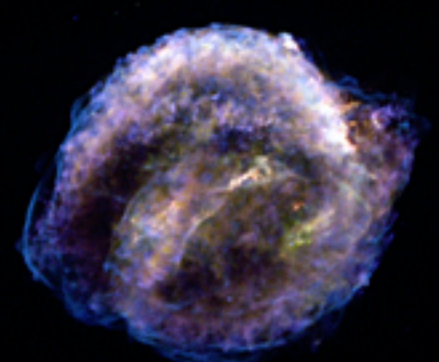
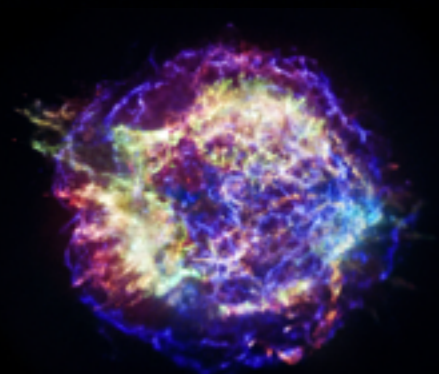
The metallicity of the intra-cluster medium as a tool for understanding its small-scale physics and the star formation history of the Universe





Aurora Simionescu
ISAS/JAXA

How many metals are there in the ICM?

How many type Ia and how many core-collapse supernovae are needed to supply these metals?

When did these supernovae explode?

How and when did the metals then get out of their host galaxies?

Ultimately, what physical processes govern the removal and mixing of the metals (galactic winds from SN/AGN, stripping, turbulence).

It has long been known that the ICM is metal rich

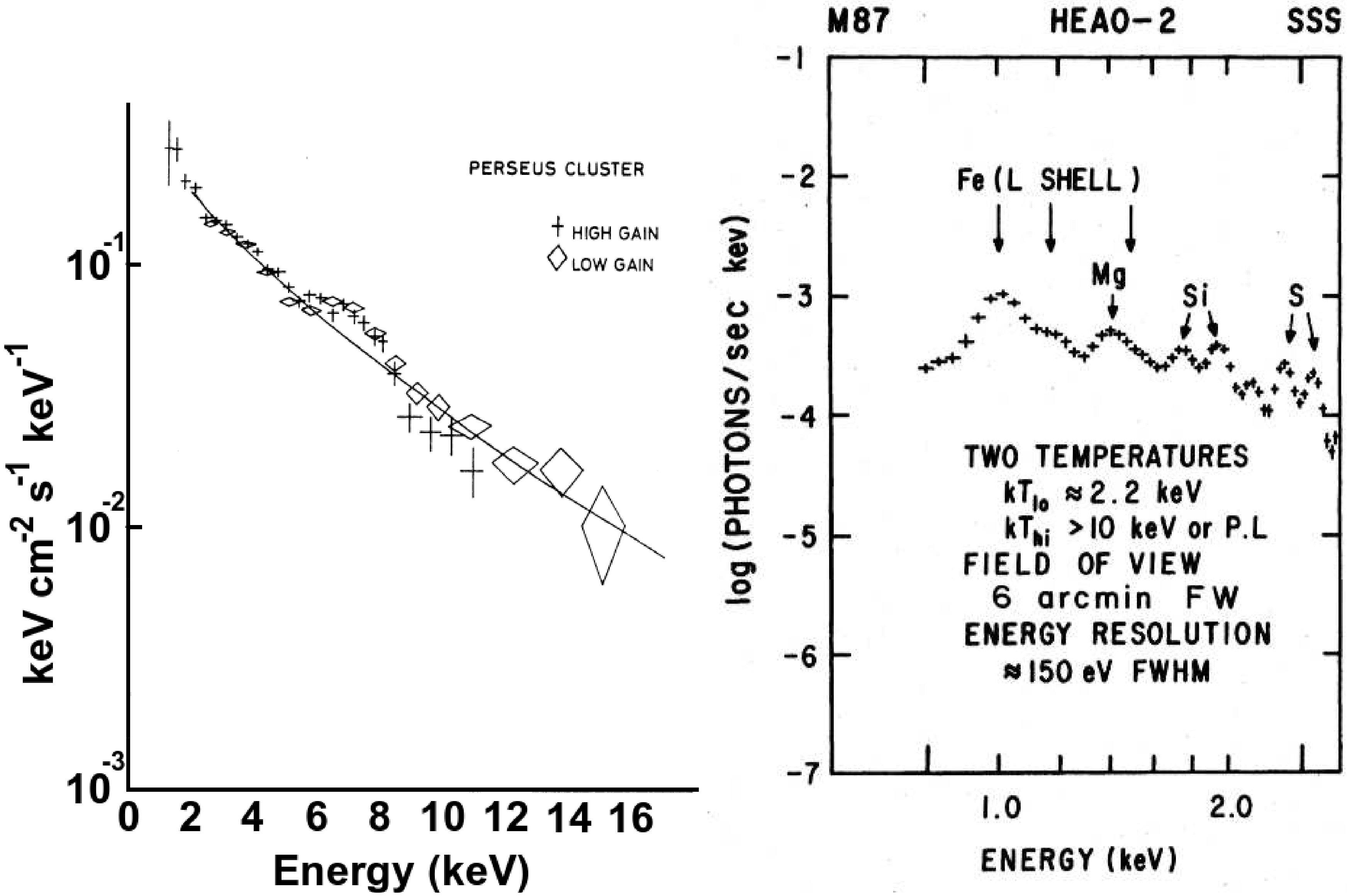
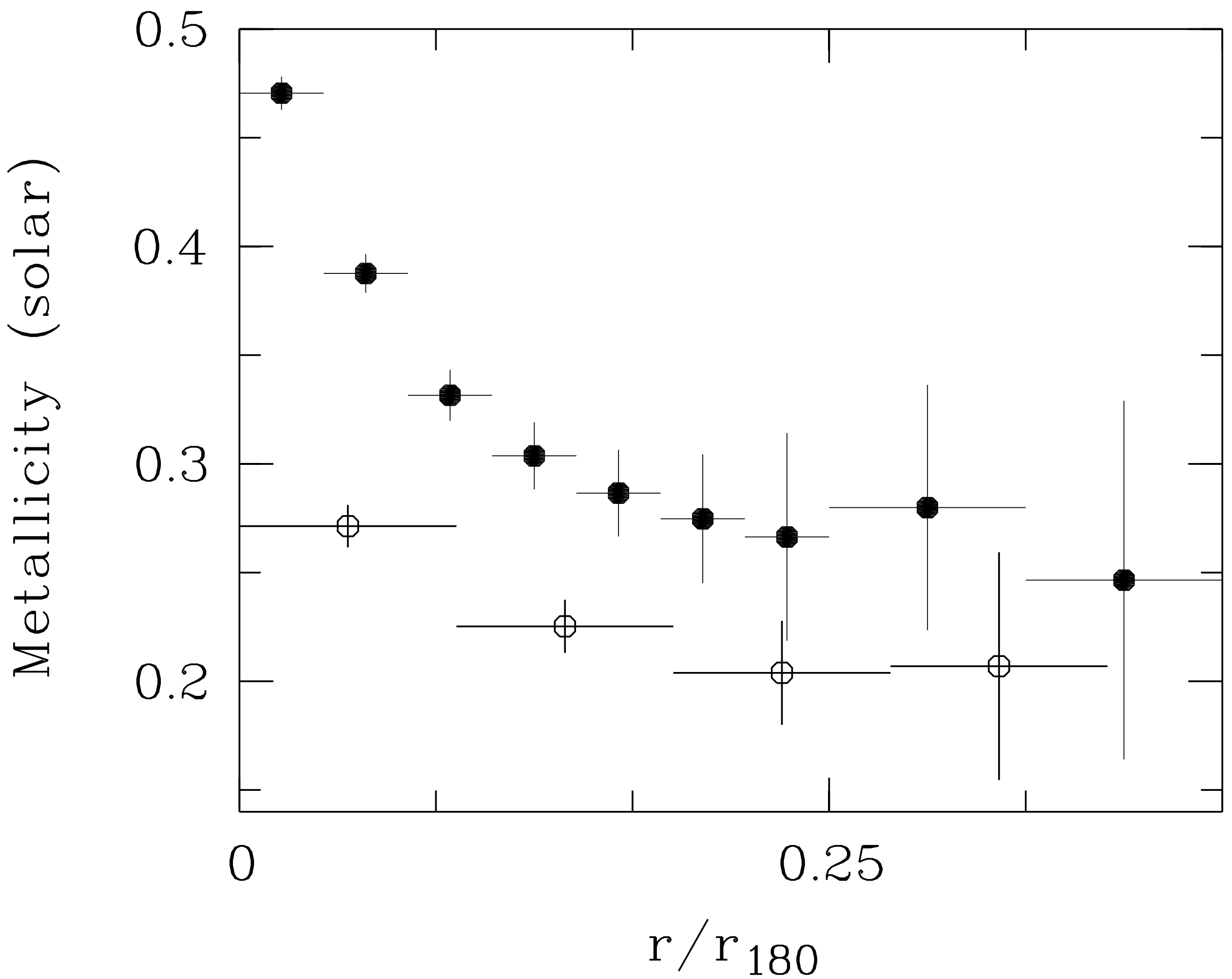


