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

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ABSTRACT

This paper will analyze how the density and intensity of a galaxy changes due to galactic evolution as two galaxies experience a close encounter. Density and intensity are both definite galactic properties that can be used to learn more about a galaxy and how it evolves. By using a N-body simulation of two galaxies from the Local Group, this problem can be computed analytically. The Sersic and surface density profiles can be calculated at certain points during the galactic merger to learn how the galaxies change through the event. During the first close encounter, MW will have a Sersic index of 0.9 and a scale length of 5 and M31 will have a Sersic index of 1 and a scale length of 4.5. After the two seperate to their maximum distance, MW will have a Sersic index of 1.5 and a scale length of 2 and M31 will have a Sersic index of 2.05 and a scale length of 0.5. These results can be used to help astronomers learn more about how the intensity and density of a galaxy (or set of galaxies) evolve during close encounters.

Keywords: Local Group (929) — Stellar Disk (1594) — Major Merger — Spiral Galaxies (1560) — Sersic Profiles

1. INTRODUCTION

The Milky Way Galaxy (MW) and the Andromeda Galaxy (M31) are both members of the Local Group. The **Local Group** is a cluster of around fifty galaxies and spans about ten billion light-years and are all gravitationally bound. These two galaxies (i.e. MW and M31) will eventually undergo a galactic merger. This is what is known as a major merger. A **major merger** is a classification of merger event in which the mass of one progenitor is no more than three times greater than the other. 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 region with their own properties. The **stellar disk** refers to the stars that make up the disk within each galaxy. These disks have their own unique kinematics and smaller regions within themselves. However, these disks are found in spiral galaxies like MW and M31. **Spiral galaxies** are galaxies with a disk region that forms arms as the galaxy rotates. When MW and M31 merge within the next seven billion years, these 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 (B. Willman & J. Strader 2012). **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 than 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

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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. In addition, since elliptical galaxies lack a defined disk, something must change over the course of the merger as the two spiral galaxies combine.

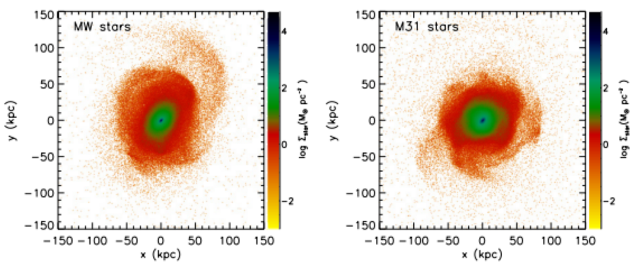

Figure 1. The distribution of particles at the end of the N–body simulation (t = 10 Gyr). Scale colour used to represent surface mass density. The centre of mass of each galaxy is at the highest-density position in its particle distribution. This shows that the two galaxies have the same centre of mass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

There are several questions relating to the evolution of the surface density profiles during the galactic merger. A very good question is how 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 affected 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 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 and scale length 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 mass of the 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

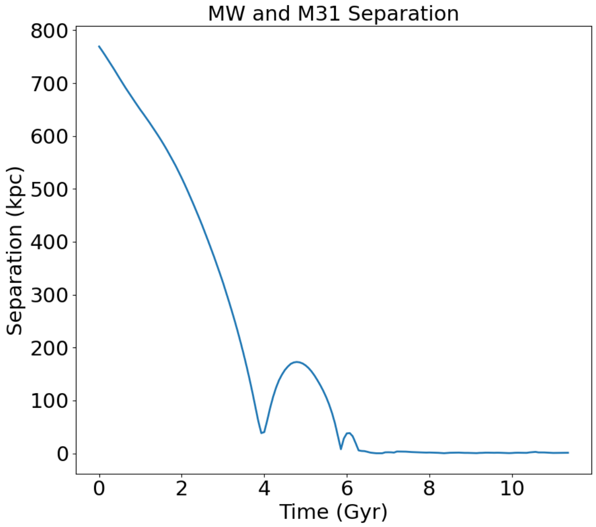

Figure 2. Plot showing the radial separation between the centre of mass of MW and M31 in kpc at a given time in Gyr. This shows us exactly when the galaxies have their first close encounter and separation.

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.

$$I_o = \frac{L}{\pi h_r^2 (2n)!} \tag{2}$$

$$I(r) = I_o e^{-(\frac{r}{h_r})^{\frac{1}{n}}} \tag{3}$$

L is the luminosity of the galaxy component which can be found using the mass-to-light ratio and h_r is the scale length. 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 of each galaxy. A fitting function will be used to help optimize the accuracy of the Sersic index to help guarantee accuracy.

