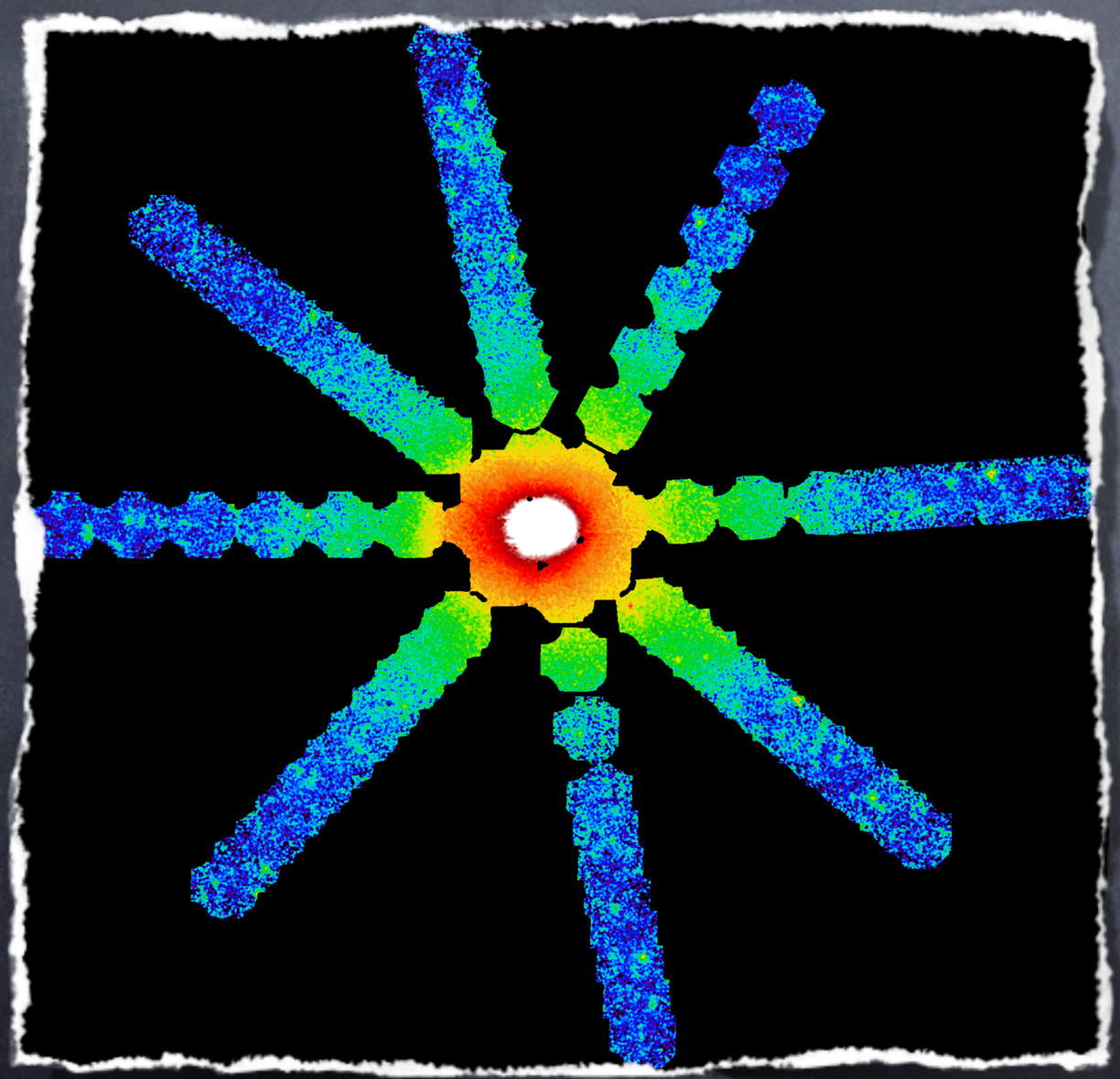
Plasma physics in the intracluster medium from the smallest to the largest scales



Aurora Simionescu

Einstein Fellow

KIPAC/Stanford

Outline

- AGN - ICM interaction
- cold-fronts (and shocks)
- what are the thermodynamic properties at the virial radius?

Disclaimer: this is an overview, not a review talk

MS0735.6+7421

Hydra A

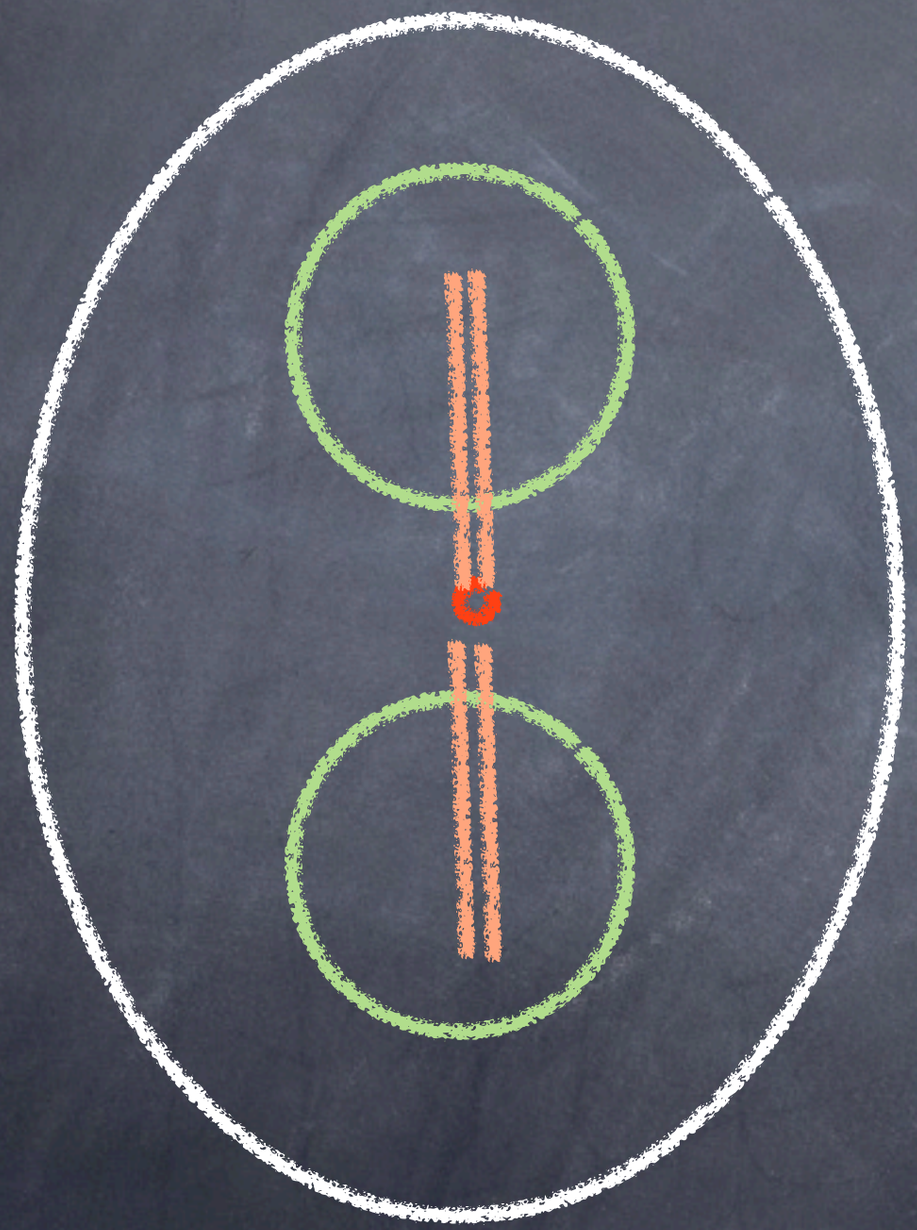
M87 / Virgo

CHANDRA X-RAY

VLA RADIO

NGC1275 / Perseus

AGN feedback

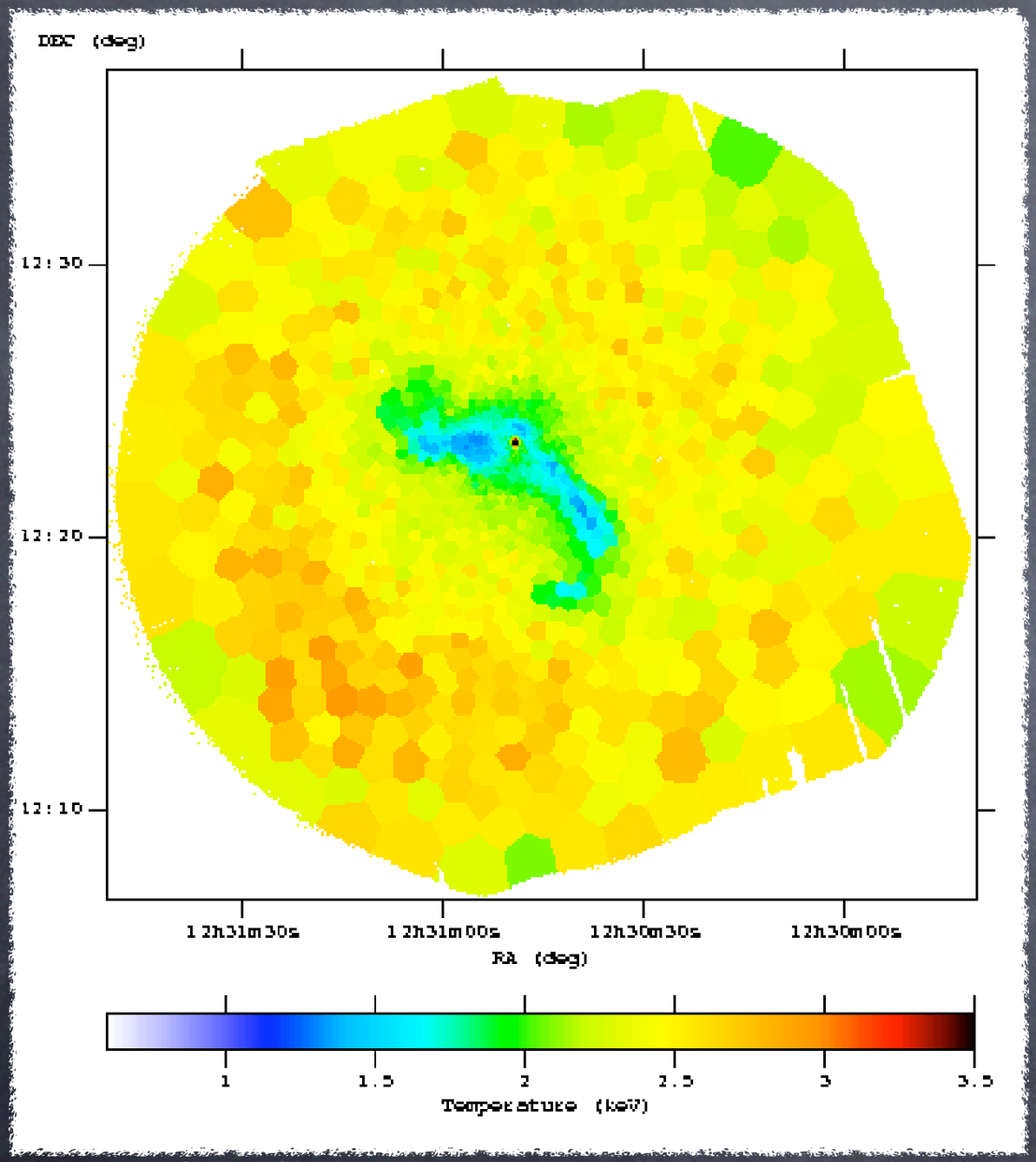


filaments: X-ray bright;
low temperature;
metal rich

shocks: high
temperature;
high pressure

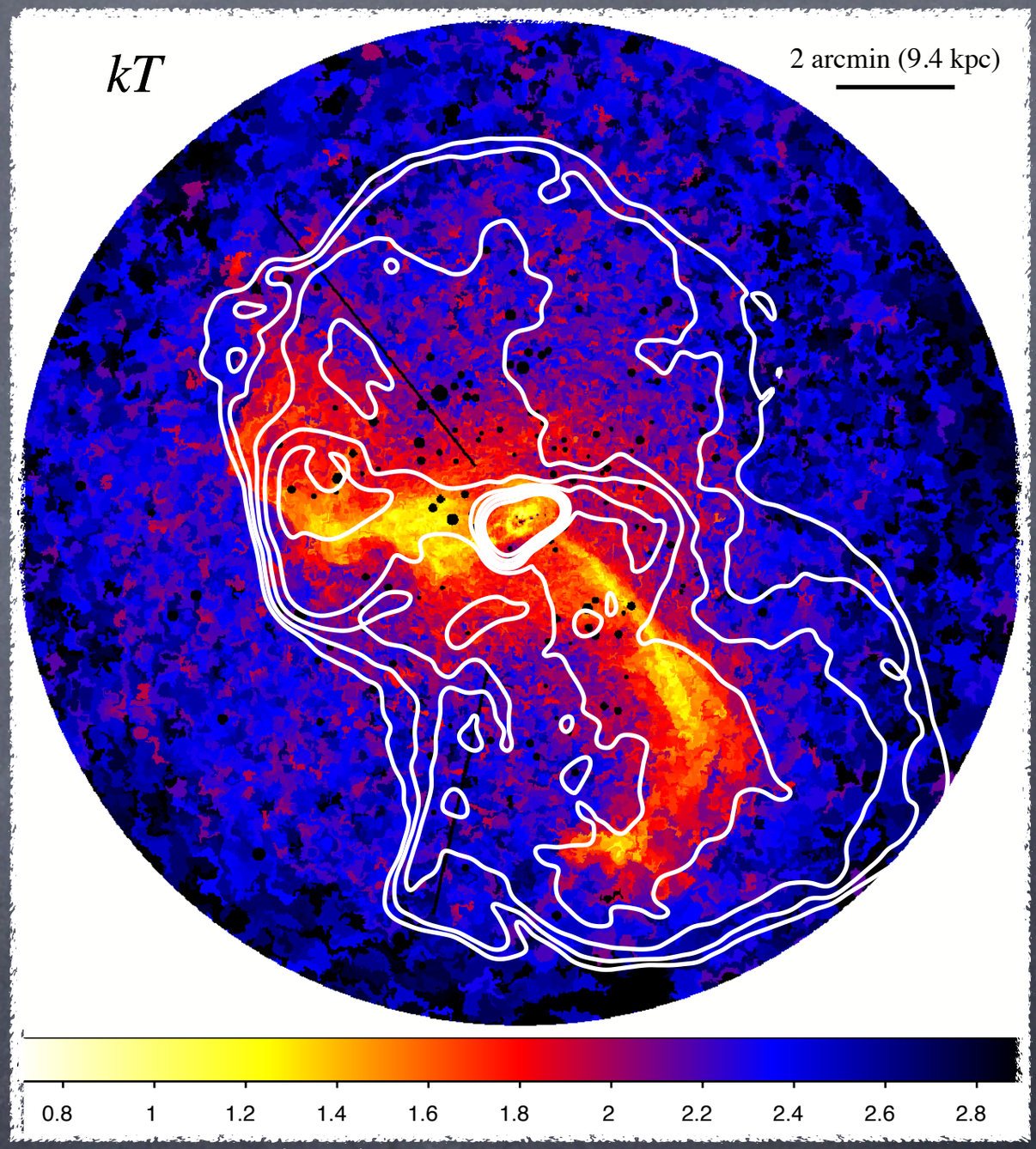
cavities: radio bright;
X-ray faint

Temperature map of M87 / Virgo (nearest cluster)



