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The Stellar Bulge Density Distribution of the Merger Remnant of MW+M31

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ABSTRACT

Th subject of this paper will explore the possibility of our own galaxy the Milky Way (MW) and our neighbor, Andromeda (M31), forming a massive elliptical type galaxy as a result of their collision. This is important because the origin of the massive elliptical galaxies we see today are an ongoing subject of research due to the fact that current models of a much younger universe, shortly after the Big Bang, show us that the first elliptical-type galaxies that formed were actually very small 'chunks' of stellar material. So the question given to us is: How did these small chunks become the massive giants we see today? Could they have formed via the major mergers of spiral galaxies? The latter is the question this paper attempts to answer by looking at the simulation data of the MW-M31 collision provided by van der Marel et al., and predicting what the merger remnant bulge would look like. What we found was that the remnant was well fit by a Sersic profile with an index value of n=5.06, which is very close to the characteristic index value of n 4 that roughly describes all elliptical galaxies. This tells us that the major merger will most likely result in an elliptical, and a massive one at that since larger n-values correspond to larger galaxies. This result tells implies that the merging of two spiral galaxies is indeed a valid method for forming today's massive elliptical galaxies.

1. INTRODUCTION

Stellar merger remnants are an important stage of galaxy evolution. Their properties, such as the stellar bulge particle distribution/morphology, will contribute much to our understanding of these processes. One way of analyzing the merger is to compare the distributions of the stellar particles, in our case the bulge particles, of the merging galaxies so as to gain a better idea of how massive the remnant will be. This will give a good estimate of the actual galaxy mass and narrow down the range of Sersic profiles that would be a best fit. Since the amount of light we see will change dramatically during and after the merger, we'll need to compare the final result to several Sersic profiles and see if one can accurately fit the data. This will give us a good estimate of the size and luminosity of the merger and tell us if the predictions for elliptical galaxies are accurate, or if we need to gather new information.

Galaxies are currently defined as massive, gravitationally bound systems that have stars and dust, where stars are born and dying in multiple stages and can be explained by baryons and Newton's laws of gravity. (Willman & Strader 2012) Most importantly, the key characteristic that defines a galaxy is that it must have dark matter. Galaxy evolution occurs when the stars age and become redder, along with the accretion and expulsion of gas by a central black hole. Collisions with other galaxies can also happen, which will dramatically effect the evolution process, whether by merging two galaxies into one or simply passing by one another and exchanging their material. Understanding these galaxy mergers, as well as galaxy evolution as a whole, will help us better understand how the universe became what we see today and can even gives us some insight as to what the early universe (shortly after the Big Bang) might have looked like. Sersic profiles, which are the measure of a galaxy's light intensity with respect to the distance from the center of that galaxy, are one of our best tools in seeing if our theories actually match our observations. If they do match, then that means that the predictions that we make about the future stages of galaxy evolution are accurate and can be trusted.

Major mergers occur when two giant galaxies of roughly equal mass merge into a single body and create tidal structures known as 'tails' and 'bridges'. These structures are created due to the interacting tidal forces between the two disk galaxies. (Barnes & Hernquist 1992) This is important because so much material can be ejected into these 'tail' structures that it can become bound structures and form smaller dwarf galaxies. This in turn, will greatly affect the morphology and particle distribution of the final remnant. The number of tails depends entirely on how much mass there is between the colliding galaxies. When is comes to major mergers, such as the one in our simulation, the tails will be extremely long, curved, and binary, (Duc 2013) so we

Figure 1. On the right is the optical image of the prototypical merger NGC 7252 taken by ESO. On the left, is a HI map superimposed onto it by NRAO/VLA. Notice the very distinct tail-like structures coming from the merger, which is a clear indication for a major merger. From paper written by Duc+2013

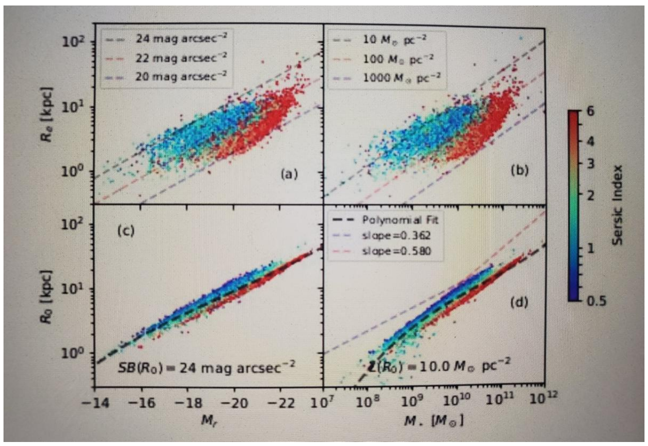

Figure 2. Top panel (a) is the effective radius, Re, on the y-axis and the absolute magnitude, Mr. Top panel (b) is Re vs. stellar mass. Bottom panel (c) is galactic radius, Ro vs. Mr. Bottom panel (d) is Ro vs. stellar mass. Notice how the more massive the galaxy is, the larger the Sersic index needed to compare it to. From paper written by J. Sanchez Almeida 2020

should expect to see such structures within our merger remnant. It should look something similar to Figure 1. We we also be utilizing graphs of the Sersic Profiles similar to ones seen in Figure 2. The final remnant should be an elliptical, considering that the current theory is that elliptical galaxies mostly form through mergers.

