



# GALACTIC GEOMETRY AND THE ROTATION OF THE MILKY WAY

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8.13 Experimental  
Physics 1 – Fall 2021

# Experimental Goals

- **Derive a Rotation Curve of the Milky Way**
- **Compare results with predictive models**
  - i.e. classical models vs. newer models
  - What do they reveal?

# Theory of Gravitation and Rotation

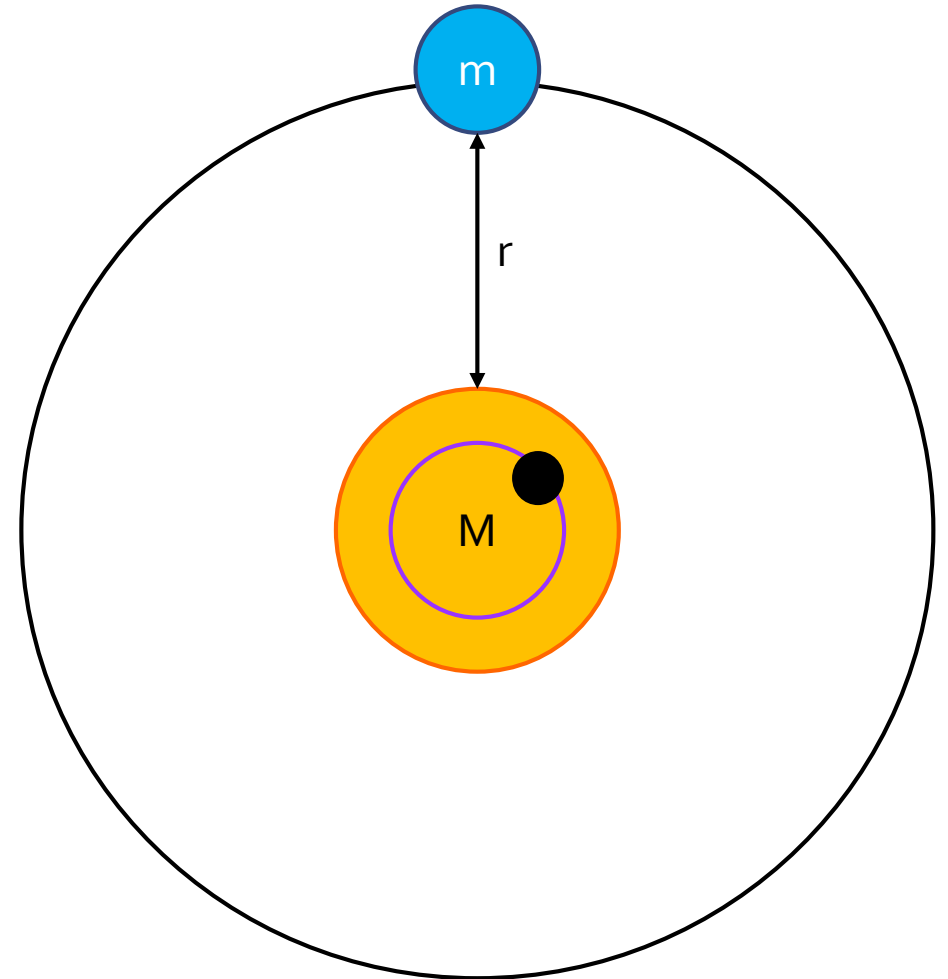
- What we know: *centripetal forces*
  - Newton's law of gravitation  $\leftrightarrow$  centripetal force:

$$\frac{mv^2}{r} = \frac{GmM}{r^2} \Rightarrow v(r) = \sqrt{\frac{GM}{r}}$$

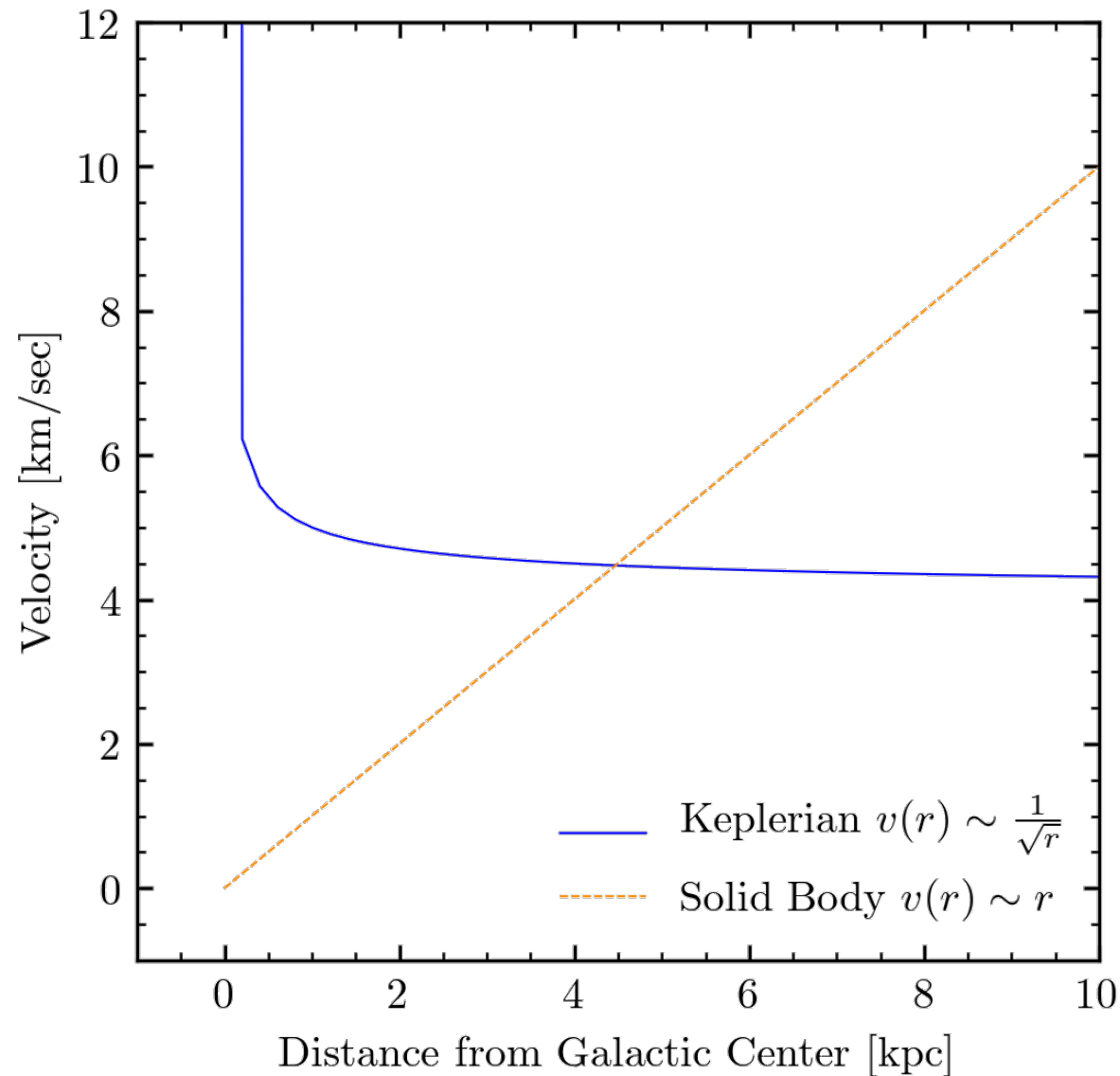
- Hence, Keplerian prediction:  $v(r) \sim \frac{1}{\sqrt{r}}$
- What about *internal* to central object?

