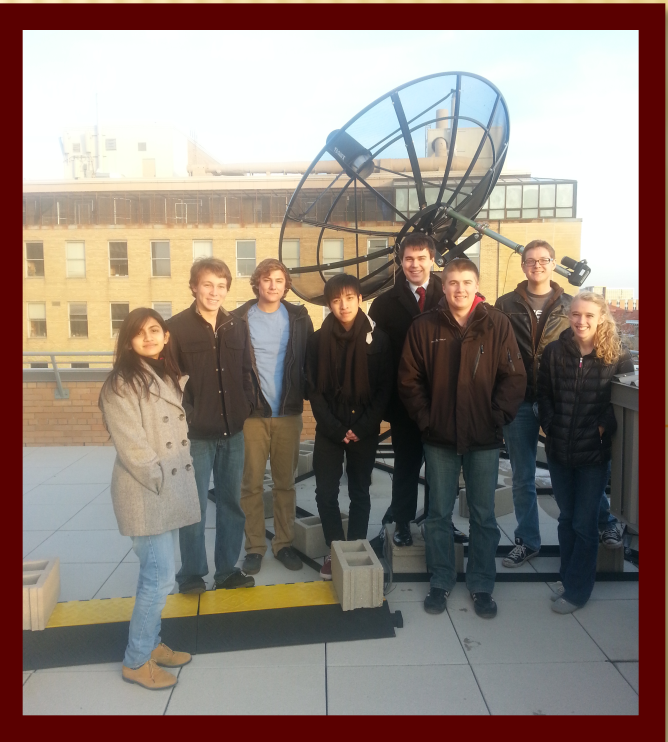
# SMALL RADIO TELESCOPE PROBES DARK MATTER


Adam Birenbaum, Ryan Bossler, Tenzin Choedak, Felipe Gutierrez, Daniel Hesse, Briana Indahl, Nathan Oster, Jessie Otradovec, Pooja Rawat, Snezana Stanimirovic, Claire Murray.

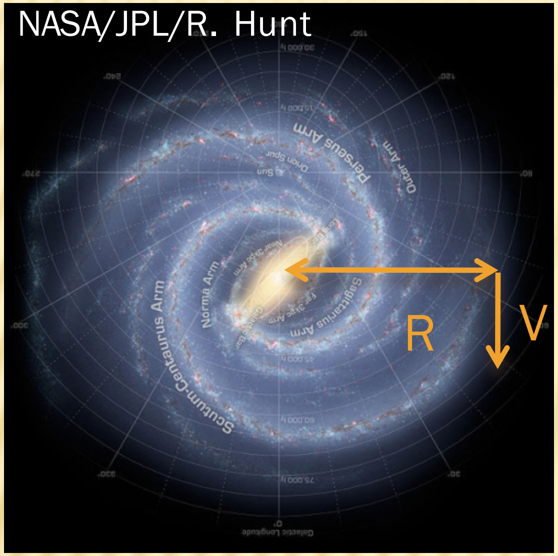
Affiliation: University of Wisconsin-Madison Astronomy Department

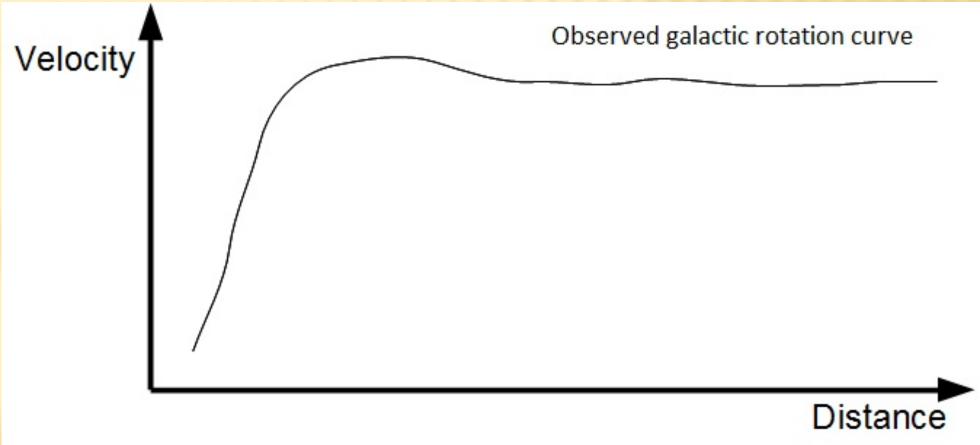

THE UNIVERSITY of WISCONSIN MADISON



# GALACTIC ROTATION CURVE

- <u>Definition</u>: Orbital speed of stars and gas clouds as a function of distance from the galactic center




- Importance:

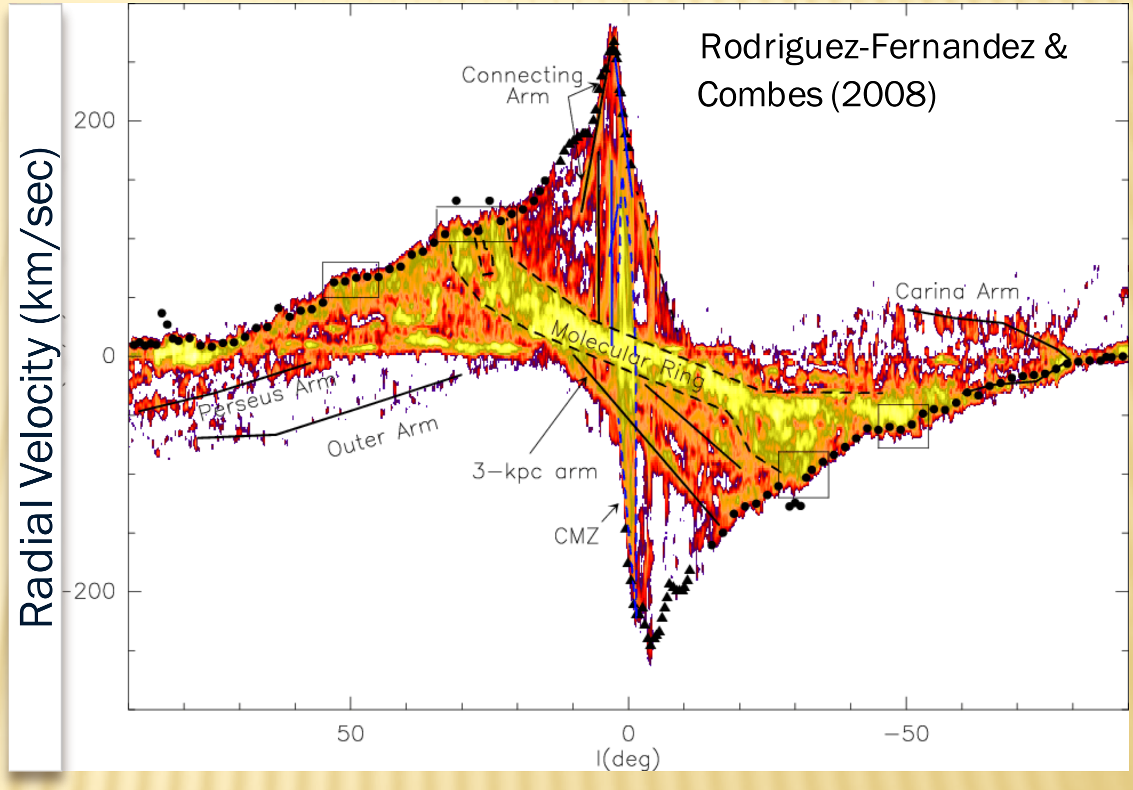
1. Provides estimate of the total mass in the Milky Way (G is the gravitational constant)

