

ASTROPHYSIKALISCHES INSTITUT POTSDAM

Formation and Evolution of DM Halos in Different Environment

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Collaboration

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Cosmological simulations

$$\Omega_{CDM} + \Omega_{\text{bar}} + \Omega_{\Lambda} + \Omega_{\text{curv}} = 1$$

- $\Omega_{\text{curv}} = 0$ (spatially flat)
- $\Omega_{\Lambda} = 0.7$
- $h = 0.7$
- $n = 1$
- $\sigma_8 = 0.9$

ART (**A**daptive **R**efinement **T**ree) code (A. Klypin, A. Kravtsov, A. Khokhlov)

High resolution simulation of selected objects

Starting point: low mass resolution simulation

- $80 h^{-1}$ Mpc box
- 128^3 particles, $m_p = 2.0 \times 10^{10} h^{-1} M_\odot$

Finding halos

- Friends-of-friends algorithm
- Bound-density-maxima algorithm

Defining objects (clusters, groups, voids)

High mass resolution

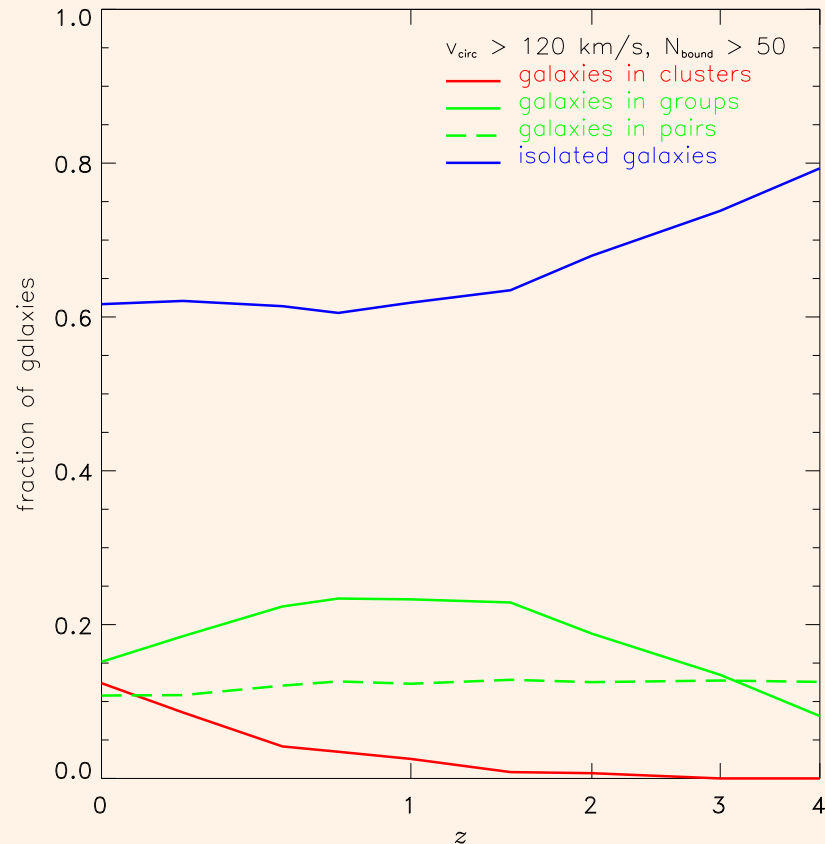
- $80 h^{-1}$ Mpc box
- 1024^3 particles, $m_p = 4.0 \times 10^7 h^{-1} M_\odot$

Definition of environment

Finding of virialized systems using a friends-of-friends algorithm with a linking length of 0.2 times the mean inter-particle distance.

