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# Modeling Rotational Curve of Milky Way Galaxy with Dark Matter

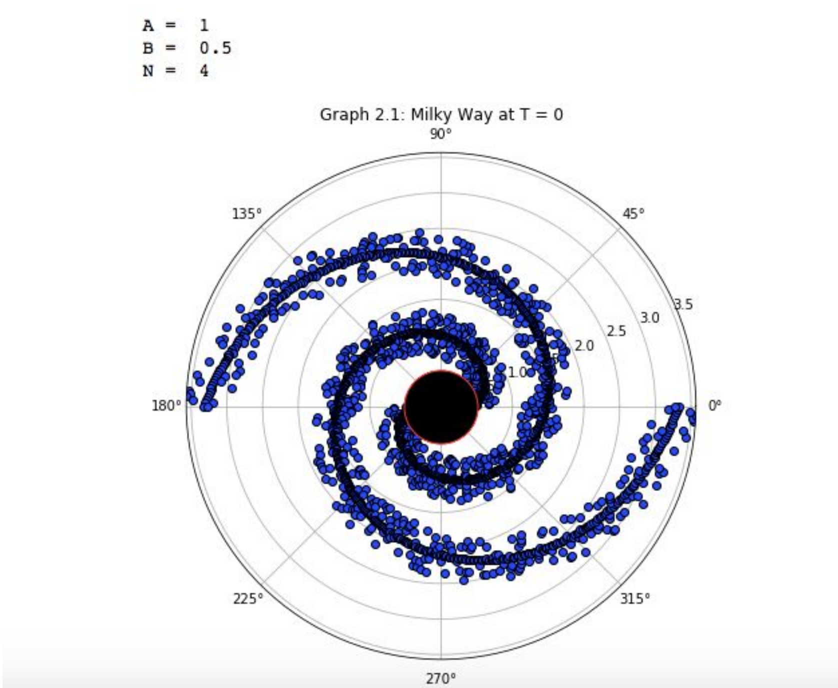
## Abstract

The goal of this final project was to model the rotation curves of our Milky Way galaxy and prove the necessities of including dark matter into current scientific galactic models. Dark matter is the reason why there seems to be a discrepancy between observed and expected rotation curves of spiral galaxies including our own, which was set out to be illustrated by using python 3.0 and statistical approaches. The project was broken up and presented in two main parts: galactic visualization and model of the milky way galaxy without dark matter and a visualization with dark matter.

## Introduction

Firstly, a poisson mass distribution of the galaxy with the average mass of the milky way galaxy being $1.15 \cdot 10^{12}$ solar masses was created to accurately distribute the mass of the entire galaxy into the galactic visualization developed later on. In the galactic model a total of fourteen rings, or seven radiuses from the center of the model on each side, were used in relation to the poisson mass distribution created earlier on. In this case, the plotted poisson graph showed that most of the mass of the milky way, or our galactic model, was at the center which was essentially the seventh ring of the fourteen total rings used. According to a new formula describing the scaffold structure of spiral galaxies, discovered by Harry I. Ringermacher from the General

Electric Research Center and Lawrence R. Mead from the department of physics and astronomy from the University of Southern Mississippi, a galactic model of spiral galaxies could be developed using polar coordinates axes which is exactly what the project uses to create the galactic visualizations. The formula used was the following: $r(\phi) = A/log(Btan(\phi/2N))$ where A and B are scale parameters of the entire structure, phi is the angle of parallelism, and N is an additional parameter although it does not need to be an integer. Two functions in python were created to make the model work, one of these functions was named “galaxyshape” which simply returned the above equation. After this function was made, a for loop was created to append empty lists of radius, omegas, point masses, and original angles which created the overall structure and shape of the model. The other function that made the model work was named “movestars” which actually outputted the shape and structure of the spiral galaxy at any time t. For example, this is what the model looked like at t = 0 using the parameters from the above formula where A = 1, B = 0.5, and N = 4:



It can be noted from the galactic model, which does not yet incorporate dark matter, that a total of fourteen rings were used where most of the mass is distributed at the center which is the seventh ring.

## Calculations and Method

Initially before creating the first galactic model, the total number of points in the model and calculations were 2,000 where each point represented a cluster of stars. After the initial base model of the galaxy and poisson mass distribution graphs were created, the next step was to plot and illustrate the actual rotation curve of this exact model which still does not incorporate dark matter. In most published works, this rotation curve is the expected rotation curve of the milky way undergoing Keplerian motion. Since the rotation undergoes Keplerian motion, an orbital velocity formula for each point on the model, where a point represented a cluster of stars, was devised: $\sqrt{G*(M/Np/spp)/R}$ where G represents Newton's gravitational constant in units including parsecs and solar masses, M represents the total mass of the galaxy including dark matter in kilograms, $Np$ represents the number of points used, $spp$ represents the amount of stars per point which was roughly one million, and R represents the radius of the galaxy in kilometers.

