Views on Galaxy Clusters

Giuseppe Tormen
Astronomy Department
University of Padova - Italy

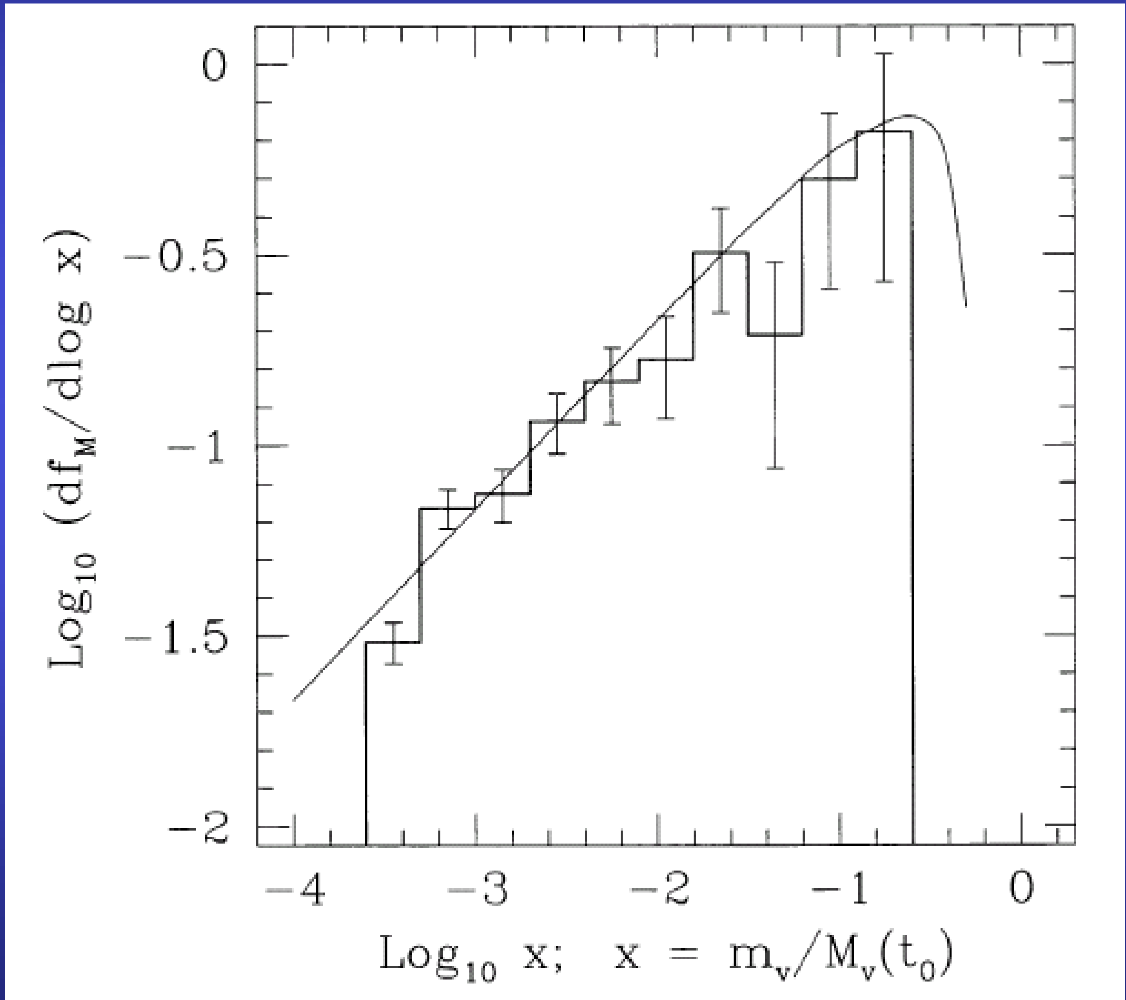
In collaboration with:
Elena Rasia, Lauro Moscardini, Klaus Dolag

Computational Cosmology - ICTP, June 2005

Outline

- Global properties of infalling satellites **at** merging
- Evolution of satellite properties **after** merging
- Properties of the ICM **at redshift zero** as a function of its merging history
- Resimulation techniques
- Effect of extra physics on radial profiles

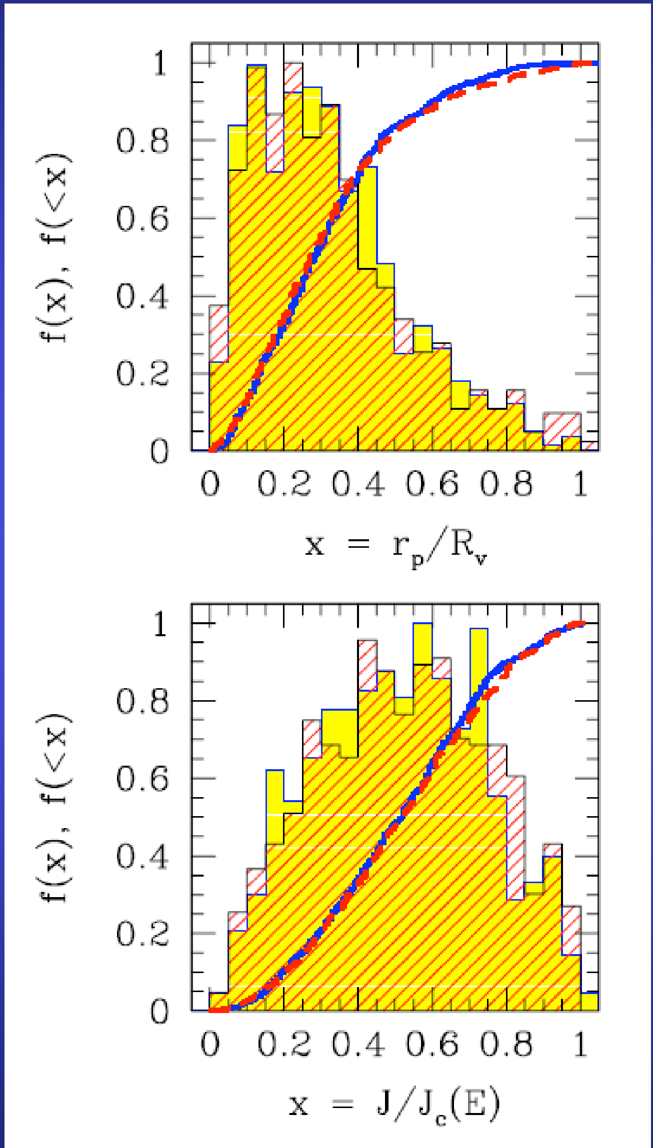
Mass function of satellites at merging time



- The mass function of infalling satellites is a power law with slope ~0.5.
- Merging history is dominated by few massive merging events

(GT 1997)

Orbits of satellites at merging time

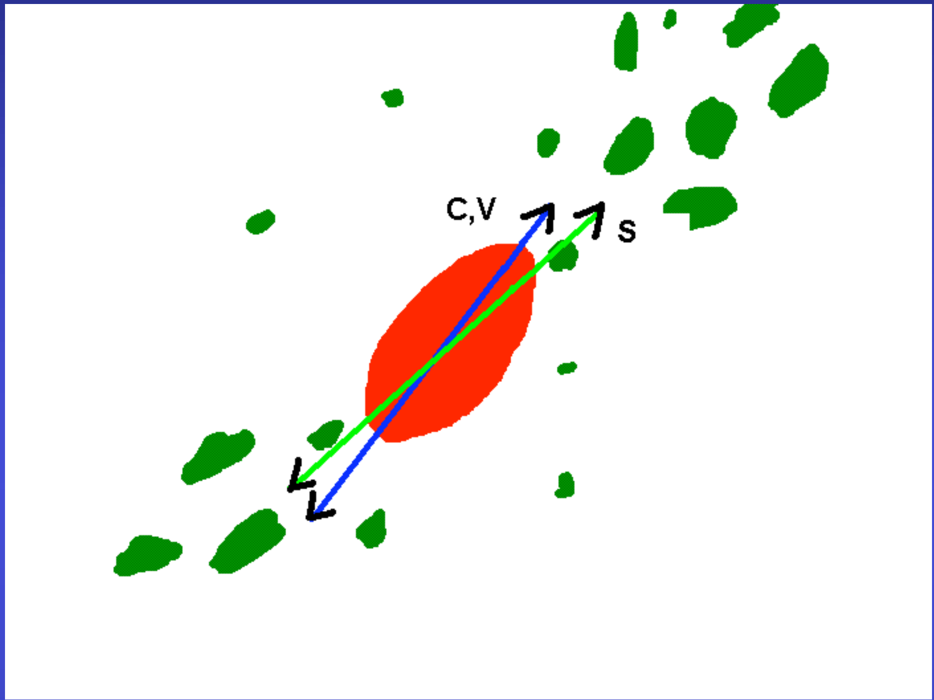


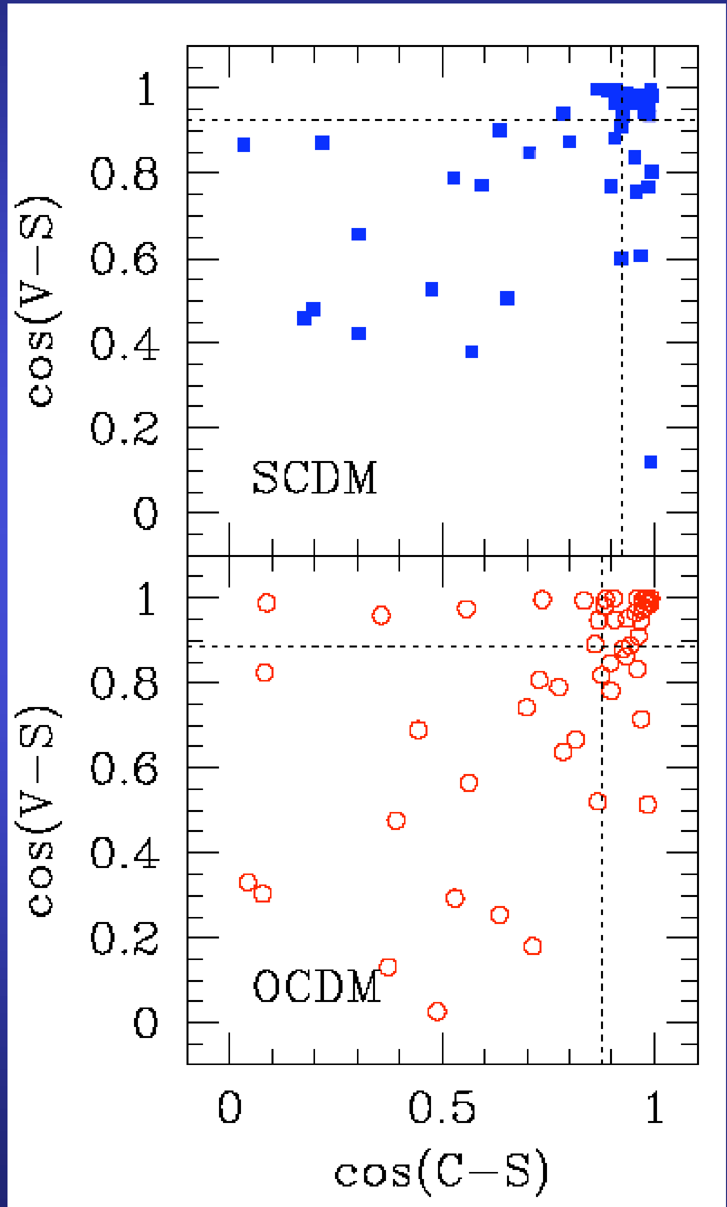
Circularity: $\epsilon \equiv J/J_c(E)$

- Mean circularity: ~0.5
- Mean pericenter: ~0.3 Rv
- More massive satellites merge on slighty more radial orbits

(GT 1997; GT, C.Frenk & S.White - unpublished)

Alignment of infall and final system





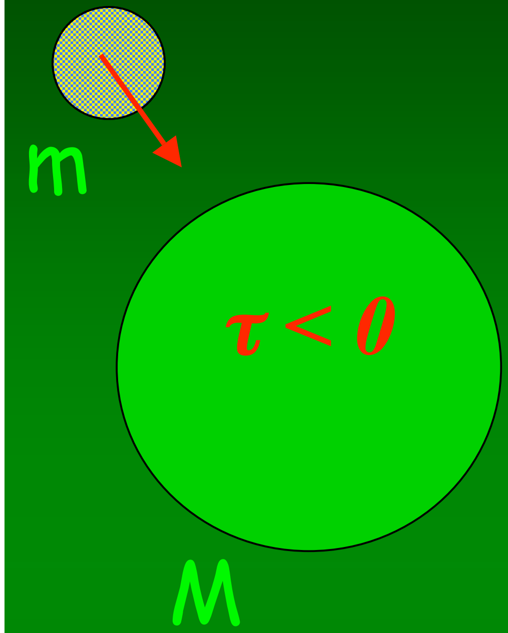
Clusters align their final mass and velocity ellipsoids to the infall pattern of satellites.

