Why Do Only Some Galaxy Clusters Have Cool Cores?

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8 Years of Science with Chandra
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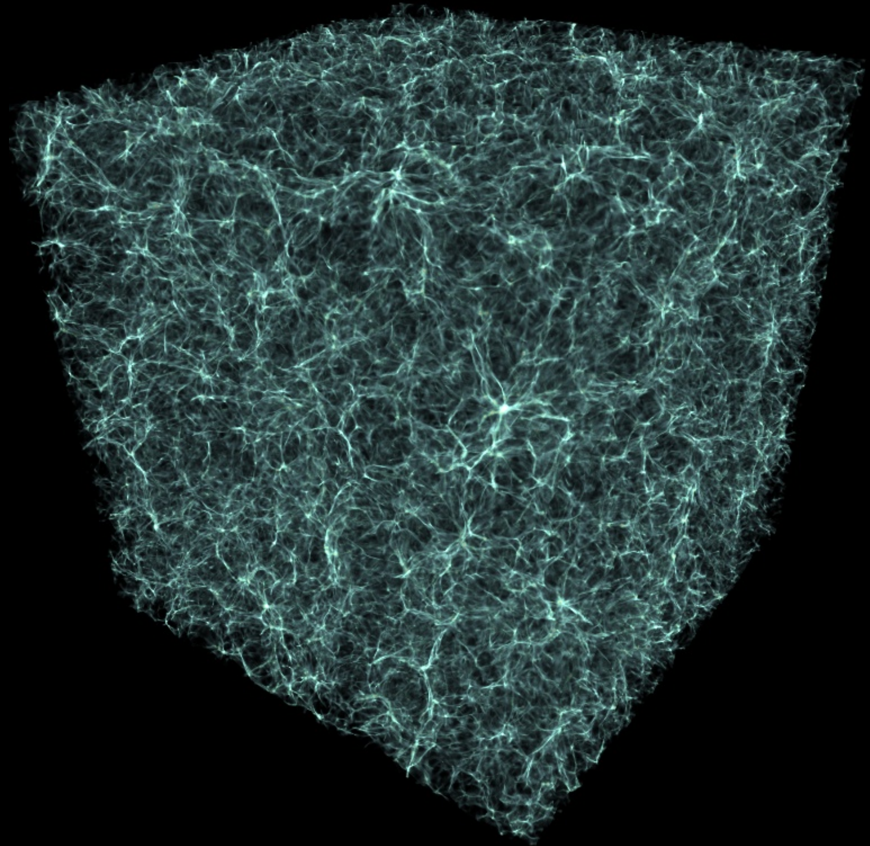
Adaptive Mesh Refinement (AMR) Simulations of Cluster Formation and Evolution

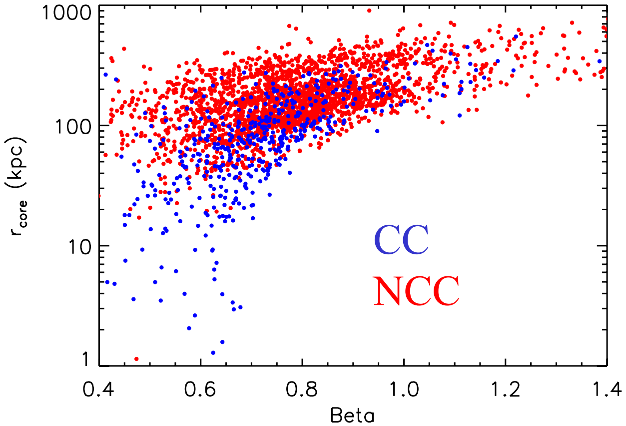


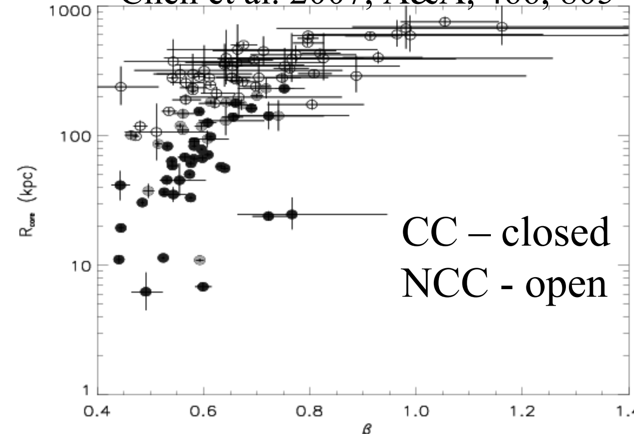
Enzo (e.g., O'Shea et al. 2006, http://cosmos.ucsd.edu/enzo)

- ΛCDM with $\Omega_m = 0.3$, $\Omega_b = 0.026$, $\Omega_\Lambda = 0.7$, $h = 0.7$, and $\sigma_8 = 0.9$.
- AMR achieves 15.6 h^{-1} kpc resolution in dense regions.
- $(256\ h^{-1}\ \mathrm{Mpc})^3$, 7 levels of refinement => 1500 clusters with $>10^{14}\ M_\odot$ for $z < 1$
- Dark matter mass resolution is $10^{10}\ h^{-1}\ M_\odot$.
- Baryon physics includes radiative cooling, star formation, supernova (Type II) feedback. => *Approximate balance of heating and cooling.*
- *First simulation to produce both cool and non-cool cores in same volume.*

