MW/M31 Halo Major Merger Remnant Structure Project Proposal

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1 INTRODUCTION

Dark matter, although yet to be identified, is now considered to be an essential part of the universe, surrounding galaxies in a halo structure. The need for a dark matter halo model became apparent in the last century when observational evidence showed that more mass was needed beyond baryonic matter for spiral galaxies to be stable (Ostriker et al. 1974). Since then, advances in computation and simulations have revealed to us ever finer details in halo structure. In this project, I will explore how dark matter halo structure changes through a major merger using an N-body simulation of the Milky Way (MW)-M31-M33 system (van der Marel et al. 2012).

Understanding the structure of individual haloes can inform us greatly about its merger history (Drakos et al. 2019a). Absent of observational data for a single galaxy over its lifetime, we can only learn about the evolution of a galaxy through a snapshot of its present state. This is why simulations are a great way for us to learn what evolution histories led to the formation of the galaxies that we currently see. Studying how major mergers change the structure of haloes through simulations will allow us to connect the present halo structure with its merger history. This can then be applied to probe the merger history of the galaxies we observe. Understanding changes in halo properties over a merger event at a high-resolution can also help us better model merger events for lower resolution simulations (Drakos et al. 2019b).

The connection between merger history and the resulting halo structure has been extensively studied. For example, past studies using merger simulations have found major connections between orbital parameters and the resulting halo shape (Drakos et al. 2019a), as well as between the energy of the merger encounter and the final mass distribution (Drakos et al. 2019b). In another simulation study, Abadi et al. (2010) also demonstrated complexities in the effects of the merger history of a halo on the way it contracts in galaxy assembly. As shown in Figure 1, Drakos et al. (2019b) also provides the interesting result that the virial mass of the merged halo is not merely the sum of the virial masses of the initial haloes.

On this topic, further work could be done in exploring a wider variety of mergers, as studies like Drakos et al. (2019a) only explored mergers of identical haloes. Overall, more exploration needs to be done on the exact contribution of halo mergers to the shape and density profile evolutions of galaxies in the universe as a whole. This project will explore the contributions of each merger halo to the properties of the remnant halo, e.g. shape, spin, and density profile.

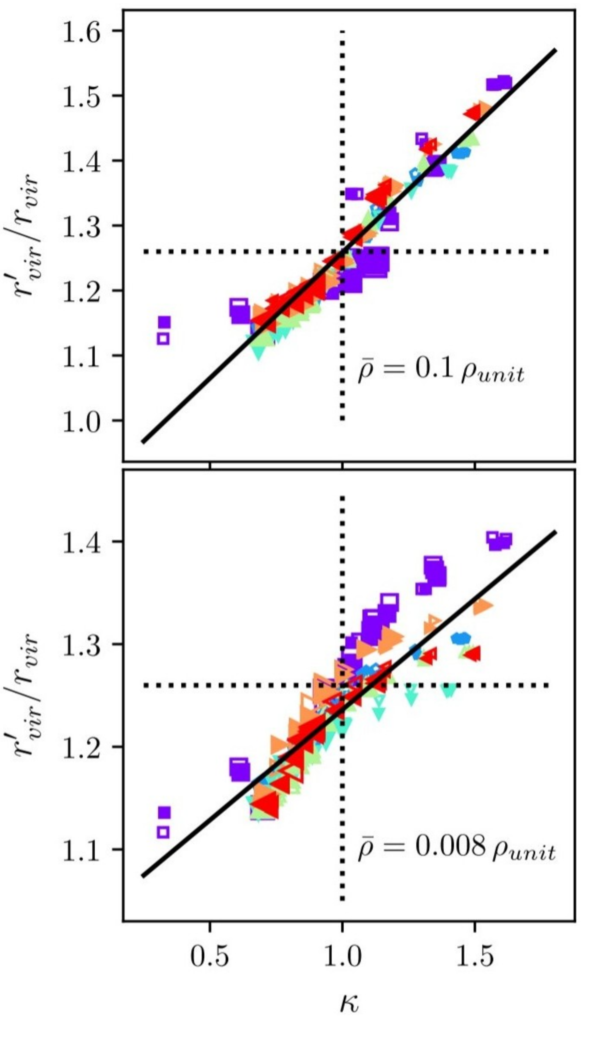

Figure 1. The change in virial radius r'_{vir}/r_{vir} as a function of the relative energy change κ. Virial mass scales as r^3_{vir}, so this figure also shows a wide distribution in mass scaling after merger despite starting with two equal mass haloes. Figure taken from Drakos et al. (2019b), the colors and symbols are described in the paper as well.

