ICM Velocity Tomography of Galaxy Clusters

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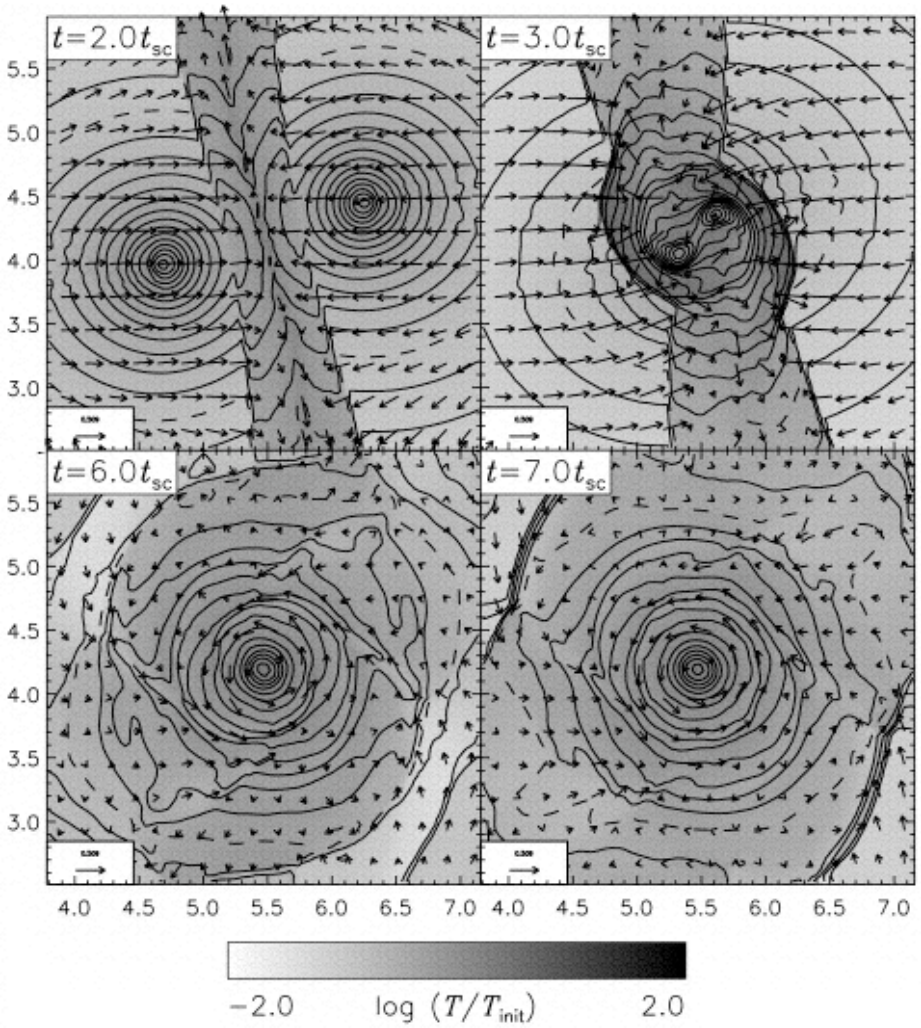
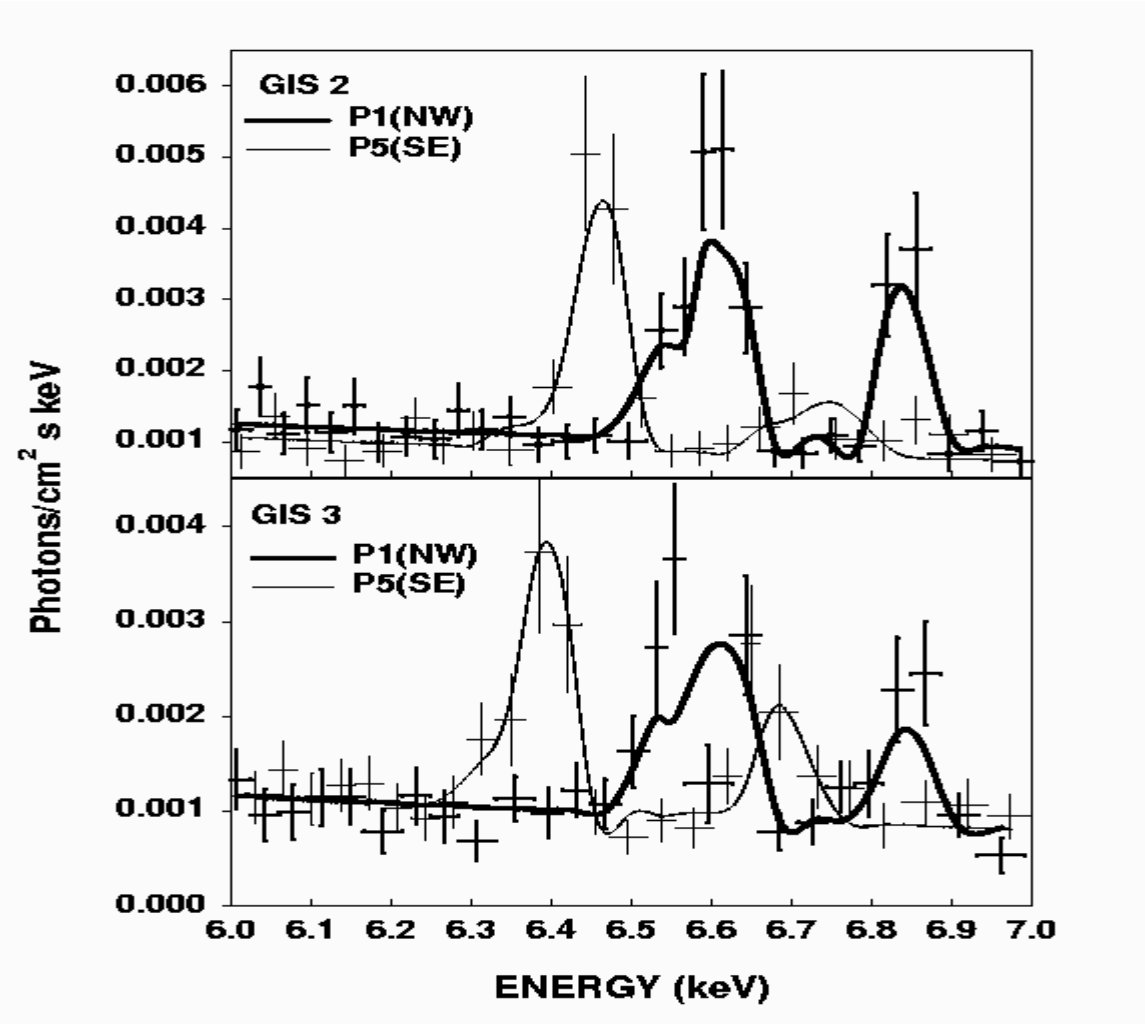
- Why should we look for ICM bulk velocities?
  - Cosmology – Assumptions used to estimate mass and baryon fractions
  - Cluster Evolution – merging frequency, energetics, connection to X-ray substructures (cold fronts, plumes).
  - Discrepancy with lensing masses (e.g. A1689?, A2218 (Machacek et al. 2002)
  - We can nail down the evolutionary stage by comparing (Sb_e, T_e and V_r) to Num.+Hydro simulations of cluster mergers (e.g. Ricker 1998, 2002; Takizawa 2000; Roettiger et al.1997, 1998; Burns 1999)