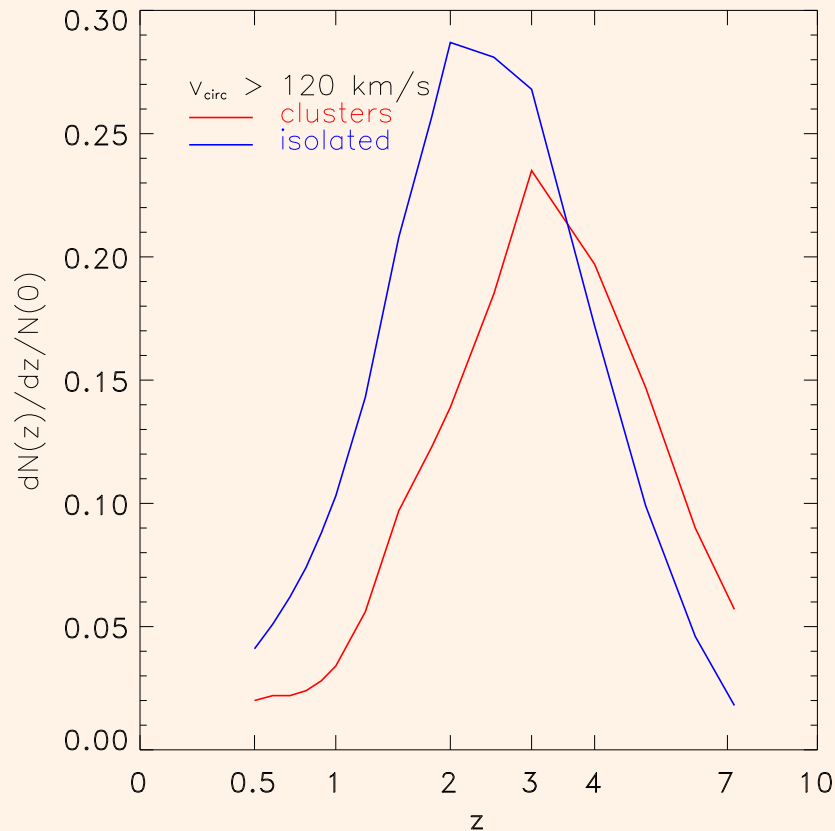
- Isolated galaxies:
one halo within the virialized system
- Galaxies in clusters:
many halos in a virialized system of mass $M > 10^{14} h^{-1} M_{\odot}$
- Galaxies in group:
three or more halos in a virialized system of mass $M < 10^{14} h^{-1} M_{\odot}$
- Galaxies pairs: the remaining galaxies

Galaxies in different environments



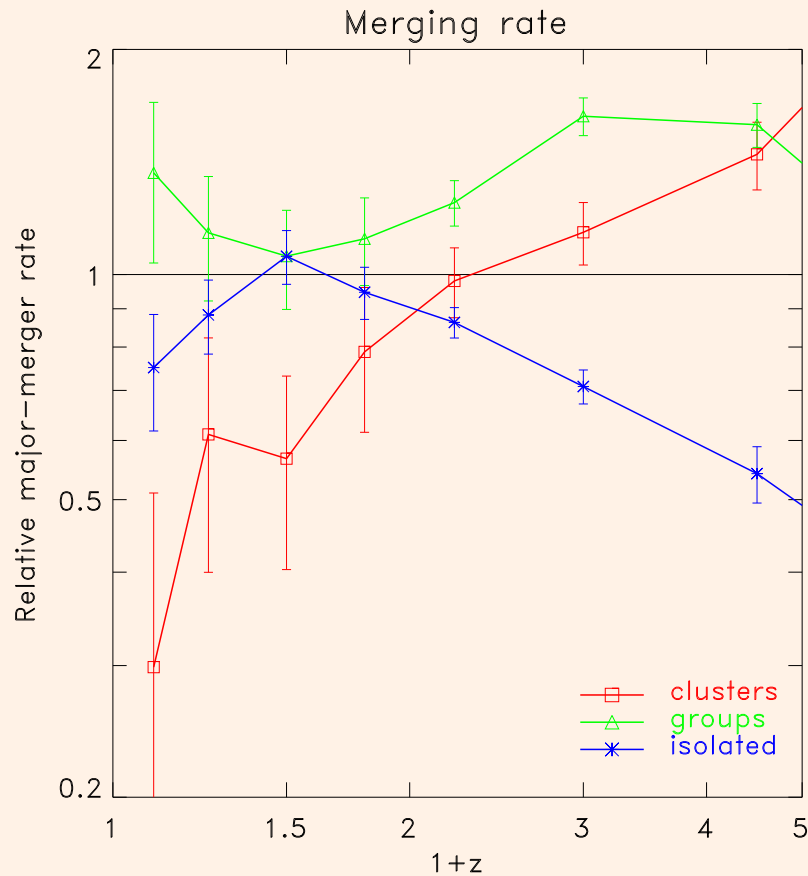
Λ CDM simulation with $h = 0.7$, $\Omega_m + \Omega_\Lambda = 1$, $\Omega_\Lambda = 0.7$. The mass resolution in the $60h^{-1}$ Mpc box is $m_p = 1.1 \times 10^9 h^{-1} M_\odot$. 4787 halos with $v_{\text{circ}} > 120$ km/s exist at $z = 0$.

