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SURFACE BRIGHTNESS ANALYSIS OF THE MILKY WAY-M31 MAJOR MERGER REMNANT

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ABSTRACT

It is well-known that our own galaxy and Andromeda, located 2.5 million light-years away, are on a direct collisional path, and are expected to begin interacting in a few billion years. This morphological event is intriguing in many ways, but in particular because it will be between the two most massive spiral galaxies in the Local Group, with equal mass (MW-M31-M33 mass ratio of 10:10:1 (van der Marel et al. 2012)). The ultimate goal of this project is to understand what happens structurally to the stellar disks of the two galaxies and describe the resultant surface brightness profile of the new galaxy and fit it to a Sersic profile. The main questions we sought to answer in this project were: what do the initial and final stellar brightness profiles look like? Do they agree with the classical Sersic profile for spiral galaxies initially, and for elliptical galaxies post-merger? Simulating the formation and evolution of the merger remnant of these two galaxies will help us better understand the galactic morphology of other similar merger objects in our own Local Group, including older elliptical galaxies we are currently seeing at higher redshifts, and answer questions about their structure, scale, and star-formation rates.

Keywords: galaxy merger: general — galaxy morphology – galaxy interaction – galaxy merger: individual(Milky Way, M31)

1. INTRODUCTION

Galaxy mergers are an integral aspect to understanding how galaxies have evolved throughout time. In fact, it is thought that most existent galaxies were probably affected by some aspect of a merger at some point in their lifetimes (Barnes et al. 1992). These mergers are not considered "quick" phenomena by human standards, so observing a complete merger in real time is not possible, but simulating one can still present great insight. By attempting to understand this merger, we can better characterize the merger fraction of the nearby galactic population.

One benefit to studying the remnant of this particular spiral-spiral merger is that we can perform a galactic archaeology of sorts for other elliptical merger remnants and possibly determine characteristics about their progenitor galaxies. Usually bigger galaxies will "eat" smaller galaxies, but a merger of two equal-mass spirals is unique in that, "When these dynamical events occur, the structures of these systems often become very peculiar and distorted, especially when the merging galaxies contain a similar amount of mass in a major merger" (Conselice et al. 2014).

The majority of theoretical predictions regarding the MW-M31 merger conclude that the merger remnant's radial mass profile will be more extended that the parent galaxies' current profiles, suggesting that it will be elliptical in nature, and the paper this project is based on, (van der Marel et al. 2012), is no different. In order to answer the fundamental questions about the brightness profiles, we first had to find the initial mass profiles of the Milky Way and M31 independently because we only had mass information, not luminosity. After using this to determine the corresponding brightness profiles, we compared the results to known literature, and secondly, to find the brightness profile of the remnant left behind after the two galaxies are finished merging. For the purpose of this project, we considered only the stellar disk component of the remnant and a dissipation-less model (does not include gaseous components). The Sersic brightness profile is a useful way of measuring the light concentration within a galaxy (Conselice et al. 2014).

The Milky Way currently has a luminosity of approximately $L_\nu = 1.5 \times 10^{10}$, while Andromeda is about $L_\nu = 2.7 \times 10^{10}$. For spiral galaxies like Andromeda and the Milky Way, they are roughly well-described in the papers (Gilbert et al. 2012) and (Schodel 2014) to behave with exponential brightness profiles, with Sersic indices of n = 1. Once they merge, theoretically, it is expected they will morph into an elliptical galaxy with a Sersic index closer to n = 4, otherwise known as the de Vaucouleurs profile, which goes as $r^{1/4}$, meaning as the radius tends towards infinity, the overall surface brightness of the remnant will decrease faster. If an elliptical remnant has a cusp in its surface brightness profile, its disk can also be fitted with a n 1 model, which is used in (Lahen et al. 2018).

This project attempts to answer several questions about mergers, but many fundamental questions about them still remain, including: what are the realistic parameters that should be used for merger remnants and parent galaxies (Barnes et al. 1992), how is star formation affected, how have merger rates changed throughout time from the first galaxies to now, how do progenitor galaxies with bulges relate to the remnant ellipticity?

