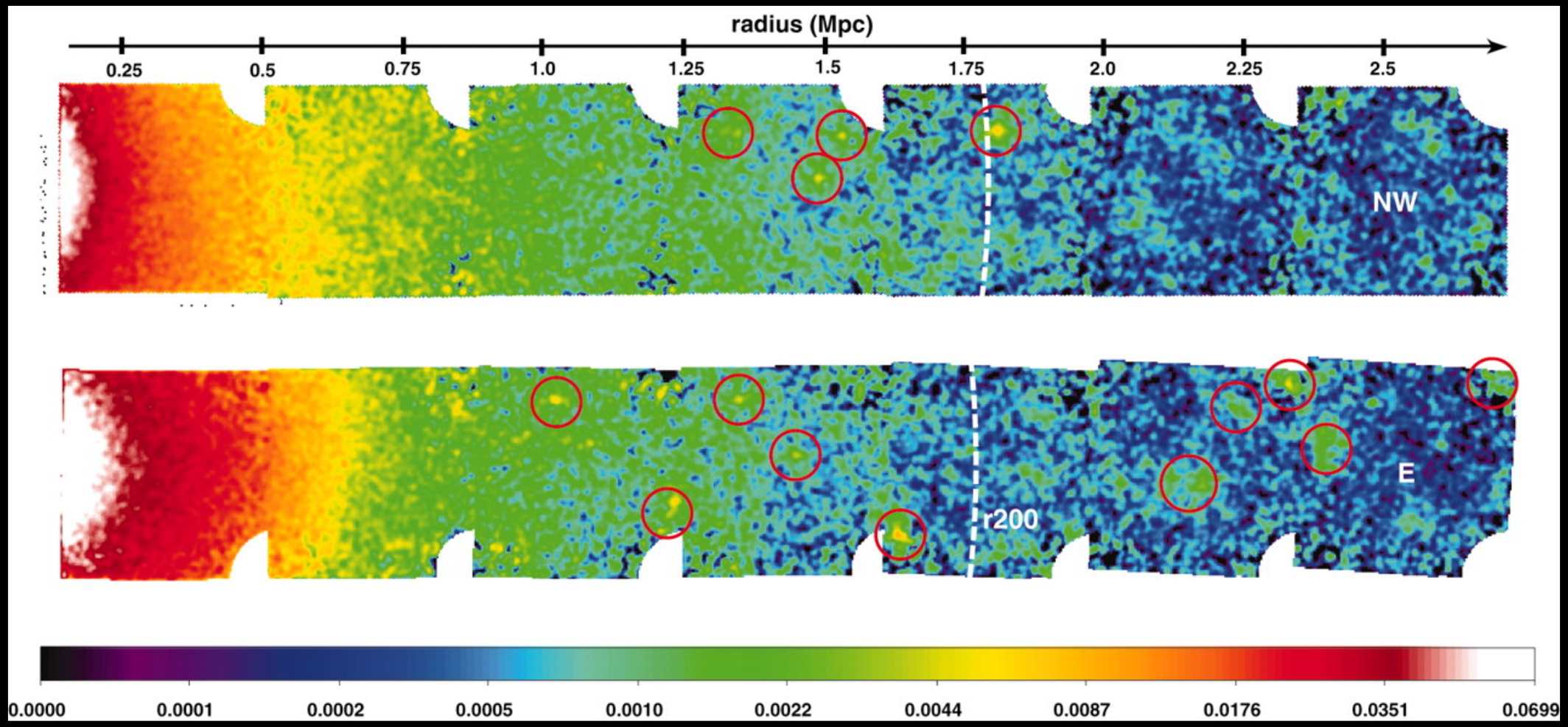
A Decade of Cluster Outskirts Studies with Suzaku



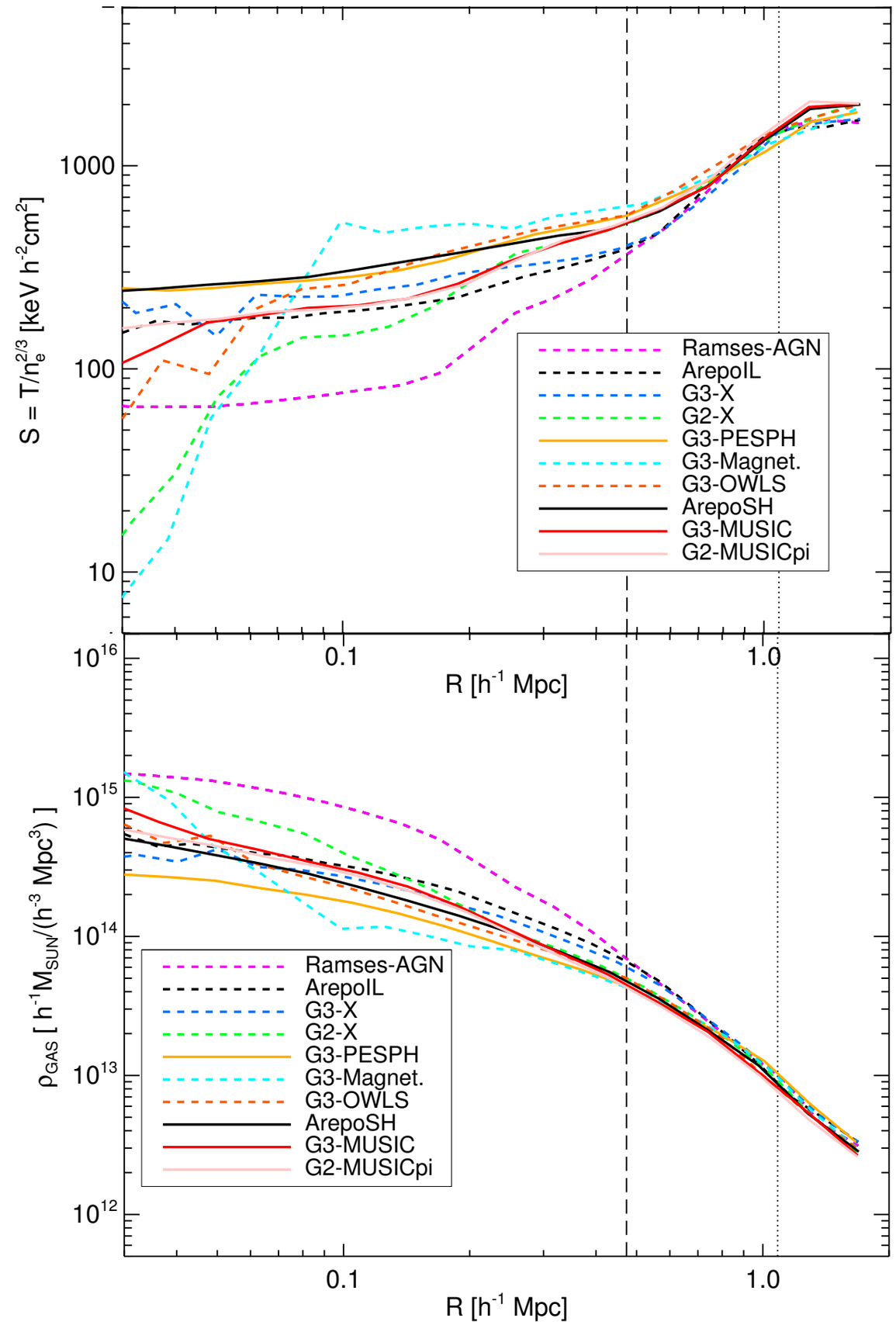
Aurora Simionescu
SRON

S. A. Walker, A.S., et al, SSRv, arXiv181000890
F. Mernier et al., SSRv, submitted

I. Thermodynamical properties

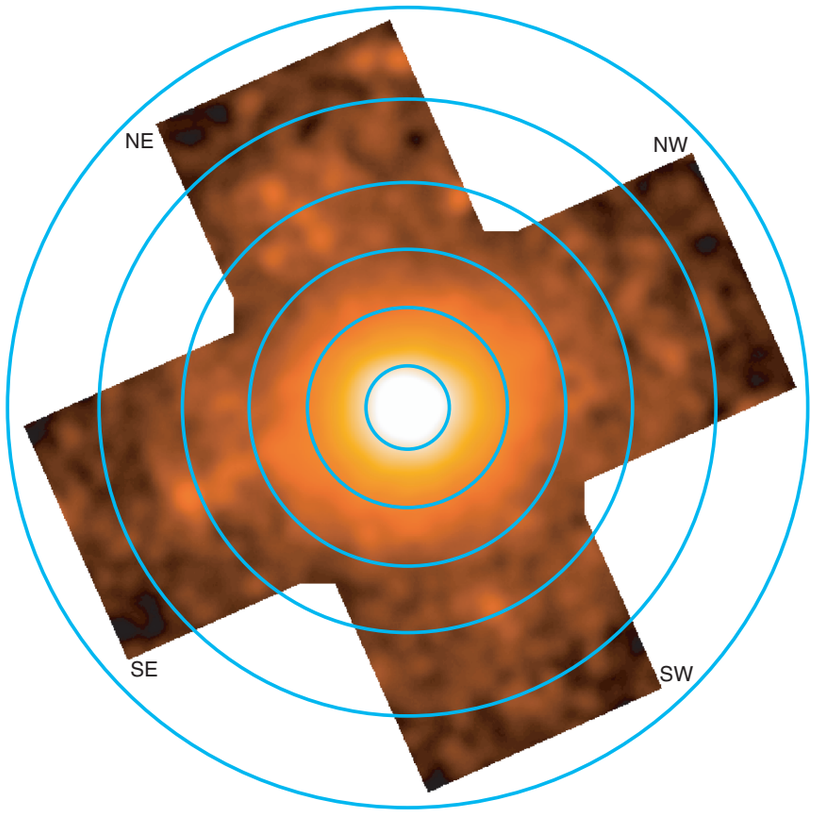
WHAT WE THINK WE KNOW:

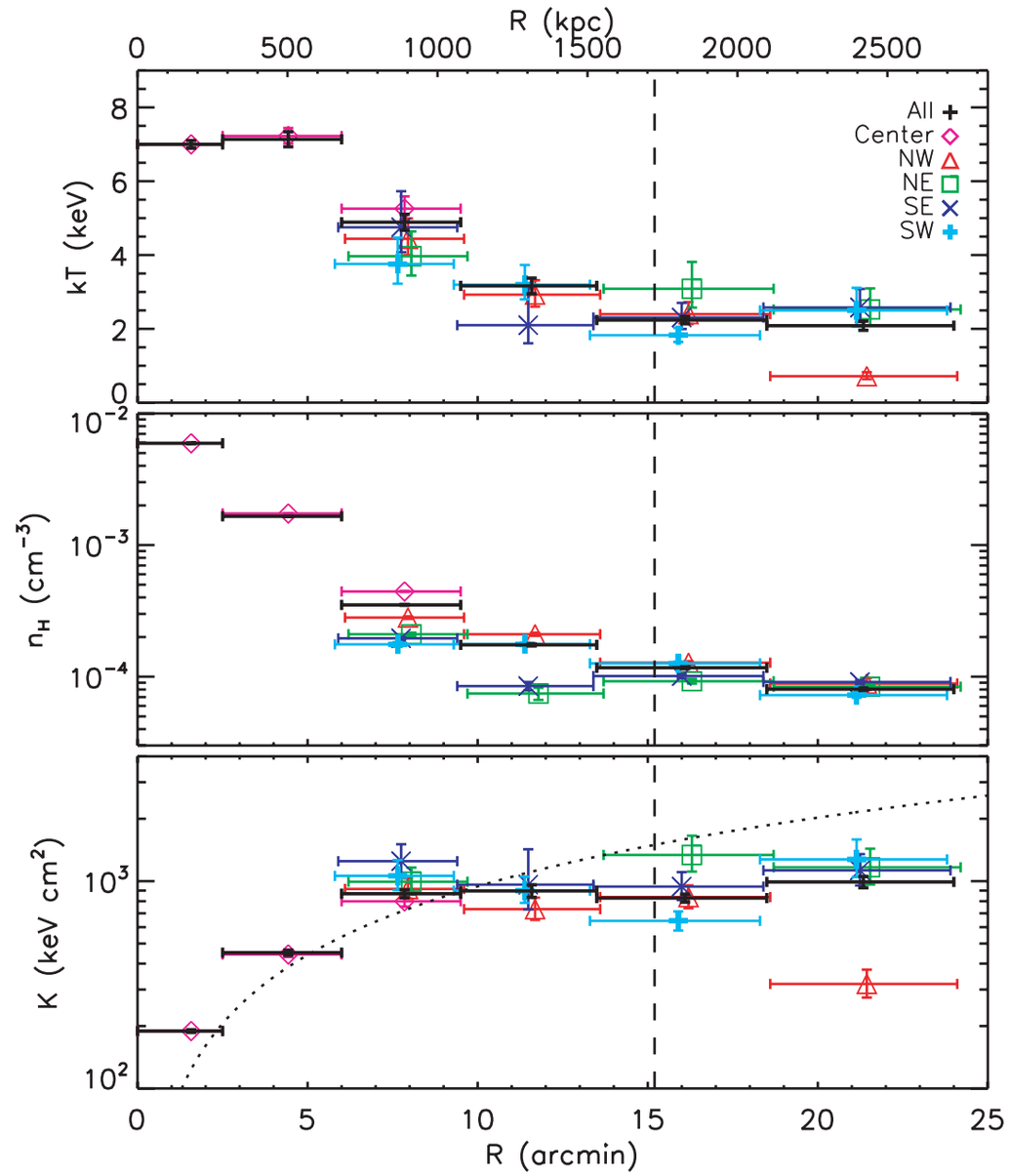
- Entropy should look like a power-law
- Pressure should look like a gNFW model
- You can then solve for expected kT and n_e shapes
- This is very stable to various assumptions of the numerical simulation



nIFTy radiative simulation cluster comparison project (Sembolini et al. 2016)