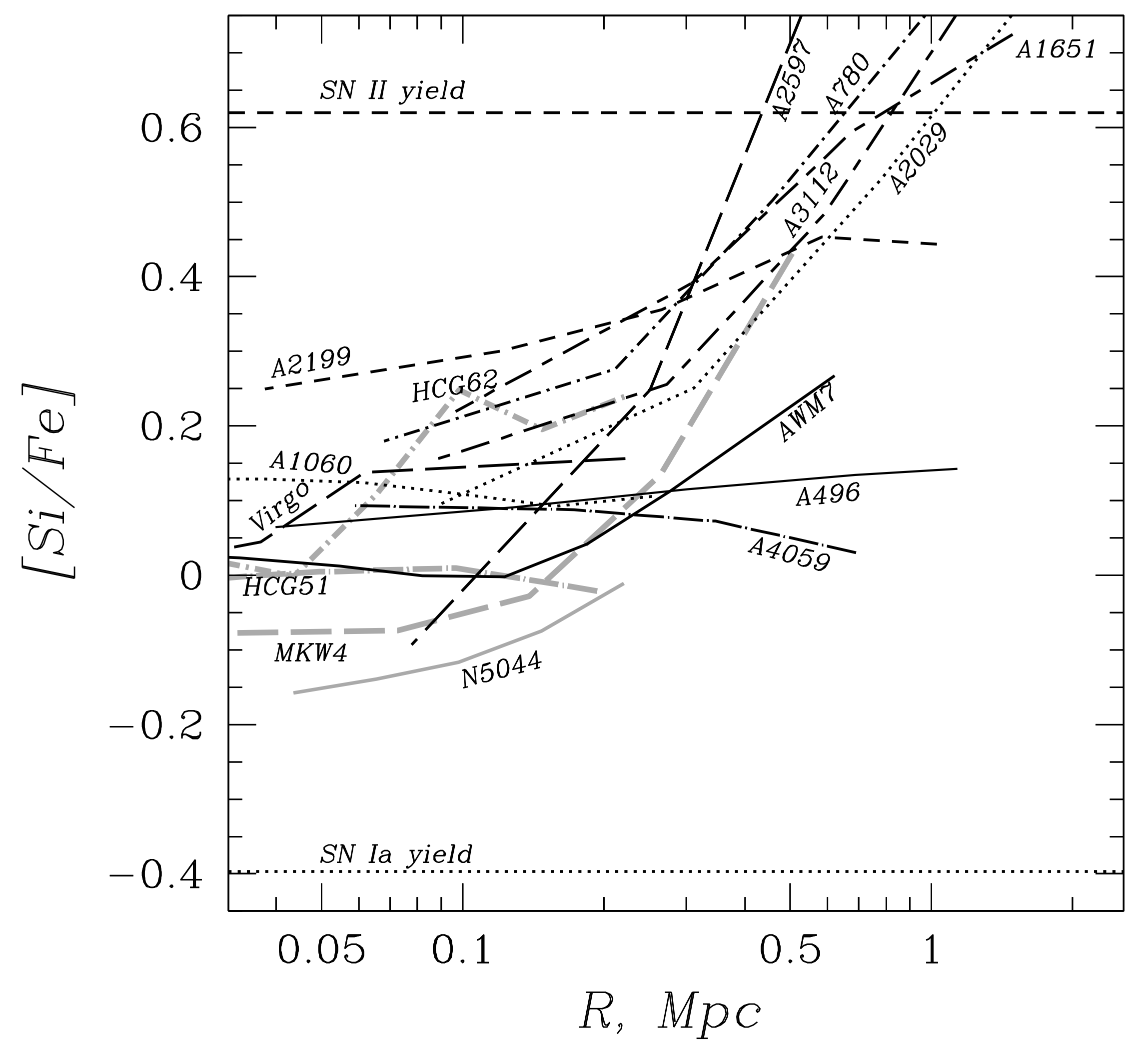
Fig. 3 *Left panel:* Spectrum of the Perseus cluster obtained by *Ariel 5*. The first cluster spectrum with observed Fe-K line emission (hump at ~7 keV). From Mitchell et al. (1976). *Right panel:* Line emission observed in M 87 with the *Einstein* satellite. From Sarazin (1988), based on the work published by Lea et al. (1982).

from Werner et al. 2008

Differences in metal abundance and chemical composition suggested by early studies



deGrandi&Molendi 2001 (BeppoSAX)



Finoguenov et al. 2000 (ASCA)

SNcc products (mainly lighter elements like O,Ne,Mg,Si,S) uniformly distributed;
the central galaxy adds mainly Fe from SNIa at late times.

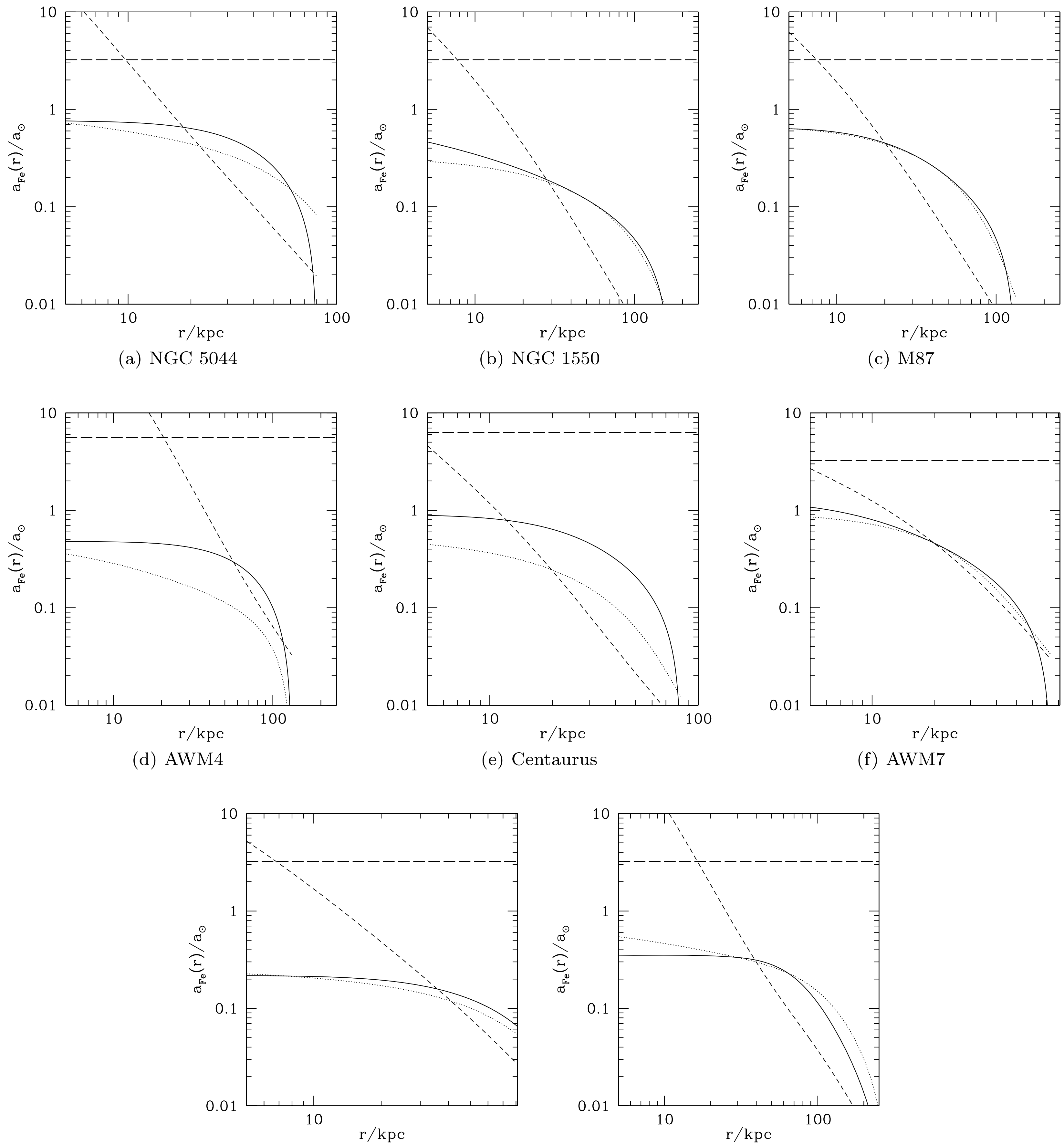
STELLAR LIGHT PROFILES MUCH MORE PEAKED THAN FE DISTRIBUTION

Missing physics ingredient #1:

the AGN in the central galaxy is spreading out the metals?