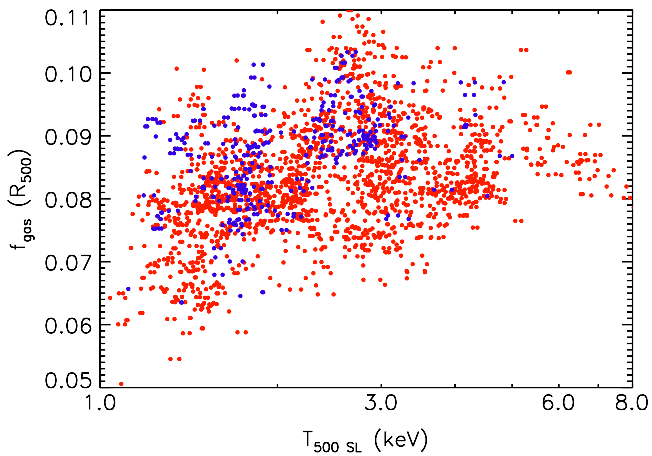
simulations

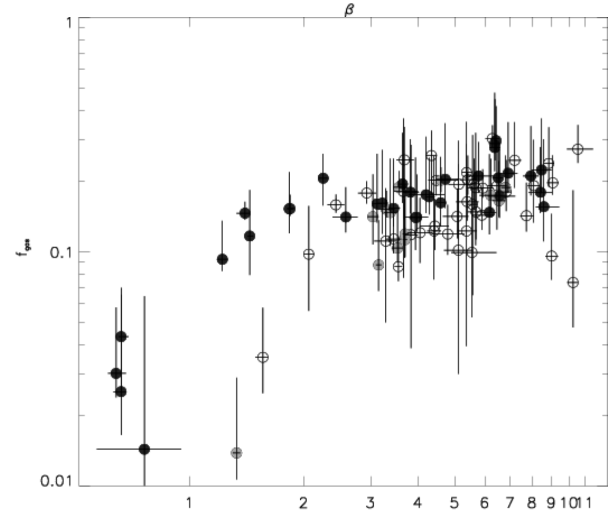
Chen et al. 2007, A&A, 466, 805



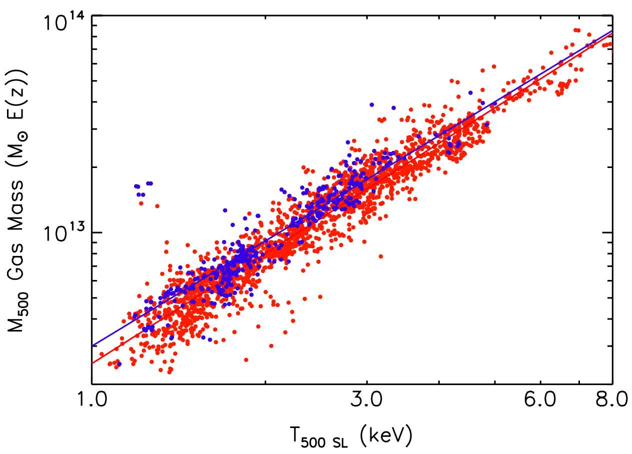


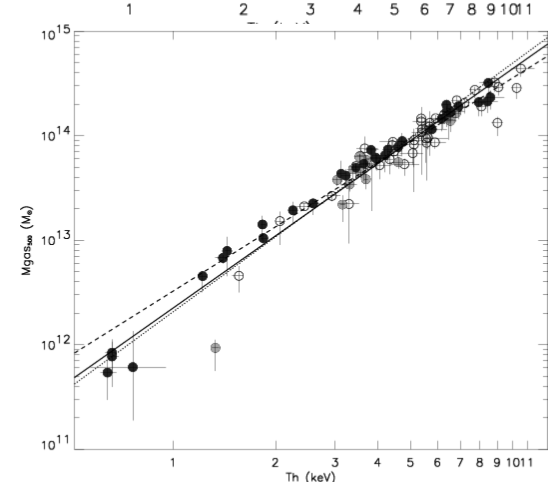
r_{core}
vs.
beta





