Determining The Structure and Dynamics of the Milky Way Galaxy

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Experimental Goals

- **Overlying Question:** What is the mass distribution of the Milky Way?
- Determine how velocity varies with distance from the center of the galaxy
- Determine the density distribution of the galaxy

Galactic Coordinates

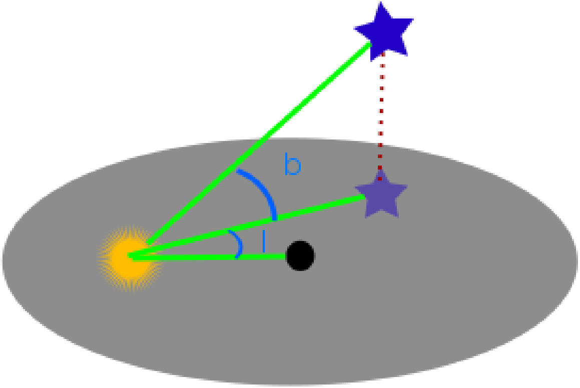
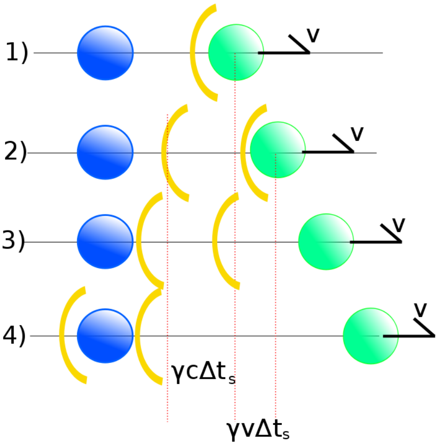


Figure: b is the angle above the galactic plane, l is points angle in the galactic plane

Relativistic Doppler Shift



- $\lambda_{obs} = (c\gamma + v\gamma)\Delta t_{src}\lambda src$
  $= c\sqrt{\frac{1+\beta}{1-\beta}}$
- $\nu = \frac{c}{\lambda}$

Doppler Shift

$$\nu_{obs} = \nu_{src}\sqrt{\frac{1-\beta}{1+\beta}} \quad (1)$$

Known Structure of Galaxy

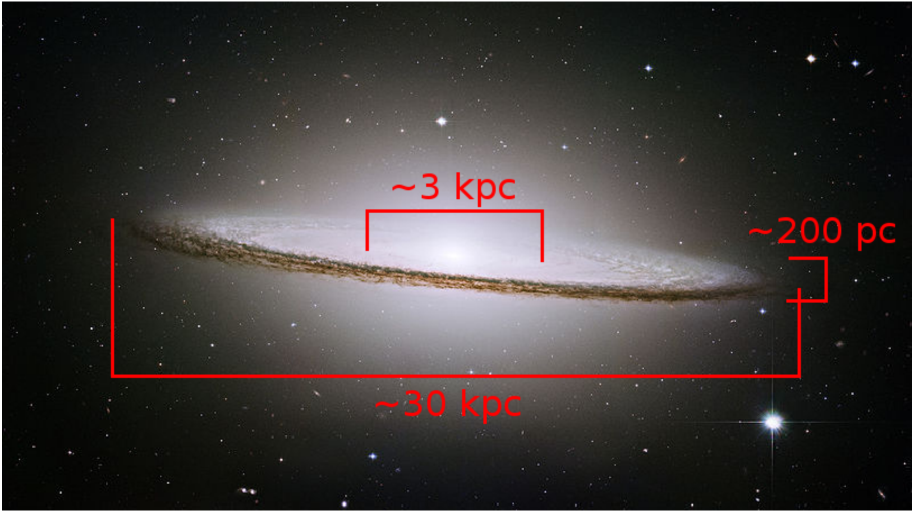
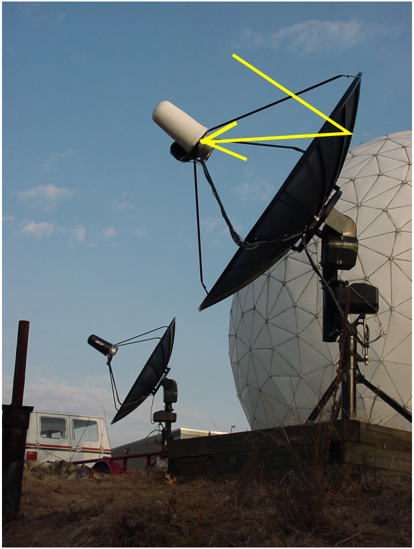


Image from: http://en.wikipedia.org/wiki/File:M104_ngc4594_sombrero_galaxy_hi-res.jpg

