Dark Matter Halo Mass Function From HPC N-body Simulations

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Background:

- Dark matter (DM) dominates the matter in the Universe. Because of self-gravity, DM collapses and becomes clumpy, building the large-scale hierarchical structures. Baryons assemble within DM potential wells and form galaxies.
- Because we can not directly observe DM halos, numerical simulations is the only way one can study their dynamics and other properties. Using N-body simulations, we can obtain the Halo Mass Function (HMF), which provides the abundance of DM halos as a function of their mass. The HMF depends weakly on cosmological redshift and is one of the basic tools in modern cosmology.
- We use GIZMO --- a flexible, multi-method magneto-radiation-hydrodynamics code with self-gravity. It is designed to simultaneously capture advantages of both hydrodynamics via grid-based/adaptive mesh refinement (AMR) schemes[2] and collisionless dynamics of stars and DM.

Introduction

Employing a high-resolution cosmological zoom-in simulations focusing on a high-density environment and an average cosmological field at redshift z= 6-12, a low mass-end excess has been found compared to the theoretical Sheth-Tormen distribution [Fig. 1] (Sadoun et al 2016[1]). It was thought this excess is due to the inclusion of a baryonic physics, which is expected to have the largets effect on low-mass halos. Our goal was to test this excess with numerical simulations.

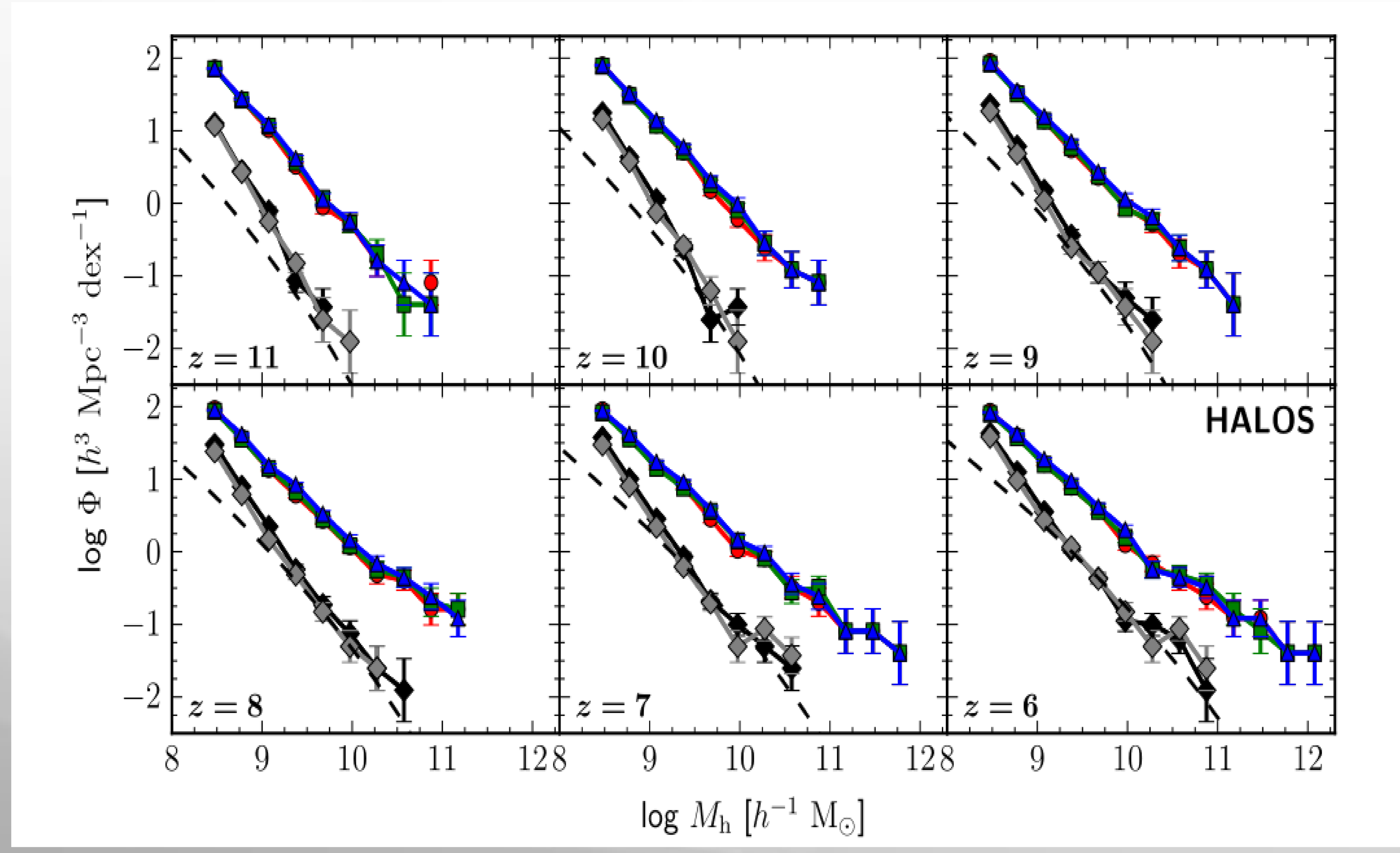


Fig 1.evolution of the halo mass functions for the three different galactic winds and two different initial conditions (marked with different color dots) at different redshifts. Mh is the total halo mass, DM+ baryons. The dashed line corresponds to the theoretical Sheth-Tormen HMF

