International X-ray Observatory (IXO)

Measuring the True Velocity of Superwinds with IXO

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Abstract

The International X-ray Observatory (IXO) will revolutionize our understanding of starburst-drivenwinds and the role of stellar and Supernova feedback in galaxy formation and evolution. The majority of the energy and the metals in galactic winds reside in hot X-ray-emitting gas that is kinematically decoupled from the slower cooler gas studied with optical/UV spectroscopy. Thus *only X-ray observations can constrain whether metals are ejected from galaxies*. We demonstrate how the high spectral resolution ($\Delta E \sim 2.5$ eV FWHM at E=1 keV, $\Delta E \sim 4$ eV at E=6 keV) and high through-put of the X-ray Micro-calorimeter Spectrometer (XMS) will allow the true velocity of the hot gas in superwinds to be measured for the first time.

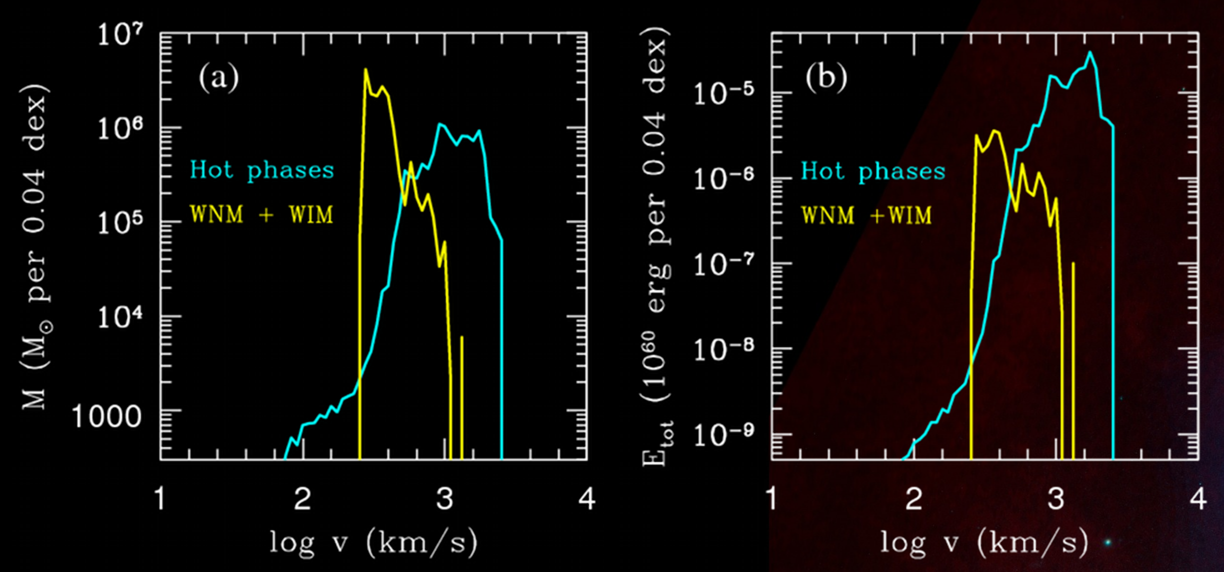


Fig 1: Gas mass (a) and total energy (b) as a function of velocity in a hydrodynamical simulation of a starburst-driven superwind. Theory predicts that the hot phases (6.3 < log T < 8.3, shown in cyan) have systemically higher outflow velocities than the WNM and WIM phases (3.8 < log T < 4.2, shown in yellow) that are currently used to estimate velocities in superwinds.

