Probing of Interactions between Galaxies and Hot Plasmas in Clusters

a possible energetic flow on cosmological timescale

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Motivation:

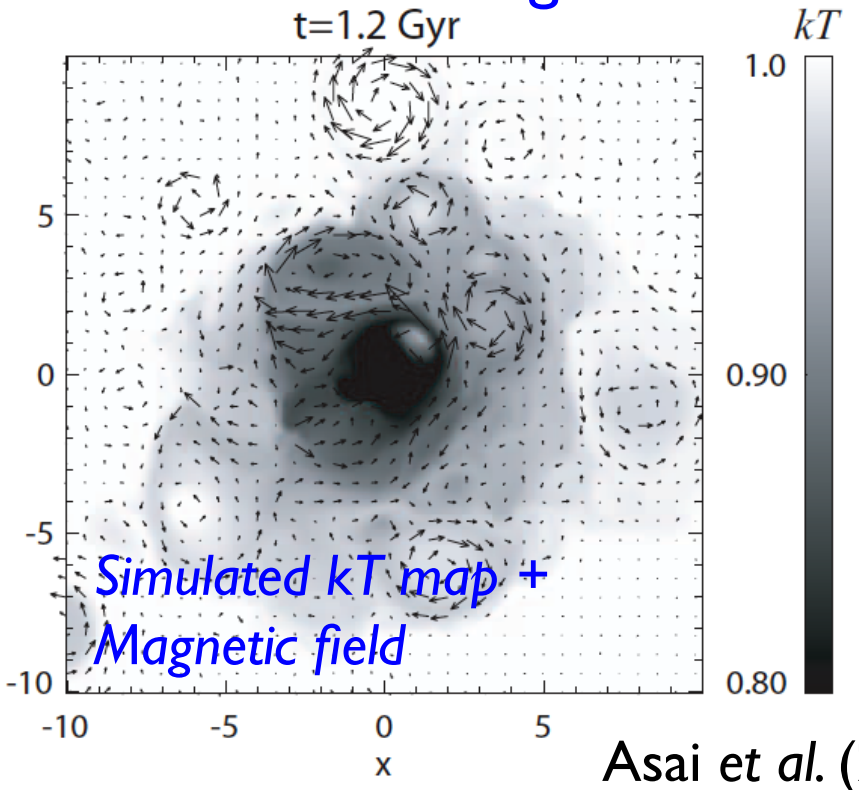
Is there a common mechanism to explain the observed phenomena of ICM ('cooling flow', turbulence) and cluster galaxies (cD formation, morphology-density relation)?

Role of EM Interactions in Clusters

- Long-range electromagnetic (EM) interactions are poorly considered.
- Nature of cosmic plasmas: collective, long-distance interactions (wave, organized motion…)
- Simple test: how strong do cluster member galaxies interact with ICM?

The key is to measure:

Radial galaxy number(light) profiles / radial ICM mass profiles for clusters with different-redshifts



Asai *et al.* (2007)

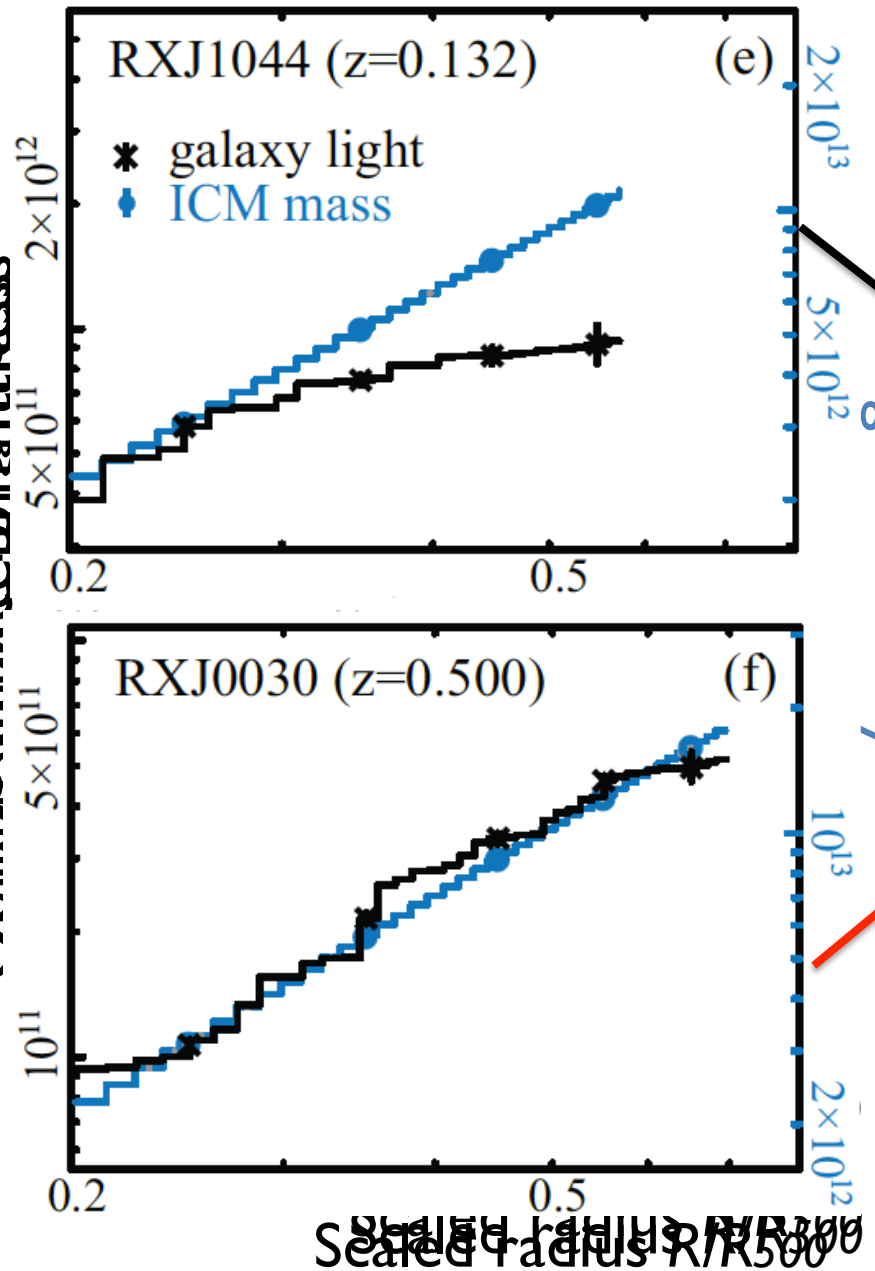
Systematic Study on Galaxy vs. ICM Dist.