I will assume that the Sersic index at the start of the simulation is one and the scale length to be five. I also expect to see these values change as the simulation moves forward in time. The galactic merger will effect the density of the stars and thus change the Sersic profiles.

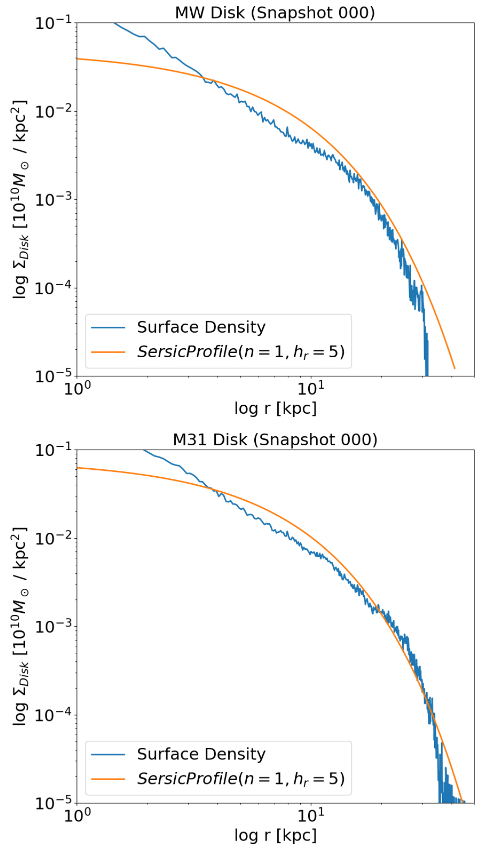

Figure 3. The initial Sersic profiles and surface density plots of MW and M31. Sersic profiles fitted to the surface densities by varying the Sersic index and mass-to-light ratio. These are the conditions of each galaxy before any close encounters (i.e. t = 0 Gyr).

4. RESULTS

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 used the accepted values for both the Sersic index and scale length. This provides a good baseline moving forward as we know that these values and plots are correct.

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, except the Sersic index and scale length were left unknown. I used a fitting function, but because the curves are not uniform, the algorithm had some difficulty determining a good fit. Ultimately, the final values for this calculation were checked by eye. We can see that the Sersic index has decreased for the MW disk and remained constant for the M31 disk. The

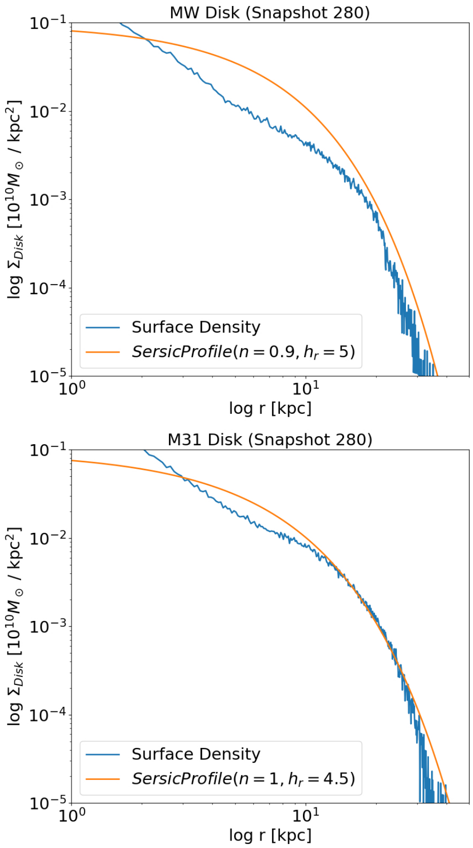

Figure 4. The Sersic profiles and surface density plots of MW and M31 at Snapshot 280. These are the conditions of each galaxy during the first close encounter (i.e. t = 4 Gyr).

