Exploring the Outskirts of Merging Galaxy Clusters

S. W. Randall - CfA

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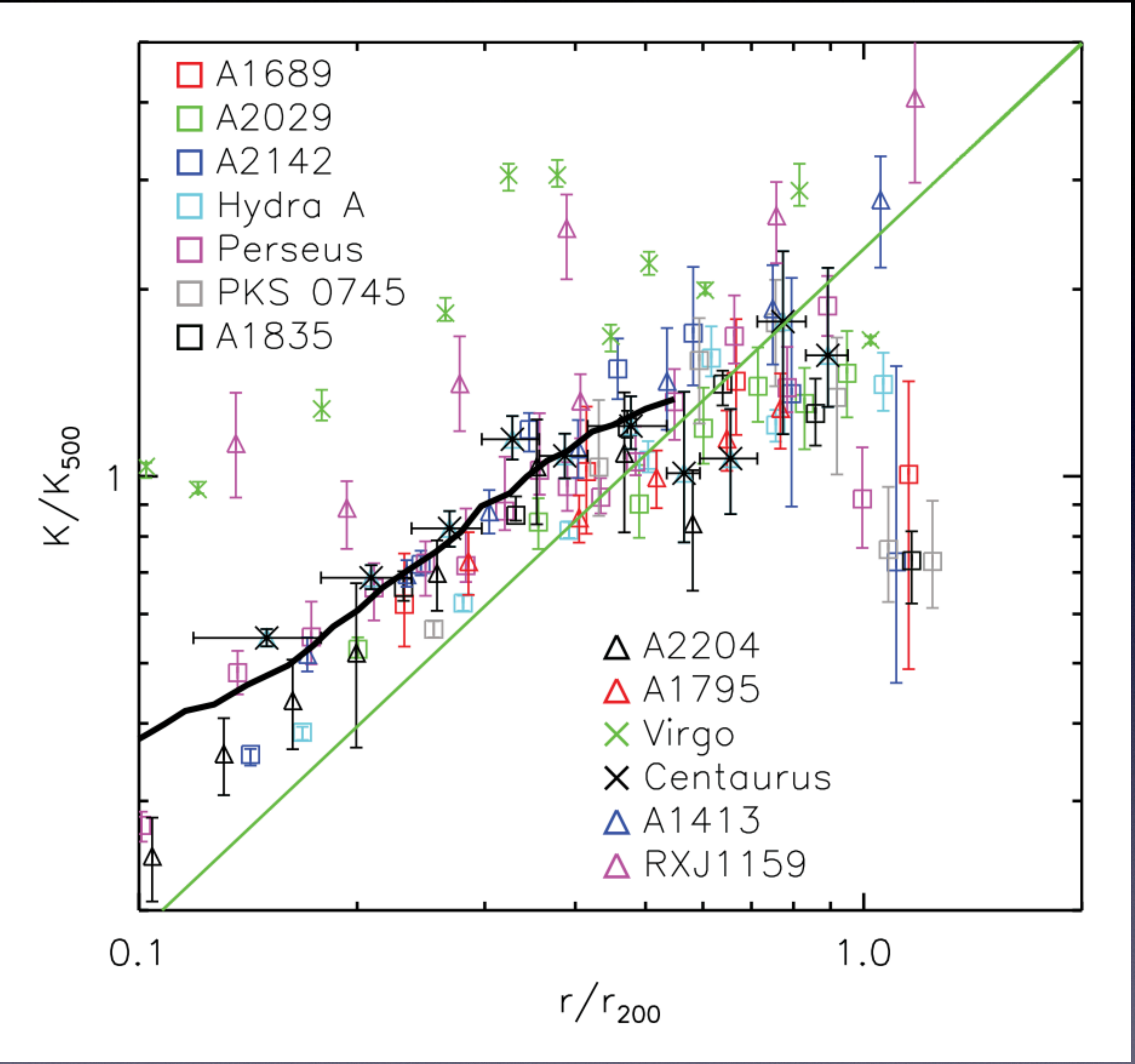
Cluster Outskirts and Suzaku

- Suzaku, with its low and stable background and reasonably high effective area, allowed for the first systematic studies of the ICM in clusters out to their virial radii
  PKS0745 (George+09); A2204 (Reiprich+09); A1795 (Bautz+09); A1413 (Hoshin+10); A1689 (Kawaharada+10)...

- Observations have generally found entropy profiles that flatten below self-similar predictions (Voit +05), and baryon fractions that rise above the cosmic value near the viral radius



Walker+13
(Black line from XMM REXCESS sample of Pratt+10)

Entropy Flattening

- Various explanations have been proposed:
  - Gas clumping (Simionescu+11)
  - Weakening accretion shocks (Lapi+10; Cavaliere+11)
  - e-i non-equilibrium (Hoshino+10; Akamatsu+11)
  - Non-thermal pressure support (Lau+09)

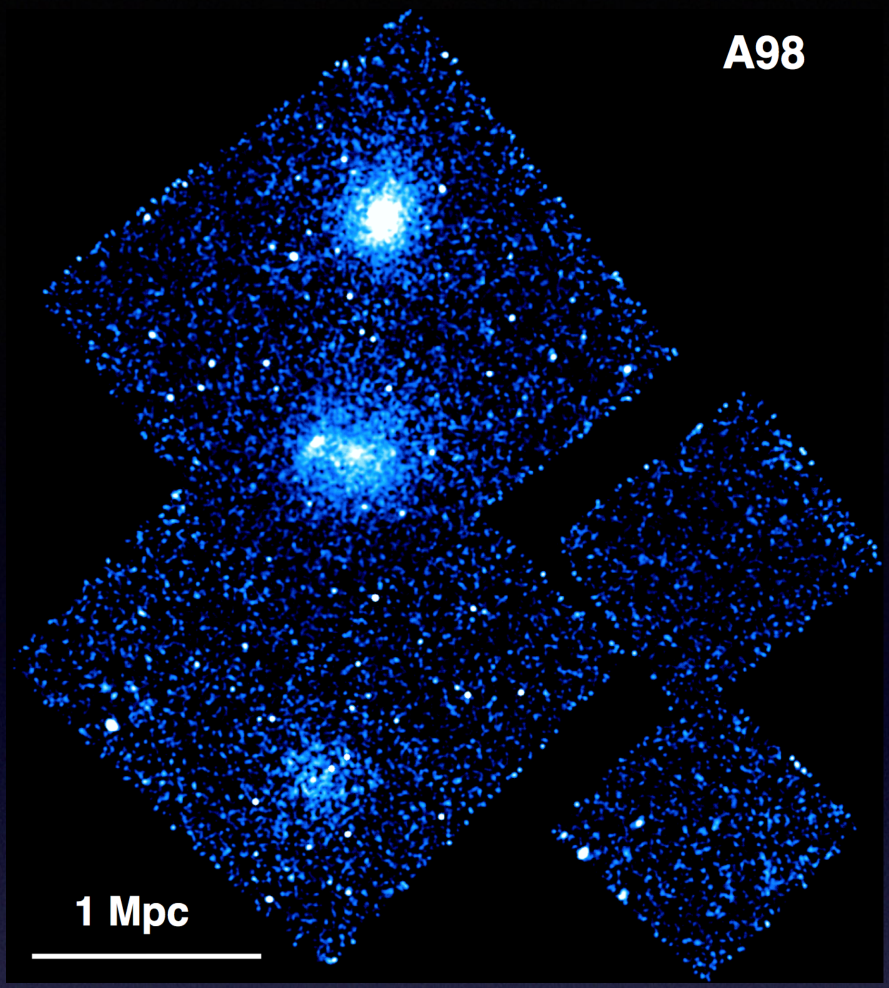
- Gas clumping is generally thought to be the most likely cause (e.g., Walker+13), although the clumping factors required generally disagree with predictions from simulations (Roncarelli+06, Nagai+11)

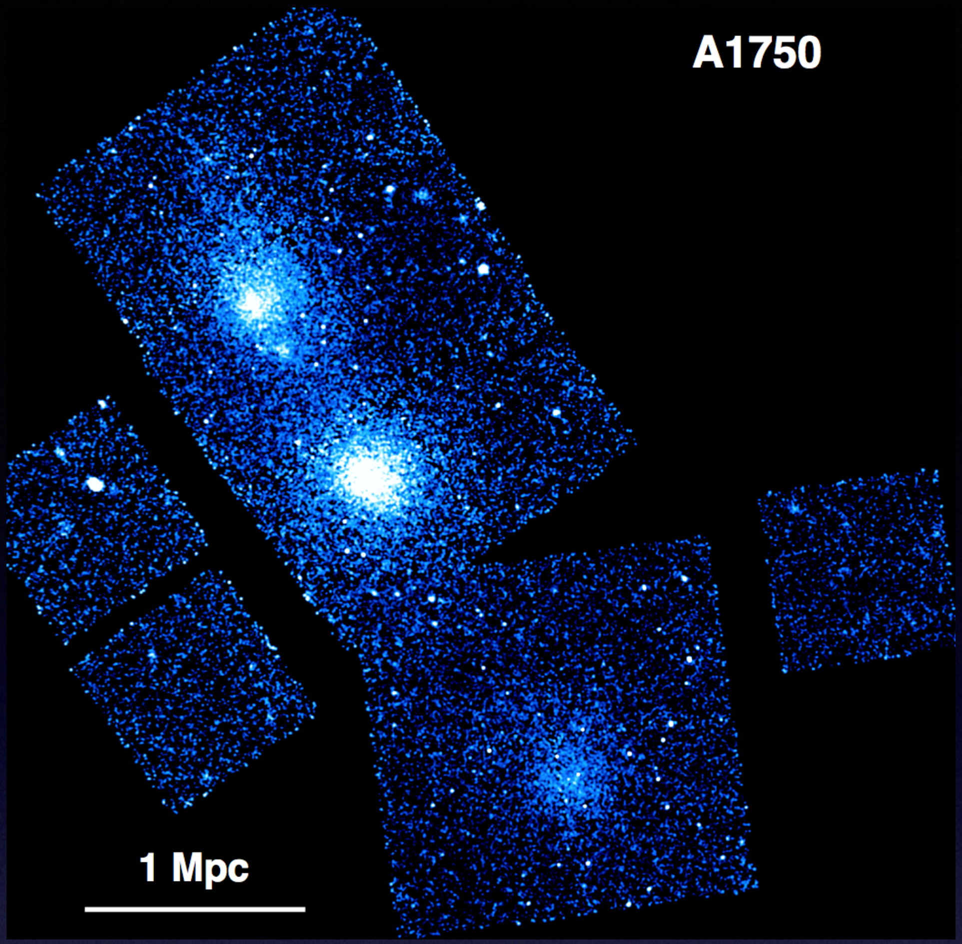
Why Merging Clusters?

