Modelling the Milky Way dark matter halo

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1 Introduction

In the current cosmological standard paradigm about 23% of the energy and matter content of the Universe is dark matter and $\sim 1\%$ is barionic matter. In the context of galaxy formation where structure grows hierarquicaly, barionic matter start to cluster inside dark matter halos where galaxies start to form. Therefore studing the properties of these dark matter halos lead to a better understanding of the galaxy formation processes. In particular the morphology, kinematics, dynamics and formation history of galaxies are strongly related with the host dark matter.

Crucial theoretical efforts have been made in order to model these dark matter halos properties. Hernquist, Plummer, Dehnen, derived analytical expresions for the density profiles of spherical dark matter halos. Using cosmological simulations Navarro et al found an analytical expression for DM profiles in a cold dark matter universe, they also study spherical cuspy halos. More recent studies have suggested that halos in a ΛCDM Universe are triaxial Jung& Suto 01.

The halo potential of the halo would affect the orbits of satellite galaxies and globular clusters, furthermore knowing the position, line of sight velocities and tangential velocities of these objectes would led to derive the mass of the halo. To this aim the mass of the Milky Way have been derieved for several gro

One powerful to measure the mass of the Milky way is using extended (360) substructures in the halo such as streams, this observations have revealed that the Milky Way halo is not **dynamically old and it is not relaxed**.

Observations of the Sagitarius stream [Ibata et al., 2001] have lead to test dark matter models of the Milky Way due to the distances, radial velocities and the positions of the stars. Several groups have attempt to reproduce the stream, (Ibata et al 01 (Spherical) ,Helmi 04 (Prolate), Johnston et al 05 (Oblate halo), Law et al 05,Fellhauer et al 06 (Spherical) , Martinez Delgado et al 07 (Oblate), Law, Majewski, Johnston 09, Law & Majewski (Triaxial), Vera-Ciro 2013, These models are explained in detail in §2. Despite these efforts there is not a concistent model that fully reproduce the Sagitarius stream.

More recently Pearson14 used the Palomar 5 stream which is closer in order to test the previous models at a different radius. They found that none of the previous triaxial models can reproduce the Palomar 5 stream. Also the point that stream-fanning

In all of the above efforts the halo is model as a static halo...

The LMC ...

- First observed by Ibata 94
- Large population of young relatively metal rich Sgr M-giant wrapping 360 across the sky (Majewski 03)
- debris streamer continues through the North Galactic Pole passes over the solar neighborhood toward the galactic anitcenter. (Belokurov 06)

- Evolution in metallicity distribution function.

Efforts trying to modelled the stream.

- Johnston 95, 99
- Velazquez & White 95
- Edlesohn & Elmegreen 97
- Ibata et al 07
- Gomez-Flechoso et al 99
- Helmi & White 2001
- Martinez-Delgado et al 2004

MW DM halo:

- Ibata et al 01 (Spherical)
- Helmi 04 (Prolate)
- Johnston et al 05 (Oblate halo)
- Law et al 05
- Fellhauer et al 06 (Spherical)
- Martinez Delgado et al 07 (Oblate)
- Law, Majewski, Johnston 09 ()
- Law & Majewski (Triaxial)

2 The Milky Way Dark Matter halo

2.1 Vera Ciro13

[Vera-Ciro and Helmi, 2013] study a dark matter halo that is oblate in the center and triaxial in the outskirts.

This study is motivated by expectations that the disk would modify the

The motivations are that the disk is expected to modify the

inner halo shape towards one that is oblate, in which case disk stability is ensured.

also if the halo is oblate at the inner the disk stability is ensured.

They argue that the triaxial halo configuration of [Law and Majewski, 2010] it's not common in the LCDM model due to the small c/a ratio compared to LCDM predictions.

*** Is this actually an issue - can't the MW be an outlier? *** How much of an outlier is the Law model vs average properties

They integrate orbits of test particles in the potential Eq.**??** for a period of 2gyr backwards and forwards.

For every test particle they select 10 random locations in its orbit and store the position and velocity. orbit of this test particle from which they have positions and velocities.

With this methodology they reproduce observables that might be compared with the Sgr stream.

The results from this numerical experiment is that

They find a good fit in some parts of the orbits (see Fig.2 of that paper) and that the fit does not depend strongly on the parameter r_a of the halo potential.