(GT 1997; GT, Frenk & White unpublished)

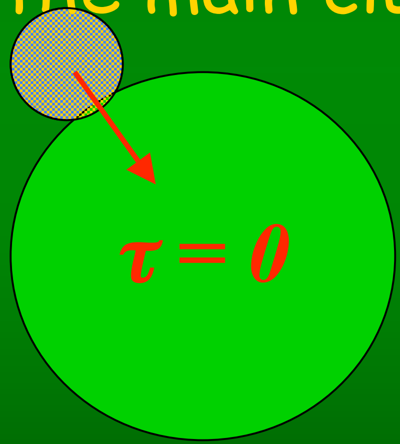
Evolution of satellites after merging

- The latest Chandra X-Ray observations show detailed X-Ray features possibly related to merging events, like gas inhomogeneities, shocks and cold fronts.
- In this context can simulations help in the interpretation of these features?
- We can ask "simple" questions like:
  - How long do merging structures survive?
  - How do they affect the thermal equilibrium (morphologically and dynamically) of the ICM?
  - What are the observable signatures of merging events?
  - How long do these observable last?

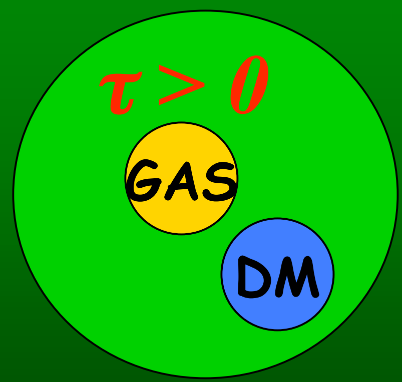
Merging events



For each merging event, set time in Gyrs from the moment when the satellite first crosses the virial radius of the main cluster.



Gas stripping



Bin results in mass ratio: m/M

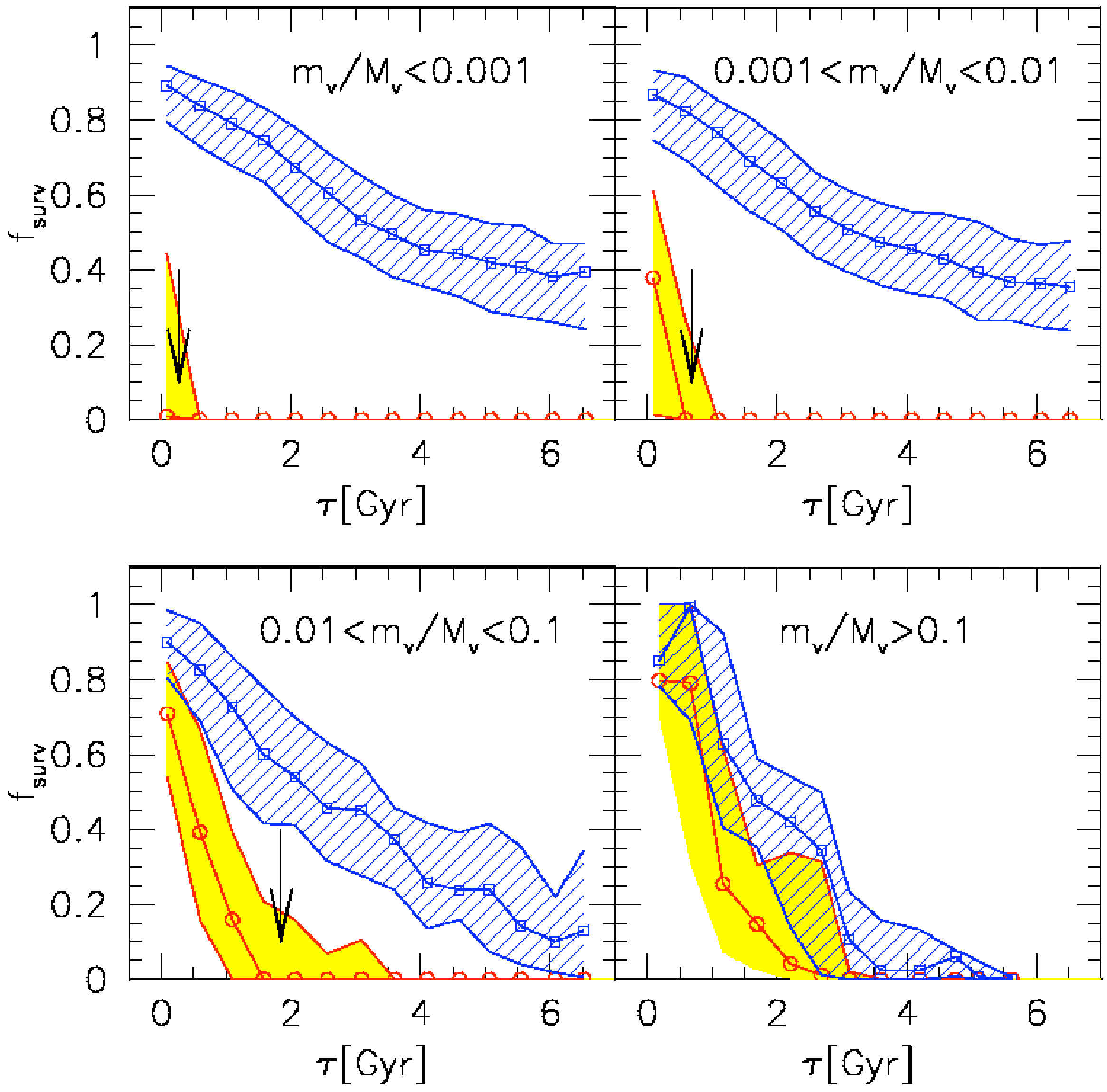
Self-bound mass fraction

Curves:

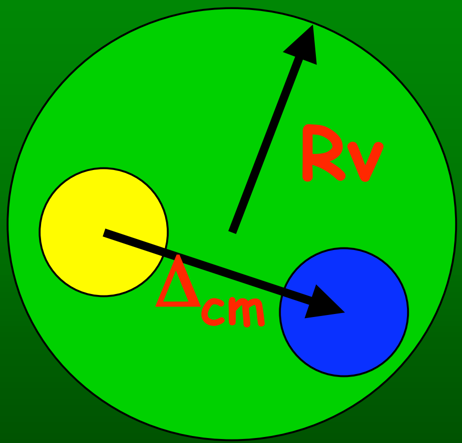
Dark Matter

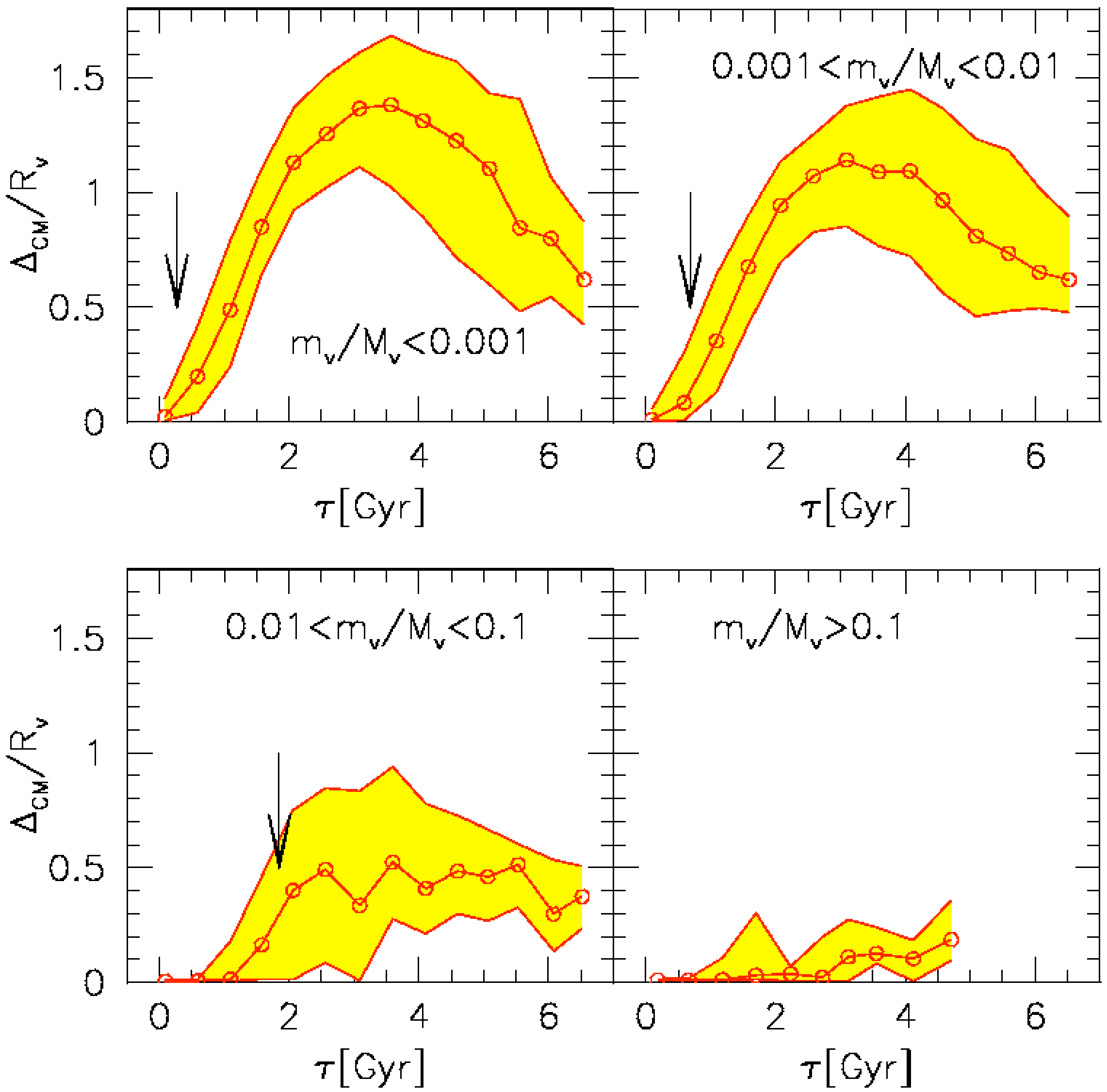
Gas

(GT, L.Moscardini & N.Yoshida 2004)



