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
- Generate a map of part of the galaxy

Galactic Coordinates

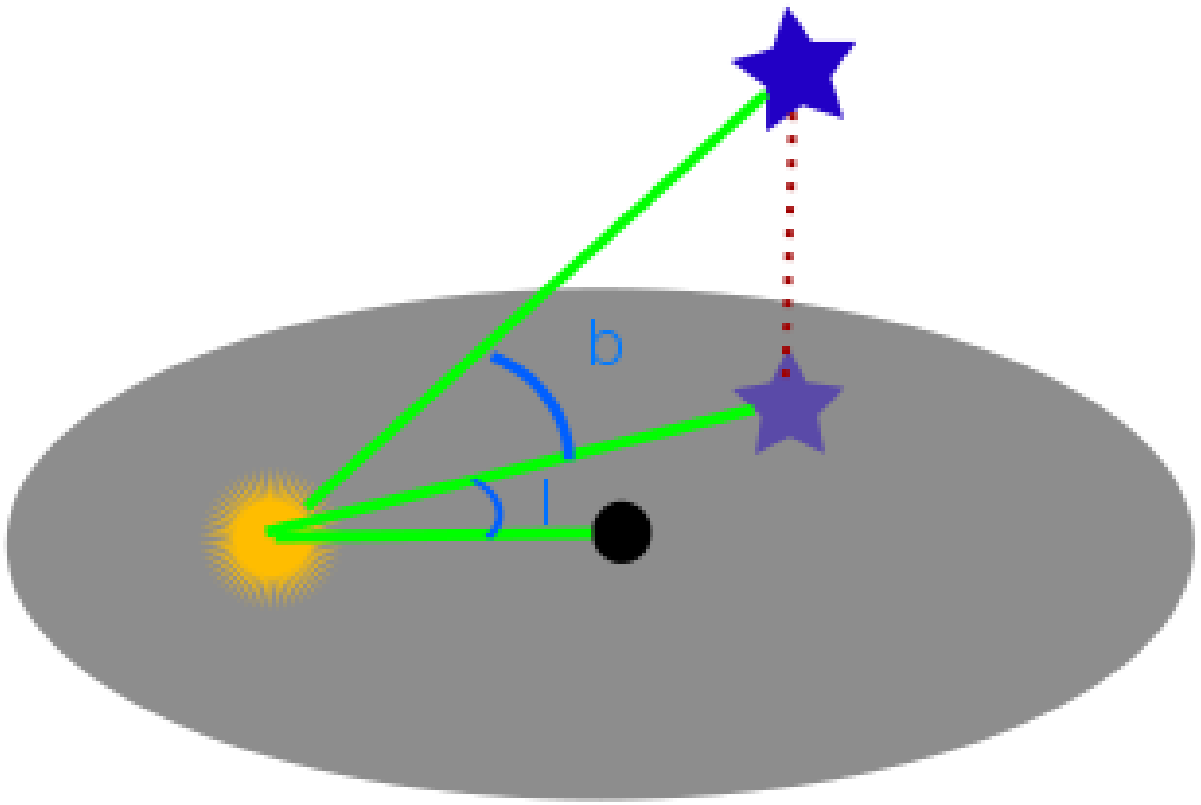
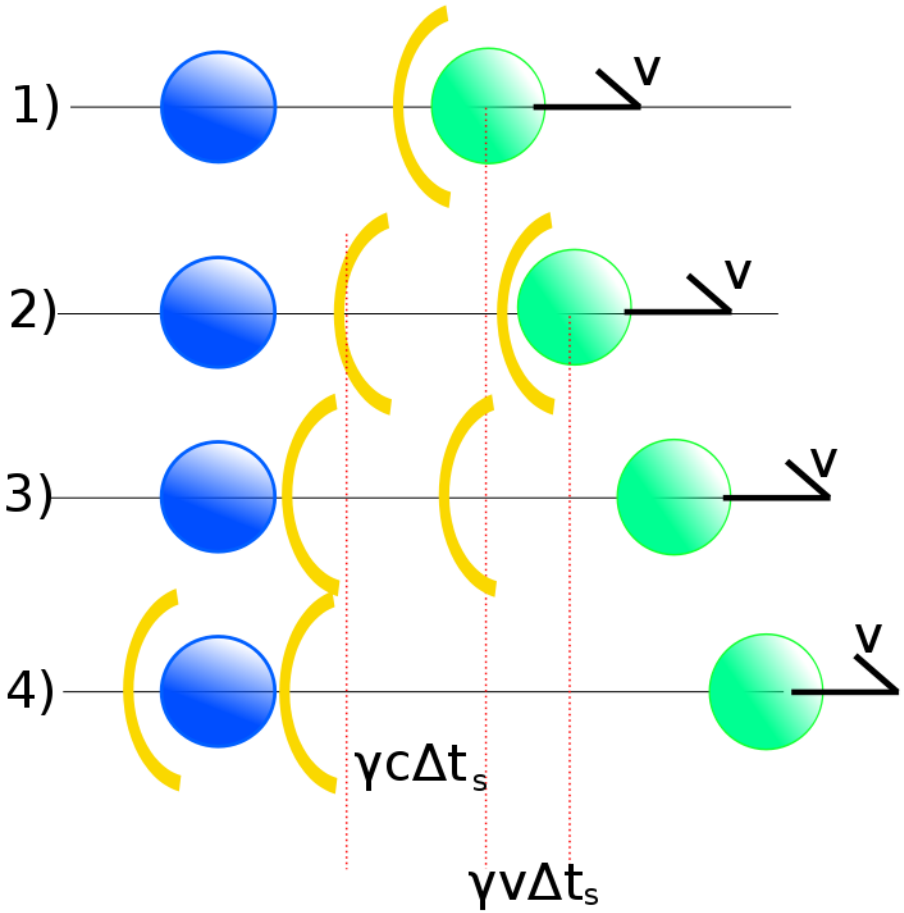


