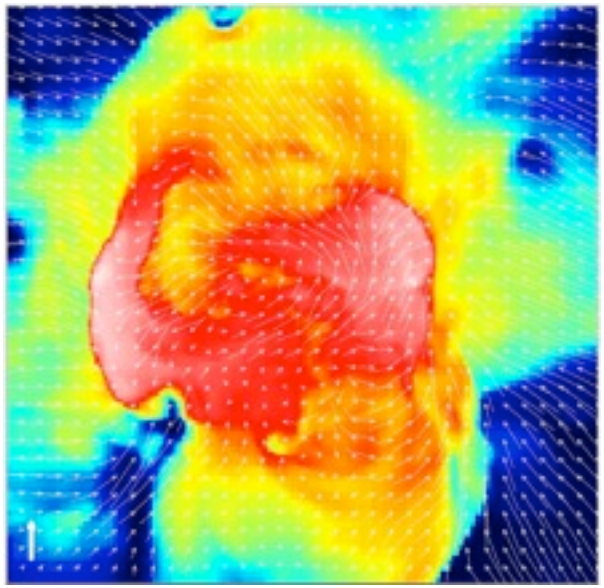
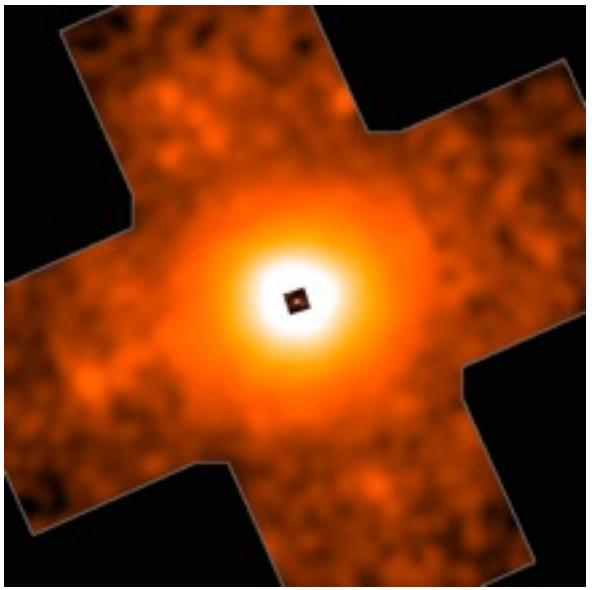
Gas Motions in the Outskirts of Galaxy Clusters





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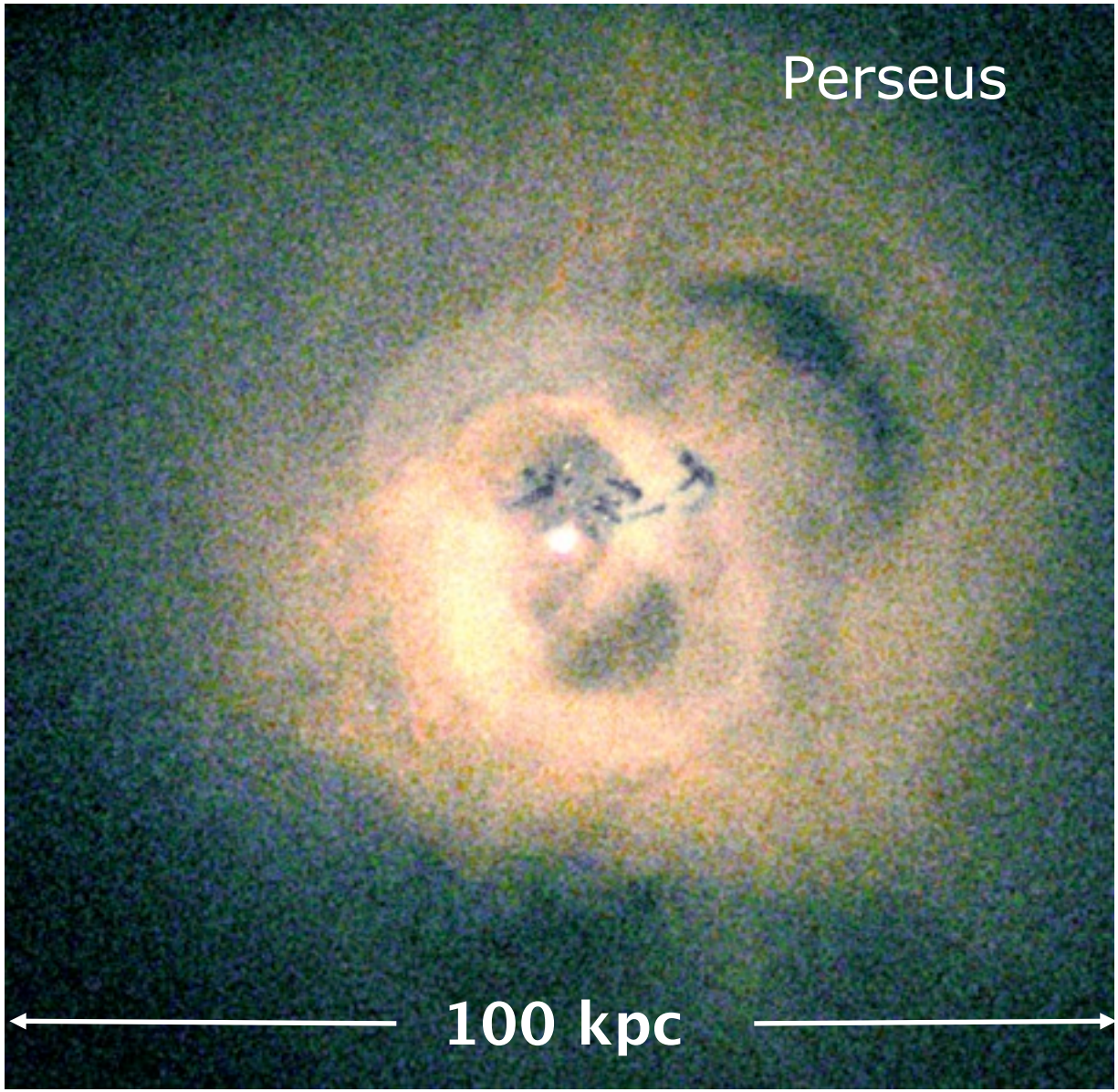
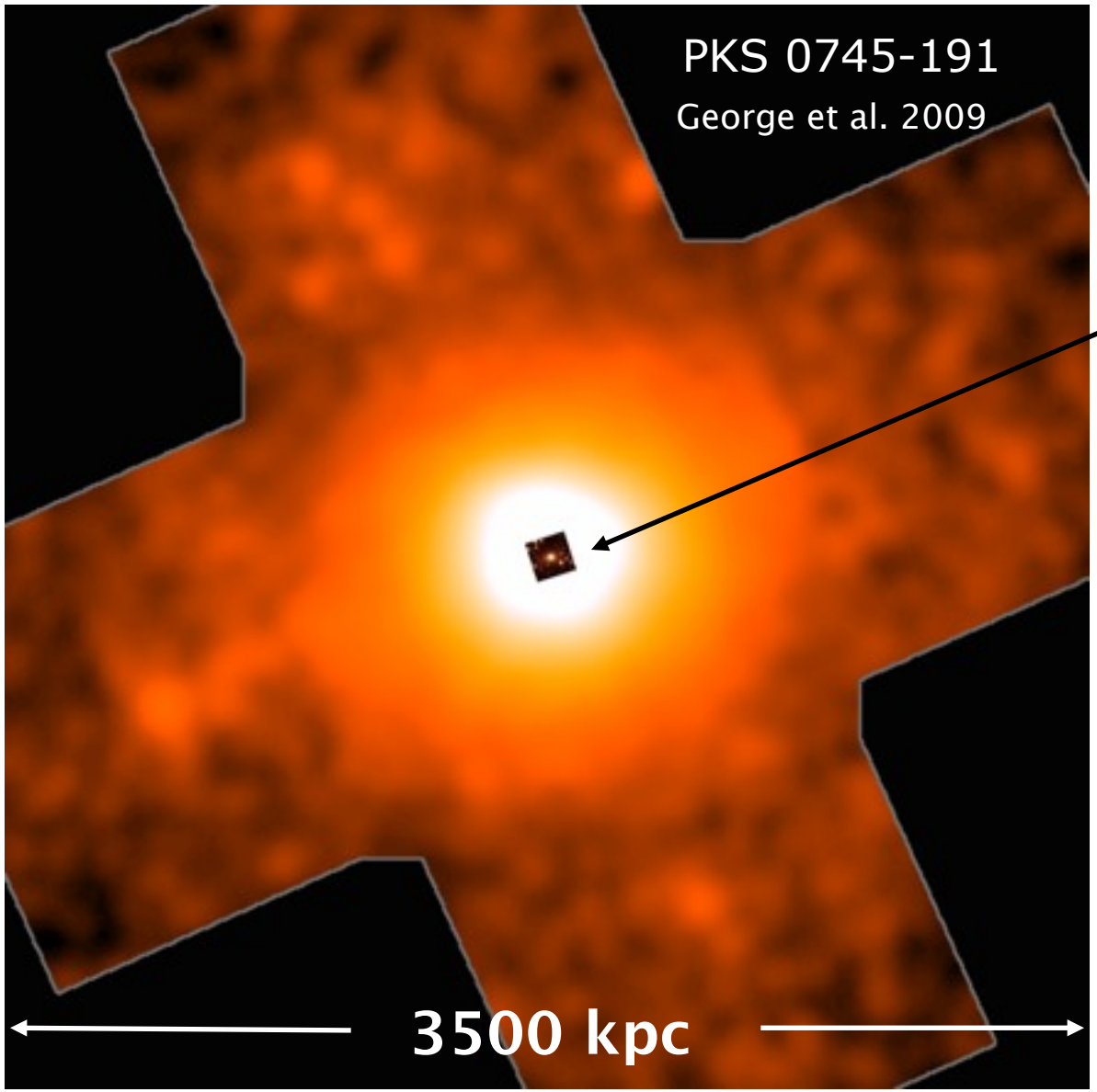
The Physics of the ICM: Theory & Computation
University of Michigan, Ann Arbor
August 24th 2010