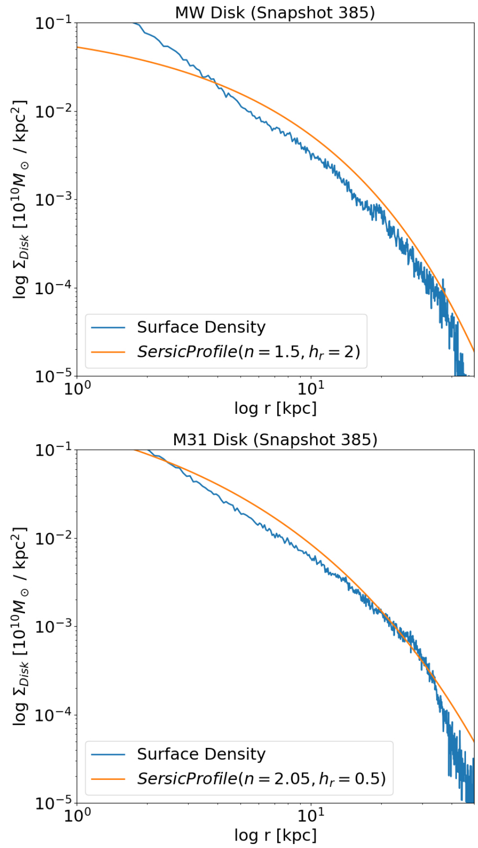

Figure 5. The Sersic profiles and surface density plots of MW and M31 at Snapshot 385. These are the conditions of each galaxy during the maximum seperation following the first close encounter (i.e. t = 5 Gyr).

scale length of the MW disk remained constant and decreased for M31.

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 4. We can see that the Sersic index has now increased for the MW disk and also increased for the M31 disk. The scale length of MW and M31 have also both decreased.

5. DISCUSSION

In Figure 3 we can see initial plots for the Sersic profiles and surface densities of MW and M31. The Sersic index of 1.0 and scale length of 5 were selected for both galaxies. The known value of the Sersic index is one, at least when the disks are orientated face on (B. A. Pastrav et al. 2013). This is a proper exponential Sersic profile.

In Figure 4 we can see that the Sersic index of the disk of MW decreased to 0.9 and remained constant for M31. For Mw, this represents a ten percent decrease. The scale length of MW remains the same and decreased to 4.5. This also represents a ten percent decrease. 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 (relative to their initial brightness) and M31 will have the same brightness. The scale length describes how the surface intensity drops over the galactic radius. Since MW and M31 are spiral galaxies, the scale factor is how many kilo-parsecs it takes for the intensity to drop by a factor of e. This means the intensity of M31 decreases faster at this time.

It is likely that the values found here are off by a small factor. As aforementioned, the calculated fits were not accurate so the values were chosen by eye. This means that there may be a value that matches the surface density better by a factor of a hundredth.

In Figure 5 we can see that the Sersic index of the disk of MW now increased to 1.5 and increased to 2.05 for M31. This represents a sixty-seven percent increase and a one hundred and five percent increase respectively.

That means MW experiences a total Sersic index increase of fifty percent and M31 experiences a one hundred and five percent increase 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 a greater brightness after the first close encounter of the merger and M31 will also have a higher brightness (both relative to their initial brightness and their brightness during the first close encounter).

It is likely that the values found here are off by a small factor. As aforementioned, the calculated fits were not accurate so the values were chosen by eye. This means that there may be a value that matches the surface density better by a factor of a hundredth.

6. CONCLUSIONS

The goal of this paper is to analyze how the density and intensity of a galaxy changes due to galactic evolution as two galaxies experience a close encounter. Density and intensity are both definite galactic properties that can be used to learn more about a galaxy and how it evolves. By using a N-body simulation of two galaxies from the Local Group, this problem can be computed analytically. The Sersic and surface density profiles can be calculated at certain points during the galactic merger to learn how the galaxies change through the event.

It is important to look at both of the results from the time of the first close encounter and the subsequent separation together. We can see that not only do the Sersic indices change, but so can the scale lengths of the galaxies. Both of these values do not change in the same way for each galaxy at the same point in time, even if the initial values are the same. We can see that they do also change from the first close encounter to their maximum separation. Not only this, but it can be concluded that this will continue as more close encounters occur before MW and M31 finally merge.

This also is how the project could be further expanded. The final result of the merger remnant can be analyzed to give a complete picture of how the Sersic index and scale length change over the entire merger. It would also be beneficial to include the M33 galaxy in the calculations, as it interacts with MW and M31 as they merge meaning that it will likely affect the results. Another future direction is to include the evolution of the bulge, as it will also have a change in its Sersic index and surface density as the galaxies merge. There is also a possible influence from the dark-matter halo closer to the galactic edge (T. Takamiya & Y. Sofue 2000).

7. ACKNOWLEDGMENTS

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