$$M(r) = \rho \frac{4}{3} \pi r^3 \Rightarrow v(r) = \sqrt{\frac{\rho G 4 \pi r^2}{3}}$$

- Hence, solid mass prediction:  $v(r) \sim r$



# Theoretical Models of Rotation Curves



Keplerian:

$$v(r) \sim \frac{1}{\sqrt{r}}$$

Solid Mass:

$$v(r) \sim r$$

# Computing Velocities – Geometry of the Galaxy

- Radius:

$$r = R_0 \sin \frac{l\pi}{180'}$$

- Doppler Shift:

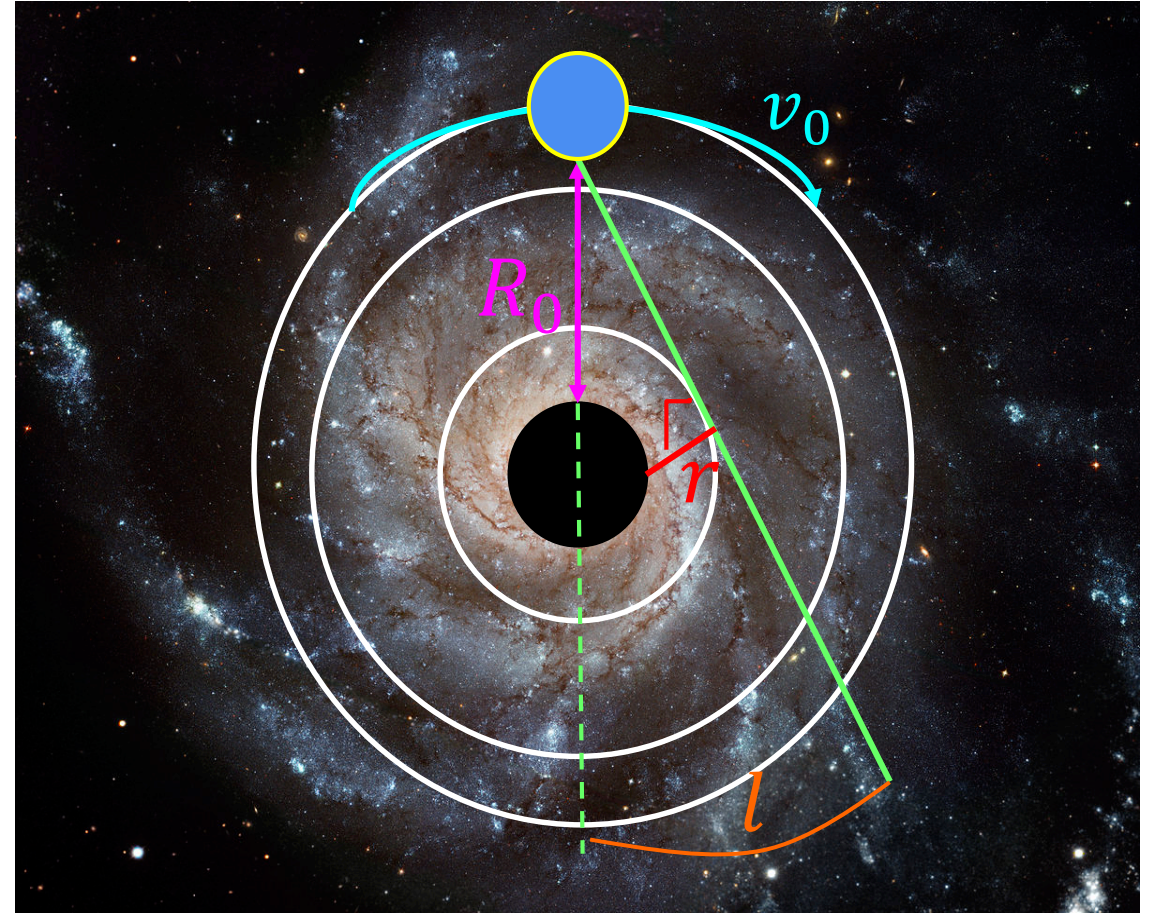
$$v_{shift} = c \frac{f_0 - f_{red}}{f_0}$$

- Max radial velocity along line of sight:

$$v_{max} = c \frac{f_0 - f_{red}}{f_0} - v_{lsr}$$

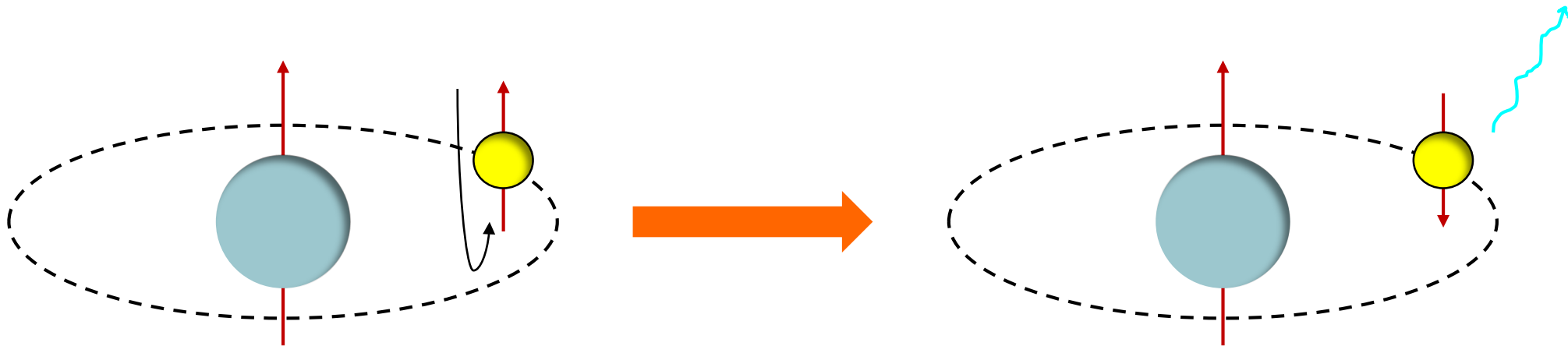
- Galactic velocity:

$$v(r) = v_{max} + v_0 \sin \frac{l\pi}{180}$$



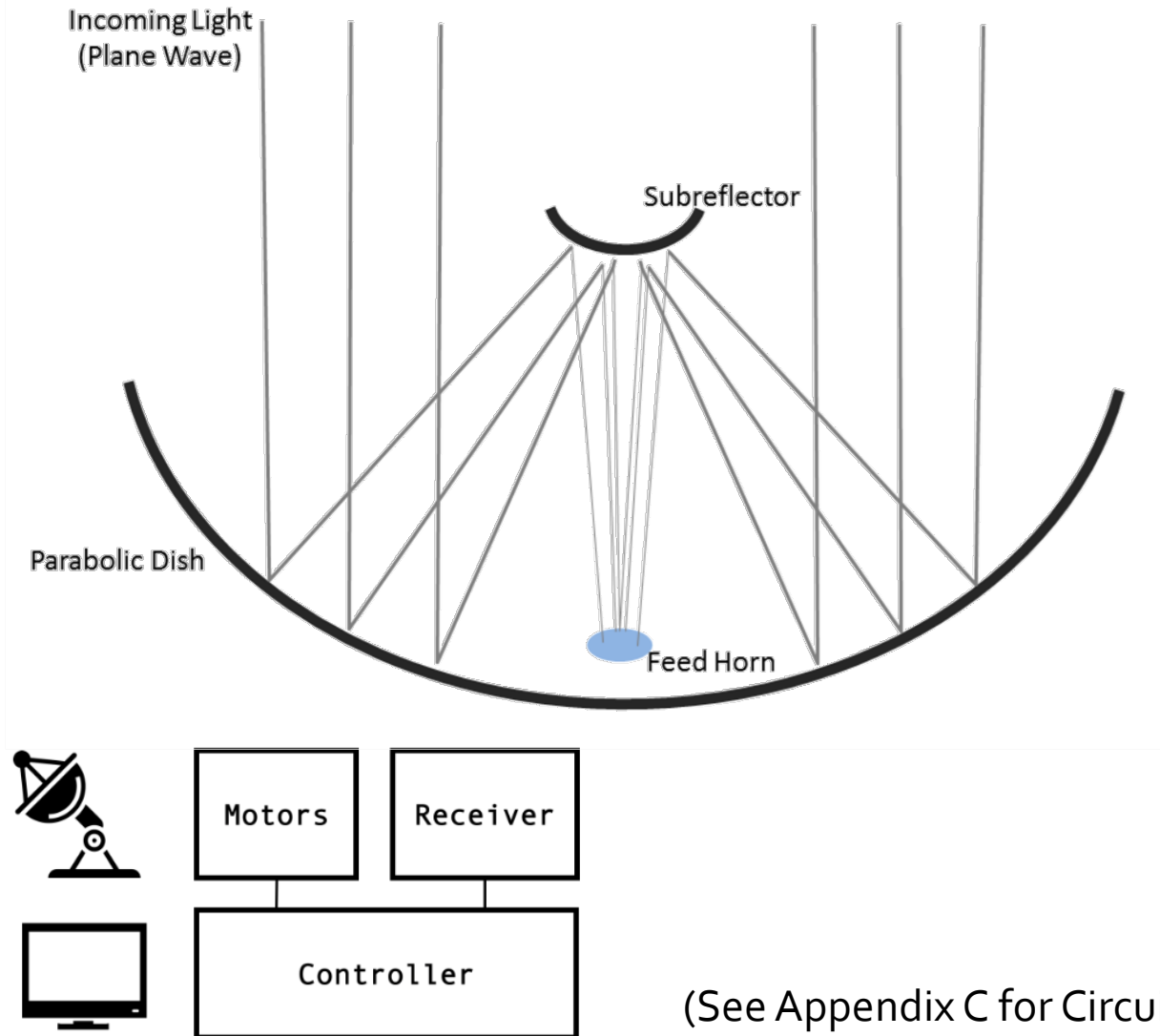
# Theory of the 21cm Line of Hydrogen

- Optical light often suffers from absorption from stars and interstellar dust
  - Use instead the radio-wave range
- Quantum mechanics: discrete angular momentum → parallel & antiparallel states allowed
  - Electron transitions between two states of the 1s H atom configuration → spin flip
  - Energy  $E = hf_0$ , 21cm line frequency given by  $f_0 = 1420.4$  MHz



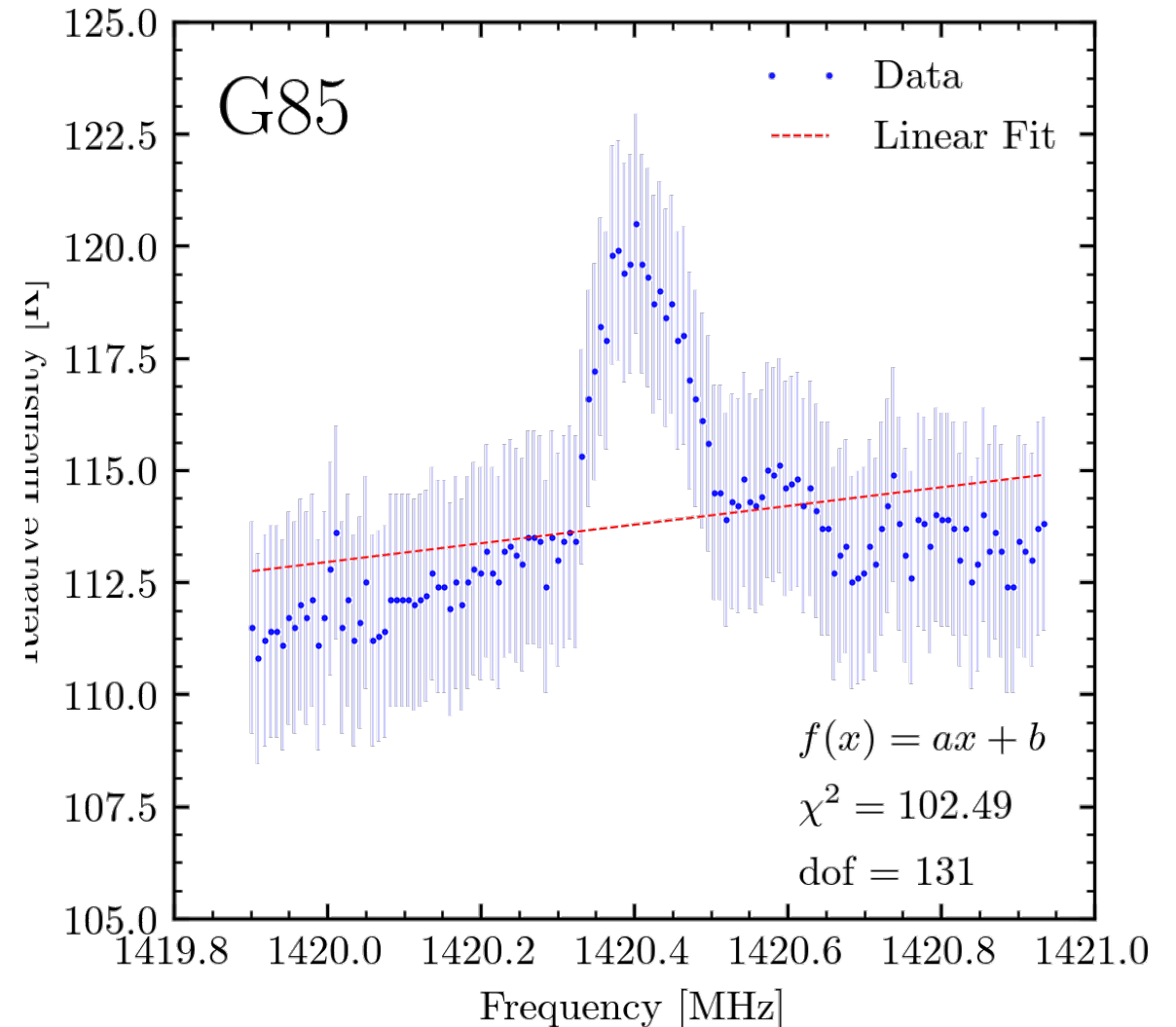
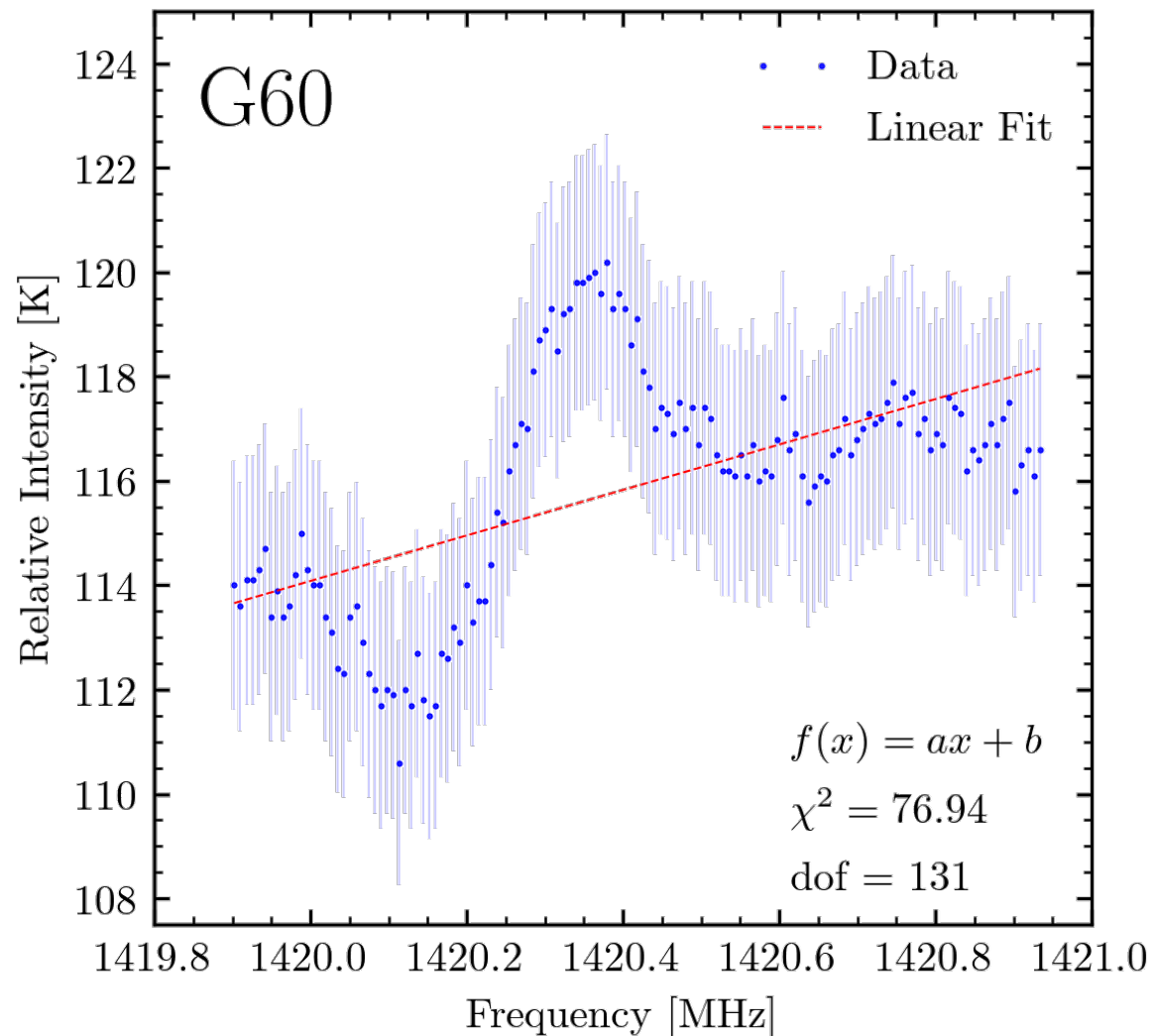