In the second part of this paper they study the effect of torques in the Sgr stream. The authors argue that there are two torques, one from the triaxiality of the halo itself and the other due to the LMC. Interestingly, the major axis of the triaxial potential in [Law and Majewski, 2010] is in the direction towards the LMC. They studied the magnitude of both torques and found that both have an equal effect on the Sgr stream.

As a result, they modify the parameters of the halo model in order to account for the additional torque of the LMC, these new parameters are now more consistent with those expected from the LCDM model. For the orbit integration they also take into account the potential of the LMC. With these considerations, they find a better fit for the Sgr stream (see Fig.5 of that paper).

3 How common is the Milky Way

3.1 There's no place like home? Statistics of Milky Way-mass dark matter haloes (MBK10)

The MW dark matter halo range between $[1 \times 10^{12} - 3 \times 10^{12}]$ typical $Rvir = 200h^{-1}$. It is not common to have large satellites as the MW.

3.2 The shape of the gravitational potential in cold dark matter haloes (Hayashi07)

Goal: Study the shape of the gravitational potential of CDM halos. Radial dependence of triaxilaity in the potential of CDM halos.

Main Results: Near the center the halo is prolate $c/a = 0.72 \pm 0.04$ and $b/a = 0.78 \pm 0.08$. in the outer regions the halo is more sphereical.

Method: Simulate 7 MW sized halos and 4 dwarf galaxies and meauser the b/a, c/a ratios at $z = 0$