9 YEARS AGO (HOW IT ALL BEGAN):

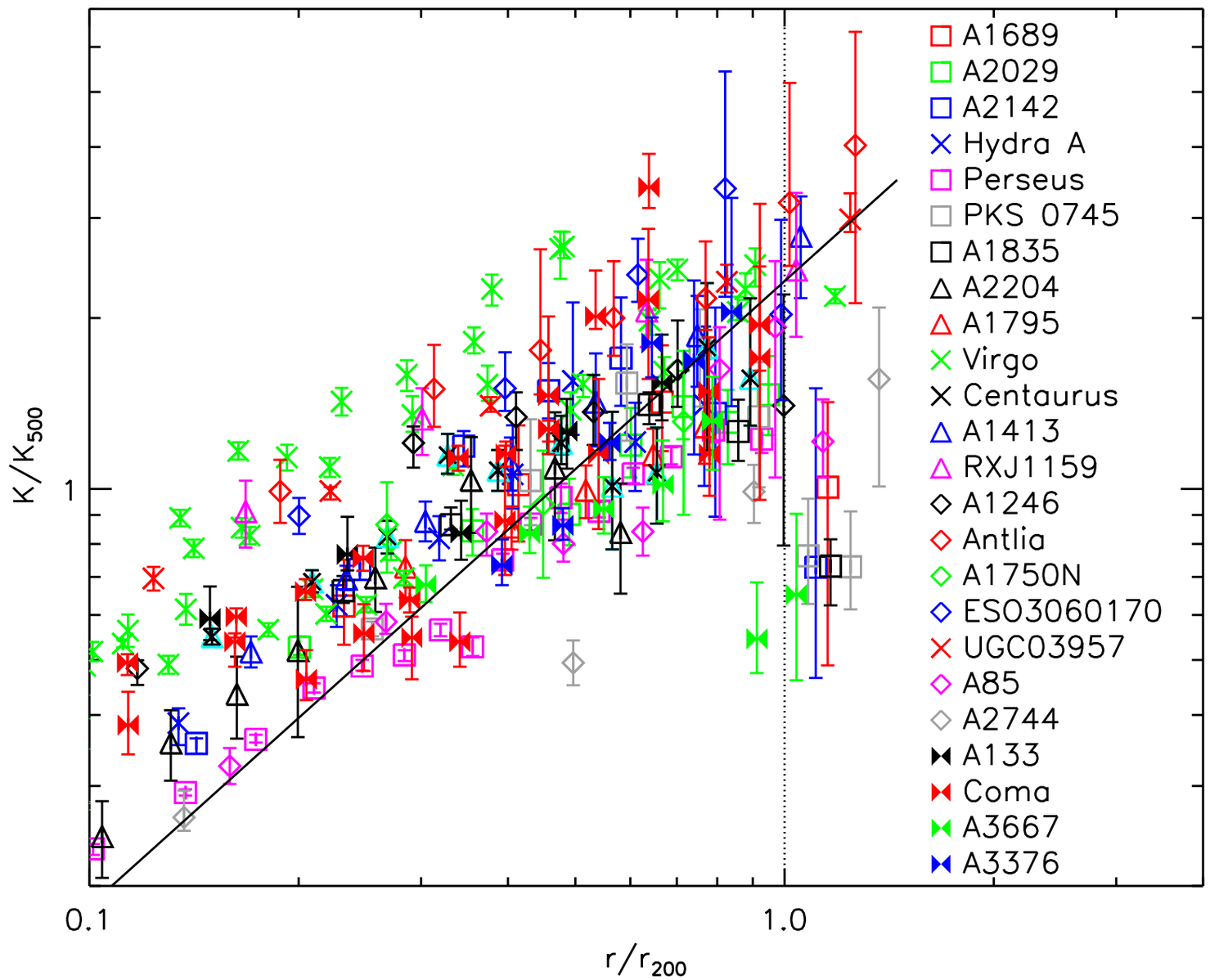


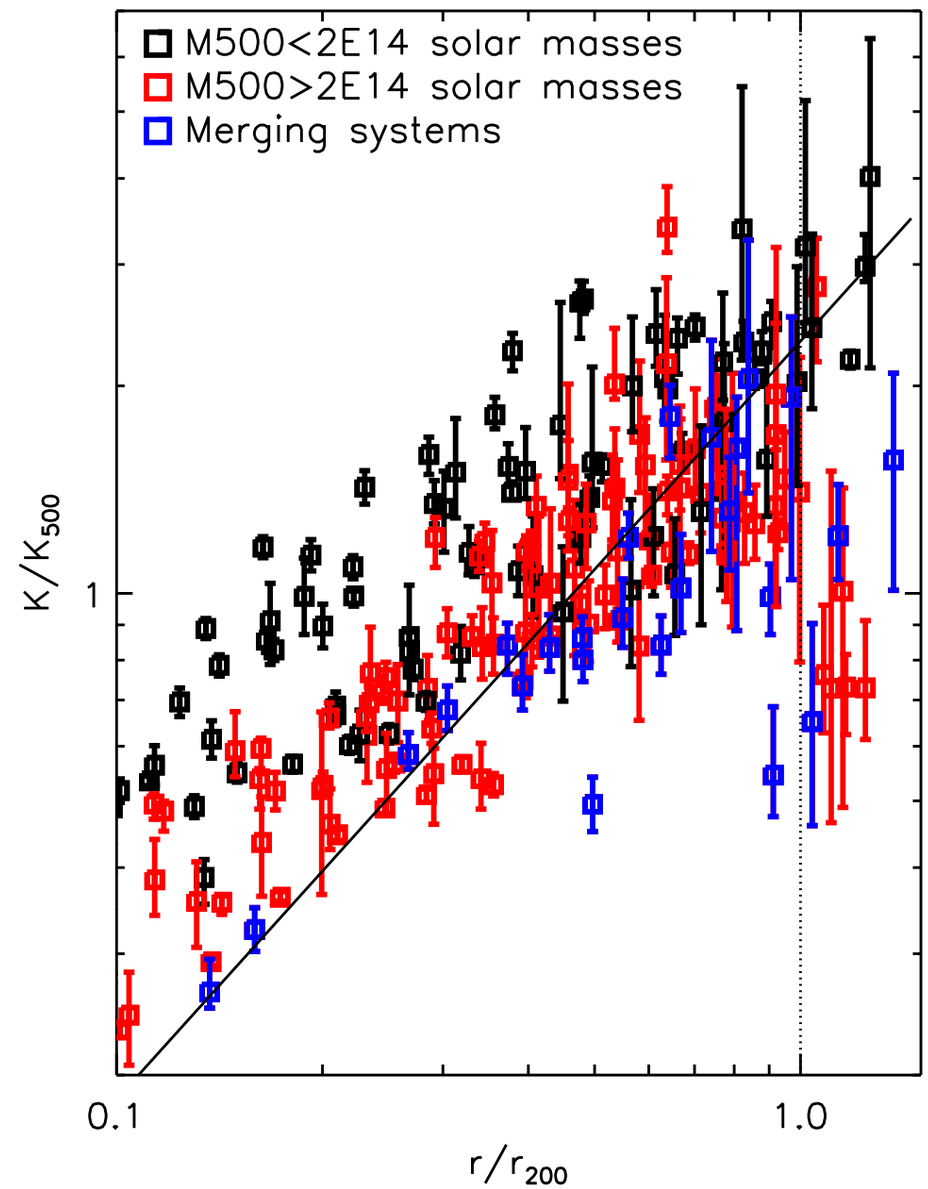


PKS0745-191 (George et al. 2009)

Qualitatively correct, quantitatively wrong

(issues with subtracting Galactic foreground, CXB variance, stray light)

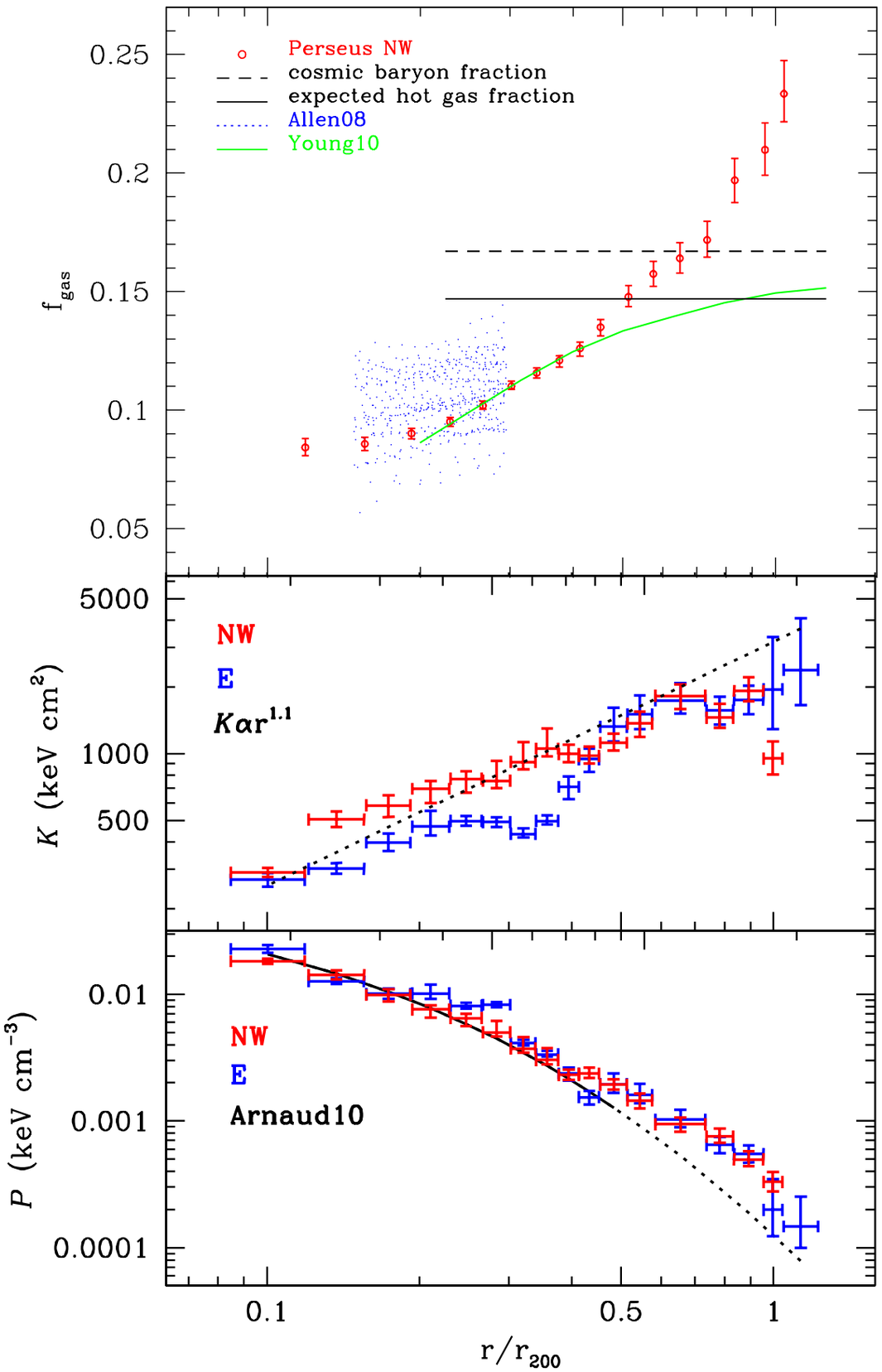




Does the comparison to this baseline power-law even make any sense for low-mass systems (at any radius)?

