Studying the Gravitational Dark Matter Wake of M33 During the Merging of the Milky Way and Andromeda

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QR Code to Animation

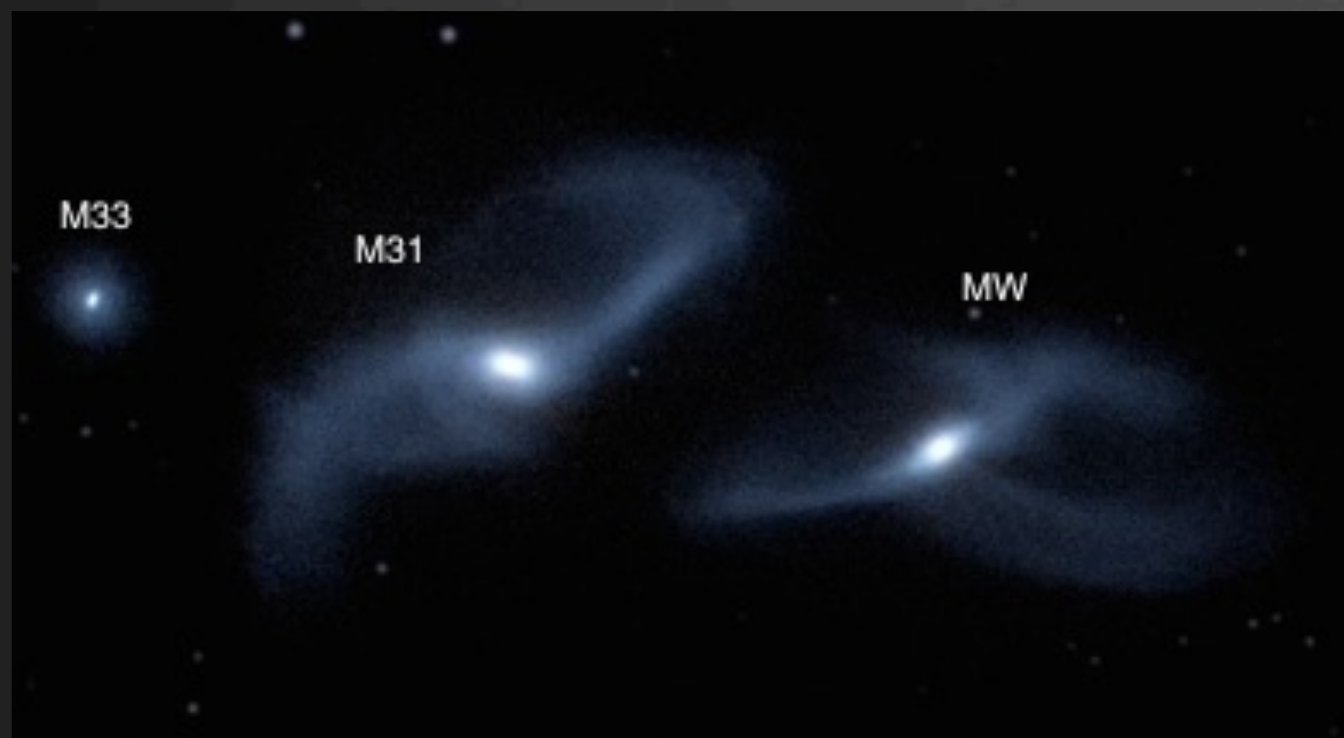

Figure 1. Snapshot of the MW, M31 and M33 during the simulation produced by van der Marel, Besla , et al.(2012). In this snapshot, the MW and M31 have just recently had a close encounter

Abstract

We investigate the effects of dynamical friction experienced by M31's satellite galaxy M33 in the near future and throughout the impending Milky Way-Andromeda-M33 merger. This project was an extension of an in-class assignment run by Dr. Gurtina Besla. We use the merger simulation presented by van der Marel, Besla, et al. (2012) with approximately 10^6 dark matter particles to analyze the density and morphology of the gravitational wake induced as M33 orbits within the dark matter halo of Andromeda and ultimately within the halo of the Andromeda-Milky Way merger remnant. We explore the density and time evolution of the induced wake M33 of M33 as well as its orbit.

