Suzaku Broadband Spectroscopy of Galaxies & Clusters of Galaxies

Mark Bautz, MIT Kavli Institute
for the Suzaku Team

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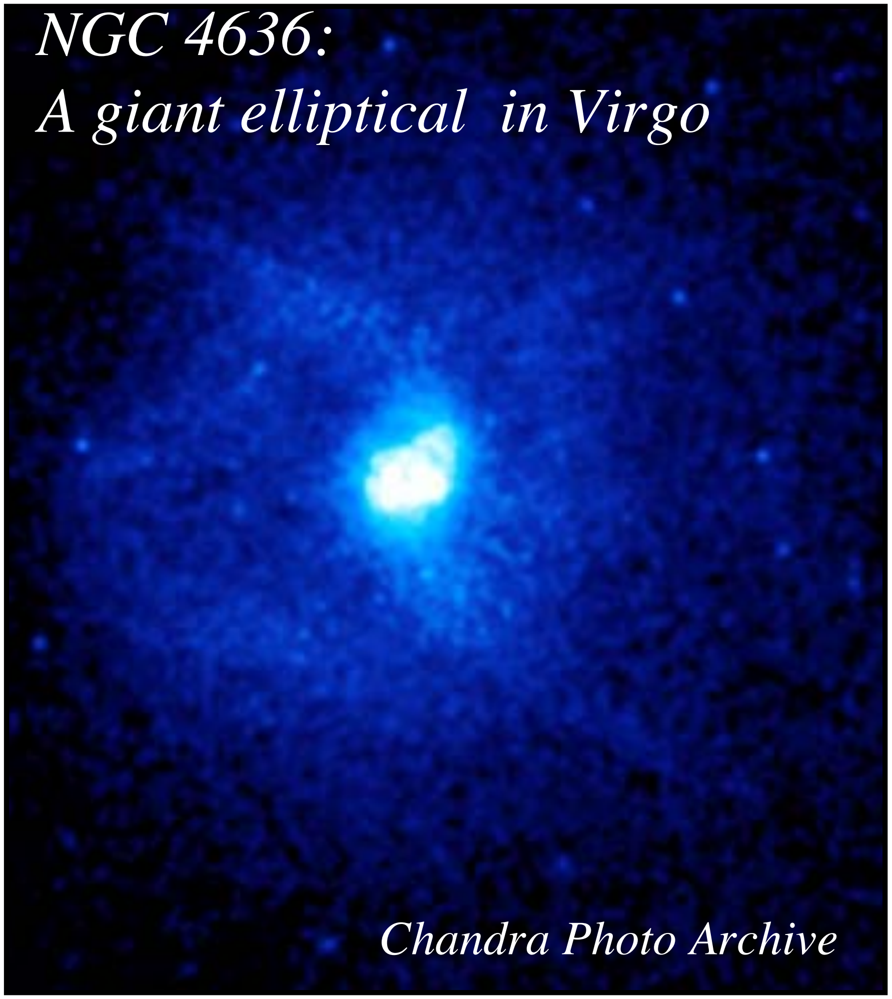
Overview:

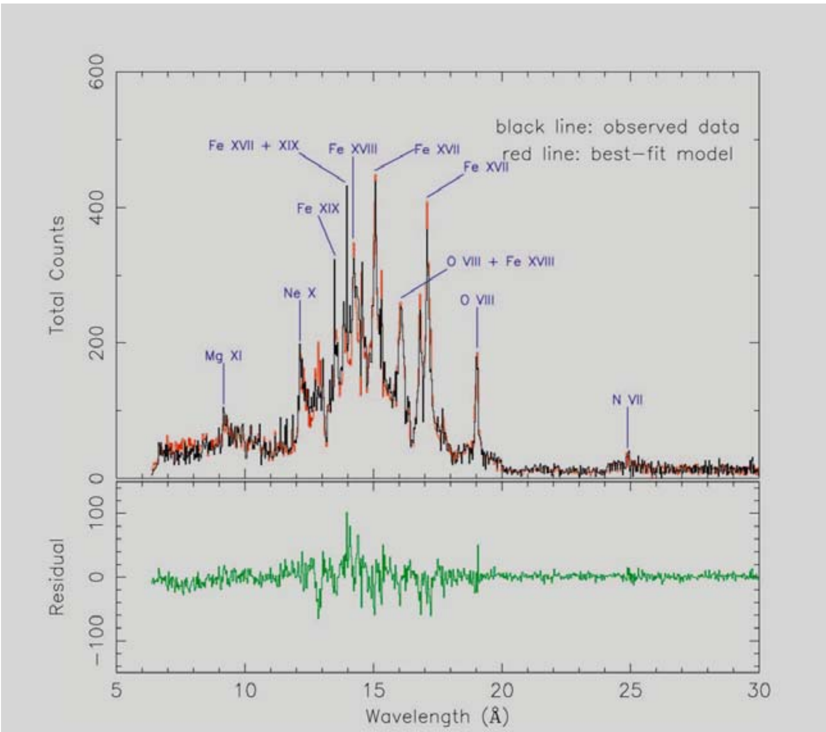
- Abundances in galaxies & clusters.
- Toward cluster temperature profiles to the virial radius.
- Limits on 'soft-excess' emission.

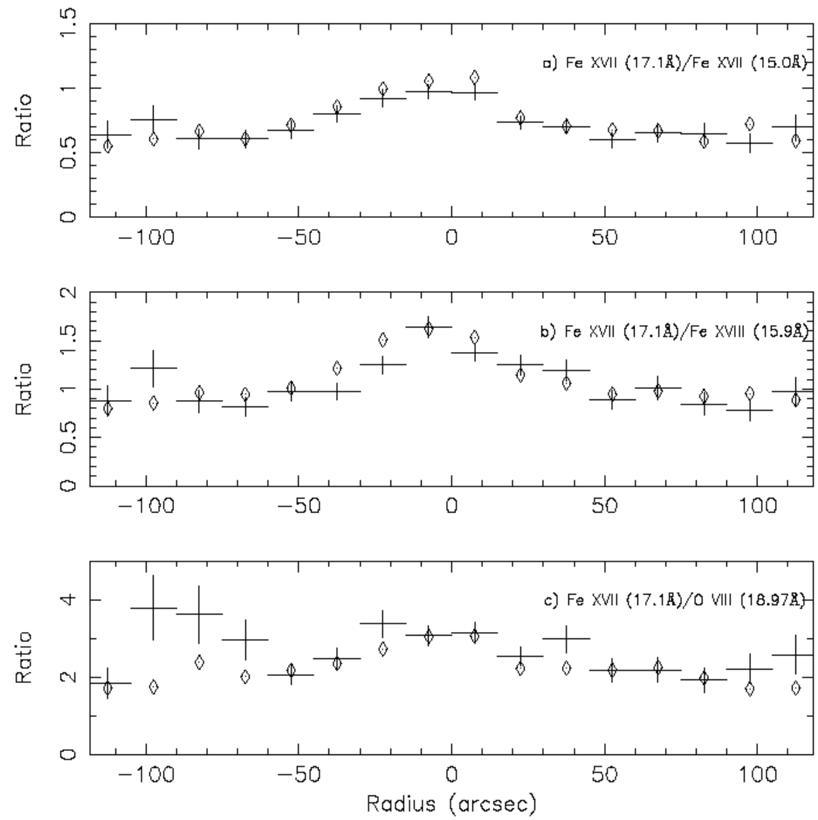
Elemental Abundances in NGC 4636



- ISM abundance patterns in elliptical galaxies are puzzling:
  - Stellar populations are old and stars are metal-rich
  - Expect high (super-solar) abundances in the hot ISM, especially of Fe, due to SNIa enrichment
  - Generally observe sub-solar abundances
- Abundance patterns should reveal relative roles of Type Ia and Type II SNe in enriching the ISM (& ICM)

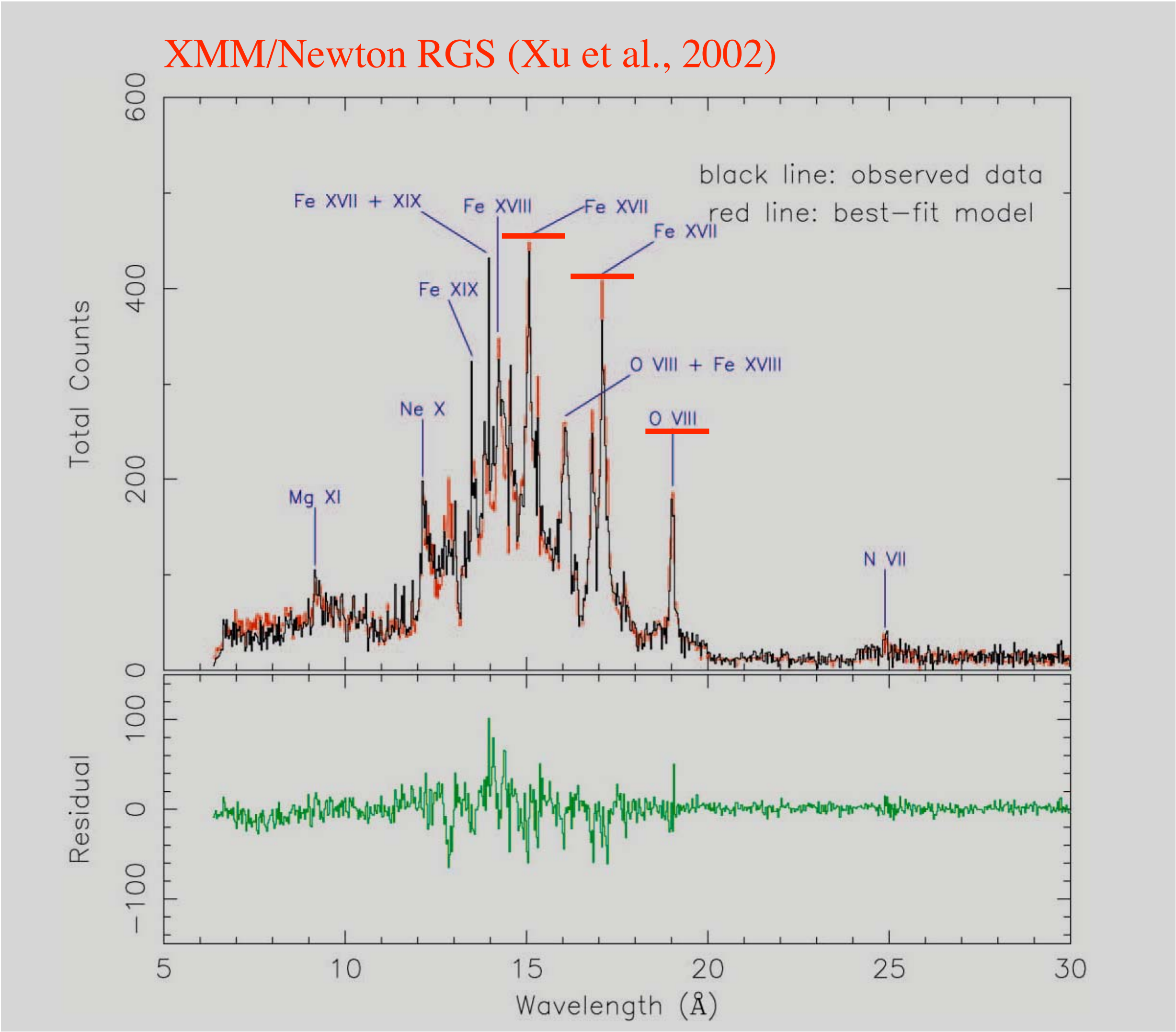
XMM-Newton Grating Spectrum of NGC 4636 (Xu et al., 2002)





