Cosmological simulations of Milky Way-like galaxies

Pol Mollitor

Laboratoire d'Astrophysique de Marseille

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in collaboration with E. Nezri (LAM), R. Teyssier (Univ. of Zurich)

related to two OCEVU projects:

- J. Lavalle, S. Magni (LUPM):
  Indirect/Direct detection of dark matter, cosmic rays
- + L. Lellouch, C. Torrero (CPT):
  Direct detection of dark matter, Astrophysical aspects versus QCD

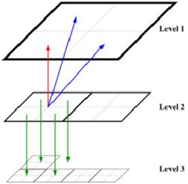
Journée scientifique du GT Cosmo d'OCEVU

28th May 2014

Outline

RAMSES

This code is a grid-based hydro solver with adaptive mesh refinement.
Idea: use the Particle-Mesh algorithm on a set of adaptively refined grid.
Method:
each cell is recursively refined if the number of particles per cell exceeds some threshold.
Hydrodynamics: Godunov scheme.



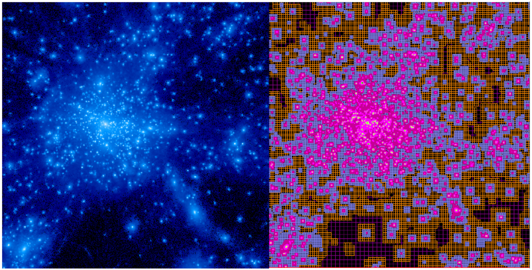


Figure : Adaptive Mesh Refinement

Star formation and Supernovae feedback

Star formation:

- Infall of cold gas $\longrightarrow$ stars.
- Model the gas conversion into stars by a Schmidt law

$$\dot{\rho}_g = -\epsilon_{ff}\frac{\rho_g}{t_{ff}} \text{ for } \rho > \rho_0$$

  with
  - t_{ff} free-fall time
  - ρ_0 threshold density
  - ϵ_{ff} star formation efficiency

$\longrightarrow$Transform gas into star particles.

Supernovae feedback can be modelled as follows:

- Type II SN, relevant for stellar masses $\approx 8 - 40\mathrm{M}_\odot$.
- Short living stars.
- $\approx$ 10-20 Myr after the star (particle) creation : explosion.
- $\approx$ 20 % of the star (particle) mass is re-injected into the gas.
- Energy per explosion $\approx 10^{51}$ erg.
- Dissipation of SN energy time scale = 20 Myrs.

Reheats the gas. Balance between star formation and SN feedback. Drives central dark matter density.

Zoom simulation

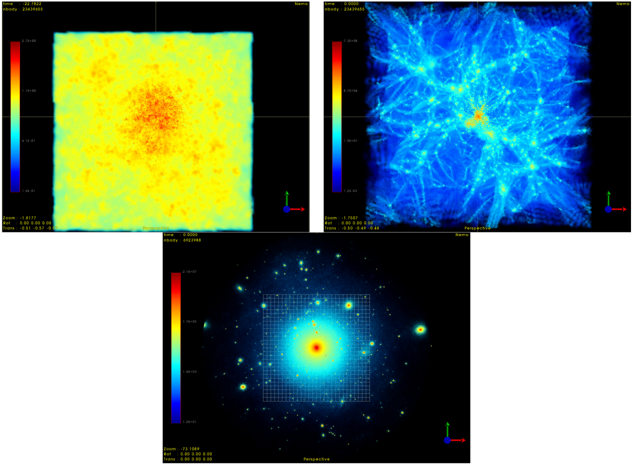


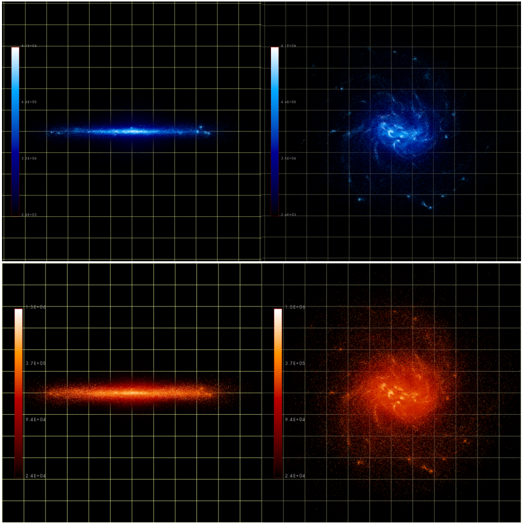
Figure : 3 Boxes showing: The primordial DM density fluctuations, the evolved structure and the zoomed halo.

