The Expected Shape of the Milky Way's Dark Matter Halos

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Outline

Motivation

Evidences of Dark Matter (DM)

Rotation Curves

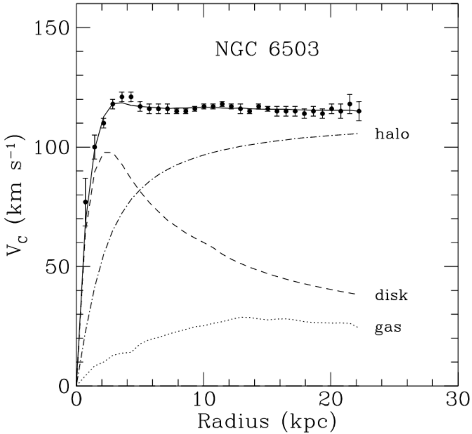


Figure: Bertone et al. 2005

The Cosmic Background Radiation (Cold Dark Matter)

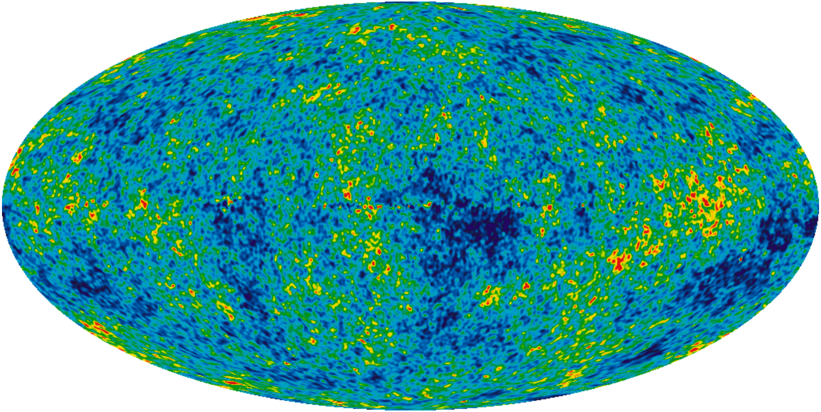


Figure: Taken from https://map.gsfc.nasa.gov/media/121238/index.html **(WMAP)**

The Large-Scale Structure of the Universe

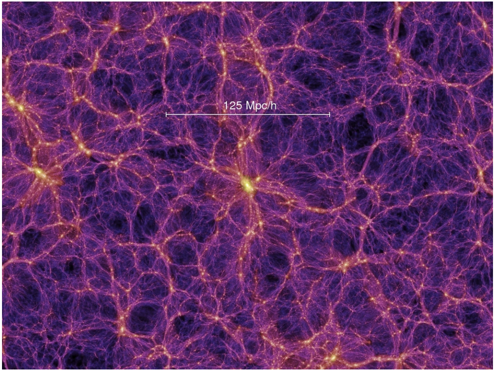


Figure: Taken from https://wwwmpa.mpa-garching.mpg.de/galform/virgo/millennium/ **(Millennium)**

DM density in our Milky Way (MW)

- **Why DM?** – We have not measured DM directly.
- **DM density field** is needed to couple theory and observations.
- DM evidence is not that far: MW
- **Why DM in our MW?** – MW is the only object of which we have tridimensional view from the interior.

MW is the only object of which we have tridimensional view from the interior

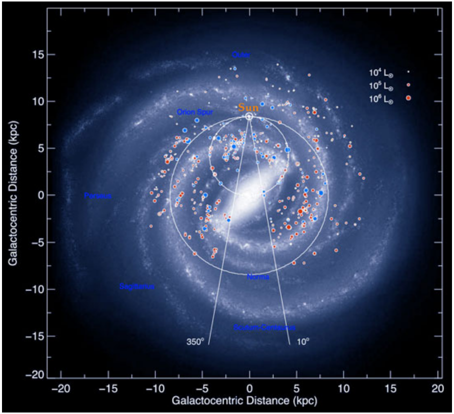


Figure: Taken from https://imagine.gsfc.nasa.gov/science/objects/milkyway1.html **(Millennium)**

