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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 Ire 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 project entitled "orbital analysis an velocity measurements" which Ire 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 with time, so these galaxies become closer to each other.Thus, the shorter orbits of M31MW and M31M33 will result in stronger gravitational interactions betIen the MW, M31 and M33. In other words, stronger gravitational interactions betIen galaxies will render the impact of tidal fields betIen galaxies stronger, which will consequently 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). Given that, this project is to investigate the tidal evolution of M33's dark matter halo, emphasizing on two points: 1.mass loss of dark matter, 2.change of internal dark matter profile.

'Dark matter' has long been a much-contested topic in the area of astronomical sciences. The majority of mass in the universe is in the form of dark matter. According to the cold dark matter theory, I know that dark matter could only interact with baryons via gravity. As dark matter predominates the mass of galaxies, dark matter will control the gravitational filed of galaxies or the depth of potential Ill. If the total mass of dark matter decreases in the galaxy, the galaxy will not retain part of its baryons nor 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 will 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 will formed a merged remnant, and M33 will lose 23.5percent of its stars which, in other words, will be stripped off M33 (see the first graph on the right of figure1) (Marel et al. 2012). This result indicates that the mass of M33 will lose due to the tidal evolution of MW and M31 merger process. Elsewhere, in Boylan Kolchin et al(2012)'s research, astronomers could potentially detect the signal of dark matter annihilation, if the internal dark matter density becomes high enough(Boylan-Kolchin et al. 2011). If the internal dark matter density of a satellite decreases, the expected annihilation signal will be loIr. So the change of internal dark matter density profile of a satellite galaxy(like M33) is very important to indicate whether astronomers can detect the signal of dark matter annihilation in order to do the future dark matter detection experiments. Then, the questions will be focus on M33.

Boylan Kolchin et al.(2012) is indeed inspirational for this project. 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 an intriguing question. HoIver in this project, the mainly focus is to study 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 I have.

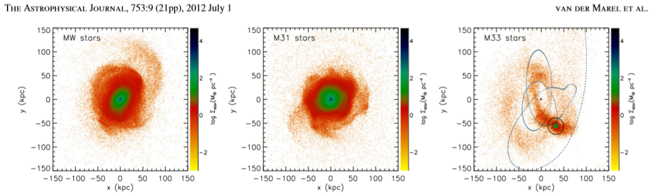

Figure 1. :illustrates the mass distribution of the MW, M31 and M33 in the final snapshot of the simulation, when the MW and M31 have coalesced. The final snapshot of the M33 simulation is on the very right. In the last simulation Snapshot of M33, 23.5 percent stars of M33 that will be stripped from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

2. THIS PROJECT

In this paper, I will study the change of M33's dark matter halo profile and internal dark matter profile during the period of M31 and M33's orbit evolution. I 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 will create a program to compute Jacobi Radius and examine how much mass is outside this radius as function of time. Making a plot of "Jacobi Radius vs Time" is to show whether the Jacobi Radius decrease. And creating the dark matter halo mass profile and internal dark matter mass profile is to check whether the mass profiles will decay in the future. The other question is to try to solve what happened to internal dark matter density profile of M33, whether it will change.

As detailed in the introduction, the dark matter will control the gravitational field or the depth of potential Ill of galaxies. The change of M33 dark matter total mass matters whether M33 will lose its baryons or accrete less gas in the future. Thus, it is important to know the change of M33 dark matter halo mass profile to predict the evolution of M33. In addition, if the internal dark matter density profile of M33 will be high enough to produce a dark matter annihilation signal, which matters whether human can do dark matter detection experiments of M33 in future. 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, which Prof. Gurtina,Besla provided, I will count mass per particle from each simulated coordination of M33 to make dark matter halo mass profile one by one. After selecting some samples from 800 snapshot files, I will use Hernquist Mass profile to modify 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 of all, according to Jacobi Radius equation, I have to define two equations in the code. The first one is to count mass per particle, which is in the range betIen center of mass position of M33 and M31, as host mass from both M33 and M31 reading files. The second one is to count mass per particle, which is in Jacobi radius of M33, as satellite mass. Next, I have to initialize the Jacobi radius, because I 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 will bring the initial Jacobi radius, as the index, to Jacobi mass equation, when it is reading the second snapshot. And I can see how much mass per particle still in the initial Jacobi radius, and get new Jacobi mass. Through new Jacobi mass and second host mass, I will get new Jacobi radius. Since I get new Jacobi radius, I can bring it to the third snapshot and repeat above steps until I have 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, I can use those data to plot. From the Jacobi Radius vs time plot, I will see if M33 lose the dark matter mass. After getting Jacobi radius, I will select several samples of snapshot files, in 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). I will see the change of dark matter halo/internal dark matter mass profile in different timeline, and I can see the mass loss of dark matter more obviously. Through using Hernquist profile, I can modify the dark matter halo mass/ internal dark matter profile of M33. I can calculate the internal dark matter density profile by divided spherical volume. Then according to the dark matter internal density profile of different timeline, I can decide that whether M33 will 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 will strip into tidal streams in which the internal gravitational balance between dark matter and stars has broken. Thus, part of internal dark matter of M33 will go out of 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 made the radius of M31 and M33 ten times smaller. The blue line is Jacobi Radius vs time,and the red line is magnitude distance of M31M33 orbit vs time of M31 and M33 orbit. So I 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.

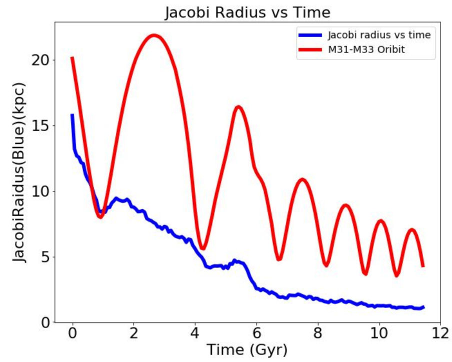

Figure 4. Jacobi radius vs Time, y axis is distance in kpc, x axis is time in Gyr. The blue line is Jacobi radius vs time, the red line is the diameter of M31 and M33 orbit vs time. the result I put ten times smaller M31 and M33 orbit is to show the relation betIen each time step more obviously.

In figure 5, the M33 dark matter halo mass profile is from four perihelion of M33 and M31 orbit in timeline. So as time goes by, this plot indicates that M33 will lose dark matter due to the tidal influence from M31 and M33. The depth of the potential well of M33 will decrease, which means that M33 could not retain more baryons nor accrete more gas.

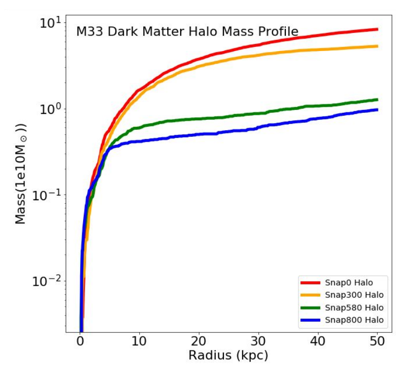

Figure 5. M33 Dark Matter Halo Mass Profile, the y axis is mass in unit of 1e10times solar mass, x axis is the distance to the center of M33 in unit of kpc. Four snapshot had taken to plot on, they are snapshot 0 300 580 800. Snapshot 0 is the initial dark matter halo profile of M33. And M33 will appear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

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