# Small Radio Telescope (SRT) Apparatus



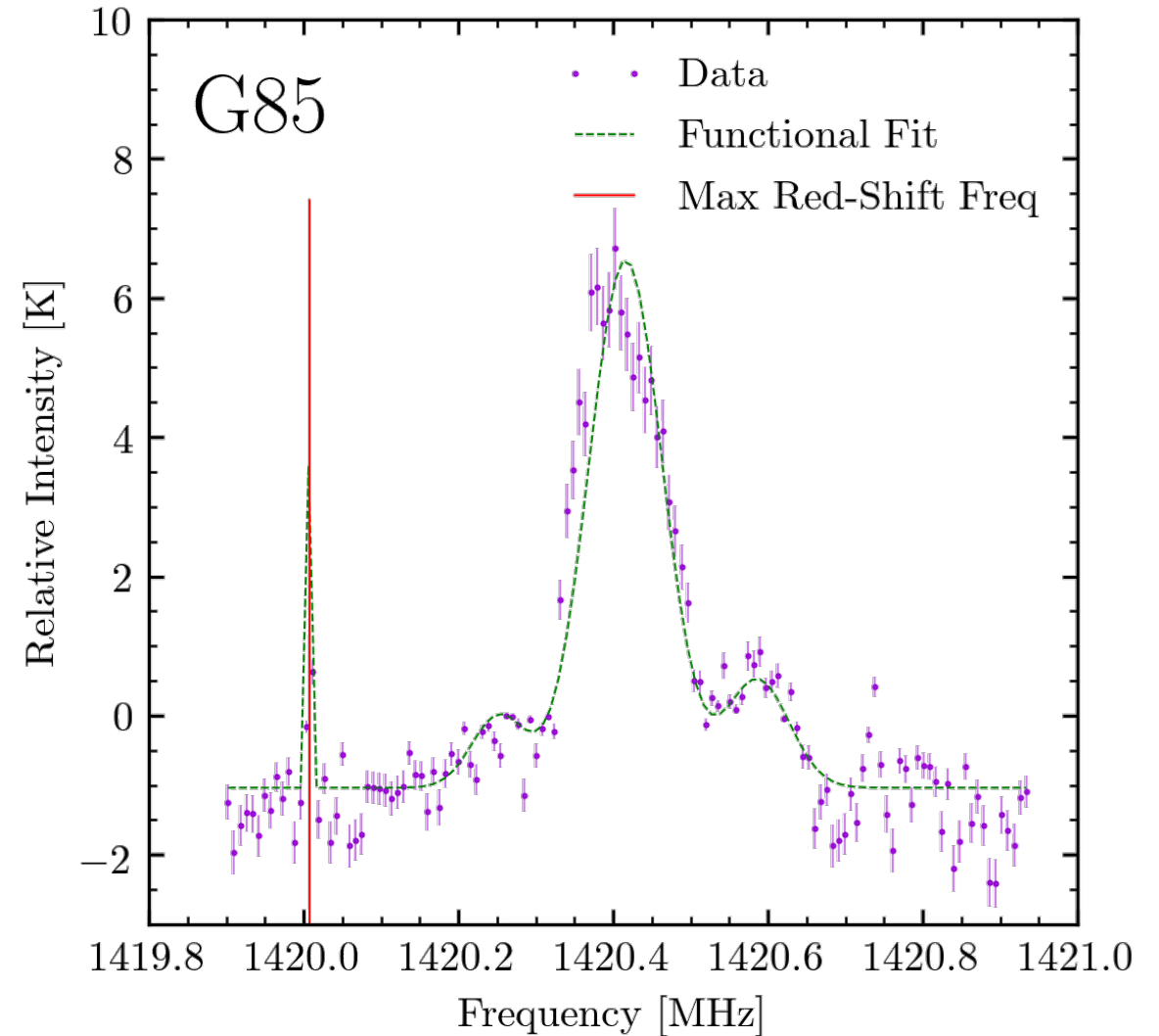
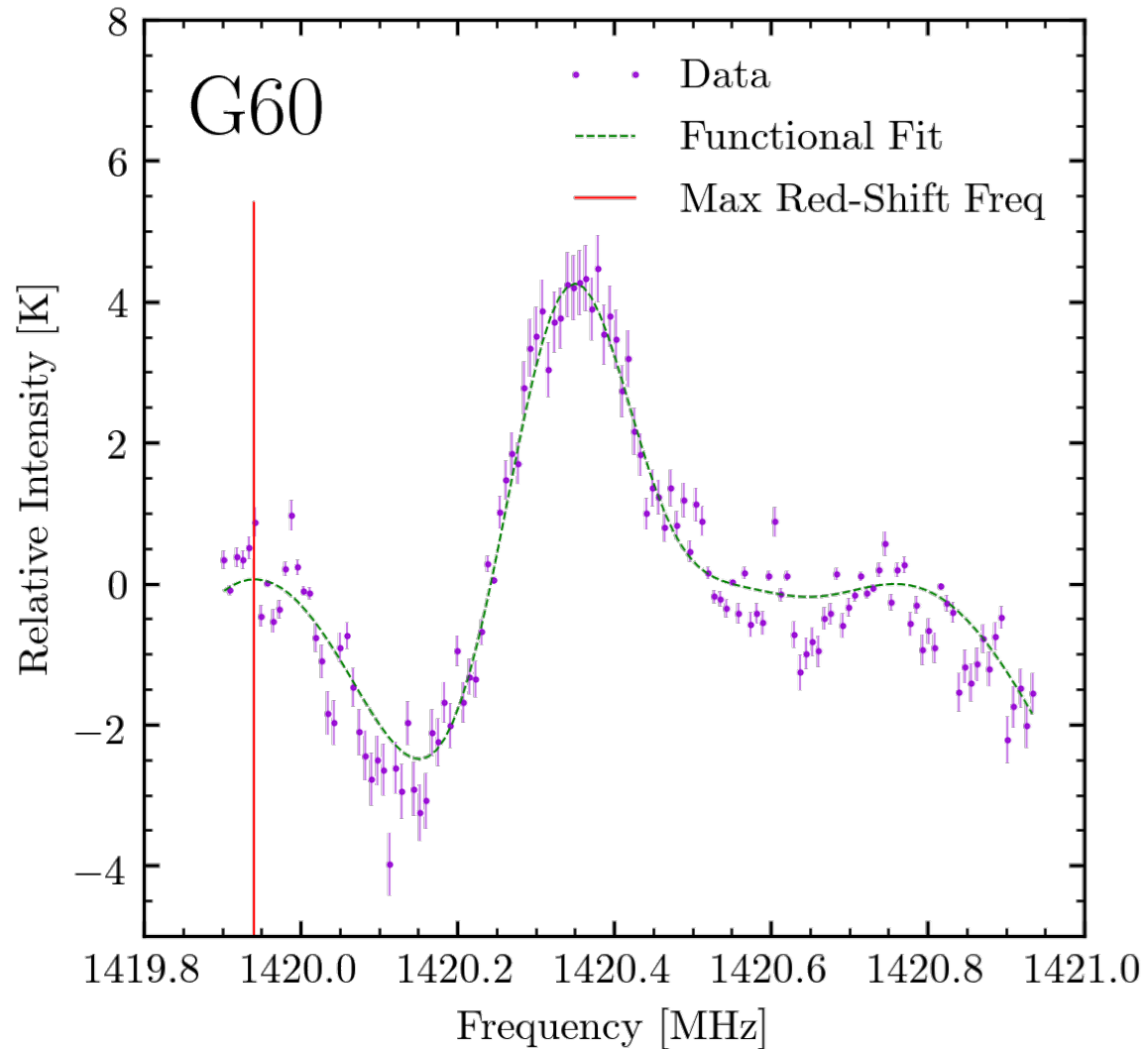
(See Appendix C for Circuitry )