Goals for IXO observations of starbursts

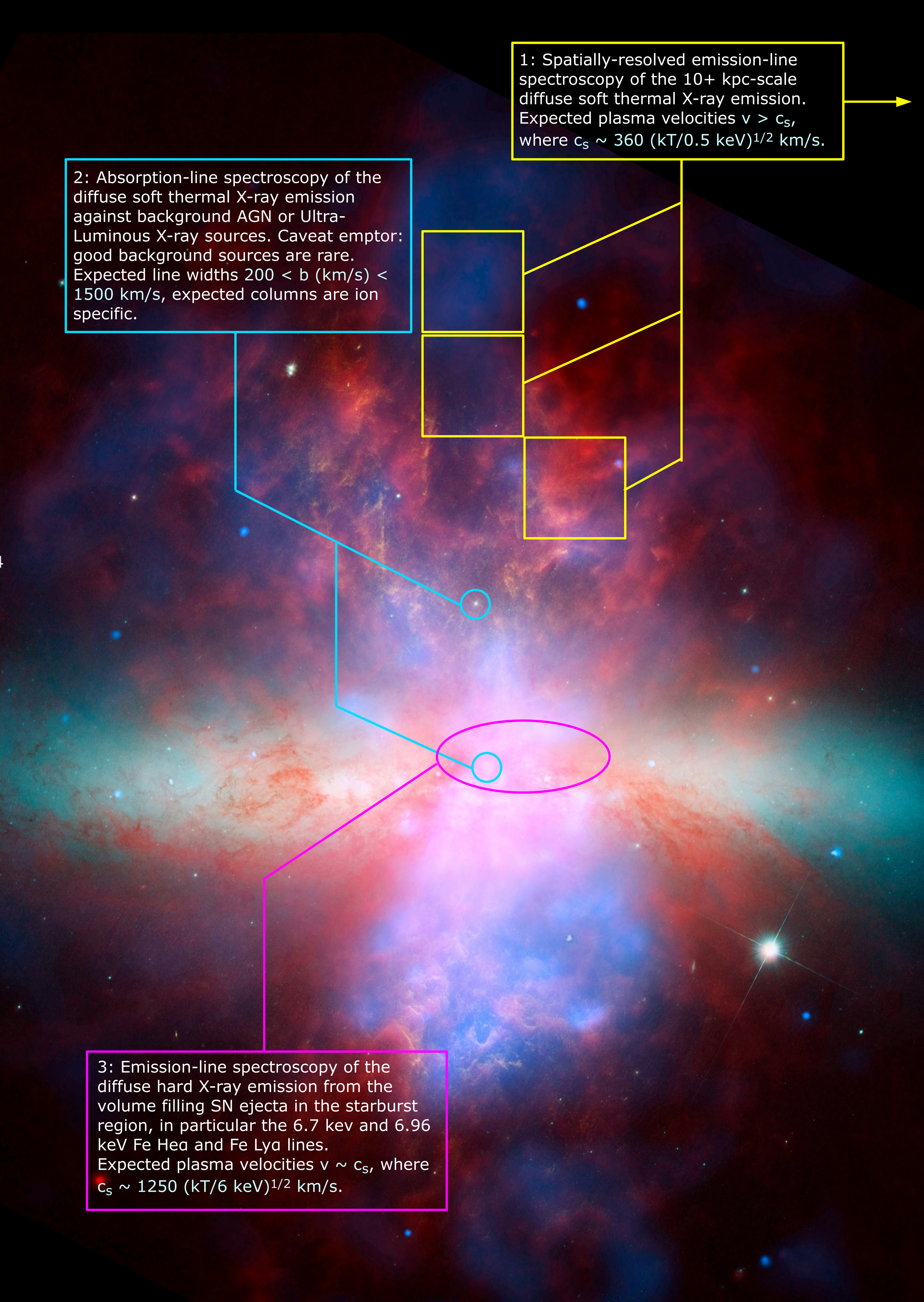
- Detect and measure the X-ray line shifts and widths associated with bulk gas motions caused by the collective energy feedback from supernovae and stellar winds in nearby star-forming galaxies, either in soft therm X-ray emission, hard X-ray line emission, or in absorption along lines of sight to background X-ray sources such as AGN or ULXs.
- Measure both velocities and elemental abundances in ***multiple regions*** in or around each targeted starburst galaxy.
- Compare hot gas velocities to galactic escape velocities to assess prospect of metal-enriched gas escaping.
- Obtain measurements of the SN-heated gas in a sample of starbursting galaxies covering a broad range in galaxy mass ($10^8 < M_{baryon} < 3 \times 10^{11}$, or $0.03 < L_K/L_{K*} < 10$) in order to ascertain the critical galaxy mass above which winds can not eject material in the IGM.