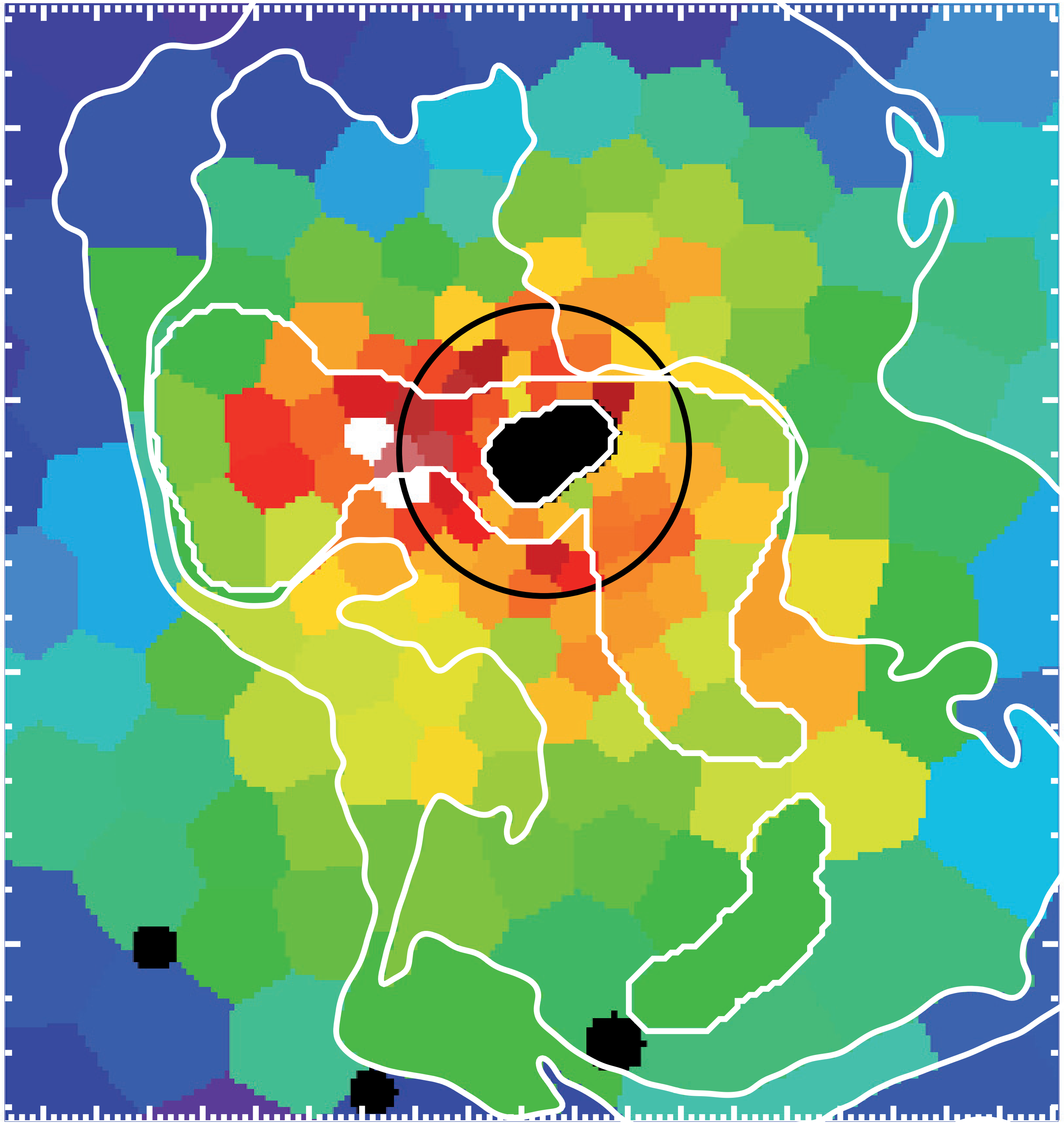
Metal distribution allows to infer the diffusion coefficient!

Rebusco et al. 2006



(a) NGC 5044
(b) NGC 1550
(c) M87
(d) AWM4
(e) Centaurus
(f) AWM7
(g) A1795
(h) Perseus