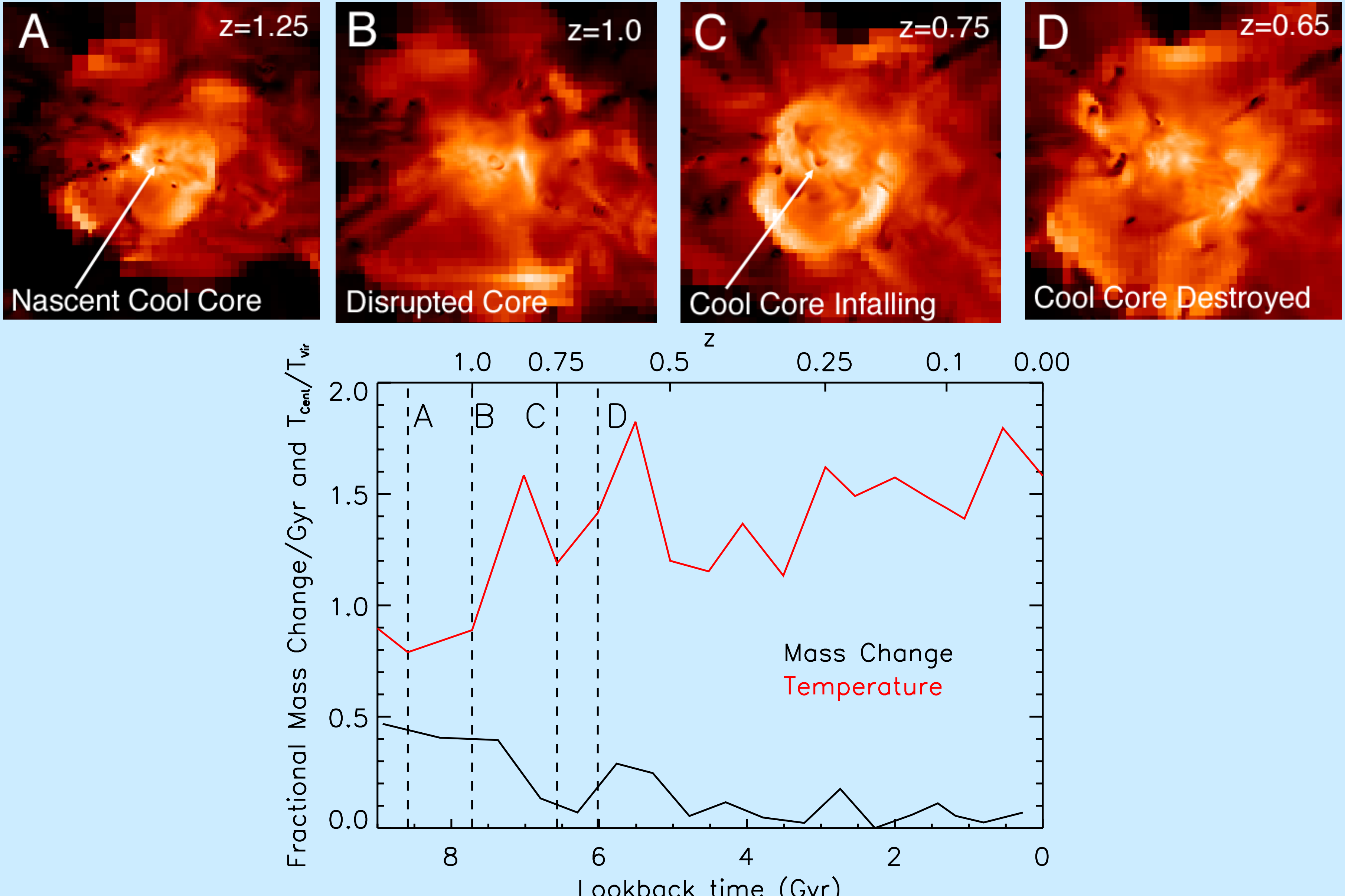
gas fraction
vs.
temperature





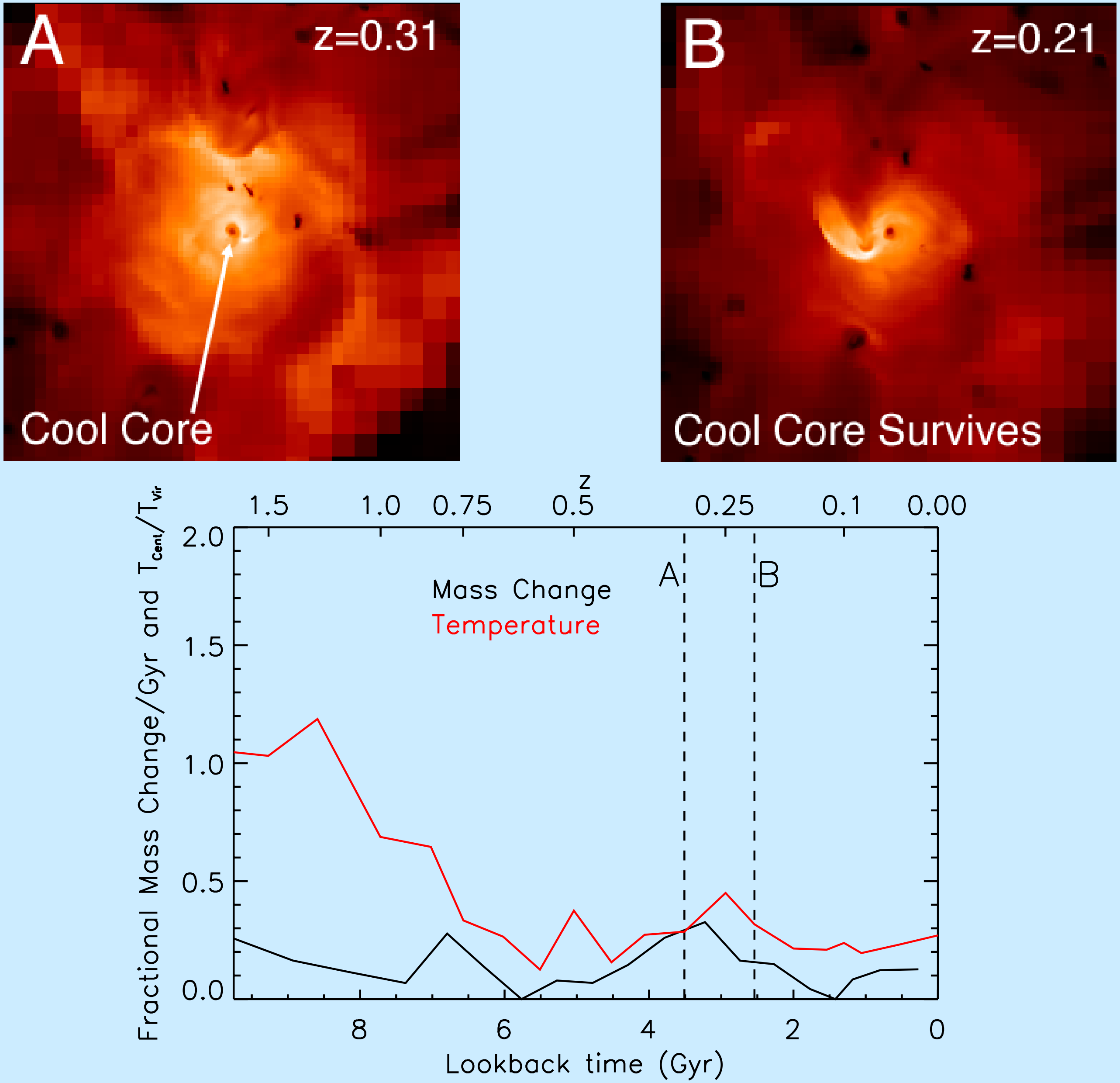
gas mass
vs.
temperature

Evolution of a Non-cool Core Cluster



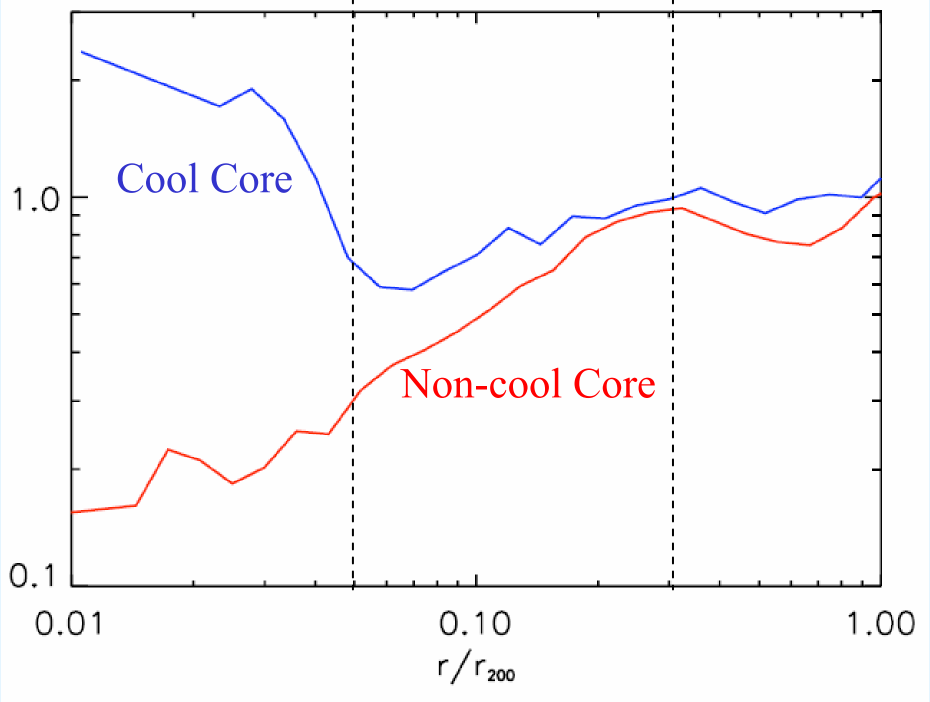
NCC clusters suffer major mergers early in their