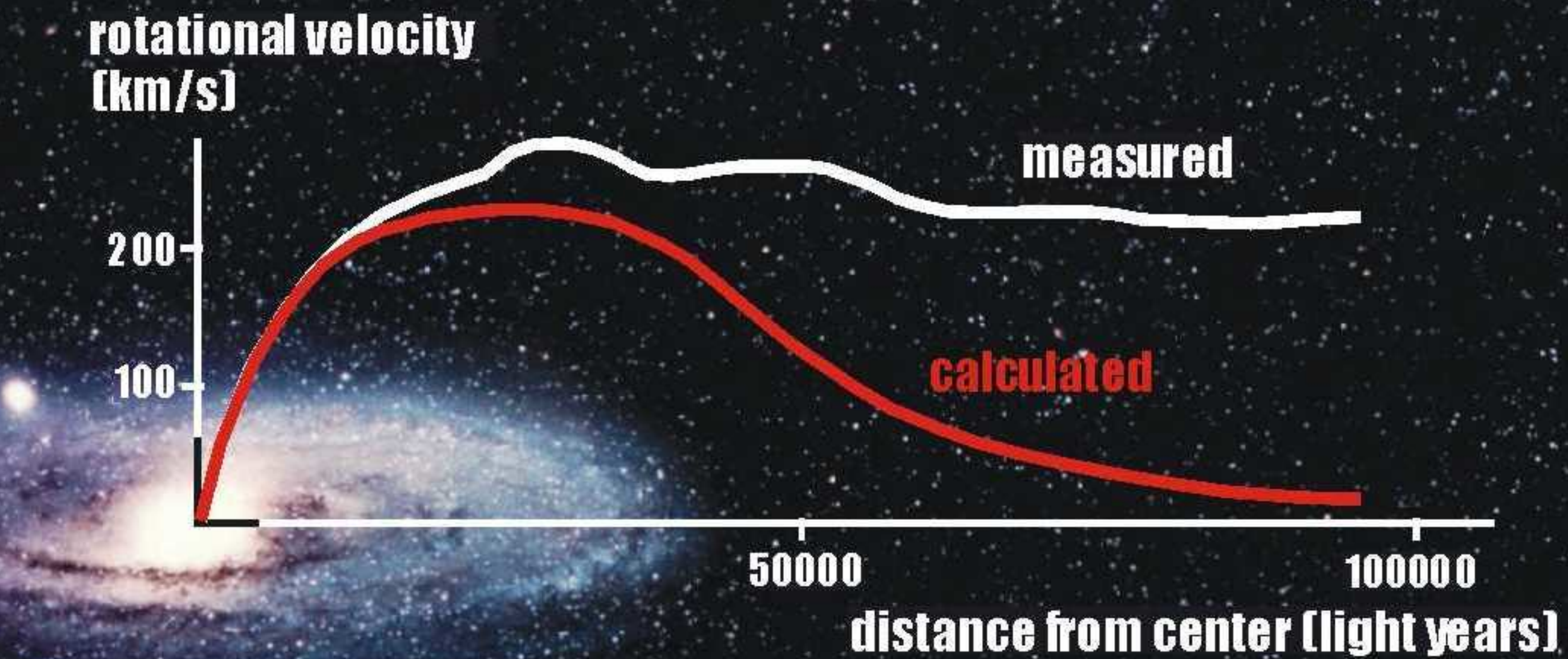
$$M(< R) = \frac{RV^2}{G}$$

# SCIENTIFIC MOTIVATION

2. Tells us how fast clouds/stars in the Milky Way move toward/away from us (radial velocity component).

3. Allows us to measure dark matter profile.

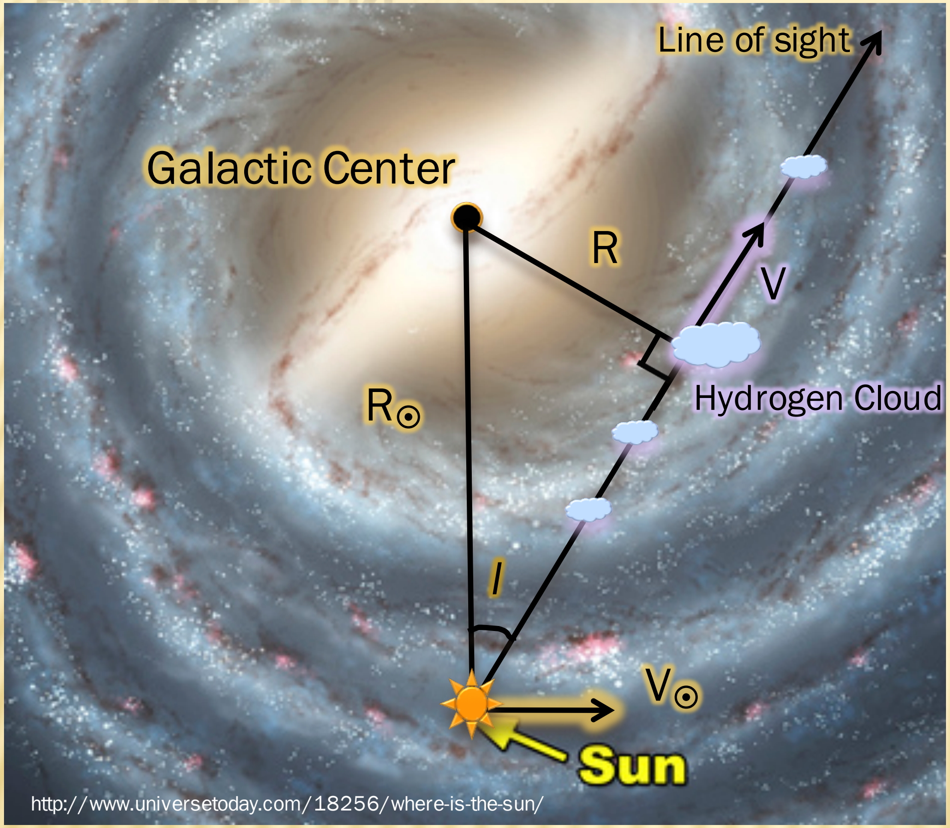





- The predicted orbital velocity due to visible mass different from observed velocity.
- There must be additional (DARK) matter

http://www.universetoday.com/wp-content/uploads/2011/12/Rotationcurve_3.jpg

# METHOD: HOW WE MEASURE MILKY WAY'S ROTATION




*l* = Galactic longitude
V = Orbital velocity of cloud
R = Distance from galactic center to cloud
$V_\odot$ = Orbital velocity of the sun (220 km/s)
$R_\odot$ = Distance from the sun to the Galactic Center (8.5 kpc)