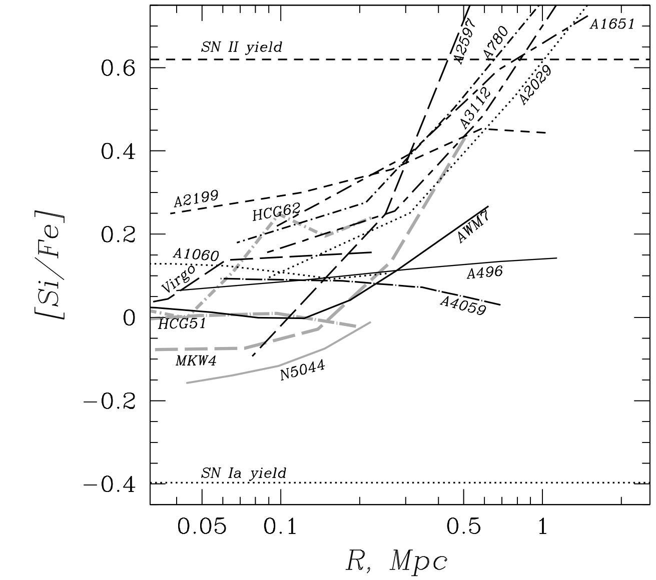
Observations of Metal Transport by AGN

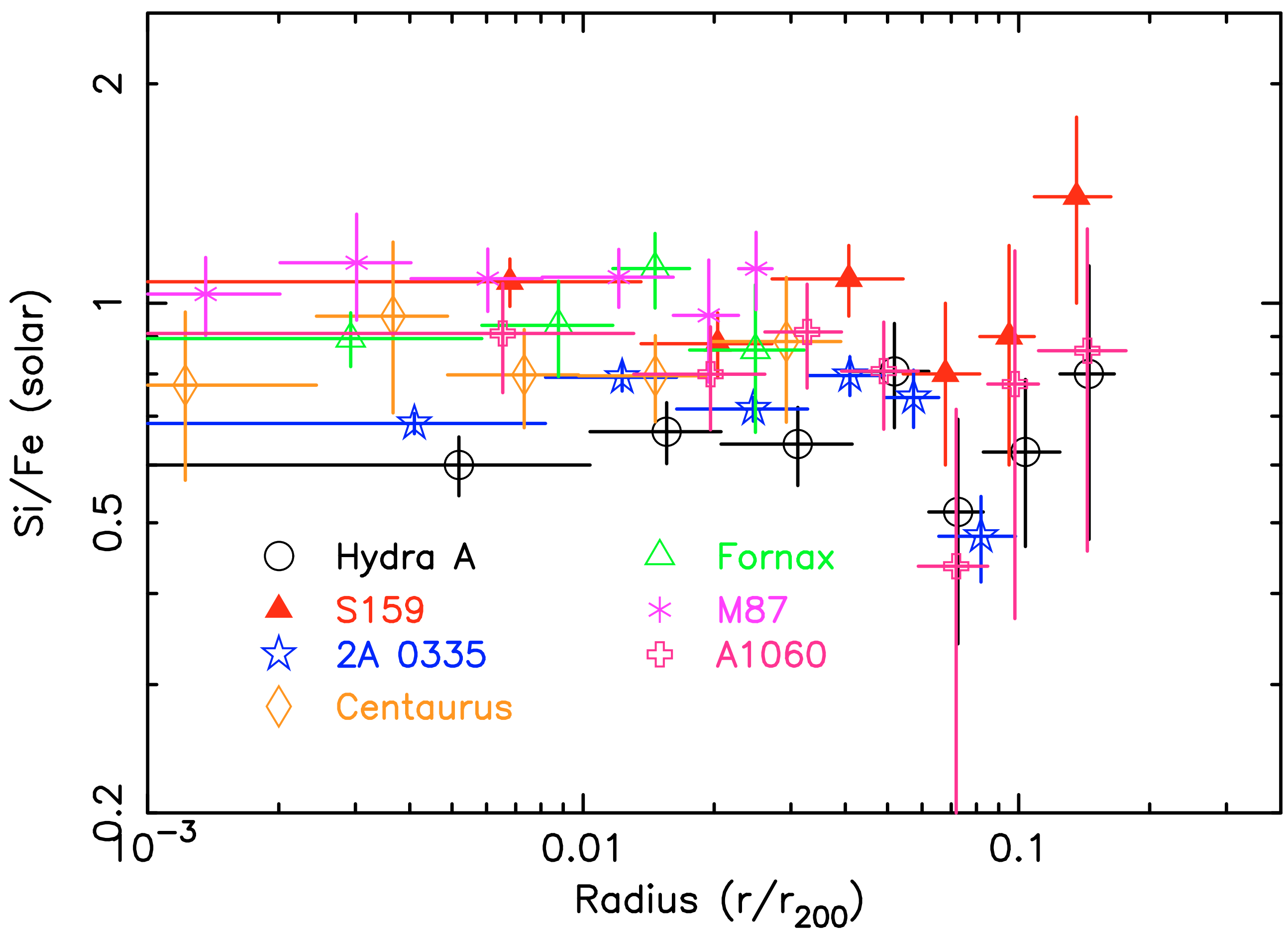


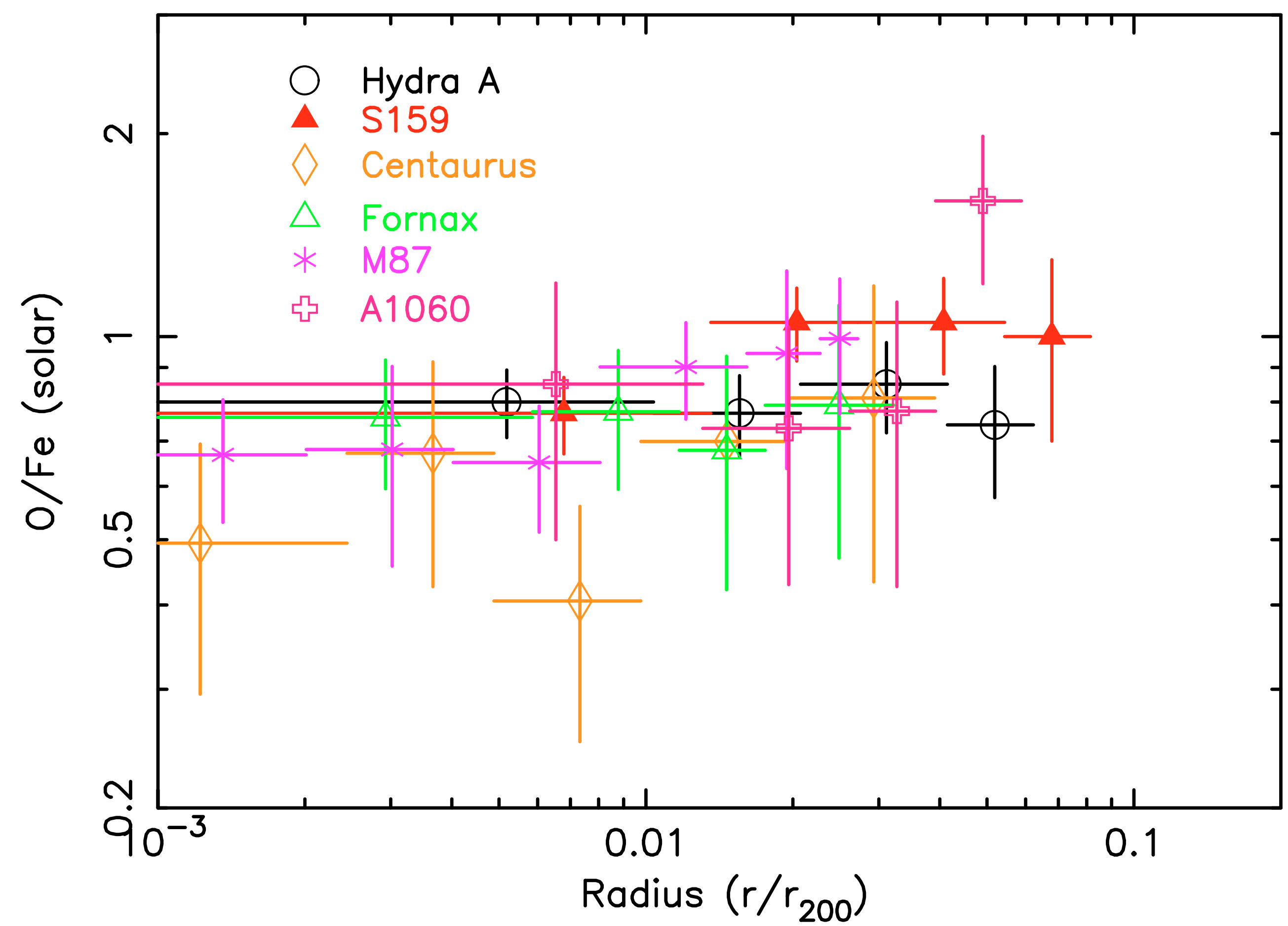
M87 Fe map (Simionescu et al. 2008)

Higher Fe abundance along the directions corresponding to radio lobes: the AGN is spreading out the metals!

Metal Abundance Ratios in Cluster Cores - More recent measurements with XMM-Newton and Suzaku



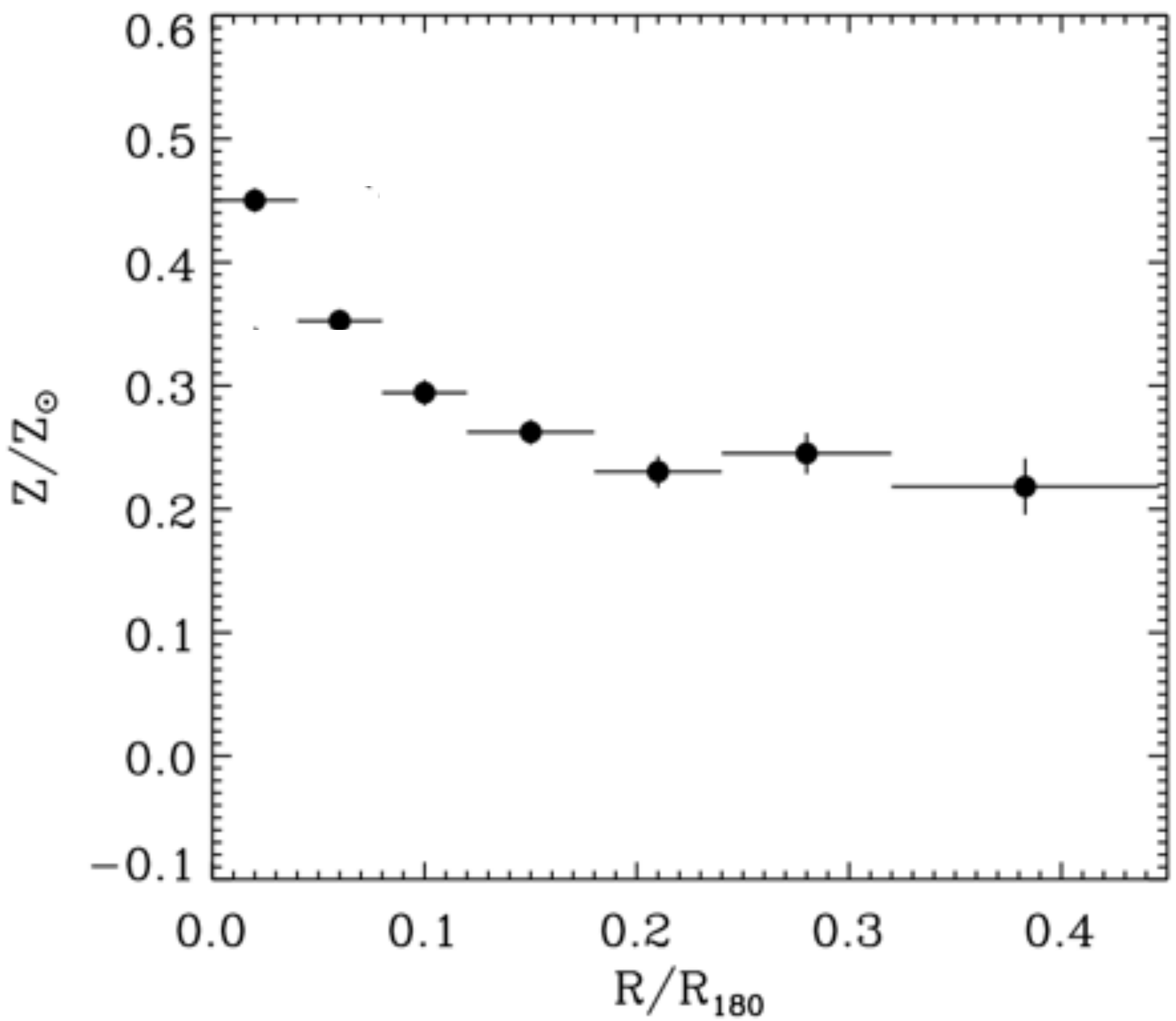




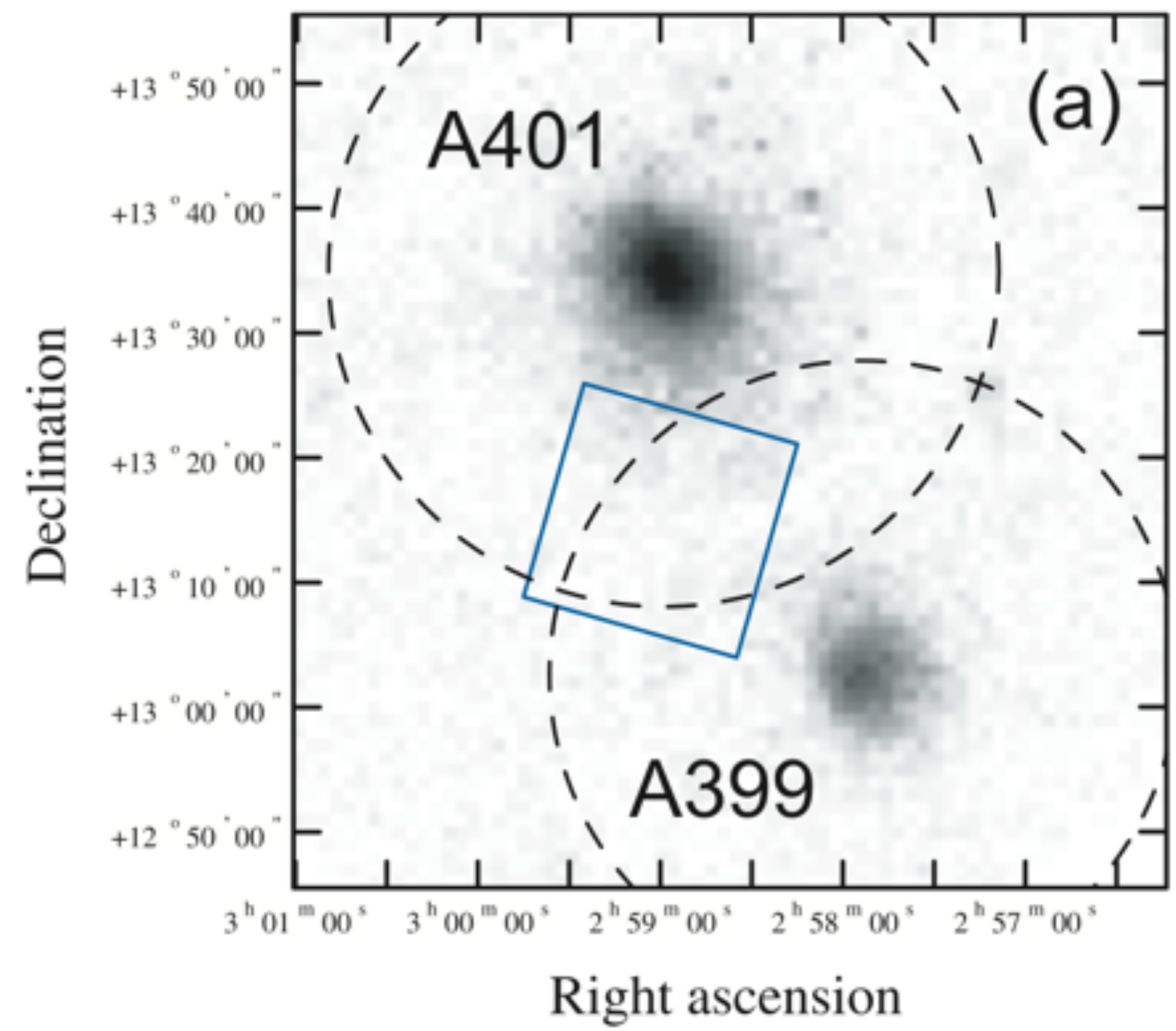
Simionescu et al. 2009

Si/Fe profiles constant with radius; very marginal evidence for increasing O/Fe with radius. Chemical composition (ratio of SNIa to SNcc that contributed to enrichment) seems constant.