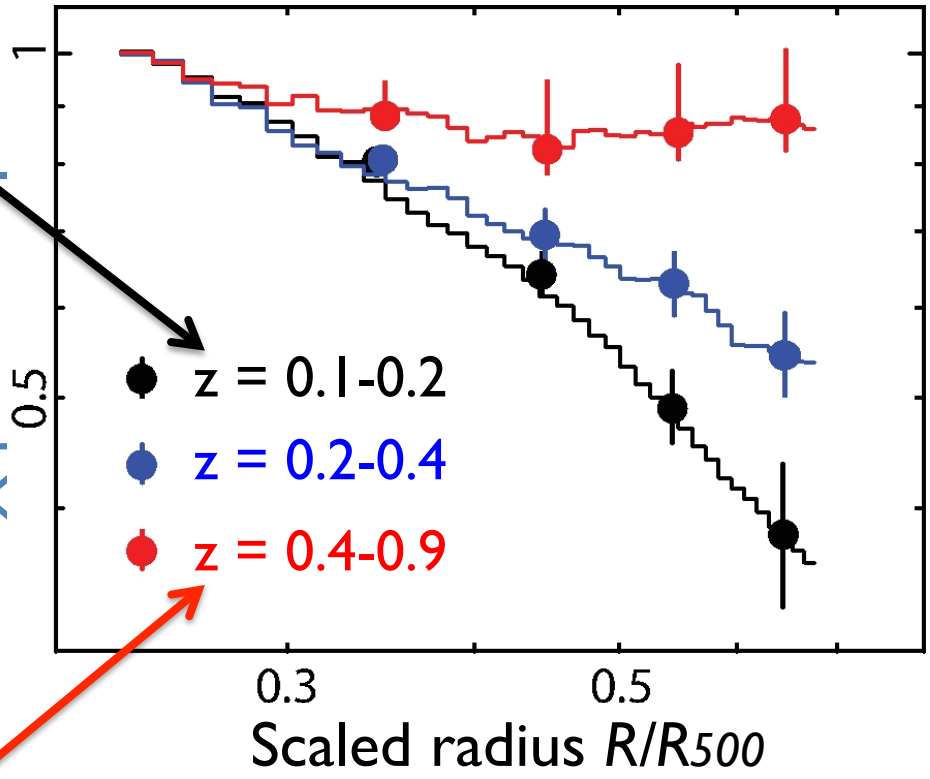
Two samples are studied:

1. Large redshift range (z = 0.1-0.9; Gu+2013, *ApJ*, 767,157)
   - Cluster number = 34
   - Total mass = 2-8 10^{14} Msun
   - Relaxed morphology
   - Our own optical photometric and archival XMM/Chan. data
   - Member selection: color-mag. and background subtract

2. Large sample number (339 clusters; 258 in this talk)
   - Redshift = 0.0-0.5
   - Total mass = 0.1-15 10^{14} Msun
   - Morphology-unbiased
   - SDSS DR9 phot-z (M_r < -21) and archival XMM/Chan. Data
   - Redshift uncertainty Δz = 0.012~0.022

Sample I. Normalized Galaxy vs. ICM Profiles

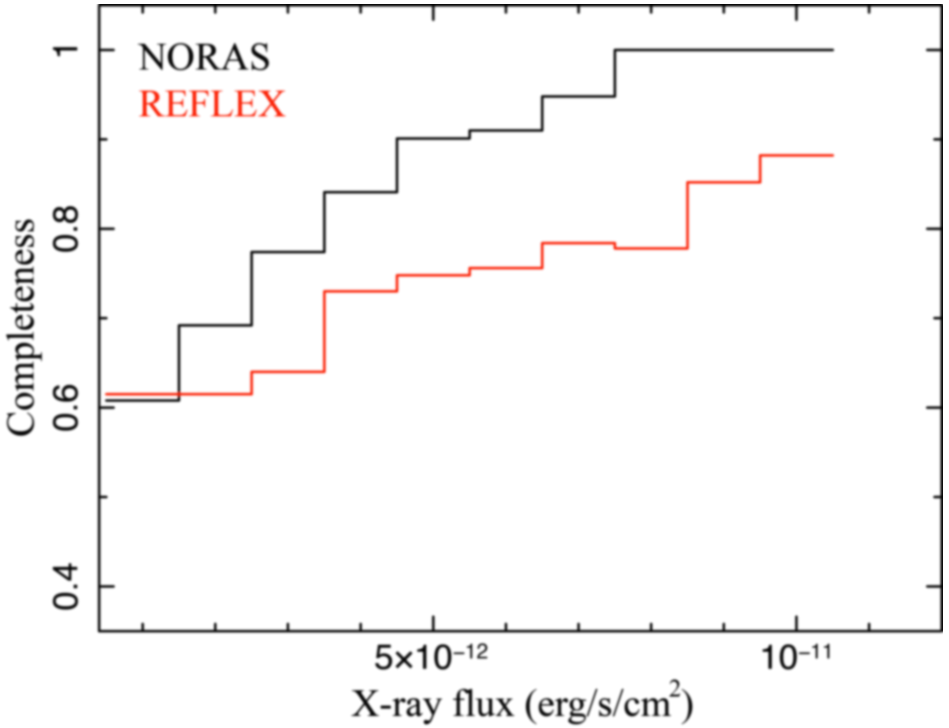




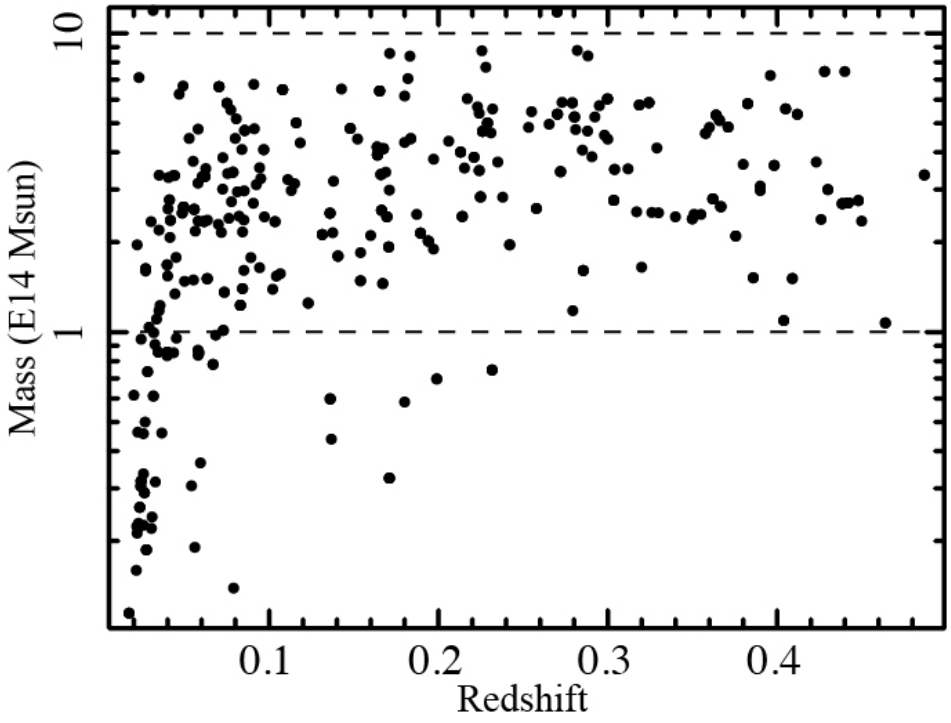
❖ Dynamical friction is insufficient to create the evolution.