3.3 Meausuring a, b, c.

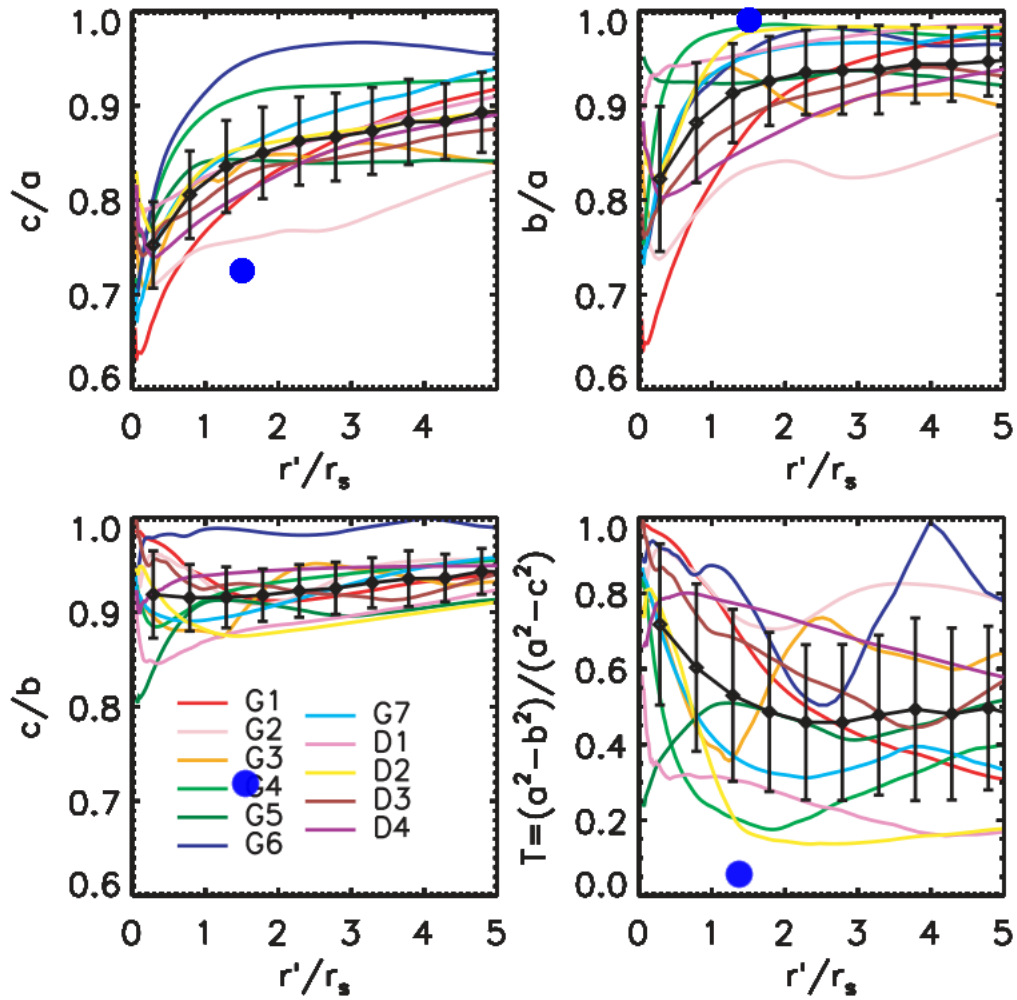
Rememer $c < b < a$

3.4 Halo shapes

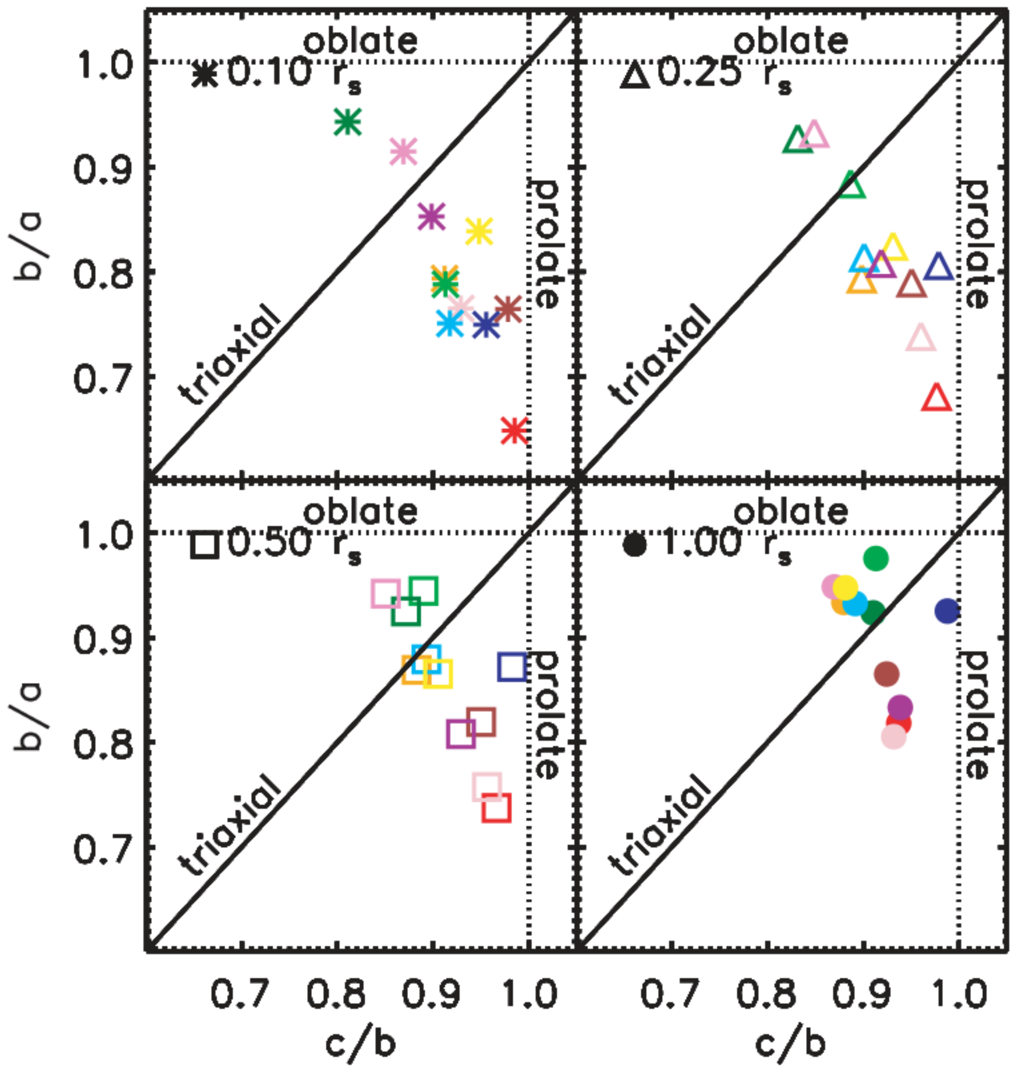
The monopole dominates in the outer regions of a centrally conentrated mass distribution, the n in the outer regions the potential is more spherical.

$$T = (a^2 - b^2)/(a^2 - c^2) \tag{1}$$

- $T = 0$ -¿ Oblate
- $T = 1$ -¿ Prolate



c/a
r'/r_s
b/a
r'/r_s
c/b
r'/r_s
G1
G2
G3
G4
G5
G6
G7
D1
D2
D3
D4
T=(a^2−b^2)/(a^2−c^2)
r'/r_s



From the figure:

- c/b is almost constant.

