Possible Evidence to Explain the Mystery of the Cosmos: Dark Matter

Galaxy Rotation Curves and Dark Matter

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Figure 1: Scan here for our full report and references

Introduction

Have you ever wondered how galaxies keep their structure as they move across the universe? When examining a galaxy through its rotation curves, we can understand the forces shaping the structure of a galaxy. Galaxy rotation curves are the plot of the rotational velocities of stars within the galaxy against their radial distance from the galactic centre. The velocity of stars is dependent on the gravitational forces experienced by the stars, and therefore is dependent on the mass distribution within the galaxy.
By plotting the rotation curve of the galaxy Andromeda, we can compare the observed rotation curve to the rotation curve predicted by Newtonian mechanics, which is a crucial step for validating Newtonian mechanics in describing galactic behaviour. By encountering deviations from our predictions, we explore a possible reason for any differences that are observed. The enables us to gain insight into the mysterious force of dark matter influencing the behaviour of galaxies.

The Expected Curve

What does Newtonian gravity predict about the shape of a galaxy rotation curves?
Galaxies are so large and empty so Newtonian mechanics can be used to predict and analyse its behaviour.
We assume the dense region within a galaxy can be modelled as a sphere of constant density, with mass **M**. The region with less mass distributed across it, is considered negligible hence the mass remains a constant **M**.
This equation models the orbital velocity of a star within a galaxy, derived from centripetal and gravitational equations.

$$v = \sqrt{\frac{GM}{r}}$$

On the left is the velocity relationship for the dense region
On the right is the velocity relationship for the 'empty' region

$$M(r) = \frac{4}{3}\pi r^3 \rho \qquad M(R) = M \in \mathbb{R}^+$$

$$v = \sqrt{\frac{G(\frac{4}{3}\pi r^3 \rho)}{r}} \qquad v = \sqrt{\frac{GM}{R}}$$

$$v \propto r \qquad v \propto \frac{1}{\sqrt{R}}$$

Thus combining these two relationships we can form the expected rotation curve for a galaxy.