Evidence Suggesting Metal Enrichment in Cluster Outskirts



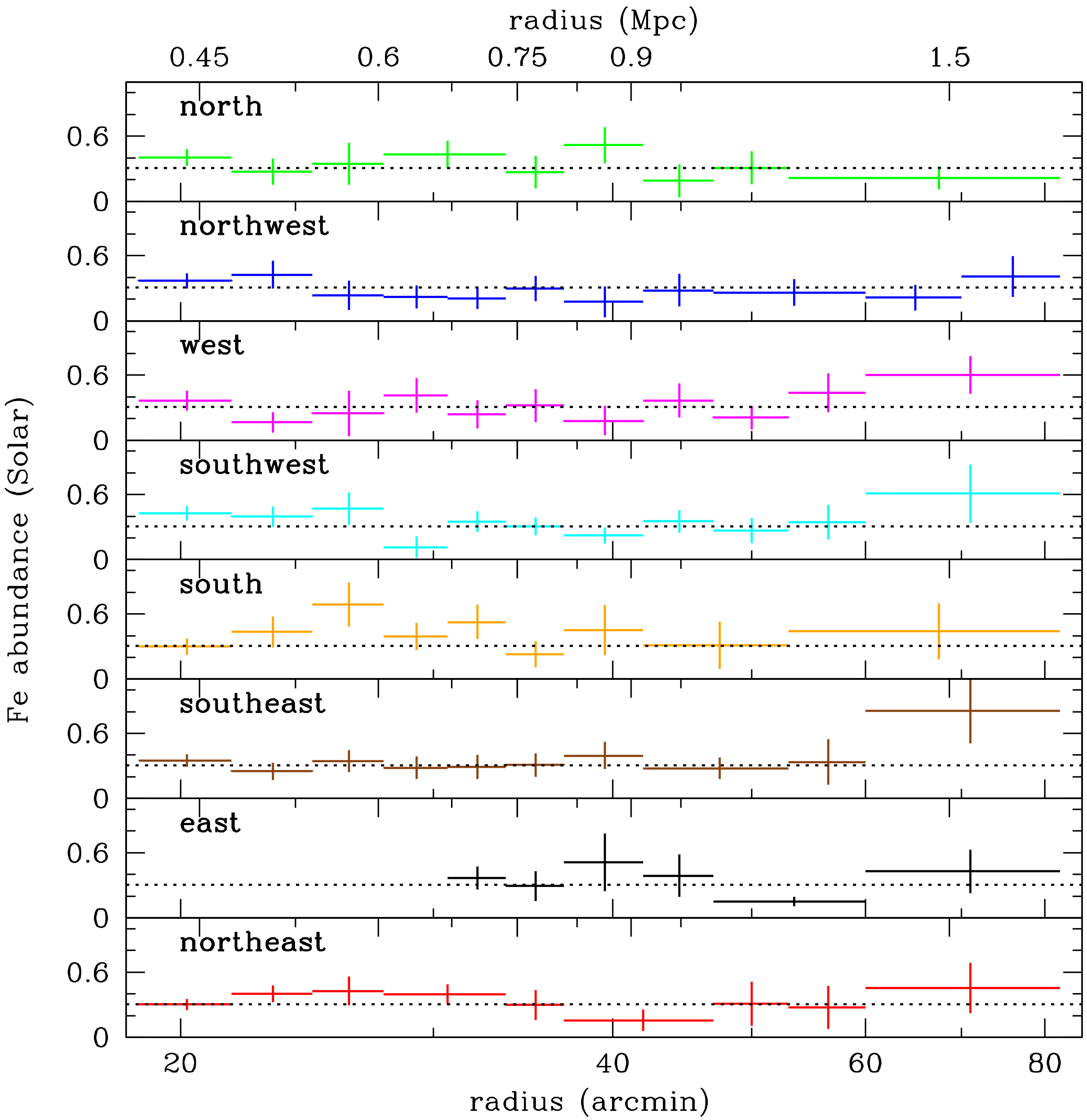
Leccardi et al. 2008
average metallicity profile of a sample of clusters with XMM

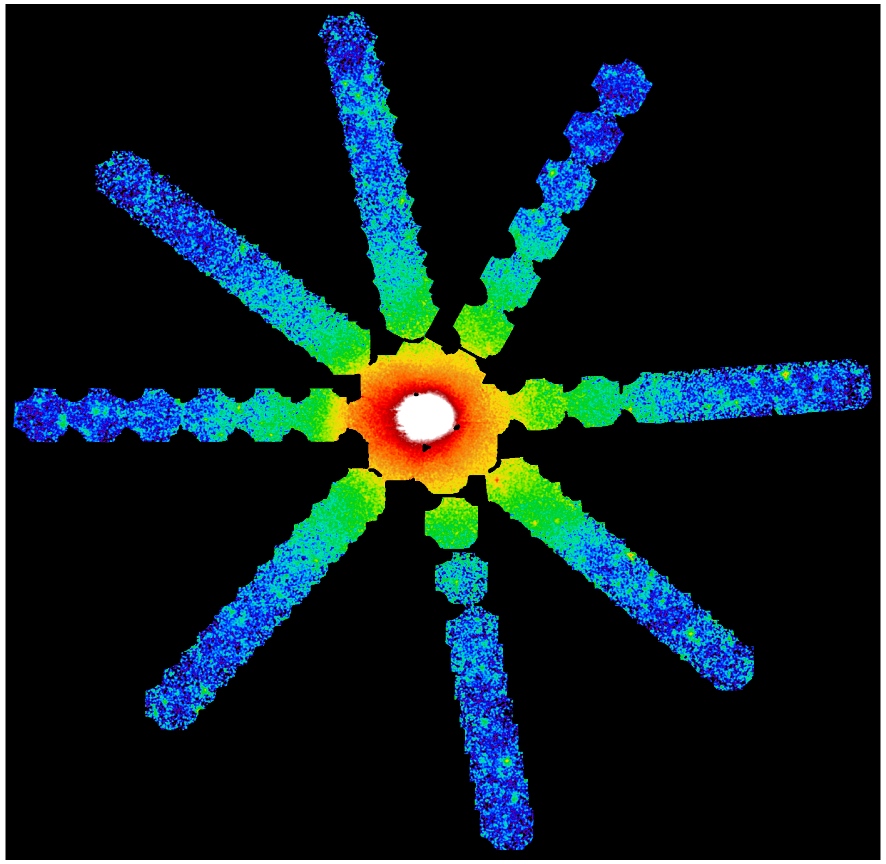


Fujita et al. 2008
abundance in the compressed region between two merging clusters with Suzaku

Abundances difficult to measure; usually solar ratios assumed between different elements by necessity