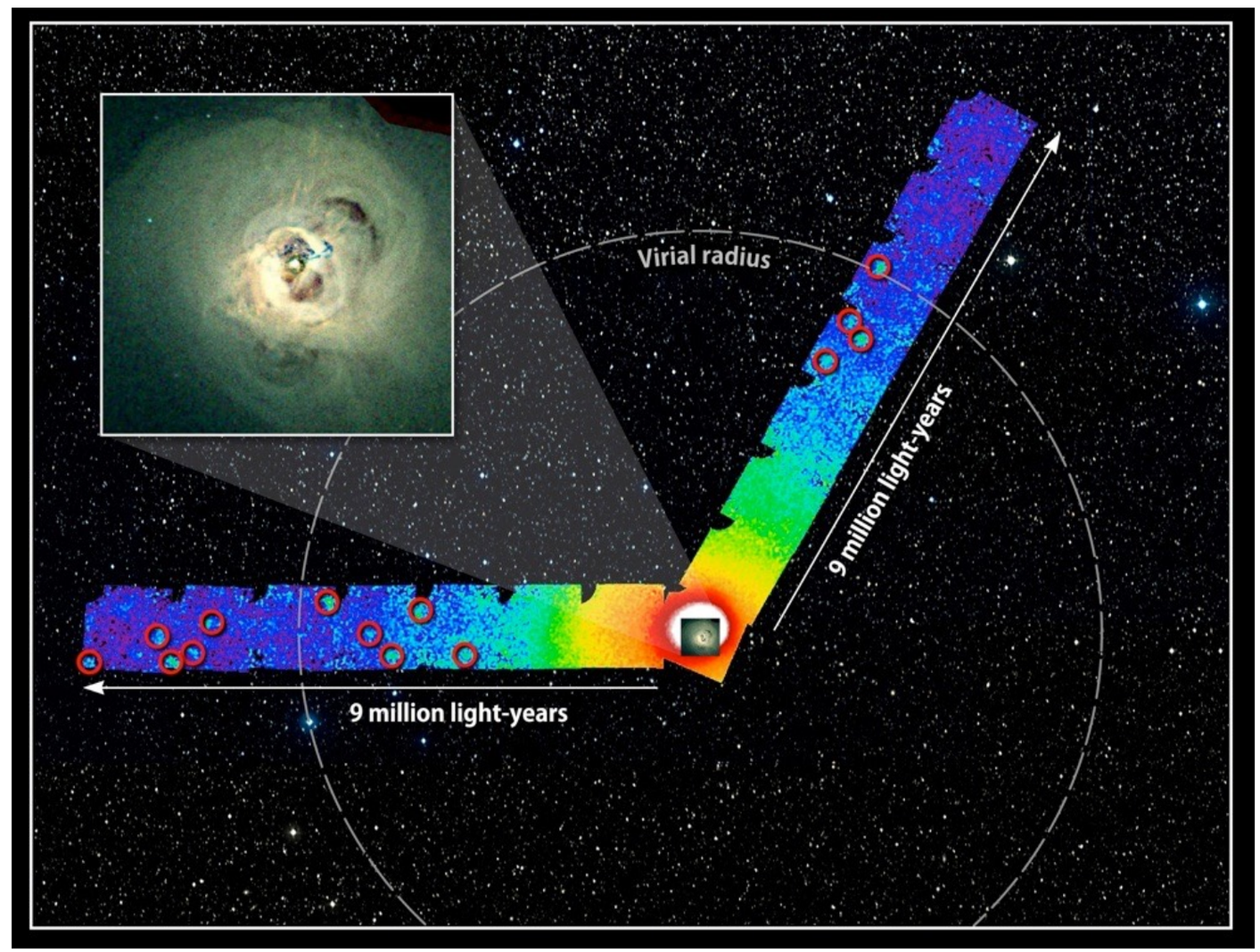
Can we come up with anything better? [Need simulations that match fgas(r) for low mass systems!]

7 YEARS AGO:

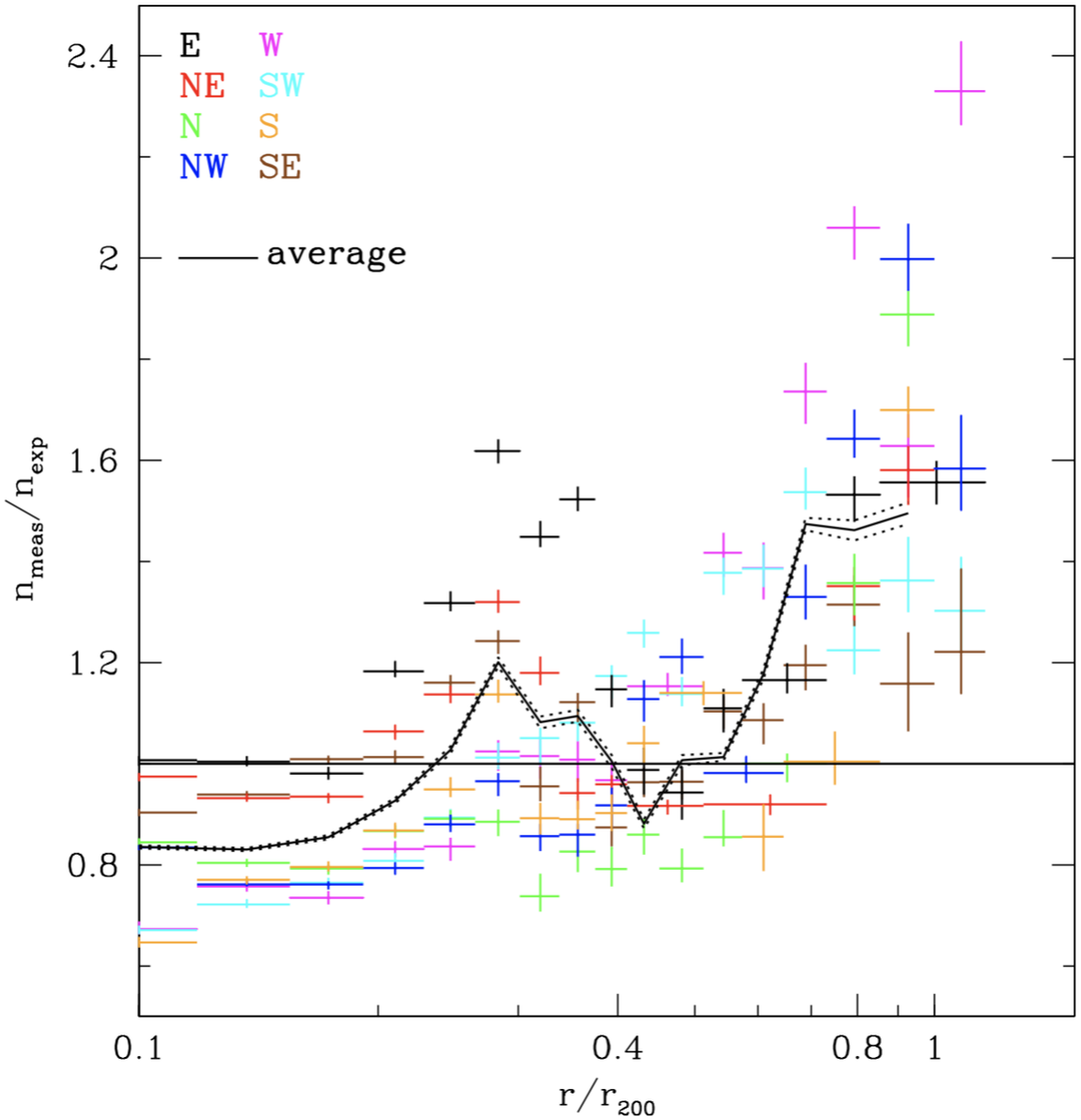


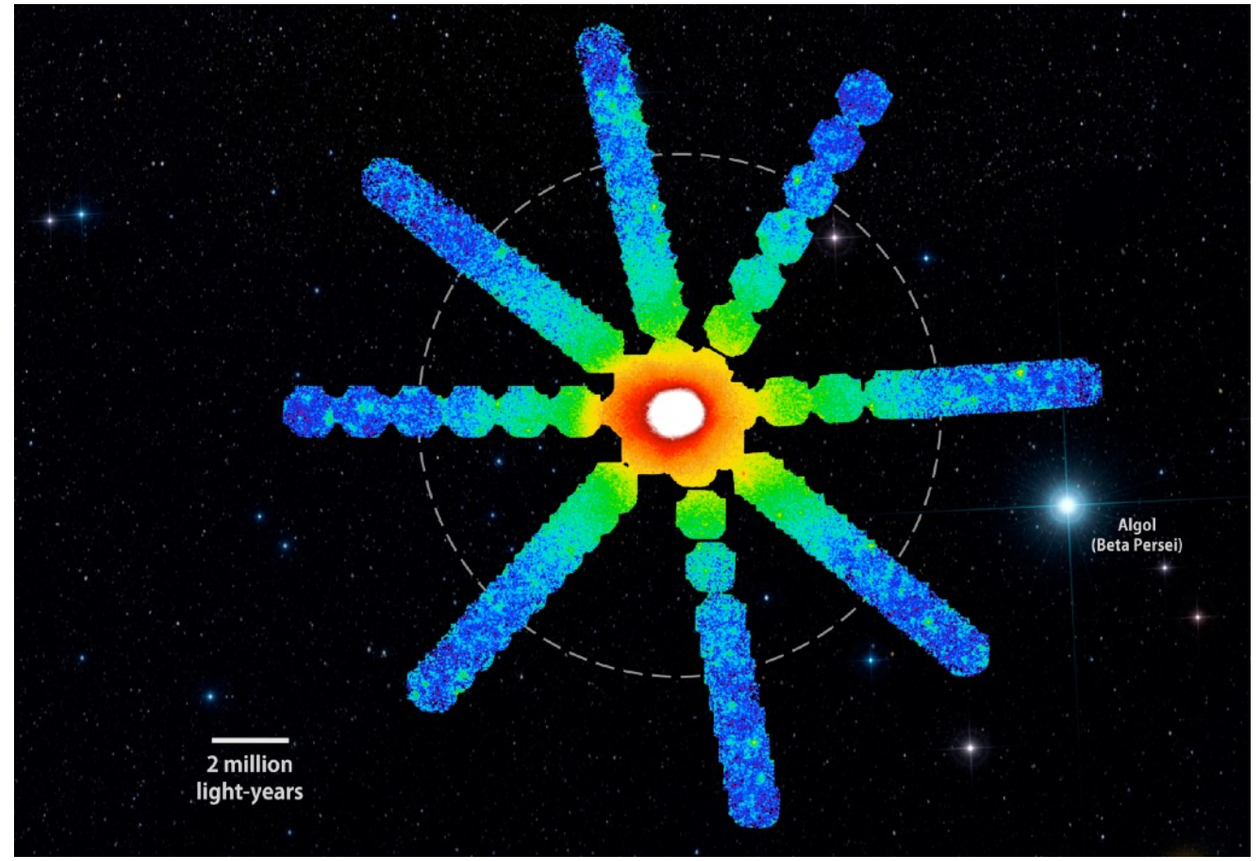
Perseus Pilot Project
(Simionescu et al. 2011)

Qualitatively correct,
quantitatively incomplete
(issues with coverage at r200)



Azimuthally resolved Gas Clumping in Perseus





$$n_e^{\text{expected}}(r) = P(r)^{3/5} K(r)^{-3/5}$$

Both “macroscopic clumping” (due to E-W large-scale sloshing asymmetries) and “microscopic clumping” (along relaxed N-S axis) must be present.

