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MW+M31 Stellar Major Merger Remnant: Stellar disk particle distribution/morphology

ZEHAO DONG†

†Department of Astronomy, University of Arizona, 933 N Cherry Ave, Tucson, AZ, 85721, United States
‡zehaodong@arizona.edu

Abstract

In this study, we investigate the stellar density profile of the major merger remnant formed from the anticipated collision between the Milky Way and M31 galaxies in approximately 4 billion years. Understanding the distribution and morphology of stellar disk particles within the merger remnant is crucial for advancing our knowledge of galactic evolution, as mergers play a significant role in determining the morphological and star formation characteristics of galaxies. We focus on the research question: What is the final stellar density profile for the combined system, and is it well fit by a Sersic profile? This question holds importance as it helps elucidate the relationship between galaxy mergers and morphology, as well as the composition of the remnant in connection to its age and the mass ratios of the merging galaxies. Our findings indicate that the final stellar density profile of the merger remnant is consistent with a Sersic profile, agreeing with predictions for elliptical galaxies. These results contribute to a more comprehensive understanding of the impact of mass and structure on merger remnants and the broader implications for galaxy interactions and mergers in the universe.

Keywords: Major Merger, Elliptical Galaxy, Galaxy Merger, Merger Remnant, Sersic Profiles

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1. Introduction

In approximately 4 billion years, the Milky Way and M31, also known as the Andromeda Galaxy, are anticipated to collide and merge, creating a stellar major merger remnant (van der Marel et al., 2012). Major mergers involve the interaction of two massive galaxies, leading to significant morphological transformations and the formation of new galactic structures. Therefore, studying the distribution and morphology of stellar disk particles within the resulting remnant formed from the merger between the Milky Way and M31 galaxies is crucial for advancing our understanding of galactic evolution, as mergers are pivotal in determining the morphological and star formation characteristics of galaxies (Barnes & Hernquist, 1992; Duc et al., 2013; Mihos & Hernquist, 1994).

A galaxy is a gravitationally bound system consisting of stars, stellar remnants, gas, dust, and dark matter, while galaxy evolution refers to the processes by which galaxies form, interact, and transform over time. Understanding how galaxies evolve is essential for exploring the broader context of cosmic history and the development of structures in the universe (Willman & Strader, 2012 AJ). The interaction between the Milky Way and M31 represents a major merger, with both galaxies exhibiting similar masses and barred-spiral structures, and it offers an invaluable opportunity to study the complex processes underlying galaxy evolution (Barnes & Hernquist, 1992; Duc et al., 2013).

A combination informs our current understanding of galaxy mergers and their remnants of observational data and computational simulations. In their seminal work, Toomre & Toomre (1972) theorized that spiral galaxy mergers typically lead to the formation of elliptical remnants. However, more recent research by Querejeta et al. (2015) suggested that galactic collisions can also form S0 galaxies, adding complexity to our understanding of merger outcomes. Furthermore, the role of mergers in influencing star formation rates has been a topic of ongoing debate. Pearson et al. (2019) argued that while some mergers exhibit bursts of star formation, only 10–20% demonstrate this behavior. The upcoming merger between the Milky Way and M31 presents an opportunity to examine these diverse outcomes, as this dry merger is expected to yield a remnant dominated by older stars (van der Marel et al., 2012). Consequently, exploring the final stellar density profile of the combined system and its relation to Sersic profiles and predictions for elliptical galaxies will provide critical insights into the morphological and star formation characteristics of merger remnants. Sersic is a mathematical function describing the surface brightness of elliptical galaxies ($I(R) = I_0 \exp[-(R/R_e)^{1/n}]$, where $I(R)$ is the intensity at radius R, I_0 is the central intensity, R_e is the effective radius, and n is the Sersic index; Sersic 1968).

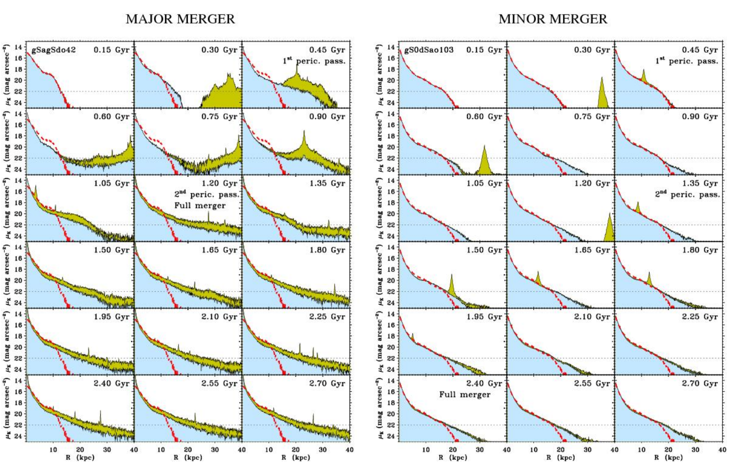

Figure 1. Time evolution of the surface brightness profiles of the stellar material in two models that result in an S0-like remnant. This plot indicate the possibilities of the formation of S0 galaxies. Querejeta et al. (2014)