Method

We used GIZMO to run a 512^3 particles in 20 Mpc box length with periodic boundary conditions (with and without baryons). The following steps were required to complete this research:

- To create initial conditions for simulations at z=200.
- Use GIZMO to run from z=200 to z=0.
- Use a halo finder to obtain DM halos mass distribution function (HMF)[3]

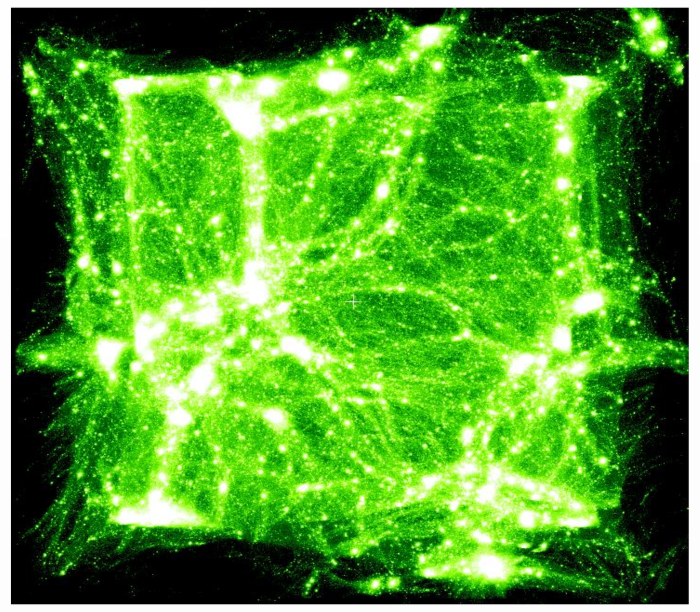
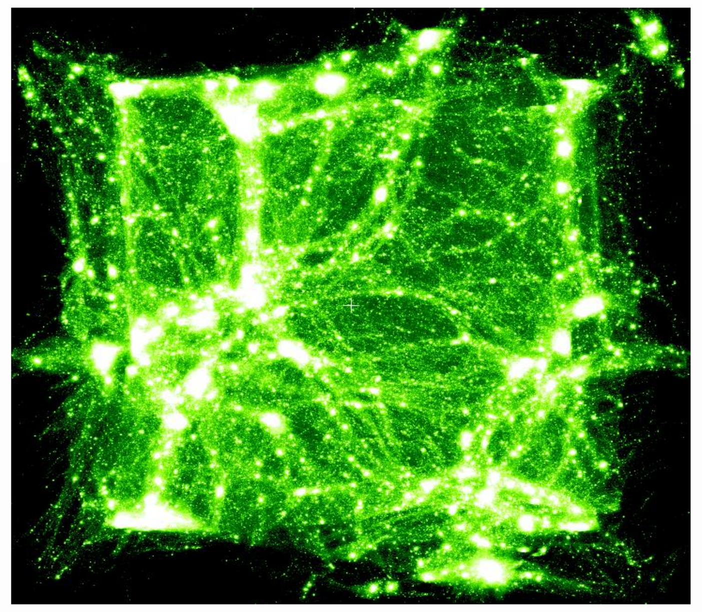


