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Comparison Between Simulated and Observational Results of Galaxy Formation for Large Scale Structures

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Abstract. The Millennium simulation is the largest numerical simulation of how minor fluctuations in the density of the universe's dark matter distribution are amplified by gravity to develop into the large scale structures(LSS) and galaxy clusters seen today(Springel et al. 2005). Although the simulations have been compared with the astronomical observations of the local universe, the simulations have not been widely compared with high redshift, early universe observations. In our study we compare the simulation data(Wang et al. 2008; Guo et al. 2008(in preparation)) for the first time with observations from the COSMOS survey(Scoville et al. 2006). Three quantities are proposed to characterize the structures and the structures distribution, namely the percent area occupied by LSS at each redshift, the average area of LSS and the shapes as characterized by the square root of the area divided by the circumference. We calculate these quantities for both the observations and the simulations, and quantify discrepancies between the existing simulations and observations. In particular, the simulations exhibit earlier development of dense structures than is seen in the observational data.

1. Percent Area

Regions of high galaxy density in a redshift slice are selected. Dividing the area of the selected regions by the total area, the percent area for the given density level in the redshift range is obtained. Fig 1 clearly shows that the percent area occupied by high density LSS is sharply reduced at high z. This is consistent with the theoretical view of the structure formation. Secondly, the percent area at higher densities in the observations is slightly bigger than simulation percent area at low redshift; however, at higher redshift, the percent area is bigger in simulation data. Therefore, there are fewer structures at higher densities than predicted in the simulation at high redshifts.

2. Average Diameter

Dividing the area at each density by the number of regions, the average area and the diameter of the regions at each density can be obtained. In Fig 2, both simulation and observation data agree with respect to the areas or sizes of the LSS; the average diameters at low redshifts are bigger than those at higher redshift, which indicates that larger regions collapse as the universe ages. However, similar to what was seen in percent area, the simulation measures reach higher densities. In addition, the observed LSS are bigger at low densities and smaller at high densities.

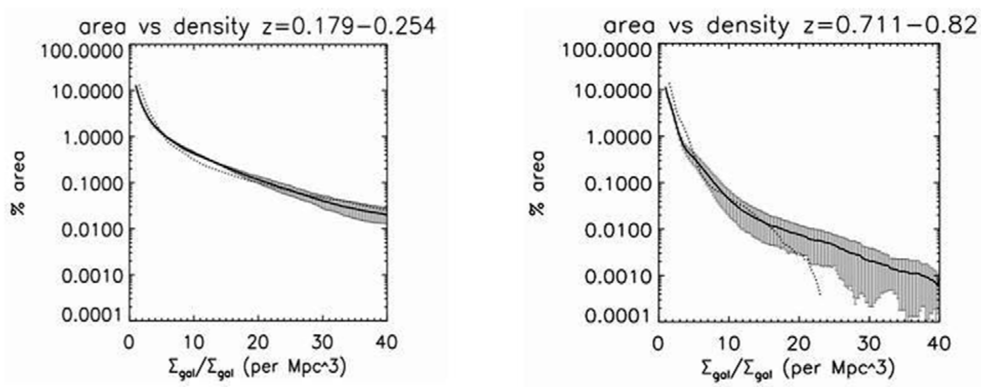

Figure 1. Percent areas versus density in selected redshift ranges. The dotted curve is the observational data; while the solid curve and error bar is mean and standard deviation of 3 Millennium simulations made for COSMOS.

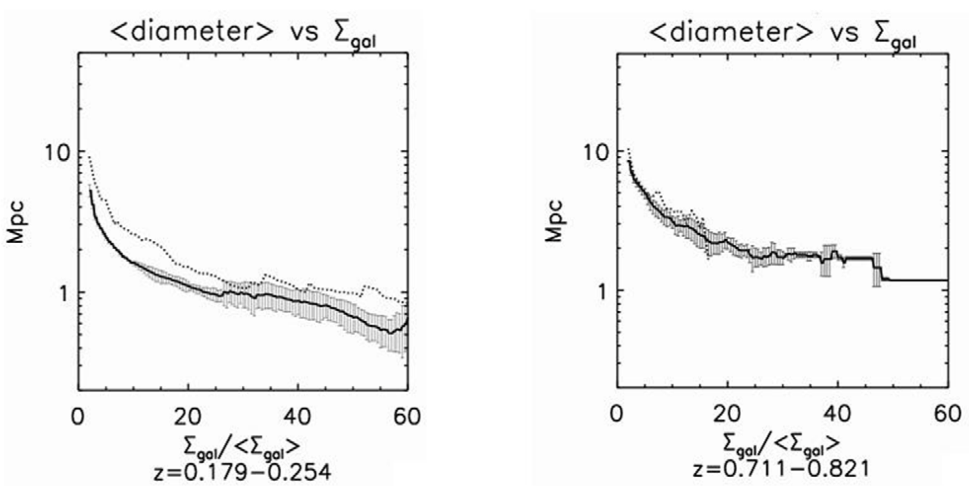

Figure 2. Mean diameters of structures shown as a function of environmental density in selected redshift ranges. Dotted curve is from COSMOS observations; solid curve and error bar is mean and standard deviation of 3 Millennium simulations made for COSMOS.

3. Elongation

In order to characterize the shapes or elongation of the LSS, we calculated the ratio of the square root of the region areas to their circumferences. we normalize this ration by a factor $\frac{\sqrt{\pi}}{2\pi}$ such that for a circle, the elongation is 1 (Fig 3). At the higher densities, the elongations approach unity for both simulation and observation data. This indicates that the structures get virialized and thus rounder in higher density environments where the galaxies are scattered gravitationally. At lower densities, the LSS are much more elongated (elongation < 1) and are similar as as function of density and redshift between the observations and simulations. Thus, we find for the first time that the overall evolution of the shapes is quite similar.

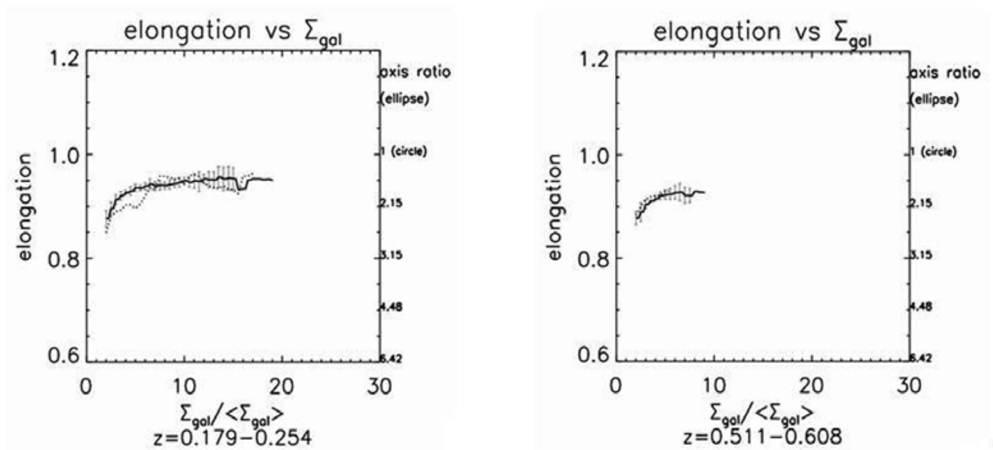

Figure 3. Mean elongations of structures versus density level in different redshift ranges. Dotted curve is observational curve; solid curve and error bar is mean and standard deviation of 3 Millennium simulations made for COSMOS.

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References

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