evolution, destroying embryonic cool cores.

Evolution of a Cool Core Cluster

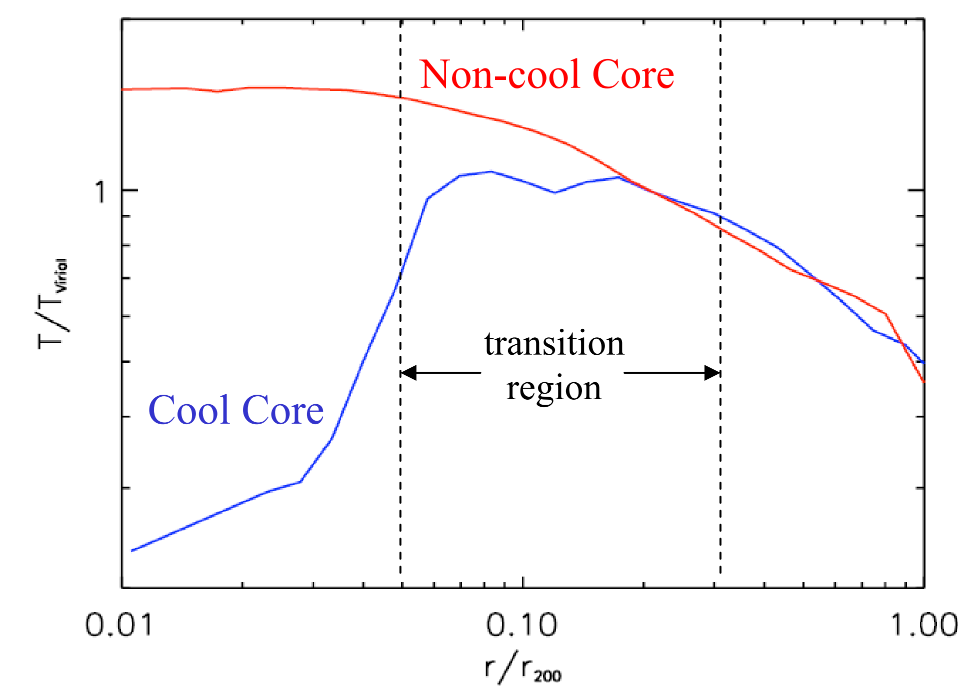


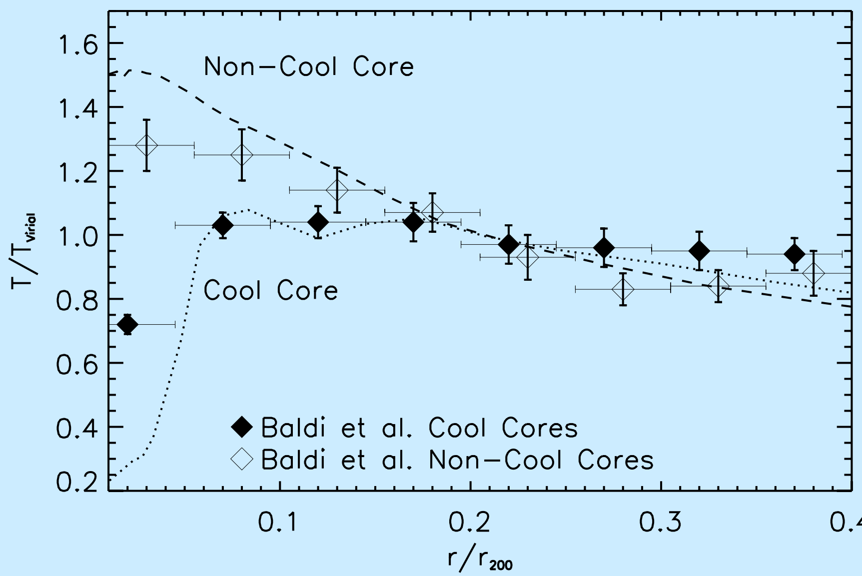
Cool core clusters avoid major mergers with high fractional mass changes early in their histories.

