Exploring the Virialization Region of Merging Galaxy Clusters

S. W. Randall - CfA

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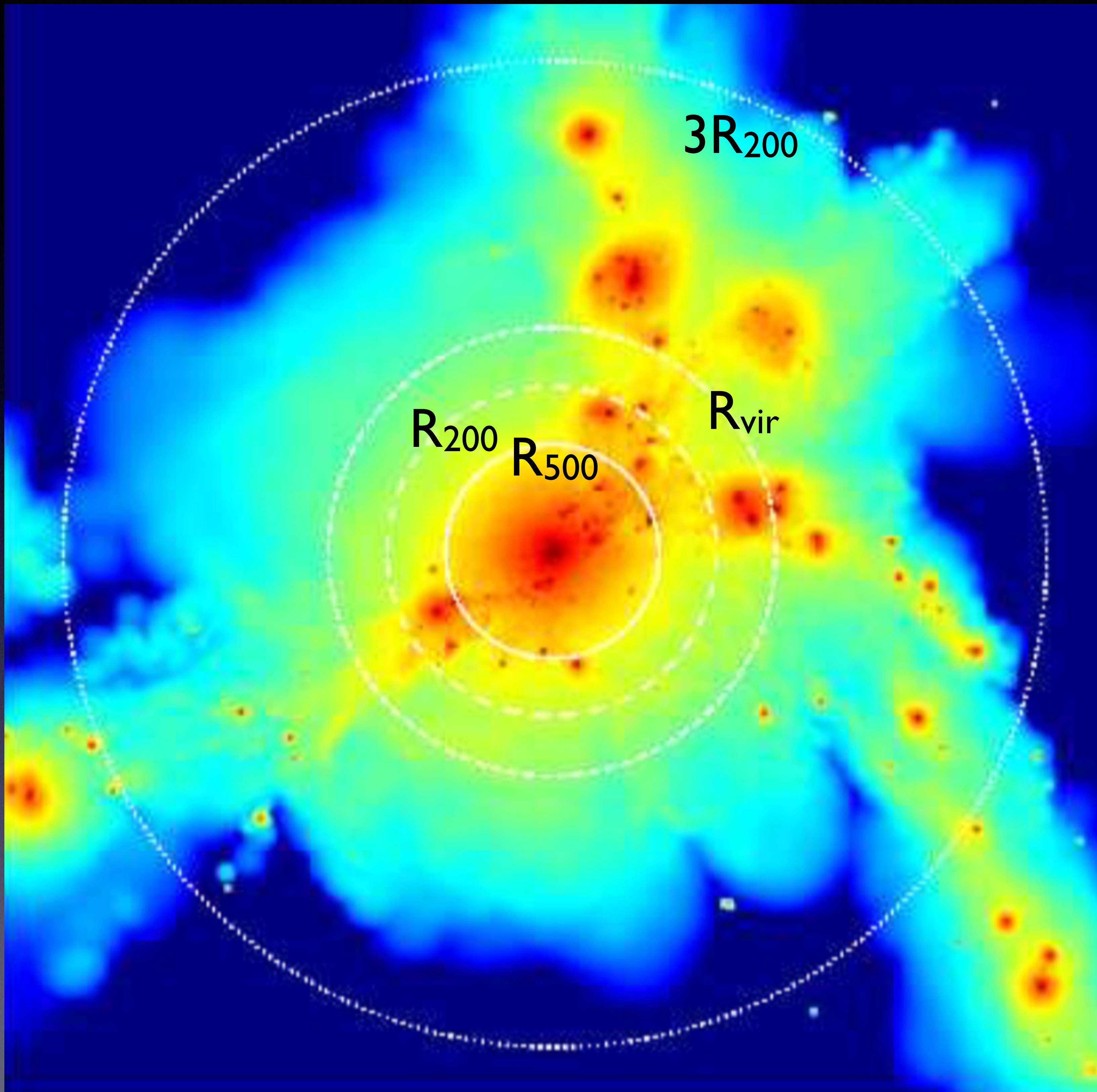
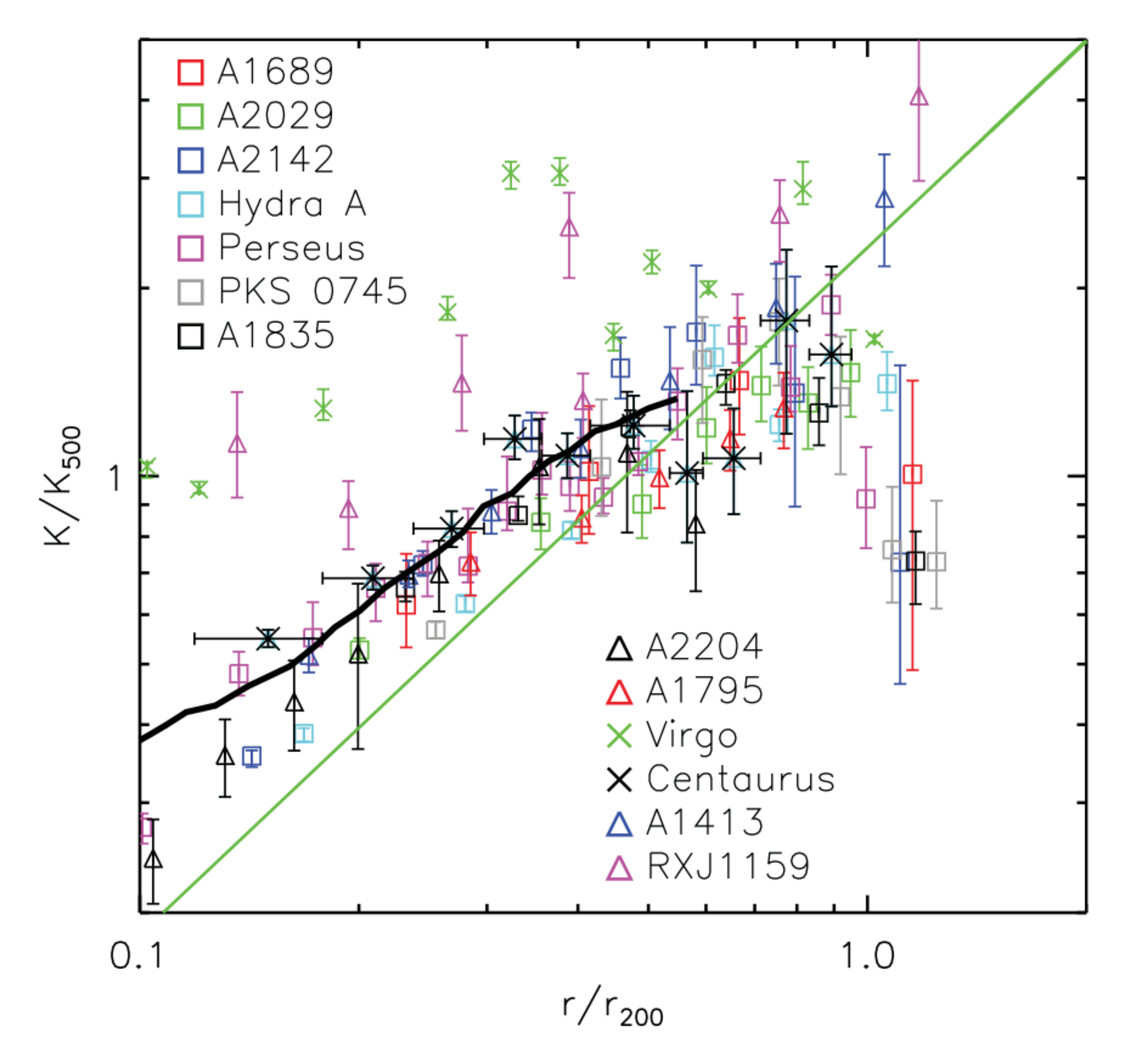


Reiprich+13, Roncarelli+06

- Most X-ray observations can only probe to up to ~R_{500} (Chandra, XMM)
- Suzaku, with its low background, could explore out to ~R_{200}, allowing significant progress
- The virialization region is relatively unexplored, and important for understanding cluster outskirt physics and the growth of clusters

Cluster Outskirts with Suzaku



$K \sim kT/n_e^{3/2}$

Walker+13

Entropy Flattening

Gas clumping (Simionescu+11)?

Weakening accretion shocks? (Lapi+10; Cavaliere+11)

e-i non-equilibrium? (Hoshino+10; Akamatsu+11)

Non-thermal pressure support? (Lau+11)

