# Dark Matter Discovery

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## Background and Introduction

- 95 % of the universe is calculated to be composed of matter that has never been observed or detected.
- Physics still lacks a fundamental understanding of dark matter in regards to its origins and composition.
- This research group focused on using a similar structure and technique that famed astronomer Vera Rubin used in her quest to discover dark matter.
- According to classical physics, objects in a rotating system at small radii should be moving faster than those at larger radii.
- Rubin, while measuring the radial velocity of the Andromeda galaxy by analyzing the Hα emission line noticed a quite peculiar trend. The rotation curves could not be explained by the amount of mass that was visible.
- Dark matter does not interact with light, however it does possess gravitational properties.

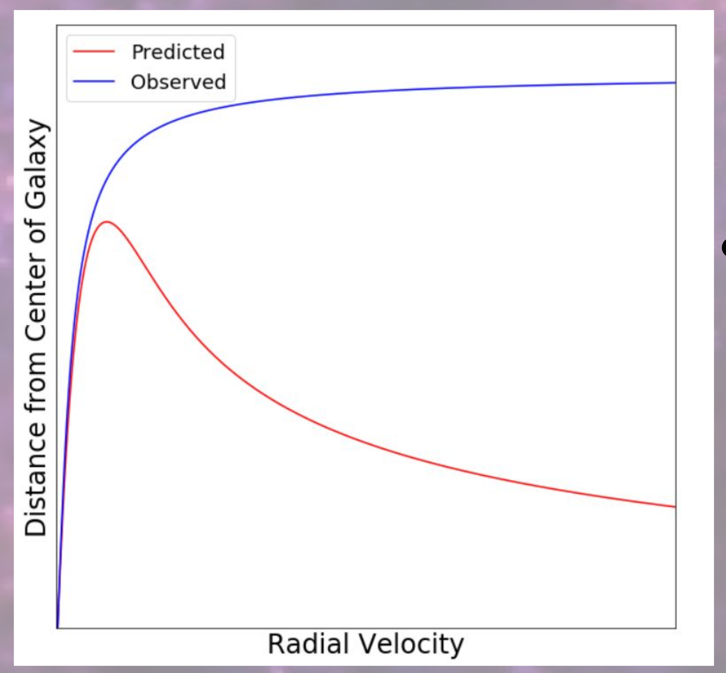


Figure 1 : The red rotation curve depicts the predicted radial velocity of matter within a galaxy.The blue rotation curve was introduced by Rubin as the observed model and accounts for the existence of both baryonic and dark matter

## Results

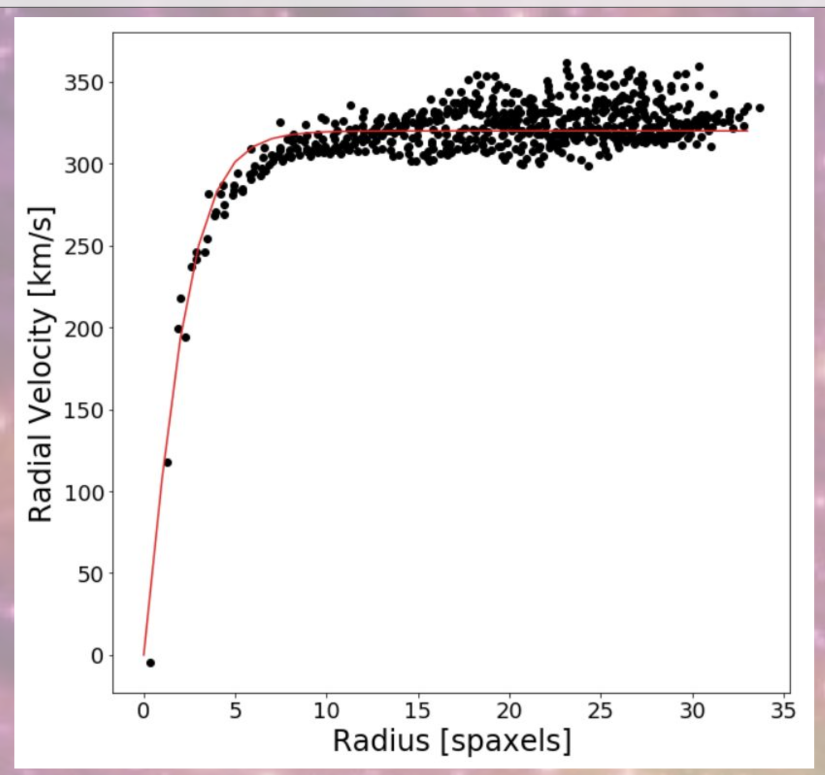


Figure 6: Radius vs Velocity plotted of stars in the galaxy shown in the methods section.

