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The Evolution of the Velocity-Dispersion Profile of Dark Matter Particles in the Halo of M33

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1. INTRODUCTION

The topic of this study focuses on the tidal evolution of dark matter in **satellite galaxies**, galaxies that are gravitationally bound to a larger host galaxy. We are specifically examining how the kinematics of **dark matter halos**, a region surrounding the visible part of a galaxy that interacts through gravity, evolve under external tidal forces from host galaxies. The interaction between the host and satellite galaxy can have a significant effect on the structure of the dark matter halo of the satellite galaxy, and since galaxies are defined by having a large component of their mass in the form of dark matter (C. S. Frenk & S. D. M. White (2012)), understanding how dark matter evolves helps us better understand the galaxy as a whole. These tidal forces affect the dark matter distribution and therefore, the velocity-dispersion profile of the particles. The velocity distribution can help us understand how the distributions of both dark matter and baryonic matter change within the satellite galaxy under external influences of a host galaxy, as well as provide insight into the nature of dark matter itself.

A galaxy is defined as a gravitationally bound set of stars whose properties cannot be explained by a combination of baryons (gas, dust and stars) and Newton's laws of gravity. These galaxies can undergo structural changes from internal or external sources, known as galaxy evolution and understanding the evolution of the dark matter halos of galaxies, specifically satellite galaxies helps our broader understanding of galaxy evolution. Dark matter not only contributes most of the galaxy's mass, but its behavior also influences how galaxies form and evolve. In context of a host and satellite galaxy, how satellite interacts with larger structures. Tidal interactions, namely **tidal stripping** or when a host galaxy takes stellar matter from a satellite galaxy, can lead to mass loss of the satellite as well as changes in the internal dynamics of dark matter halos (J. Wolf & et al. (2010)), which could lead to disruption of the very structure of the galaxy itself. Studying these effects helps us understand how galaxy assembly occurs, the histories of potential mergers and the overall impact of tidal forces on the growth and transformation of galaxies. Specifically, these interactions can help create better models of galaxy formation as whole.

As our satellite galaxies orbit the host galaxy, tidal forces cause stripping of mass, namely dark matter, although baryonic matter is also lost. This can be seen in Figure 1 (H.-F. Wang et al. (2022)), where over time most of the matter is getting stripped from the satellite galaxy, where now today, almost no dark matter is present. It also shows that these stripping events occur in waves, or periodically and that there are differences in the percentage of matter being stripped between baryonic and dark matter.

It is important to understand how the velocity dispersion within the inner dark matter due to its association with the stability and survival of the satellite itself. Questions such as does the velocity dispersion within the **Jacobi Radius**, the radius at which the gravitational influence of both the host and satellite galaxy are equal, of the dark matter halo increases or decreases as the galaxy is tidally stripped? Or how does the Jacobi radius evolve over time within the satellite? Overall, how does tidal stripping affect overall stability of the dark matter halo of a satellite galaxy? This final question is studied in (G. A. Dooley et al. (2016)),which simulated how a Milky Way-like host galaxy would affect the structure of different types of satellite galaxies.

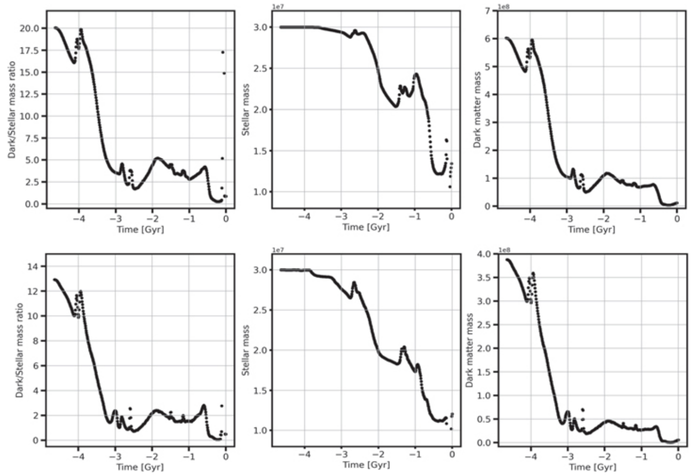

Figure 1. Shows the dark matter, baryonic matter, and the ratio of the two over a period of 4.7 Gyr's of Sagittarius dwarf spheroidal galaxy, a satellite of the Milky Way Galaxy. The top line shows the aforementioned three graphs at a radius of 5 kpc of its center and the bottom line at a radius of 2 kpc. This figure shows that stripping occurs in waves, and the stripping occurs on both dark and baryonic matter,however, this stripping occurs at different rates.

2. THIS PROJECT

In this paper, we will determine how the average velocity dispersion of the dark matter halo of M33 evolves over time within it's Jacobi Radius and how that Jacobi Radius itself changes over time.

This paper will answer how the velocity dispersion within the Jacobi Radius of the dark matter halo changes, how the Jacobi radius evolves of the dark matter halo of the satellite evolves over time, and how the stability of the dark matter halo is affected by tidal stripping.