They study 7 galaxies how is this statistically significant?, always 3 galaxies are outside the error bars

The MW values according to [Law and Majewski, 2010] are: $c/a = 0.72$ $b/a = 0.99$, $c/b = 0.72$, $T = 0.042$

3.5 The shapes and alignments of dark matter halos Schneider, D(2012)

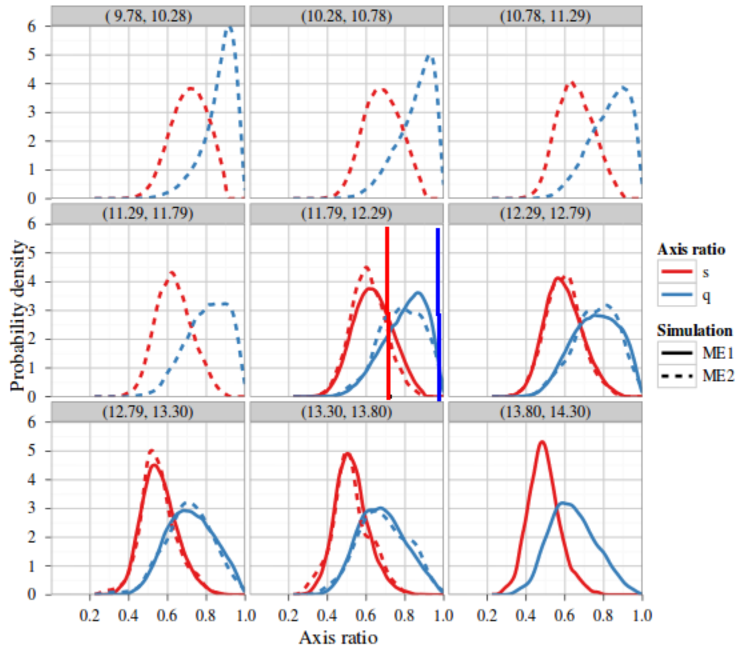
They study halos from $z = 0 - 1$

Halos: they can resolve down to the 10% of the virial radius. They use MilleniumI & II.