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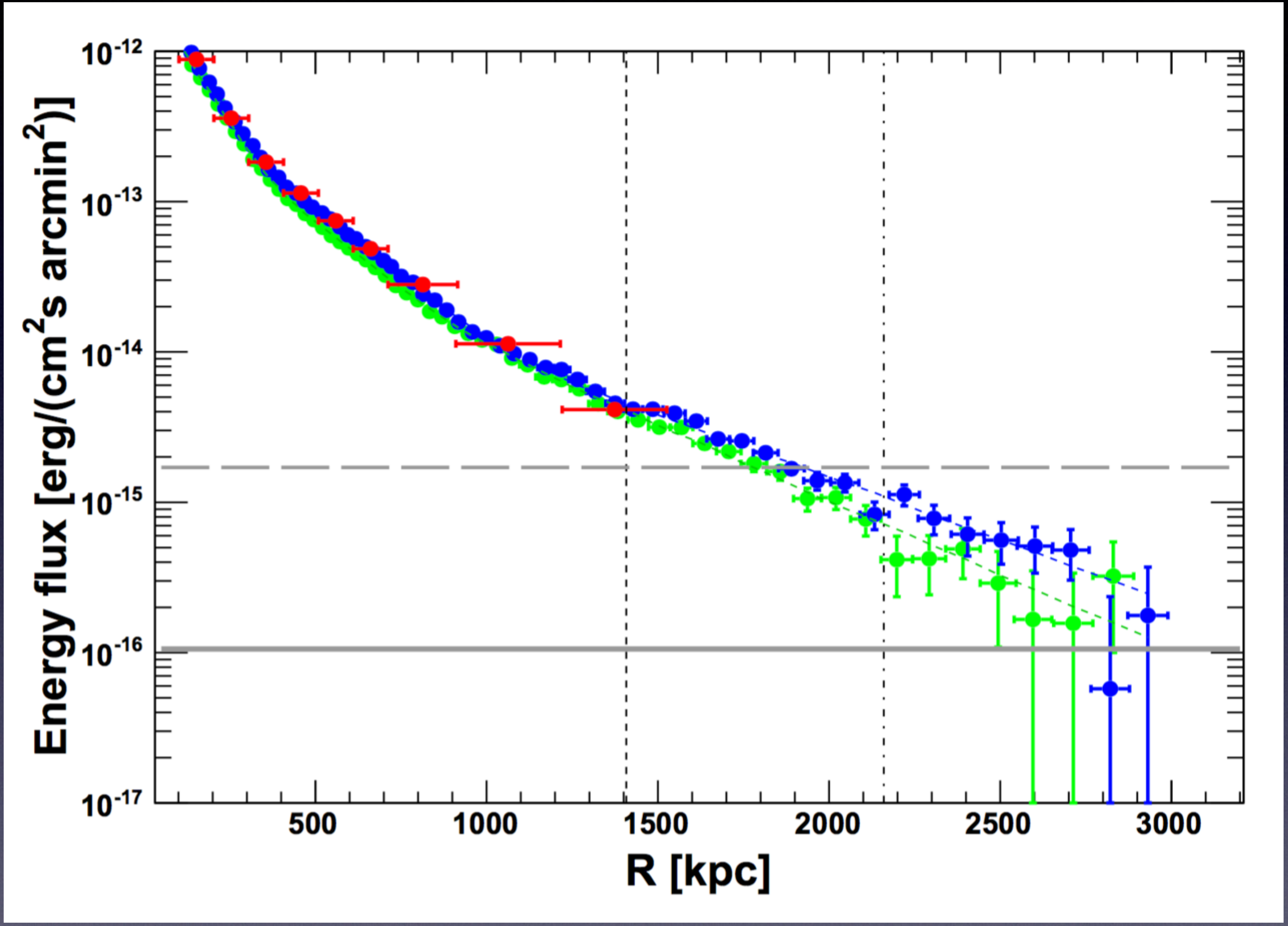
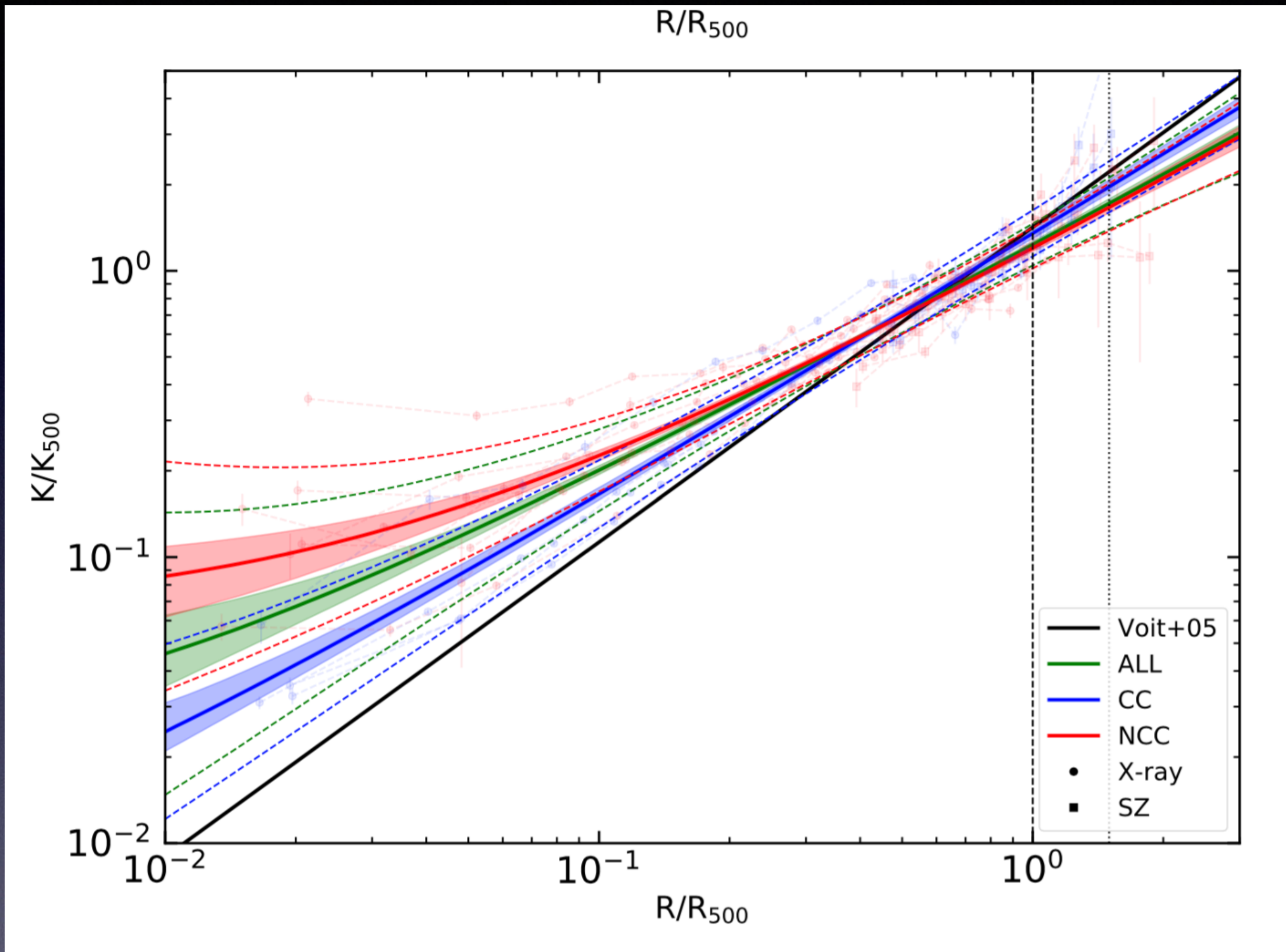
Abell 2142



- X-COP project combines X-ray and SZ observations to measure ICM profiles out to R_{200} (Eckert+17)
- Deviations like clumps are largely “filtered out” by using the median azimuthal surface brightness instead of the mean

