The virialized mass of dark matter halos in cosmological simulations

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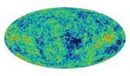
Outline

- Motivation for a virialization-based approach
- Definition of static mass
- Relation with virial mass
- Mass function of collapsed objects
- Evolution and scaling
- Tracking of main halo progenitor
- Summary

Introduction

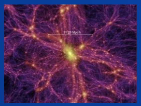


Collapsed structures we see today have their origin in tiny quantum fluctuations at inflation. Their formation goes through gravitational collapse.

Structure formation is hierarchical: small structures collapse first, followed by galaxies, and then clusters of galaxies (bottom-up). Interestingly, the stars in more massive galaxies tend to form earlier, which is known as *downsizing*.

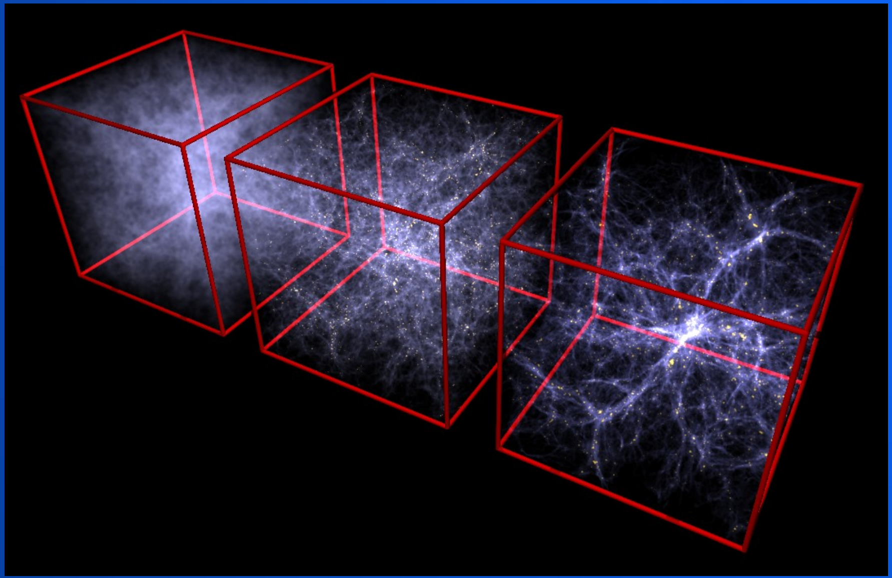
The currently accepted cosmological model is ΛCDM, which assumes that the most of the matter in the Universe does not interact via electromagnetic radiation and became nonrelativistic very early, and that the Universe is experiencing recent acceleration. In this model, bottom-up formation can take place.

The collapsed objects formed by dark matter (hereafter dark matter halos) may host visible galaxies, if baryonic gas succeeds in forming stars via cooling flows.



The quantification of the material associated to collapsed structures is thus very important in order to understand the formation and evolution of these structures.

N-body Cosmological Simulations

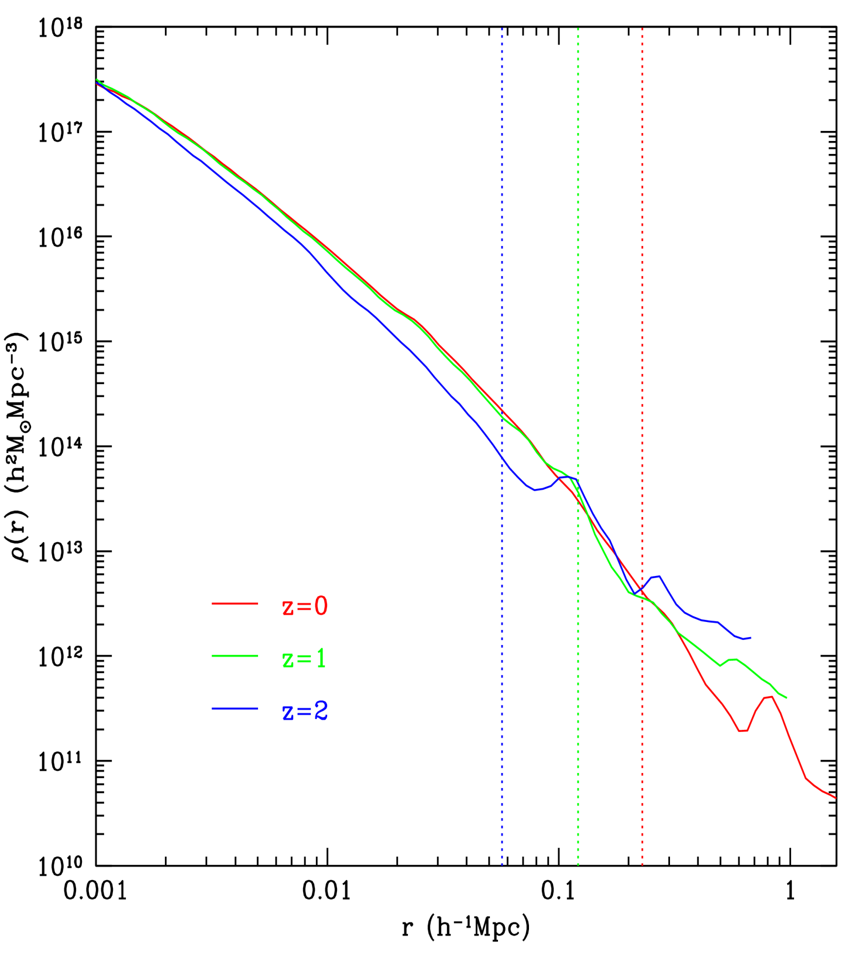


Credits: V.Springel and L. Hernquist. MNRAS, 339, 312 (2003)