Observational constraints on the MW's DM halo

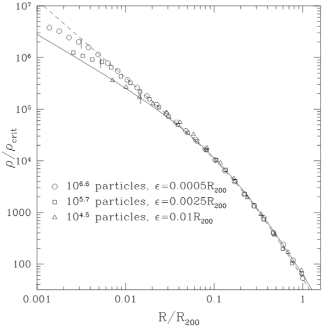


Figure: Gighna et al. 2000

The DM density field is often reduced to a radial profile:

$$\rho(\vec{r}) \rightarrow \rho(r) = \frac{\delta_c \rho_{crit}}{\frac{r}{r_c}\left(1 + \frac{r}{r_c}\right)}, \qquad (1)$$

which is universal in a hierarchical model of formation [1].

Radial profiles omit angular dependence of density (**shape**).

DM halos are NOT spherical but **triaxial** [2] (accretion)

Why do we want to define a shape?

Besides being a more complete characterization of density, it can keep memory of past events of formation.

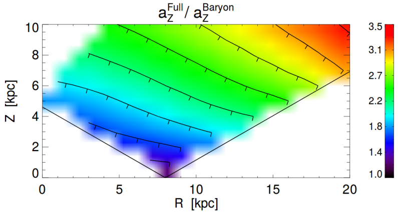


Figure: Simulated a_z comparison: Total Vs Baryon-contribution

Loebman et al. 2012

- [3, Loebman et al. 2012] deduced an oblate (**not spherical**) DM halo to account for discrepancies.

Using the Sagittarius stream [4, Law & Majewski 2010].

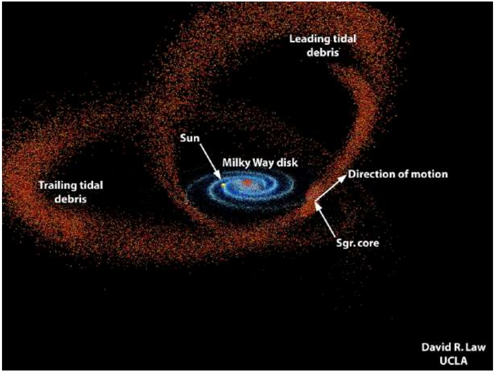


Figure: Taken from https://phys.org/news/2017-07-astronomers-chemical-abundances-stars-nearby.html

- **Variation of parameters**: Match simulations with observations.
- DM cannot be axisymmetric to account for the stream properties.
- DM halo is axisymmetric, nearly oblate.

Axis orientation??

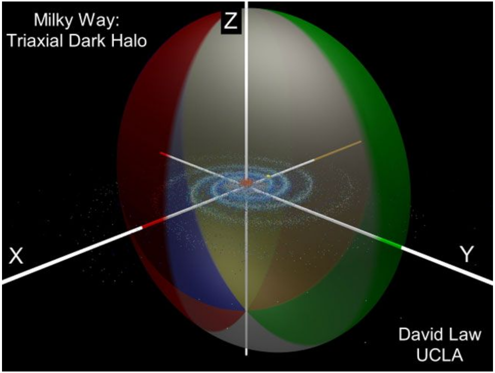


Figure: Taken from http://www.solstation.com/x-objects/darkhalo.htm

The utility of Cosmological simulations

- Support tool for observation and theory.
- Evolution of DM and gas in a ΛCDM cosmology
- Feedback processes: Supernovae explosions, Black hole radiation.
- Chemical enrichment

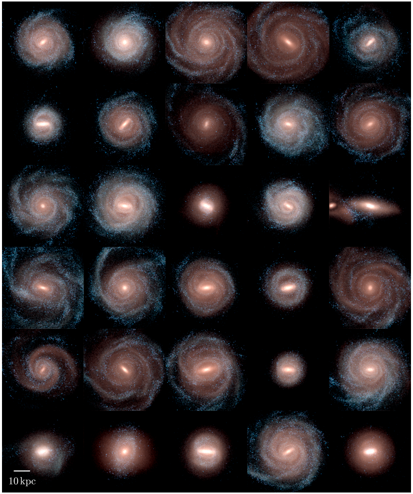


Figure: Auriga simulations. http://auriga.h-its.org

- We focus on AURIGA [5] simulations made with AREPO [6].
- **Degrees of realism**: Levels of Resolution. DM-only/Magneto HydroDynamics (MHD).