$a < b < c$

$s = a/c$, $q = b/c$

For the MW this is: $s = 0.72$, $q = 0.99$



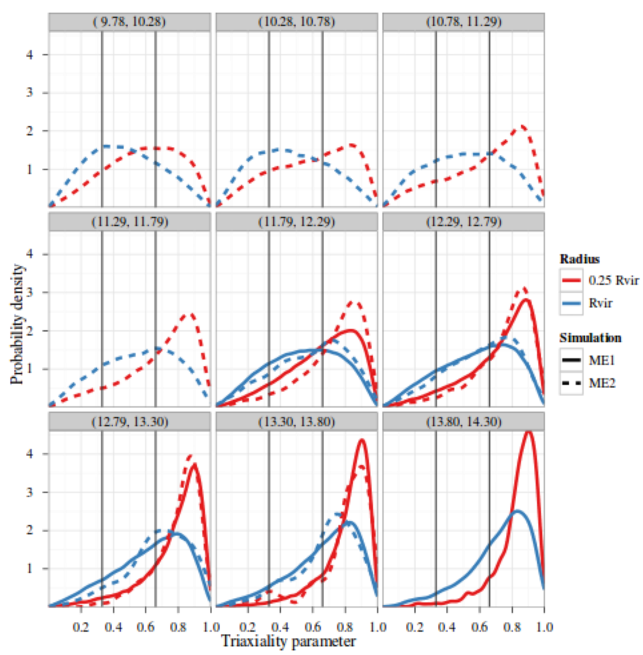
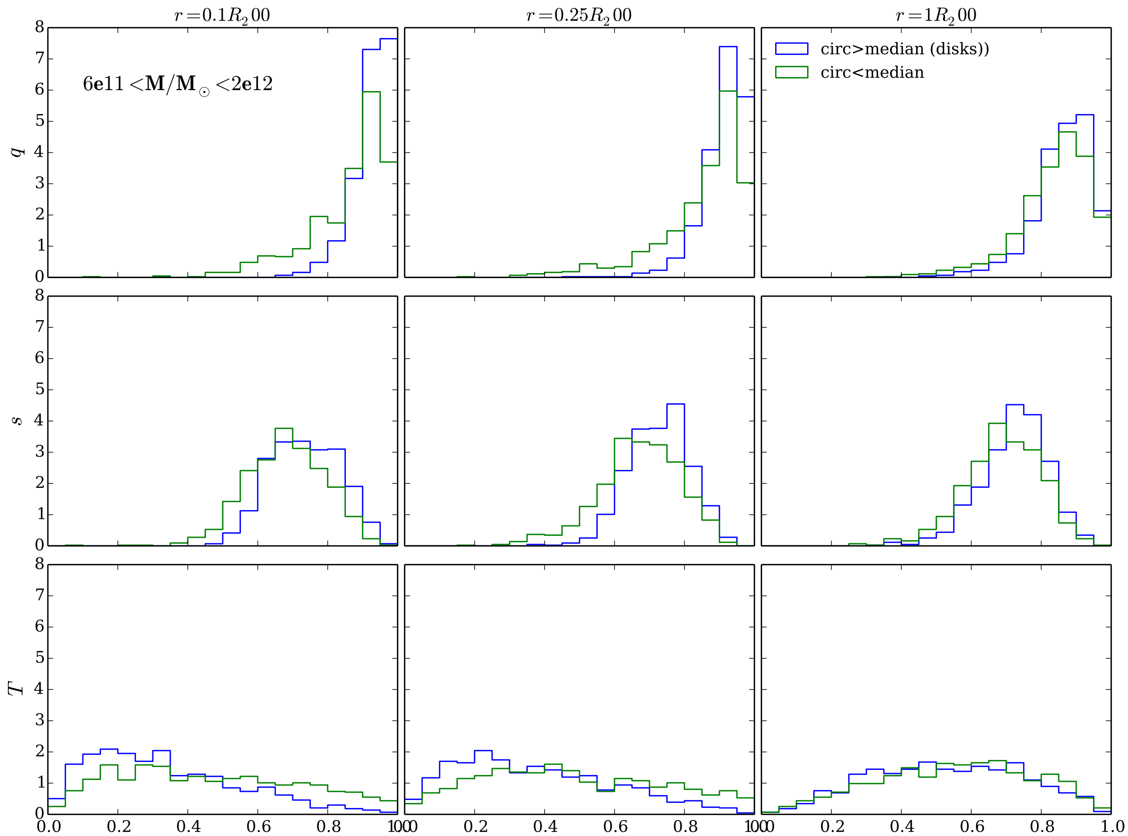


Figure 6. Triaxiality parameter, $T \equiv (a^2 - b^2)/(a^2 - c^2)$ at $z = 0$. The panels indicate bins in $\log_{10}(M_{200}/h^{-1}M_{\odot})$. $T \lesssim 0.33$ indicates an oblate ellipsoid while $T \gtrsim 0.66$ indicates a prolate ellipsoid.

3.6 Illustris halos



conclusion: Halos are more oblate in the center and at the outskirts are more triaxials

3.7 How the shape changes in time: (Vera-Ciro2011)

Goal: Determine the shape of the MW Dark Matter halo.

Main Results: individual halos changes with time, from prolate at earlier times to triaxial/oblate at present time measured in the virial radius. The halo shope is affected by accretion processes, if accretion is due to filaments the halo tends to be more prolate. When the accertio is more isotropic the halo is triaxial/oblate. The shape of the Dark Matter halo at diffeent radii shows the accertion history of the halo.

4 Alignments

4.1 Hayashi

Angle between the principal axes of the isopotential and the corresponding axis at larger radii. Solid lines show the results when the length of the axis differ from more than 5 percent, while dashed lines for axes with less tan 5 percent of length difference.

The main results are that in almost all the cases the 7/11 the axes are well aligned as a function of radii. (Why this happens?)

Minor axis in 6/11 tend to be alligned wih the total angular momentum vector (better that 25 at $r = 5r_s$), disks would tend to form on the plane of the major and intermediate aes of the halo. In prolate halos this plane doesn't have circular symmetry.