Simionescu et al. 2007

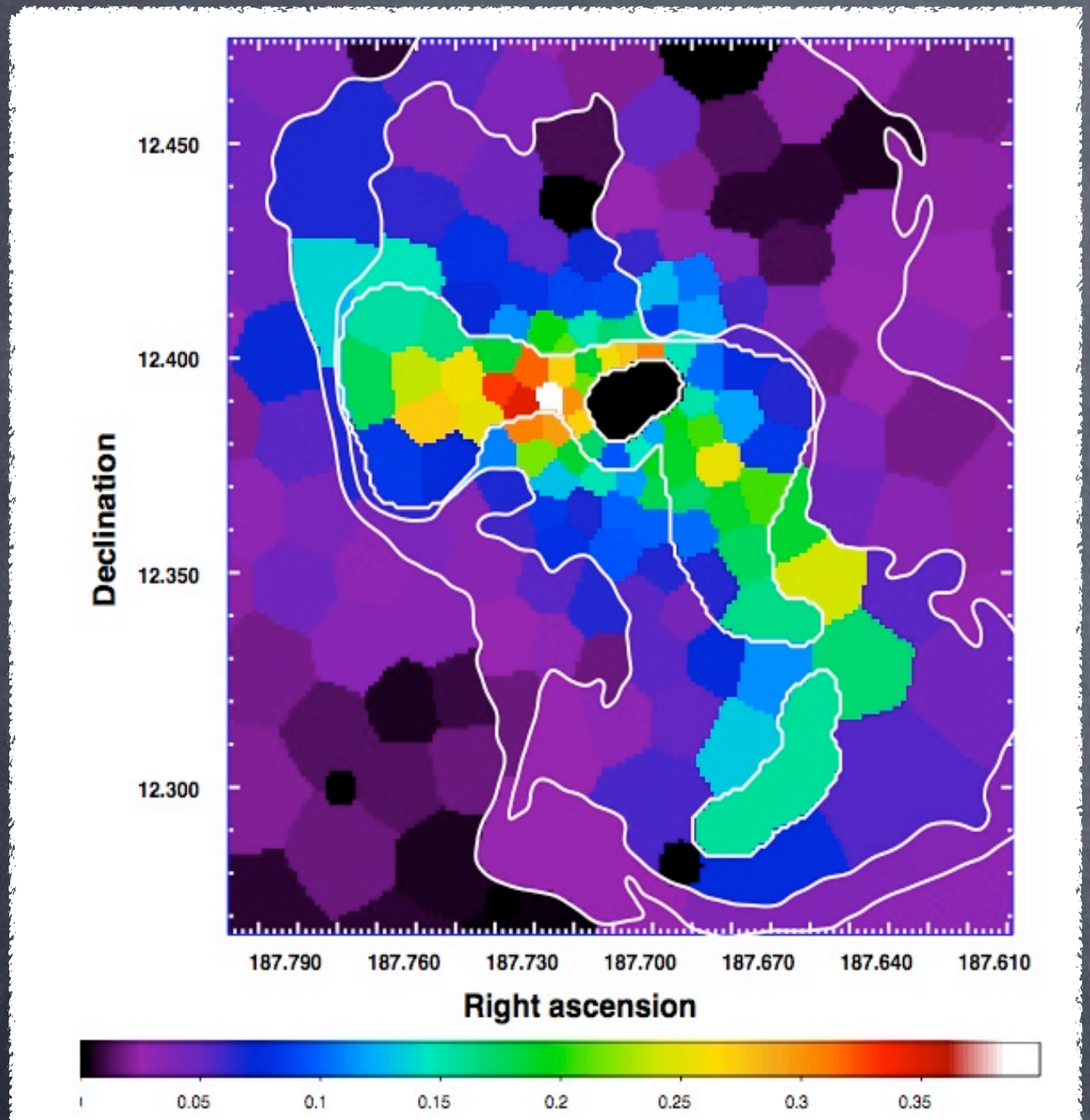
120ks XMM

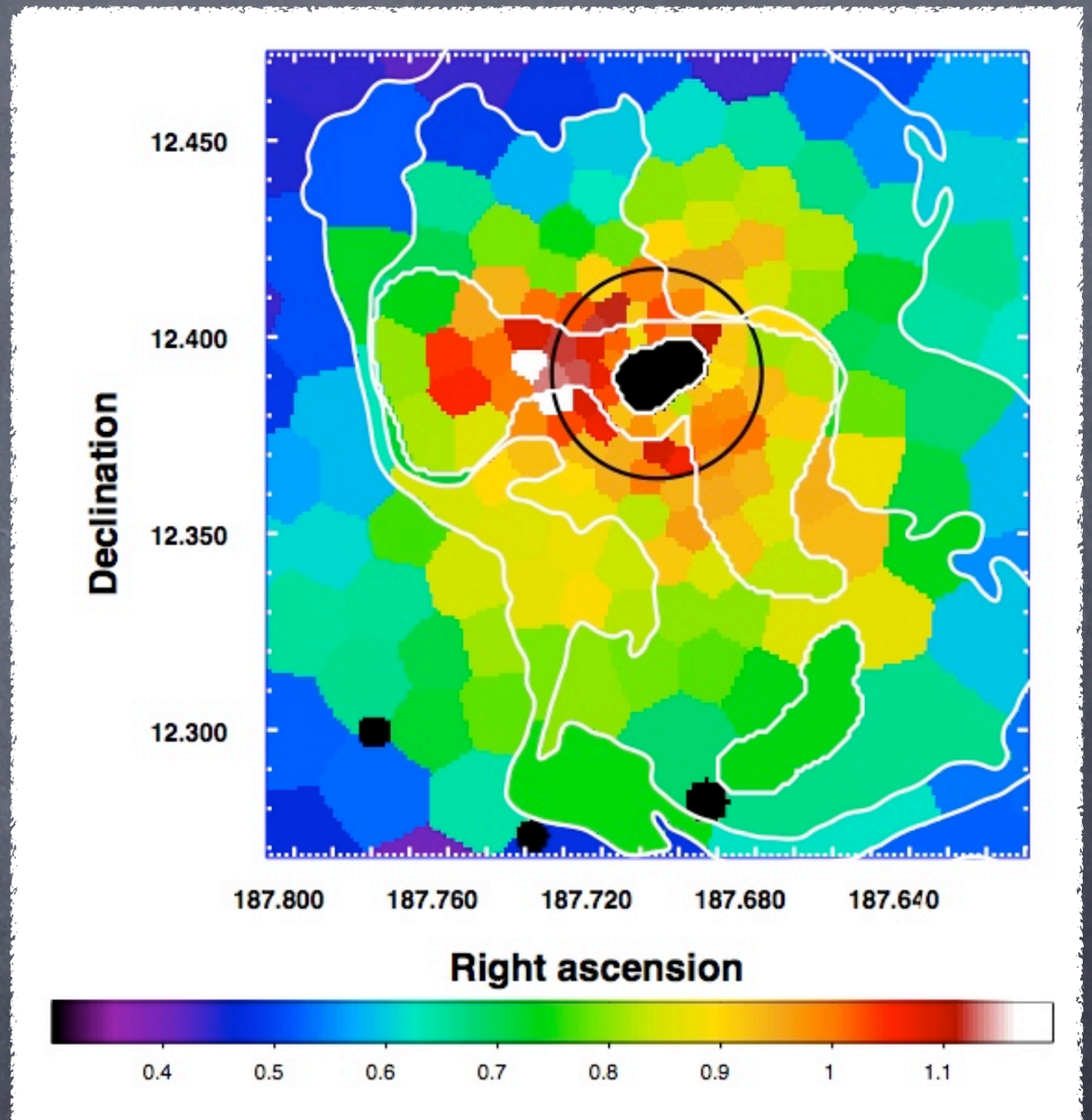


Million et al. 2010

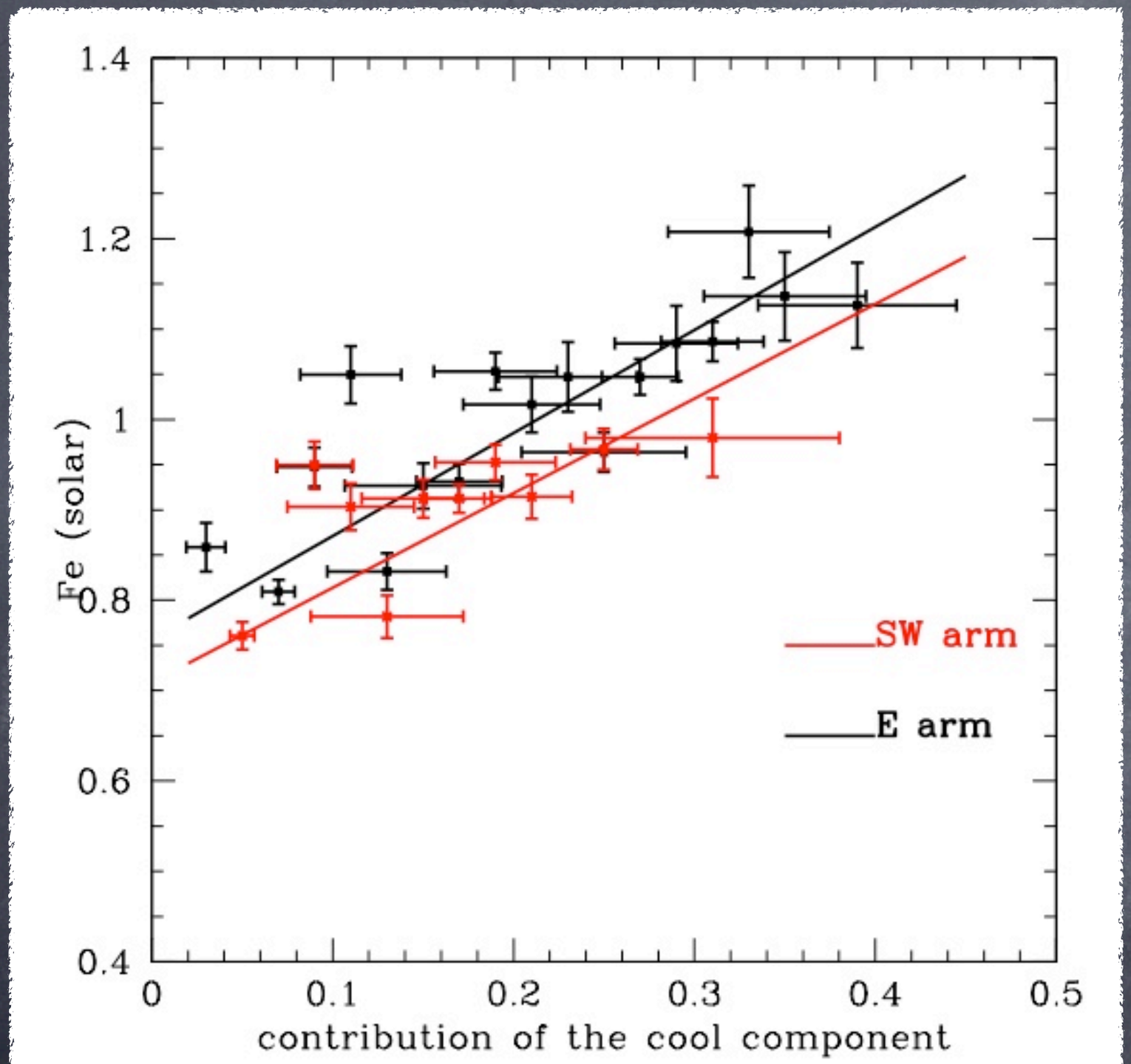
574ks Chandra

Cool gas is metal rich





Simionescu et al. 2008



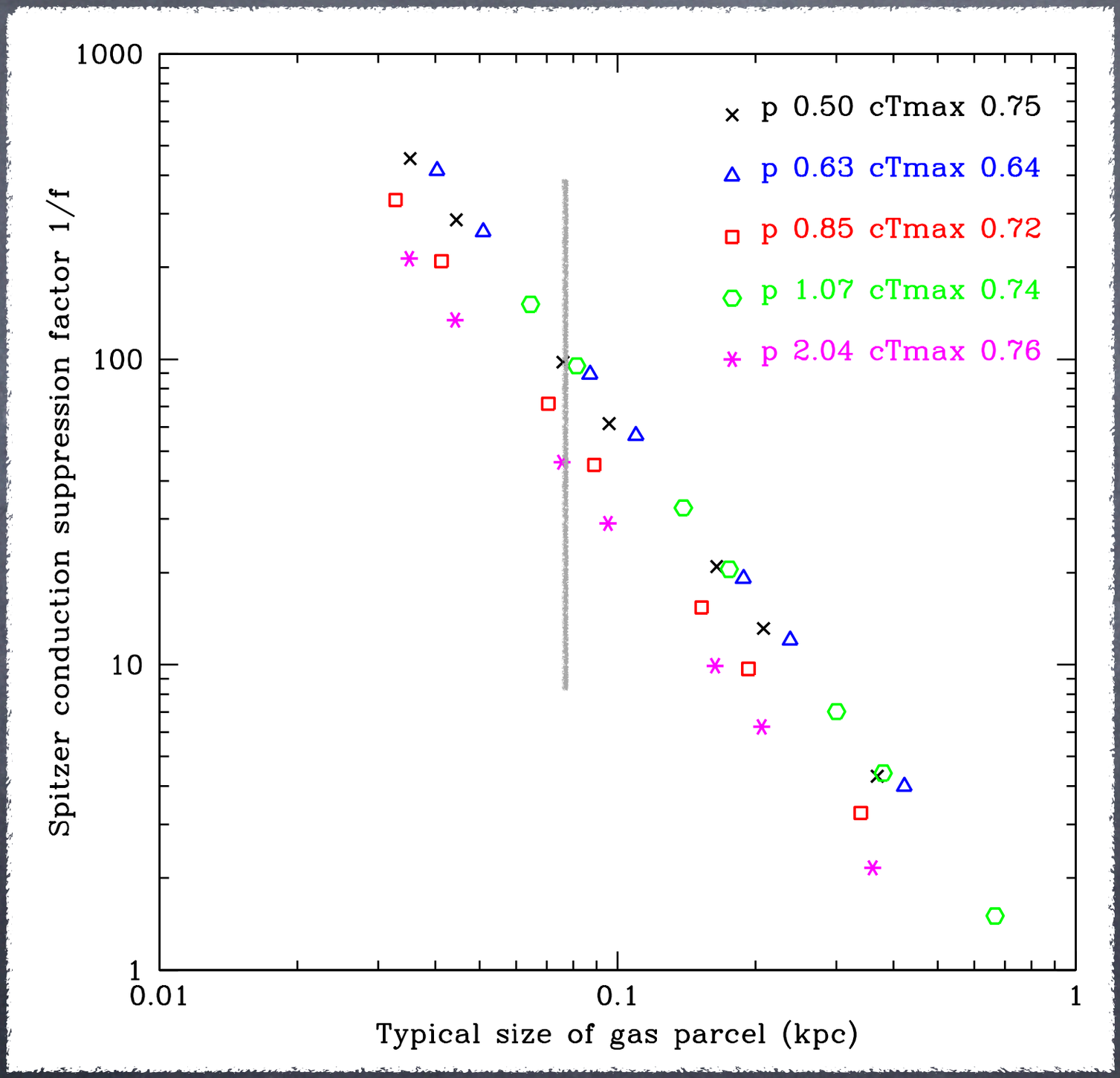
Z~2.2 solar,

$M \sim 5 \times 10^8 M_{sun}$

$M_{Fe} \sim 1.5 \times 10^6 M_{sun}$

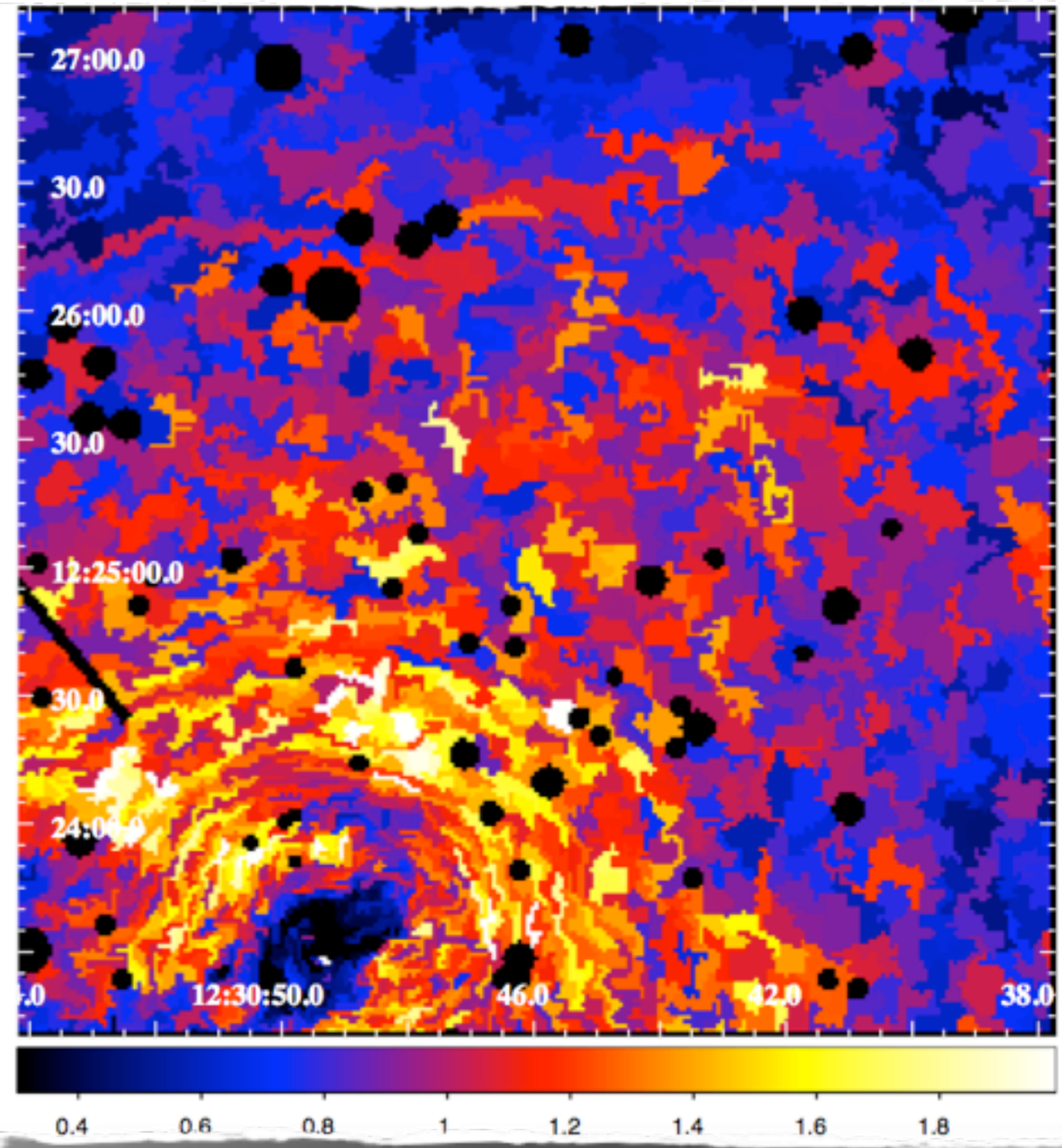
