Cluster Outskirts with Strobe-X

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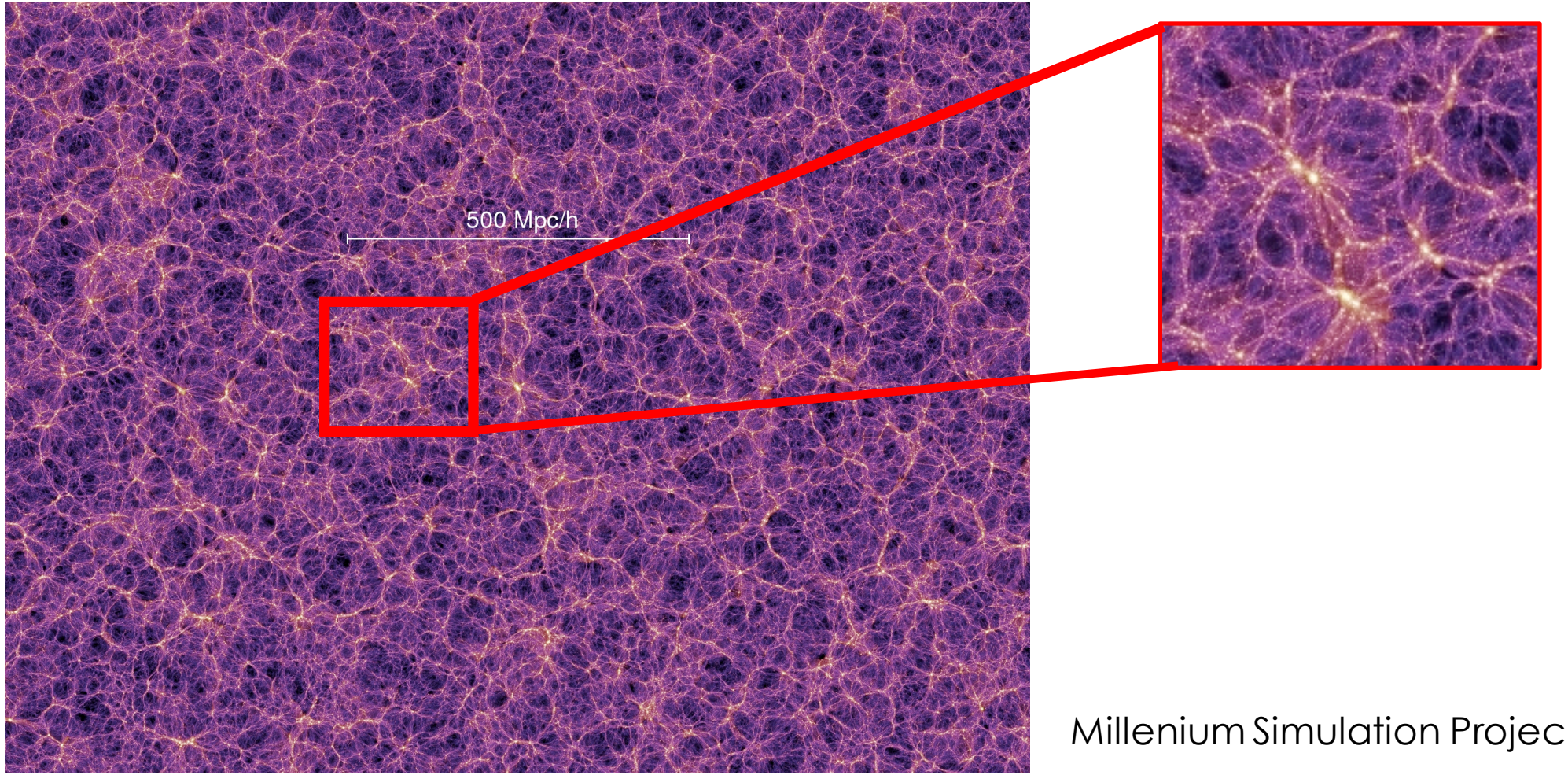
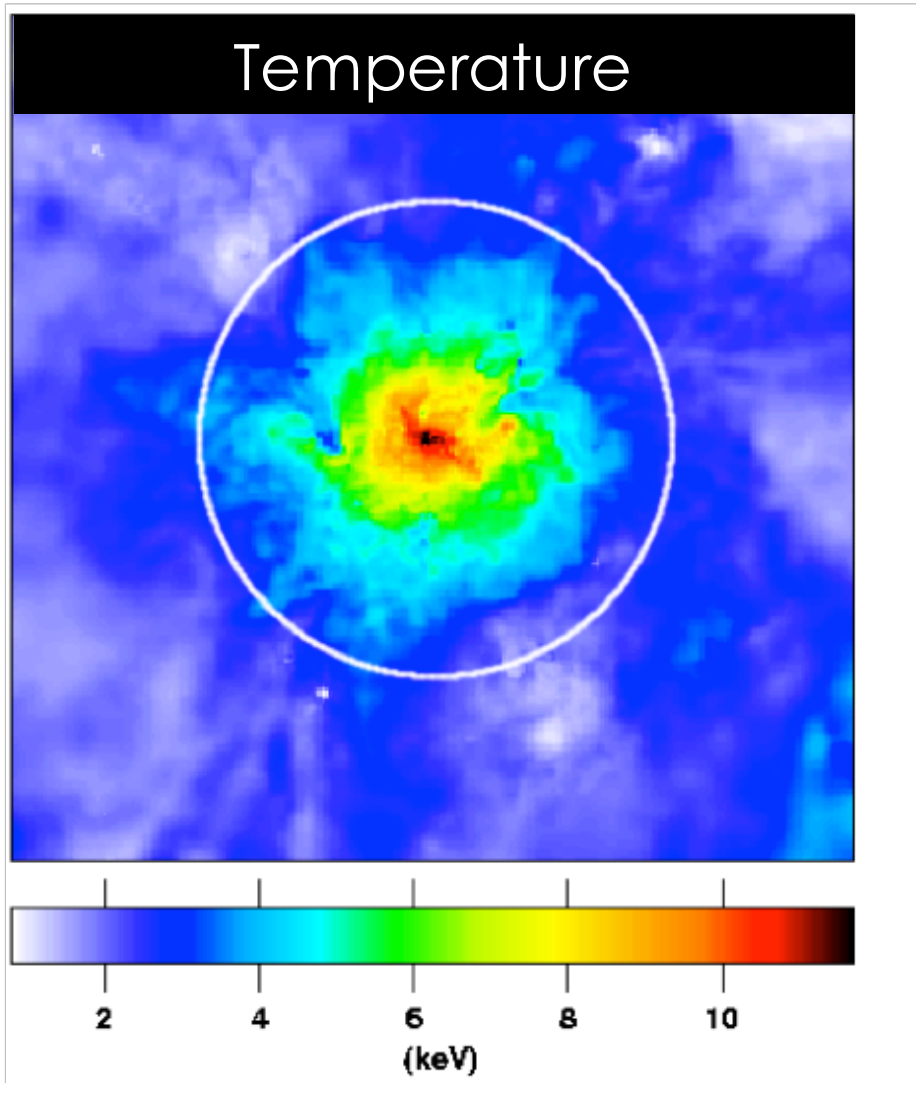
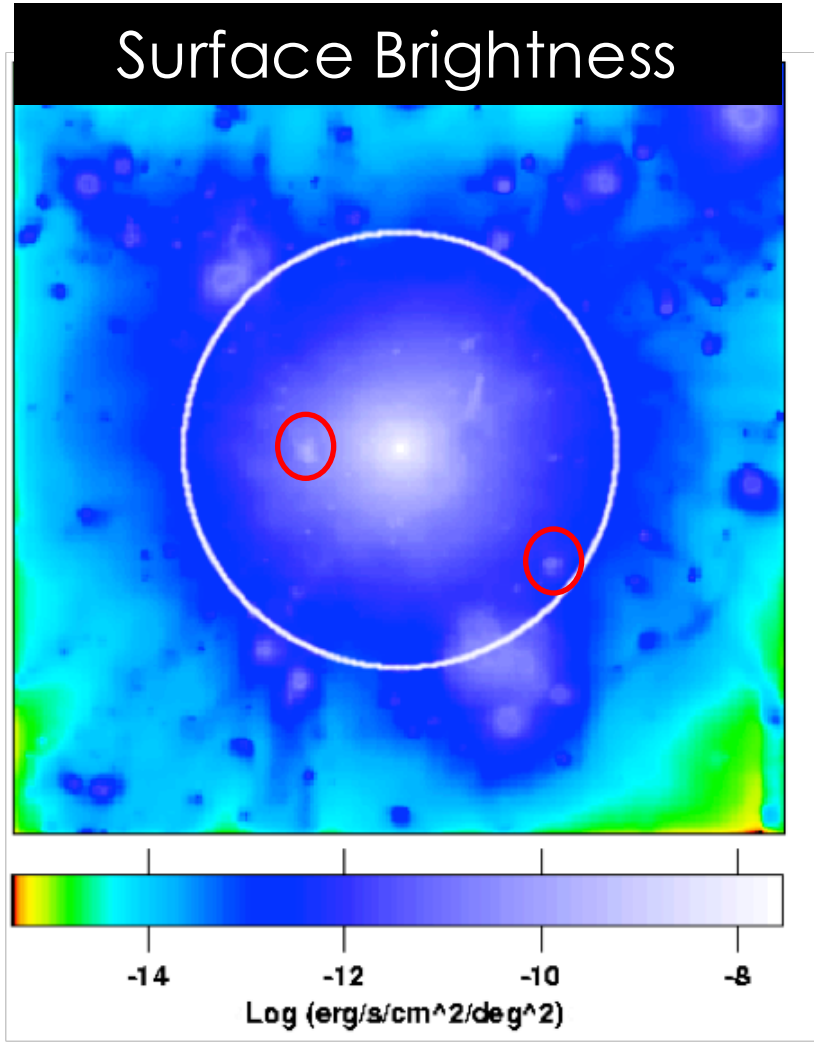
Clusters are Connected Through Filaments