- Assume that hydrogen clouds move on circular orbits around the Galactic center.
- $V_r = R_\odot \sin(l)(V/R - V_\odot/R_\odot)$
- Measure radial velocities of HI clouds at a known distance from the GC to estimate orbital velocities.
- Objects of known GC radius found only in the inner Galaxy. ($0° < l < 90°$, $270° < l < 360°$)
- Applied the Tangent Point Method for $20° < l < 75°$.
- For clouds at tangent points:
  $R = R_\odot \sin(l)$
  $V = V_r + V_\odot \sin(l)$

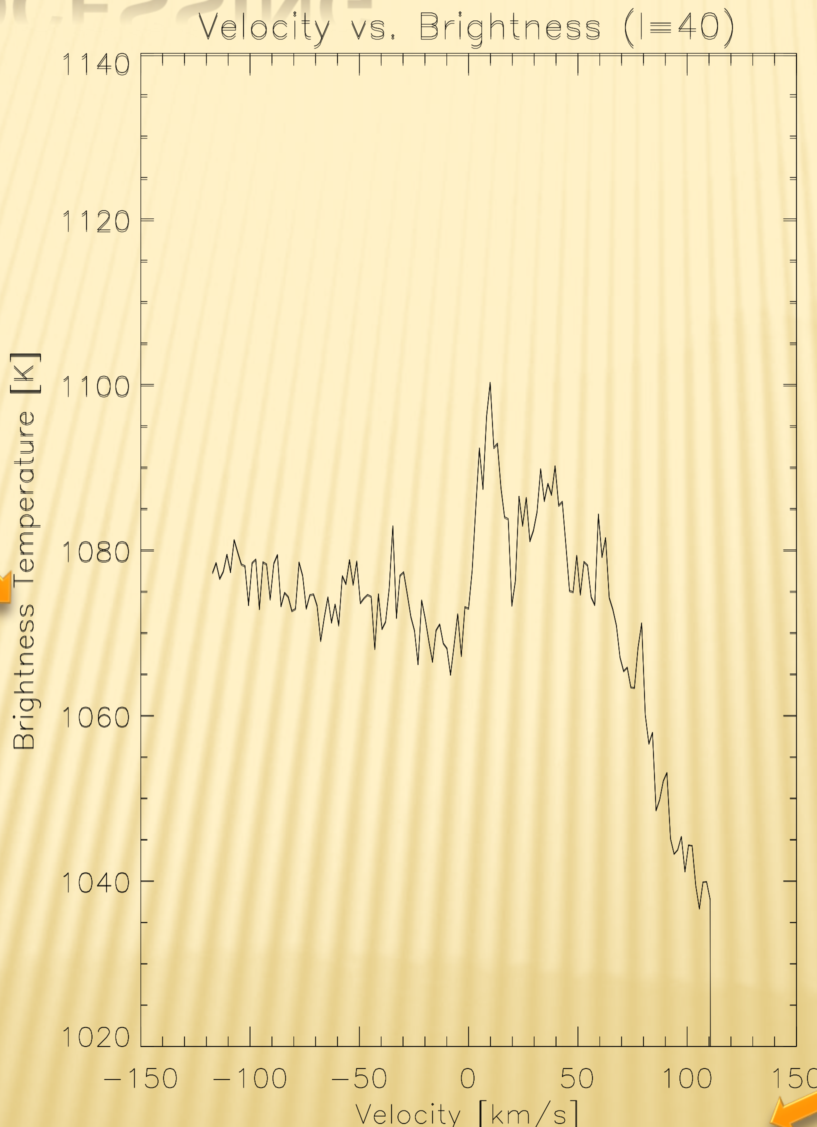
# THE TELESCOPE


SRT (Small Radio Telescope)

- Located on the roof of Sterling Hall
- 2.3 meter aperture
- Developed by the Haystack Observatory/MIT
- Operational since early 2013
- Detect emission lines from atomic hydrogen at a frequency of 1420.405 MHz.
- Integration time ~20 sec per position

# DATA PROCESSING

Multiply the Artificial Intensity Units by 0.1 to convert to Brightness Temperature