Introduction

Dynamical friction is a force first discussed by Chandrasekhar in 1943. It is one of the key components of why galaxies merge. It can provide key insight for us to determine the future evolution and shape of our own galaxy. Dynamical friction acts as a drag force between dynamical bodies. We investigate the effects between a large body and comparably smaller body: M31 and M33, respectively. As M33 passes through the dark matter halo of M31, local particles of M31 are perturbed by M33's presence and move toward it. However, since M33 is moving through the halo, the perturbed particles move to where M33 used to be and then a small few are collected behind it. The perturbed particles trailing M33 act to slow down its overall velocity. From the simulation and by using the center of masses of M33 and M31, we see in Figure 2 how M33 is on a decaying orbit around M31 as time progresses. We use an integrator to show the future of M33 beyond the end of the simulation. The integration begins after the merge between M31 and the MW because the mass of the system that M33 orbits roughly doubles in size.

Summary

- Wakes are important in our understanding for galactic evolution, especially in our own system
- Looking for a gravitational wake in the dark matter halos of M31 and the MW caused by presence of M33
- M33's orbit is decaying due to dynamical friction.
- The simulation needs to be of higher resolution to help sift out a distinct wake
- M33 is a three dimensional system and experiences constant tidal forces, stripping it apart

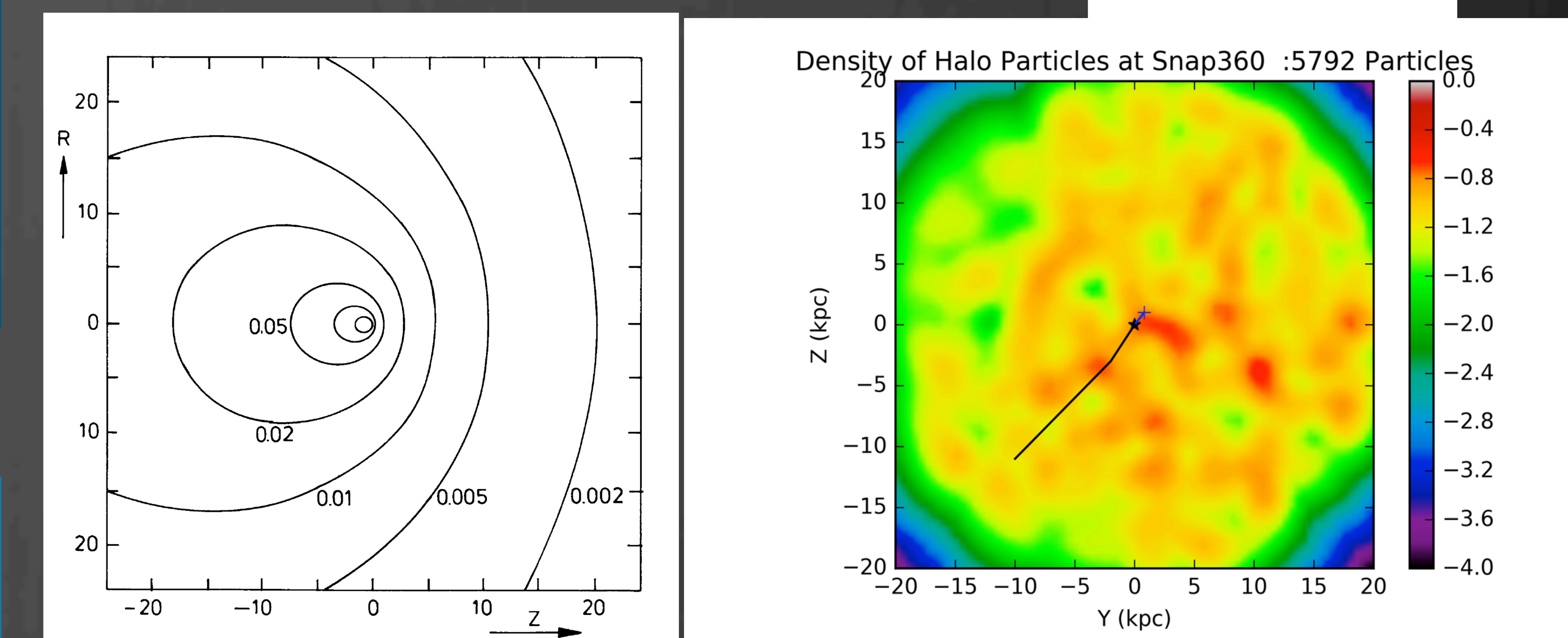

Figure 4A and 4B. A) Density contours predicted by Mulder in 1983. The numeric values refer to the percent of over density seen at that contour. B) Density plot of the combined halos of MW and M31 about the center of mass of M33. The blue describes the direction of M33. The black line describes the previous locations of M33. The colors are scaled logarithmically, the white/red areas are the most dense and the least dense are black/purple.

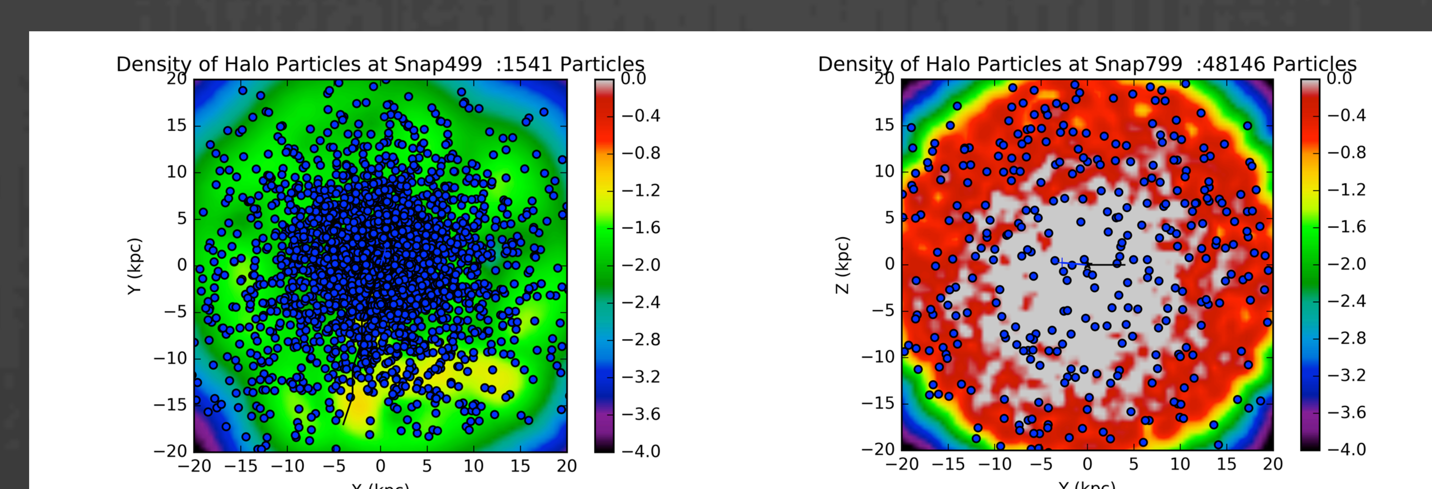

Figure 3A and 3B. These plots describe the local density of the combined halos around the center of mass of M33. White/Red describes the highest density of particles, black/purple is the lowest density. Overplotted is the distribution of dark matter particles of M33 as seen by blue dots. A) and B) have been taken from two times, where A) is in the middle of the simulation and B) is at the very end. This plot aims to how spread out M33 has become over time and can no longer be treated as a point mass.