Despite our current knowledge, there are still unanswered questions we have regarding stellar bulge distribution/morphology. According to Querejeta et al,there are intermediate mergers that are not present in their database. This is important because studies show that intermediate encounters and multiple minor mergers may have been as relevant for the evolution of some galaxies, such as S0 (elliptical) galaxies. (Querejeta et al. 2015) This begs the question: What would our models and simulations look like if we were to include these intermediates? What parameters would have to be adjusted in order to accurately create them? However, a better question to work with is: Can massive elliptical galaxies form from the major merger of two disk galaxies? This is an important question because as far as we can tell, early elliptical galaxies were small 'nuggets' of stellar material in comparison to what we see today, and although we have some good ideas about how they grew, it is still unclear what the primary process for forming ellipticals is.

2. THIS PROJECT

What we're specifically focusing on in this paper is the final bulge result for the combined system of the Milky Way (MW) and Andromeda (M31), and seeing what information we can gather. The questions this paper aims to answer about this topic are: (1) What is the final stellar bulge density profile for the combined system?, (2) Is it well fit by a Sersic profile?, and (3) Does it agree with predictions for elliptical galaxies? This project will be able to answer these questions via the data used in the simulation.

The open question we'll be addressing is whether or not this merger is a valid method for forming a massive elliptical galaxy. This is because the most likely way for large ellipticals to form is through merging. As we observe today, a galaxy can gradually grow in size by accumulating the surrounding gas and stars in its local environment. However, there wasn't much material to accumulate in the early universe, so the only way to grow to the large masses we see today is through dry mergers, which occur when the merging galaxies have little or no gas left for star formation.

This question is an important one to answer because there are plenty of galaxies that aren't 'quenched', meaning they still have plenty of gas for active star formation, and these galaxies are also merging, just like the dry ones. There can be mergers between two quenched galaxies, mergers between two gas-rich galaxies, and mergers between one of each. While it's easy to assume that two gas-rich galaxies will result in a gas-rich remnant, this isn't necessarily going to be the case every time. The goal of this project is to try and be able to accurately predict what the resulting merger of MW and M31 will be based on the bulge density profiles and Sersic profiles. If the results are favorable, we may accurately predict what the future remnant of all galaxy mergers will be.

3. METHODOLOGY

The simulation and corresponding data come from a paper written in 2012 by van der Marel et al., where a combination of N-body simulations and semi-analytic orbit integration was used. N-body simulations are simulations used for dynamical systems of particles. They are also used in astrophysics for few-body systems, such as the system of MW-M31-M33 we're studying for this paper. Typically, these simulations are used to describe the motion of particles, but large bodies such as planets, stars, and galaxies, can be treated as points in space in order to study how they will change, thus making N-body simulations a valid method for studying their orbital evolution.

For this project, the first thing we found were the mass profiles of each galaxy, then of the merger remnant using the code from Lab 5. Afterwards, the code from Lab 6 will be used to find what the density profiles should look like, then can go about finding a Sersic profiles. In order to do this, the use of the code from Homework 6 to accurately predict when the two galaxies will merge in the future. The result we get tells us that the merger will happen about six gigayears from now. However, it is best to use the very last snapshot of the galaxy trajectories, long after the merger has occurred, in order to find the profile with the best fit for the remnant. The result will look similar to Figure 2, but should have different values for the galactic bulge mass and for the Sersic index values.

After finding the mass profiles, the next thing to find is the Sersic profiles of each galaxy separately, then of the combination of the two. This profile is given by the equation:

$$I(r) = I_e exp^{-7.67/((r/R_e)^{1/n}-1)} \tag{1}$$

where r is the radius of the galaxy (kpc), Re is the half mass radius (kpc), and n is the Sersic index. Ie is defined by another equation:

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

where L is the luminosity of the galaxy. Solve for Ie, then plug it into Eq.(1). Once this is done, we then use the mass profile of the galaxies to find the bulge mass, then find Re for that bulge mass. Finally, we graph the results.

The graphs created by the code should look something like this: AS you go further and further out in radius, the intensity in brightness we see is expected to decrease accordingly, which is what we see in Figures 3 and 4.

