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Fate of Stars at Sun's Location in the Milky Way, M31 and M33 Disks

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ABSTRACT

This simulation tests how particles in our galaxy that have similar attributes to the Sun are affected over time. This is measured by tracking the amount of particles in a given radius over time. It's valuable understand galaxy evolution by starting to observe the change in our own and neighboring galaxies. I plan to demonstrate the change in radial distance of particles throughout each galaxy over 10 Gyr. This product can be used to support understandings of the conservation of angular momentum and how that affects particles in the galaxies over time. I found that the particles migrated further from the center of mass. This is a similar conclusion to (van der Marel et al. 2012) and demonstrates that the particles are affected by velocity and rotational dynamics.

Keywords: Major Merger — Gravitationally Bound — Galaxy Merger — Spiral Galaxy — Velocity Dispersion

1. INTRODUCTION

With the procession of time, particles spread out in a galactic disk change velocity and position. The interaction by the merger of galaxies also affects the status of these particles. The study of particles captured or ejected from mergers allows the formation of theories to the evolution of galaxy structures in the universe. This project uses computational techniques to measure the changes in position and velocity data of the solar-like particles. The analysis outlined in this paper will involve comparing the motion observed in the Milky Way to models of M31's and M33's motion and using techniques to determine the most likely motion of the solar-like particles.

Simulating the merger of M31 and M33 informs predictions of the change in observable system over time. To understand how our Sun moves through the Milky Way, we can look to the migrations of similar stars in these other galaxies. This also informs us about the change to similar galaxies and what we should expect to observe from their mergers in the universe. According to (Sparke & Gallagher 2010), a galaxy is a massive system of stars, gas, and dust that is held together by gravity. (Sparke & Gallagher 2010) also explains galaxy evolution, referring to the processes that shapes the formation and evolution of galaxies over time. Stars at the Sun's location in M31, or any other galaxy, are subject to the gravitational forces of the other stars and the distribution of dark matter within the galaxy. By measuring the movement of these stars over time, we can understand the distribution of mass in the galaxy. If stars at the Sun's location in the M31 and M33 are found to be moving in a certain direction, it could indicate the presence of a dense concentration matter. Studying the movement of stars in galaxies also provides insights into the physical processes that govern the behavior of galaxies, such as mergers with other galaxies, interactions with the intergalactic medium, and star formation. By understanding these processes, we could simulate galaxy evolution and test predictions about the future evolution of galaxies.

A star's position in its parent galaxy is not stationary. The rotation, angular velocity, mass distribution, and interactions with nearby systems influence star location throughout time. Stars undergo their own precession and wandering much like planets do around their host star. The observed orbital velocity of stars as a function of its distance to the center of the galaxy does not match with Kepler's Laws. In Figure 1, the density of stellar particles are shown as they change over time in the Milky Way. Density of these particles decrease as the rotational mechanics distribute particles further out from the center of the galaxy.

The current proposed solution to problem of different theoretical and observed results has to do with the existence of dark matter. The lack of observed decreas-

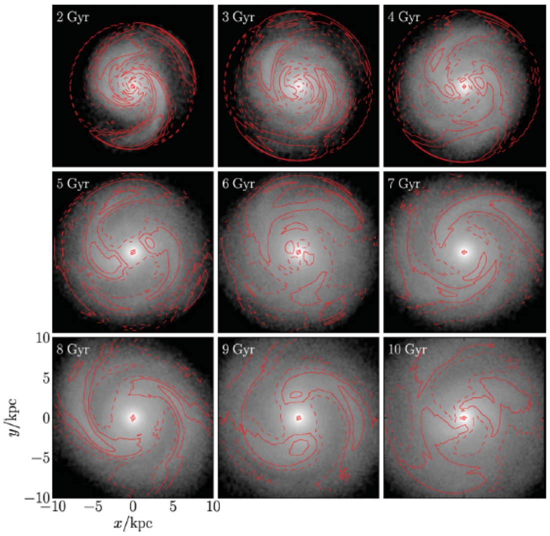

Figure 1: From (Roškar et al. 2012): Stellar density maps for simulation run at several times. Contours of densities derived with Fourier equations are in red with contours drawn at -50,-20,-5,5,20,50 % densities. Negative contours are indicated by dashed lines. This shows uncoiling of the Milky Way galaxy and the spread of stellar particles throughout the galaxy as time goes on.

ing orbital velocity with increasing radius from galactic center is that invisible dark matter halos surround the galaxy and this extra mass causes orbital velocity to level-off further from the galactic center. Interactions with these neighboring galaxies and the intergalactic medium affect the movement of stars in M31 M33. Improving our observational and computational techniques can help to better understand the movement of stars in the galaxy. In (Roškar et al. 2012) dark matter is included in the simulations and further shows orbital resonances created by the changing distribution of matter.