Simulations

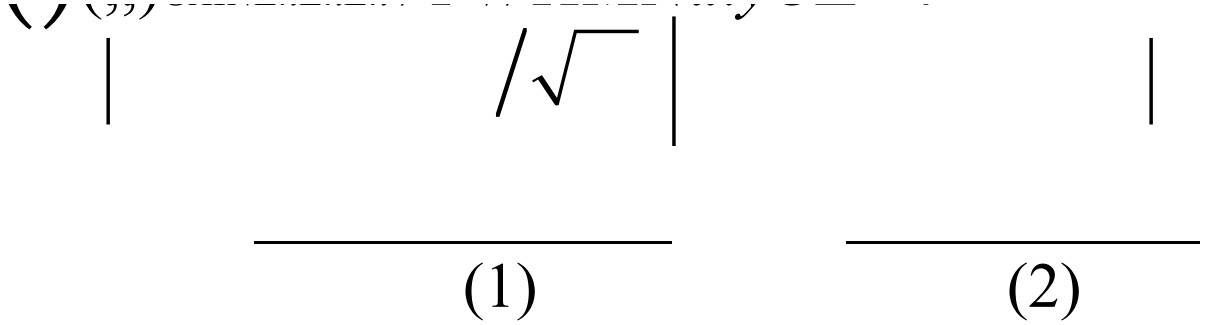


e.g. Ricker 1998

How to measure it.