Formation of halos in different environments



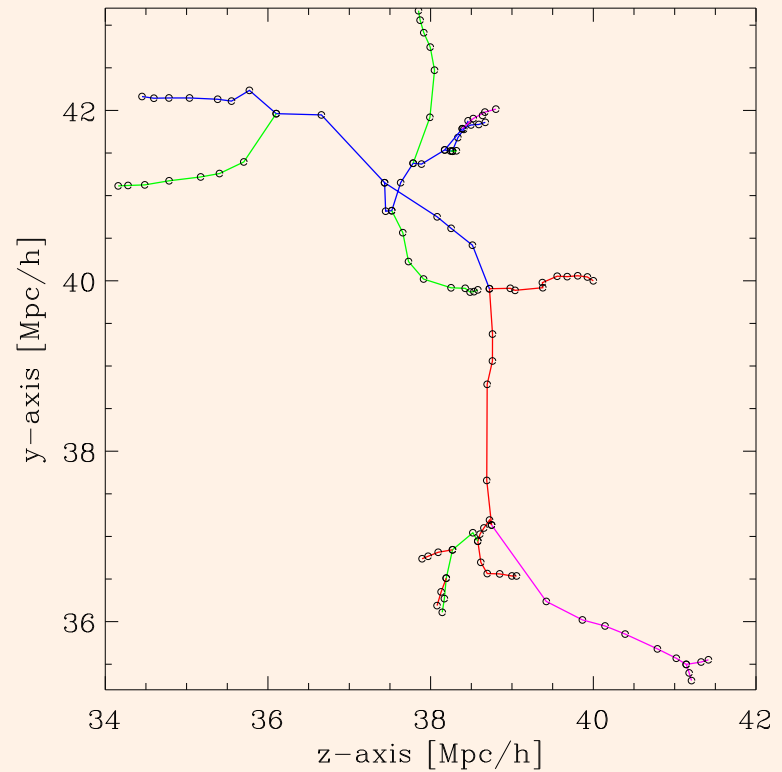
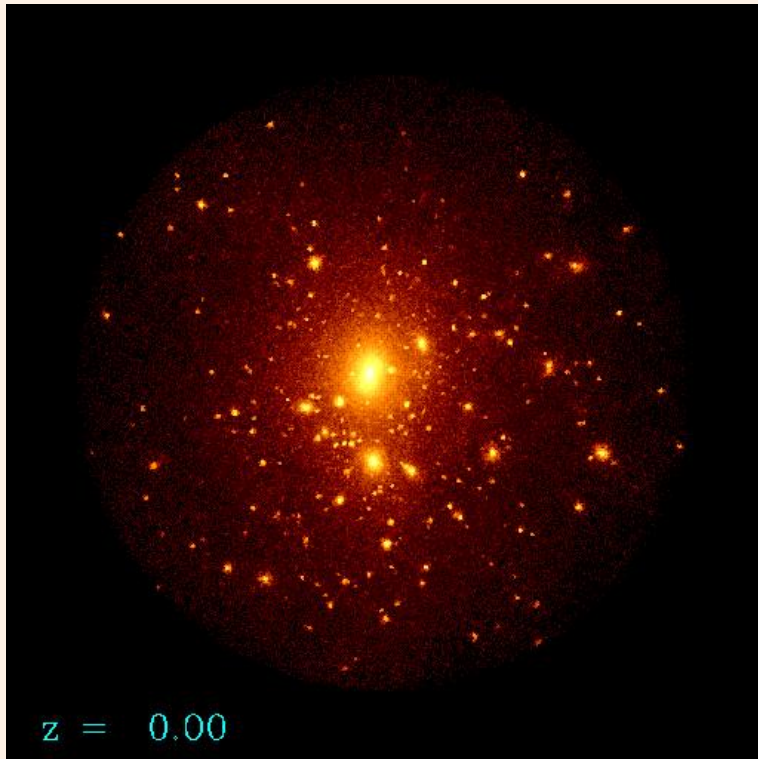
The distribution of “formation redshifts” defined as the redshift when the most massive progenitor of the corresponding present-day halo reaches the maximum circular velocity higher than 50 km/s. All the $z = 0$ halos with the maximum circular velocities in excess of 120 km/s were selected.