In collaboration with Erwin Lau and Andrey Kravtsov (U.Chicago)

Chandra Observation of Perseus

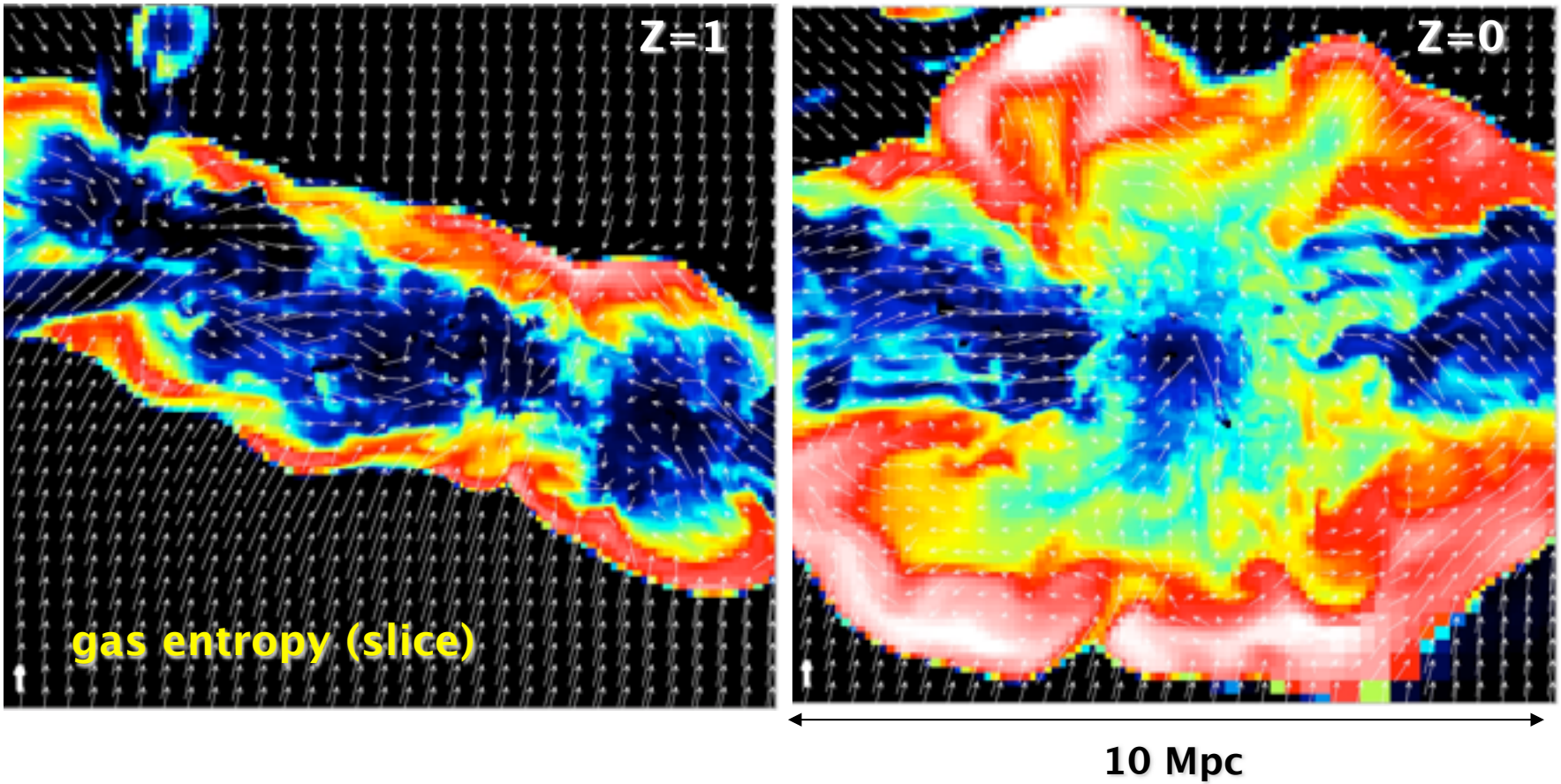


Zooming out on X-ray Clusters with Suzaku



Simulations predict ubiquitous gas motions in the ICM

N-body+Gasdynamics with Adaptive Refinement Tree code

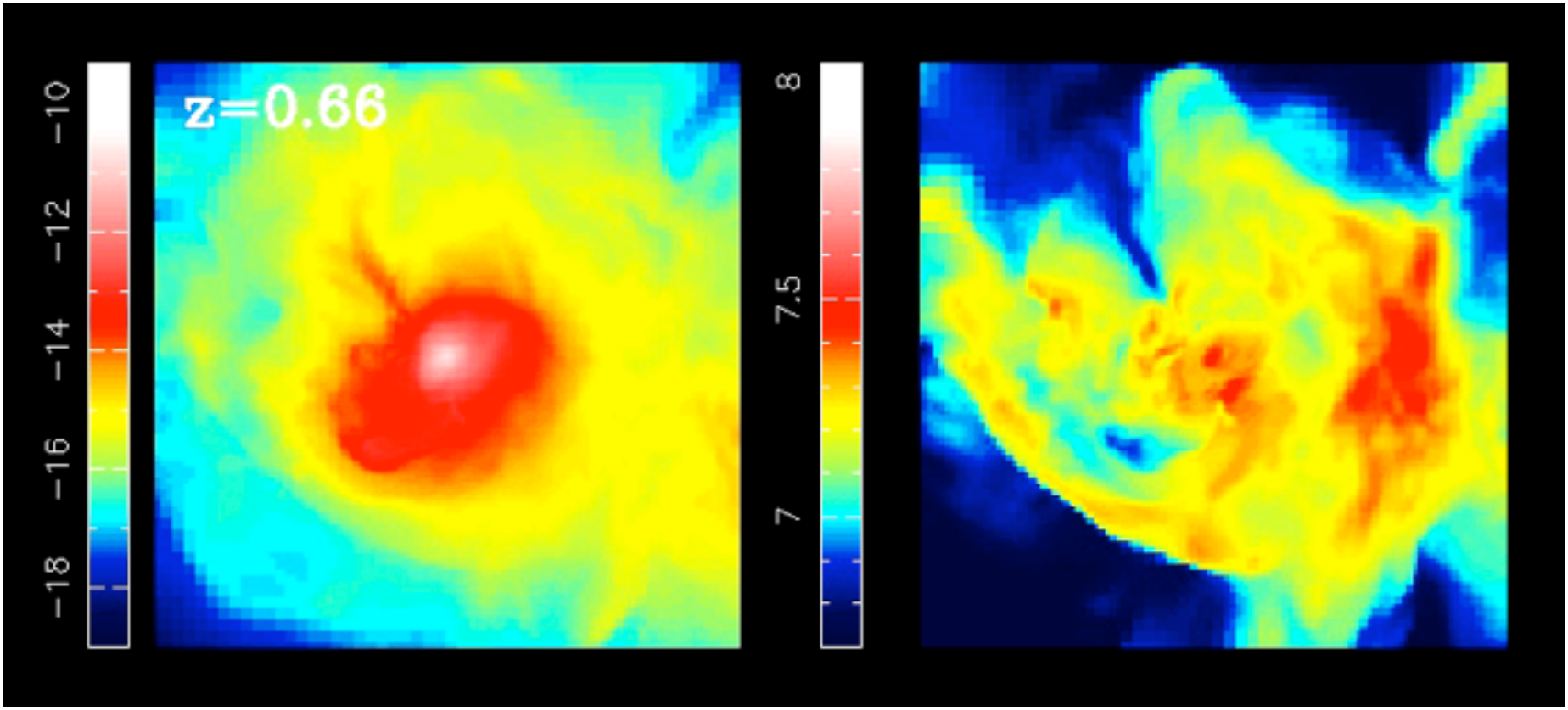


Norman & Bryan 1999, Nagai, Kravtsov & Kosowsky 2003
Sunyaev, Norman & Bryan 2003; Rasia et al. 2004, 2006;
Dolag et al. 2005; Nagai et al. 2007; Lau et al. 2009

