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Galactic Mergers and Evolution: Stellar Density and Sersic Profile Development Due to Tidal Forces

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1. INTRODUCTION

The Milky Way Galaxy (MW) and the Andromeda Galaxy (M3) are both members of the Local Group. The **Local Group** is a cluster of around fifty galaxies and spans about ten billion light-years. These two galaxies (i.e. MW and M31) will eventually undergo a galactic merger. This event will cause both galaxies to undergo serious cosmological changes. One thing that will evolve over the merger is the structure of MW and M31. Both galaxies have a stellar disk and stellar bulge region with their own properties. The **stellar disk** and **stellar bulge** refer to the stars that make up the disk and bulge components respectively within each galaxy. When MW and M31 merge within the next seven billion years, these two regions will interact with each other and combine. The dynamical forces, namely the tidal forces, will influence the result of this merger and the ongoing evolution of the two galaxies.

Density is a property of a galaxy that influences many different phenomena related to galactic evolution (P. Torrey et al. 2012). A **galaxy** is a gravitationally bound set of stars, gas, and dust whose characteristics and behaviour cannot be explained with Newton's laws of gravity. **Galactic evolution** is the process of the galaxy and its components changing over time. By observing the surface density of the galaxies as they merge over time we can learn about how galactic mergers influence evolution. With how old the universe is, it is difficult to see the whole picture that is galactic evolution. A galactic merger can hopefully allow us to see how a galaxy evolves in a shorter amount of time.

We know that after MW and M31 merge, the merger remnant will have a significantly larger radius that the original galaxies (R. P. van der Marel et al. 2012). With this, the surface density after the merger should follow a distribution similar to a de Vaucouleurs profile (A. Brooks & C. Christensen 2016). This means that the new elliptical merger remnant will have its density scale with the radius to the power of a quarter (outside of 1 kpc from the centre). Figure 1 shows the particles originating from MW and M31 respectively after the merger. It can be seen that the shape of the merger remnant consisting of MW and M31 should be elliptical when viewed face on.

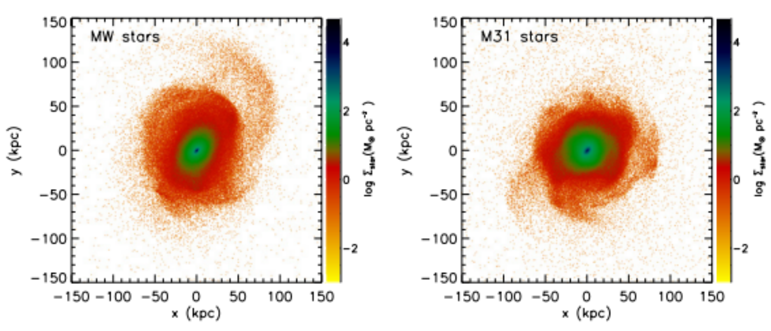

Figure 1. The distribution of particles at the end of the N-body simulation (t = 10 Gyr). Scale colour used to represent surface mass density. The centre of mass of each galaxy is at the highest-density position in its particle distribution (R. P. van der Marel et al. 2012).

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There are several questions relating to the evolution of the surface density profiles during the galactic merger. A very good question is how will the forces acting on the galaxies during the merger change their surface density profiles. Hopefully, by analyzing the way the galaxy surface density changes throughout this interaction and compare it to the initial densities and the density of the merger remnant, we can learn more about how galactic mergers and their density profiles impact galactic evolution. There is also the question of how the merger will impact the form of the two galaxies. As aforementioned, the merger remnant should be elliptical. The shape and density of the merger remnant could help us learn how to more easily identify other similar merger remnants. In the same vein, something must happen to the spiral arms of MW and M31 as the galaxies go from a spiral classification to an elliptical merger remnant. The tidal forces acting on the spiral arms cause them to evolve in such a way that the arms lose their definition during the merger. The simplest way to attempt to solve any of these questions is to use a simulation of the galactic interactions (R. P. van der Marel et al. 2012).

2. THIS PROJECT

The topic of this paper is to investigate the surface density and Sersic profiles of MW and M31. The **Sersic profile** is a method used to analyze the surface density of a galaxy by using the relation between the galaxy's radius and intensity.

The question I will be answering is how the surface densities and Sersic profiles of the disks of MW and M31 evolve over the course of the galactic merger.

