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DM Halo Merger Remnant: Density Profile/Shape (Pre vs Post Merger)

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ABSTRACT

Using an N-body simulation, we look at the shape of the dark matter halo remnant of the merger between the Milky Way and M31 when they collide in approximately 6.2 Gyrs from now. The understanding of halo evolution and merger histories is important to get a better picture of the dark matter distribution and evolution across the universe and its impact on galaxy formation and evolution. We are particularly interested in looking at the final distribution of the dark matter halo i.e. is it prolate, oblate or triaxial? Observationally, dark matter halos seem to have a triaxial density distribution while N-body simulations usually result in a more axisymmetrical distribution after a major merger. Our results show a triaxial distribution almost tending to a prolate halo with a traixiality parameter of $\tau \approx 0.77757$. This simulation does not take into account dynamics of baryonic matter. However, the set of data used for this simulation includes the particles from both the bulge and disk of each galaxy. Therefore, the dark matter particles of the halo has accounted for the potential of the disk. The result is very similar to that of (Abadi et al. 2010) where ignoring the assembly of a central galaxy results in a prolate halo.

Keywords: Major Merger, Spiral Galaxy, Dark Matter Halo, Galaxy Merger, Merger Remnant

1. INTRODUCTION

Our galaxy, the Milky Way (MW), is on track to eventually collide with M31, the Andromeda Galaxy, located at about 2.5 million light years from us. The collision between two galaxies is known as a galaxy merger. Throughout this process, each galaxy's dark matter halo will merge too. This is one of the key aspects of halo formation and evolution. Halos form in hierarchical order where small structures merge with other halos forming denser and more massive structures.

Dark matter makes up five-sixths of all matter and it is scattered throughout the universe forming a network of filaments. A dark matter halo (DMH) is defined as the point where these filaments intersect and form higher density structures. These gravitationally bound halos are where we find galaxy groups and clusters (Drakos et al. 2019a). Therefore, studying the evolution and assembly of DMHs is key to understanding galaxy formation and evolution and vice versa. After all, our knowledge of this relationship is so poor that a galaxy has been defined as "a gravitationally bound collection of stars whose properties cannot be explained by a combination of baryons and Newton's laws of gravity" (Willman & Strader 2012), leaving dark matter out of the definition for now. The study of this relationship is also of great importance to develop a better understanding of our current cold dark matter theory.

There have been many studies to understand the structure of cold DMHs. Observationally, halos tend to have a triaxial mass distribution, that is, different distribution and length in each axis (Knebe & Wießner 2006). N-body simulations like those used in Abadi et al. (2010), have shown that the assembly of the central galaxy affects the three dimensional shape of the halo as it tends to be more axisymmetrical, almost oblate in the presence of a central galaxy (Figure 1). In the simulations where baryonic matter was ignored, the halo tends to be more prolate so the question of why in observations halos are triaxial remains unanswered (Abadi et al. 2010).

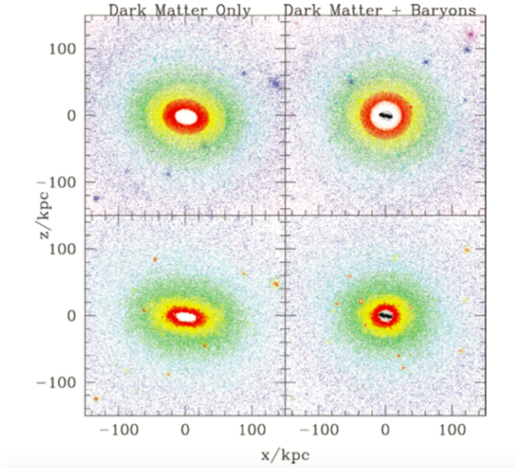

Figure 1: Abadi et al. (2010) The left panel shows dark matter particles from two different simulations. We can see that even though they are not triaxial, once a stellar disk is present (right panel), the halo becomes more spherical.