- Dark-matter only (no gas)
- Concordance ΛCDM cosmological model:
  $\Omega_m=0.3$ $\Omega_\Lambda=0.7$ $\sigma_8=0.9$ h=0.7
  (1st year WMAP, Spergel et al. 2003)
- Bound Density Maxima Halofinder (Klypin et al. 1999)

- More than 10^8 particles are tracked from $z\simeq40$ to $z=0$.
- Good resolution: selected collapsed objects have ≳2,000 particles inside R_{vir} (which is the radius of a sphere enclosing a given overdensity)
- Different box sizes probe different scales: these simulations cover masses ranging 10^{10}-10^{15} $M_\odot$.

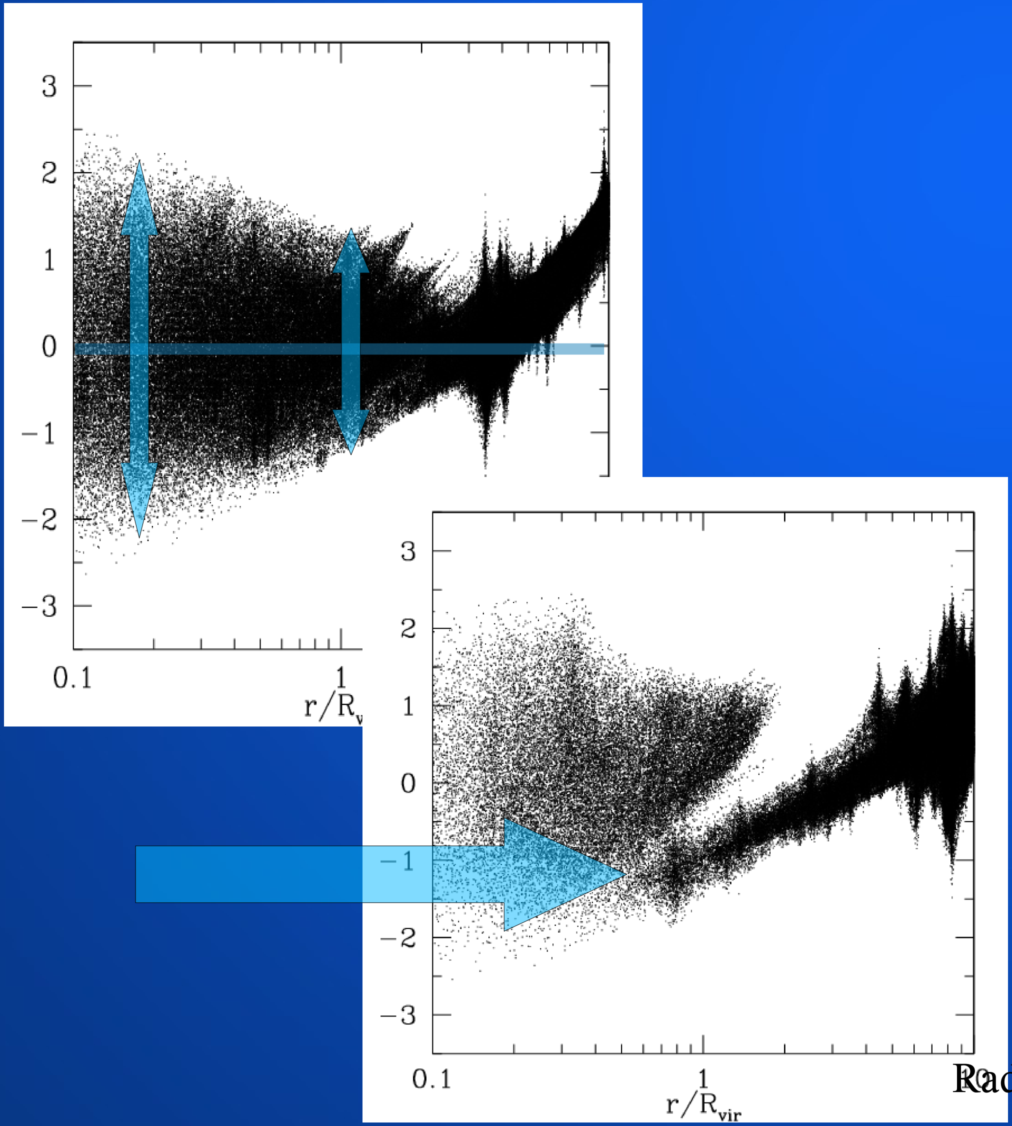
Motivation (i)



- The evolution of this density profile of a Galactic-size halo does not show a significant change from redshift *z=1* (green) to *z=0* (red) in physical coordinates.