While galactic mergers result in a new galactic form, the intermediate steps are just as important. The density and intensity of stars within a galaxy are very important parameters for a galaxy and by calculating and analyzing these values during the merger we may be able to see how these distributions evolve and are effected by the forces taking place in the merger event.

3. METHODOLOGY

In order to answer this question, I will have to complete a number of steps using the N-body merger simulation. The N-body simulation is referred to as such because it is a simulation modeling "N" number of particles used to represent the stars within a galaxy (R. P. van der Marel et al. 2012). This simulation in particular contains the stars for MW, M31, and M33 within all of their galaxy components (i.e. halo, disk, and bulge). The simulation contains the three dimensional positions and velocities of all these particles as well as their mass and position in time. I will be looking at surface density and Sersic profiles at various times for the disk regions of both MW and M31.

As previously stated, I will look at both the evolution of the disk (i.e. particle type 2). I would like to analyze the two galaxies at specific points in time using the LowRes files of the simulation. The LowRes files can be used since density is a value that does not depend on the tracking of each individual particle within the system. I will look at the initial conditions (i.e. snapshot 000), the first close encounter at four gigayears (i.e. snapshot 280), and the time they separate after that encounter at five and a half gigayears (i.e. snapshot 385). These values were found using Figure 2 to look at the separation between MW and M31 during the galactic merger.

At these times, I will calculate the Sersic profile for each galaxy and find the associated Sersic index that fits best. To do this, I will need to first compute the centre of mass of each galaxy for the given snapshot and the masses of each relevant component. I will need to do this so that I can then find the surface density for the disk using the equation below.

$$\sigma = \frac{M_{ann}}{\pi(r_n^2 - r_{n-1}^2)} \tag{1}$$

In order to use this equation, we must first create an annulus that encloses the majority of the galactic region. With this, you can find the sum of the mass enclosed at each annulus then take the difference between the current point and the one previous to find the mass at the current annulus value. This value is M_{ann}. r_n is the current radius from the annulus and r_{n-1} is the radius in the index before. This allows us to calculate our surface density over the entire component of the galaxy σ. With the surface densities, I can then calculate the Sersic profiles using the equations below.

$$I_e = \frac{L}{7.2\pi R_e^2} \tag{2}$$

$$I(r) = I_e e^{-(2n-\frac{1}{3})((\frac{r}{R_e})^{1/n}-1)} \tag{3}$$

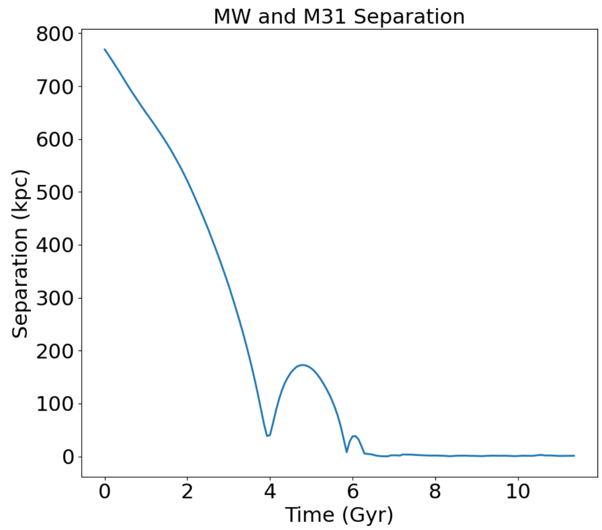

Figure 2. Plot showing the radial separation between the centre of mass of MW and M31 in kpc at a given time in Gyr.

L is the luminosity of the galaxy component which can be found using the mass-to-light ratio and R_e is the half light radius. With those values the Sersic profile $I(r)$ can be calculated at each value of r, r being the distance from the centre of the galaxy in kilo-parsecs. n is then the Sersic index that best aligns the function in Equation (2) to the surface density.

By over-plotting the surface density profile and sersic profile, I can determine which Sersic index is most accurate. I will plot these values at all three snapshots for both the disk and bulge. A fitting function will be used to help optimize the accuracy of the Sersic index to help guarantee accuracy.

I expect to find that the Sersic index at the start of the simulation one for the disk. I also expect to see this value change as the simulation moves forward in time. The galactic merger will effect the density of the stars and thus change the Sersic profiles.