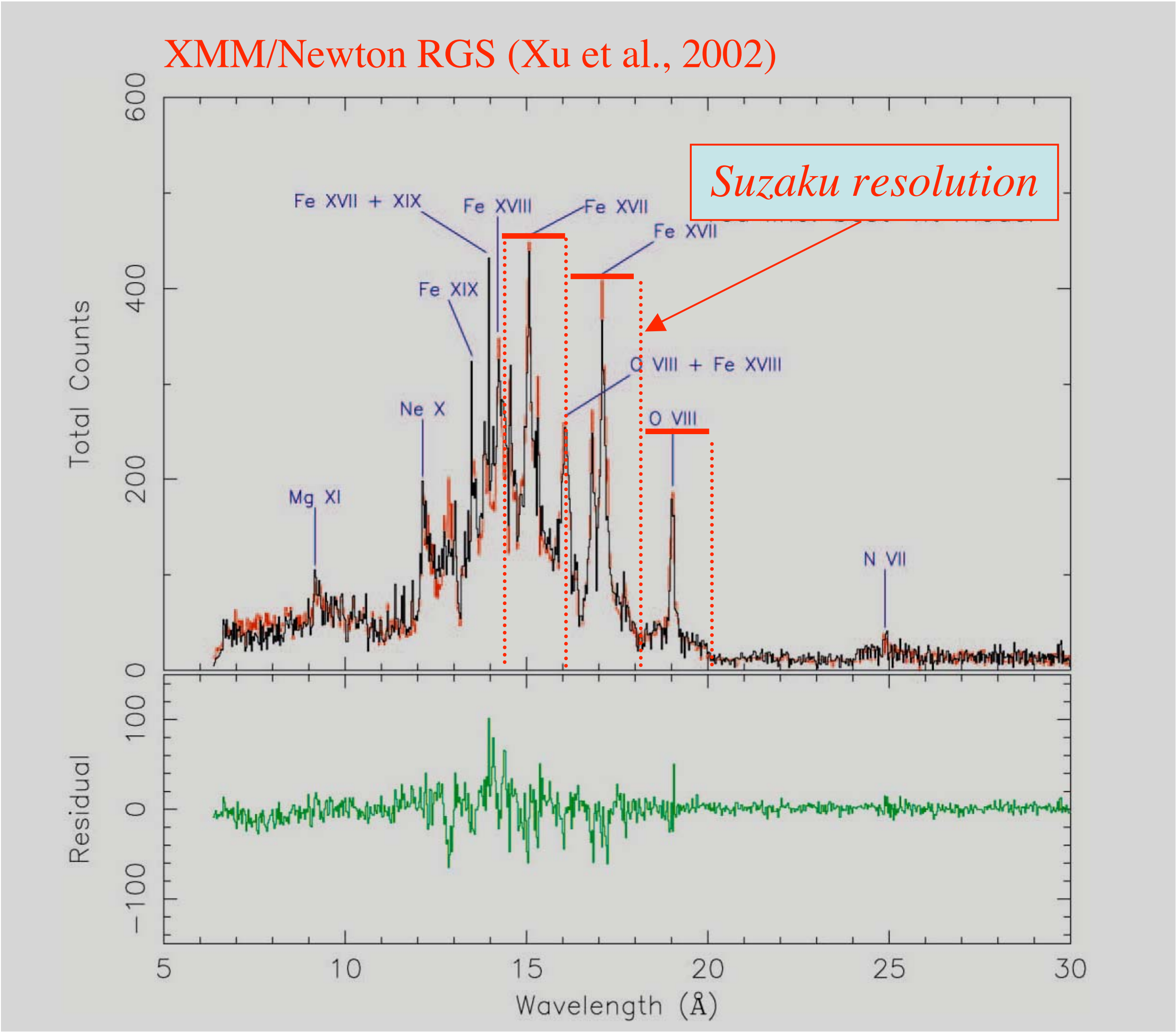
- Fe XVII line ratio profile indicates resonant scattering in core
- Large optical depth limits turbulent velocity to < ~0.1 c_s
- Grating spectra only probe core of galaxy

Suzaku Resolves OVII from Fe XVII



- Fe XVII line ratio is sensitive to resonant scattering.
- O VIII sensitive is to oxygen abundance.

Suzaku Resolves OVII from Fe XVII



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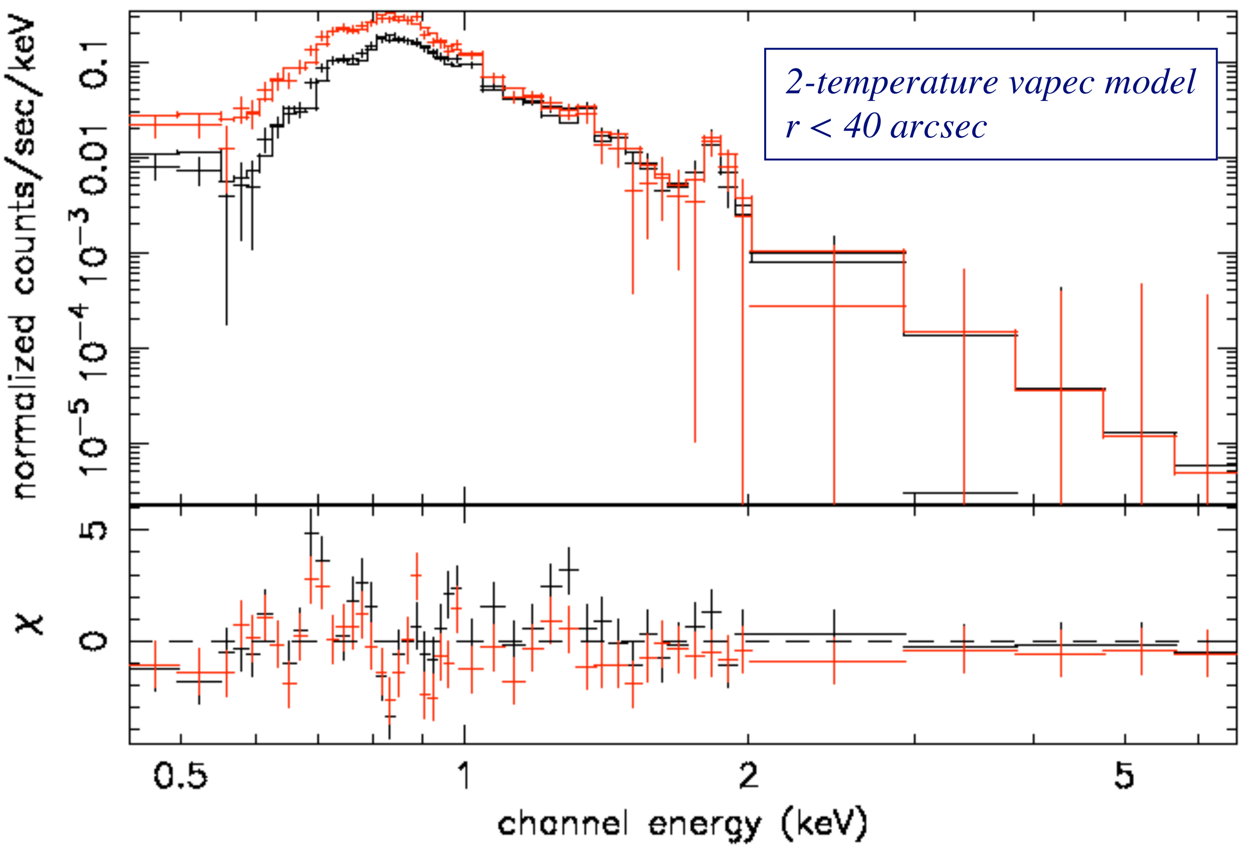
Suzaku Spectrum of NGC 4636

Tozuka, Fukuzawa, Arnaud et al.



Suzaku Spectrum of NGC 4636

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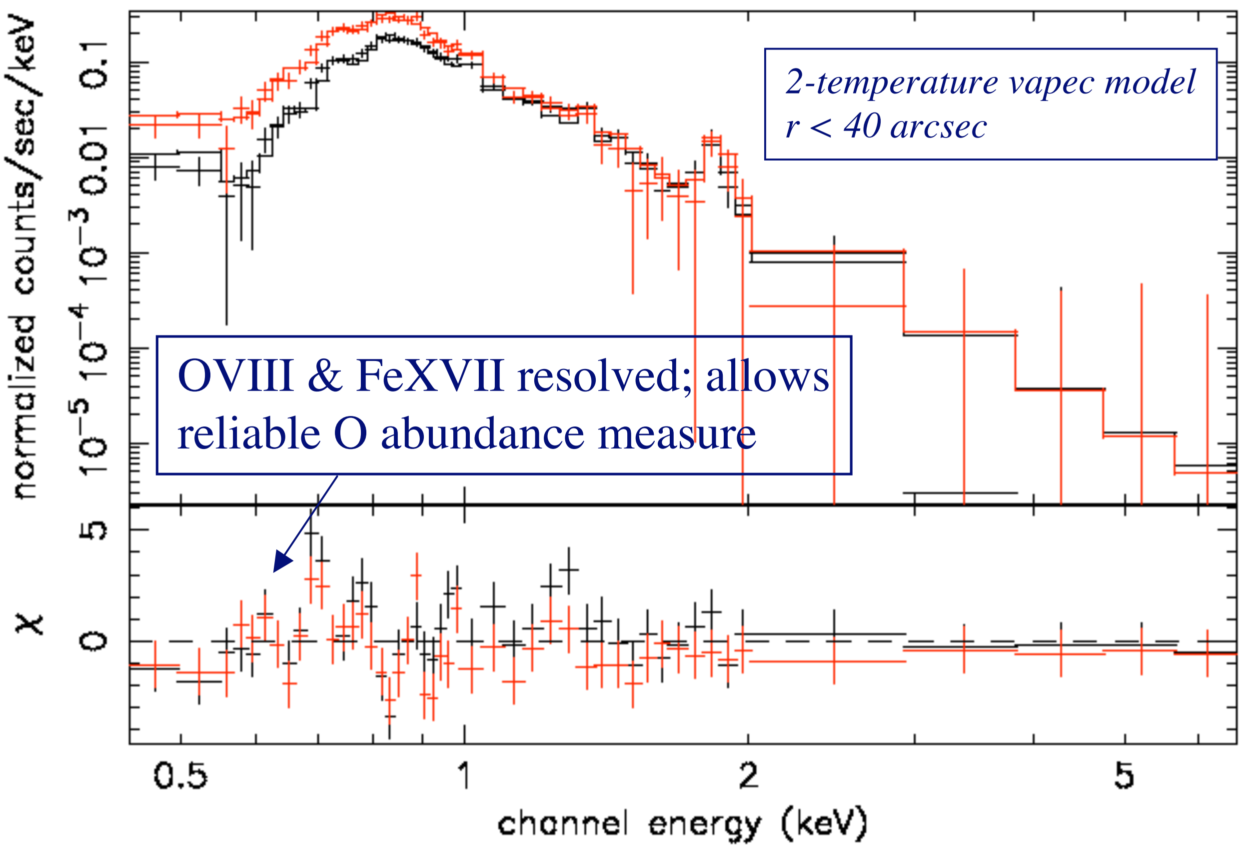
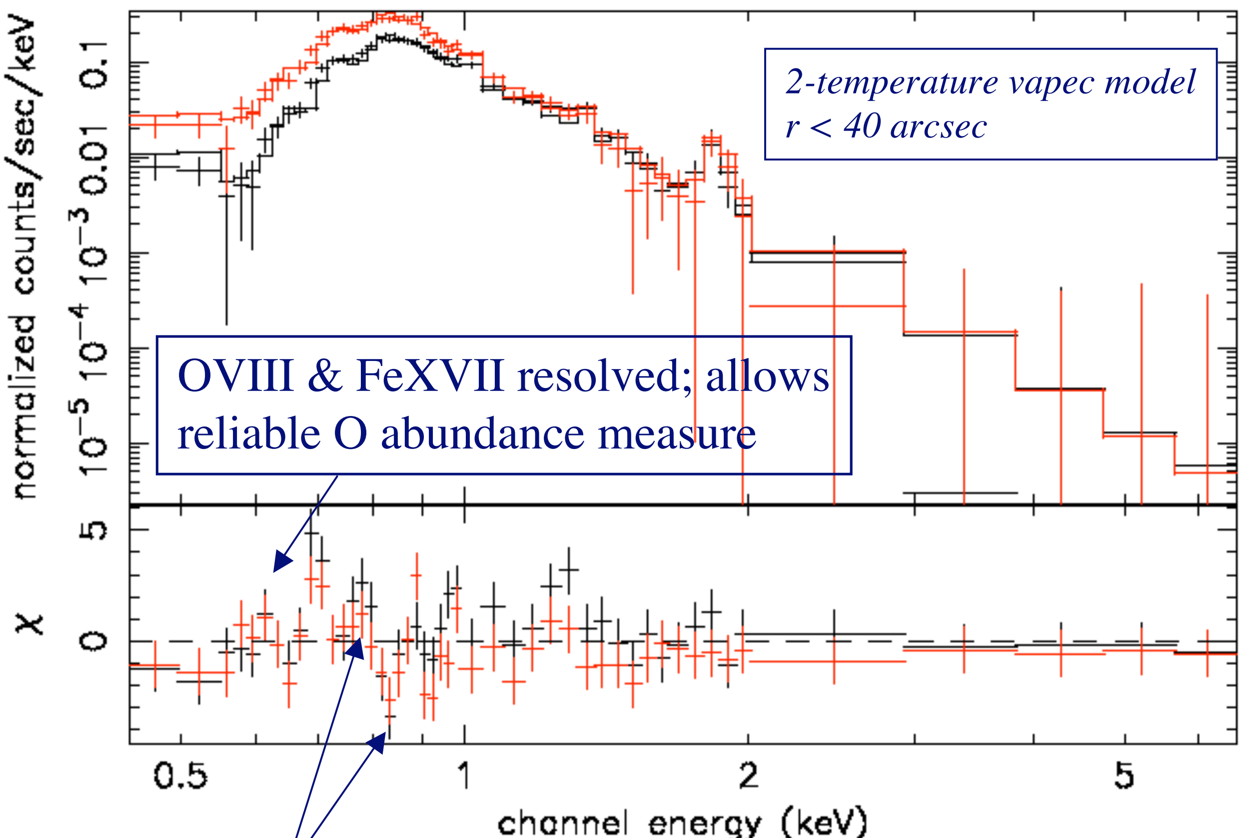