Comparison of Simulated CC & NCC Clusters

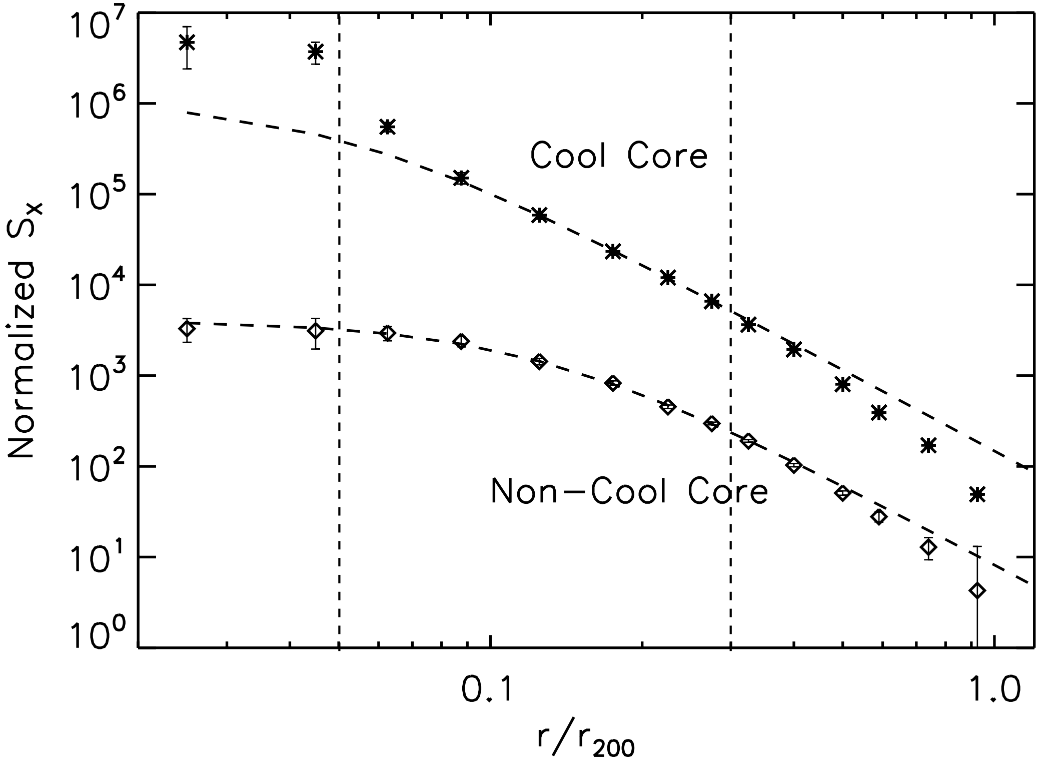


- NCC baryon properties approximate that of a polytropic gas in hydrostatic equilibrium.
- In contrast, CC cluster gas shows a broad "transition region" with relatively constant temperatures and baryon fractions.

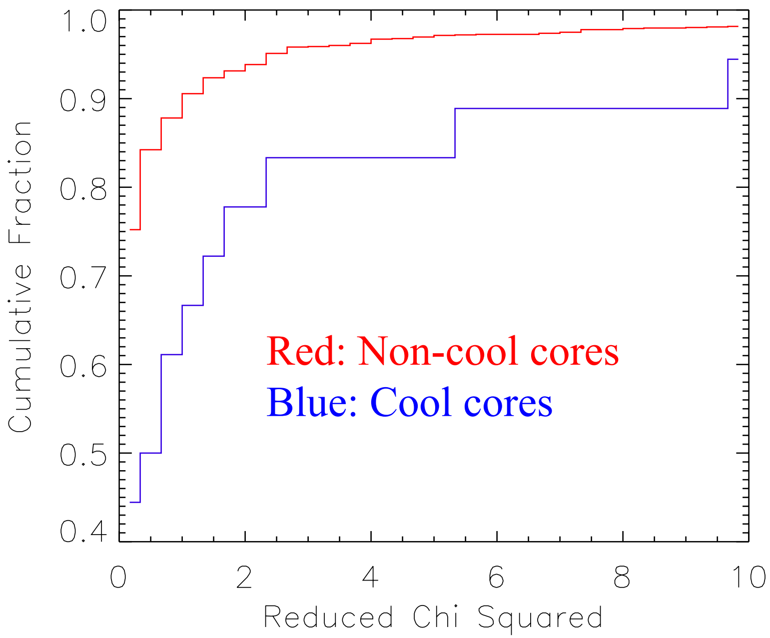




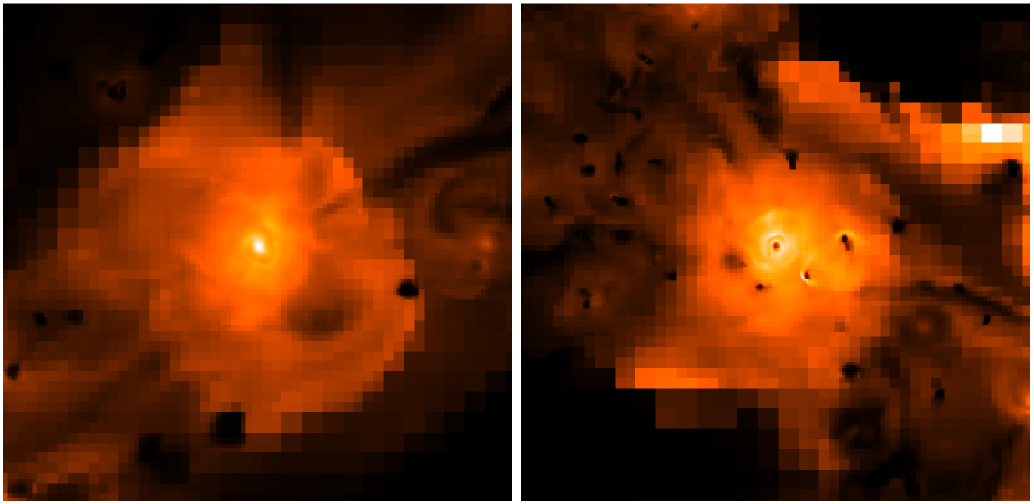
Synthetic X-ray Surface Brightness Profiles for Numerical Clusters