# Intensity Spectra and Fitting to the Background

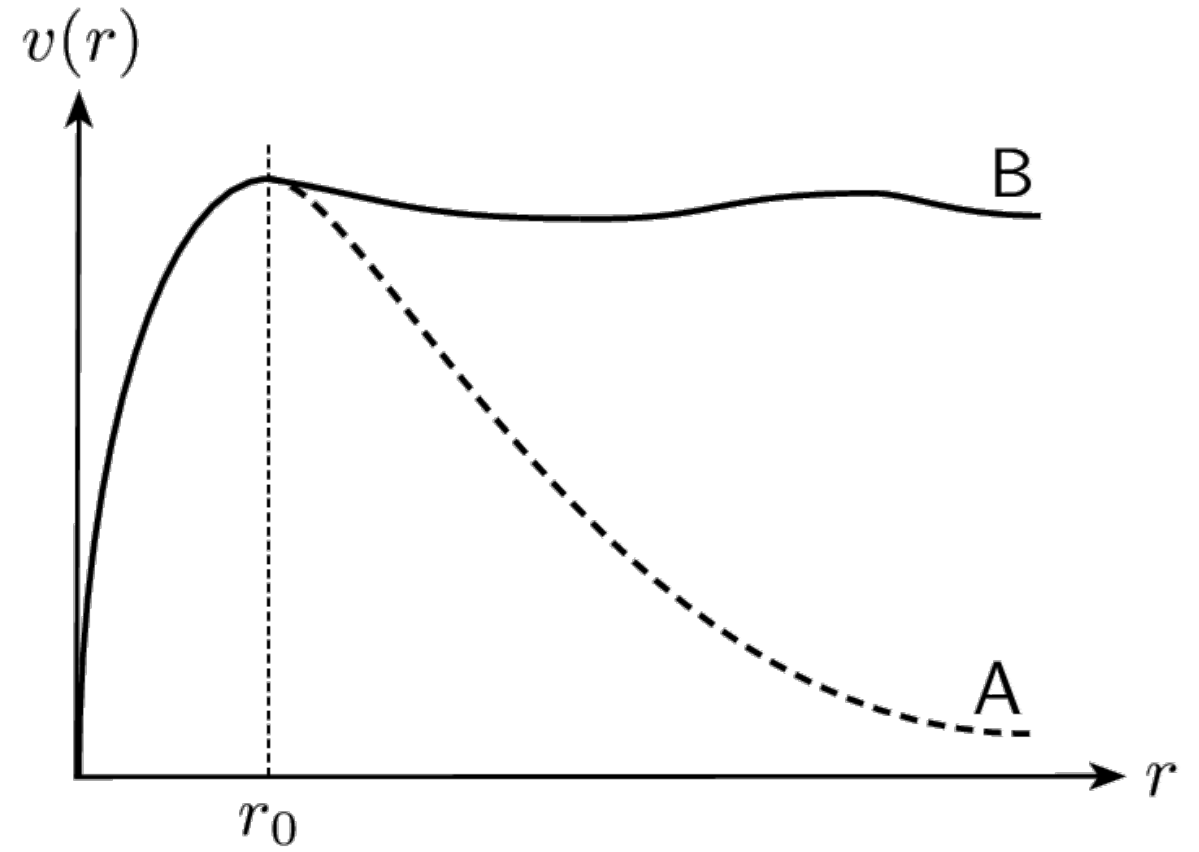
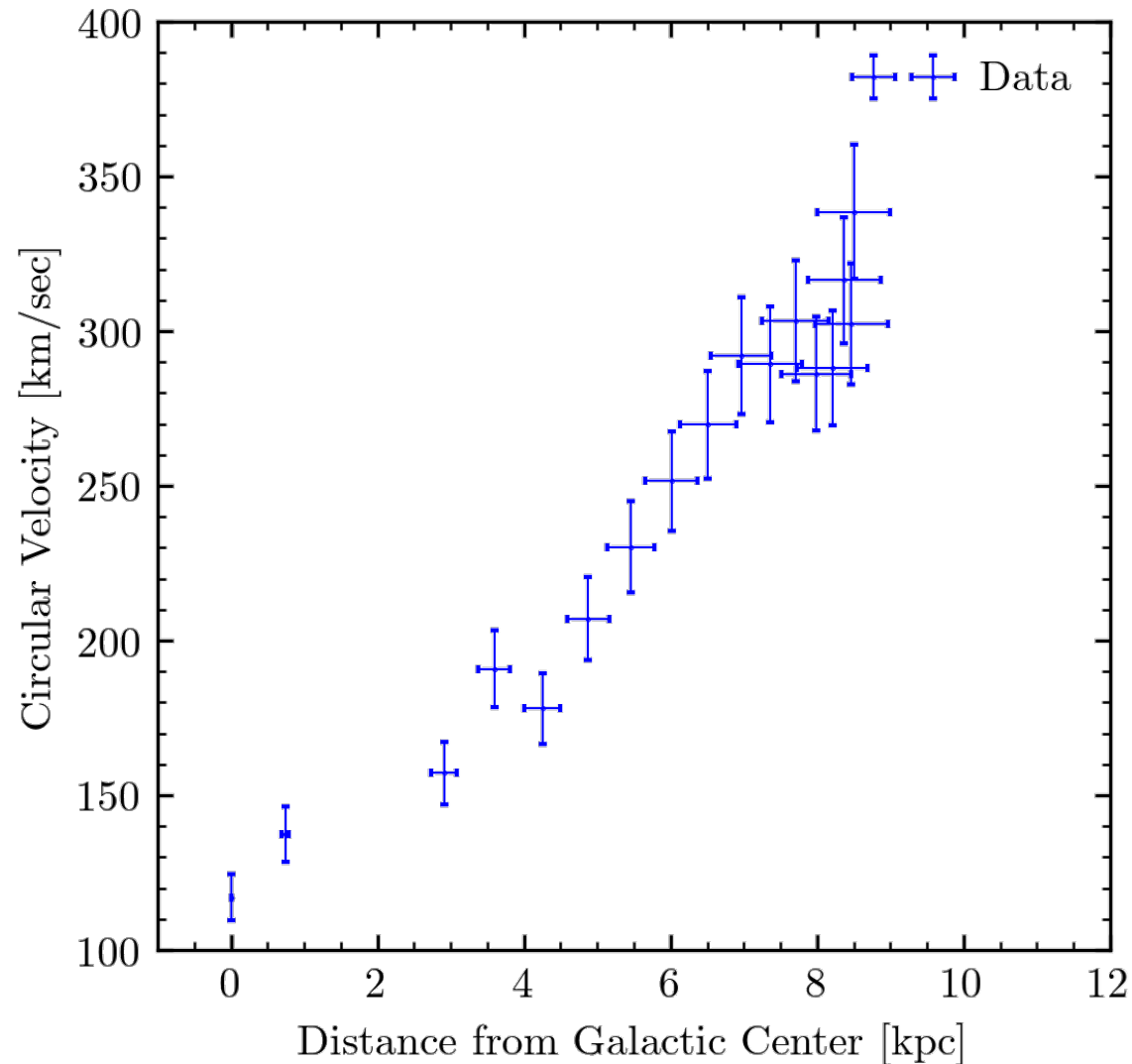