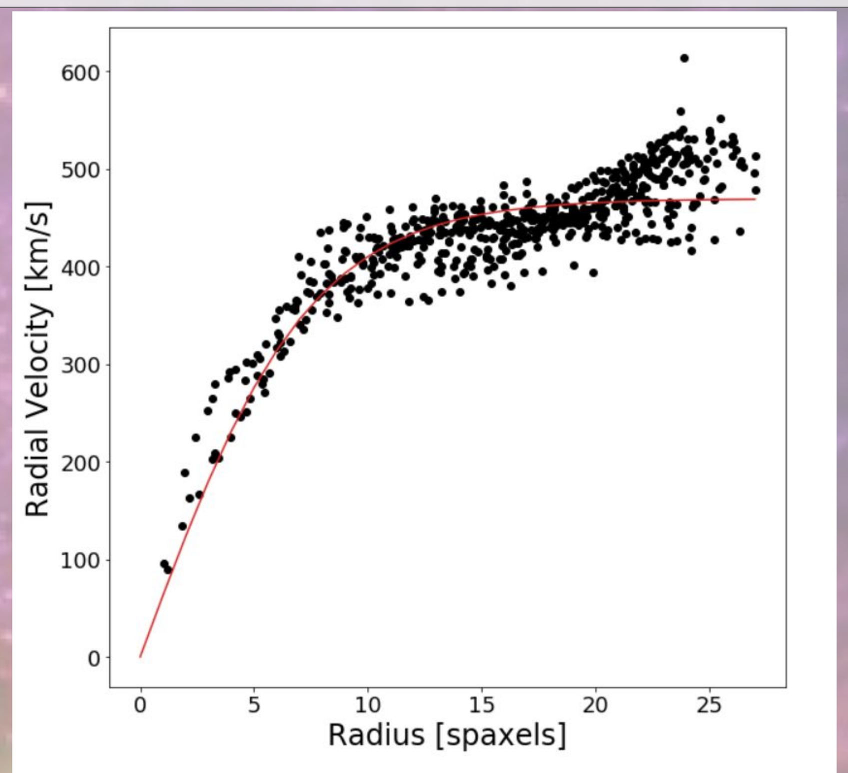


Figure 7: The rotation curve found for the previously mentioned galaxy. It shows that at large radii, the radial velocity is almost constant.

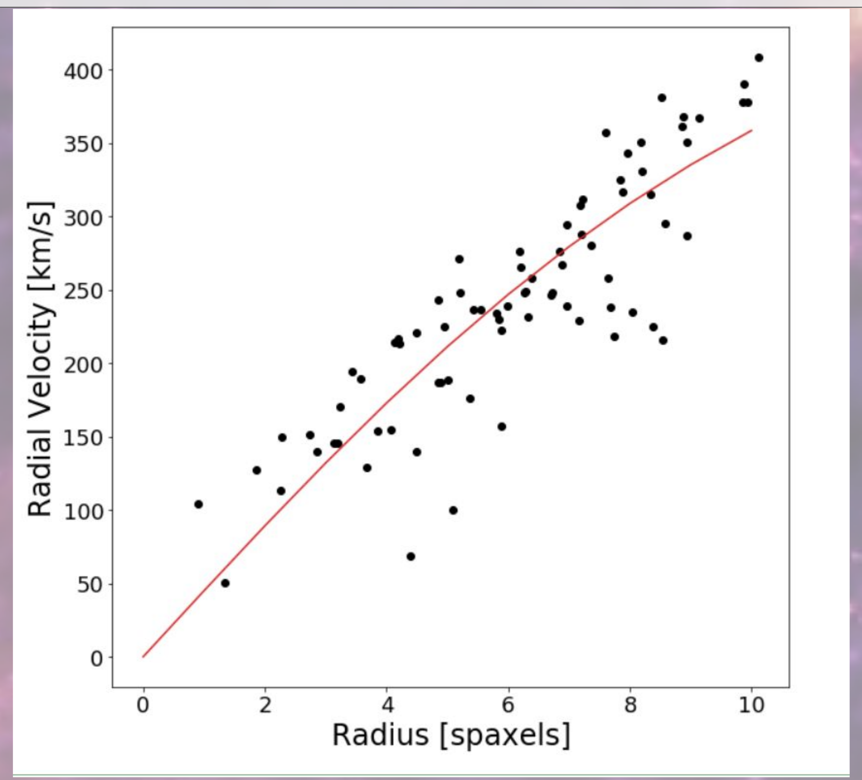


Figure 8: Another rotation curve of a galaxy that seemingly has no asymptotic velocity, this was one of the curves that didn't follow the theory very well. For this galaxy, the hydrogen was clustered in the center, so there was little data at high radii.