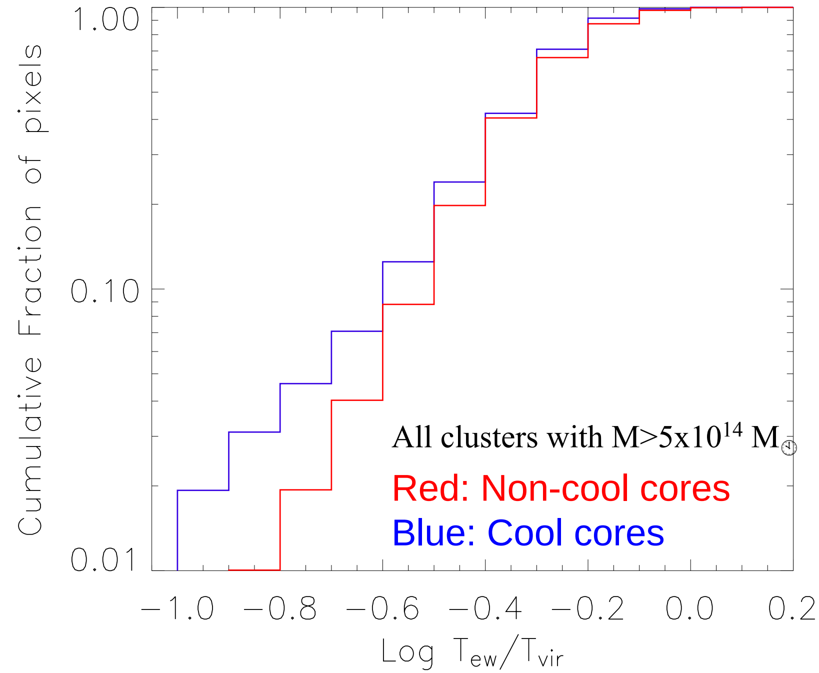
- Cool core clusters are fit poorly by beta models ($S_x=S_0[1+(r/r_c)^2]^{1/2-3\beta}$) between r_{500} and r_{200} .
- Non-cool core clusters are fit well to beta-models.
- Gas mass in CC clusters over-estimated by 3-5x.



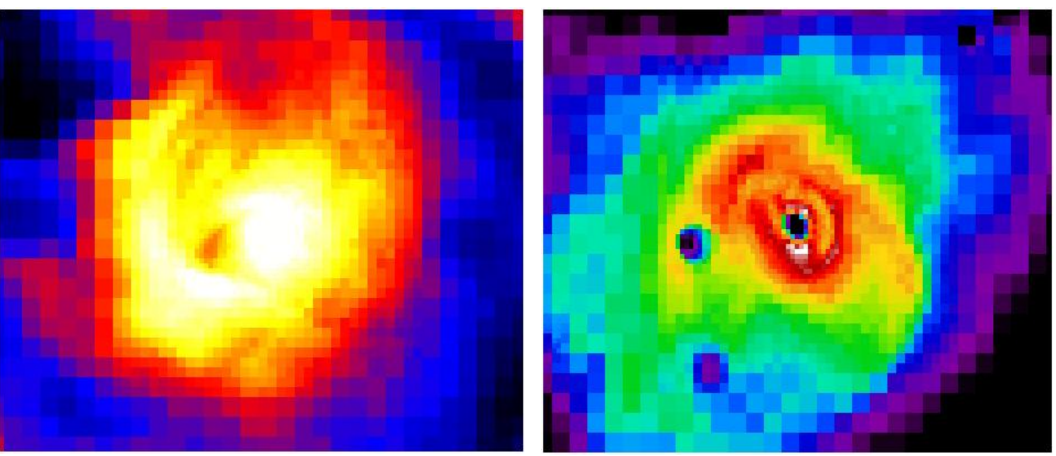
Emission-Weighted Temperature



6 Mpc $M_{200} = 2 \times 10^{14}\ M_\odot$

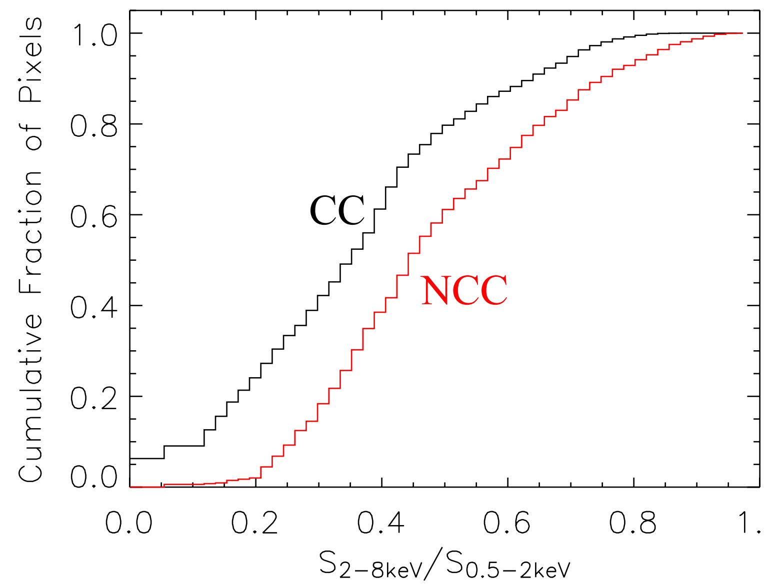


Hardness Ratios (2-8 keV/0.5-2 keV)