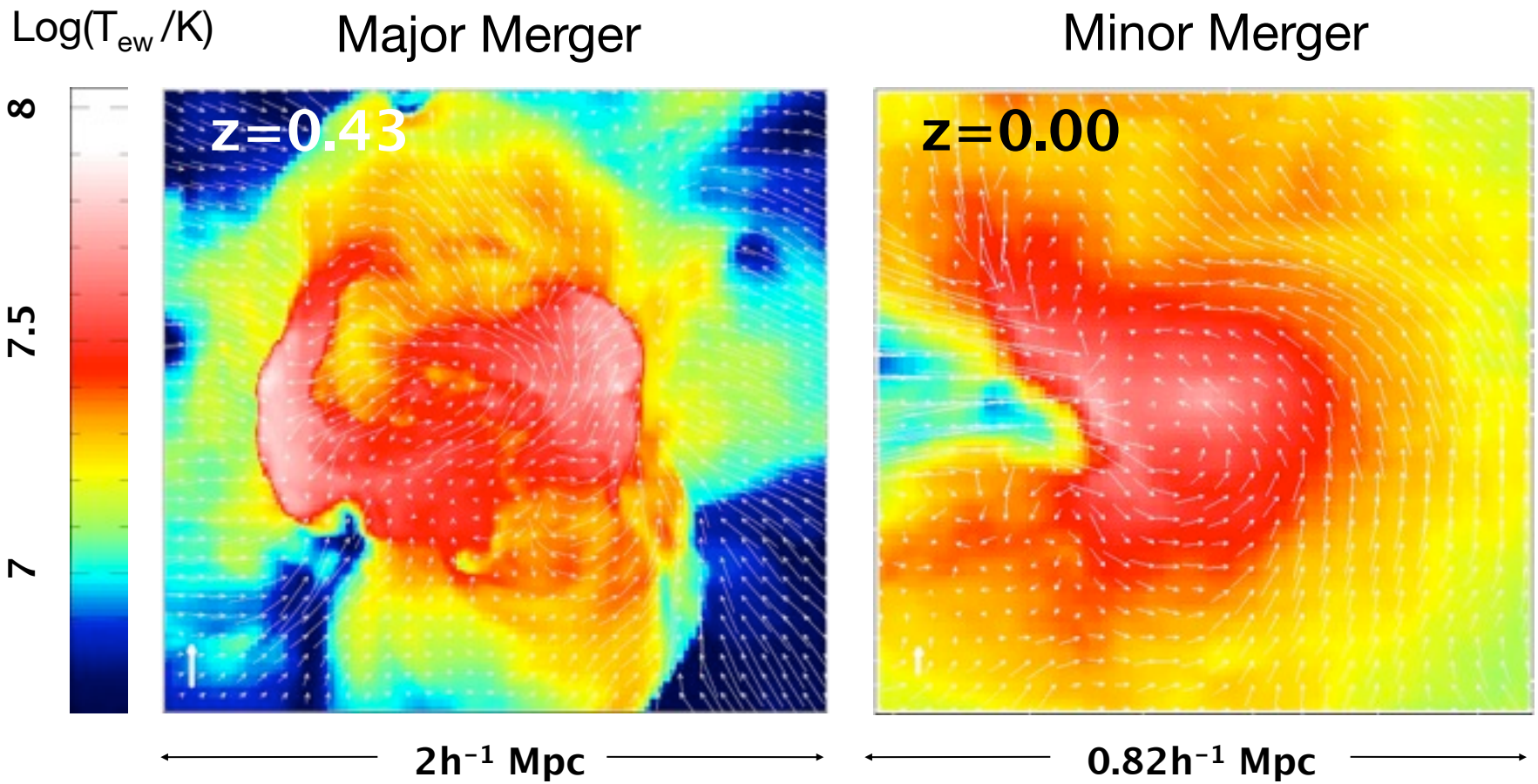
Major merger is rare, but catastrophic

X-ray surface brightness

Temperature



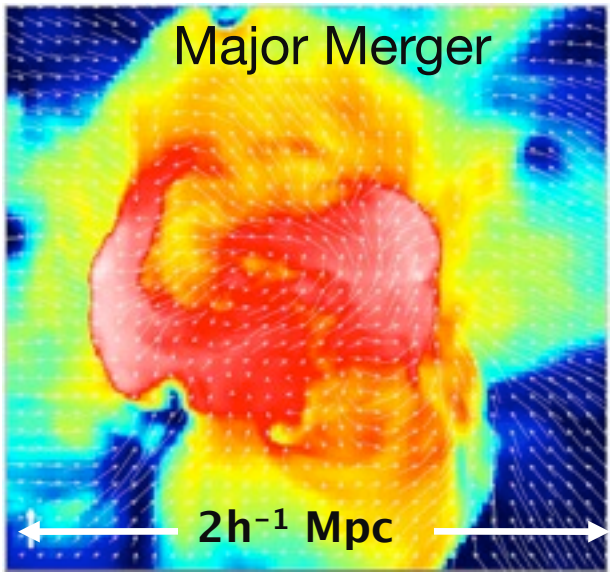
Minor mergers are more ubiquitous

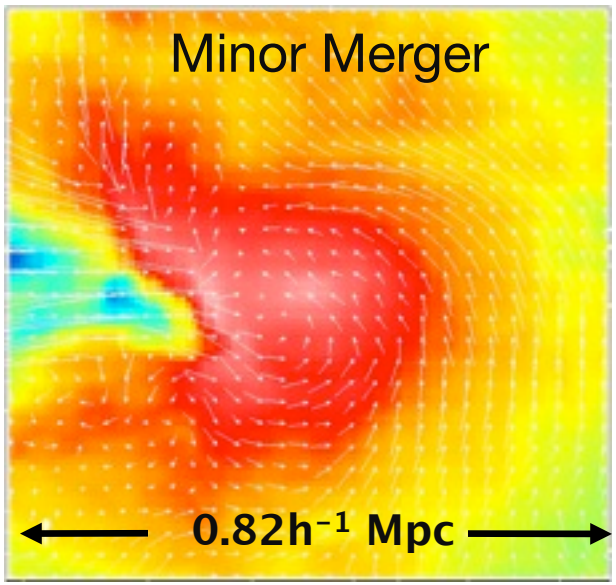


v~1000km/s
M~1-3 (transonic)

v~300km/s
M~0.3 (subsonic)

Why care about gas motions in the ICM?