Sample II

Sample Completeness



Total mass (M_{500}) vs. redshift

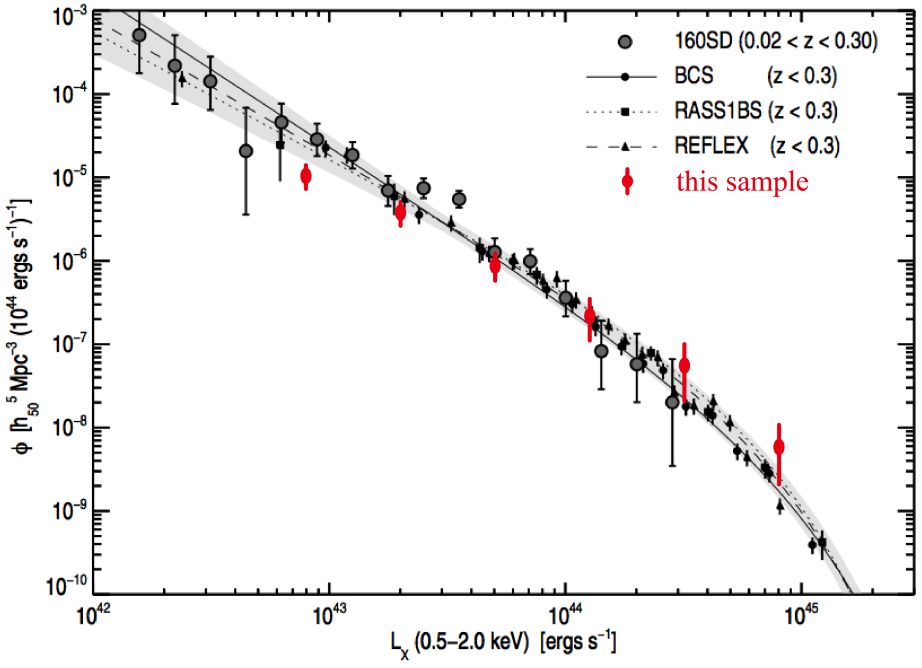


- All SDSS-XMM/Chan. clusters
- 80-90% completeness (at >5e-12) relative to X-ray limited sample

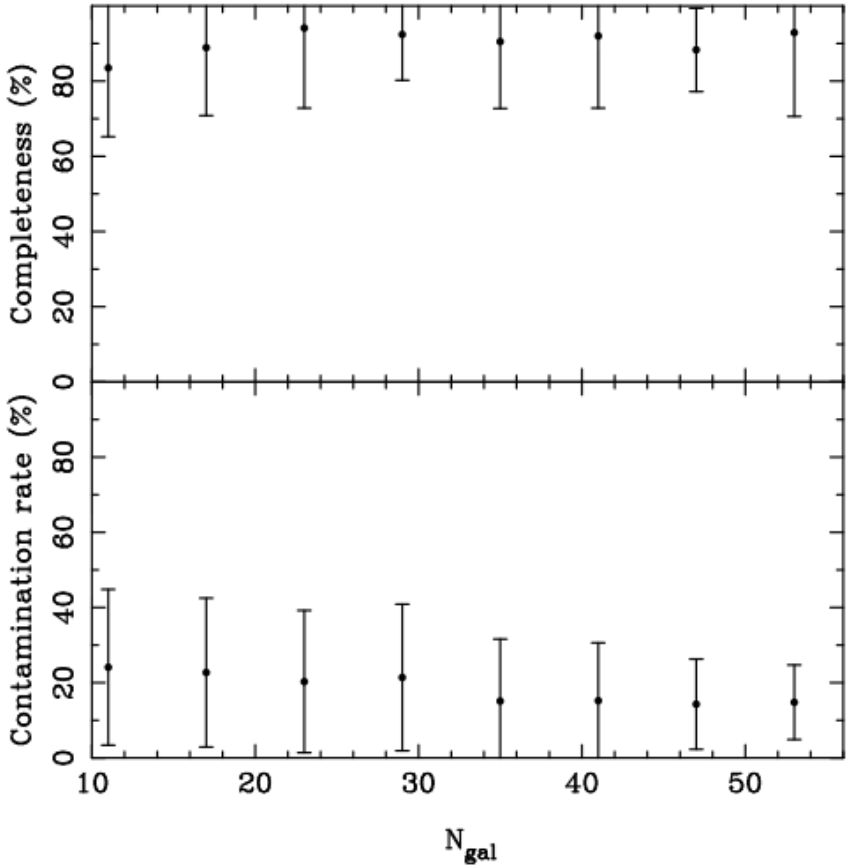
- *(This work)* $M_{500} = 10^{14\text{-}15}$ Msun selected

Sample II

X-ray Luminosity Function



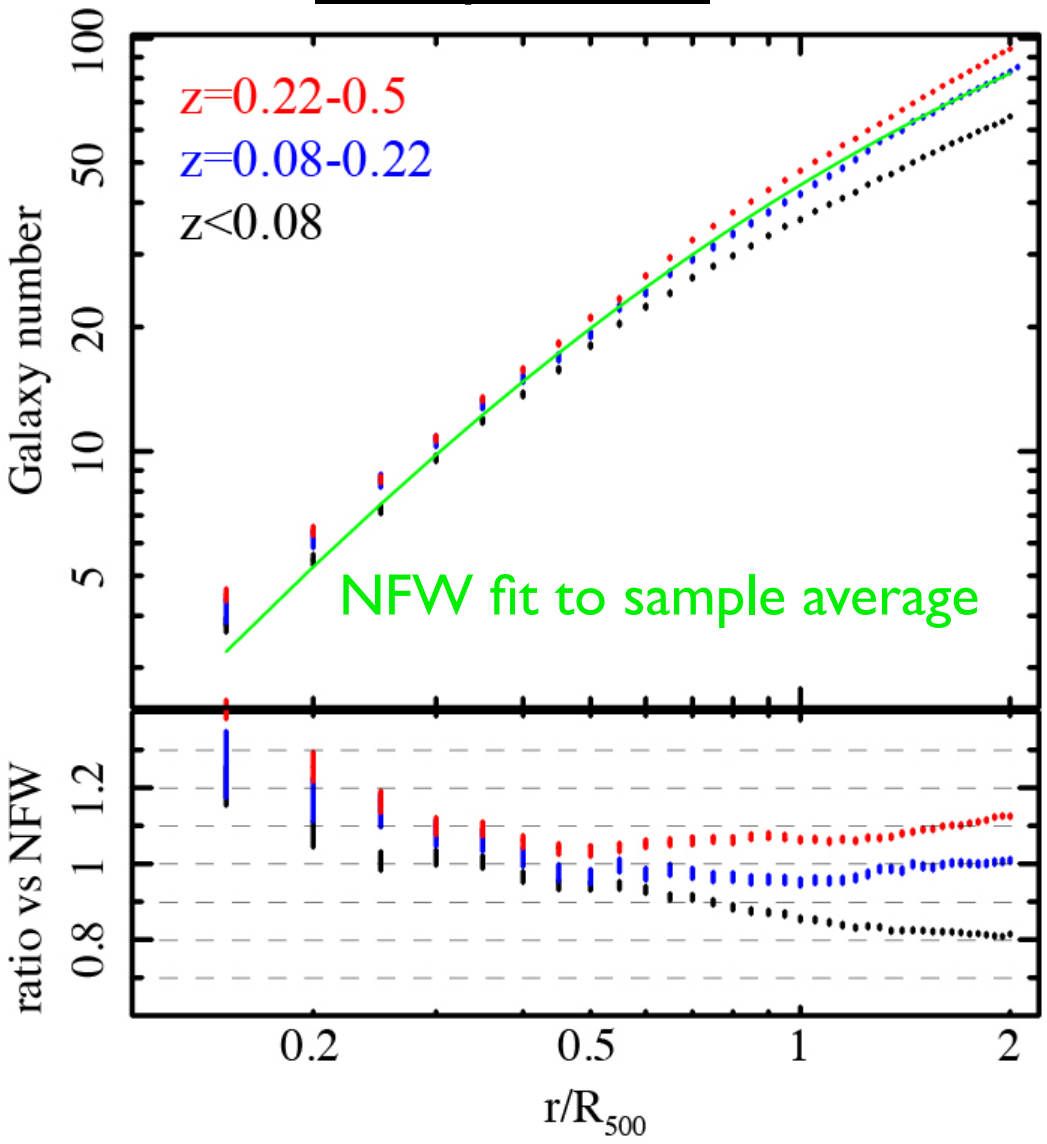
Member Gal. Comple./Contami.