Expected hot gas velocities in superwinds

Currently there are NO direct measurements of the velocity of the X-ray-emitting gases in starburst-driven outflows. However, we do know the following:

- Gas motions must be comparable to galaxy escape velocities to be significant in ejecting metals.
- Hydrodynamical simulations suggest that v_{HOT} is significantly higher than the velocities measurable at optical or UV wavelengths (v_{WIM}, v_{WNM}).In this case v_{HOT} will be several hundred to several thousand km/s, see Figure 1 above.
- Even if the simulations are wrong, v_{HOT} must be comparable or higher than the sound speed in the X-ray emitting gas c_s, for which we have existing temperature measurements from Chandra and XMM-Newton.
- Observed line-of-sight (LOS) velocities will be lower than the intrinsic velocity, but even in the case of roughly edge-on starbursts (e.g. M82) the geometry typically only decreases the LOS velocity by a factor ~2 from the intrinsic velocity.

Possible Methods of Measuring Hot Gas Velocities with IXO



Velocity Measurements in the Soft X-ray Band

In this poster we will concentrate on exploring the technical feasibility of measuring velocities in the soft X-ray-emitting diffuse plasmas of nearby starburst galaxies with superwinds, even though the spectral resolving power of the IXO XMS will be at its lowest at soft X-ray energies. We must be able to measure line energy shifts and line broadening of ~ a few x 100 to a few 1000 km/s.

We find that the IXO XMS is sensitive enough to obtain high quality spectra (>10^4 counts, E=0.3-2 keV, see Figs. 2 & 4) for even the faintest currently known sub-regions of superwinds in reasonable exposures (< 100 ks). With such spectra we can measure individual line shifts with uncertainties $\sigma_{cen} \sim 50$ - 100 km/s, and line widths with uncertainties of σ_{FWHM} ~100 km/s over all lines in a single spectrum (Fig. Y). Mapping velocities over different regions in a superwind (for example, in 5 apertures totaling ~5 x 10^4 diffuse counts) will further improve the accuracy of the final wind velocity determination.