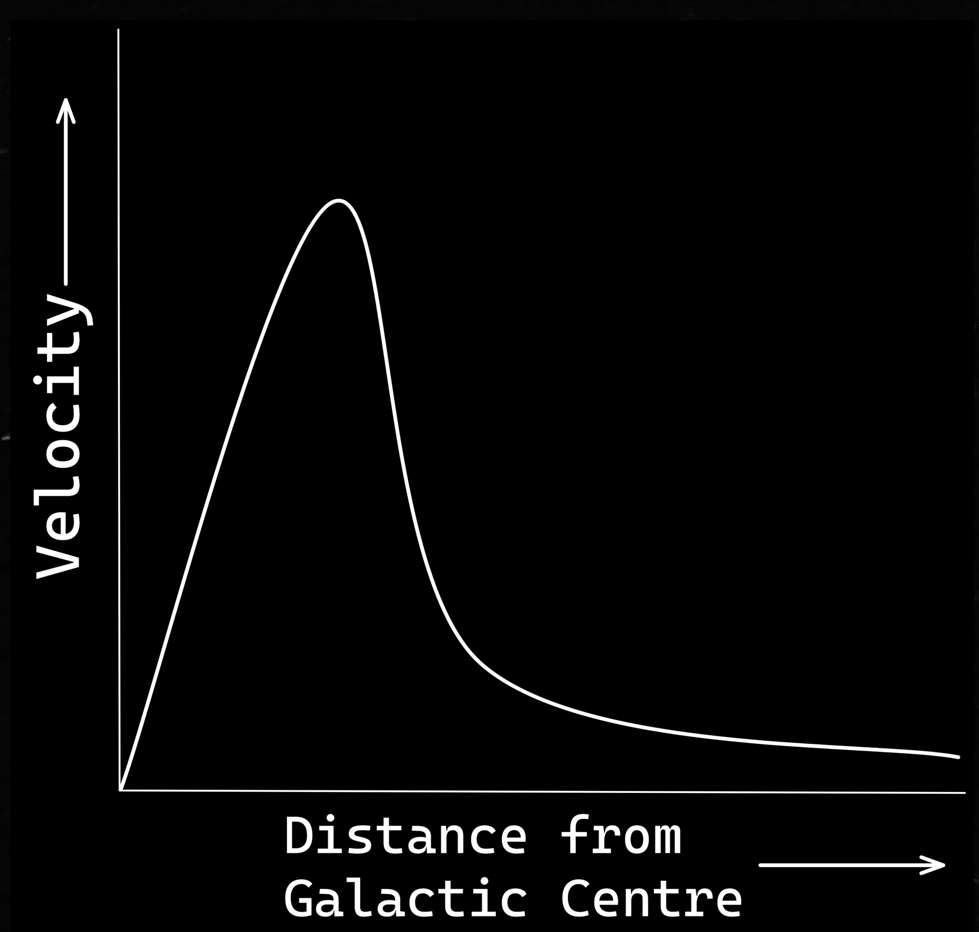


Figure 2: The expected rotation curve for a galaxy

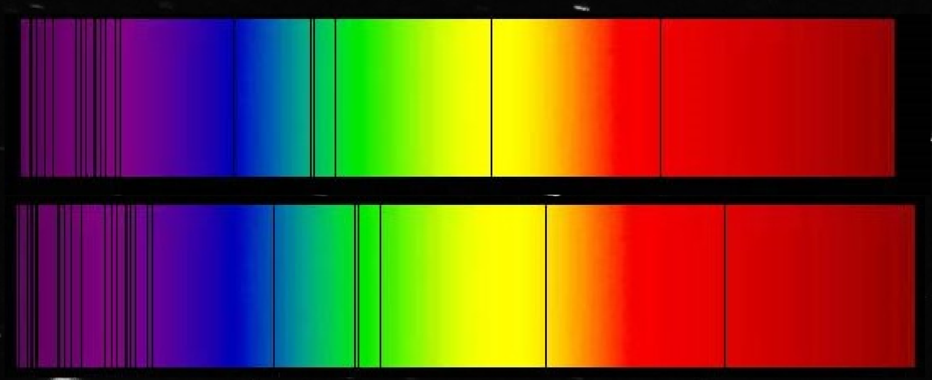
How is Mass Distributed?

Normal matter is the familiar stuff in a galaxy, like stars, planets, gas, dust: anything which interacts with light.
A star like our sun emits light. Scientists use optical and infrared telescopes to find areas of light in a galaxy. We assume that the more luminous (emits more light) a body is, the more mass it contains. When simply converting luminosity to mass, we can depict where mass is within a galaxy, because stars with more mass will emit more light.