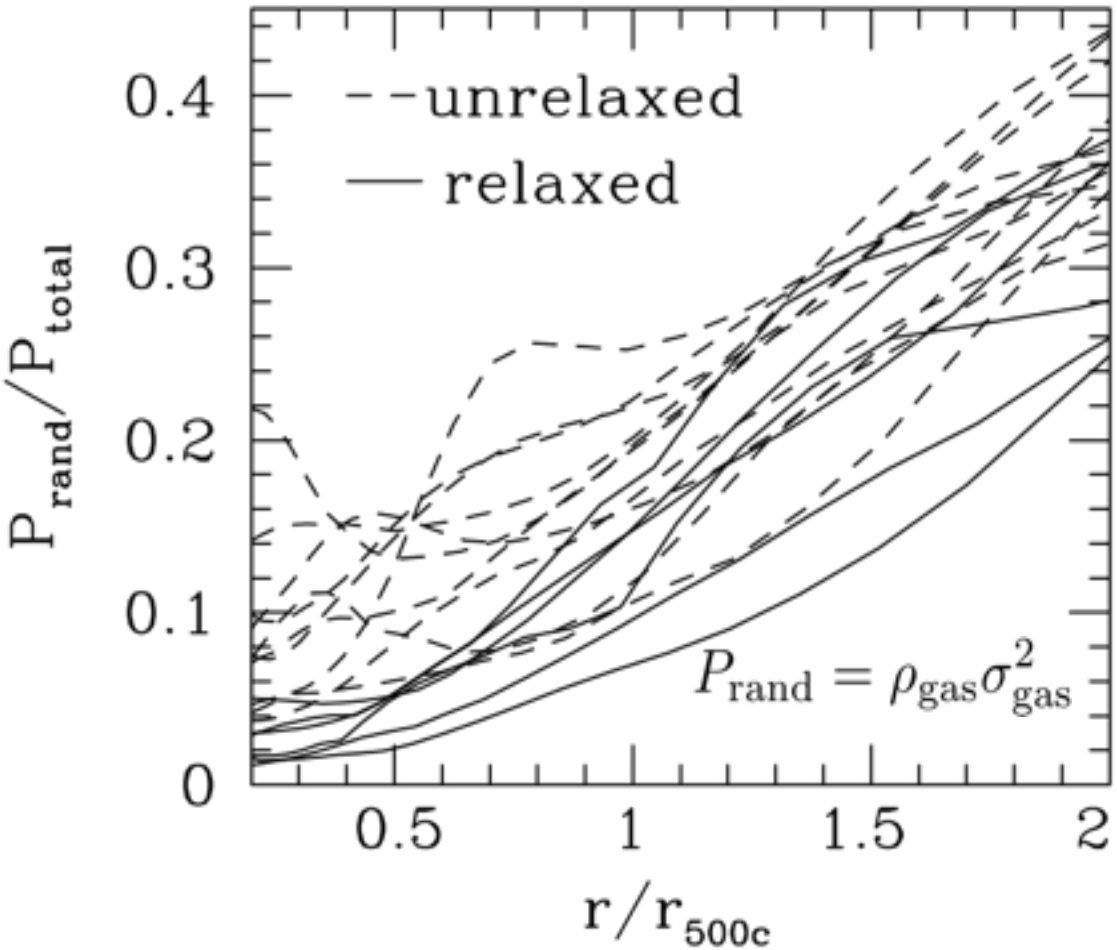




- Gas (bulk+turbulent) motions are ubiquitous in the ICM.
- Implications
  - Hydrostatic mass modeling
  - ICM temperature and entropy profiles
  - X-ray/SZE observable-mass relations
  - Metal distribution (e.g., by mixing)
  - Particle acceleration
- Drivers of gas motions
  - Accretion/Mergers (on large scales)
  - Energy injection from SNe/AGN (in cluster cores)
- Effects of gas motions ~5-30% at $r=r_{500}$, but know very little about its nature.
  - Observations (e.g., pressure fluctuations or X-ray/lensing mass comparisons)
  - SPH/Eulerian simulations

Gas motions provide nonthermal pressure

Sample of 16 simulated clusters in ΛCDM model with ART code

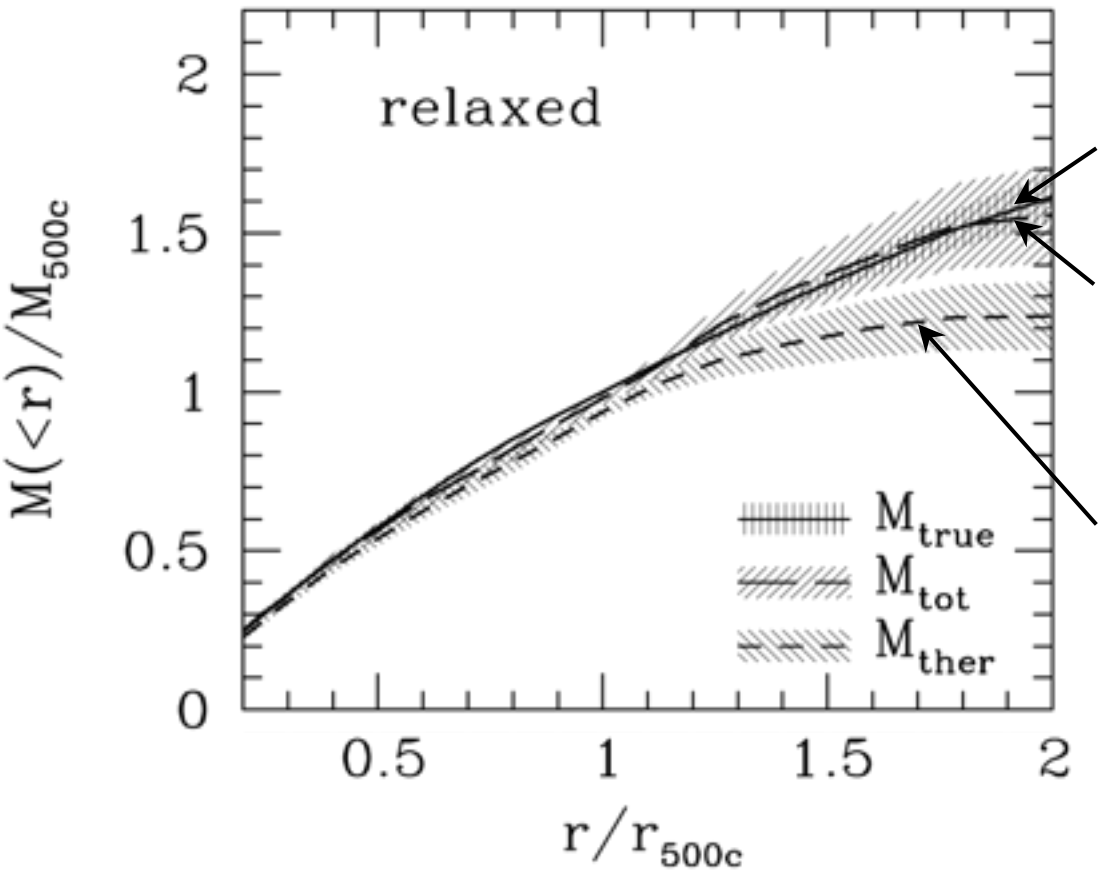


cluster-centric radius in units of r_{500c}

Lau, Kravtsov, Nagai 2009, ApJ, 705, 1129

Effects of gas motions on mass profile measurements

$$M_{tot}(<r) = \frac{-r}{G\rho_{gas}}\left(\frac{dP_{therm}}{dr} + \frac{dP_{rand}}{dr}\right)$$