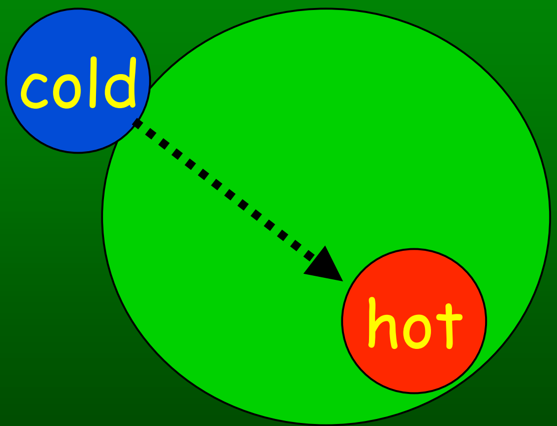
ICM-DM separation

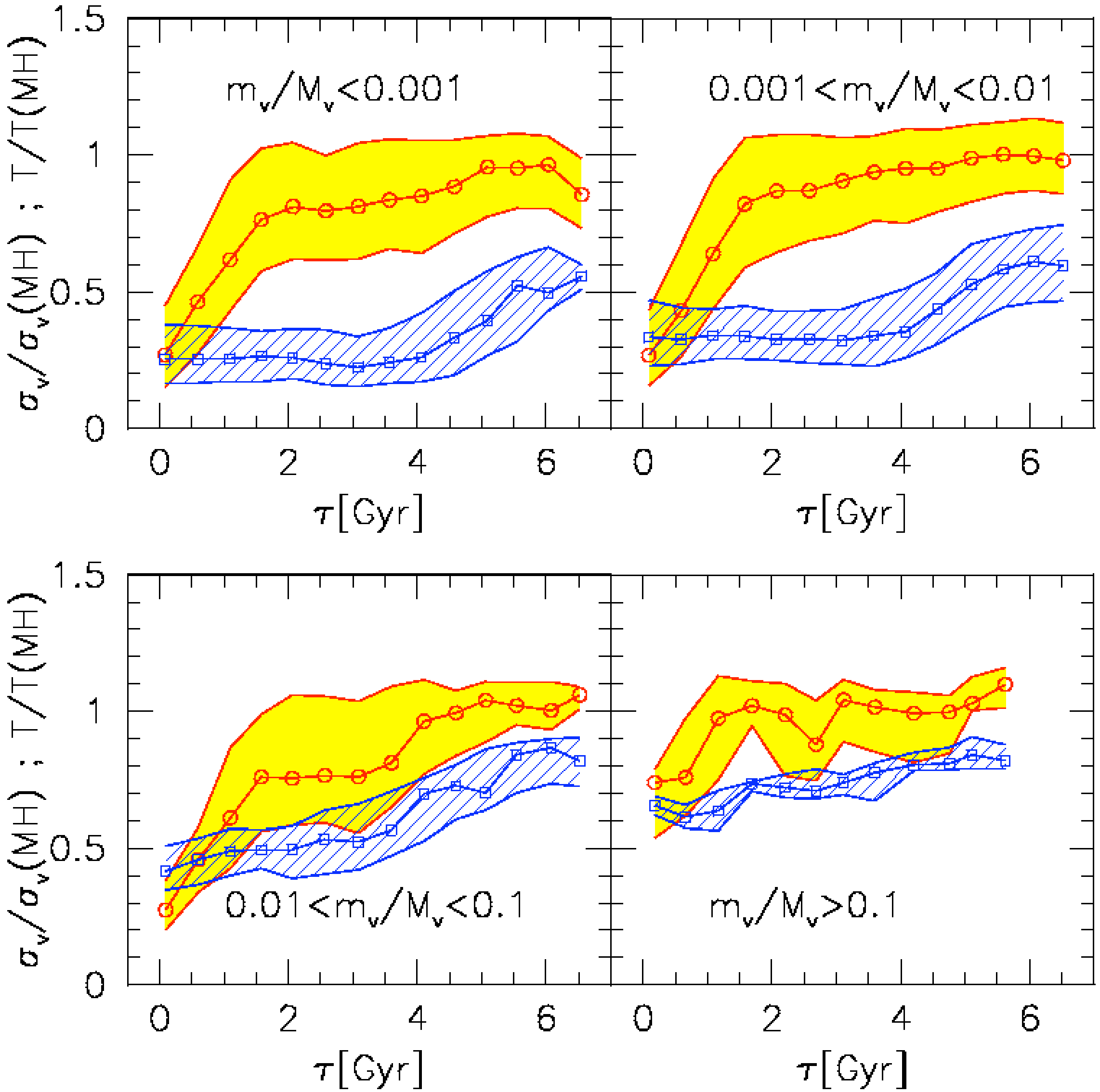




Thermalization: all particles

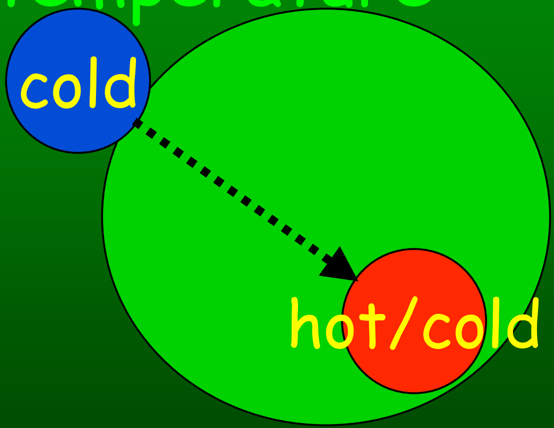
Evolution of satellite DM velocity dispersion and ICM temperature