Urban et al. 2014

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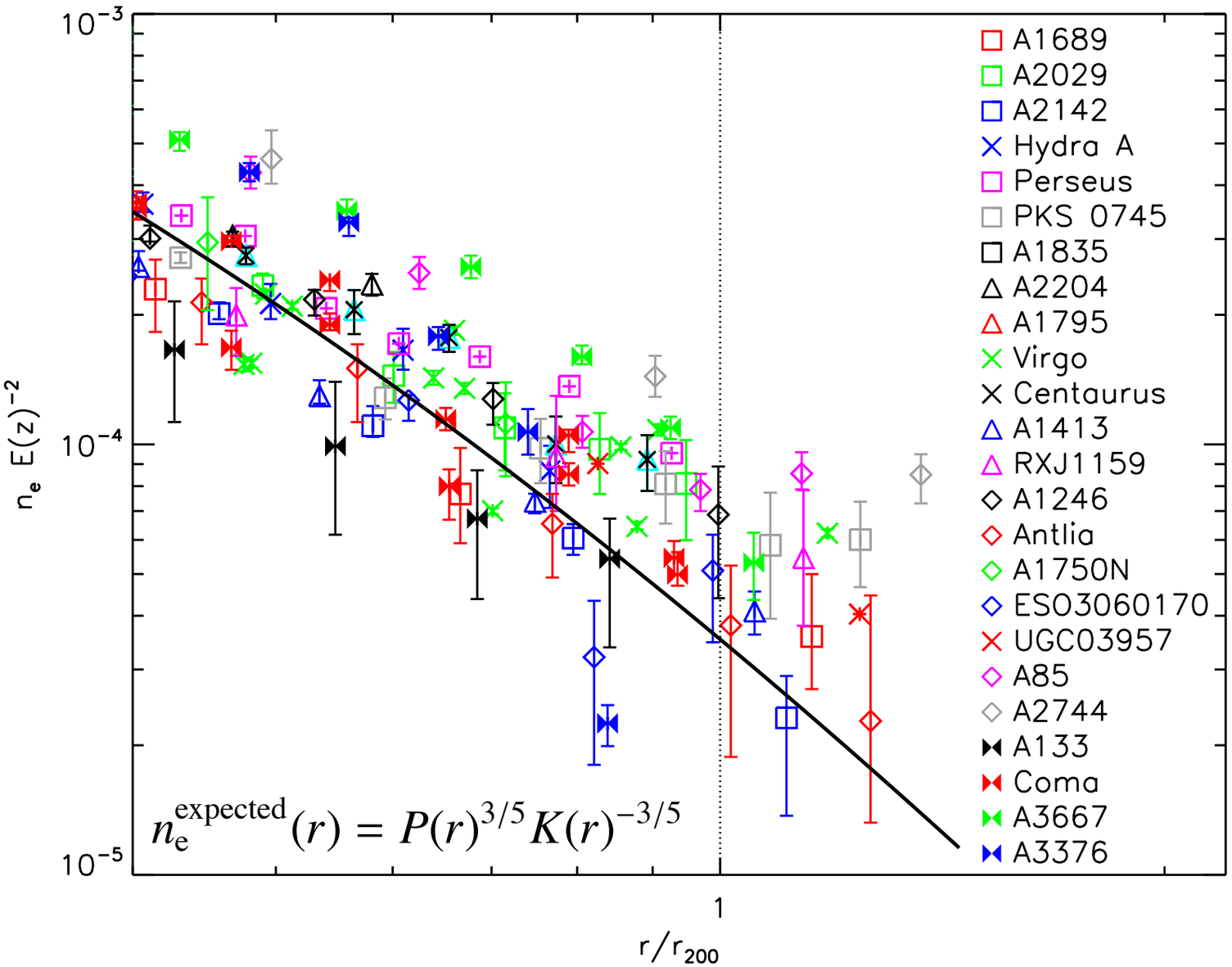
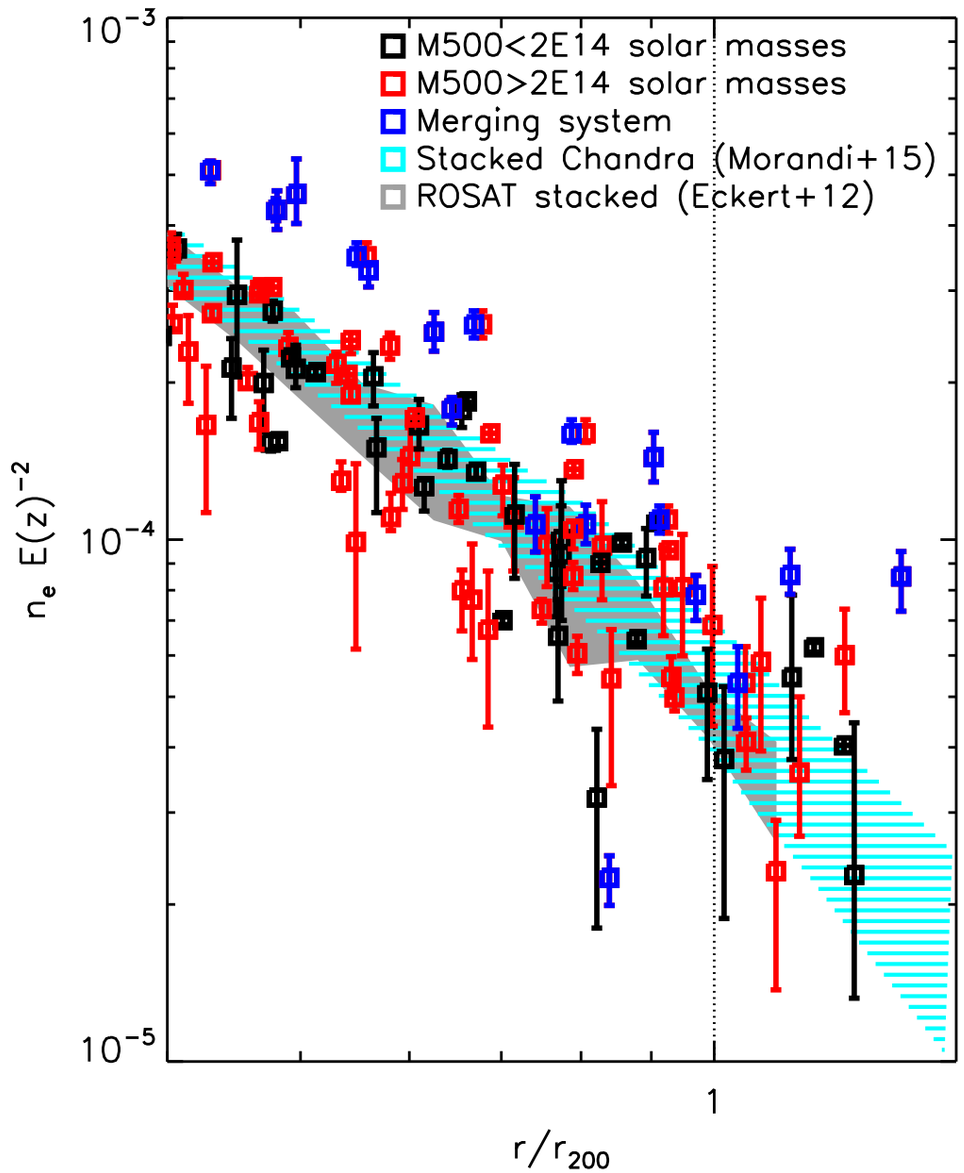
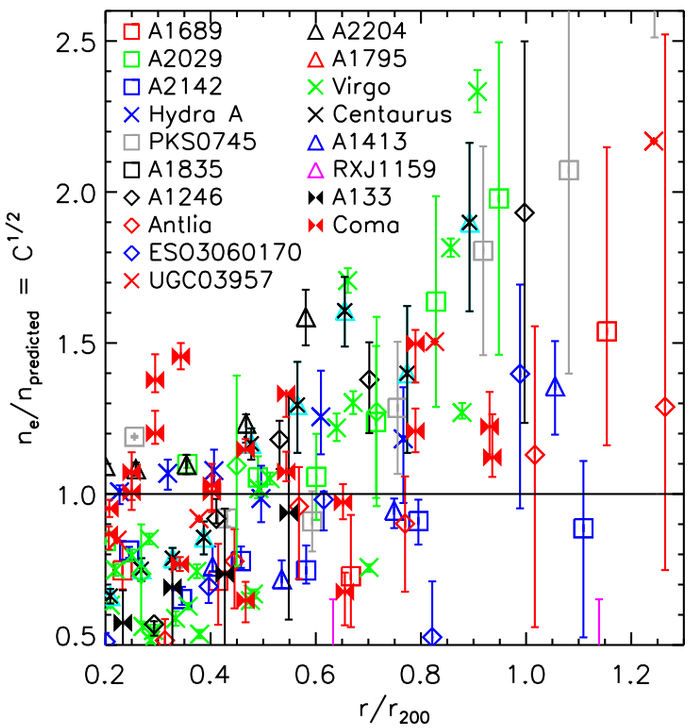




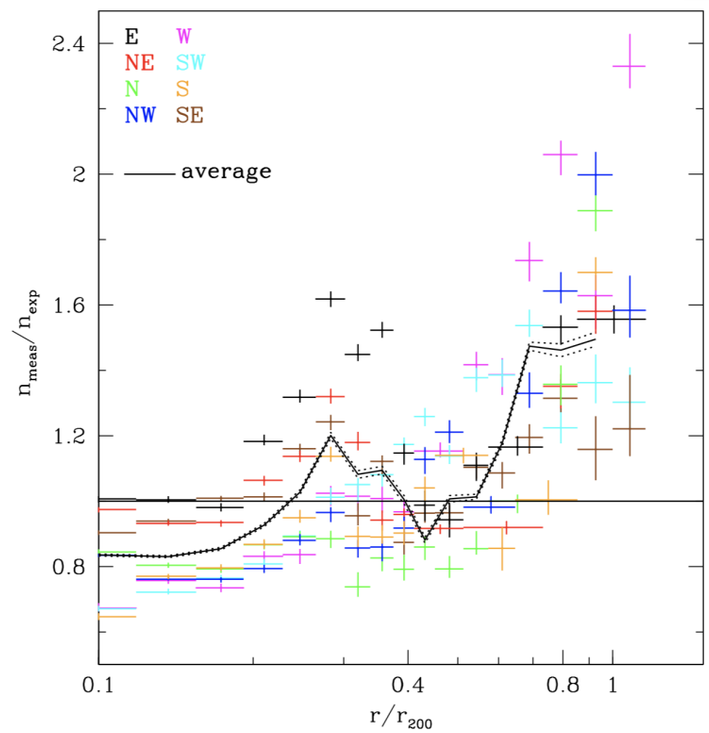
Suzaku (all)

Walker et al. (2018)



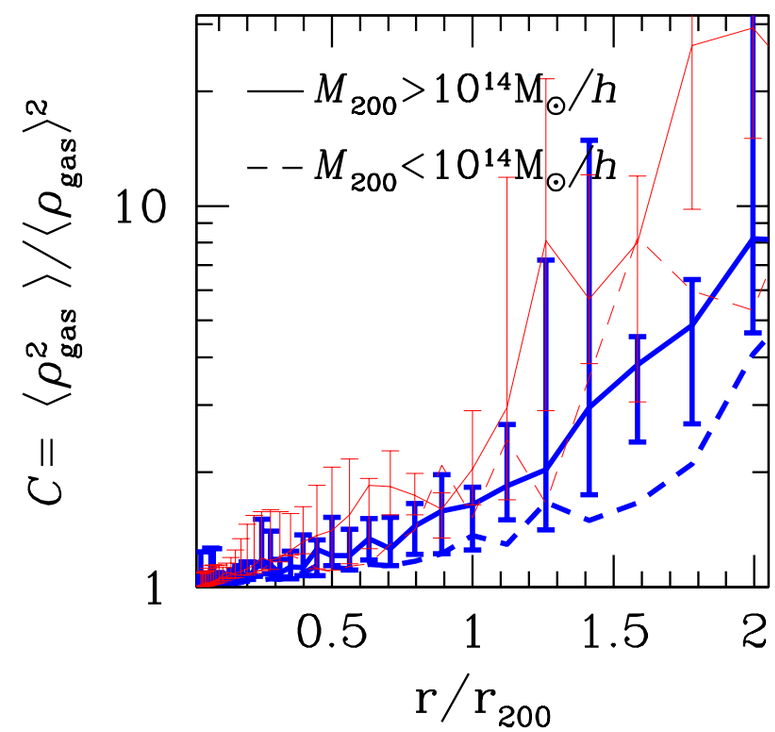
Suzaku (Perseus)

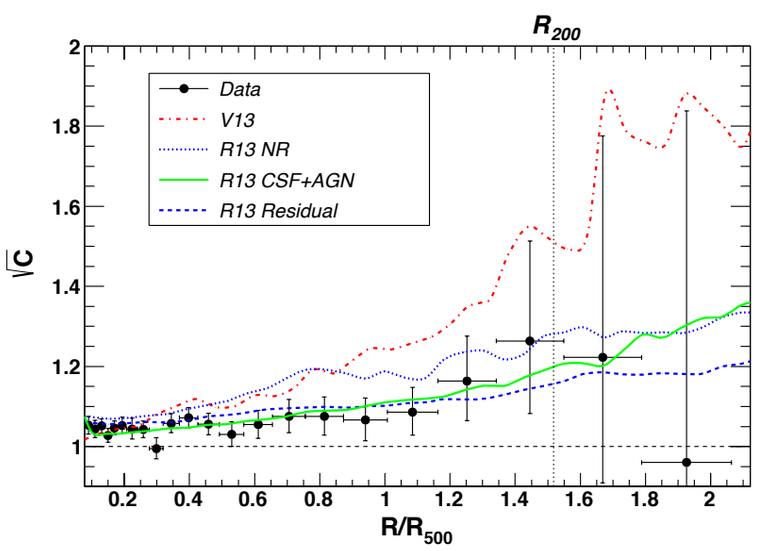
Urban et al. (2014)

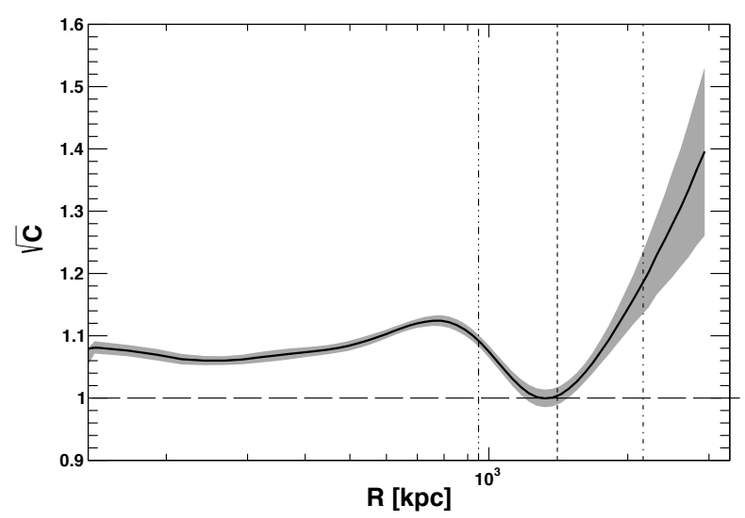


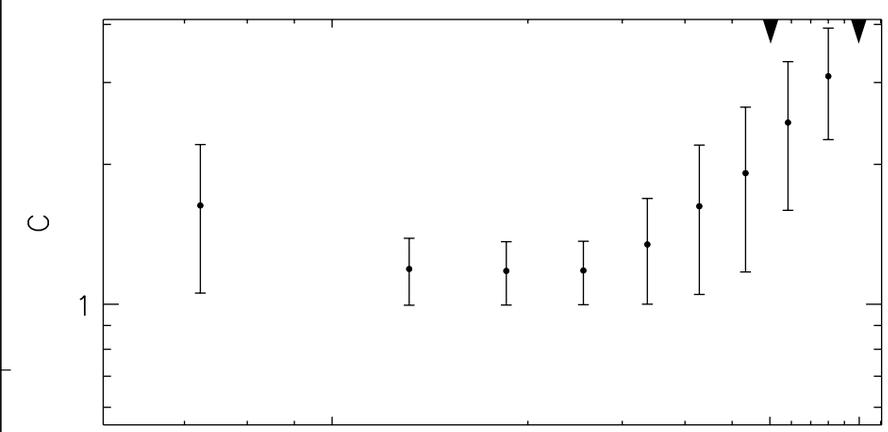
Hydro-sim

Nagai&Lau (2011)









ROSAT

Eckert et al. (2015)