2. THIS PROJECT

The project will use computational techniques to measure the changes in position and velocity data of the solar type particles. The analysis will involve comparing the motion observed to models of M31's and M33's motions and determine the most likely motion of the solar-like particles.

Using the known values for our Sun's radius and velocity in the Milky Way provided in (Martínez-Barbosa et al. 2015), we can extend this to similar particles that exist in M31 and M33. Then the radial velocity and other forces on the particles will need to be accounted with the current model for the change in the structure of M31 and M33 over time. This calculation will need to be produced in two ways: with and without dark matter. This is to check that the current dark matter theories in the field correspond to what is observed in the simulation. This will also tell us about the change in the density of stars in the radii chosen.

The position of solar-like particles in M31 and M33 will change over time as they drift away from the galactic center. They may even become unbound due to change in magnitude in velocity due to the merger. With the velocities of stars not decreasing at these greater radii, the particles should continue to move away from the eight kpc range at a steady rate. The structure of M31 may then be an elliptical galaxy by the end of the merger with M33 as discussed in (Sparke & Gallagher 2010). This result will help us to construct a theory for what should happen to our solar system and galaxy with the eventual merger of the Milky Way and M31.

3. METHODOLOGY

N-body simulation is a simulation of a dynamical system of particles, usually under the influence of physical forces, such as gravity (see n-body problem for other applications). N-body simulations are widely used tools in astrophysics, from investigating the dynamics of few-body systems like the Earth-Moon-Sun system to understanding the evolution of the large-scale structure of the universe.[1] In physical cosmology, N-body simulations are used to study processes of non-linear structure formation such as galaxy filaments and galaxy halos from the influence of dark matter. Direct N-body simulations are used to study the dynamical evolution of star clusters.

First, the xyz components of each particle in each of the galaxies are assigned indexes to sift through the data. Then limits are introduceed to narrow the particles to those within 8.92 kpc and 30 km/s in the z direction defined in (van der Marel et al. 2012). The perspective of the galaxy must also be changed due to their inclination when we observe them. This is fixed with a rotating frame function to transpose the radial and velocity vectors of each particle. Then the particles are plotted at their distance from their galactic center. As multiple plots are made, the difference in amount of particles at any given radius will show the motion of the particles over time to see where they will end up in 10 Gyr.

With the provided data, the code will limit particles in M31 and M33 that have a radius of about eight kpc from the center of the galaxy and similar velocity in the z direction as the Sun. This means the galactic center of each galaxy needs to be estimated first which in itself is a value that can vary depending greatly. The proper motion of particles in M31 and M33 should be

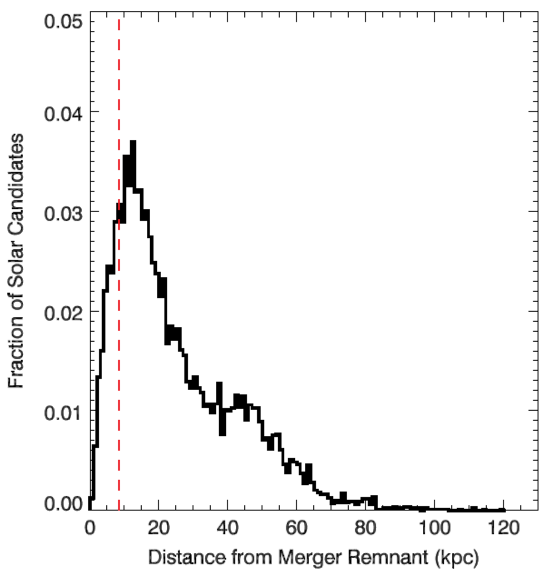

Figure 2: From (van der Marel et al. 2012):Radial distribution of candidate suns with respect to the center of MW-M31 remnant, at the end of the N-body simulation (t=10 Gyr) for the canonical model. The red dashed line indicated the current distance

$$r \approx R_sun \approx 8.29kpc$$

of the Sun from the Galactic Center. All candidate suns start out from that distance. Most candidate suns (85.4 %) migrate outward during the merger process. This is what I am trying to reproduce to show that solar like particles migrate from their beginning position over time.

included to account for change of the galaxy over time. Then the merger of the two galaxies and the change to their velocity distributions should also be calculated to measure how this event will affect the solar-like particles we selected. To compare the simulation ran, figures comparing the radius from galactic center should be included, much like in (van der Marel et al. 2012). The correct particle types will also need to be selected, first excluding halo and bulge particles as these account for separate regions in the galaxy, then possibly repeating the simulation to account for the dark matter to see if this produces a result similar to (Kafle et al. 2018).