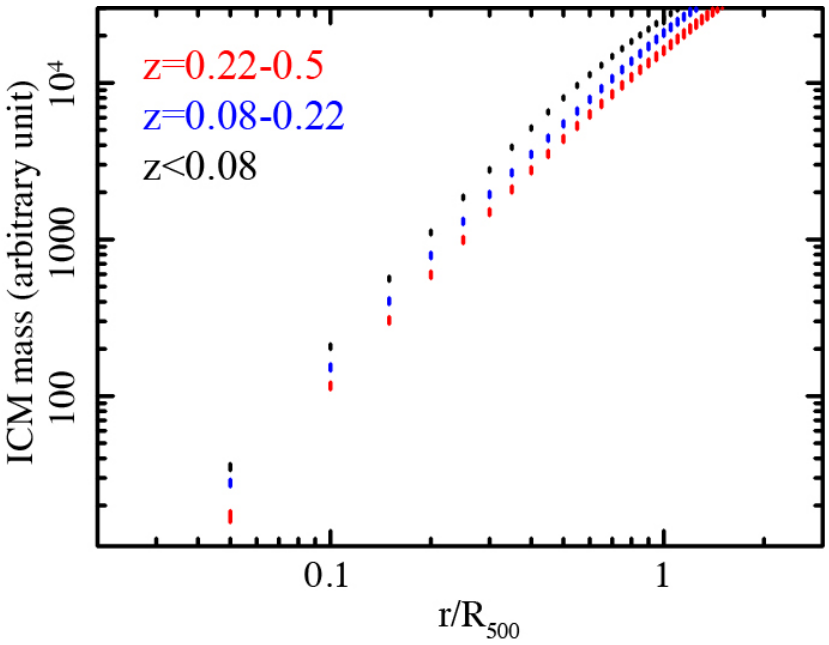
- 2971 galaxies (M_r < -21) found as member by SDSS DR9 spec-z; 2664 are in our phot-z sample ➔ ~90% completeness
- 3609 galaxies defined as member by phot-z, 763 are fore/background by spec-z ➔ ~20% contamination

Sample II. Integrated Profiles

Galaxy number



ICM mass

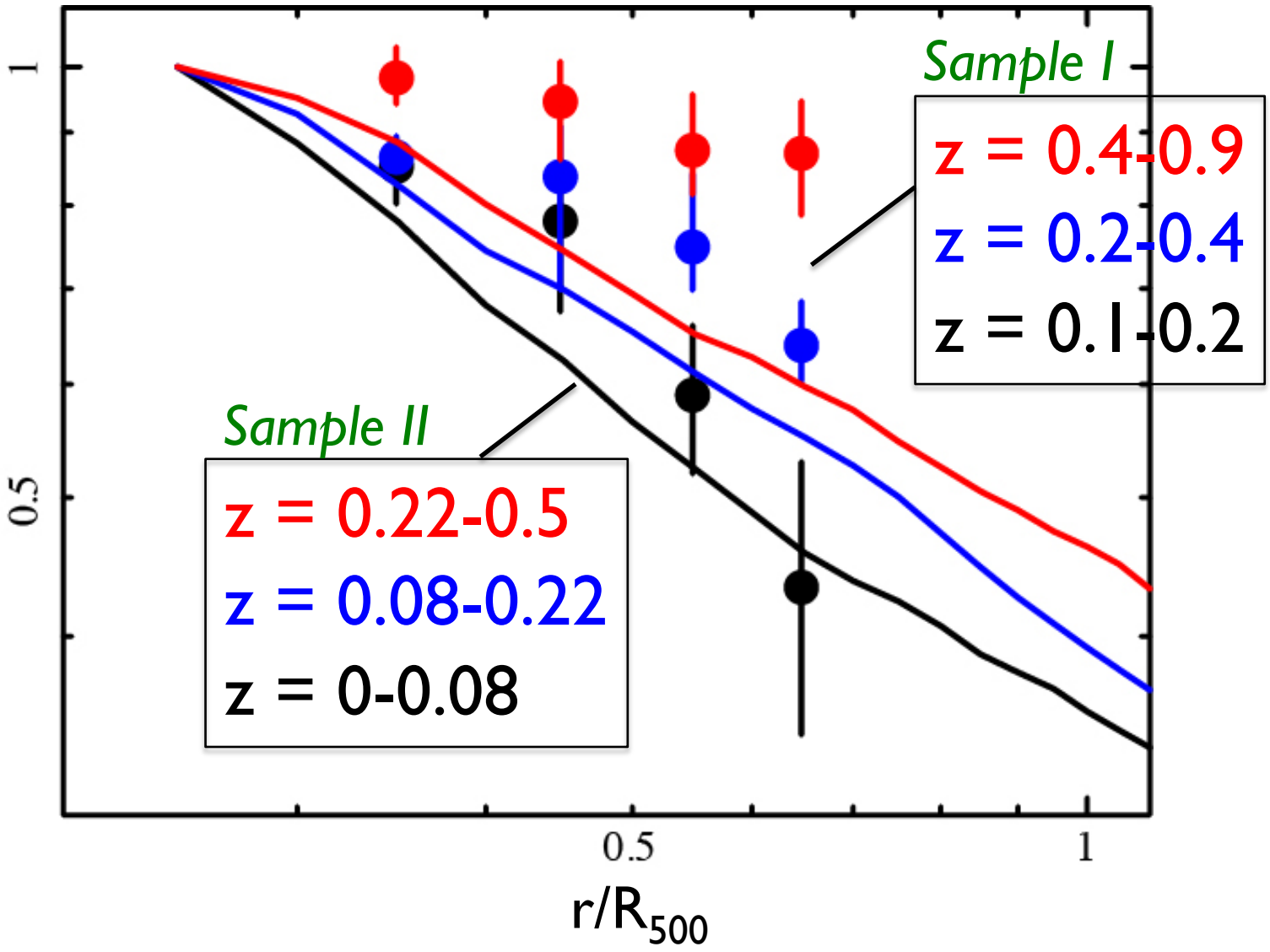


If consider gradient alone

- Galaxy profiles exhibit evolution.
- ICM shows weak/no change.