Despite considerable progress in our understanding of galaxy mergers, several open questions remain. For instance, the exact classification of the merger remnant of the Milky Way and M31, whether it will be an elliptical galaxy or an S0 galaxy, is still debatable. Another open question pertains to the final stellar density profile of the combined system and whether it is well fit by a Sersic profile. Additionally, the role of gas dynamics and stellar feedback in shaping the merger remnant remains to be determined. Researchers are utilizing observational data, simulations, and analytical models to address these open questions and further our understanding of major mergers in the context of galaxy evolution. Methods include multiwavelength observations to constrain the properties of merger remnants and advanced computational techniques that incorporate hydrodynamics, star formation, and feedback processes in simulations (e.g., Barnes & Hernquist, 1992; Duc et al., 2013; Querejeta et al., 2015).

2. This Project

In this paper, we will investigate the distribution and morphology of stellar disk particles within the remnant formed by the merger of the Milky Way and M31 galaxies. We will specifically explore the final stellar density profile for the combined system, determining whether it is well fit by a Sersic profile and whether it aligns with predictions for elliptical galaxies.

Our project aims to address the open question of how the stellar disk particle distribution and morphology in the merger remnant of the Milky Way and M31 can inform our understanding of galaxy formation and evolution, particularly in the context of similar-mass barred-spiral galaxy mergers. We will address this question by analysising the final stellar density profile for the combined system will be, whether it is well fit by a Sersic profile, and if it agrees with predictions for elliptical galaxies.

This open question is crucial for advancing our understanding of galaxy evolution, as mergers play a significant role in determining the morphological and star formation characteristics of galaxies (Barnes & Hernquist, 1992; Duc et al., 2013). By analyzing the stellar disk particle distribution in the merger remnant of the Milky Way and M31, we will gain insights into the influence of mass and structure on merger outcomes and their broader implications for galaxy interactions and mergers in the universe. Consequently, our study will contribute to the knowledge base necessary for deciphering the complex relationships between galaxy mergers, morphology, and the evolution of galaxies in the cosmos.

3. Methodology

This study utilizes N-body simulations, as detailed in van der Marel & Besla (2012), to model the collision and merger of the Milky Way and M31 galaxies. An N-body simulation is a numerical method used to predict the dynamical evolution of a system of interacting particles, in this case, stars within galaxies. These simulations take into account the gravitational interactions among the particles and their initial conditions to compute the system's future state.

In the methodology, I employed Python to investigate the nature of the major merger remnant resulting from the Milky Way (MW) and the Andromeda galaxy (M31). This involved generating density profiles for both MW and M31, as well as their remnants post-merger. Subsequently, I plotted the Sersic profiles for these galaxies and the remnant in conjunction with their corresponding density profiles.

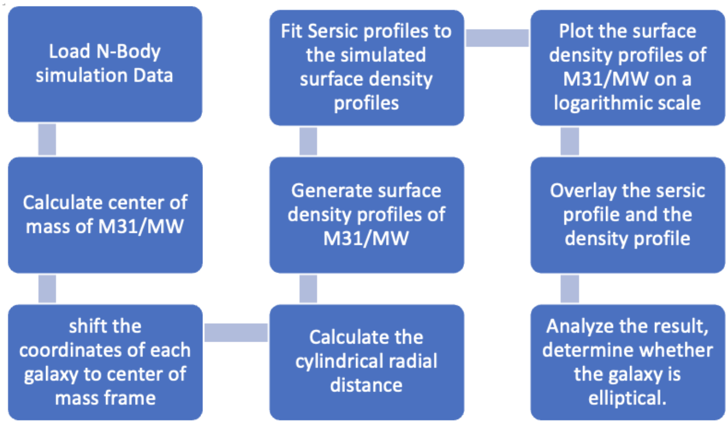

Figure 2. This flowchart shows the process of my calculation and plotting. It also clearly shows the way I use the N-body simulation Data to plot the density profile, and using sersic equation to build sersic profile, and finally use those profiles to varify our the prediction for the remnant galaxy

By comparing the Sersic profiles and density profiles of the remnant, I determined the Sersic index (n) values for each galaxy. The Sersic index serves as an indicator of a galaxy's morphological features, with different n values corresponding to different light distributions in a galaxy.