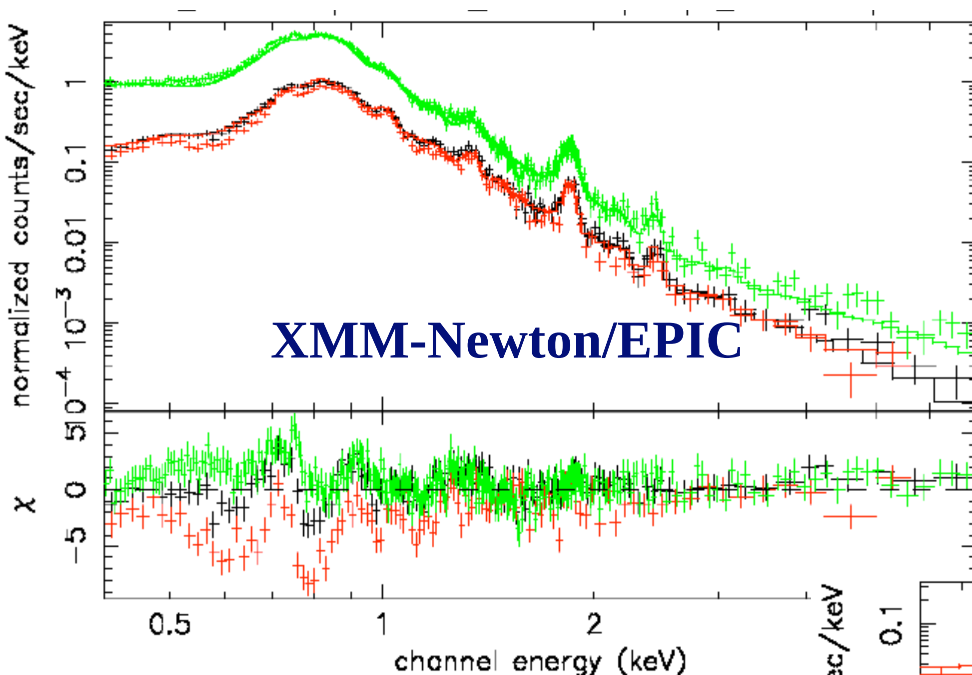
Suzaku Spectrum of NGC 4636

Tozuka, Fukuzawa, Arnaud et al.



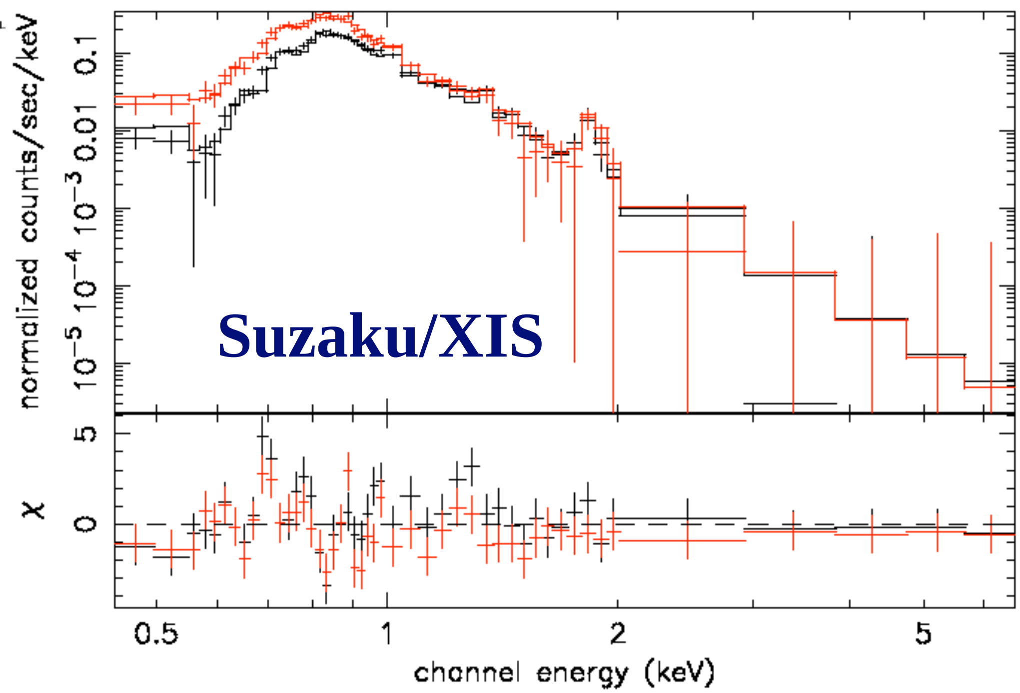
Residuals from optically-thin model fit (possibly) indicative of resonant scattering

XMM & Suzaku Spectra of NGC 4636



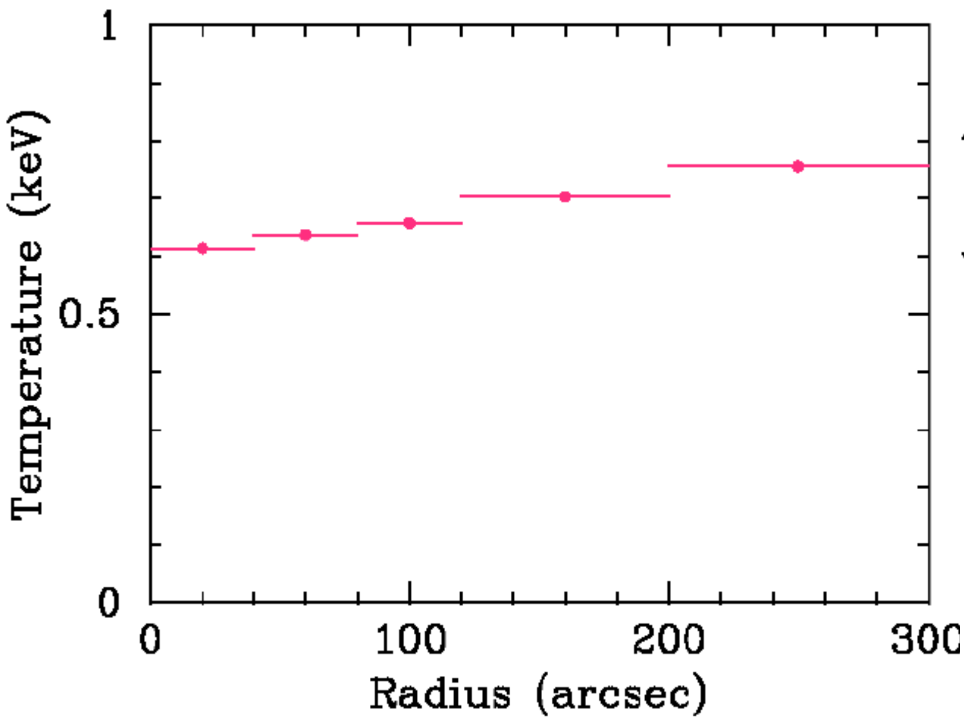
Different XMM CCDs differ on resonant scattering

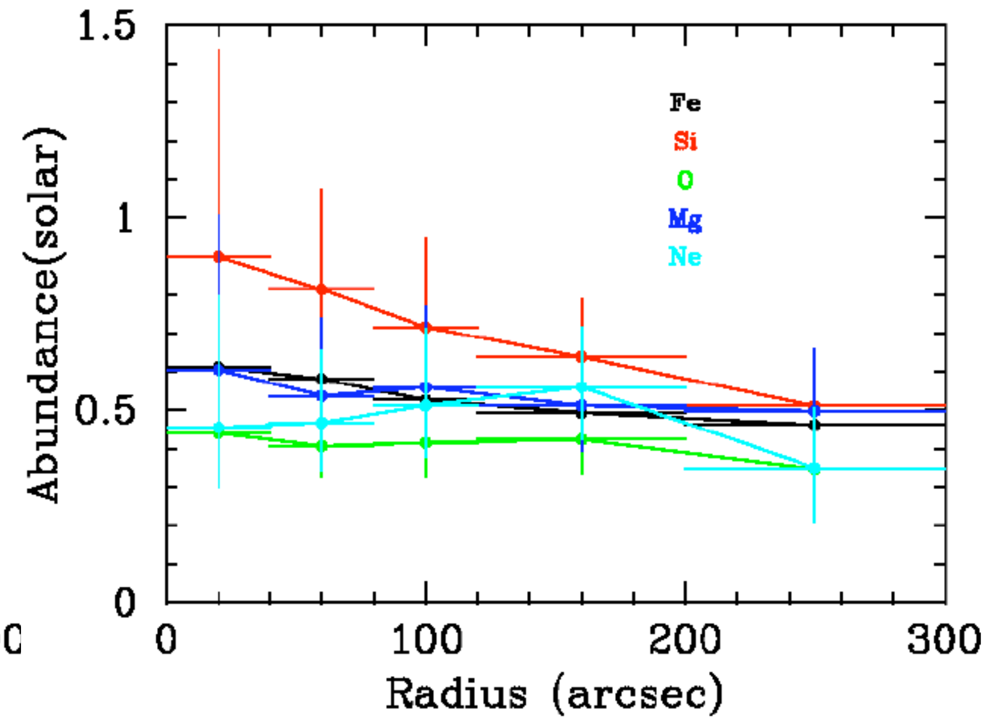
Suzaku XIS appears consistent with resonant scattering model