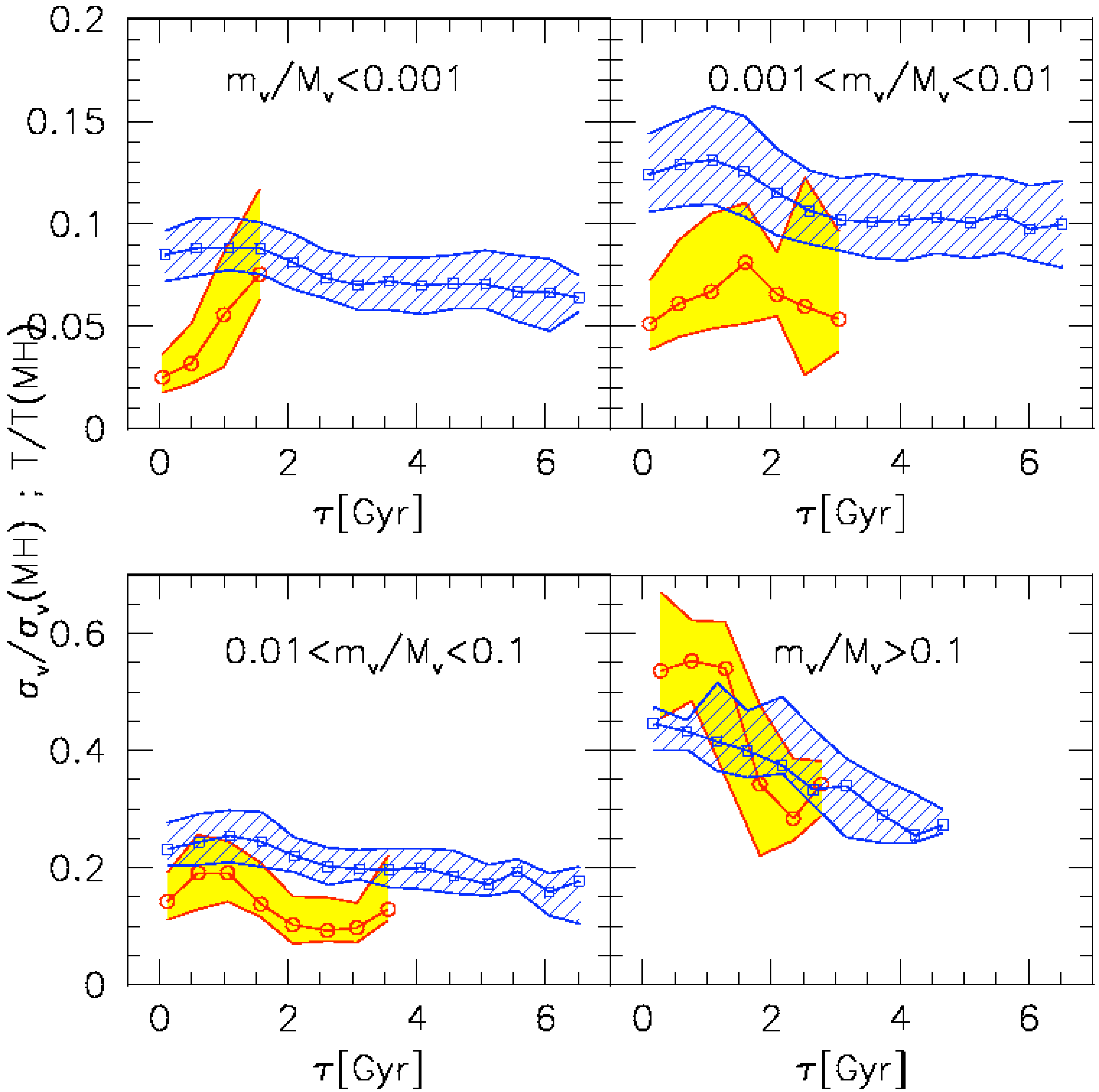




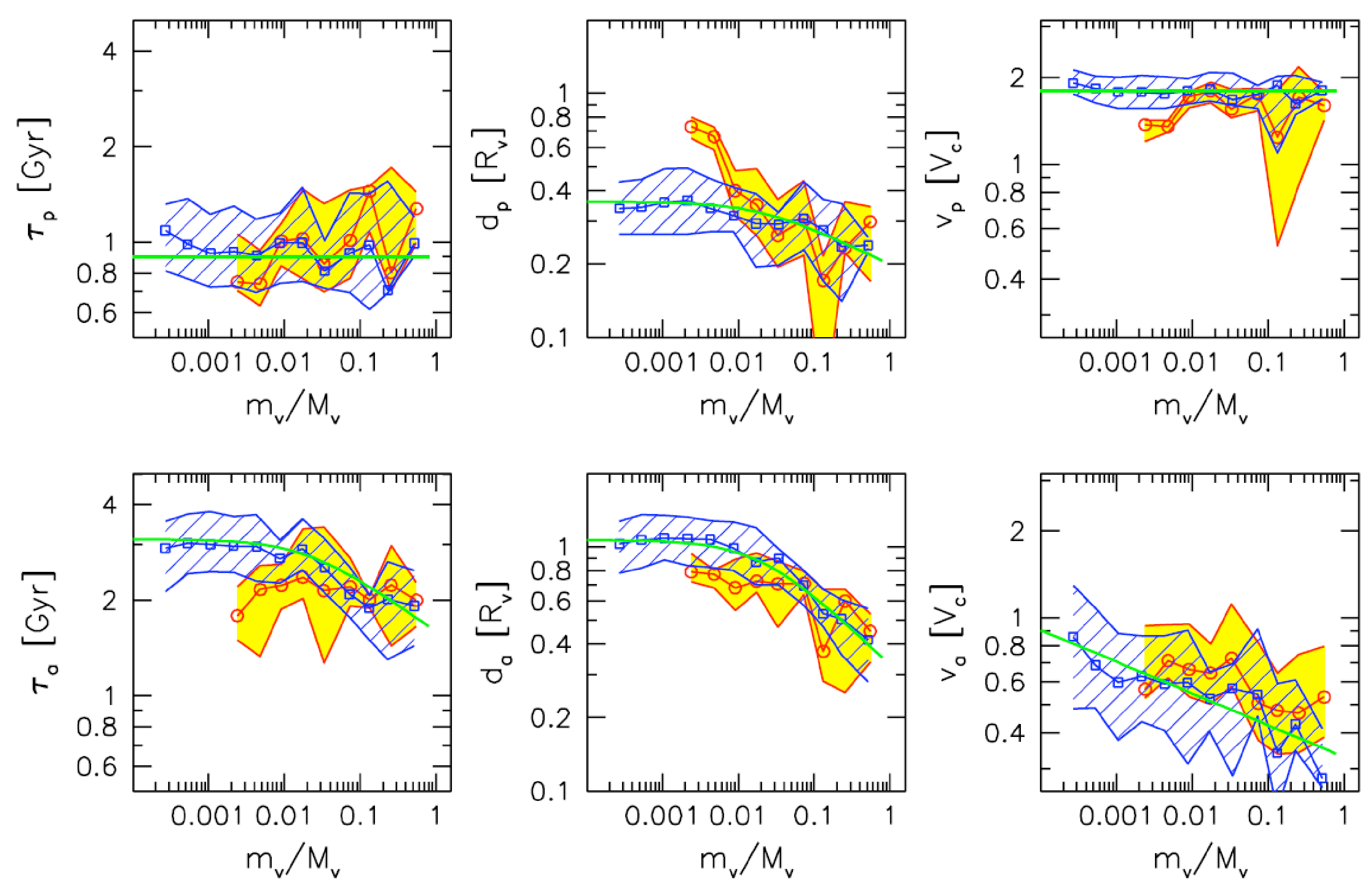
Thermalization: self-bound particles

Evolution of satellite DM velocity dispersion and ICM temperature

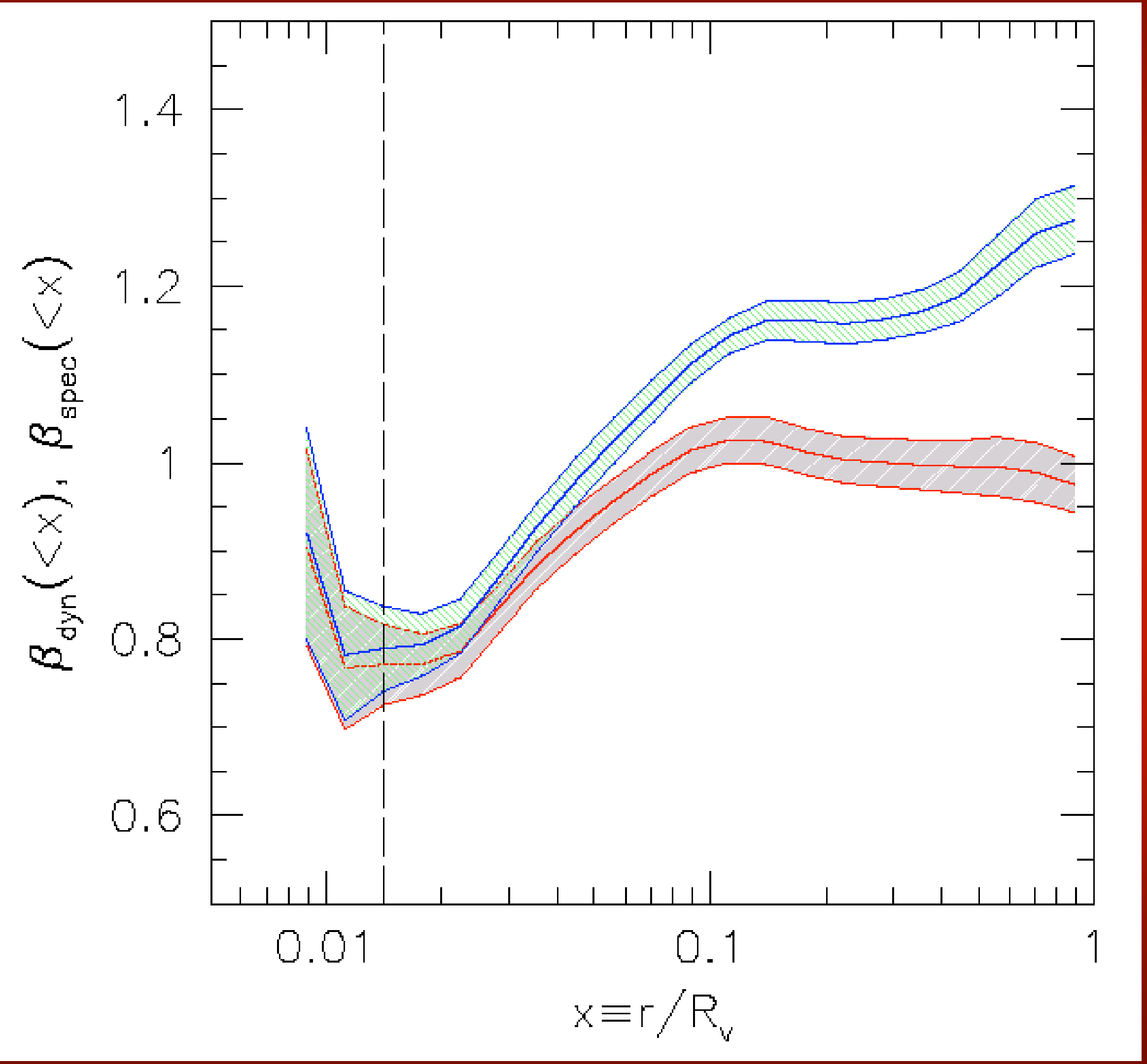




Peri/Apo-centric properties



DM-GAS energy balance



$$\beta_{dyn} \equiv \frac{\sigma^2_{DM}}{k_b T/\mu m_p + \sigma^2_{gas}}$$

$r > 0.1\ R_v$:
Energy equipartition for DM and GAS

$r < 0.1\ R_v$:
GAS has more energy than DM

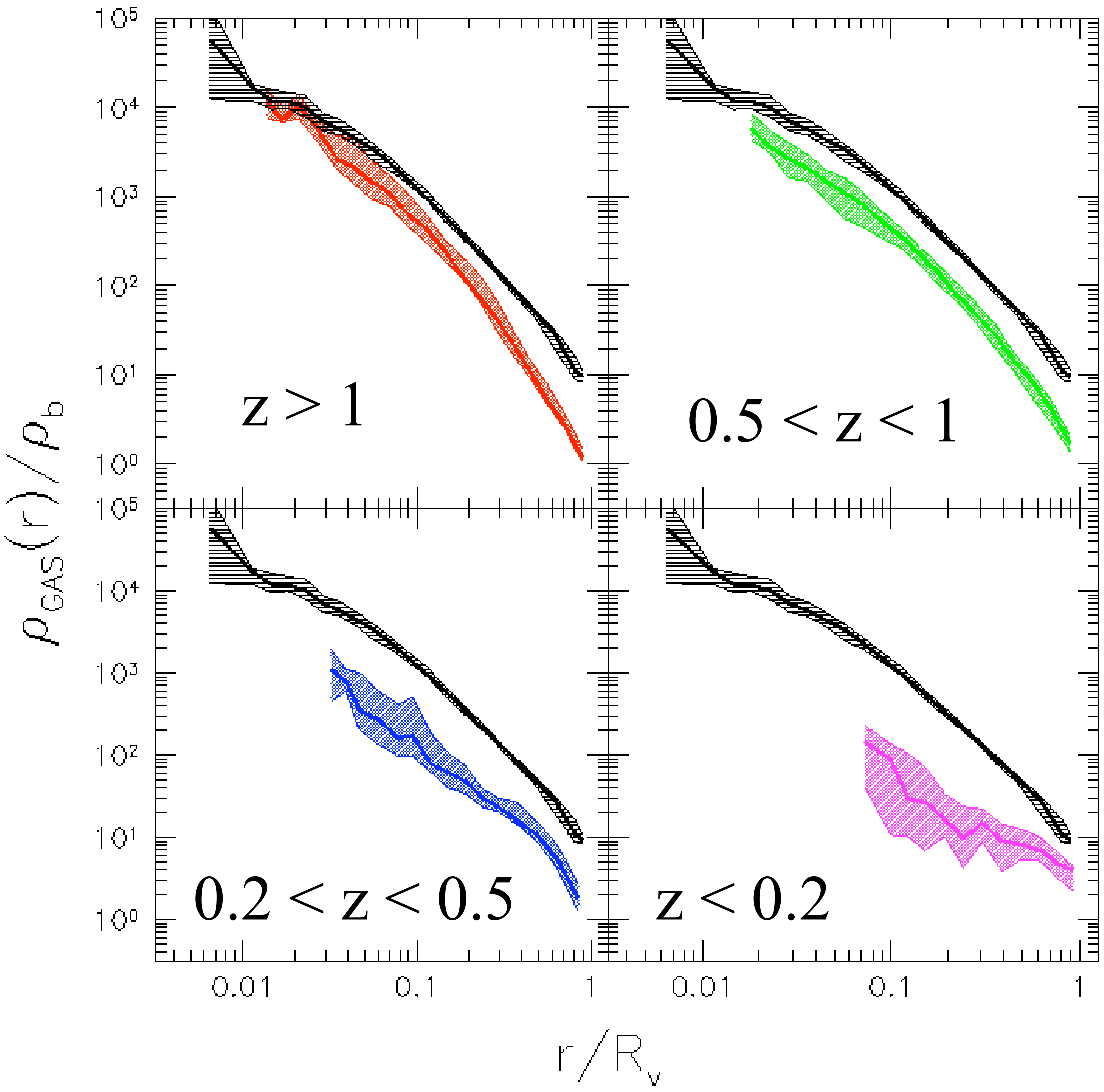
(E.Rasia, GT & L.Moscardini 2004)

Decomposition of the ICM

- In the cluster at redshift z=0, select the DM and ICM particles that:
  1. Entered the cluster at different epochs
  2. Entered the cluster carried by satellites of different mass

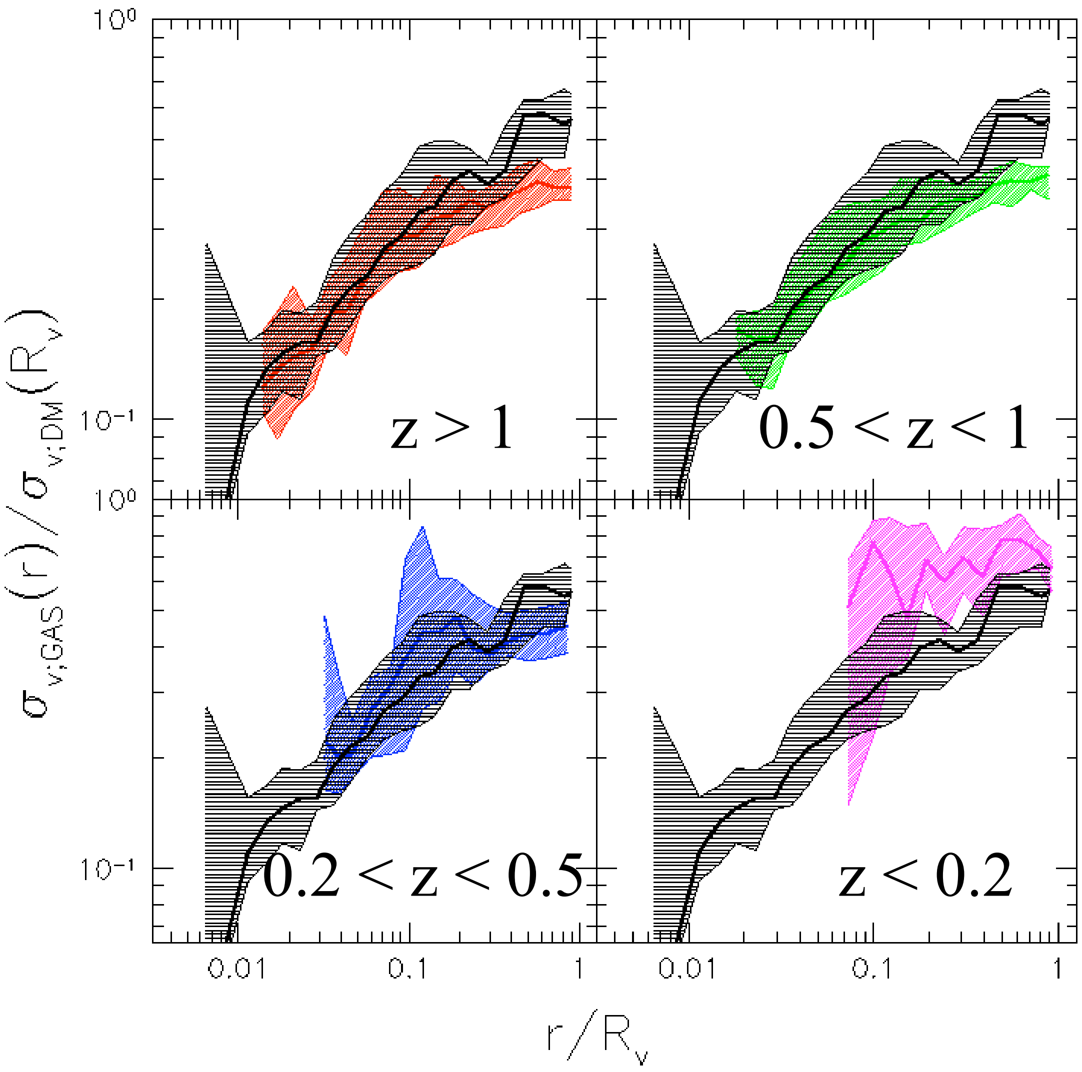
Decomposition in redshift: gas density

- Gas accreted at higher redshift settles at smaller distances from cluster center at z=0.