Another answered question is the effect that mergers have on halo structure. Simulations that have been done to study major mergers between DMHs, e.g. Drakos et al. (2019a), have shown that that the remnant tends to be larger and more elongated along the merger axis resulting in a prolate or oblate structure. The density profile of the remnant also seems to increase as a function of radius without having a significant change in the central density compared to the individual halos. These results seem to be similar in simulations where baryonic matter is accounted for. These simulations have only used isolated and equal mass halos; how halo assembly occurs between different mass mergers and other surrounding halos is still an open question for investigation. (Drakos et al. 2019b)

2. METHODOLOGY

Using the data from the N-body simulation (a simulation of a dynamical system of particles influenced by laws of physics) used in van der Marel et al. (2012a), we look at the MW and M31 merger and discuss the density profile and shape of the merger's halo.

To approach these questions, we combine the DM particles data from MW and M31 at a snapshot that represents 6.2 Gyrs from now. This is the time at which both galaxies completely merge. Once we have the set of merger particles, we plot the isodensity contours for all combinations of axes, i.e x-z, y-z and x-y (similar to those in Figure2). To do this, we rotate the halo so that the angular momentum vector is aligned with the z-axis. The next step is to plot the density projections. In order to visualize the structure of the remnant, the ratio of densities have to be calculated in the three axes. We find the triaxiality degree using the same method as Knebe & Wießner (2006). We define a as the long axis, b as the intermediate axis and c as the short axis i.e. $a > b > c$ and axial ratios $a : b : c$. The triaxiality degree τ is given then by

$$\tau = \frac{(a^2 - b^2)}{(a^2 - c^2)} \tag{1}$$

The halo is oblate when $\tau = 0$ and prolate with $\tau = 1$. If $0 < \tau < 1$, then there is a triaxial distribution. We expect these figures to be very similar to those of Figure 2, shown below, with density profile increasing as a function of radius and a prolate or oblate structure. Because this simulation has not accounted for the effect of the assembly of a central galaxy, we suspect the final shape will resemble that of a prolate distribution Abadi et al. (2010). These N-body simulations (Abadi et al. 2010) were consistent with the simulations done by Drakos et al. (2019b), where researchers used identical halos for the mergers and the remnant halos resulted more axisymmetrical. In the case of the MW and M31, both have almost an identical mass, so we should expect similar results.

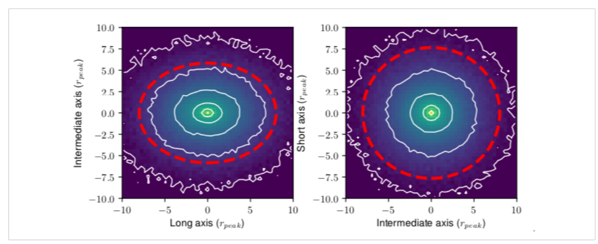

Figure 2: Drakos et al. (2019a) Isodensity contours of the halo remnant are shown in white and the projected fit of the axial ratios is shown in red. We can also appreciate the shape of the halo with the left panel being more elongated and the right panel almost circular.

3. THIS PROJECT

The aim of this project is to understand the process of galaxy mergers and the effect that has on the structure and the mass distribution of the halo remnant. We look at the halo remnant after the Milky Way and M31 have merged and study the density profile and final shape of the DMH. The goal is to answer whether the 3-D dark matter distribution is prolate (two short axes), oblate (two long axes) or triaxial. As mentioned before, previous simulations have shown major merger halos to be almost spherical with some elongation along the merger axis (Drakos et al. 2019a). This specific project only looks at the remnant shape. Whether the elongation corresponds to the merger axis will remain as an open question.