Suzaku Temperature & Abundance Profiles for NGC 4636

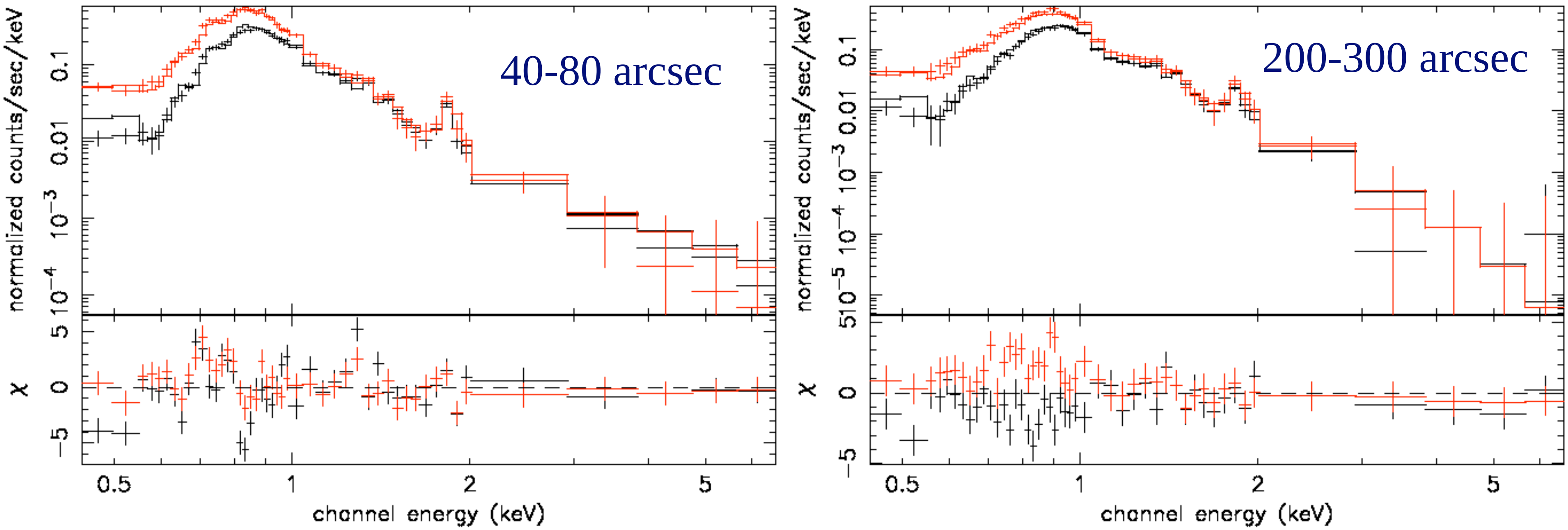
Tozuka, Fukuzawa, Arnaud et al.





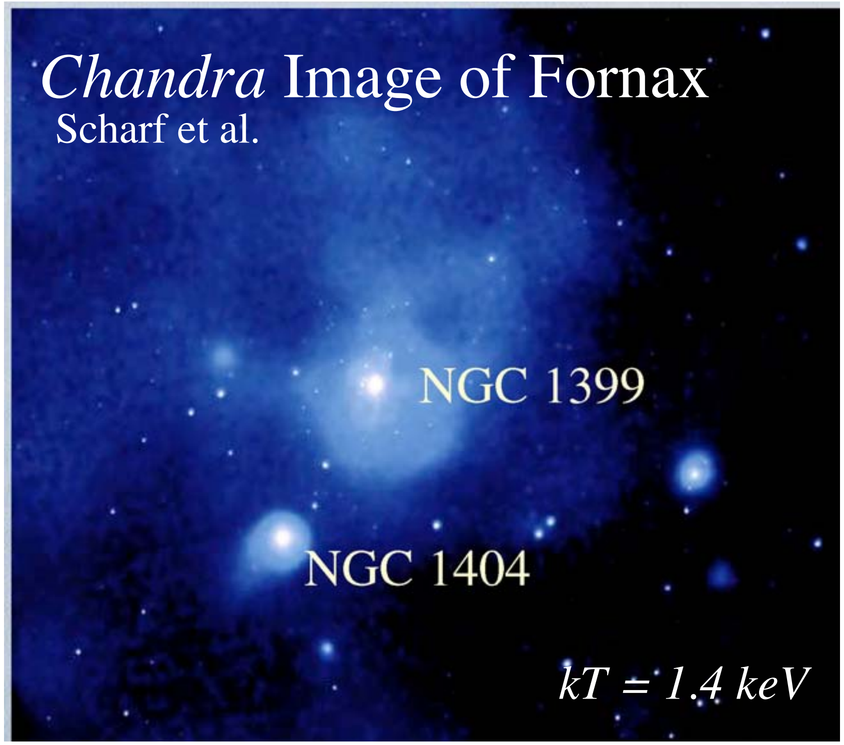
- Confirms & extends temperature gradient observed by RGS
- Reveals spatially uniform, sub-solar oxygen abundance and O/Fe ratio outside of galaxy core
- Remains difficult to explain these abundance patterns

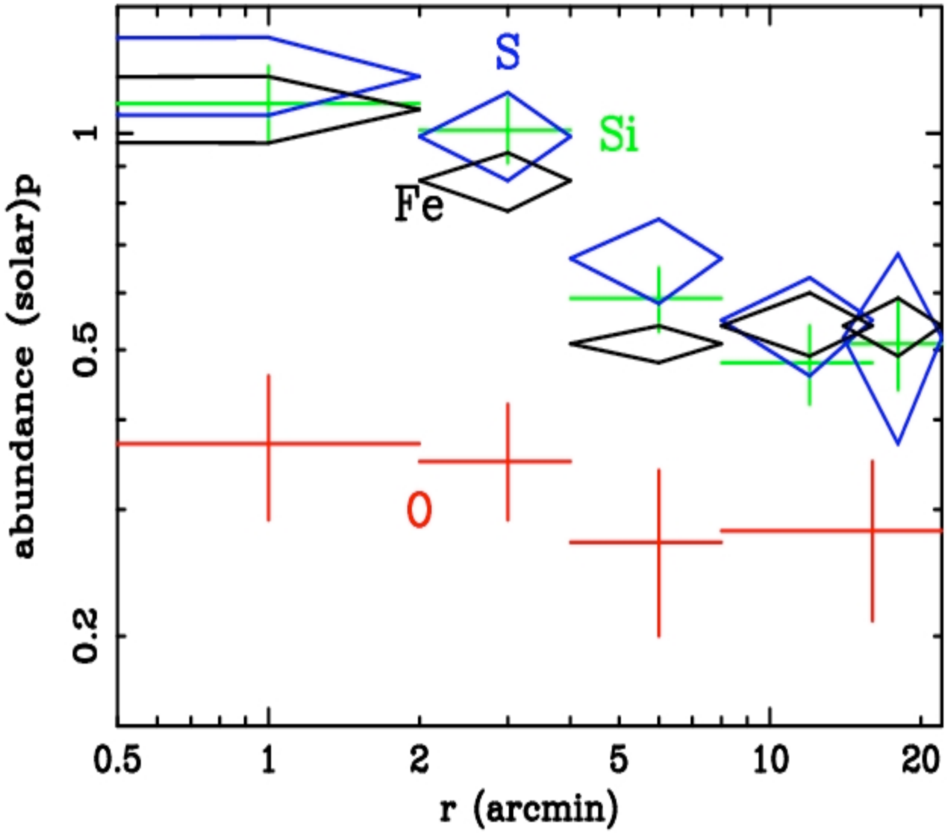
Mapping Resonant Scattering in NGC 4636?



In conjunction with RGS, Suzaku spectra may provide constraints on ISM velocity structure with radius

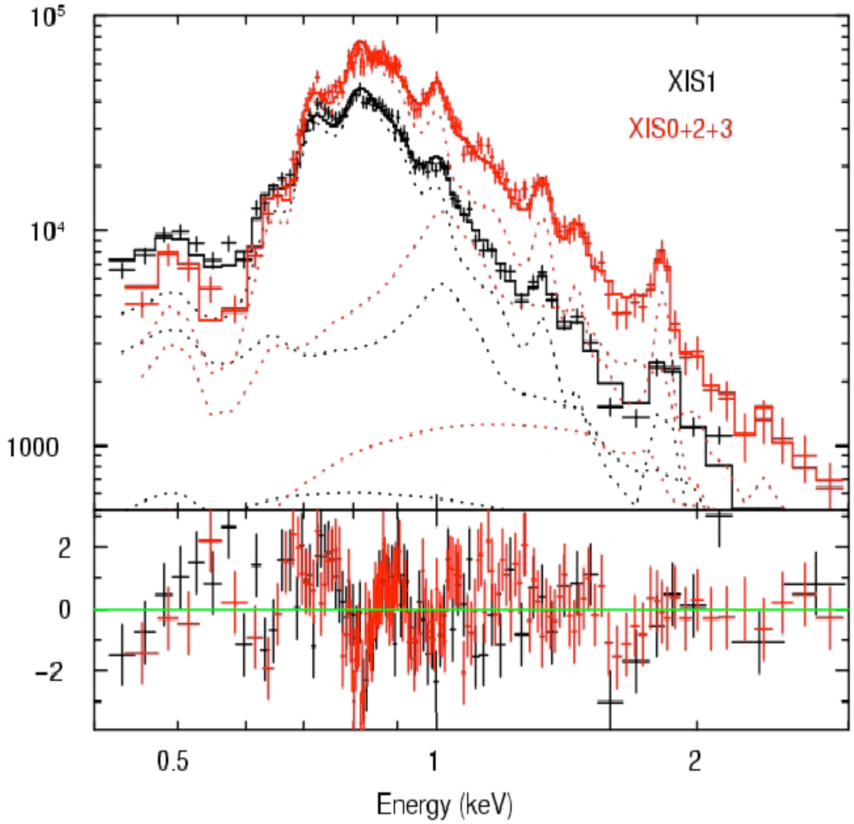
Abundances in the Fornax Cluster *K. Matsushita et al.*