Dependence on environment



The relative merging rate of the population of cluster, group, and isolated halos. The ratio of the merging rate of particular population to the mean merging rate of all objects ($\propto (1+z)^{3.0}$) is plotted. Values larger than unity imply that this population has a higher rate than the overall population.

Clusters of galaxies

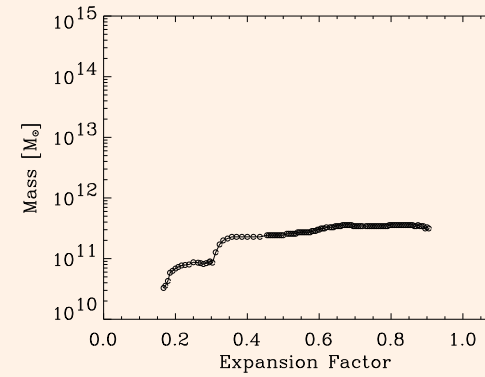
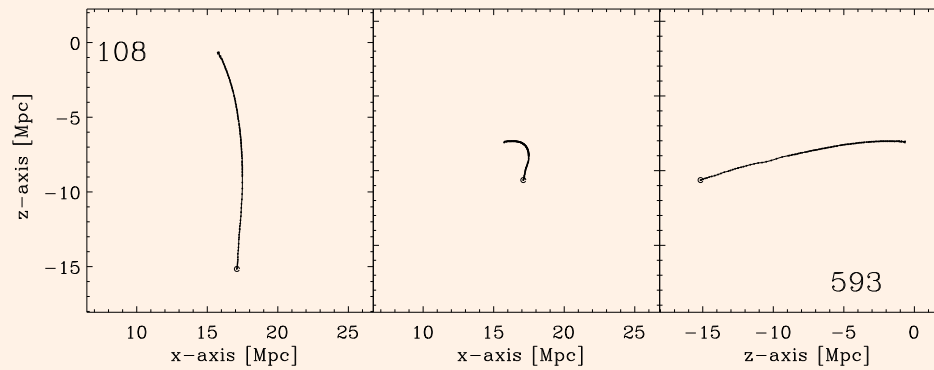
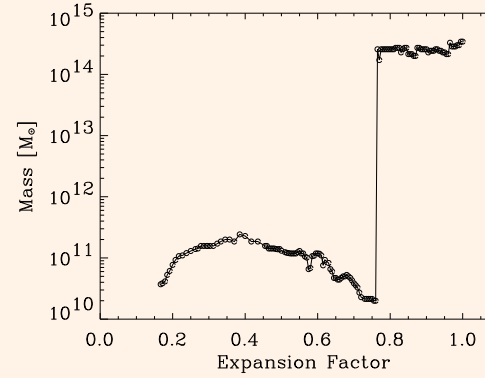
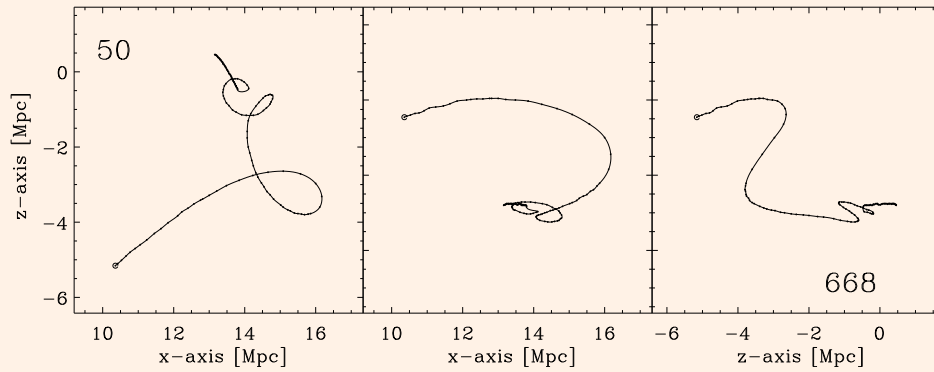
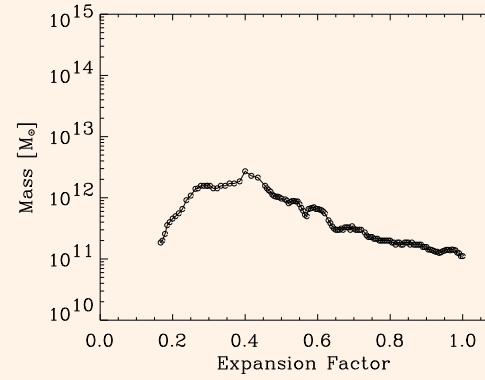
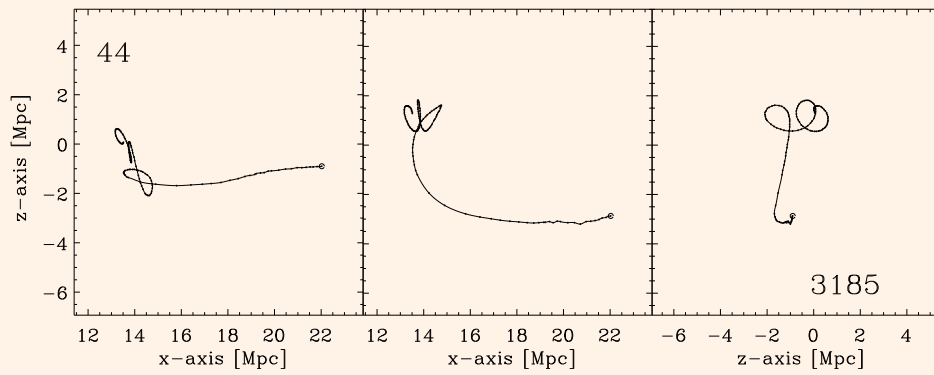