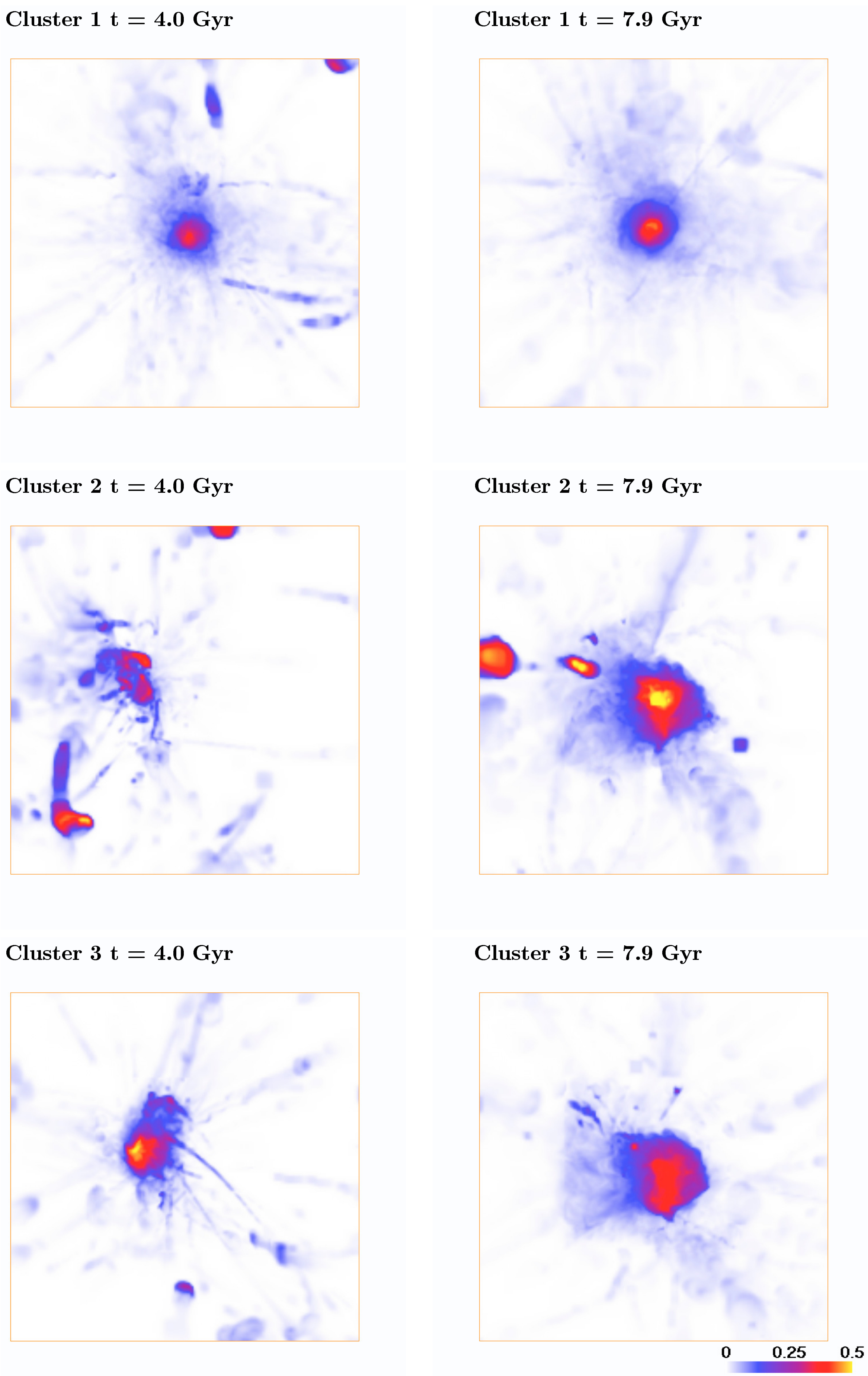
Iron spread smoothly throughout the Perseus cluster





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

Werner et al. 2013, *Nature*



Domainko et al. 2006

Ram-pressure stripping of member galaxies should produce a central peak and a patchy metallicity distribution. It should be hard to mix metals radially once the steep entropy gradient is in place.

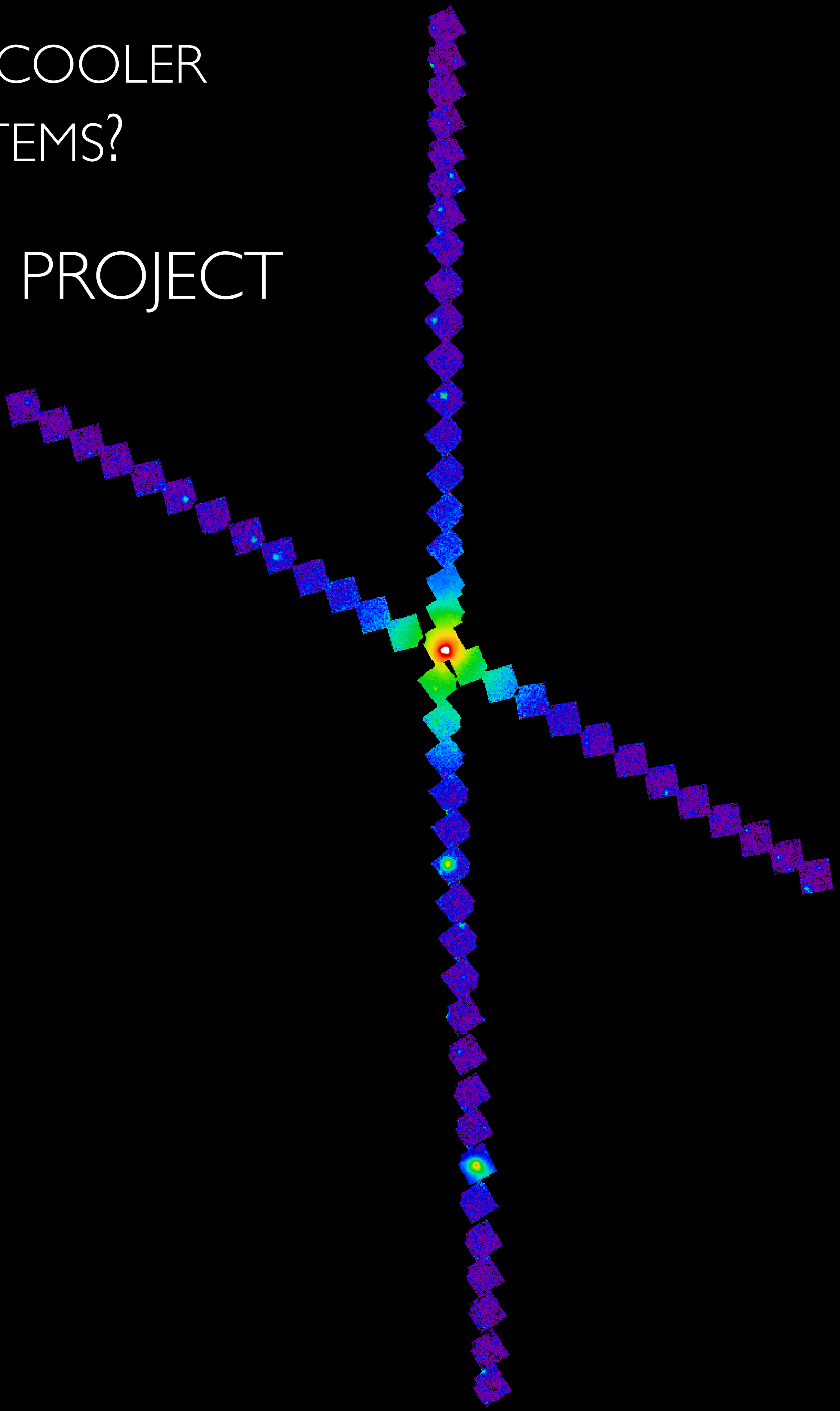
The uniform iron distribution suggests that, instead, galactic winds at z~2 were mainly responsible for getting the metals out of the galaxies and into the IGM/ICM — *most metals must have been produced more than 10 Gyr ago*!

Missing physics ingredient #2:

HOW RELIABLE ARE THESE PREDICTIONS FROM A DECADE AGO? CAN THE MIXING OF RAM-PRESSURE STRIPPED METALS BE MUCH MORE EFFICIENT THAN SUGGESTED IN THIS PLOT?

What about metals in cooler (more line rich!) systems?