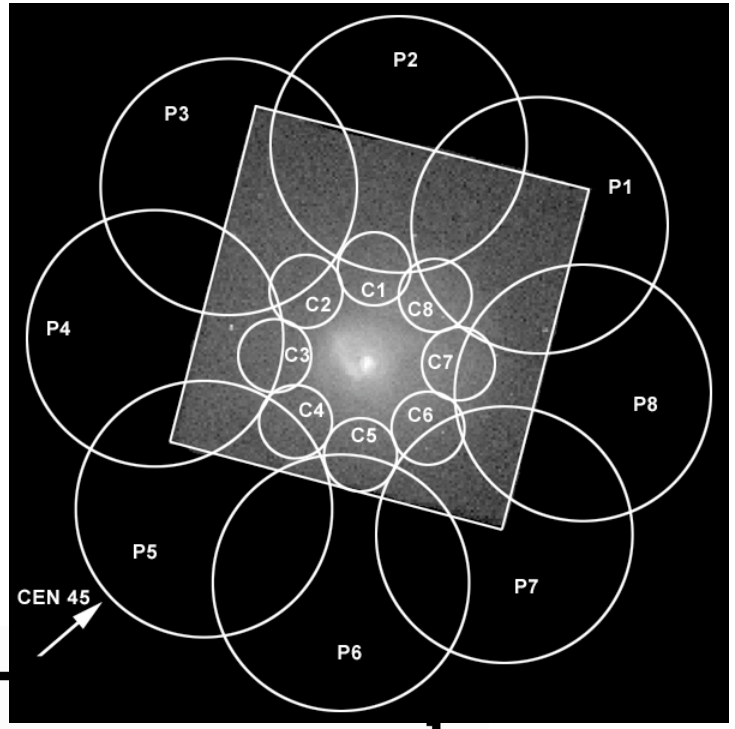


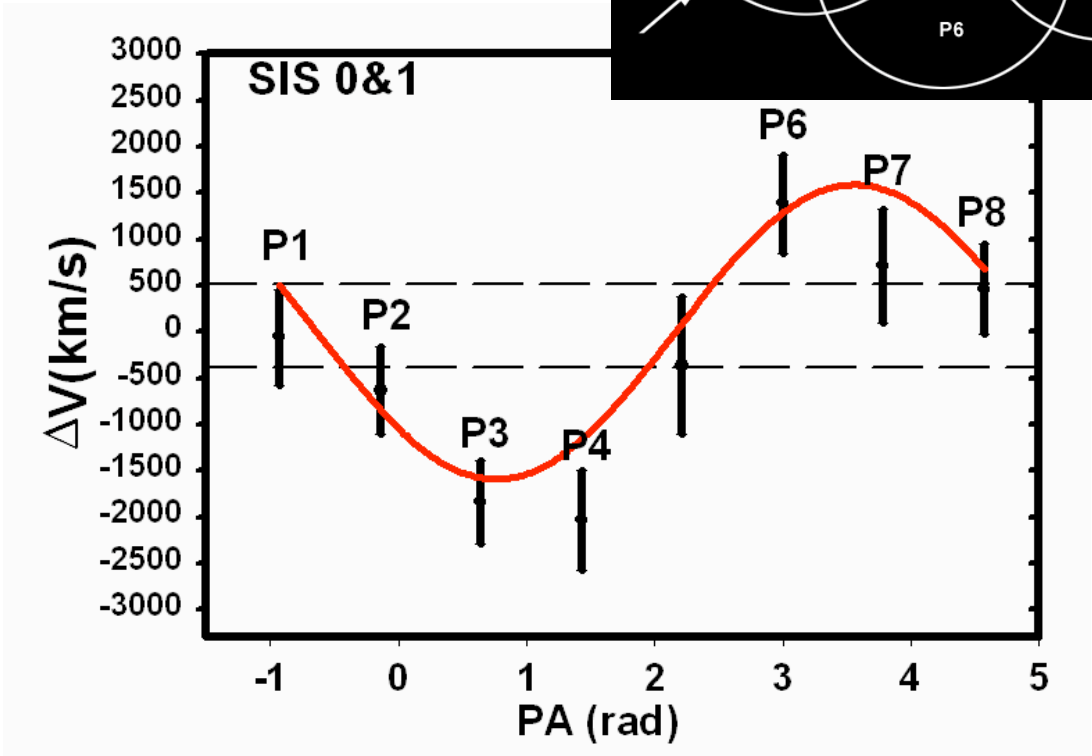
Gain Issues

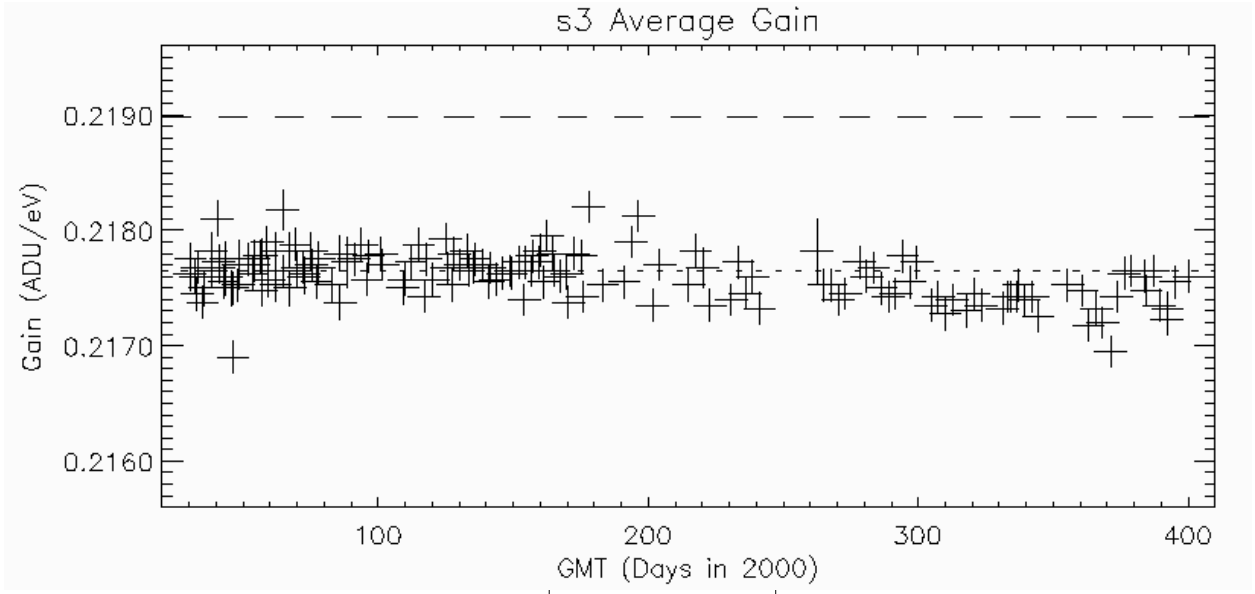


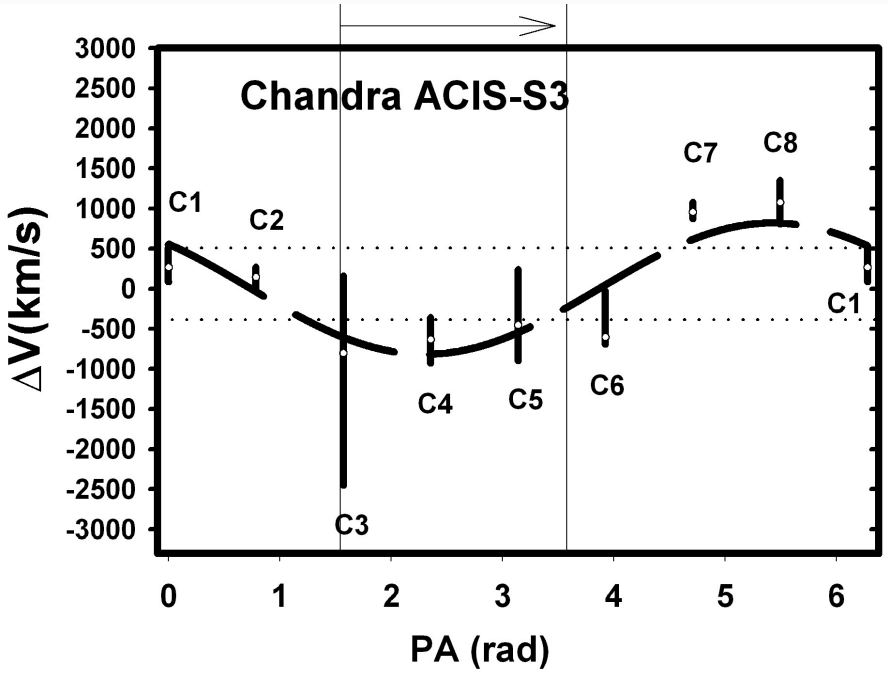
(1) (2)

ASCA GIS _ ~ 1500 km/s
SIS _ ~ 800-900 km/s
Chandra S3 _ ~ 300-500km/s
EPIC MOS _ ~ 300-500 km/s?


P2
P3
P1
P4
P8
P5
P7
P6
C1
C2
C8
C3
C7
C4
C6
C5
CEN 45


SIS 0&1
ΔV(km/s)
PA (rad)
P1
P2
P3
P4
P6
P7
P8
3000
2500
2000
1500
1000
500
0
-500
-1000
-1500
-2000
-2500
-3000
-1
0
1
2
3
4
5