Tchernin+16



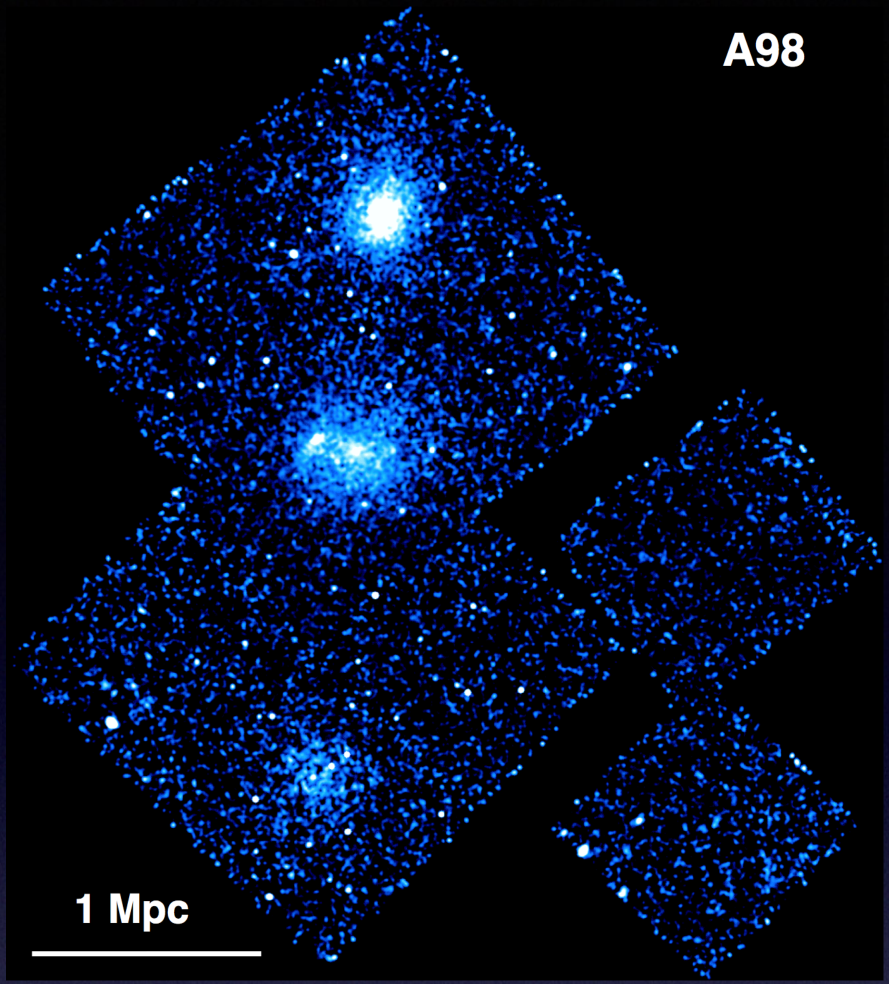
Ghirardini+19

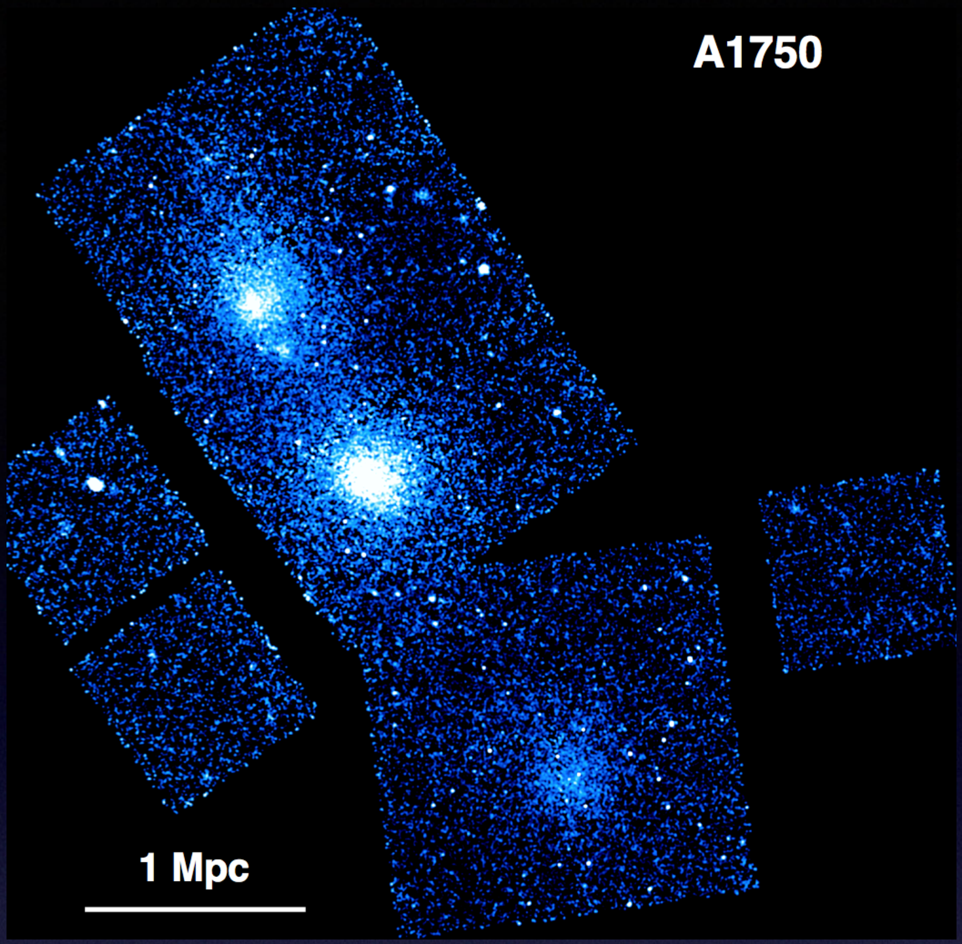
- Most recent X-COP sample finds profiles consistent with self-similar, after clumps are removed
- Little to no difference between CC and NCC systems, implies connection to merging history instead of current merging rate (although c.f. Ecker+12)

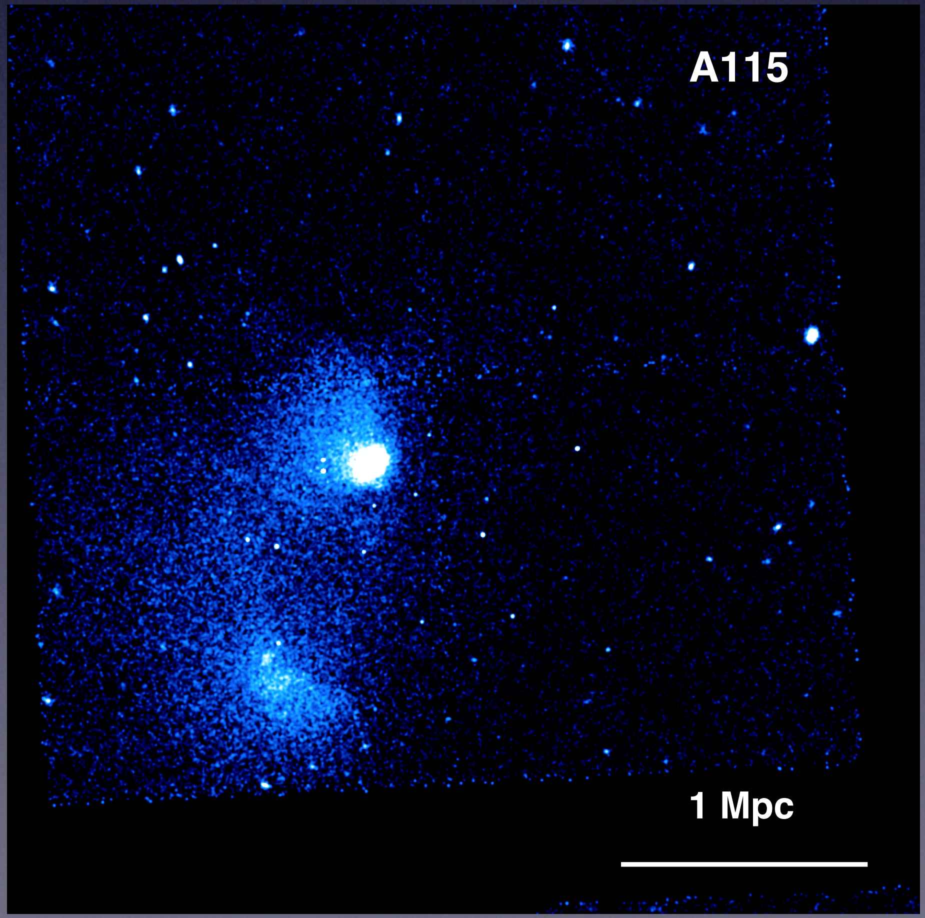
Merging Clusters

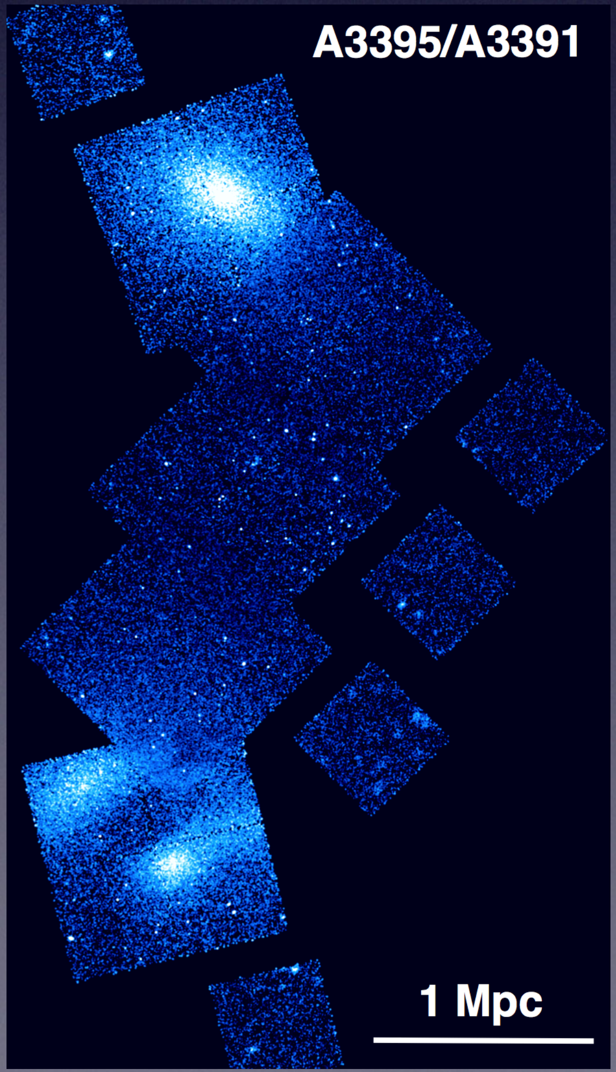
- Simulations show that much of the interesting physics associated with cluster growth is happening in the dynamically active parts of the virialization region, where clusters connect to the cosmic web

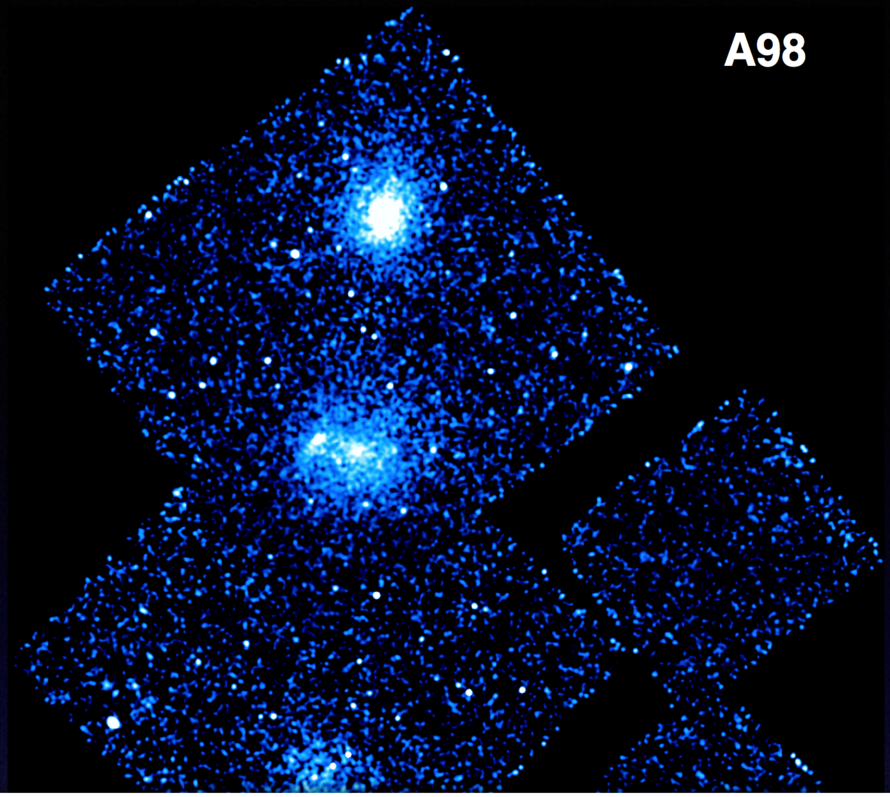
- How do we find these active systems if not all NCCs are currently dynamically active, and how do we know where the active regions are?