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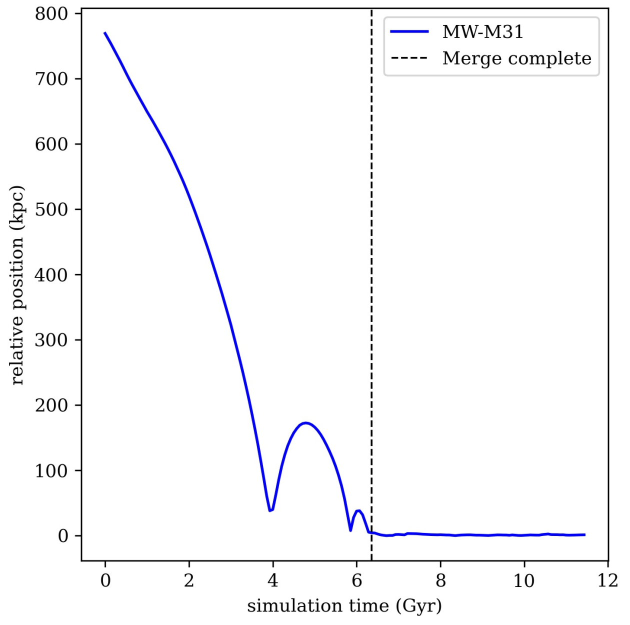

Figure 2. The relative positions of the center of masses of MW and M31 over the course of the simulation. After the black dashed line, the relative position effectively flattens, showing that the two systems have merged.

2 PROPOSAL

2.1 Proposal

The specific question I want to answer in this project is: What is the contribution of the MW vs. M31 halo particles to the density profile of the merged remnant? To explore the contributions, it will be interesting to explore the distribution of halo particles from both MW and M31 within the merged remnant to see if either system contributes more at certain radii. It will also be interesting to compare properties of the merged states with the individual haloes, such as density profile parameters and spin axis orientation, to see if the merged system properties reside somewhere between the two systems or are vastly different from both. Following Drakos et al. (2019b), I will also explore how the radius of the halo changes after merger. Below I describe the methods I plan to use to answer this research question.

2.2 Methods

For this project, I will be using the high-resolution particle simulation for the MW-M31-M33 system described in van der Marel et al. (2012). The simulation provides an accurate projection of the eventual merger between MW and M31. First, I will identify the relevant snapshots. I define the merged state as the snapshot after which the distance between the center of masses of MW and M31 is less than 5 kpc. This snapshot is identified as number 90, which corresponds to 6.357 $Gyrs$ in simulation years (see Figure 2). However, to ensure that the merged system is stabilized, I will use the last snapshot of the simulation to study its density profile.

To find the contributions of MW and M31 halo particles in the density profile of the merged system, I will plot the density profiles of both systems individually, and then overplot the overall density profile by concatenating the particle arrays. Code for computing the mass profile (enclosed mass at different radii) already exists from past assignments; the density at the ith radial bin is simply

$$\rho_i = M_{enc,i+1} - M_{enc,i}, \tag{1}$$

where ρ is the density, M_{enc} is the enclosed mass. The radius r_i at which the density is ρ_i would then be

$$r_i = \frac{R_{i+1} + R_i}{2}, \tag{2}$$

where R is from the radial bin values for the enclosed mass.

Then, I will compare the halo density profiles of the merged system and the individual systems. I will model using the NFW profile (Navarro et al. 1997):

$$\rho(r) = \frac{\rho_0}{\frac{r}{R_s}(1 + \frac{r}{R_s})^2}, \tag{3}$$

where ρ_0 and R_s are free parameters that will be fitted for each halo. For simplicity, I will use the curvefit function in the SciPy Python package to fit the profile. The NFW profile strikes a good balance between simplicity and physicality, which makes it an ideal model to compare density profiles before and after merger.

Next, I will compare the spin axis orientations. Lab 7 of this course contains code that computes the angular momentum vector of a set of particles, which is synonymous with spin axis orientation; I will use this code to compare orientations of individual haloes and the merged system.

Lastly, I will compare the virial radius of the individual haloes and the merged system, following the analysis of Drakos et al. (2019b). I define the virial radius r_{vir} as the radius at which the dark matter density is 360 times the average dark matter density of the universe, as explained in lecture 10. Given that the MW and M31 haloes are similar in mass, I will compute the ratio between the radii of the merged system and the individual halos, r'_{vir}/r_{vir}, and compare it with Figure 1 to see if the merged system gains or loses internal energy from the merger. I will also compute the enclosed mass within the virial radius of all systems to see if the merged mass is the sum of the individual halo masses.

2.3 Hypothesis

Because the haloes of MW and M31 in the simulation are similar in size, I expect them to have near equal contribution to the final density profile, meaning that the halo particles from MW and M31 will be equally distributed throughout the remnant halo. I expect the NFW profile parameters to be vastly different for the merged system compared to the individual haloes, as the shape of the galaxy changes dramatically through the merger (elliptical vs. spiral). I also naively hypothesize that the orientation of the spin axis for the merged system will be somewhere in between the spin axes of MW and M31. Lastly, as Drakos et al. (2019b) suggests, I don't expect the mass enclosed in the virial radius of the merged system to be a mere sum of those of individual haloes.

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