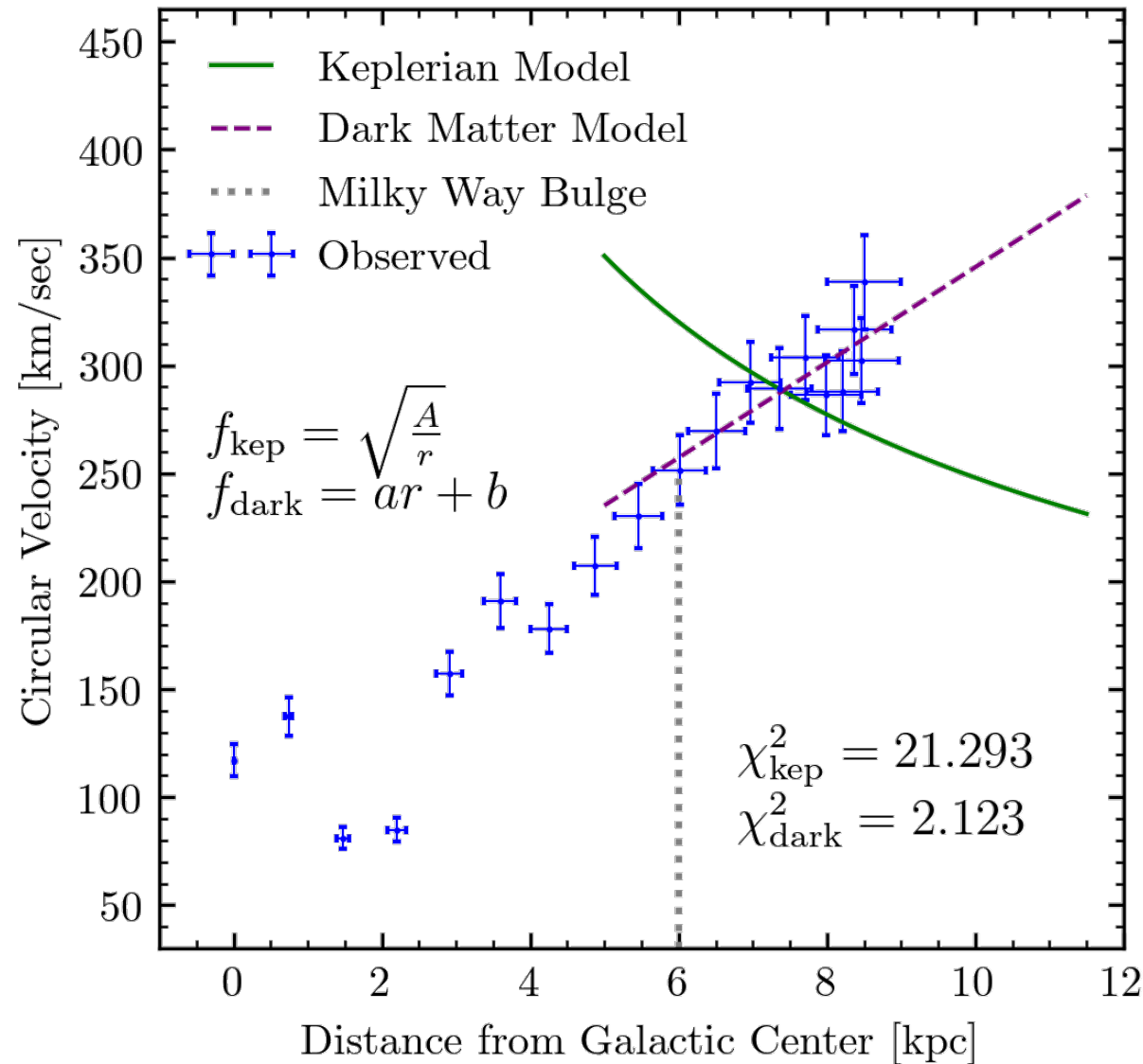
# Background-Subtracted Fits to the Red Shift



