CONSTRAINED SIMULATIONS OF THE LOCAL UNIVERSE

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Simulating the Local Universe

This project is part of an international collaboration between different institutions around the world with the aim of generating the most accurate simulations of the formation of the Local Universe from cosmological initial conditions. We are using some of the most powerful supercomputers in Europe such as the Marenostrum supercomputer at BSC (Barcelona) as well as the HLRB2 Altix 4700 at LRZ (Munich). In these kind of simulations, the smaller Fourier modes of the random power spectrum are substituted by observational constrains in order to recover our real environment. These observational data come from MARK III (Willick et al. 1997), SBF (Tonry et al. 2001), nearby X-ray clusters of galaxies (Reiprich & Böhringer 2002) and the Karachentsev (2005) catalogues.

Different N-body simulations, with different resolutions, box sizes, codes and goals, have been performed up to now:

Large field $L_{box}=160\ h^{-1}Mpc$ **Code: ART**

$N_p=1024^3$ $M_p=2.54\ 10^8\ h^{-1}M_o$ Model: ΛCDM (WMAP3)

The most important large structures can be observed in this simulation: Coma, Local Supercluster, Virgo, etc.

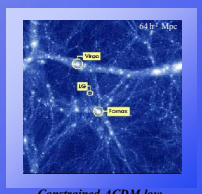
Standard field $L_{box}=64\ h^{-1}Mpc$ **Code: GADGET-2**

Low resolution

$N_p=256^3$ $M_p=1.30\ 10^7\ h^{-1}M_o$ Models: ΛCDM, OCDM and SCDM (WMAP)

Unconstrained and constrained simulations were carried out. Its main goal was searching of Local Group candidates in every boxes in order to compare different characteristics, following the *Macciò et al. (2005)* criteria.

Virgo, Fornax and the Local Supercluster are the main structures that can be observed.



Constrained ΛCDM low resolution simulation

High resolution Local Group simulation

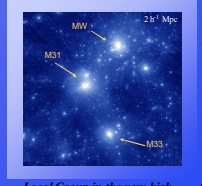
$N_p=5.2\ 10^7$ $M_p=2.03\ 10^6\ h^{-1}M_o$ Model: ΛCDM (WMAP3)

A region of 5 h^{-1}Mpc radius around the Local Group candidate was resimulated with 2048^3 effective particles. Some properties of the Local Volume were analyzed.

Very high resolution Local Group simulation

$N_p=6.4\ 10^7$ $M_p=2.54\ 10^5\ h^{-1}M_o$ Model: ΛCDM (WMAP3)

Resimulated region of 2 h^{-1}Mpc radius with 4096^3 effective particles. Detailed analysis of substructure of the Local Group members .



Local Group in the very high resolution simulation

The numerical Local Group

	$M_{vir}(h^{-1}M_o)$	$R_{vir}(h^{-1}kpc)$	V_{max}(km/s)	Subhalos	$M_{subhalos}(h^{-1}M_o)$
M31	5.69×10^{11}	173.5	127.9	436	$7.5\times10^{10}-5.1\times10^{6}$
Milky Way	4.63×10^{11}	162.0	130.6	273	$3.6\times10^{9}-5.1\times10^{6}$
M33	2.24×10^{11}	127.2	111.8	101	$1.1\times10^{9}-5.1\times10^{6}$

$d_{M31\text{-}MW}=0.91\ h^{-1}Mpc$

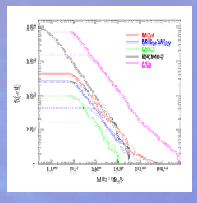
$v_{M31\text{-}MW}=-192.6$ km/s

Local Hubble flow (5 h^{-1}Mpc)

$H_{loc}/H_o=0.95$ $\sigma_H=117.8$ km/s

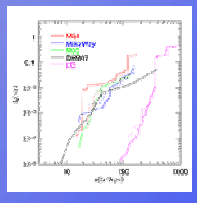
Substructures

Some properties of the members of the Local Group were studied and compared with the "*Via Lactea*" halo, simulated by Diemand, Kuhlen & Madau 2007 (DKM07).



High (dashed) and very high (solid) resolution simulations were used. For DKM07, the mass of particles are 2.09×10^4 and $5.64\times10^5\ h^{-1}M_o$

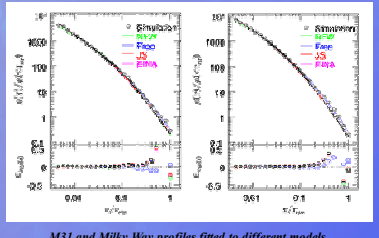
Fraction of mass of the host halo, that belongs to substrutures, as a function of the distance to the center of the halo



Subhalo mass function

Dark Matter Density Profiles

Density profiles of the members of the Local Group were fitted using different models:



M31 and Milky Way profiles fitted to different models

The best fits with 2 degree of freedom are obtained with Einasto and Jing & Suto models

$$\frac{\rho(r)}{\rho(<r_{vir})}=\frac{c^3}{3g(c)}\rho_{prof}(y) \qquad \chi^2=\sum_{i=1}^{n}(\log\rho_{sim,i}-\log\rho_i)^2$$

$$c\equiv\frac{r_{vir}}{r_s} \qquad g(y)\equiv\int_0^y x^2\rho_{prof}(x)dx \qquad y\equiv\frac{r}{r_s}$$

Navarro, Frenk & White (1995)
α=1 β=2 c=free

Jing & Suto (2000)
α=free β=3-α c=free

$$\rho_{prof}(y)=\frac{1}{y^{\alpha}(1+y)^{\beta}}$$

FREE
α=free β=free c=free

Einasto & Haud (1989), **Navarro et al.** (2004)
μ=free c=free

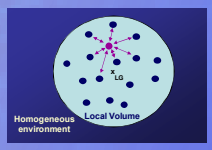
$$\rho_{prof}(y)=\exp(-2\mu y^{1/\mu})$$

Mass and motion in the Local Volume

Whiting (2005) studied the relation between Newtonian accelerations and peculiar velocities in observed galaxies within a 10 Mpc volume around the Local group (LG). He found no correlation between these quantities and concluded that peculiar velocities could not be the result of mass fluctuations.

In order to check this, we have measured peculiar velocities and accelerations for haloes found in 10 Mpc volumes around every LG candidate found in every low resolution simulations.

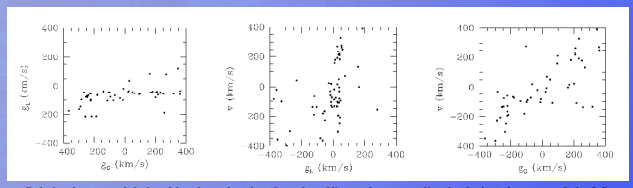
We have compared the Newtonian accelerations obtained by considering only mass inside the volumes (*local accelerations*) and the real ones obtained from N-body results (*global accelerations*)



Local acceleration model

Results

- *Local and global accelerations are not equivalent and there is no correlation between them.*
- *The peculiar velocity of halos in the LV of LG-like objects is clearly correlated with the global acceleration with a non-negligible scatter, however, there is not correlation between local accelerations and peculiar velocities.*

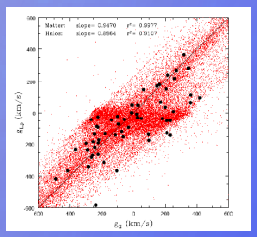


Relation between global and local acceleration (in units of linear theory predicted velocity) from one of the LG candidate found in the constrained ΛCDM low resolution simulation.

Conclusions

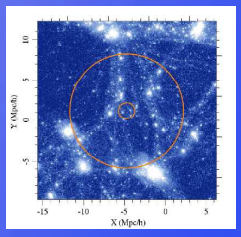
Modeling gravitational field inside the Local Universe from pairwise Newtonian forces between galaxies does not seem to be valid approximation because it neglects two main contributions:

Effects of matter in substructures and in diffuse medium



Local accelerations computed from the dark matter particles inside the LV (small points) and halos (solid points) in which accelerations have been computed by the average of all particles inside them (thick points).

Tidal field from external mass distributions



Local Volume and Local Group (marked by orange circles). Important external structures can be seen close to the LV border.

Future prospects

These constrained simulations are a natural laboratory to study, within a cosmological framework, the dynamics of the matter. Incorporating baryons to our simulations will allow to study the formation of disks, the history of stellar formation and others important properties that can be compared with the most current observations.

References

- Einasto J., Haud U., 1989, A&A, 223, 89
- Jing Y. P., Suto Y., 2000, ApJ, 529, L69
- Karachentsev I. D., 2005, AJ, 129, 178
- Klypin, A. et al., 2003, ApJ, 596,19
- Macciò, A. V., Governato, F., & Horellou, C., 2005, MNRAS, 359, 941
- Martinez-Vaquero, L. A., Yepes, G., Hoffman, Y., 2007, MNRAS in press, arXiv:0704.3385
- Navarro J. F., Frenk C. S., White S. D. M., 1995, MNRAS, 275, 720
- Navarro J. F. et al., 2004, MNRAS, 349, 1039
- Reiprich, T. H., Böhringer, H. 2002, ApJ, 567, 716
- Springel, V. 2005, MNRAS, 364, 1105
- Tonry, J. L. et al., 2001, ApJ, 546, 681
- Willick J. A. et al., 1997, ApJ, 109, 333
- Whiting, A. B., 2005, ApJ, 622, 217
- Zaroubi, S., Hoffman, Y., & Dekel, A. 1999, ApJ, 520, 413