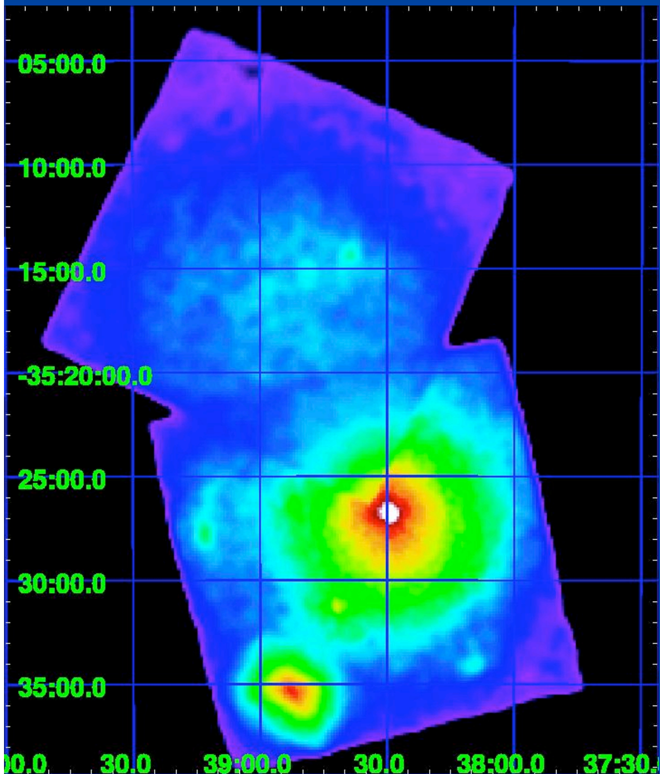
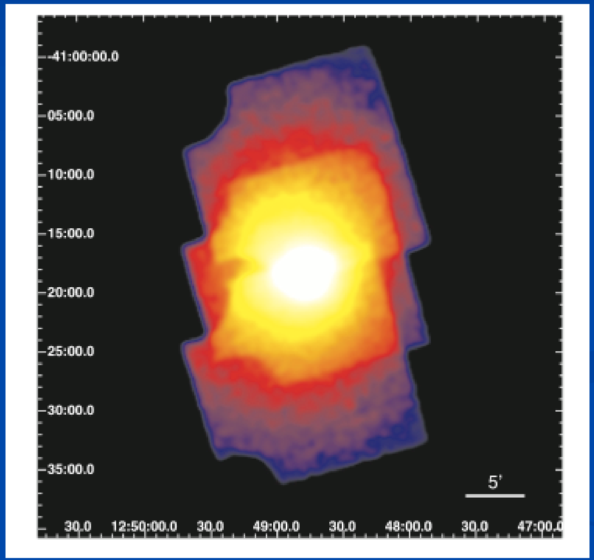
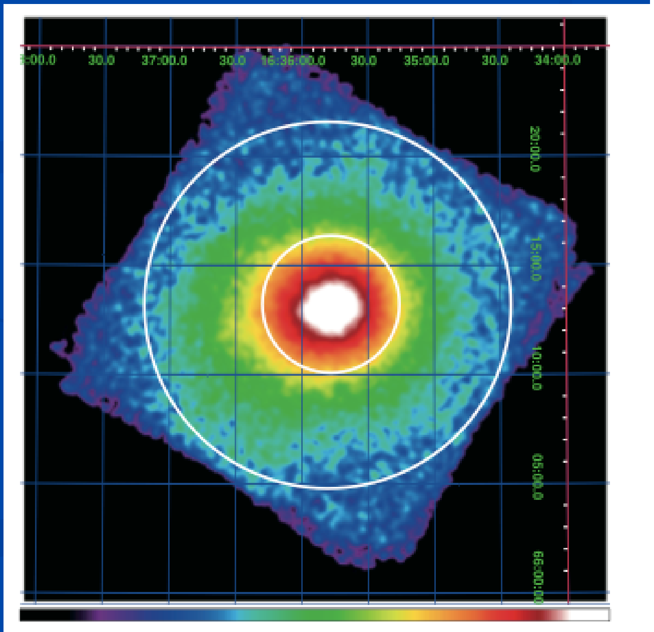
Probing New Astrophysical Regimes in Groups and Clusters with *Suzaku*





Abell 2218
(Takei et al.)

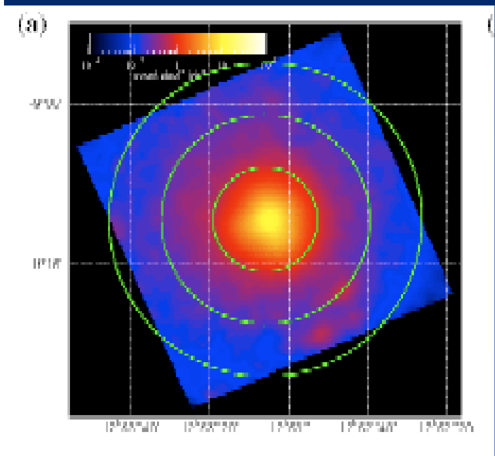


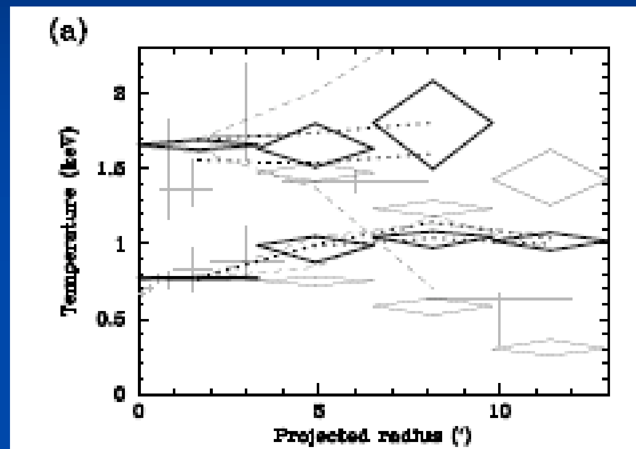
Centaurus
(Ota et al.)

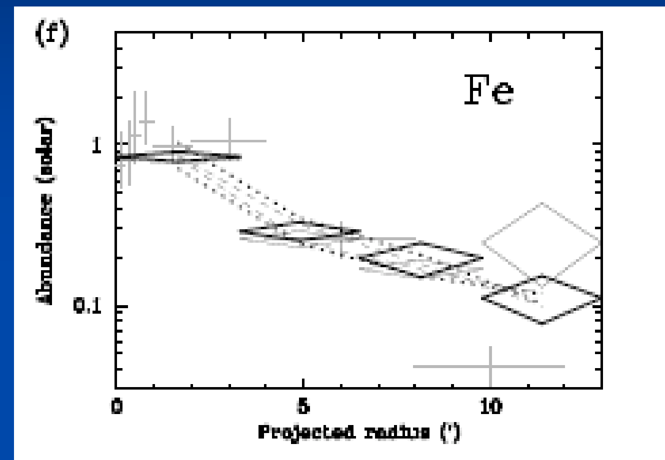
Fornax (Matsushita et al.)

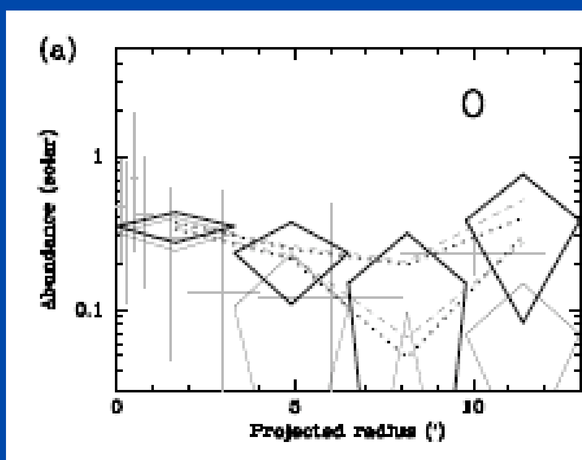
Michael Loewenstein, NASA/GSFC-UMD/CP- CRESST

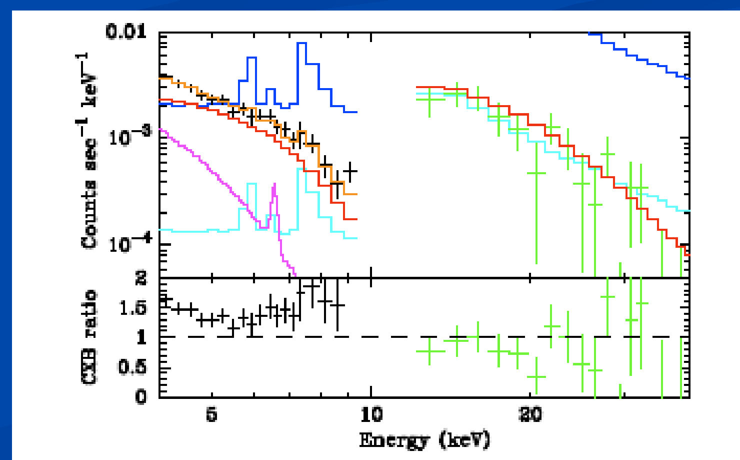
An Example of What *Suzaku* Can Do: HCG 62







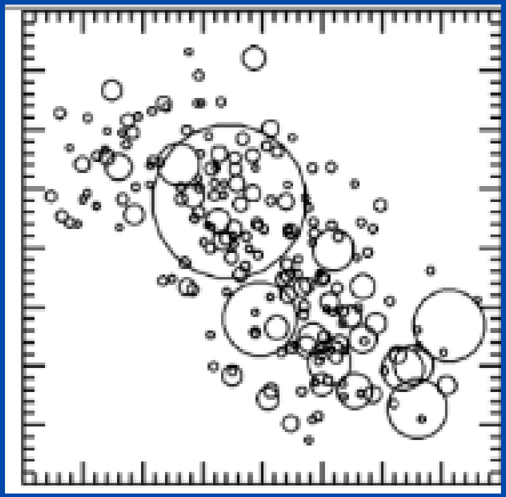




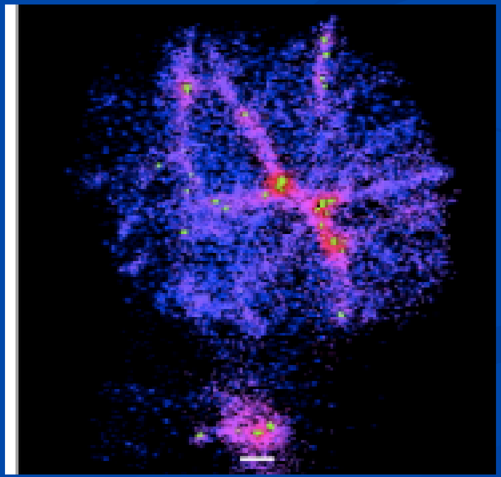
Tokoi et al. 2008

What's the Matter in the Universe?

