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

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## Fundamental Questions to be Solved

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"?



## Role of Member Galaxies

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

#### When galaxies interact with the ICM,

 $v_{galaxy} \sim v_{ICM\_sound} \implies specific energy: galaxies \sim ICM$  $S_{galaxy} << S_{ICM} \implies free energy: galaxies >> ICM$ 

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

Makishima+01; Takahashi+09; Gu+12



- 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 ( $\Delta z$ ~0.01-0.03)
- Member galaxies are 80-90% complete at M<sub>r</sub><-21 (contanimation~10-20%)

Luminosity Function









## Radial Profiles of Galaxies, ICM, and DM



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Galaxies exhibit a steeper distribution in nearby clusters.





Galaxy vs. ICM vs. DM





 ♦ Evolution of galaxy-to-ICM profiles does not depend strongly on cluster or galaxy mass.
♦ Dynamical friction alone cannot explain this evolution.

## Summary & Discussion

By studying the SDSS/Chandra+XMM data of 340 clusters,

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