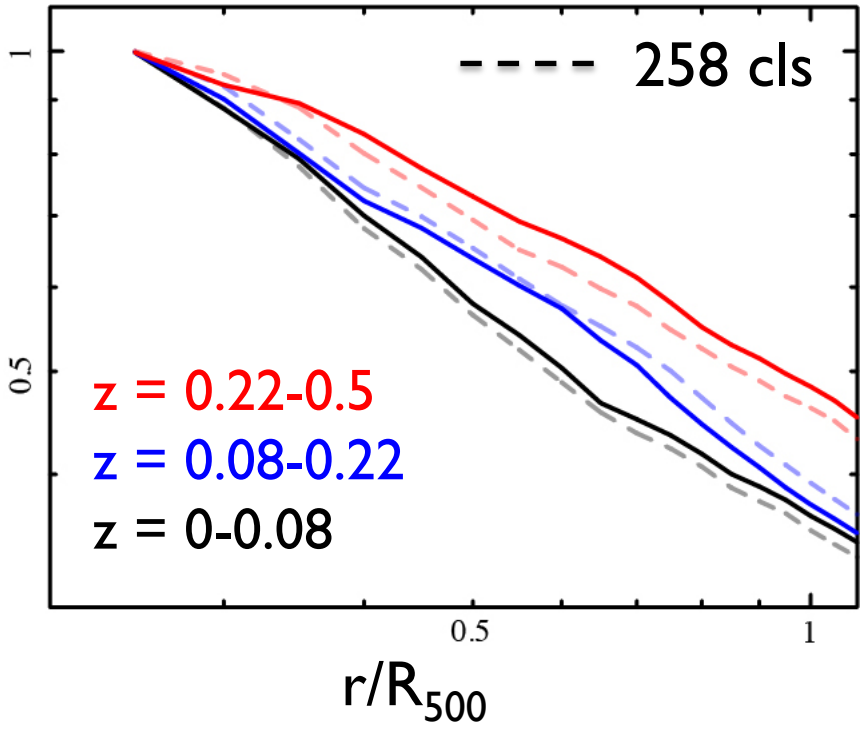
Sample II. Galaxy vs. ICM

Normalized Galaxy number vs. ICM mass ratio

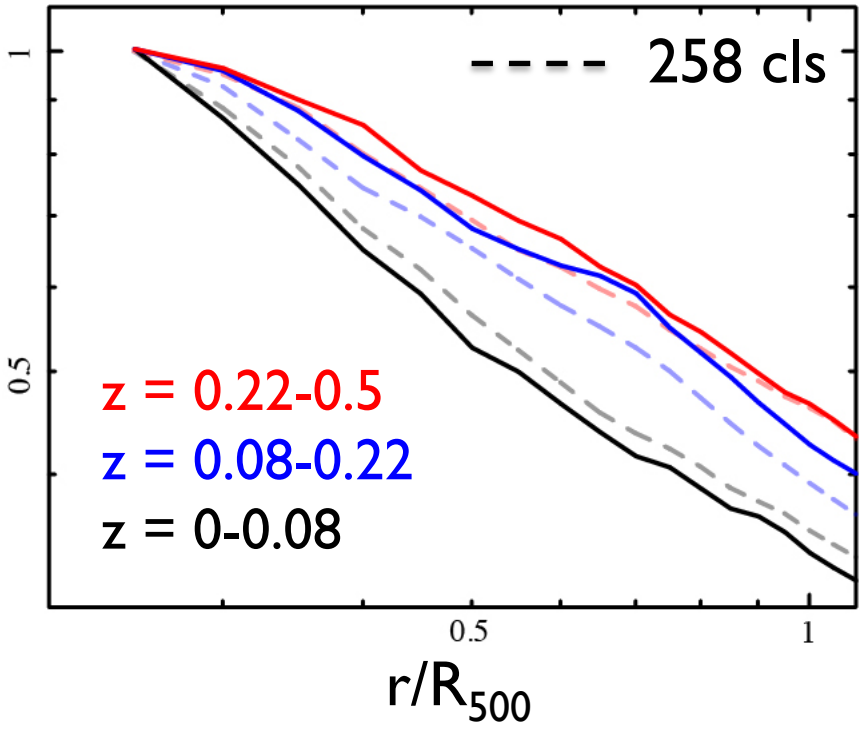


Sample II. Galaxy vs. ICM

Low mass clusters ($M_{500}<3\times10^{14}$)



Fainter galaxies ($L_r<1\times10^{11}$)



- ✧ Evolution of galaxy-to-ICM profiles does NOT depend on cluster or galaxy mass.
- ✧ Gravitational effects cannot fully explain this evolution.

Summary

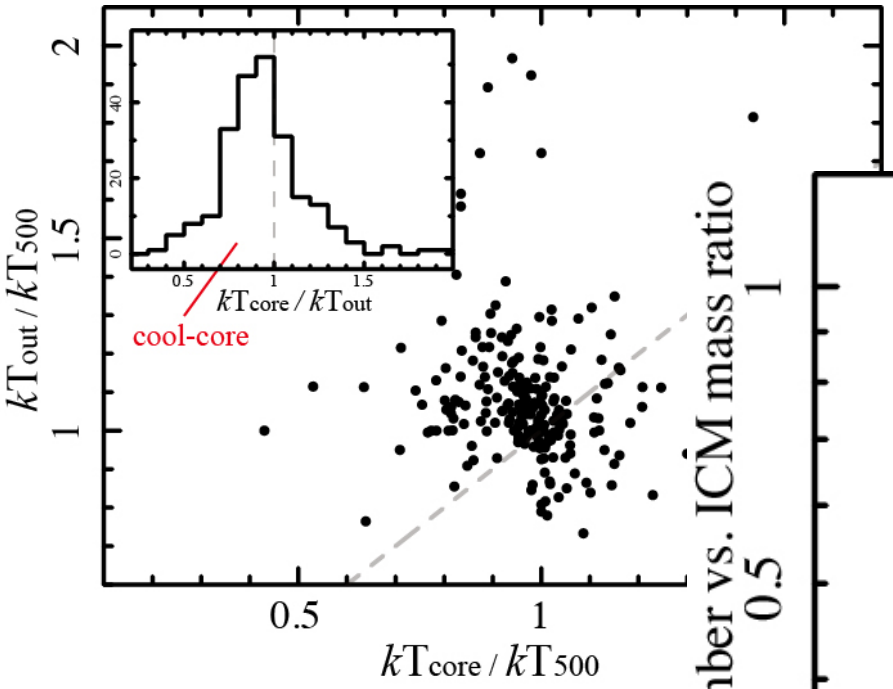
Member galaxies become centrally-concentrated relative to the ICM from z = 0.9 to z = 0.1.

