The Zeldovich Universe: Genesis and Growth of the Cosmic Web
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The place of the Local Group in the cosmic web

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Abstract. We use the Bolshoi Simulation, a Dark Matter (DM) only cosmological simulation, to find the most probable place of the Local Group (LG) in the cosmic web. We use pairs of halos with isolation and kinematic properties consistent with observations as our LG simulacra. The cosmic web is defined using a tidal tensor approach. We find that the LG's prefered location is regions with a DM overdensity in the range $0 < \delta < 1$, which makes filaments and sheets the preferred environment. We find that there is a strong alignment between the LG and the cosmic web. The orbital angular momentum is preferetntially perpendicular to the smallest tidal eigenvector. The vector connecting the two halos is strongly aligned along the the smallest tidal eigenvector and perpendicular to the largest tidal eigenvector; the pair lies and moves along filaments and sheets. We do not find any evidence for an alignment between the spin of each halo in the pair and the cosmic web.

Keywords. cosmology: large-scale structure of universe; cosmology:dark matter; cosmology: simulations; Galaxy: formation

1. Introduction

2. Finding the cosmic web in numerical simulations

We use a web finding algorithm based on the tidal tensor computed from the gravitational potential field computed over a grid. We define the tensor as:

$$T_{ij} = \frac{\partial^2 \phi}{\partial r_i \partial r_j}, \tag{2.1}$$

where the index $i = 1, 2, 3$ refers to the three spatial directions in euclidian space and ϕ is a normalized gravitational poterntial that satisfies the following Poisson equation $\nabla^2\phi = \delta$, where δ is the matter overdensity.

The algorithms finds the eigenvalues of this tensor, $\lambda_1 > \lambda_2 > \lambda_3$, and use them to classify each cell in the grid as a peak, filament, sheet or void if three, two, one or none of the eigenvectors is larger than a given threshold $\lambda_{\rm th}$. Each eigenvalue has associated to it an eigenvector (e_1, e_2, e_3) which are the natural basis to define local directions in the web. Details describing the algorithm can be found in Forero-Romero et al. (2009).

3. Local Groups in cosmological simulations

We construct a sample of MW-M31 pairs at $z \sim 0$ by using multiple snapshots from the simulation asking for consistency with the following criteria:

- Relative distance. The distance between the center of mass of each halo in the pairs cannot be larger than 1.3 Mpc.

- Individual halo mass. Each halo has a mass in the mass range $5 \times 10^{11} < M_{200c} < 5 \times 10^{13}\mathrm{M}_{\odot}$.
- Isolation. No neighboring halos more massive than either pair member can be found within 5Mpc.
- Isolation from Virgo-like halos. No dark matter halos with mass $M_{200c} > 1.5 \times 10^{14}\mathrm{M}_{\odot}$ within 12Mpc.

With the selection criteria we select close to 6×10^{3} to build our main pair sample. From it we select to restricted samples according to the tolerance in kinematic constraints. These samples are named 2σ and 3σ, and correspond, respectiveley to two and three times the observational errors in the radial vecloty, tangential velocity and separation. The number of paris in each sample is 46 and 120.

4. The place of the Local Group in the Cosmic Web

5. Alignments with the cosmic web

There is wide evidence showing that DM halo formation properties only depend on environment through the local DM density. Whether they are located in sheet or a filament is irrelevant as long the local density is the same.

However there is long story of measuring aligments (shape, spin, peculiar velocities) of individual halos with the cosmic web. In a recent paper Forero-Romero et al.(2014)Forero-Romero, Contreras, & Padilla presented a study using the same simulation we have at hand together with the same definition for the cosmic web we use here. They also presented a comprehensive review of all the previous results from simulations that also inspected the alignment of halo shape and spin.