$$L_{\text{box}} = 80h^{-1}\text{Mpc}$$

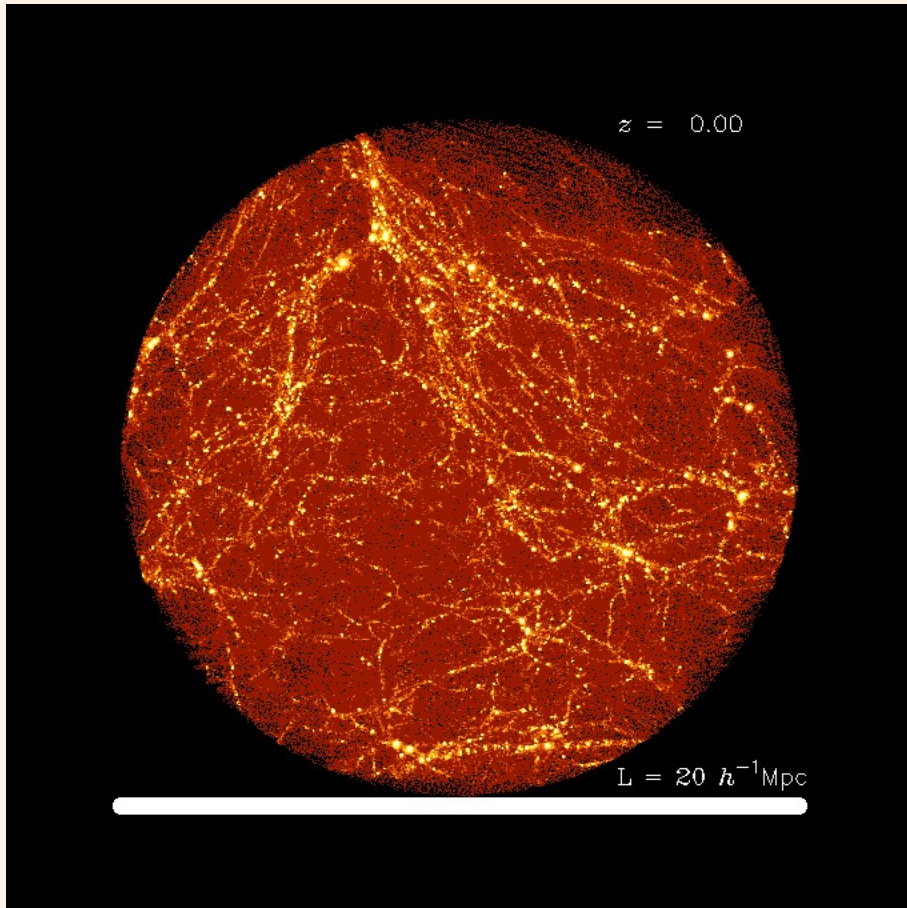
$$r_{\text{sphere}} = 3h^{-1}\text{Mpc}$$

$$\text{cluster resolution: } N_p = 512^3 \Rightarrow m_p \approx 3.2 \times 10^8 h^{-1} M_{\odot}$$