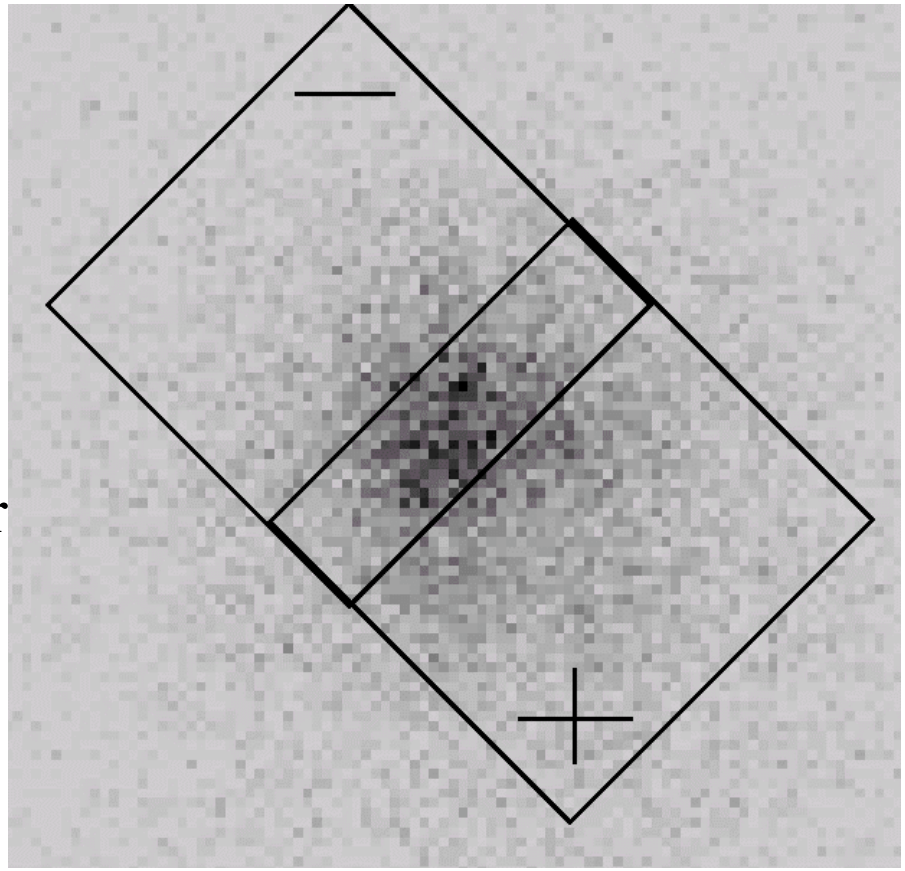

s3 Average Gain
Gain (ADU/eV)
0.2190
0.2180
0.2170
0.2160
100
200
300
400
GMT (Days in 2000)


Chandra ACIS-S3
ΔV(km/s)
3000
2500
2000
1500
1000
500
0
-500
-1000
-1500
-2000
-2500
-3000
C1
C2
C3
C4
C5
C6
C7
C8
C1
0
1
2
3
4
5
6
PA (rad)

How to Overcome Gain Concerns

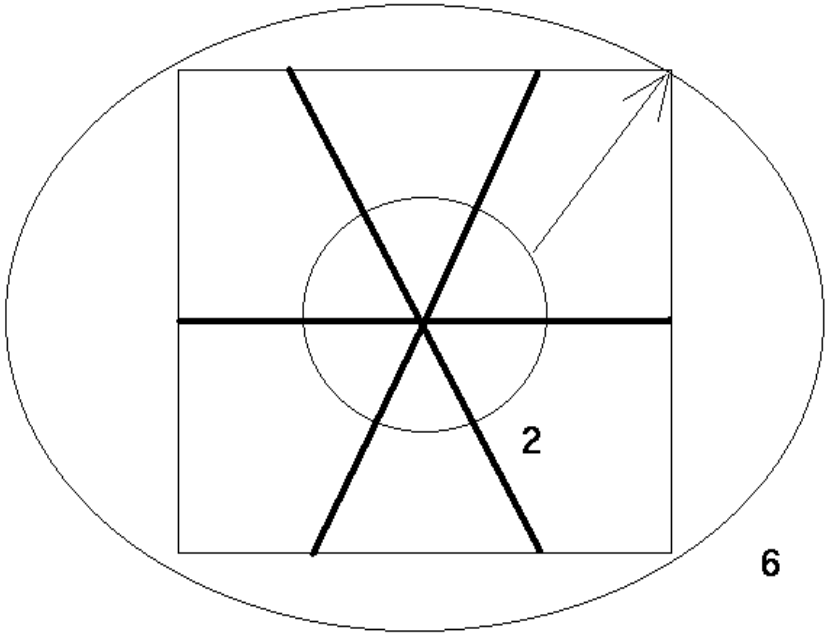
Multiple pointings in the same CCD location

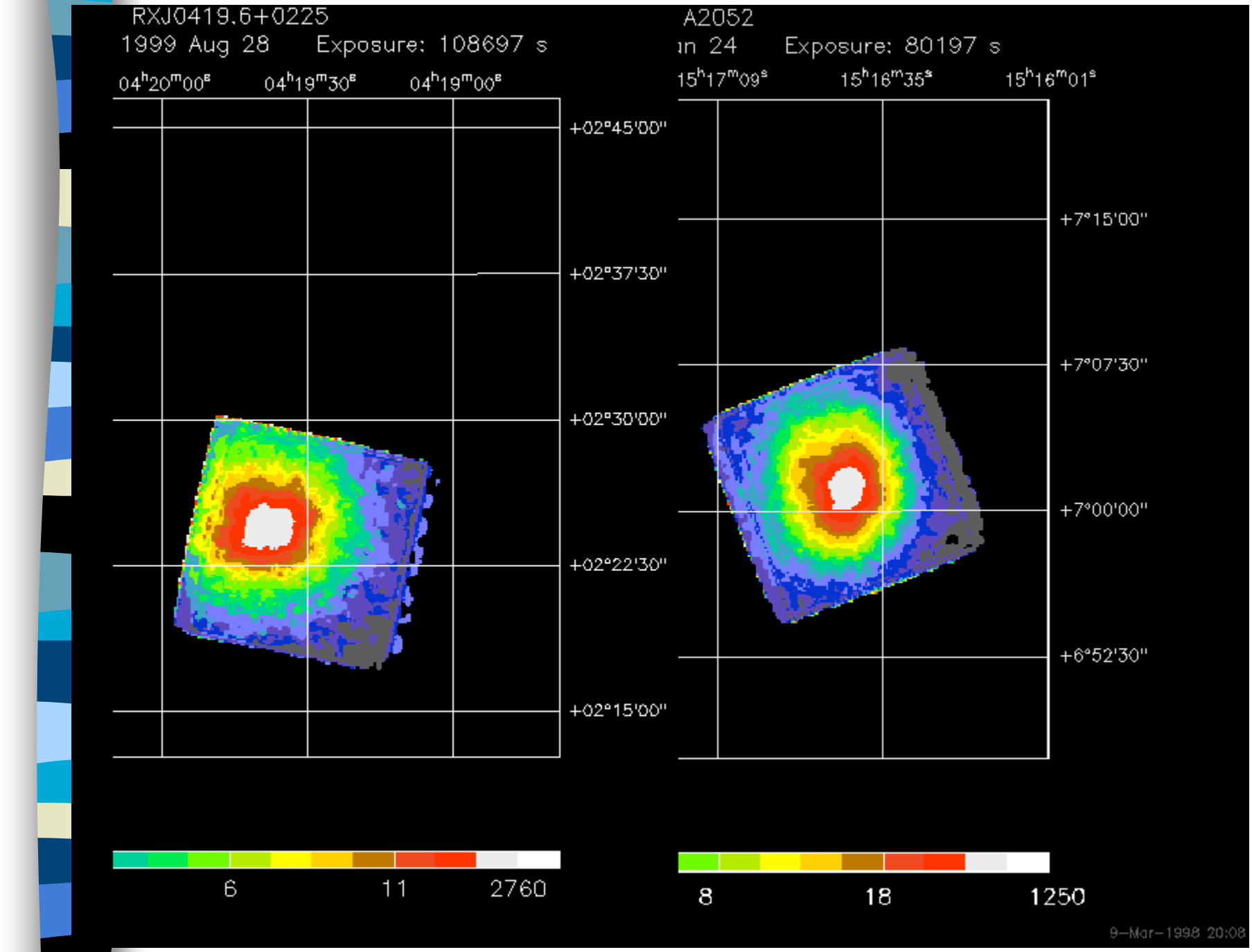
Requires prior knowledge of velocity distribution.