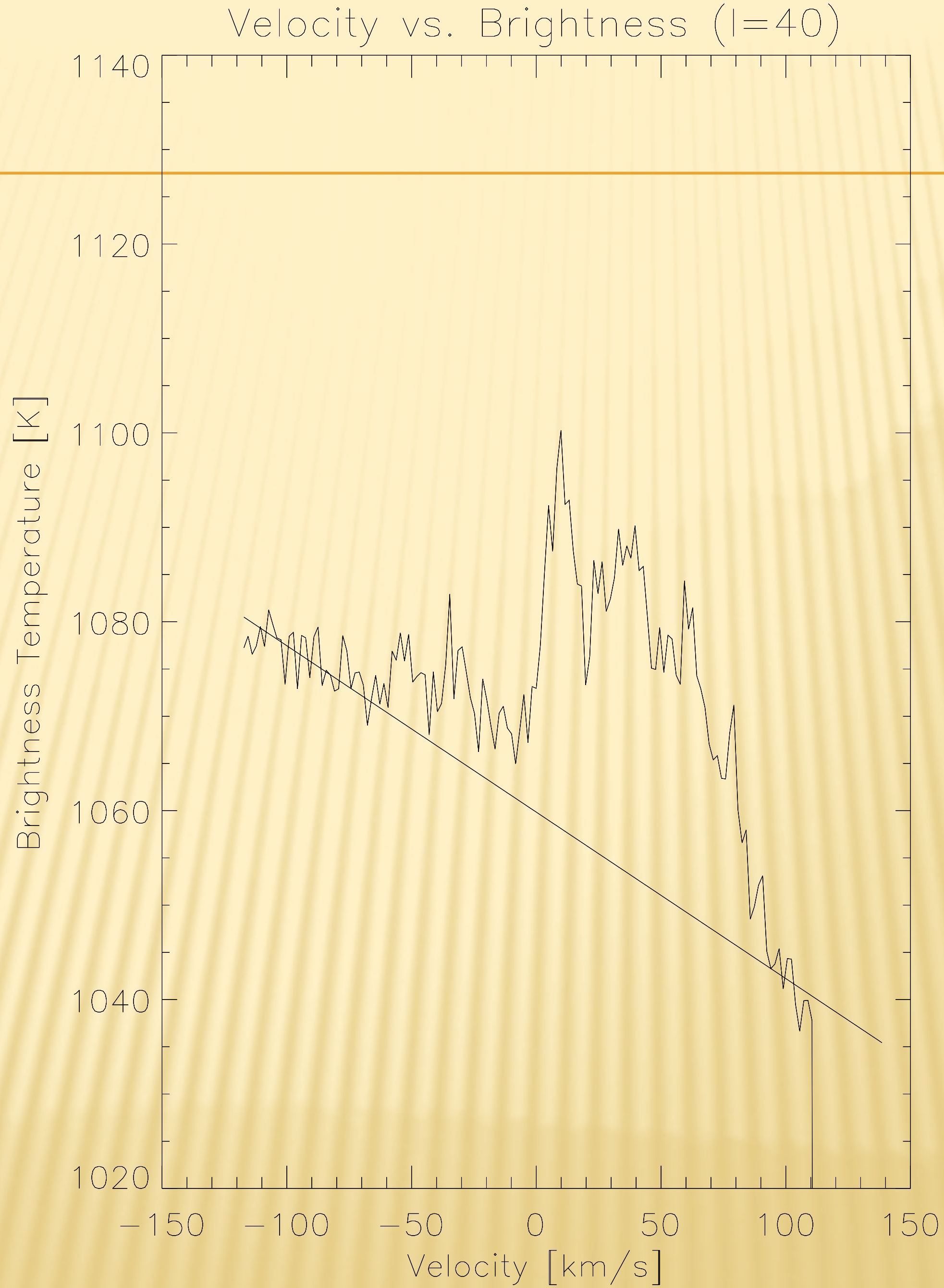


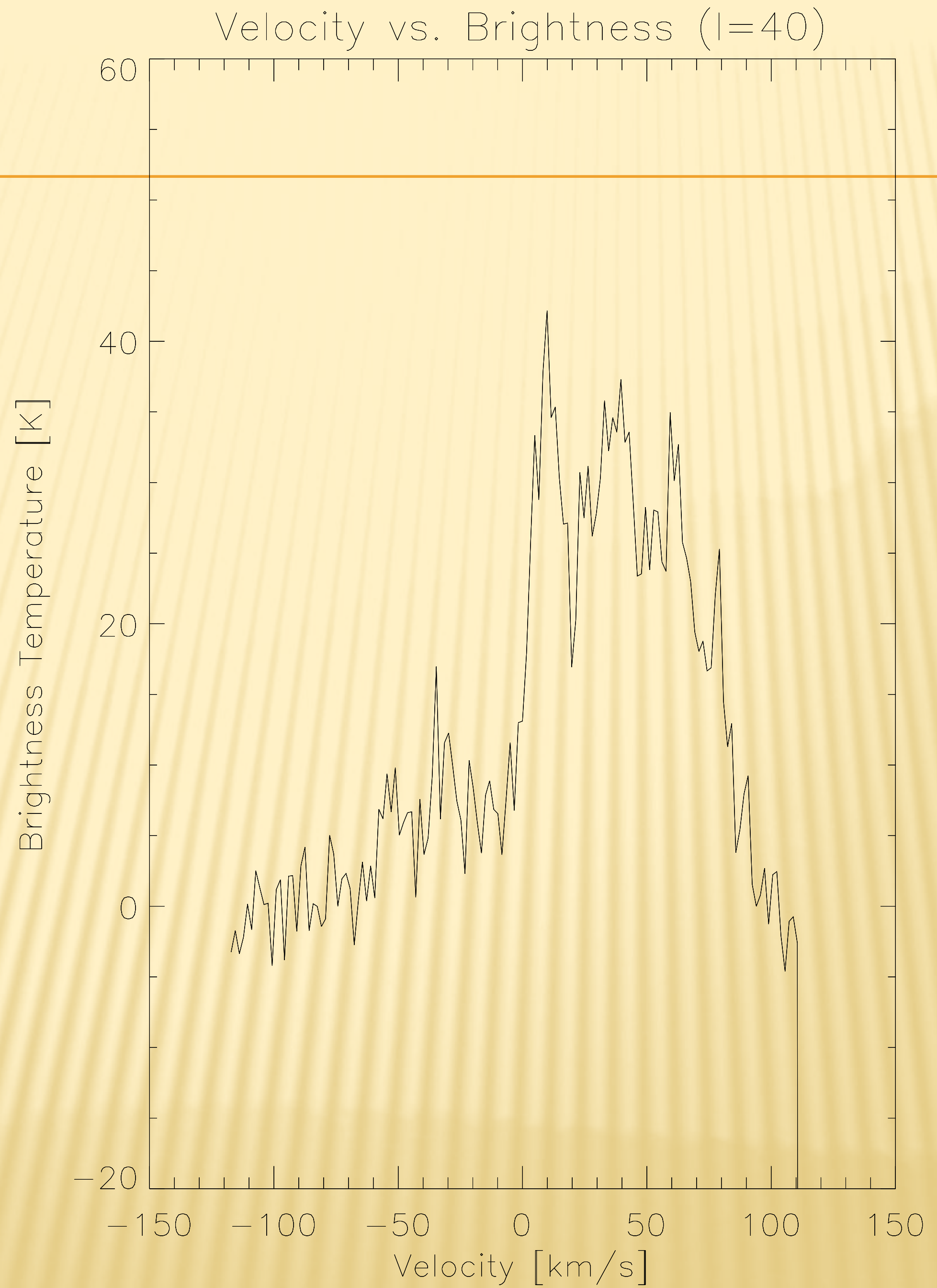

The first step is to average all the spectra at a certain point

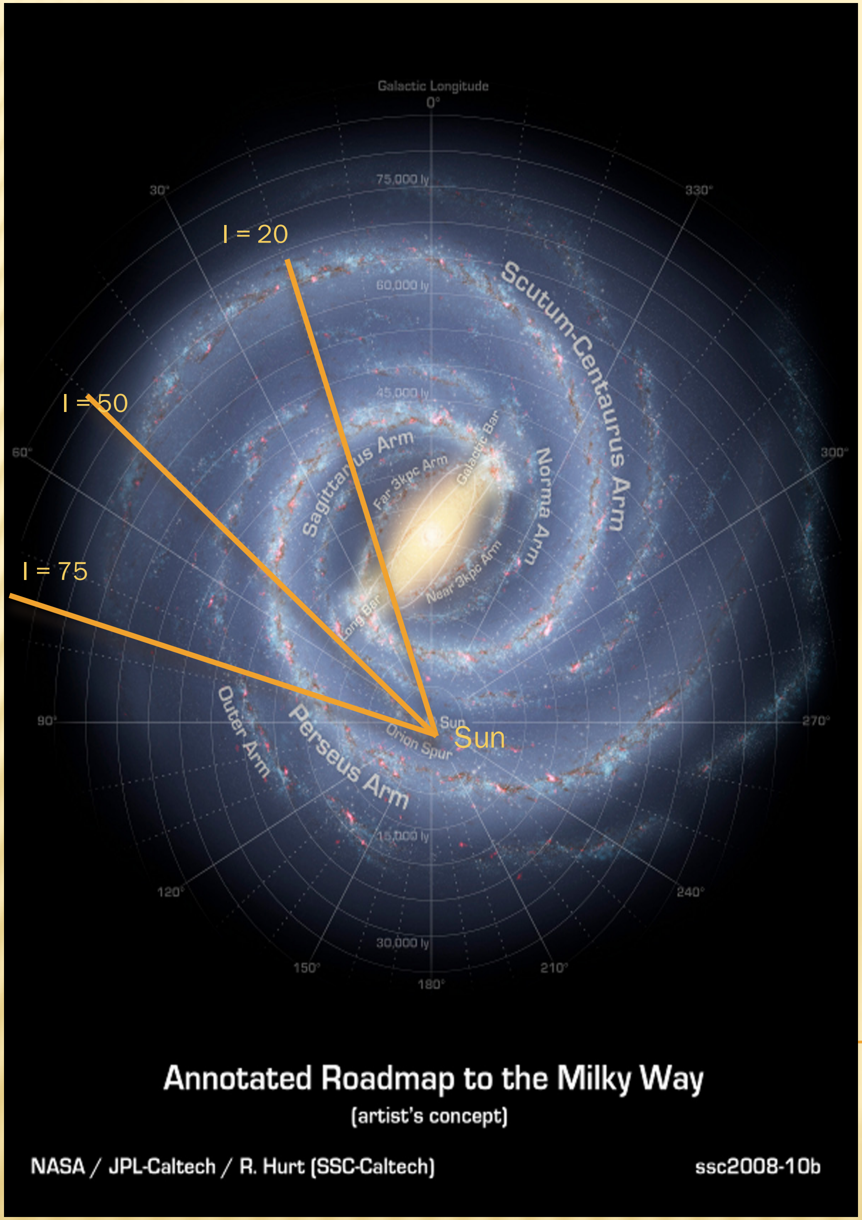
We used the Doppler Equation to convert from frequency to radial velocity