As seen in Figures 6 and 7, the asymptotic velocity levels off at the end, showing evidence of dark matter influence. If we went by the matter that we can see, the velocity curves would start decreasing as the radius increases. But including the dark matter, the rotation curves become constant at a certain point in the radius, an asymptote which can vary galaxy to galaxy. Most of the graphs followed these patterns, though some didn't, like figure 8, though these were due to the galaxies position, type, or composition interfering with the data. These show how our method does have limits, and other methods would need to be used to analyze the galaxies that don't work, such as red galaxies, merger galaxies, and so on.

## Methods

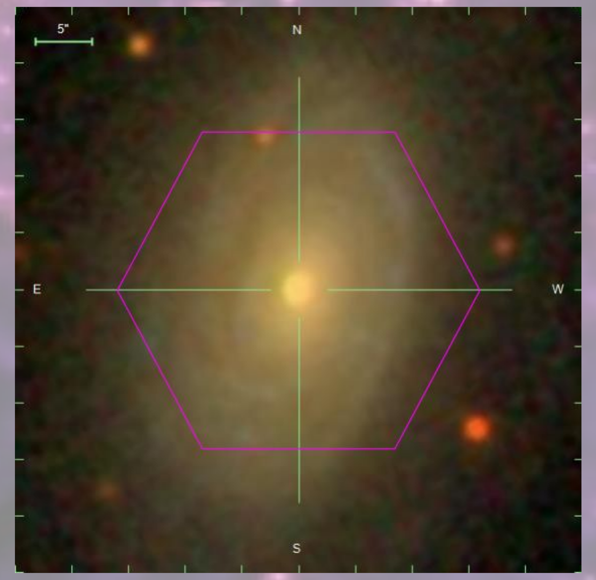

Figure 2: Galaxy with MaNGA ID: 1-339041

- We chose a galaxy from the MaNGA dataset that shows signs of recent star formation. These galaxies have very prominent Hα lines which will benefit our data analysis. (Figure 2)

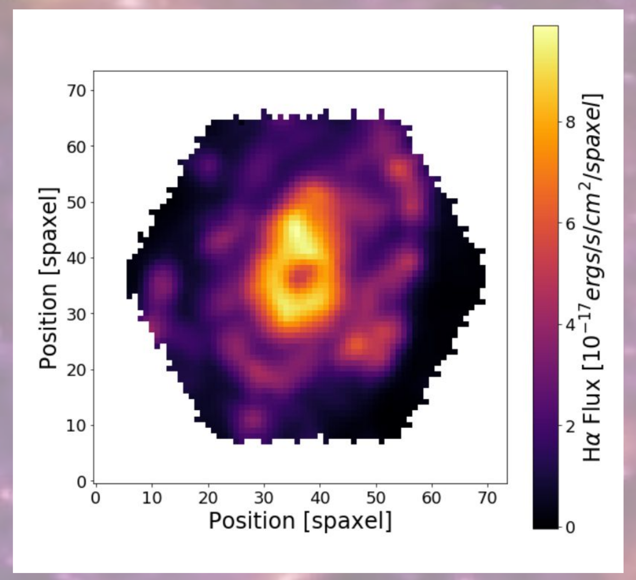


Figure 3: Analysis of hydrogen in the above galaxy. Yellow areas have the most hydrogen.

- To ensure that we chose a galaxy with a large amount of hydrogen, we analyze the galaxy using a zeroth moment calculation around the Hα line. (Figure 3)
- The MaNGA dataset contains optical spectra for each pixel within the hexagon in figure 2. We were able to use this data to find the observed wavelength of the Hα line at each pixel using first moment calculations (Figure 4)

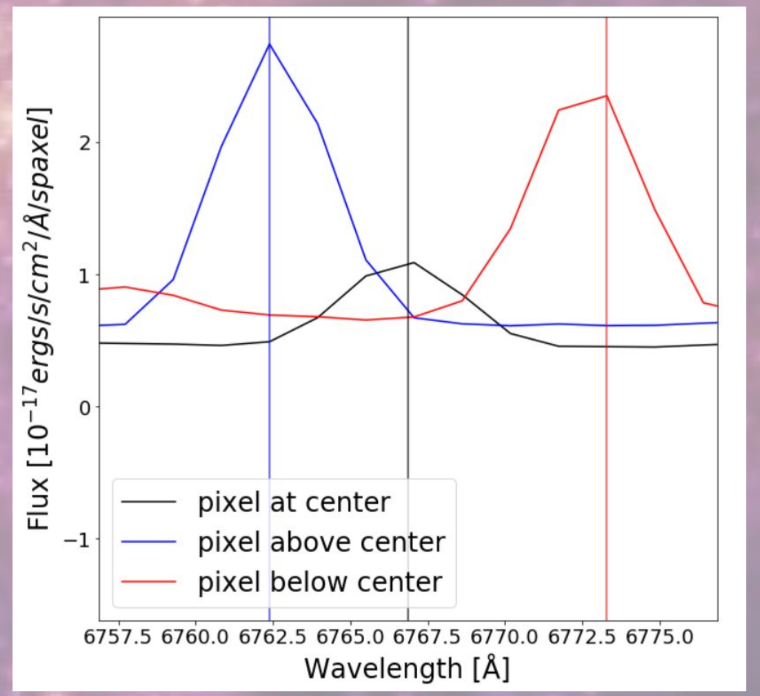


Figure 4: Optical spectra for three pixels in the galaxy. By eye you can see that Hα peak is at a different wavelength for each pixel.

