An evolving Milky Way dark matter halo, the influence of the Large Magellanic Cloud.

introduction

1 Introduction

In the current cosmological paradigm about 23% of the energy and matter content of the Universe is dark matter and 1% is barionic matter. Understanding the nature of the Dark Matter is one of the most important challenges of the physics. Astrophysical constraints are useful to test the predictions of the dark matter nature.

In the context of galaxy formation where structure grows hierarchicaly, barionic matter collapase inside dark matter halos where galaxies start to form. Therefore Galaxy formation processes are strongly related with the evolution of these dark matter halos and in particular the morphology, kinematics and dynamics of galaxies are usfeul observables that help to constrain halos properties.

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. More recent studies have suggested that halos in a ΛCDM Universe are triaxial (Jung& Suto 01).

Satellite galaxies and globular clusters that orbit around the host halos would give a hint about the mass and shape of the halo if the the position, line of sight velocities and tangential velocities were known. such observations have been made for several objects around the milky way and different research groups have constrain the mass of the milky way but there is not a consistent agreement yet.

Due to the dynamical friction satellite galaxies and globular clusters would decay into the halo of the MW. During this process the satellite would be distroyed leaving tidal streams (toomretoomre72), these streams where expected to be observed in the Milky Way (lblb95, jhonston96). The first satellite galaxy observed inside the Milky Way halo was the Sagittarius dwarf galaxy (ibata94) and the streams were observed (ivezic00, yanny00, ibata01b). A full observation of the stream was made by (majewsky03), the stream have a width (> 20) (belokurov06) and it warps for more than 360(majewsky03, piladiaz13, belokurov14) around the milky way, the velocity space is ($> 20km/s$) (koposov13) which suggest that the Sgr stream is dynamically hot.

With these observations several groups have attempt to reproduce the stream and found different halo shapes, (Ibata et al 01 (Spherical) ,Helmi 04 (Prolate), Johnston

New techniques are being developed with the aim of constraining the halo with multiple streams at different distances at the same time (Bonaca14). These techniques prevent the underestimate or overestimate of the halo mass.

However all of the studies that constrain the dark matter halo using streams assume a static dark matter halo, (Buist & Helmi15) claim that if the dark matter halo is changing in time misalignments on the orbit of long streams could appear.

The Milky Way dark matter is not isolated in fact it is interacting with a massive satellite $1 \times 10^{11} M_{\odot}$, the Large Magellanic Cloud (LMC) which is in it's first passage about the MW and is currently at the pericenter at 50Kpc from the galactic center. Such a massive satellite inside the virial radius ($R_{vir} \sim 261 kpc$) of the MW should be distorting the MW dark matter halo.

A detail study of the influence of the LMC in the MW dark matter halo shape is needed in order to prevent biases in the streams models. The aim of this work is study these influence for this aim we model the MW as an spherical halo that is distorted by the LMC. We integrate analytically the orbit of the LMC until the MW halo virial radius of $261 Kpc$, from these initial conditions we used N-body simulations to study the distortion of the LMC in a first passage scenario.

2 The Milky Way Dark Matter halo

2.1 Vera Ciro13

(**?**) 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 (**?**) it's not common in the LCDM model due to the small c/a ratio compared to LCDM predictions.

*** Is this actually an issue - canâĂŹt 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 (**?**) 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 ThereâĂŹs 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.