In order to obtain an accurate representation of the radius of the galaxy a conversion from light years to kiloparsecs was used, using the diameter of the milky way to be 100,000 lightyears. This new converted value in kiloparsecs was then divided by two (which represents the radius from the center) and then dividing that value by seven since there are seven rings from the center in the model, which represents the radius in kiloparsecs of one ring in the galactic model. A graph with accurate and converted units of the expected rotational curve of the galaxy was plotted and compared with an image showing the expected rotational curve of the galaxy with Keplerian motion using the orbital velocity function that had just been created:

Graph 3.1: Expected Rotational Curve

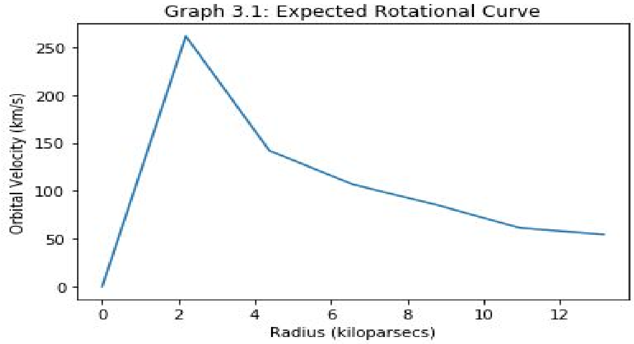
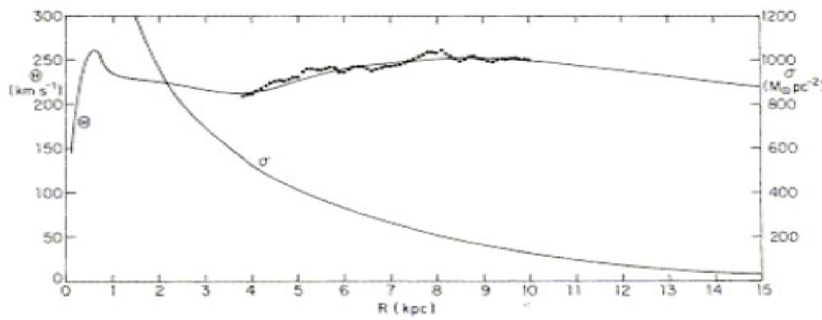



Image 1: Expected Rotational Curve With Keplerian Motion

Out[6]:




It can be seen above that the graph run by the cell and the image are very similar and have accurate representation of units, which shows that as the radius of the galaxy in kiloparsecs increases, the orbital velocity decreases.

Next, the project deals with incorporating dark matter into the galactic model to satisfy the initial purpose of the project. In this part, an additional eighth ring is added to the model to represent the dark matter mass of the galaxy. The calculations are once again repeated in the same process, except this time 120,000 light years are converted to kiloparsecs and then divided by two and then divided by eight, which represents the radius of one ring of the galaxy which includes dark matter mass. A new function was then created to find the new orbital velocity of the galaxy which now incorporates the additional eighth ring. With a lot of array indexing and further calculations involving creating a new poisson mass distribution of the galaxy which included the eighth ring, a new graph of the observed rotational curve with dark matter was plotted and compared with an up to date image of the observed rotational curve of the milky way

