Simulation Description

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1 Simulations

We used a large N-body simulation dubbed `Multidark` to extract statistics of halo parameters on cosmological scales. The data we use for this paper is publicly available through a database interface first presented by Riebe et al. [2011]. Here we summarize the main characteristics of the `Multidark` volume. More details can be found in Prada et al. [2012].

The simulation was run using an Adaptive-Mesh Refinement (AMR) code called ART. Details about the technical aspects and comparisons with other N-body codes are given in Klypin et al. [2009]. The simulations follows the non-linear evolution of a dark matter density field sampled with 2048^3 particles in a volume of $1000h^{-1}$Mpc . The physical resolution of the simulation is almost constant in time $\sim 7h^{-1}$kpc between redshifts $z = 0 - 8$. The cosmological parameters in the simulation are $\Omega_m = 0.27$, $\Omega_\Lambda = 0.73$, $n_s = 0.95$, $h = 0.70$ and $\sigma_8 = 0.82$ for the matter density, dark energy density, slope of the matter fluctuations, the Hubble constant at $z = 0$ in units of 100km s^{-1} Mpc^{-1} and the normalization of the power spectrum, respectively. These cosmological parameters are consistent with the results from WMAP5 and WMAP7 [Komatsu et al., 2009, Jarosik et al., 2011]. With these characteristics the mass per simulation particle is $m_p = 8.63 \times 10^9 h^{-1}\mathrm{M}_\odot$, which means that group-like halos of masses $\sim 10^{13}h^{-1}\mathrm{M}_\odot$are sampled with at least 1100 particles.

Dark matter halos are identified using a Bound-Density-Maxima algorithm (BDM). The code starts by finding the density maxima at the particles' positions in the simulation volume. For each maxima it finds the radius R_{200} of a sphere containing a mass overdensity given by

$$M_{200} = \frac{4\pi}{3}\Delta\rho_{\rm cr}(z)R_{200}^3 \tag{1}$$

where $\rho_{\rm cr}$ is the critical density of the Universe and $\Delta = 200$ is the desired overdensity. This procedure allows for the detection of both halos and sub-halos. In our analysis we kept only the halos.

1.1 Concentration Estimates

The estimation for the concentration values is done using an analytical property of the NFW profile (see Sect. **??**) that relates the circular velocity at the virial radius:

$$V_{200} = \left(\frac{GM_{200}}{R_{200}} \right)^{1/2}, \tag{2}$$

with the maximum circular velocity

$$V_{\max}^2 = \max \left[\frac{GM(< r)}{r} \right]. \tag{3}$$

The $V_{\max}/V_{200}$ velocity ratio is used to determine the halo concentration, c (the ratio between R_{200} and the scale radii of the NFW profile), using the following relation [Klypin et al., 2011]:

$$\frac{V_{\max}}{V_{200}} = \left(\frac{0.216c}{c} \right)^{1/2} \tag{4}$$

where $f(c)$ is

$$f(x) = \ln(1 + c) - \frac{c}{(1 + c)}. \tag{5}$$

For each BDM overdensity the $V_{\max}/V_{200}$ ratio in order to find the concentration c by solving numerically the previous two equations. This method provides a robust estimate of the concentration compared to a radial fitting to the NFW profile, which is strongly dependent on the radial range used for the fit [Klypin et al., 2011, Meneghetti and Rasia, 2013]. Comparison of these two methods to using halos where the NFW functional fit yield a small systematic offset of $(5 - 15)\%$, with the concentration derived by the velocity ratio method being higher [Prada et al., 2012].

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