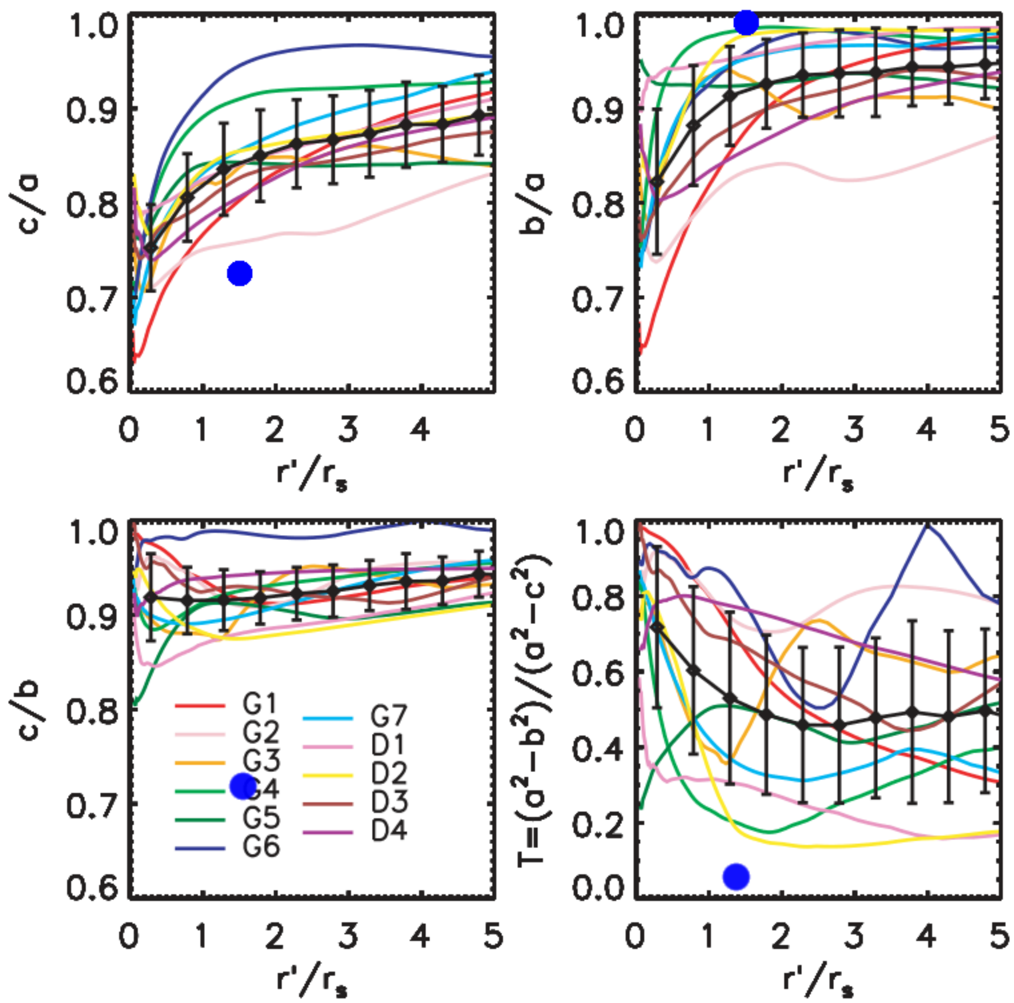
Rememer $c < b < a$

3.4 Halo shapes

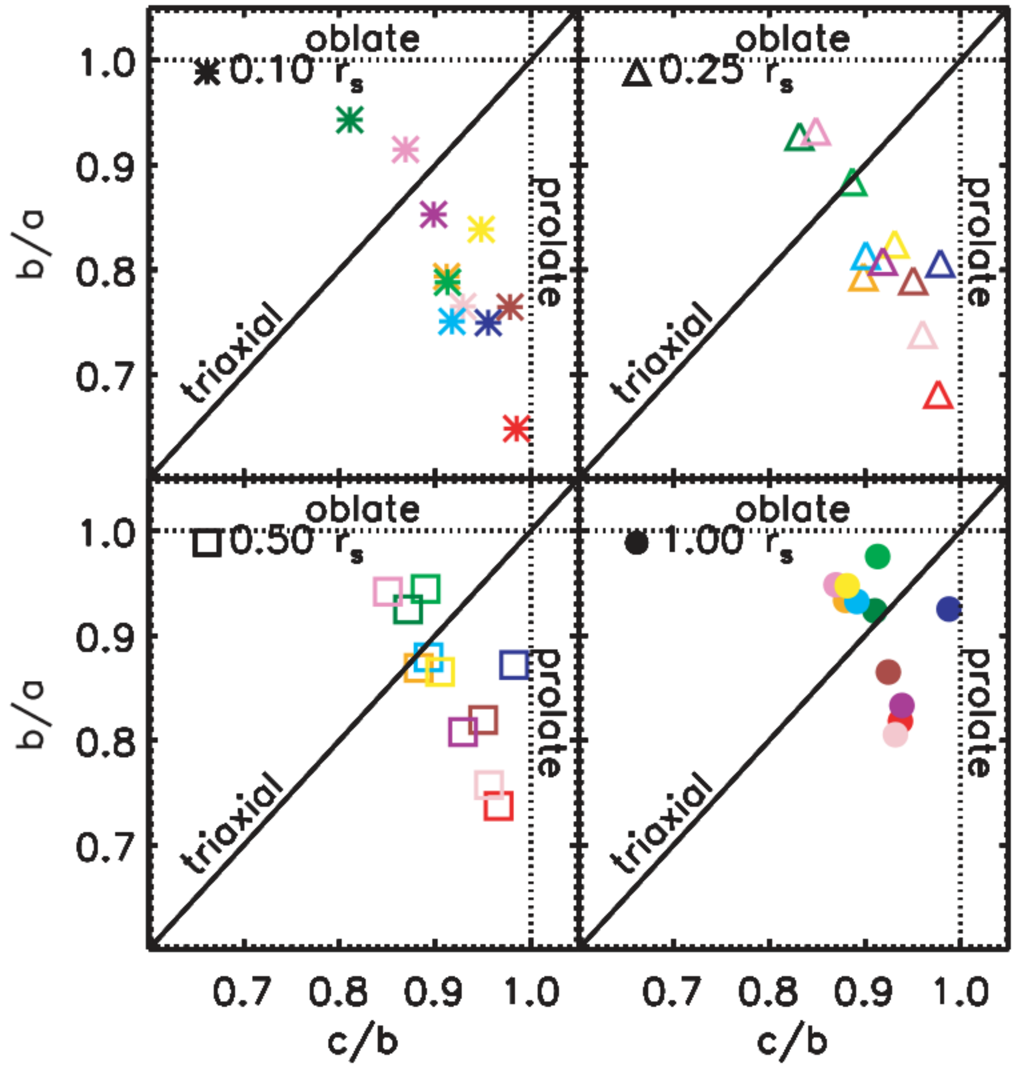
The monopole dominates in the outer regions of a centrally conentrated mass distribution, the n in the outer regions the potential is more spherical.

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

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



c/a
b/a
c/b
T=(a²−b²)/(a²−c²)
r'/r_s
G1
G2
G3
G4
G5
G6
G7
D1
D2
D3
D4



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 (**?**) 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)

