Tracing the Inner Density Profile of M33 During the Milky Way and M31 Collision

Jenny Calahan

February 2018

1 Theory

Dark matter makes up a significant portion of our universe and it is poorly understood. Astronomers are on the way of being able to better measure and explore dark matter though brand new theories and observations. The current leading model is the λCDM model that affects the universe at large. It has been able to successfully reproduce the cosmic microwave background, accelerated expansion of the universe, and the distribution of galaxies at large. However, smaller scale observations have not been well explained through the λCDM model.

When it comes to the dark matter profile of the center of galaxies, there is a disagreement among astronomers. So called the ‘core’ vs ‘cusp’ argument. If a galaxy has a dark matter ‘core’ in it’s center, the density profile goes as r^{-1} and has a velocity rotation curve proportional to $r^{1/2}$. A ‘cusp’ center has a density profile that is constant (r^0) which leads to a velocity dispersion that goes linearly with radius. So, if we can observe the velocity rotation curves, we can determine whether a galaxy has a core or a cusp. That should be easy enough to model and observe, right?

Wrong. As it turns out, observations seem to support the core model while theory (powered by the λCDM model) continues to support the cusp model. Since the first N-body models to present day models turn out to support cusp profiles regardless of a galaxy’s size, mass, or cosmology. There are possible additions to models that can turn the cusp into a core, but they all involve heavy baryonic interaction with the dark matter in the core. For example, a star formation rate of around $10M_{odot}/yr$ can force a cusp into a core. Observations can also be improved, and there are many factors that go into measuring a galaxy’s velocity rotation curve. Over time observations and theory have improved in accuracy, but there the two have get to converge. The most recent observations come to a $\rho \; \alpha \; r^{-0.2}$ and the most recent simulations suggest $\rho \; \alpha \; r^{-0.8}$.

Dwarf galaxies, such as the nearby M33, are the ideal laboratories to test our theories of dark matter. Dwarf galaxies have a high ratio of dark matter to baryonic matter, and M33 is right in our back yard. We can explore the ’core’ vs 'cusp' dilemma with a high resolution simulation M33, and further explore how the dark matter profile is affected by interactions of baryonic matter as it goes through the Milky Way-M31 collision. The key questions to ask in this project will be

1. How does the dark matter profile of of M33 evolve over time? i.e. Before the collision, what is the density profile of M33? At the end of the collision? In between?

2. Does the dark matter profile become more or less dense over time? Does this affect the core vs cusp model? As dark matter is stripped, does density decrease constantly, or more towards the outside of the core?

3.Does the inner dark matter density profile fit well with the Hernquist profile over time?

This questions will help to complete our understanding of dark matter, especially as it interacts with baryonic matter in a collisional situation.

2 Method

Throughout this project I will be attempting to observe the inner dark matter density profile. I can indirectly measure the density profile via velocity dispersion close to the center of the galaxy. I would like to define the 'inner' region to be around 20% of the size of the baryonic matter of the galaxy. M33 is around 18,396 parsecs across, 20% of that is 3,679 parsecs. So I will be exploring the dark matter particles within 1836 parsecs of the center of mass. I will be able to measure the velocity dispersion before and after the collision relatively easily by just using the first and last time shots. The most interesting part of that velocity distribution is the slope, so to measure the velocity distribution over time, I can find the slope of the distribution at each point in the collision to come up with a final graph of slope vs time. The change (or lack in change) of the slope will be interesting and can suggest any sort of evolution of a core or cusp inner CDM region.

In order to measure the validity of the Hernquist profile, I will plot the Hernquist model vs the dark matter density at various times in the collision. There are also ways to calculate how 'good of a fit' the data is to the model, and I can take that value and plot the 'goodness of the fit' over time to see how the dark matter evolves over time according to the Hernquist profile. I will certainly be able to use my exisiting code from Hw 5 to aid in this part of the project.