Orbits of cluster halos



The evolution of a void

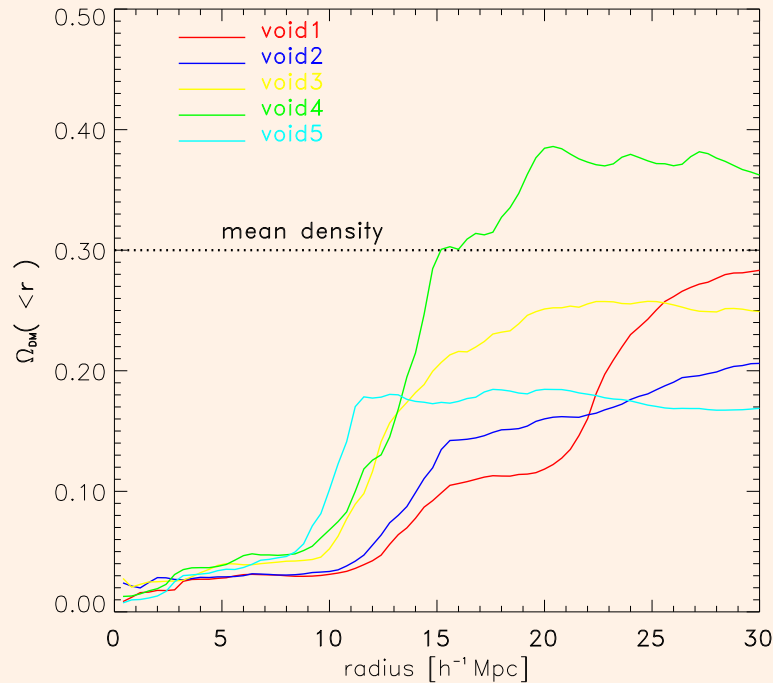


490 steps with $\Delta a = 0.002$

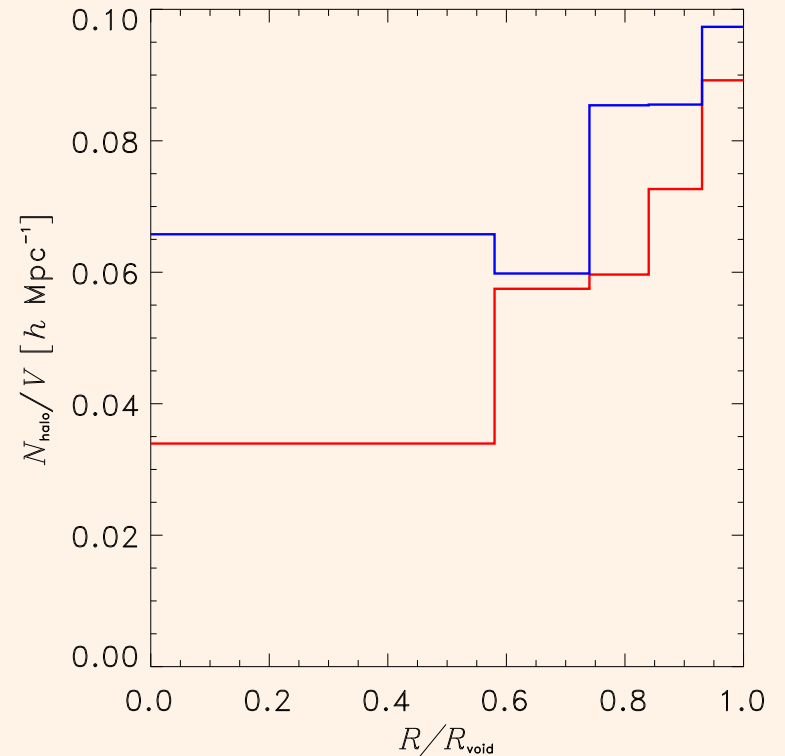
1377280 particles in the void
($m_p = 4.0 \times 10^7 h^{-1} M_\odot$)

After the final size ($r = 10 h^{-1} \text{Mpc}$ at $z = 0$) has been reached the camera is flying around the void to get an idea of the three-dimensional structure.

Void profile

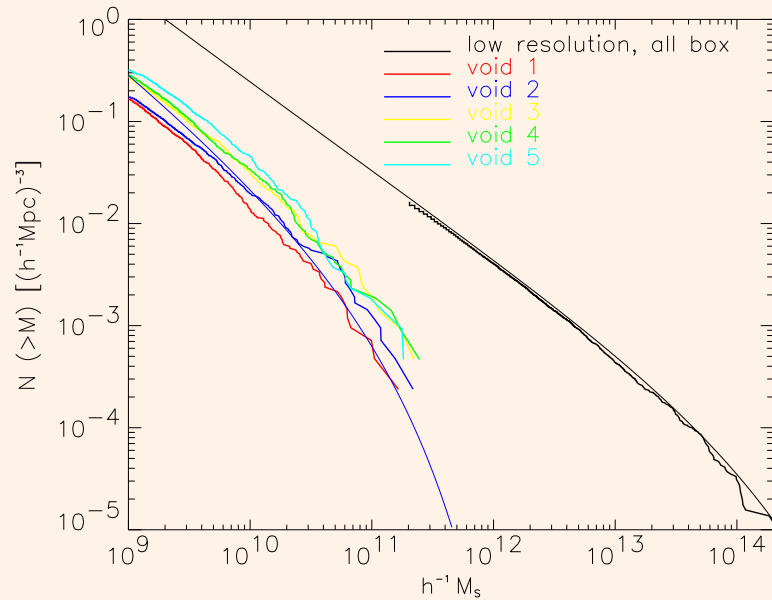


The density is shown within spheres of radius r centered at the void center. Inside the void the density is typically by a factor of 10 smaller than the mean density.