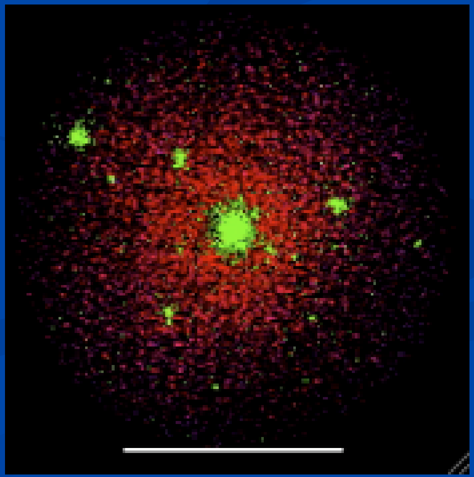
- Most of the matter in the universe is dark matter, collapsed into a hierarchy (10^7-10^{15} $M_{\odot}$) of halos
- Galaxies are dissipative baryon structures embedded in dm subhalos (that may be embedded in larger halos…) [Weinberg et al. 2008]



Z=0



Z=3



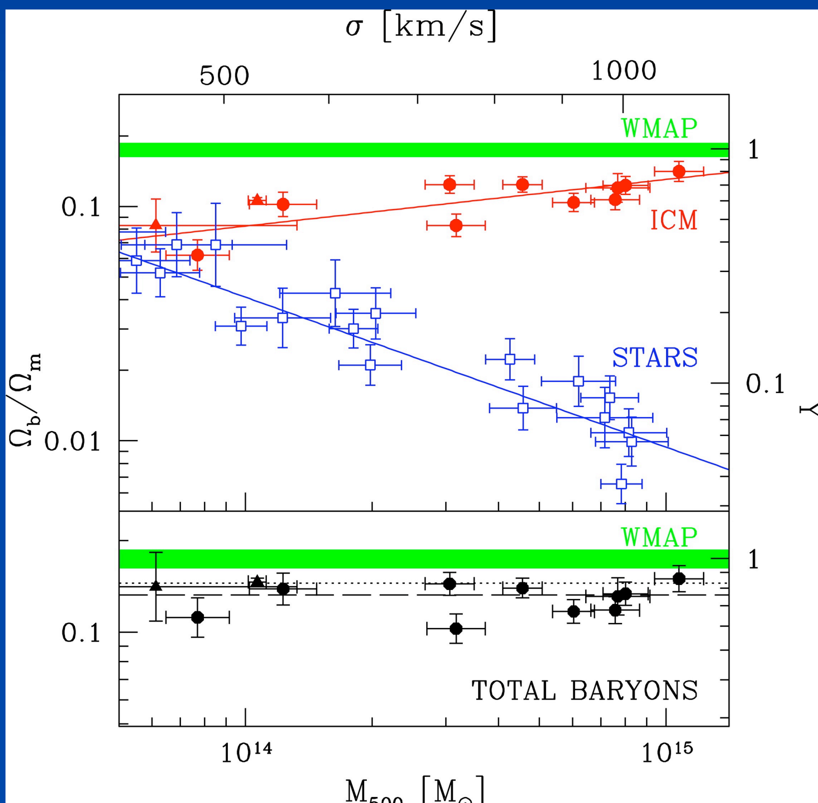
Z=0

Clusters and Groups in Context

- "Leftover" intergalactic gas, heated to X-ray temperatures, is retained in large (>10^{13} $M_\odot$) halos where it is chemically and thermodynamically influenced by galaxy feedback
- X-ray groups and clusters trace the Large Scale Structure in the Universe (cosmology), but the mapping depends on the "gastrophysics" of the feedback -- which leaves an imprint in the thermal and abundance structure of the ICM/IGM

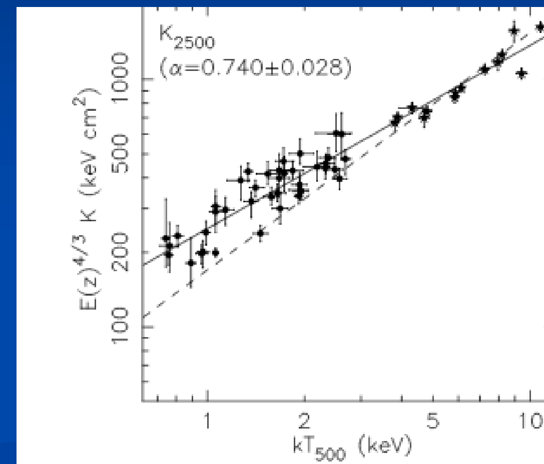
Clusters versus Groups

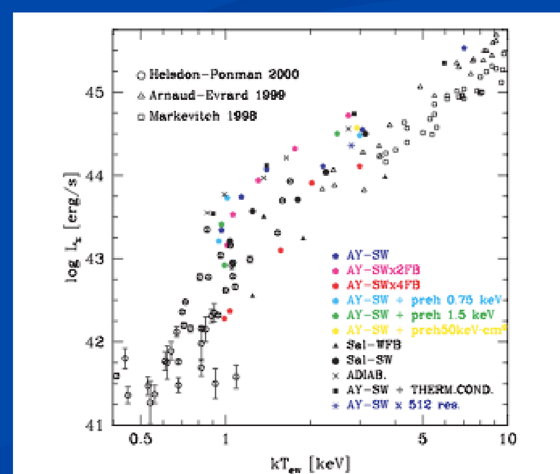
Galaxies: Groups have proportionally more stars and are more affected by feedback (globally)



(Gonzalez et al. 2007)

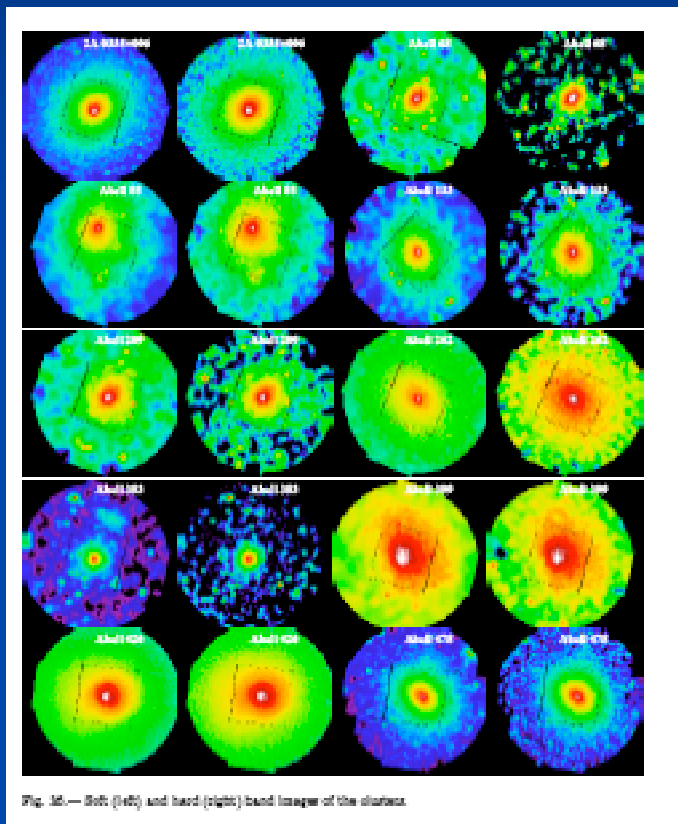
S-T (Sun et al. 2008)



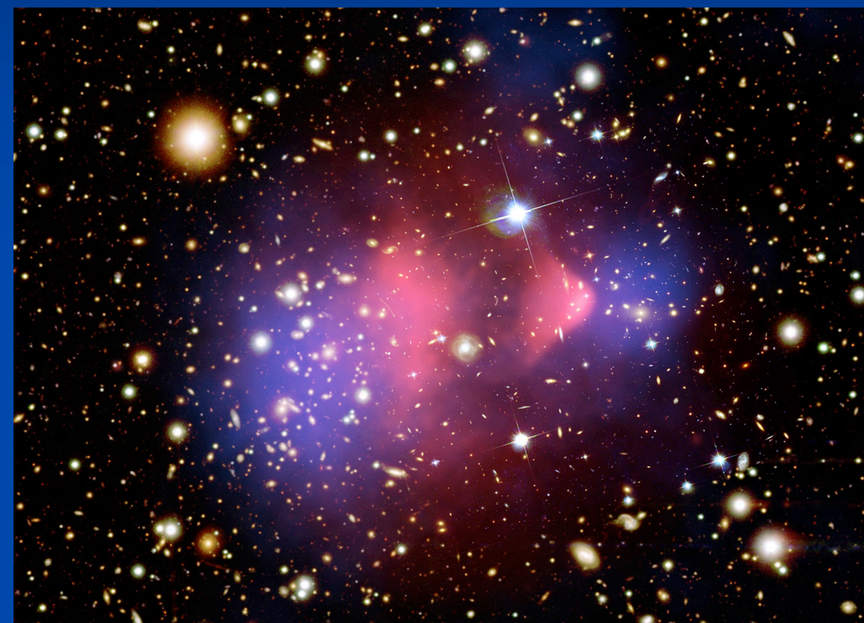


L-T (Romeo et al. 2006)

Clusters -- Relaxed and Tense



How relaxed? Scaling?
Chemical evolution?



Particle acceleration?
Plasma and shock physics?
How a merger proceeds?

Format of this Talk

The issue: what do we wish to investigate?

What *Suzaku* has: capabilities that other X-ray observatories lack, of relevance to the issue at hand

What *Suzaku* can do: how these capabilities apply to the issue at hand

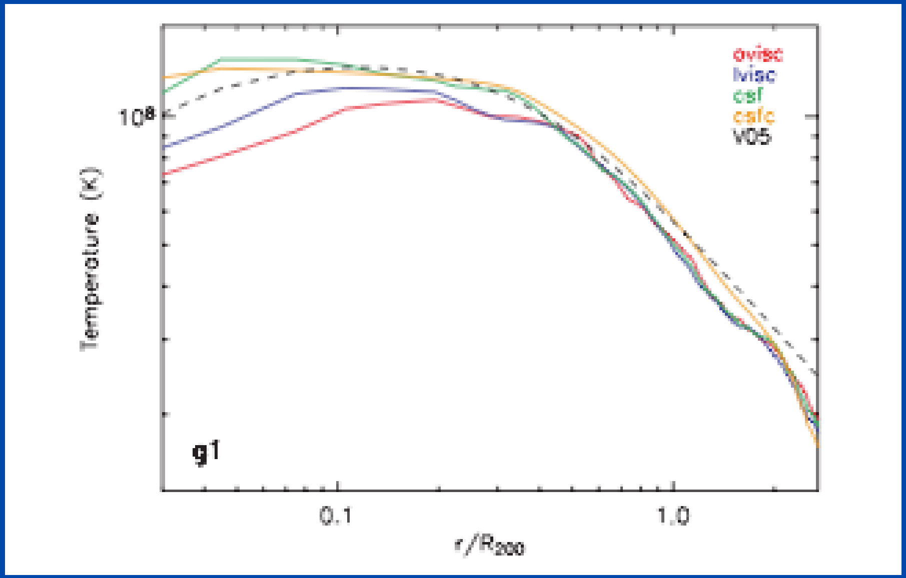
What *Suzaku* has done: instances of this application

case studies

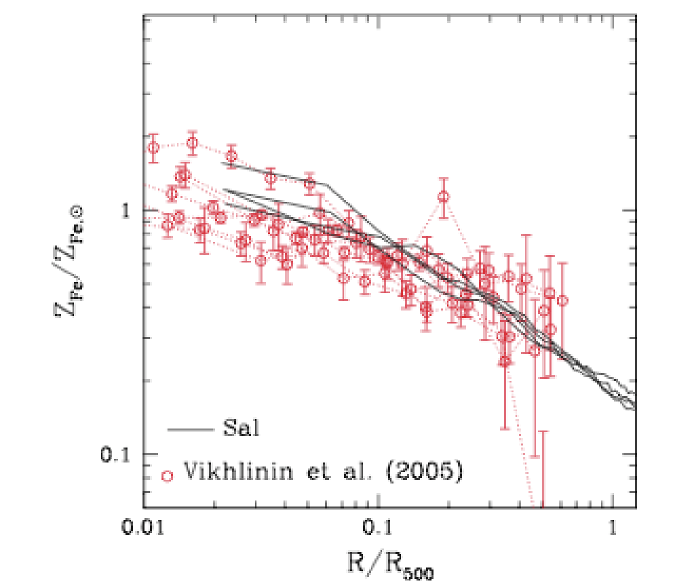
Synergy: complementary X-ray obs.

To the Virial Radius

The issues: Does *kT* and *Z* decline as predicted?
Or is there "missing physics" (transport, dissipation, etc.)