Because this collision will be between two galaxies with roughly the same mass, I expect to see a distribution of stellar particles that show two main tails coming from the remnant. According to the paper written by Duc, "...major mergers between spiral galaxies are long..., curved and binary. A main tail and a counter-tail are formed from each colliding galaxy. At the post-merger phase, the two counter-tails have already

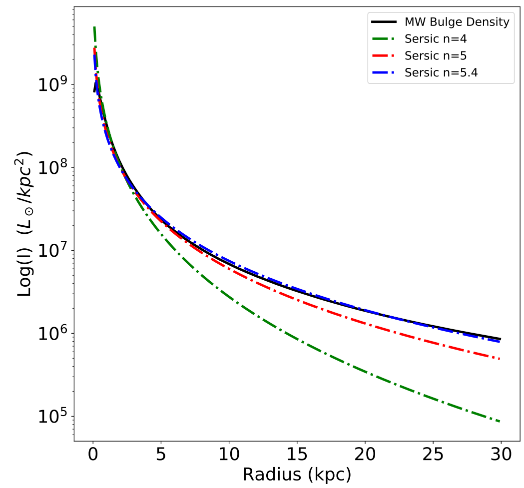

Figure 3. Initial MW bulge mass (solid black line) and different Sersic profiles (dotted lines) before the merger, with index values of n=4 (green), n=5 (red), and n=5.4 (blue). The x-axis is the distance from the galactic center and the y-axis is the log of the light intensity, I. The blue Sersic profile is the profile of best fit for the galactic bulge mass. Figure from In Class Lab 6

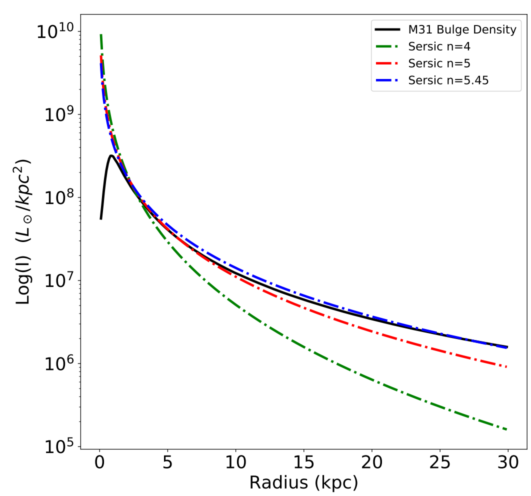

Figure 4. Initial M31 bulge mass (solid black line) and different Sersic profiles (dotted lines) before the merger, with index values of n=4 (green), n=5 (red), and n=5.4 (blue). The x-axis is the distance from the galactic center and the y-axis is the log of the light intensity, I. The blue Sersic profile is the profile of best fit for the galactic bulge mass. Figure from In Class Lab 6

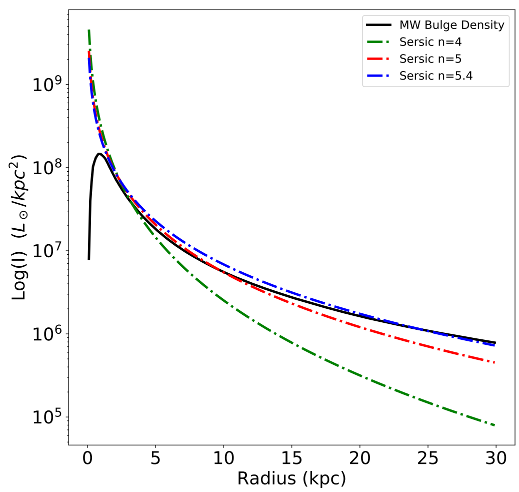

Figure 5. MW bulge mass (solid black line) and different Sersic profiles (dotted lines) after the merger, with index values of n=4 (green), n=5 (red), and n=5.4 (blue). The x-axis is the distance from the galactic center and the y-axis is the log of the light intensity, I. The blue Sersic profile is the profile of best fit for the galactic bulge mass. Figure from Final Project code.

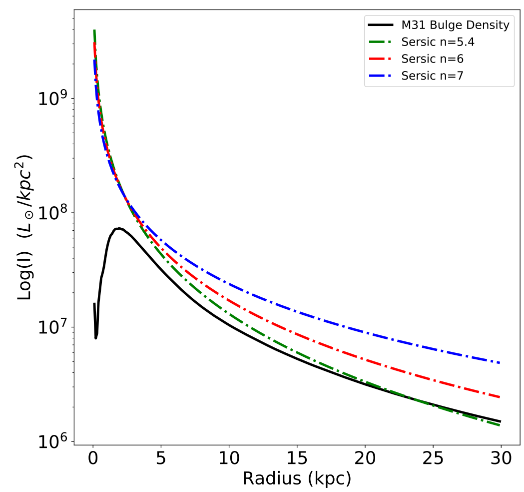

Figure 6. M31 bulge mass (solid black line) and different Sersic profiles (dotted lines) after the merger, with index values of n=5.4 (green), n=6 (red), and n=7 (blue). The x-axis is the distance from the galactic center and the y-axis is the log of the light intensity, I. The green Sersic profile is the profile of best fit for the galactic bulge mass. Figure from Final Project code.