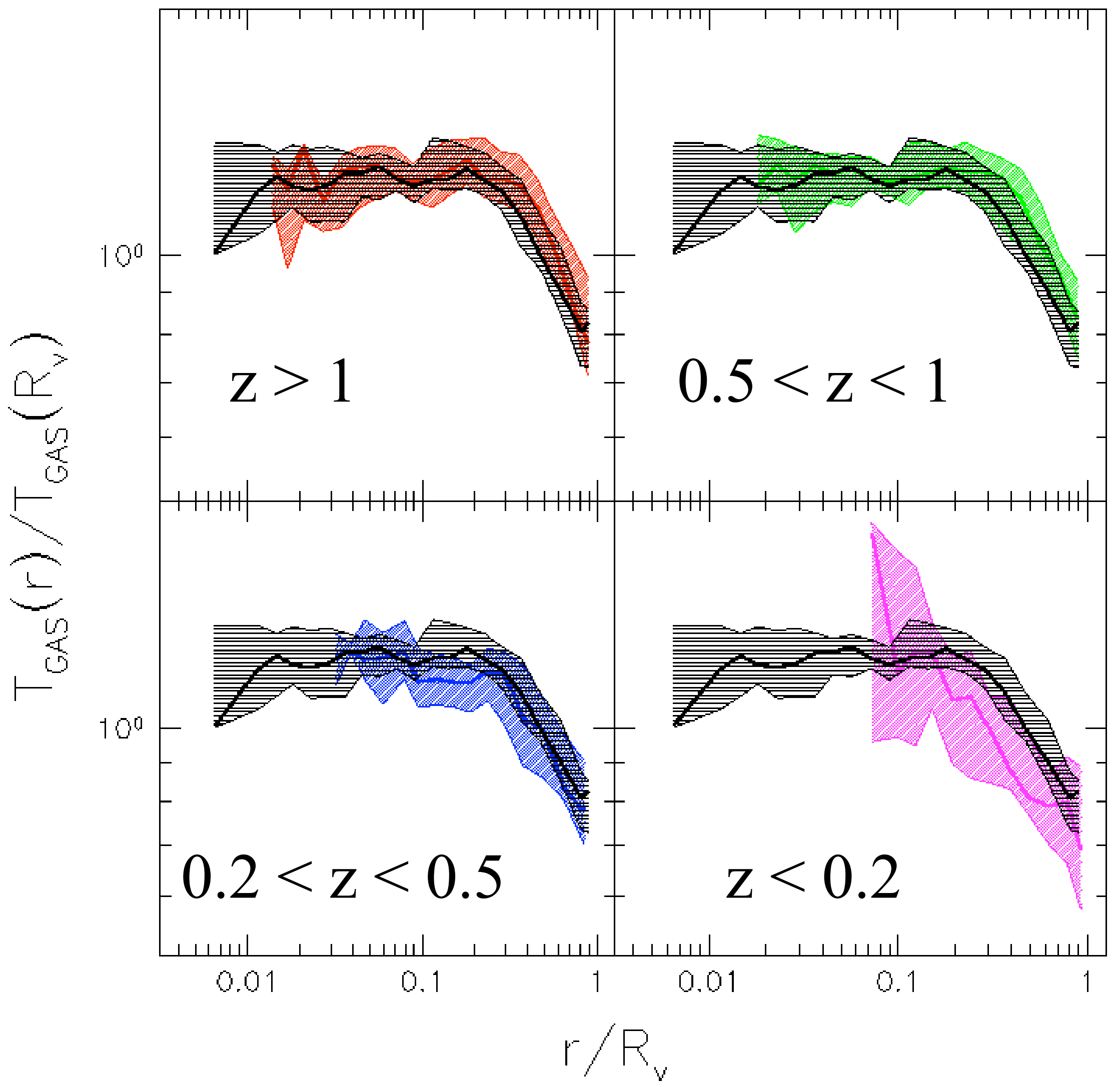
Decomposition in redshift: gas velocity dispersion

- Gas accreted at higher redshift has smaller velocities at large radii at z=0.
- Gas accreted recently moves faster.



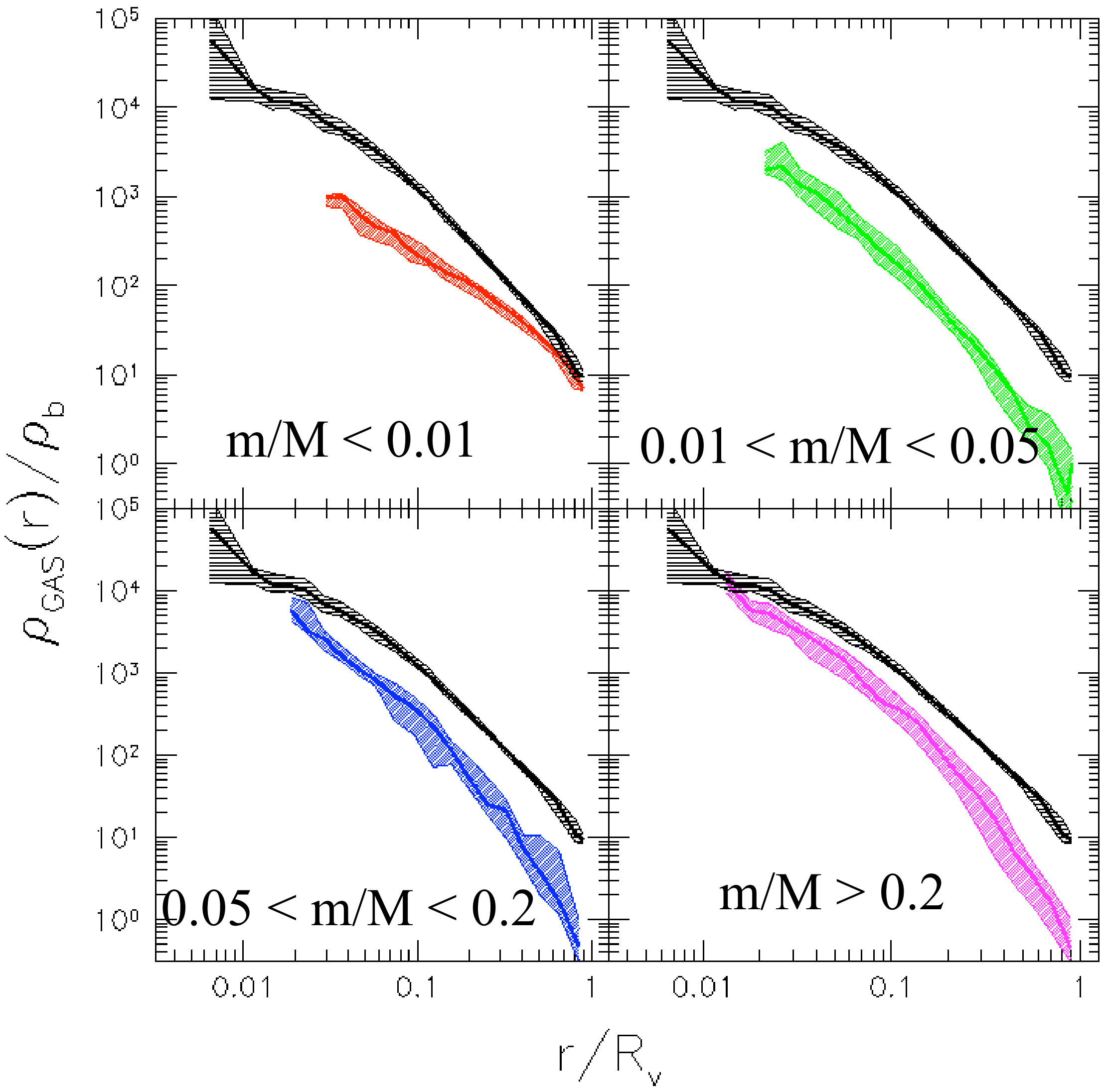
Decomposition in redshift: gas temperature

- Gas accreted at higher redshift is hotter at large radii at z=0.
- The opposite for gas accreted at lower redshift.



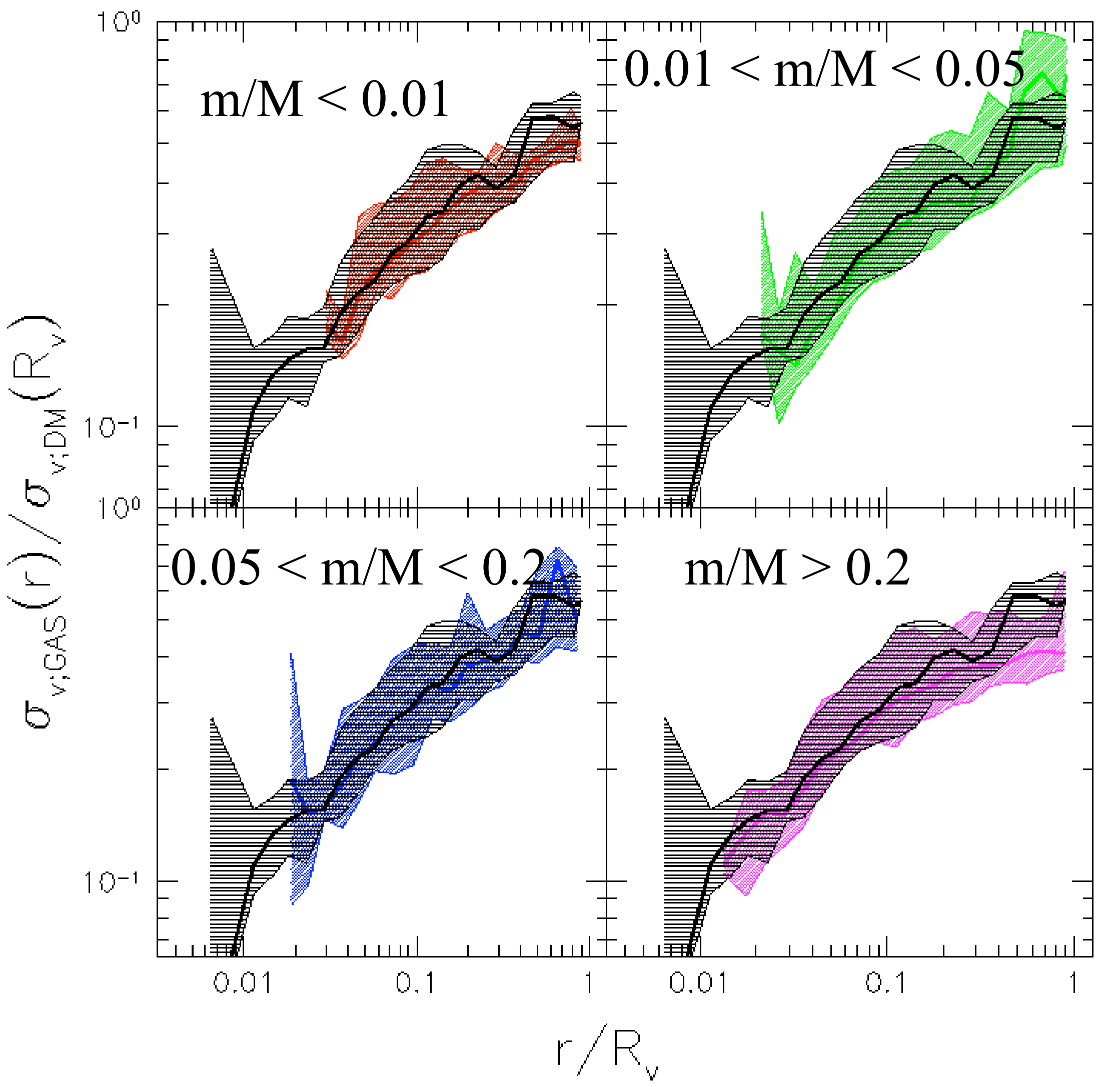
Decomposition in progenitor mass: gas density

- Gas accreted in big (m/M) lumps settles at smaller distances from cluster center at z=0.