ASCA SIS SAMPLE

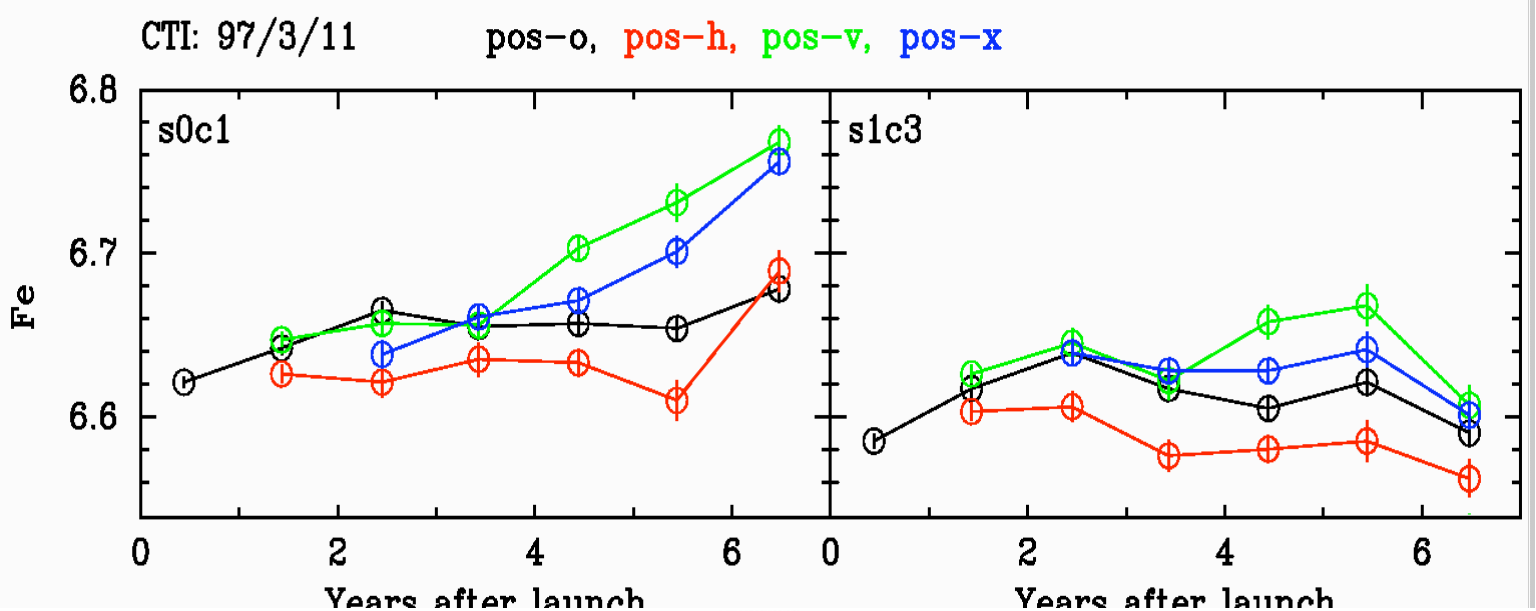
•1-CCD mode, roughly centered on the cluster, z <~ 0.1, #cnts > 30 kcts/inst. Careful for sudden change of spectra.

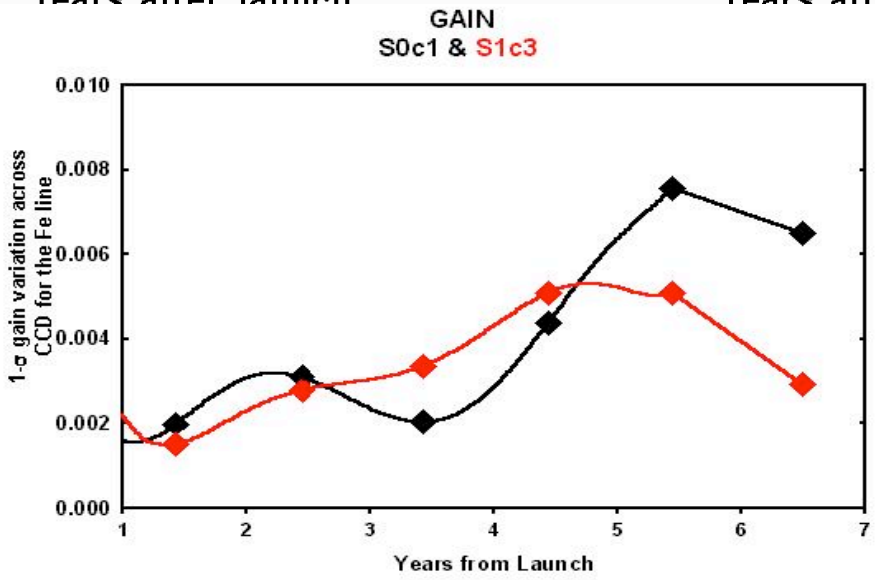



RXJ0419.6+0225
1999 Aug 28 Exposure: 108697 s
04h20m00s
04h19m30s
04h19m00s
+02°45'00"
+02°37'30"
+02°30'00"
+02°22'30"
+02°15'00"
6
11
2760
A2052
in 24 Exposure: 80197 s
15h17m09s
15h16m35s
15h16m01s
+7°15'00"
+7°07'30"
+7°00'00"
+6°52'30"
8
18
1250
9-Mar-1998 20:08

