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Dark Matter Halo : the behavior under tidial forces in M33

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1. INTRODUCTION

The behavior of the dark matter halo in M33 due to the tidal forces caused by MW and M31 is yet to be understood. M33 is a spiral galaxy, third most massive member of the local group with the Milky Way (MW) and Andromeda (M31). It is believed that M33 is a satellite of M31 because it is gravitationally bound to the Andromeda galaxy. In detail, we will quantify and plot the evolution of M33's dark matter halo while it orbits the MW-M31 system. Specifically, I will study the change in M33's dark matter profile owing to mass loss from tides and quantify the mass loss rate as a function of time.

According to the definition from Willman & Strader (2012) a packet of stars hold together by more than baryon matter and gravitation define a galaxy. Baryon matter means gas and stars. So a galaxy also bound stars with dark matter. Galaxy evolution is defined by the modification of the morphology and/or the internal dynamics due to collision, star age or the super massive black hole in the center (Willman & Strader 2012)

Dark matter play an important role in galaxy formation and evolution. The depth of the potential well is increased by Dark Matter, which allow the galaxy to form stars by accretion of gas. Dark matter halo merge to form bigger structures, but as they merge, the smaller halo is not necessarily absorbed immediately and can become a sub-halo of the all structure (Delos 2019). This phenomenon is due to "Violent relaxation", defined from Lynden-Bell (1967) as a loss in the equilibrium of the system. The potential evolve due to a redistribution of the gravitational forces that makes the kinetic energy of the stars chaotic. By studying how the density profile of a satellite sub-halo of smaller size evolves due to tidal forces, we will be able to understand how dark matter mass loss impacts how galaxies are able to retain their baryonic matter. Since most of the mass comes from the dark matter halo, if it is tydaly removed, it is easier for the baryonic matter to escape. We would be able to predict how a subhalo merge with a larger Dark Matter halo by understanding the evolution of the mass profile of dark matter due to tidal forces. Figure 1 below shows the density profile of a Dark Matter Halo as a function of radius at different times. This study did not take into account the dynamical friction between the small sub-halo and the larger halo that merged together. We will also ignore friction in our analysis. In this figure we can see how the density profile of a Dark Matter halo is distributed without any tidal forces acting on it. This model will be helpful to compare the result we get under tidal forces and owing to mass loss. We know almost nothing about the behavior of Dark Matter except that even though we cannot see it, it interacts with normal matter via gravity. That property will allow us to predict the behavior of Dark Matter structure as the galaxies and halos merge during a collision using a simulation. Also, Wechsler & Tinker (2018) describes well how galaxies and dark matter halos are connected.

An important question in the field is how the growth and evolution of galaxies is connected to the growth and evolution of dark matter halos. Scientists think that the Baryonic matter has a direct impact in the density profile of dark matter halo (Grillo 2012).

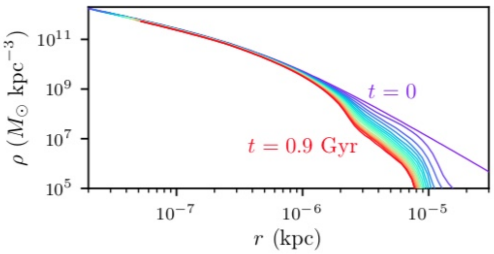

Figure 1. Delos (2019) Density Profile Evolution Of Halo as a function of radius at different times.

2. THIS PROJECT:

In this paper we will study the change in M33's dark matter profile owing to mass loss from MW and M31 tides and quantify the mass loss rate as a function of time.

We will be able to answer the connection of growth and evolution between the galaxy and the dark matter halo.

The galaxies are constantly changing under mass loss or gain. Analyzing how the density profile of the dark halo evolve over time owing to mass loss will describe the connection between dark matter halo and the galaxy

3. METHODOLOGY:

A plot of density profile shows how the density is distributed over some radius. Therefore, studying its evolution under some tidal forces I will show how the density profile of M33 halo evolve over time using snapshots as MW and M31 approaches one another. Figure 2 below is an example of density profile using different mass ratio of dark matter halo over stellar mass. This plot comes from Conroy et al. (2011) and give us more information about what the density profile of a dark matter halo look like ignoring mass loss.

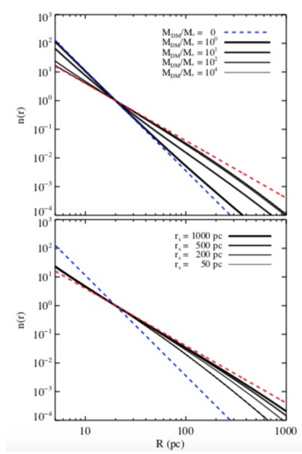

Figure 2. Conroy et al. (2011) Dark Matter Halo density profile with different mass ratio.