- Galaxies lose kinet./poten. energy to ICM/DM by $10^{44\text{-}45}$ erg/s per cluster ➔ a hidden energetic flow on cosmological timescale.

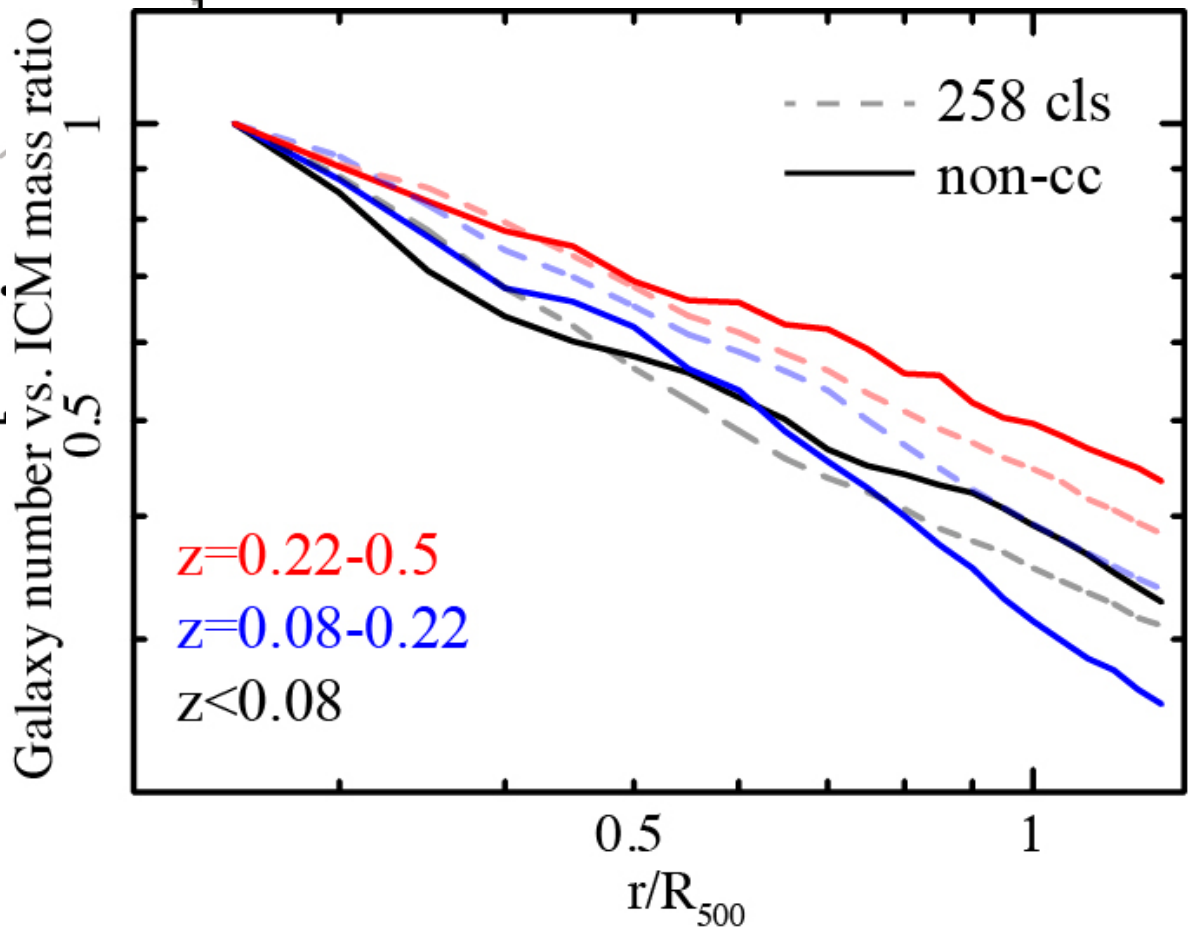
- Yet to explore:
  (1) Actual mechanism of the interaction
  (2) Effects of the long-range EM interaction (*esp. via magnetic field*) in suppressing cooling flow / galaxy evolution / structure formation.