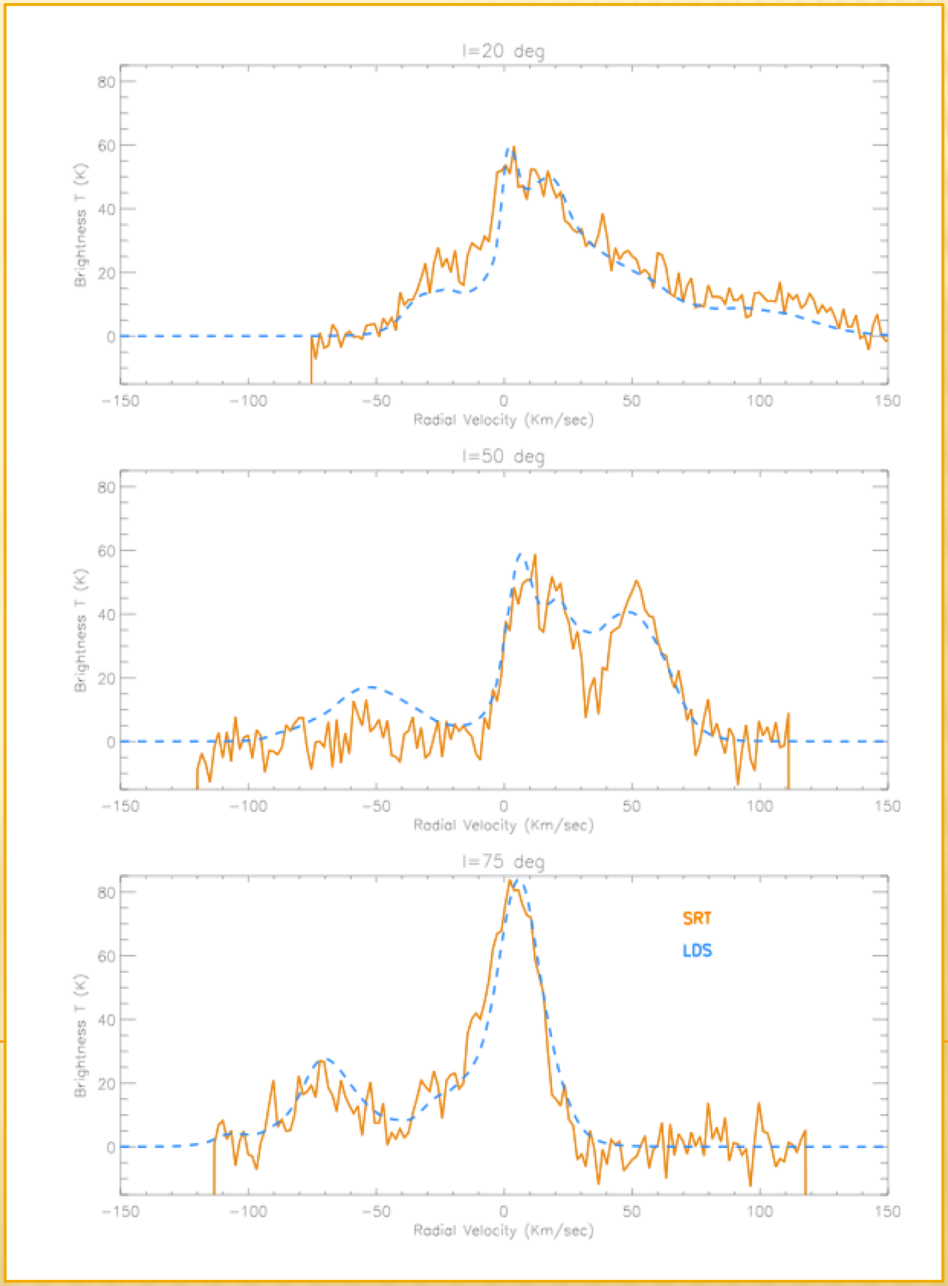
$$f = \left(\frac{c + v_r}{c + v_s}\right) f_0$$

The next step is to perform a linear fit to the data to remove the background (sky + electronics) contribution.