Figure: b is the angle above the galactic plane, l is points angle in the galactic plane

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

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

Known Structure of Galaxy

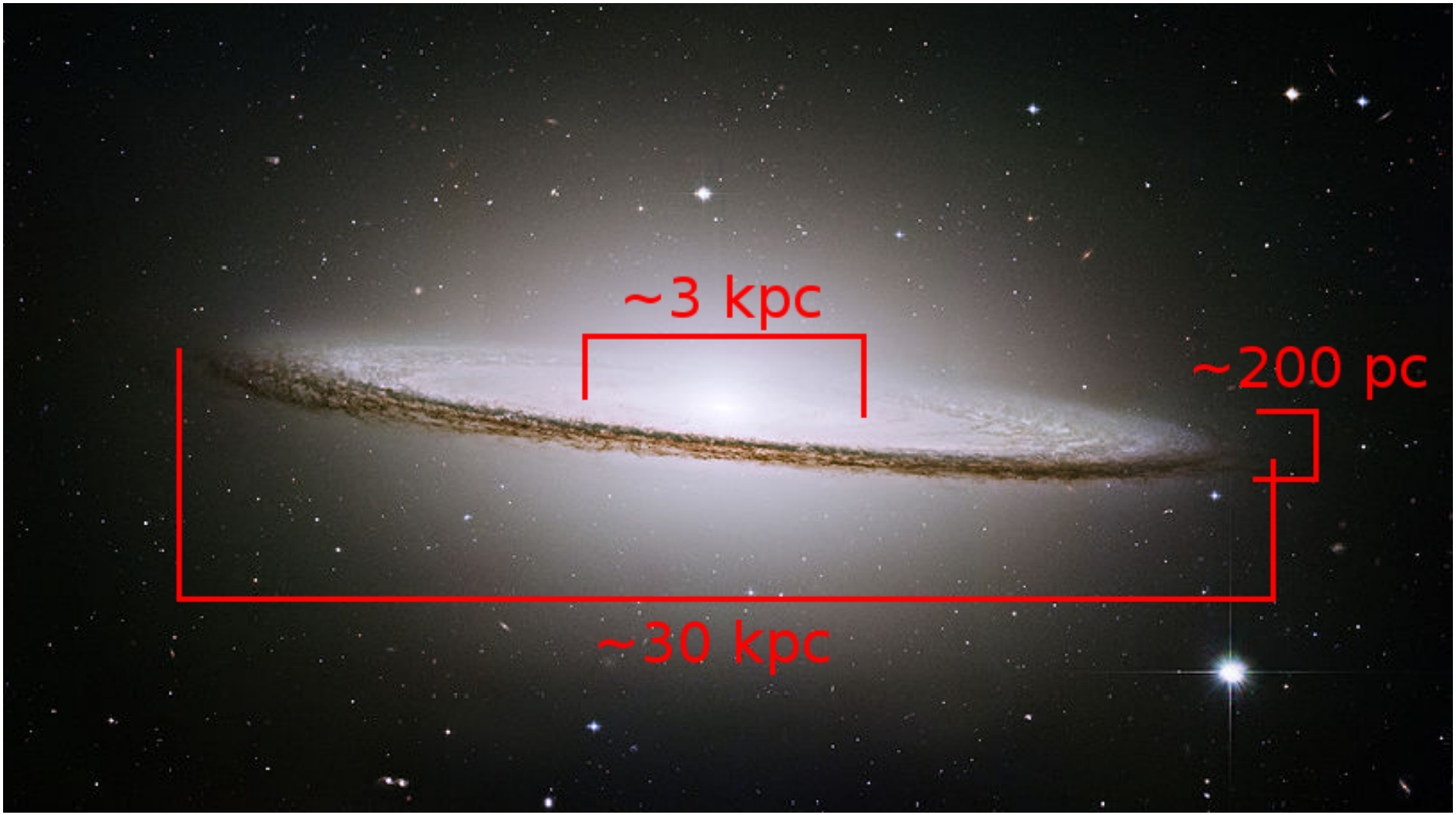


Image from: http://en.wikipedia.org/wiki/File:M104_ngc4594_sombrero_galaxy_hi-res.jpg

