Probing of Interactions between the Hot Plasmas and Galaxies in Clusters over a Cosmological Timescale

Liyi Gu

(University of Tokyo)

N. Inada, P. Gandhi, T. Kodama, M. Kawaharada, S. Konami, K. Nakazawa, H. Xu, Z. Wen, & K. Makishima

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Why galaxies are much more concentrated than the ICM?

Why galaxies are much more concentrated than metals in ICM?

Why the cool dense ICM in cluster center does not suffer radiation-induced “cooling flow”?

Kawaharada+09

A1835 RGS spec.
Role of Member Galaxies

清扫 Dynamical friction (Ostriker 99; El-Zant+04; Kim+05)
清扫 Ram pressure stripping & wake (Gunn & Gott 72; Vollmer+01; Gu+13)
清扫 Minor merger & sloshing (Ascasibar & Markevitch 06; ZuHone+10)
清扫 MHD turbulence & heat diffusion (Subramanian+06; Ruszkowski & Oh 10; Parrish+10)

When galaxies interact with the ICM,

\[ v_{\text{galaxy}} \sim v_{\text{ICM\_sound}} \implies \text{specific energy: } \text{galaxies} \sim \text{ICM} \]

\[ S_{\text{galaxy}} << S_{\text{ICM}} \implies \text{free energy: } \text{galaxies} >> \text{ICM} \]

Energy flow from galaxy to ICM:

\[-dE/dt \sim N \pi R^2 n m_p v^3\]

\[ \sim 2 \times 10^{44} (N/300)(R/10 \text{ kpc})^2(n/10^{-3})(v/500 \text{ km s}^{-1})^3 \text{ erg/s} \]
A Magnetosphere Model

- Member galaxies strongly interact with the ICM in a MHD configuration
- Heat flux transfers along field lines via thermal conduction
- Galaxies fall to the center of potential over cosmological timescales
All clusters (340, z<0.5) available with SDSS+XMM/Chandra
70-90% complete relative to other catalogs (e.g., NORAS)
~35000 member galaxies selected using phot-z (Δz~0.01-0.03)
Member galaxies are 80-90% complete at M_r<-21 (contamination~10-20%)
Consistent with other results
Radial Profiles of Galaxies, ICM, and DM

Abell 644
z = 0.0704
R_{500} = 1213 kpc
N_{500} = 48 gals

Galaxy density (mpc^{-2})

Total Grav. Mass (Msun)

ICM density (cm^{-3})
Radial profiles of all clusters

Radial profiles of all clusters

Galaxy density

(mpc$^{-2}$)

Total Grav. Mass

(Msun)

Radius (mpc)

ICM density

(cm$^{-3}$)
Averaged radial profiles for high-z, med-z, and low-z clusters; $R_{500}$ and $\rho_{\text{crit}}(z)$ corrected.

Galaxies exhibit a steeper distribution in nearby clusters.
Galaxies evolved to be more centrally-concentrated relative to ICM/DM, while ICM expands slightly towards low-z.
Evolution of galaxy-to-ICM profiles does not depend strongly on cluster or galaxy mass.

Dynamical friction alone cannot explain this evolution.

\[ F_{\text{dyn. fric.}} \sim -4\pi \rho_{\text{tot}} \left( GM_{\text{galaxy}} \right)^2 / v^2 \]
By studying the SDSS/\textit{Chandra}+\textit{XMM} data of 340 clusters,

- Member galaxies have become centrally-concentrated relative to the ICM and DM from $z = 0.5$ to $z = 0$.
- ICM slightly expands relative to DM though it keeps radiating.
- Dynamical friction alone is insufficient.
- Galaxies lose kinetic/potential energy to ICM/DM by $10^{44-45}$ erg/s per cluster: a hidden energetic flow on cosmological timescale.