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Stellar Disk Remnant Distribution in the Milky Way M31 Merger Event

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ABSTRACT

Keywords: Galaxy Merger, Major Merger, Dry Merger, Merger Remnant, Stellar Disk, Stellar Bulge, Sersic Profile

1. INTRODUCTION

Over long enough periods of time, galaxies that are gravitationally bound will eventually merge, this is known as a galactic merger. A galactic merger is defined as the merging of two or more galaxies. This can occur with multiple parameters and classifications, but for the sake of this project we will only be looking at a major, dry merger. When the merging galaxies are roughly the same mass, the merger is considered to be a major merger. A merger is described as dry if there is a low amount of gas within each of the merging galaxies. Each of the merging galaxies is made up of multiple regions; the stellar bulge, the stellar disk, and the dark matter halo. For the sake of studying the stellar remnant of a merger we will be looking at just the bulge and disk matter. The stellar bulge refers to the area of a galaxy that is concentrated in the center of the galaxy. The stellar disk refers to stars that orbit along the axis of rotation. The bulge of a galaxy will be have a much higher surface area to brightness ratio, since the stars in the bulge are much more tightly packed. A galactic merger that is of great interest to us is the future merger of the Milky Way (MW) and the Andromeda (M31) galaxies. This merger is considered to be a major merger with the galaxies having roughly the same masses, $M_{MW} = 1x10^{12}M_{\odot}$ and $M_{M31} = 1.6x10^{12}M_{\odot}$ (van der Marel et al. 2012). One aspect of this merger is the stellar distribution and dynamics of the galaxies as they merge, and those of the new merged galaxy. It is possible to describe the distribution of the stellar material of a galaxy with a Sersic profile. A Sersic profile models the distribution of stars by relating the distance from the center to the intensity of the light. In order to study the dynamics of the merging galaxies, it could be useful to keep track of the number of stars that are ejected from their host galaxy. This will occur when the velocity of the star has exceeded the escape velocity for the host galaxy.

In order to talk about galaxies merging, we must first define what is meant by the term galaxy. A galaxy is a gravitationally bound set of stars whose properties cannot be explained by a combination of baryons and Newton's Laws of gravity(Willman, Strader 2012). According to this definition if the dynamics of a collection of stars can be explained from just directly observable mass and Newton's Laws, then it would not be considered a galaxy. In order for a cluster of stars to be considered a galaxy, there must be something else influencing the properties of the stars. This something else is known as Dark Matter. While we do not yet know what Dark Matter is, we do know that is essential in describing the properties we see when observing galaxies. Galaxies themselves are not static objects, but also evolve through internal and external interaction. The term galactic evolution refers to the total combined effect of internal and external factors on the galaxy. This can take the form of the Super Massive Black Hole at the center causing an outflow that removes gas from otherwise star forming regions, to the gravitational stripping of stars through interactions with another galaxy. It is important to study how the distribution of the stars is effected by the merger since it might give us a better understanding of how larger galaxies may have come to be. If we can study the dynamics of star distributions found within galaxies, we may be able to determine whether or not that galaxy was the product of a merger. By studying the stars that are ejected from a galaxy during a merger, it may be possible to determine the fates of individual stars, such as the fate of the Sun during the M31/MW merger.

Based on our current understanding of the remnants of galactic mergers, it is possible that S0, lenticular, galaxies may be the result of galactic mergers. When undergoing a major merger, it is not likely that any of the properties of the stars will be preserved directly, but may be recreated in the new merged galaxy. The simulated data for the distribution of disk-bulge material is consistent with that observed in actual S0 galaxies (Querejeta et al. 2015).