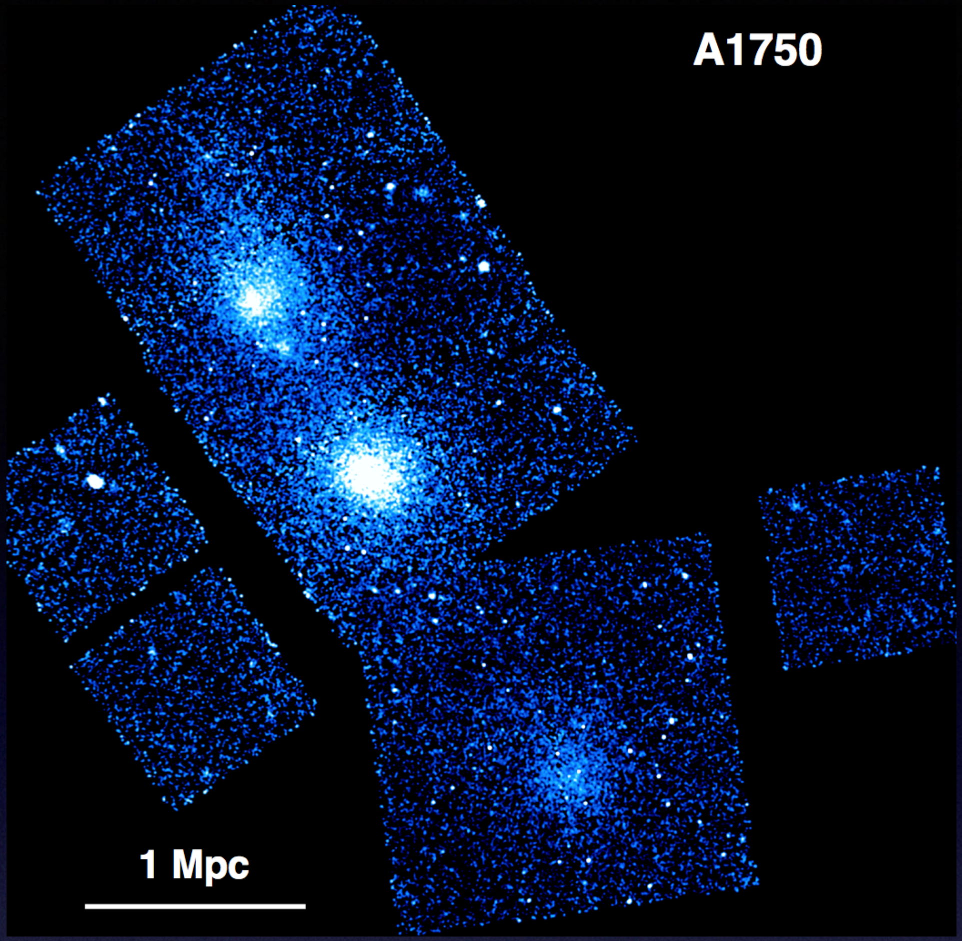

A98
1 Mpc


A1750
1 Mpc


A115
1 Mpc


A3395/A3391
1 Mpc

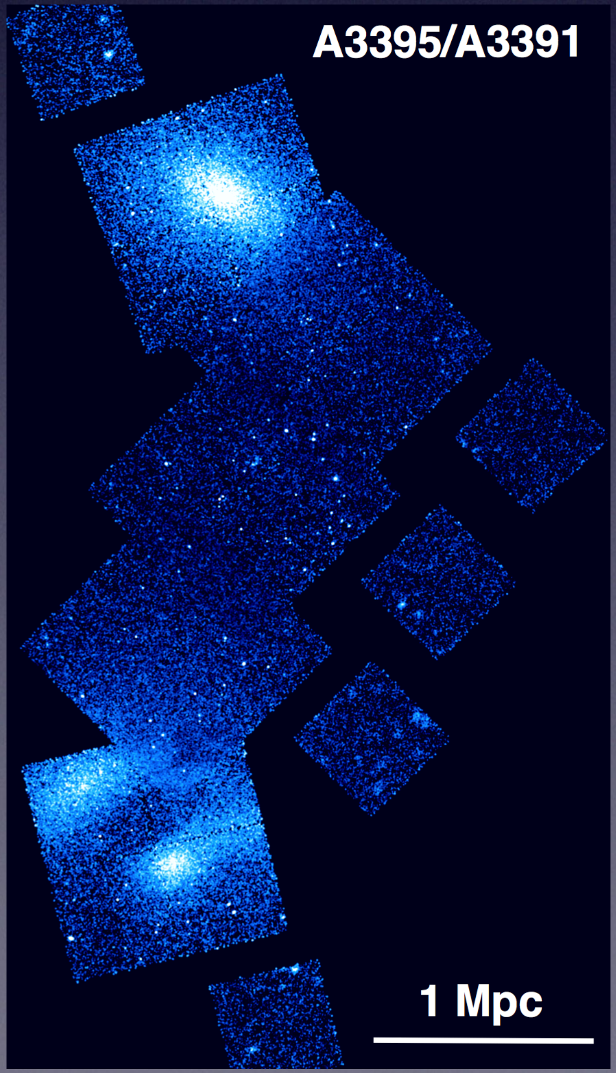




- Consider "binary" pre-merger systems

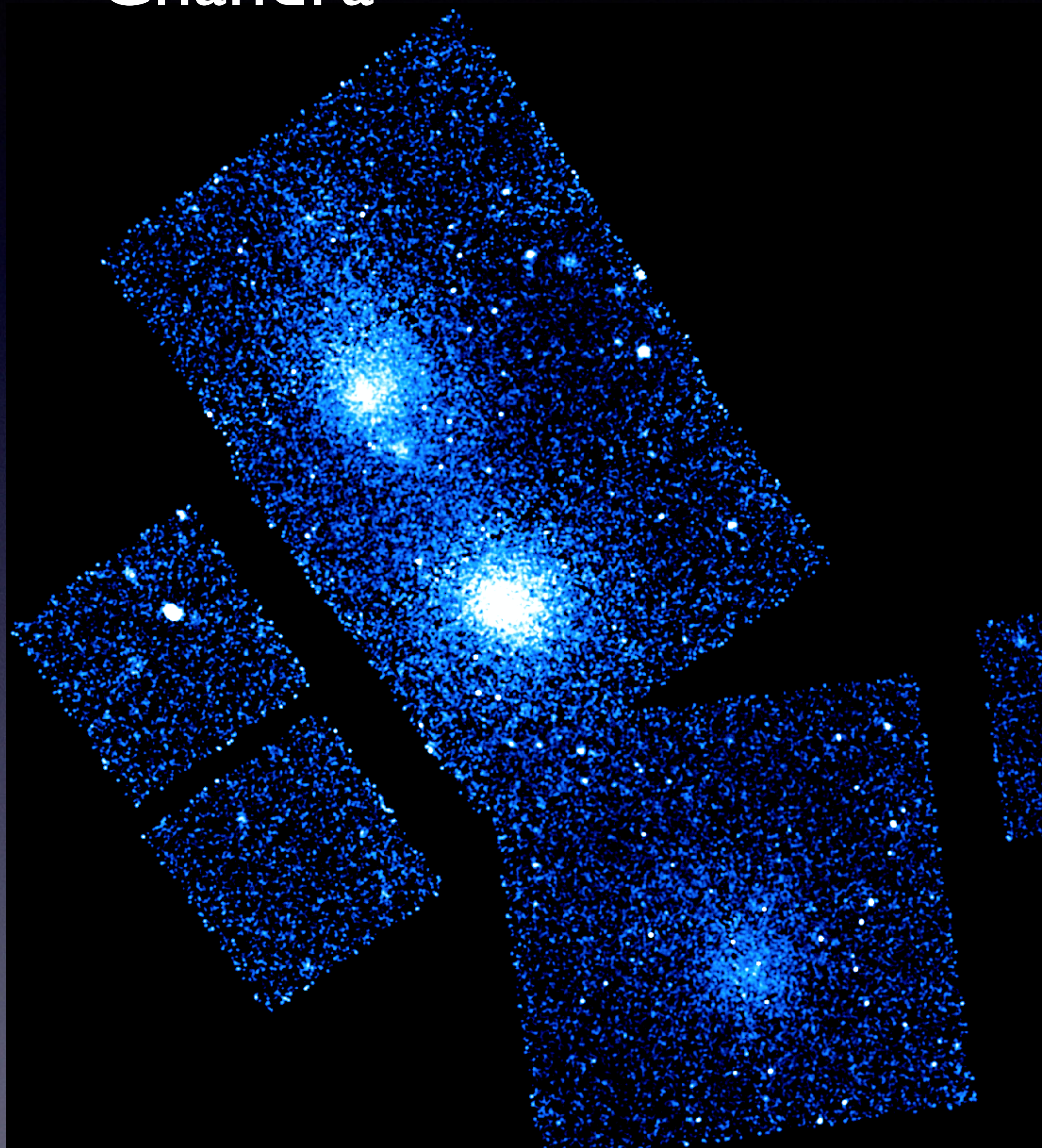
- Currently merging, dynamically active

- The LSS filament should follow the merger axis, so we can can directly compare dynamically active and less active regions