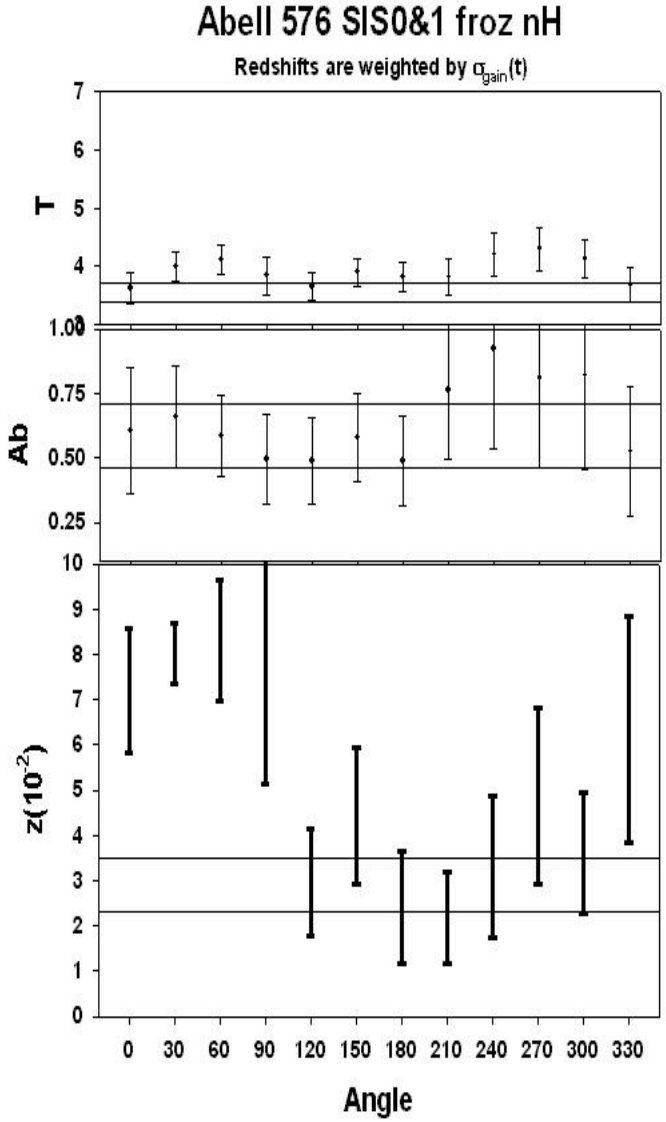
Gain Fluctuations

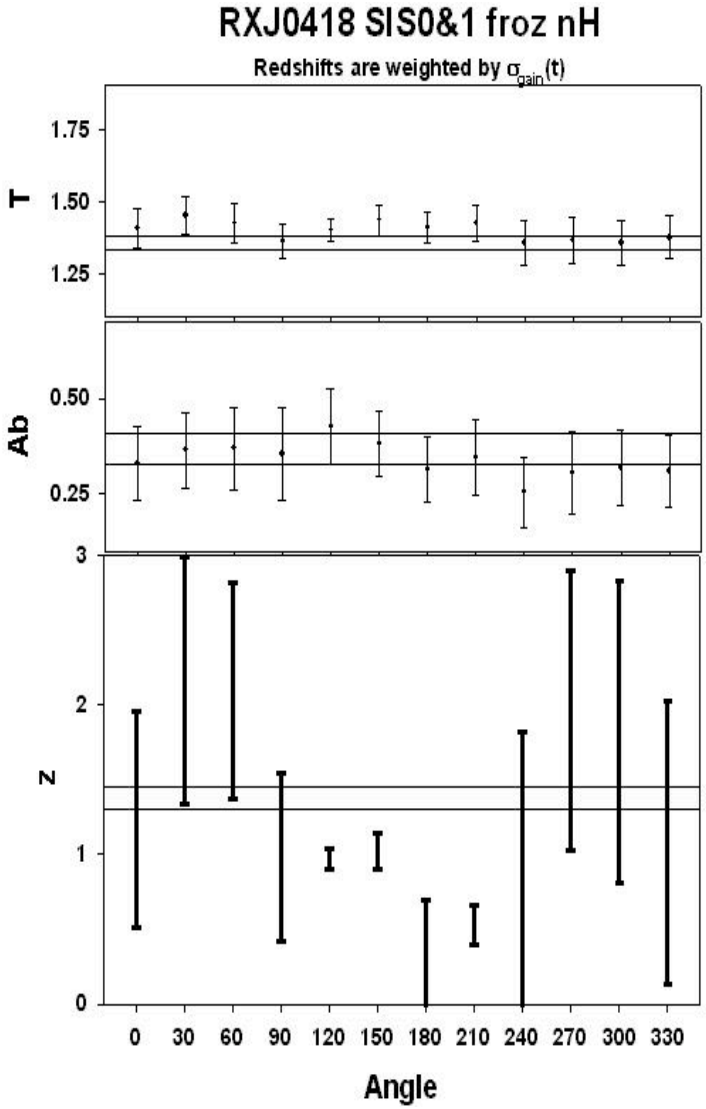
(Dotani et al.)