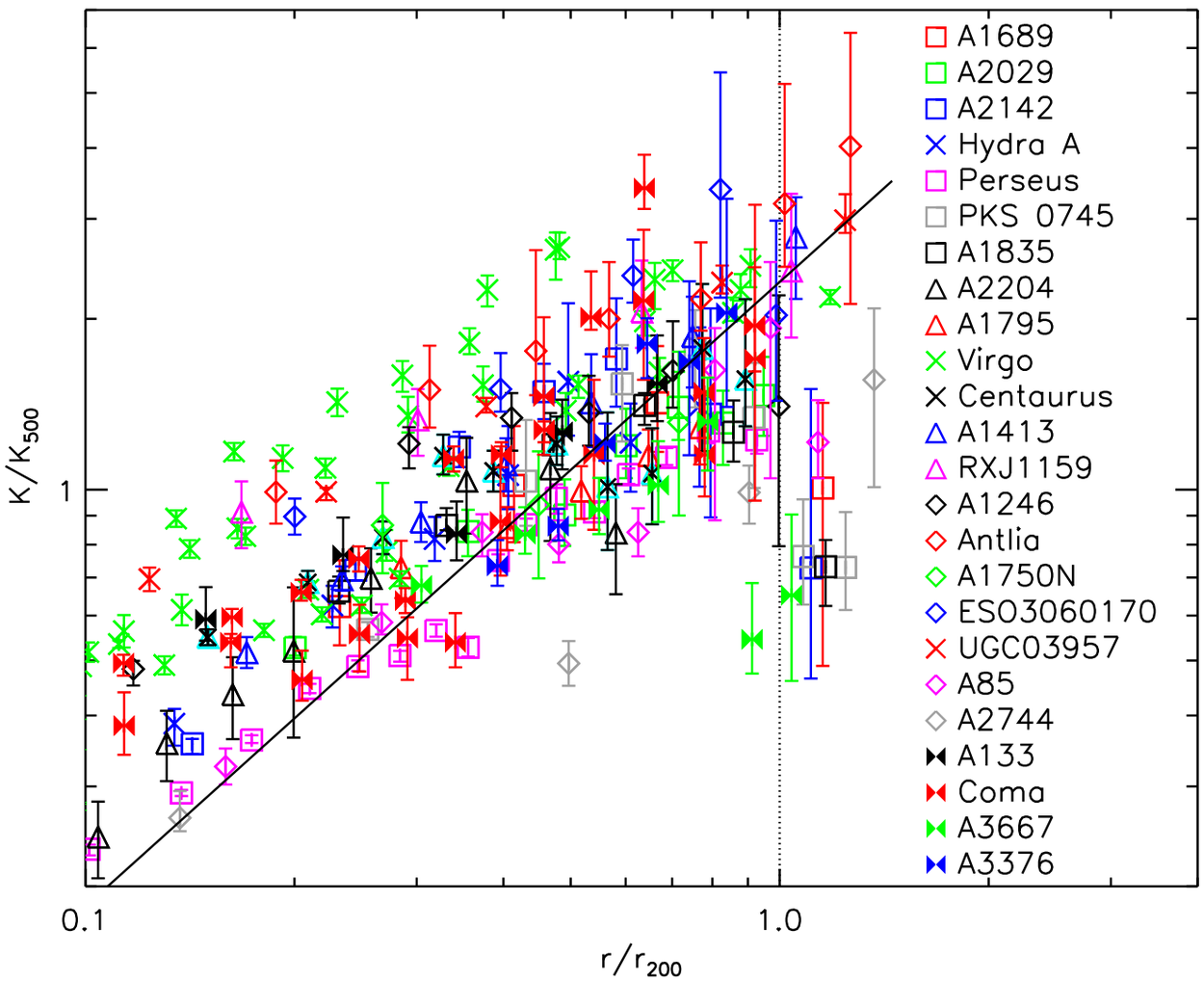
X-COP (A2142)

Tchernin et al.(2016)

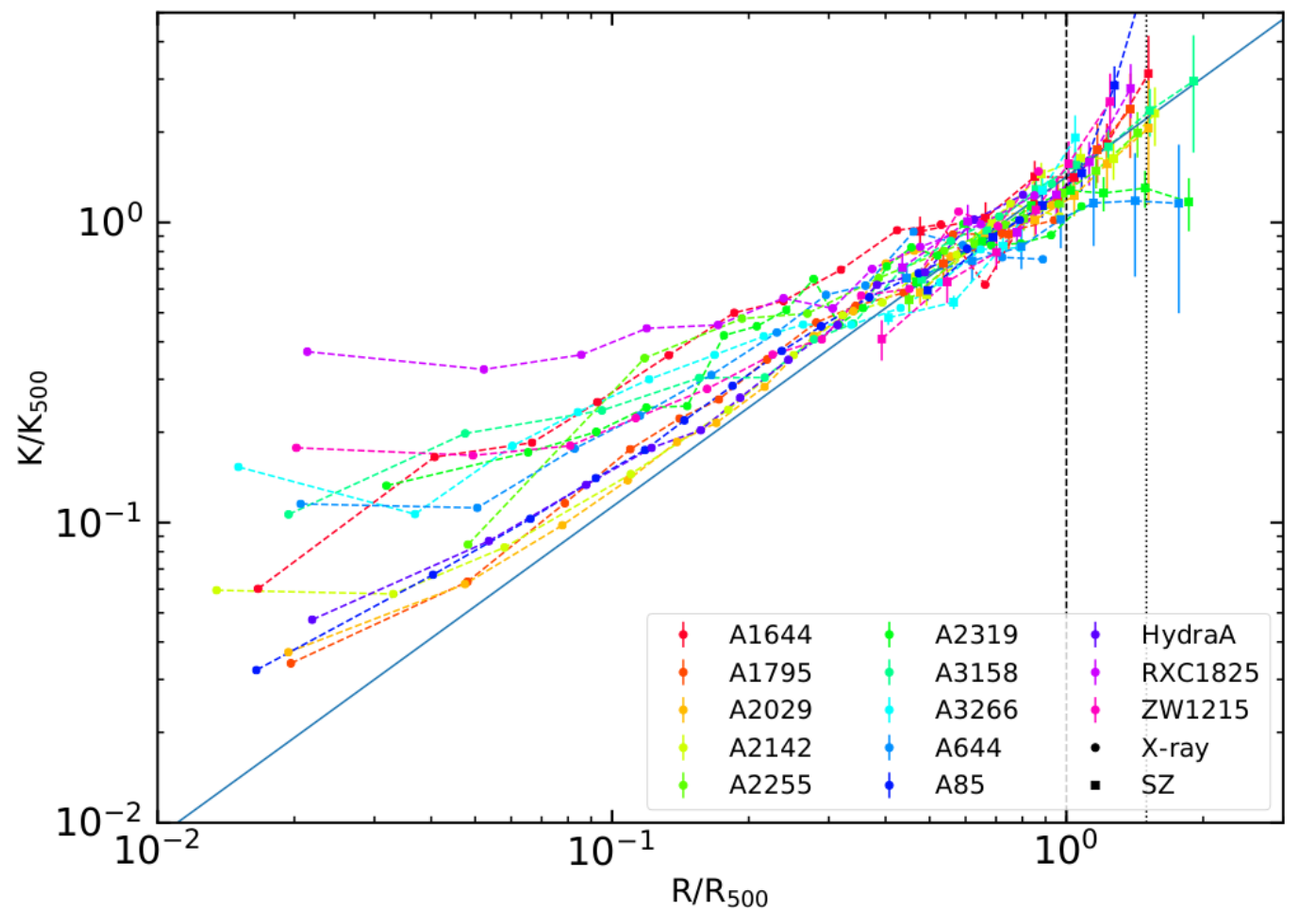
Chandra (A133)

Morandi&Cui (2014)
(also A1835,
Morandi et al. 2013)

Suzaku (not clumping corrected!)



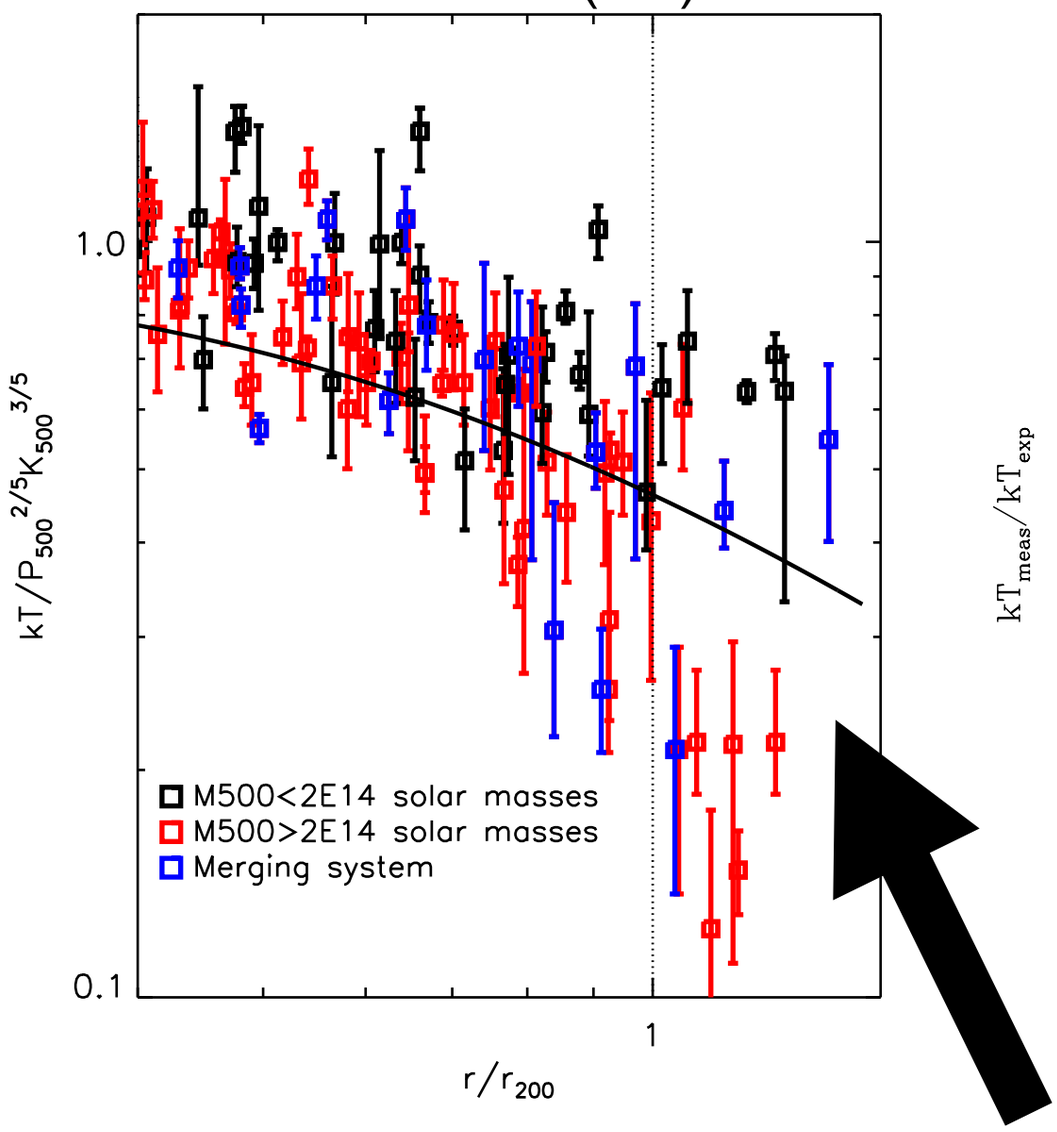
X-COP (clumping corrected!)



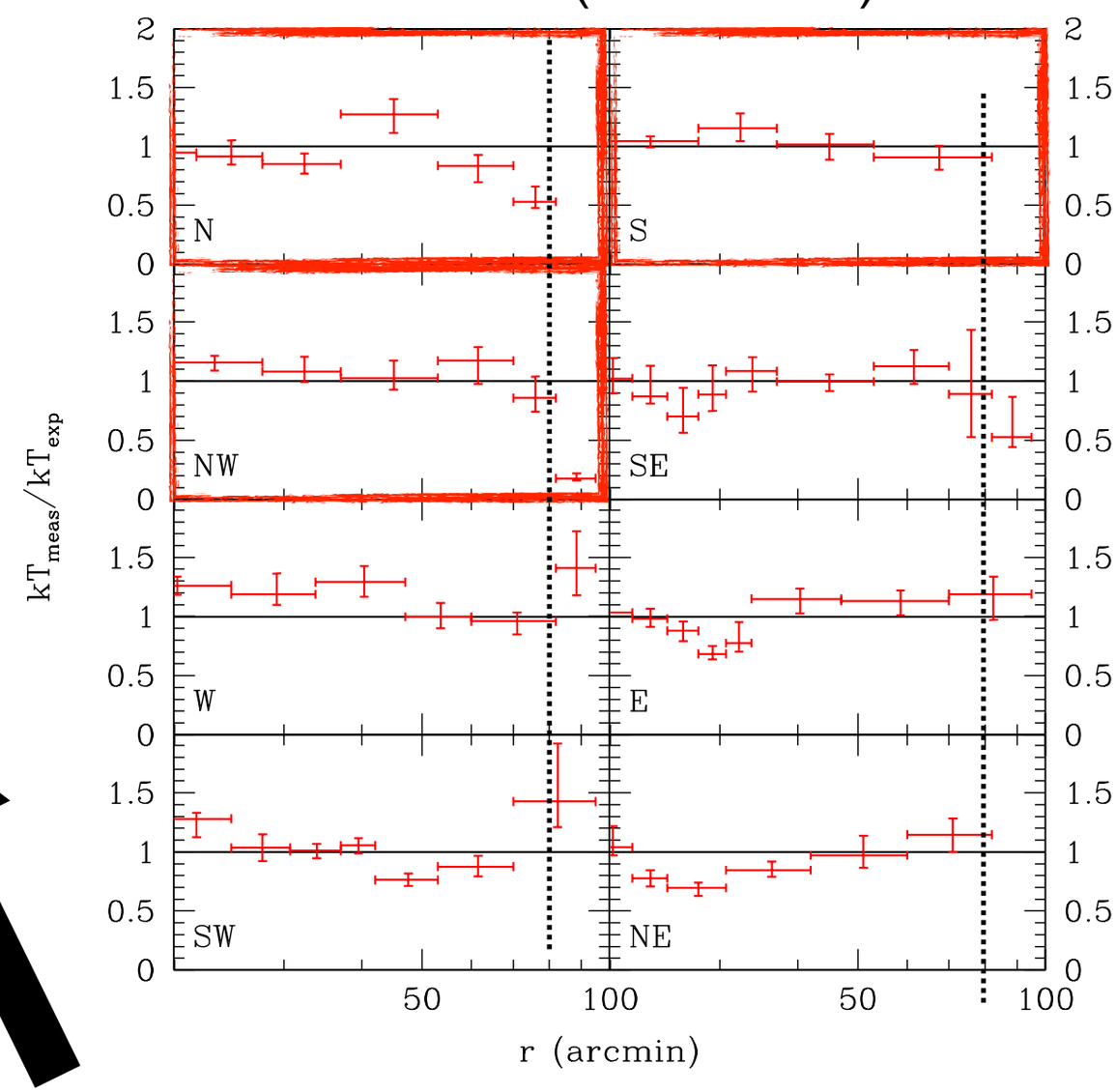
The disagreement is much smaller than it seems!