Millenium Simulation Project

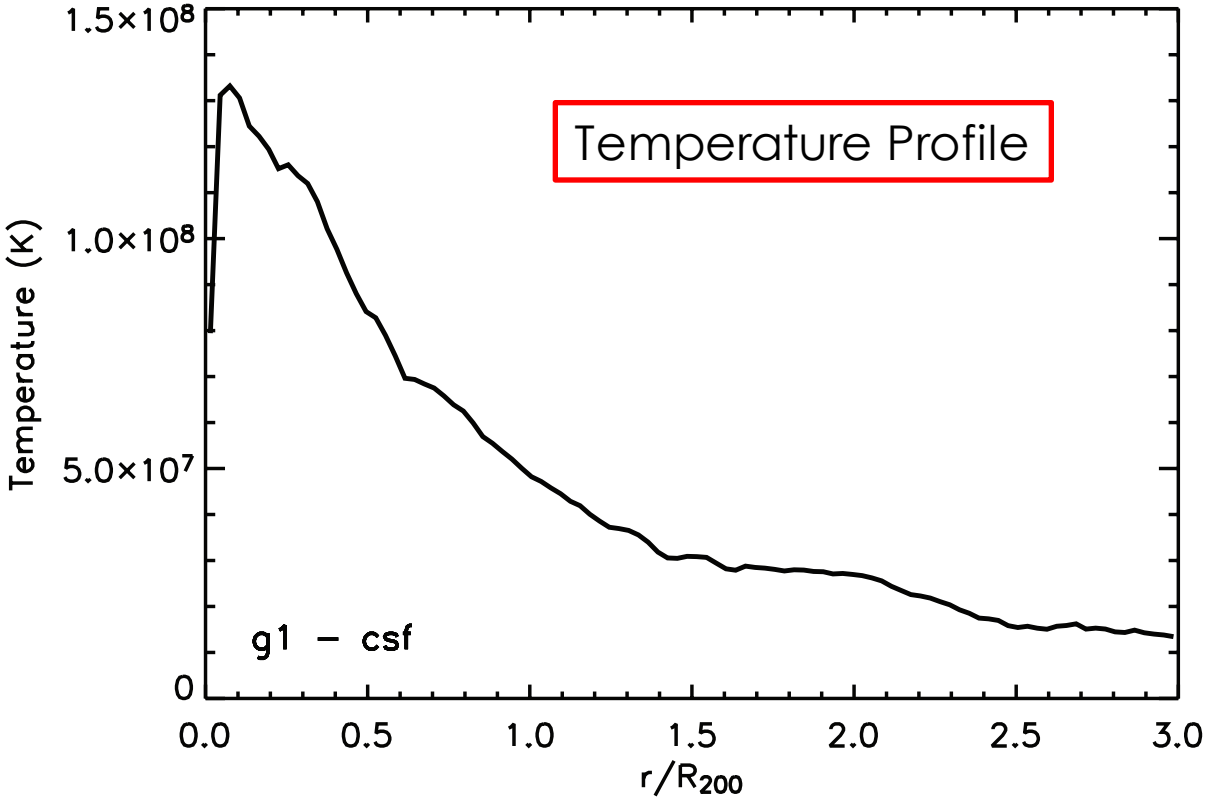
Zooming on to Clusters

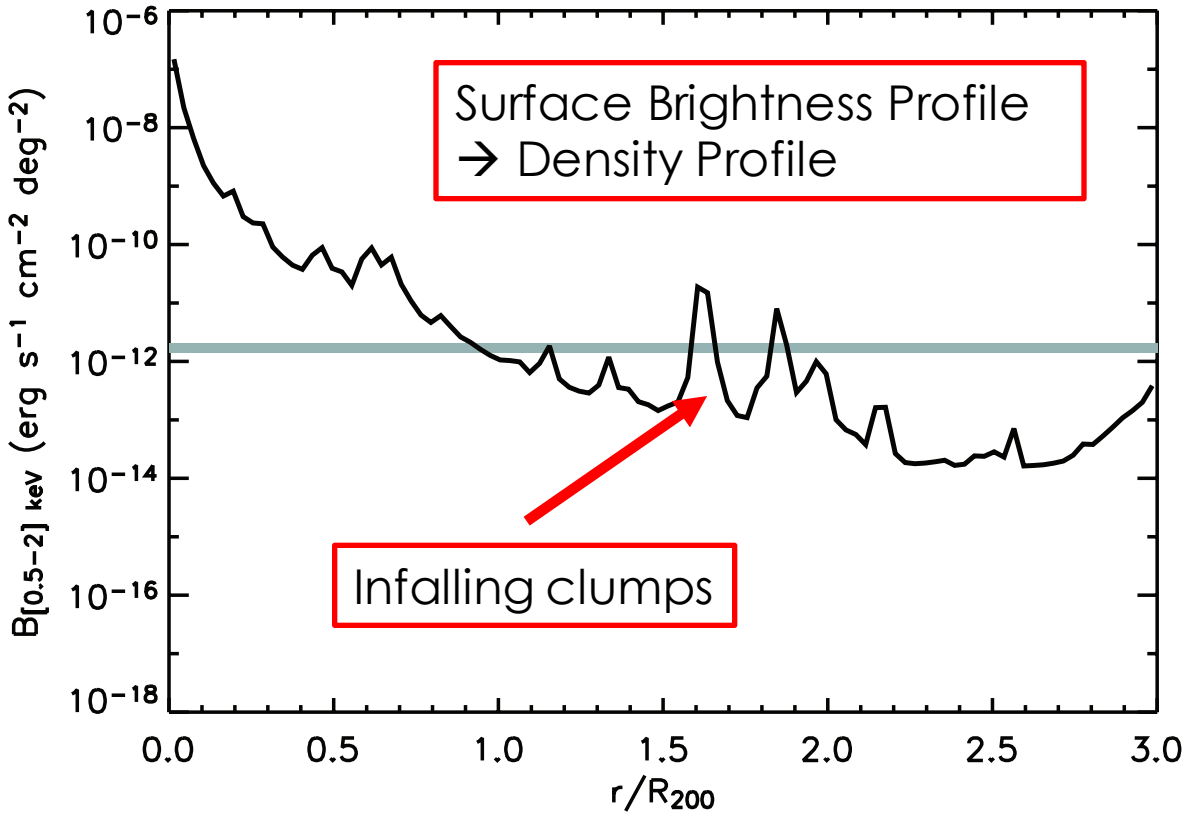




Vazza+2006

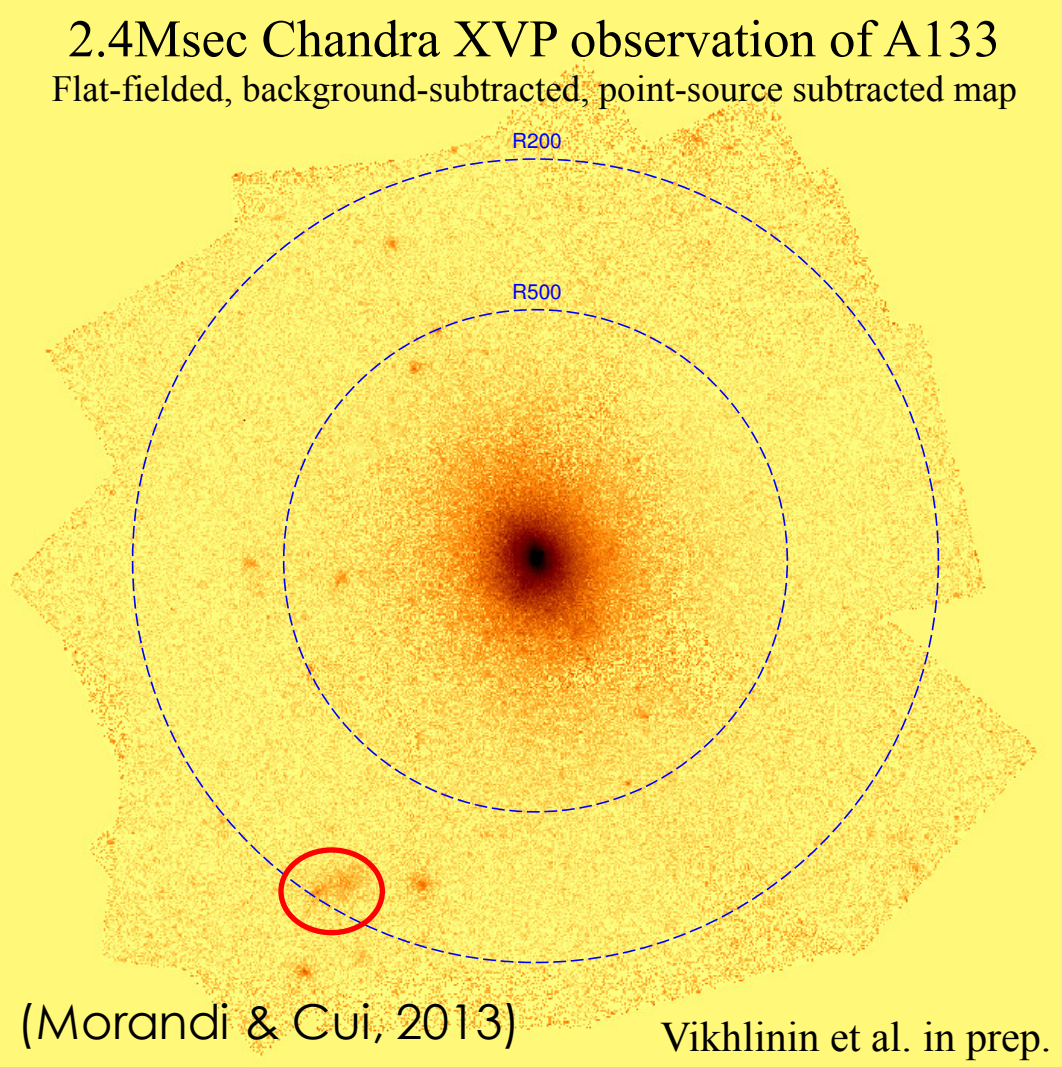
Observables at Cluster Outskirts





Vazza+2006