Simulations and observations

A study of the shape in terms of the radius: [7, Vera-Ciro et al. 2011].

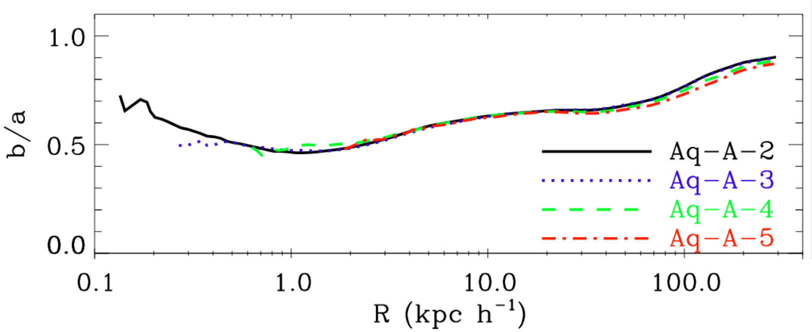


Figure: Halos evolve towards oblate shapes. Vera-Ciro et al. 2011.

Correlation with historic shape.

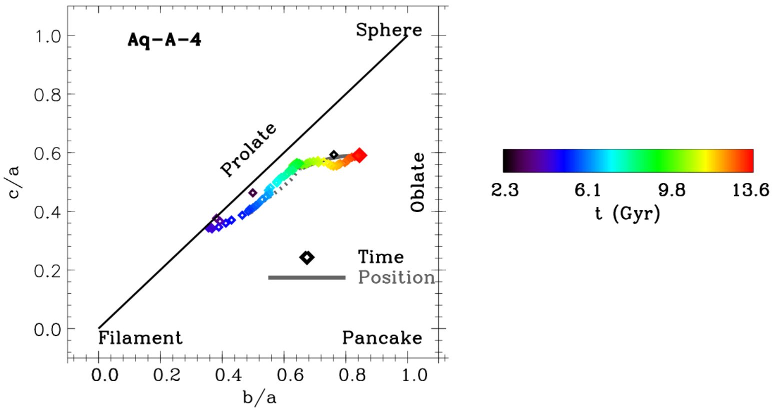


Figure: Historical and radial correlation. Vera-Ciro et al. 2011

Improvement on observational constraints: [8, Vera-Ciro and Helmi 2013]

The DM halo assumptions:

- Axisymmetric at inner parts.
- Triaxial on the outer-skirts.
- Smooth transition.

Our Study

Objectives of this thesis

- Study the shape of the DM halo in terms of the radius on **AURIGA** simulations.
- Study the correlation of the radial and historical profiles.
- **Analyze the relation or the effect of baryons on the DM halo shape.**

The shape-calculation method

We follow Vera-Ciro et al. 2011 ([2, Allgood et al. 2006]).

Shapes are determined by the semiaxes a, b, c of the halo ellipsoid.

First we choose a radius R. We calculate the reduced inertia tensor for all particles within the defined sphere:

$$I_{ij} = \sum_k \frac{x_k^{(i)} x_k^{(j)}}{d_k^2} \tag{2}$$

But this is not sufficient: **Spherical bias**.

We recalculate by iteratively rescaling:

Once obtained the first semiaxes, we perform the scale transform:

$$(x, y, z) \rightarrow (x, y/q, z/s) \tag{3}$$

$$q = b/a \tag{4}$$

$$s = c/a, \tag{5}$$

This redefines the *sphere* contour and the *distance* in the inertia tensor.

Repeat until convergence: changes in semiaxes are less than 10^{-6}

Corvergence analysis

Resolution does not visibly affect DM-only halo shapes.