We need to get together and actually make a fair comparison of these results.

Suzaku (all)



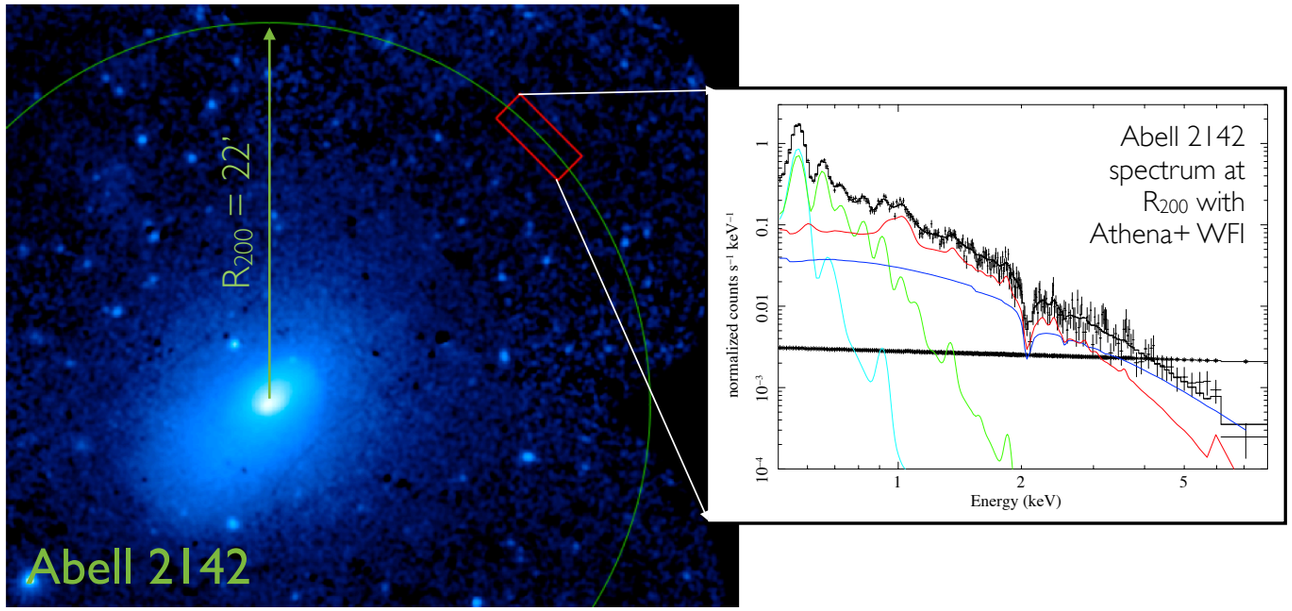
Suzaku (Perseus)

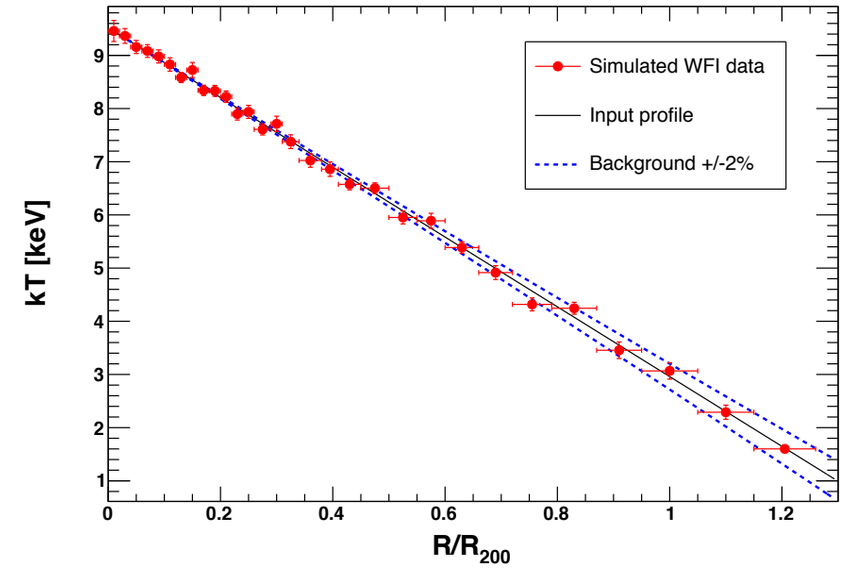


What's this??

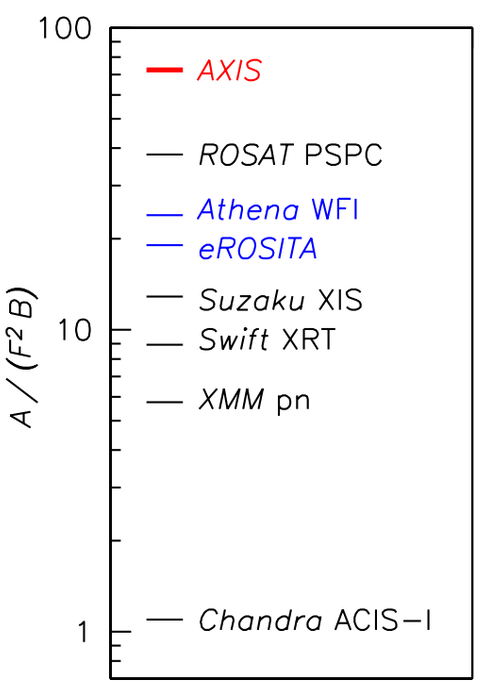
Opposite trend than electron-ion non equilibrium?
Opposite trend than non-thermal pressure support?

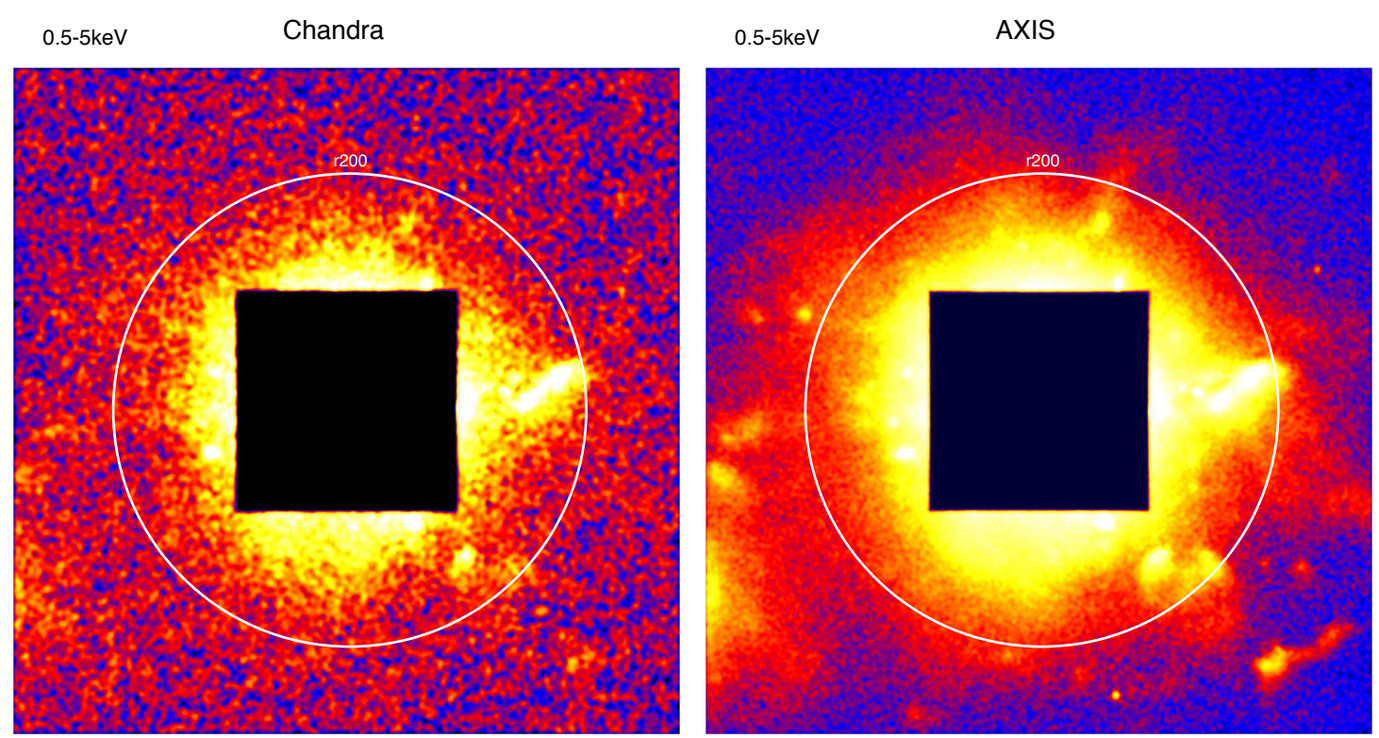
Maybe just residual systematics? What kind of systematics?
Does this disagree with X-COP at all?