Direct Imaging of Cluster Outskirts

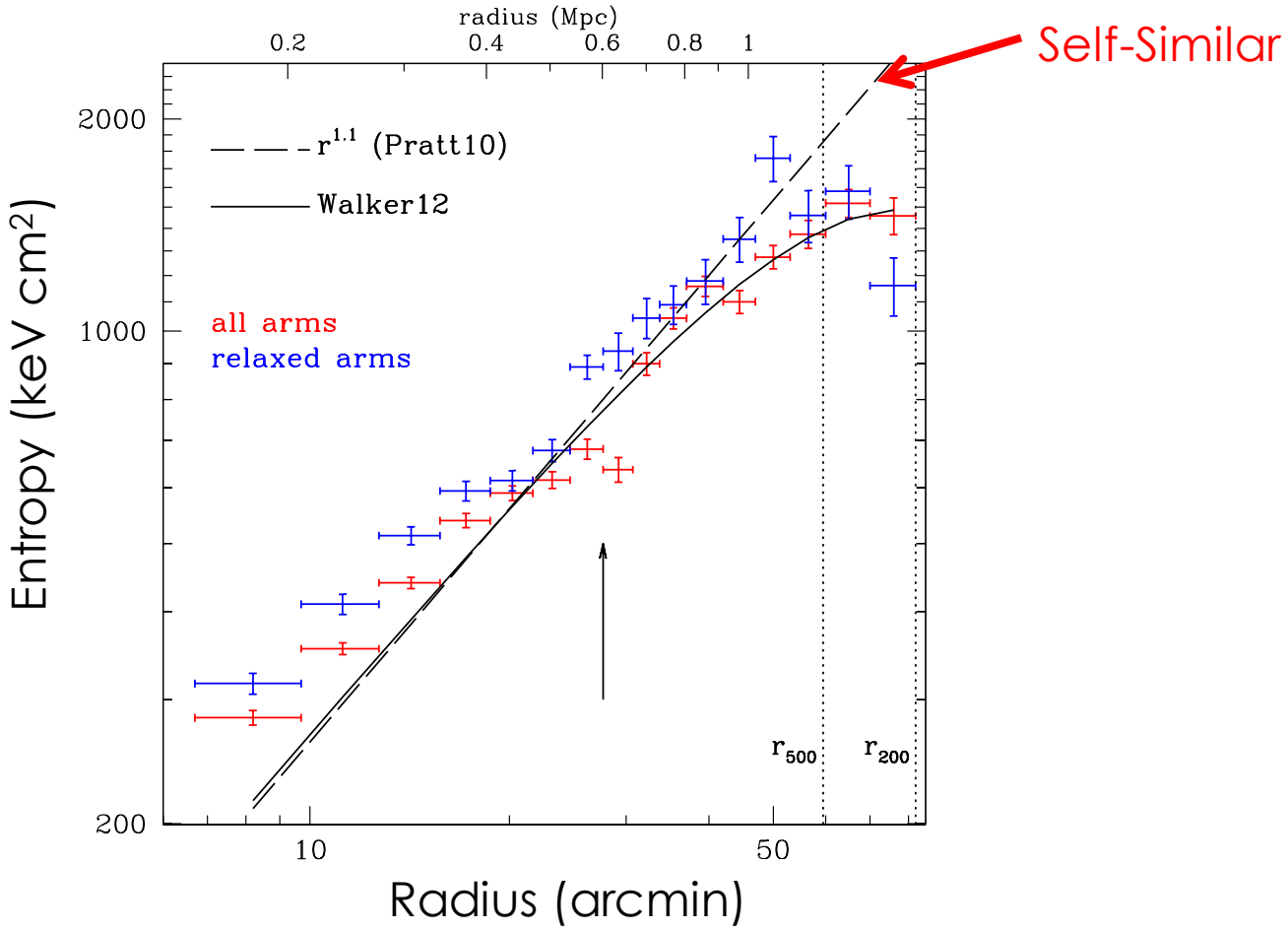


- Infalling clumps are imaged by Chandra observations of A133
- Clumping factor is $c = \frac{<n_e^2>}{<n_e>^2}$
- c~2-3 at $0.9R_{200}$ (Nagai & Lau 2011)
