I constructed a model of the rotation of the galaxy using a simple bulge model. This model yields the curve expected without the gravitational effects of dark matter. Two mathematical models were used, one for the rotation of an object inside the bulge of the galaxy and one of an object outside of it. Distinctly lower rotational speeds for objects with large radii are observed, an attribute which conflicts with collected data, strongly supporting the existence of dark matter in the outer reaches of our galaxy.

### WHAT IS DARK MATTER?

Matter that does not interact with the electromagnetic field, making it “invisible.” Its composition is yet unknown. Candidates include WIMPs, MACHOs, and axions. It makes up 27% of the universe.

### WHAT DOES A FLAT ROTATION CURVE MEAN?

Indicates more mass in the galaxy exerting a gravitational force.

Expected rotation curve (luminous curve) shows the speeds at which objects would rotate without that extra mass (dark matter).

### ABSTRACT

I constructed a model of the rotation of the galaxy using a simple bulge model. This model yields the curve expected without the gravitational effects of dark matter. Two mathematical models were used, one for the rotation of an object inside the bulge of the galaxy and one of an object outside of it. Distinctly lower rotational speeds for objects with large radii are observed, an attribute which conflicts with collected data, strongly supporting the existence of dark matter in the outer reaches of our galaxy.

### RESULTS

#### Expected rotation Curve of the Milky Way Galaxy

![Expected rotation Curve of the Milky Way Galaxy](image)

#### MATHEMATICAL MODEL – WITHIN THE BULGE

Use a ratio expression to find an expression for the bulge section

\[
m \propto \frac{M_{\text{bulge}}}{V_{\text{entire bulge}}} = \frac{\frac{2\pi x}{2\pi} \times M_{\text{entire bulge}}}{\frac{2\pi x}{2\pi} \times M_{\text{entire bulge}}} = \frac{x}{R} \times M_{\text{entire bulge}}
\]

Plug in this expression for the mass of the bulge into \( \frac{GM}{r^2} = \frac{m v^2}{r} \), where \( m \) is mass of the star and \( M \) is mass of the bulge section, and get:

\[
v = \sqrt{\frac{GM_{\text{entire bulge}} \times R^2}{2 \pi x}}
\]

#### MATHEMATICAL MODEL – OUTSIDE THE BULGE

\[
\sum F = ma
\]

\[
\sum F = \frac{m v^2}{r}
\]

\[
\frac{GM}{r^2} = \frac{m v^2}{r} = \frac{GM}{r}
\]

\[
v = \frac{GM}{r}
\]

### Functions of the Model

Using a bulge radius (R) of 2.5 kpc, the model predicts rotation of objects with \( r < R \) as a linear function \( v = 159.8 r \). For objects with \( r > R \), object rotation is predicted by the function \( v = 632.418 \times r^{-0.5} \).

### EXPLANATION OF MODELS

- For objects inside the radius of the bulge, a proportionality method is used comparing a sphere created using the radius of the given object and the whole bulge sphere.
- For objects outside of the bulge, Newton’s shell theorem can be used to treat the sphere as a single point mass.

### IMPLICATIONS

The difference in rotational speeds at large radii indicates that at these large radii there is a gravitational force accounted for by dark matter. The large radii at which this phenomena occurs indicates that the dark matter likely exists in a halo at the edges of the galaxy.

### REFERENCES AND ACKNOWLEDGMENTS

**References**


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