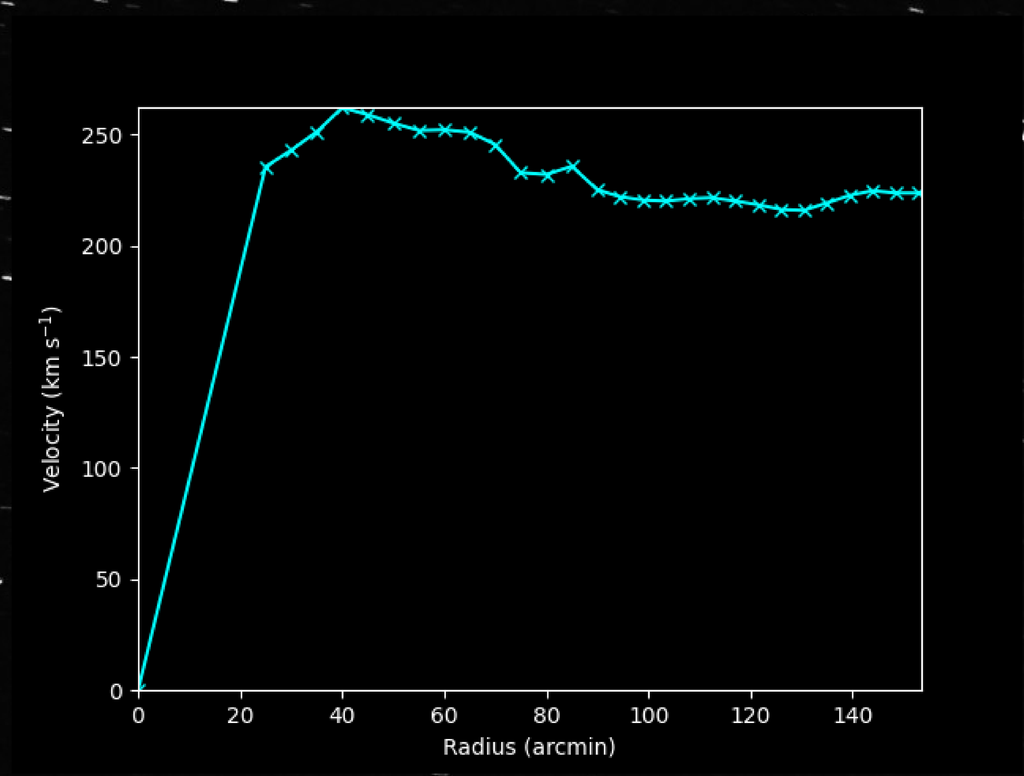
Obtaining Rotation Curves

When observing light from stars within galaxies, we can identify the wavelengths of known absorption lines. If the star is moving away from us, the absorption line will be redshifted (ie. higher than the laboratory value). The faster the star is moving, the higher the redshift, z. The velocity of the star can then be found:

$$z = \frac{\Delta\lambda}{\lambda} = \frac{v}{c}$$



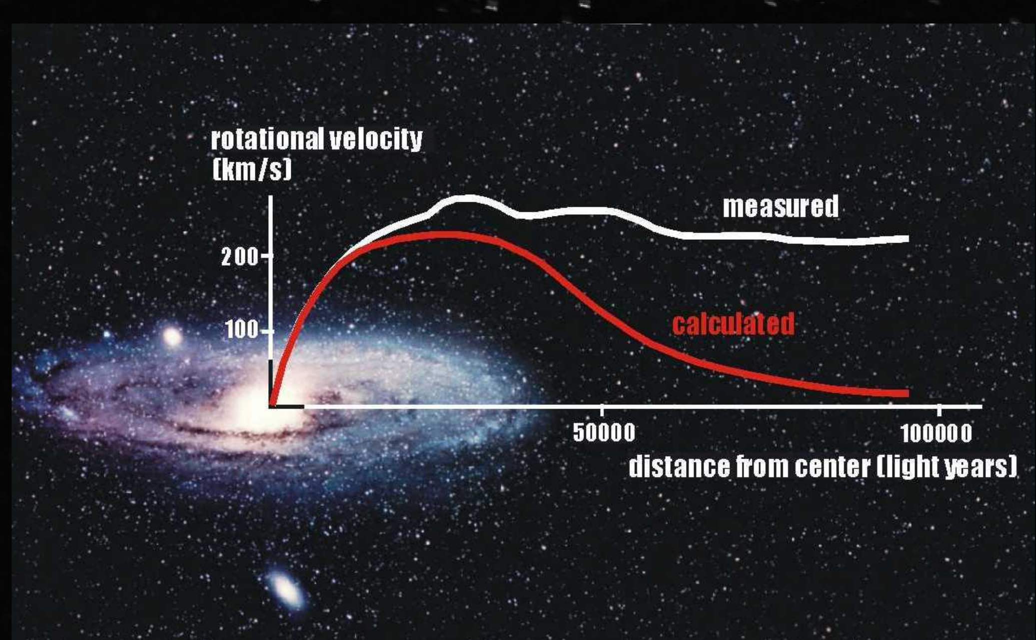
What do we Observe?



This is the galaxy rotation curve produced using Matplotlib for the Andromeda galaxy. The data we used for our plot (1) was obtained from a classroom activity from the Royal Observatory Greenwich. Clearly the plot for Andromeda deviates from the predicted curve created using Newtonian mechanics, in Figure 2.
Astrophysicists observe that a similar rotation curve is obtained for many other galaxies (2), the plotted graph displays that galaxies generally have rotation curves that are fairly flat to as far out as they could be measured.

Discussion

Using the plotted graph from observed data we are able to conclude that stars at the outer edges of Andromeda are orbiting at faster rates than predicted. So, why do the results differ from the predictions we make?