Simionescu et al. 2008

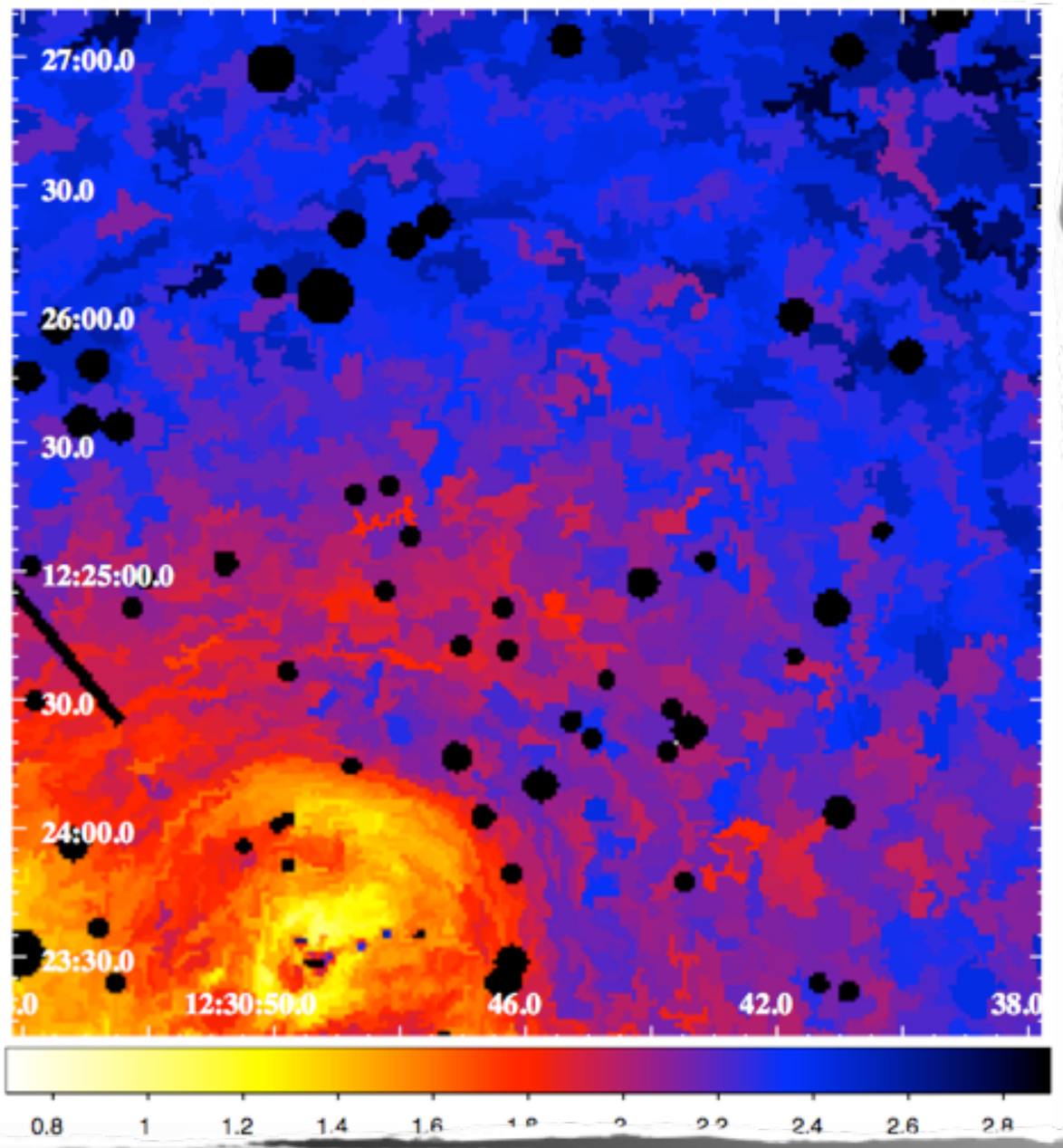
Conduction suppression in the azimuthal direction ?



Simionescu et al. 2008

Conduction and no turbulence?



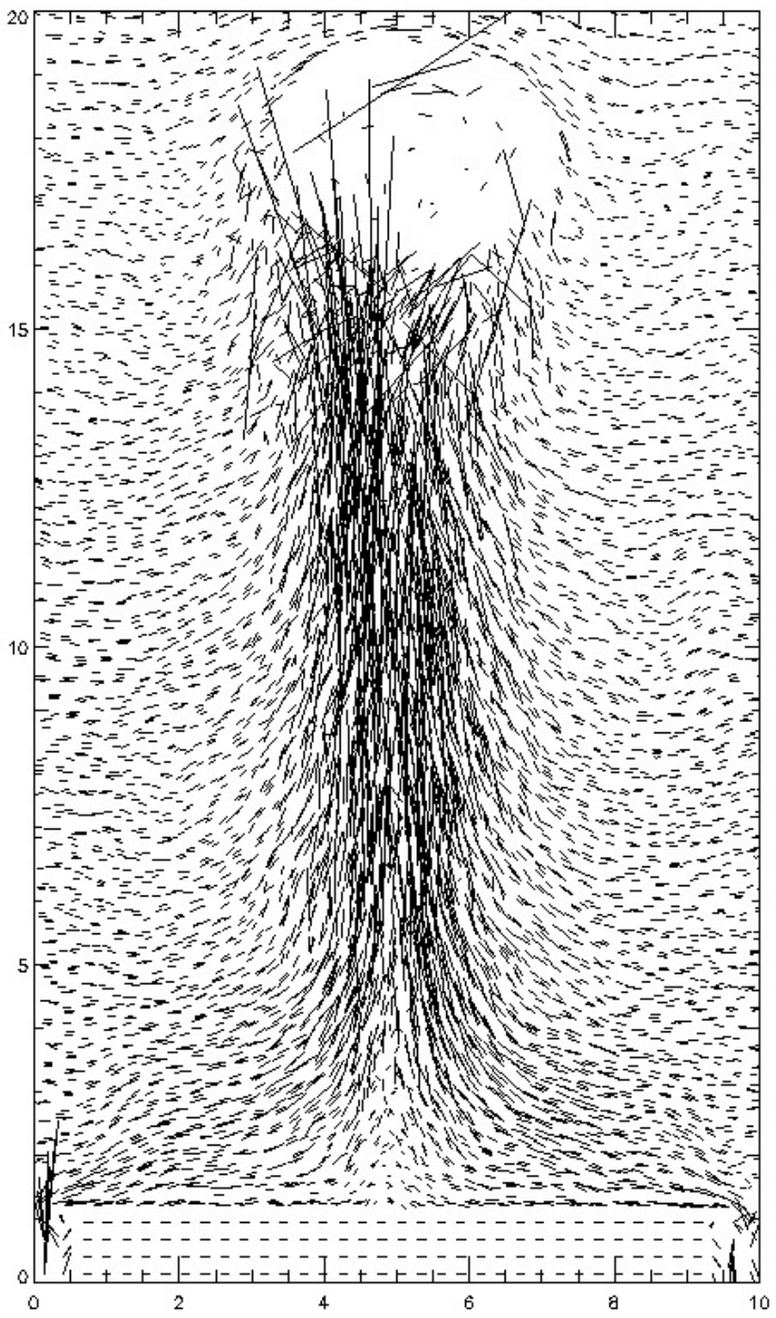


Metallicity (Solar)

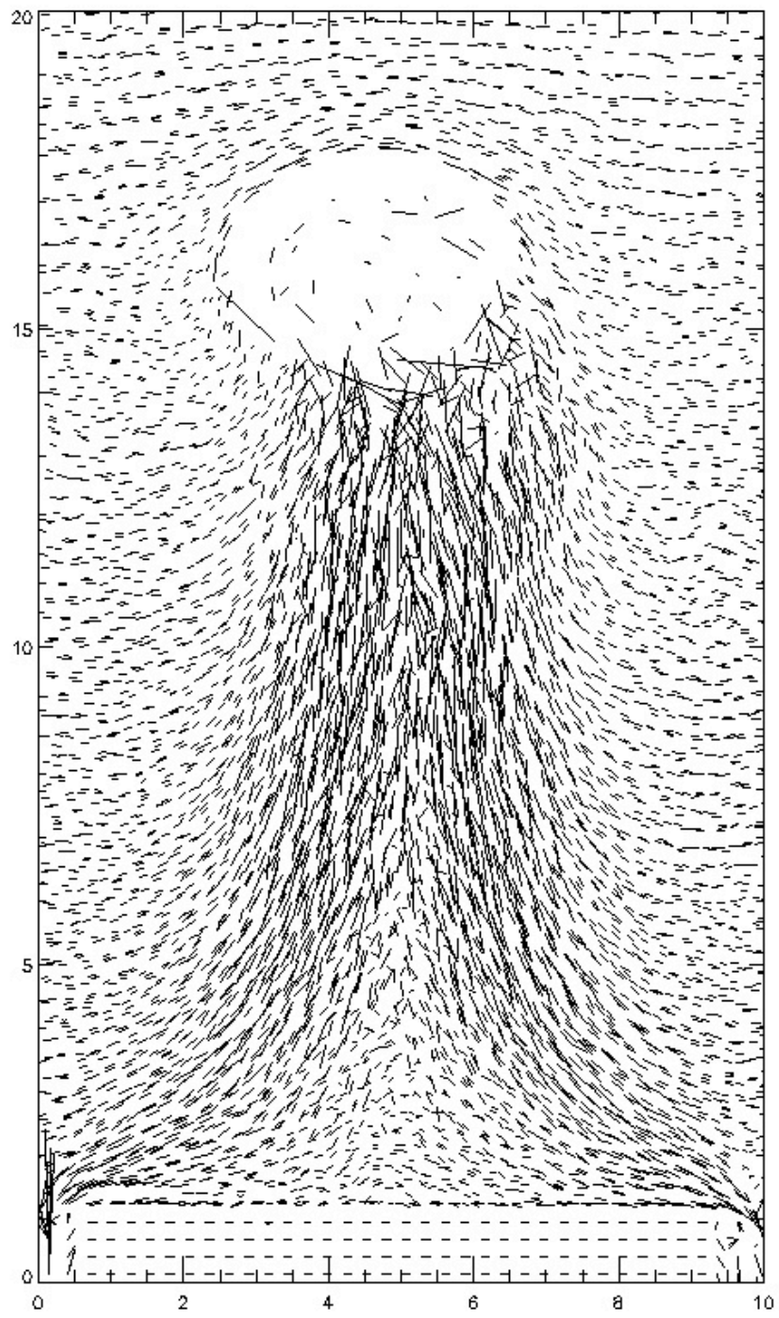
kT (kev)

Million et al. 2010

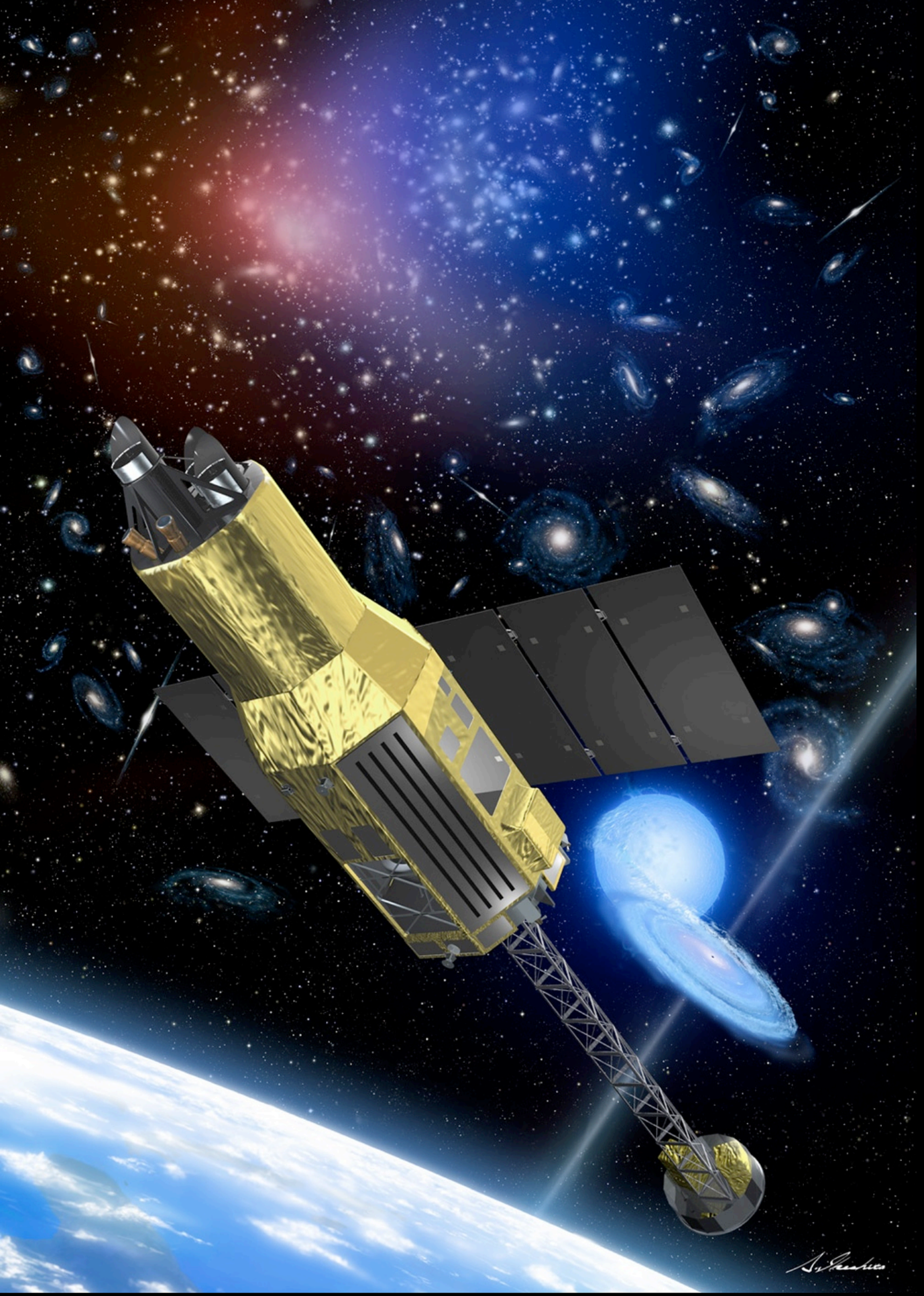
My cartoon picture of magnetic fields in M87