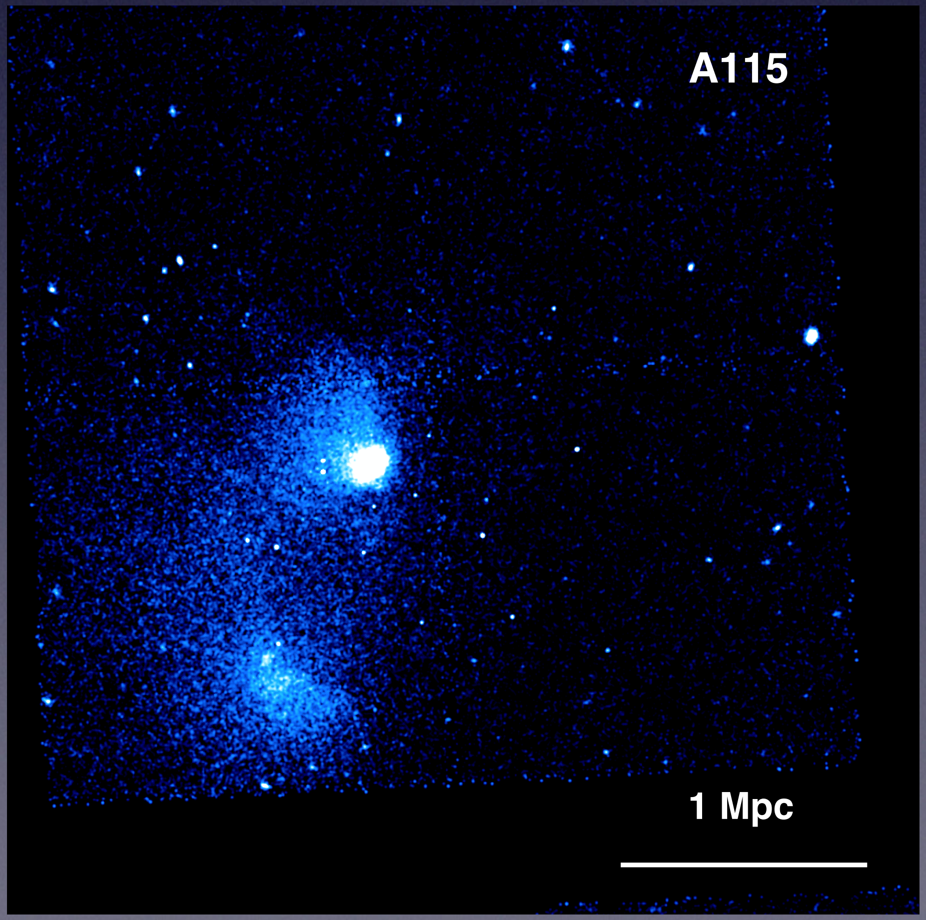
- The large majority of work has been done on relatively relaxed, non-merging clusters, even though mergers represent the growth of structure formation in action
- Simulations (Nagai & Lau 2011) and observations with ROSAT and Planck (Eckert+12,13) find differences between dynamically relaxed and unrelaxed systems, with the latter more closely following self-similar expectations
- Early stage major binary mergers are expected to take place along large scale structure filaments, can directly compare ICM properties along and off the filament
- The physics of interface region between the ICM and the putative WHIM is very poorly studied

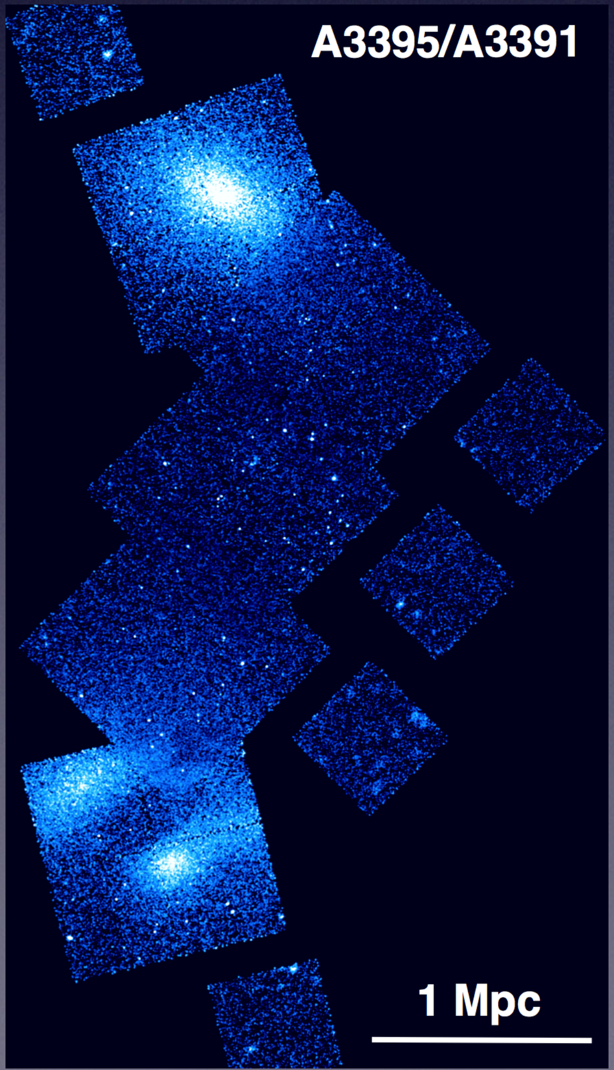
Why Merging Clusters?

- Important verification of structure formation models; e.g., are clumps preferentially found along LLS filaments, as predicted by simulations (Nagai & Lau 2011), or are clumps destroyed in more dynamically active regions, as suggested by Urban+14?
- Splash radius predicted between 1-2xR_{200}, but is expected to be at smaller radii (and therefore more easily detectable) in high accretion-rate (i.e., merging) systems (Lau+15; More+16; see also talk by Camille Avestruz)