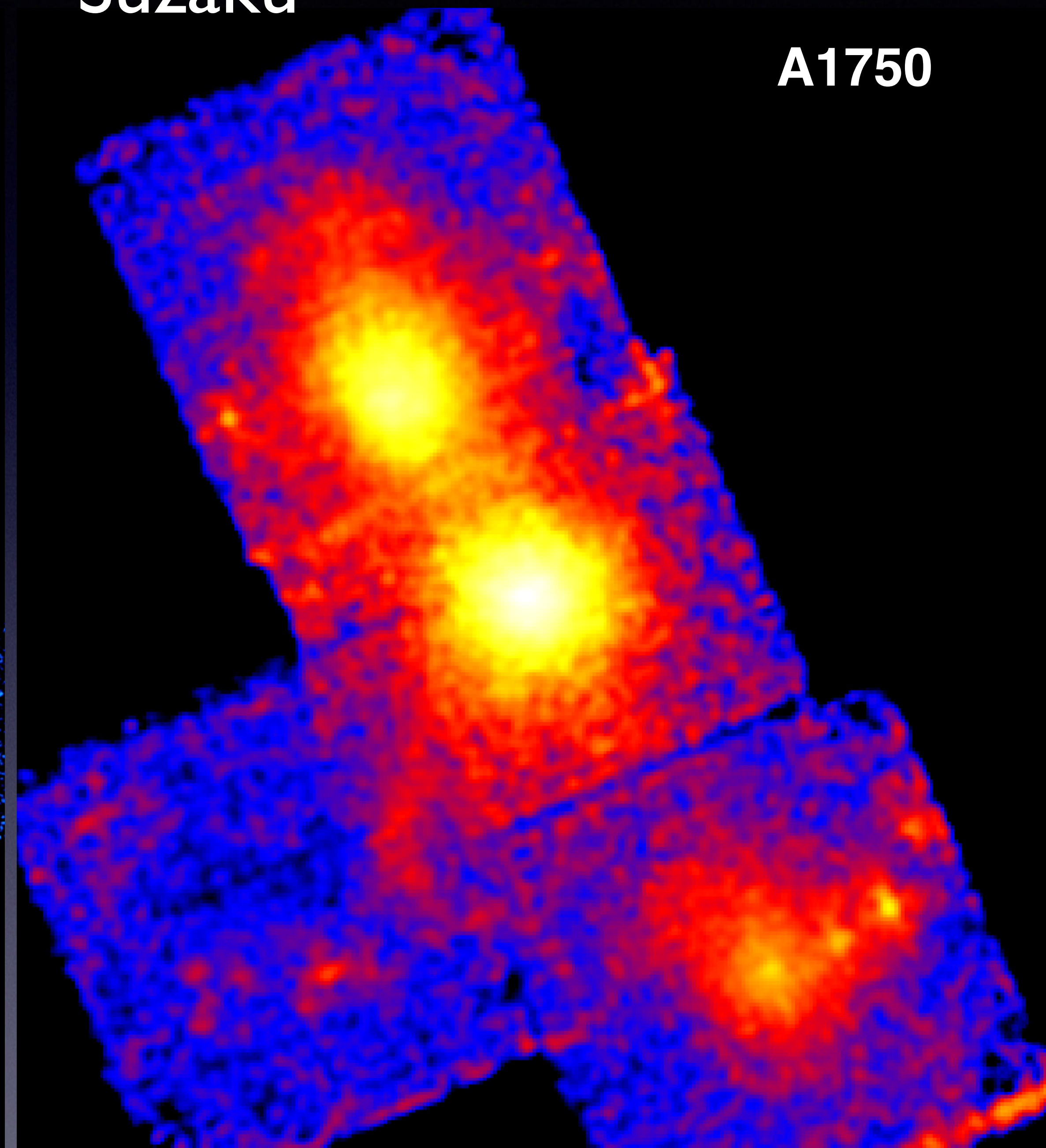


Abell 1750

Chandra

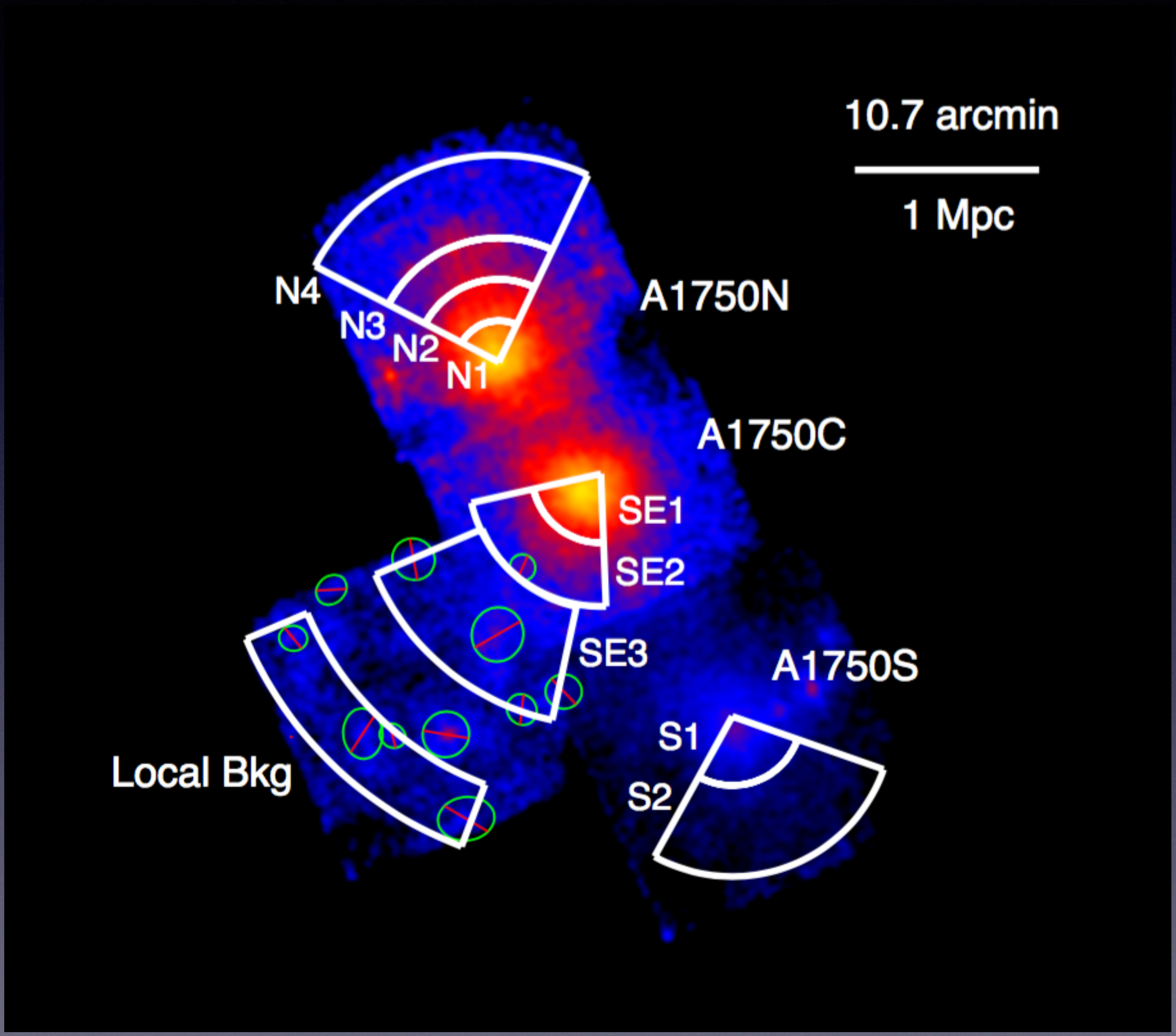


Suzaku



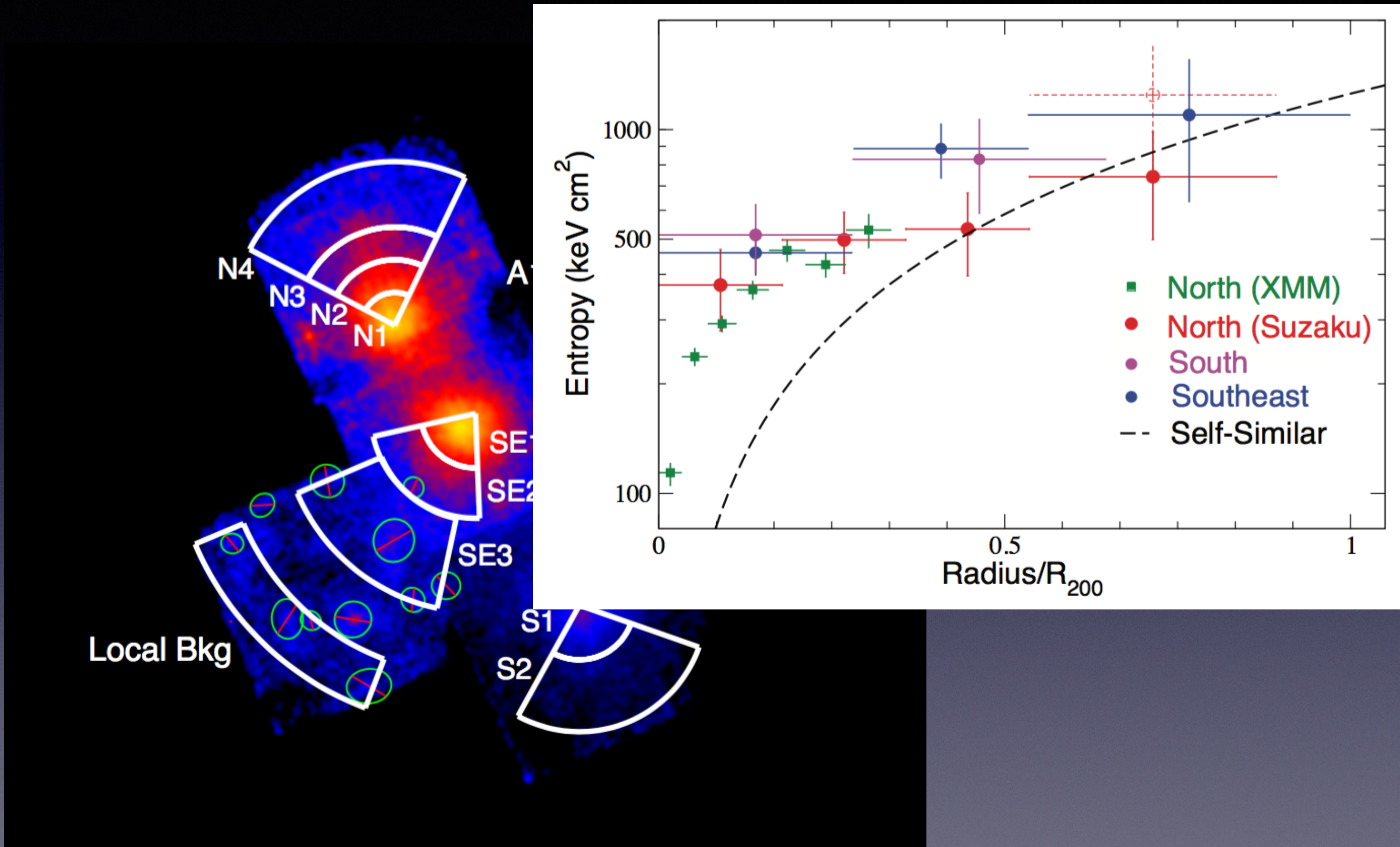
kT ≈ 3-4 keV; z=0.085

Abell 1750



Bulbul, SWR+16

Abell 1750



Bulbul,SWR+16

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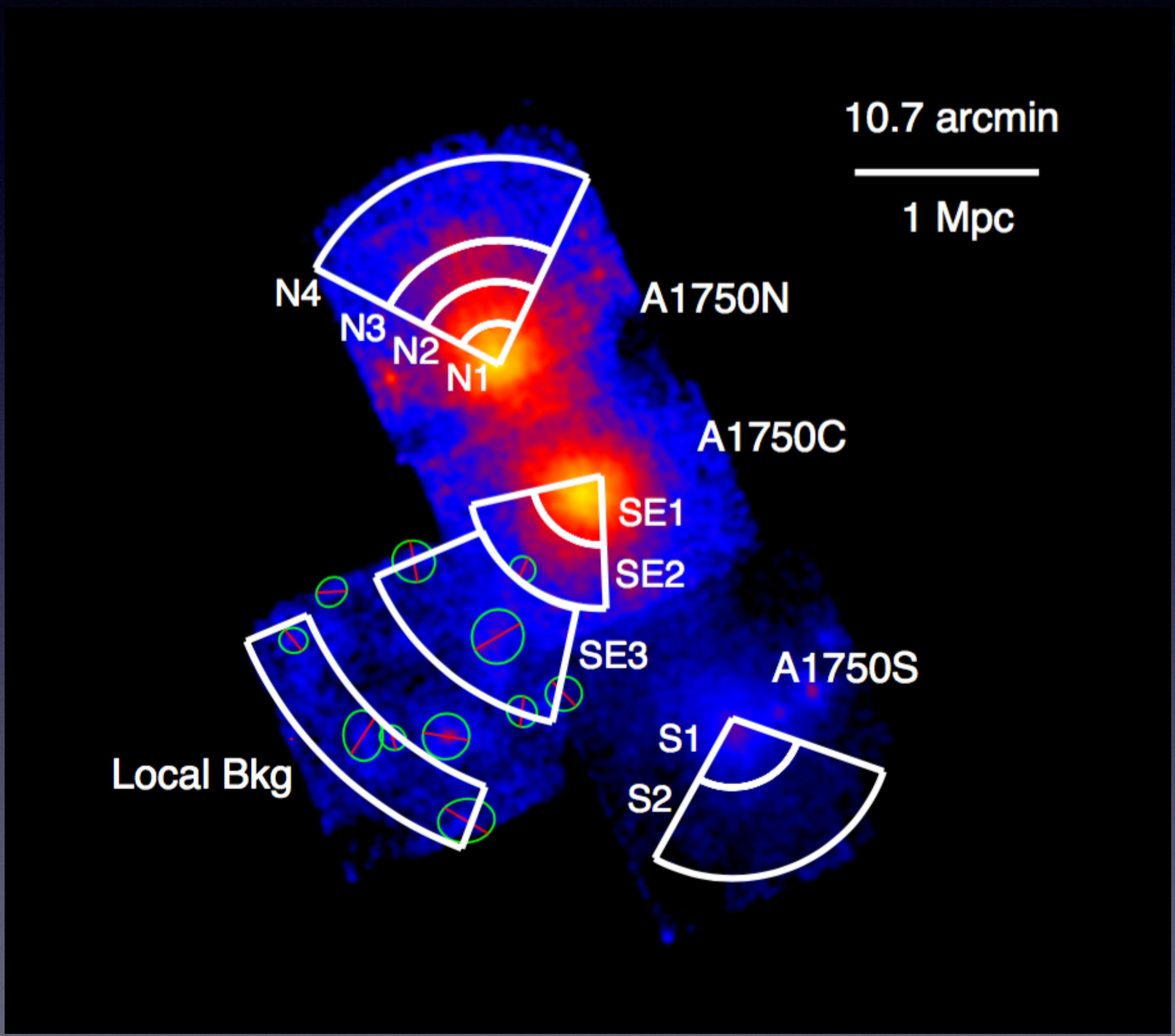