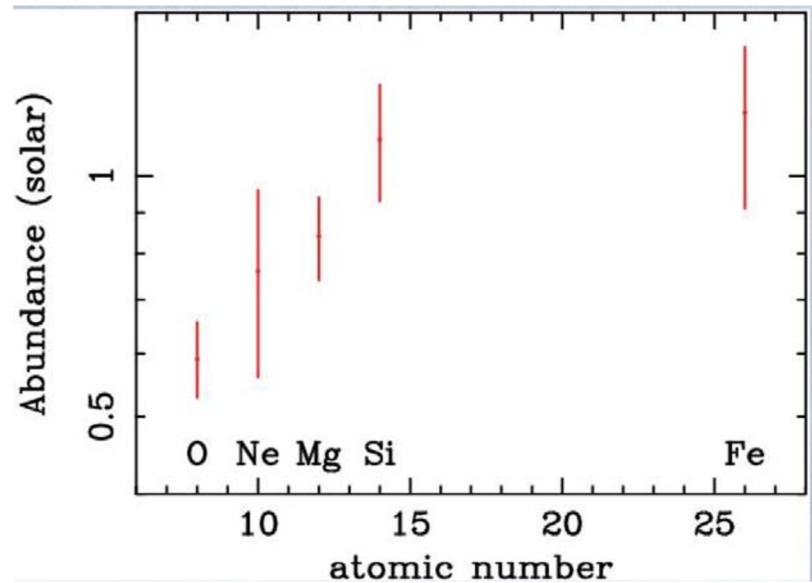


- Enhanced central Fe, Si, S abundance implies enrichment by cD
- Si, S, Fe abundances are comparable & near solar
- O ~ < 1/2 solar; well-mixed in ICM, unlike Fe, Si S
- SNIa (which produce little O) must dominate enrichment near cD
- A common (Type Ia) origin for Fe, Si & S challenges SNe models

Abundances in NGC 1404



K. Matsushita et al.



- Si & Fe ~ solar ; O/Fe ~ 1/2; O, Ne, Mg ~ stellar metallicity
- SNIa must contribute Si, possibly with enhanced Si/ Fe ratio

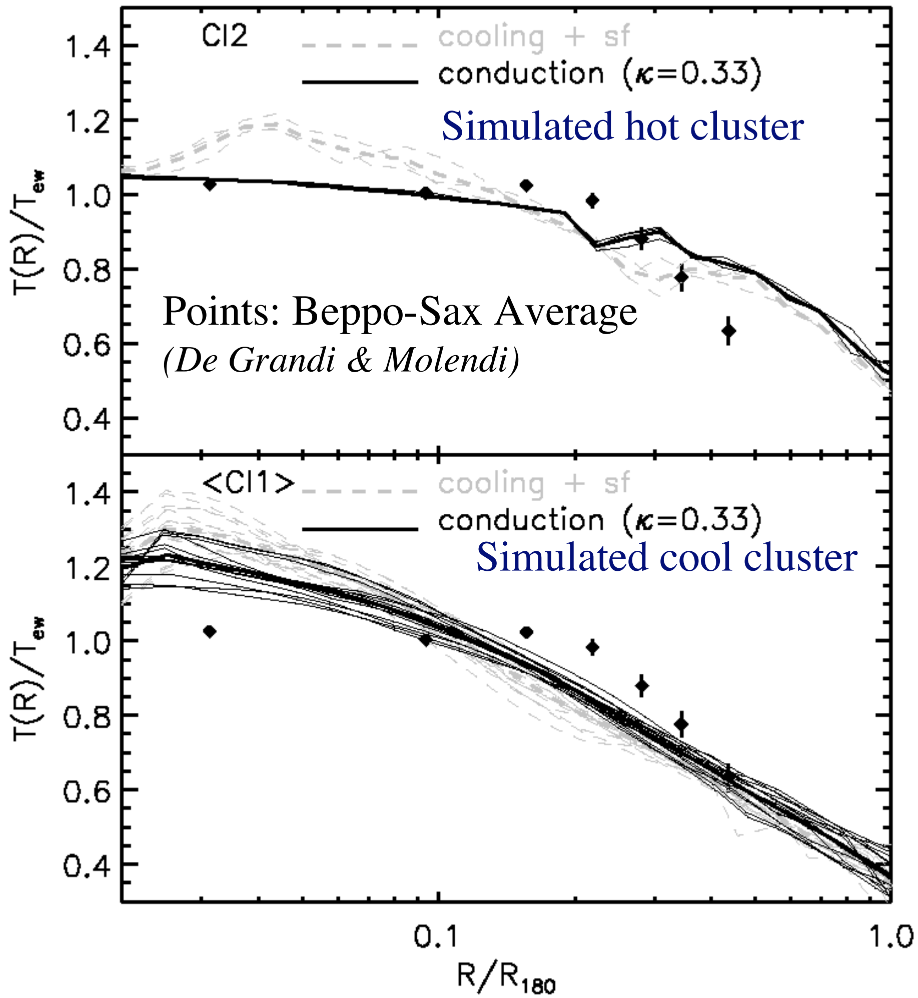
(cf M87, Mitsushita et al., 2003)

First *Suzaku* Results on Galaxy & Cluster Abundances

- Spectral resolution separates O and Fe-L lines, allowing reliable O abundance maps.
- O/Fe ratio subsolar (0.5); Si/Fe ~solar.
- Spectral residuals in NGC 4636 consistent with resonant scattering detected by XMM-Newton RGS.
- Type Ia enrichment important in core of Fornax; oxygen is spatially uniform.
- Abundance patterns & distribution have implications for SN models (Si production in Type Ia).

Cluster Temperature Profiles to the Virial Radius

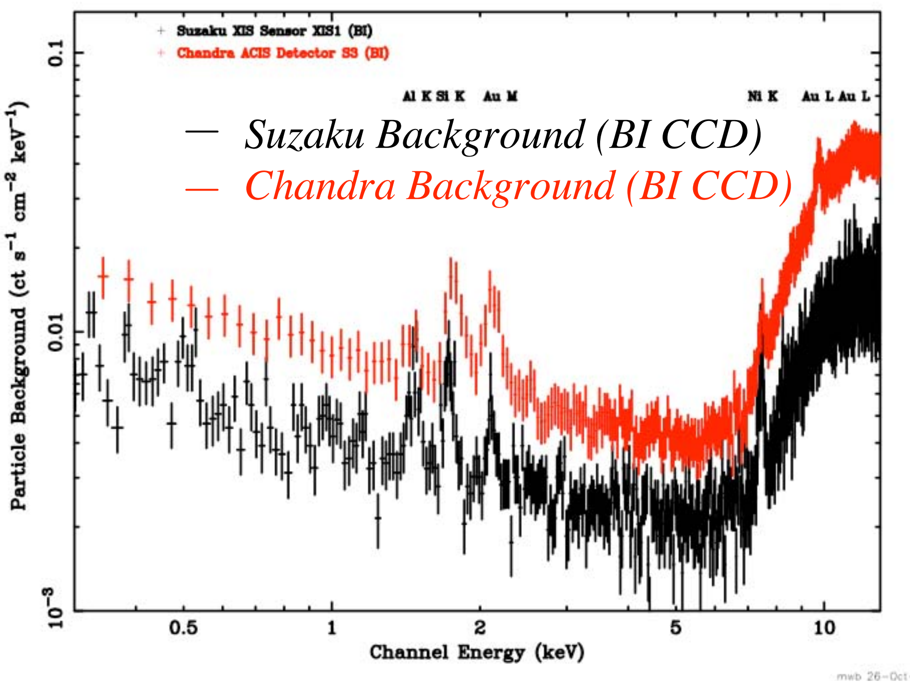
Dolag et al., 2004



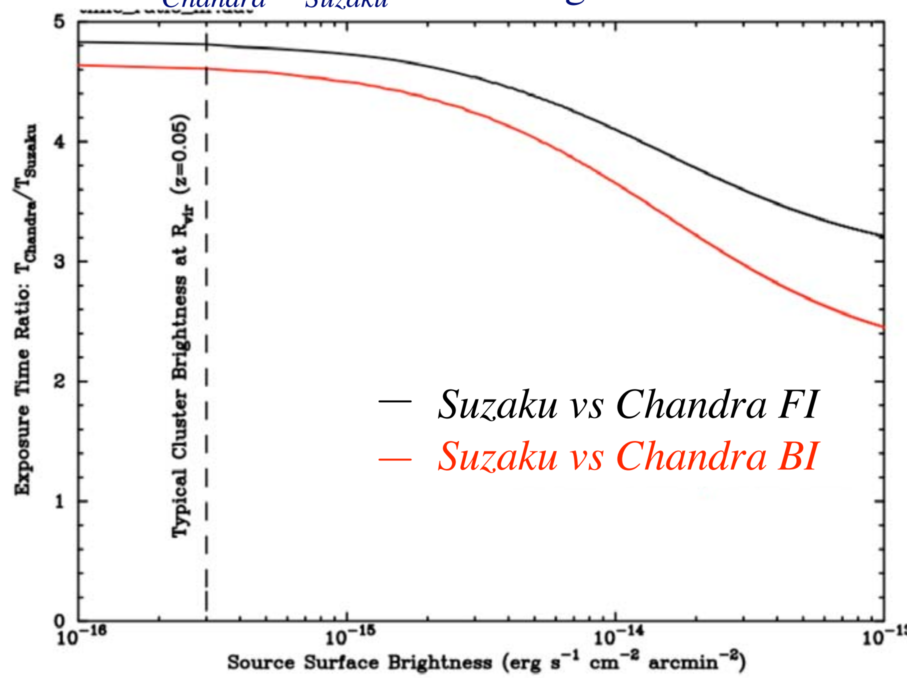
- Temperature profiles are needed to infer cluster mass.
- Clusters should show " self-similar" profiles if gravity predominates in cluster formation.
- Hydrodynamical/N-body simulations show T falls steadily at large radii.
- Available data typically extend to only 1/2 the virial radius.

Suzaku/XIS Particle Background

Suzaku vs. *Chandra* particle background



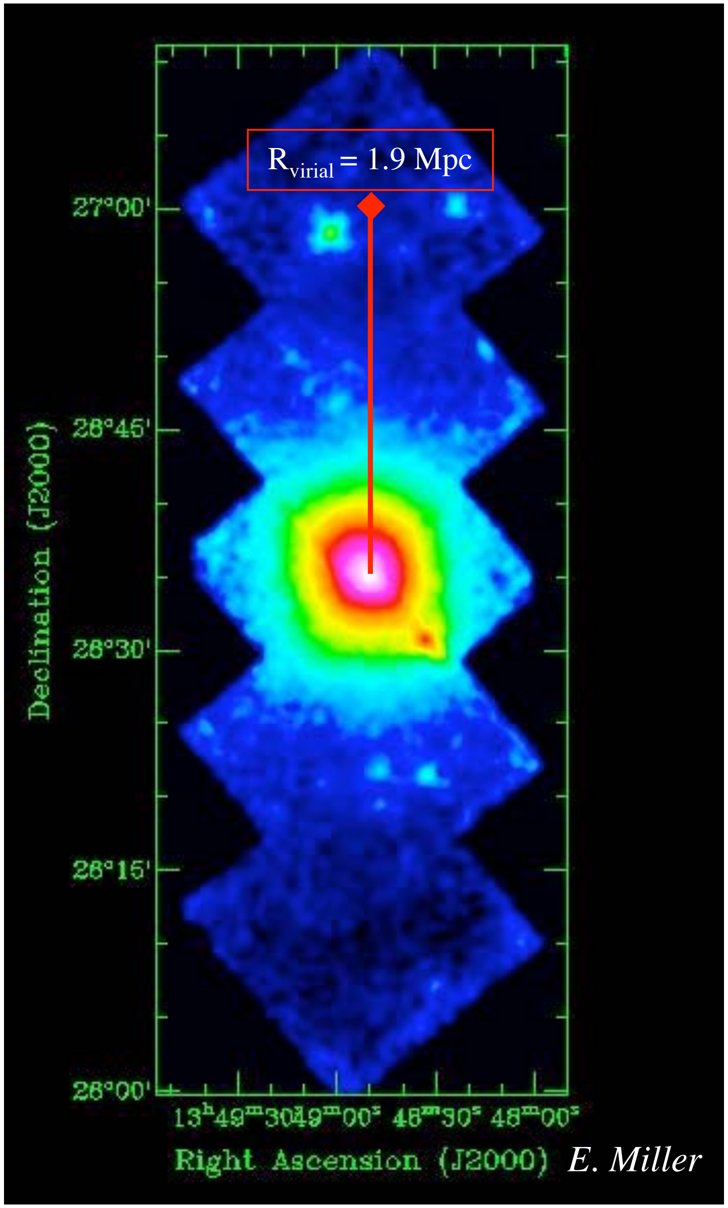
Suzaku speed advantage vs. Chandra:
$T_{Chandra}/T_{Suzaku}$ to fixed signal:noise vs SB