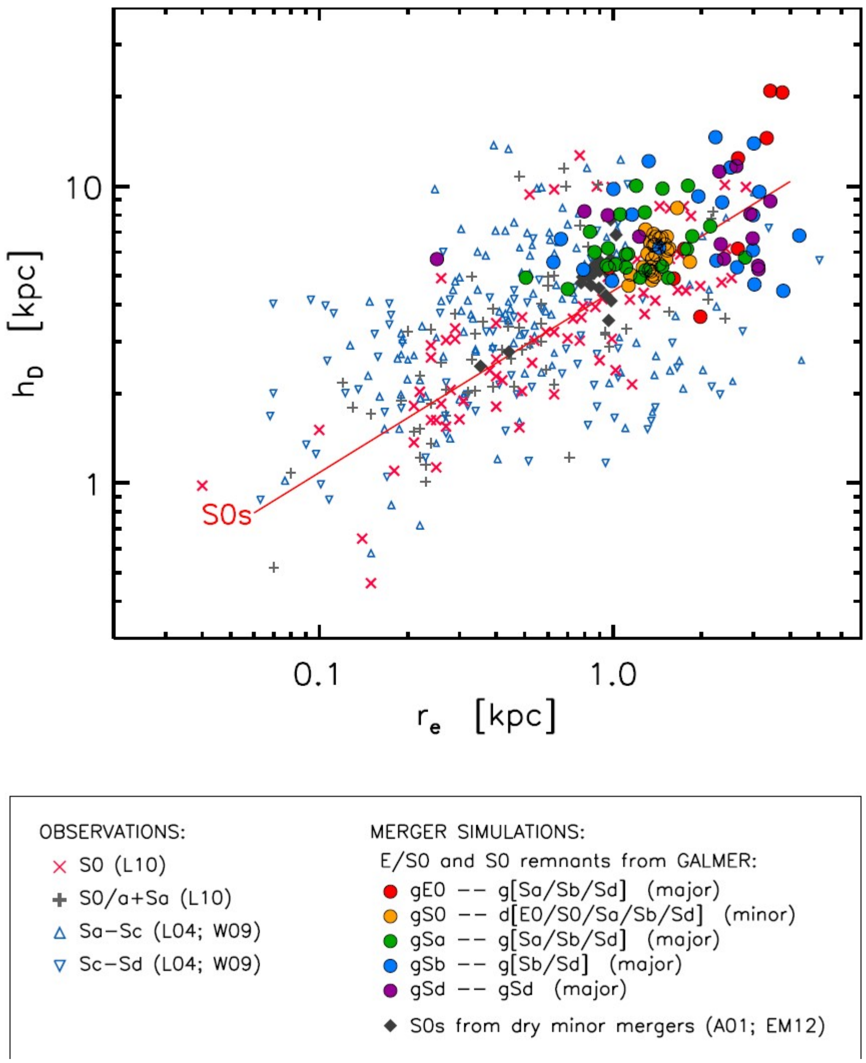

Figure 1. Distribution of the remnants from both simulated and observational data. Observational data was collected for S0 and S0-like galaxies. The red line is a linear fit to the observational data. The data is plotted in the $log(h_d) - log(r_e)$ plane, where h_d is the disk scale length, r_e is the effective radius. The plot contains both minor and major dry mergers.

One of the open questions in the study of galactic merger remnants, is what is the range of remnant dynamics and orbital structures are permitted by the merger process? (Barnes, Hernquist 1992) This question is about what the possible distribution of stellar matter might be after a merger, and also what are the possible kinematics of the remnant stellar material.

2. MW-M31 MERGER STELLAR REMNANT

In this paper we will study the distribution and dynamics of the stellar remnant of the MW-M31 merger event. This will be done by examining the Sersic profile for the stellar material, disk+bulge, for both M31 and MW separately. At each time snapshot, I will be looking for what percentage of stars will be ejected from their host galaxy.

I look to answer the question concerning the distribution and dynamics of the stellar remnant. By studying the Sersic profile, I hope to be able to determine if there are limitations to where the stars from the disk and the bulge are able to be found. I hope to be able to determine a range for the velocities of bound stars within the new merged galaxy.

This in an important question to solve in the study of galactic evolution since, it can give us some useful insight into the possible origins of some of the galaxies we see. We still do not have a complete understanding of the origins of some of the largest galaxies. If we can determine that the kinematics and distribution of the stars within them, we may be able to use models and simulations similar to this one in order to generate a model that could produce a history for any galaxy.

3. METHODOLOGY

The simulation we are using is presented in van der Marel et al. 2012, and uses an N-Body model to simulate the merger. This simulation assumes collisionless particles. It deals with the evolution of not just M31 and MW but also the smaller satellite to M31, M33. An N-body simulation is done when the number of particles in a system exceeds what is reasonable to do by hand. This is done by calculating some interaction between each particle individually. In this simulation the only force considered is gravity, since the particles are considered collisionless. These N-body simulations used both the stellar mass and the dark matter mass.