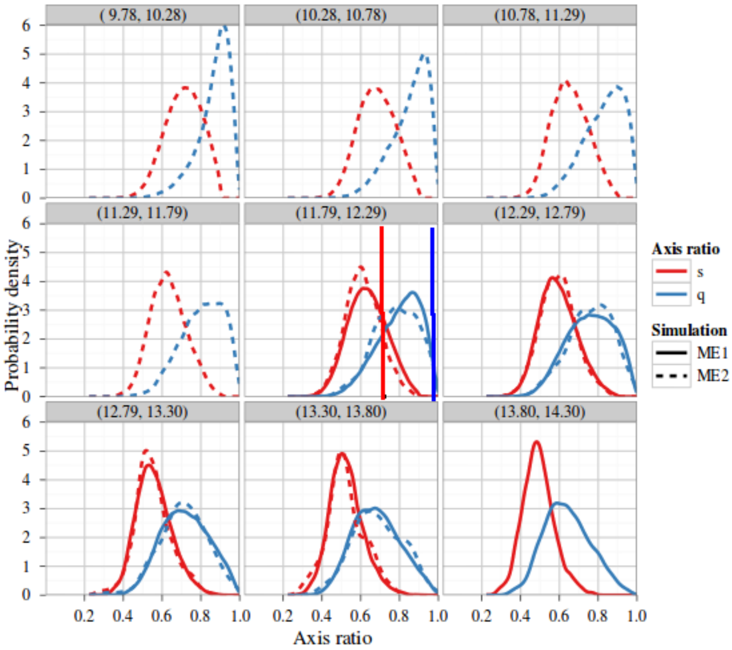
They study halos from $z = 0 - 1$

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: $s = 0.72, q = 0.99$



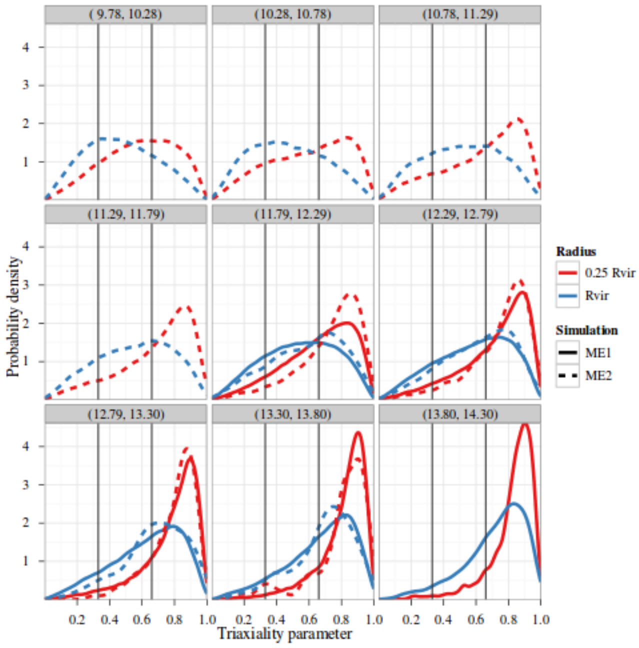
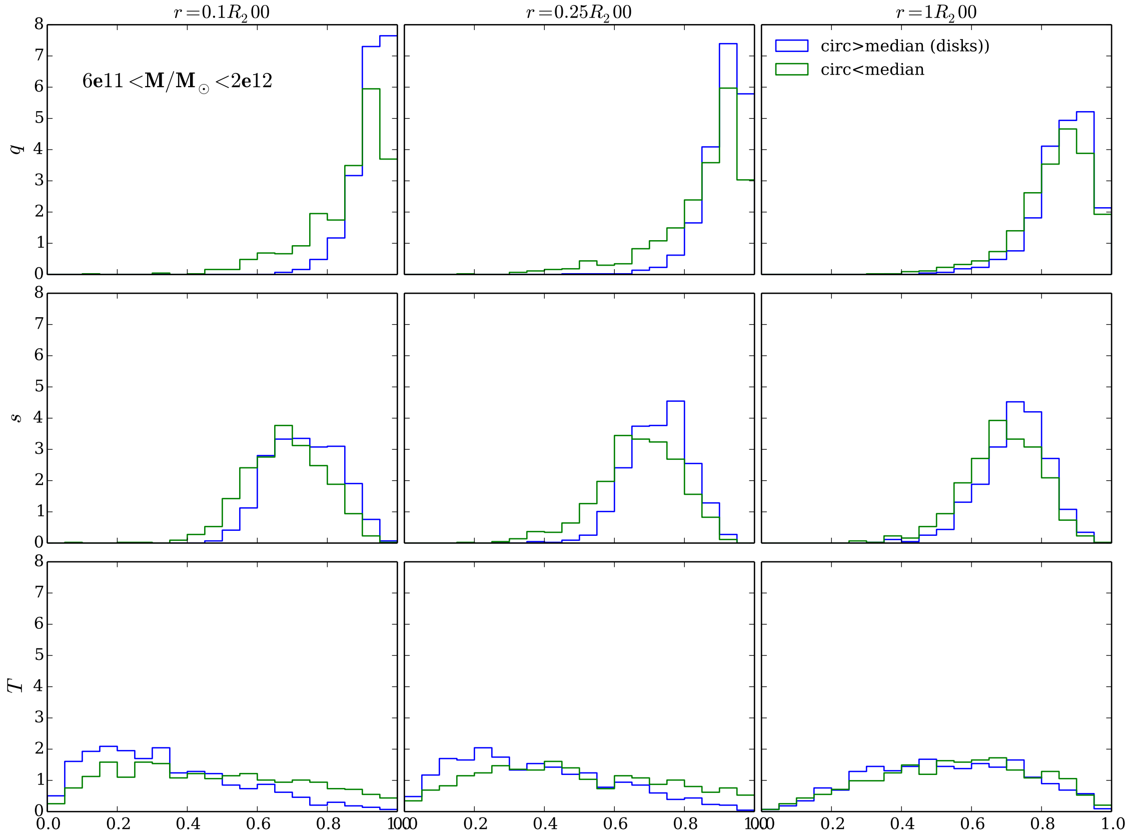