- c = 1 → ICM is not clumpy
- Surface Brightness:

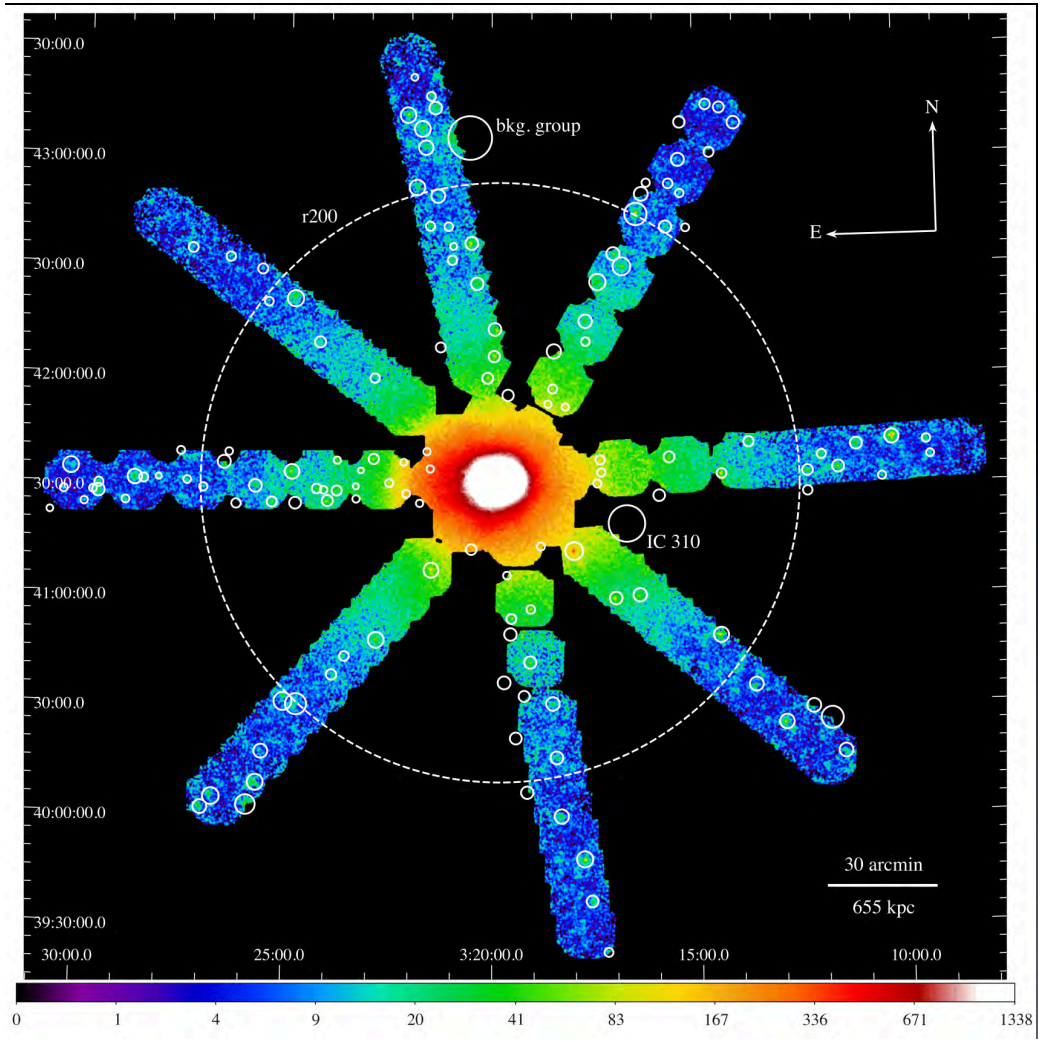
$$SB \propto \int n_e^2 \wedge dl \propto C(R)\rho(r)^2$$

- If clumpy, SB (n_e) is overestimated
- Entropy $S \propto n_e^{-2/3}T$ is underestimated

