Contribution to the validation process of the DYABLO cosmological simulation code

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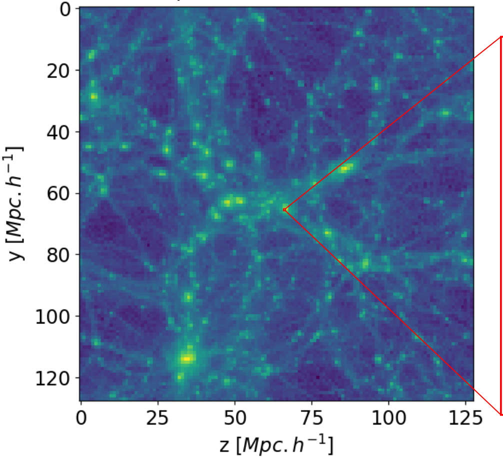
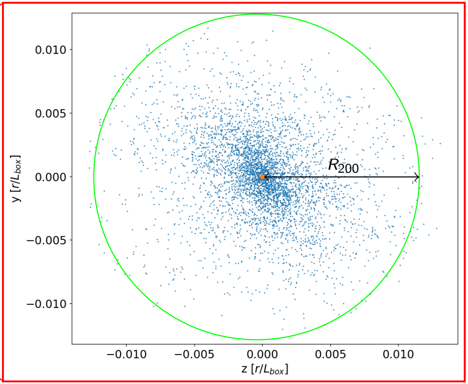
A new cosmological code, DYABLO

Snapshot at redshift $z = 0$



Dark matter particles distribution from DYABLO

Dark matter halo



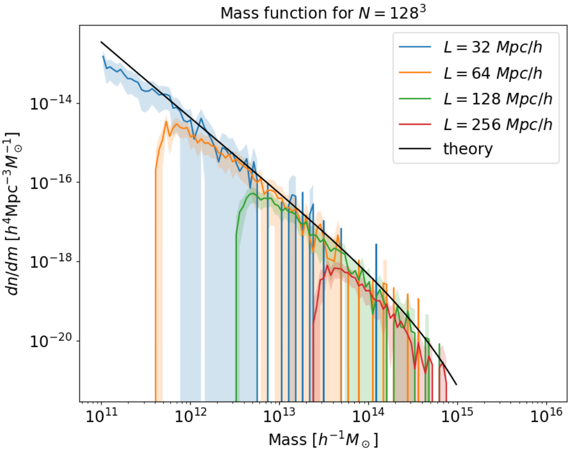
Halo detected by HOP [1]

Goals

- DYABLO validation by comparing properties of the halos with literature.

- Study of the properties of dark matter halos (simulation with 2 million particles and $L_{box} = 32\ Mpc/h$, gives ~ 850 halos) at redshift $z = 0$ (today):
  - Abundance in function of the mass
  - Shape
  - Density profile and concentration
  - Kinematics (Spin and particles velocity)

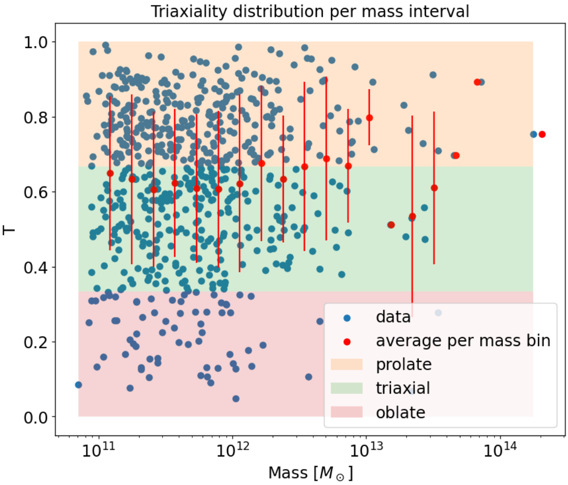
Halo abundance per mass interval



- Different size of box
  $\implies$ different resolution
- L=32 Mpc/h ($\sim$ 47 Mpc)*
  is more resolved.
- Lot of small halos but
  less of massive halos.

* Mpc/h is conventional unit in cosmology

Halo Shape



* Each dot is a halo.

- Triaxiality [2]:

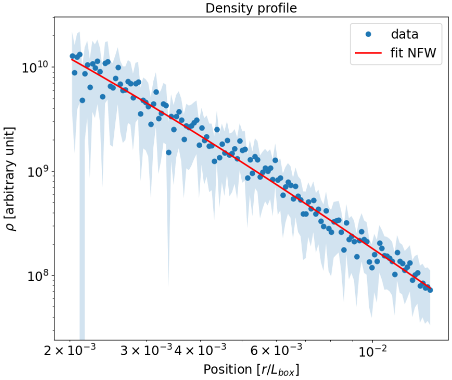
$$T = \frac{{\lambda_3}^2 - {\lambda_2}^2}{{\lambda_3}^2 - {\lambda_1}^2}$$

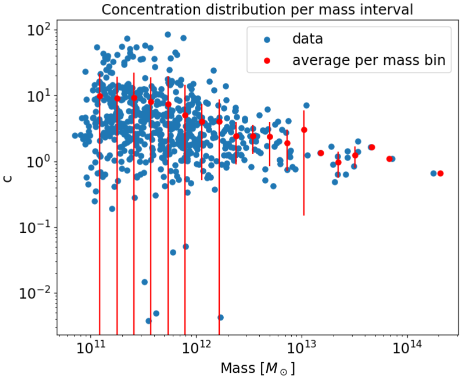
where $\lambda_1 < \lambda_2 < \lambda_3$ are eigenvalues of inertia matrix.

