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Tidal Evolution of M33's Dark Matter Halo—Mass loss of Dark Matter and changes to internal dark matter profile

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1. INTRODUCTION

The spiral galaxy M33, which is located in the constellation Triangulum, is the third largest member of our Local Group of galaxies. Also, M33 and M31 are the closest massive galaxies to the Milky Way, and all of these galaxies(MW,M31,M33) are spiral galaxy. Thus, there are the large amounts of dark matter which were expected to dominate these galaxies, particularly in the outskirts of galaxies' disks, according to optical measurement of the rotation of spiral galaxies (Blok 2010). As indicated by the orbital analysis an velocity measurements which were presented in van der Marel 2012, M31 and the MW will merge at t = 5.86 Gyr (Marel et al. 2012). During the process of merging, the orbit of M31MW and the orbit of M31M33 will reduce within time, so these galaxies become closer to each other.Thus, shorter the orbits of M31MW and M31M33 will result in stronger gravitational interactions between the MW, M31 and M33. In other words, stronger gravitational interactions between galaxies will cause the impact of tidal fields between galaxies stronger that will change the morphology and kinematics of the inner and outer structures of all galaxies. In addition, the bound mass of a smaller satellite galaxy (like M33) will decrease over time, due to the tidal field of a massive galaxy(Boylan-Kolchin et al. 2011). Therefore, the proposed topic of the project is to study and analyze the tidal evolution of M33's dark matter halo, and put emphasis on two points: 1.mass loss of dark matter, 2.change of internal dark matter profile.

'Dark matter' is always the controversial and hot topic in the area of science. The majority of mass in the universe is in the form of dark matter. And according to the cold dark matter theory, we know that dark matter could only interact with baryons via gravity. As dark matter are dominated the mass of galaxies, so dark matter would control the gravitational filed of galaxies or the depth of potential well. If the total mass of dark matter decreased in the galaxy, then the galaxy would not retain part of its baryons or even accrete more gas. In other words, the change of the total dark matter mass of the galaxy controls the evolution of the galaxy. Therefore, studying the mass loss of the dark matter halo could help us to understand the evolution of satellite galaxies (like M33) which are affected by strong tides.

After t = 10 Gyr, the MW and M31 have formed a merged remnant, and M33 would lose 23.5percent of its that stars will be stripped from M33 (see the first graph on the right of figure1) (Marel et al. 2012). This result indicate that the mass of M33 will lose, due to the tidal evolution beside MW and M31 merger process. Otherwise, in Boylan Kolchin et al.(2012)'s research, astronomers could potentially detect the signal of dark matter annihilation, if the internal dark matter density is the highest enough(Boylan-Kolchin et al. 2011). If the internal dark matter density of a satellite were decreased, then the expected annihilation signal would be lower. So the change of internal dark matter density profile of a satellite galaxy(like M33) is very important to indicate that if astronomers could detect the signal of dark matter annihilation to do the future dark matter detection experiments. Then, the questions comes to M33.

After reading of Boylan Kolchin et al.(2012), I got some inspirations.Is the central dark matter density profile of M33 sufficiently high enough to produce a dark matter annihilation signal. And will that density profile change in the future. Everything related to dark matter is still a open question, in this field. However in this project, the mainly focus is studying and understanding the tidal evolution of M33's dark matter halo through mass loss of dark Matter and changes to internal dark matter profile based on the limited evidence we have.

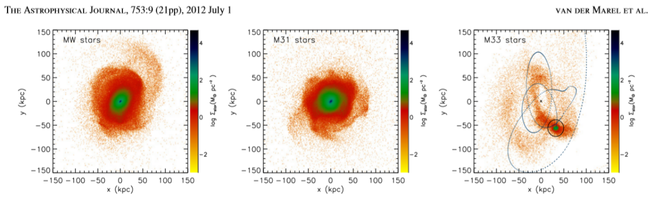

Figure 1. :illustrates the mass distribution of the MW, M31 and M33 in the final snapshot of the simulation, when the MW and M31 have coalesced. The final snapshot of the M33 simulation is on the very right. In the last simulation Snapshot of M33, 23.5 percent stars of M33 that will be stripped from M33. Much mass per particle is outside the Jacobi radius of M33 Marel et al. (2012).

2. THIS PROJECT

In this paper, we will study change of M33's dark matter halo profile and internal dark matter profile, during the period of M31 and M33's orbit evolution. We want to simulate the outer/internal dark matter mass profile and internal density disk/dark matter halo profile of M33 based on the simulation data of the merger of M31 and MW. The specific question of this project is to prove that M33 will lose dark matter mass due to the tidal influence from M31 and M33. I would create a program to compute Jacobi Radius and examine how much mass is outside this radius as function of time. Then making a plot of 'Jacobi Radius vs Time', to show will the Jacobi Radius decrease. And creating the dark matter halo mass profile and internal dark matter mass profile to check will the mass profiles decay in the future. The other question is trying to address what happened to internal dark density profile of M33, will it change.

As we introduced in introduction, the mass budget of a galaxy is dominated by dark matter, this dark matter also controls the depth of the potential well. The mass loss of the dark matter halo is important to understanding the evolution of satellite galaxies, such as M33 which is subject to strong tides. This in turn controls whether a galaxy can retain its baryons or even accrete more gas. Thus the depth of the potential well controls the evolution of the galaxy. Could the internal dark matter density profile of M33 sufficiently high enough to produce a dark matter annihilation signal, which matters can we observe dark matter in the future research area. So, it is also important to understand the change of internal density profile of M33.