Milky Way-like Halo

Run	R_{97} (kpc)	$M_{97,\mathrm{tot}}$ (10^{10})	$M_{97,\mathrm{gas}}$ (10^{10})	$M_\star$ (10^{10})	$M_{97,\mathrm{dm}}$ (10^{10})	R_{200} (kpc)	$M_{200,\mathrm{tot}}$ (10^{10})
A	344.9	227.52	23.96	18.23	185.32	253.69	186.68
A-DM	329.28	19.79				243.53	165.13
B	233.99	71.04	7.96	5.58	57.49	176.47	62.83
B-DM	220.85	59.73				162.90	49.42
C	244.60	81.15	9.58	5.50	6.60	181.83	68.73
C-DM	236.41	73.27				176.01	62.35

Primary numerical parameters of the simulated halos at $z = 0$, A, B and C referring to the hydrodynamical versions and *-DM to the corresponding dark matter only simulations. We show the radius of the sphere whose mean density is equal to 97 (respectively 200) times the critical density of the universe at redshift 0. The further columns give the total mass and DM mass inside R_{97}, the gas mass and stellar mass inside $R_{97}/10$. The corresponding numbers of gaseous cells, star particles, and DM particles are given next. In all the runs, the spatial resolution reaches 150 parsec at $z = 0$.

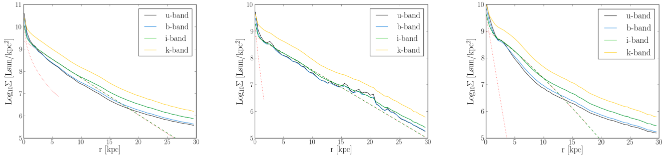
Halo B: the stellar galaxy maps



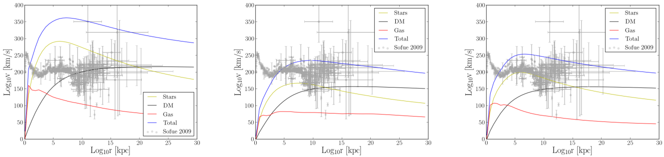
Projected stellar luminosities for Halo B at redshift 0 in U-band (blue) and K-band (red). One grid cell is 5 kpc $\times$ 5 kpc. Luminosities (units are solar luminosities) were computed from SSP integrated magnitudes calculated by the code CDM 2.5 (Marigo et al. (2008)), using the age and metallicity of the star particles. Visualization is done with glnemo2.

Galaxies at redshift 0

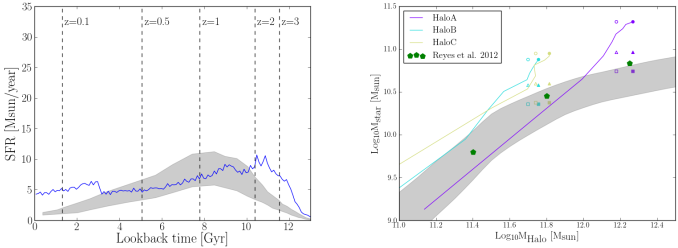
Surface brightness profiles:



Velocity rotation curves:



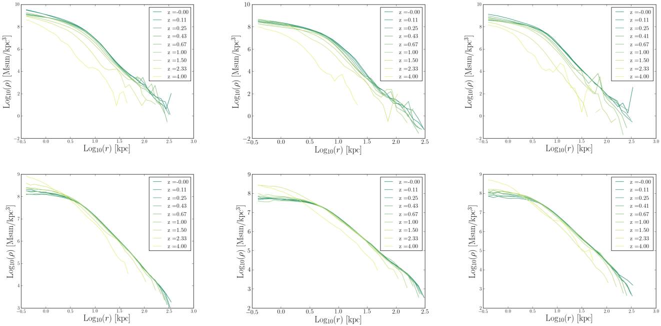
Formation History



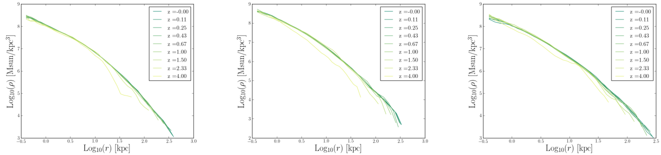
Left panel: Star formation history compared to Behroozi et al. (2013) for $M_{\text{halo}} = 10^{12}$.
Right panel: M_{star} versus M_{halo} compared to Moster et al. (2013) at redshift 0.

Density profiles for the three halos over redshift

Hydro Run: Stellar and dark matter density profiles.

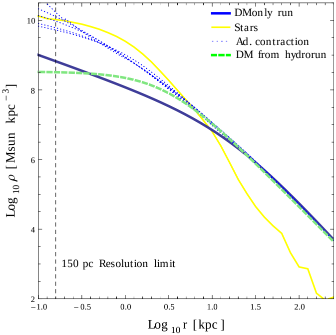


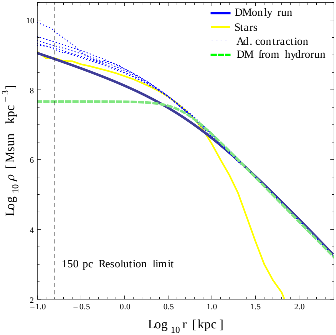
DM-only Run: dark matter profile



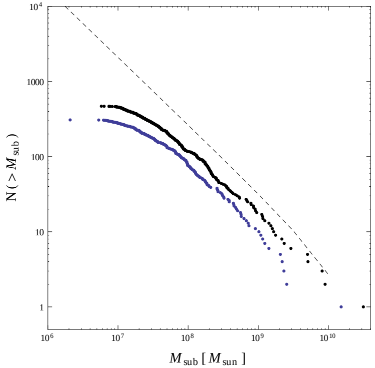
Adiabatic Contraction

Cusp / core transformation.
Adiabatic contraction at r$\sim 5 - 10$ kpc.

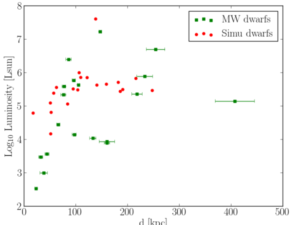




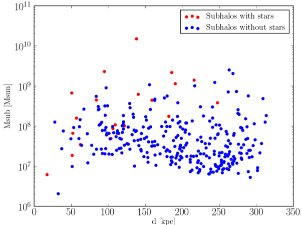
Satellites



$N(>M_{sub})$
$M_{sub}\,[M_{sun}]$



MW dwarfs
Simu dwarfs
Log10 Luminosity [Lsun]
d [kpc]



Subhalos with stars
Subhalos without stars
Msub [Msun]
d [kpc]

Conclusions

- Zoom simulations with RAMSES.
- A lot of MW observational properties.
- Interplay between star formation and SN feedback → Impact on dark matter profile.
- Caveat with star formation history → need for a different/additional feedback scheme?
- Analyse of satellites.

Perspectives:
Improvement of spiral galaxy simulations.
Realistic framework for astroparticle calculations related to dark matter detection.

Hot topics in galaxy formation.
Workshop CosmoLam: Semianalytic models (SAMs) and hydrodynamic simulations (HSs)
10-13 June 2014
supported by OCEVU...
http://lamwws.oamp.fr/cosmowiki/WorkshopCosmoSamSim