Cool core/ Non-cool core

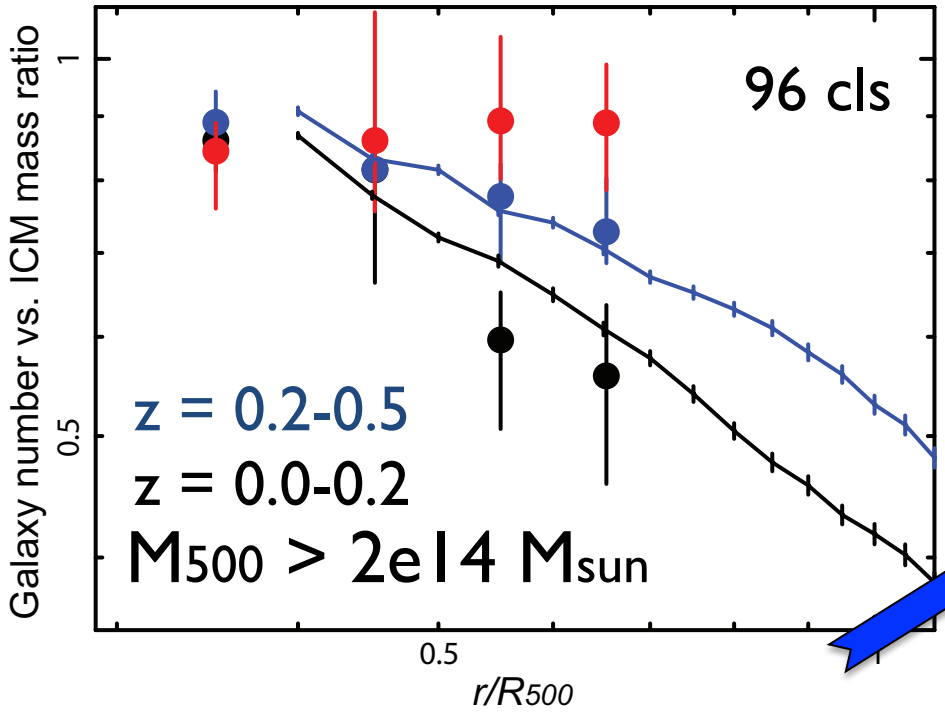
Core *k*T vs. *k*T at 0.2-0.5 R500



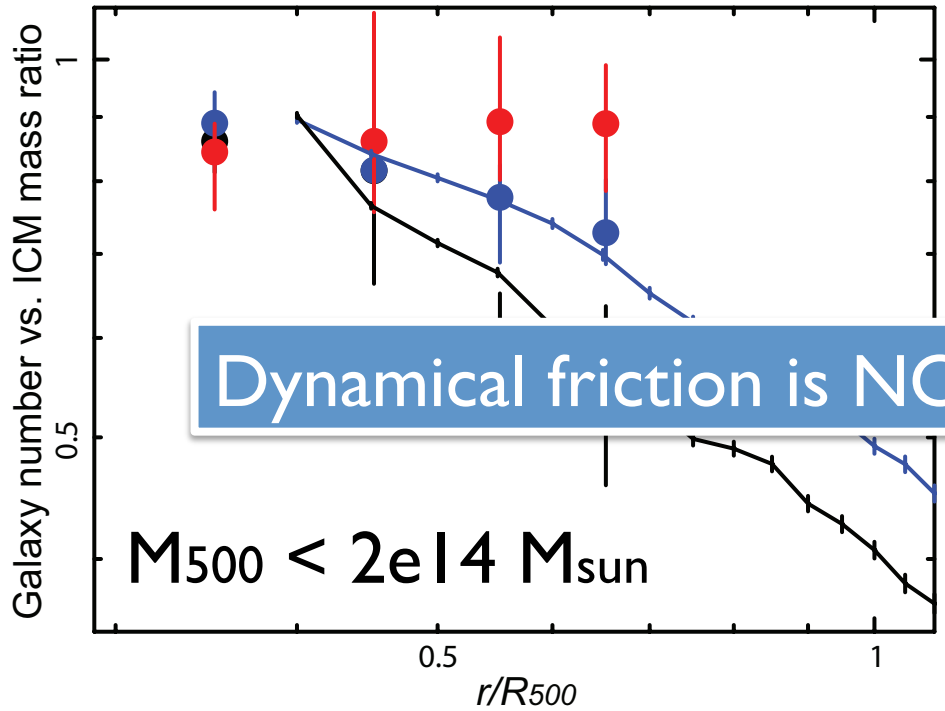
Galaxy number vs. ICM mass for NCC

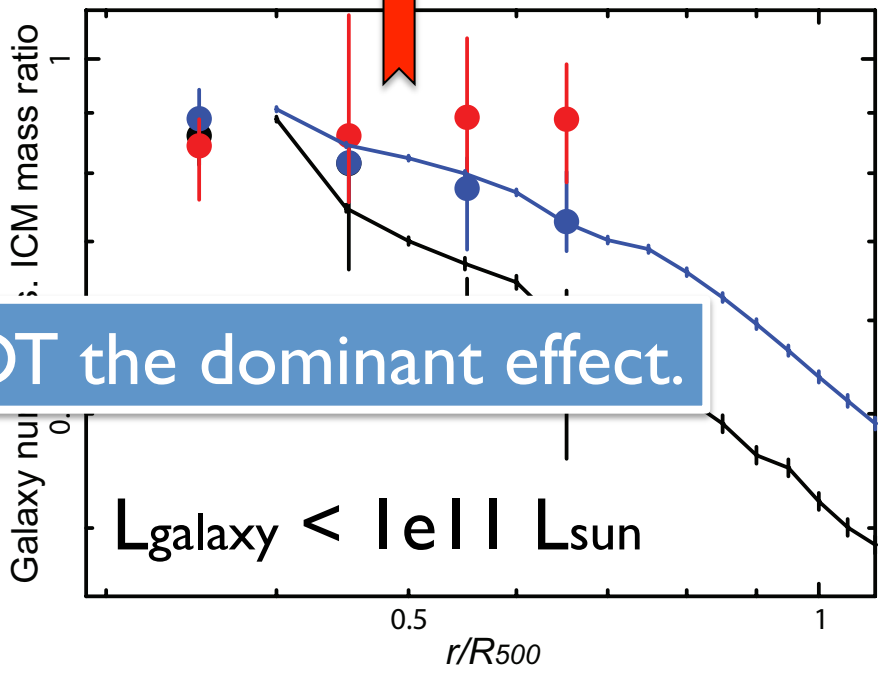


Gravitational Effects
e.g., dynamical friction



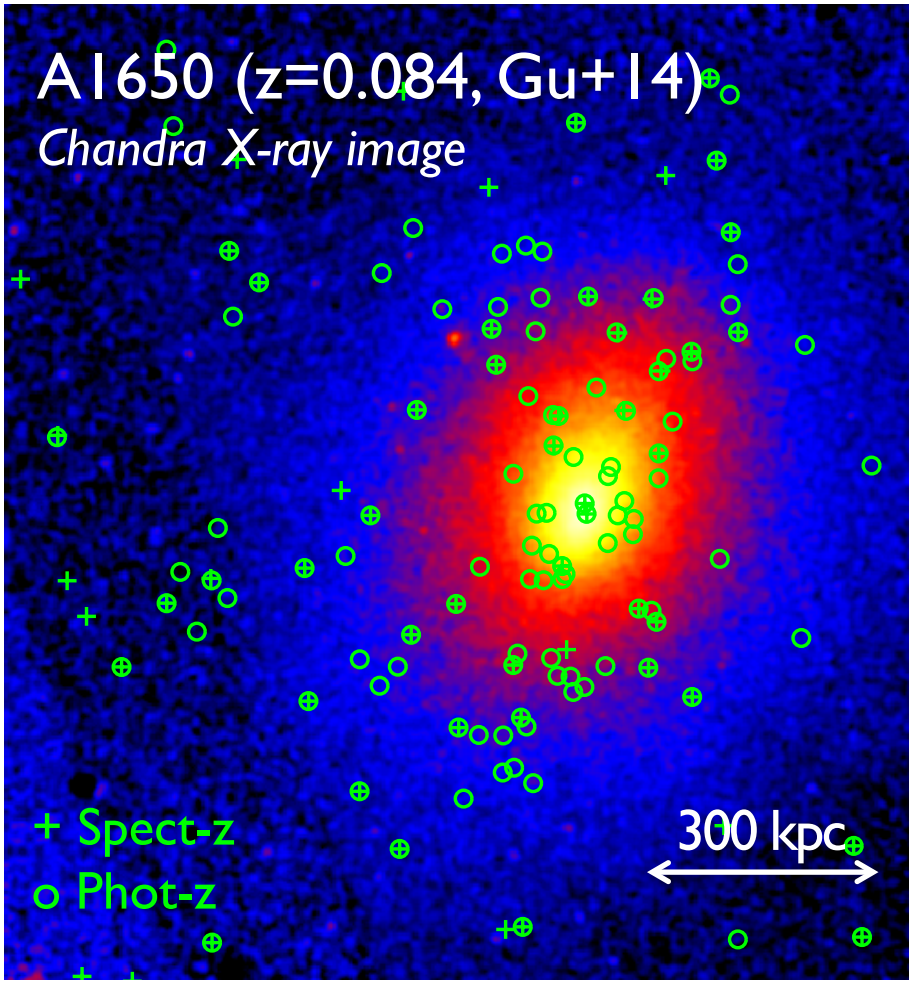
✧ Evolution of galaxy-to-ICM profiles does NOT depend on cluster mass or galaxy mass.