Velocity vs. Brightness (l=40)
Brightness Temperature [K]
60
40
20
0
−20
−150
−100
−50
0
50
100
150
Velocity [km/s]



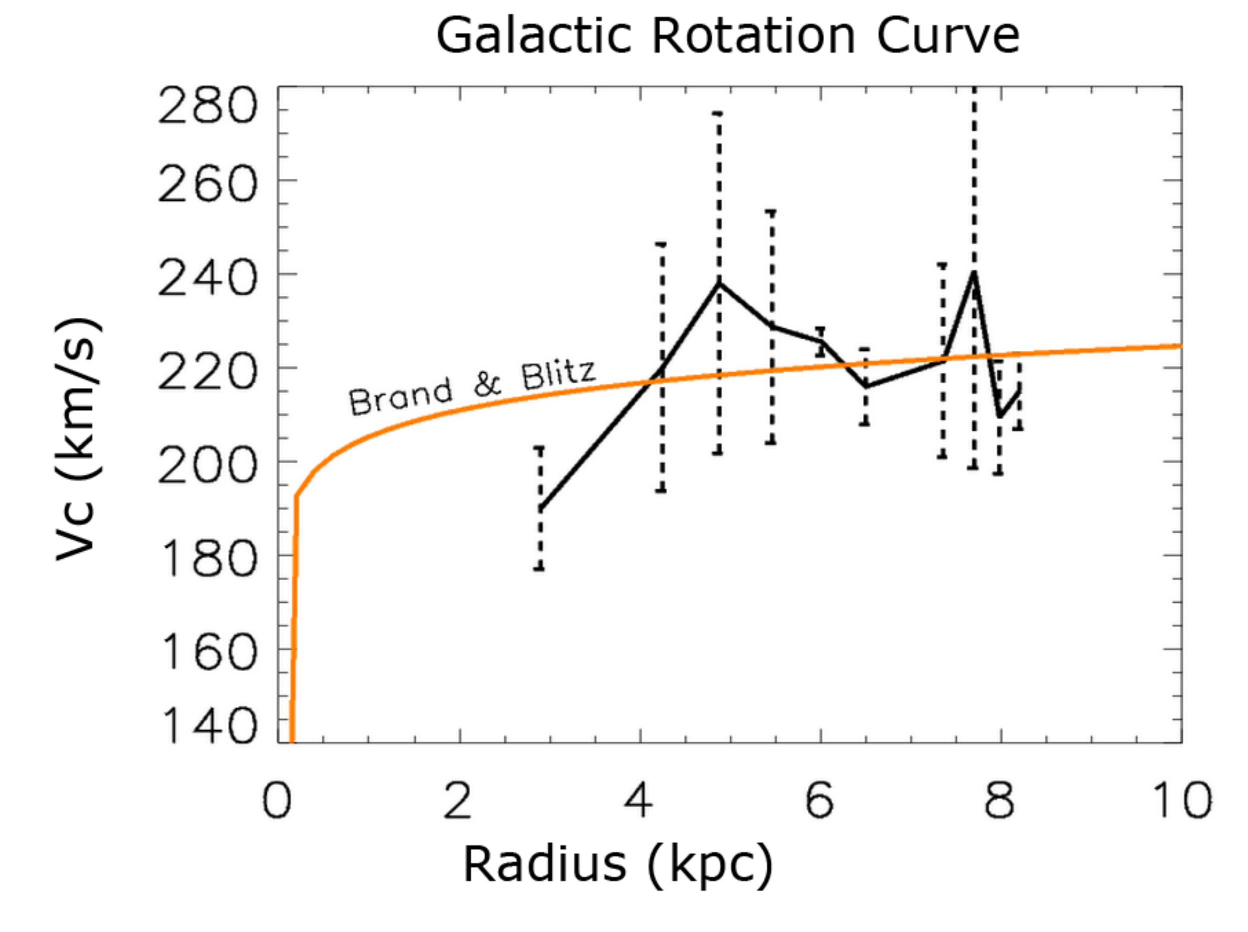




LDS = Leiden-Dwingeloo survey

SRT = Small Radio Telescope

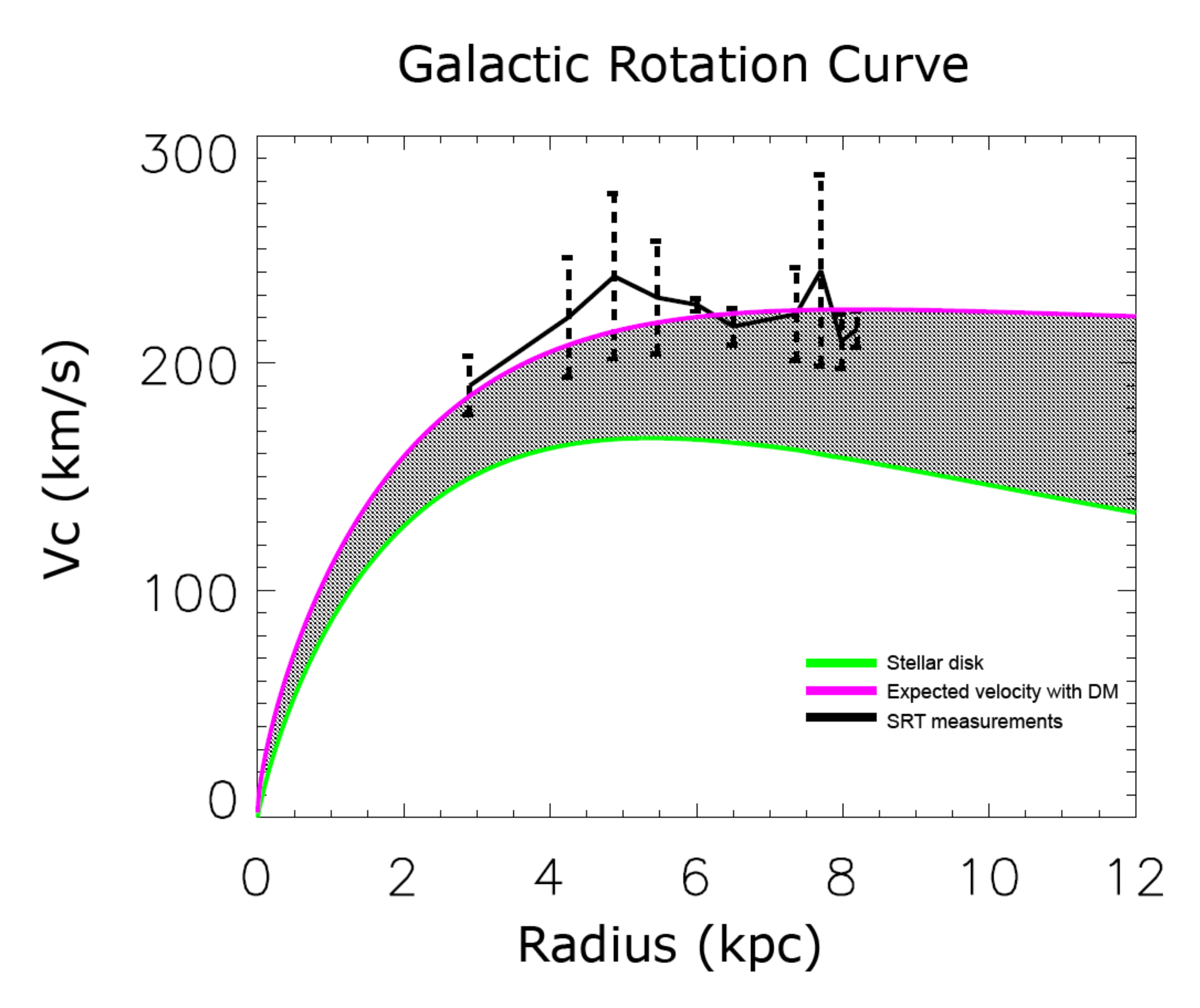
# RESULTS

- Our results show good agreement with Brand & Blitz (1993)'s best fit of their observations.
- We have large error bars, but we see no indication of a drop in velocity at higher radii.
- In fact, We observe a relatively constant rotation curve



# RESULTS CONT.

- We compare our results with D'Onghia et al. (2012) theoretical model for an exponential stellar disk with $4x10^{10}$ M$_\odot$.
- We observe that the stellar disk does not contribute enough to the rotation curve.
- The extra contribution must be from the dark matter halo, mass ~$10^{12}$ M$_\odot$.



# CONCLUSIONS: WHAT TO TAKE AWAY

- Calculated rotation curve:
  - Relatively constant at 200-220 km/sec
  - Agrees with other published results
  - Suggests presence of a large amount of dark matter in the outskirts of the Milky Way
  - Estimated total mass of the Milky Way within 8 kpc is roughly $10^{11}\ M_{\odot}$ or $2 \times 10^{41}$ kg

# LOOKING TOWARD THE FUTURE

- Redo the experiment by increasing observing time. This would better define the hydrogen peaks in the spectra and allow more precise measurements.

- Reduction of background radio interference. A second SRT has been installed at Pine Bluff, a rural setting 15 miles west of Madison where the interference is much lower than on campus. Error bars on data points will be significantly reduced.

# EXTRAS

# CONCLUSIONS

We have measured the speed at which stars and interstellar gas orbit the Galactic Center of the Milky Way at different radii, the so-called "Galactic Rotation Curve," by using the 2.3 diameter Small Radio Telescope (SRT) located on the roof of Sterling Hall. Knowing this curve allowed us to estimate the total mass of the Milky Way, calculate kinematic distances to objects within the