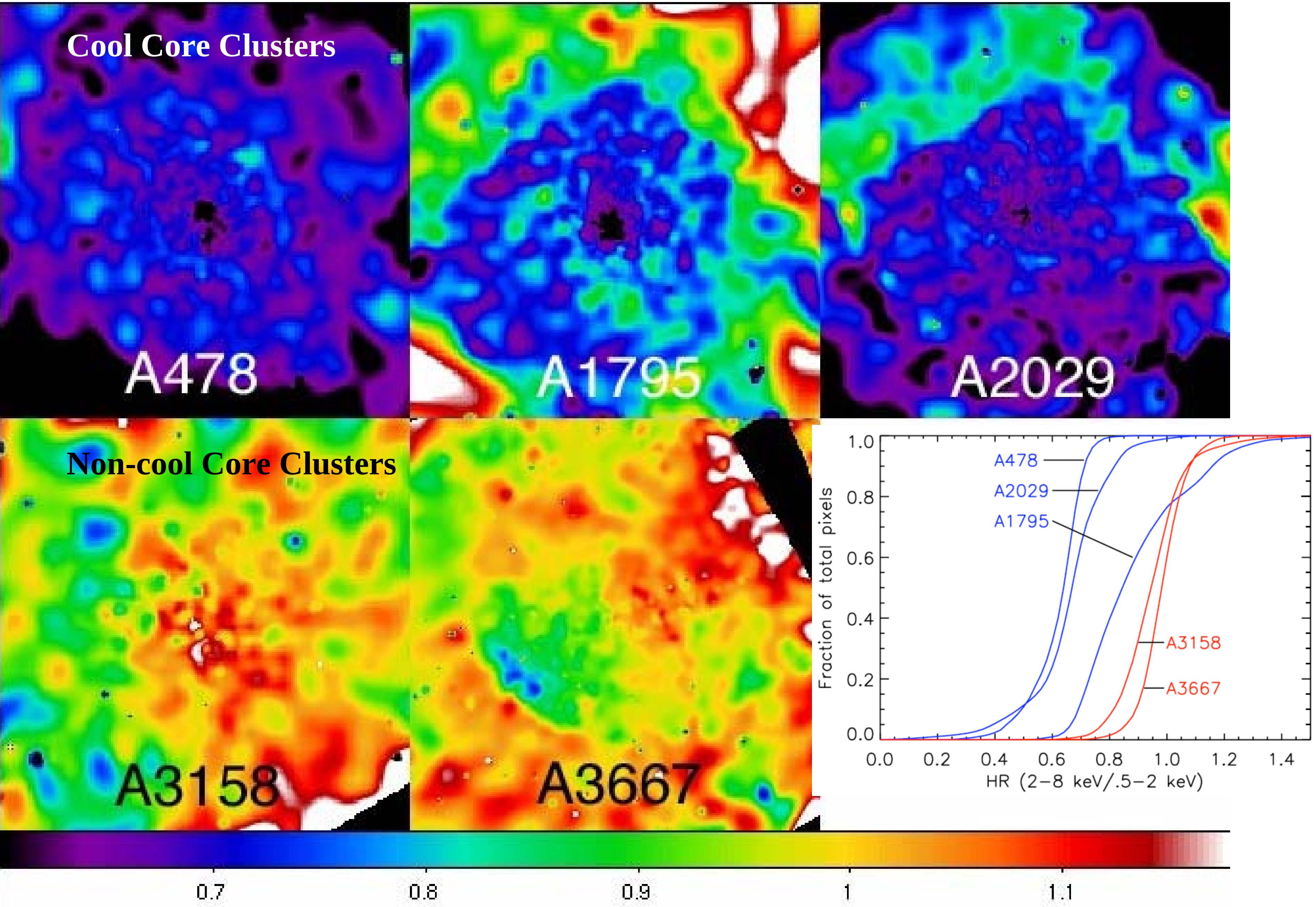
3 Mpc $M_{200} = 5 \times 10^{14}\ M_\odot$