The main results from these studies is that shape presents the strongest alignment signal. In this case the DM halo major axis lies along the smallest eigenvector e_3, regardless

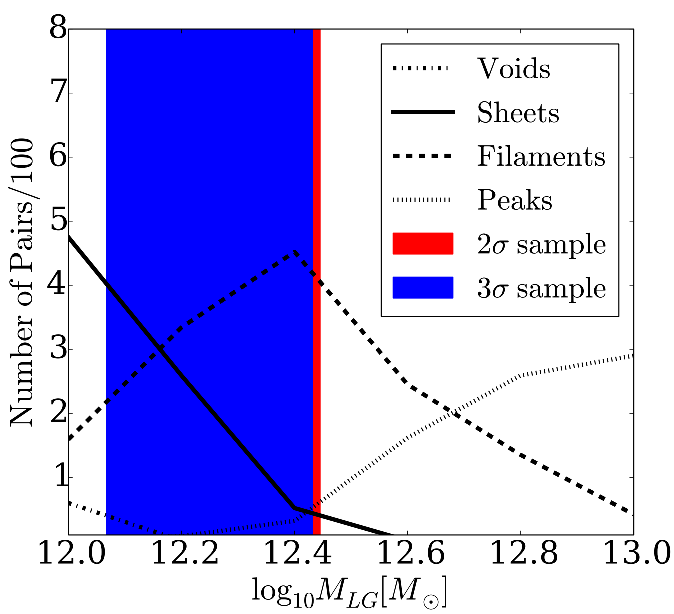

Figure 1. Path of pre-solar grains from their stellar sources to the laboratory.

of the web environmet. This alignments is stronger for higher halo masses. Concerning spin alignment the simulations show a weak antialignment with respect to e_3 for halo masses larger that $10^{12}\mathrm{M}_{\odot}$, and no alignment signal for masses below that threshold. The peculiar velocities show a strong alingment signal along e_3 for all masses.

In our case we test for the alignment of the orbital angular momentum of the pair, the vector connecting the two halos and the spin of each halo. The results are summarized in the Figure XXX

6. Overview

7. Conclusions

Here, we have summarized results on the expected place of the Local Group in the cosmic web. Our results are based on cosmological N-body simulations and the tidal web method to define the cosmic web. We constructed different Local Groups samples from dark matter halo pairs that fulfill observational kinematic constraints.

We found a tight correlation of the LG pairs' total mass with the scalar web properties (overdensity, ellipticity and prolateness). For the LG pairs closer to the observational constraints their total mass is in the range $1 \times 10^{12}\mathrm{M}_{\odot} < M_{LG} < 4 \times 10^{12}\mathrm{M}_{\odot}$ preferred overdensity value is constrained to be in the range $0 < \delta < 1$.

We also found a tight aligment of the pairs with the cosmic web. The vector joining the two LG halos is aligned with the lowest eigenvector and antialignned with the highest eigenvector. This means that pairs are aligned along the filaments and lie along sheets. These alignments are tighter as the pairs' kinematic conditions are closer to observations.

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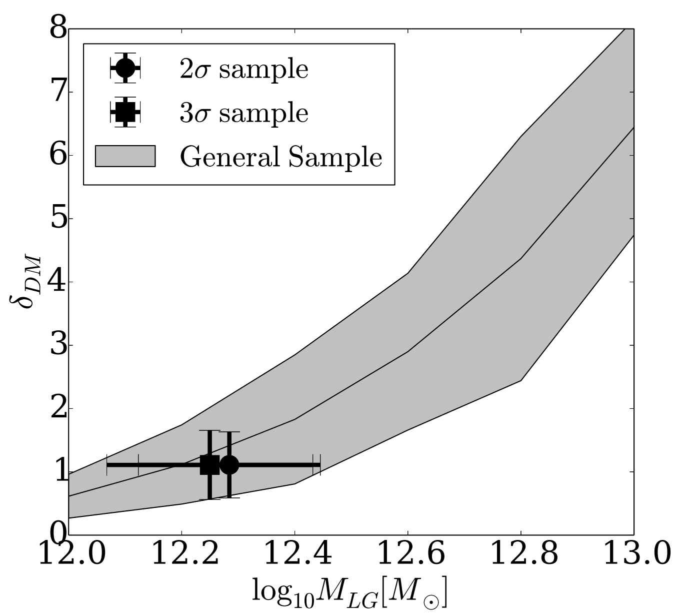

Figure 2. Path of pre-solar grains from their stellar sources to the laboratory.