B=1uG



B=5uG



Astro-H

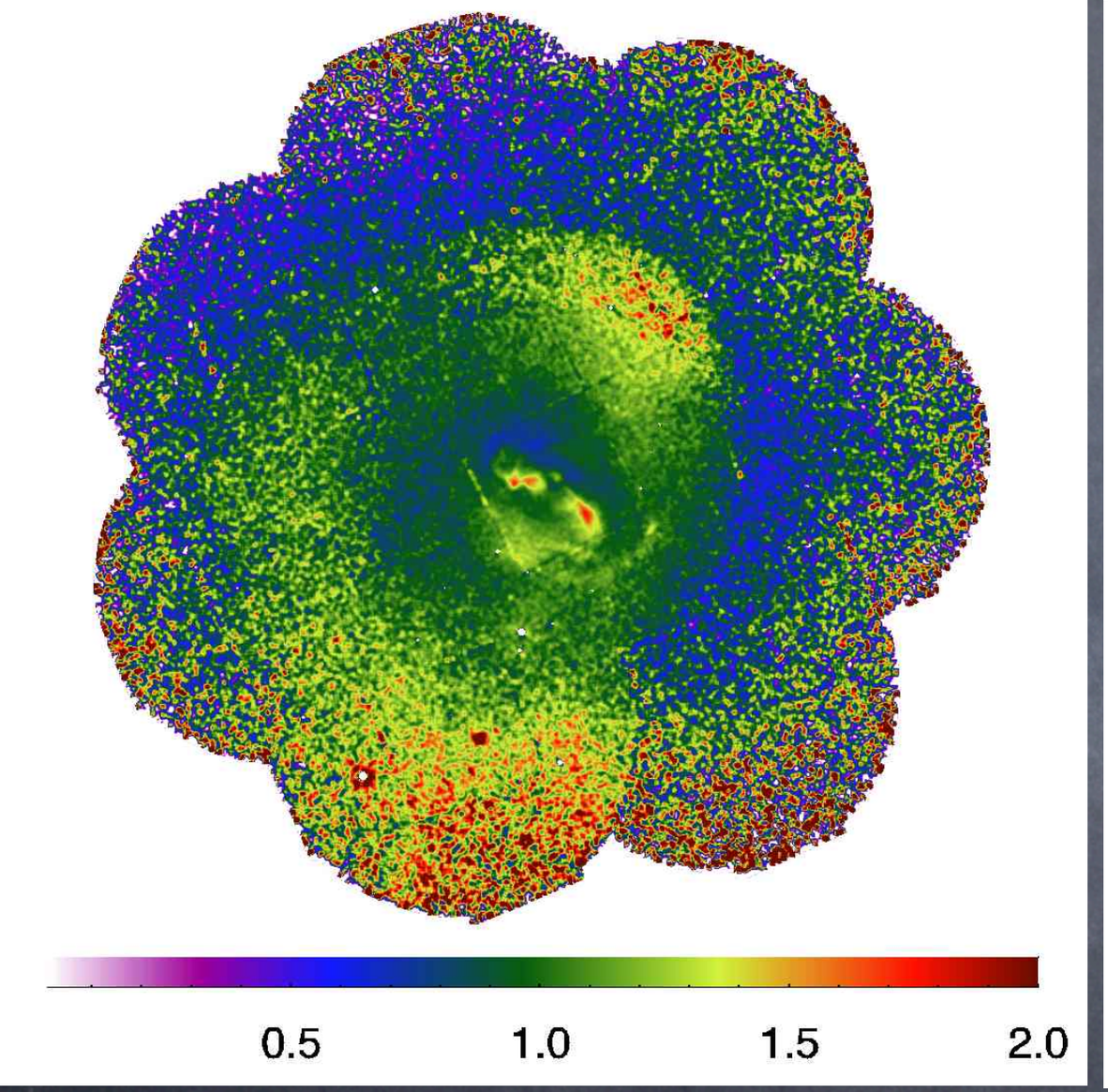
high spectral resolution calorimeters can:

- test multiphase structure
- measure the abundances of the different gas phases separately
-measure the turbulent line broadening and line shift of each component separately

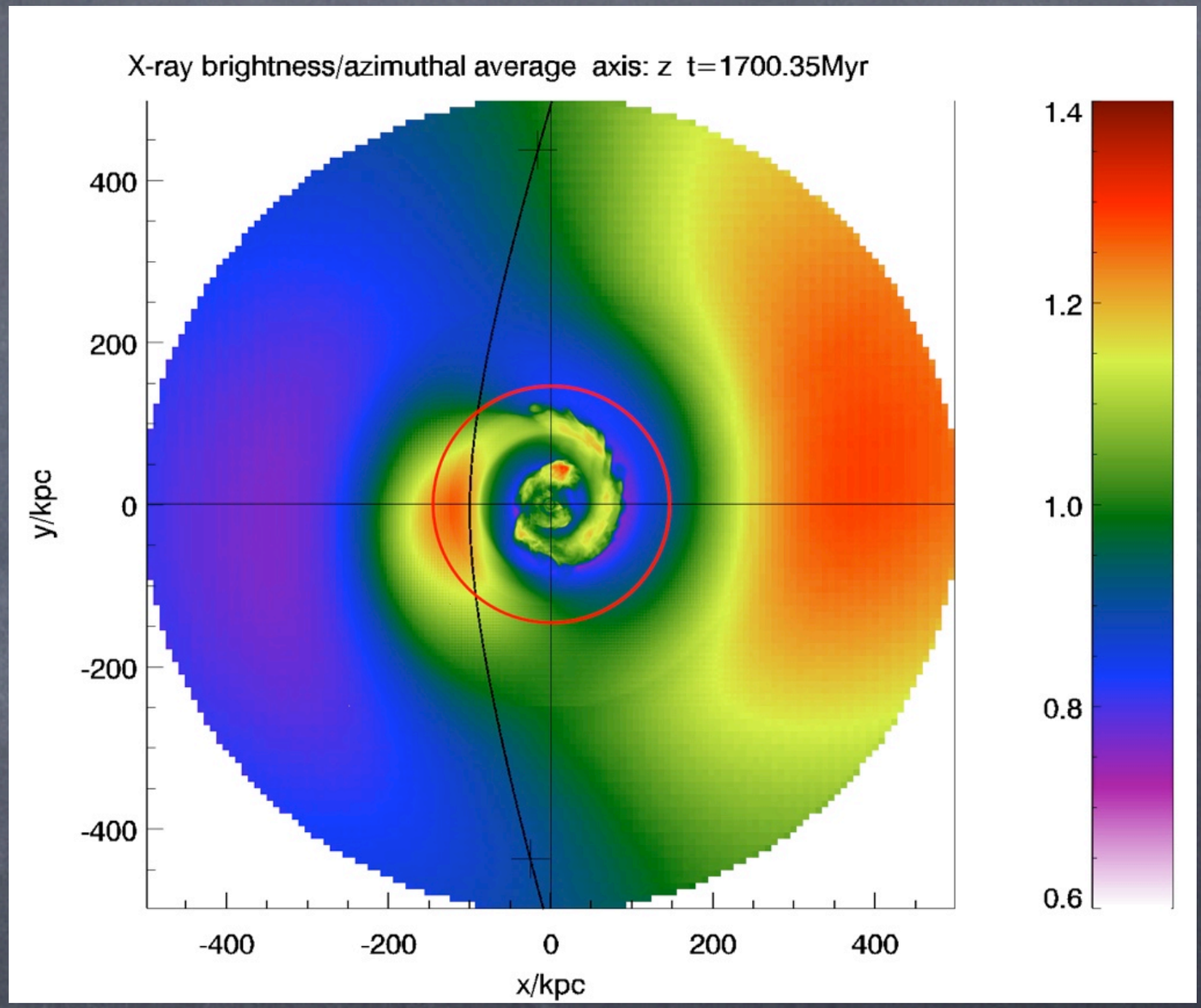
Outline

- AGN - ICM interaction
- cold-fronts (and shocks)
- what are the thermodynamic properties at the virial radius?

Classical sloshing in M87

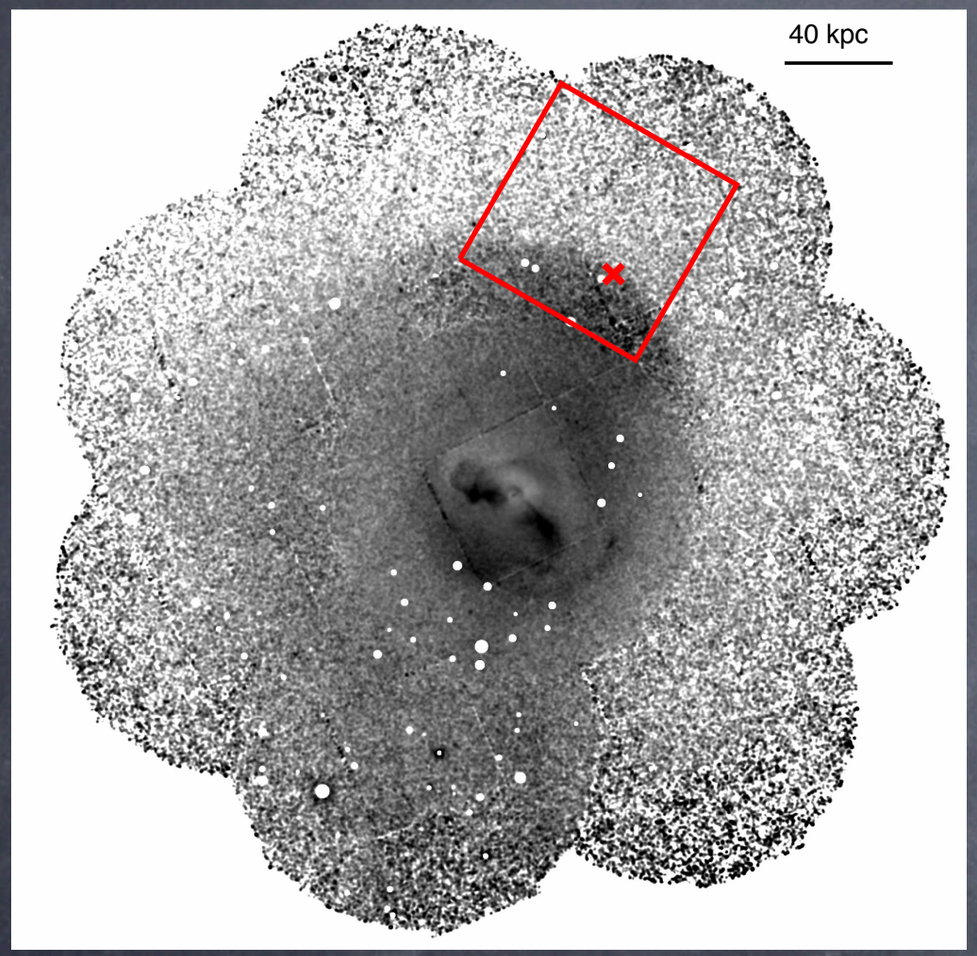


Simionescu et al. 2010



Roediger et al. 2011

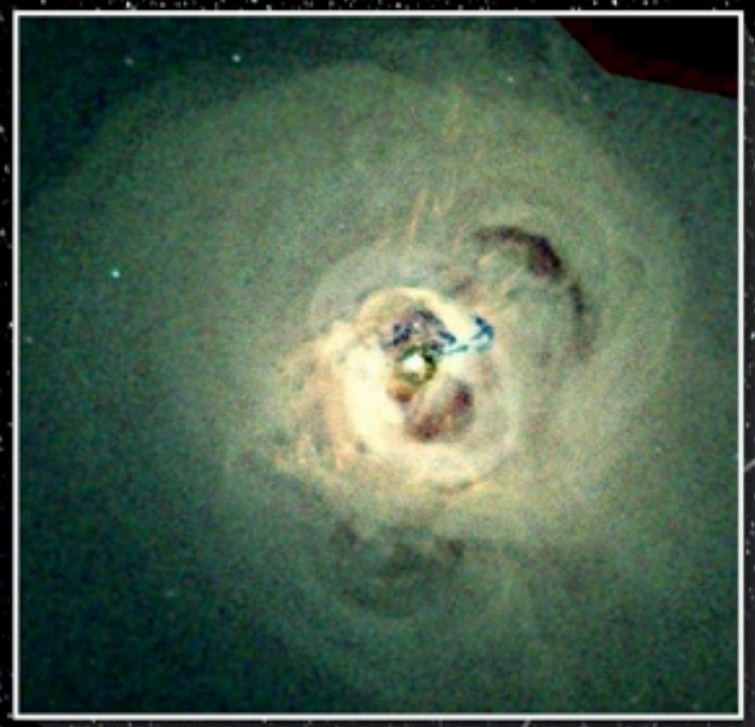
Chandra LP of the M87 cold front



- what is the width of the fronts?
- do KH instabilities develop at the cold fronts?
- is there an underlying rotational/spiral flow associated with these fronts?
- is there a magnetized depletion layer?

Outline

- AGN - ICM interaction
- cold-fronts and shocks
- what are the thermodynamic properties at the virial radius?

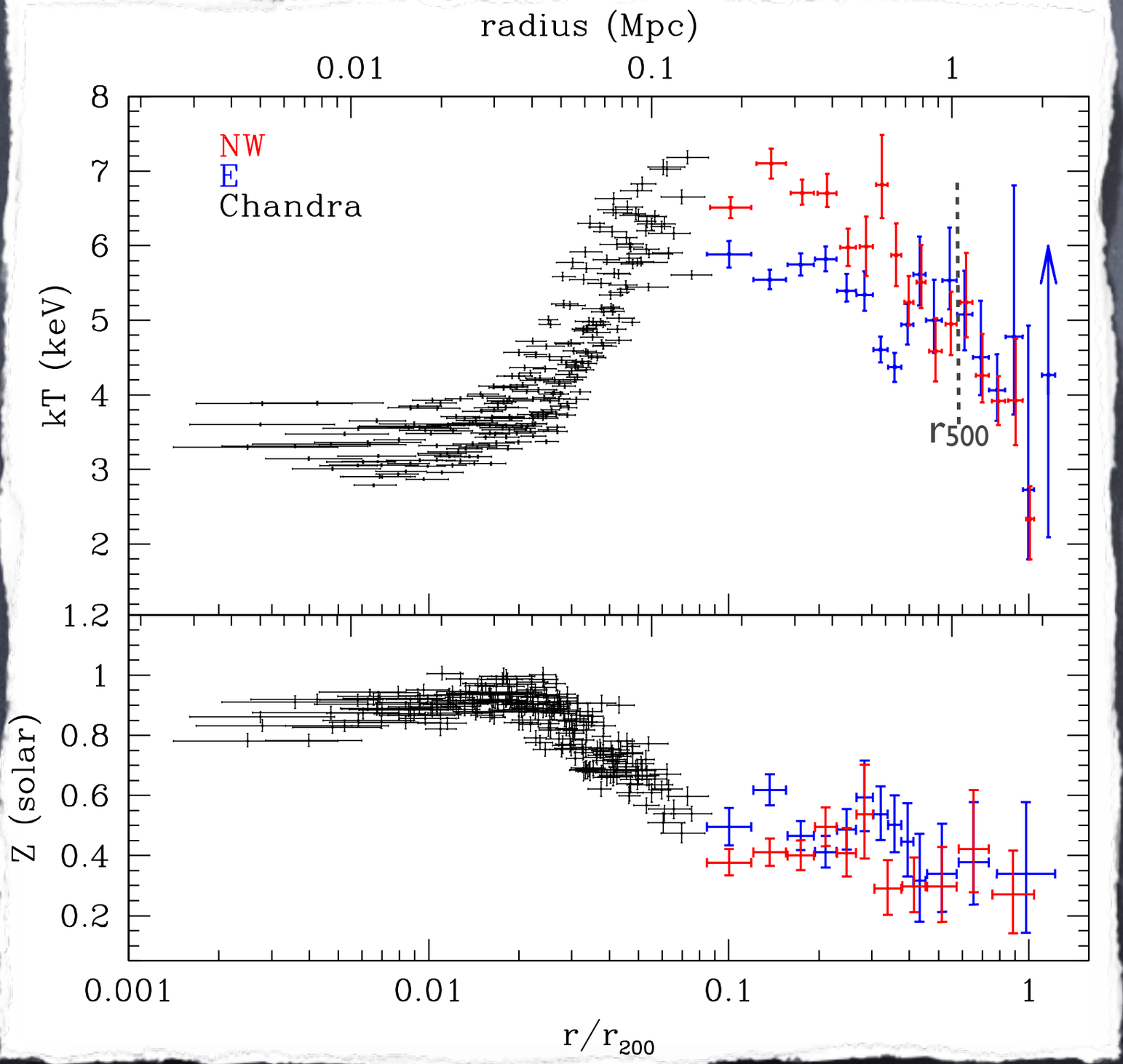


Virial radius

9 million light-years

9 million light-years

Projected temperature and metallicity profiles:



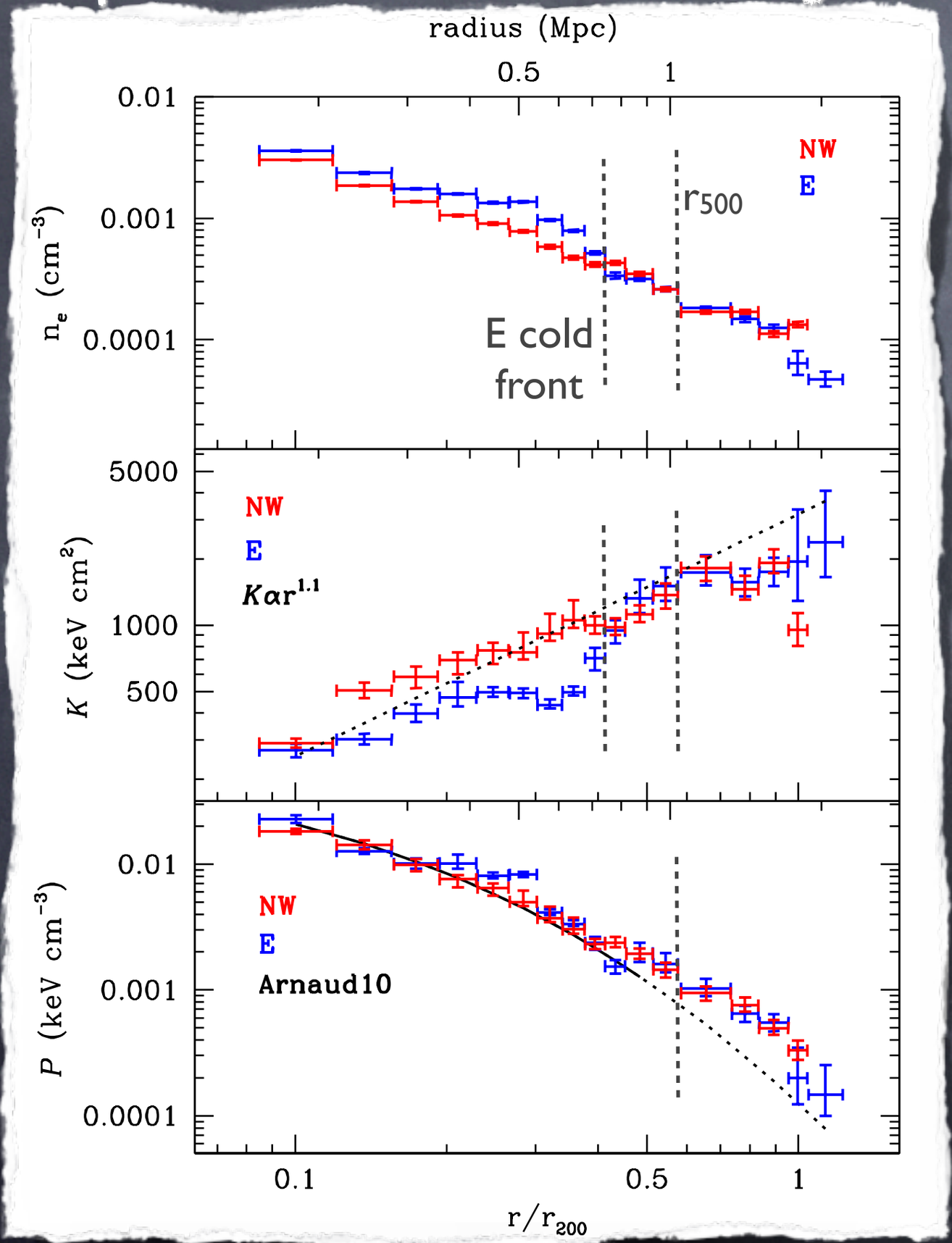
excellent agreement with Chandra data

detailed profiles spanning 3 decades in radius

profiles between r_{500} and r_{200} resolved for the first time

metallicity profile measured for the first time until the virial radius

Deprojected thermodynamic profiles:

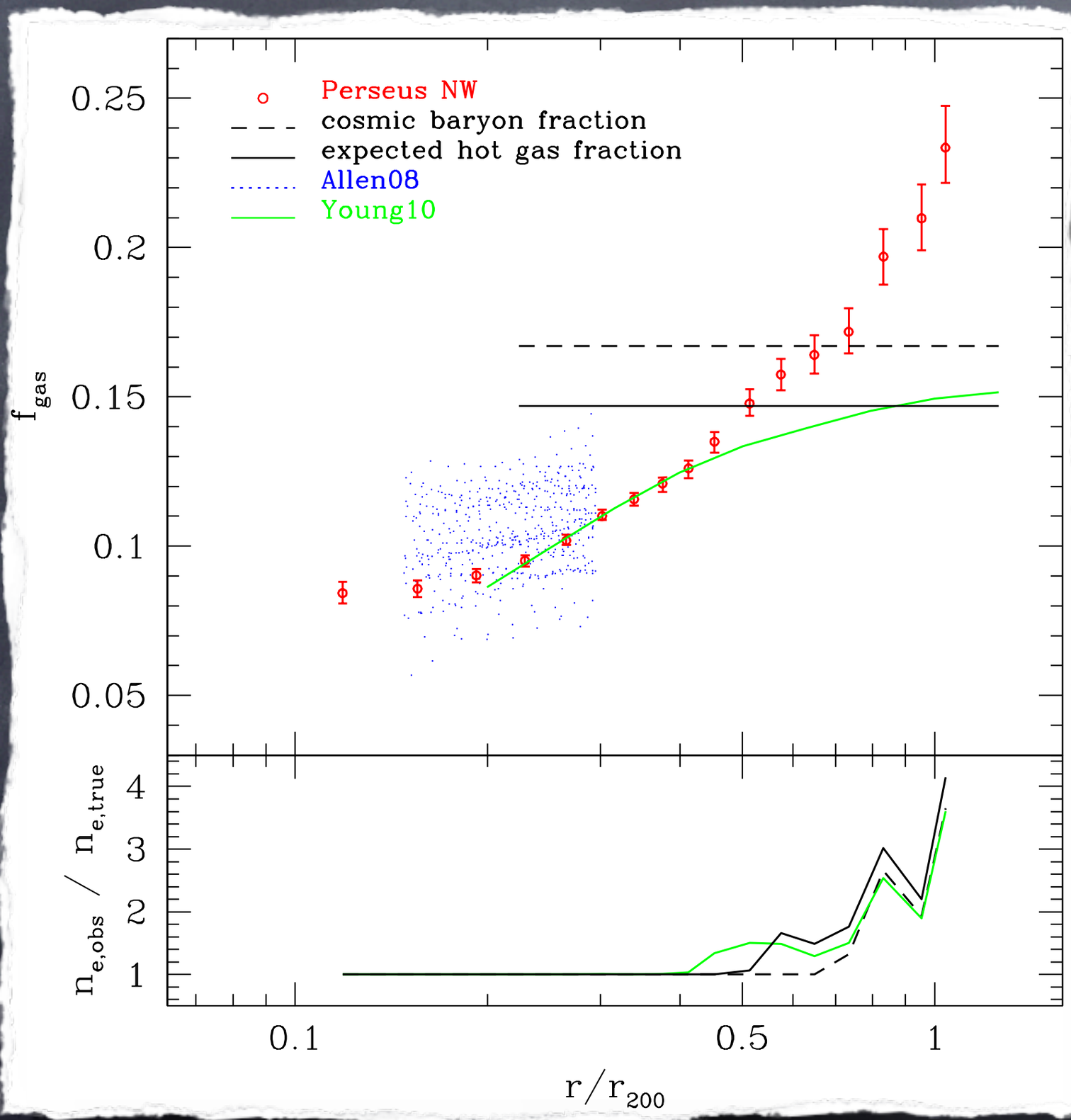


shallow decline of electron density at large radii

entropy appears to flatten at large radii compared to the expected power-law

pressure at large radii greater than predicted by numerical simulations (fitted to XMM data inside r_{500} by Arnaud et al. 2010)

Gas mass fraction profile towards the NW:



good agreement with previous observations and numerical simulations at $r<0.4r_{200}$

f_{gas} value matches cosmic mean at $r\sim r_{500}$

f_{gas} exceeds cosmic mean at large radii ($r>0.6-0.7r_{200}$)

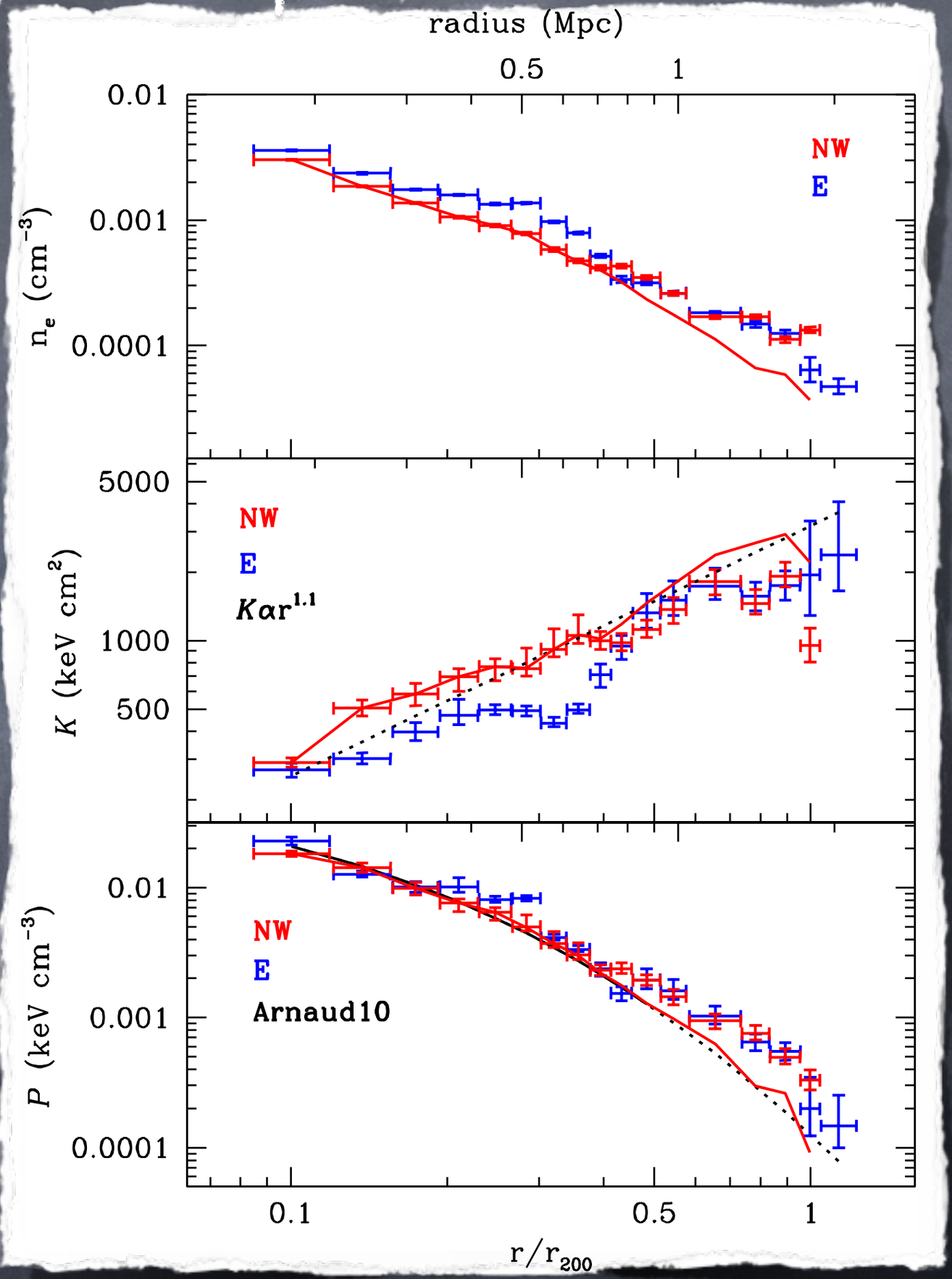
most likely cause: the gas is clumpy

bottom panel shows the first measurements of the gas clumping factor

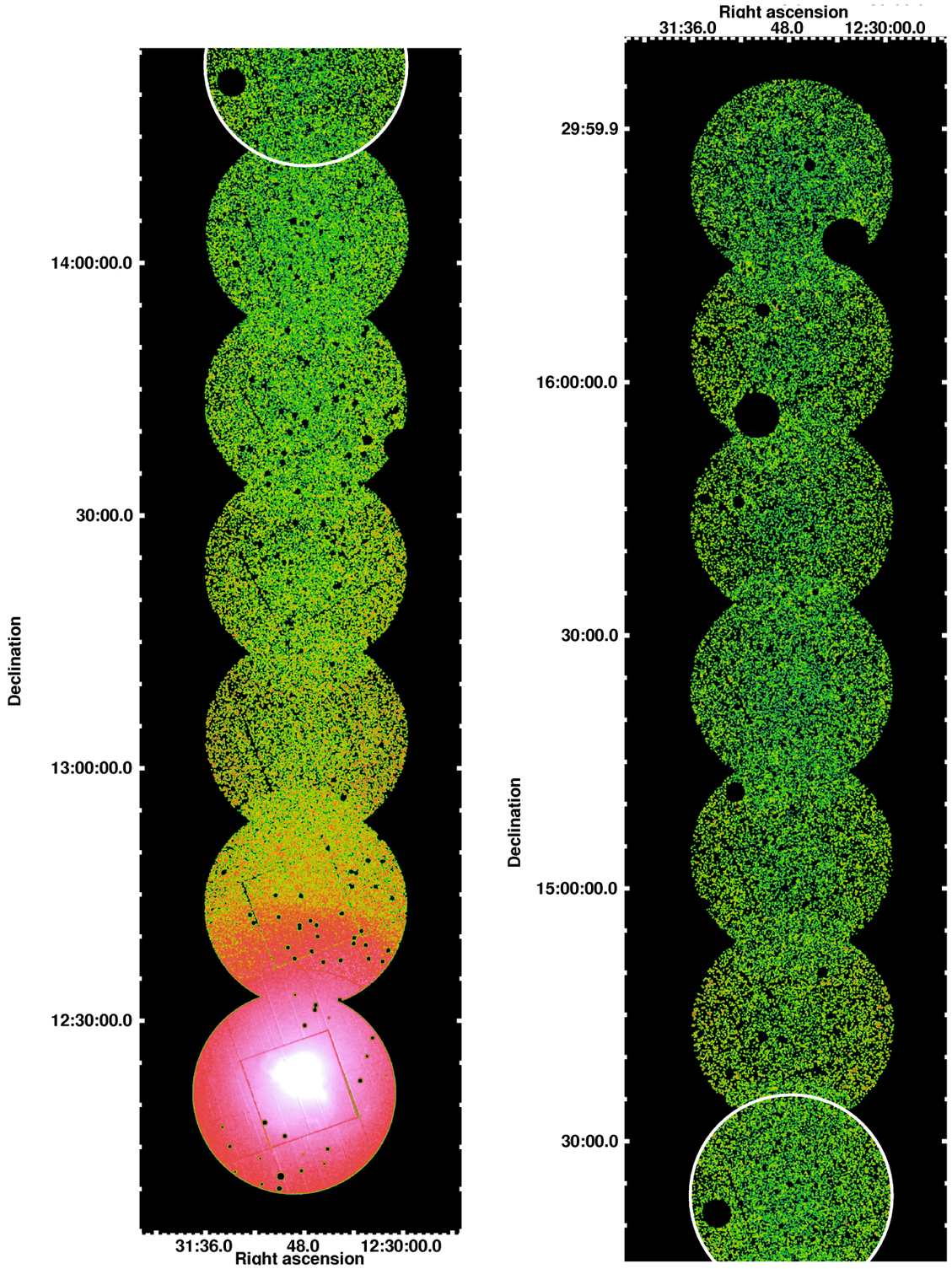
Corrected thermodynamic profiles:

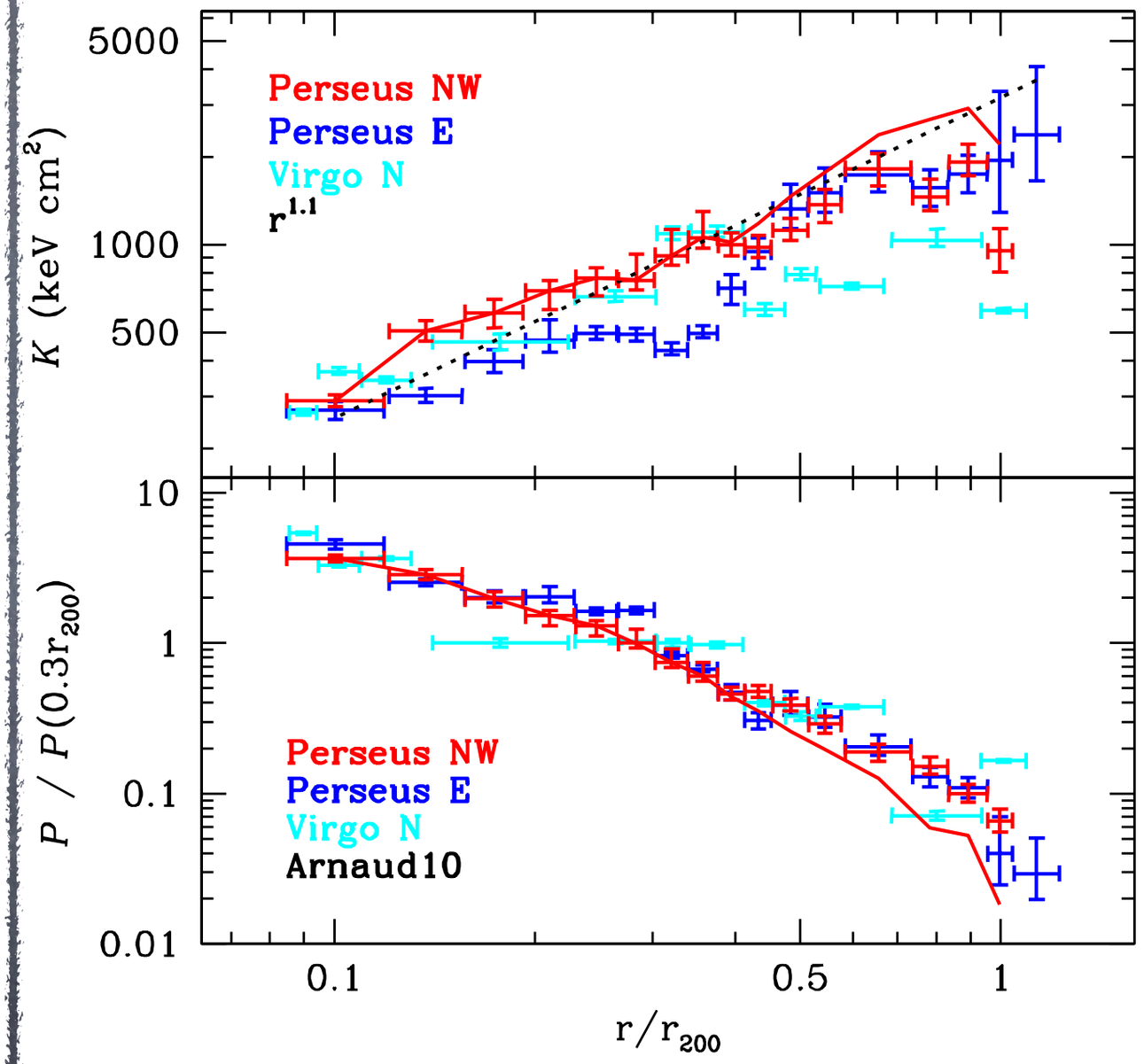
correcting for clumping (red lines) brings measurements into agreement with expected trends

other mechanisms, e.g. $T_e \neq T_i$ would explain entropy flattening but not explain pressure and f_{gas} profiles



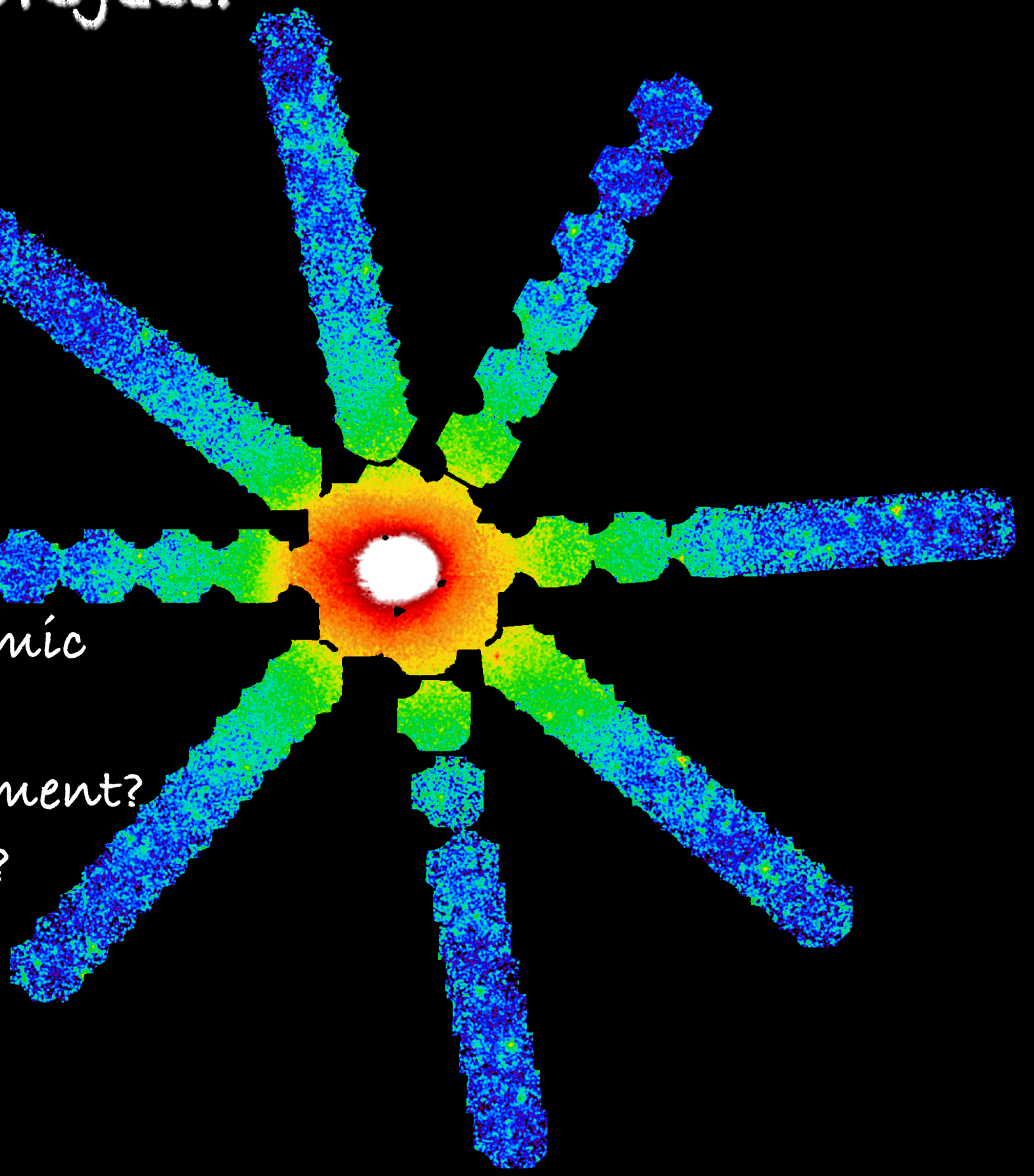
Virgo pilot project:





Urban et al. 2011

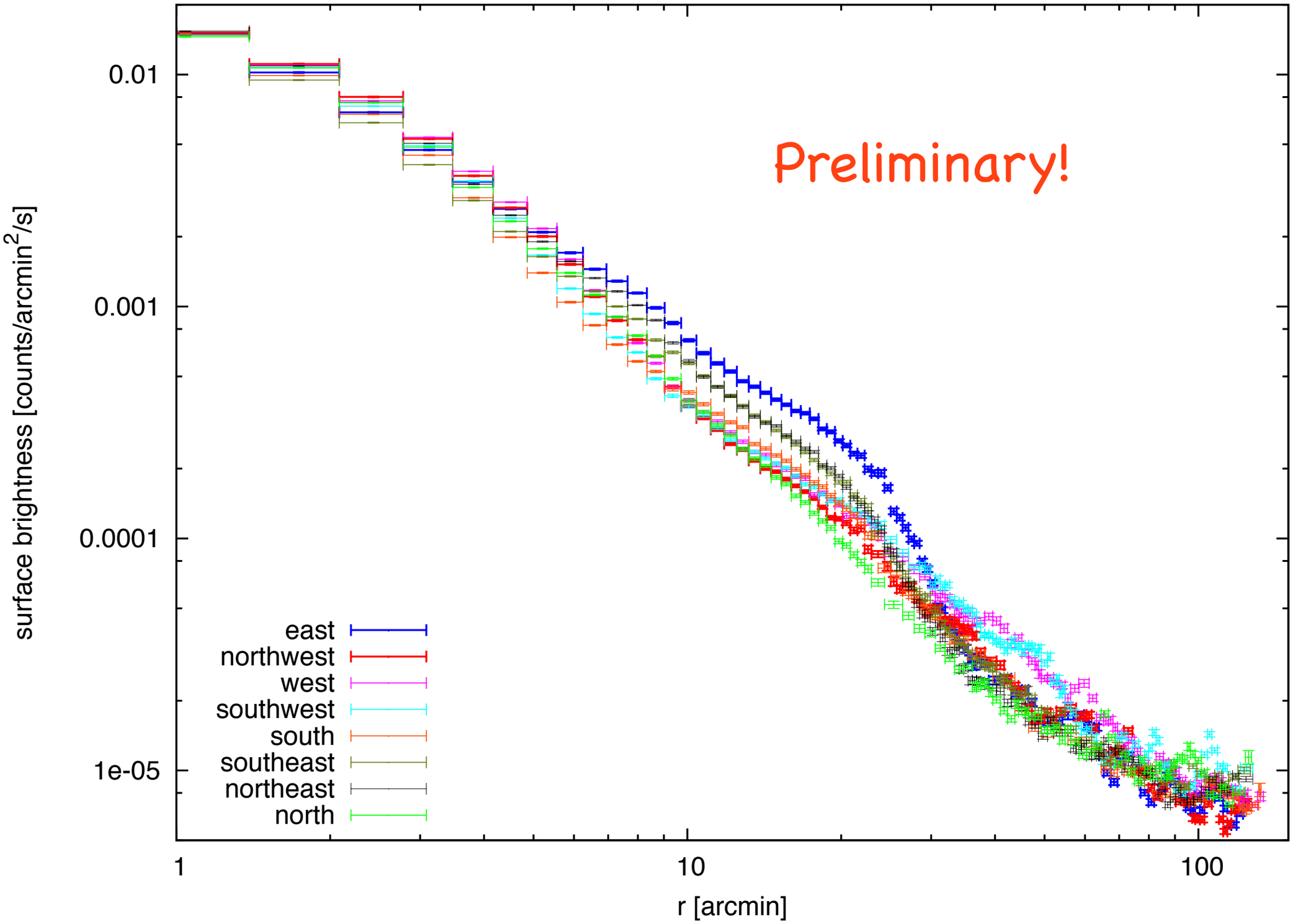
The Perseus Key project:



How do the thermodynamic profiles vary with azimuth/ LSS environment?

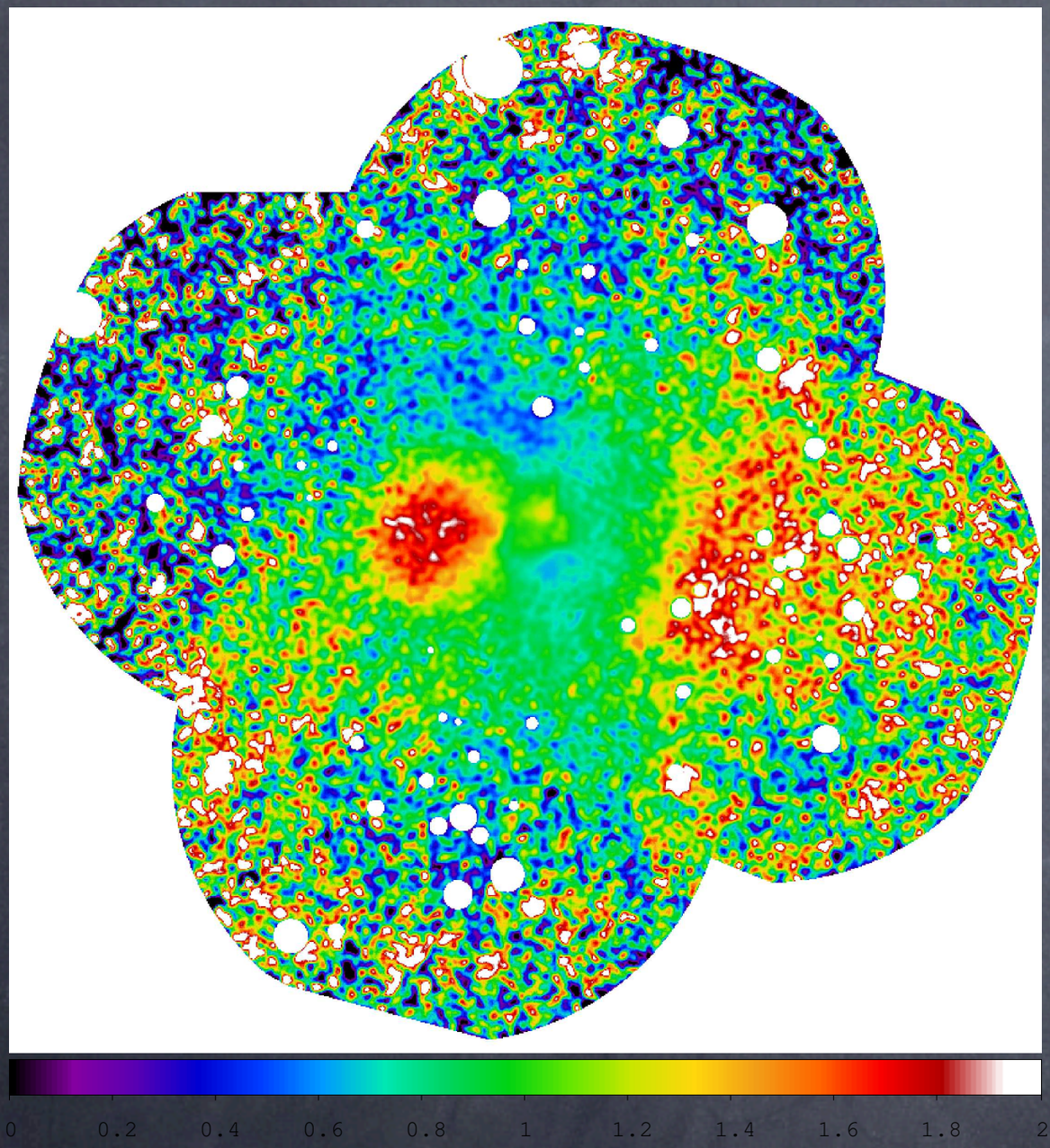
Is the NW arm "special"?

