# Modeling the Milky Way Rotation Curve

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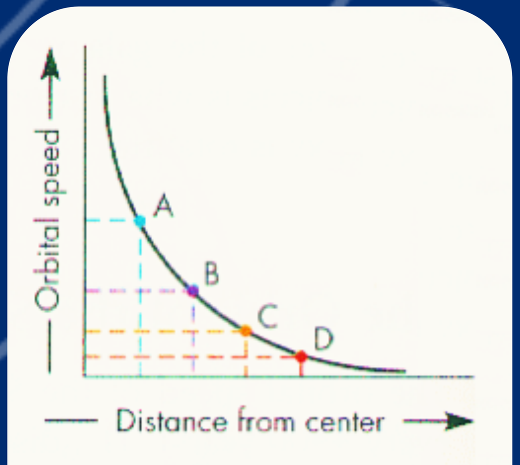
## Abstract

The purpose of this project was to construct a rotation velocity curve of the Milky Way Galaxy. Using Johns Hopkins University's Small Radio Telescope, I collected data on the radio frequencies of different parts of the galaxy and successfully recreated a rotation curve with a domain up to 8 kiloparsecs (kpc). By doing this, I hoped to find empirical evidence for unobservable matter in the galaxy. Because of the large deviation of the constructed rotation curve and the expected Newtonian rotation curve, I can conclude that there is indeed a large amount of matter that is undetectable by modern instruments.

## Background

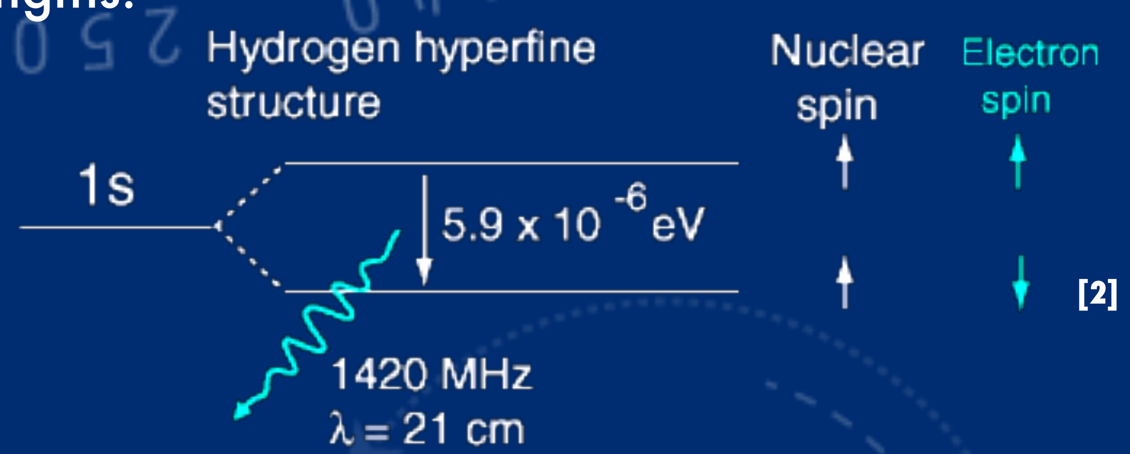
According to Newton's law of gravity and Keplerian rotational motion, the velocity should decrease as orbital radii increases. The velocity is calculated by recording the radio frequencies of the orbitals.



Rotation curve for planet-like rotation

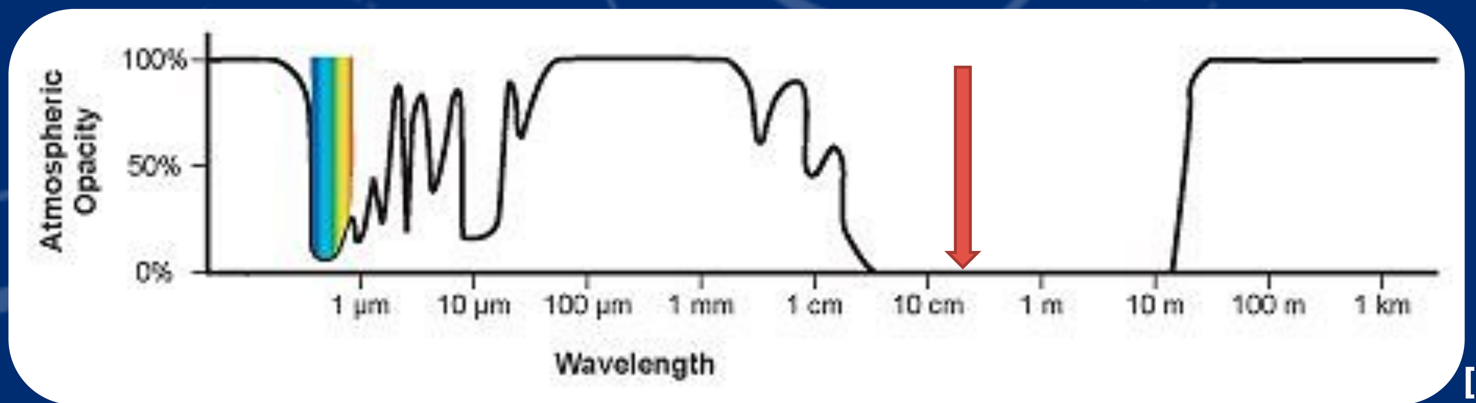
[1]