Next… 20 (?) years

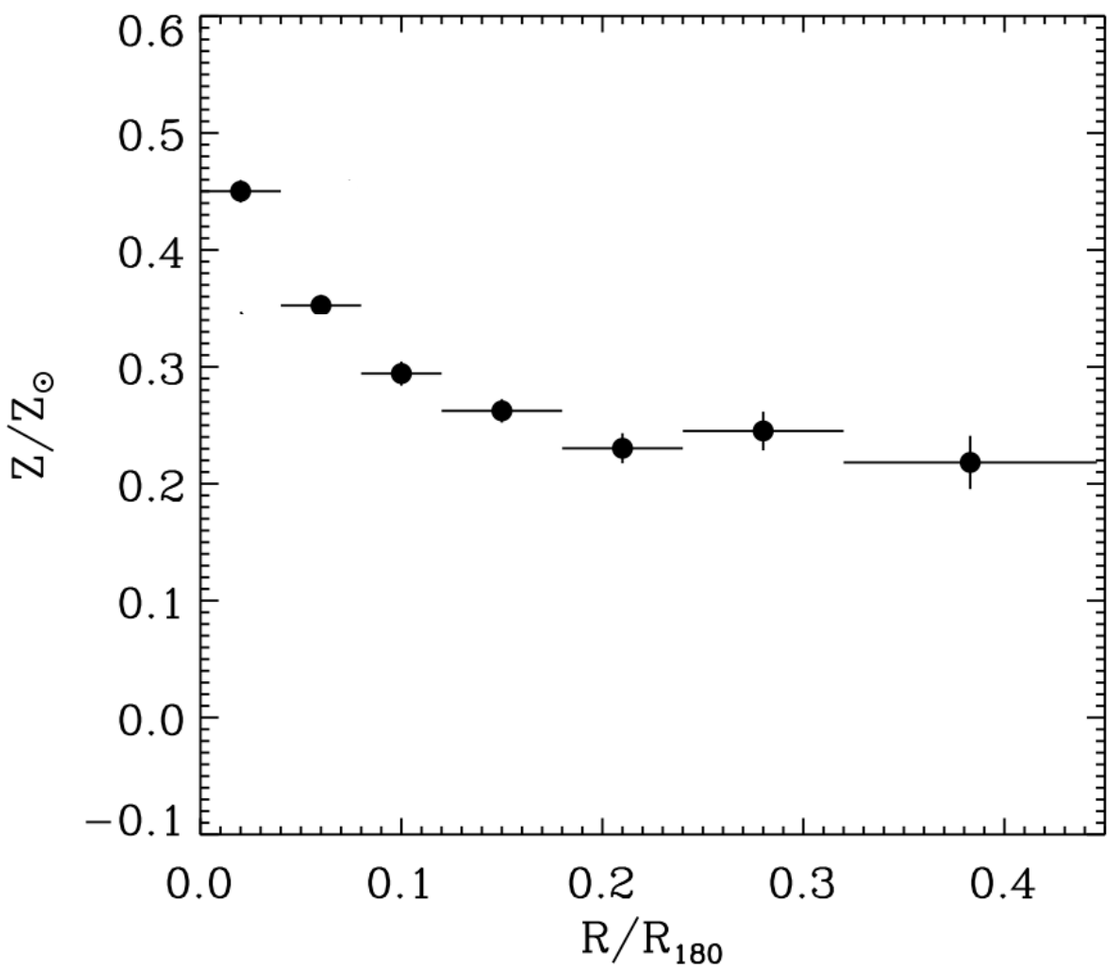




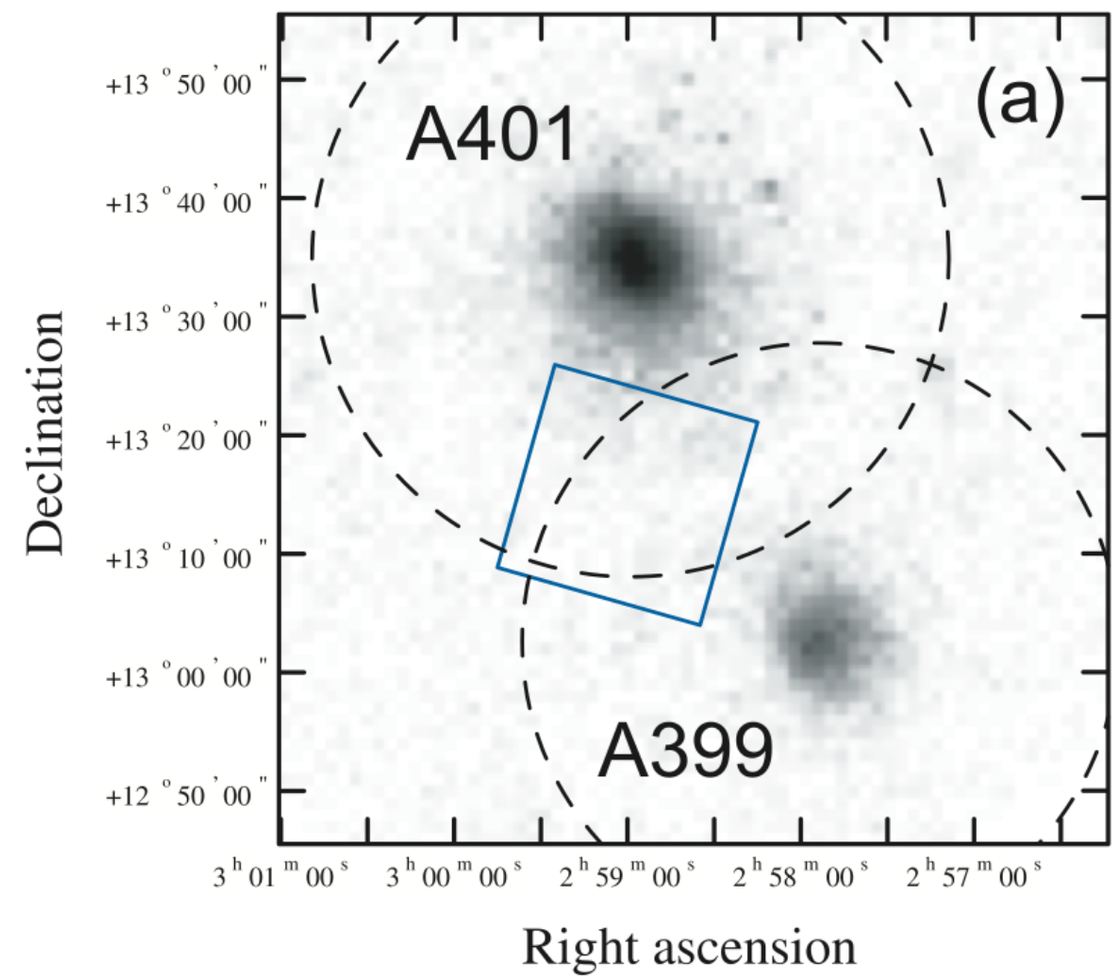
II. Outskirts chemistry

10 years ago (How it all began):

Early Evidence Suggesting Metal Enrichment in Cluster Outskirts



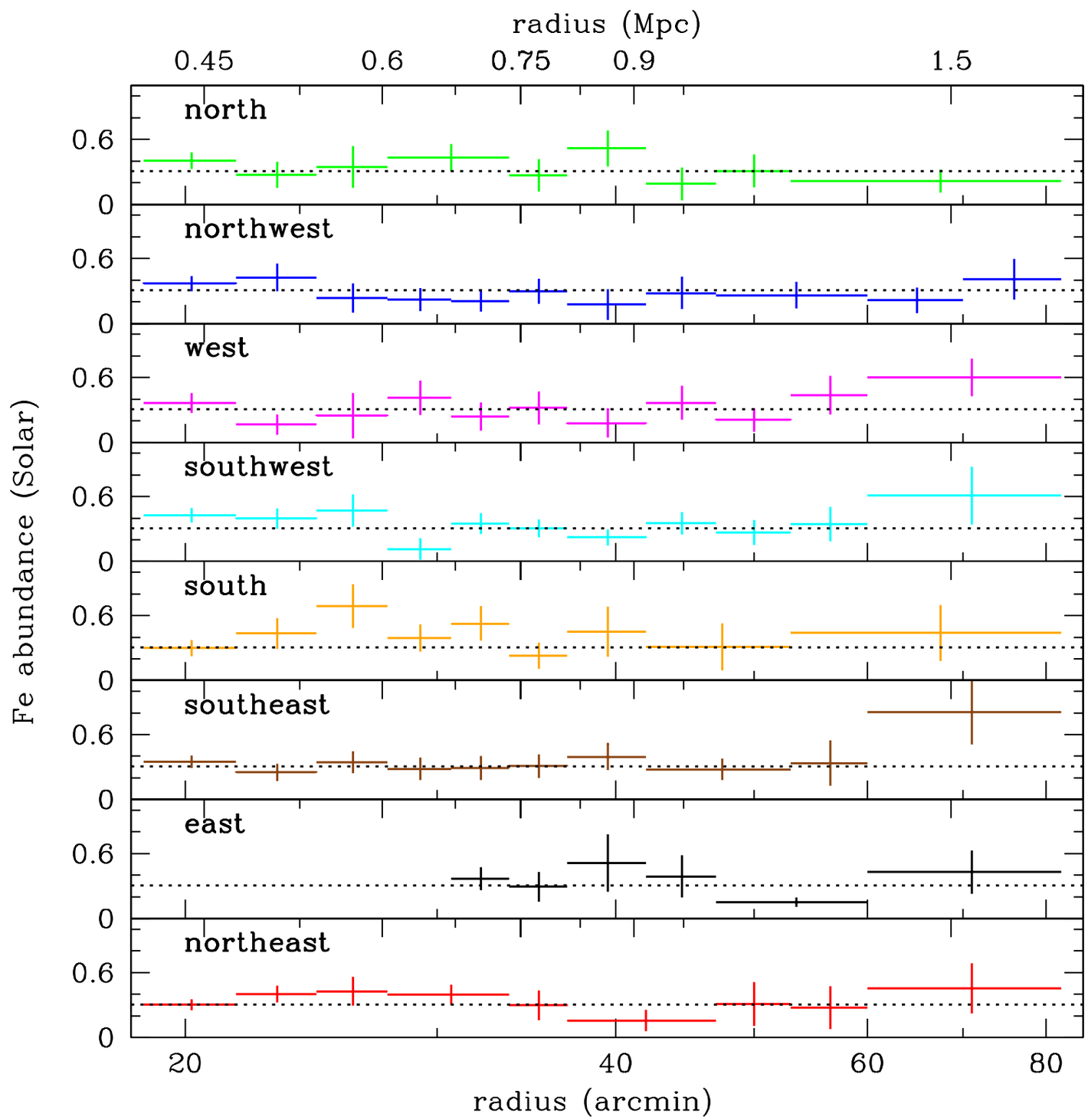
Leccardi et al. 2008
average metallicity profile of a sample of clusters with XMM

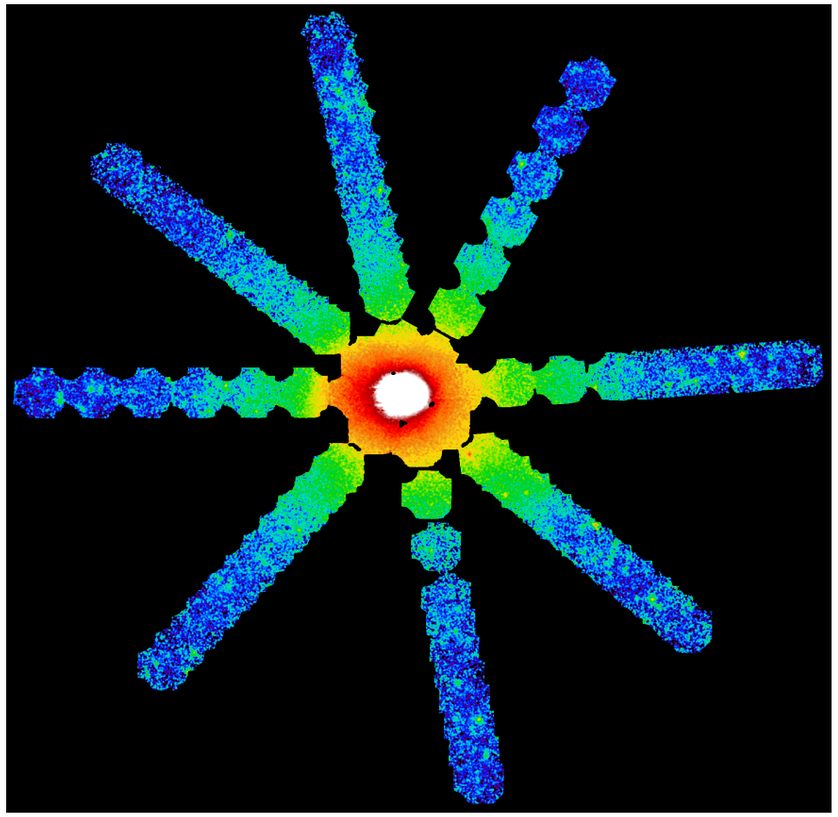


Fujita et al. 2008
abundance in the compressed region between two merging clusters with Suzaku