Entropy Profiles out to R_{200}



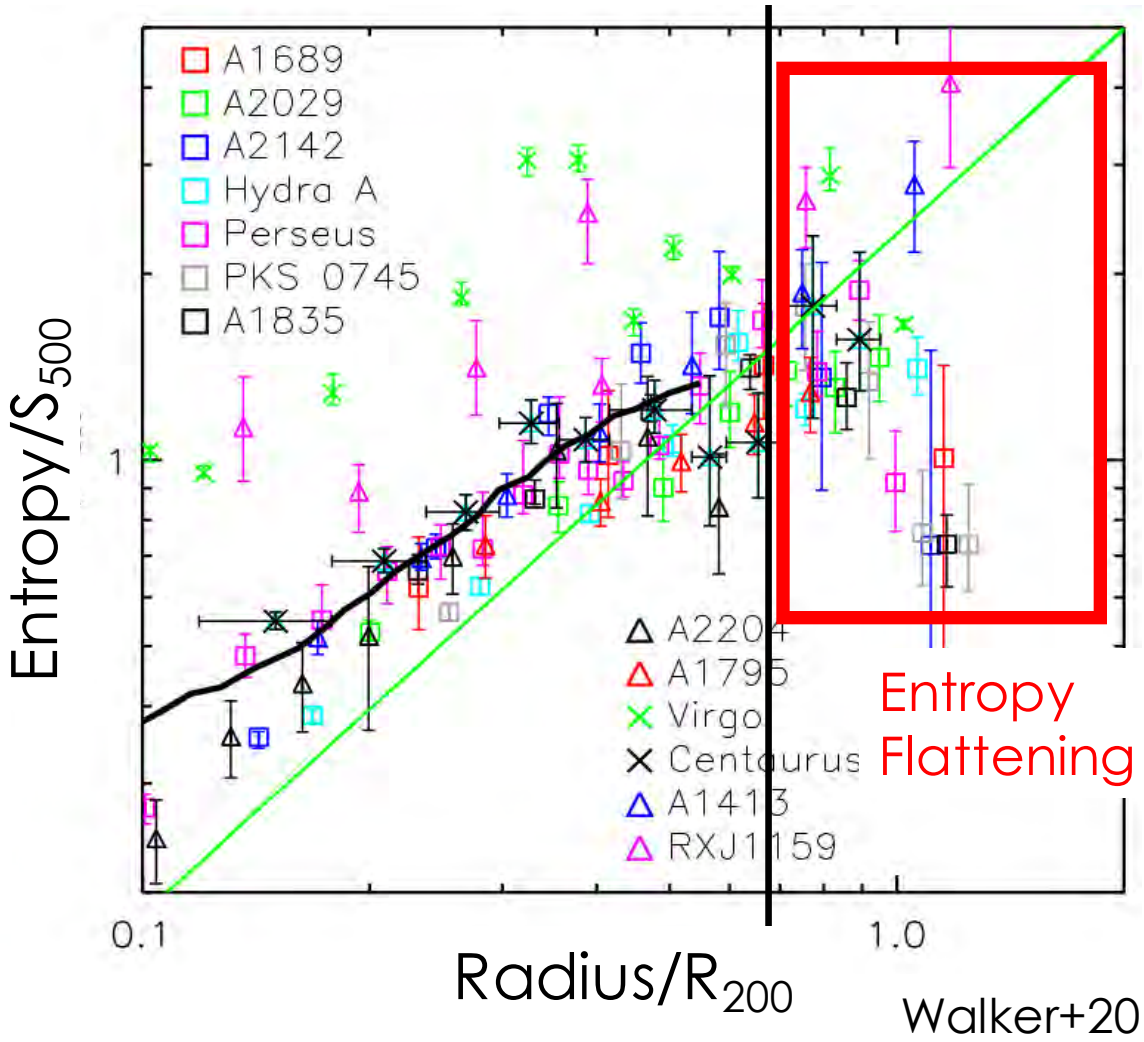
Self-Similar



Urban+2014

Entropy Profiles of Nearby Clusters

- Suzaku's low particle background allowed to measure entropy out to R_{200}
- Entropy excess in cluster cores due to AGN feedback
- Entropy flattening at R_{200}



Walker+2012b

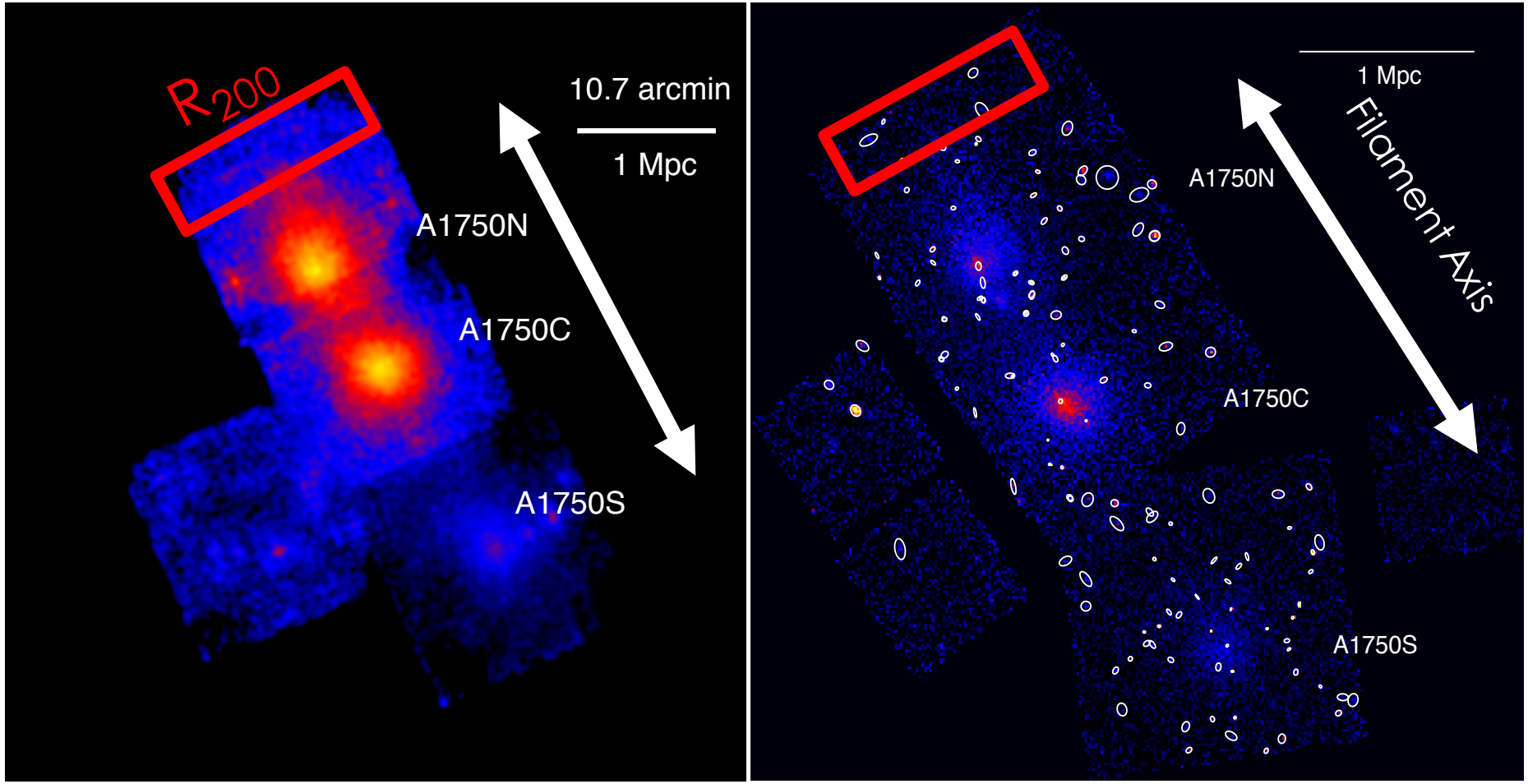
Key Questions

- What is the temperature and abundance of ICM at cluster outskirts
- What is entropy at R_{200}?
- Any indication of entropy flattening or self-similarity?
- Could we detect extended warm gas (kT<1keV) beyond the virial radius?
- If so, what is the abundance, temperature, and mass of the gas
- Could we detect the bridge filamentary gas connecting cluster pairs?