Roncarelli et al. 2006



Fabjan et al. 2008

Synergy:XIS+*Chandra*+*XMM-Newton*

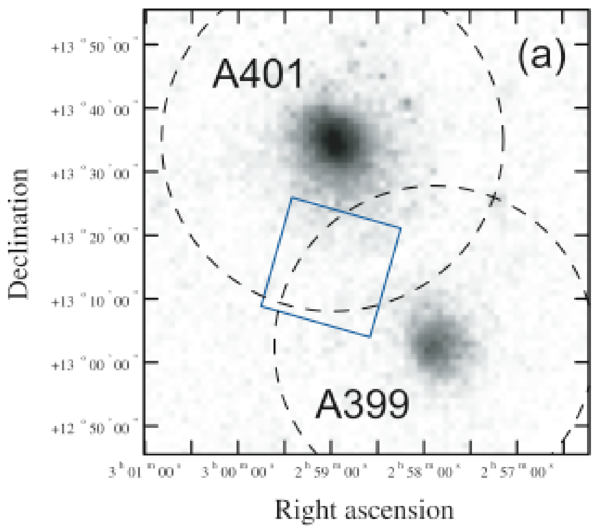
To the Virial Radius

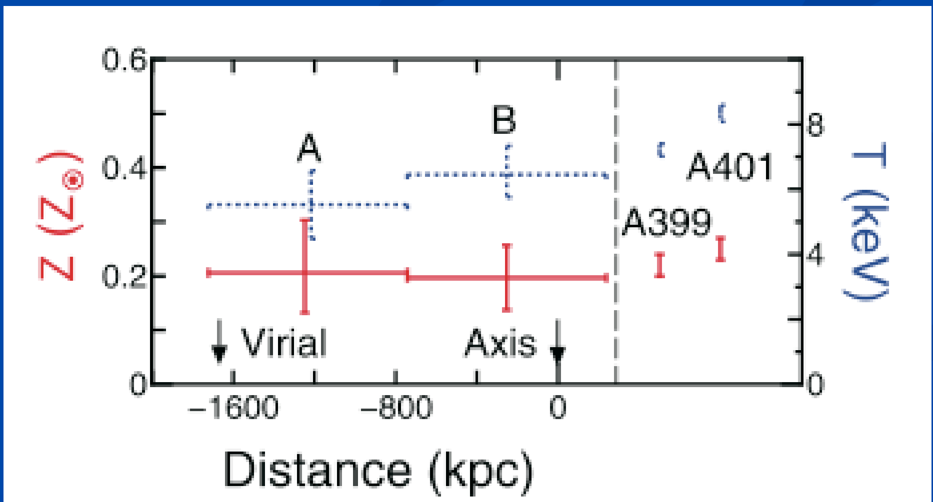
What *Suzaku* has: low background

What *Suzaku* can do: measure *kT*, Z to R_{virial}
(for some clusters)

What *Suzaku* has done: (a) A399/401 -- Fujita et al. 2008

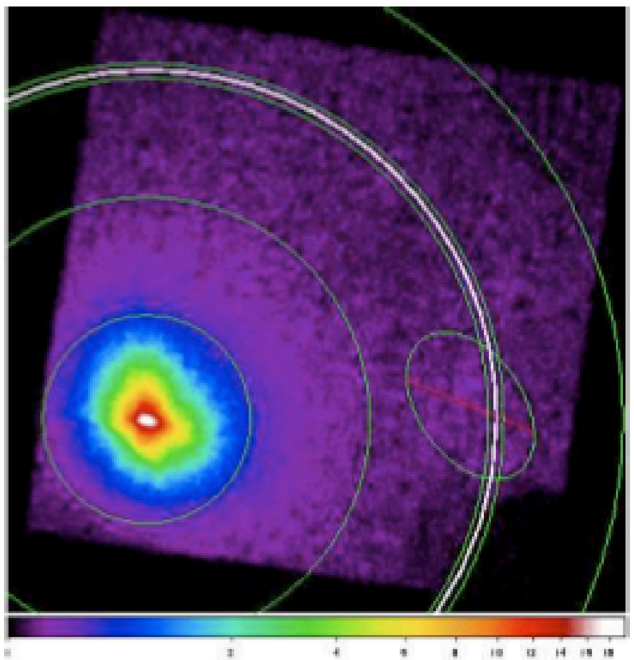
super-wind proto-cluster pre-enrichment
???

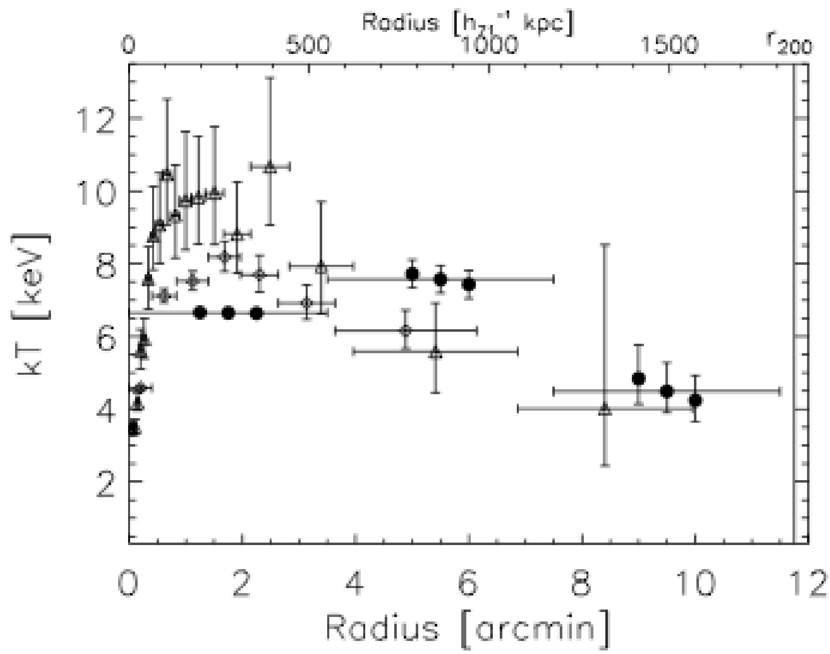




To the Virial Radius

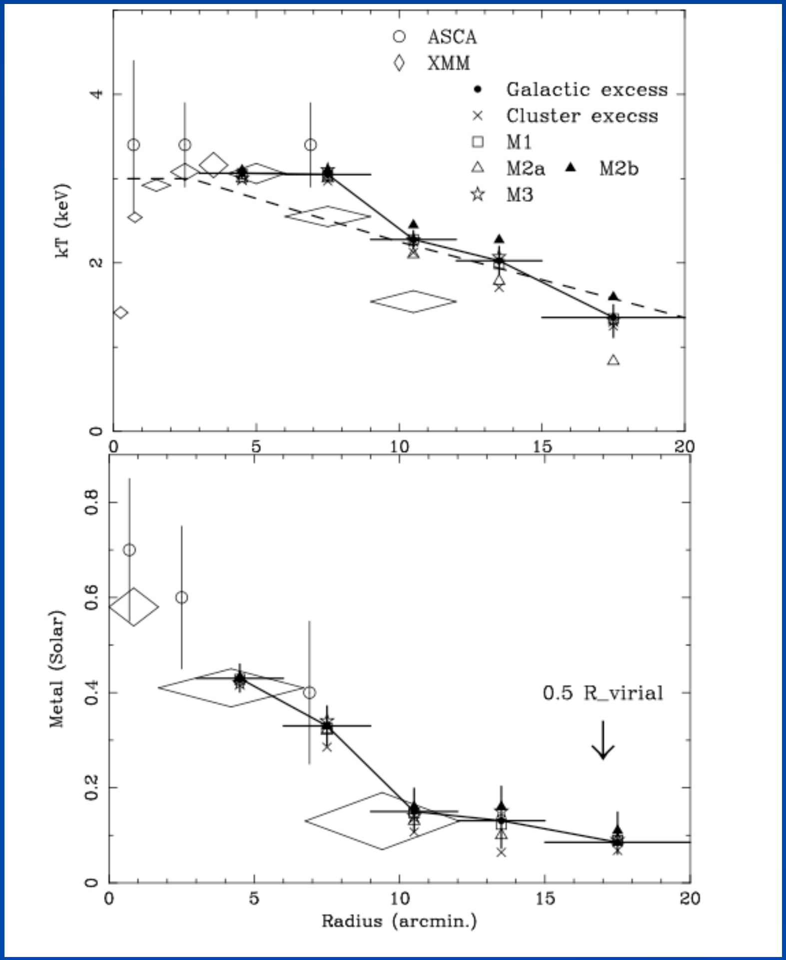
What *Suzaku* has done: (b) A2204 -- Reiprich et al.

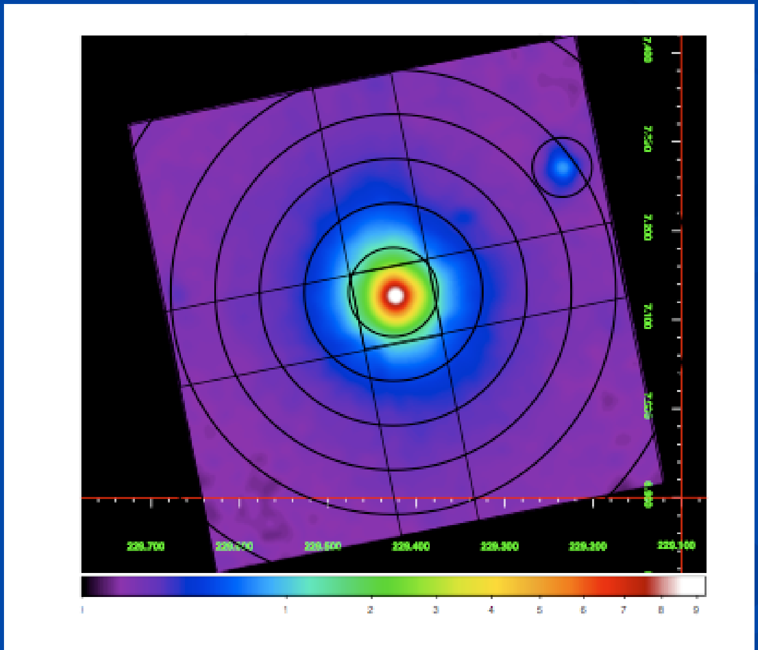




To the Virial Radius

What *Suzaku* has done: (c) A2052 -- Tamura et al., PASJ in press





The Soft Component, WHIM

The issue: What is the nature of the soft excess (if real)? Are previous claims of OVII from WHIM or SWCX or..?

What *Suzaku* has: $E/\Delta E$ and sensitivity at low E

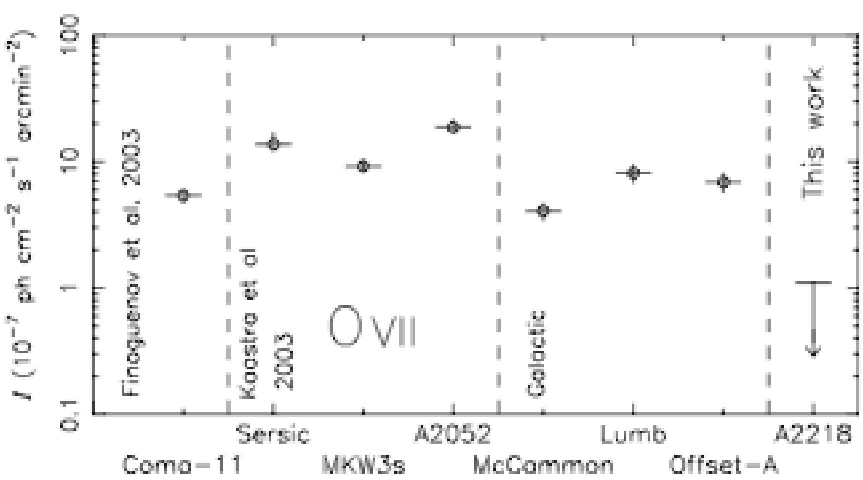
What *Suzaku* can do: look for emission in (or near) the OVII and OVIII lines (thermal)