Conclusion

In this extension of an in-class project, we have examined the simulation from van der Marel, Besla, et al. (2012) to look for the effects of dynamical friction in the form of a gravitational wake following M33. The investigation of the gravitational wake is an important endeavor to help us better understand the morphology of galactic evolution. We explored the possibility of a gravitational wake by attempting to observe the population density of the combined halos of the MW and M31 around a localized area defined by the center of mass of M33 at each time step for 10 Gyr into the future. The animation of the densities at each timestep was not able to distinctly show a wake similar to Mulder's predicted outcome, given by Figure 4. Our analysis of the velocities, as exampled in Figure 5 also did not provide distinct evidence in favor of a clear wake either. It is likely that in order to see such a small effect we would need to analyze a simulation with 10-100 times more particles.

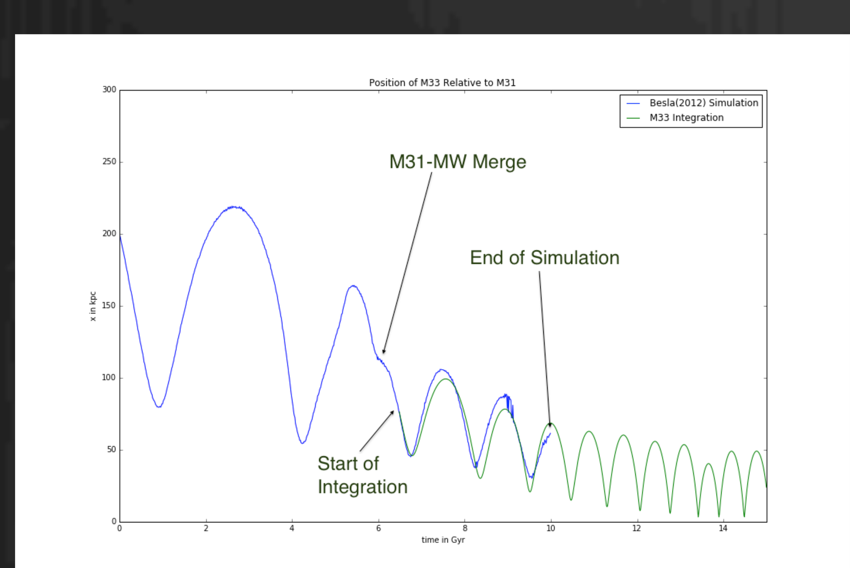

Figure 2. Shows the predicted orbit for M33 during the simulation and the calculated orbit beyond the simulation. The satellite decays steadily until it will merge fully with M31-MW. The blue line shows the difference between the center of mass of M33 and M31 during the simulation. The integration (green) starts after the merge of the MW and M31.

