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Impact of Dynamical Evolution of Galactic Mergers on Galaxy Morphology

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ABSTRACT

This paper examines the morphological connections to galaxy evolution, and how morphology can aid in understanding a galaxy's collision and merger history. Using morphology to understand evolution is as old as the study of Galaxy Evolution itself, and having evidence to support existing ideas further strengthens the connection between morphology and history. We study this connection using simulation data from R. P. van der Marel et al. (2012), which models the collisions and final merger between M31 and MW.

Keywords: Galaxy — Galaxy Evolution (594) — Sersic Profiles — AGN (16) — Stellar Disk (589) — Stellar Bulge (578) — Merger (608)

1. INTRODUCTION

The morphological classification of galaxies is intrinsically related to the interactions that the galaxy has experienced over its lifetime. One such possible interaction is a **merger**, which occurs when "2 or more galaxies collide and their central black holes have merged (B. Willman & J. Strader 2012)." When studying galaxy evolution, it is often more effective to examine the impacts of galactic mergers than observing a galaxy evolving independent of any disturbances. A galaxy's dynamical evolution during a merger with another galaxy reveals information about it's evolutionary track (A. Brooks & C. Christensen 2016).

The connection between a galaxy's evolutionary track and its morphology is "a fundamental question in the field of galaxy formation and evolution" (R. Kannan et al. 2015). A **galaxy** is "a gravitationally bound set of stars whose properties cannot be explained by a combination of baryons (gas, dust and stars) and Newton's laws of gravity (B. Willman & J. Strader 2012)." **Galaxy evolution** is a broad term that refers to the way a galaxy grows and changes over the course of its lifetime. One of the oldest methods used to classify galaxies, the Hubble sequence, is based on morphology. The Hubble sequence is based on the Hubble 'tuning fork', which distinguishes between a galaxy's spheroidal **bulge** and it's exponential **disk**. Within this bulge in an active galaxy is the **AGN**, or Active Galactic Nuclei. The AGN is "a central region of an active galaxy" and is where new stars are formed within active galaxies. A galaxy's stellar bulge is "a spheroidal region at the center of a galaxy which mostly contains old stars" as opposed to a galaxy's stellar disk, which is "the disk part of a galaxy," per the Unified Astronomy Thesaurus. Another definition for stellar disks is as the flat, thin component that contains most of a galaxy's baryon material and orbits very close to the galactic plane.

Gathering information based on the qualities of the bulge and disk are still extremely important today, and represent the crux of the issue surrounding morphology - what can a galaxy's morphology tell us about its past, present, and future? Our current understanding is that mergers are the origin of classical bulges (like those in an elliptical galaxy) and processes like gravitational instability are the origin of psuedo bulges (like those that align with disk-like profiles) (R. Kannan et al. 2015). Fig. 1 shows simulations of a primary galaxy being perturbed by a smaller companion galaxy. With time evolving from left to right, we see how the smaller galaxy disrupts the structure of the primary galaxy. From this simulation, we see the basics of how close tidal encounters interfere with existing structure and leave behind remnants that have an elliptical morphology.

A pressing open question relates to inconsistencies between models and observations. Observations show a sizeable amount of bulgeless galaxies (R. Kannan et al. 2015), but this does not align with the predicted findings consistent with the cold dark matter model that is used today.

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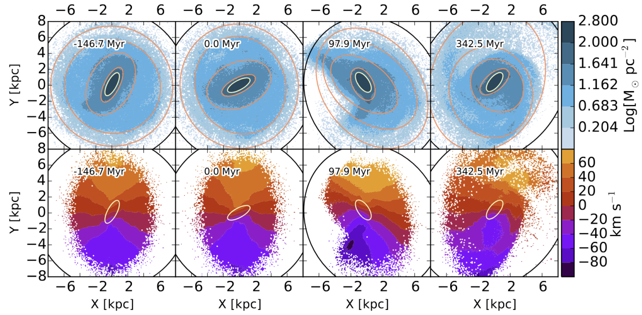

Figure 1. Time evolution of a primary galaxy's disk. At leftmost panel, companion galaxy has not yet been introduced. At 0.0 Myr primary galaxy has closest approach to its perturber. Note the strong effect the companion galaxy has on primary galaxy's morphology.(S. A. Pardy et al. 2016)

2. THIS PROJECT

In this paper, we will study the changing stellar surface density profile of the Milky Way (MW) and M31 as the two collide and eventually merge. This is considered a **major merger**, which occurs when "the ratio of stellar mass progenitors are 1:3 or greater (C. J. Conselice 2014)." In our simulation we will compare the density profiles of both the bulge and disk components.