- Spectral fits to regions N3 and N4 reveal a soft component:

  N3: $kT_1 = 2.9^{+0.9}_{-0.7}$, $kT_2 = 1.0 \pm 0.1$

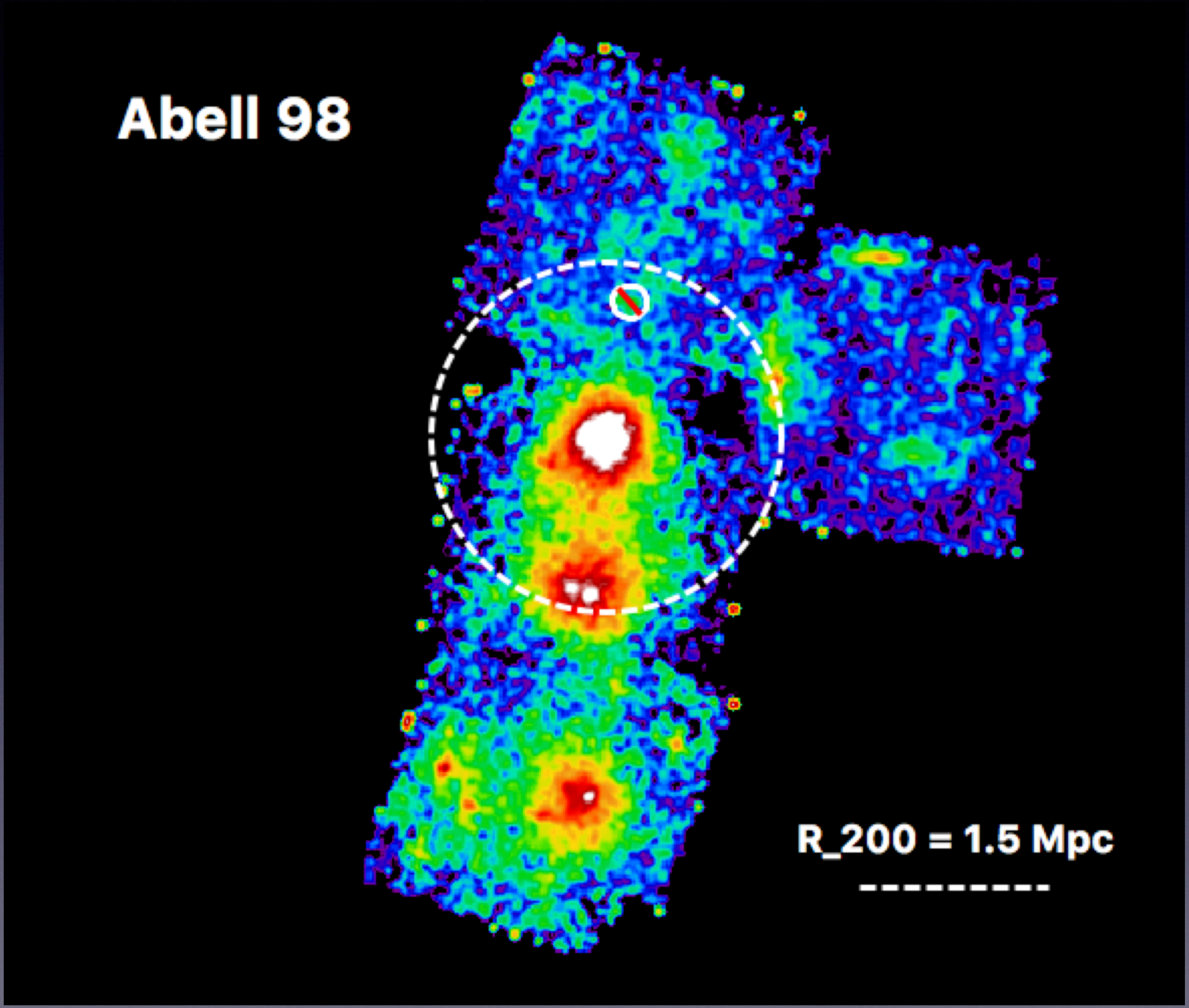
  N4: $kT_1 = 2.1^{+0.7}_{-0.5}$, $kT_2 = 0.8^{+0.2}_{-0.1}$

- Not detected to the SE

- Temperature and density are consistent with the dense end of the WHIM (but can't rule out disrupted groups or clumps)