Decomposition in progenitor mass: gas velocity dispersion

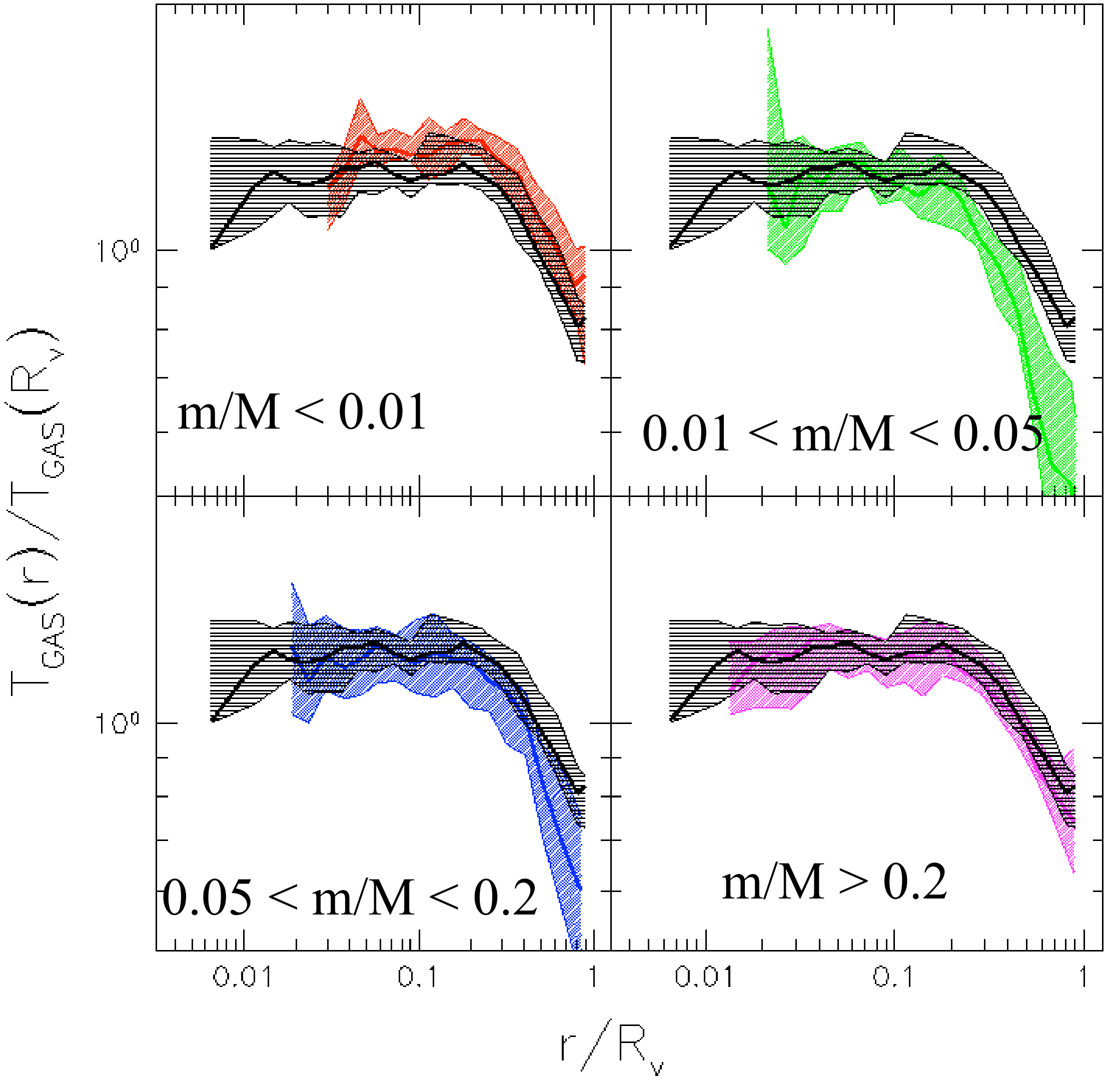
- Gas accreted in very big lumps have marginally smaller velocities at large radii at z=0.



Decomposition in progenitor mass: gas temperature

•Gas accreted in small lumps is hotter at large radii at z=0.

•Gas accreted in intermediate mass lumps is cooler.



Conclusions (Part 1-2)

- The anisotropic infall of satellites leaves an imprint on the (shape) and alignment of the final mass and velocity dispersion.
- More massive satellites land on slightly more radial orbits, sink deeper in the cluster, slow down more quickly, but retain their ICM for longer times.
- Thermalization of the satellite ICM happens in ~2 Gyr regardless of satellite mass.
- Satellite cores may become cooler.

Conclusions (Part 1-2)

- ICM accreted at earlier times is more concentrated in the center; it retains residual velocities.
- ICM accreted at late times stays in the cluster outskirts, is cooler and has larger motions.
- ICM accreted in large lumps settles in the center, at average velocity and temperature.
- ICM accreted in small lumps stays in the outskirts, at overall average velocity but slightly higher temperature.

Outline

- Global properties of infalling satellites **at** merging
- Evolution of satellite properties **after** merging
- Properties of the ICM **at redshift zero** as a function of its merging history.
- Resimulation techniques
- Effect of ++ physics on radial profiles

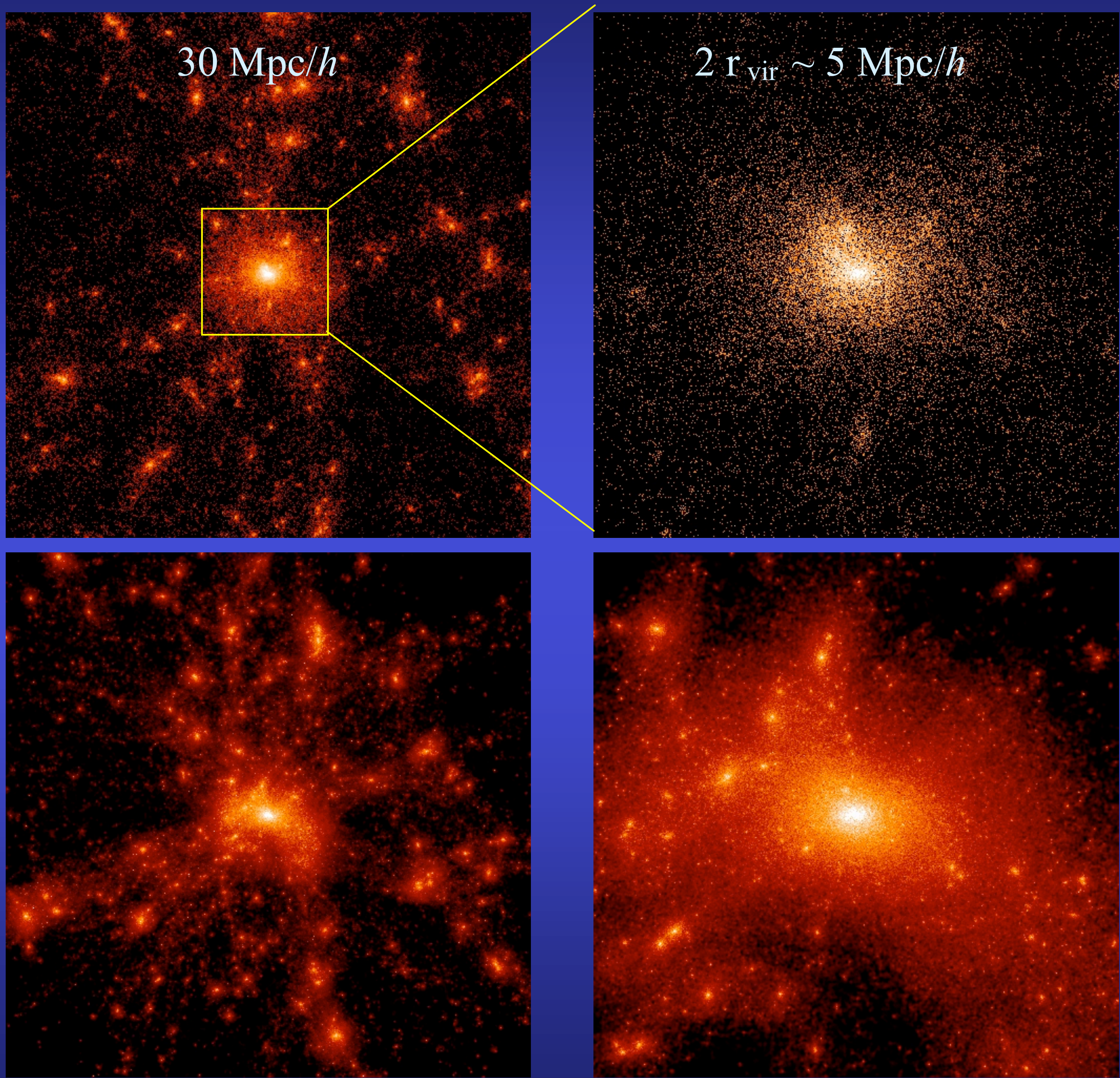
Resimulation of individual systems

- The highest resolution on single systems is achieved with re-simulation techniques (ZIC: Zoomed Initial Conditions)
- Starting from a cosmological box, select a region containing the system of interest.
- Go back to the initial conditions and… ZIC:
  - increase the mass and force resolution at the location of the proto-system
  - Decrease the mass and force resolution outside the proto-system
- With this technique the computational effort is focussed on the region of interest, and the resolution can be improved by factors of 10-100-1000-…

(B.Lanzoni 2002, PhD thesis)

parent simulation

$N \sim 3\ 10^4$



resimulation

$N \sim 10^6$

Resimulations of individual systems (2)

- In Padova our group has produced a sample of re-simulated clusters with SPH hydrodynamics including and radiative processes.
- This is among the highest resolution samples presently existing.
- 10 resimulations containing of order 30 systems, of mass > 5.e13 Msun/h, simulated with different recipes:
  1. N-body (Dark Matter only)
  2. No. 1 plus non-radiative hydrodynamics (2 flavours)
  3. No. 2 plus star formation and feedback
  4. No. 3 plus thermal conduction
- Post processing: halo catalogues, merging history trees, radial profiles, evolution of substructure.