True mass profile in simulations

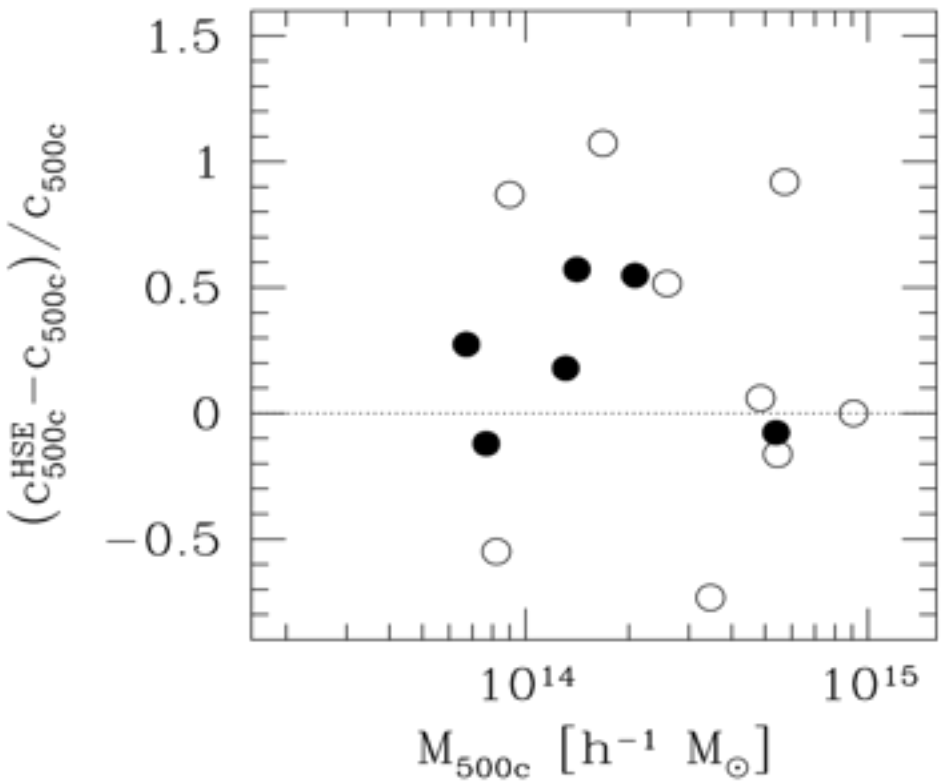
Mass profile from hydrostatic equilibrium taking into account turbulent pressure

Mass profile from hydrostatic equilibrium neglecting turbulent pressure

cluster-centric radius in units of r_{500c}

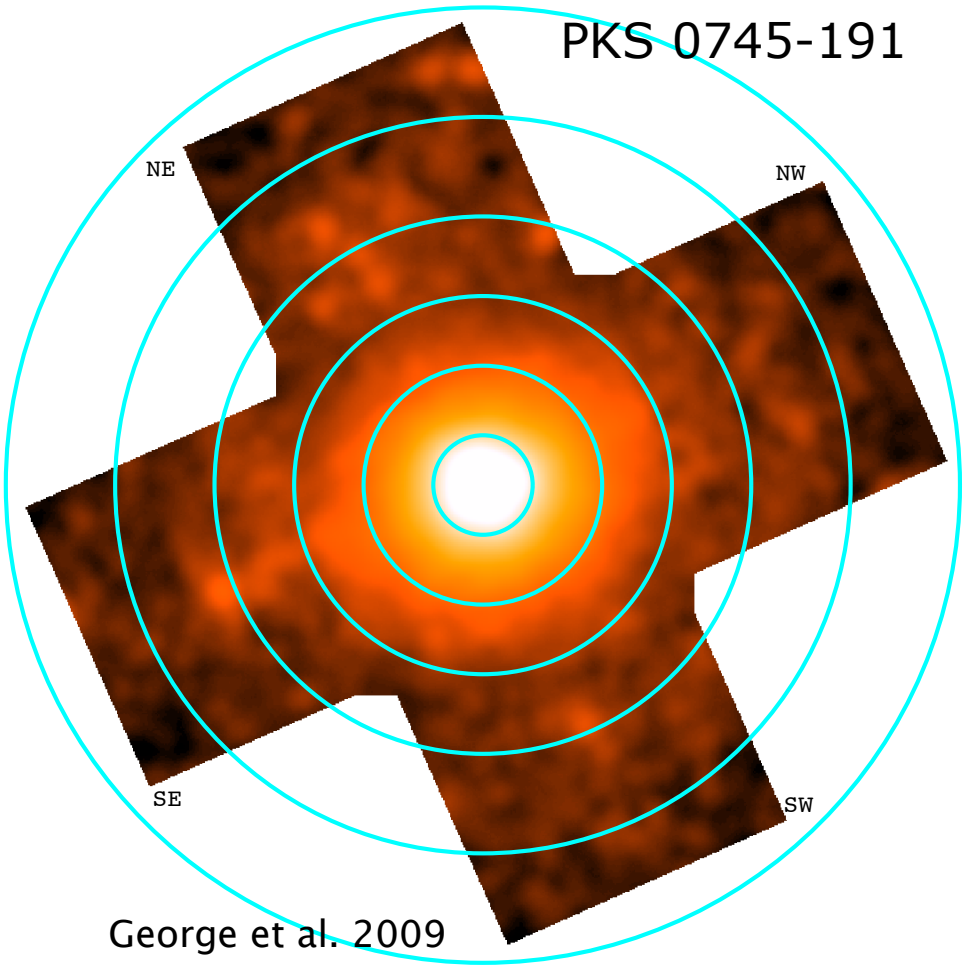
Gas Motions: Effects on X-ray Estimated Concentration