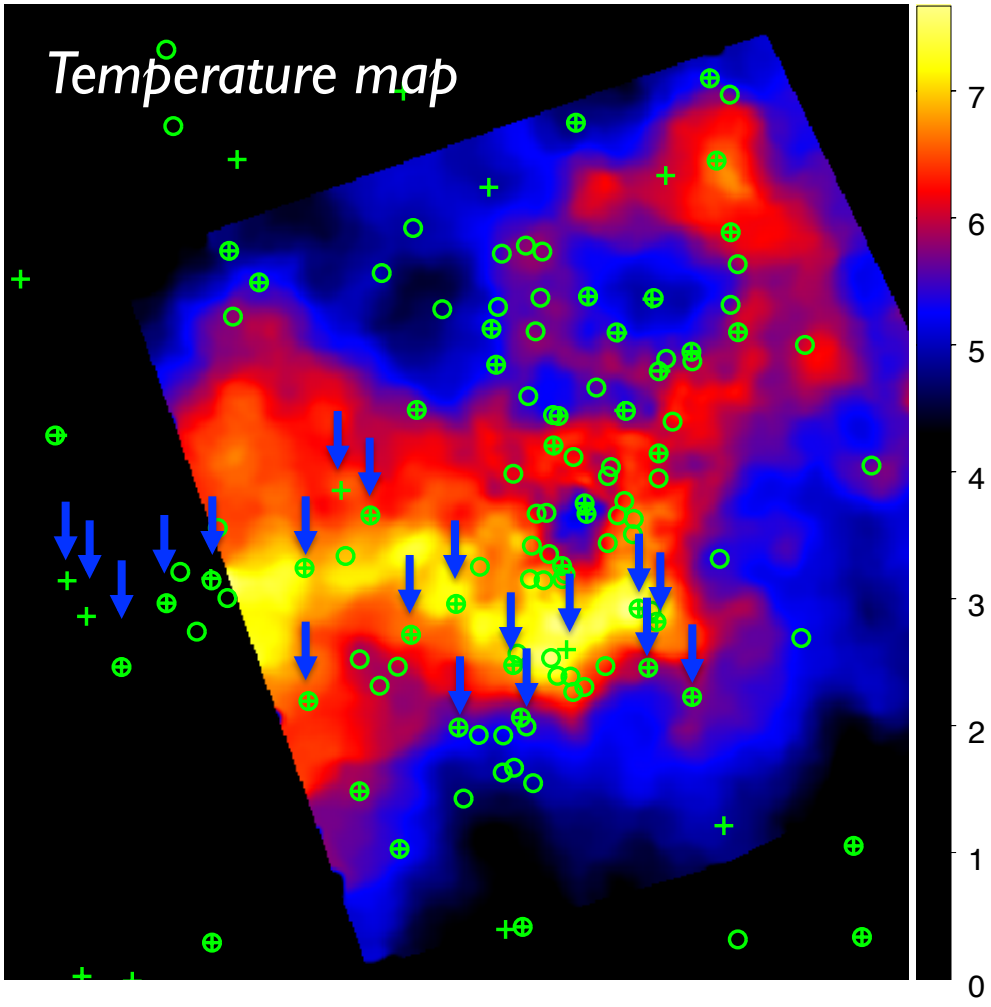




Dynamical friction is NOT the dominant effect.

Possible Inter: Clumpy Infall

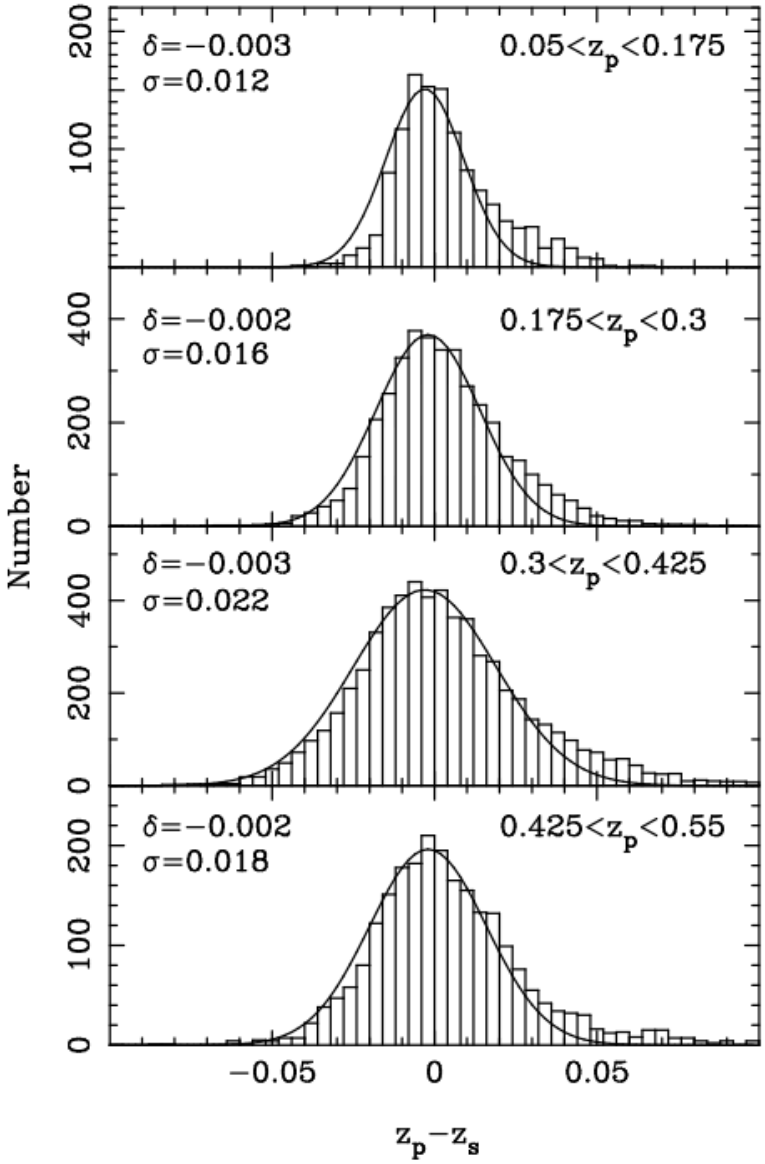




Group infall/minor mergers: energy dissipation ~ 10^{60} erg *(suppress cooling!)*, galaxy color change along the infalling filament

Photometric accuracy

Photometric-z – Spectroscopic-z



Member number vs. phot-z gas