Fig 2. DM+Baryons simulation at z=0



DM only simulation at z=0

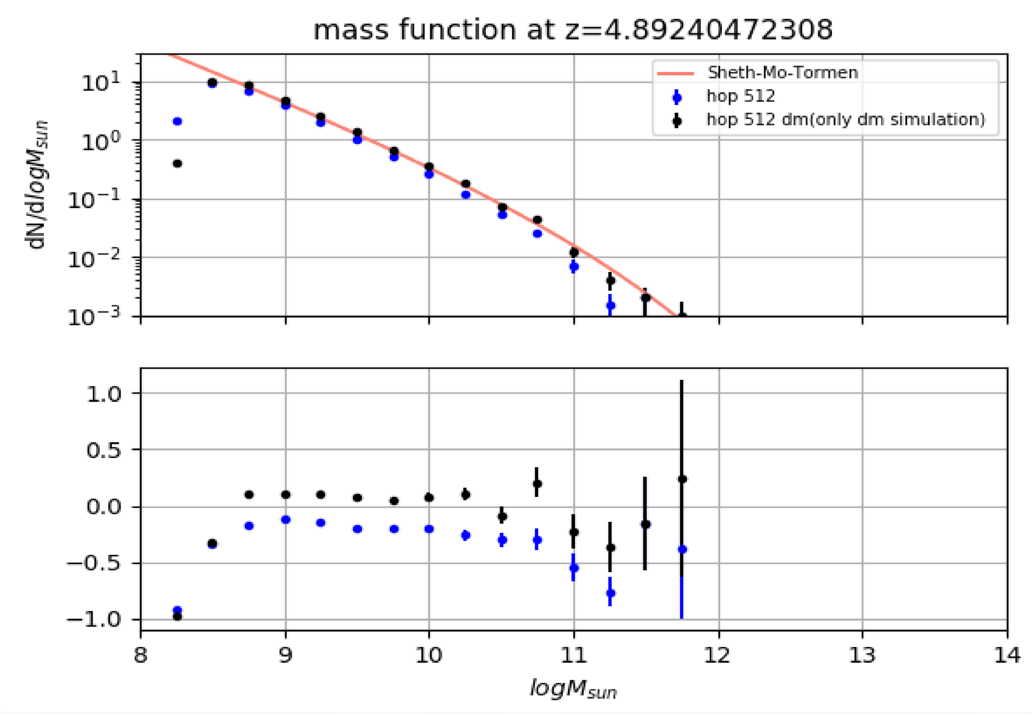


Fig 3 The halo mass functions for the 512^3 particles 20 Mpc simulations. No low-mass end excess was found.

Fig. 2 shows the snapshots of the simulation (with and without baryons) at z=0. Large-scale structures formed and are visible. The DM collapsed and formed long filaments and halos, while baryons assembled in DM halos and formed galaxies (too small to be visible in Fig.2).

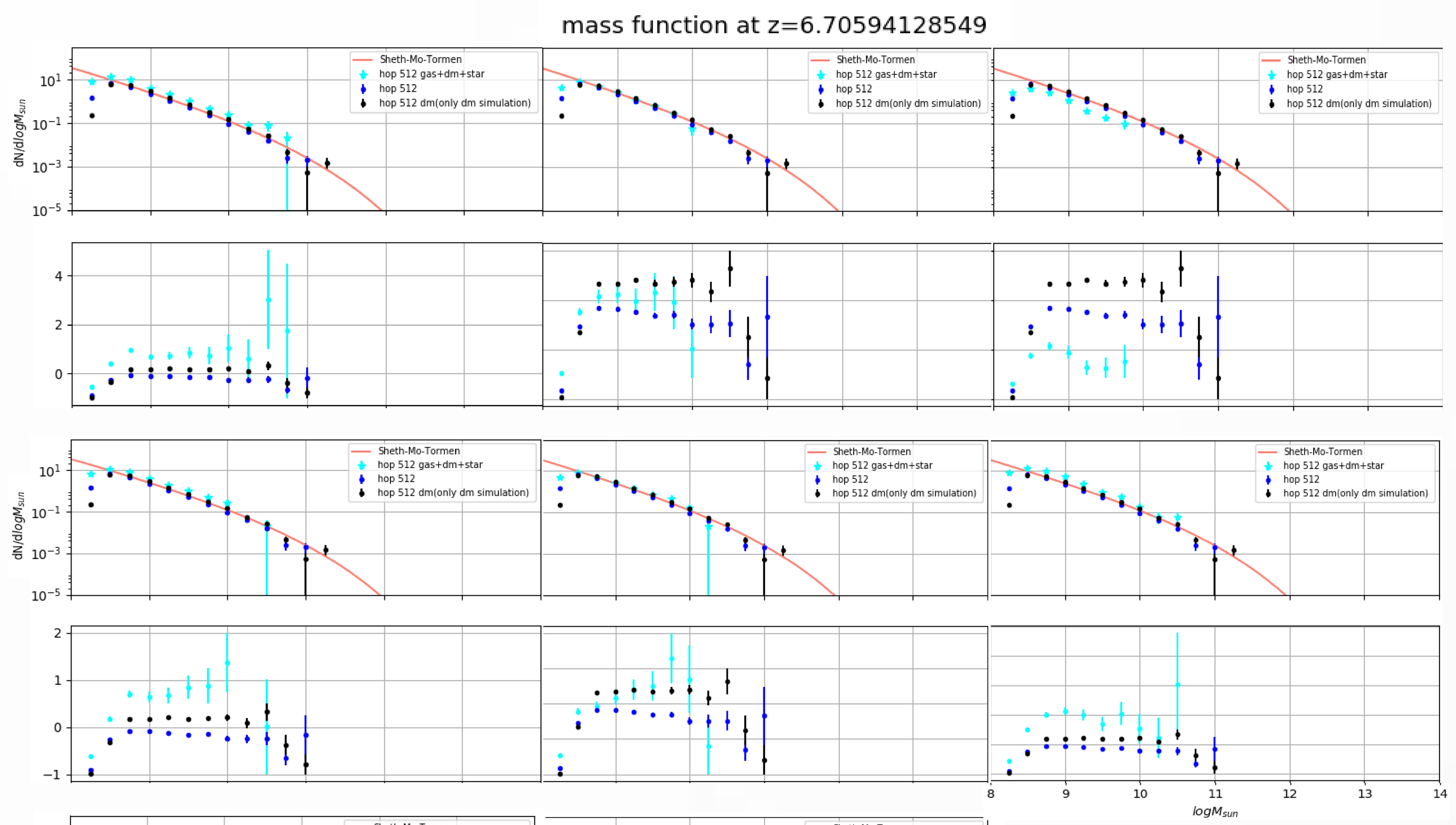
Fig. 3 is the HMF we obtained for the whole 20 Mpc box at z= 4.89, The HMF fits the theory curve very well.

