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# Dark Matter Halo Shape after a Major Merger

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## 1. INTRODUCTION

### 1.1. *Topic Introduction*

Every galaxy is theorized to have a cluster of dark matter that surrounds its disk and extends far beyond its visible boundary. These dark matter halos are necessary to explain the formation of galaxies; while invisible, these dark matter clusters exert the gravitational force needed to condense gas and dust to form galaxies. Dark matter halos accrete in uneven "filaments" or "sheets" in space, leading to clumpy, asymmetric halos (K. T. E. Chua et al. 2019). Due to this, each dark matter halo has unique properties, such as its shape or substructures (N. E. Drakos et al. 2019). When galaxies merge, their dark matter halos also merge with each other, changing their properties. This project is designed to examine how a galaxy merger influences the shape of the combined dark matter halo.

### 1.2. *Relevance to Galaxy Evolution*

Since the shape of each dark matter halo is unique to a galaxy, it is closely entwined with the galaxy's growth and merger history (N. E. Drakos et al. 2019). Dark matter clusters are, theoretically, the only site of galaxy formation; therefore, understanding their evolution has implications for the galaxy's evolution. Discovering patterns in dark matter halo properties could shed light on greater cosmological trends.

### 1.3. *Our Current Understanding*

Galaxy mergers and dark matter halos are modeled using N-body simulations. The baryon components of a galaxy are difficult to simulate, so many of these simulations are done with only the dark matter particles, in what is referred to as a DMO simulation (K. T. E. Chua et al. 2019). While these simulations are good approximations for dark matter-dominant regions of a galaxy, they are not accurate for the bright, baryon-dominant components of a galaxy (M. G. Abadi et al. 2010). Dark matter halo studies are primarily interested in studying the shape, spin, concentration, and mass profile of these structures.

### 1.4. *Open Questions*

There are many uncertainties when using N-body simulations to examine dark matter halos. One of the biggest questions is regarding the effect baryons have on the final shape of the halo, especially on the "inner" halo, where the galaxy is located (K. T. E. Chua et al. 2019). Papers such as M. G. Abadi et al. (2010) outline one way to tackle the inclusion of baryons in a simulation of this nature (see Figure 1). Active galactic nuclei can also pose issues in determining the properties of dark matter halos, since they eject baryons and dark matter from the galactic center (K. T. E. Chua et al. 2019). In many simulations, such as N. E. Drakos et al. (2019), two equal-size galaxies are used to examine how a major merger influences the dark matter halo. In actuality, this scenario is very rare; it is much more common for galaxies of different sizes to merge.

## 2. PROPOSAL

### 2.1. *Proposal*

For this project, I will examine the shape of the halo post MW-M31 merger, and determine whether it is triaxial, oblate, or prolate.

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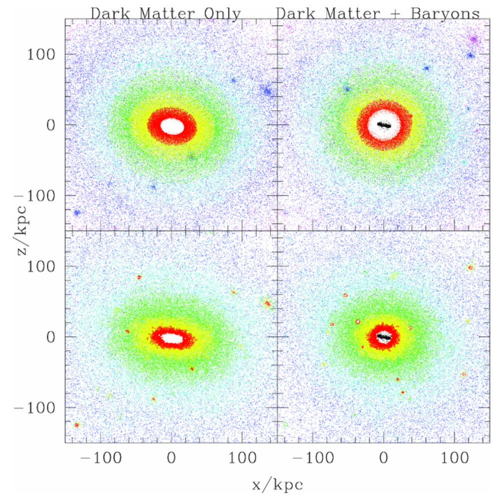


**Figure 1.** Figure 4 from M. G. Abadi et al. (2010). A good example of how the baryon component of a galaxy could possibly alter the shape of a dark matter halo. This simulation was used to compare the shapes of a dark matter only halo (left) to a halo where the baryon component of the assembling galaxy was included (right). In the scenario where the baryons were included, the halo is noticably rounder

### 2.2. *Methods*

In order to examine this question, I will use a modified version of the N-body simulation described in R. P. van der Marel et al. (2012). Only the dark matter halo particles are necessary in order to examine this scenario, so the disk and bulge particles will not be examined. While M33 is involved in this event, only the Milky Way and M31 merge, so only their particles will be considered in this simulation. I will examine the combined halo remnant after the merger has occurred, and the dark matter halo has settled – about 9 GYR in the future, or around snap number 630 in the files.

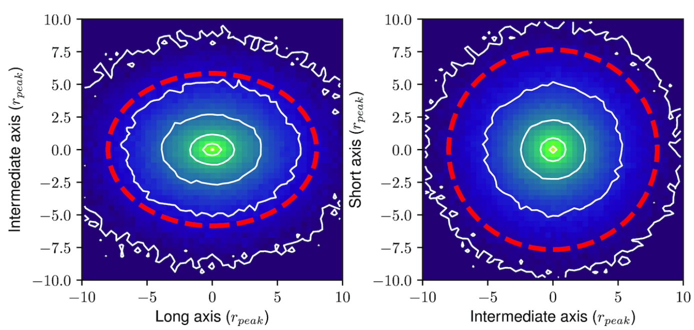


**Figure 2.** Figure 6 from N. E. Drakos et al. (2019). The results of a simulation of a major merger between two equal-sized galaxies. Plotted on top of a diagram of the halo particle distribution are iso-density contours (white) and the shape ratio (red). The shape ratio generally agrees with the iso-density contours. This diagram is very similar to what I intend to produce with my project.

Each galaxy has its own set of files, with positions, velocities, and masses for each particle at each snapshot in time. In order to examine the combined dark matter halo, I will need to concatenate the arrays for the positions of each dark matter particle in each galaxy for snapnumber 630. I will be using the high-res version of the file, since I am only examining one snapnumber instead of a sequence. Finally, I will use the python package *photutils* to plot elliptical iso-contours on 2-D histograms of the spatial projections to determine the axial lengths. I will have to plot the projection in x versus the projection in y to find the axial lengths in those directions, and then plot x versus z to obtain the axial length in the z-direction. Photutils will return the axial lengths of the plotted iso-contours. Once all three axial lengths are obtained, they can be compared to determine the shape of the halo. The halo is considered oblate if

$$x = y > z \tag{1}$$

The remnant is considered prolate if

$$z > x = y \tag{2}$$

If all three axes are different lengths, then the remnant is considered triaxial.

### 2.3. *Hypothesis*

Following from the results of N. E. Drakos et al. (2019) and M. G. Abadi et al. (2010), I expect to find that the combined dark matter halo of the merged galaxies becomes more axisymmetric. Galaxies on radial orbits will generally form prolate halo remnants, while galaxies on tangential orbits will form oblate remnants (N. E. Drakos et al. 2019). M33 and M31 are on mostly radial orbits, so I expect the halo remnant to be more oblate in shape.

## REFERENCES


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