- Virial radius is however, increasing: the mean matter density decreases $\rho_m(a)=\rho_{m,0}a^{-3}$ as the Universe expands and the boundary of fixed overdensity corresponds to a larger radius.

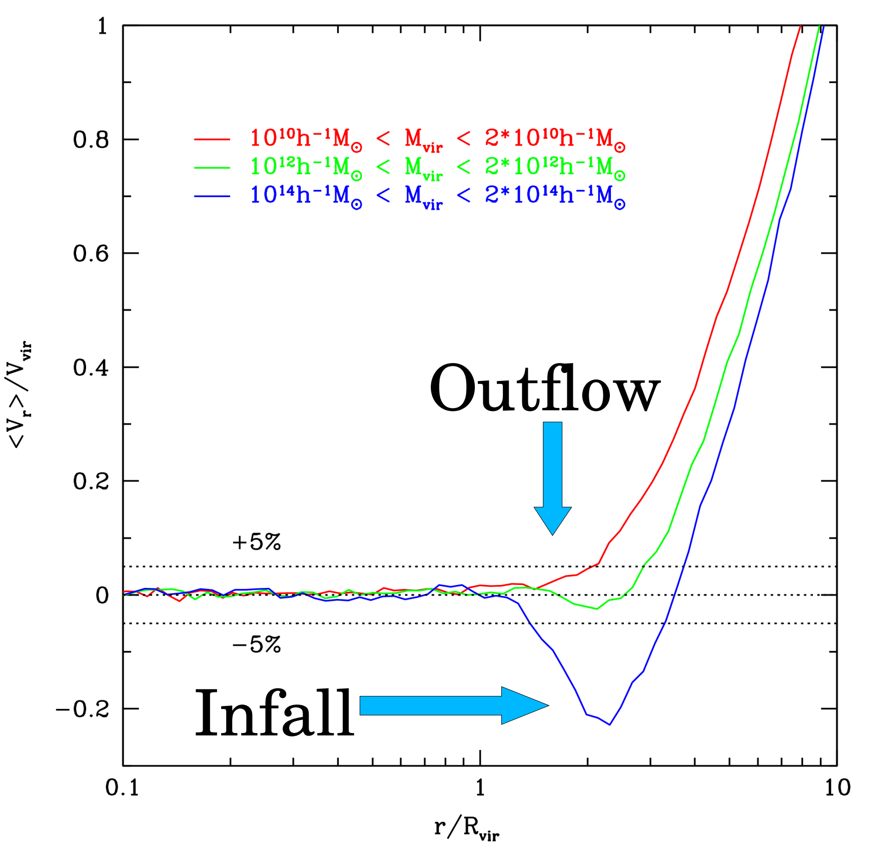
Motivation (ii)



- Galaxy-size halos show a smooth transition from the relaxed inner parts (extending up to >1R$_{vir}$) to the outer Hubble flow
- Cluster-size halos show a disturbed region of infalling material (even at <1R$_{vir}$)

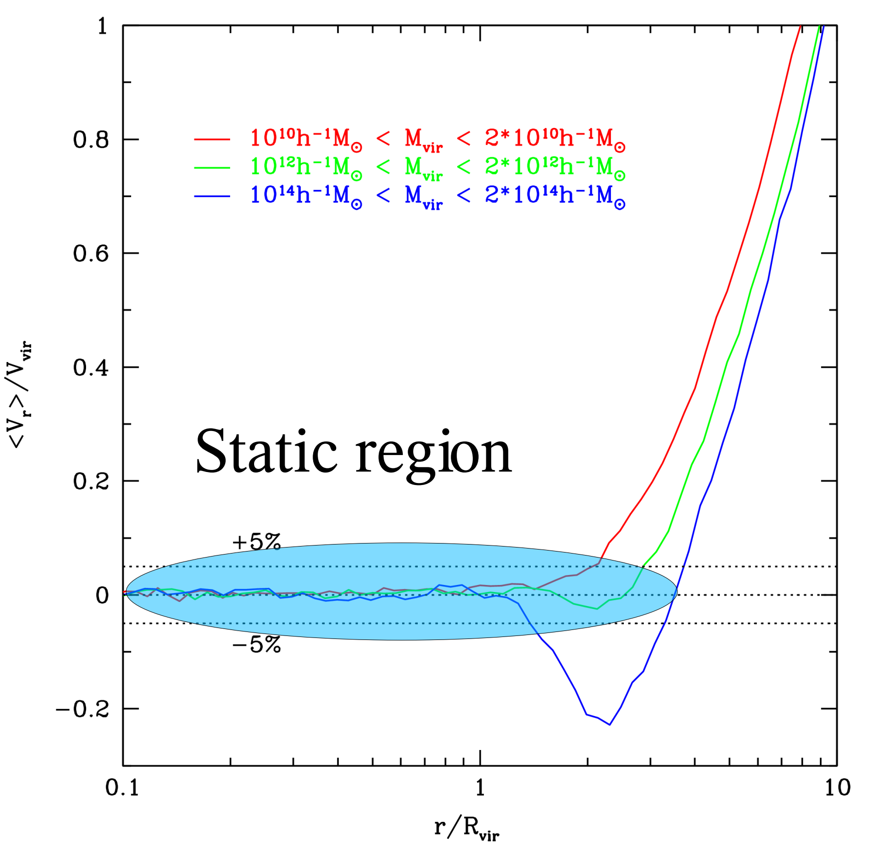
Radial velocity in units of virial velocity, $V_{vir}^2=GM_{vir}/R_{vir}$