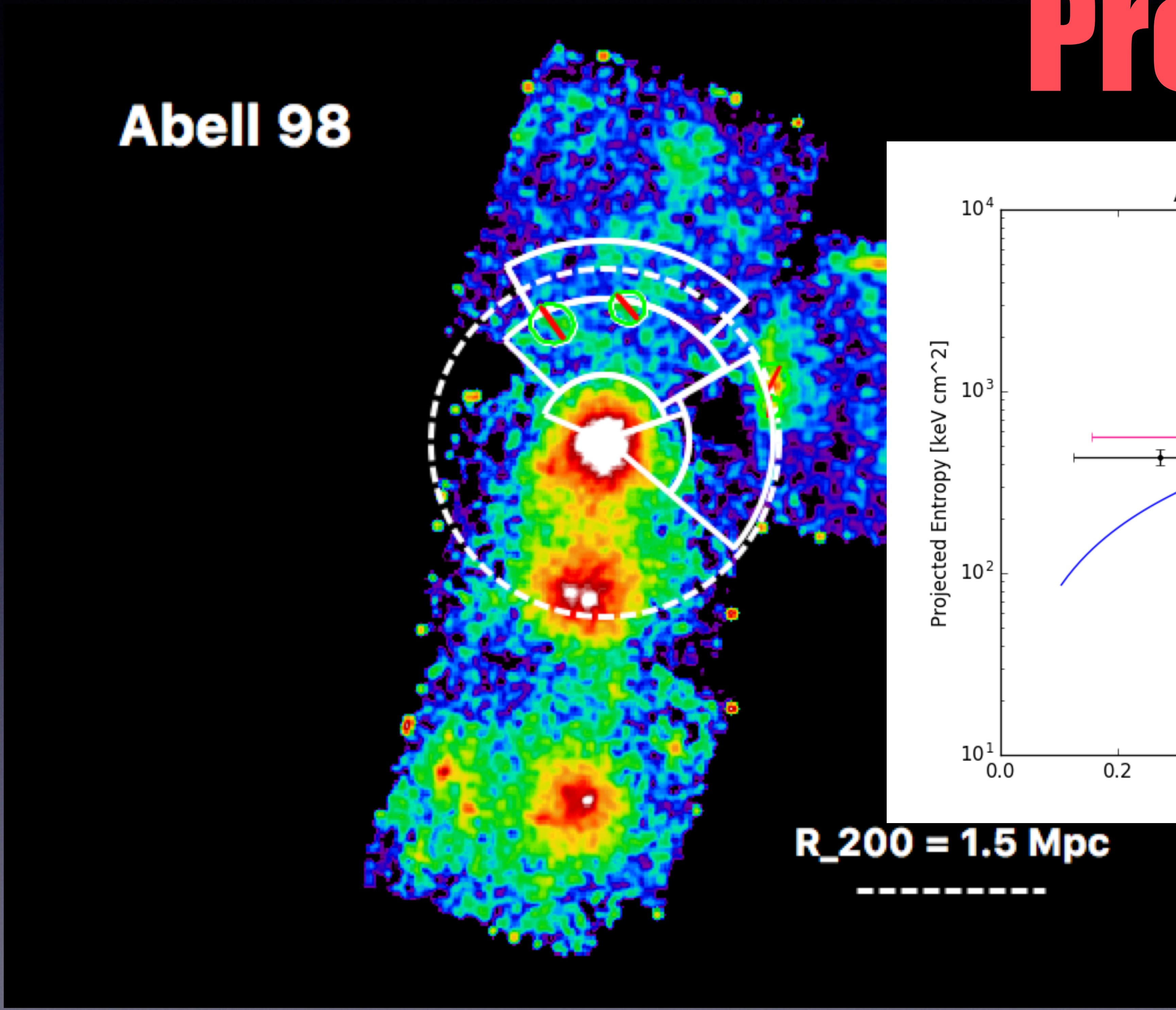
- Such detections are <u>very</u> rare (A222/223, Werner+08)

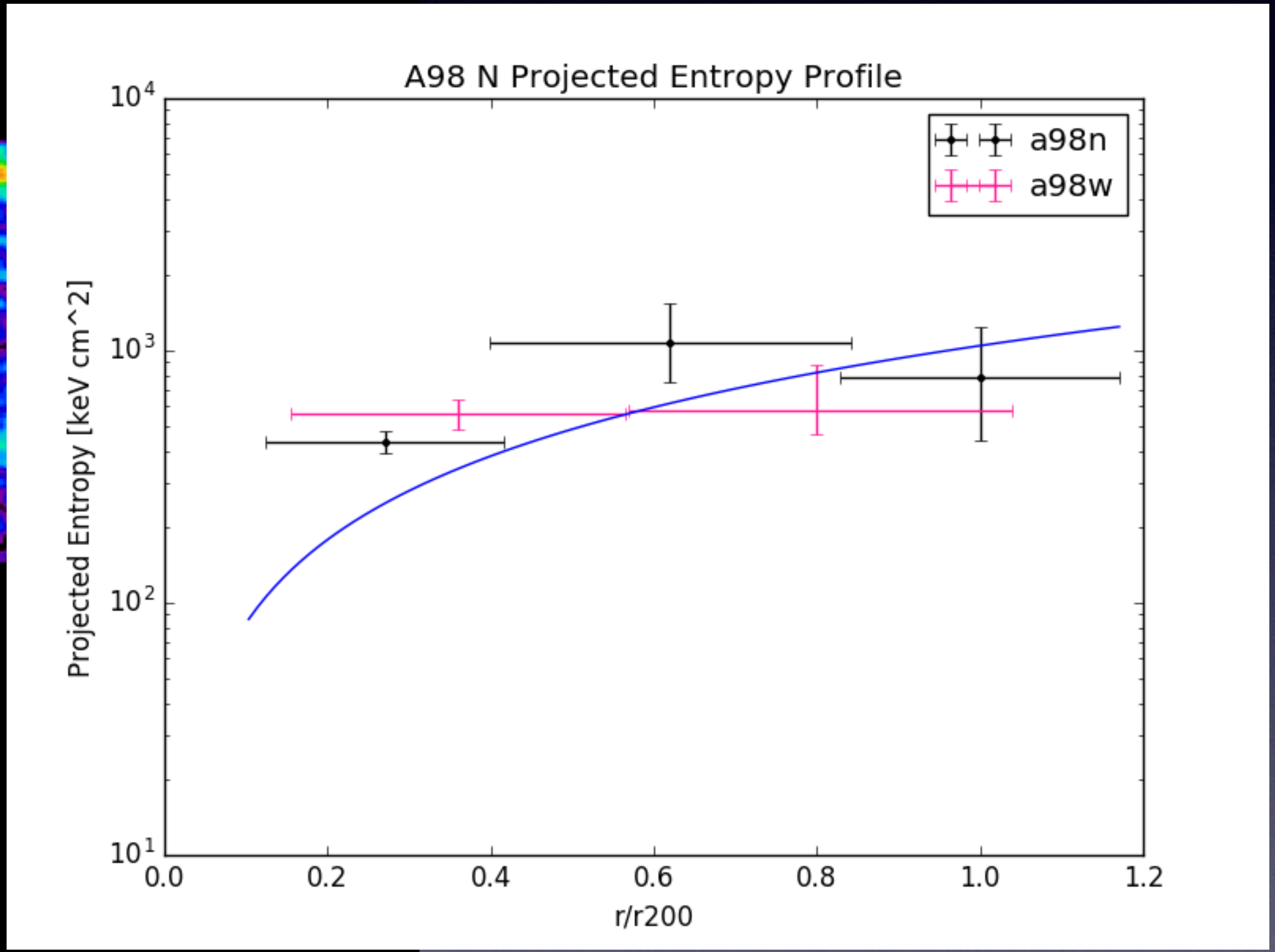
Abell 98



Abell 98

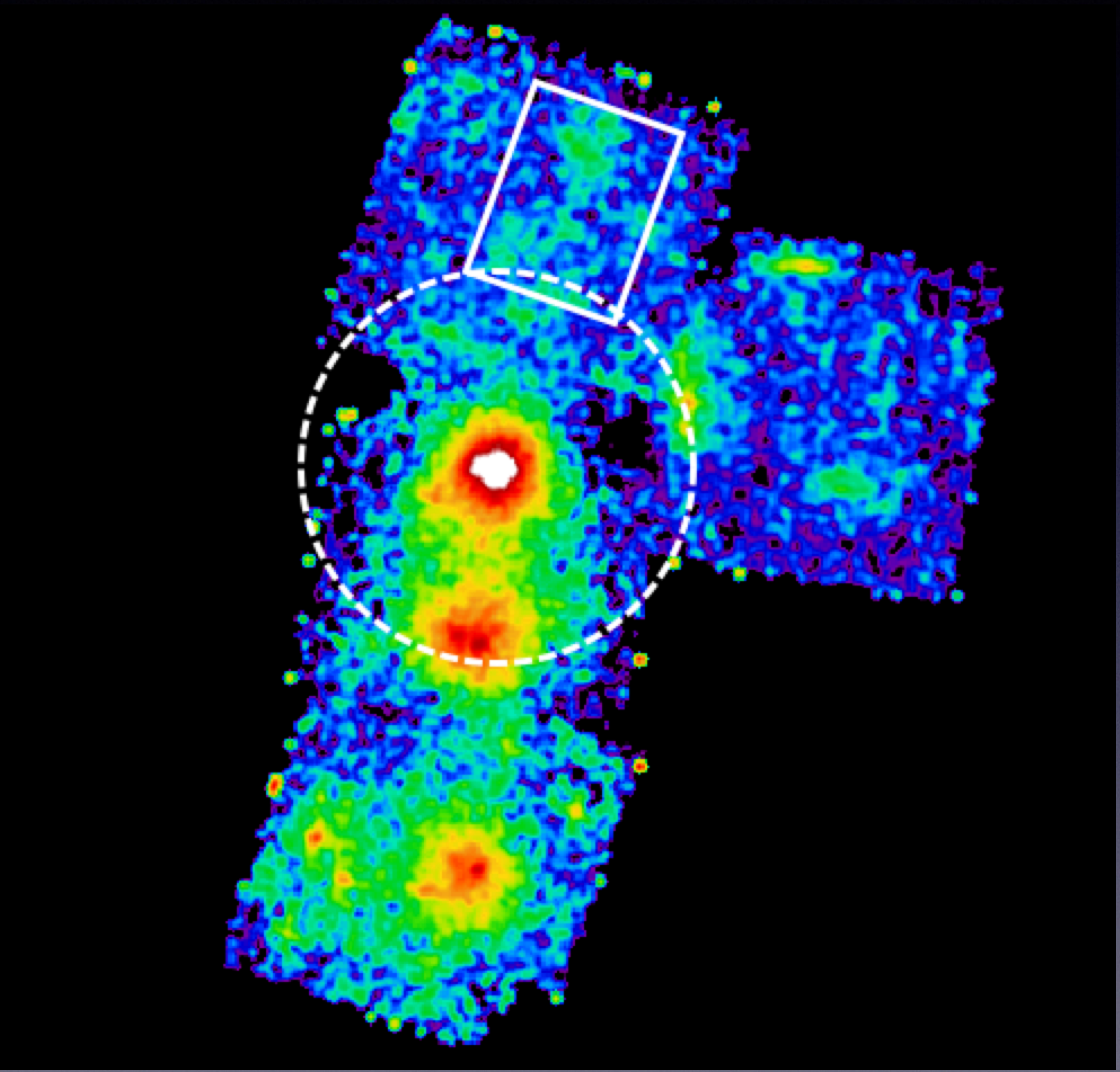
Preliminary





Alvarez,SWR+in prep.