Experimental Setup and Data Collection

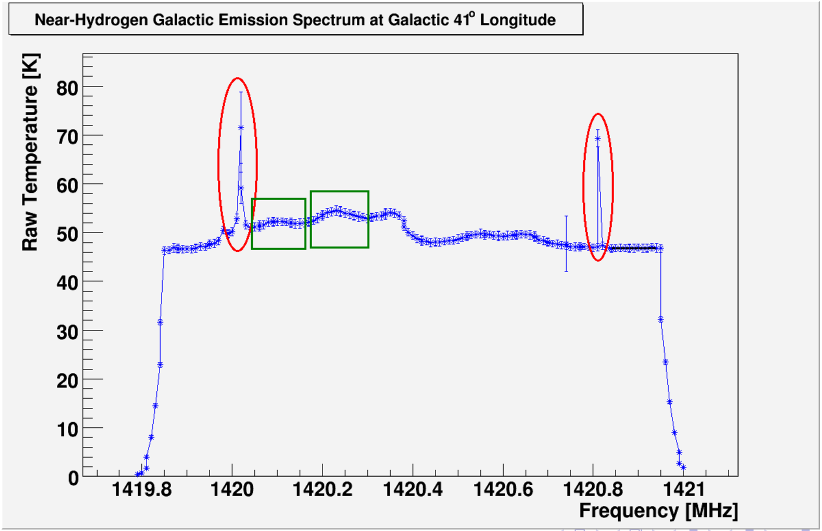


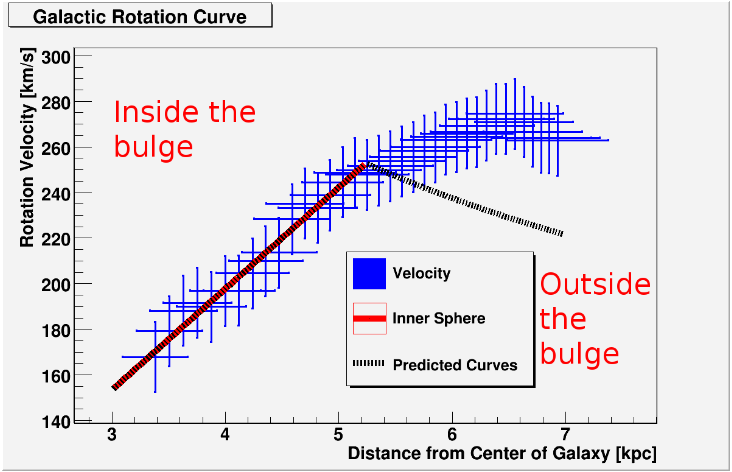
- MIT's small radio telescope
- Measures antenna temperature $\propto$ power
- Scan 35 points for 10 minutes each from $l = 25^\circ$ to $l = 60^\circ$
  - $b = 0^\circ$
- Beamwidth = $7.4 \pm .5^\circ$

Keplerian and Newtonian Predictions

- Under the assumption that nearly all mass is located in the bulge. Given this, Newton and Kepler predict:
- Inside the bulge
  - Assuming constant density
  - $\frac{4G\rho\pi r^3}{r^2} = \frac{v^2}{r}$
  - $v = \sqrt{\frac{4}{3}G\rho\pi r}$
- Outside the bulge
  - $\frac{GM}{r^2} = \frac{v^2}{r}$
  - $v = \sqrt{GM}\frac{1}{\sqrt{r}}$

Data
Frequency Spectrum




Galactic Rotation Curve
Rotation Velocity [km/s]
300
280
260
240
220
200
180
160
140
3
4
5
6
7
Distance from Center of Galaxy [kpc]
Inside the bulge
Outside the bulge
Velocity
Inner Sphere
Predicted Curves

Results do not match predictions!

- Keplarian predictions match data within the bulge, but remain roughly constant outside
- Fitting predictions to observations yields terrible fit
- Possible existence of dark matter may explain observations

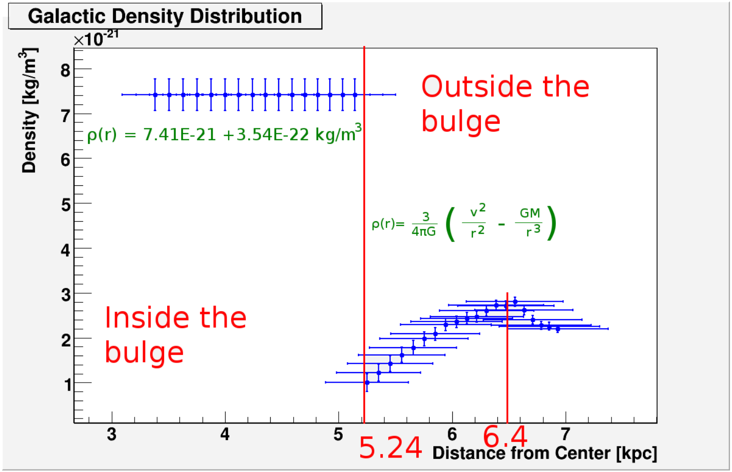
- Assuming an isotropic dark matter distribution
- $\frac{G\left(M+\frac{4}{3}\pi r^3\rho(r)\right)}{r^2} = \frac{v^2}{r^2}$

Isotropic Radial Density Distribution

$$\rho(r) = \frac{3}{4\pi G}\left(\frac{v^2}{r^2} - \frac{GM}{r^3}\right) \tag{2}$$

Results

Density Distribution



Error Analysis

Random Errors

- $\Delta T_{Raw} \approx 1\%$
- Many runs, low random error in measurements
- Fitting curve
  - $\Delta \nu_{min} \approx 3\%$
  - ΔBaseline$\approx .4\%$

- $\Delta l \approx .5^\circ$
- Frequency binning: $\Delta\nu \approx .007$MHz
- Uncertainty in known values
    - $\Delta R_{sun} = 5$ kpc
    - $\Delta t_{sun} = 15359$ m/s (15%)

Conclusions

- The velocity of the galaxy within the central bulge behaves as expected
- Outside the central bulge, Kepler's and Newton's predictions, assuming all of the mass is contained in the center of the galaxy, fail
  - Velocity curve levels off around at around 5 kpc
  - Dark matter may be able to explain

Acknowledgements

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