Electrons are excited by absorbing energy, but since nature always prefers the lowest energy state, these electrons release the absorbed energy as photons. Hyperfine structures are energy states within an energy level such as 1s in hydrogen. Photons emitted by hyperfine structures are very low energy and have long wavelengths.




[2]

Hydrogen's characteristic 21 cm hyperfine wavelength is useful in astronomical observations because the Earth's atmosphere is most transparent to radio waves, as can be seen in the image below. The arrow shows $^1H$'s emission, especially the lack of interference by atmosphere.




[3]

Hydrogen's hyperfine emission is normally extremely weak, but its abundance in the universe amplifies its signal and allows its use as a measure of the velocity of celestial objects relative to Earth.

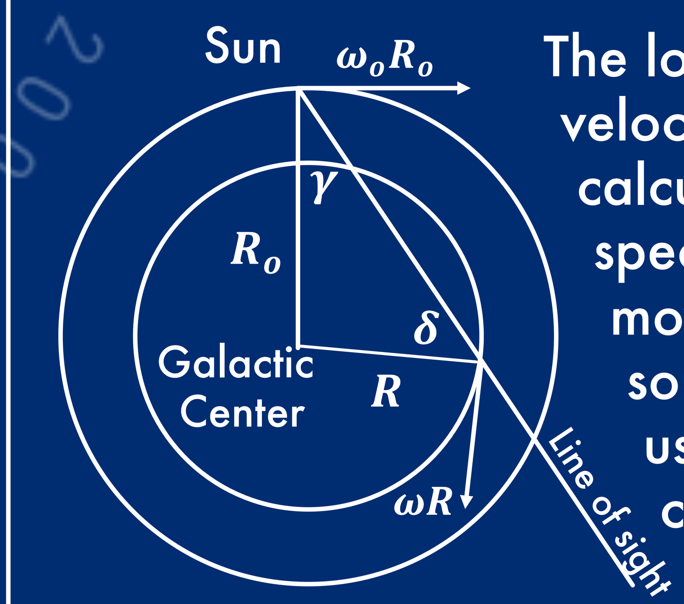
## Data Collection

Using JHU's 2.5 m Small Radio Telescope (SRT), I collected 10 days worth of data. The C script written by MIT to operate the SRT outputted the raw frequency spectra and relevant variables into a .rad file.

## Calculations

Radio frequency is recorded by the telescope, but it must be converted to velocity before analysis can take place.

$$v_{orbital} = \frac{(f - f_{observed})v_{light}}{f} - v_{lsr}$$




The local standard of rest velocity is the velocity at which the Sun moves and is calculated by the SRT software. The radio spectra is slightly shifted due to the movement of the Earth and of the source, so vector geometry must be used to get the difference in components in the line of sight.