The simulation should produce a result of a histogram with amount of particles at the original radius 8.92 change over time. This will support the hypothesis that particles in each galaxy are not stagnant and are influenced by angular momentum and their orbit to migrate throughout the galaxy.

The position of solar-like particles in M31 and M33 will change over time as they drift away from the galactic center. They may even become unbound due to change in magnitude in velocity due to the merger. With the velocities of stars not decreasing at these greater radii, the particles should continue to move away from the about eight kpc range at a steady rate. The structure of M31 may then be an elliptical galaxy by the end of the merger with M33. This result will help us to construct a theory for what should happen to our solar system and galaxy with the eventual merger of the Milky Way and M31.

4. RESULTS

Here Figure 3 is the plotting of particles at present time in M31. Due to the limits placed on particles in the code, there is a large amount of counts around the 8.92 kpc radius. These are the original solar type particles that we will track over time.

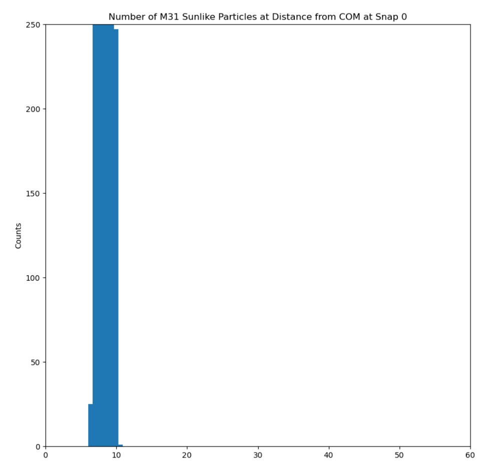

Figure 3: Frequency of particles at radial distances from galactic center of M31 at present time. The y axis is number of particle counts, the x axis is radial distance from galactic center in kpc. There is a large number of particles at the defined radius that it continues out of the y axis bounds.

The position of solar type particles in Figure 4 is now at 10 Gyr. The magnitude of counts at 8.92 kpc previously has decreased. More counts have appeared throughout the disk radius of the galaxy.

The remaining figures simulate the position change of solar-like particles over time for M33 and the Milky Way galaxy. This is important to compare how each galaxy differs in composition. Figure 5 shows that M33 has a lower number of particles than the other two galaxies. Much like M31, Figure 6 has the resulting solar-like particles of M33 distributed throughout the radius of the

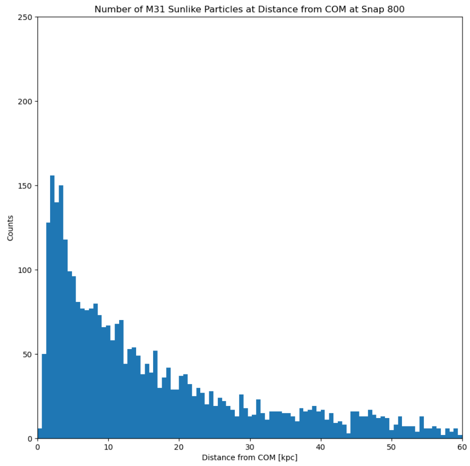

Figure 4: Frequency of particles at radial distances from galactic center of M31 at 10 Gyr. The y axis is number of particle counts, the x axis is radial distance from galactic center in kpc

galaxy, with a concentration towards the center. The present amount of solar-like particles in the Milky Way in Figure 7 extend past the figure y axis bounds like in 3. There is a higher amount of solar-like particles nearer to the galactic center of Milky Way in Figure 8 than for M31 in Figure 4.