Mean radial velocity profiles



- Low-mass halos (red) show *outflow* preceding Hubble flow
- High-mass halos (blue) show *infall* of the material in their surroundings
- Galaxy-size halos (green) show an extended region with no net radial velocity due to the balance between infall and outflow

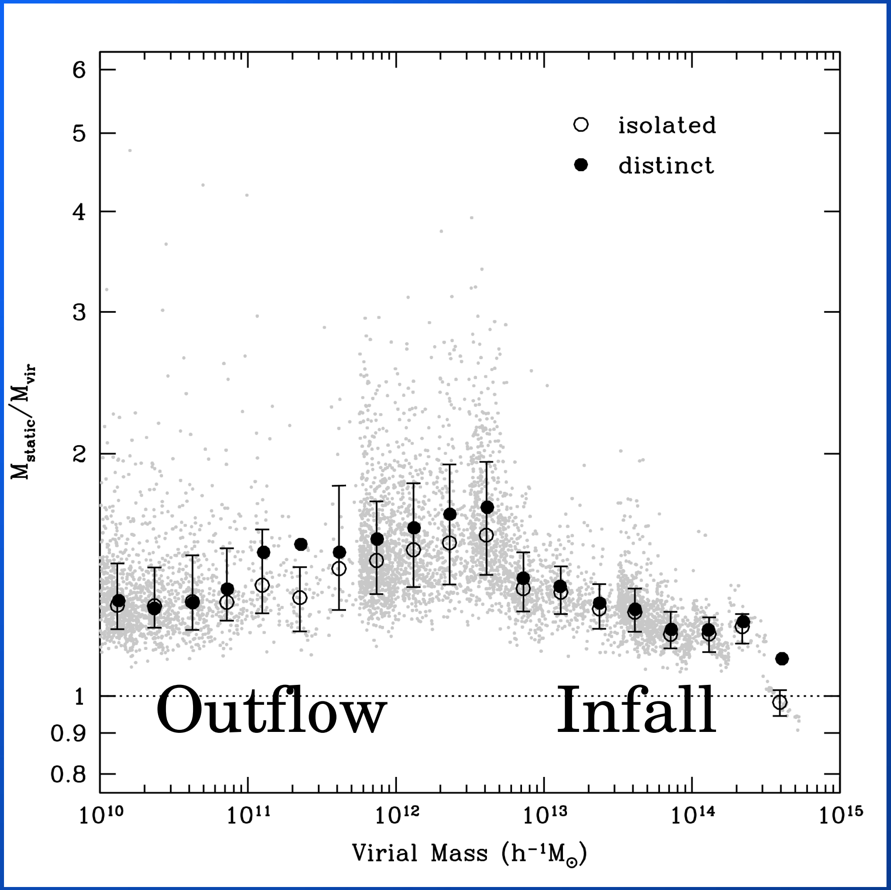
Static mass



- The mass inside the region with no net infall or outflow is a more accurate measurement for the mass of the system which is actually *virialized*.
- To identify this region with a good signal-to-noise ratio, we choose a threshold of $5\%V_{vir}$

Static mass vs. Virial mass

- The ratio M_{sta}/M_{vir} rises with increasing virial mass for halos with outflow, as this is weaker for bigger halos.
- Halos showing infall present just the opposite behavior, because the infall is more prominent for bigger halos.