The Virgo Cluster Key Project



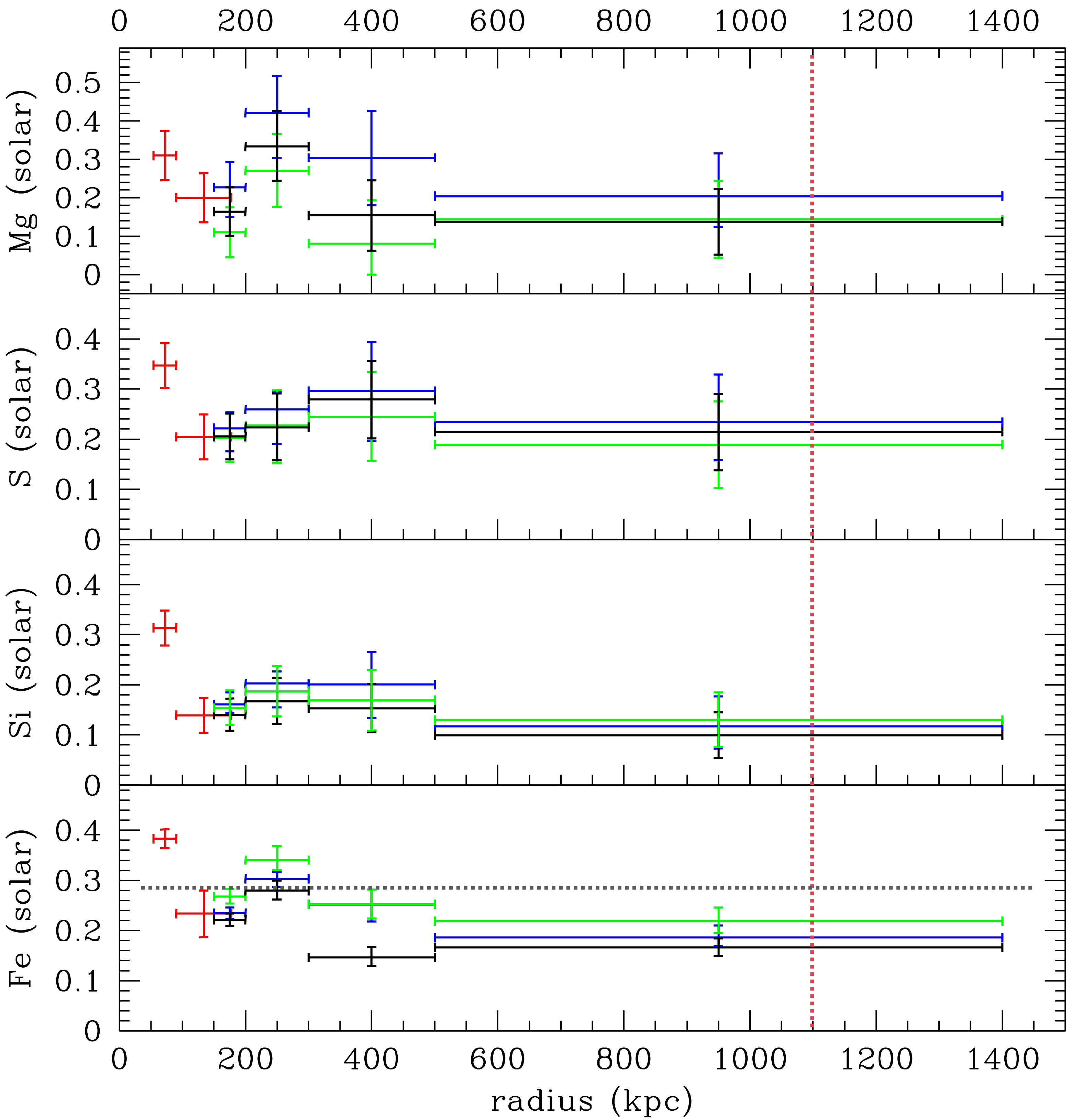
60 Suzaku pointings

4 different directions

over 1Ms total exposure

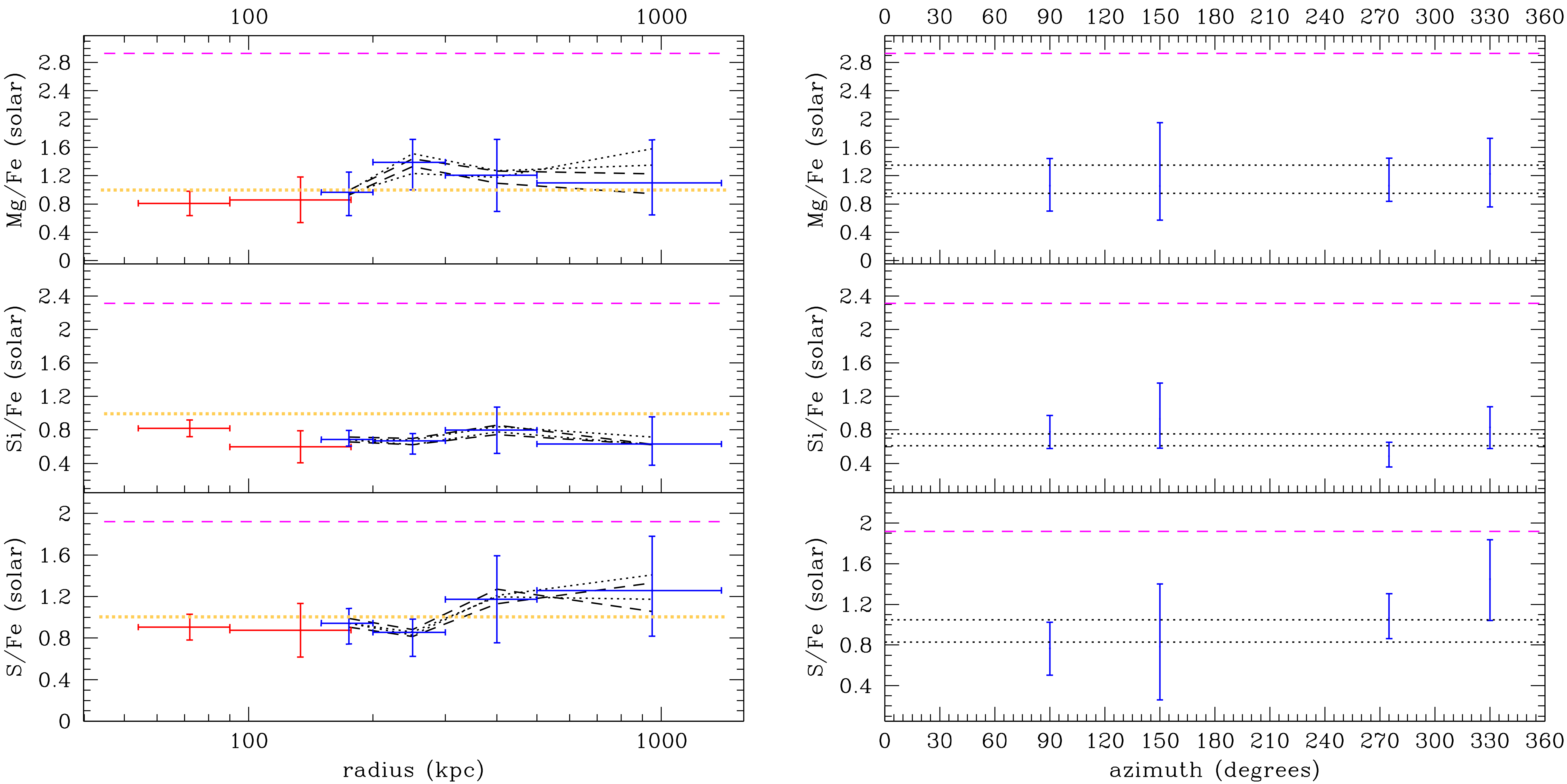
AO 7-8

Virgo Cluster KP: First Detection of SNcc metals beyond 1/2 r200

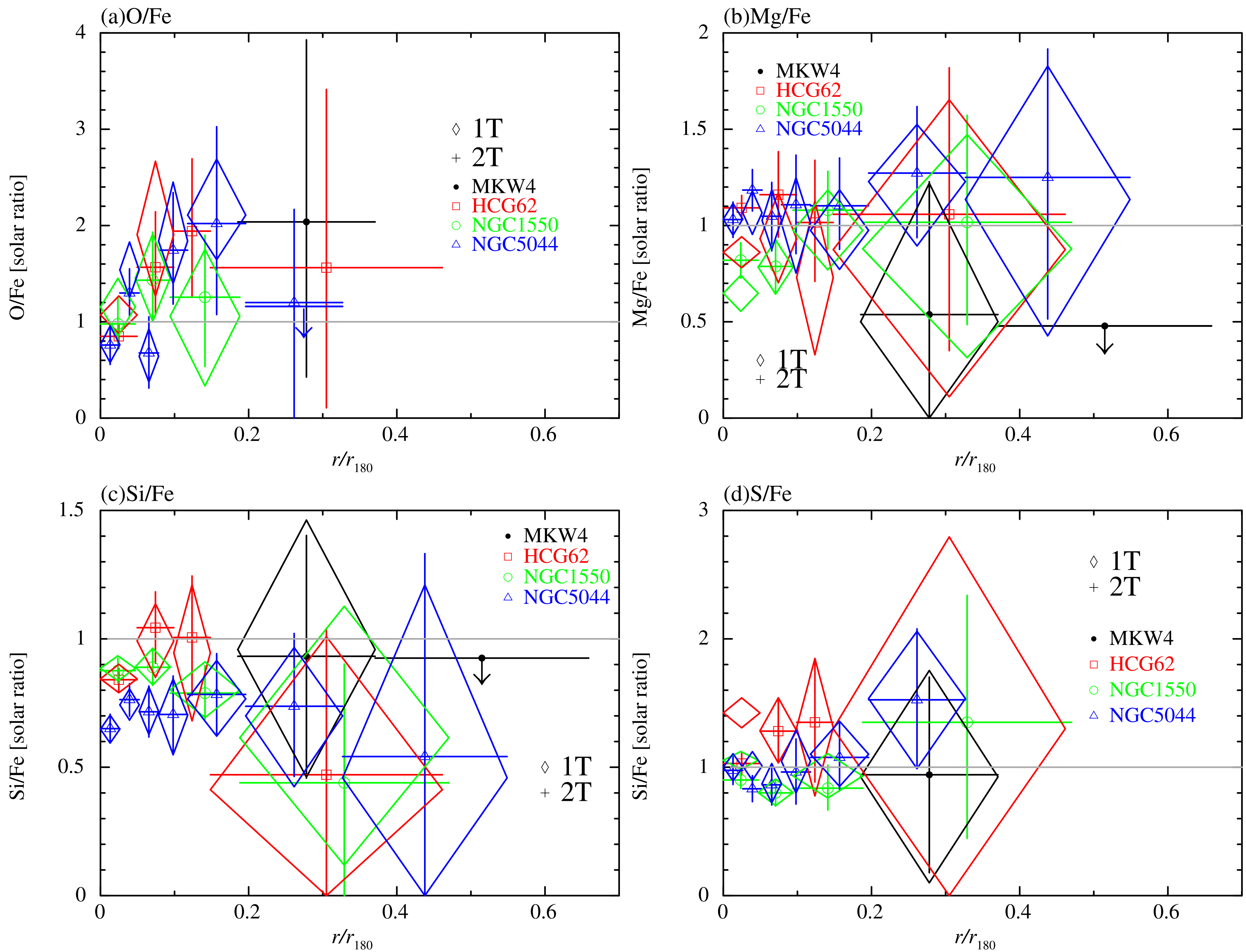


Black: vapec 1T
Blue: vapec 2T (kTcool=0.6 keV)
Green: spex 2T
Red: archival Suzaku (Simionescu et al. 2010)

Virgo Cluster KP: Mg/Fe, Si/Fe, S/Fe Profiles



Nearly constant Mg/Fe, Si/Fe and S/Fe as a function of radius and azimuth: composition of the ICM is uniform from the cluster centres all the way to the virial radius. Metals must have been thoroughly mixed. Cluster outskirts chemical composition not dominated by SNcc products as previously believed.



