HALO SHAPES AND THEIR RELATION TO ENVIRONMENT

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Abstract. Using high resolution DM simulations we study the shape of dark matter halos. Halos become more spherical with decreasing mass. This trend is even more pronounced for the inner part of the halo. Angular momentum and shape are correlated. The angular momenta of neighboring halos are correlated.

1 Introduction

According to the hierarchical scenario of cosmological structure formation the backbone of galaxy formation and evolution are the halos of cold dark matter, which emerge from a Gaussian primordial density fluctuation field and assemble through gravitational processes. The properties of the dark matter halos are of great interest to understand the observed distribution of galaxies. To study halos in different environments we have performed a series of numerical simulations using the new MPI version of the Adaptive Refinement Tree code (Kravtsov et al. 1997). In the simulations we adopt the flat \Lambda\text{CDM} cosmology with ($\Omega_{m} = 0.3$, $\Omega_{\Lambda} = 0.7$, $h = 0.7$, and $\sigma_{8} = 0.9$). We have chosen a simulation box of $80h^{-1}\text{Mpc}$ side length. In the simulation Box80G the whole $80h^{-1}\text{Mpc}$ volume was resolved with $512^{3}$ equal-mass particles ($3.2 \times 10^{8}h^{-1}M_{\odot}$). The force resolution was $1.8h^{-1}\text{kpc}$. In a second run (Box80S) we have resimulated in the same box a spherical volume of $10h^{-1}\text{Mpc}$ radius and approximately mean cosmological density with 150 million particles ($4.9 \times 10^{6}h^{-1}M_{\odot}$). In this case the force resolution was $0.15h^{-1}\text{kpc}$.

To find halos within the simulation we have used the hierarchical friends-of-friends algorithm (Klypin et al. 1999) which bases on the minimal spanning tree (MST) of the particle distribution. The minimal spanning tree of any point distribution is a unique well defined quantity which describes the clustering properties of the point process completely (e.g., Bhavsar & Splinter 1996). The minimal spanning tree of $n$ points contains $n-1$ connections. We are using a fast MPI algorithm which calculates on 8 CPUs the MST of the $512^{3}$ particles within about

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10 minutes. After topological ordering we cut the MST using different linking lengths in order to extract catalogs of friends-of-friends particle halos. Note, that cutting a given MST is also a very fast algorithm. We start with a linking length of 0.17 times the mean inter-particle distance which corresponds roughly to objects with the virialization overdensity \( \rho/\rho_{\text{mean}} \simeq 330 \) at \( (z = 0) \). Decreasing the linking length by a factor of \( 2^n \) \( (n = 1, 2, \ldots) \) we get samples of objects with roughly \( 8^n \) times larger overdensities which correspond to the inner part of the objects of the first sample. With this hierarchical friends-of-friends algorithm we can also detect substructures of halos. With our halo finder we have detected about 90,000 halos with more than 50 particles in Box80G and about 70,000 in the high resolution region of Box80S. For the following analysis we have restricted ourself to halos with more than 1000 particles.

2 Shape and mass of halos

It is well known that dark matter halos have triaxial shapes and tend do be prolate (e.g. Faltenbacher et al. 2002). Their shape can be characterized by the three eigenvectors of their inertia tensor. Here we want to study how the mean ratio of the minor axis to the major axis depends on mass. In Fig. 1, left panel we show the mean axial ratio \( c/a \) for 500 halos per bin. Filled circles are halos from the simulation Box80G, filled triangles are halos from Box80S. Over three orders of magnitude we find a decreasing \( c/a \) with increasing mass of the halo. This is in accordance with Allgood et al. (2005) who used a slightly different method for shape determination starting from isolated spherical halos. In the right panel we show the same for the inner part of the halo. Here we have chosen a linking length of \( 0.17/4 \) which corresponds roughly to 64 times the virial overdensity. In this case the variation of shape is even steeper.

3 Shape and angular momentum

From the two simulations we have selected more than 10,000 halos with masses of dwarf galaxies \( (4.0 \times 10^9 h^{-1} M_\odot) \) until masses of galaxy clusters \( (3.4 \times 10^{14} h^{-1} M_\odot) \). The left panel of Fig. 2 shows the angle between the angular momentum and the major axis for 5753 halos in the mass range \( 3.2 \times 10^{11} h^{-1} M_\odot \leq m_{\text{halo}} \leq 3.4 \times 10^{14} h^{-1} M_\odot \) selected from the simulation Box80G. For more than 76% of the halos the angle between the angular momentum and the major axis is larger than 60°. The right panel of Fig. 2 shows the angle between the angular momentum and the major axis for 4875 halos in the mass range \( 4.9 \times 10^9 h^{-1} M_\odot \leq m_{\text{halo}} \leq 1.0 \times 10^{12} h^{-1} M_\odot \) selected from the simulation Box80S. Again more than 75% of the halos show an angle larger than 60° between the angular momentum and the major axis. If the ratio between minor axis and major axis increases the halo becomes more and more spherical. Therefore, the major axis is not well defined and the scatter of the angle between the angular momentum and the major axis increases.
Halo Shape

Fig. 1. Mean axial ratios c/a depending on mass. Left: Objects with virial overdensity (relative linking length of 0.17) Right: Objects with 64x virial overdensity (relative linking length of 0.0425)

Fig. 2. Angle between angular momentum of dark matter halos and major axis. Left: 5753 halos in the mass range $3.2 \times 10^{11} h^{-1} M_{\odot} \leq m_{\text{halo}} \leq 3.4 \times 10^{14} h^{-1} M_{\odot}$. Right: 4875 halos in the mass range $4.0 \times 10^{9} h^{-1} M_{\odot} \leq m_{\text{halo}} \leq 1.0 \times 10^{12} h^{-1} M_{\odot}$

4 Angular momentum of neighboring halos

For clusters of galaxies the major axis reflects the main infall direction along the filaments respective the infall direction of the last major merger (Faltenbacher et al. 2005). The shape of neighboring galaxy clusters is correlated (Faltenbacher et al. 2002). For a wide range of masses we want to compare the angular momentum
of neighboring halos. In Fig. 3 the cumulative distribution of the absolute value of the cosine between the angular momenta of two neighboring dark matter halos is shown. One can clearly see a signal of correlation. In case of random distribution of the same number of halos the mean value of the cosine would be 0.5 with a standard deviation of 0.002. Here we find a mean value of 0.518. The mean to the next 3 or 7 neighbors is 0.511 rup. 0.509. This is still a signal of correlation. The orientation of the angular momentum is correlated with the shape of the dark matter halo (Fig. 2) as well as with the orientation of the stellar disk (Bailin et al. 2005). Therefore, a correlation of the angular momenta of neighboring halos could be important for weak lensing studies where a random distribution of galaxy shapes is assumed.

Fig. 3. Cumulative distribution of the absolute value of the cosine between the angular momenta of two neighboring dark matter halos for halos in the same mass range as in Fig. 2.

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