A98
1 Mpc

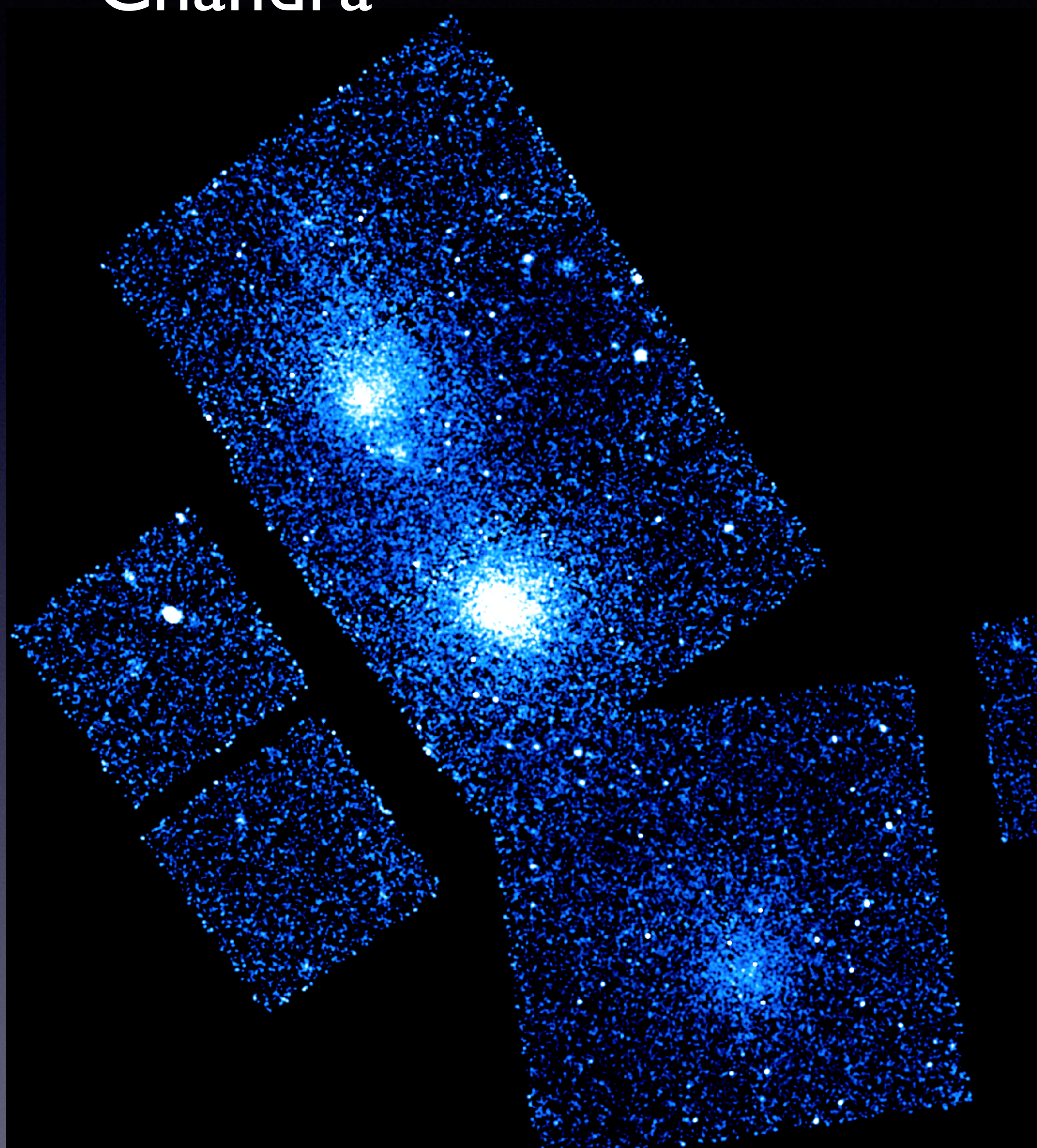

A1750
1 Mpc


A115
1 Mpc

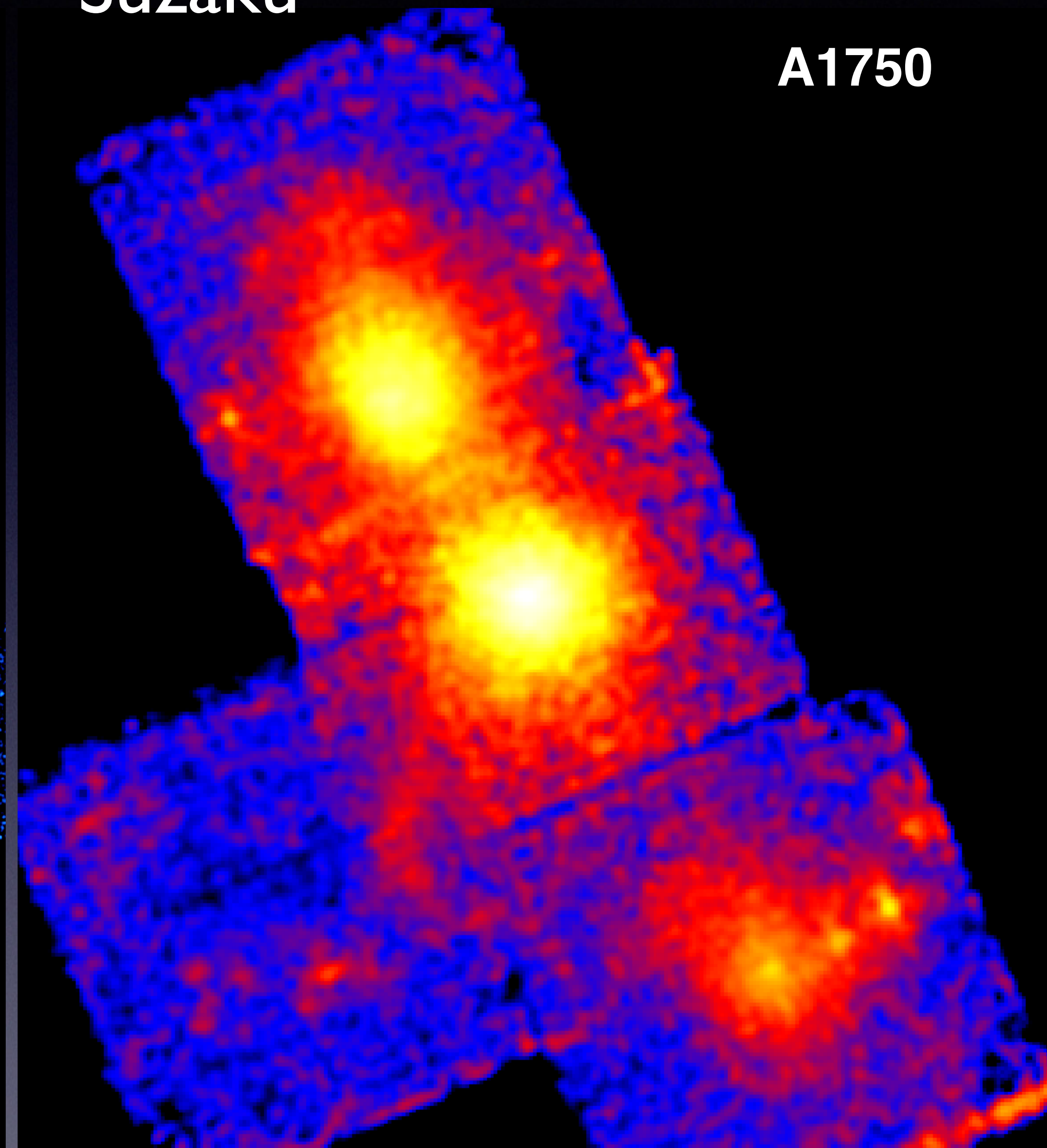

A3395/A3391
1 Mpc

Abell 1750

Chandra

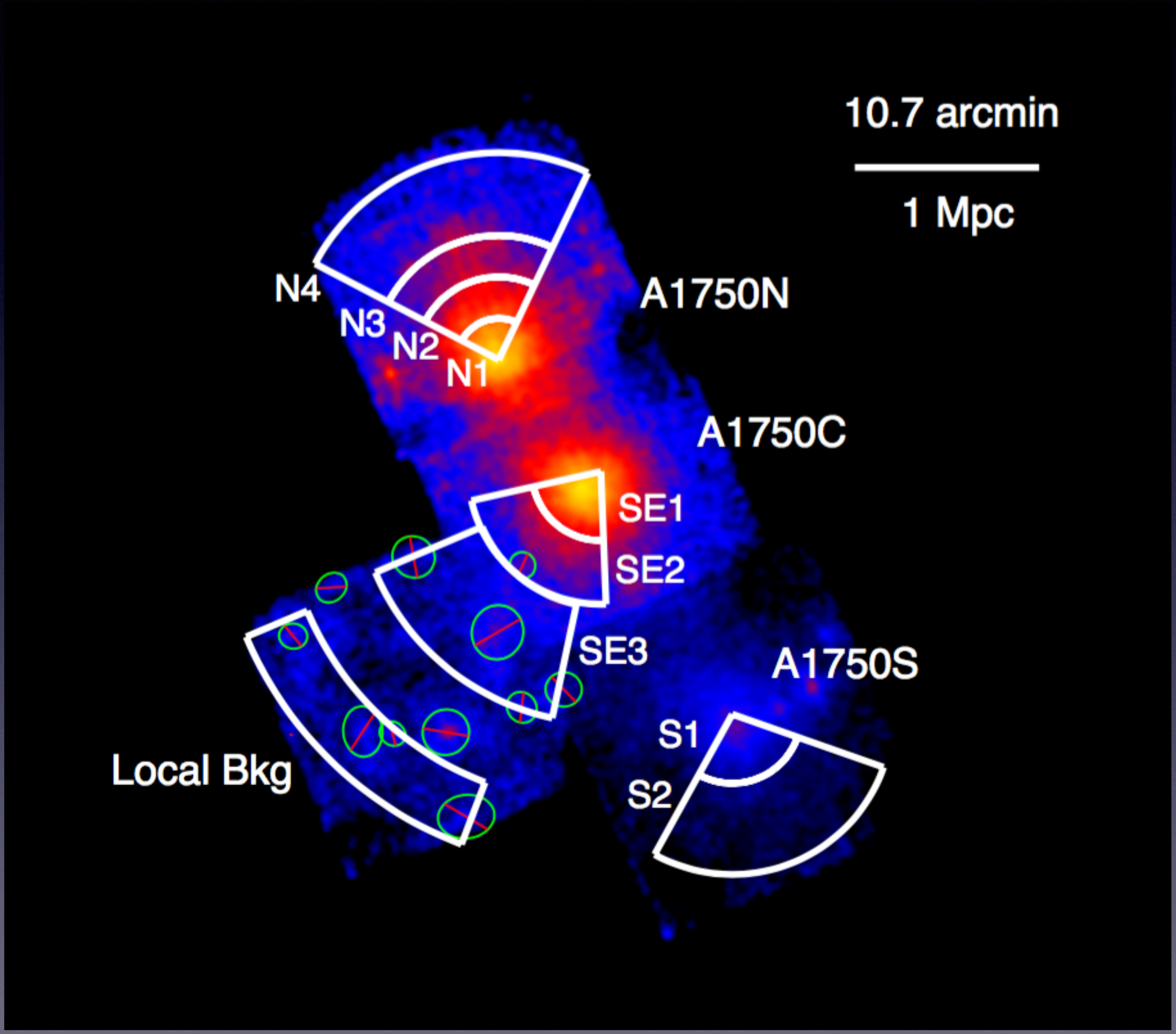


Suzaku



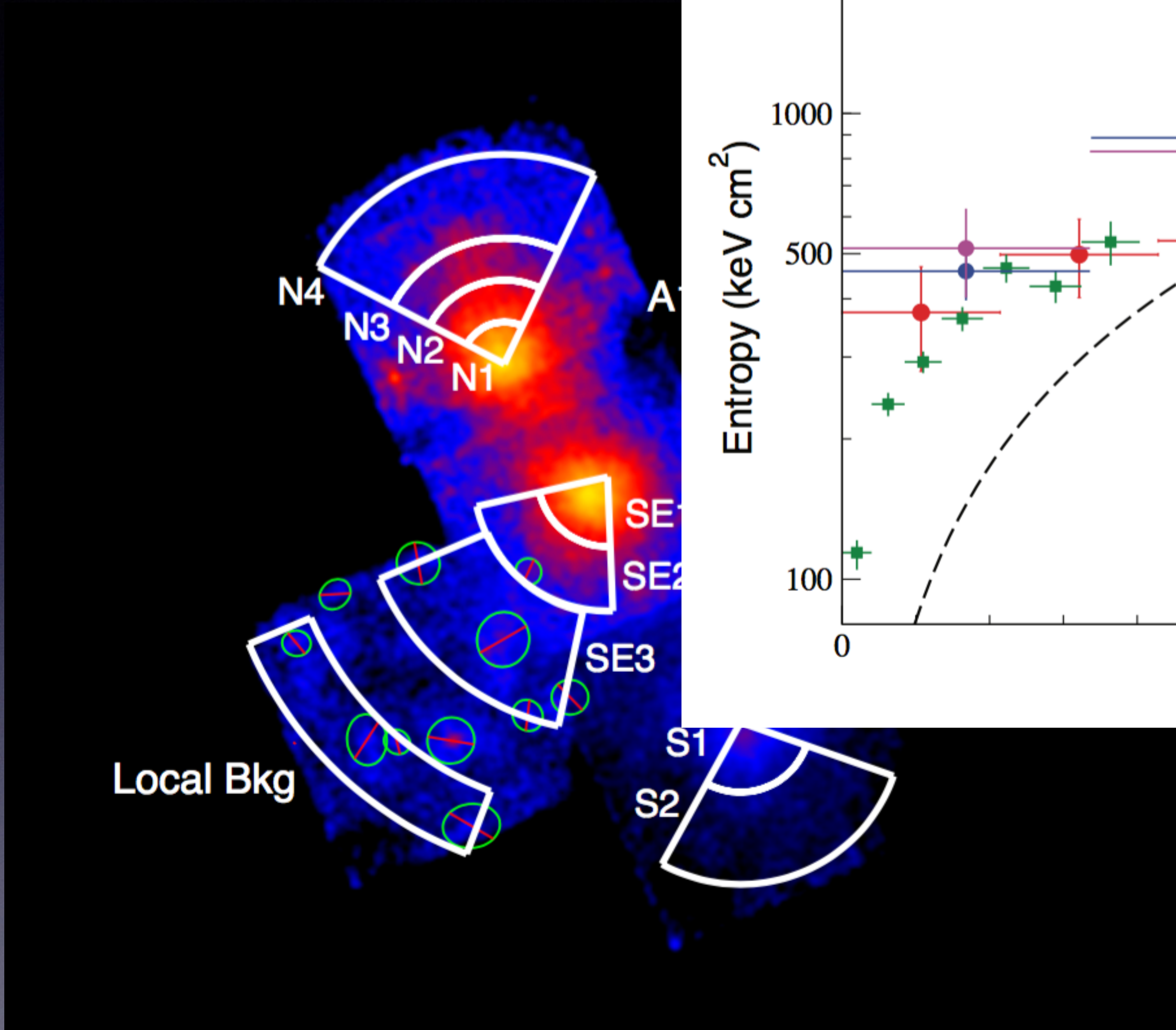
kT ≈ 3–4 keV; z=0.085