Nearly constant chemical composition of the ICM in galaxy groups.

Sasaki+2014

Summary

The ICM is metal-rich, from the cluster centres all the way to the virial radius.

The chemical *composition* of the ICM stays roughly constant throughout the entire cluster volume. The metals are (surprisingly?) well mixed! Lots of Fe must have been produced at the same time as Mg,Si,S (early!).

AGN (and SN winds) likely helped to get the metals out of the galaxies at early times; at present the AGN are stirring and spreading the metals produced by the BCG in the cluster cores.

Open issues

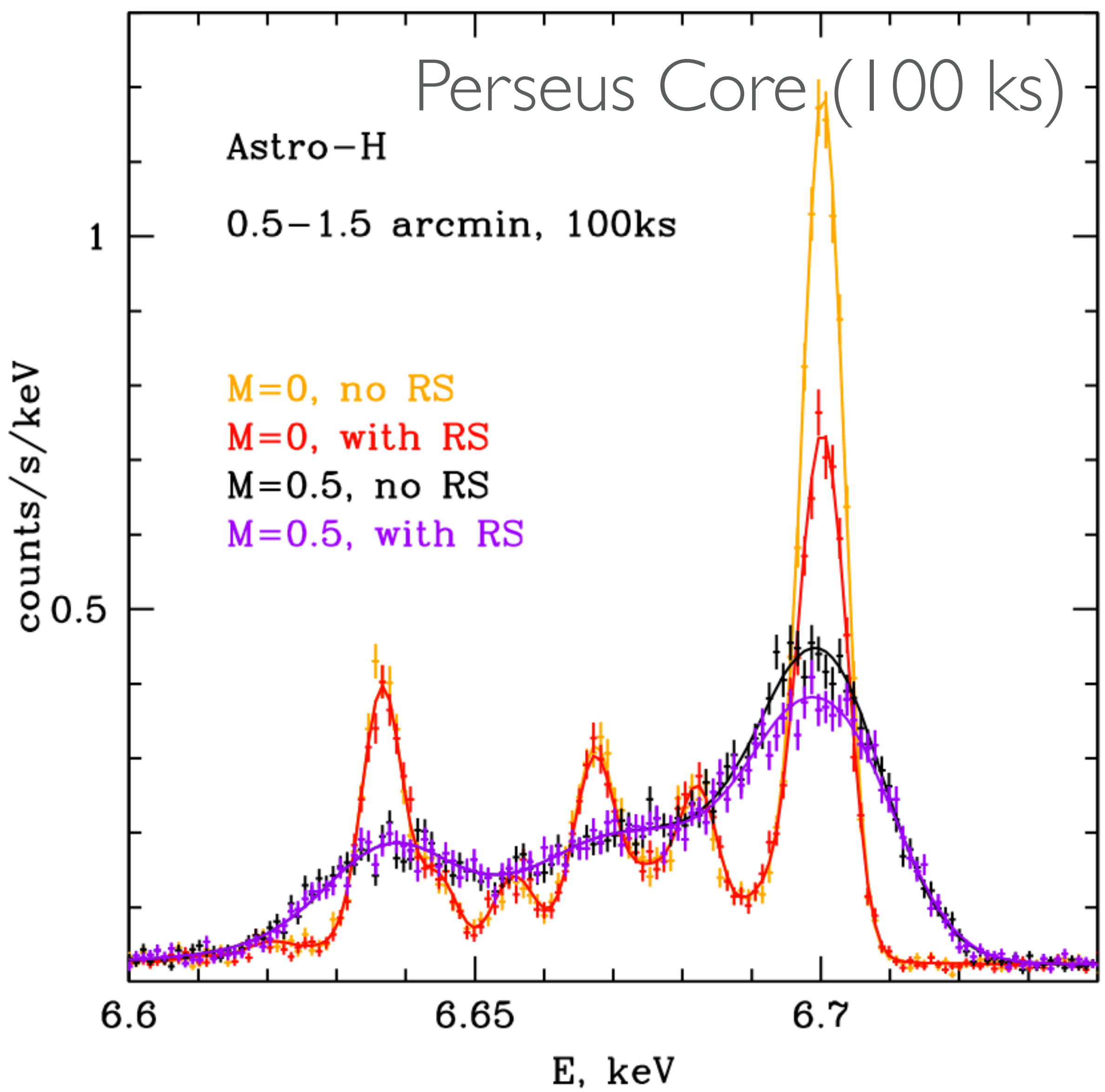
Do we understand why the mixing of metals is so thorough? Is it because they were produced early on and expelled from their host galaxies by powerful galactic winds? Or can strong turbulence in the ICM explain this?

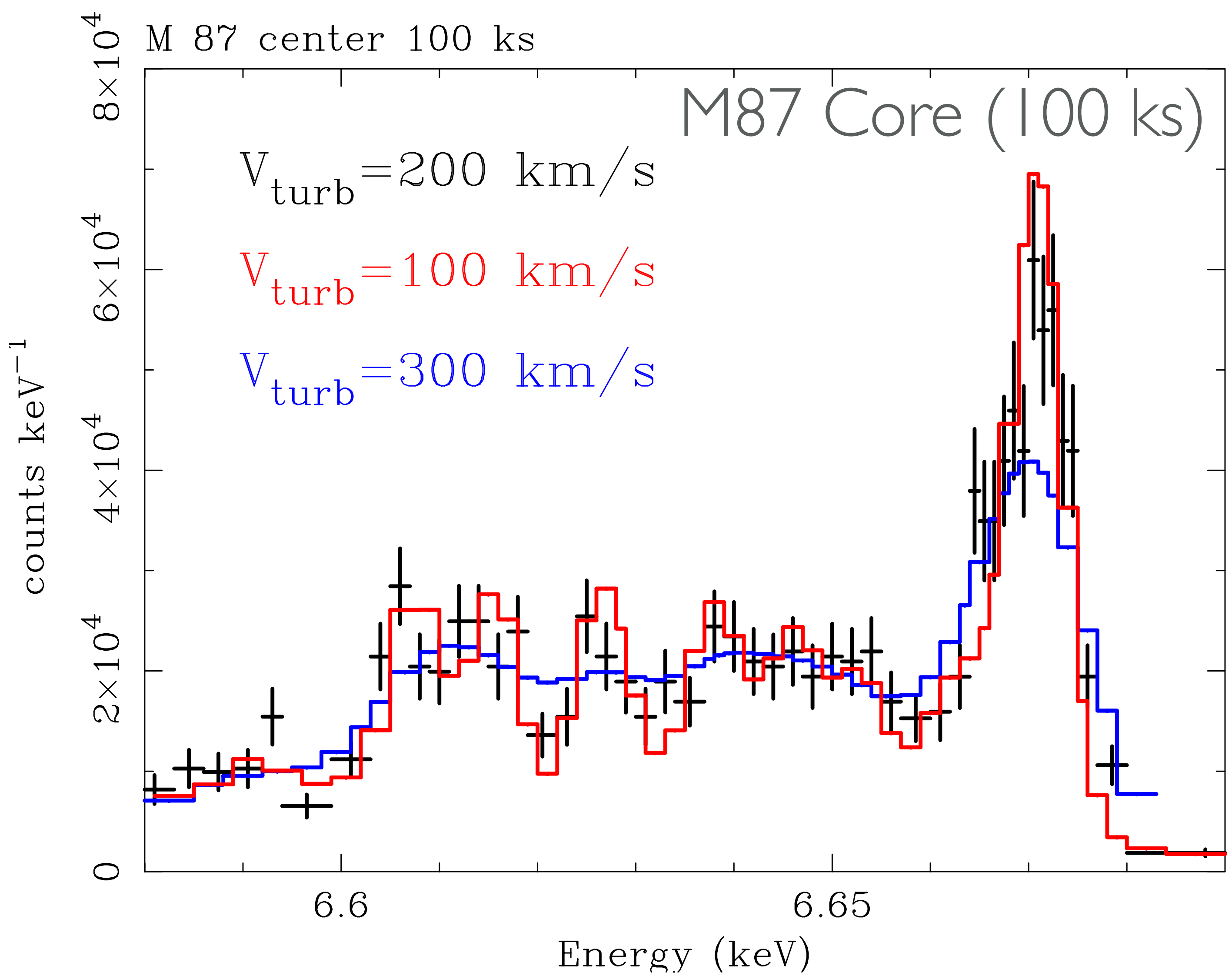
Do we understand how galactic winds are driven and how the AGN help distribute the metals both at high redshift and today? What can we learn about the underlying ICM physics by looking at the mechanics of metal redistribution by AGN?

What will Astro-H bring?

The Fe-K line complex with Astro-H

Kitayama et al. 2014





Estimate turbulence from *both* line broadening *and* resonant scattering (the latter less prone to projection of bulk flows along line of sight contributing to line broadening.)

—> Study the turbulence due to AGN feedback that is presumably responsible for broadening the metal peak compared to the light distribution of the BCG

Future: summary

The improved spectral resolution of Astro-H will allow us to study the dynamics of the ICM from line shifts and widths, and measure the chemical abundance ratios with much better precision → study turbulence, viscosity, kinetic energy due to gas motions, and constrain SN yield models

Lots of new input to constrain numerical models!

This will be a crucial stepping stone for future satellites like DIOS, ATHENA