In order to model the Sersic profile for I will be modifying Lab 6 in order to calculate the profile for both the disk mass and the bulge mass. In order to get the time evolution nature of the simulation, I am fitting a model for the combined mass at only specific time snapshot, every 50 snapshots. This will produce a model with 16 different snapshots of how the stellar mass will be distributed. I have chosen to only pick a small number of the snapshots in order to reduce the amount of computation that is required. This process is carried out on both the MW and M31 data. At each snapshot, the two profiles are plotted on the same plot in order to more easily compare the distributions. Once the profile has been fit, the next step is to generate a 2D Histogram in order to give another visualization of the distributions. In order to determine whether a star has been ejected from its host galaxy, I am calculating the escape velocity for the galaxy at the given snapshots, and then going through the given particles and calculating their radial velocity. If the radial velocity exceeds the escape velocity, the star index is be added to an array. In the end the percentage of the ejected stars is be calculated.

The Sersic profile is the most important equation in this paper, as it relates the intensity to the radius. The profile is calculated using;

$$I = \frac{L}{4\pi D^2}$$

Where I is the intensity of the light for a given radius, L is the luminosity, and D is the radius from the center. This is a special case of the Sersic profile in that we are assuming a mass to light ratio of one, that is $\frac{M}{L}$, this lets us calculate using the luminosity, which is useful since we can get the half-mass radius, or the radius at which the mass has decreased by 0.5. This is calculated by setting boundary conditions for the mass, as $Low = \frac{TotalMass}{2}$ and $High = Low + 0.01Low$. Indices are then set by looking for the range of mass values so that either Mass ¿ Low or Mass ¡ High. In order to determine whether a star has been ejected, we must calculate the escape velocity of the host galaxy. While the galaxies are separate this is a straightforward calculation using the escape velocity formula;

$$v_{esc} = \sqrt{\frac{2GM}{r}}$$

Where M is the mass of the host galaxy and r is the radius of the star from the center of mass of the galaxy. When the galaxies finally merge, we will need to take into account the combined mass of the galaxies. The equation stays the same except we must replace the mass of a single galaxy, M, with the combined mass of MW and M31, M_{MW-M31}. This will increase the escape velocity that the star will have to overcome.

The plots I plan to produce will show the Sersic profile for both of the galaxies at each time evolution snapshot. This will be done in two separate plots and a combined plot at the end in order to compare the two distributions at the end of the merger event. From this same data I will produce a 2D histogram that will show the number of stars from each galaxy at each radius. This will be done in multiple plots as to keep the information easily visible. In order

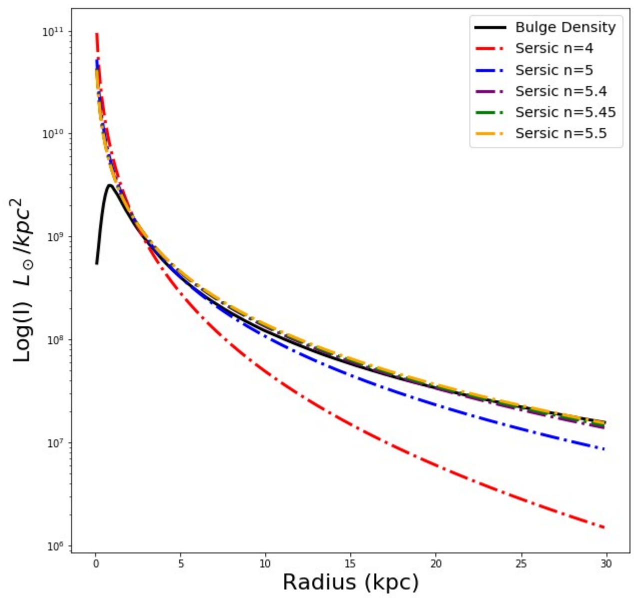

Figure 2. This is a Sersic profile for the bulge particles calculated using the foundation for the code. Using this I will decide on which Sersic index is most appropriate to use.

to convey the rate of star ejection, I will produce a plot at the end that shows the percentage of stars at each of time snapshot that have been ejected.

I predict that the distribution of stars from each galaxy will be roughly similar in the remnant. This is due to the fact that during a major merger the disk and bulge components are not preserved. If this is the case, then we would expect to see a mixing of the material. If the simulation was to run for a longer time span, then it might be possible that the distributions could return to pre-merger conditions. I expect no more than 50% will be ejected, since the majority of the stars are located closer to the center of the host galaxy than on the edges.

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