Solid: relaxed clusters
Open: unrelaxed clusters

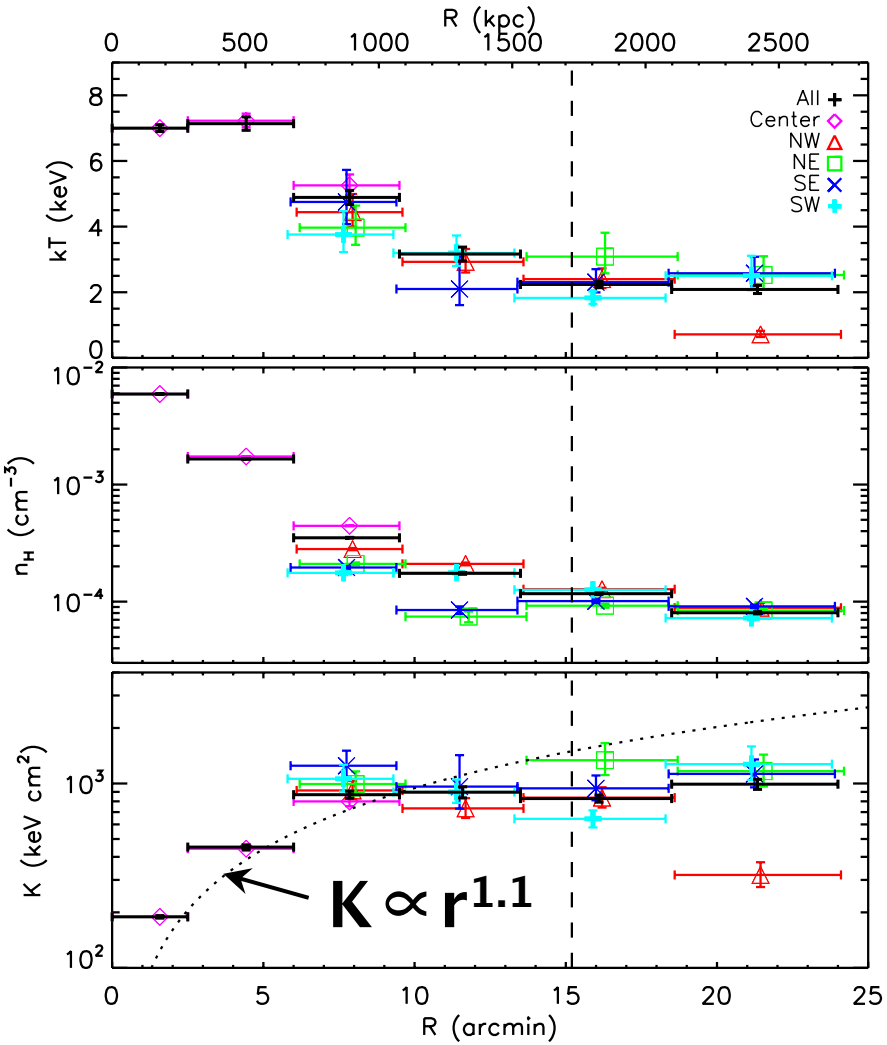


- Gas motions also bias concentration $c=r_{500}/r_s$ measurement from hydrostatic analysis, by ~20%.
- Can help explain higher concentration reported in X-ray analysis (e.g. Buote et al 07) compared to CDM prediction.