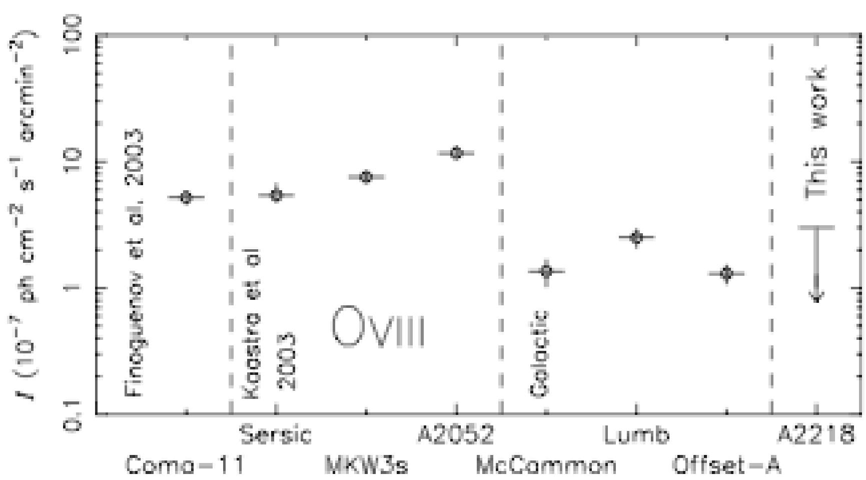
Synergy: XIS+*XMM-Newton*

The Soft Component, WHIM

What *Suzaku* has done:

Upper limit to (redshifted) OVII, OVIII around Coma and Abell 2218 -- lower than previous “detections” (Takei et al. 2007, 2008)



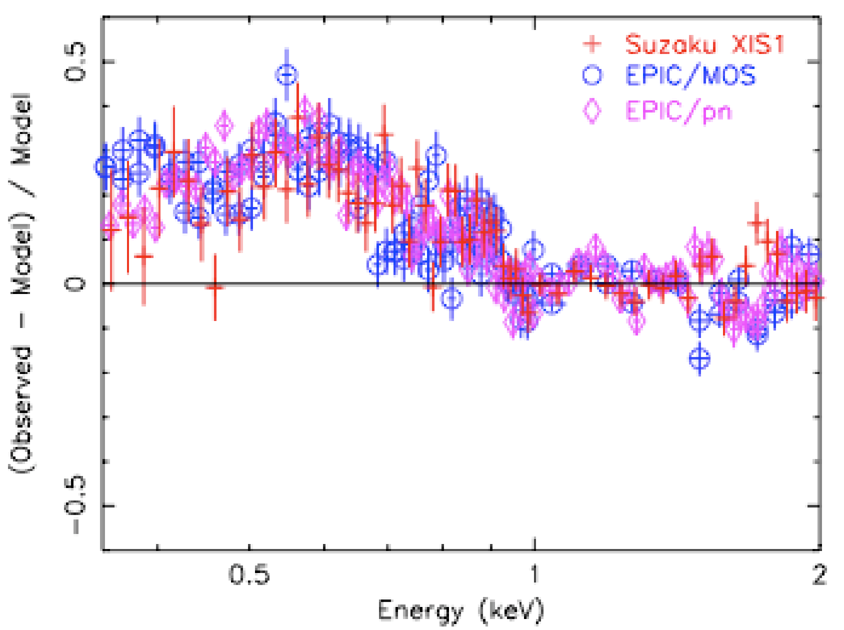


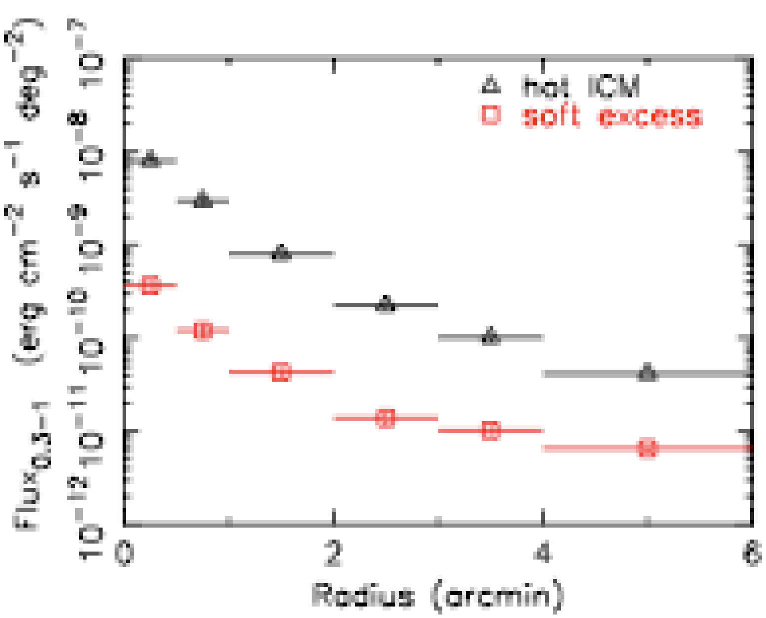
Fujita et al. 2008 derive an even smaller limit in the A399/A401 “link” region

The Soft Component, WHIM

What *Suzaku* has done:

Confirm the soft excess in Sersic 159-03, upper limit on OVII (Werner et al. 2007). A non-thermal origin is favored (the emission is also centrally peaked).





Bulk Flows

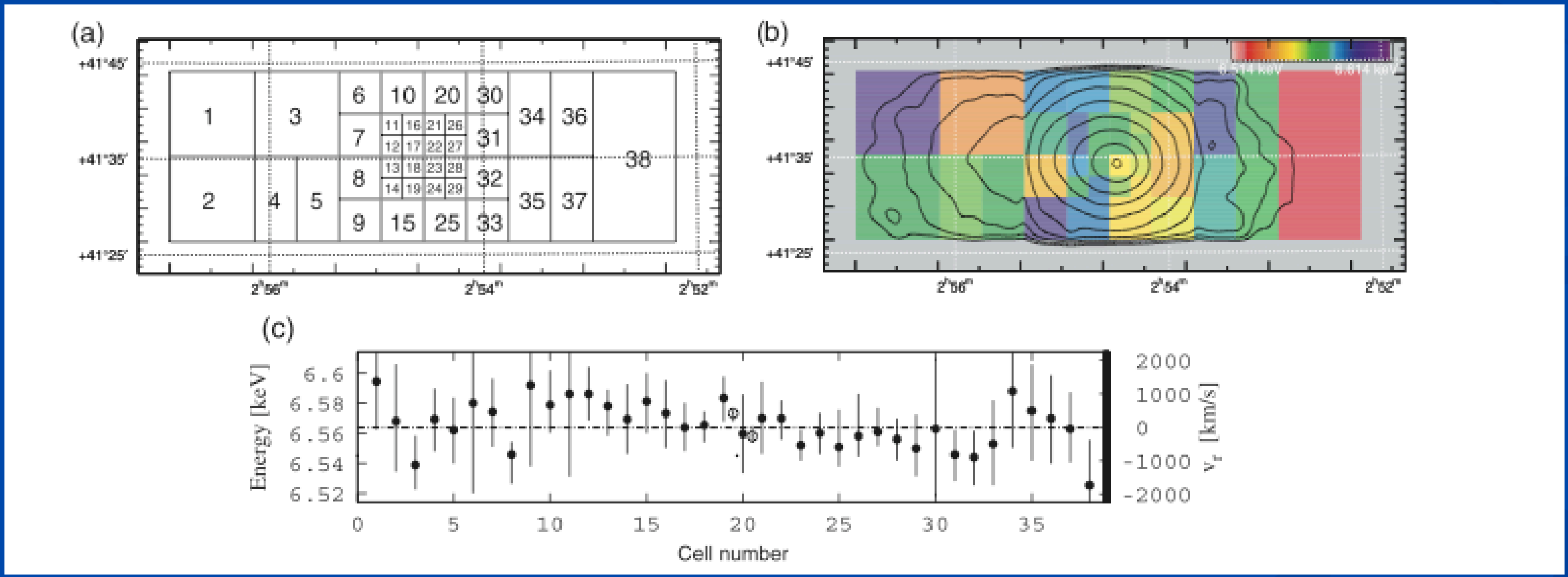
The issue: Bulk flows of ~1000 km/s naturally arise during cluster formation in a ΛCDM universe and are predicted to persist for Gyrs. Can we measure these and use them as a probe of the dynamical state and evolution? Are previous marginal detections real?

What *Suzaku* has: $E/\Delta E$

What *Suzaku* can do: measure line shifts and widths

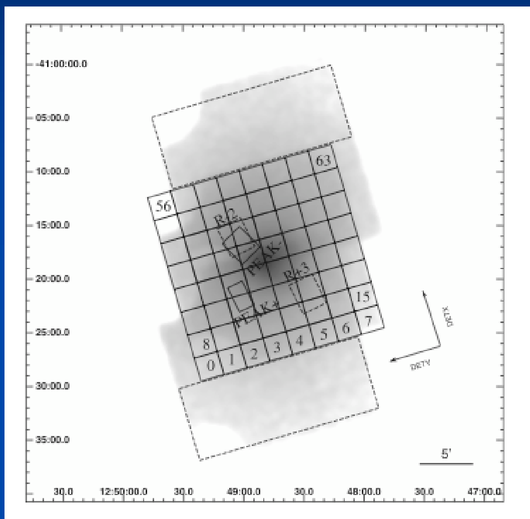
Bulk Flows

What *Suzaku* has done: Not detected a significant ΔV or σ_{turb} at the ~1500 km/sec level in the best cases from FeKα



The elongation in AWM 7 cannot be due to rotation (Sato et al. 2008)

The Case of the Flow that Fell



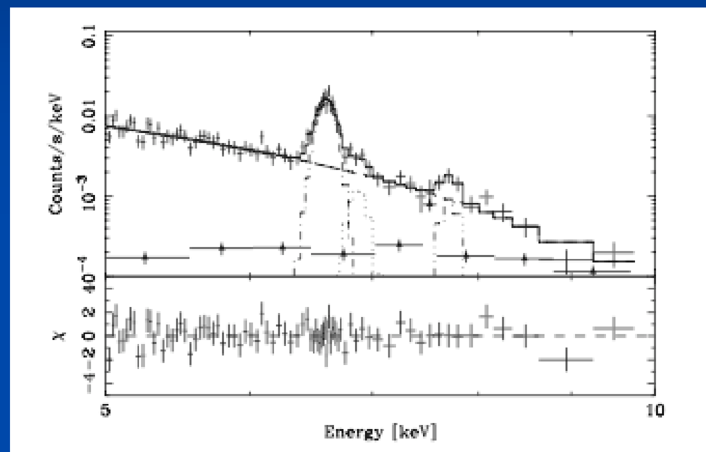
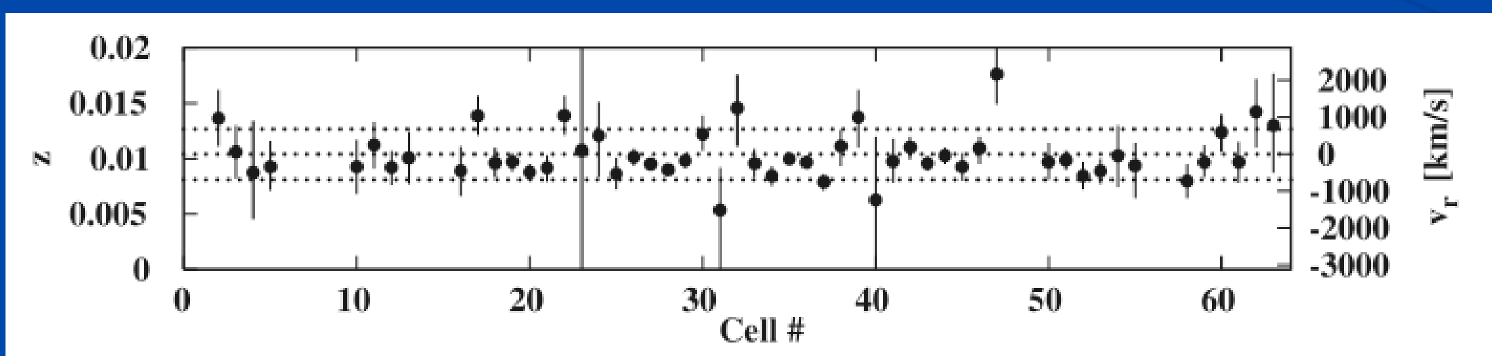


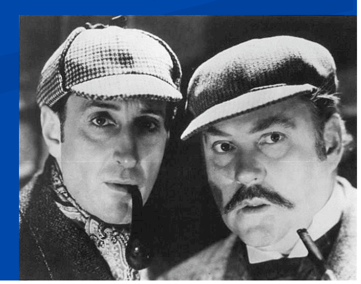
Table 2. Comparisons of velocity differences measured with Suzaku and Chandra.