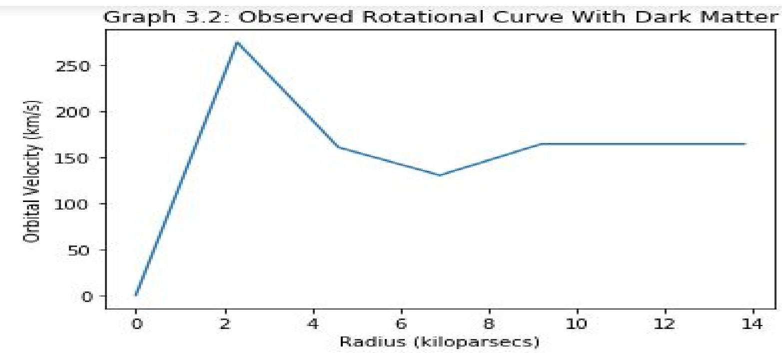
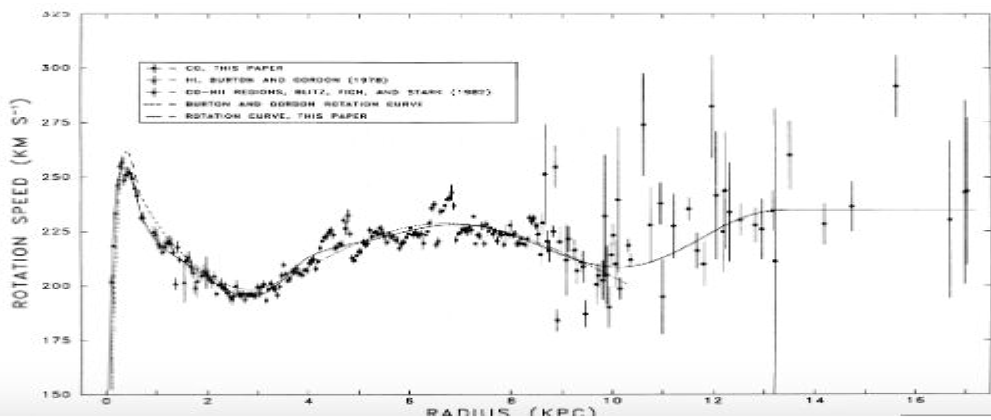
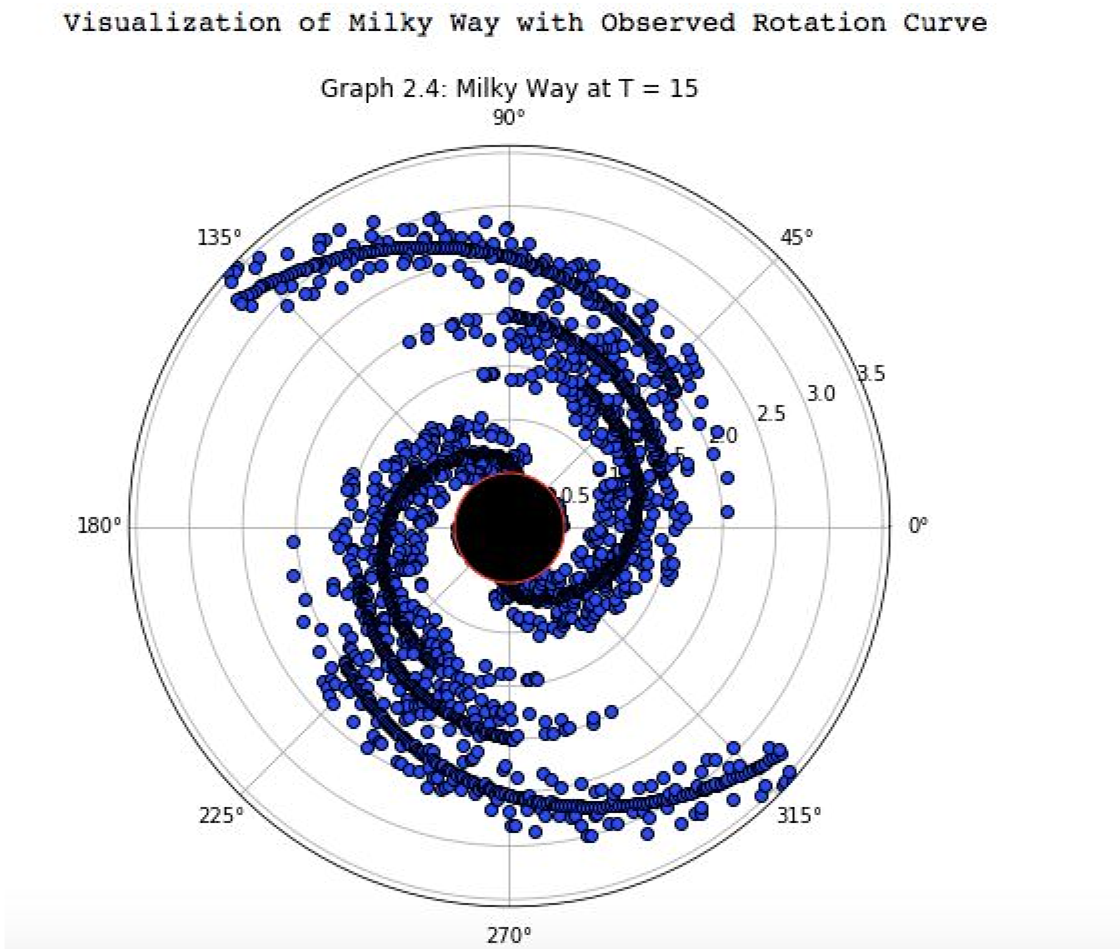



Image 2: Empirically Observed Rotational Curve

ut[11]:




As seen above, both graphs of the rotation speed of the galaxy in kilometers per second versus radius in kiloparsecs line up quite well. In particular, both graphs illustrate roughly the same highest value of orbital velocity (around 250 km/sec) and follow the same curve given the interval of radius in kiloparsecs along the x axis. As discussed earlier in the abstract, the project successfully proves the necessity of including dark matter into today's galactic models of spiral galaxies and emphasizes the importance of dark matter in the shape and structure of these galaxies. The final visualization of the milky way galaxy including dark matter mass at a specific time (here it is at t = 15) shows that the presence of dark matter in spiral galaxies like our own is clearly evident and important in maintaining their form and structure with respect to time.




## Conclusion

Dark matter is a very complex and profound concept in physics, researchers are puzzled by its mysteries and existence in the physical world to this day. Overall the initial method of the project, which included visualizing a spiral galaxy mathematically in polar coordinates and axes, supported its purpose. The similarities of the visual graphs and illustrations displayed, compared with actual data and up to date scientific graphs, indicates that without the presence of dark matter, galaxies would not be able to maintain their shape and form, especially our own. One day physicists will be able to understand the true roots and origins of dark matter with further study of rotation curves and structures of galaxies of all kinds.