Most of the halos show a well alignment as a function of radius. Regarding the alignemnt of the potential with the angular momentum, they found that the minor axis tends to be alignment

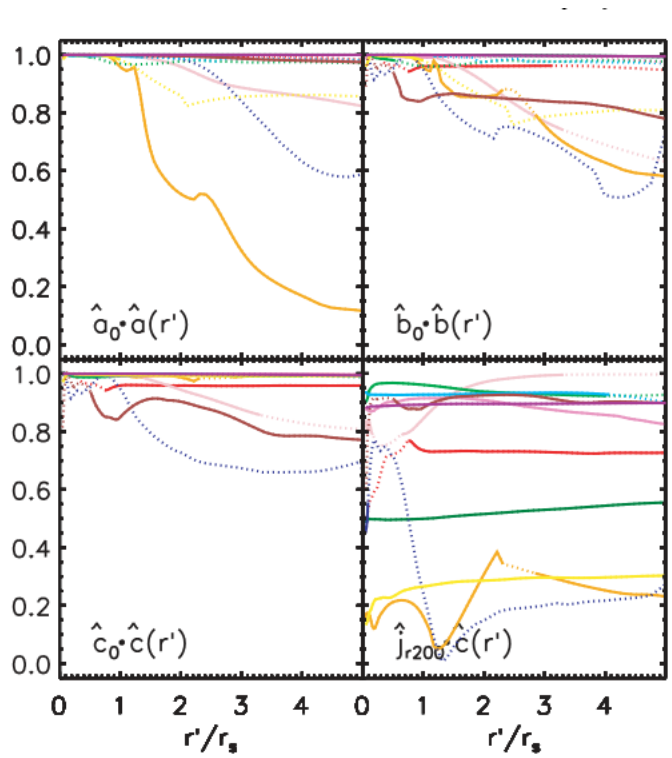
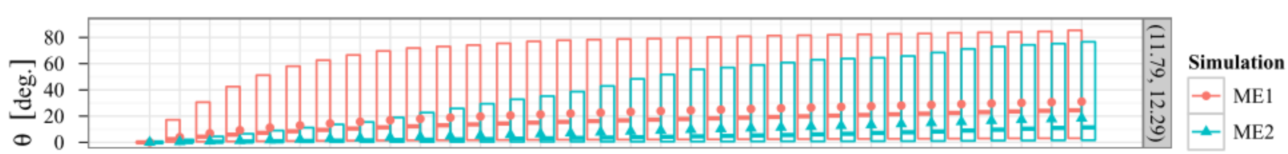


Figure 5. Alignment of principal axes as a function of radius. Vector $\hat{a}(r')$ represents the unit vector along the major axis of the halo, and $\hat{a}_0 = \hat{a}(r' \simeq r_{\rm conv})$. Dotted lines indicate radii where $c/b > 0.95$ and/or $b/a > 0.95$. For these nearly axisymmetric systems two of the axes' directions are poorly determined. In eight of the 11 haloes, the principal axes are well aligned with radius throughout the main body of the halo. In most haloes $\hat{j}_{r200} \cdot \hat{c}(r) \simeq 0.9$, indicating alignment of 25° or better between the minor axis and the angular momentum vector of the halo.

with the angular momentum vector 6 of 11 by < 25. This is important because discs tend to be align with the halo's angular momentum.

4.2 Schneider et al, 2012

Using the reduced inertia tensor (which reduces the effect to the alignment in comparison with the non-reduces intertia tensor) to measure halo shapes for halos at $z = 0.5$ in the Millenium I and II simulations. [?] found that halos major axis alignment tend to be perpendicular to the outskirds of the halos.



[?] also argue that the main difference between the Millenium I and II simulatios are due to the difference in resolution between the simulations. In Millenium I subhalos in the inner part of the halos are not resolved which makes that the angle between tha mayor axis increase.

5 Questions

1. Is the MW common in LCDM 2. What is the $\hat{L}$ of the MW, is it common in LCDM? 3. Is the triaxial shape of the DM halo related with the large scale structure in which the MW is embeded.

6 Numerical Simulations

References

R. Ibata, G. F. Lewis, M. Irwin, E. Totten, and T. Quinn. Great Circle Tidal Streams: Evidence for a Nearly Spherical Massive Dark Halo around the Milky Way. , 551:294–311, April 2001. doi: 10.1086/320060.

C. Vera-Ciro and A. Helmi. Constraints on the Shape of the Milky Way Dark Matter Halo from the Sagittarius Stream. , 773:L4, August 2013. doi: 10.1088/2041-8205/773/1/L4.

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