Understanding the impact of tidal stripping on satellite galaxies is important for expanding our understanding of dark matter itself. This is crucial because through interactions between the host and satellite galaxy, we can see how the dark matter halo of the satellite is affected through the parameters we are investigating. Through our desired study, we can quantify the effects of the interacting dark matter.This can help us better understand the mechanisms that drive satellite disruption and how these mechanisms are affected through tidal stripping.

3. METHODOLOGY

The simulations used in this study are based on N-body models of M31. These models are composed of two main components: a base galaxy model representing M31 itself, and a GSS component derived from a N-body simulation of a satellite galaxy's disruption (R. P. van der Marel et al. (2012)). N-body simulations refer to the methods used to study the evolution of complex systems with many gravitationally interacting particles. Each particle in the simulation represents a mass element, and the gravitational interactions between these elements are computed over time to see how the system evolves.

The approach to these questions are to use the N body simulation to investigate how M33's dark matter halo is distrubed by M31, its host galaxy. This will be done using the halo particles of each respective galaxy and all calculations will be done solely with these particles in mind.

The first calculation would be obtaining the **velocity dispersion** or σ. This value can be calculated using the standard deviation formula by first calculating the mean velocity, Vmean (km/s) from the use of N bodies, or number of particles, and then obtaining the squared average deviation (km/s) from the mean:

$$V_{mean} = \frac{1}{N}\sum_{i}^{N} v_i \tag{1}$$

$$\sigma = \sqrt{\frac{1}{N}\sum_{i}^{N}(v_i - V_{mean})^2} \tag{2}$$

Next, I would need to calculate the Jacobi Radius. This could be achieved by obtaining the radius of each particle in the simulation, then summing the mass of all the particles contained within the Jacobi radius:

$$R_j = r\left(\frac{m_{\rm sat}}{2m_{\rm host}}\right)^{1/3} \tag{3}$$

where Rj is the Jacobi Radius (kpc), r is the distance from M33 and M31 (kpc), msat is the mass of the satellite of M33 (Msun), and mhost is the mass of M31 (kpc). Naturally, this is going to change overtime due to the nature of the process we are investigating, so doing this at different time steps will naturally allow us to show how the velocity distribution changes, as well as the mass within the Jacobi radius. We can obtain all of this information directly from our simulation, and I would want to use all of the snapshots before the merging of the Milky Way and M31, and possibly after as the simulation shows M33 is not merged when the other galaxies do. This can partially be shown as in Figure 2, with a plot of the average velocity dispersion of the satellite galaxy and another of the distance of the satellite from its host galaxy. I would want to plot the velocity dispersion specifically within the half-mass radius rather than the entire galaxy and perhaps show how the half-mass radius changes over time as well.

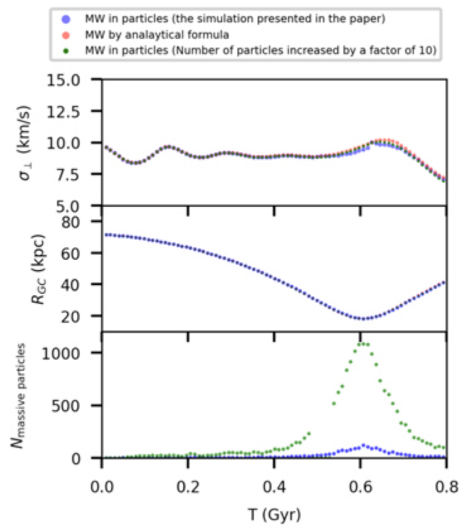

Figure 2. This figure is taken from H.-F. Wang et al. (2022), and displays the average-velocity dispersion, distance, and number of massive particles over a small period of time of the satellite galaxy Sagittarius around the Milky Way galaxy for two types of simulated data and from analytic formulas.

The plots I will create will show the velocity dispersion within the Jacboi Radius over time and a plot of the Jacobi Radius itself changes overtime. Another graph I will create will display how the amount of dark matter within the Jacobi Radius changes over time as well. These plots will serve to answer how the velocity dispersion within the Jacobi Radius changes over time, and how the Jacobi Radius changes over time. It will also explain how the strucutre of the dark matter is changing with the inclusion of how the amount of dark matter within the Jacobi Radius changes as well.

I propose that overtime, the amount of dark matter in the system will decrease periodically. This periodicity is caused by the orbit of the satellite around the host galaxy and throughout this periodicity, the velocity distribution within the half-mass radius will undergo periods of increasing velocity, while generally the trend of the velocity will decrease over time. As dark matter is stripped from the outside of the dark matter halo, the dark matter will become more concentrated near the center of the satellite or within the half-mass radius itself, causing this increase in velocity dispersion. However, mass is still lost, so overtime the total velocity dispersion will decrease, and so will the velocity dispersion within the half-mass radius. I think this will occur because naturally, overtime if you lose mass within a system, you are losing energy. If you lose energy, you will lose velocity. The reason of the peaks in velocity distribution initially are due to a loss of gravitational potential energy from this loss of outer mass in the satellite, which condenses the mass towards the center of the satellite, so within that area, there will be a spike in average velocity dispersion.

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