Figure 6. Triaxiality parameter, $T \equiv (a^2 - b^2)/(a^2 - c^2)$ at $z = 0$. The panels indicate bins in $\log_{10}(M_{200}/h^{-1}M_{\odot})$. $T \lesssim 0.33$ indicates an oblate ellipsoid while $T \gtrsim 0.66$ indicates a prolate ellipsoid.

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.

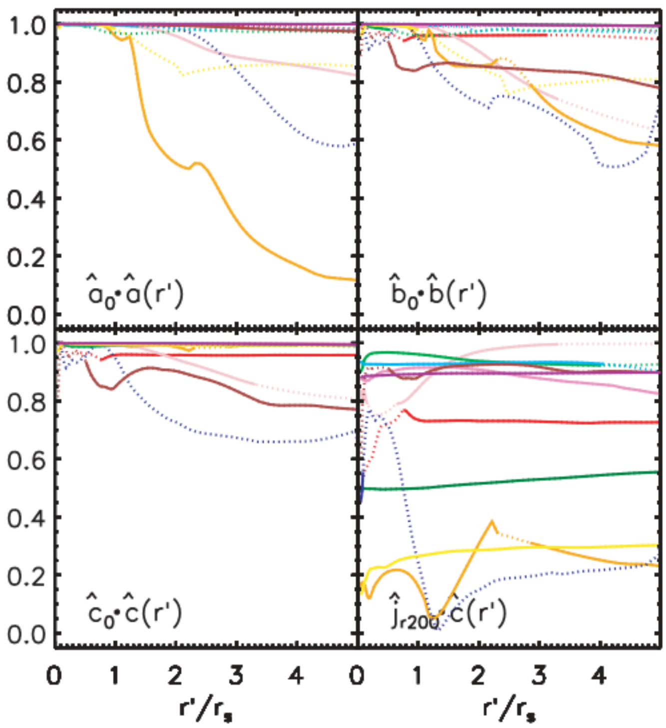


Figure 5. Alignment of principal axes as a function of radius. Vector $\hat{a}(r')$ represents the unit vector along the major axis of the halo, and $\hat{a}_0 = \hat{a}(r' \simeq r_{\mathrm{conv}})$. Dotted lines indicate radii where $c/b > 0.95$ and/or $b/a > 0.95$. For these nearly axisymmetric systems 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.

