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Time evolution of M33's dark matter halo

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1. INTRODUCTION

A majority of a galaxies dark matter is known to reside in its outer halo, otherwise known as the Dark Matter Halo. Due to the uneven spread of mass in the galaxy, differences in gravity are experienced across the galaxy. This leads to tidal forces that shift the galaxies mass around, including its dark matter, which also has an affect on these tidal forces. This force changes with time due to the shifting mass, so we can observe how it changes by observing the change in the galaxies mass profile. The Hernquist Profile is a theoretical model that estimates total mass enclosed within a given radius based on the galaxies halo mass. M33 is a spiral galaxy, meaning it has branches of gas and dust that spiral around the core of the galaxy. It also orbits around Andromeda, making it a satellite galaxy. Most of a galaxies dark matter is known to exist in a radius around the outer edge of the galaxy, known as the Dark Matter Halo. Cold Dark Matter theory refers to the theoretical effects and properties of dark matter. It states that dark matter moves slowly, and has a weak gravitational effect on surrounding bodies. This fits in with models of the effect dark matter has on tidal evolution of galaxies such as M33.

Understanding dark matters affect on tidal evolution helps us to understand galaxy evolution. Since dark matter exerts a force on objects around it, it influences the evolution of galaxies. A galaxy is is a conglomeration of stars, gas, and dust held together by gravity. Galaxy evolution describes how a galaxy develops and changes with time. This includes changes in density, metallicity, composition, and shape. Knowing how the density changes throughout the galaxy gives us a dynamic view of the galaxy and helps us understand how the presence of dark matter and the galaxies evolution are correlated.

According to cold dark matter theory, virialized dark matter halos form around galaxies. These halos can have sub-halos, and so on and so forth. These halos can be affected and perturbed such as tidal stripping and dynamical friction. (1) The Lambda Cold Dark Matter theory is also the most accepted framework for the evolution and effect of dark matter. (3) The figure below shows the surface density of M33's stars and gas from different perspectives. It shows how density can change both with distance from the center and how it can differ depending on the object of interest. In this case, it shows gas and stars, but in my case, I'm interested in dark matter.

The degree to which dark matter actually affects its surrounding bodies is an open question. Cold dark matter theory only approximates the gravitational affect, but we don't have a definitive quantity. The affect dark matter has on the tidal evolution of galaxies is another open question. One study from Green et al used DASH library simulations of the tidal evolution of sub-halo density profiles. (1)

2. THIS PROJECT

The goal of this project is to look at the time evolution of the inner dark matter density halo of M33. The goal is to see how its concentration changes with time, and whether it's well-fit by a Hernquist profile. This entails looking at the change in the density of M33 at several different radii with time, and drawing conclusions about how dark matter influences the tidal evolution of a galaxy.

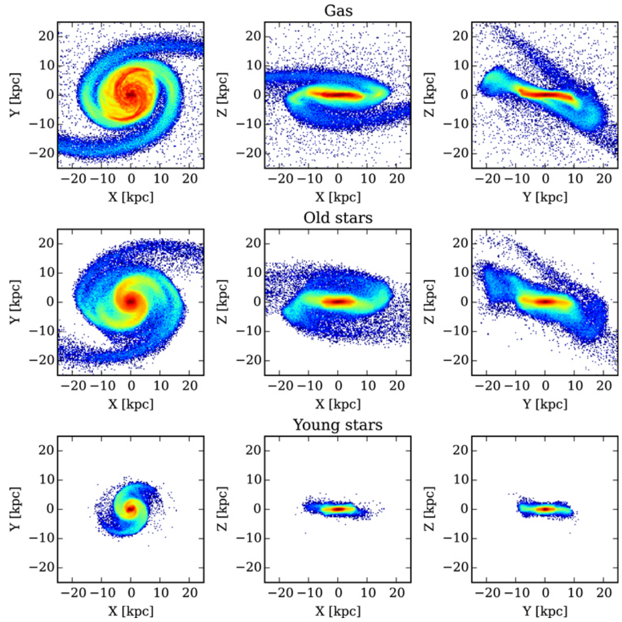

Figure 1. Surface Density of M33 from various perspectives (2)

I'll be addressing the open question on how dark matter tidally evolves with time.

By better understanding on dark matter halos evolve with time, we can better understand how dark matter is correlated to a galaxies evolution. By understanding how dark matter density changes with time, we can see its effects on surrounding bodies. This study will help us see how dark matter concentration changes based on distance from the center and with time.

3. METHODOLOGY

An N-body simulation is a simulation that approximates the physical behavior of astronomical objects such as galaxies based on various parameters, such as gravity and mass. I'll be using mass profile simulations to calculate the density.