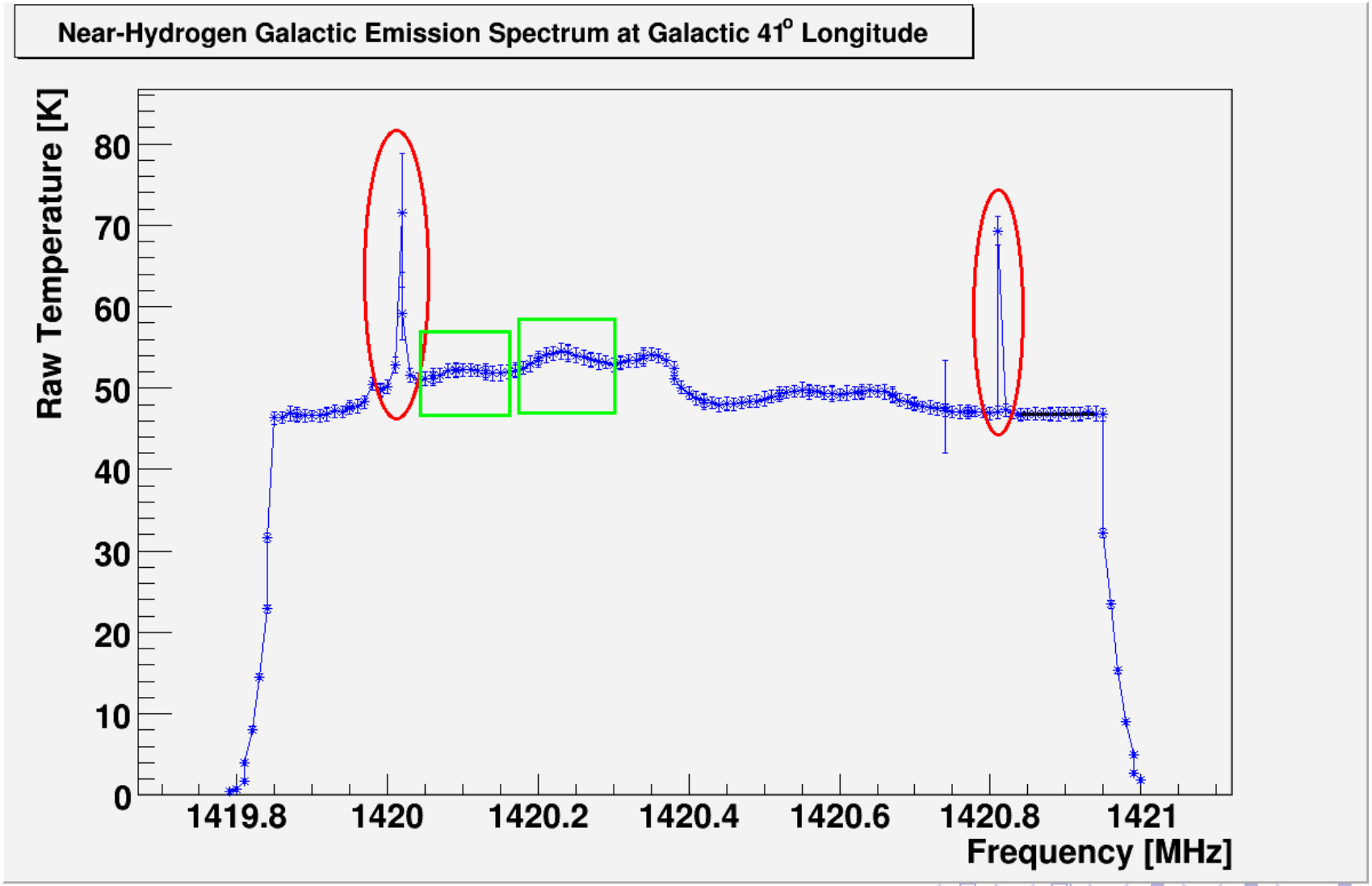
Experimental Setup and Data Collection

- MIT's small radio telescope
- Measures antenna temperature $\propto$ power
- Scan 35 points for 10 minutes each from $l = 25°$ to $l = 60°$
  - $b = 0°$
- Image from:

  http://www.haystack.mit.edu/edu/undergrad/srti/srt-intsetup.jpg

Data

Frequency Spectrum



Analysis

Galactic Rotation Curve

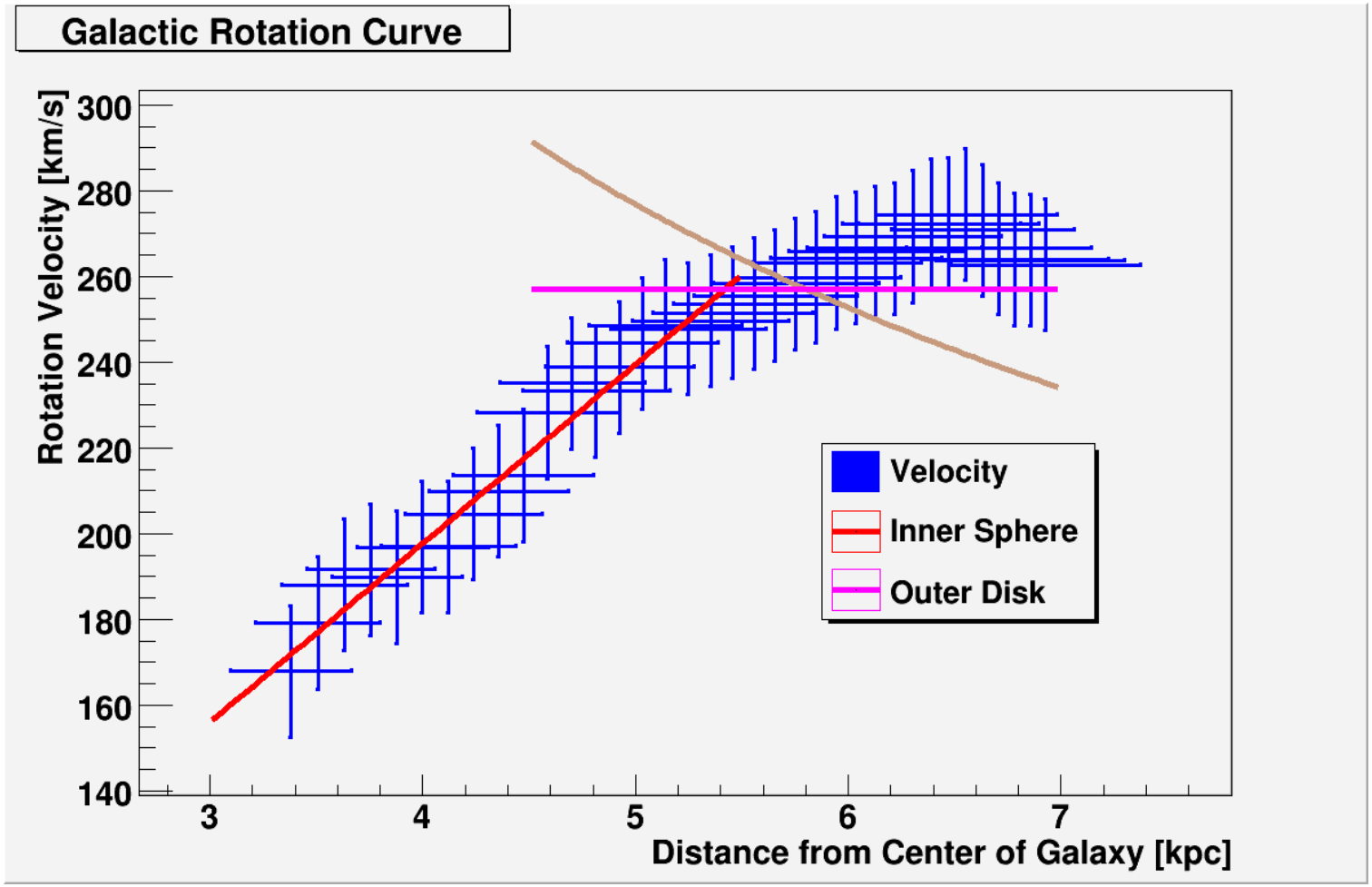
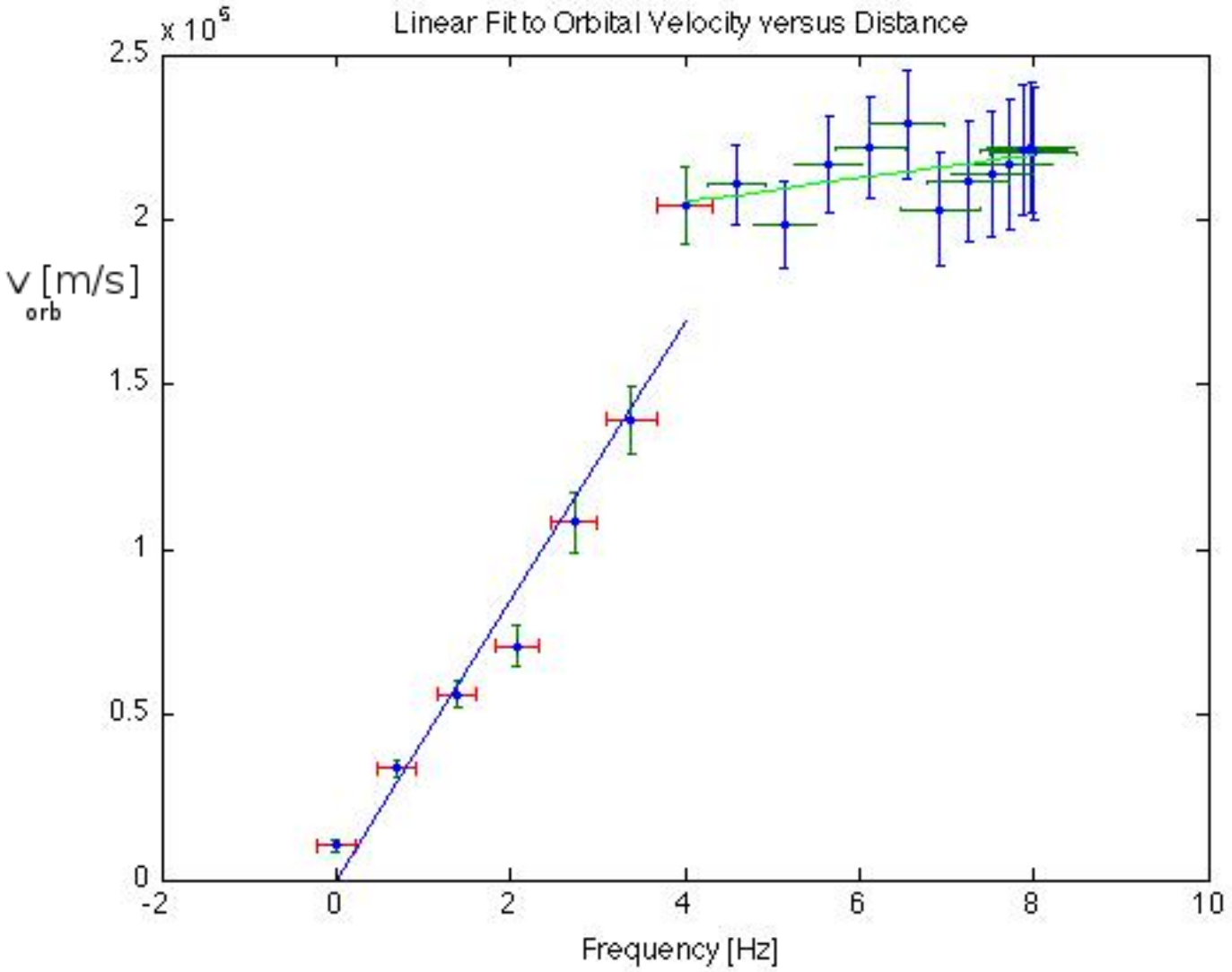


