Dark Galaxies and Lost Baryons
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The MareNostrum Galaxy Formation Simulation Project

G. Yepes[1], L. Martinez-Vaquero[1], A. Khalatyan[2], S. Gottlöber[2], M. Hoeft[3] and R. Teyssier[4]

[1]Universidad Autónoma de Madrid
[2]Astrophysikalisches Institut Potsdam
[3]Jacobs University, Bremen
[4]CEA, Saclay

Abstract. The goal of this unprecedented large scale numerical project is to run state-of-the-art cosmological simulations of galaxy formation with two different numerical techniques: the particle based code GADGET-2 and the Eulerian AMR code RAMSES, starting from the same initial conditions. Both codes are fully parallel with MPI and can make efficient use of thousands of processors of the Marenostrum Supercomputer in Barcelona, where these two numerical experiments are being run.

1. Simulations

This simulation is part of the *MareNostrum Numerical Cosmology Project*, an international collaboration aimed at performing grand challenge cosmological simulations (Gottlöber & Yepes 2007). It is done with the TREEPM-SPH GADGET2 (Springel 2005) and uses 1024^3 dark matter particles and 1024^3 gas particles in a computational box of $50h^{-1}$ Mpc on a side. A random realization of the initial power spectrum in the Concordance ΛCDM model ($\Omega_M = 0.3$, $\Omega_\Lambda = 0.7$, $\sigma_8 = 0.9$, $n = 1$) was set at $z = 60$. Different physical processes are included such as, radiative and Compton cooling, UV photoionization and a multiphase model of the ISM (Springel & Hernquist, 2003). We also include thermal and kinetic feedback due to SNII explosions. The spatial resolution is set to 0.5 comoving kpc. The simulation needs a minimum of 800 processors of MareNostrum and it is currently at z=5.1 after more than 150 years of total cpu time consumed.

The same initial conditions that were used in the GADGET-2 simulation have been taken to generate initial conditions for the AMR code RAMSES (Teyssier 2002) with 1024^3 dark matter particles and more than 4 billions AMR cells. Constant spatial resolution was set to $2h^{-1}$ kpc physical. This simulation is done by the french HORIZON project, led by R. Teyssier, and is also run at MareNostrum using 2048 processors with 64 processors dedicated to I/O only. 20 Tb of data have been generated so far. After 117 years of cpu, the simulation is currently at z=1.9. It also includes different baryonic physics such as: Star formation, supernovae feedback, metal enrichment, metal dependant cooling amd background UV heating.

Although these two codes are supposed to solve identical mathematical equations (i.e. self-gravitating fluid mechanics in an expanding universe), implementation differences in both the baryonic sub-resolution physics and the numerics make the comparison of the numerical results extremely useful to estimate the robustness of the combined theoretical predictions for the high redshift galaxies formed in the simulations.

2. Comparison of results

We have started to compare results from the two simulations. First of all we have compared the halo mass functions. The agreement is striking over 3 decades in halo mass. The only difference resides at the low mass end, where RAMSES tends to have a poorer numerical resolution, while GADGET still follows halo with as few as 20 particles. We note that the largest halo to form in our virtual universe at redshift 5.2 has the same computed total mass within 0.1 % for the two codes.

We have also compared in detail the gas distribution in the most massive halo obtained by the two codes. The noisy appearance of GADGET results is due to the irregular sampling in a particle-based flow solver. But this does not mask the fact that both large scale and small scale details of the flow structure are very similar between the two codes. However, this is not true for the gas temperatures. We find larger discrepancies between the two simulations. This fact is currently under investigation.

One of the most important results come from the observational luminosity functions derived from the stars generated in the simulations. Both simulations agree very well at the high luminosity tail, the only part of the curve that will be ever accessible to observations. At the low luminosity end in the UV luminosity function, some discrepancy starts to show up that can be atrributed to the different numerical resolutions of the two simulations. Since the overall agreement is excellent, this is a strong confirmation that both simulations have performed as expected with a great level of physical realism.

3. Conclusions

These two numerical experiments are among the highest resolution simulations of galaxy formation ever done so far. Having them run with two completely different codes make them unique. The preliminary results obtained from comparison of the two data sets encourage us to pursue in this ambitious project despite the extreme computational requirements to carry out them. We will continue the evolution towards later redshifts and will generate a catalog of objects with observational properties that will constitute one of the best databases to compare with future observational evidences of the epoch of galaxy

For further information about the two projects the reader can visit the following web sites: `http://astro.ft.uam.es/marenostrum/` and `http://www.projet-horizon.fr`

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References

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