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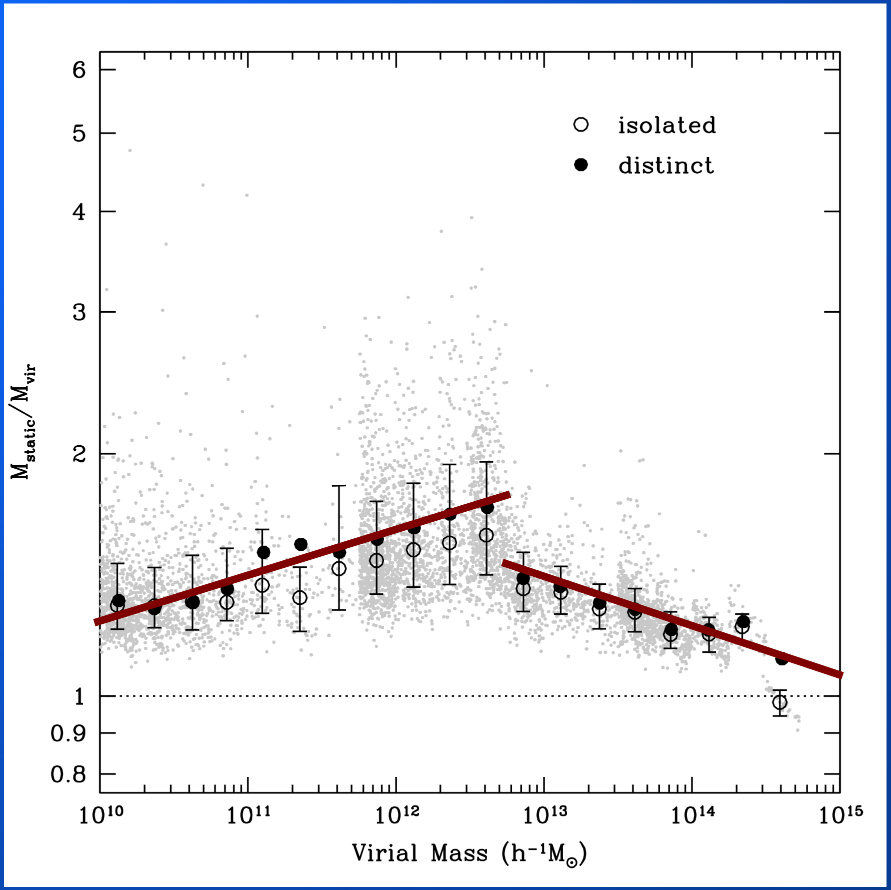
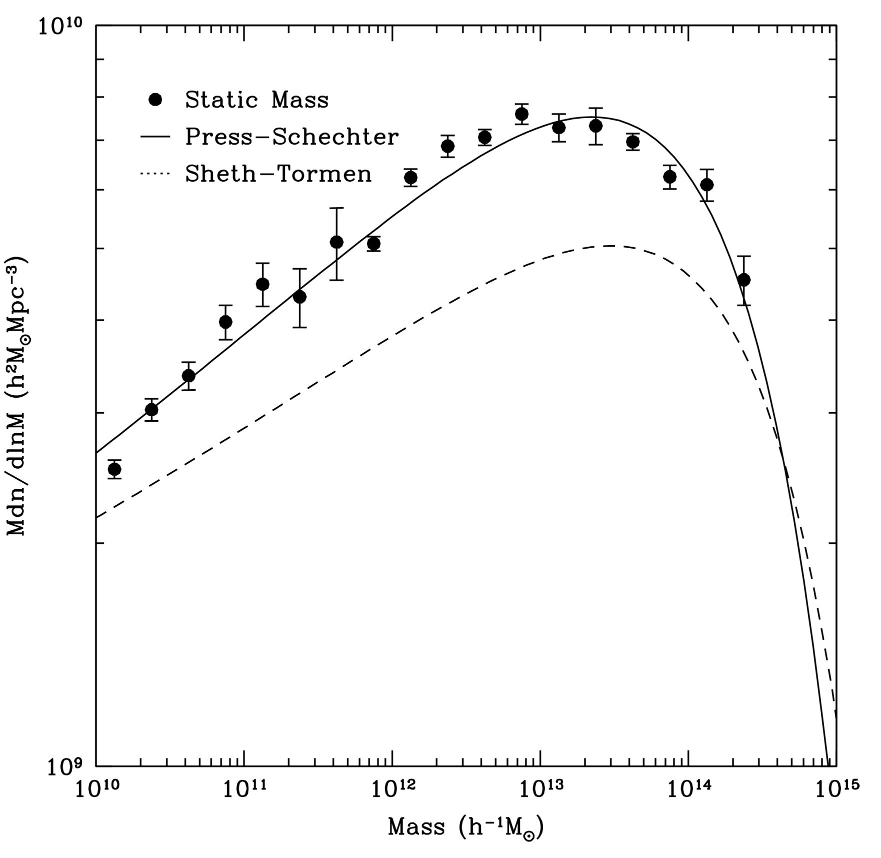