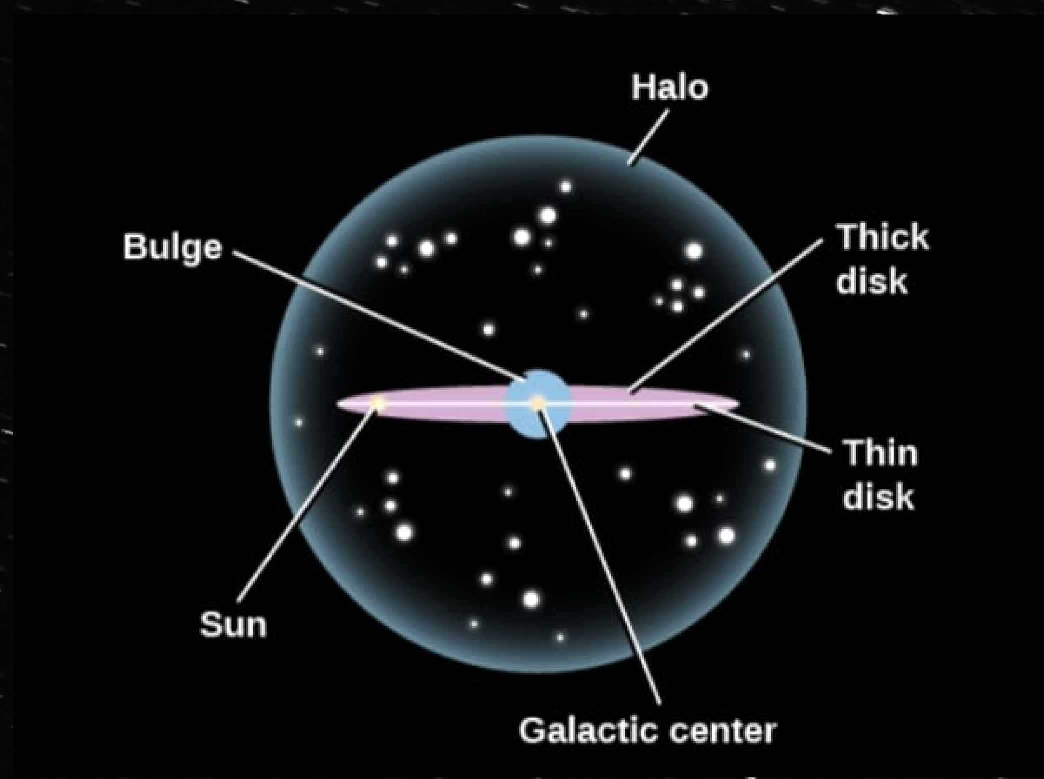
There is certainly some other force accelerating these outer stars. The 'additional' velocity of outer stars can be due to extra gravitational forces in Andromeda caused by some form of mass not taken into account when predicting rotation curves.

As discussed previously, the mass distribution of a galaxy is calculated using the luminosity mass ratio, meaning scientists only know of existing mass due to the property of luminosity (emission of light). This suggests that the extra forces are most likely caused by some matter which does not emit, reflect or interact with light at all and hence appears invisible. Scientists refer to this invisible matter as dark matter.

Dark matter

Using observed data and the distribution of luminous matter, we can predict the distribution of dark matter. Essentially, the extra force seen in the observed graph is due to the additional gravitational forces of the dark matter, therefore assumptions can be made of where this dark matter lies in galaxies by looking at the distances from the galactic centre where the velocities in the predicted and observed graphs differ.

Using this method, data scientists model dark matter within a galaxy to be distributed as a spherically symmetric halo.



Definitely Dark Matter?

Research is still ongoing as to what this extra force may be. Dark matter remains a theory, as all attempts of **directly** measuring dark matter have been unsuccessful. However, scientists are almost certain that dark matter is some sort of particle, due to many other observations.

Gravitational lensing occurs in high mass regions (e.g.clusters of galaxies) as smaller stars behind huge clusters become distorted when viewed from a telescope. This is due to clusters acting as lenses, refracting light passing nearby because of such high mass. Applying mass-to-luminosity ratio, visible matter contained in one of these clusters can be measured. Then we observe that the distortion appears more than we predict. Visible matter simply does not account for the observed lensing, which provides further evidence for dark matter.
Another piece of evidence for dark matter is the temperature observations of the cosmic microwave background. When scientists look at the skymap, there are spots that deviate from the average temperature. Astrophysicists analyse this background using its power spectrum. However, normal matter alone is insufficient to explain the observations; hence, dark matter must be added to the equations to produce a viable result.

Conclusions

By analysing galaxy rotation curves, we are provided with evidence for the possible existence of dark matter, which could explain the mystery of the cosmos. Through our research in this project, we discover luminous matter alone is not sufficient for the mass in a galaxy, leading us to conclude that dark matter is likely to exist!

References

(1)Royal Observatory Greenwich. rmg.co.uk. https://www.rmg.co.uk/sites/default/files/import/media/pdf/Post16-Plotting-the-Rotation-Curve-of -M31-(HL).pdf,2019.