Research Assignment 2: Proposal

Ethan H. S. Figureido[1]

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1 INTRODUCTION

A majority of the matter in the universe takes the form of dark matter: a collisionless particle that doesn't emit radiation, and interacts only gravitationally with other matter. Dark matter clusters into filaments that form halos where they intersect. These halos are the sites of galaxy formation, and they have great influence on the structure and dynamics of the galaxies they encompass, determining their evolution.

As they are the sites of galaxy formation and evolution, their properties are linked to the evolutionary history and properties of galaxies. The structure of these halos in particular is key to understanding galaxy formation and evolution. Understanding how different environments produce different halo structures will provide insight into galaxy merger histories (Drakos et al. 2019). For example, the shape of a halo is connected to the previous major merger, being stretched along the merger axis (Despali et al. 2016). Understanding what environments different shapes emerge in will help us understand galaxy merger histories, and may make them a powerful indicator of a galaxy's merger history.

Our understanding of galaxy evolution has been crafted by galaxy modeling and observation; observation acting to refine the constraints of our simulations. From this, we have learned much about the relationship between dark matter halos and the baryonic matter within them. Dark matter halos grow through accretion of surrounding matter, and mergers. This growth is anisotropic, and will create triaxial and prolate halo shapes in isolation. Baryonic processes like black hole feedback, radiative processes, and star formation work to smooth the shape of the halo, giving it an oblate shape. Fig.3 from Prada et al. (2019) illustrates the effects of baryonic processes on halo shape by comparing the axes ratios of halos from magneto-hydrodynamic simulations, which include baryonic effects, and dark matter only simulations which don't. These simulations provide insight into how halos are shaped by the baryonic matter that they encompass.

Much of the uncertainty surrounding this topic stems from the variety of methods used and inadequate resolution. Further, the exact effects of baryons on dark matter haloes is still being hashed out. The differing environments, and the assumptions and uncertainties of different simulations has produced evidence favoring all possible halo configurations, as discussed in Chua et al. (2019) and Prada et al. (2019). Many of the open questions surround the reliability of observations and assumptions used to constrain simulations.

2 PROPOSAL

The following is the proposal for a study of the shape and evolution of the MW-M31 merger dark matter remnant using data from the simulation found in the van der Marel et al. (2012) study.

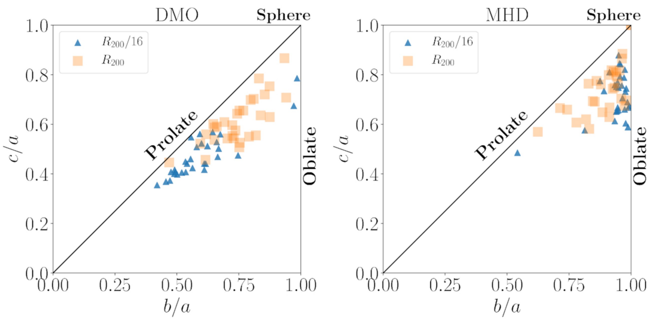

Figure 1. Figure 3 from Prada et al. (2019). Plotting the axes ratios for 30 simulated dark matter halos for dark matter only (DMO, left) and magneto-hydrodynamic (MHD, right) simulations. Triangles indicate data for the inner regions (R200/16 (14kpc)) of the halos. They visualize three main population trends: DMO simulations are rounder in the outer regions than the inner, MHD simulations are rounder in the inner regions than the outer, and MHD halos are rounder than DMO halos

2.1 This Proposal

Using the MW-M31-M33 simulation data, I aim to determine if the shape of the combined dark matter halo of the MW-M31 merger is oblate, prolate, or triaxial, and discuss how it evolves over time.

2.2 Methods

Dark matter halos take four main shapes: spherical, oblate, prolate, and triaxial. In a galactocentric reference frame an oblate spheroid is a sphere stretched along its y-axis, giving it a grapefruit shape, and a prolate spheroid is a sphere stretched along its z-axis, giving it an American football shape. A triaxial shape has different lengths for all three of its axes.

To answer the question of merged halo shape, we must determine when the MW-M31 merger is completed in the simulation, combine the halo particle data of both galaxies, and determine the edge of the dark matter halo before we can analyze the data.

A galaxy merger is considered complete when there is only one discernible center of mass (COM). Using the OrbitCOM code from homework 6, we can determine the snapshot where the merger is complete. By graphing the separation of the COM of the MW and M31, we can identify the snapshot where the separation of their COM is approximately zero (or oscillates closely about zero), implying a completed merger, as seen in Fig. 2. From here, we can combine the MW and M31 halo particle arrays to get a complete set of particles for the merged halo.

Using the splashback radius, the radius where particles reach the apocenter of their first orbit, we can determine the edge of our halo. Of the three definitions of the halo edge (Rvir, R200, and the splashback radius), the splashback radius tends to be the largest, to our benefit.

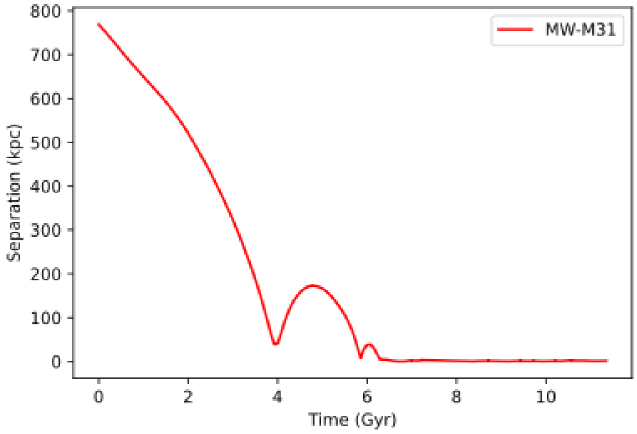

Figure 2. Graph of COM separation for the MW and M31. The separation drops to zero at approximately 6.3 Gyr, slightly larger than the value found in van der Marel et al. (2012) of 5.86 Gyr.

After a chaotic merger of two massive galaxies, particles are scattered to large radii. Including these particles is essential to understanding how the shape of the dark matter halo changes overtime, as these particles fall into the denser regions of the halo.

From here we will plot the particle positions to visualize and interpret the shape of the halo. Plotting cross sections along the xy, xz, and yz planes will help fit ellipses to each spatial plane and determine ellipticity values. Making a 3D-plot of the outer edges of the halo will also help with visualization. These plots can be made for each snapshot. Using the data from each, it is possible to create an animation that we can analyze to determine how the shape is altered over time.

2.3 Hypothesis

From Despali et al. (2016) a shape elongated along the merger axis is expected. Radiative processes, star formation, and AGN feedback are absent in this simulation. These processes generally smooth the halo to create a more oblate shape, so the simulation is expected to favor a non-oblate shape. Further, because these halos are so large, we expect the growth of the halo to begin with an initially triaxial shape. Combining the above, a triaxial halo with its longest axis in the direction of the merger axis is expected as the merged halo shape.

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