the simplification gained leads to scale down the entire system. Moreover, the hemispherical shape increases the field of view (FOV).

In this paper the advantages of curved focal plane will be detailed through two applications: spectrometry and large FOV telescopes. In spectrometry, the curved sensor could have two bending radii through the sample. In astronomy, large FOV and miniaturization with good resolution can only be achieved by curving the focal plane; the difficulty is to curve in a hemispherical shape large detectors. The advantages are highlighted by the E-ELT project.

Despite this high interest in curved detectors, technologies to achieve this hemispherical shape are not well developed. Few solutions exist, which mainly consist in structuring the die in sub-devices. We propose a solution to curve an IR sensor with a fill factor equal to 100%. To do so, we developed a dedicated bonding process which allows curving silicon using its mechanical properties. A curved uncooled infrared detector has been performed without mechanical and electrical damage.