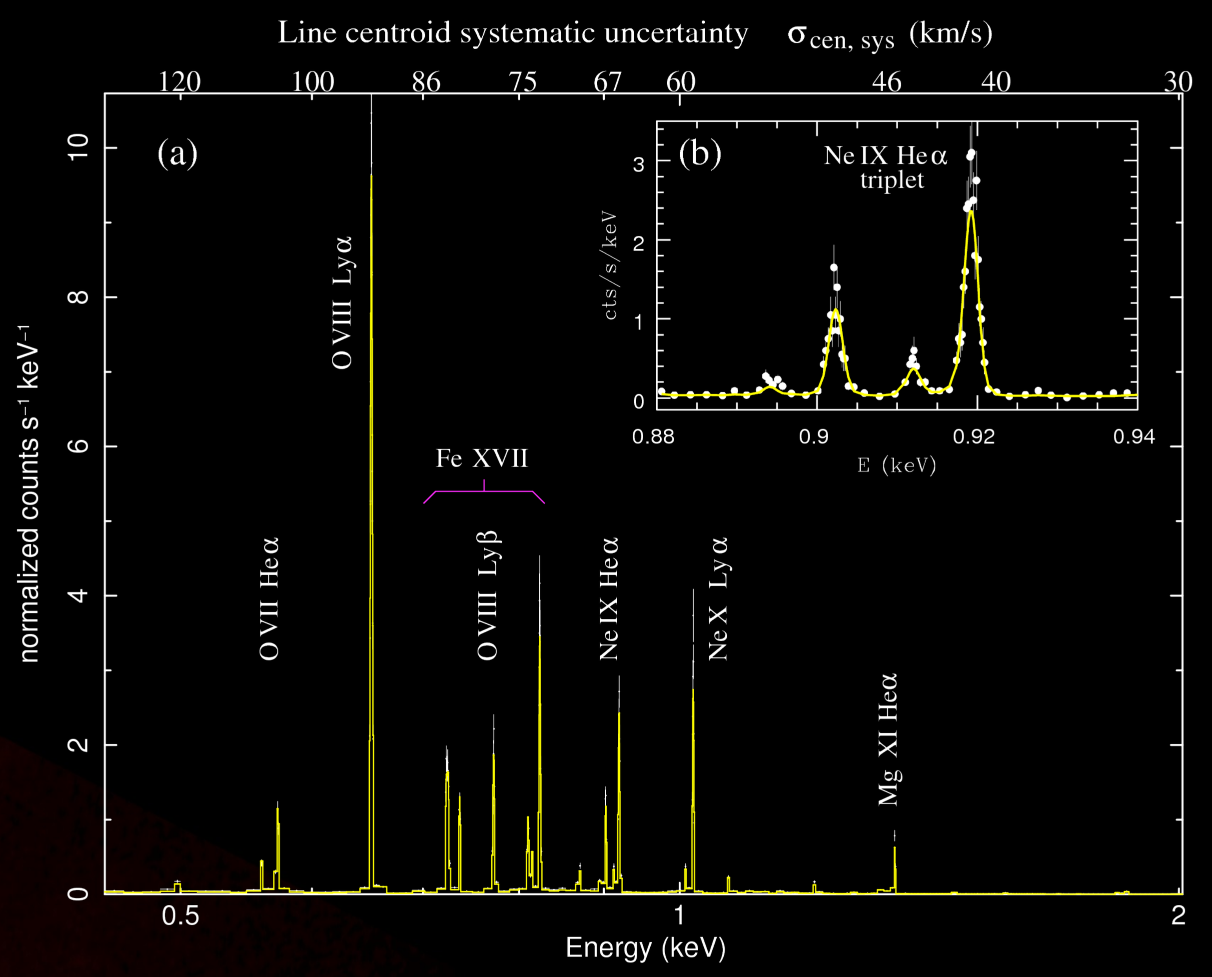


Figure 2: (a) A simulated IXO XMS spectrum of a small region within a superwind, illustrating the relative strength of the line emission. The simulation is of a SN-enriched kT=0.4 keV thermal plasma with ~11000 counts in the E=0.3-2 keV energy band.

The 0.2 eV systematic uncertainty in the absolute XMS energy scale dominates the net uncertainty in derteming a line velocity or redshift, and is shown in terms of the associated velocity uncertainty along the top of the plot. (b) A close-up of the spectrum shown in panel (a) around the energy of the Ne IX Heα triplet, illustrating both how well resolved the lines are, and the small error bars on both line and continuum emission.