To approach this problem, I'll be looking at the density profile of M33 as several different snapshots so I can see how it changes with time. To calculate density profile at each snapshot, I'll calculate the mass at several different radii, and divide by volume. I'll do this for multiple snapshots so I can observe any changes in the density profiles. Since there are so many snapshots to look at, I'll likely look at more critical events in the lifespan of M33, such as when it reaches apogee or perigee. Afterwards, I'll fit it to a Hernquist profile to see how they compare. The figure below shows a single mass profile for the first snapshot of M33. I'll be making several of these mass profiles so I can then calculate their density profiles.

In order to calculate mass profiles, I'll need to calculate the galaxies center of mass, which can be done by looping through a reduced radius. I'll calculate the mass profile by looping through several radii and adding the masses that match the criteria to an array. I'll make a loop that calculates the mass profiles for each snapshot. Then, I'll divide the mass profiles by the volume of the sphere at different radii to get the density profiles. I'll subtract the outer shell volume from the inner shell volume to get local density so it can be fitted to a Hernquist profile. I'll use the calculated mass profiles to calculate the Hernquist density profiles for each snapshot.

I'll make a plot that takes a number of critical points in the galaxies lifespan and plots several evolving density profiles. Each line will represent a different radius as its density evolves over time, and the plot will graph density vs time. That way, I can see how each profile evolves differently with time.

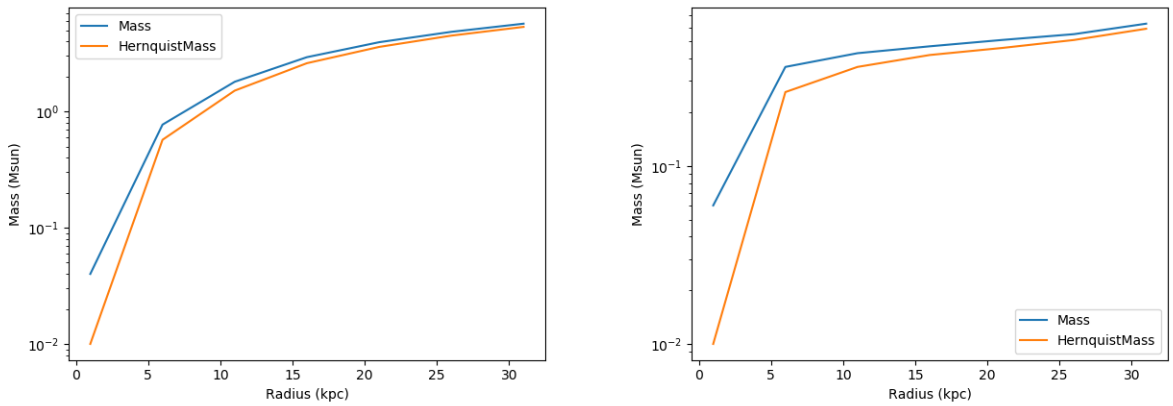

Figure 2. Mass Profiles of M33 0th and 800th snapshots, respectively.. Compares halo mass to hernquist mass model. It remains well-fit by the hernquist profile throughout the simulation.

I think I'll see a drop in the both over time and further out from the center. M33 is orbiting around Andromeda, which likely has a tidal effect on M33. M33 itself is also subject to its tidal forces, which will spread its mass around making it less dense. I believe the density profile will be well fit with the hernquist density profile. The mass profile at the first snapshot is well fit by a hernquist mass profile, so it stands to reason that the density profile will also be well fit.

4. RESULTS

The first figure shows the density vs time at several different radii. 6kpc was used as the smallest radius value since the data becomes sporadic at lower volumes. Density drops universally over time. The further from the center, the lesser the volume. The second image shows the hernquist density for 6kpc and 11kpc compared of their density profiles over time. The hernquist density profiles were much larger than the density profiles, so they were multiplied by a scale factor to be more properly compared. The shift in hernquist mass is proportional to the shift in standard density.