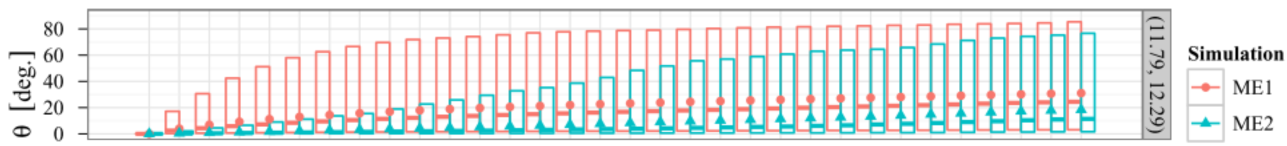
The main results are that in almost all the cases the 7/11 the axes are well aligned as a function of radii. (Why this happens?)

Minor axis in 6/11 tend to be alligned wih the total angular momentum vector (better that 25Âř 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 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

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.

Dynamical friction

6 Dynamical friction

IC

7 Initial Conditions

7.1 Orbit integration

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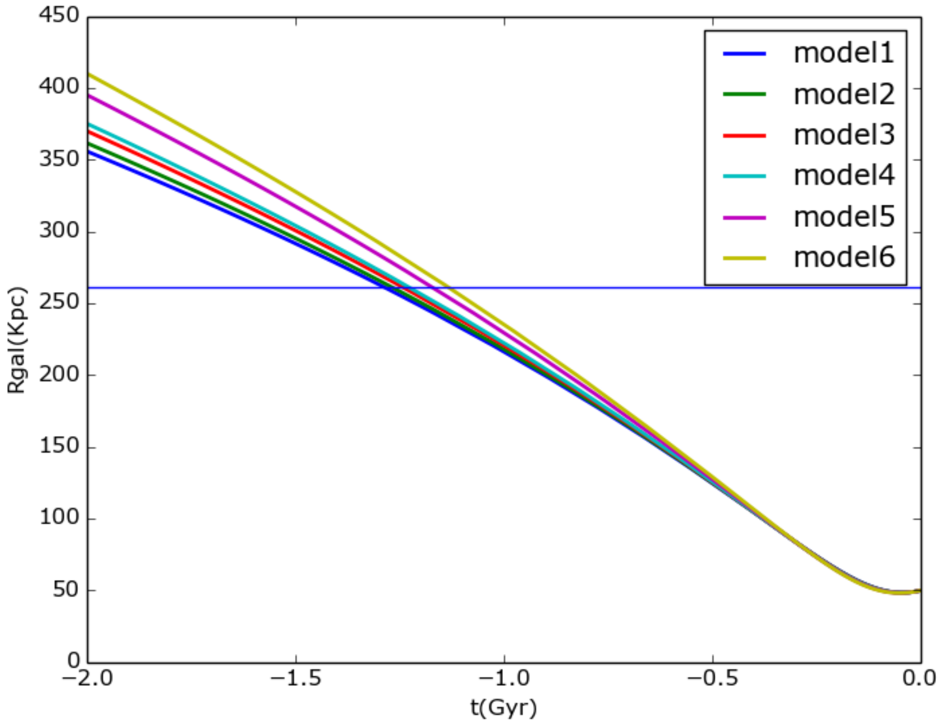
The orbit of the LMC is integrated backwards analiticaly:

The initial condition for all the orbits is the actual position $(X, Y, Z) = (-1, -41, -28)kpc$ and $(vx, vy, vz) = (-57, -226, 221)km/s$

Model	x(kpc)	y(kpc)	z(kpc)	vx(km/s)	vy(km/s)	vz(km/s)
model1	40.8	241.7	-89.68	-17.31	-156.68	-8.76
model2	40.4	243.46	-84.75	-17.45	-161.62	-12.02
model3	39.75	245.96	-77.89	-17.59	-168.41	-16.84
model4	39.28	247.32	-73.32	-17.61	-172.55	-20.25
model5	37.77	251.57	-58.65	-17.69	-187.15	-32.25
model6	36.47	254.04	-47.05	-17.41	-197.12	-42.85



450
400
350
300
250
200
150
100
50
0
Rgal(Kpc)
−2.0
−1.5
−1.0
−0.5
0.0
t(Gyr)
model1
model2
model3
model4
model5
model6