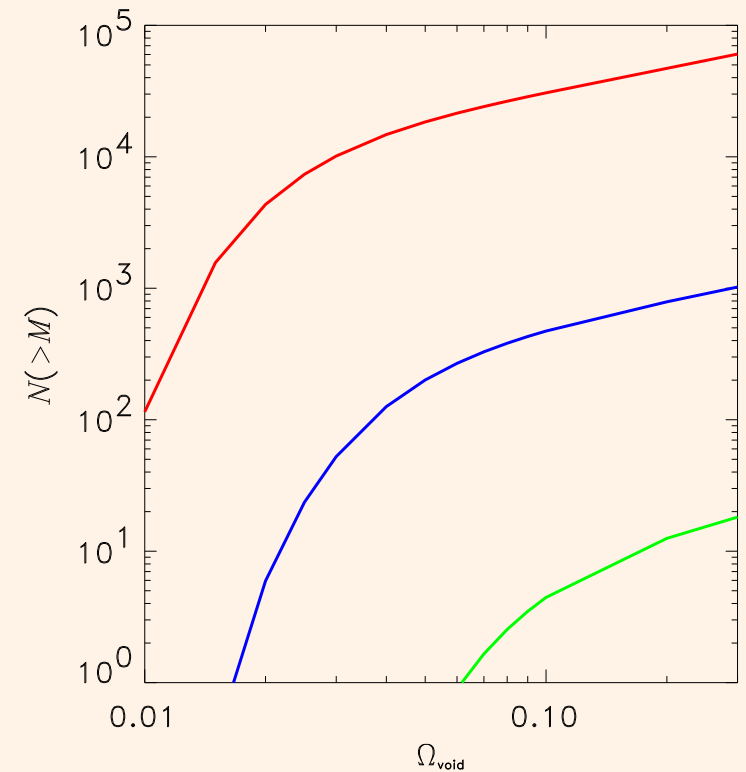


Mean number density of halos with circular velocities $55 \text{ km/s} < v_{\text{circ}} < 120 \text{ km/s}$ (red line) and $20 \text{ km/s} < v_{\text{circ}} < 55 \text{ km/s}$ (blue line) in shells of equal volume ($V_{\text{void}}/5$) for five

Mass function



Mass function of DM halos: The black solid line shows the cumulative mass function $N(>M)$ in the whole $80h^{-1}\text{Mpc}$ simulation. The colored lines show the mass functions in voids. The thin lines are the Sheth-Tormen predictions of mass functions.



The number of halos with the virial mass larger than $10^{12}h^{-1}M_{\odot}$ (green), $10^{10}h^{-1}M_{\odot}$ (blue), and $10^8h^{-1}M_{\odot}$ (red) inside a typical void of radius $10h^{-1}\text{Mpc}$ as a function of the average density of the void Ω_{void} .

Summary

Halos in clusters form earlier than isolated halos of the same mass. At redshifts $z \lesssim 2$ the major merger rate of all halos evolves as $(1+z)^{3.0}$, in good agreement with observations. At present halos in clusters have a much lower probability of recent major-merging than isolated galaxies. The cluster and group halos have a higher rate of major merger events in the past.

The density in voids is by a factor of 10 smaller than the mean density, the density increases slightly with radius. The more massive objects are concentrated towards the outer regions of the void. There are more than 50 objects with circular velocities $v_{\text{circ}} > 50$ km/s in a typical void of $20 h^{-1}$ Mpc diameter and almost 1000 with $v_{\text{circ}} \sim 20$ km/s.

To compare the model predictions with observations one would have to study a void in the distribution of galaxies with limiting magnitude M_B between -17.5 and -18.5 which roughly corresponds to our threshold mass of $2 \times 10^{11} h^{-1} M_{\odot}$. Assuming with Mathis and White (2002) a luminosity $M_B = -16.5$ for a galaxy hosted by a halo of $3.6 \times 10^{10} h^{-1} M_{\odot}$ we predict about five of these galaxies to be found in the inner part of a typical void of diameter $20 h^{-1}$ Mpc.