Calculating the Rotation Curve of the Milky Way Galaxy

By Isabella DiReinzo, Jungyu Baeck, and Fatimata Ndong

Motivations

The primary motivation for creating our code was to model the rotational dynamics of the Milky Way galaxy. By calculating the orbital velocities of enclosed masses, consisting of stars, gas, and dark matter at varying radii from the galactic center, we tried to understand how the different structural components of the galaxy (the bulge, disk, and halo) contribute to the observed rotational velocity.

Our project was also motivated by the desire to deepen our understanding of galactic dynamics, especially the role dark matter plays in shaping the rotation curves of galaxies. By comparing the modeled rotation curve with actual observations, we can infer the distribution of dark matter throughout the Milky Way. This project also reinforces the evidence supporting the existence and significance of dark matter in galactic structures.

Through our project, ultimately, we were able to use Python to better understand galactic dynamics as well as the role dark matter plays in the rotation curves of galaxies, and we could explore the concept of galactic rotation curves and the evidence for dark matter.

Methods

The first step we took to calculating the rotation curve of the milky way was to first identify the 4 main components of the galaxy. These included Sagittarius A, a supermassive blackhole located at the center of our galaxy, the galactic bulge, the galactic disk, and the halo component. However after completing calculations with the black hole it was apparent that it had a miniscule effect on the overall rotation curve of the galaxy so therefore it was not included in our final calculations.

Moving on with the remaining elements we proceeded to calculate and graph the rotation curve of the bulge, disk, and halo. In order to do this we first imported the necessary packages from python which were astropy.units, astropy.constants, and numpy. Then we defined a function for calculating orbital velocity which was the base equation for orbital velocity, V = sqrt(GM/R), with M and R defined as inputs as they would change based on which galactic element we were solving for. We first calculated the orbital velocity of the bulge component by inputting the mass as 1e10 solar masses and creating an array of values which represented the different radii of the bulge. After running these values through the orbital velocity function, we were able to graph them using matplotlib.pyplot and AI.

Next we repeated this process for the galactic disk by defining its total mass as 1e11 solar masses and defining its total radius as 10 kiloparsecs. Now instead of using these values to calculate for orbital velocity we used them to solve for the density of the disk by dividing the mass by 2pi x r^2. With now having the density we could define a function for finding the enclosed mass of the disk with the radius and density set as inputs to fulfill the equation of pi x r^2 x density for the enclosed mass. After this step we then set up a function to calculate for the total enclosed of the milky way with the mass of the bulge, radius and density of the disk set as input. This was a simple function of adding the mass of the disk and bulge together.

After that step we then followed what we did for the bulge and inputted the correct values in the function calculating orbital velocity to solve for the rotation curve of the disk component and graphed it. The last element we needed to add into our calculations was the halo component. Again we started off by defining the halos total mass and radius and used those two numbers to solve for the density of the halo. We then defined a function for calculating the enclosed mass of the halo and used the equation 4/3 pi r^3 x density to solve for the enclosed mass. After we added the mass of the halo component to the equation to solve for the total enclosed mass of the milky way. Next we defined M_halo as a value for the enclosed mass of the halo and imputed that with the radius to solve for the orbital velocity of the halo.

Finally we were able to create a graph for the halo. The final part of our process is to solve for the orbital velocity of the milky way using the total enclosed mass of the galaxy which we previously defined as a function. We followed the same steps as the previous elements and created a graph representing the rotation curve of the galaxy. To further assess our accuracy with our final graph we imported a file containing the data of the rotation curve of the andromeda galaxy.

Results and Conclusions

Looking at the final graph including all of the components plus the final rotation curve of the milky way galaxy, we can assess the results given to us. The bulge component seems to peak at 200 km/s at 0 kiloparsec (around its center) and decrease as its radius gets bigger. The disk component hits a peak of 200 km/s at around 10 kiloparsec while the halo component increases at a constant rate throughout its entire radius. The black line, which represents the rotation curve of the galaxy, hits a peak of 217 km/s at 10 kiloparsec and begins a short decrease. It's important to note that the curve does not decrease by a lot. Compared to data from the imported file of the andromeda galaxy's rotation curve we see a similar peak of velocity at 10 kiloparsec and a slow decrease that remains relatively constant. Without the presence of dark matter its constancy would not be possible as it is hypothesized that the rotation curve should dramatically decline as its radius gets larger. Looking back at our calculated data we can infer that there is a heightened presence of dark matter at about 10 kiloparsec due to its dramatic increase in velocity but an overall existence of dark matter in the entire galaxy due to the rotation curves ability to remain relatively constant.

Throughout the entirety of the project we were able to work individually on our code and then use each other as references when we had questions or weren't quite sure if we were going about calculating elements the right way. Each one of us worked on the bulge, disk, and halo component of the project.