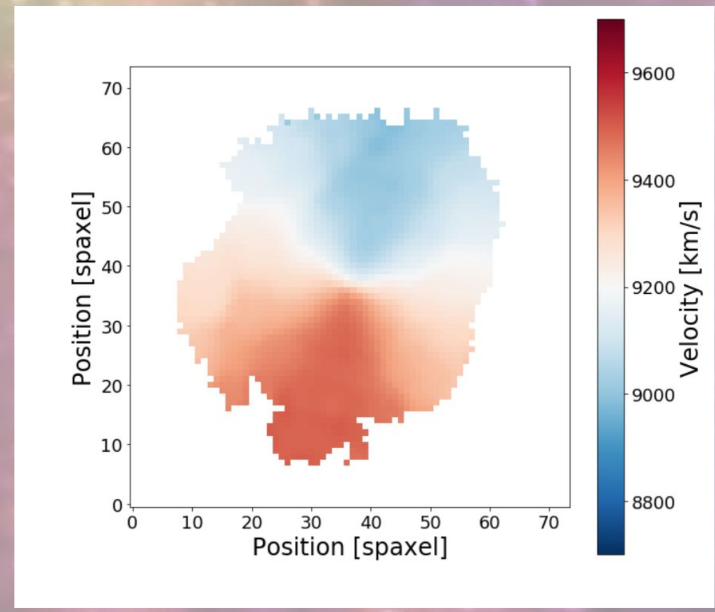


Figure 5: Velocity map. We can clearly see that there are two distinct regions.

- Using formulas for redshift, we can then find the velocity at each pixel. From this we can create a velocity map for this galaxy. In Figure 5 we can see that half of the galaxy is moving away from us while the other half is moving toward us relative to the center. This is evidence of the galaxy rotating. (Figure 5)

## Discussion & Conclusions

From collecting data from galaxies from the MaNGA survey, it's shown that dark matter is abundant in every galaxy. As stars are further away from the center of the galaxy, their velocity doesn't decrease which can be explained by the dark matter in the galaxy. By subtracting the part of the rotation curve that is caused by baryonic matter, we can infer that what is left over must describe dark matter. We can then calculate the mass of dark matter contained by the galaxy and compare it to the amount of baryonic matter. The future goal would be to calculate the comparison of dark matter to baryonic matter in each galaxy to explore if Vera Rubin's estimate is constant. Vera Rubin found that there was four times more dark matter than baryonic matter in the Andromeda galaxy.

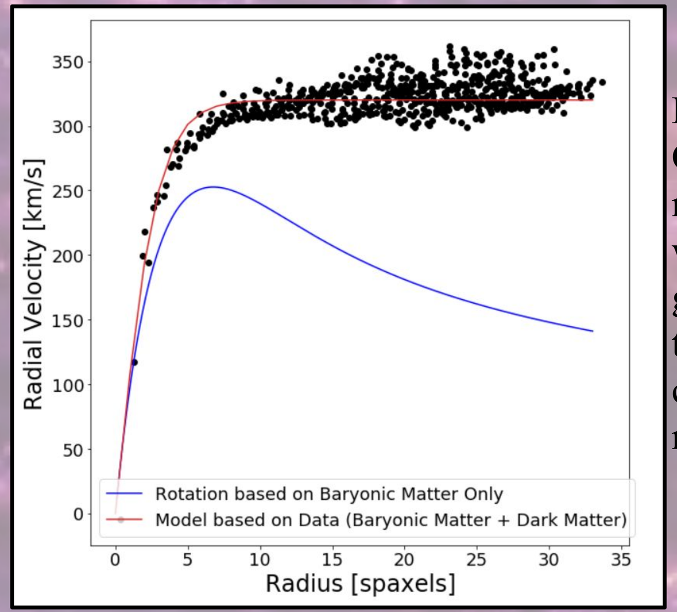


Figure 9: This is the same rotation curve as figure 6. Overplotted is a rotation curve based solely on baryonic matter. By subtracting the red curve from the blue one, we would obtain a theoretical model of the dark matter in the galaxy. Unfortunately, the blue curve was fit by eye rather than the real baryonic data. In future works we would create a better baryonic model to then have a better dark matter model.