Best Targets: Nearby Merging Clusters

Suzaku Observations

Chandra Observations



A1750

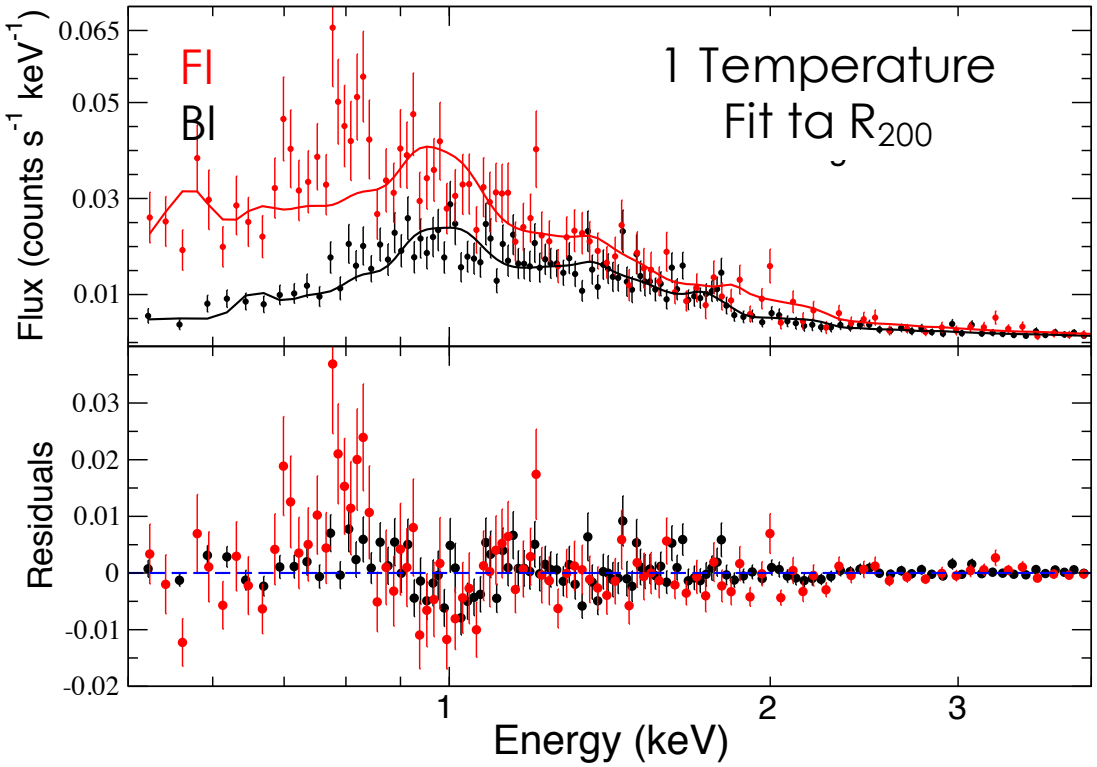
Z=0.08

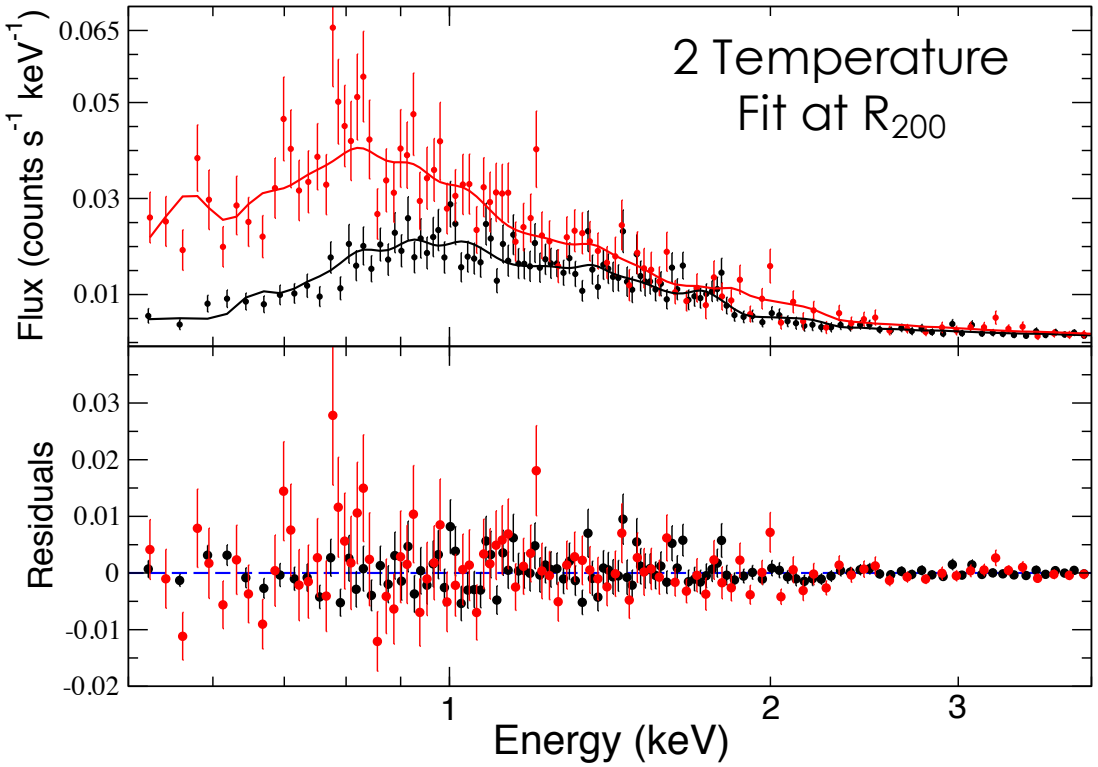
Bulbul+2016

Detection of a Warm Gas Along the Filament

A warm gas kT~0.8 keV is detected at 4 σ level by Suzaku

Scale > 650 kpc