2. THIS PROJECT

The code created in this project aims to answer the questions: what do the brightness profiles of the stellar disks of M31 and the Milky Way look like now (initially), and what does their merger remnant brightness profile look like? This is important because knowing the answers to these questions can help us gauge what other galaxies looked like before their mergers, if two equal-mass spirals truly do result in an elliptical remnant as we expect, where the location of the Sun will be afterwards and how star formation rates will be affected, etc. Even though we are only considering the disk component for these purposes, it's noted that it has been found that the elliptical light concentration closely correslates with central massive black hole mass (Conselice et al. 2014).

For this project, we assumed a dissipation-less model, meaning we did not take into account the effects of the gaseous components for the stellar disk, because it only a small contribution to the overall mass of the galaxy. This means that it is possible the brightness profiles found may be slightly less bright because they do not include gas, which some simulations do, such as in (Hopkins et al. 2009), which had a dissipational component in the center and an outer dissipation-less component. The latter is the result of violent relaxation, where the particles' energy changes due to the overall potential change, which is also one reason (van der Marel et al. 2012) found that the Sun is displaced in their simulation. Violent relaxation and phase mixing in N-body simulations are also key components to understanding the internal dynamics of mergers. Phase mixing is a mechanism that will drive relaxation, causing a phase-space density to become more uniform, and subsequently determining if an remnant will be elliptical in nature.

The main motivation for choosing this project personally was to see what could be said about the star formation rates based on these surface brightness profiles, and hopefully use this as a parameter for similar spiral galaxies/spiral merger remnants we see in the visible universe. Star formation rates are correlated with surface brightness because as gas is depleted, less bluer stars are being formed, so "the remnant matures after coalescence, it gets dimmer and redder" and "the stellar population evolves predominantly passively" (Lahen et al. 2018). This luminosity analysis may also help us classify more irregular-type galactic objects and narrow down parameters for other spiral and elliptical galaxies.

3. METHODS

The basis of this project comes from the collision-less N-body simulations and semi-analytic orbit integrations from (van der Marel et al. 2012). Their simulations were used to determine the approximate times when the Milky Way, M31, and M33 make pass-bys and subsequently merge completely. They also aim to determine the remnant's galactic classification and the fate of the Sun's location after the merger. They also assume a dissipation-less model. This project uses 3 main text files from this simulation that contain the time elapsed from now until 10 Gyr from now, and the corresponding (x,y,z) positions and (vx,vy,vz) velocities of each of the three galaxies at any particular point in time. Using these, we were able to calculate the three-dimensional position and velocity vectors for the center of mass (COM) reference frame for each galaxy, and find the difference between the vectors of a galaxy with respect to another. The orbit integrations then can be used to find the motion of the galaxies' COM. Using these, the simulation is able to model the dynamical evolution between the galaxies as their separation becomes smaller, orbits decay, and they make three pass-bys before finally merging completely. The entire simulation uses a combination of all the codes we have written this year for homework to analyze the kinematics and structure of M33, M31, and the Milky Way from now until approximately 12.5 Gyr from now.

$$I(x,y) = I(r) = I_e \exp\left\{-b_n\left[\left(\frac{r}{r_e}\right)^{(1/n)} - 1\right]\right\}$$

Figure 1. The Sersic profile, where Re is the half-light radius, Ie is the intensity at R=0, and n is the Sersic index.