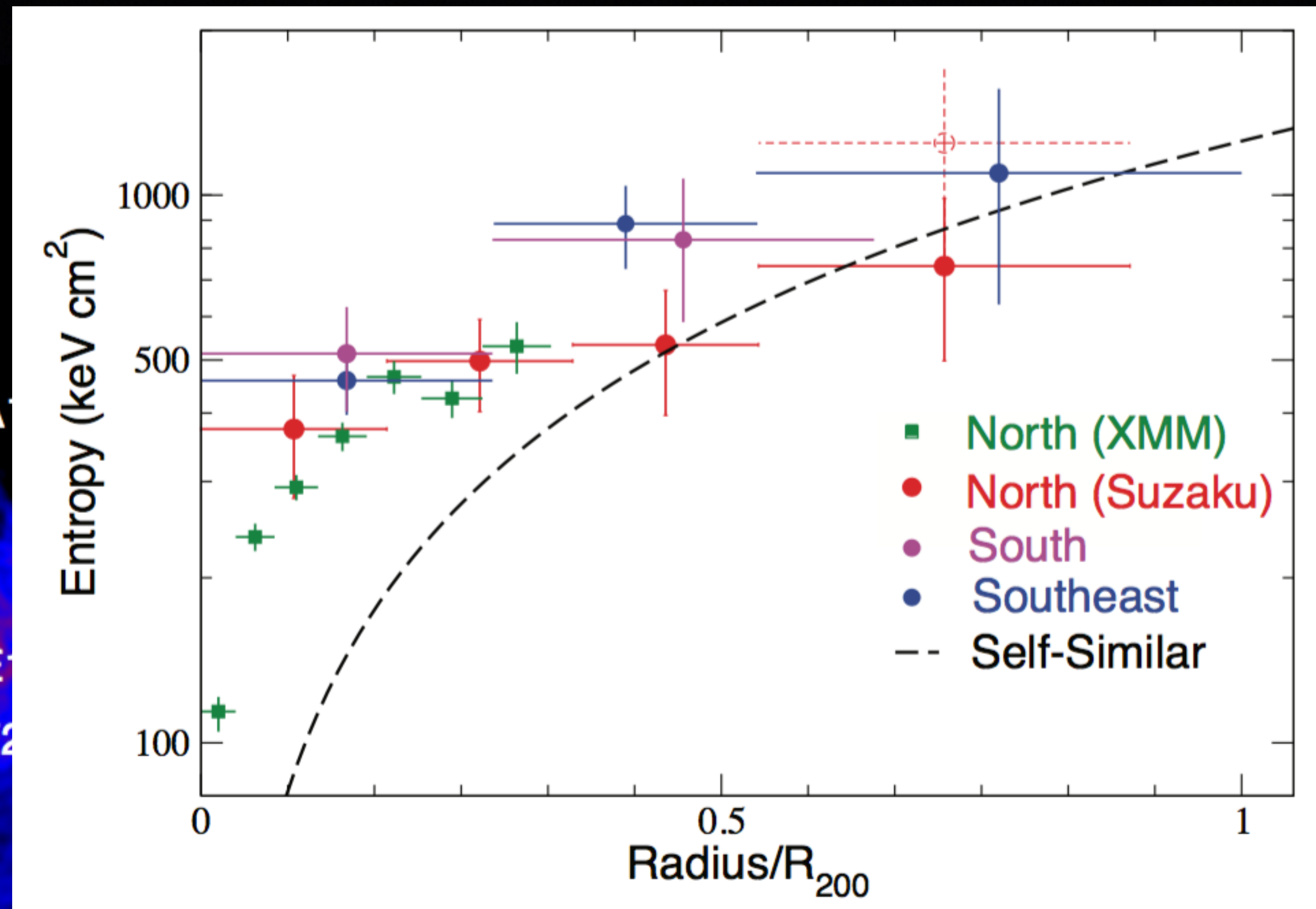
Abell 1750



Bulbul,Randall+16

Abell 1750

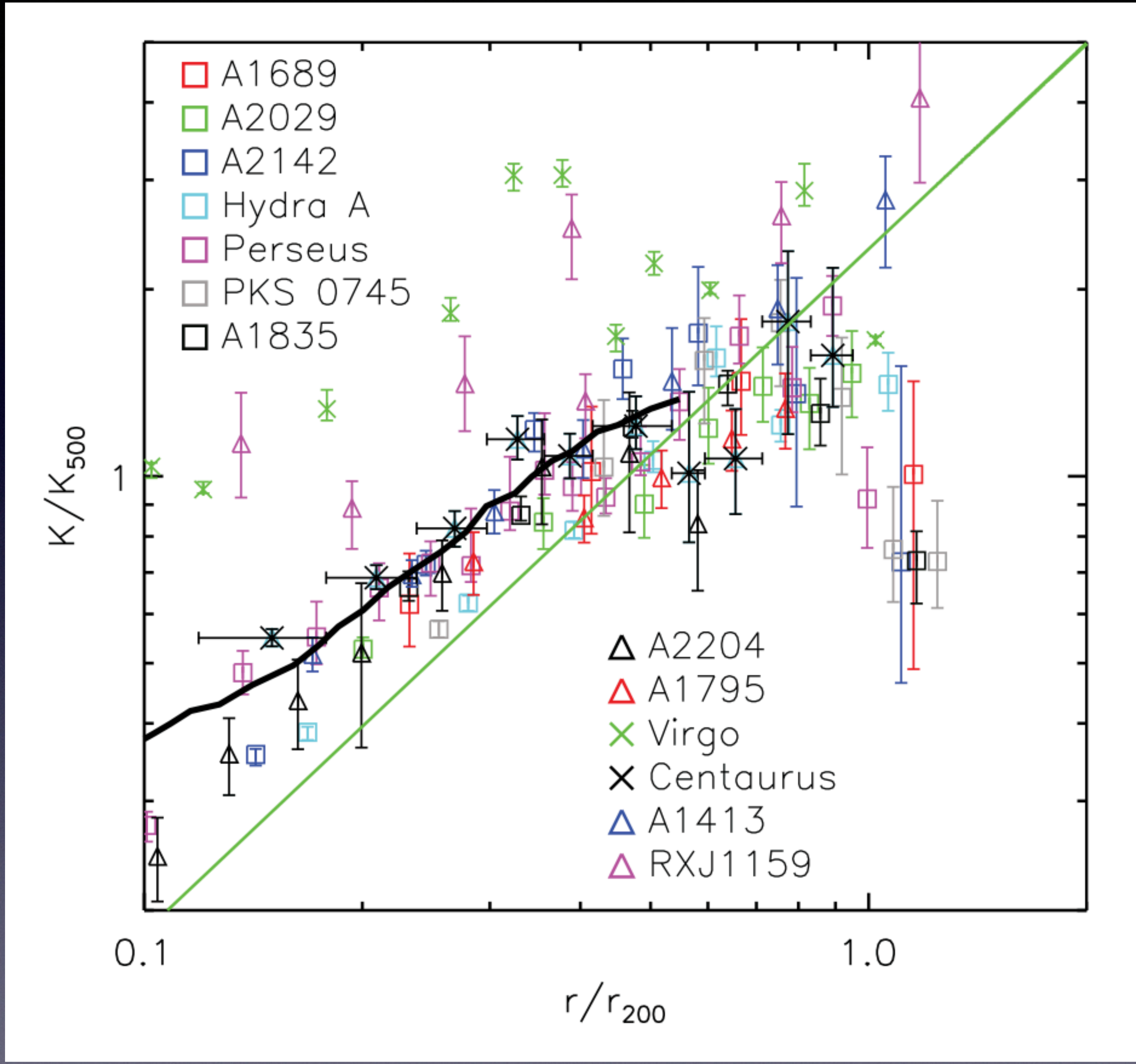




Bulbul,Randall+16

Abell 1750

- No evidence for entropy flattening at the viral radius, either along or off the putative LSS filament