Perseus & arms Sx



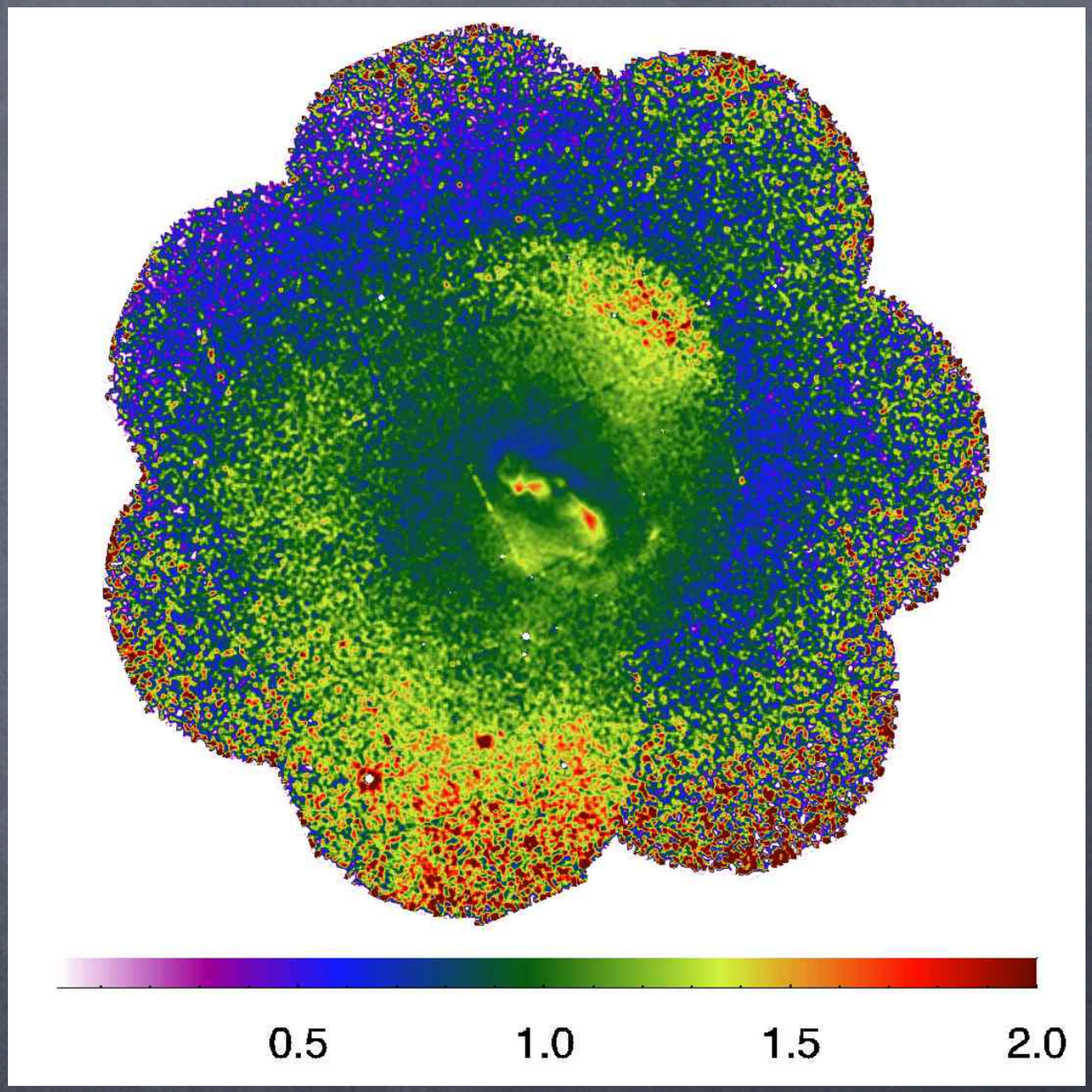
Urban et al. in prep

Large scale "sloshing"?



Perseus

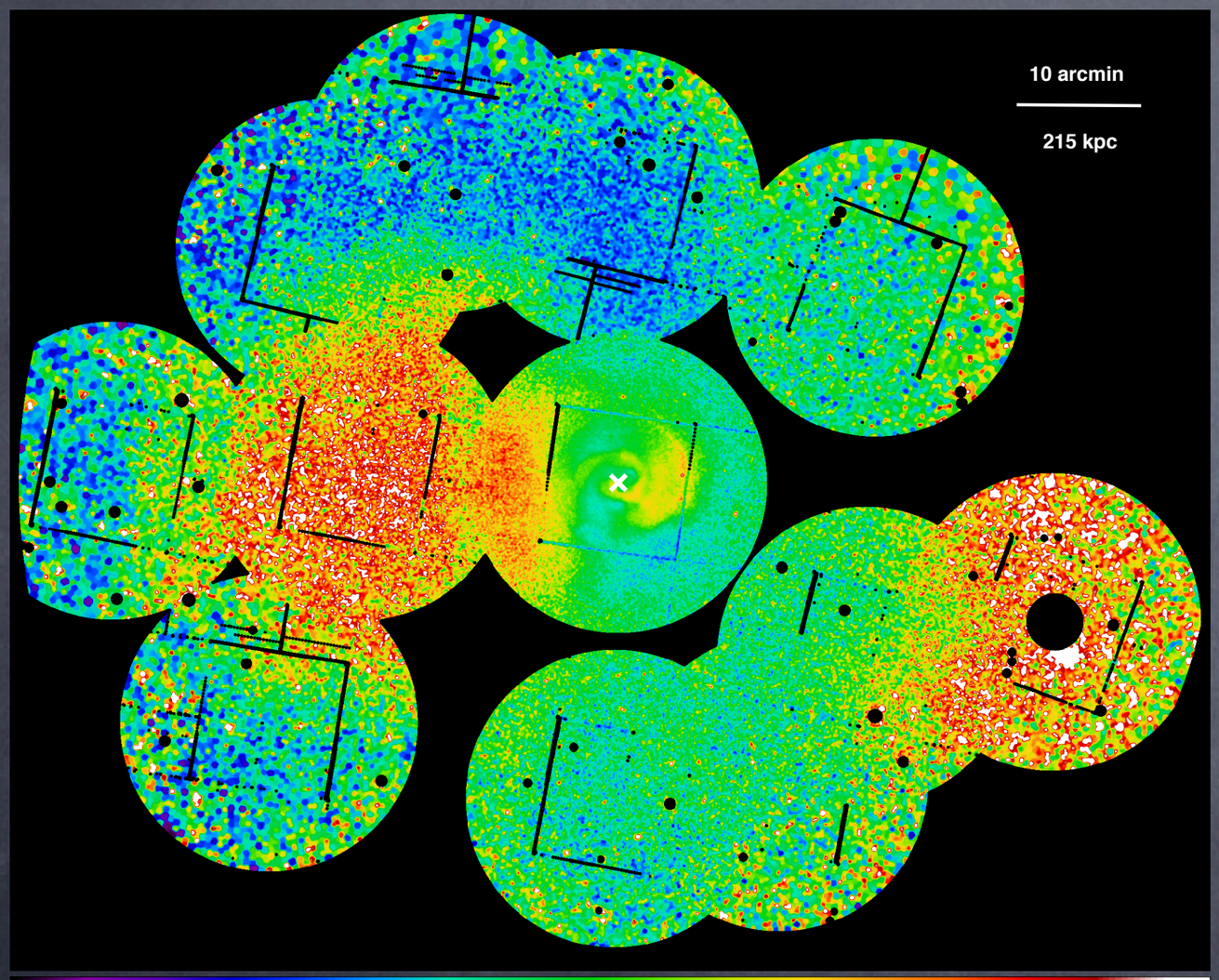
(Simionescu et al. 2012)

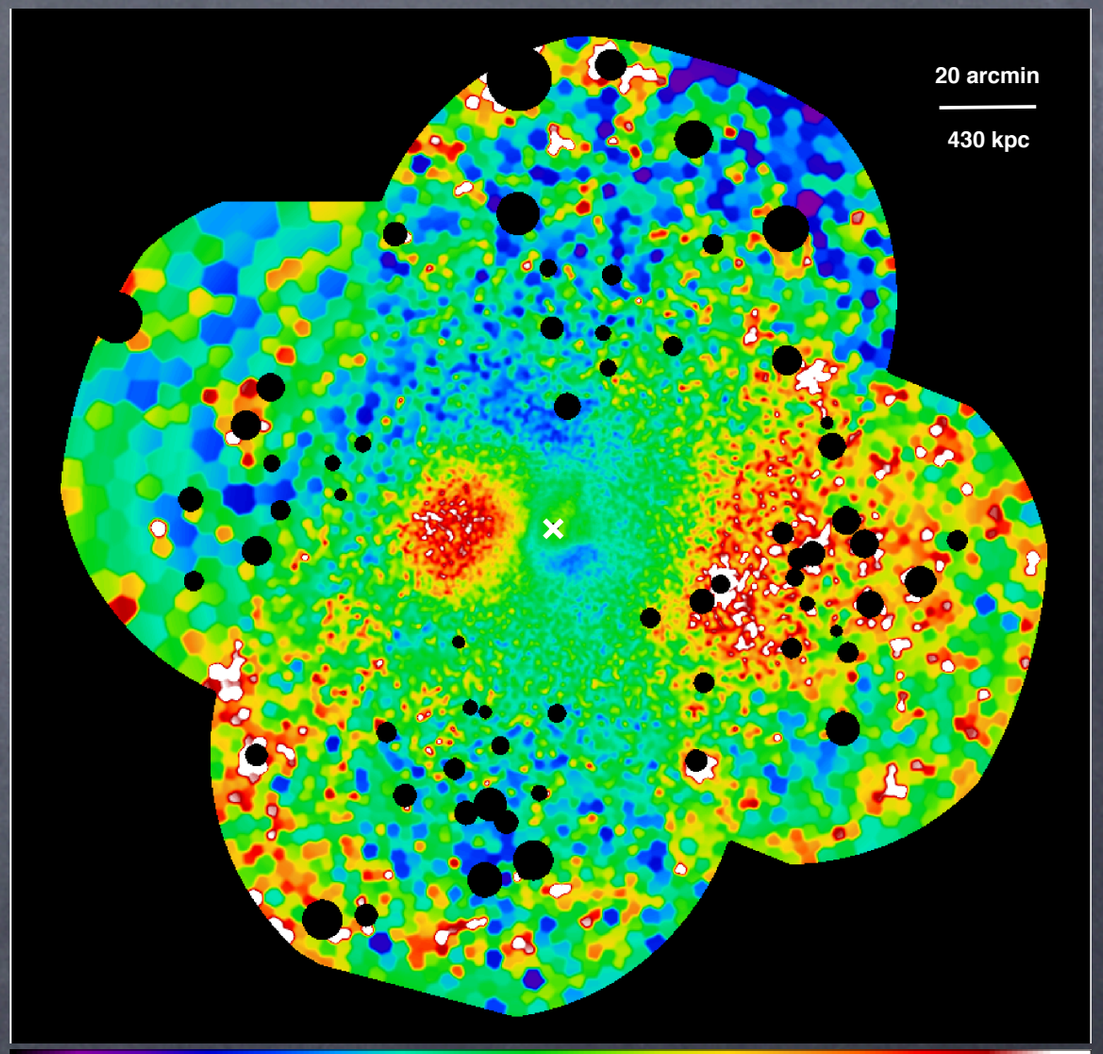


Virgo

(Simionescu et al. 2010)

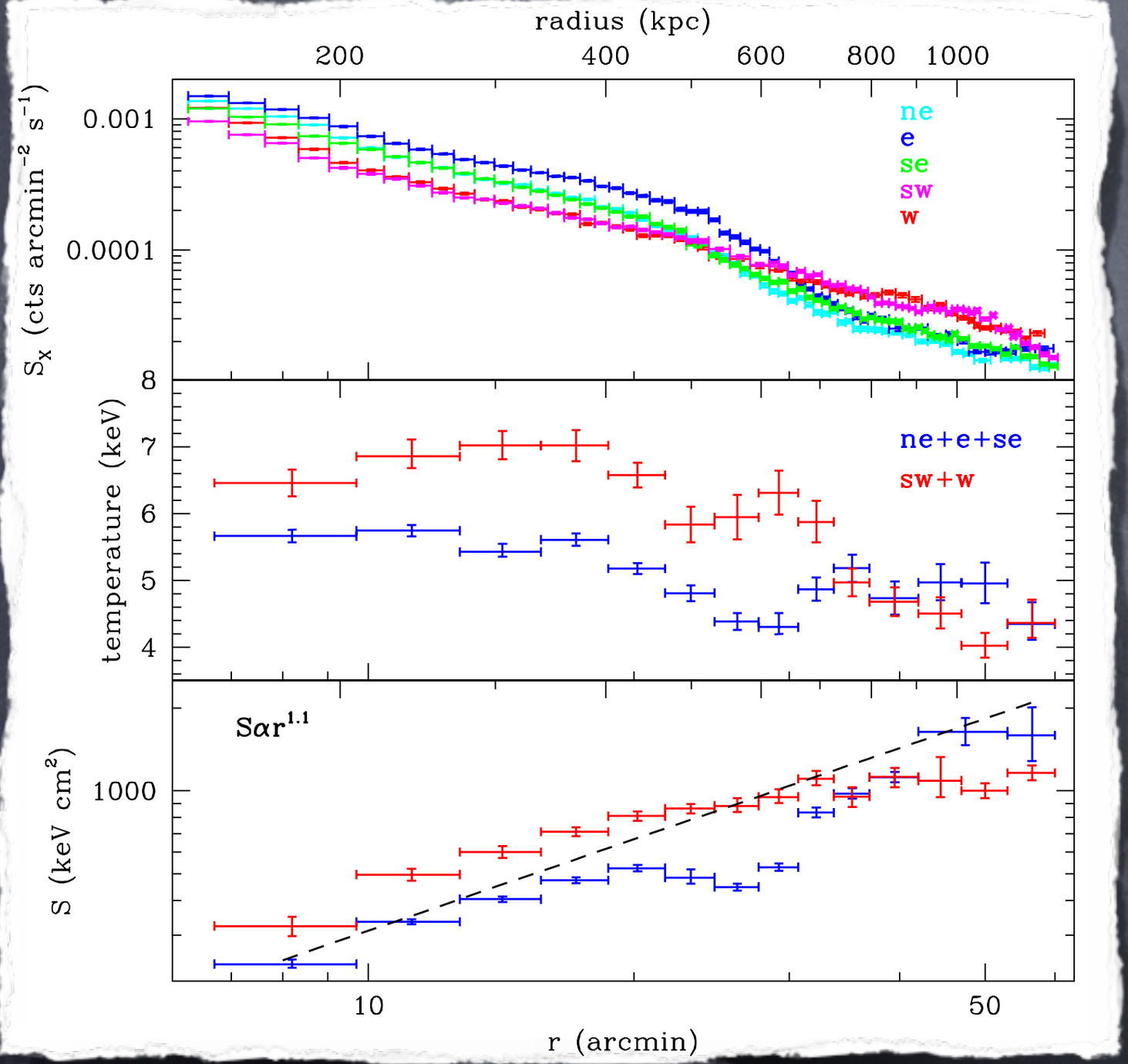
The Perseus cluster on large scales





Simionescu et al. 2012

Large scale "sloshing"?

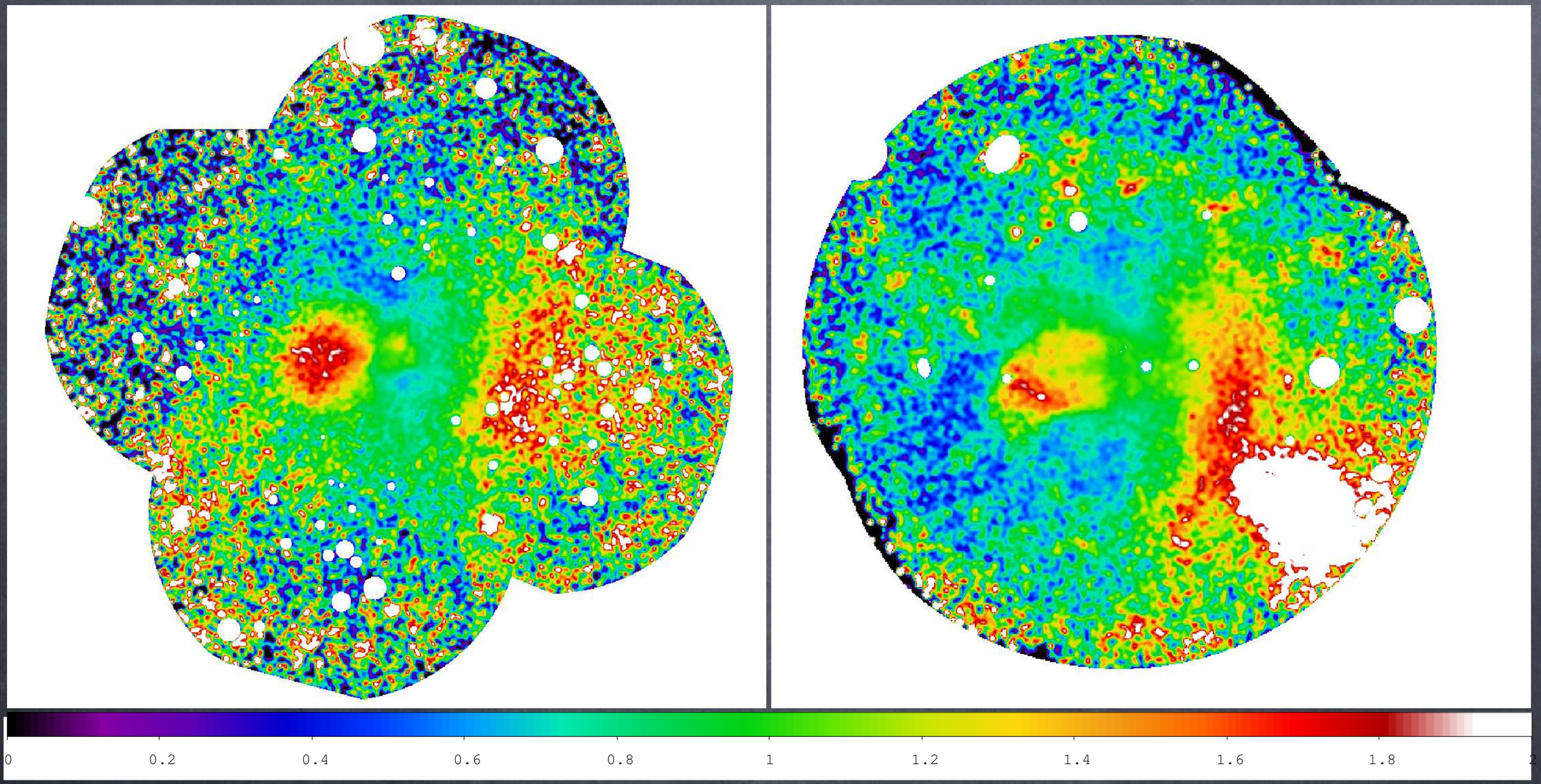


what merger parameters can trigger such large-scale motions?

does the coherence of the "spiral" from ~10 kpc to >1 Mpc imply anything about viscosity of ICM?