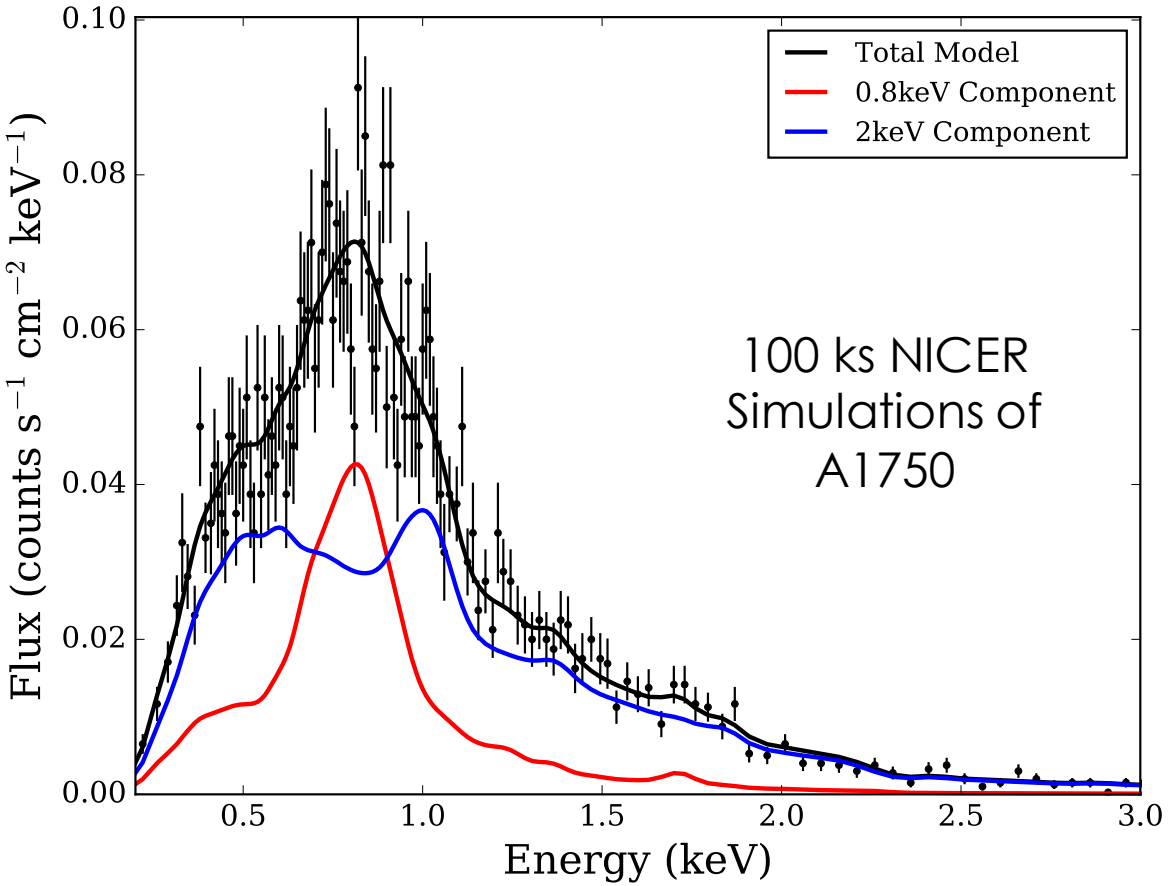




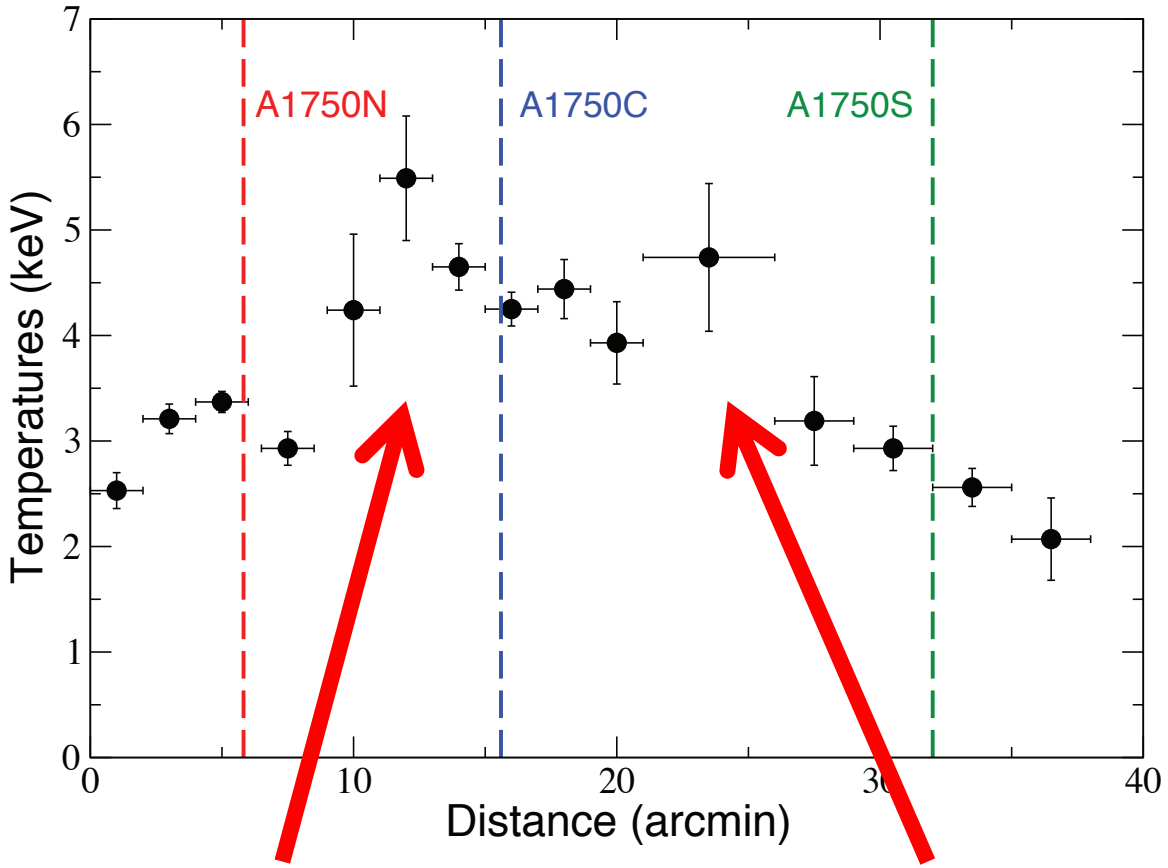
Bulbul+2016

NICER Observations of A1750

- Origin of the gas is unknown
  - Stripped halo gas
  - Stripped from ICM?
  - Dense end of WHIM?
- 100 ks NICER observations will detect the gas at 5σ level
- Off-axis X-ray background observations might be necessary!