Resimulations of individual systems (3)

- Mass resolution 1.13e9 Msun/h:

  → 1+ million gas particles per massive cluster

- Force resolution 5 kpc/h:

  →2+ orders of magnitude in size of systems

- Total computational effort:

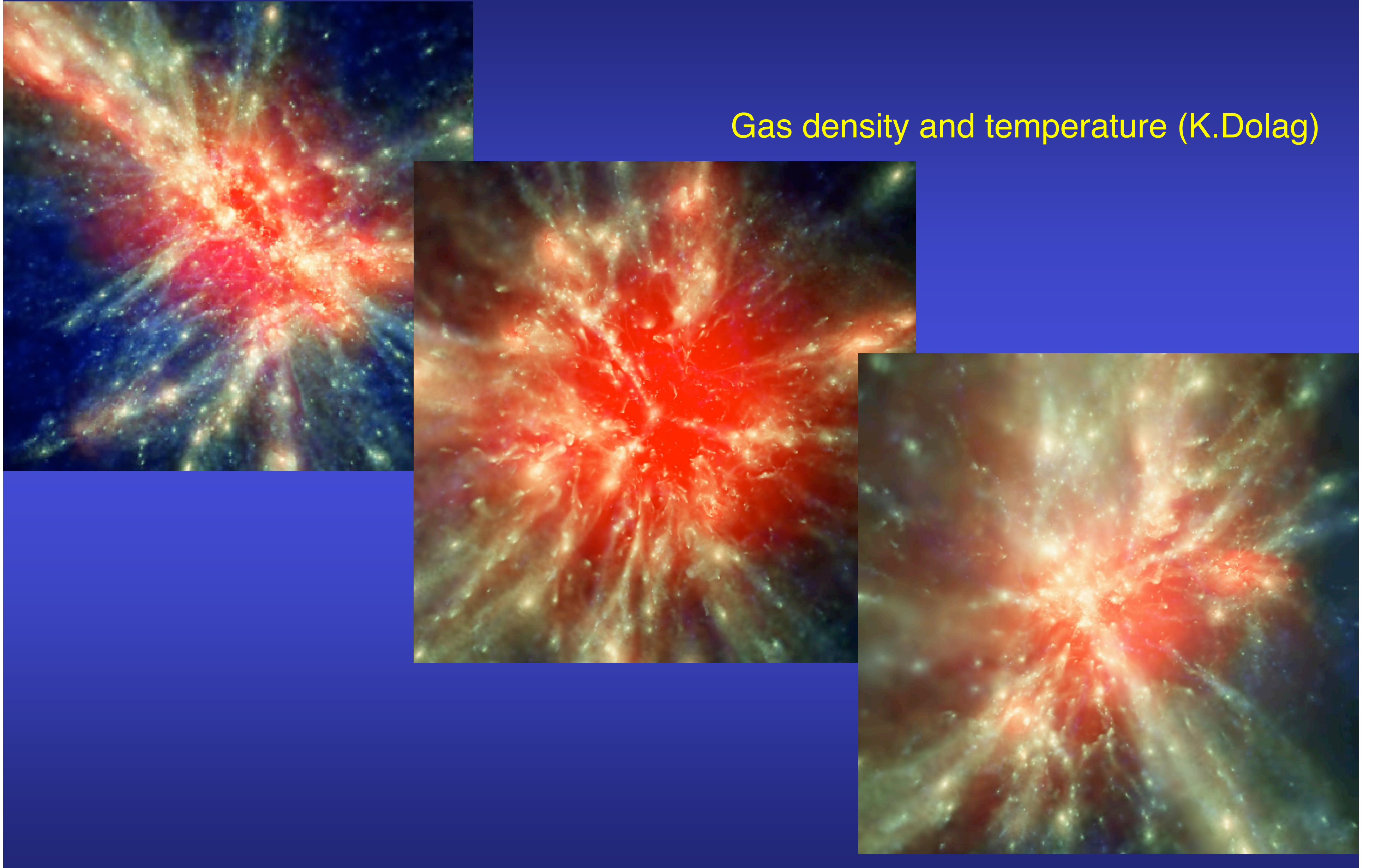
  of order 100.000 CPU hrs

  (Cineca, IBM-SP4; Padova, IBM-SP3;

  MPA Garching, IBM-Regatta)

Re-simulations of Individual clusters

Gas density and temperature (K.Dolag)

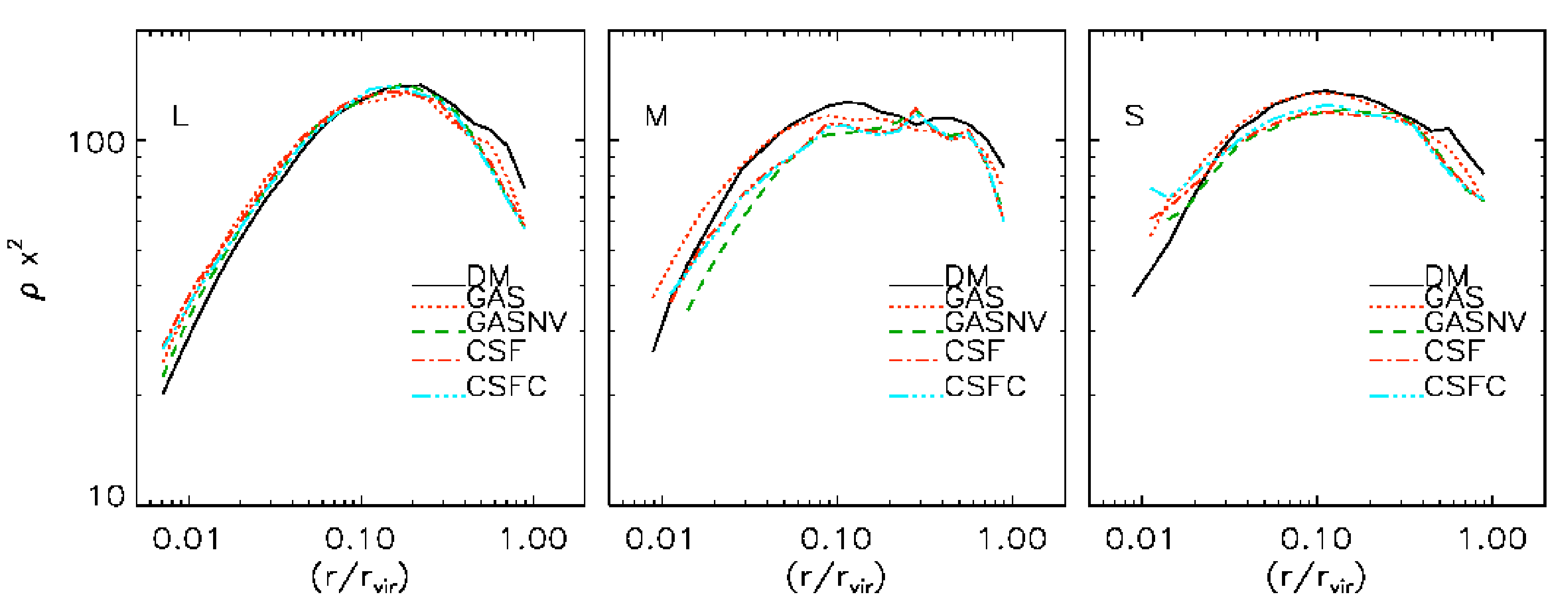


Formation of a galaxy cluster

movie

(K.Dolag 2004)

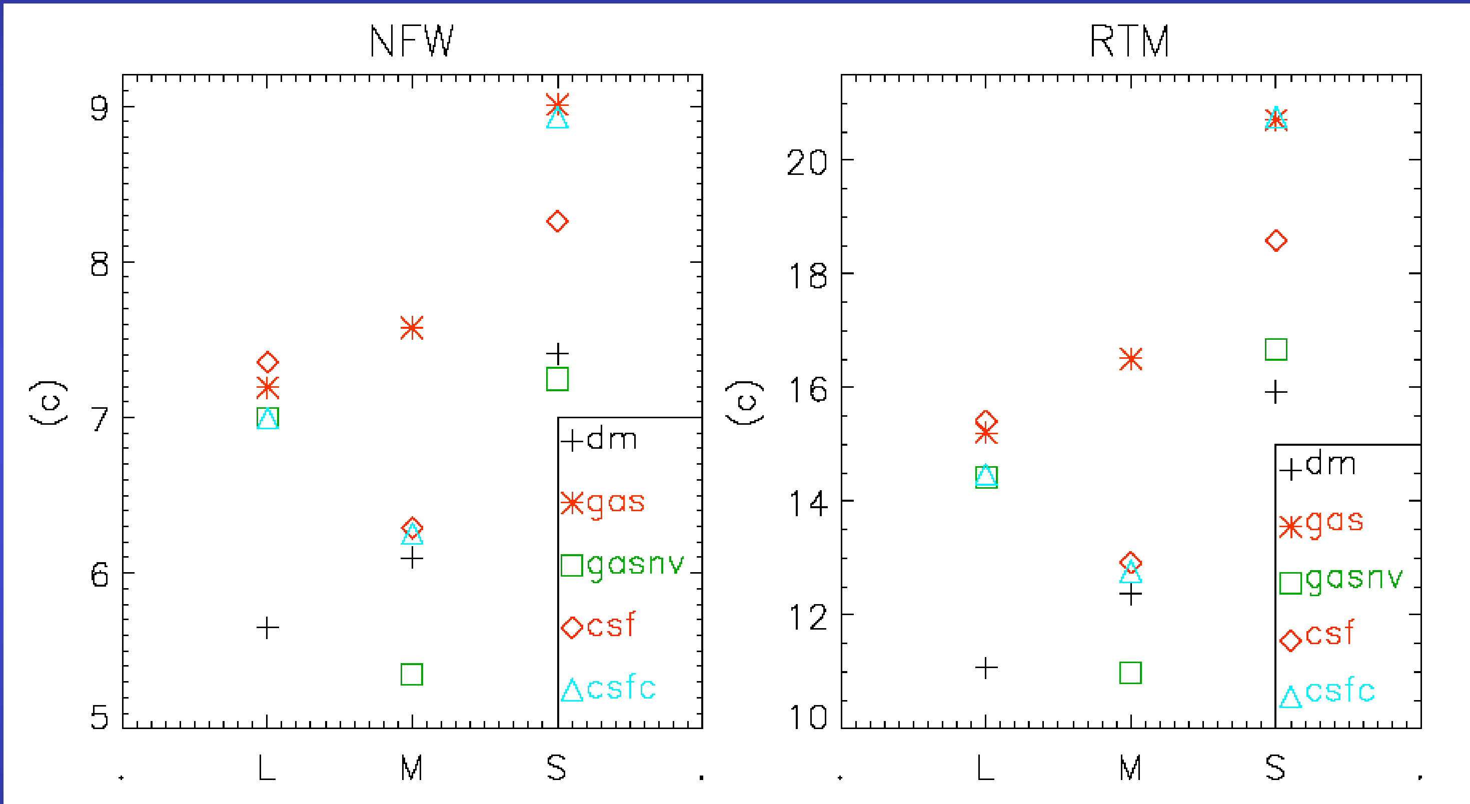
DM density profiles



R.Brunino, laurea thesis (2005)

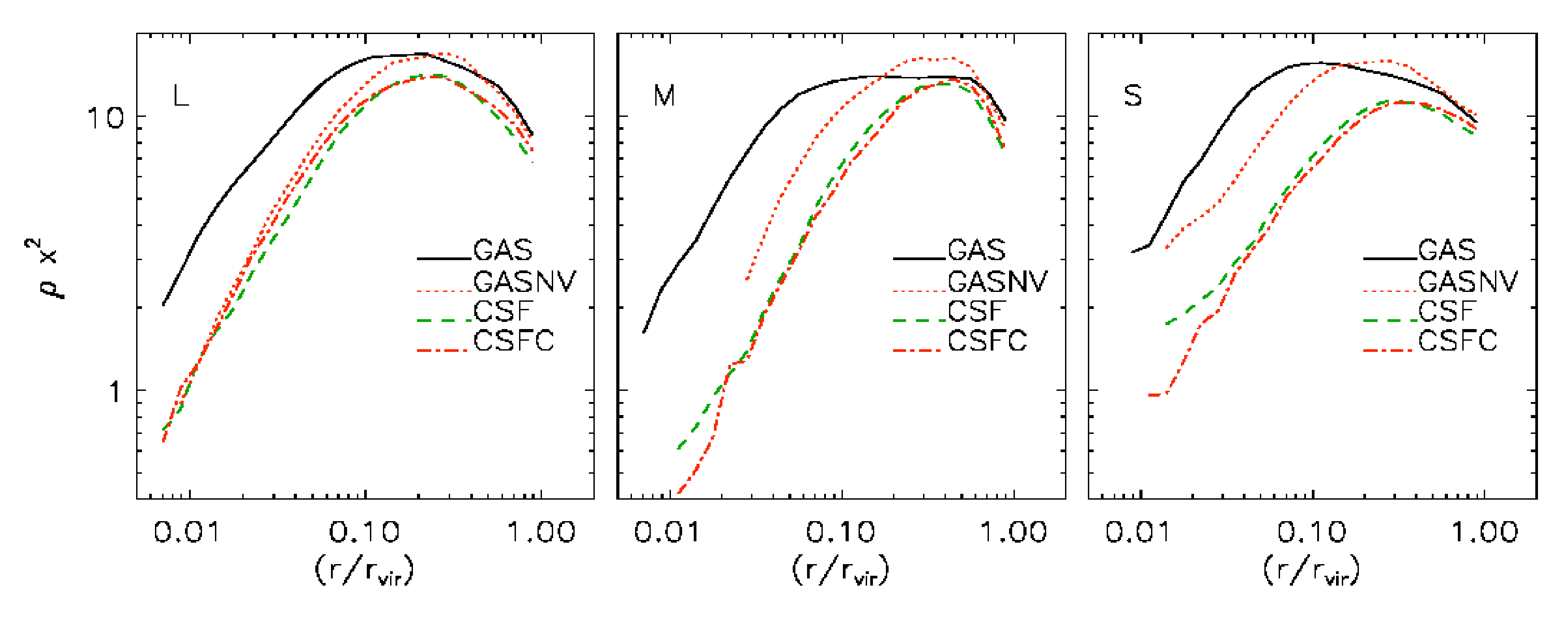
- Presence of GAS makes DM more centrally concentrated by 20+ percent, even for non-radiative SPH.