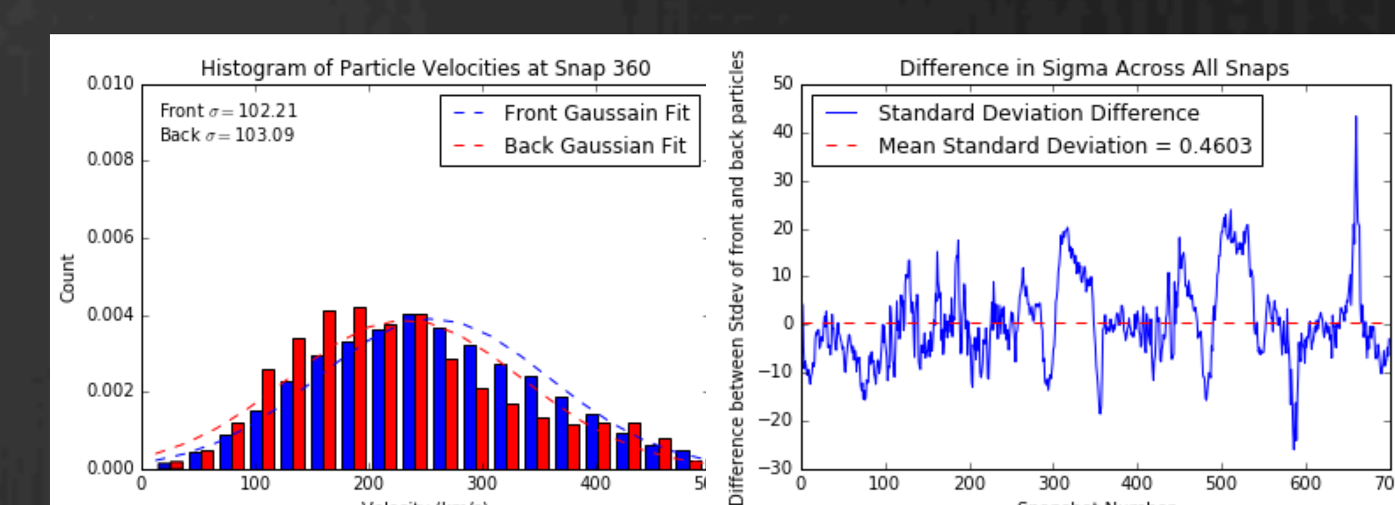

Figure 5A and 5B. A)A histogram of the velocities in the local area. The blue bars describe the particles in front of M33 and the red bars describe the number of particles behind M33. The blue and red dashed lines are Gaussian fits to each respective set of particles. B) A plot (blue line) showing the difference between the standard deviation of the particles in front and behind M33 across the entire simulation. The red line is the average standard deviation for the entire simulation.

Results

In Figure 2, we show that M33 is on an inspiraling orbit and is steadily decaying, so we know that the satellite is slowing down. Eventually it will completely merge with the MW-M31 merger. Therefore, we know it is interacting with the dark matter particles and a wake is created. Otherwise, it would remain in a steady orbit. The ideal case for the wake being seen is exampled by Figure 4A. This plot was created by Mulder in 1983 for idealized case where a point mass traveling through a sea of particles and as the point mass travels through the medium, the medium responds by creating local overdensities to act to slow the point mass. In Figure 4B we look specifically for the shape of an over density that looks akin to Figure 4A, but the wake does not readily present itself. The tidal forces on M33 have significantly stretched out its shape so that it can hardly be treated as a point mass any more. Figures 3A and 3B show the spreading out the dark matter particles of M33 over time. Therefore, it comes with little surprise that when we look for the wake, it is obscured and difficult to distinguish from the surrounding particles. In Figures 5A and 5B we try another approach to sift out the wake by analyzing the velocities of the particles in front and behind the wake. We hypothesized that the particles behind M33 would have a consistently larger standard deviation compared the particles in front of M33. We see from Figure 5B that the average standard deviation over all time steps is slightly in favor of the particles in front of M33 instead of behind.

Methods

- Simulation of MW, M31, and M33 used was put forth by van der Marel, Besla, et al. (2012)
- We found the center of mass of M33 and then took an enclosed a radius out to 25 kpc within the combined halos of MW and M31.
- Employed a density smoothing function to assist in showing a wake behind M33
- We also used an integrator based off of a Hernquist halo profile and accounted for dynamical friction to show M33 is decaying in it's orbit.

Works Cited and Acknowledgements

Mulder, W. A. "Dynamical Friction on Extended Objects." *Internal Kinematics and Dynamics of Galaxies* (1983): 189-90.

Van der Marel, G. Besla, et al "The M31 Velocity Vector. III. Future Milky Way M31–M33 Orbital Evolution, Merging, And Fate Of The Sun." *ApJ The Astrophysical Journal* 753.1 (2012): 9.

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