- Prolate : cigar
  Oblate : curling stone
  Triaxial : between the two

- Triaxial halos
  but massive $\rightarrow$ prolate
  (agreement with literature)

Halos density profile and concentration



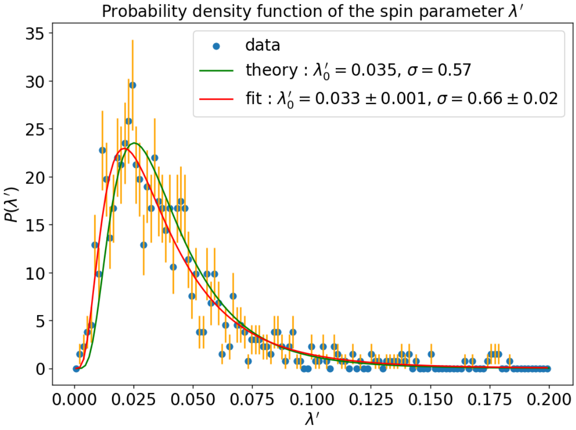


- Navarro-Frenk-White model [3, 4]:

$$\rho(r) = \frac{\rho_s}{(r/r_s)(1+r/r_s)^2}$$

- Concentration [4]: $c = \frac{R_{200}}{r_s}$
- Decreasing trend of c as found in literature [4].

Halo Spin



- Spin parameter [5, 6]:

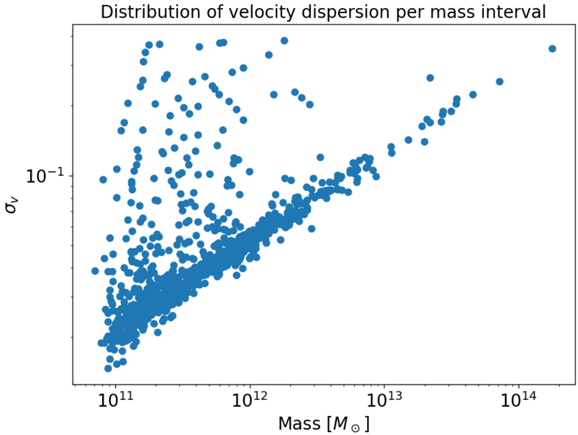
$$\lambda' = \frac{J}{\sqrt{2} \cdot M \cdot V \cdot R_{200}}$$

- $$\lambda' \sim \frac{E_{k,rot}}{E_{k,tot}}$$

$\Longrightarrow$ measure halo rotation

- Almost no rotation.
  (consistent with literature)

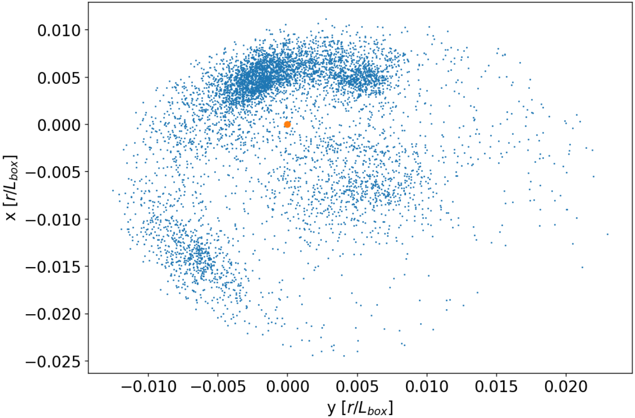
Halo's particles velocity



- σ_v: standard deviation of the velocity in one halo. σ_v increase with the mass.
- Massive halos
  $\Longrightarrow$ fast particles
  $\Longrightarrow$ hotter halos
- Few strange halos above the linear trend.

* Each dot is a halo.

Shape of strange halo



- Imperfect detection with HOP code [1].

Conclusion

- Properties of the halos from DYABLO are consistent with literature.
- Refine the study by using more resolved simulation output to work on a larger number of halo.
- Change parameter in the halos detection code HOP.

Bibliography I

[1] Daniel J Eisenstein and Piet Hut. “HOP: a new group-finding algorithm for N-body simulations”. In: *The Astrophysical Journal* 498.1 (1998), p. 137.

[2] Emilie Thélie et al. “First look at the topology of reionisation redshifts in models of the epoch of reionisation”. In: *Astronomy & Astrophysics* 658 (2022), A139.