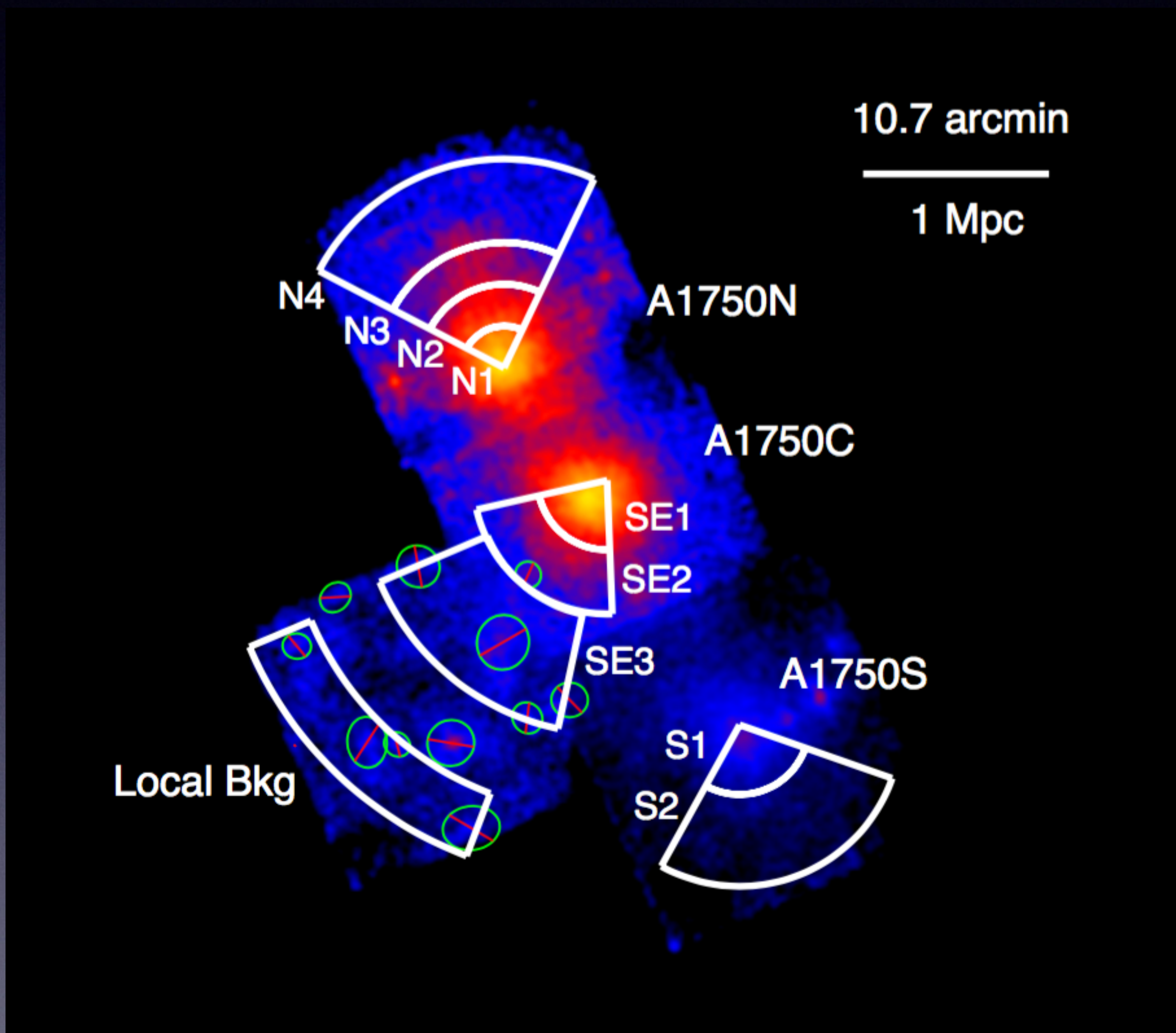
A1689
A2029
A2142
Hydra A
Perseus
PKS 0745
A1835
A2204
A1795
Virgo
Centaurus
A1413
RXJ1159
K/K_{500}
1
0.1
1.0
r/r_{200}

Walker+13

Abell 1750

- No evidence for entropy flattening at the viral radius, either along or off the putative LSS filament
- 5 systems that show moderate to no entropy flattening in Walker+13 are cooler (2-3 keV), with the exception of A1413
- Independent studies of other low-temperature systems tend to show the same (Su+15; Tholken+16; Wong+16)
- Lead us to suggest in Bulbul+16 that lower kT systems tend to show less entropy flattening (shortly after independently suggested by Tholken+16), and that mass is a more important predictor of clumping than dynamical state (more observations are needed)

Abell 1750



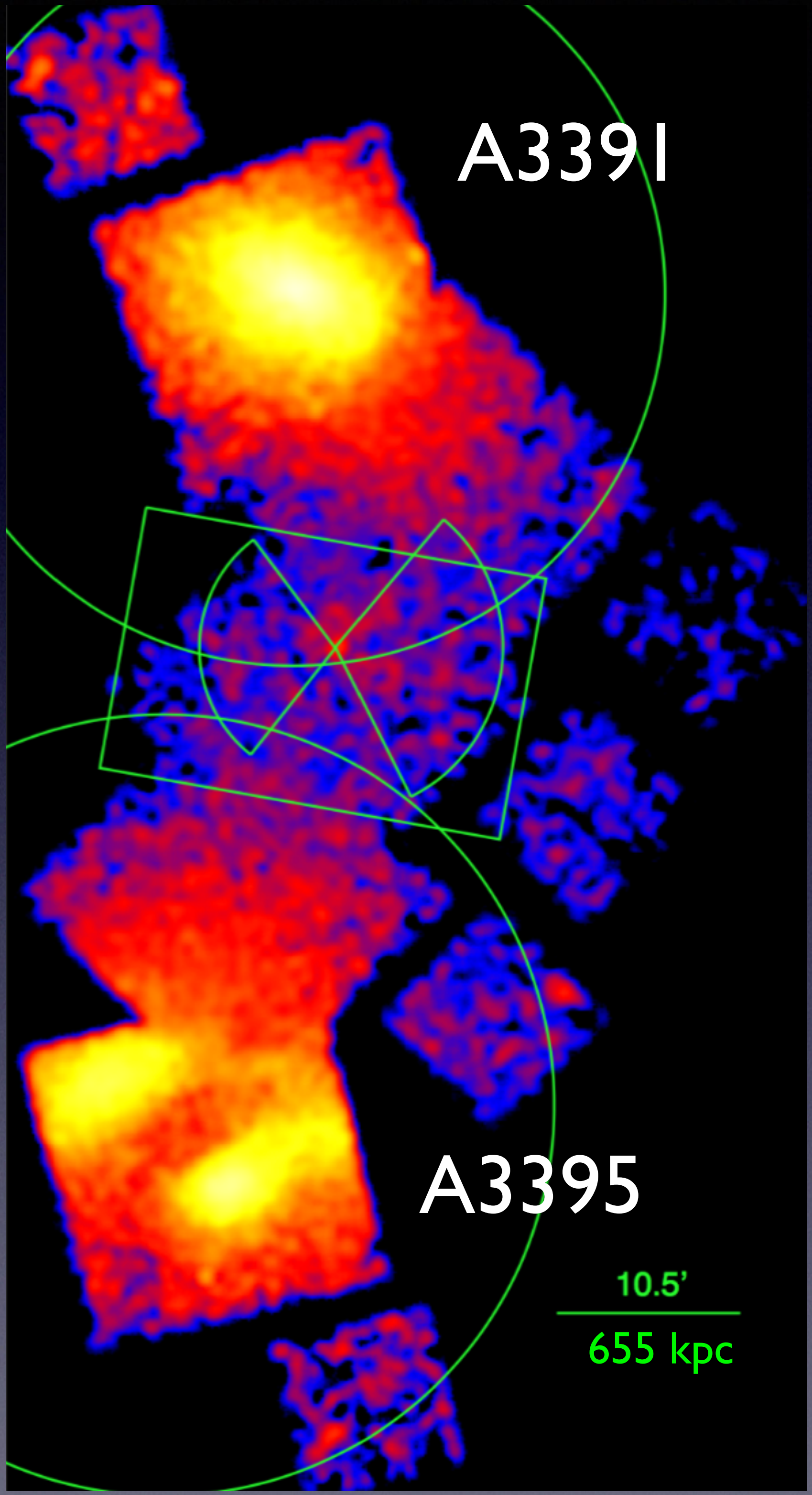
- Spectral fits to regions N3 and N4 reveal a soft component:

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 SE, but should have been if same surface brightness
- 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)

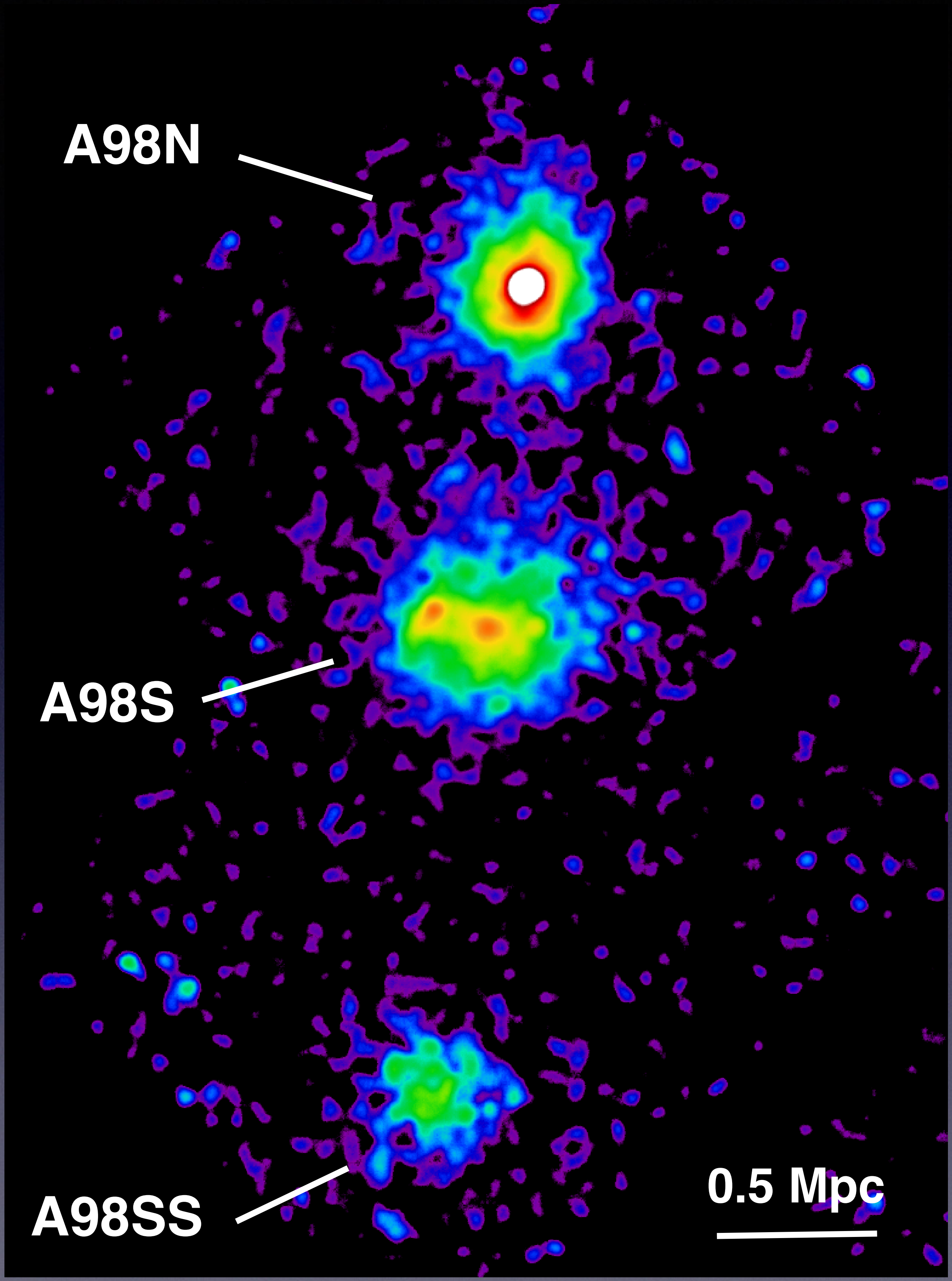
Abell 3395/3391



Alvarez,Randall+17

- Intercluster filament first reported from ROSAT and ASCA observations (Tittley & Henricksen 01)
- Marginally detected with Planck (PC+13)
- Ram pressure stripped group in the filament/cluster outskirts
- See Gaby Alvarez's poster (#4) for details