Data that we find based on the evolution of the bulge's density profile will give us information that addresses the uncertainty about the relatively high number of bulgeless galaxies. If the density profile of the bulge component decreases, it could indicate a correlation to the findings in external literature.

The overarching question within this field of study is about connecting how galaxy interactions impact morphological classifications of galaxies. Our study will show how the morphology of MW and M31 evolve, which will give us further information about the creation of bulgeless remnant galaxies.

3. METHODOLOGY

The simulations in this paper come from R. P. van der Marel et al. (2012), which models the merging of the MW-M31-M33 system using collisionless N-body simulations and semi-analytic orbit integrations. An N-body simulation models the interactions of a dynamical system of N particles, setting a small set of initial conditions that can vary depending on what aspect of the simulation is of interest. The exact number of particles used throughout the simulations was based on a set of data determined in the paper, outlined in Table 1 (R. P. van der Marel et al. 2012). There were three components of each galaxy in the simulation; the dark matter halo, stellar disk, and stellar bulge.

Because we are concerned with morphology, we are only investigating the visible components of each galaxy. Thus, the stellar disk and stellar bulge are the only relevant particle types. When choosing what resolution of simulation data to use, it is important to remember that a stellar density profile is just a distribution. Because the model is accounting for such a large scale of particles, there are no appreciable benefits for using HighRes data. Thus, because LowRes data is just as effective, we will proceed using LowRes.

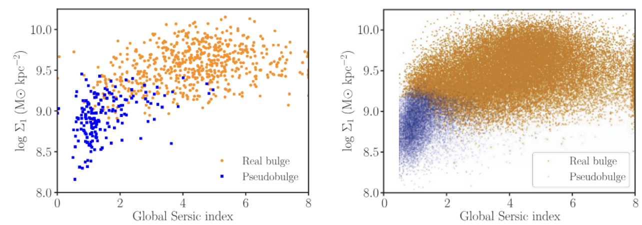

Figure 2. Difference between the Sersic profiles for bulges and for pseudobulges. Real bulges exhibit higher Sersic indices, which indicate that they are larger and brighter than pseudobulges. The left panel shows the sample data from the paper and the right panel shows the simulated, predicted types based on sample data. This shows how significantly Sersic indices can differ across different galaxy components. (H. M. Yesuf et al. 2020)

The most important calculation in this code is that of the **Sersic profile**:

$$I(R) = I_0 e^{-kR^{1/n}} \quad (1)$$

The Sersic Profile is a specific stellar density function that describes how the intensity of a galaxy (I) varies with the distance from the galactic center (R). I_0 is the intensity at distance R = 0. n is the Sersic index, which controls the degree of curvature in the profile. The best fit values of n correspond to galaxy size and luminosity - a small n fits to a less centrally concentrated profile, while a large n fits with bigger and brighter galaxy profiles. For example, elliptical galaxies generally fit best to n = 4 while spiral galaxies generally fit approximately n = 1.

In practical computations, we actually employ a modified Sersic profile:

$$I(R_e) = I_e e^{-L((r/R_e)^{1/n}-1)} \quad (2)$$

which describes effective intensity (I_e) accounting for an effective radius (R_e). R_e is also called the half light radius, which is the 2D radius that contains half the light of the initial intensity. r is the true distance from the galactic center.

The plots from our simulation will show a density profile, overlaid by a Sersic profile. The density profile will show how intensity changes with distance, and the steepness of that curve informs the Sersic profile, which is a smooth logarithmic curve. Based on how these distributions change we will have a new conception of what M31 and MW will look like after their multiple collisions and eventual merger.

Based on early trials, I think we will find that changes are most prominent in the outer disks. It would make sense that regions of high concentration would be essentially unchanged after a merger, as the bulge is closest to the central supper-massive black holes which will always be surrounded by the highest intensity of light in the galaxy. The resulting increase of light in the disk should indicate that the galaxy has a more elliptical makeup now, because light is more evenly distributed radially.