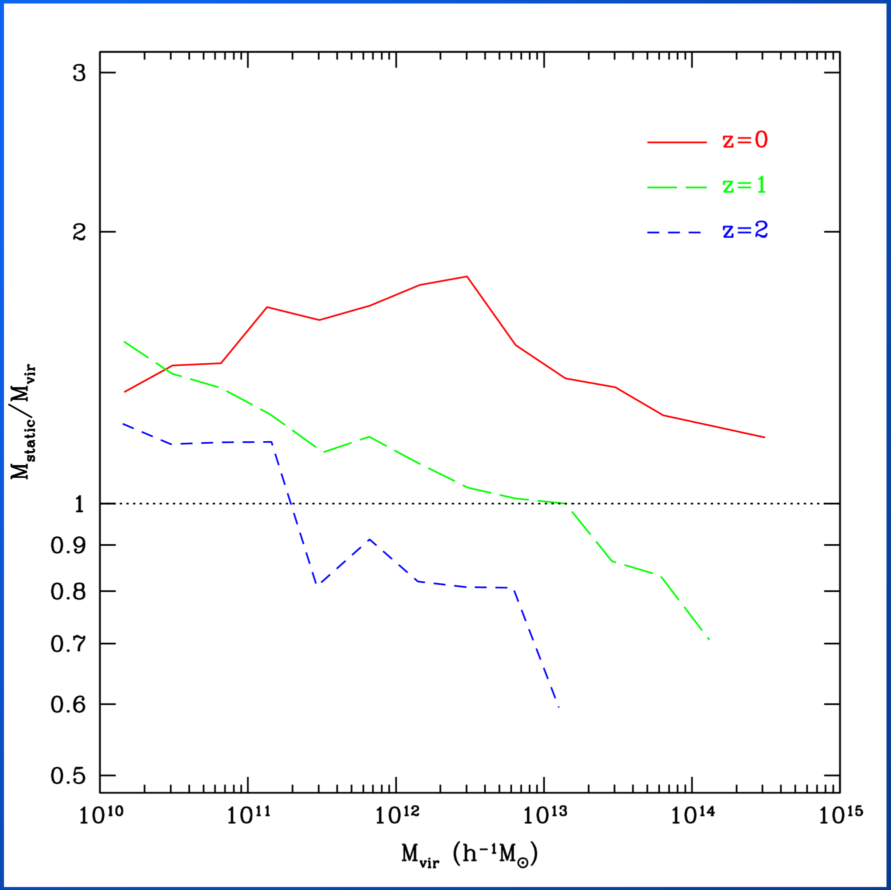
Mass function



- Virial mass function is accurately fit by the Sheth & Tormen (ST) function.
- Static mass function is well approximated by the Press & Schechter (PS) function, which is an unexpected result: PS lacks of the main improvement (spheroidal collapse of dark matter halos) incorporated by ST.

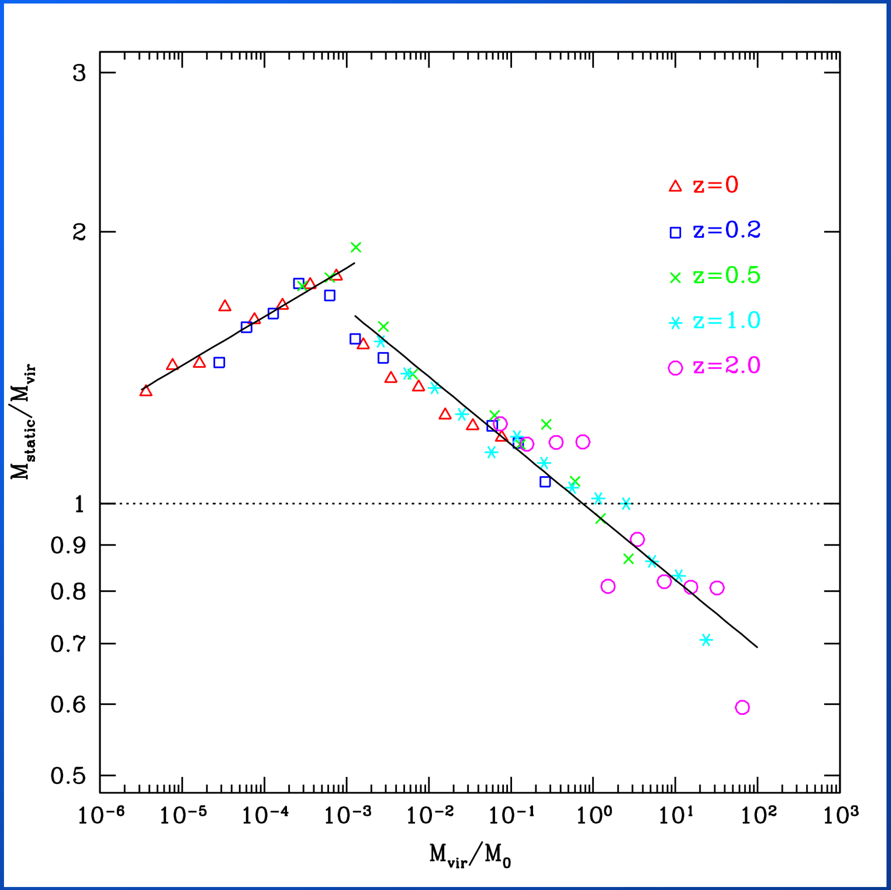
Scaling (i)

- This relation between static and virial mass evolves with redshift, but the overall shape still resembles that of *z*=0, except for a shift in mass.
- This suggests the study of the relation built from the overlapping of these curves for all the redshifts available.