Suzaku measurements of cluster outskirts

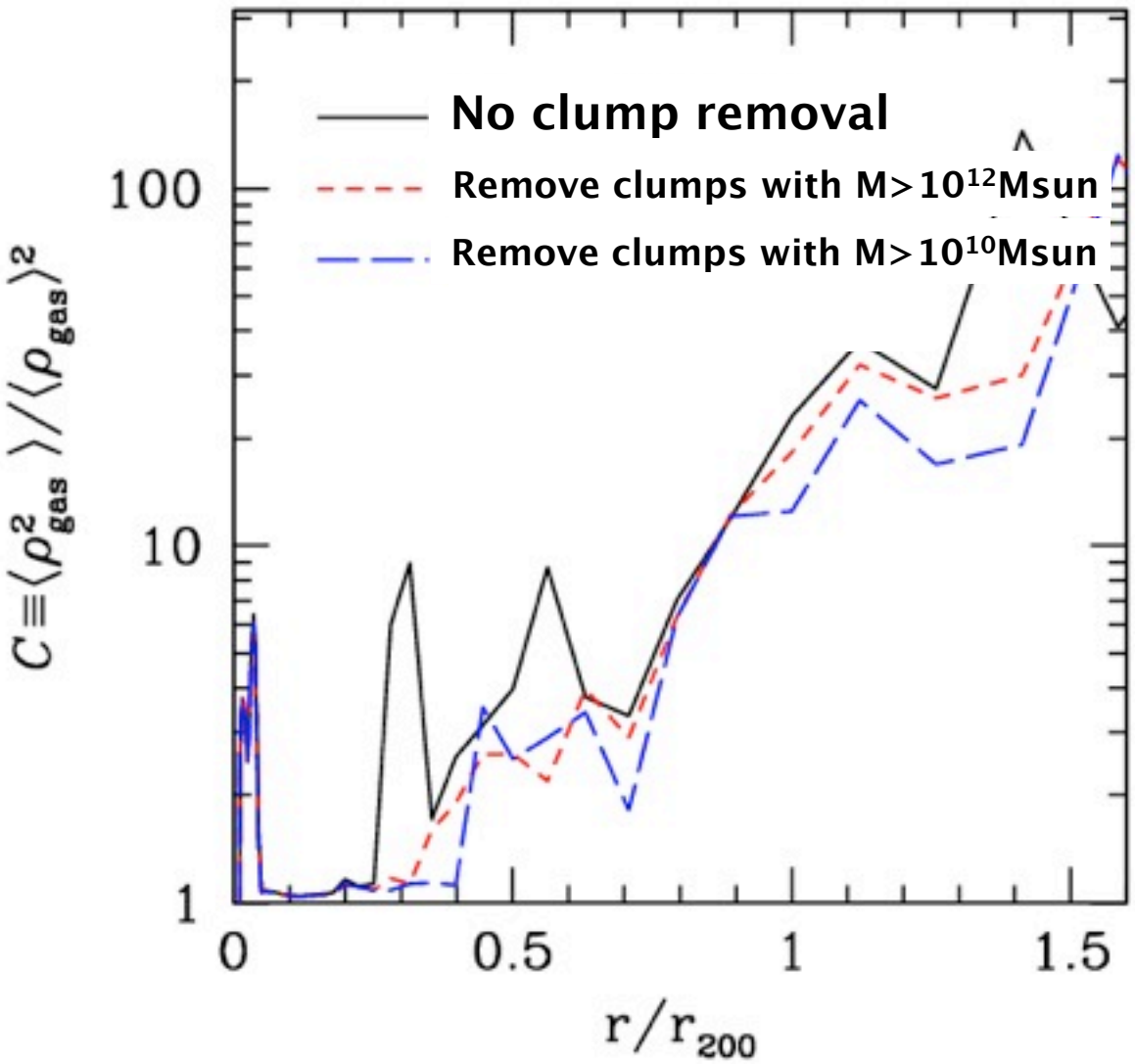


George et al. 2009



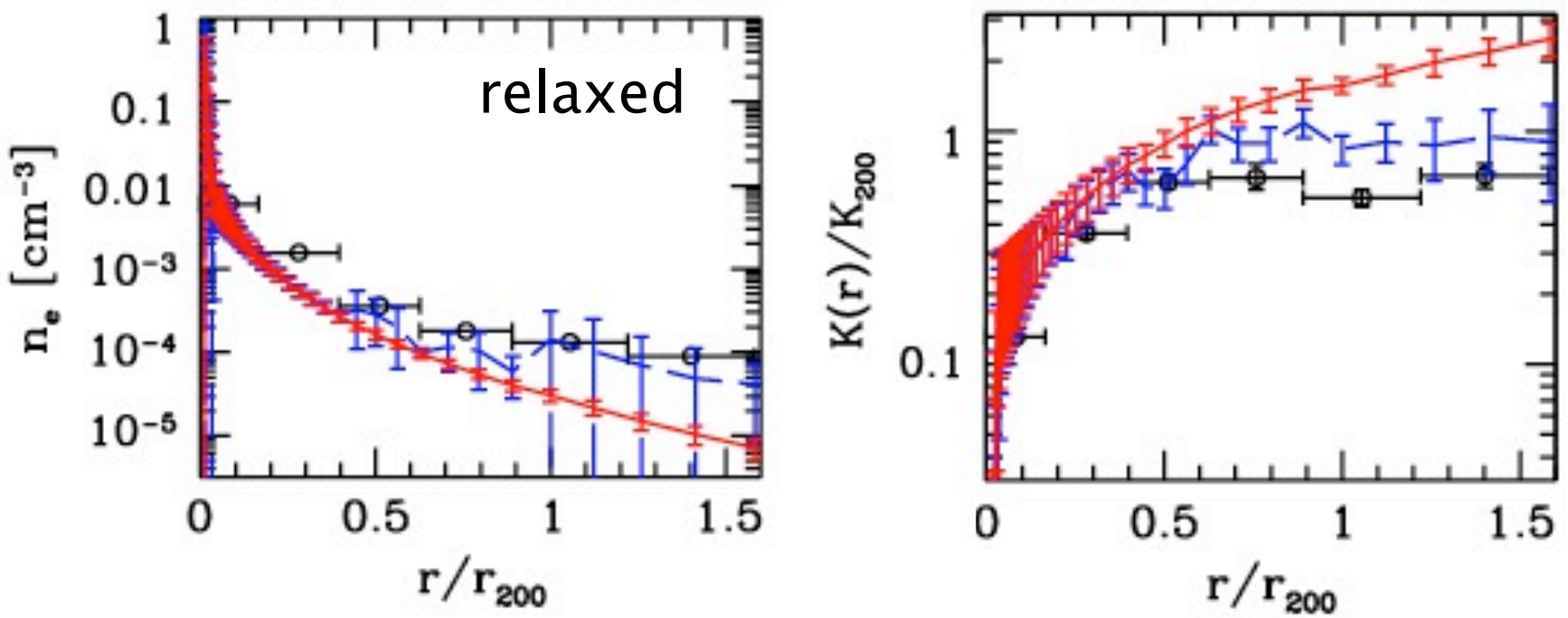
Suzaku measurements are inconsistent with the prediction based on hydrodynamical cluster simulations (e.g., Voit et al. 2005)

Gas clumping in cluster outskirts



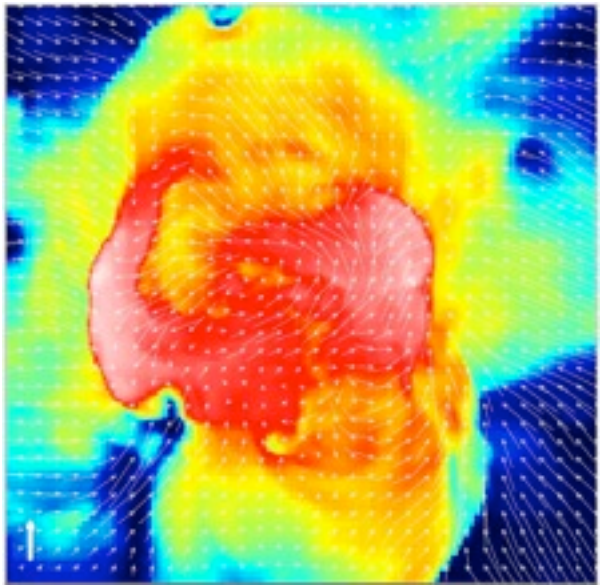
Lau, Nagai, Kravtsov, in prep.

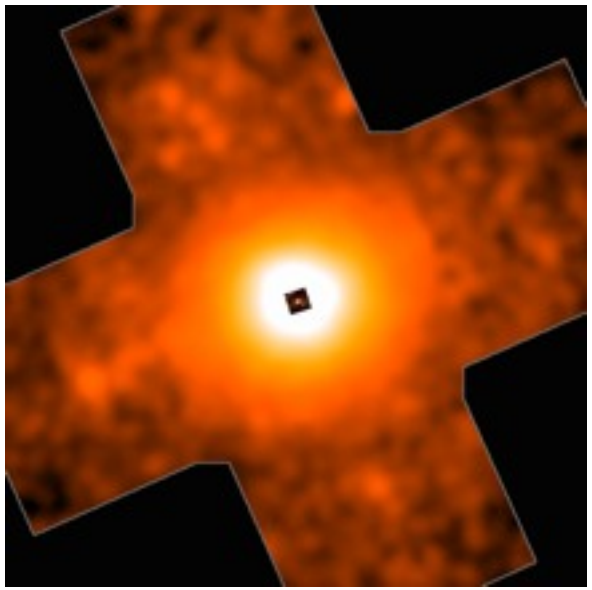
Bias in X-ray measurements of cluster outskirts



Gas clumping can lead to significant overestimate of gas density in cluster outskirts.

Summary





- Gas motions are ubiquitous in the outskirts of galaxy clusters and have important implications for interpreting X-ray and SZE observations (see L. Shaw's talk)
- Nonthermal pressure provided by gas motions have significant effect on the mass and ICM profiles.
  - Increases toward cluster outskirts
  - Larger in dynamically active clusters
- Upcoming *Astro-H* mission can directly probe the ICM gas motions in clusters.
- Gas clumping is also important in studying thermodynamic structure of the ICM in cluster outskirts.