Region	Suzaku/XIS	Chandra/ACIS
	Δv (km s^{-1})*	Δv (km s^{-1})†
PEAK−, PEAK+	$-660 \pm 390 (\pm 660)$	2900 ± 700
R−2, R+3	$-540 \pm 360 (\pm 660)$	2400 ± 1000

* The velocity difference derived from the XIS spectra. The 68% statistical errors and (the 68% systematic errors) are quoted.
† The velocity difference and the 1σ error derived from the Chandra ACIS spectra (Dupke, Bregman 2006).

Ota et al. 2007: Centaurus Cluster





The Hard Component

The issue: Non-thermal electrons naturally arise during cluster formation in a ΛCDM universe from merger shocks but should cool in 0.1Gyr. Are they re-produced, re-injected, or re-accelerated (radio synchrotron)? Do they significantly contribute to the cluster energy density? How robust are previous (marginal) detections [systematics]?

What *Suzaku* has: HXD (lower background, smaller FOV)

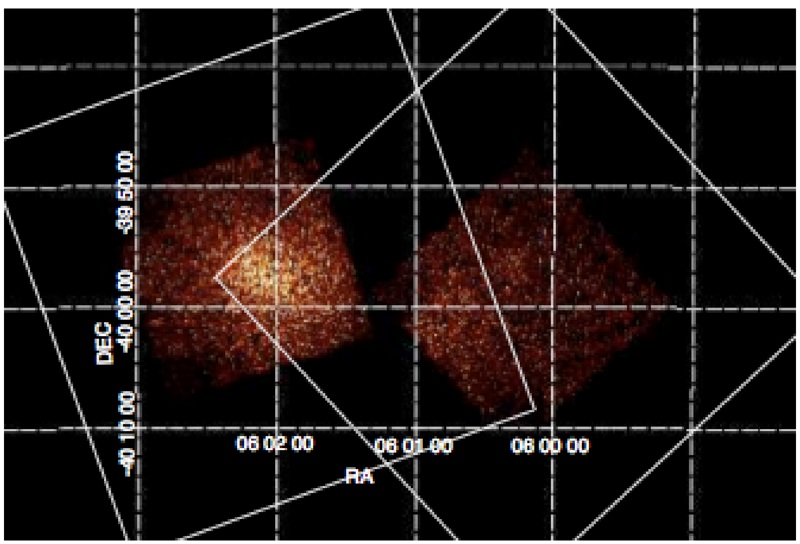
What *Suzaku* can do: look for hard X-rays from IC scattering off the CMB

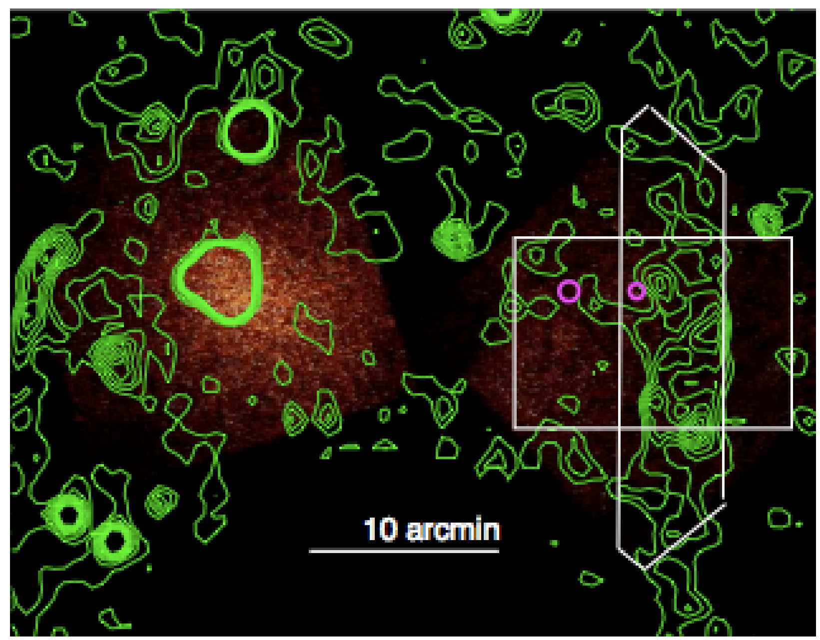
The Hard Component

What *Suzaku* has done: limits approaching detections with Beppo-SAX in Abell 3376 (Kawano et al., PASJ in press)

Other HXD: RXJ1347.5-1145, Ophiuchus

West Relic: $B>0.03\mu G$ (HXD), $B>0.1\mu G$ (XIS)





More Merger Physics

The issue: What is the nature of the SE clump in the (hot, luminous, $z=0.45$) cluster RXJ1347.5-1145?

What *Suzaku* has: HXD, $E/\Delta E$, low background

What *Suzaku* can do: id and measure high kT gas

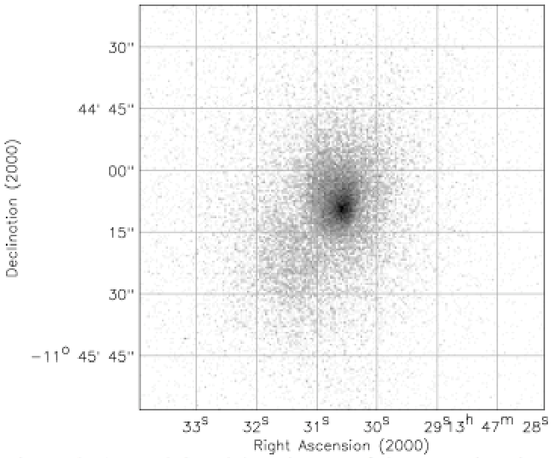
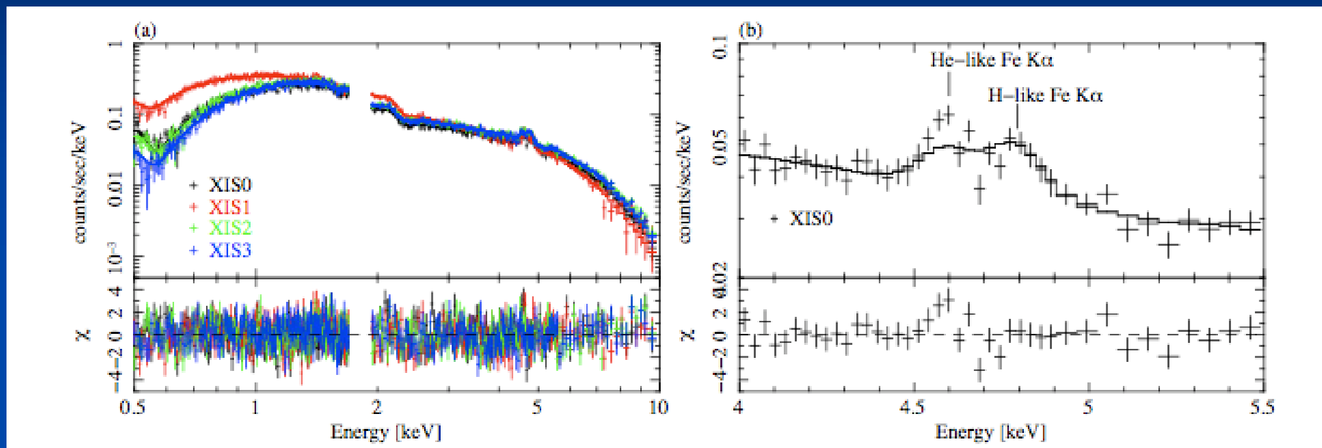


Figure 2. A raw 0.3–7.0 keV image of the central regions of RX J1347.5−1145 on a finer spatial scale (pixel size 0.492 × 0.492 arcsec^2, equivalent to 1 × 1 raw detector pixels).

What *Suzaku* has done: [case study]

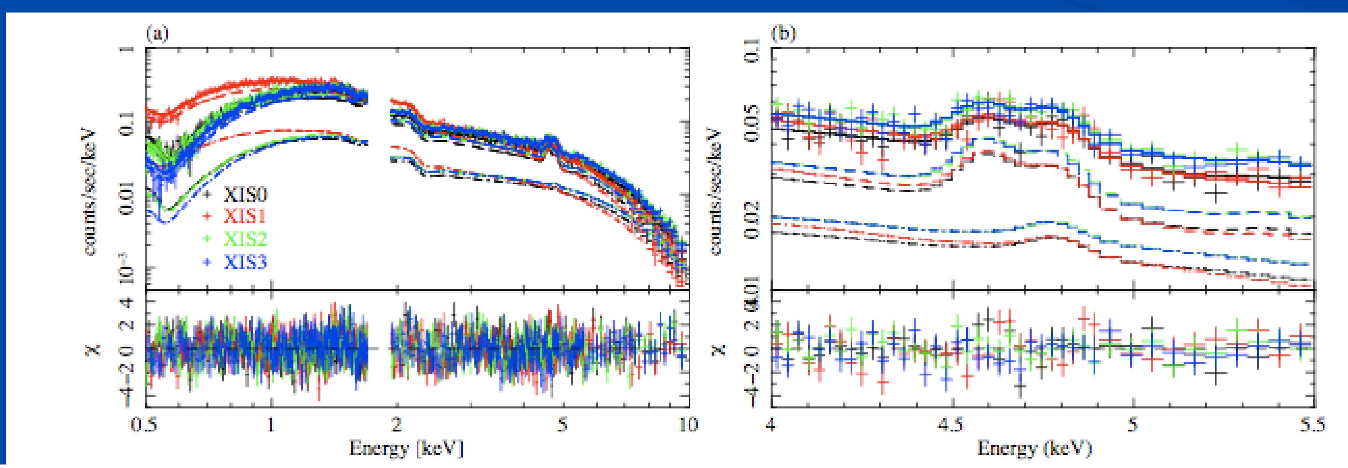
Synergy: HXD+XIS+*Chandra*

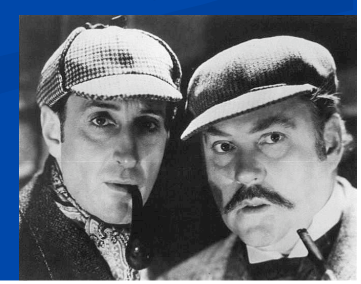
The Case of the Skew Bullet



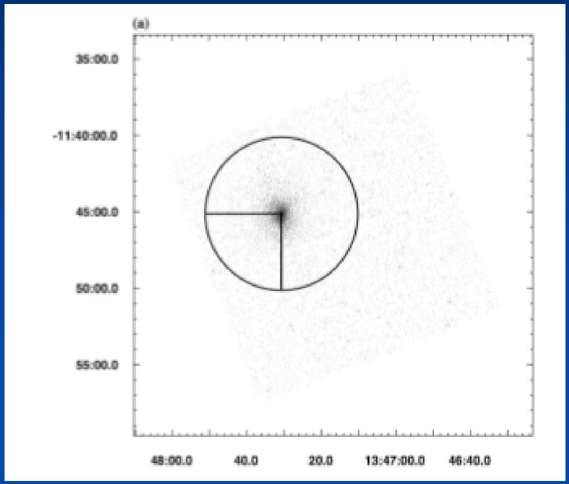
Ota et al., A&A, in press

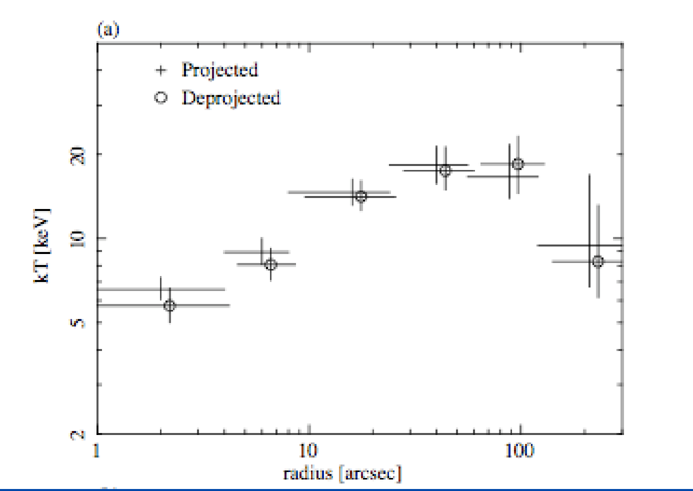
Clue: two temperatures (10, ~30 keV) required to reconcile continuum, Fe-line ratios (global spectrum)