4. RESULTS

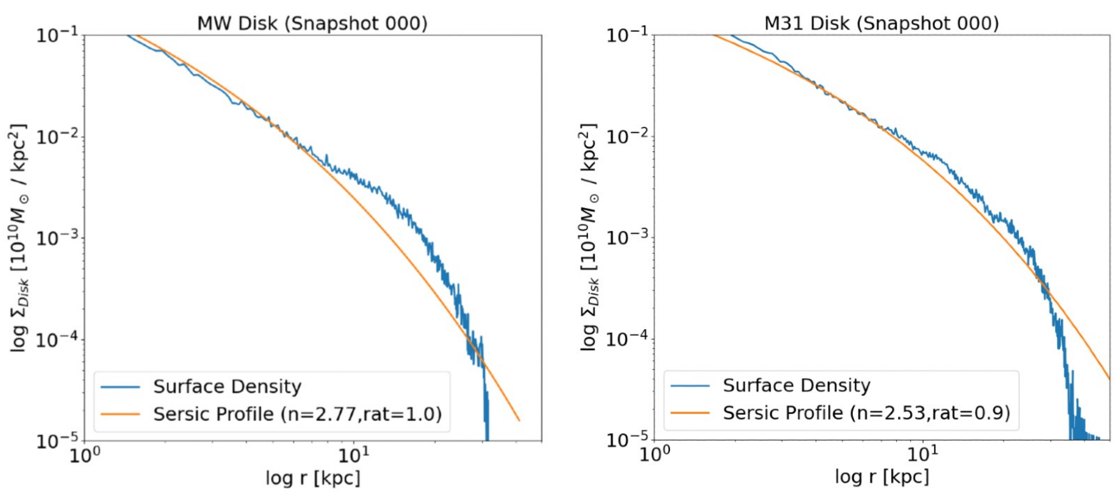

Figure 3. The initial Sersic profiles and surface density plots of MW and M31. Sersic profiles fitted to the surface densities by varying the Sersic index and mass-to-light ratio. These are the conditions of each galaxy before any close encounters (i.e. t = 0 Gyr).

Figure 3 represents our initial conditions for the disk regions of MW and M31. The surface density profiles were fitted for both galaxies using the methods described in Section 3. The Sersic profiles were calculated using Equation

(3) and fitting them to align with the density profiles by vary the Sersic index and mass-to-light ratio. By adjusting the bounds, the Sersic profiles could be made to align as closely as possible with the inner region of the galaxy. This was done due to the lower noise in the region and the possible influence from the dark matter halo closer to the galactic edge (T. Takamiya & Y. Sofue 2000).

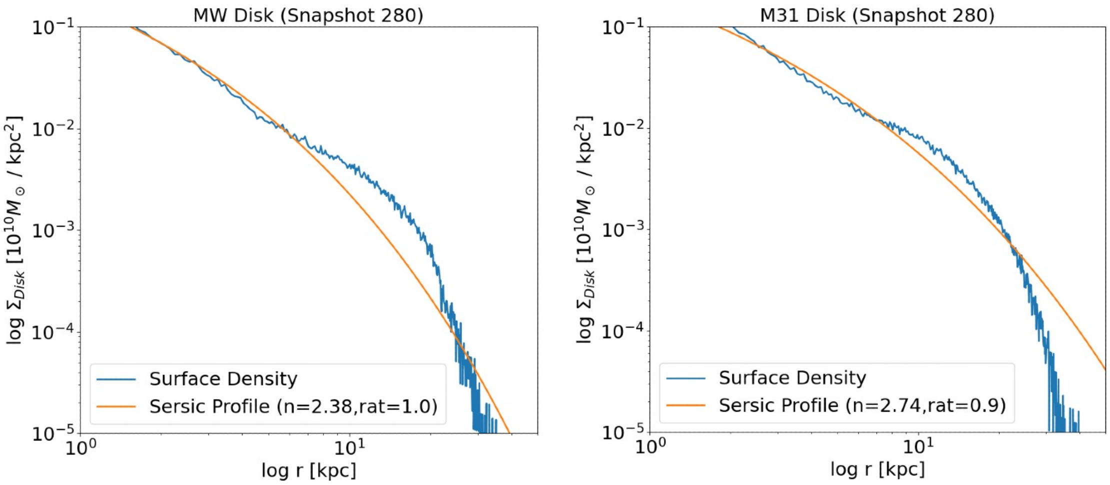

Figure 4. The Sersic profiles and surface density plots of MW and M31 at Snapshot 280. These are the conditions of each galaxy during the first close encounter (i.e. t = 4 Gyr).

