Spatial Distribution and Motions of Galaxies in Clusters

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A Sample of 8 Clusters Formed in the Concordance LCDM Model

$\Lambda$CDM $80h^{-1}$ Mpc: $\Omega_0 = 0.3$; $\Omega_\Lambda = 0.7$; $h = 0.7$; $\sigma_8 = 0.9$; $H_0 = 1.0$

$m_{DM} = 3 \times 10^8 h^{-1}$ Msun; $\epsilon$ peak $= 2h^{-1}$ kpc

$M_{vir} \sim 0.5 - 3 \times 10^{14} h^{-1}$ Msun
The physical processes included in simulations:

Gasdynamics: Eulerian AMR Adaptive Refinement Tree (ART) code

Collisionless N-body dynamics of DM and stars

Radiative cooling and heating of gas:
metallicity dependent net cooling/heating equilibrium rates tabulated for $100 < T < 10^9$ K

Star formation using observationally-motivated phenomenological recipe (Kennicutt 1998)

Thermal stellar feedback

Metal enrichment by SNII/la

Advection of metals

Stellar mass loss based on population synthesis models
High-resolution dark matter only resimulation of one of the clusters
Number density profile of subhalos vs DM profile

Cluster-centric distance in units of the virial radius
Radial distribution of subhalos in dissipationless simulations does not match observations

Diemand, Moore & Stadel 2004

Gao et al. 2004

factor of two difference in abundance of galaxies and subhalos?

projected cluster-centric radius in units of the virial radius
2-point correlation function of galactic halos dissipationless simulation vs SDSS

\[ n_h (>V_{\text{max}}) = n_g (>L_r) \]

SDSS CF: Zehavi et al. 2003

Simulation CF: Kravtsov et al. 2004

See also Collin et al. 1999
Kravtsov & Klypin 1999
Tidal mass loss introduces a strong radial bias for subhalo samples selected using bound mass

(Nagai & Kravtsov 2004)
Subhalo number density profile depends on how the subhalos are selected!

- subhalos selected using bound mass today
- subhalos selected using the mass they had at the accretion epoch
- subhalos selected using Vmax today

Cluster-centric distance in units of the virial radius
Stellar mass is preserved much better than the total bound mass.

- All: $r/r_{\text{vir}} < 1.00$
- Filled: $r/r_{\text{vir}} < 0.30$

Stellar mass vs. total bound mass.
Comparison to observations

surface density profile

\[ \frac{\Sigma(R)}{\Sigma_{\text{vir}}} \]

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- **Dark Matter**
- \( M_* > 10^{10} \, h^{-1} M_\odot \)
- \( M_{\text{tot}} > 2 \times 10^{11} \, h^{-1} M_\odot \)

**R/R_{200}**

projected cluster-centric radius in units of \( R_{200} \)
Concentration parameter of galaxy profiles vs concentration of the cluster DM profile

\[ c_{Gal} \text{ [2D]} \quad c_{DM} \text{ [3D]} \]

concentration of galaxy profile
concentration of DM profile
Velocity bias of subhalos

$b_v \sim 1.3$ at $r \sim 0.5 r_{\text{vir}}$

Colin et al. 2000; Ghigna et al. 2000; Diemand et al. 2004; Gao et al 2004

![Graph](image_url)

Projected cluster-centric radius in units of the virial radius.
Statistics of galaxy motions in simulated clusters

Note the galaxy velocity bias, $b_v \approx 1.1$, smaller than for subhalos in dissipationless simulations.

- Mean radial velocity
- Radial component of velocity dispersion
- Velocity anisotropy

3D velocity dispersion
Tangential component of velocity dispersion
Sound speed profile

Cluster-centric radius in units of $R_{500}$
On average, galaxies in clusters move with Mach~1.4

(Faltenbacher et al. 2004)
Summary

- Radial distribution of subhalos in clusters depends sensitively on how the subhalos are selected. *Comparisons with observations are tricky!*

- Radial distribution of galaxies in LCDM clusters is in good agreement with observations

- Velocity bias of galaxies is smaller ($b_v \sim 1.1$) than the velocity bias of subhalos selected by mass or Vmax

- On average, galaxies in simulated clusters move supersonically with the average Mach number of $\sim 1.4$
  
  $\Rightarrow$ *Interesting implications for evolution of cluster galaxies and heating of the intracluster medium*

  For details see (to appear on astro-ph in the next two weeks): Nagai & Kravtsov 2004; Faltenbacher, Kravtsov, Nagai & Gottloeber 2004