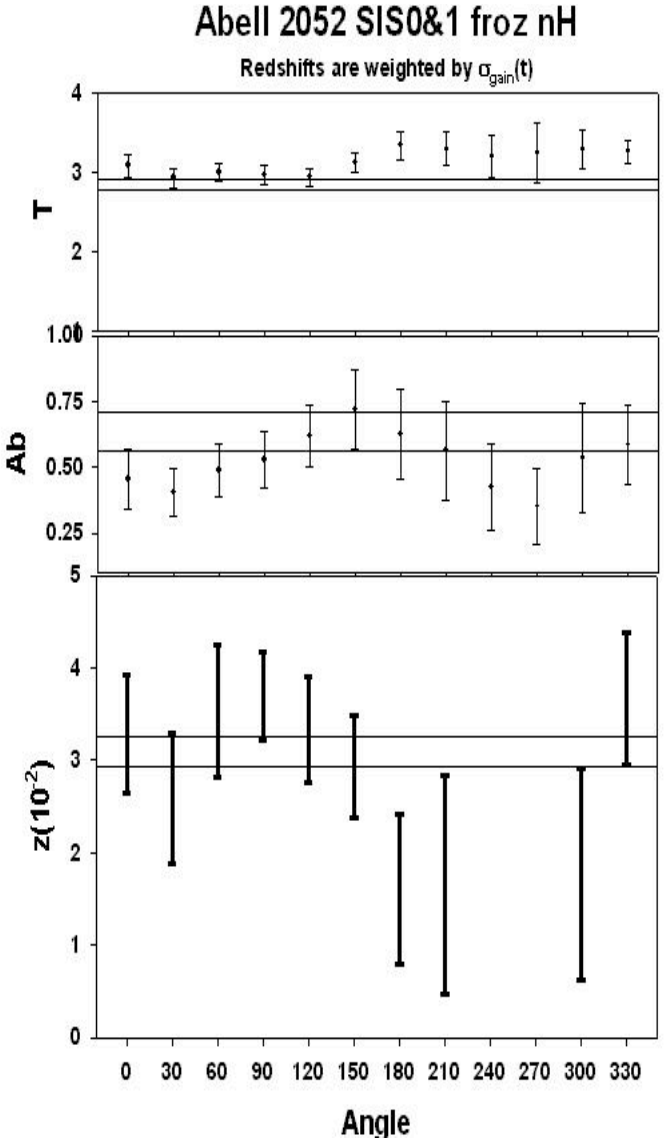


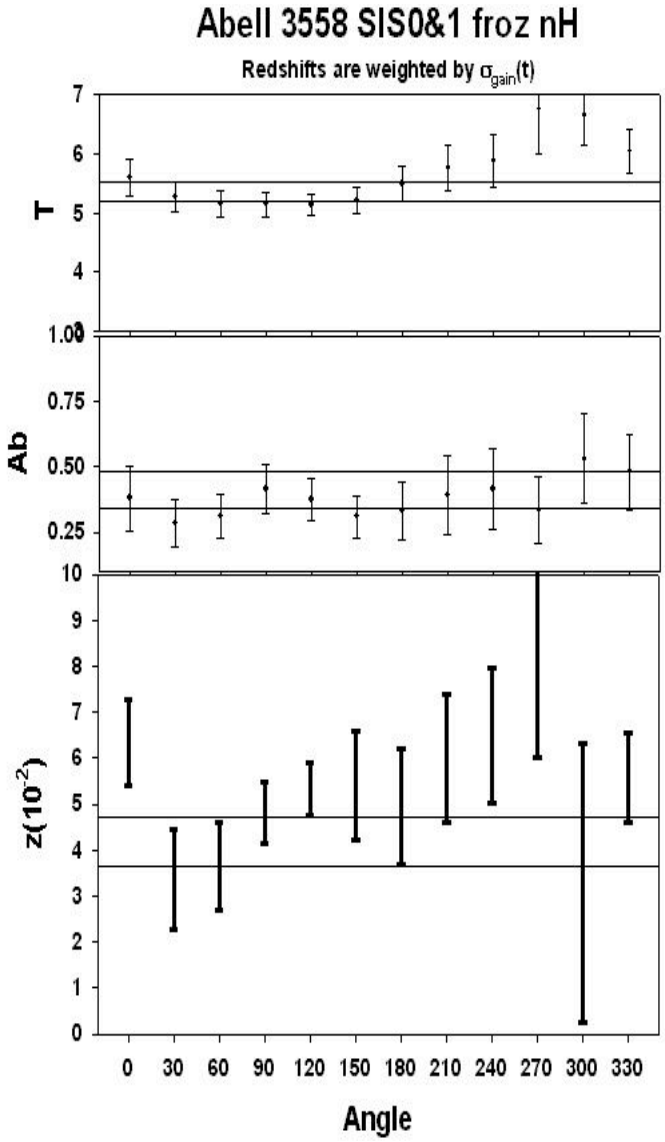
Best Cases


Abell 576 SIS0&1 froz nH
Redshifts are weighted by $\sigma_{gain}(t)$
T
Ab
z(10^{-2})
Angle
0 30 60 90 120 150 180 210 240 270 300 330

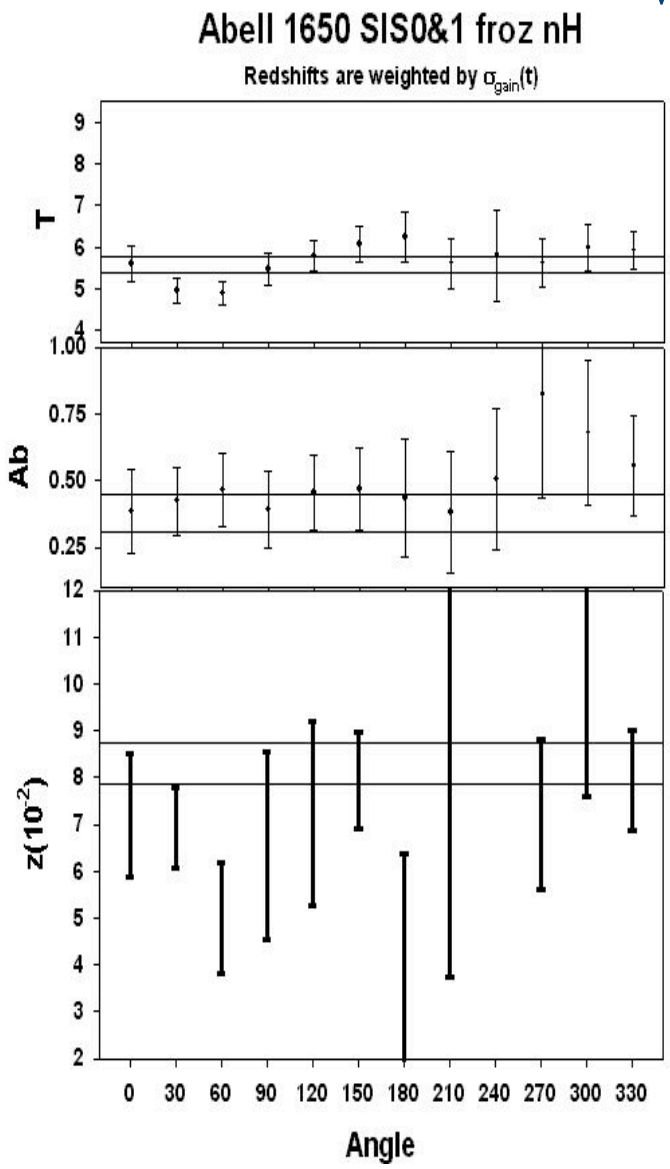

RXJ0418 SIS0&1 froz nH
Redshifts are weighted by $\sigma_{gain}(t)$
T
Ab
z
Angle
0 30 60 90 120 150 180 210 240 270 300 330