[3] Giuseppe Tormen. “The rise and fall of satellites in galaxy clusters”. In: *Monthly Notices of the Royal Astronomical Society* 290.3 (1997), pp. 411–421.

[4] Risa H Wechsler et al. “Concentrations of dark halos from their assembly histories”. In: *The Astrophysical Journal* 568.1 (2002), p. 52.

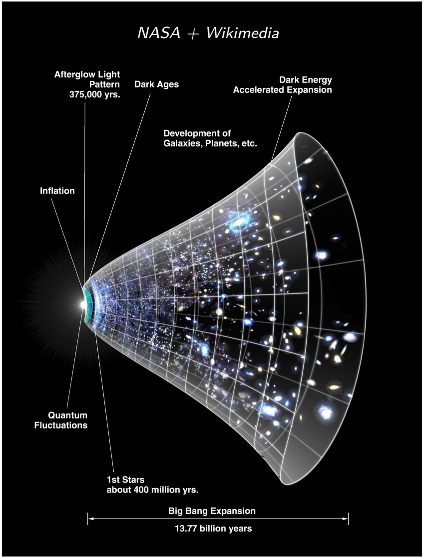
Bibliography II

[5] Dominique Aubert, Christophe Pichon, and Stephane Colombi. "The origin and implications of dark matter anisotropic cosmic infall on ≈ L* haloes". In: *Monthly Notices of the Royal Astronomical Society* 352.2 (2004), pp. 376–398.

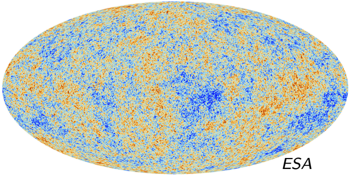
[6] James S Bullock et al. "A universal angular momentum profile for galactic halos". In: *The Astrophysical Journal* 555.1 (2001), p. 240.

[7] Edmund Bertschinger. "Simulations of structure formation in the universe". In: *Annual Review of Astronomy and Astrophysics* 36.1 (1998), pp. 599–654.

Introduction



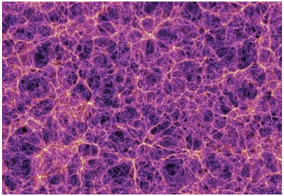
Planck Cosmological Microwave Background



ESA

Simulations [7]

Cosmic web

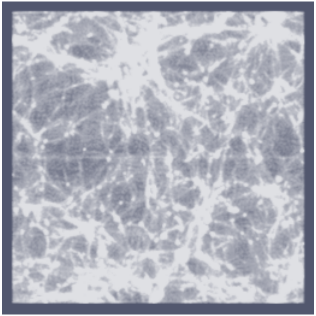


V.Springel

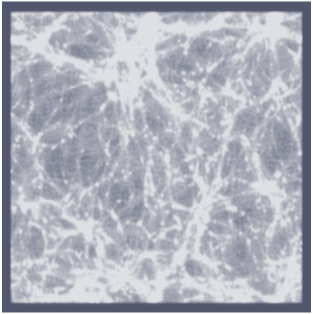
Problem in the simulation

Output of the simulation:

Before

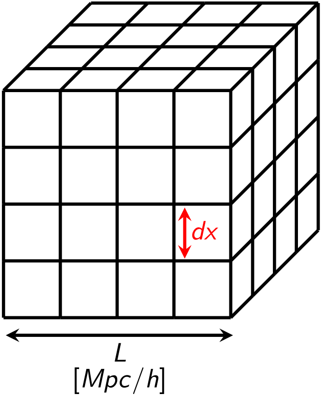


After



- Issue in the boundary between the 2 processors

Some details on DYABLO simulation



- Cubic lattice of N^3 cells and particles.
- Size of the box : $L = N \times dx \times h$ with dx the size of the cell and $h = \frac{H_0}{100} = 0.6774$ the dimensionless Hubble constant.
- Adaptative grid to refine regions with high number of particles.

Some simulation parameters

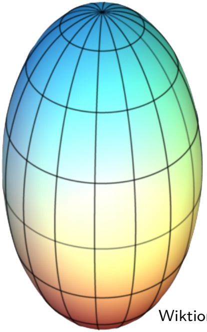
Distribution of energy in our universe:

$$\Omega = \Omega_m + \Omega_v = 1$$

where: $\Omega_m = 0.3075$ (Baryons + DM)
$\Omega_v = 0.6925$ (Dark energy)

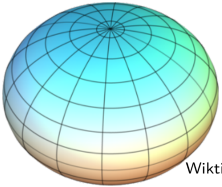
Shape illustration

Prolate



Wiktionary

Oblate



Wiktionary

To summarize

- Abundance of the halos in function of their mass in accordance with the theory for little structure.
- Halos are mainly triaxial but massive ones tend to be prolate.
- Density profile fit with the NFW model established for this object in the literature.
- Concentration decrease with the mass.

To summarize

- Halos hardly rotate as seen in models [5, 6].
- The more massive the halo, the faster the particles.
- The halo detection code shows some limits.