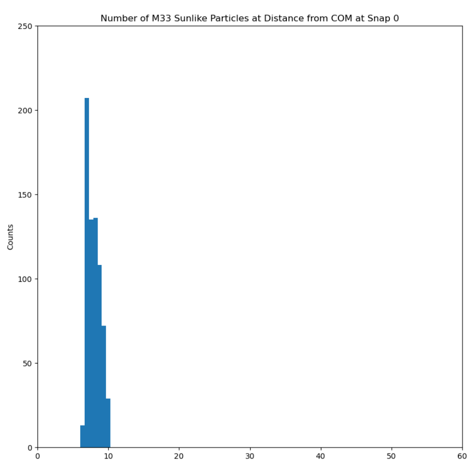

Figure 5: Frequency of particles at radial distances from galactic center of M33 at present time. The y axis is number of particle counts, the x axis is radial distance from galactic center in kpc

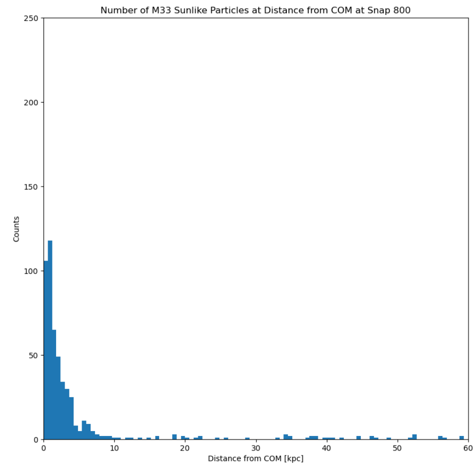

Figure 6: Frequency of particles at radial distances from galactic center of M33 at 10 Gyr. The y axis is number of particle counts, the x axis is radial distance from galactic center in kpc

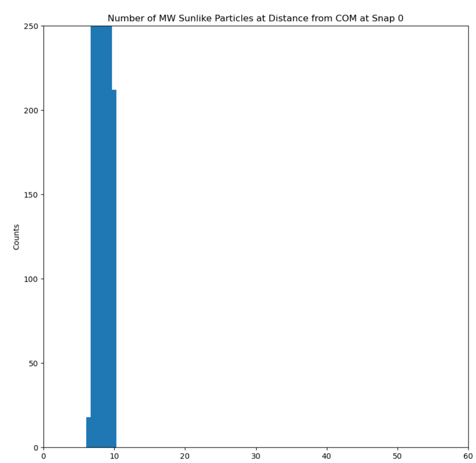

Figure 7: Frequency of particles at radial distances from galactic center of MW at present time. The y axis is number of particle counts, the x axis is radial distance from galactic center in kpc

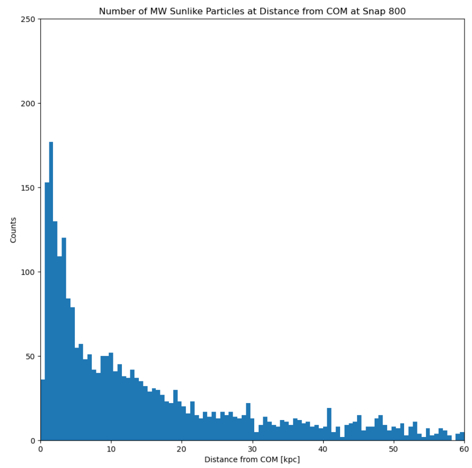

Figure 8: Frequency of particles at radial distances from galactic center of MW at 10 Gyr. The y axis is number of particle counts, the x axis is radial distance from galactic center in kpc

5. DISCUSSION

Particles with solar-type attributes have spread out further throughout the disk than the original radius limit. Showing that the velocity of the particles prove to be significant over time to displace them. Introducing the twenty % tolerance was decided after many runs of the simulation. It reduced the amount of counts in the graphs but may limit the real results from the simulation. The figures for M31 and MW have a spike of counts so large at their beginning of the simulation that it extends past the bounds of the plot but I wanted to keep each of the plots at the same ranges so it would be easier to compare the changes.

6. CONCLUSIONS

The simulation showed the change in particle distance from the center of mass of their parent galaxy over time. This can tell us that the structure of galaxies affect where the Sun will lie in about ten billion years. The angular momentum of the galaxy as a disk distributes some matter further from the center of mass, but also concentrates solar-like particles near the galactic center.

The resulting plots agree with my hypothesis due to the spread of particles over the galaxy disk over time. I consider that the differences in my figures and the one in (van der Marel et al. 2012) is due to the exclusion of the eventual merger of M31, M33 and the Milky Way in my simulation. Which is why in my figures the particles tend to skew much closer to the center of mass.

I could also plot a 3D figure to show the movement of solar-like over time as the merger occurs. I would have also liked to plot the distribution of particle density in each galaxy over time similar to Figure 1. There are several values for the radial distance of the Sun from the galactic center that could have been tested (8.34 kpc (Reid et al. 2014), 8.178 kpc (Abuter et al. 2019), and 7.9 kpc (Sparke & Gallagher 2010)).

7. ACKNOWLEDGEMENTS

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