Abell 98



Preliminary

"Filament" properties:

$kT = 1.6^{+0.8}_{-0.6}$

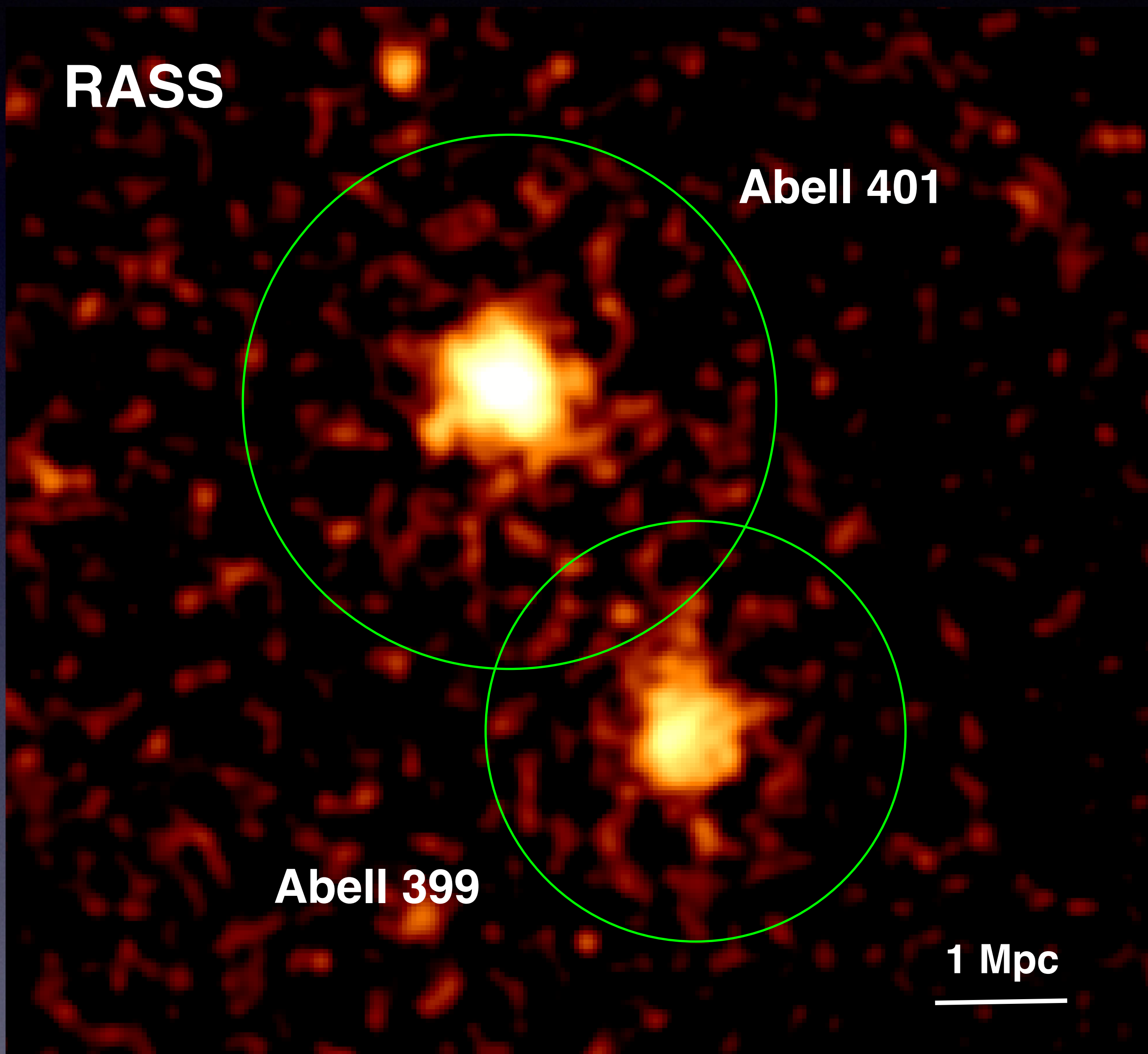
$n_e = 6.6\times10^{-5}$ cm^{-3}

$K = 950$ keV cm^2

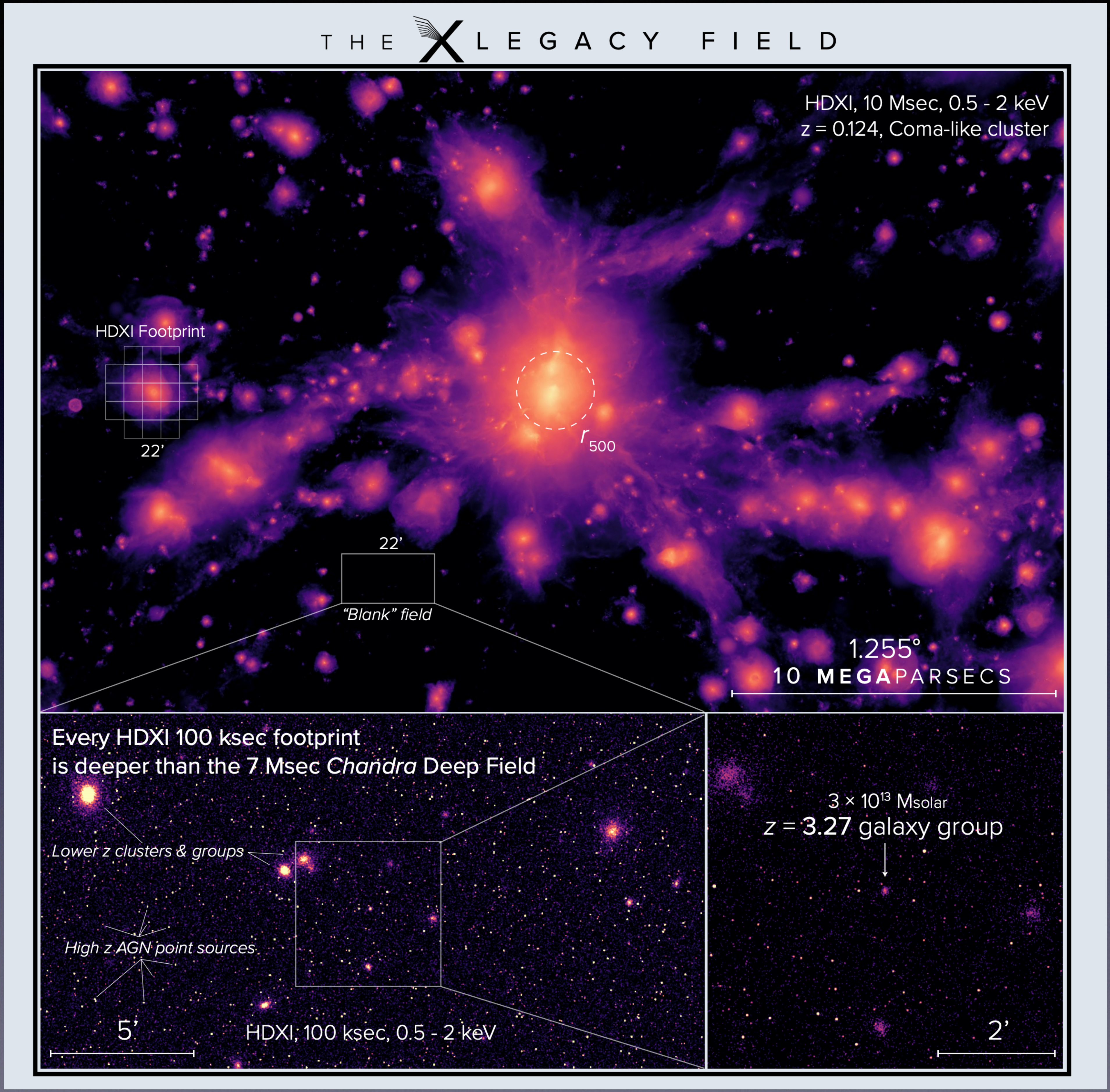
What's Going on?

- In the binary systems we looked at there's no evidence for entropy flattening at the viral radius, either along or off the putative filament, even though there is evidence for cool gas in the filament
- 5 systems that show moderate to no entropy flattening in Walker+13 are cooler (2-3 keV), with one exception (A1413)
- Independent studies of other low-temperature systems tend to show the same (Su+15; Tholken+16; Wong+16)
- In Bulbul+16 we suggested that lower kT systems tend to show less entropy flattening, and that mass is a more important predictor of clumping than dynamical state

Future Work



- Need to explore high-temperature mergers out to their viral radii
- The A399/A401 system is a strong candidate
- kT ≈ 6 keV, z ≈0.07, only intercluster filament detected with high significance by Planck (PC+13)
- Simulations show A401 can be mapped out to its viral radius with 8 Chandra pointings totaling 3.2 Msec, which implies 70 ks with Lynx (~9 ks per pointing)


THE X LEGACY FIELD
HDXI, 10 Msec, 0.5 - 2 keV
z = 0.124, Coma-like cluster
HDXI Footprint
22'
r_{500}
22'
"Blank" field
1.255°
10 MEGAPARSECS
Every HDXI 100 ksec footprint
is deeper than the 7 Msec Chandra Deep Field
Lower z clusters & groups
High z AGN point sources
5'
HDXI, 100 ksec, 0.5 - 2 keV
3 × 10^13 Msolar
z = 3.27 galaxy group
2'

Summary

- The virialization regions of merging clusters are understudied, and are important for learning about ICM physics, the growth of structure, the ICM/WHIM interface, and possibly cluster cosmology.
- Early stage, binary mergers *should* be good places to study the physics of cosmic accretion and cluster outskirts.
- Although we do find some evidence for dense WHIM/filament emission, we find *no* evidence for entropy flattening in the binary systems we looked at.
- We suggest that the outskirts of low mass systems (~< 4 keV) are less affected by accretion processes and therefore have ICM profiles that are more consistent with self-similar predictions (this has implications for using such systems for cosmology).
- Lynx and Athena will revolutionize this field, with Lynx resolving small, individual clumps.