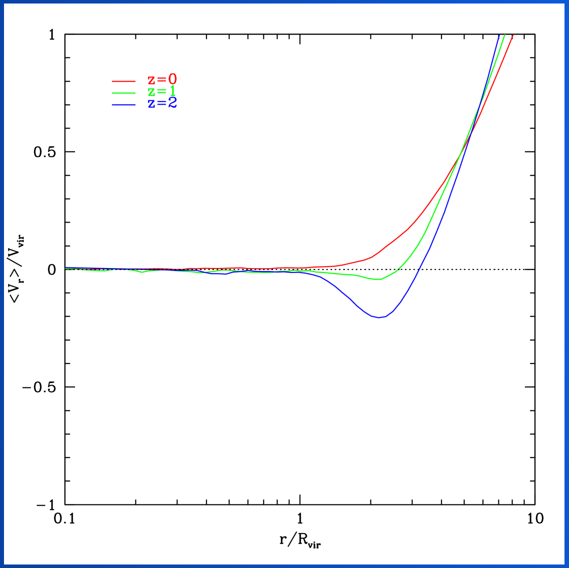


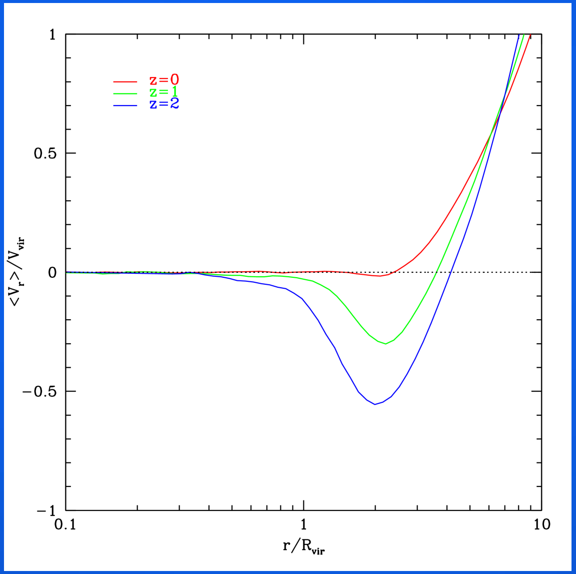
Scaling (ii)

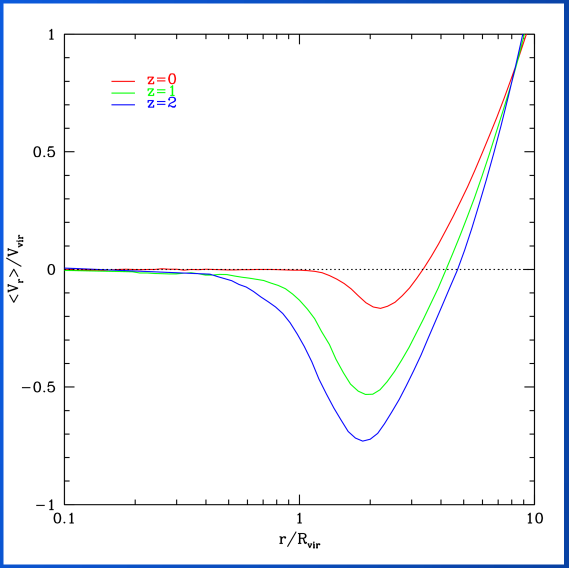
- The evolution of the relation between static and virial mass is then encoded by an evolving mass scale $M_0(z)$.
- The power-law behavior is extended up to 7 orders of magnitude, albeit with some scatter due to the reduced statistics of halos with high resolution.



Major progenitor (i)