Milky Way, and search for the existence of dark matter. In addition, this study provided us with practical experience in obtaining and analyzing data from radio telescopes. For ten different directions in the plane of the Milky Way, we measured the amount of neutral hydrogen (HI) emission as a function of radial velocity corresponding to the point closest to the Galactic Center, known as a Tangent Point. Using a simple geometrical method, we then estimated the orbital velocity and distance from the Galactic Center for each of these tangent points. Our results show a relatively constant rotation curve of roughly 200-220 km/s across our measured radii, 2.9 to 8.2 kpc. This is similar to other published results obtained with much larger and better calibrated telescopes. Our results suggest that Sterling SRT produces generally reliable Galactic HI spectra. Additionally, our rotation curve implies the total mass of the Milky Way of ~10^11 M_sun enclosed within a radius of 8 kpc.

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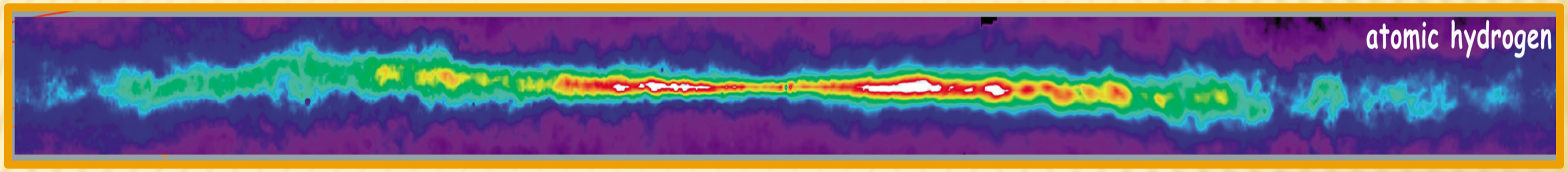



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# MEASURING THE GALACTIC ROTATION CURVE

Read telescope data files into a 2D array of HI spectra. Average all spectra to obtain a higher signal-to-noise HI spectrum.

Conversion of artificial telescope units to Brightness Temperature by mulltiplying by 0.1.

Using the Doppler Equation (2) to convert Frequency to Radial Velocity.

$$V = c\frac{(\Delta\nu)}{\nu}$$

In order to remove the background noise from the spectrum we fitted a polynomial in the regions without any HI emission and removed this model from the spectrum.

# THE GALACTIC ROTATION CURVE

- The Galactic rotation curve tells us how fast stars and gas clouds are orbiting the Galactic Center as a function of distance to the center.
- So the galactic rotation curve gives us a good idea of what is the radial velocity in different regions in the Milky Way Galaxy.
- Brand&Blitz rotation curve (without oplot of our curve?