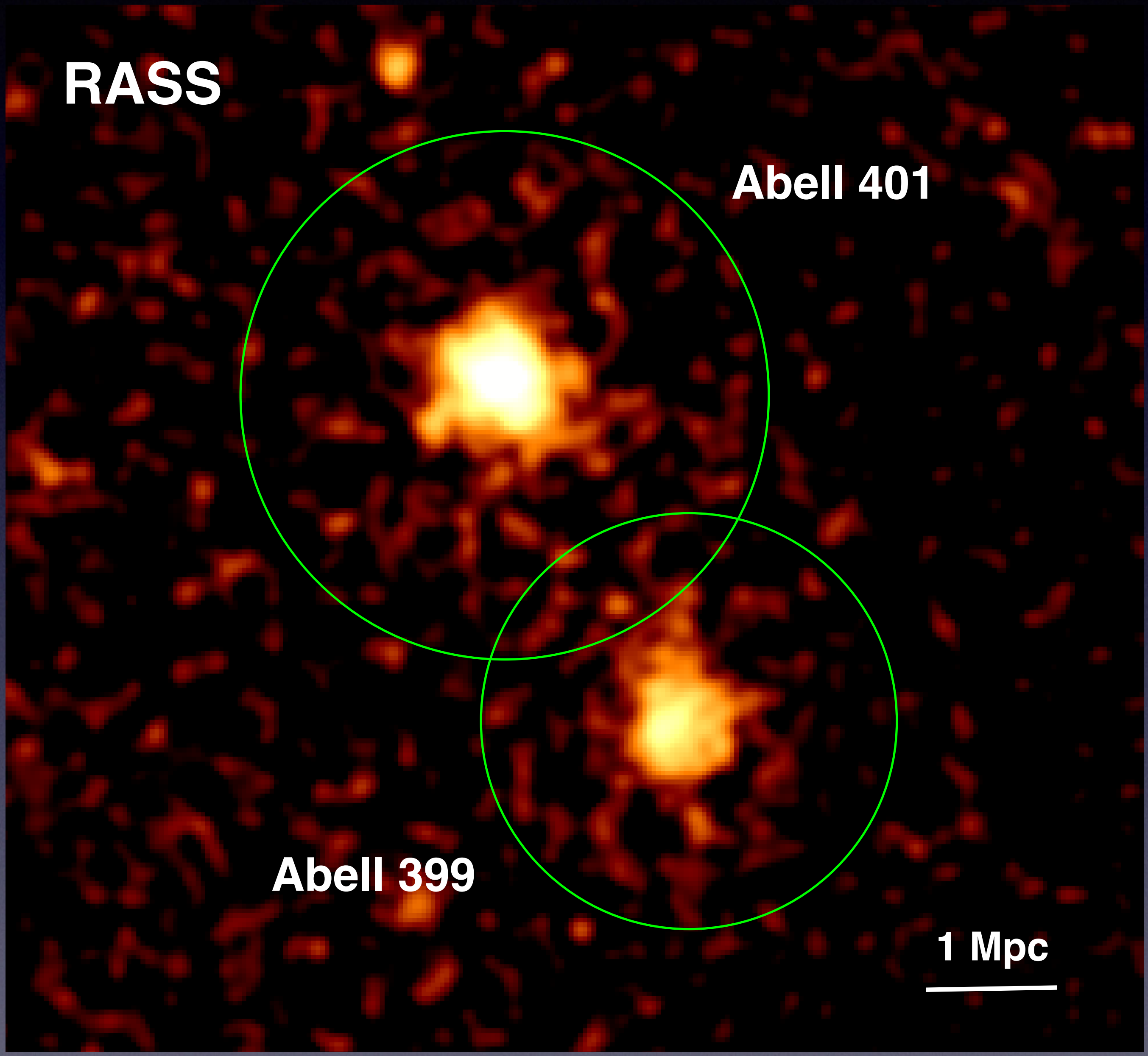
Abell 98



Paterno-Mahler,Randall+14

- No time to discuss Chandra observations of A98, but see Paterno-Mahler+14 for details!

Future Work



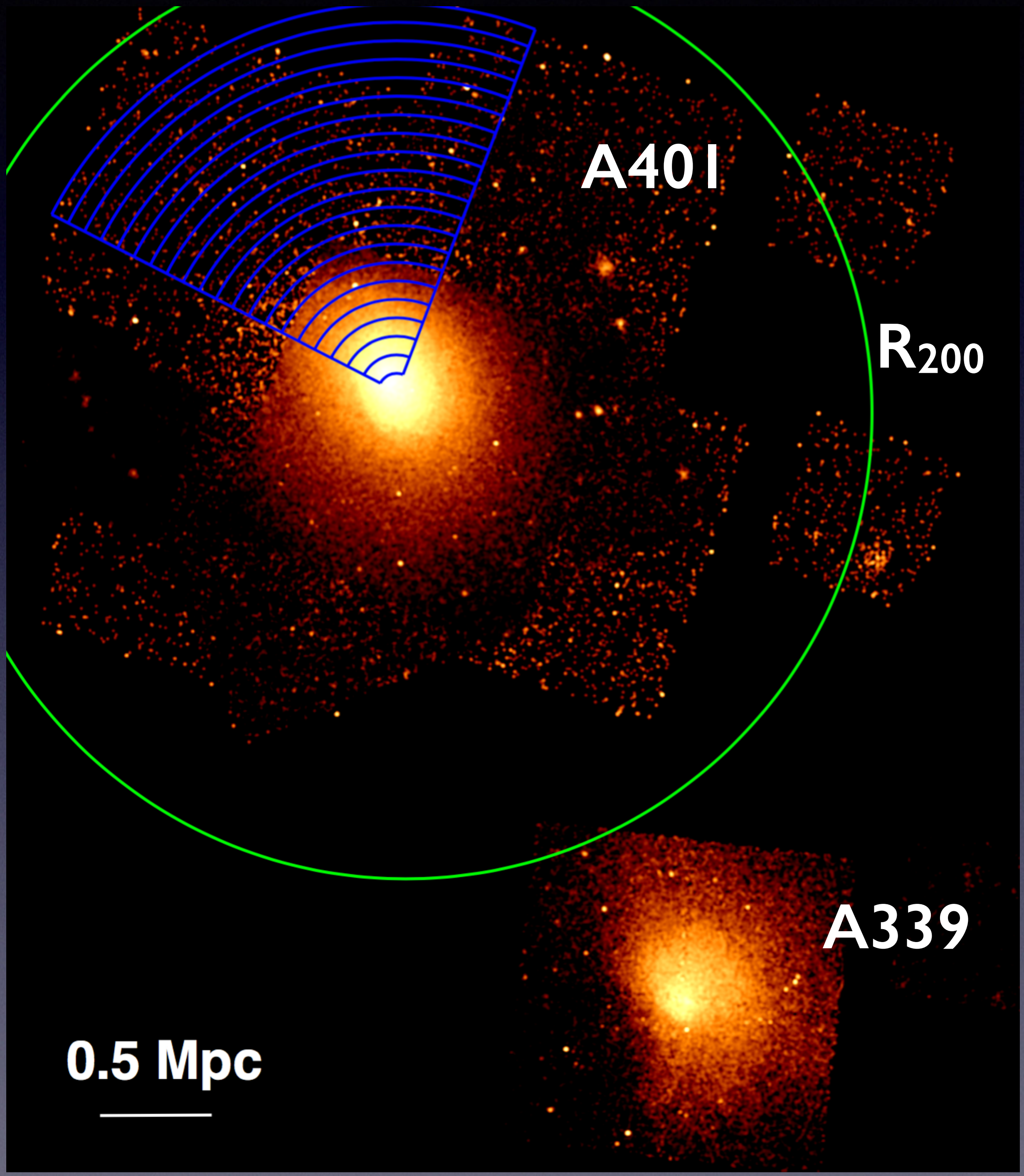
- Need to explore high-temperature mergers out to their viral radii
- The A399/A401 system is a strong candidate
- kT ≈ 6 keV, z ≈0.07, only intercluster filament detected with high significance by Planck (PC+13)
- Simulations show A401 can be mapped out to its viral radius with 8 Chandra pointings totaling 3.5 Msec, which implies 70 ks with Lynx (~9 ks per pointing)