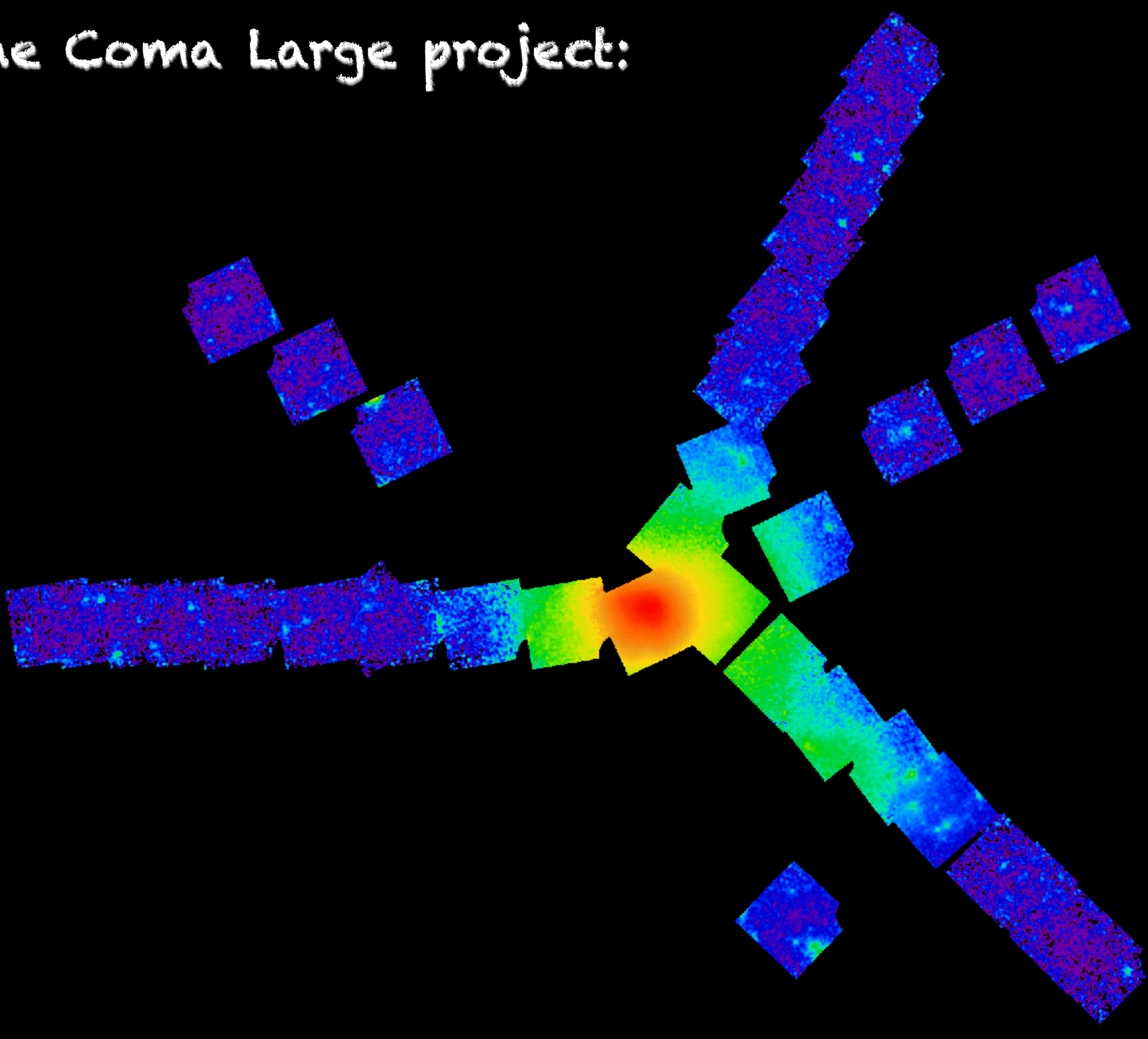
how does the cool core survive such a merger?

Large scale motions in cool core vs. non-cool core clusters

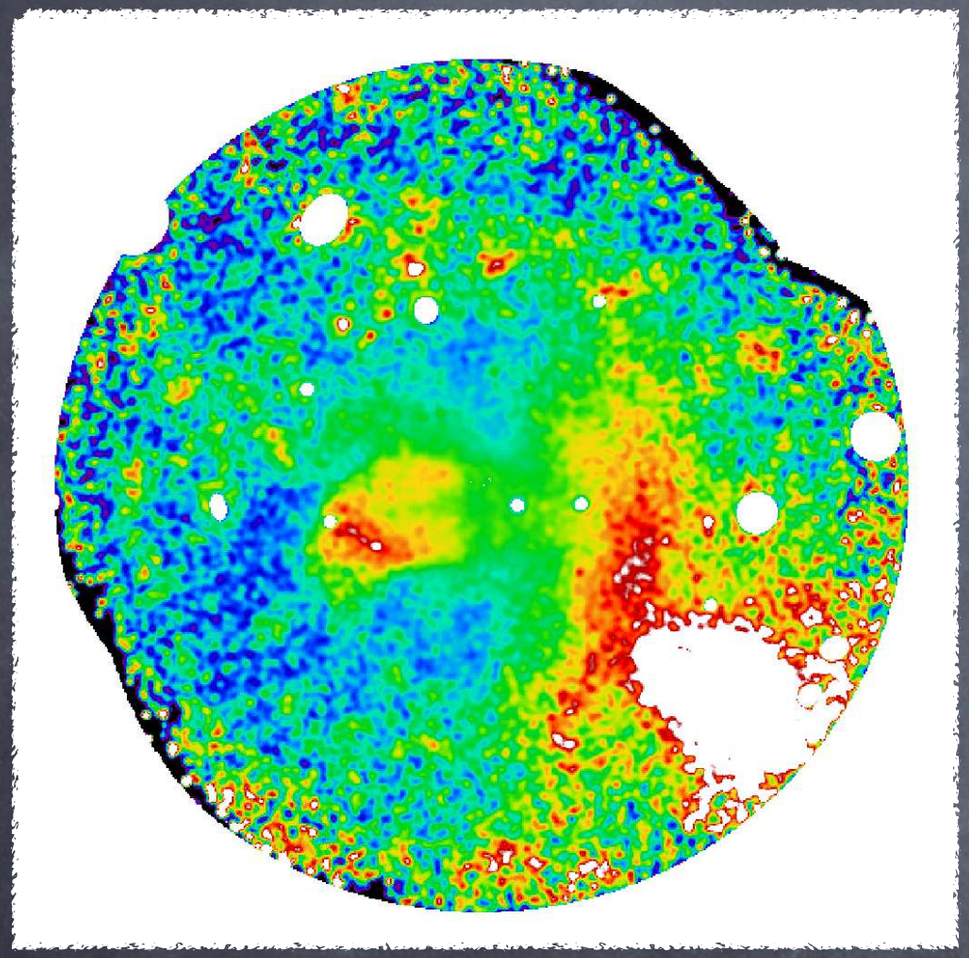


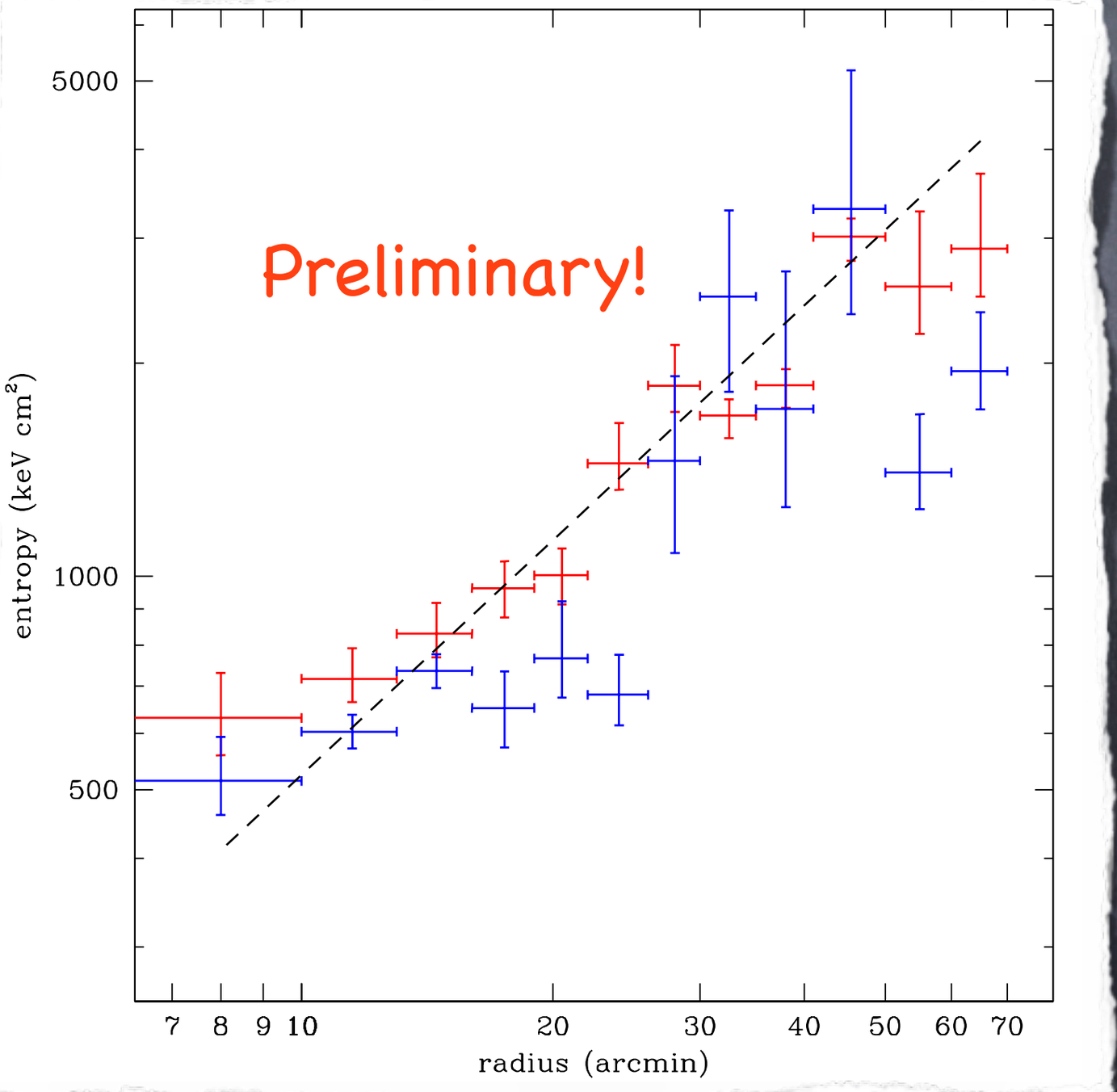
Warning: at least some degree of cosmic coincidence is definitely involved

The Coma Large project:



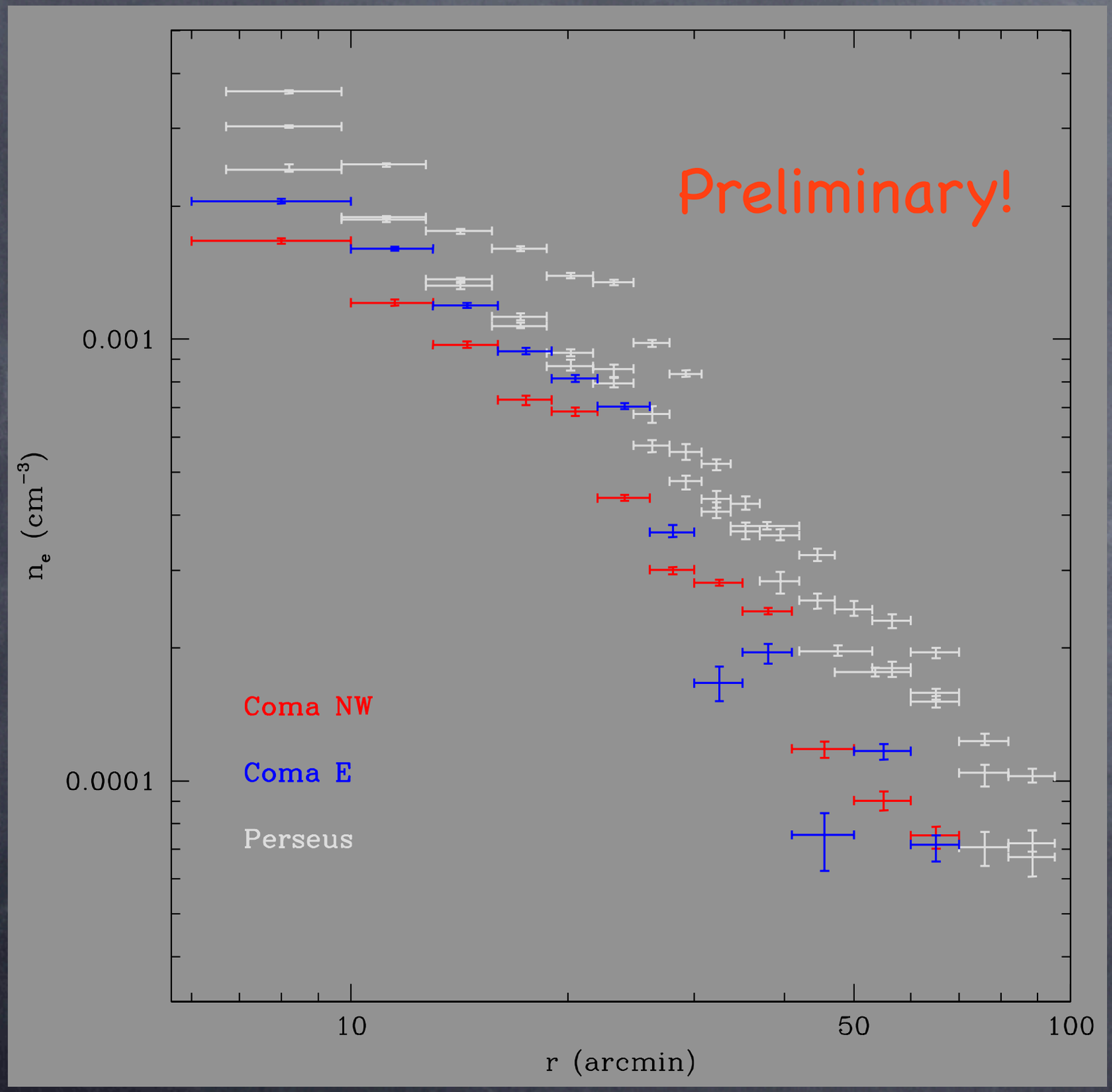
Large scale edges in Coma





In the entropy these edges look just like cold fronts - if you can have sloshing outside the cool core in CCC, what happens when you "slosh" a non-cool core cluster?

Is the Coma cluster underweight?



density at intermediate radii along relaxed E/NW directions smaller than expected

average kT probably boosted by merger and is not a good proxy for cluster mass/size

is virial radius of Coma smaller than expected?

Summary:

- AGN contribute to metal transport; this may induce turbulence and may affect geometry of B-fields; conduction is most likely anisotropic in cluster cores
- cold fronts / large scale motions may extend further out in radius than we thought
- gas in the outskirts may be clumpy, and/or NFW model may be less accurate than we thought
- the virial radius of Coma may be smaller than we thought - biases in boosting kT due to merger?