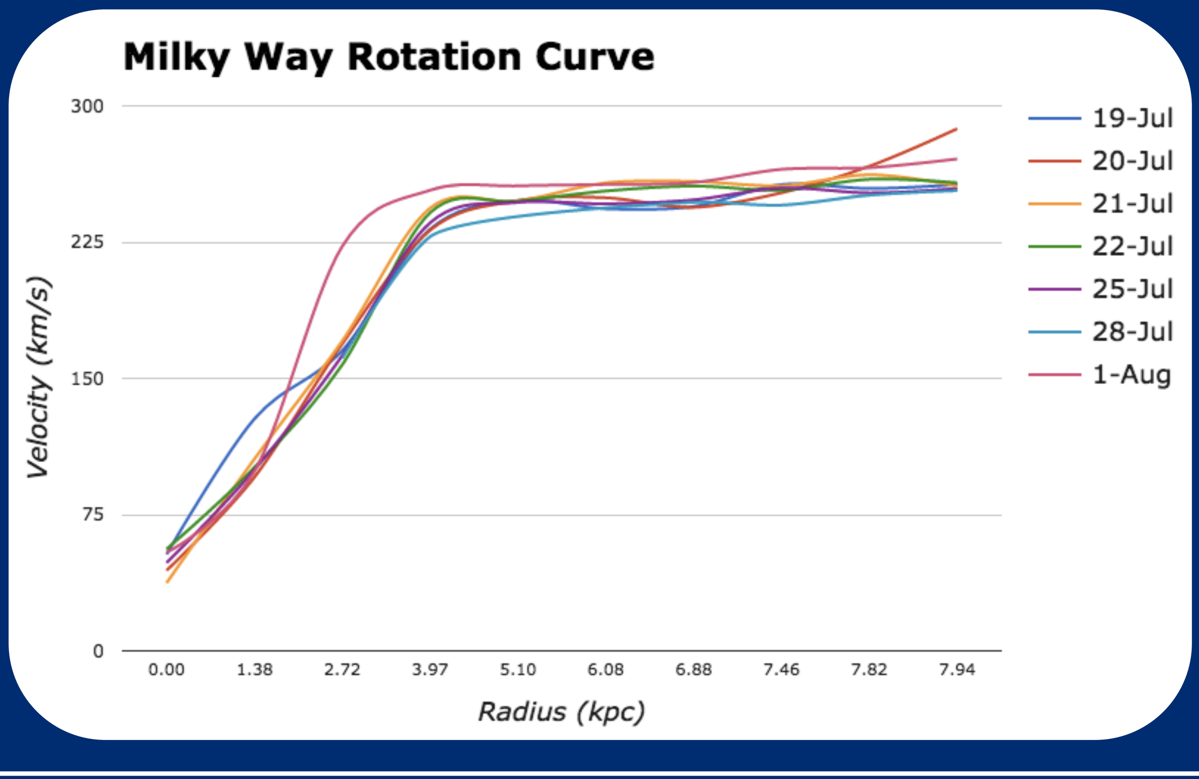
$$v = \omega R sin\delta - \omega_o R_o sin\gamma$$

After using law of sines to substitute for $sin\delta$ and making the maximum velocity of the orbital where the line of sight is tangential to the circular motion, we get the following:

$$v = v_{orbital} + v_{Earth} sin\gamma$$

Earth moves at approximately 220 km/s through space and $\gamma$ is the galactic longitude, or the angle deviation of the line of sight from the galactic center. With this, we can calculate the velocity at each orbital radius in the galaxy.

## Observed Galaxy Rotation Curve

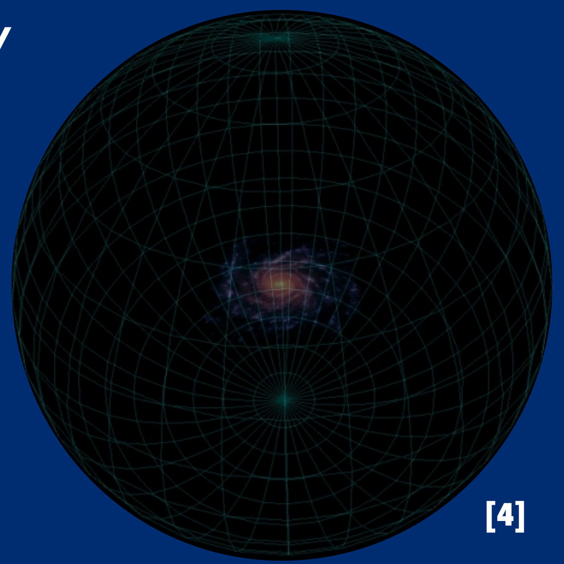



## Scripts

A large part of physics is data analysis, but using thousands and millions of data points in many data sets to do calculations by hand is unfeasible. Because of this, most if not all particle physicists use computer scripts to collect and analyze data for them. I also wrote a script in Python to process the raw .rad files into Excel spreadsheets and object text files. My code can be found here:

## Conclusion

The flattening of the rotation curve as the radius increases indicates non-Keplerian motion of the different galactic orbitals. This implies mass must increase linearly as radius increases, but the mass values as radius increases become inconsistent with observations of the outer galaxy.[5] The term "dark matter" was coined in 1922 by Dutch astronomer Jacobus Kapteyn after his studies on the motions of the stars in the Milky Way Galaxy. Fritz Zwicky first correctly claimed the existence of dark matter in 1933 through his observation of the redshifts of galaxies in the Coma cluster.[6] The inconsistency between theory and empirical evidence forms the so far unanswerable astronomical question: what makes up most of our galaxy and other galaxies? Many theories have tried to explain what dark matter is, including Weakly Interacting Massive Particles (WIMPs) and Massive Compact Halo Objects (MACHOs). Whatever dark matter is, modern instruments have not been able to detect it. Hopefully as technology advances, physicists will be able to make out the matter that constitutes most of our universe.



[4]

## References and Acknowledgements

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