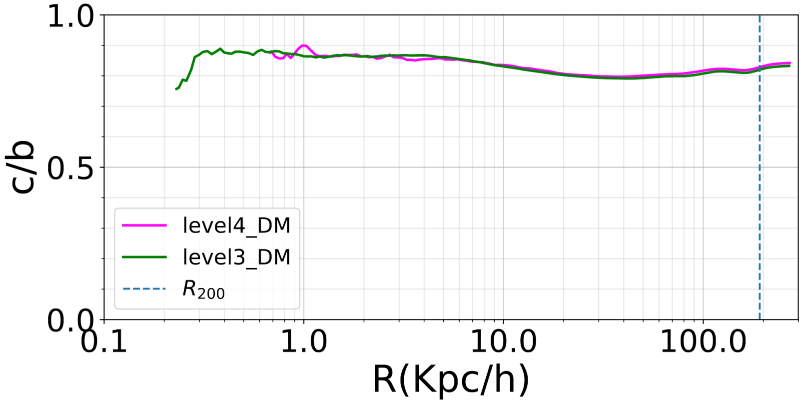


Figure: Halo 6 DM Prada et al. 2018 (in process)

MHD are affected by baryionic physics resolution (rather than a few-particle effect)

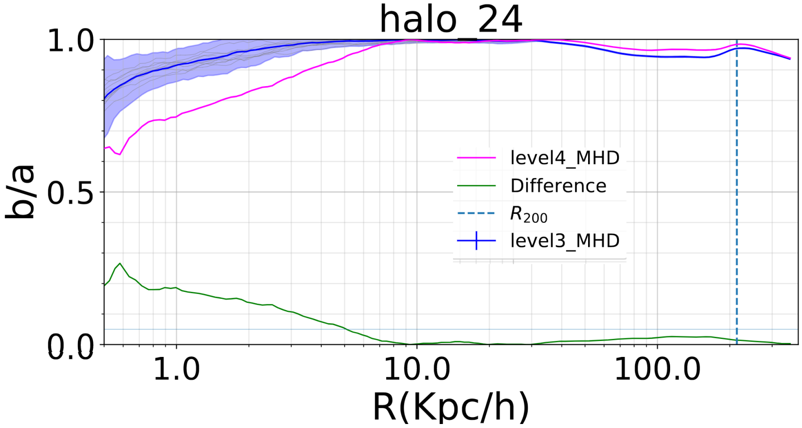
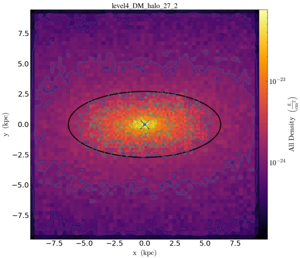
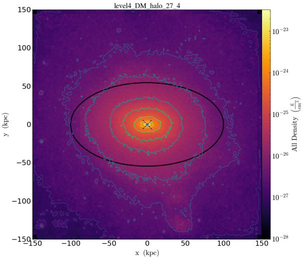


Figure: Halo 24 MHD Prada et al. 2018 (in process)

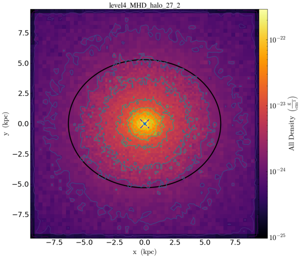
Radial dependence of shape



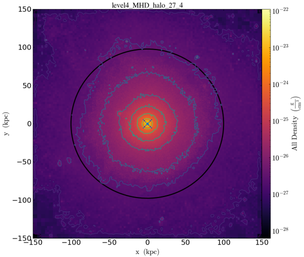
(a) halo 27 DM shape (inner)



(b) halo 27 DM shape (outer)



(c) halo 27 MHD shape (inner)



(d) halo 27 MHD shape (outer)

DM Halos are more spherical at larger radii

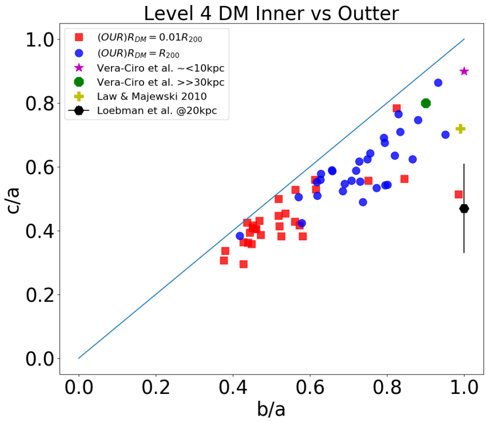


Figure: Prada et al. 2018 (in process)