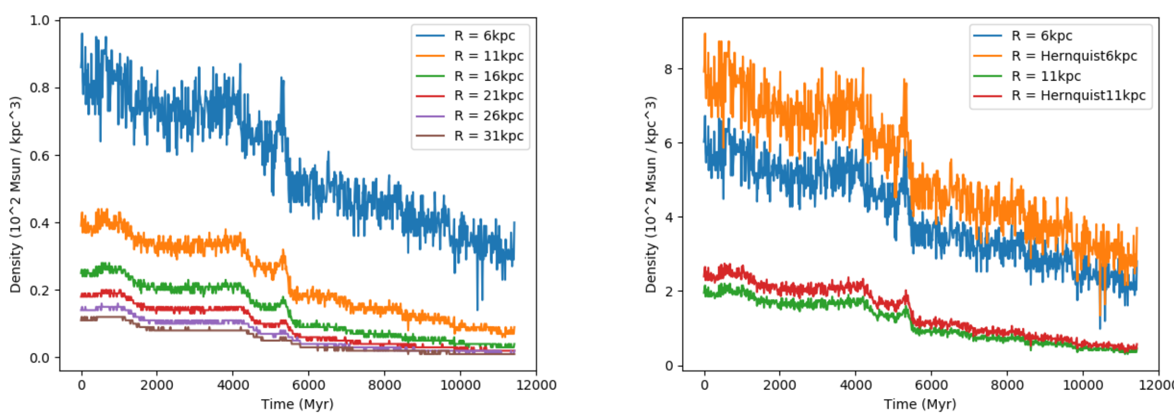

Figure 3. Left: Local Density change for several radius profiles over time. Density drops over time for all profiles, as well as with distance from the center. Solar mass had to be multiplied by a scale factor of 10e2, as the density values were too small to be graphed otherwise. Right: Hernquist Profiles for 6kpc and 11kpc vs their Density Profiles over time. Standard densities were multiplied by scale factors for more adequate comparison. Hernquist density matches the standard density profiles over time otherwise.

The graphs below show hernquist density profiles fit to standard density profiles at 5 different snapshots in M33's lifespan. The Hernquist profile always scales higher than the standard density profile, though it fits slightly better over time. In order to have nonzero values, the hernquist density profiles were multiplied by a factor of 10e4, while standard density profiles were multiplied by a factor of 10e2. Regardless, the density profiles are not well fit by a hernquist profile.

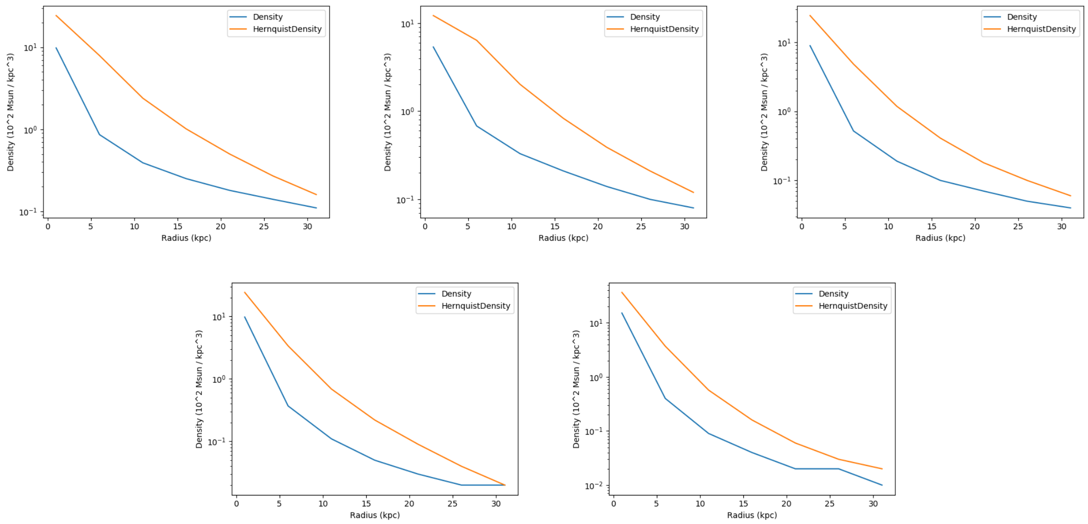

Figure 4. Hernquist profiles fitted to their density profiles at 5 snapshots: 0, 200, 400, 600, and 800. Density profiles are not well fit by hernquist profiles. Profiles are plotted in Radius (kpc) vs Density (10e2 Msun / kpc^3).

5. DISCUSSION

The density drops over time in all profiles as predicted in my hypothesis. Density also drops further from the center, though at a slower rate than the profiles closer to the center. The hernquist profile changes almost identically to the standard profiles over time, yet individual snapshots are not well fit by the hernquist profiles. This result tells us that there is evolution in dark matter density profiles. This is likely due to tidal forces spreading the dark matter further out into the galaxy. Dark matter mass drops by a factor of 10 at 31kpc by the end of the simulation, suggesting that it must be moved somewhere else, potentially due to tidal forces. This means that there are forces that the hernquist profile does not account for. This shows that the hernquist profile is not an adequate fit for all types of galaxies. As galaxies evolve, their dark matter becomes less concentrated, meaning that over time, galaxies are less subject to the gravitational pull of dark matter.

The Hernquist density profile does not fit well with the standard density profile, though it does get closer to fitting with time. If the simulation were to look further into the future, it might fit more. Since the drop in dark matter concentration corresponds to an increasingly better fit, this could mean that dark matter has an exponential effect on galaxies. The more dark matter there is, the more analytical models start to break down. This means that greater dark matter concentrations have a greater effect on theoretical models.

REFERENCES

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