Non-cool Core **Cool Core**

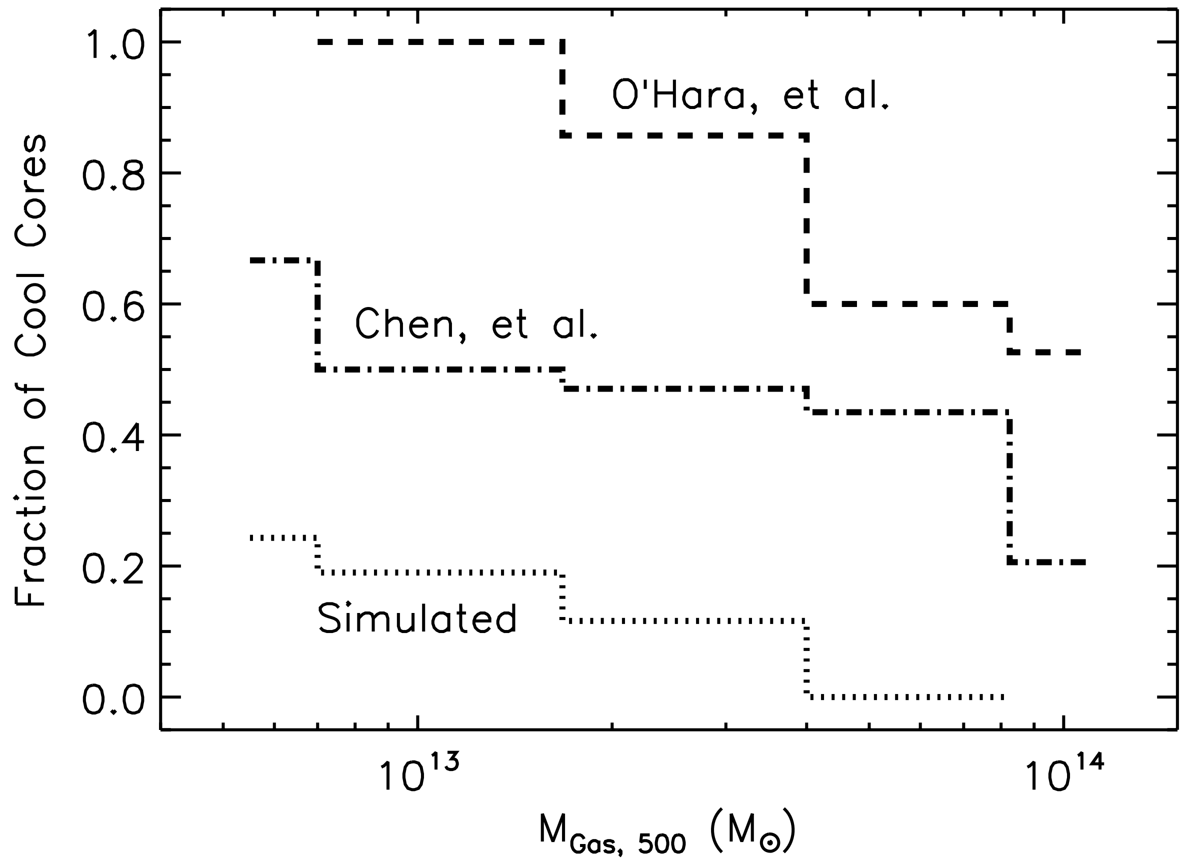


*=>Simulations predict more cold gas **outside the cores** in cool core clusters than in non-cool core clusters.*

Hardness Ratios (2-8 keV/0.5-2 keV) for Abell Clusters from Chandra

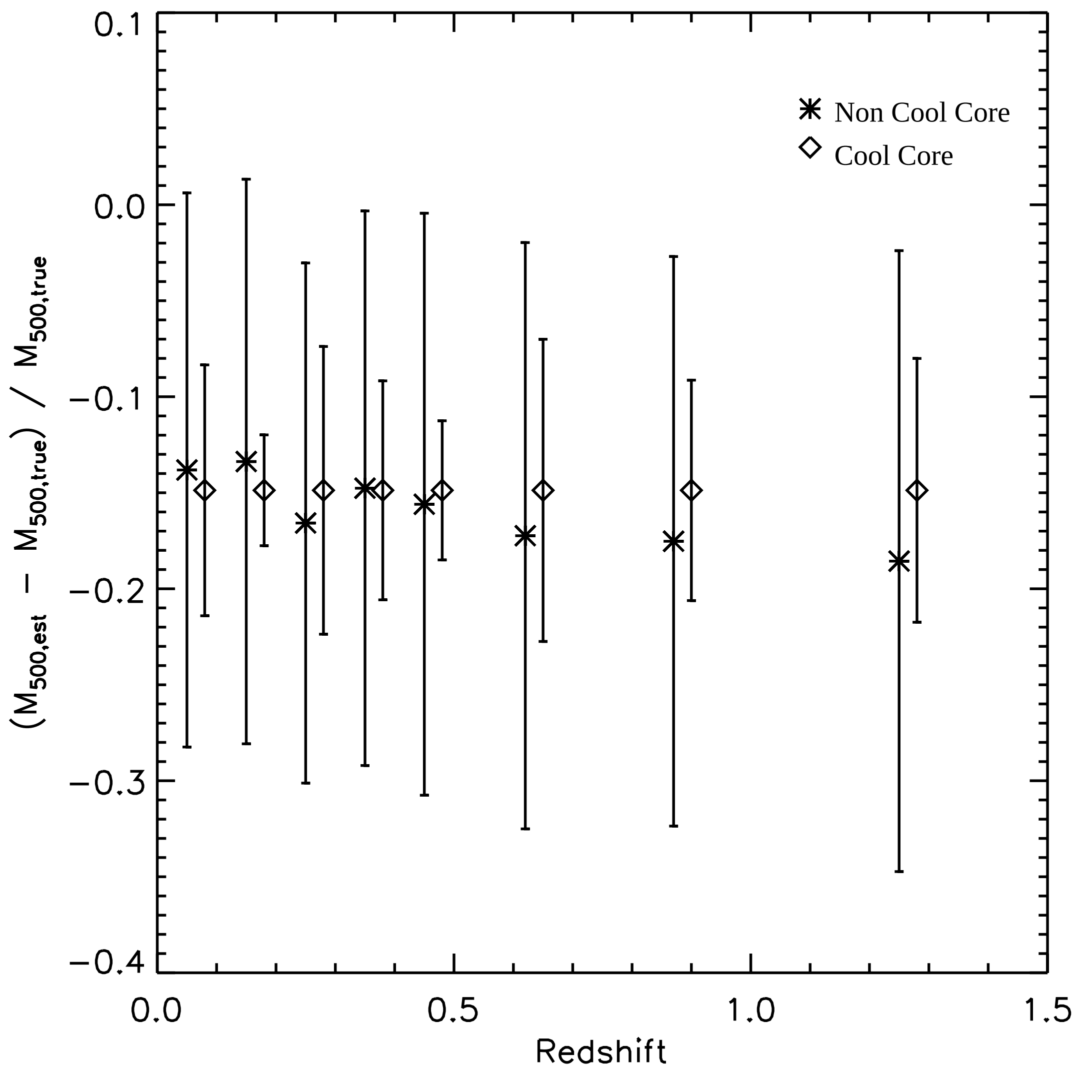


Fraction of Cool Cores is a strong function of Cluster/Gas Mass



O’Hara et al. 2006, ApJ, 490, 493
Chen et al. 2007, A&A, 466, 805

Are CC clusters in hydrostatic equilibrium?



CC clusters are biased low by ~15%, just like NCC clusters.

Conclusions

- *Non-cool core* (NCC) clusters suffer early major mergers when embryonic cool cores are destroyed. *Cool core* (CC) clusters grow more slowly without early major mergers.
- X-ray surface brightness profiles for NCC clusters are well fit by single β-models whereas the outer emission for CC clusters is biased low compared to β-models (resulting in gas masses and densities too high by factors of 3-5).
- CC clusters have roughly 40% more cool gas beyond the cores than do NCC clusters.
- CC clusters are similarly biased low in mass as NCC clusters assuming hydrostatic equilibrium.