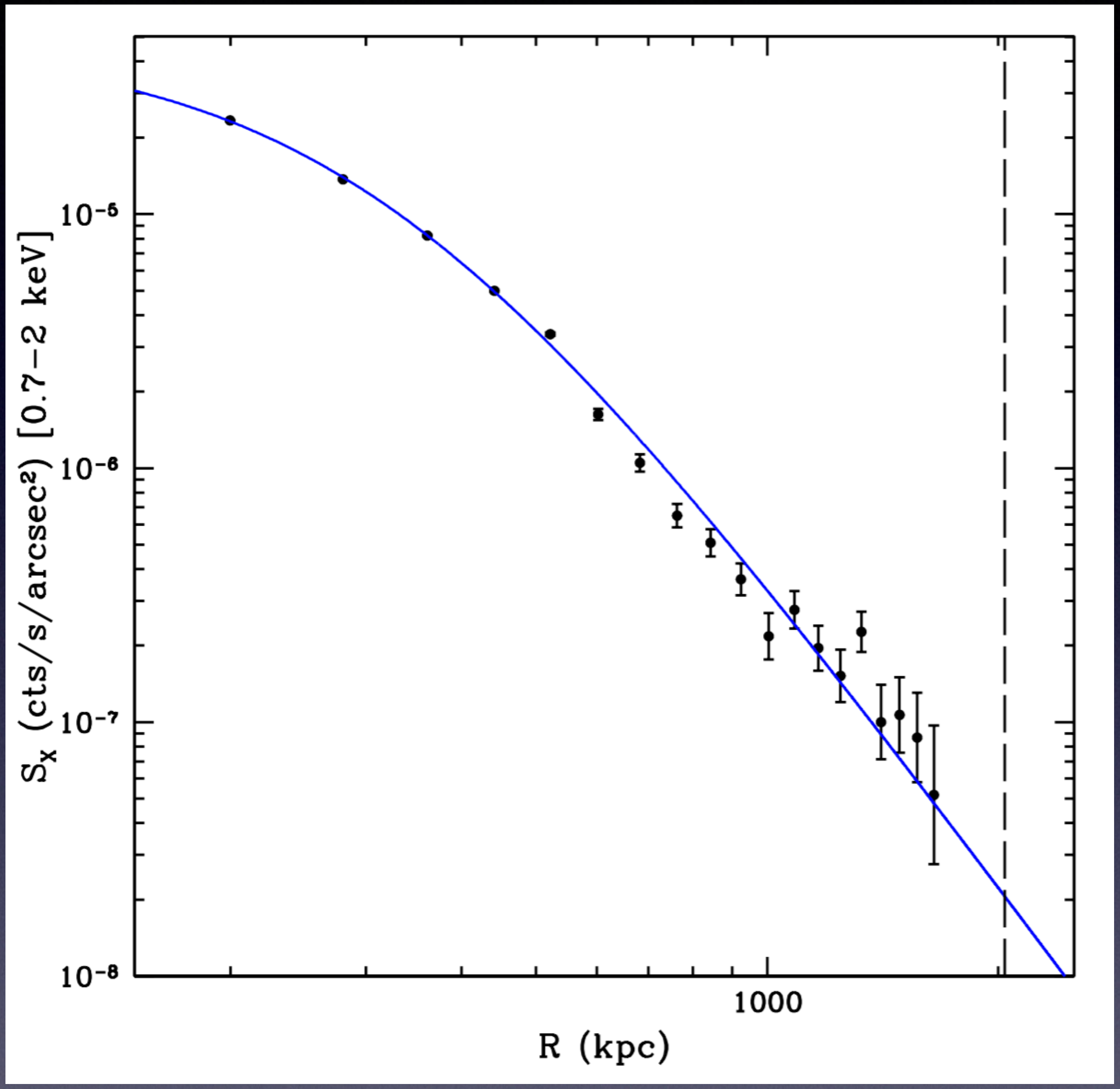
Future Work

- Athena and Lynx will both make significant contributions to the study of cluster outskirts (high effective area, good-to-great angular resolution), provided instrumental backgrounds are reasonably stable
- What about beyond R_{200}? Interface with the WHIM, accretion shocks, splashback radius, metal content of inflating gas…

Future Work

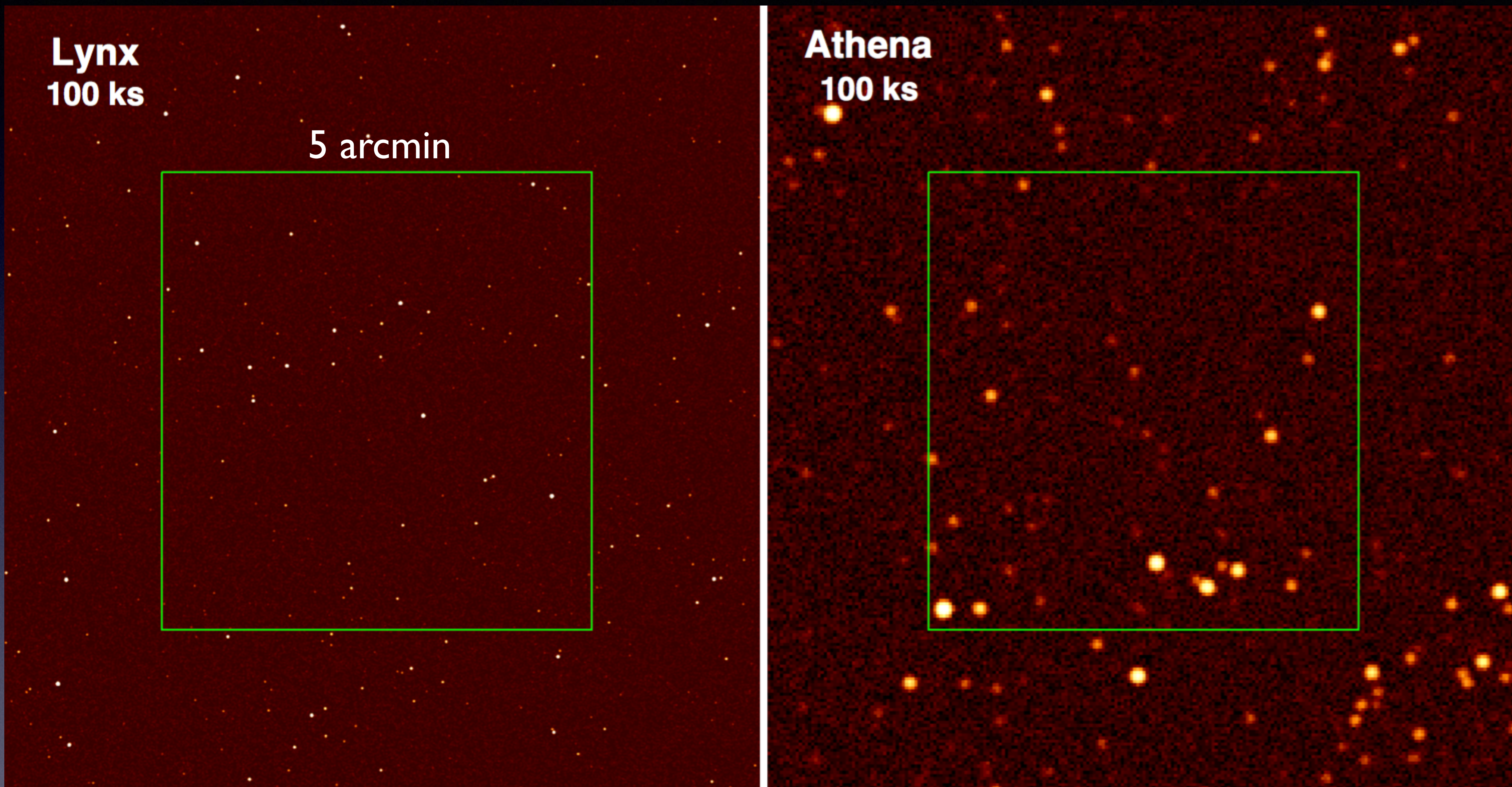
Shallow Chandra mosaic





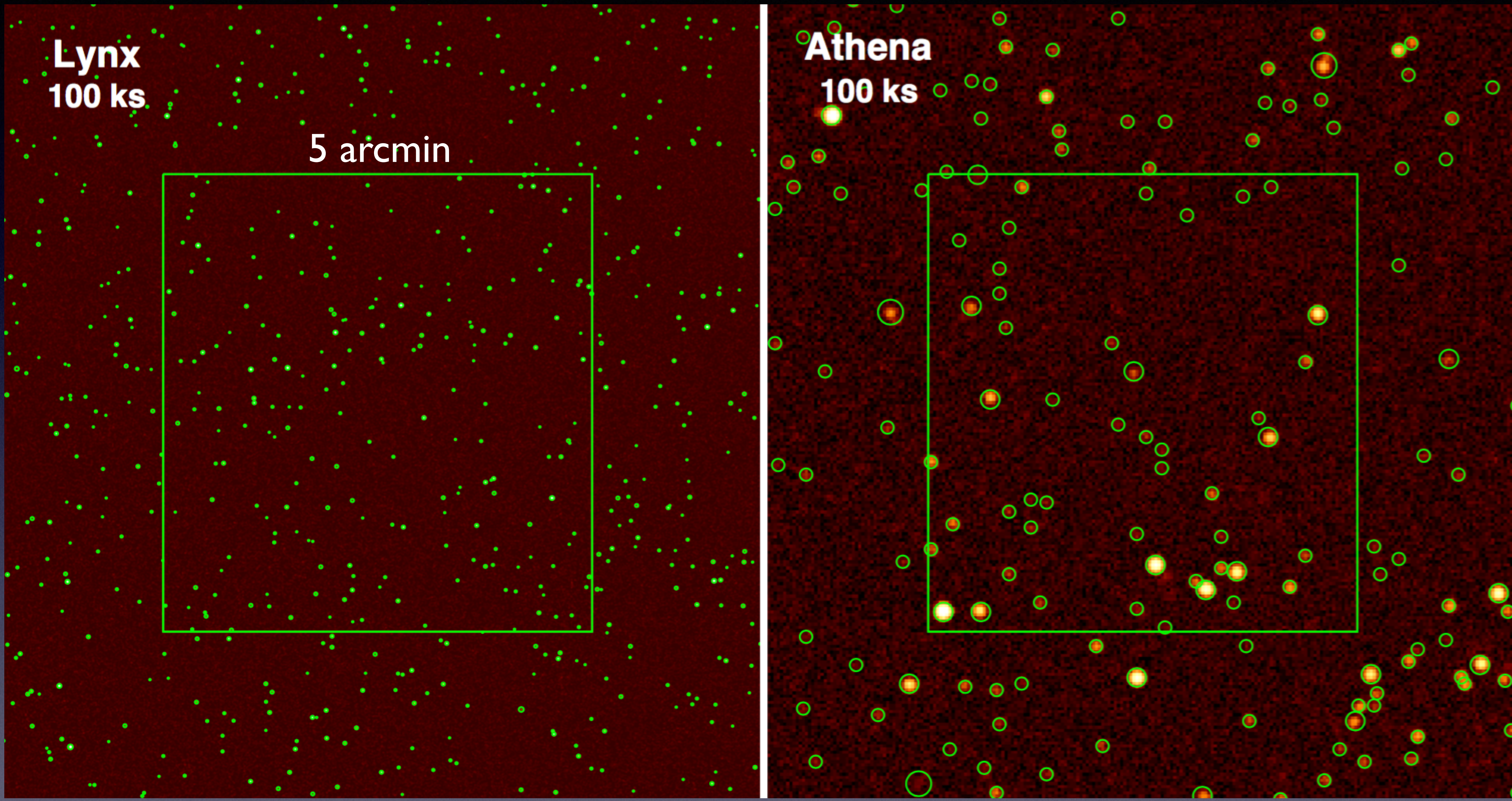
Let's foolishly assume that this profile extends out to $2\times R_{200}$, with kT=1 keV and Z=0.2 Z_{solar}