Figure: $\chi^2_{inc} = 0.82, \chi^2_{flat} = 6.91, \chi^2_{Kep} = 64.6$

Analysis

Confirmation



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
  - $\frac{GM}{r^2} = \frac{v^2}{r}$
  - $\sqrt{GM}\frac{1}{\sqrt{r}}$

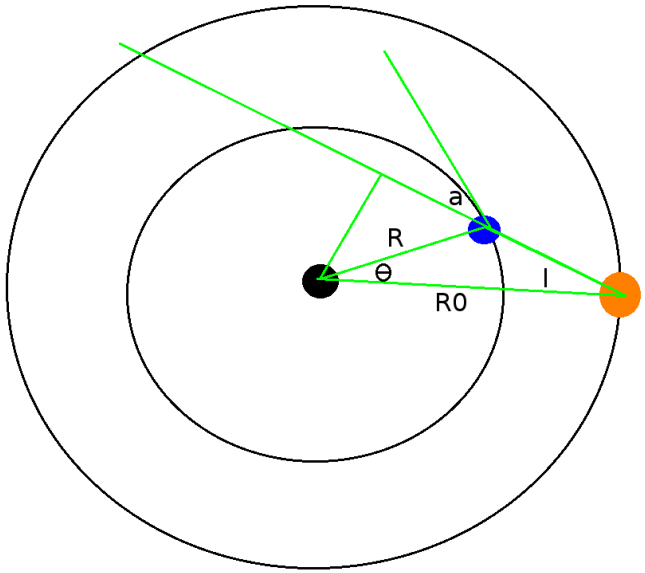
Results

Results do not match predictions!