The code created for this project computes the center of mass of each dark matter particle of each galaxy of the simulation. It then rotates the angular momentum vector and aligns it with the positive z direction. This is done to create a plot where we can visualize the density contours and over-plot a fitting ellipse for the shape of the halo. To find the best fit for the density contours, we need to try different axial ratios of an ellipse and over-plot it in each axis which will tell us the 3-D distribution that the halo has.

4. RESULTS

Figure 3, shown in page 4, shows the density distribution of the DMH along the x-z, y-z, and x-y axes. The top panel shows the distribution in each axis before the angular momentum vector has been aligned with the z-axis. Without aligning the angular momentum vector, we are looking at the halo with a random orientation. The structure is tilted with respect to every axis because of this orientation. To better visualize the structure of the halo, we look at the lower panel with plots (d), (e) and (f). Now that we have oriented the halo angular momentum vector with the positive z-axes we find that along the x-z axis, the distribution of DM is aligned with the axis and is less spherical compared to the y-z axis. On the x-y plane, looking at the halo face on, we see again a less axisymmetrical and inclined distribution. This inclination with respect to the axis might be caused by the geometry of the encounter.

Using equation (1) and the axial values of the fitting ellipse $a = 78, b = 63$ and $c = 58$, we obtain a triaxiality degree of $\tau = 0.77757$ and axial ratios $a : b : c = .74 : .81 : 1$.

5. DISCUSSION

We conclude the DMH to have a triaxial distribution inclining to a prolate shape. This result is consistent to Abadi et al. (2010) where, without the assembly of a central disk, halos resulted almost prolate in shape. Our results are also consistent with Drakos et al. (2019b) where they find that halo remnants are almost never spherical in shape but rather oblate or prolate. They also argue that prolate halos are given by a radial orbits whereas oblate halos are given by tangential orbits. This is also consistent with our results, given that the MW and M31 are on a radial orbit (van der Marel et al. 2012b). These results reinforce the suggestions that galaxy assembly and merger orbits play a key role in the density distribution of DMH (Abadi et al. 2010)(Drakos et al. 2019a).

6. CONCLUSIONS

We studied the the structure and distribution of the DMH merger remnant between the MW and M31, which will collide in about 6.2 Gyrs. Understanding halo assembly will help deepen our understanding in the evolution and distribution of DM across the universe and the role it plays in galaxy evolution. We focused on the 3-D shape of the remnant to test our current predictions and understanding of halo mergers. Using an N-body simulation from the data used by van der Marel et al. (2012a), we plot the DM particles of the merger in three axes to visualise the 3-D structure. The merger remnant between the collision of the MW and M31 DMHs has a triaxiality parameter of $\tau = 0.77757$, suggesting a triaxial, nearly prolate, distribution. Our results were consistent with with out predictions. Without the assembly of a central disk, the halo did not have a spherical distribution (Abadi et al. 2010). This result also agrees with the argument that mergers in a radial orbit will produce a prolate halo (Drakos et al. 2019b). It would be interesting to determine whether the long axis in our results correspond to the merger axis. Another question that could be answered in the future is how, using a N-body/gasdynamical simulation, the assembly of the central galaxy remnant would affect the structure of the halo.

7. ACKNOWLEDGMENTS

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1. Astropy (Astropy Collaboration et al. 2013; Price-Whelan et al. 2018 doi: 10.3847/1538-3881/aabc4f)

2. matplotlib Hunter (2007), DOI: 10.1109/MCSE.2007.55

3. numpy van der Walt et al. (2011), DOI : 10.1109/MCSE.2011.37

4. scipy Jones et al. (2001–),Open source scientific tools for Python. http://www.scipy.org/