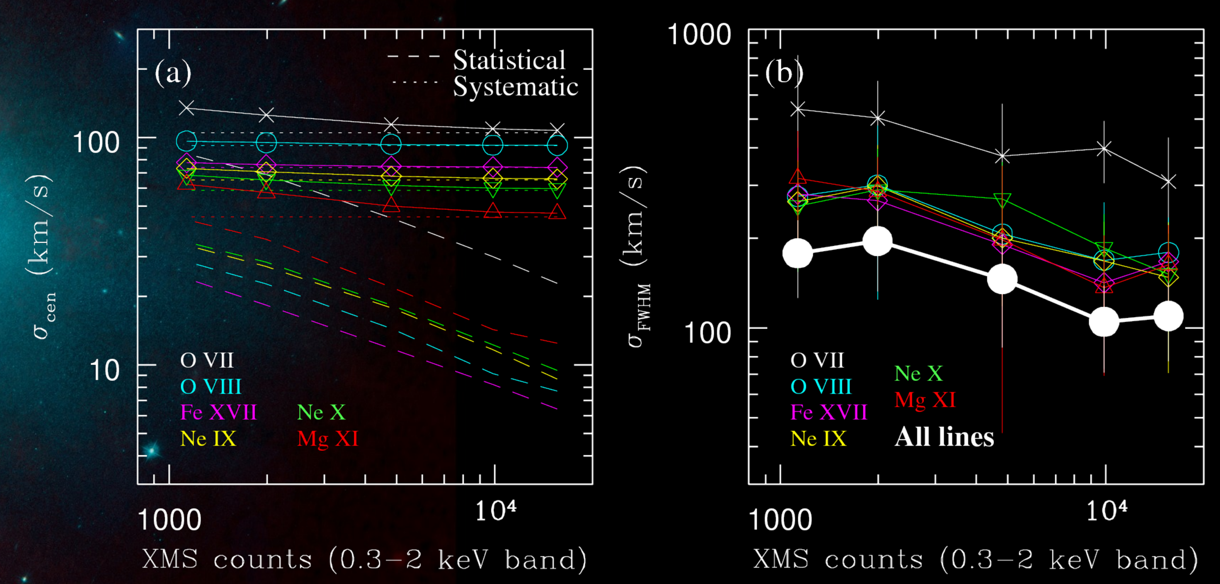


Figure 3: Estimated typical errors (68.3% confidence) in line centroid velocity σ_{cen} and line width σ_{FWHM} for fits to individual lines or triplets in an IXO XMS spectrum of a soft thermal plasma (kT=0.4 keV), as a function of the total number of XMS count in the full $E=0.3-2 keV energy band.

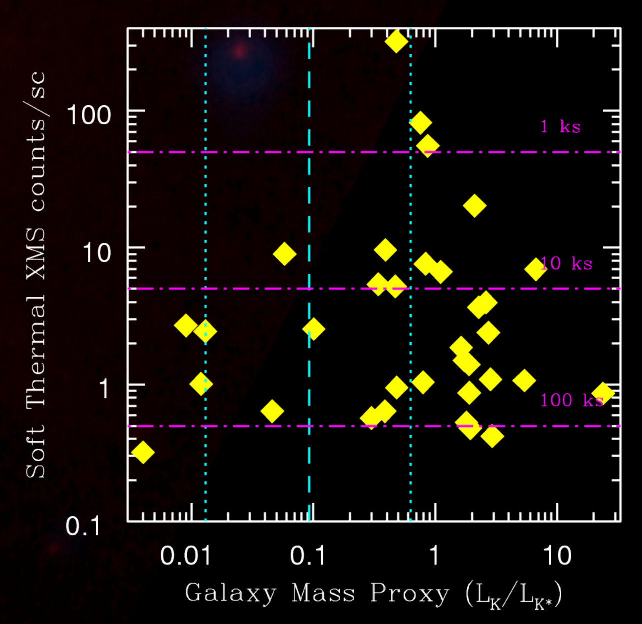


Figure 4: The predicted soft X-ray (E=0.3-2 kev) diffuse count rate in the IXO XMS for 31 nearby starburst galaxies, based on existing Chandra and XMM-Newton observations, as a function of the galaxy K-band luminosity (a proxy for galaxy mass). Vertical cyan lines show galaxy masses for which the Tremonti et al (2004) galaxy mass-metallicity relationship suggests that galaxies have lost 75, 50 and 25% of their metal content over their lifetime (possibly to galactic superwinds).

Current speculation holds that winds become ineffective at ejecting metals in galaxies with stellar masses > $10^{9.5}$ Solar masses (L > 0.1 L_*, e.g. Tremonti et al 2004; Keeney et al 2006). The sample shown in Fig. 4 would allow us to test whether winds in higher mass galaxies are indeed trapped.

The high sensitivity of IXO allows high quality observations of large numbers of starbursting galaxies to be obtained quickly: obtaining 5x10^4 diffuse counts (~50 x the number of diffuse counts in existing Chandra/XMM observations) from each of the 31 galaxies shown in Fig. 4 would only take 1.3 Ms in total.

Main image: Chandra/Hubble/Spitzer X-ray(blue)/Visible(yellow,cyan)/Infrared(red) Image of M82. Credit:NASA, ESA, CXC, and JPL-Caltech