Future Work



25 arcmin^2 region, equivalent to roughly 2′ wide, 12′ long radial bin at $2xR_{200}$ north of A401

Future Work



25 arcmin^2 region, equivalent to roughly 2′ wide, 12′ long radial bin at 2xR_{200} north of A401

Future Work

- Simulated event files (used to derive images and spectra) created with SOXS[1]
- For spectral fits, subtract independently simulated instrumental background. Simultaneously fit GH (~0.2 keV), LHB (~0.1 keV), and CXB to include background systematics. Also include a 2% systematic uncertainty on the instrumental background

Results:

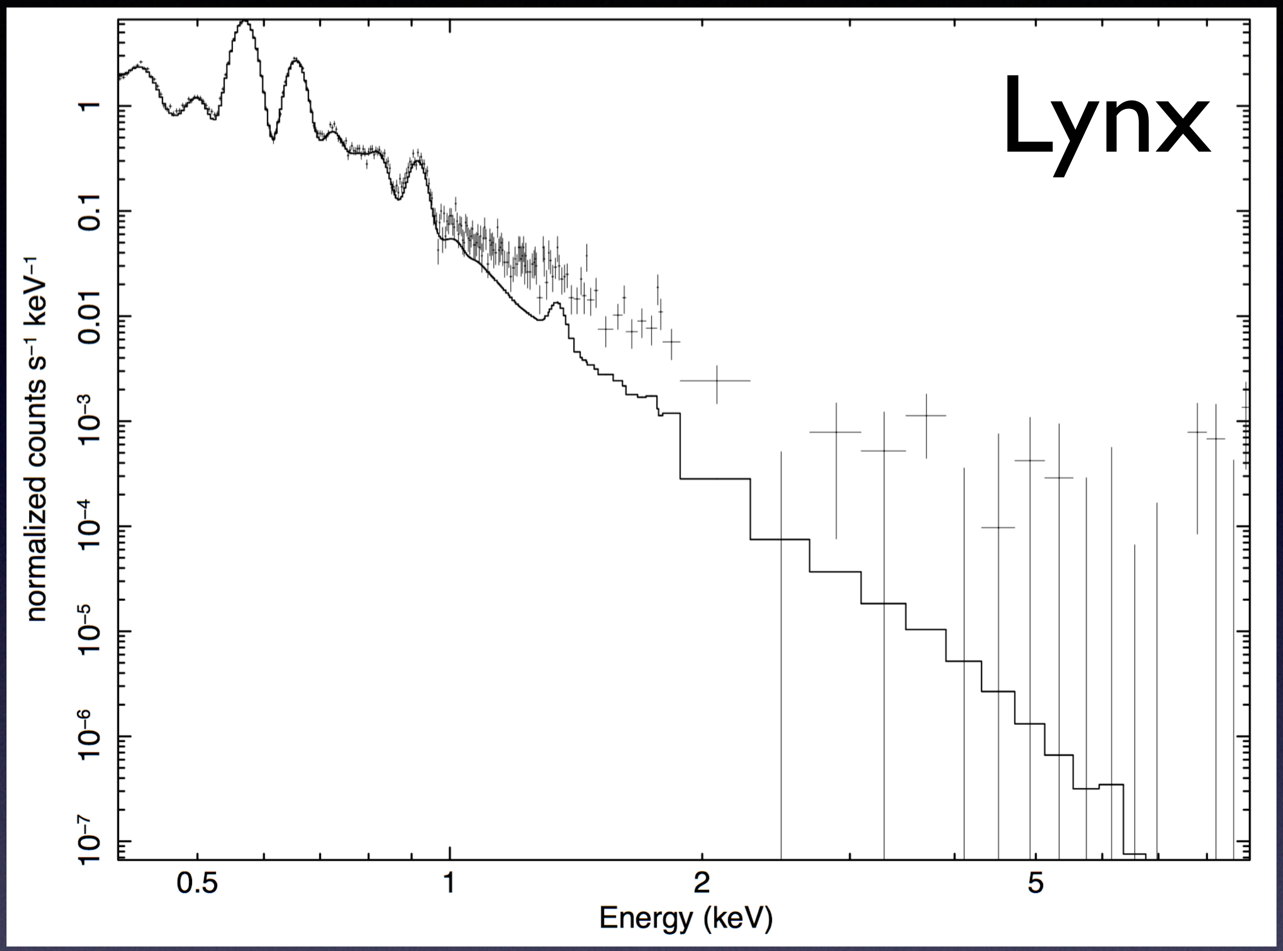
Lynx: kT = 1.09 (0.97-1.45) (90% errors)

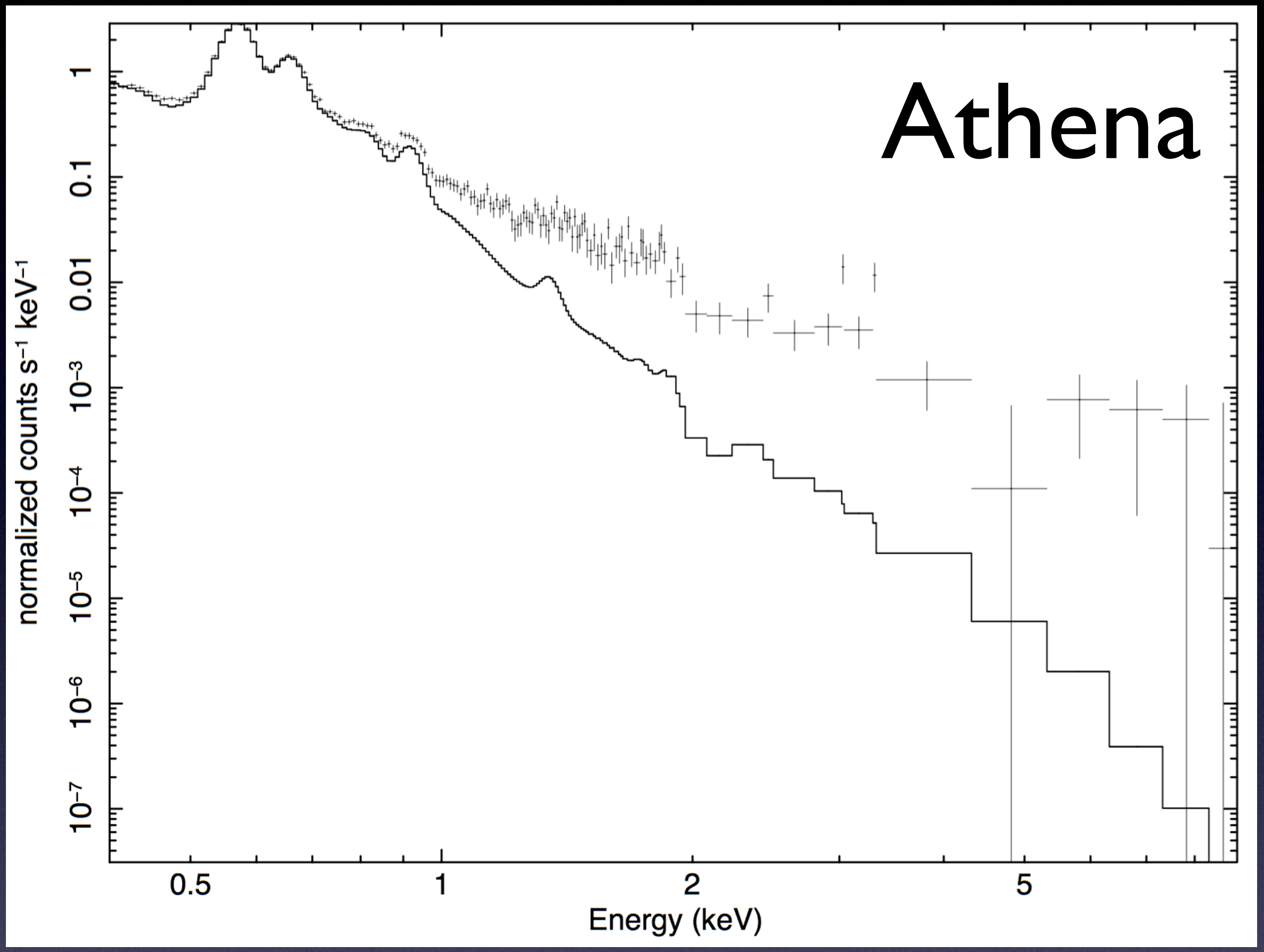
Athena: kT ≥ 0.7 keV

- Corresponds to a 0.3-3 keV source flux of ~3.0e-17 erg/cm^2/sec/arcmin^2
- The difference is angular resolution

[1]Simulated Observations of X-ray Sources; http://hea-www.cfa.harvard.edu/~jzuhone/soxs/

Future Work





- Lynx and Athena fits, with CXB power-law component removed
- Resolving out more of the point sources increases S/N, and makes it easier to deal with systematic uncertainties associated with the instrumental background at higher energies
- Increase in area (due to smaller point source regs) also doesn't hurt

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
- Lynx and Athena will revolutionize this field, allowing larger samples, studies at higher redshifts, and out to larger radii
- Due to its high angular resolution and relatively flat PSF across the FOV, Lynx will be able to probe fainter diffuse emission, in many cases well beyond the virial radius of clusters