5. ipython Perez Granger (2007), DOI : 10.1109/MCSE.2007.53

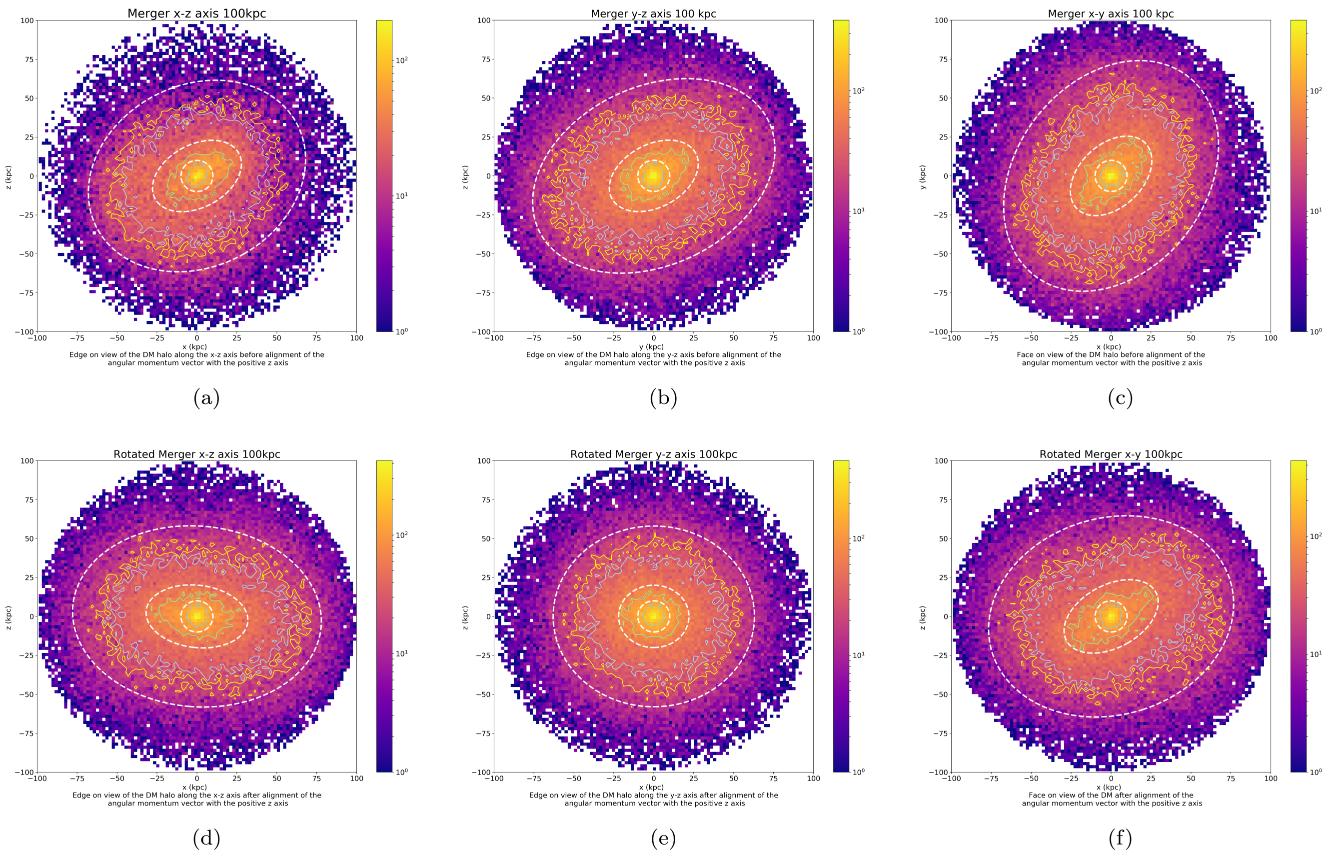

Figure 3: Panels (a)(b) and (c) form the 3-D shape of the halo remnant before the angular momentum vector has been aligned with the positive z-direction. Panels (d)(e) and (f) form the 3-D shape of the halo once the angular momentum vector has been aligned with the positive z-direction. The projected fit is shown in white dashed lines. Orientating the angular momentum vector makes it easier to see which are the long, intermediate and short axes of the halo

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