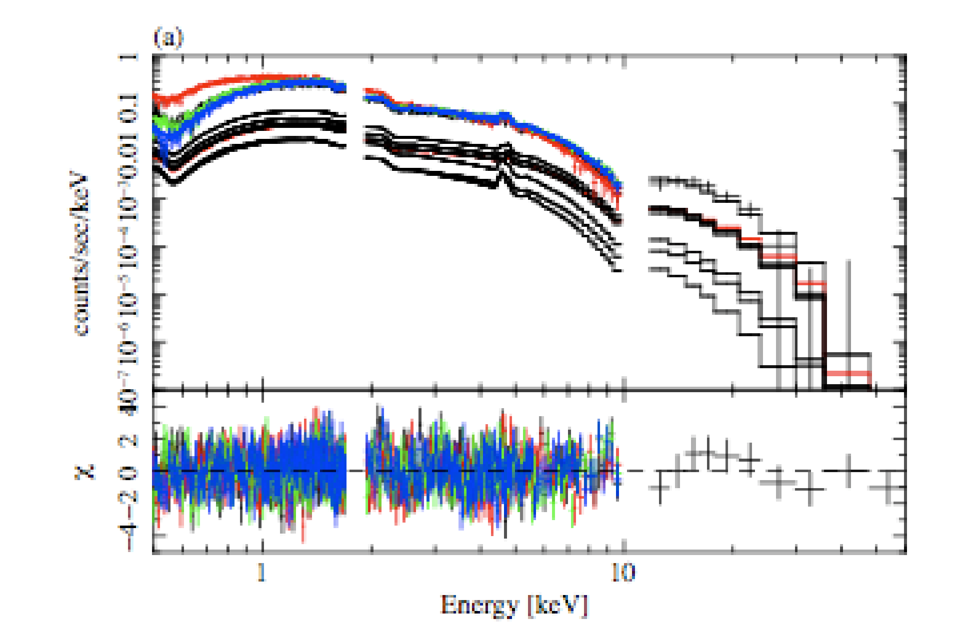




The Case of the Skew Bullet





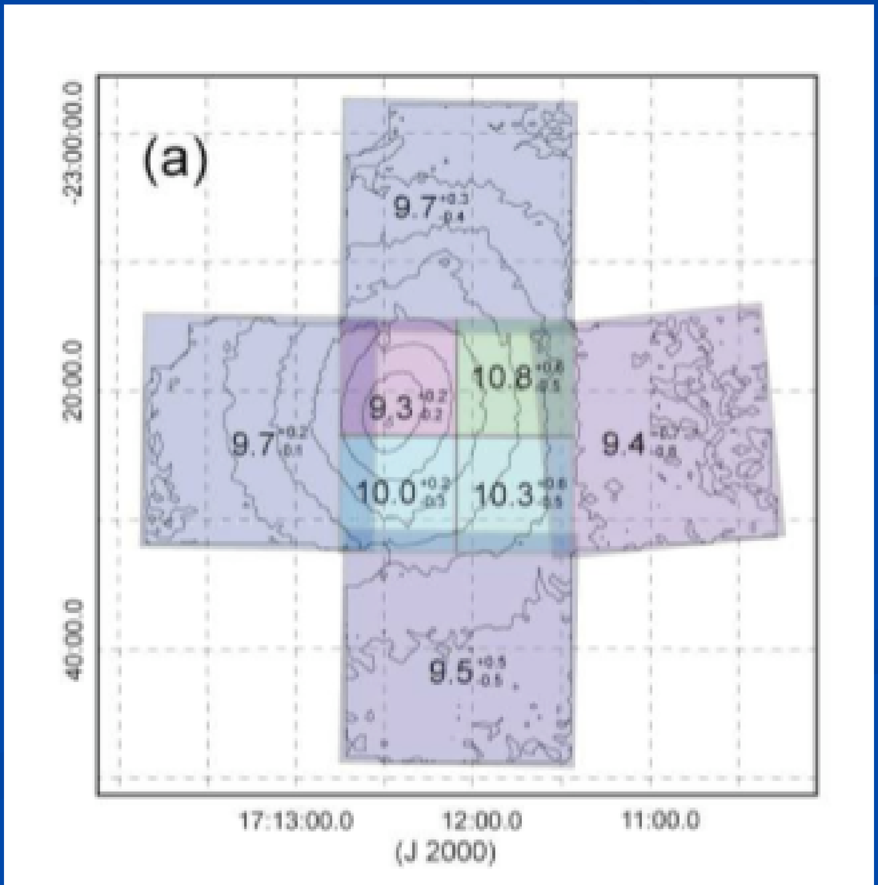


confirmed by careful joint HXD+XIS+*Chandra* analysis -- thermal HC

Recent, high-ΔV, collision of two massive clusters

(Non-)Merger Physics

Claims of a ~20 kev region in the Ophiuchus cluster not confirmed, non-thermal emission not seen, by *Suzaku* (Fujita et al., PASJ, in press)



Abundances

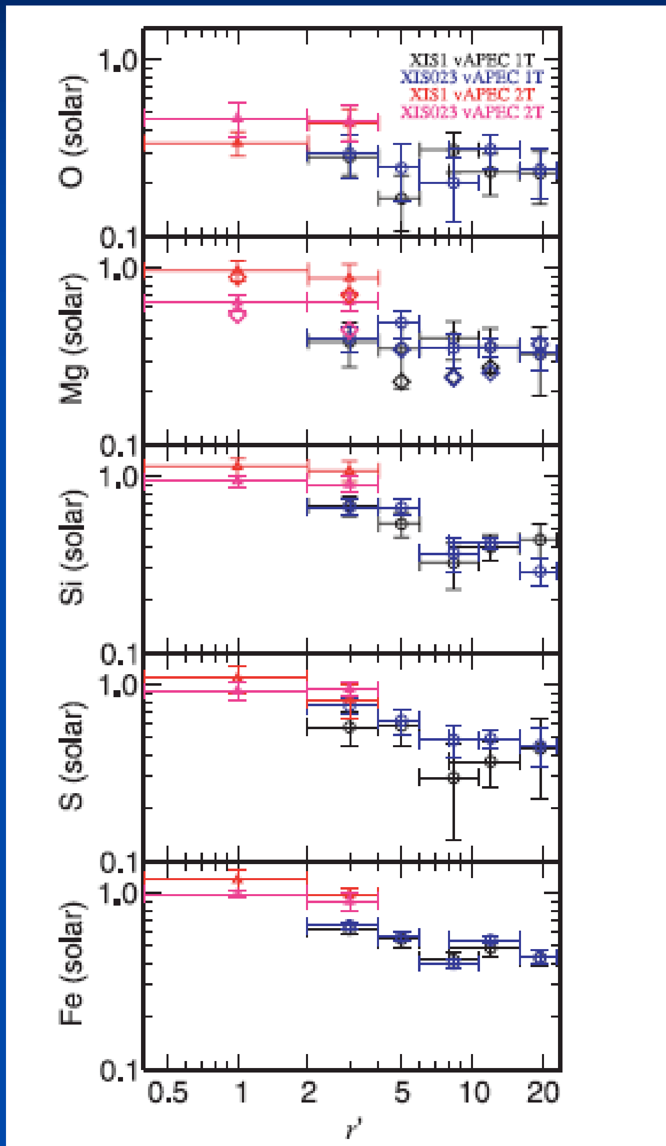
The issue: The amount and pattern of heavy elements are diagnostics of heavy element synthesis (IMF, SNII, SNIa) and transport from galaxies to IGM. This is especially true for the ICM that contains most cluster metals -- but trends with mass are also of great interest.

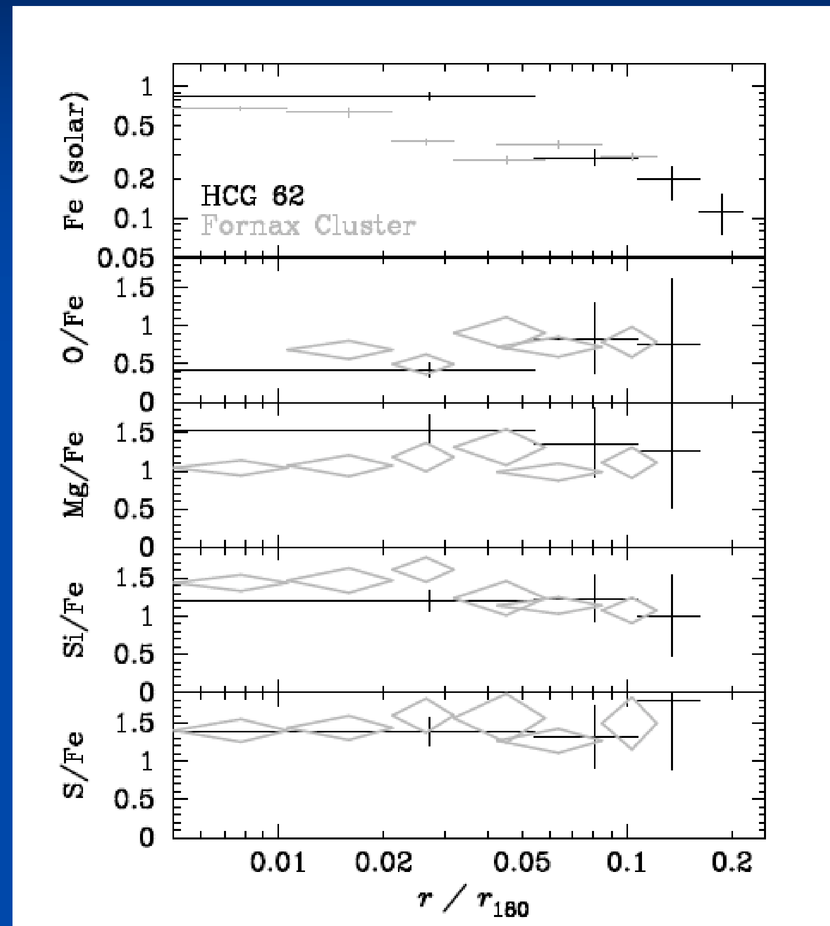
What *Suzaku* has: $E/\Delta E$, low-energy response, low background

What *Suzaku* can do: best measurements yet of Mg, O, Ar, Ne

What *Suzaku* has done: profiles, ratios, ratio-profiles

Abundance Profiles -- Groups





Matsushita et al. (Fornax),
Tokoi et al. (HCG 62)