Figure 4 is a similar plot made at about 4 Gyr in the future. This is when MW and M31 are undergoing their first close encounter. The plots were made using the same methods as Figure 3. We can see that the Sersic index has decreased for the MW disk and increased for the M31 disk.

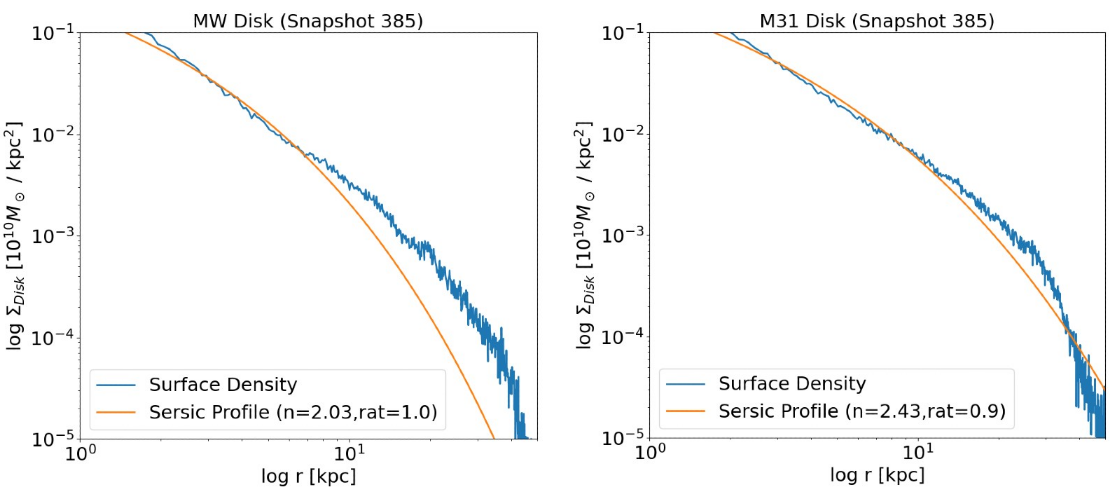

Figure 5. The Sersic profiles and surface density plots of MW and M31 at Snapshot 385. These are the conditions of each galaxy during the maximum seperation folling the first close encounter (i.e. t = 5 Gyr).

Figure 5 is another similar plot made at about 5 Gyr in the future. This is when MW and M31 are at their maximum separation after their first close encounter. The plots were made using the same methods as Figure 3 and 4. We can see that the Sersic index has decreased again for the MW disk and decreased for the M31 disk.

5. DISCUSSION

In Figure 3 we can see that the initial value for the Sersic index of the disk of the MW is 2.77 and 2.53 for M31. This does not agree with my initial hypothesis of the Sersic indices being close to 1.

The expected value is supposed to be around one, at least when the disks are orientated face on (B. A. Pastrav et al. 2013). This means that the values calculated here are in accurate, or the initial Sersic indices are larger than expected. This would mean that the intensities at the centre of each galaxy is brighter that expected.

It is likely that the orientation of the galaxies needs to be adjusted in order to achieve more accurate results. Once this is done, it may show the proper exponential profile.

In Figure 4 we can see that the Sersic index of the disk of MW decreased to 2.38 and increased to 2.74 for M31. This represents a fourteen percent decrease and an eight point three percent increase respectively. This is in agreement with the hypothesis I made.

The change in Sersic index represents a change in the intensity of the galactic disks over their radius. MW will have a lower brightness during the first close encounter of the merger and M31 will have a higher brightness (both relative to their initial brightness).

It is likely that the orientation of the galaxies needs to be adjusted in order to achieve more accurate results. The galaxies will be turned face on and their profiles recalculated.

In Figure 5 we can see that the Sersic index of the disk of MW further decreased to 2.03 and decreased to 2.43 for M31. This represents a fourteen point seven percent decrease and an eleven point three percent decrease respectively. That means MW experiences a total Sersic index decrease of twenty-six point seven percent and M31 experiences a four percent decrease over the first five gigayears of the merger simulation. This is in agreement with the hypothesis I made.

The change in Sersic index represents a change in the intensity of the galactic disks over their radius. MW will have an even lower brightness after the first close encounter of the merger and M31 will also have a lower brightness (both relative to their initial brightness and their brightness during the first close encounter).

It is likely that the orientation of the galaxies needs to be adjusted in order to achieve more accurate results. The galaxies will be turned face on and their profiles recalculated.

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