DM density concentration



R.Brunino, laurea thesis (2005)

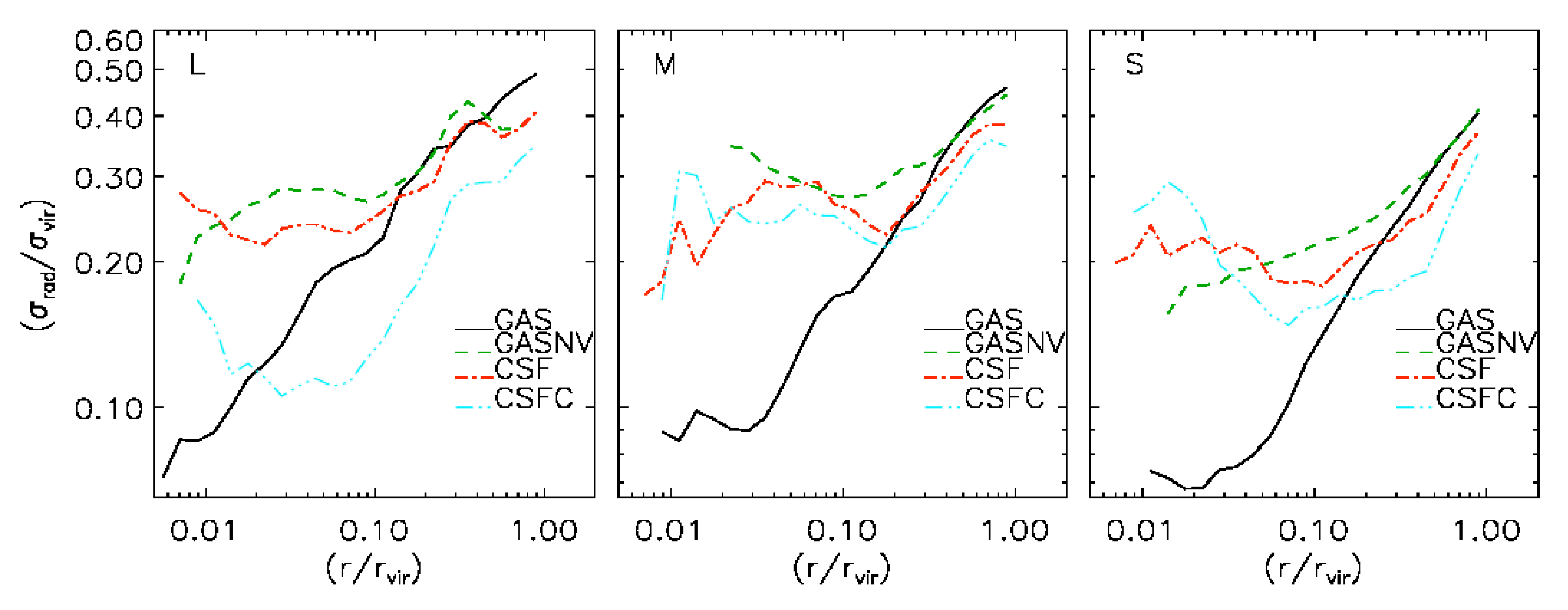
ICM density profiles



R.Brunino, laurea thesis (2005)

- New viscosity makes ICM less centrally concentrated.
- Radiative processes make ICM even less concentrated.

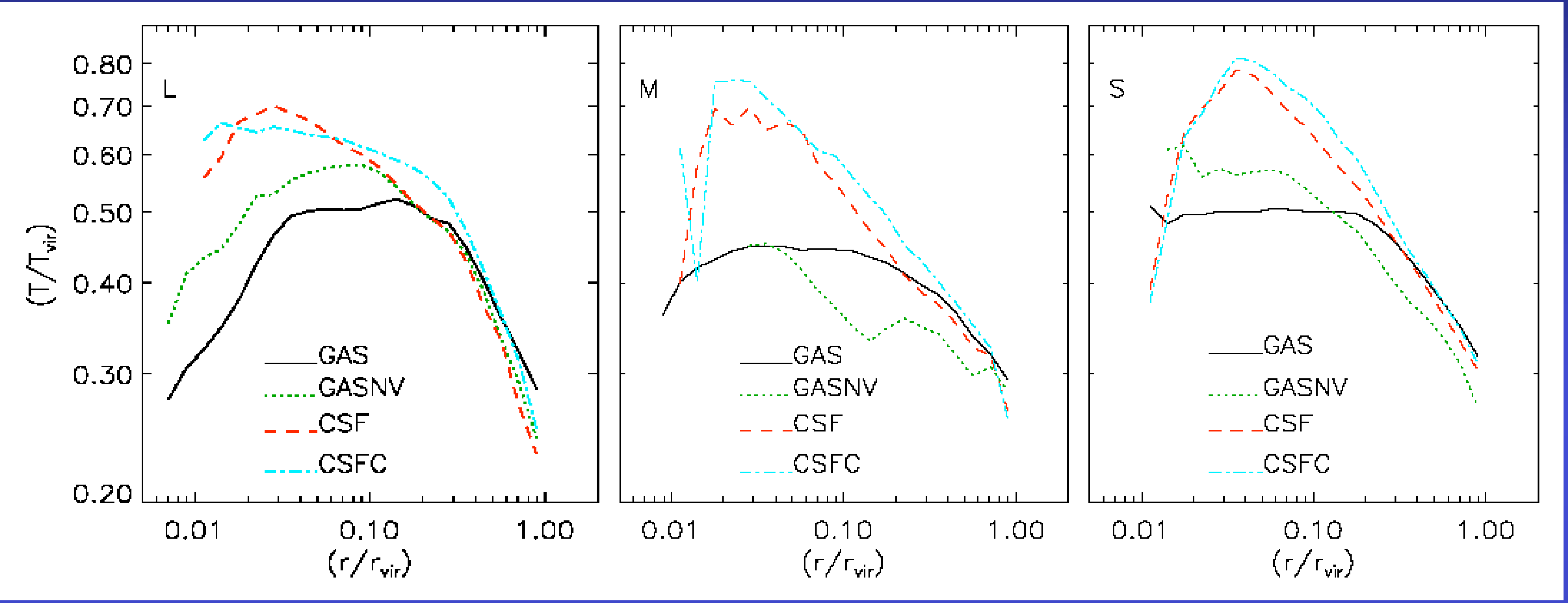
Gas velocity profiles



R.Brunino, laurea thesis (2005)

- New viscosity leaves higher ICM motions.
- Radiative processes also enhance ICM motions.

GAS temperature profiles



R.Brunino, laurea thesis (2005)

- New viscosity and radiative processes spoil ICM isothermal core.

GAS entropy profiles

- No entropy core in non-radiative case.
- Higher entropy ramp for new viscosity scheme
- Even higher with radiative processes.

R.Brunino, laurea thesis (2005)

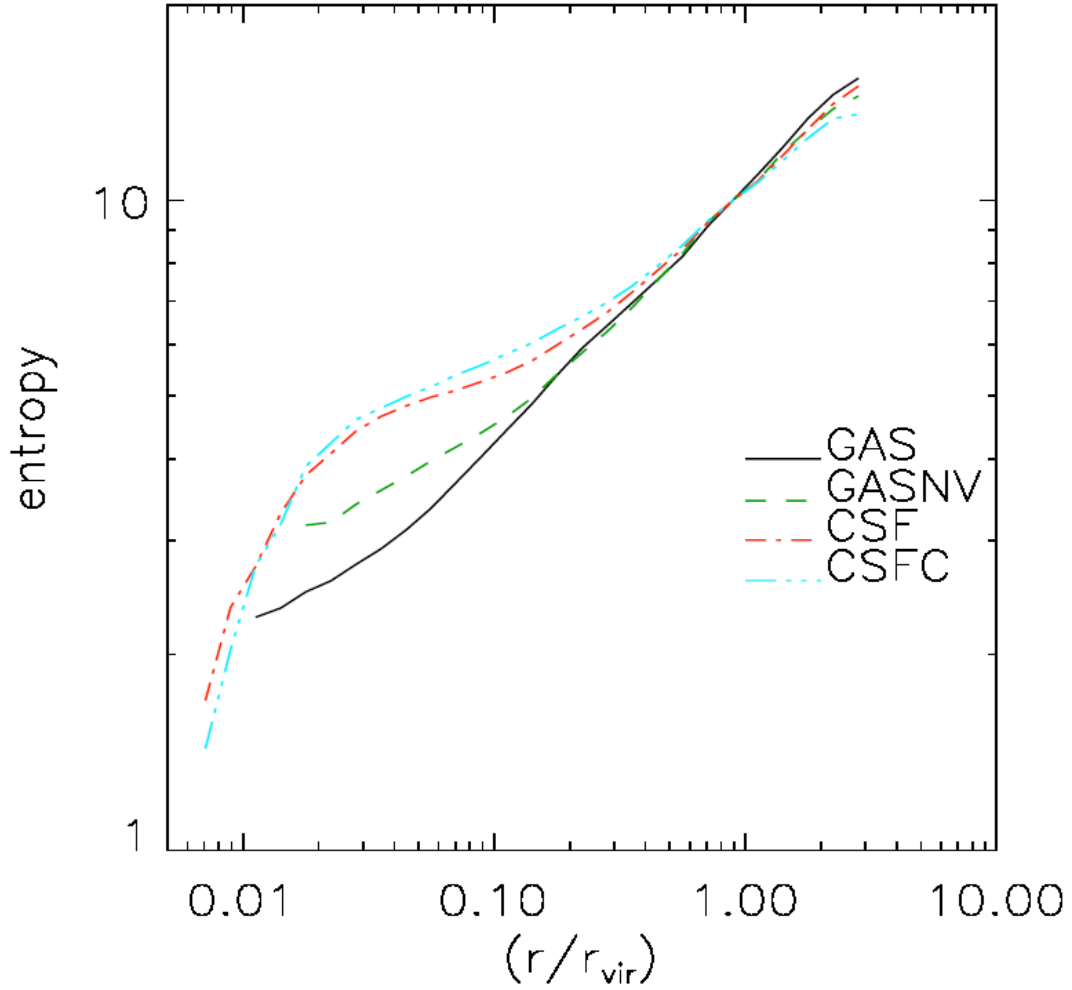


Figura 7.11: Gas entropy: $S \propto \ln T/\rho^{2/3}$, plotted to four times the virial radius.