Using the mass enclosed over some radius (30 Kpc) dividing by the volume we get a density. For the hernquist density, it is given From Hernquist (1990) by :

$$\rho(r) = \frac{M}{2\pi} \frac{a}{r} \frac{1}{(r+a)^3} ,$$

Figure 3. Hernquist (1990) Hernquist Density as a function of radius.

We worked out plots for density profile of halo in Lab 6. Density profile will help us analyze the behavior of dark matter halo under tidal forces and mass loss. This will makes more sense as MW and M31 merge together to result in a system with a strong gravitational potential that will make M33 dark matter halo to react significantly.

I expect the mass distribution to change fast due to mass loss and try to reach an equilibrium which will correspond to the initial trend.

4. RESULT :

The graph show the Hernquist density profile of M33 at snapshot 0, meaning our time frame. The tidal forces come mostly from M31 and is increasing as a function of time but is not enought for Halo to react significantly yet.

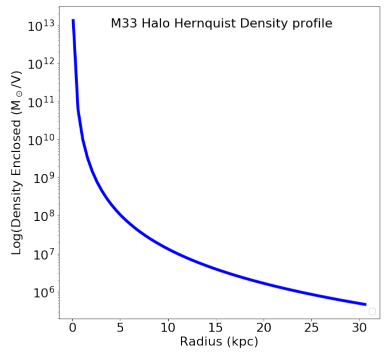

Figure 4. (Masini, 2020) Hernquist Density Profile of M33 galaxy today.

Figure 5 below show the density profile of the Dark Matter Halo of M33 galaxy. It is using snapshots 400 to 500 for the orbit the galaxy under the tidal influences of MW and M31, which correspond to 5.7 Gyr to 7.1 Gyr from now. Now the combined gravitational potential from the merger MW-M31 is huge and the Dark Matter Halo of M33 react immediately to the tidal forces.

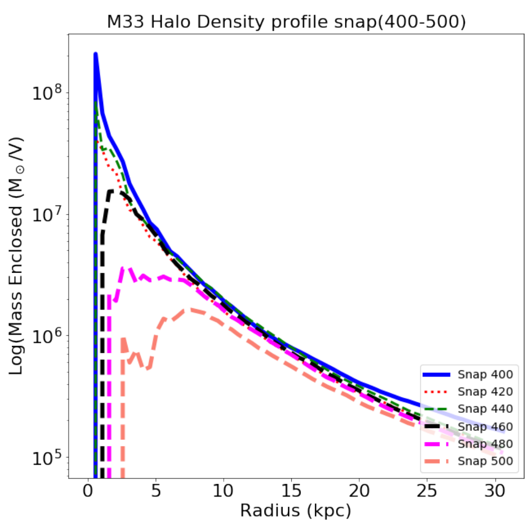

Figure 5. (Masini, 2020) Density Profile Of The M33's Dark Matter Halo from 5.7 Gyr to 7.1 Gyr.

Both plots have the same axis : logarithmic density in Y over a given radius in X. The density is given in Mass of the sun over spherical volume enclose using the given radius in X. The radius is given in Kilo Parsec.

5. DISCUSSION :

From the graph in figure 5, we can see that M33's Dark matter halo react really fast to the MW-31 system. In fact, we calculated in the code that the merger happened to be at 6.5 Gyr which reprensent the snapshot 455. Looking at the graph we see that the trend is pretty similar from 400 to 440 and in fact, it look almost the same from snapshot 0 to 440. But at snapshot 455 the density decrease faster and faster as time goes on. Moreover, mass loss can be observed later on where the density enclosed starts at near 0.5 Kpc at snap 400 and ends up starting around 2.5 Kpc for snapshot 500.

This result confirm our expectation of the fast respond of the halo due to the tidal forces.

The figure below from (Boylan-Kolchin & Ma 2004) show the density profile of the halo core particles after a simulation of a merger at 5 Gyr. Even though the radius shown on the X axis is larger than our plot, we see the trend looks similar of our result in figure 5.

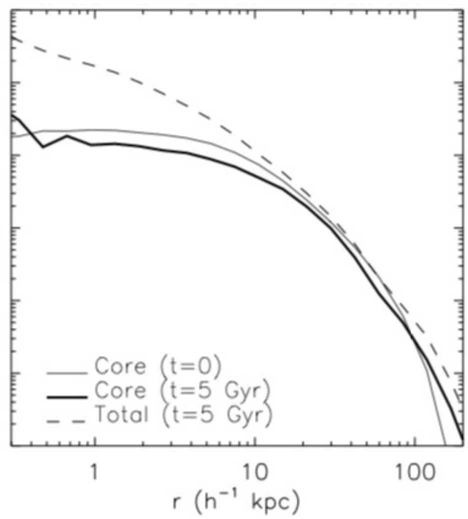

Figure 6. Boylan-Kolchin & Ma (2004) Density Profile of core particles of a collision simulation at 0 and 5 Gyr.

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