Abundance Profiles -- Abell 1060

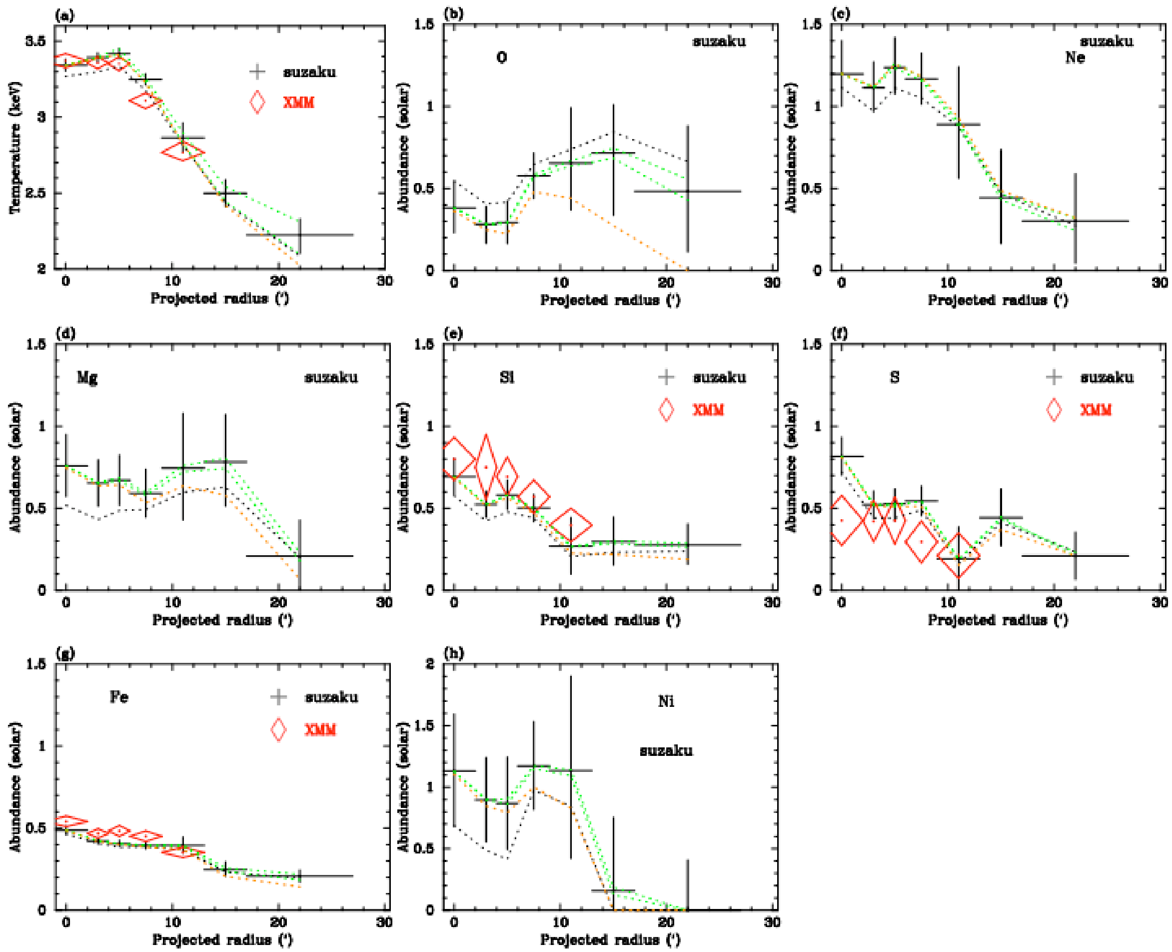
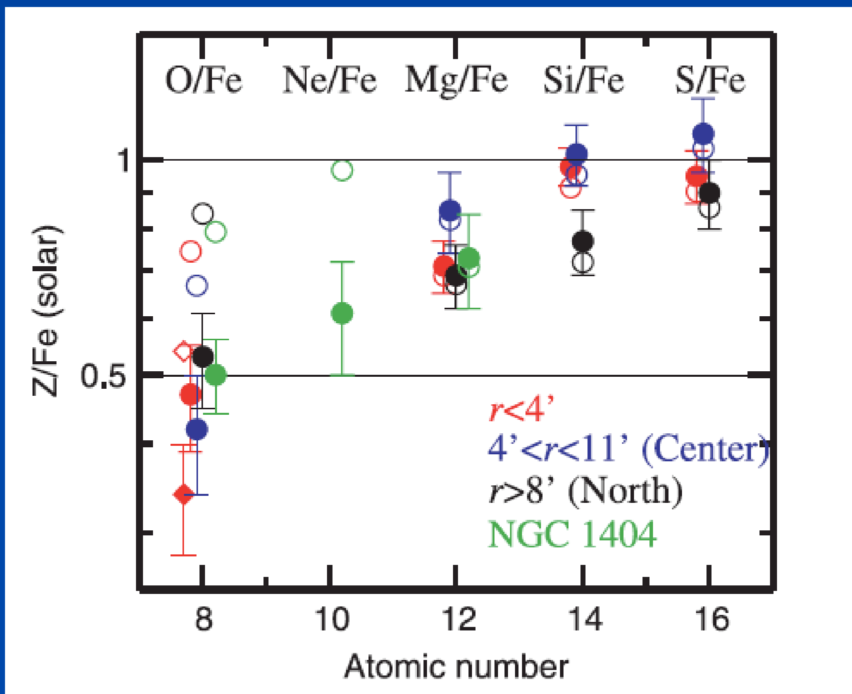


Fig. 10. (a) Radial temperature profiles derived from spectral fit of the Suzaku (black) and XMM-Newton (red) spectra at each annulus. The horizontal axis denotes the projected radius and deprojection are not conducted. The same data with table 8 are used for Suzaku. The black dotted lines correspond to shifts of the best-fit values by changing thickness of the OBF contaminant by +20%. The green dotted lines denote those when the estimated CXB and NXB levels are changed by ±10%. The orange dotted line shows the best-fit value when the Galactic component is modeled by a single *apec*. Regarding XMM-Newton, the *phabs* × *vapec* model are used for the spectral fit, and the O, Ne, Mg, and Ni abundances are fixed to 1 solar in the assumed abundance table of *angr*. (b)–(h) Radial abundance profiles derived and plotted in the same way as (a).

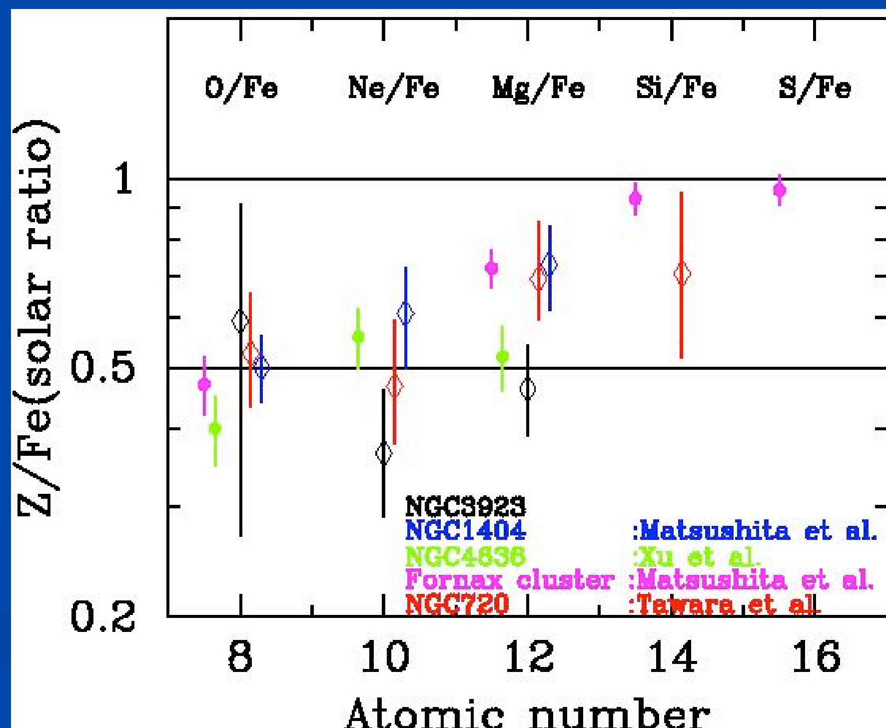
Also AWM 7
(Sato et al.)