The simulation is broken up into "snapshots" throughout time, with the final snapshot corresponding to roughly 12.5 Gyrs from now, or about 10 Gyrs after the initial pass-by. Snapshot 0 is defined as the initial time of the simulation, or the present day. Much of this code was based upon Homework 5 and In-Class-Lab-4 to find the mass profiles and use a Sersic fit. Because we do not have luminosity information from the simulation, we must use the mass information and use the mass-to-light ratio and the Sersic function to put the information in terms of luminosity, shown below in Figure 1. Within the disk, we wanted to define the mass of particles at a given radius. Instead of defining a large volume within a sphere of just one radius, we defined many, very thin, concentric shells of width 0.5 kpc out to approximately 20 kpc and determined the number of particles contained within each so that we can eventually calculate the flux through each shell. We wanted to make the change in shell radius small enough that the shells did not overlap so that particles were double-counted. We plotted the mass profiles. To begin finding the surface brightness profiles, we wrote a function to calculate the half-mass radius, or the radius at which half the total galactic mass is contained. This would then be used as the half-light radius. Mass and luminosity are related through their ratio, which we took to be 1.5 for both galaxies in this case. We then calculated the Sersic fit for each galaxy and plotted the Sersic profiles against typical fits for spiral and elliptical galaxies.

In addition to finding the initial profiles at snapshot 0, we found them at key moments throughout the merger, including t = 3.87 Gyr, the approximate time M31 and the Milky Way begin to make their first pass-by at pericenter, t = 6.2 Gyr when they finally merge completely, and t = 10 Gyr, the final snapshot of the simulation, several billion years after the merger when the stars in the disks have had a chance to mix (van der Marel et al. 2012).

4. RESULTS, DISCUSSION

Initial predictions were that the brightness would increase slightly after the first M31-MW pass-by, then steadily increase as they continued to merge, then drop off several Gyrs after merging as gas became depleted and star formation rates began to decrease. The mass profiles of M31 and the Milky Way are shown below in figures 2 and 3.

Because we used a dissipation-less model, we expected it to follow more of a n 4 elliptical Sersic fit than a cuspy n 1 fit. Unfortunately, we were not able to calculate the brightness profiles in a reasonable way in time, so we could not compare them to these predictions. The hope was to create a plot of the progenitor galaxies and their remnant's surface mass density profile, similar to the one in (Hopkins et al. 2009).

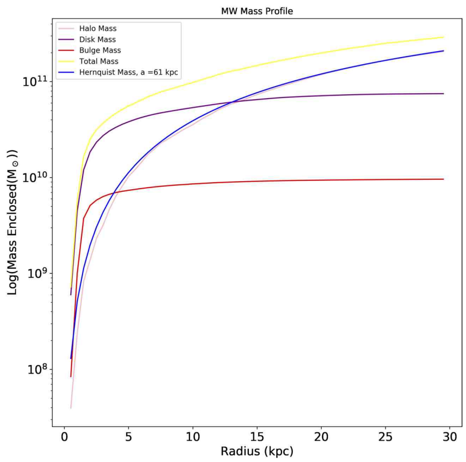

Figure 2. The general mass profile of the Milky Way.

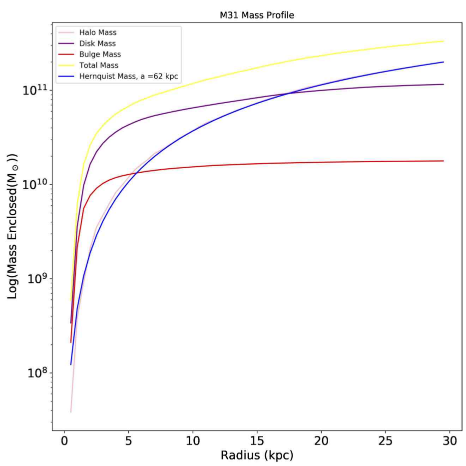

Figure 3. The general mass profile of Andromeda.

5. CONCLUSIONS

Unfortunately we were not able to come to a definite conclusion on the surface brightness of the merger remnant because of coding errors. Similar to Homework 5, it was found that the disk mass of M31 levels out logarithmically near $10^{11}M_\odot$ as the radius increases towards infinity, and for the Milky Way, it does approximately the same thing, which we expected because they have approximately the same mass currently. We expected the remnant surface brightness profile to decrease more rapidly than the progenitors at smaller radii, but then taper off more slower due to the "puffing up" of the elliptical, causing it to be brighter than the progenitors at larger radii, such as in (Hopkins et al. 2009).

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