5 YEARS AGO:

IRON SPREAD SMOOTHLY THROUGHOUT THE PERSEUS CLUSTER

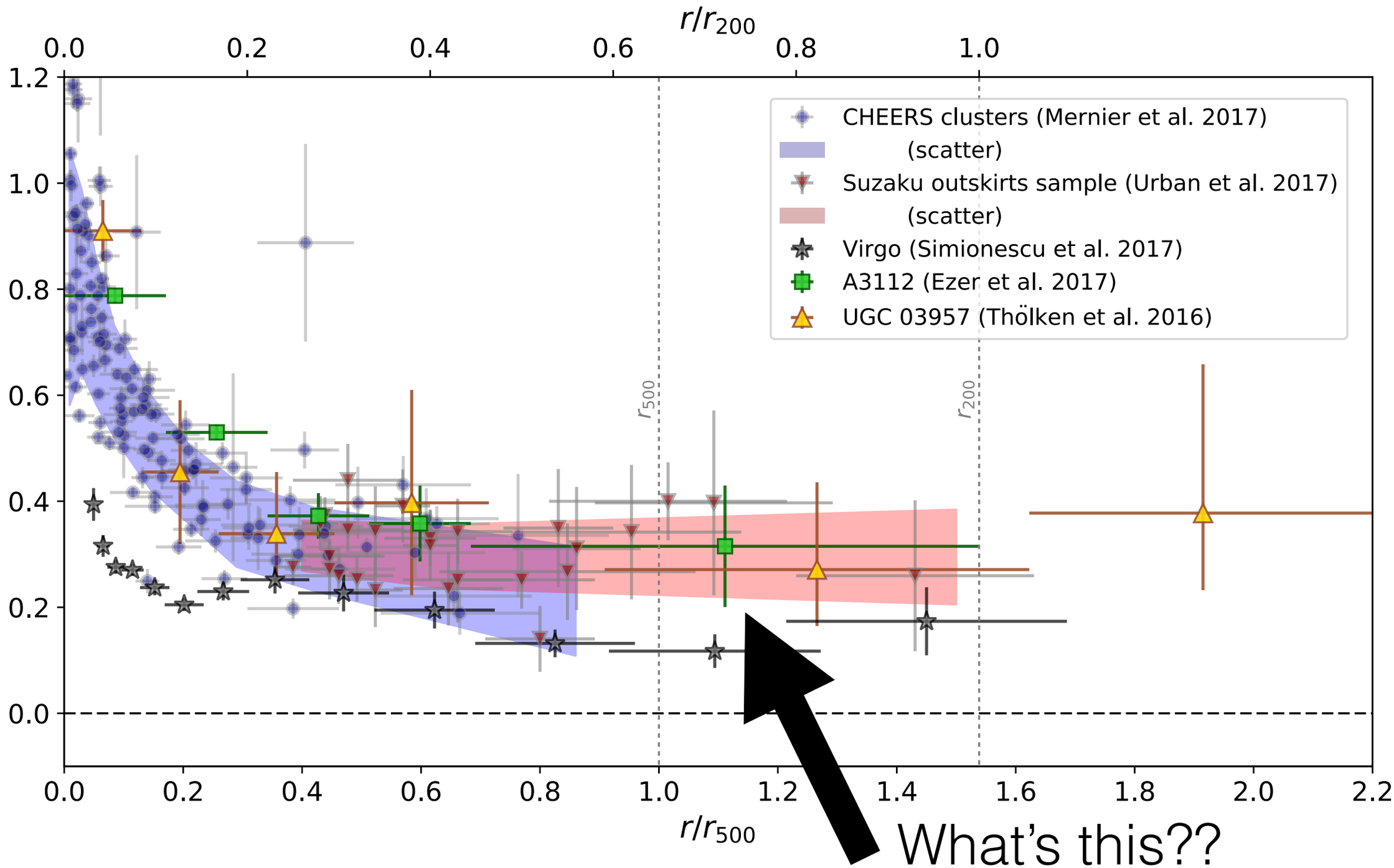




78 Fe abundance measurements across the cluster at different radii and azimuths show strikingly uniform distribution

Werner et al. 2013, Nature

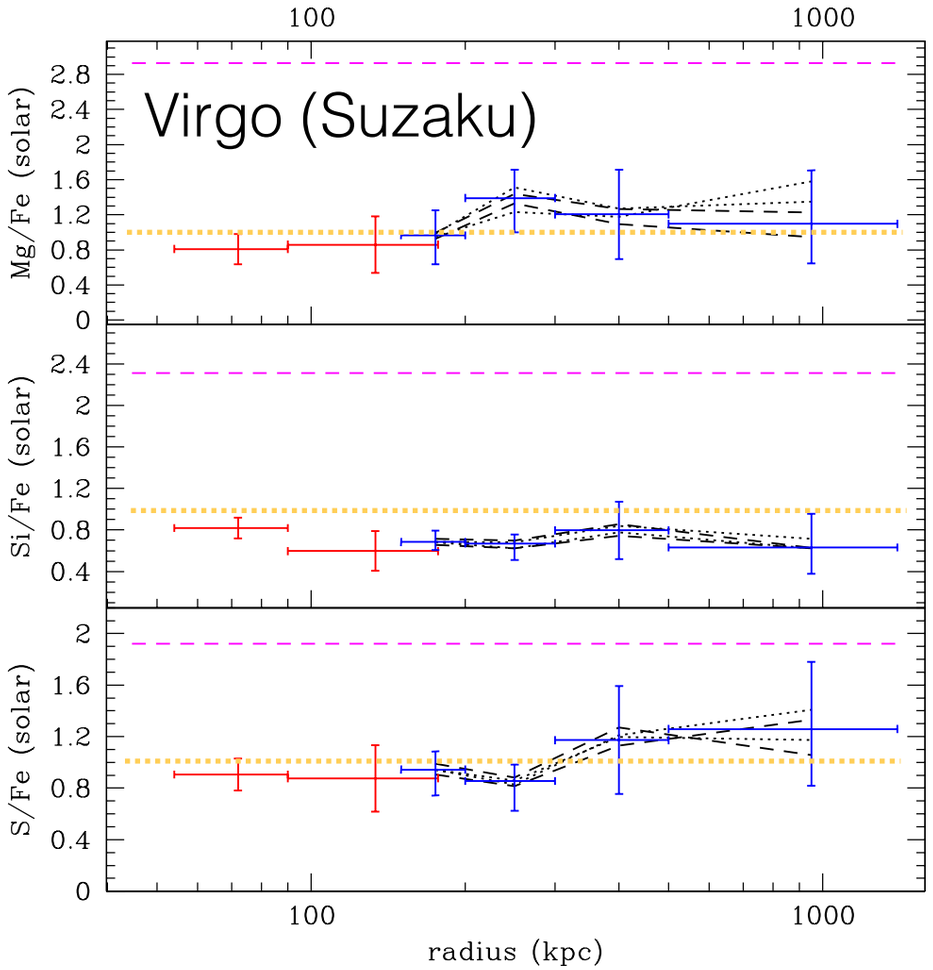
ISSI Review on Observations of ICM Enrichment, 2018

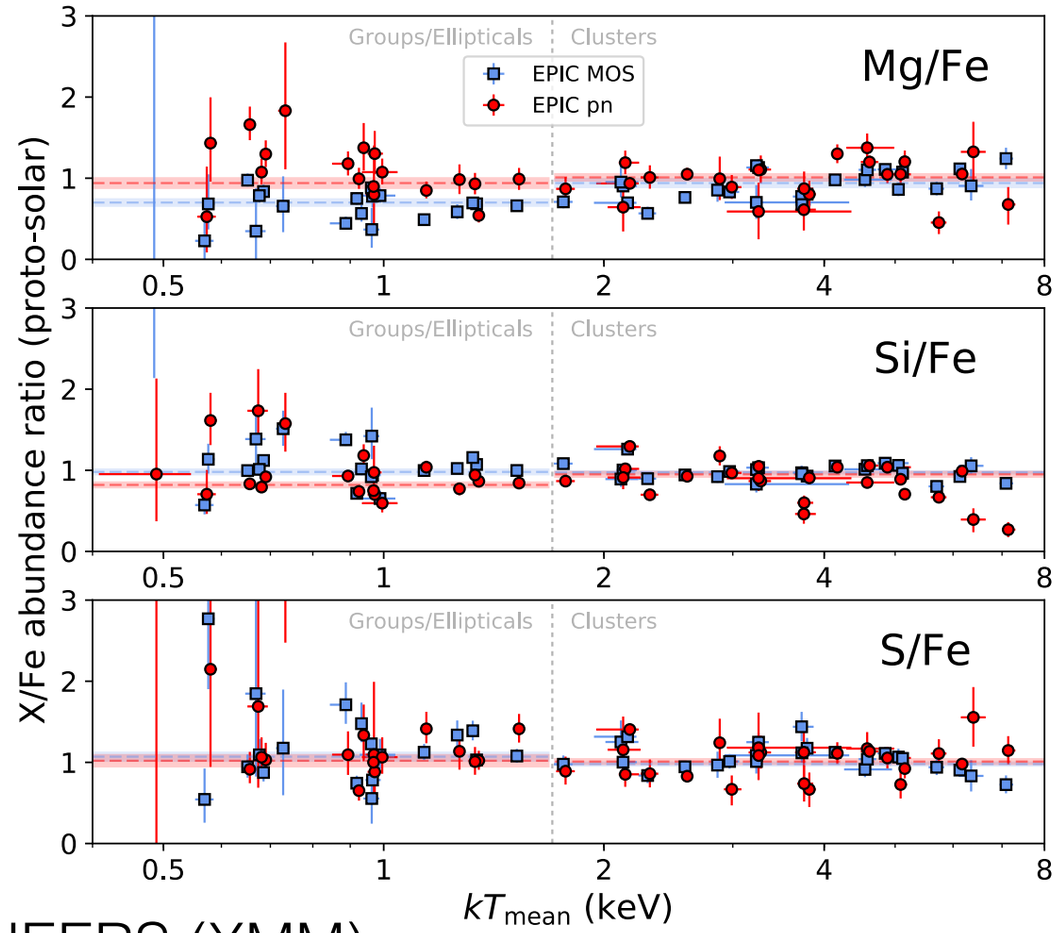


Are the outskirts of lower-mass clusters less enriched? Is it just a matter of multi-temperature / incompleteness of atomic line model??

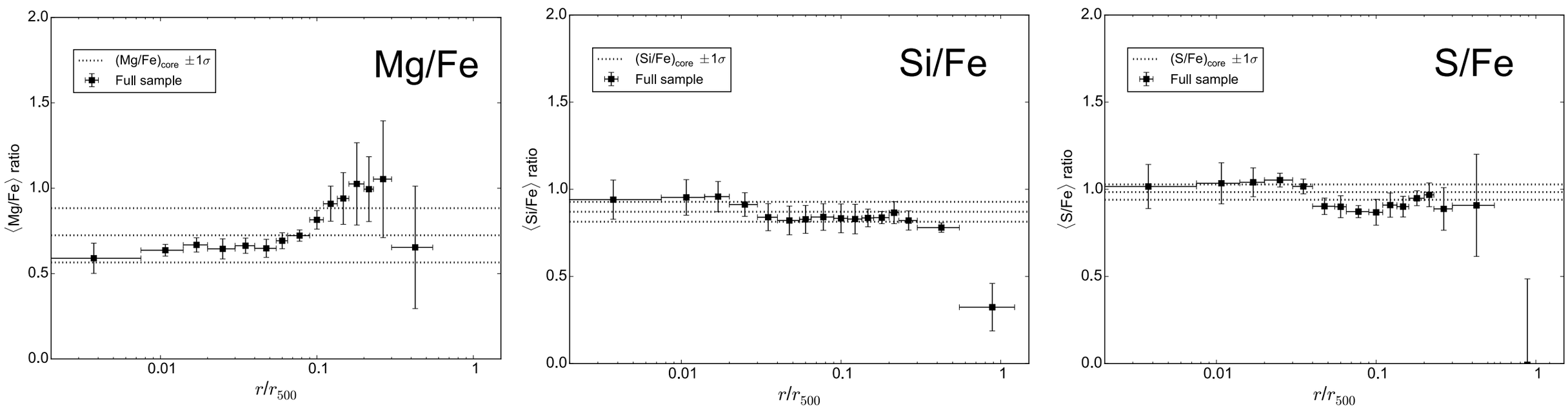
Is Virgo just weird?

alpha-element/Fe even more uniformly spread than Fe/H!





CHEERS (XMM)



Next 10 years: XRISM will let us do this with much better precision!

How were the metals spread so evenly?

- Alpha-elements produced 10-12 billion years ago during peak of star formation rate
- Uniform composition probably means most of Fe also produced around the *same time*
- Galactic winds at that epoch expelled metals out of host galaxies

Let's test this using all simulations we've got!
(Illustris, EAGLES,…)

Can we really assume that metals trace magnetic fields?

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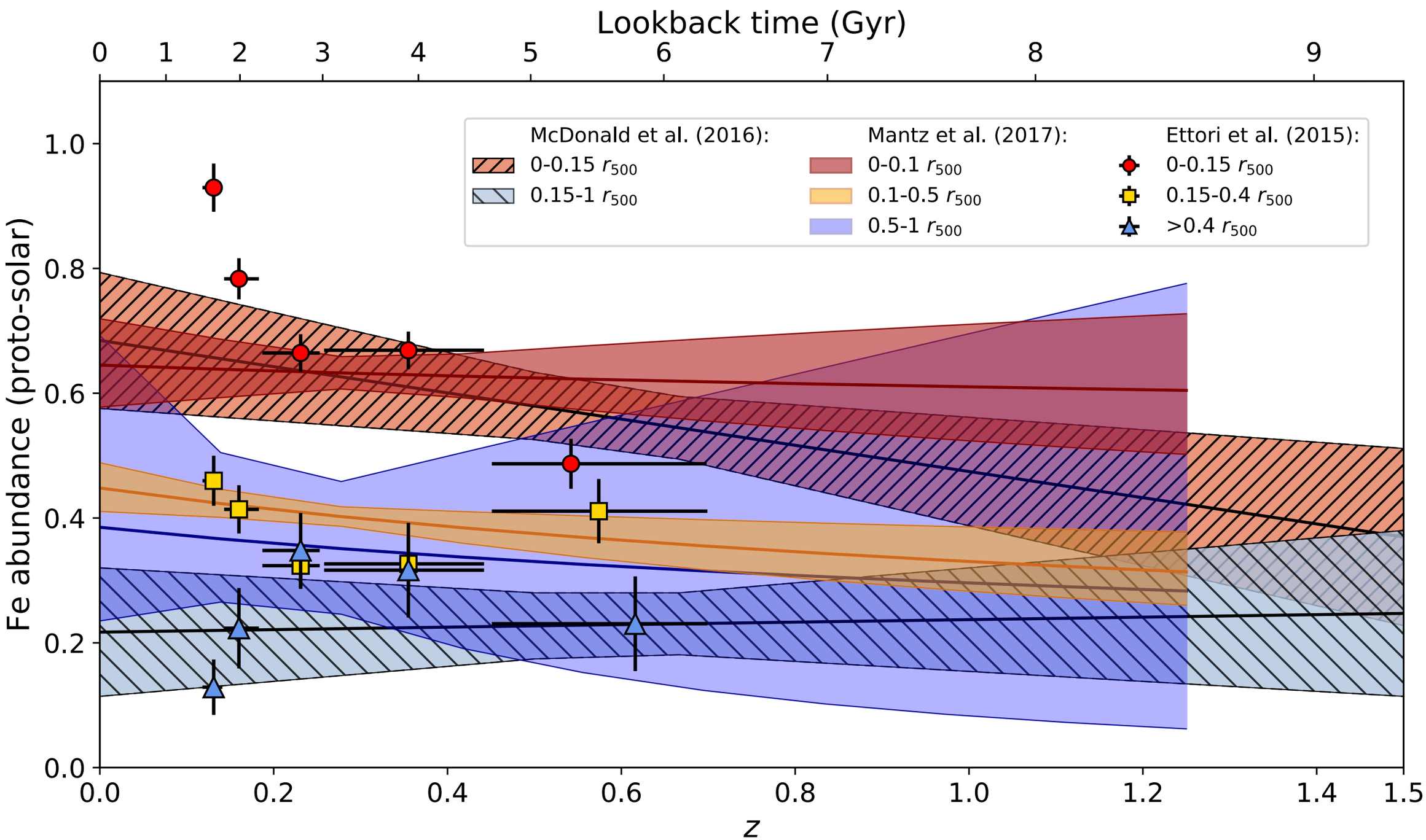

Athena/X-IFU is the future!

The SZ side

How do we control contamination in SZ observations?

What can we do with the degeneracy of the measured parameters?

How can we estimate realistic error bars?

The radio side

Should we go broad or should we go deep?

The X-ray side

What is the fairest comparison of different data sets we are combining (Suzaku, XMM, Planck)

How do clumps influence things other than density (kT, metallicity)

What is the connection between bridges and outskirts? Can we learn about one by studying the other?

The B-field side

What is the role of small scale dynamo amplification in bridges/filaments?

Can we measure B-strength in these regions?