- *Suzaku's* specific particle background is ~ 1/2 *Chandra's*
- Time to fixed S:N at faint surface brightness < 1/4 *Chandra's*

Suzaku Observations of Abell 1795

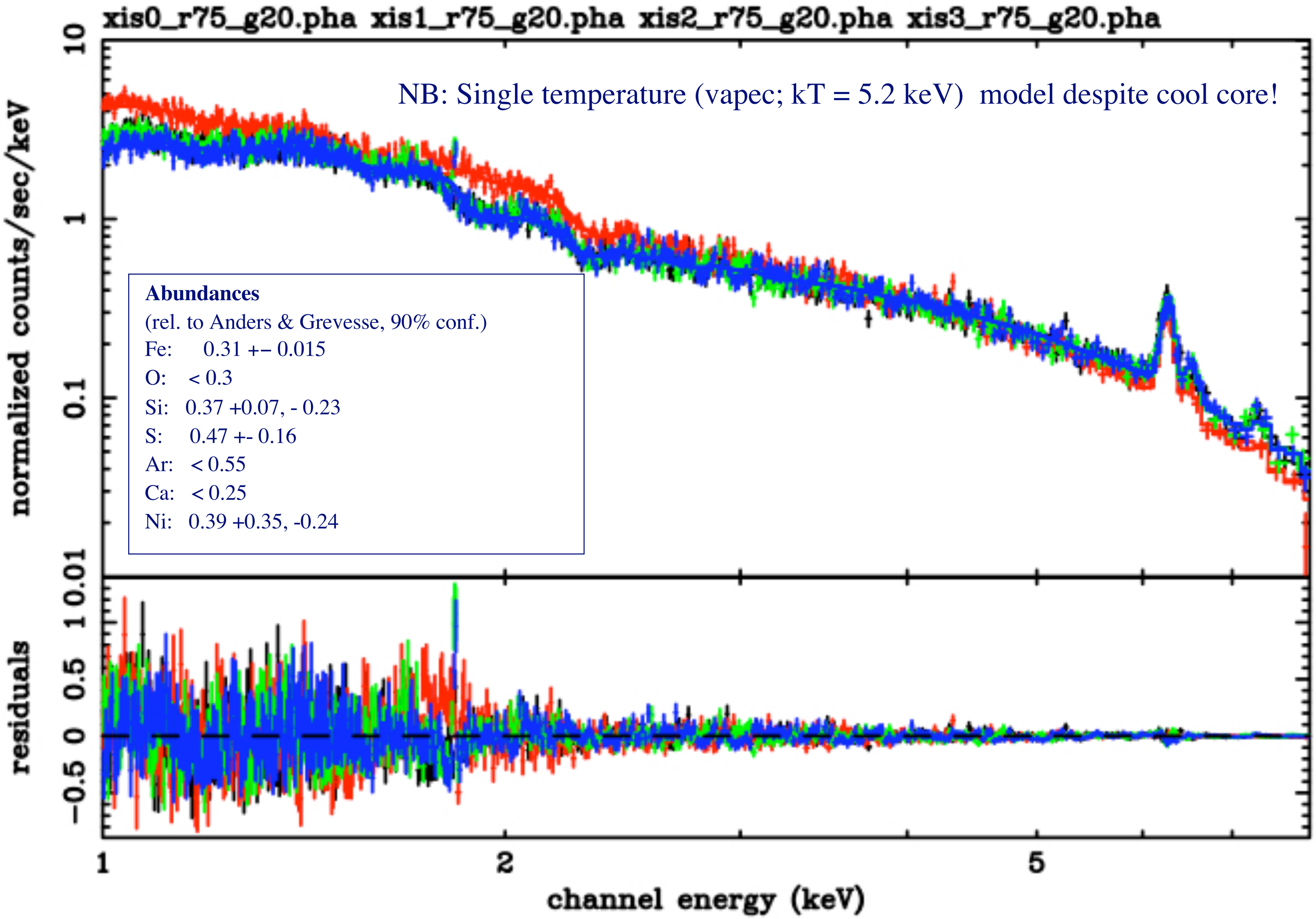
- Luminous, “cool core” cluster at z= 0.06
- Initial Goals:
  * Map emission to virial radius (~ 2 Mpc)
  * Look for ‘soft excess’ reported by XMM
- Observations:
  * 5 fields, 120 ks total
  * Map extends to r > 30 arcmin (2.5 Mpc)



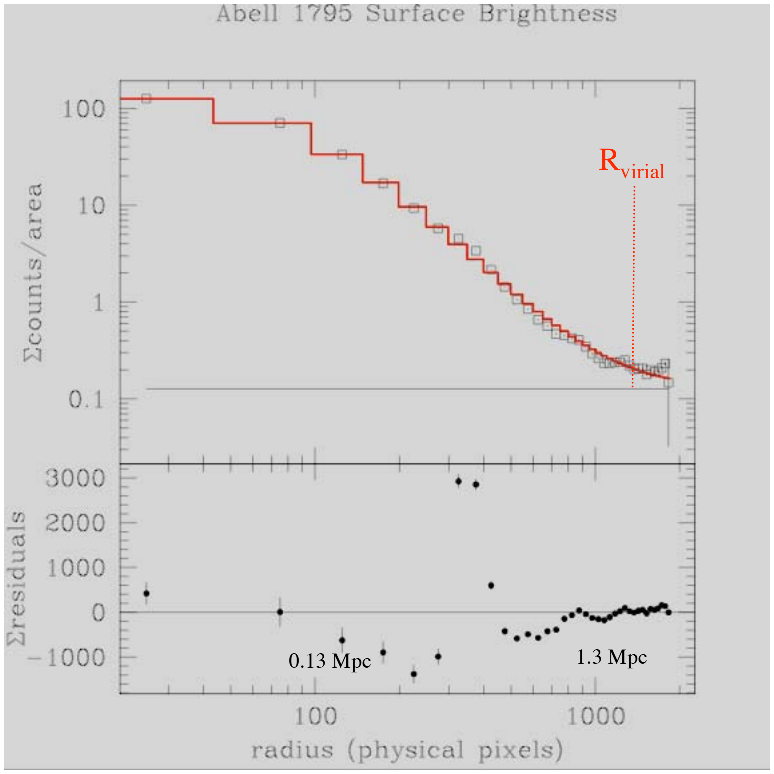
Abell 1795 (z=0.063)

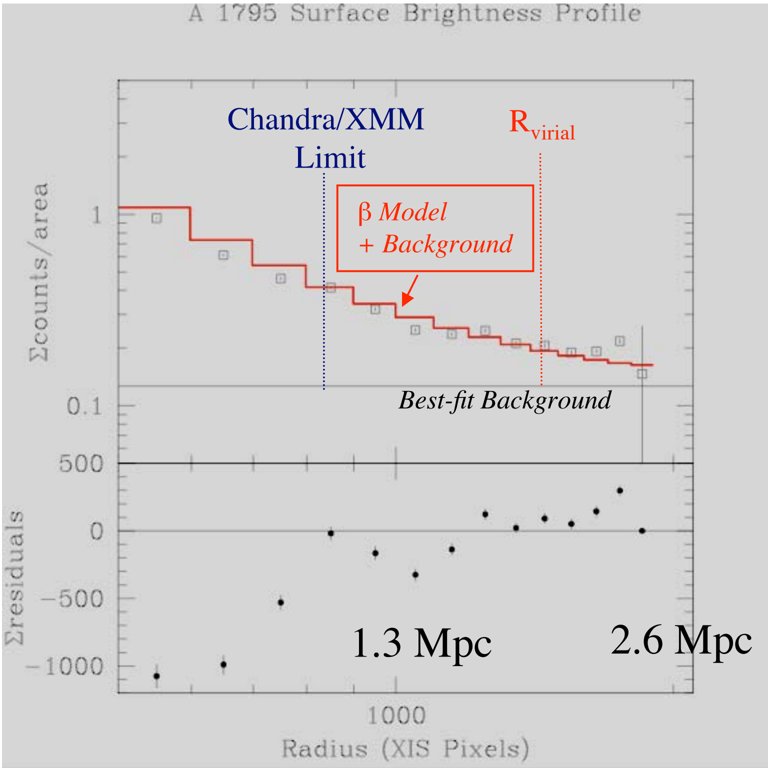
Abell 1795 Integrated Abundances

(R < 7.5’ = 550 kpc; 12 ks exposure)