MHD Halos are more spherical at larger radii

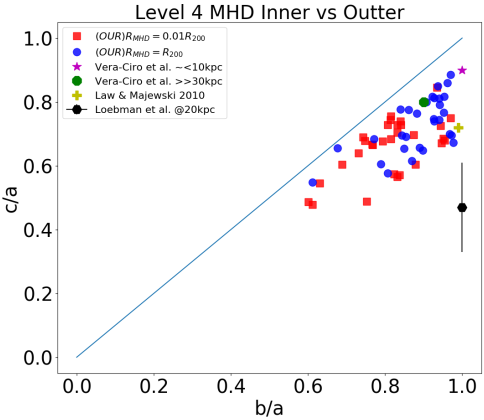
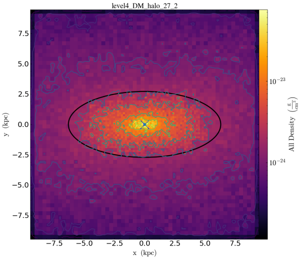


Figure: Prada et al. 2018 (in process)

The effect of gas



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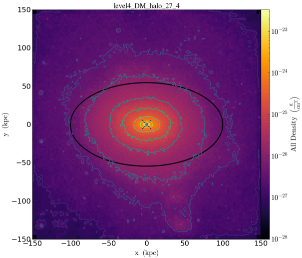
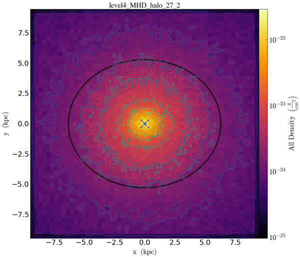
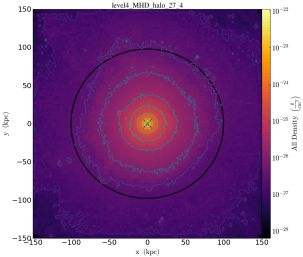


(b) halo 27 DM shape (outer)



(c) halo 27 MHD shape (inner)



(d) halo 27 MHD shape (outer)

MHD halos are more spherical than DM halos (scattering)

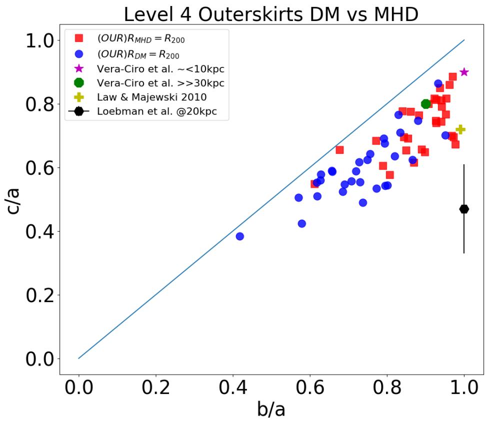


Figure: Prada et al. 2018 (in process)

Historical and radial correlations

Halos evolve towards more oblate shapes.

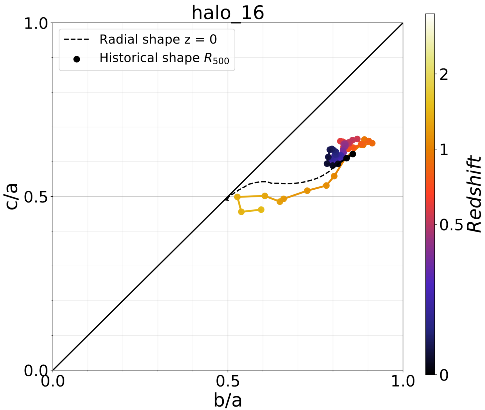


Figure: Halo 16 DM Prada et al. 2018 (in process)

Reason: systematic tendence towards oblate/spherical shapes.