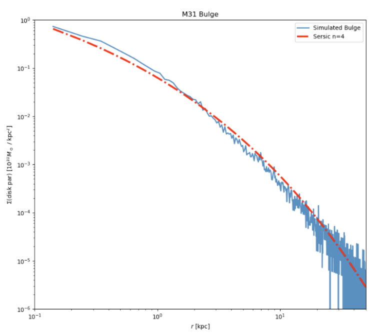

Figure 3. The Density Profile and Sersic Profile of M31 with n = 4, plot directly from lab6

In order to generate the density profiles for the Milky Way and Andromeda galaxies, as well as their merger remnant, my code employs the following calculations. First, I calculate the center of mass positions for each galaxy using the following formula:

$$X_{\text{COM}} = \frac{\sum_i m_i x_i}{\sum_i m_i} \tag{1}$$

where m_i is the mass of particle i and x_i is its corresponding position coordinate. This process is repeated for the y and z coordinates as well. Next, I compute the cylindrical radius, R, for each particle in the galaxy using:

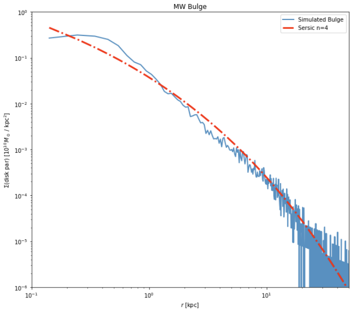

Figure 4. The Density Profile and Sersic Profile of MW with n = 4, plot based on modification

$$R = \sqrt{(x - X_{COM})^2 + (y - Y_{COM})^2} \tag{2}$$

To generate the density profile, I create annuli of increasing radii and calculate the enclosed mass within each annulus. The surface density, Σ, is computed by dividing the mass in each annulus by the area of the annulus:

$$\Sigma(R) = \frac{M_{\text{annulus}}}{\pi(R_{\text{outer}}^2 - R_{\text{inner}}^2)} \tag{3}$$

where M_{annulus} is the mass contained within the annulus, and R_{outer} and R_{inner} are the outer and inner radii of the annulus, respectively.

For the Sersic profile, the surface brightness is described by the following equation:

$$I(R) = I_e \exp\left[-b_n\left(\left(\frac{R}{R_e}\right)^{\frac{1}{n}} - 1\right)\right] \tag{4}$$

where I_e is the intensity at the effective radius R_e, n is the Sersic index, and b_n is a constant related to n such that half of the total light is enclosed within R_e. The Sersic profile is fitted to the density profiles to determine the optimal value of n for each galaxy.

By observing the density profile fit with the Sersic profile, it's easy to conclude that with $n = 4$, both the Milky Way's and Andromeda galaxy's density profiles fit reasonably well with the Sersic profile (shown in Fig 3 & Fig 4), which makes the Sersic profile of both galaxies characteristic of a de Vaucouleurs-profile. An n value of 4 in the Sersic profile implies that the galaxies exhibit properties similar to those of an elliptical galaxy or the bulges of other spiral galaxies with a more concentrated, spheroidal distribution of stars. This observation also suggests that the merger remnant will likely have a prominent bulge component. However, it is crucial to interpret these results while considering the complexity of the underlying processes and the potential influence of other morphological features, such as disk and bar structures. A more detailed analysis, including decompositions that account for various components like the disk, bulge, and bar, would be necessary to obtain a comprehensive understanding of the merger remnant's morphology.

Based on the density profile and sersic profile I already have, my hypothesis for this investigation is that the major merger remnant resulting from the Milky Way and Andromeda galaxies will exhibit a distinct morphological profile with characteristics of an elliptical galaxy, owing to the well-matched Sersic profiles with $n = 4$ for both galaxies. The motivation behind this hypothesis stems from the understanding that a Sersic index of 4 corresponds to a de Vaucouleurs-like profile, which is characteristic of elliptical galaxies and the bulges of spiral galaxies.

3.1 Results

paragraph 1

paragraph 2

figue 3

figure 4

4. Discussion

paragraph 1

paragraph 2

5. Conclusion

paragraph 1

paragraph 2

last paragraph

6. Acknowledgements

waiting for thanks

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Competing Interests A statement about any financial, professional, contractual or personal relationships or situations that could be perceived to impact the presentation of the work — or 'None' if none exist.

Notes

Appendix 1. Example Appendix Section

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