3. METHODOLOGY

This project will simulate Jacobi Radius based on tidal radius/influence. And First, reading the M31 and M33 simulation files.

$$R_j = r\left(\frac{M_{sat}}{2M_{host}(<r)}\right)^{1/3}$$

Figure 2. Jacobi radius based on tidal radius of host mass

According to the 800 snapshots files of M33,M31and MW orbit Simulation, by which Prof. Gurtina,Besla provided, we will count mass per particle from each simulated coordination of M33 to make dark matter halo mass profile, one by one. After picking some samples from 800 snapshot files, we will use Hernquist Mass profile to modified the dark matter halo mass profiles of these samples.

$$\rho(r) = \frac{Ma}{2\pi r}\frac{1}{(r+a)^3} \qquad M(r) = \frac{M_{halo} r^2}{(a+r)^2}$$

Figure 3. Hernquist Mass ProfileHernquist (1990).

First at all, according to Jacobi Radius equation, I have to define two equations in the code. One is counting mass per particle, which is in the range between center of mass position of M33 and M31, as host mass from both M33 and M31 reading files. Another is counting mass per particle, which is in Jacobi radius of M33, as satellite mass. Next, we have to initialize the Jacobi radius, because we do not know M33's Jacobi radius. I will regard the first satellite mass as the initial Jacobi mass, and use the first host mass to get initial Jacobi radius. After that, I would bring the initial Jacobi radius,as the index, to Jacobi mass equation, when it is reading the second snapshot. And we can see how much mass per particle still in the initial Jacobi radius, get new Jacobi mass. Through new Jacobi mass and second host mass, we would get new Jacobi radius. Since we get new Jacobi radius, we could bring it to the third snapshot, and repeat above steps, until calculated Jacobi radius of last snapshot. Then, writing the Jacobi Mass(1e10$M_\odot$,Time(Gyr), and Jacobi Raidus(kpc) out to new data file, we can use those data to plot. From the Jacobi Radius vs time plot, we will see if M33 lose the dark matter mass. After getting Jacobi radius, I will pick several samples of snapshot files, by which M33 is near its Perihelion of M33 and M31 orbit, and produce dark matter halo mass/internal dark matter profile(with picking range of radius to separate). We will see the change of dark matter halo/internal dark matter mass profile in different timeline, we could see the mass loss of dark matter more obviously. Through using Hernquist profile, we can modify the dark matter halo mass/ internal dark matter profile of M33. we can calculate the internal dark matter density profile by divided spherical volume. Then according to the dark matter internal density profile of different timeline, we could decide that will M33 produce a dark matter annihilation signal more or less in the future.

I think the total mass of M33 will become smaller, and the amount of dark matter will decrease, due to the tidal influence. And the internal dark matter profile of M33 will also decrease, because stars of M33 went into tidal streams that the internal gravitational balance between dark matter and stars has broken. Thus, part of internal dark matter of M33, will toward out M33. And the internal dark matter density might increase or keep the same, because the evolution of the center of M33 might capture more mass or keep the similar rate. How can other matters win black hole via gravitational field battle.

4. RESULT

This figure(figure4) is Jacobi Radius vs time, I have also plot the M31 and M33 orbit on the plot. In order to see what happened in each step, I have make the radius of M31 and M33 ten times smaller. The blue line is Jacobi Radius vs time, the red line is magnitude distance of M31M33 orbit vs time of M31 and M33 orbit. So we can see Jacobi radius will be large at aphelion and reduce at perihelion of the same orbit of M31 and M33. In addition, as the M31 and M33 orbit reduce, the Jacobi Radius decline. Thus, M33 will keep losing mass due to the tides from M31 and MW.

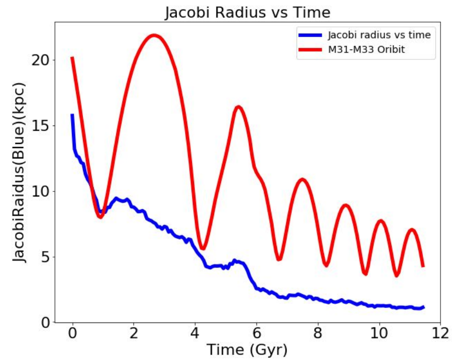

Figure 4. Jacobi radius vs Time, y axis is distance in kpc, x axis is time in Gyr. The blue line is Jacobi radius vs time, the red line is the diameter of M31 and M33 orbit vs time. the result I put ten times smaller M31 and M33 orbit is to show the relation between each time step more obviously.

On figure 5, the M33 dark matter halo mass profile from four perihelion of M33 and M31 orbit, in timeline. So as time past, this plot indicate that M33 will lose dark matter, due to the tidal influence from M31 and M33. The depth of the potential of M33 will decrease, so which means that M33 could not retain more baryons or even accrete more gas.

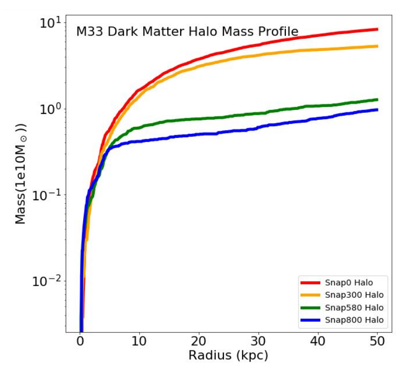

Figure 5. M33 Dark Matter Halo Mass Profile, the y axis is mass in unit of 1e10times solar mass, x axis is the distance to the center of M33 in unit of kpc. Four snapshot had taken to plot on, they are snapshot 0 300 580 800. Snapshot 0 is the initial dark matter halo profile of M33. And M33 would appear at the position of perihelion of M31 and M33 orbit, where the snapshots are 300 580 800

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