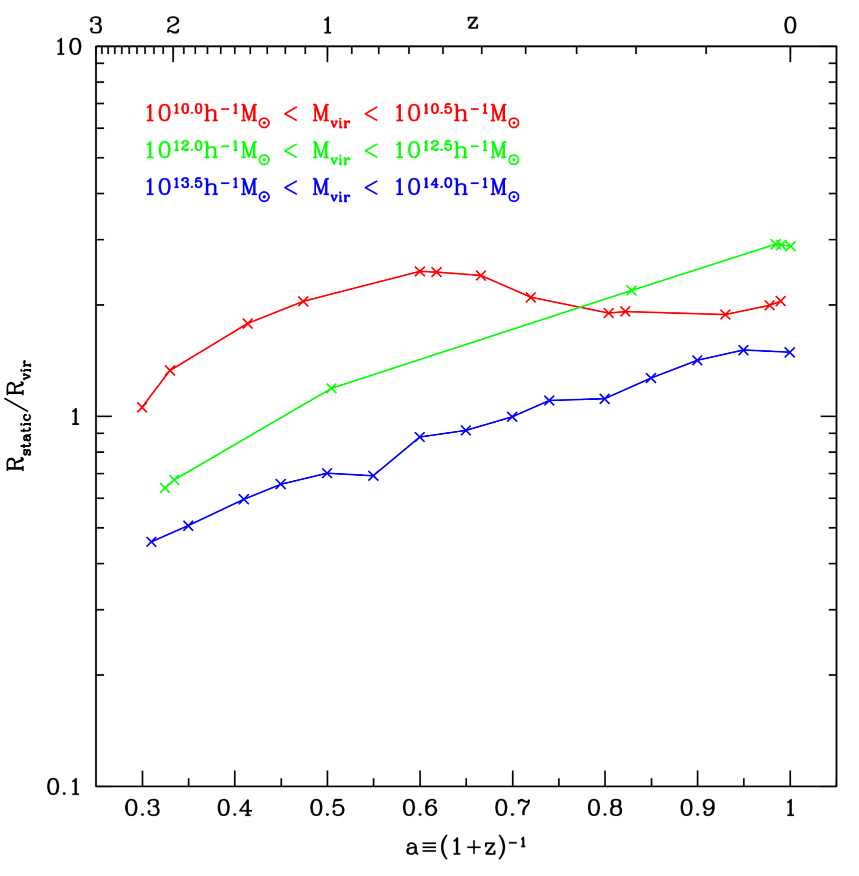






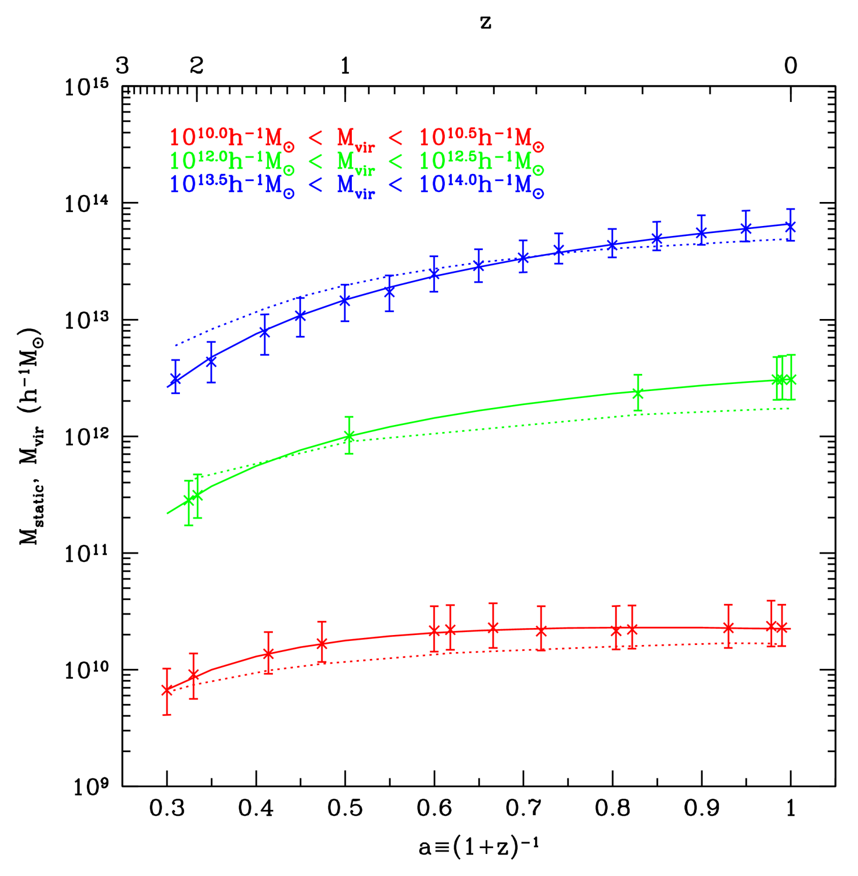
- A evolution of mean radial velocity profile is found, as already shown by Busha *et al*. 2005 for cluster-size halos.
- The timescale of this evolution is a function of the halo size at present: low-mass halos are in the outflow phase, whereas cluster-size halos are still showing infall.

Major progenitor (ii)



- The evolution of mean radial velocity profile is reflected in the evolution of R_{static}/R_{vir} ratio.
- The hierarchy of this ratio is not preserved with time: low-mass halos presented a larger static region (in R_{vir} units) than galaxy-size halos at $z \gtrsim 0.5$.

Major progenitor (iii)



- The evolution of the static mass associated to these halos is differs from the mass accretion history of the virial mass.
- Indeed, our model shows that an extra power-law factor in the evolution of virial mass is needed to fit the whole history of the static mass.

$$M_{sta}(z) = M(z=0)(1+z)^{-\mu}e^{-\nu z}$$

Summary

- Virial mass underestimates the mass dynamically associated to a halo, specially for Galaxy-size halos.
- There is a simple relation between static and virial mass, although with large scatter in individual halos.
- The static mass function is better approximated by the Press & Schechter function.
- The evolution of the relation between static and virial mass is easily encoded by an evolving mass scale M_0.
- Halos show a infall-to-outflow sequence, but the timescale of this sequence seems to be different for galaxy and cluster halos.
- The mass accretion history of major progenitor of the average dark matter halo in a mass bin, is accurately fit by a simple model based in the mass scale M_0. The difference in the functional dependence with redshift is an extra power-law factor.

Applications

- The impact of the implementation of the static mass on semianalytical models of galaxy formation deserves further investigation.
- Moreover, the coincidence of the mass scale at transition ($M \sim 10^{12} M_\odot$) with the mass delimiting star formation by cooling flows and shock heating, might be suggesting influence from the host halo into the galaxy, such as e.g. bimodality (Dekel & Birnboim 2006).
- The analysis of the mass function at the high-end is decisive as their number density is a probe of fundamental cosmological parameters, such as dark energy.