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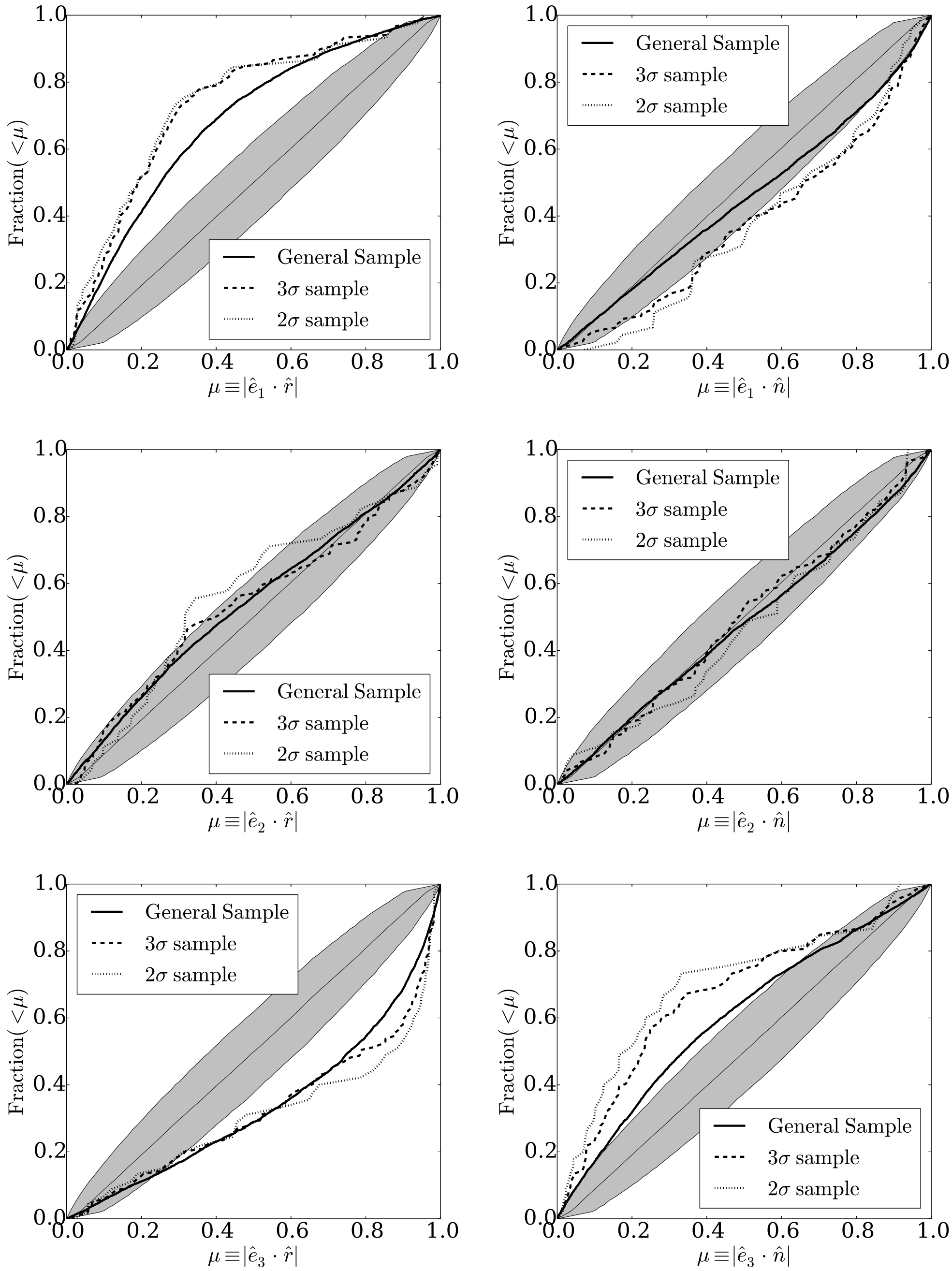

Figure 3. Path of pre-solar grains from their stellar sources to the laboratory.

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