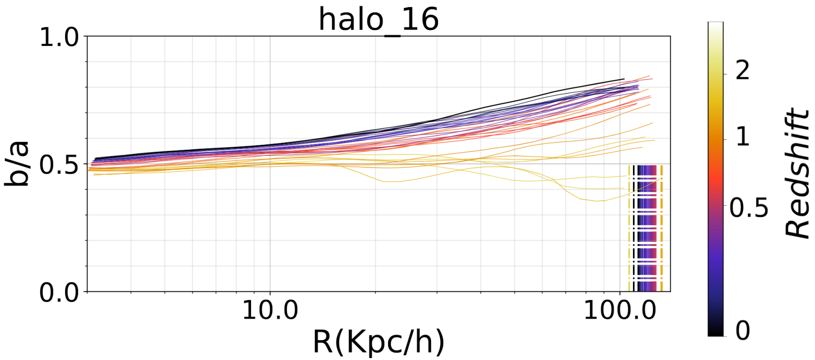


Figure: Halo 16 DM Prada et al. 2018 (in process)

Example of shape *memory* loss.

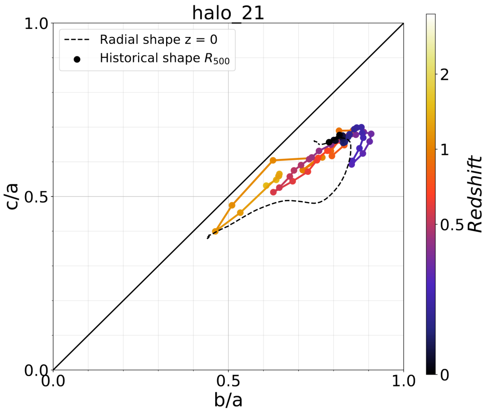


Figure: Halo 16 DM Prada et al. 2018 (in process)

Major event? **Virial radius change**

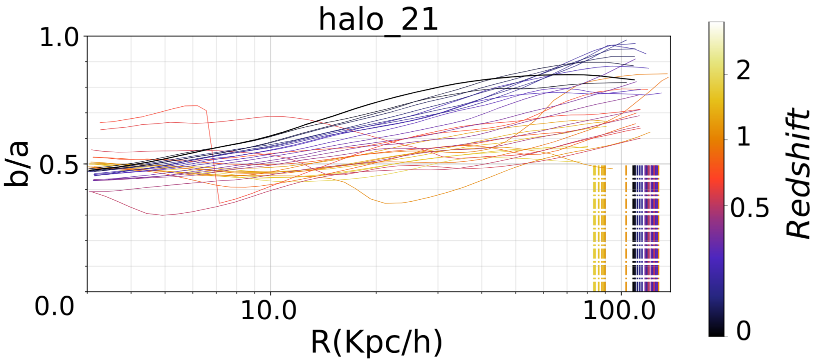
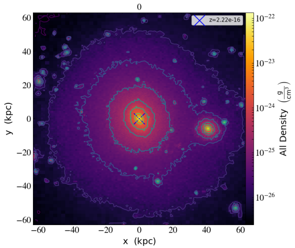
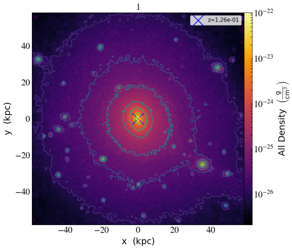


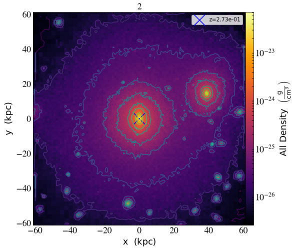
Figure: Prada et al. 2018 (in process)



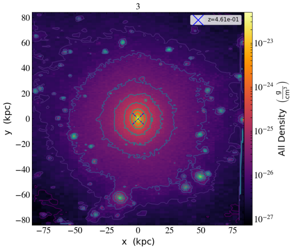
(a) halo 21 DM z=0



(b) halo 21 DM z=0.13



(c) halo 21 DM z=0.27



(d) halo 21 DM z=0.46

Prada et al. 2018 (in process)

Conclusions

- DM halos are more oblate/spherical at larger radii.
- There is a correlation between historical and radial shapes which is caused by the generalized tendency of halos to evolve towards spherical shapes.
- Presence of matter increases tendency towards sphericity (scattering)
- Our results are supported by a significant sample.

Future work

- Paper (In process)
- Study the effect of environmental structures on halo shape and orientation.
- Study the response of DM halos to the presence of matter (Adiabatic contraction).

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