Conclusion

Our results show that in both DM only and DM+Baryons there are no obvious low-mass end excess in the HMF. The inclusion of baryonic physics should not be the reason for this excess. We also divided the whole simulation box to 8 sub-volumes to test whether different average density environment will effect the HMF. Fig. 4 proves that the density environment does not lead to the low-mass end excess. Considering Sadoun ry al. (2016) simulation had only a 2.7 Mpc radius sphere volume, a reasonable explanation for this excess can be a small computational boxes used.

Results

In DM only simulation we did not find low-mass end excess, which in consonance with Sadoun results. However, in DM+Baryons simulation, we also can not find the excess in the whole 20 Mpc box [Fig 3]. Considering Sadoun's simulation is in a smaller box. We divided our whole box into 8 smaller sub-spheres and re-plot the HMFs for each one.



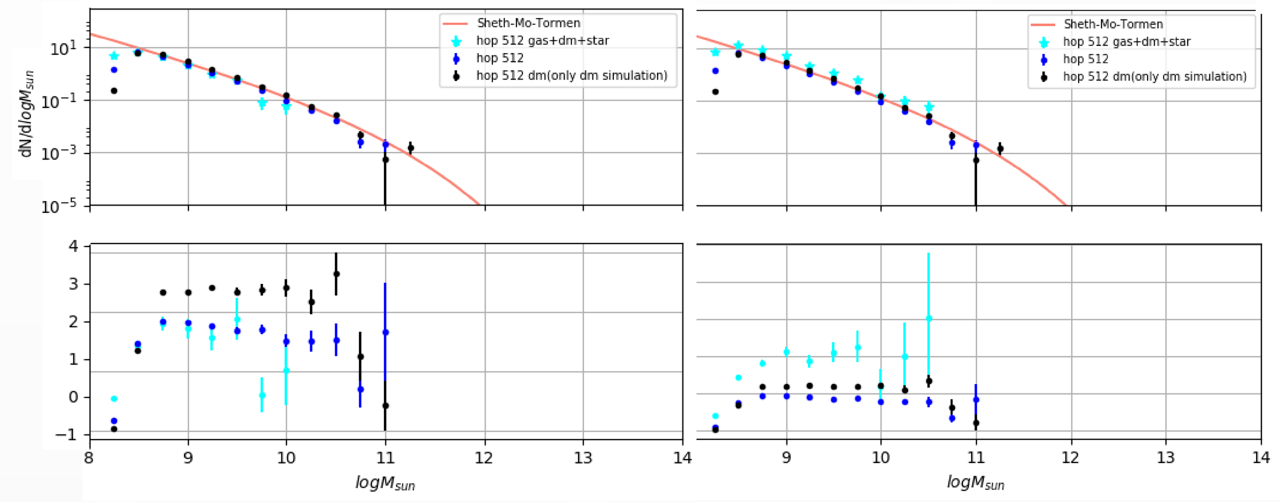


Fig 4 showed the HMF of DM only, DM+Baryons in simulation with baryons and DM only in DM only simulation. The majority of them fit the Sheth-Tormen distribution very well. Only a few has a bump in low-mass end in residual plots.

Fig 4. The halo mass functions for 8 sub-volumes

Reference:

[1]: Sadoun, R., Shlosman, I., Choi, J. H., & Romano-Díaz, E. ,2016, The Astrophysical Journal, 829(2), 71.
[2]: Hopkins, P.E., 2015, MNRAS, 450, 53
[3]: Eisenstein, D. J., & Hut, P. ,1998, The Astrophysical Journal, 498(1), 137.

Acknowledgements:

Thanks to Phil Hopkins for providing us with the current version of GIZMO. The simulations have been performed at the University of Kentucky DLX Cluster.