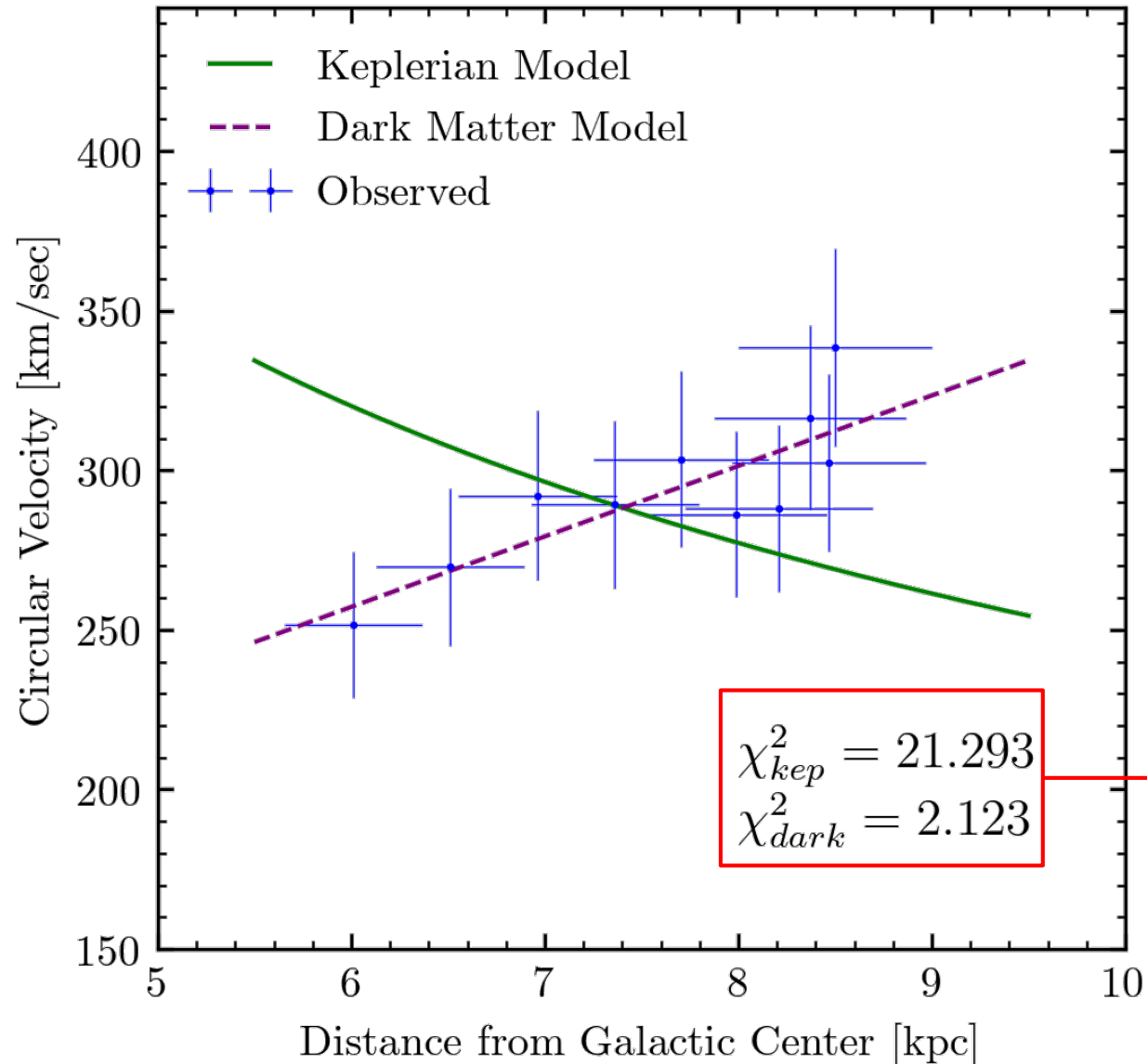
# Comparing Our Rotation Curve with Other Observations



# Fitting Velocity Data to Two Models of Rotation



# Comparing Rotation Curve Model Fits



$$\chi^2_{dark} < \chi^2_{kep}$$

# Results and Discussion of Errors

$$\chi^2_{kep} = 21.293 > 2.123 = \chi^2_{dark}$$

- We find a much stronger fit for the '**dark matter**' model

## Statistical

- Not all longitudes scanned as often as others
- Fewer sessions of data gathering than desired
- Various sources of noise in the galactic plane at different times

## Systematic

- Some low-longitude scans performed on longitudes that were partially/becoming invisible due to out of bounds of telescope view
- Fit function for red-shift frequency not precisely determined; only by inspection
- Days of data taking experienced varying weather

# Summary, Conclusion, and Future Steps

- **What have we accomplished?**
  - Derived an experimental velocity curve for the milky way
  - Explored its relationship to other models of rotational velocity
  - Confirmed that a 'dark matter' model fits the results better
  - Showed that 21cm technique is useful for studying the Milky Way
- **Where can these results lead?**
  - Probing the true mass density of potential dark matter
  - Constructing the spiral-arm structure of the milky way



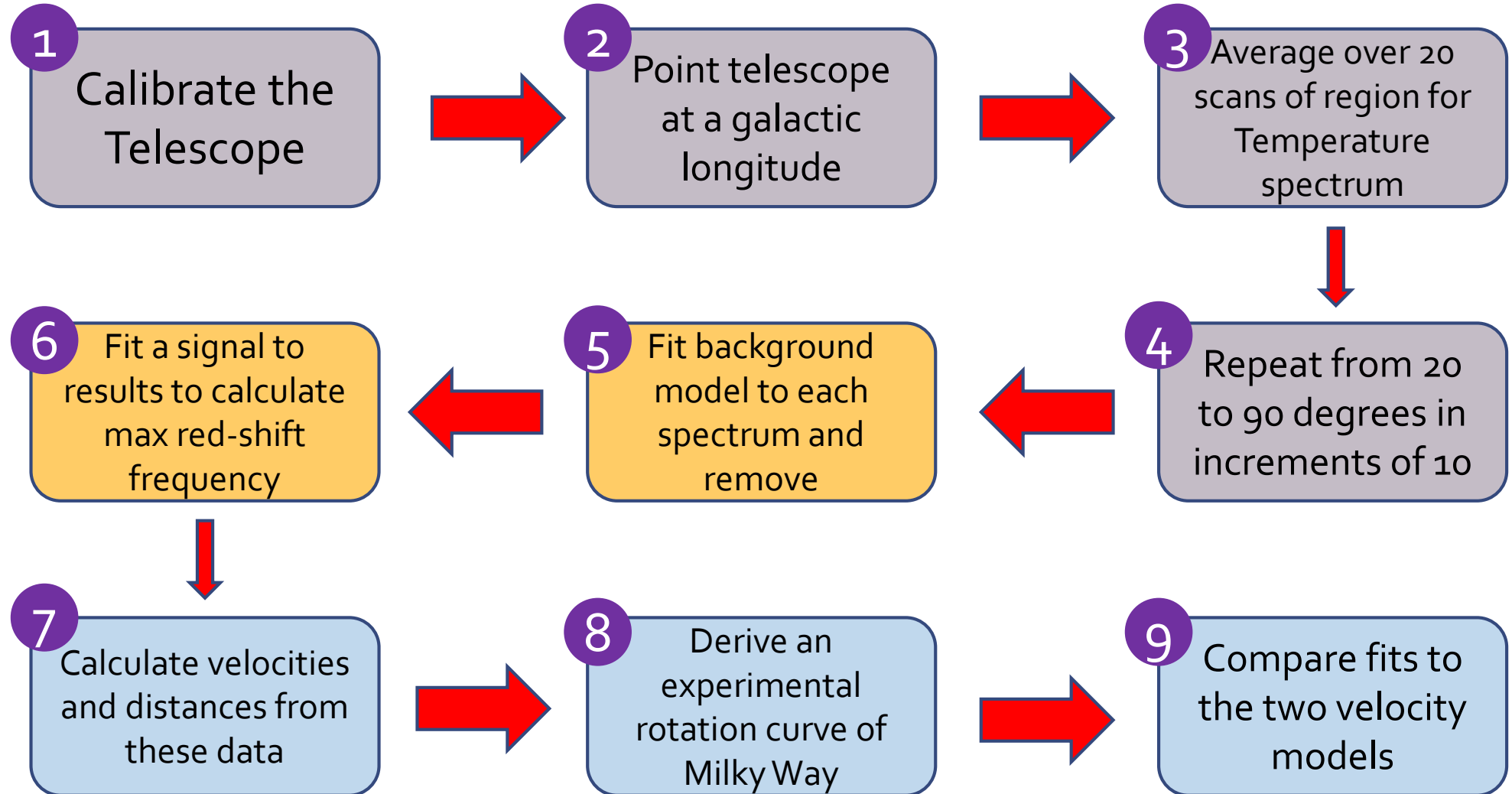
# Acknowledgements

- My lab partner, Luke Gianni, for his collaboration on this project
- The 8.13 teaching staff for their instruction and aid in the lab
- MIT's lab facilities and equipment