Abell 1795 Surface Brightness Profile



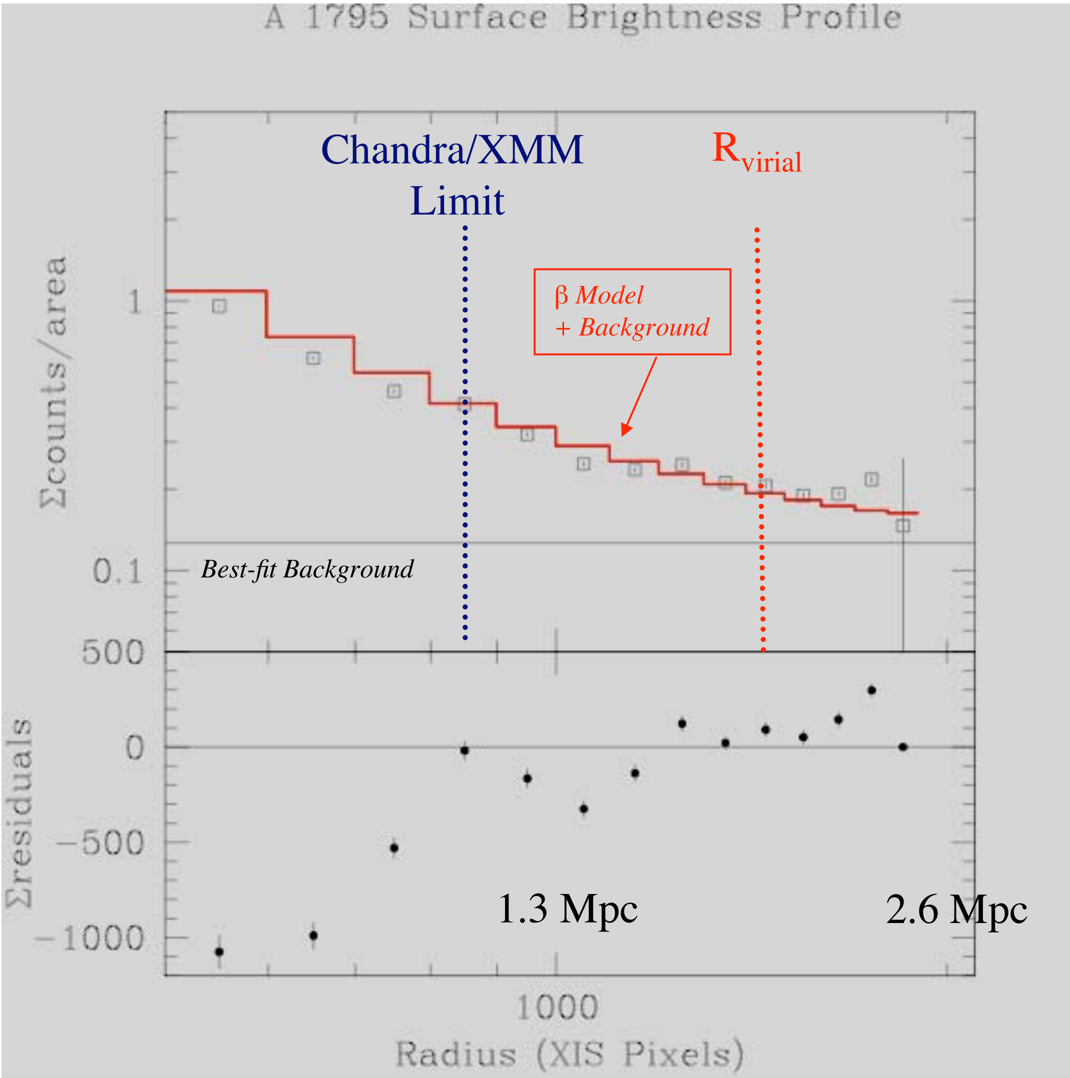


Radial surface brightness profiles from XIS0+2+3 in the 0.5 - 5 keV band. The red curves show a β-model (+ constant background) fit. 5 point sources have been excluded from the field. The horizontal line indicates the best-fit background level, and the expected virial radius at 1.9 Mpc is indicated. The maximum radius at which XMM has constrained the temperature is also indicated.

LEFT: Full radial range (to 2.6 Mpc or 36 arcmin) in 54" wide bins. **RIGHT:** 0.65 to 2.6 Mpc in 108"wide bins.

The large residuals at ~500 pixels are near chip edges. The wiggles at larger radii may be due to point sources not excluded from the profile. We clearly detect cluster emission well beyond the XMM limit. The slope of the β model is obviously incorrect, and the effects of the discrete background sources must be understood to take full advantage of the statistical power of the data.

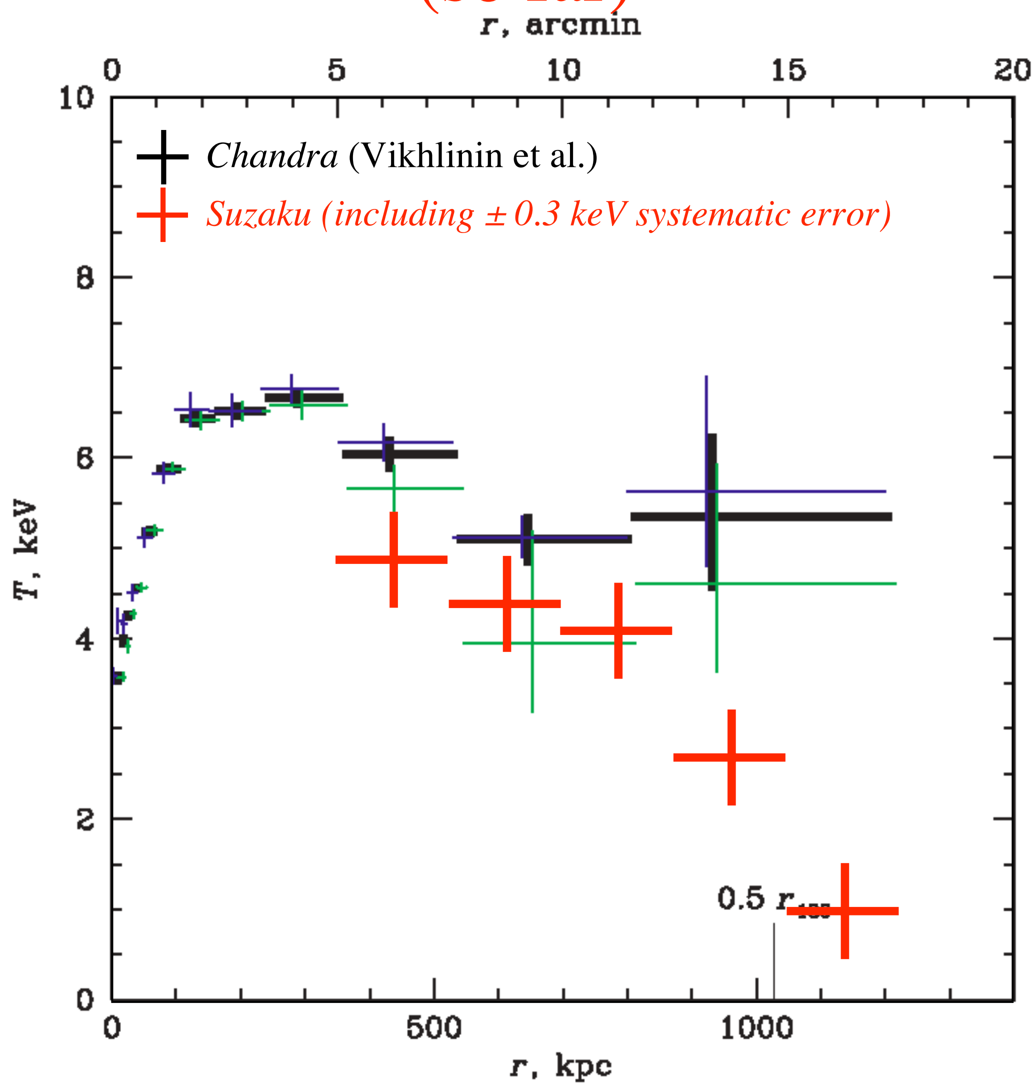
Abell 1795 Surface Brightness Profile



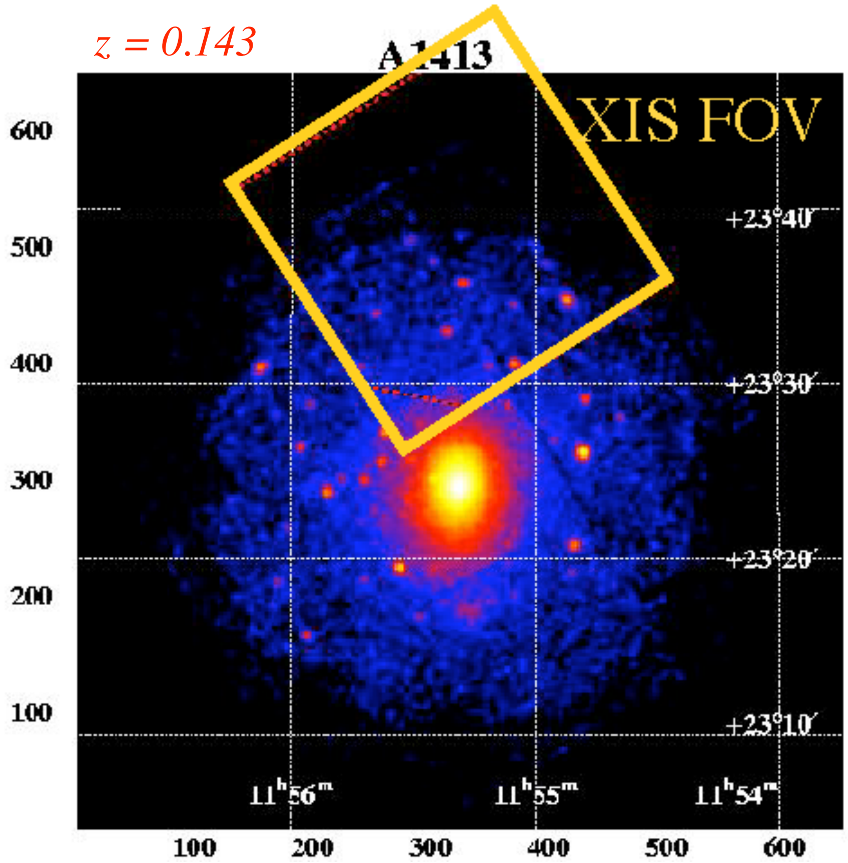
- Residuals due to faint point sources?
- Shallow CXO follow-up may be useful

Abell 1795 Temperature Profile

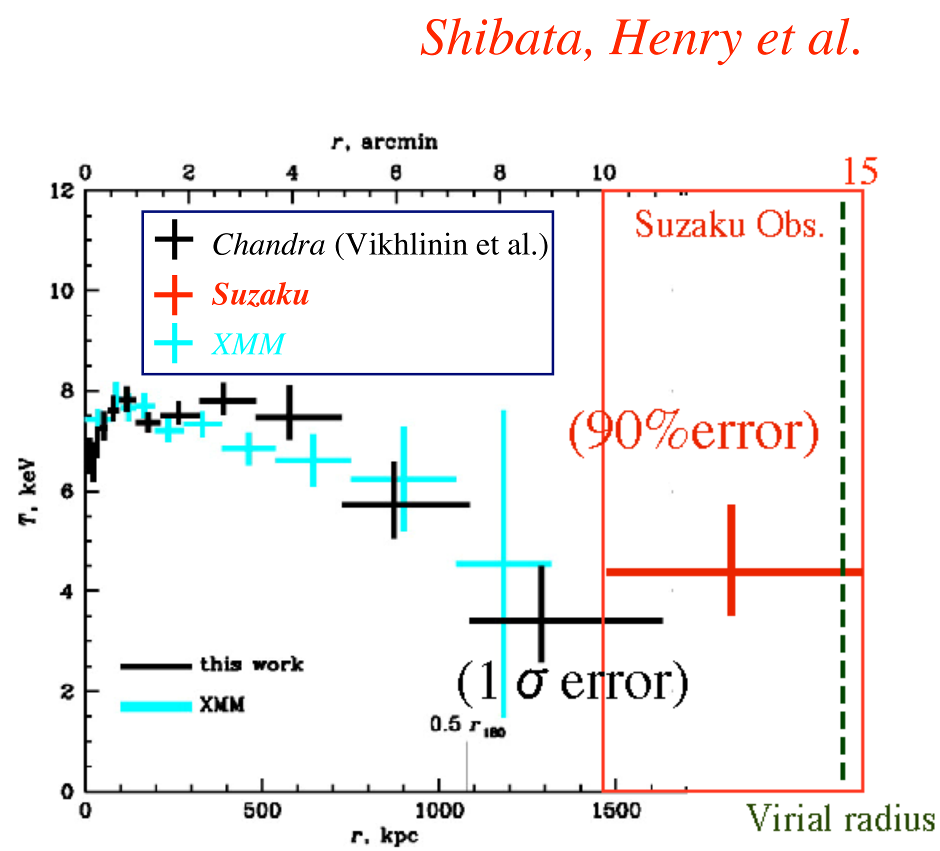
(so far)



Abell 1413 Temperature Profile



XMM MOS Image (0.2-2 keV)