- Keplarian predictions match data within the bulge, but remain roughly constant outside
- Fitting predictions to observations yields terrible fit
  - Model predicts mass of bulge to be 10^{74}kg, $\approx 6\sigma$ above known value, 10^{42}
- Possible existence of dark matter may explain observations

Mapping Sector of the Milky Way

Determining Coordinates



- Each measured velocity point can imply two different positions
- Geometry and trigonometry yield the follow relationships
- $R = \frac{v_{orb} R_{sun}}{\frac{v_{rec}}{sin(l)} \pm v_{sun}}$
- $\Theta = sin^{-1}\left(\frac{v_{rec} \pm v_{sun} sin(l)}{v_o rb}\right) - l$

Mapping Sector of the Milky Way

Results

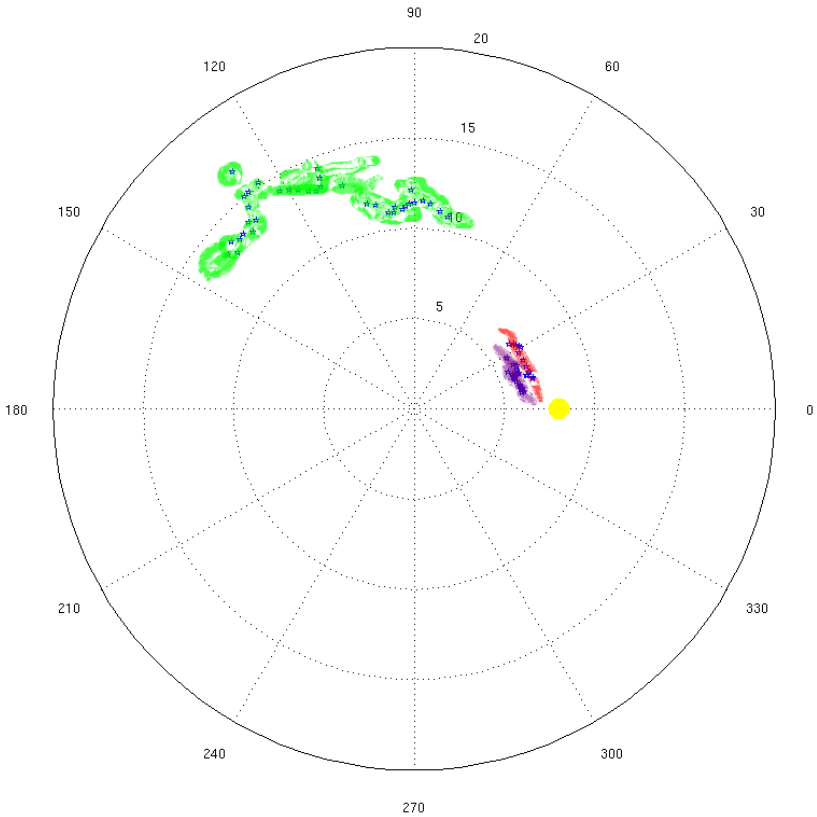


Figure: $\Delta\Theta \approx 10°, \Delta R \approx .75\text{kpc}$

Error Analysis

- Random error
  - $\Delta T_{Raw} \approx 1\%$
  - Many runs, low random error in measurements
  - Fitting curve
    - $\Delta \nu_{min} \approx 3\%$
    - ΔBaseline$\approx .4\%$
    - $\Delta v_{const} \approx 1.6\%$
- Systematic error
  - $\Delta l \approx 1.5^{\circ}$
  - 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
- Plotted a map of a small section of the galaxy

Acknowledgements

I would like to thank my partner Anna Waldman-Brown for helping me collect and analyze data as well as the Junior Lab staff for helping me work out problems I encountered along the way. I would also like to thank Sukrit Ranjan for providing advice on interpreting the output of the SRT.