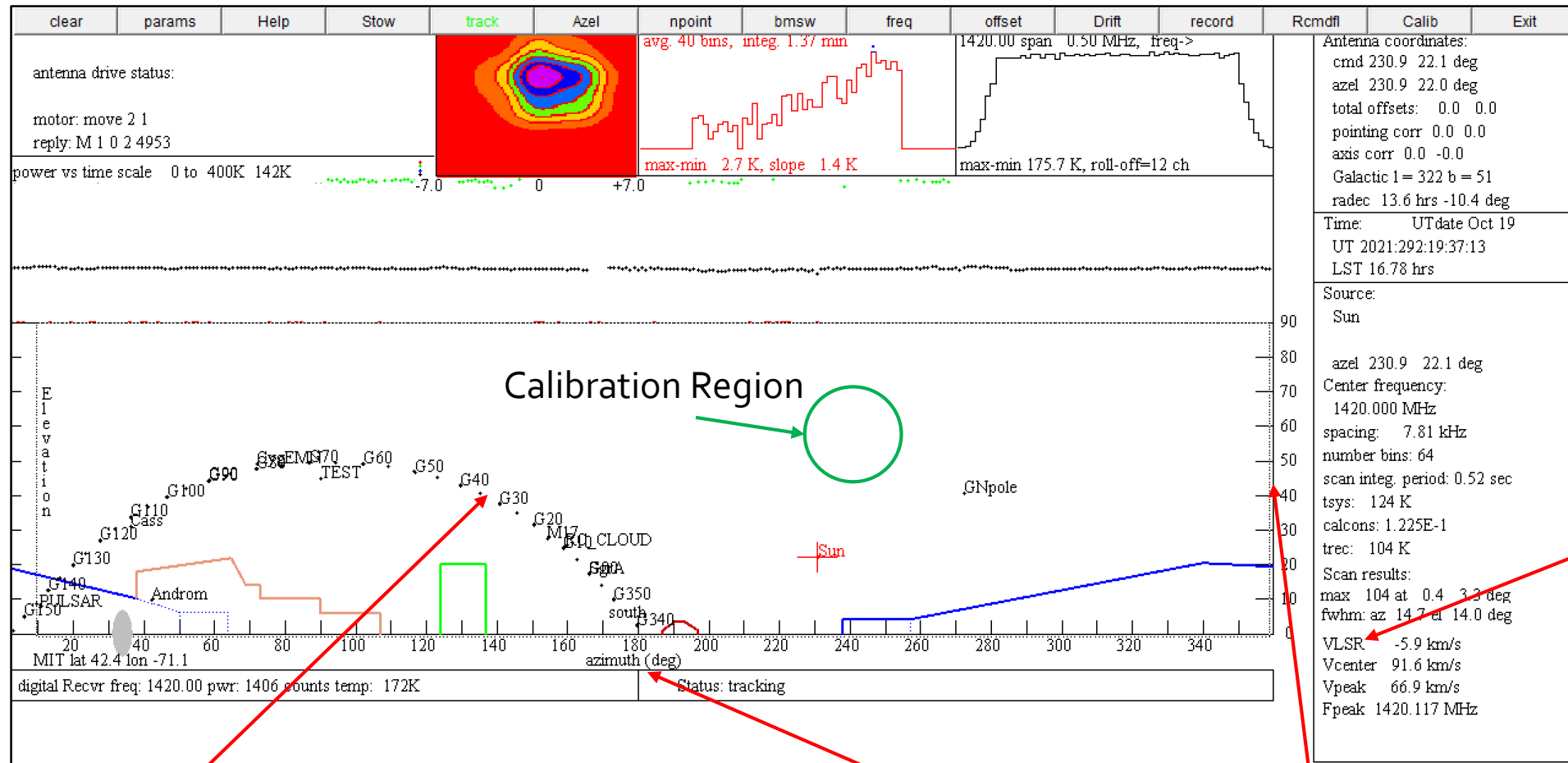
# THANK YOU!

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# Appendix A: Data Collecting Scheme



# Appendix B: Telescope and Experimental Procedure

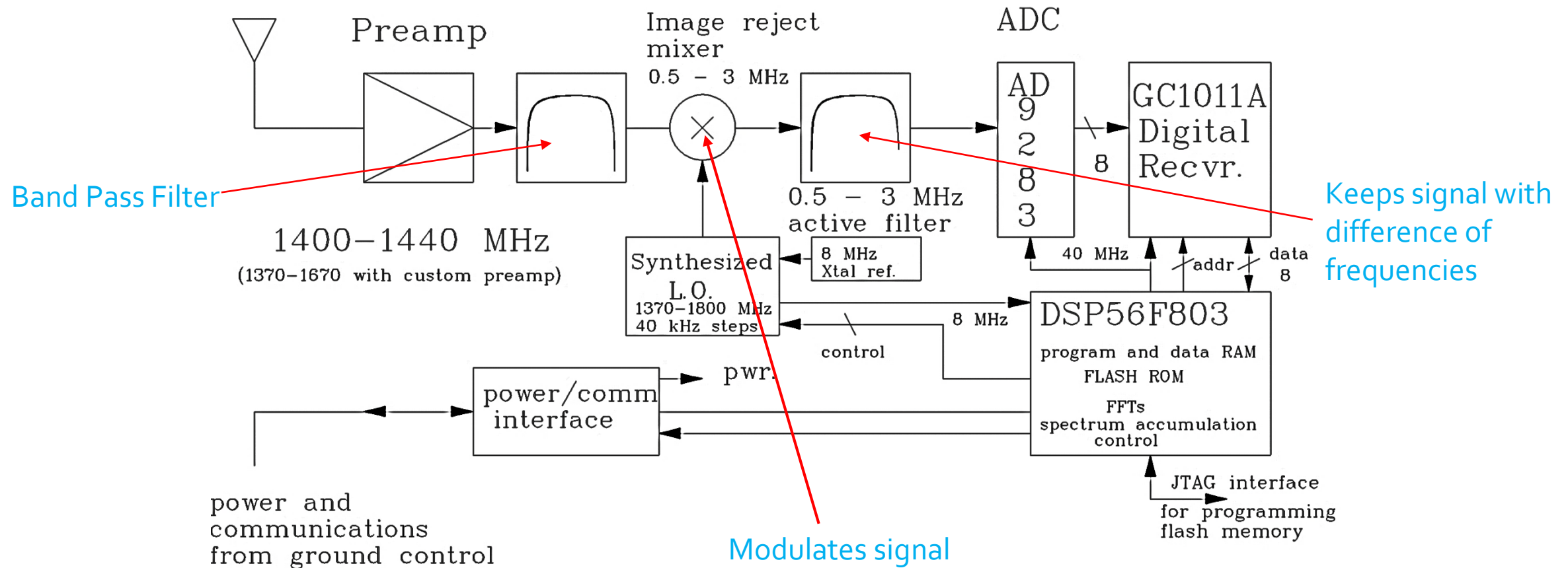


Galactic longitudes

Azimuthal axis

Elevation axis

# Appendix C: SRT Signal Chain



Digital Receiver for SRT

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# Appendix D: Functional Form for Fitting

$$f(x) = a_1 e^{\frac{-(x-\mu_1)^2}{2\sigma_1^2}} + a_2 e^{\frac{-(x-\mu_2)^2}{2\sigma_2^2}} + a_3 e^{\frac{-(x-\mu_3)^2}{2\sigma_3^2}} + a_4 e^{\frac{-(x-\mu_4)^2}{2\sigma_4^2}} + b$$