Abundance Patterns -- Groups, Ellipticals

Similar pattern within systems, and from system to system -- Fe/α≥1

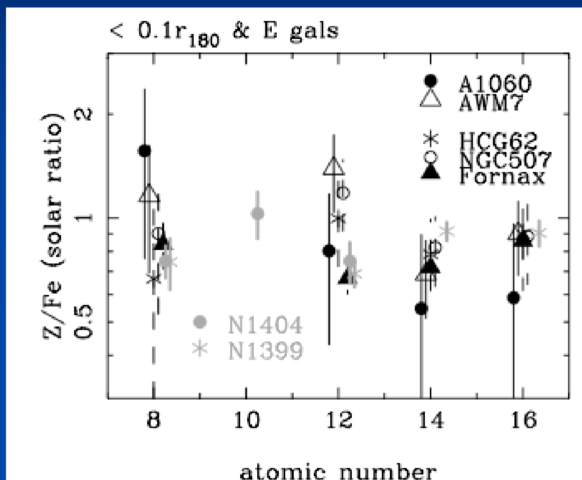


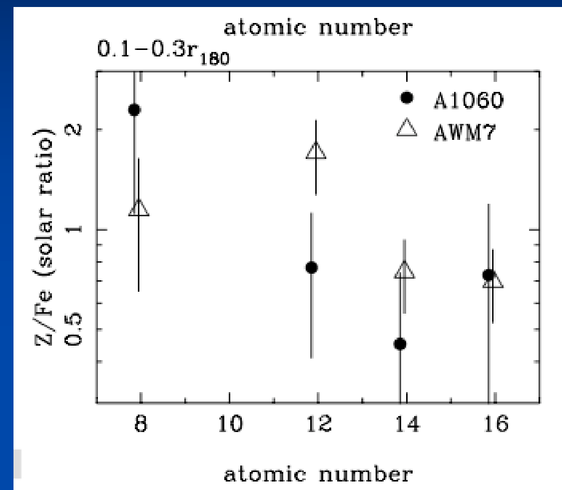
Matsushita et al. 2007



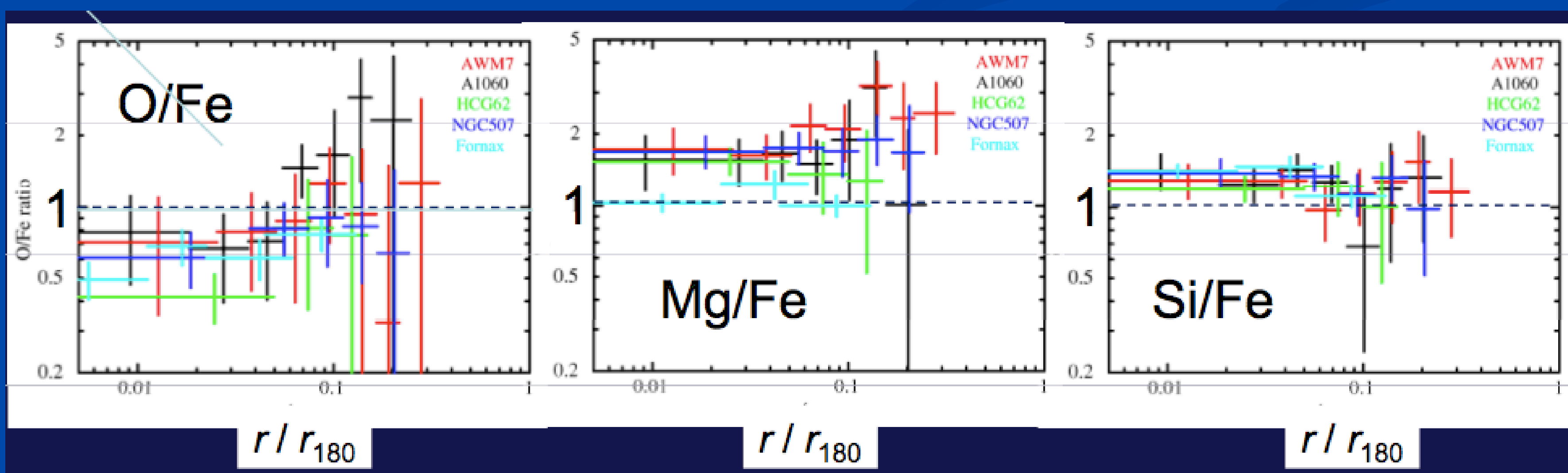
Tawara et al. 2008

Abundance Patterns



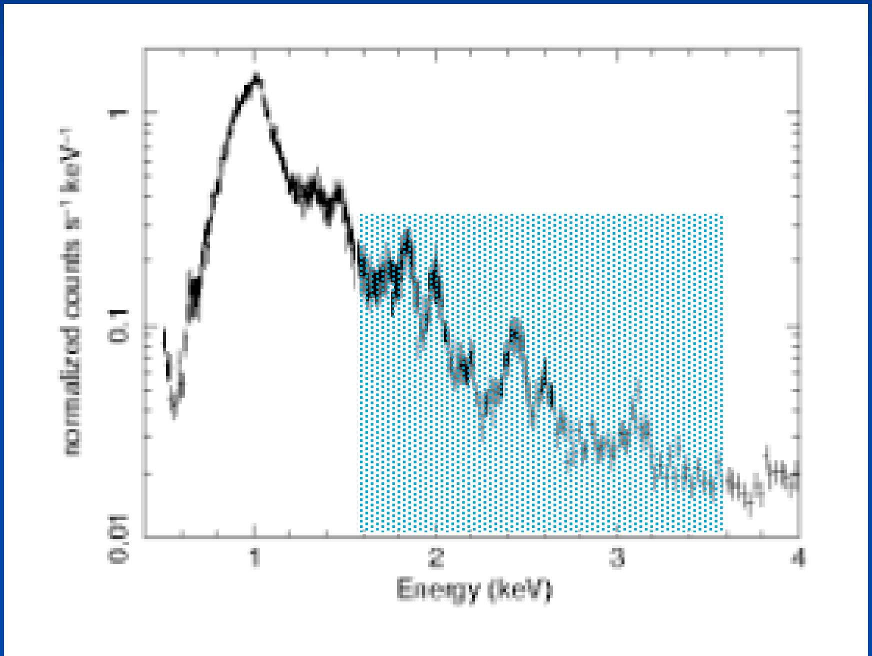


Sato, Matsushita

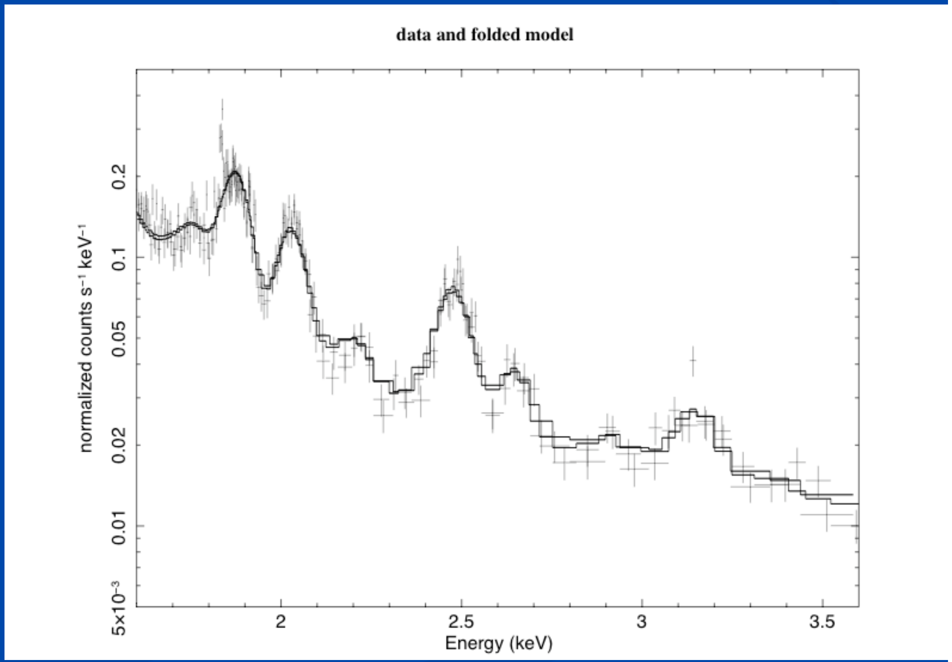


The Case of this is really an elliptical galaxy, but its what I'm working on it and beside its in a Virgo subcluster

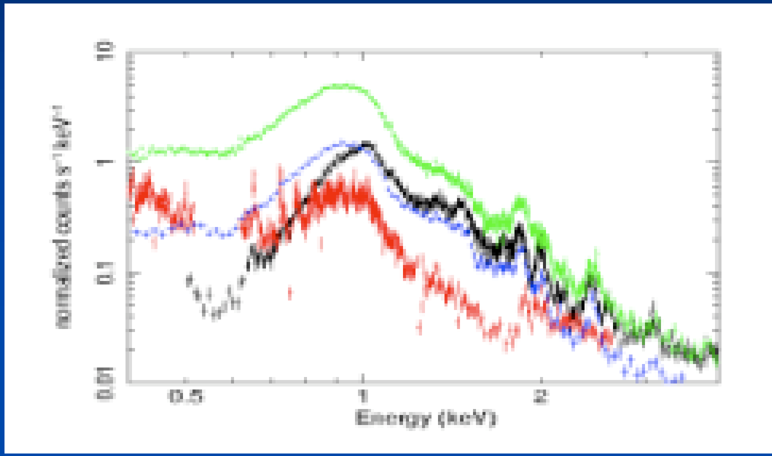
NGC 4472:

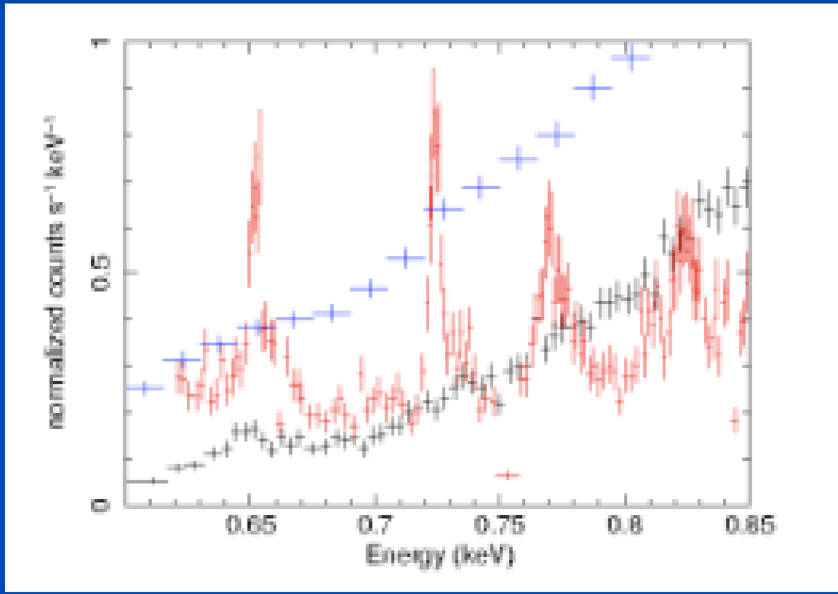


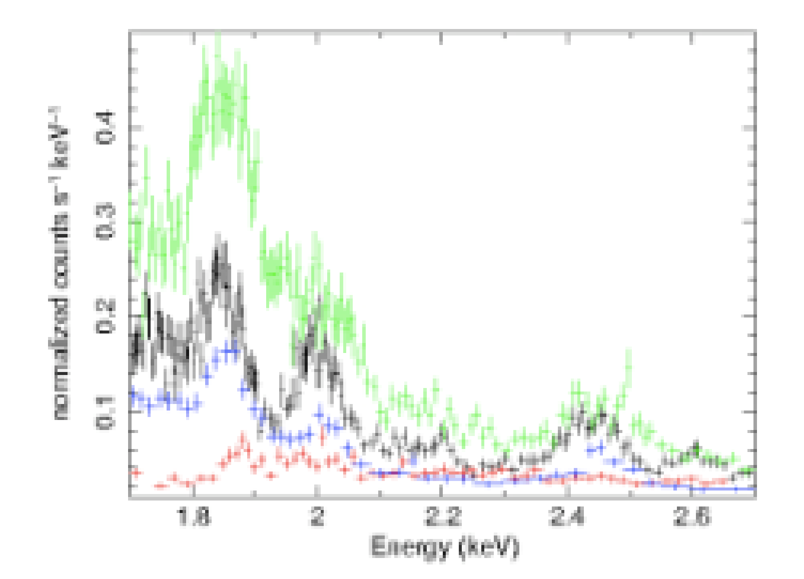
Mg XII, Si XIII, SiXIV, SXV, SXVI, Ar XVII



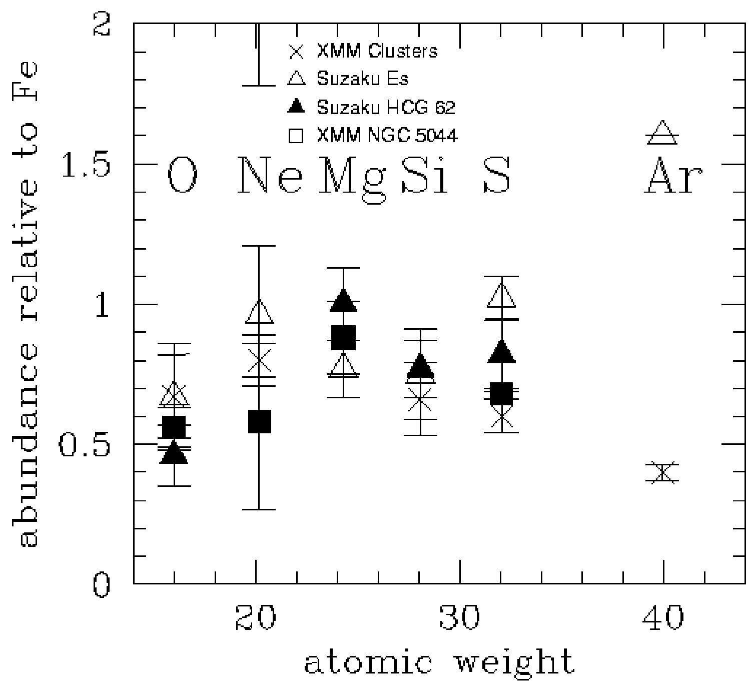
Complementarity with XMM-Newton







Abundance Patterns



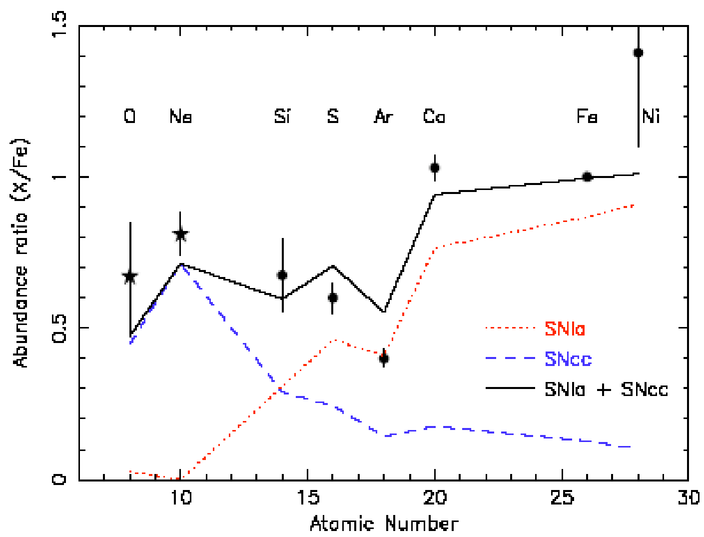


Fig. 8. Fit using the *SNIa* yields by Badenes et al. (2006), but now with additional oxygen and neon data points (stars) obtained from the RGS spectra of Sérsic 159-03 and 2A 0335+096. Here, the core-collapse model with $Z = 0.02$ and Salpeter IMF is used.

Final Remarks: *Suzaku* -- The Great De-bunker?

- Metallicities at R_{virial} are small
- No evidence for OVII from WHIM
- No evidence for large bulk flows
- No superhot region in Ophiuchus Cluster
- No detections in HXD (yet) -- see also Ajello et al.

Suzaku is refining and extending our picture of the dynamical, chemical, thermal, and nonthermal properties of the ICM/IGM -- with more to come….