dis-appeared; remain the two main tails.” (Duc 2013) Also, since this paper is exploring whether or not major mergers are a valid method for forming massive elliptical galaxies, the Sersic profile for the MW-M31 merger should have an index value of around, n=4. This is because n=4 gives us the de Vaucouleur’s profile, which is a specific Sersic profile that roughly describes elliptical galaxies.

4. RESULTS

The results from the code yielded the expected result. As seen in Figures 5 and 6, we successfully calculated the profiles for both the MW and M31 after the merger. What these two graphs show is that the total mass within the bulge of each galaxy dropped quite noticeably. This makes sense because as two galaxies of roughly the same mass come near one another, they exchange material, and sometimes even eject material out into space. The masses of every component of a galaxy, including the bulge, would understandably decrease as result of the interaction.

Once we had what the MW ad M31 would look like individually after the merger, the next thing to do was combine these results in order to get the final Sersic profile of the merger remnant. The result is what is shown in Figure 7. The profile in this figure has a line of best fit that isn’t as good as the other graphs, but it

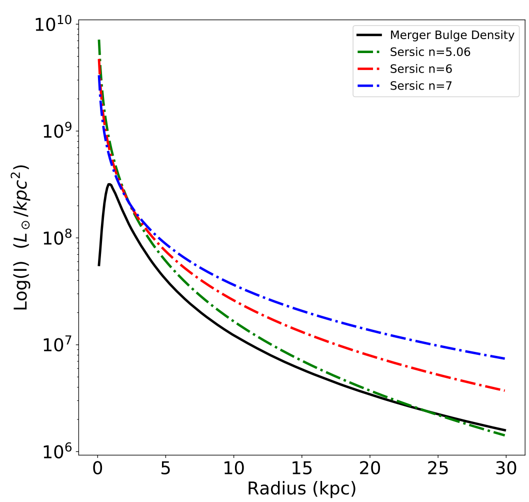

Figure 7. Final MW-M31 remnant bulge mass (solid black line) and different Sersic profiles (dotted lines), with index values of n=5.06 (green), n=6 (red), and n=7 (blue). The x-axis is the distance from the galactic center and the y-axis is the log of the light intensity, I. The green Sersic profile is the profile of best fit for the galactic bulge mass. Figure from Final Project code.

is still good enough to make a conclusion based off the data.

5. DISCUSSION

Based off of the result obtained from the code, the final bulge density of the merger remnant is well fit by a Sersic profile with the index value of n=5.06. Considering the most elliptical galaxies are roughly characterized by an index value of n=4, this heavily implies that the remnant may in fact be an elliptical galaxy that forms as a product of a major merger. This means that the hypothesis of major mergers being a valid way to form massive ellipticals is in fact correct. Most current literature on the subject also lends credence to this method of formation. The implications of this result show that current theories of galaxy formation are valid, and that we can accurately predict what the final outcome of major galactic mergers will be.

6. CONCLUSION

This paper strove to explore the bulge density of the merger remnant between the MW and M31. Specifically, we wanted to find out whether or not the major merger of two similarly massive spiral galaxies would be able to form a massive elliptical galaxy. We did this by observing the bulge density of the remnant and seeing if it was well fit by a Sersic profile. If the profile corresponded with an index value of around n=4, then this would mean that the remnant is indeed an elliptical galaxy, at least in terms of the bulge density.

What the final result told us was that the Sersic profile that best fit the bulge density of the merger had an index value of n=5.06, which is close to the characteristic value of n=4 for ellipticals. This means that the final bulge density that resulted from this galactic collision would be that of an elliptical galaxy, proving our hypothesis correct. Which means that massive ellipticals might indeed form from the collision of two spiral galaxies.

The next step would be to observe the disk density profiles of each galaxy, then the merger, and see if that has at profile of best fit with the appropriate index value. The reason we would want to this is because there three major components to galaxies: the bulge, the disk, and the halo. While we may not be able to find the Sersic profile of the halo given how far it is from the center of its galaxy, we can certainly figure out what the disk profile is using the same method we did for the bulge. All we would have to do is change the particle type within the code from 3, which are the bulge particles of any given galaxy, to 2, which are the disk particles. If both the bulge and the disk end up giving us the same traits as those of an elliptical, then it only further solidifies the fact that MW and M31 will form an elliptical galaxy.

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