4. RESULTS

Figure 3 shows the Sersic profile of the bulge of MW before collisions (snapshot number 000) and after collisions (snapshot number 801). I was fitting by eye, and chose a Sersic index of 3.9 to best accommodate the data before the collision and an index of 3.7 to fit the data after the collision. An index of 4 corresponds to elliptical galaxies and the bulges of spiral galaxies. We would expect to see the Sersic index get closer to 4 after the merger with M31. The graphs have an upper bound in x at 5 kpc because of extreme skew at higher radii. The area closest to the galactic center is most relevant to determining the actual best fit of the Sersic profile for the galactic bulge.

Figure 4 shows the graph of the MW bulge at snapshot 801 without correcting for the upper x-limit. Here, a good fit for the Sersic index was around 4.5 when accommodating the data at further radii. The large difference in best-fit Sersic indices for the same snapshot and component shows how critical the consideration for radii is.

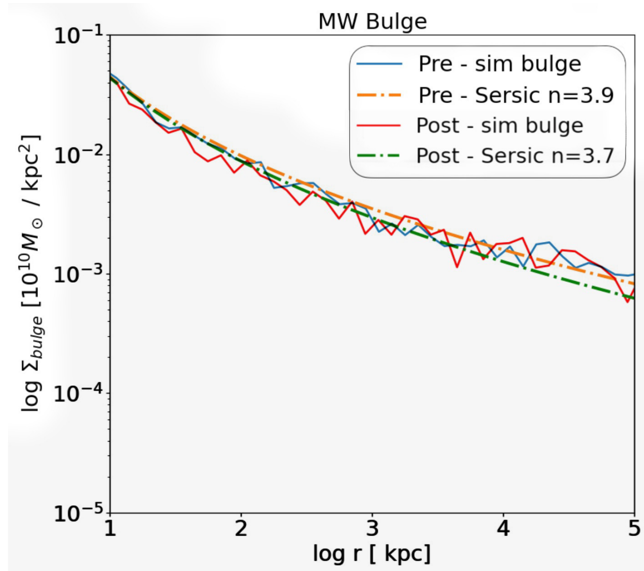

Figure 3. The blue is the simulated mass density function and the orange is the Sersic profile of MW bulge before collision. The red is the simulated mass density function and the green is the Sersic profile of MW bulge after collision.

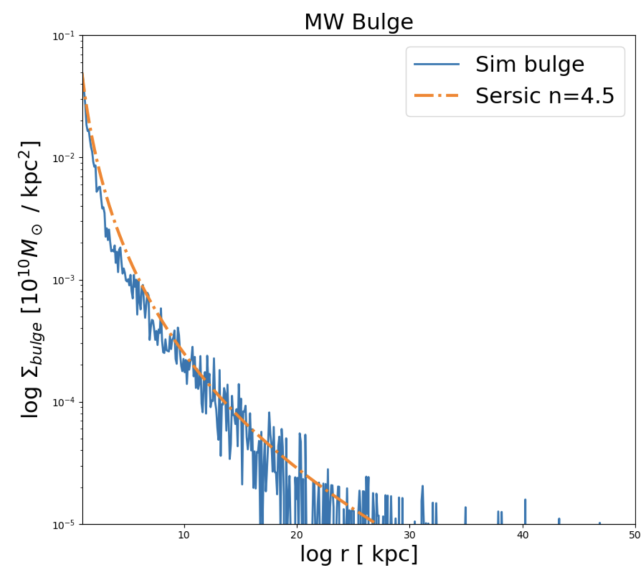

Figure 4. The blue is the simulated mass density function and the orange is the Sersic profile using index 4.5.

5. DISCUSSION

These results do not align with my hypothesis! I think something is awry with my data collection method, and a further modification needs to be made to the code.

This does not align with the literature and is indicative of a problem. I do not think this should be used to make any conclusions about galaxy evolution and its relationship to morphology because it seems incorrect.

Uncertainties in my analysis are the fit of the Sersic index, which I can address with further modifications to the code.

6. CONCLUSIONS

This paper examines the morphological connections to galaxy evolution, and how morphology can aid in understanding a galaxy's collision and merger history. Using morphology to understand evolution is as old as the study of Galaxy Evolution itself, and having evidence to support existing ideas further strengthens the connection between morphology and history.

Reaffirming what was generally upheld across the literature, the central stellar bulge of spiral galaxies was not shown to change in an appreciable way after galactic collisions and mergers. Generally, the elliptical galaxies and the bulges of spiral galaxies are well modeled by a Sersic index of approximately n = 4. Our results from the bulge of the Milky Way affirm this.

A major improvement to the code would be adding a way to compare the scale of error, but that was outside the scope of this project.

7. ACKNOWLEDGEMENTS

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