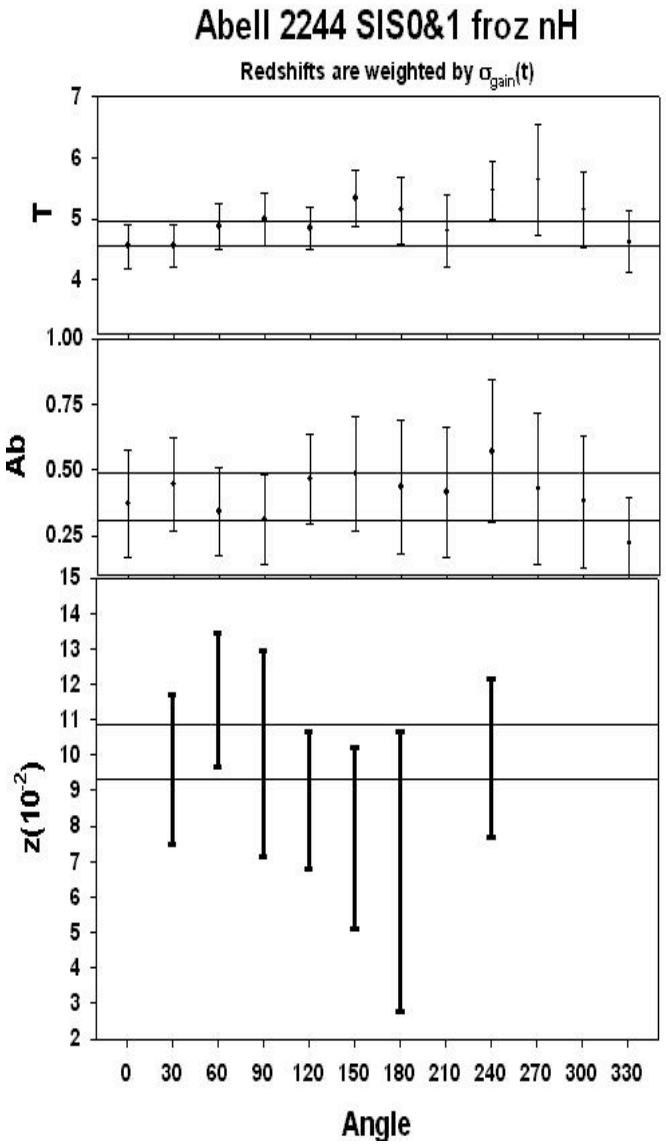
Maybe


Abell 2052 SIS0&1 froz nH
Redshifts are weighted by σgain(t)
T
Ab
z(10-2)
Angle
0 30 60 90 120 150 180 210 240 270 300 330


Abell 3558 SIS0&1 froz nH
Redshifts are weighted by σgain(t)
T
Ab
z(10-2)
Angle
0 30 60 90 120 150 180 210 240 270 300 330

Worst

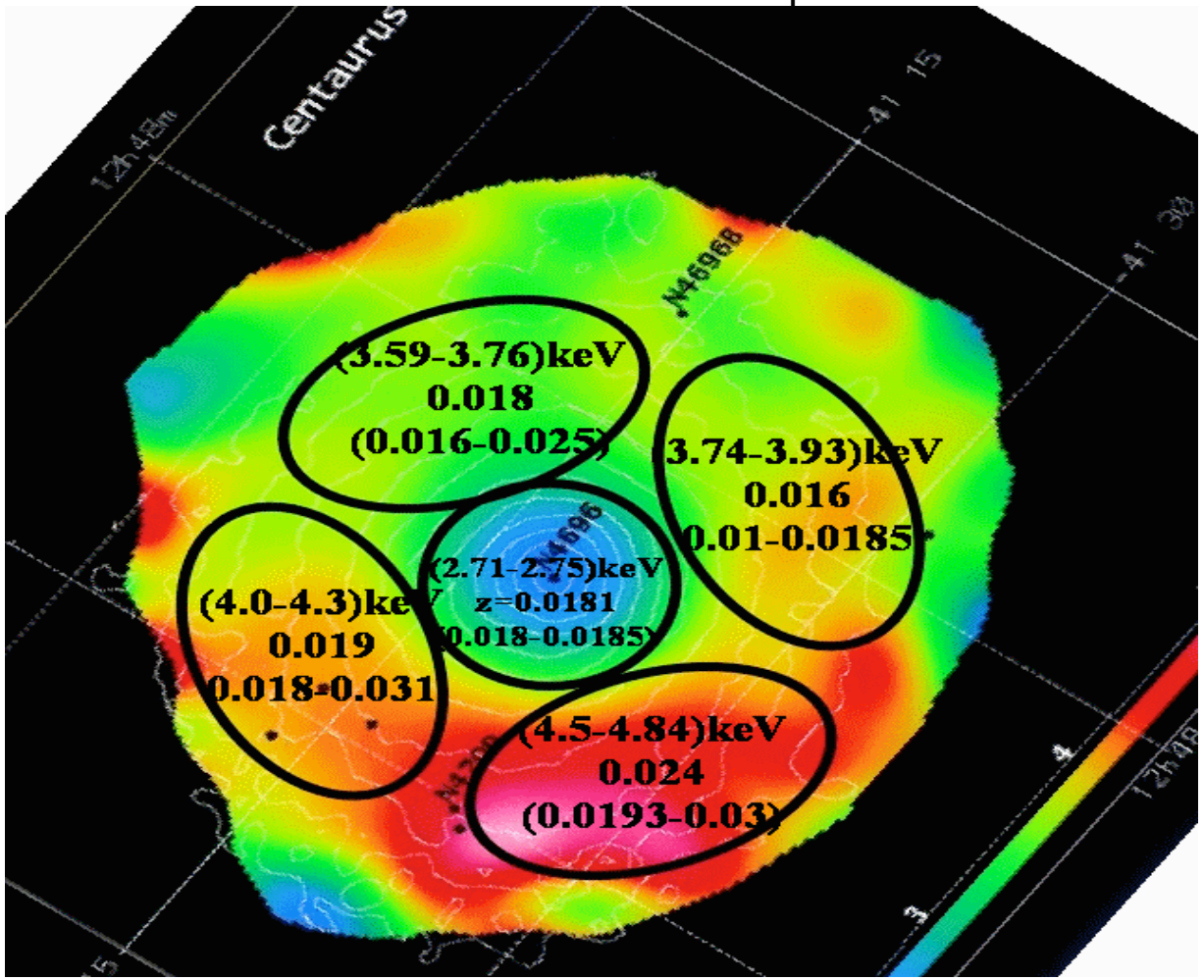

Abell 1650 SIS0&1 froz nH
Redshifts are weighted by $\sigma_{gain}(t)$
T
Ab
z(10^{-2})
Angle
0 30 60 90 120 150 180 210 240 270 300 330


Abell 2244 SIS0&1 froz nH
Redshifts are weighted by $\sigma_{gain}(t)$
T
Ab
z(10^{-2})
Angle
0 30 60 90 120 150 180 210 240 270 300 330

Discussion

- Results so far are consistent with a 10-20% of clusters having transients or rotational ICM bulk motions.
- ASCA sample is detecting the “tip of the iceberg”, i.e., the clusters that still have residual velocities on the order of several thousands km/s. Chandra and XMM archival studies will significantly improve the statistics of bulk motions in clusters and will provide “prior” knowledge about the velocity distribution that will be used to:
- provide the first “gain free” velocity maps with observations specifically tailored for velocity studies through multiple offset observations with Chandra and XMM and
- pave the way for “very” high resolution tomography by future spectrometers, such as the calorimeters on-board ASTRO-E2 and Constellation-X.

- Churazov et al. 1999

  Temperature map shows high temperature region associated with NGC 4709

  Infall of Subgroup?
- Test: Could we see this with the GIS? We find a significant (90% confidence) $\Delta z \rightarrow$ 1800km/s in the same direction as the optical studies