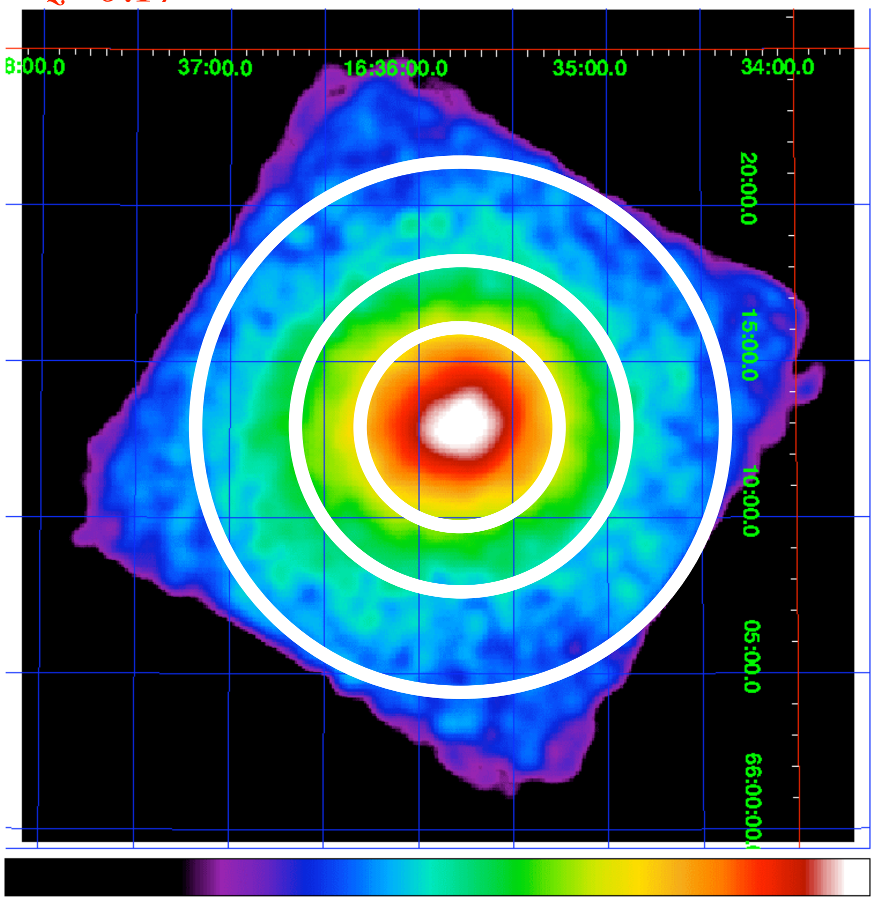


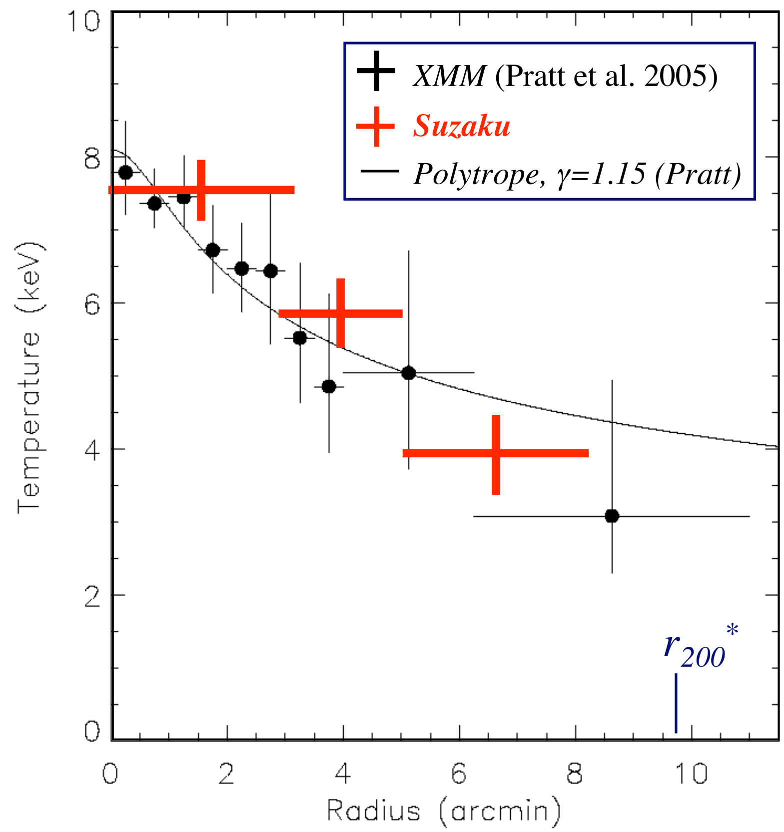
A2218 Temperature Profile

(from 1 of 4 *Suzaku*/XIS Sensors)

Takei, Mitsuda et al.

z=0.17





**but* not *in hydrostatic equilibrium*

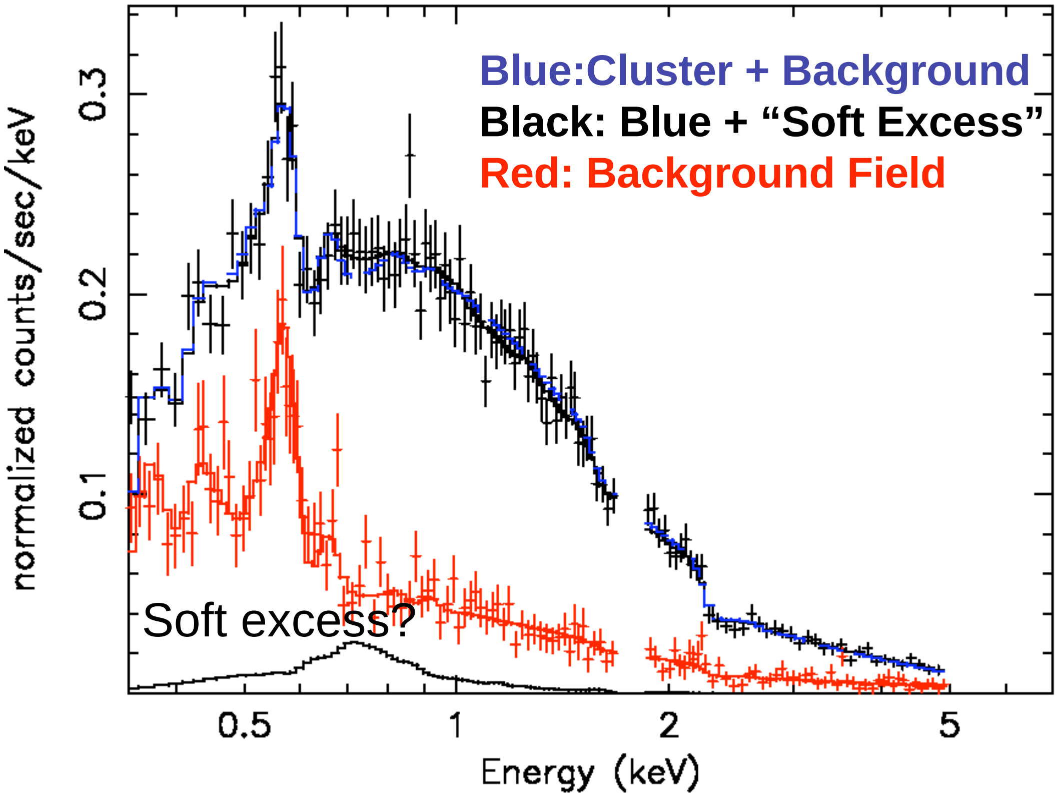
Searching for Excess Soft Emission

- Recent XMM observations (Kaastra, et al.) purport to find excess soft ($kT \sim 0.2$ keV) emission near some clusters.
- Interpreted as possible signature of ‘missing’ baryons in a Warm-Hot Intergalactic Medium
- A key issue: is the emission associated with the clusters?
- Detection of soft line emission (e.g., OVII) could answer this question. Suzaku is well-suited for a search.

Searching for Excess Soft Emission in Abell 2218 with Suzaku

Takei, Mitsuda et al.

Abell 2218, R > 3 arcmin

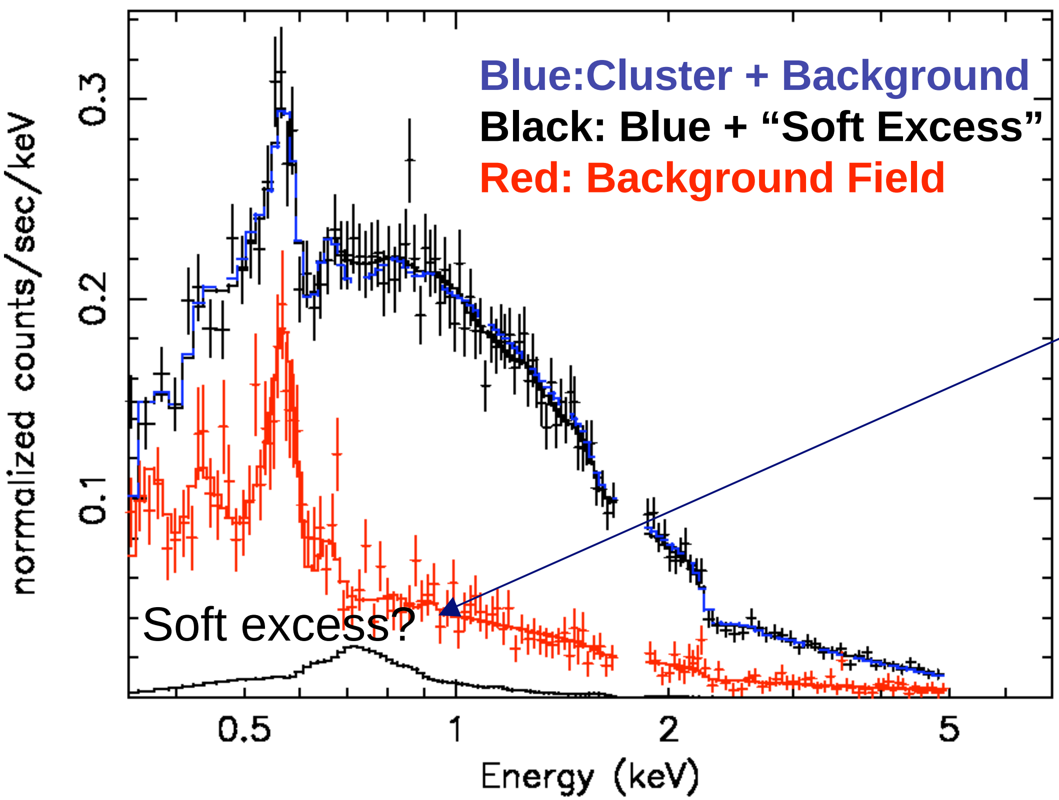


- No evidence for line emission from OVII, OVIII at cluster redshift
  ($f < 3.5 \times 10^{-17}$ erg s^{-1} cm^{-2} $arcmin^{-2}$)
- Spectral features in Galactic emission & absorption, as well as Solar wind charge exchange, complicate search, e.g.:
  $E_{OVIII}/(1 + z_{A2218}) \sim E_{OI\text{-}edge}$

Searching for Excess Soft Emission in Abell 2218 with Suzaku

Takei, Mitsuda et al.

Abell 2218, R > 3 arcmin



Possible soft continuum component <~6% of cluster L_X, kT ~ 0.6 keV, fainter & hotter than putative XMM detections

Summary

Suzaku is giving us:

- Oxygen & other abundances in galaxies & clusters, with promises of constraints on enrichment history & on SN models.
- Good prospects for cluster temperature and mass maps to the virial radius.
- New sensitivity to any soft-excess cluster emission.