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\(^{-1}\) Mpc\(^3\)), 7 levels of refinement \( \Rightarrow \) 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. \( \Rightarrow \) Approximate balance of heating and cooling.
• First simulation to produce both cool and non-cool cores in same volume.

Simulations

$R_{\text{core}}$ vs. beta

CC vs. NCC

Gas fraction vs. temperature

Gas mass vs. temperature

$M_{\text{gas}}$ (M$_{\odot}$) vs. $T_{500}$ (keV)
Evolution of a Non-cool Core Cluster

NCC clusters suffer major mergers early in their evolution, destroying embryonic cool cores.
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.
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.
Simulations predict more cold gas outside the cores in cool core clusters than in non-cool core clusters.

Emission-Weighted Temperature

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

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

Cool Core Clusters

A478

A1795

A2029

Non-cool Core Clusters

A3158

A3667

Fraction of total pixels

HR (2-8 keV/0.5-2 keV)
Fraction of Cool Cores is a strong function of Cluster/Gas Mass

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 $\beta$-models whereas the outer emission for CC clusters is biased low compared to $\beta$-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.