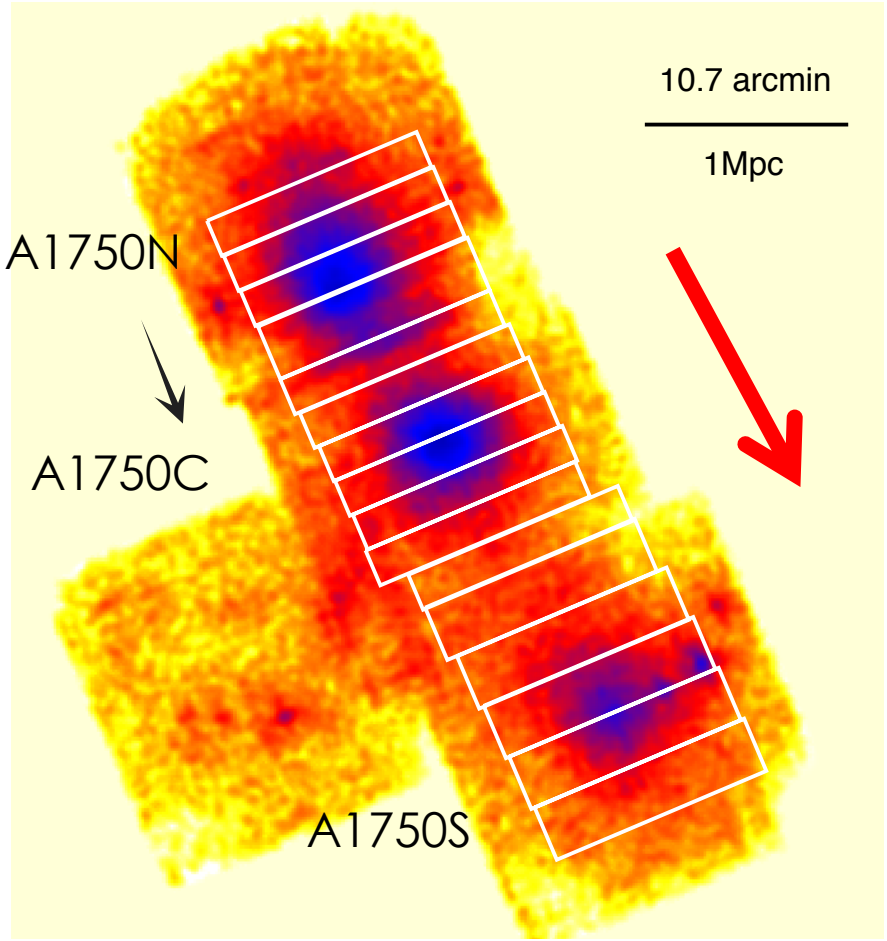


ICM in between Clusters



Shock Heated Gas
Possible Interaction
(Belsole+2004)

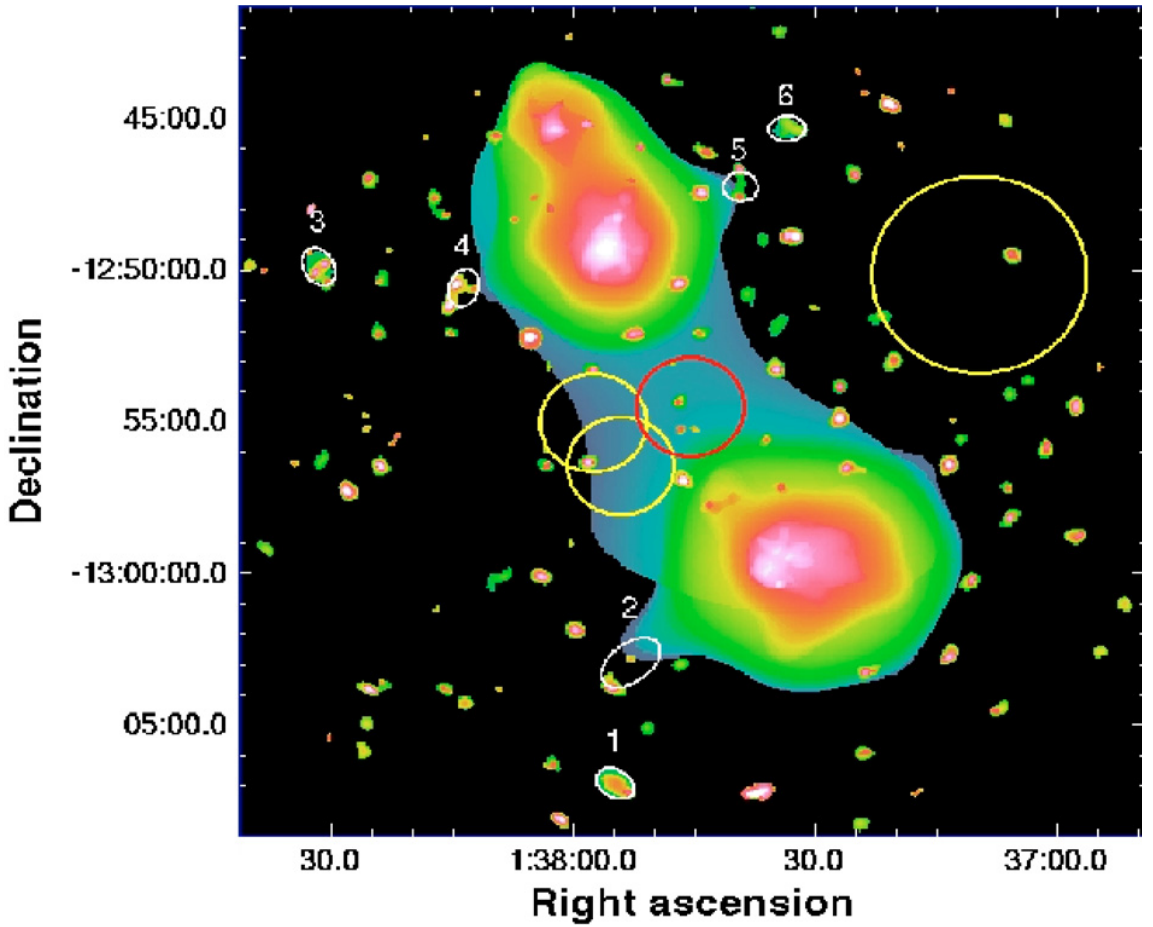
Interaction between
A1750C and A1750S
(Molnar+2013)



Bulbul+2016

Filaments Connecting Clusters

- 144 ks of A222/223 with XMM-Newton
- Connecting filament at 3σ level
- The filament is ≈1.2 Mpc wide
- Overdensity is $150\rho_{crit}$
- kT = 0.91±0.25 keV
- See also Eckert+2016, Ogrean+2018



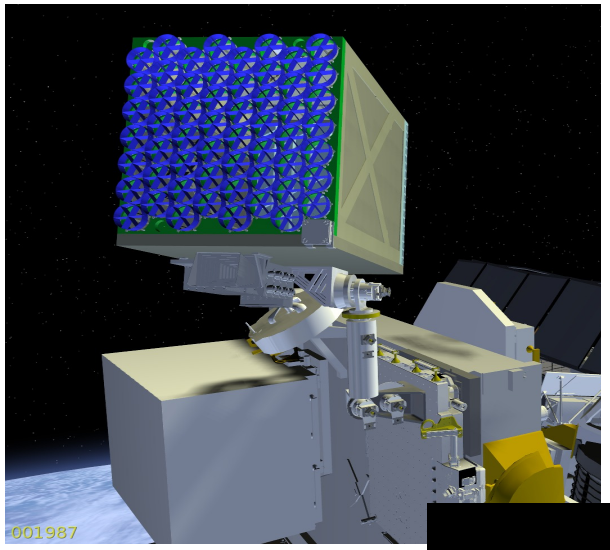
Werner+2008

Spectroscopy with Strobe-X XRCA

- NICER will provide a proof of concept for cluster outskirts studies for nearby clusters $z<0.1$
- For higher redshift clusters $z>0.2$, we need XRCA's effective area
- XRCA's low background, large effective, moderate energy resolution are the key!

Challenges

- Entering to a systematic dominated era
- Large PSF (2 arcmin)
- Scattered light from bright cluster core
- Small FOV
- Lack of imaging capability
  - Exclude point sources in the FOV
  - Unresolved cosmic X-ray background



The Way Forward

- Lessons to learn from NICER
- Along the way we will figure out how to deal with systematics
- Smaller PSF size would be an advantage
- Multi pointings is required to map the filamentary gas due to small FOV
- Pointing to observe/measure X-ray background
- Simultaneous imaging observations are essential