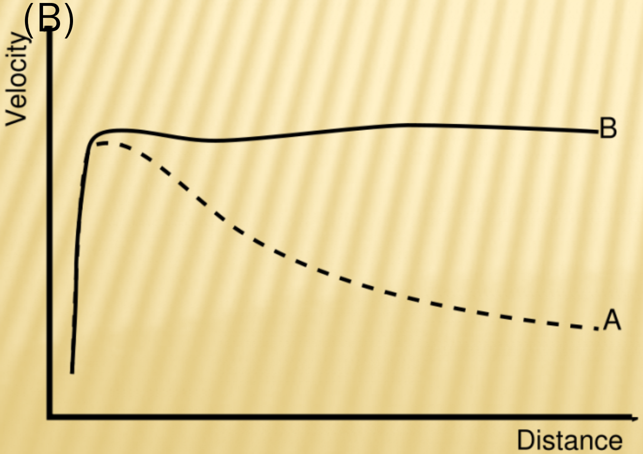
# MOTIVATION

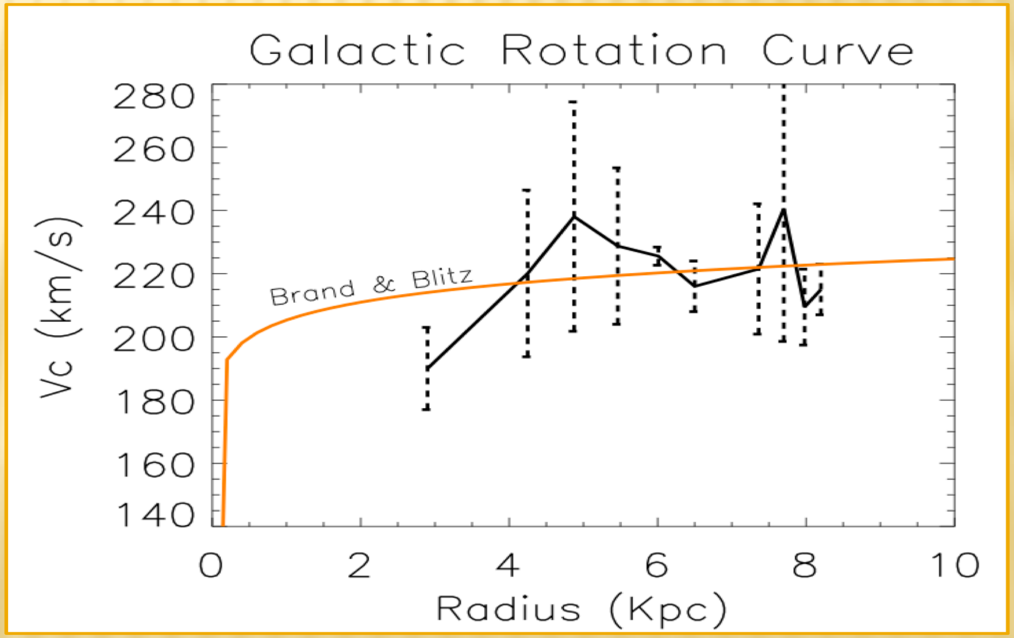
- Knowing the galactic rotation curve V(R) we can plot the radial velocity as a function of galactic longitude *l* (l – $V_r$ diagrams).
- Another important measurement that can be derived from the Galactic Rotation Curve is the distribution of mass along the galaxy. Which according to Newton, this mass distribution should decrease by the square of the distance from the center of the galaxy. (Mention Dark Matter?).
- Along with that, we learned how to collect and analyze data from a 2.3m radio telescope.

# SCIENTIFIC GOALS (SKIP)

- Radial velocity of the clouds helps us find the orbital velocity
- Mass distribution derived from orbital velocity
- Compare new telescope data to existing accepted values

Theoretical values (A) vs. Observed (B)



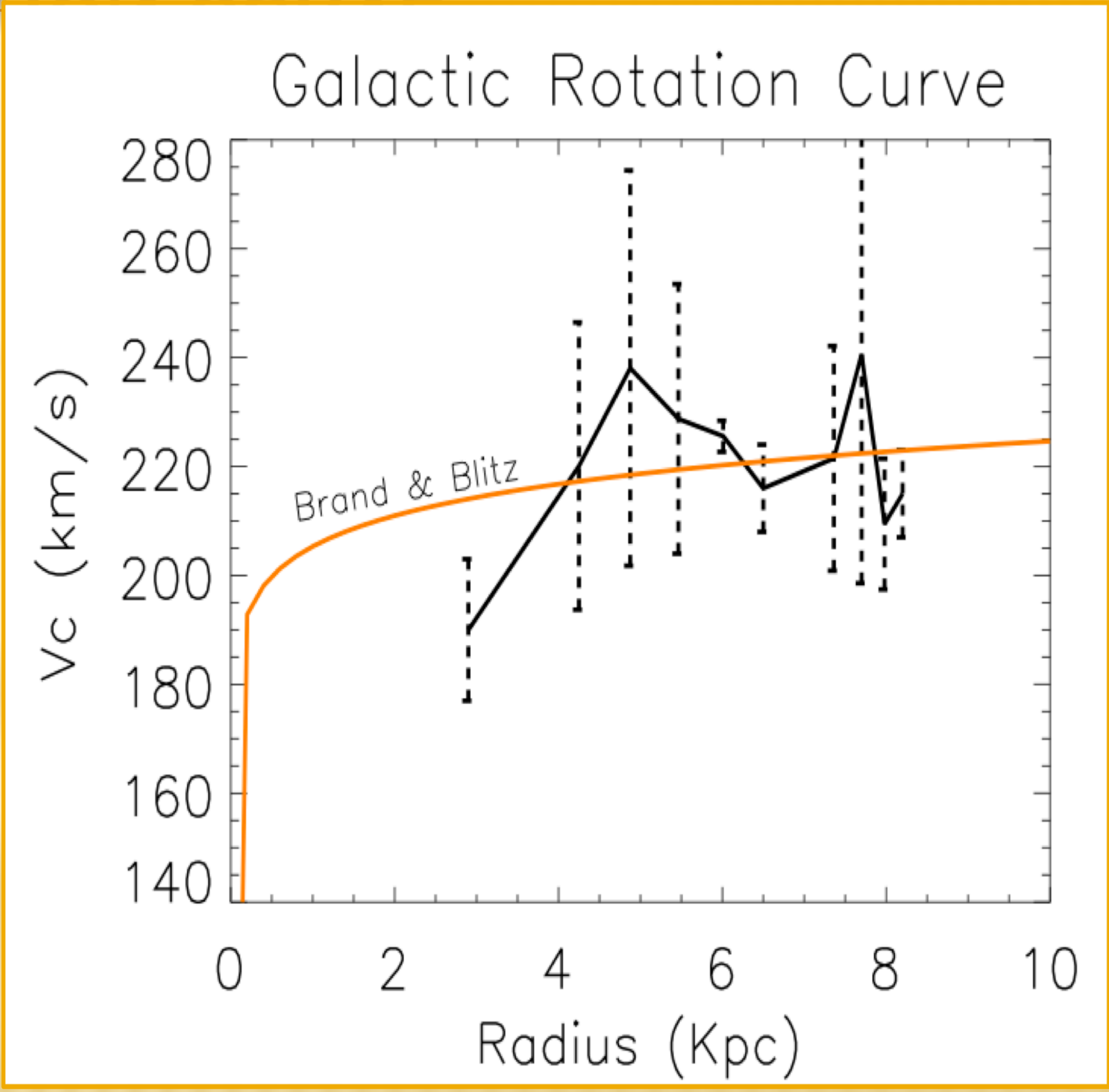




https://www.e-education.psu.edu/astro801/files/astro801/image/Lesson%208/800px-GalacticRotation2_svg.png

# RESULTS: ROTATION CURVE

The graph on the right compares our findings - marked in black and with error bars - with the rotation curve found by Brand and Blitz (1993) marked in orange.

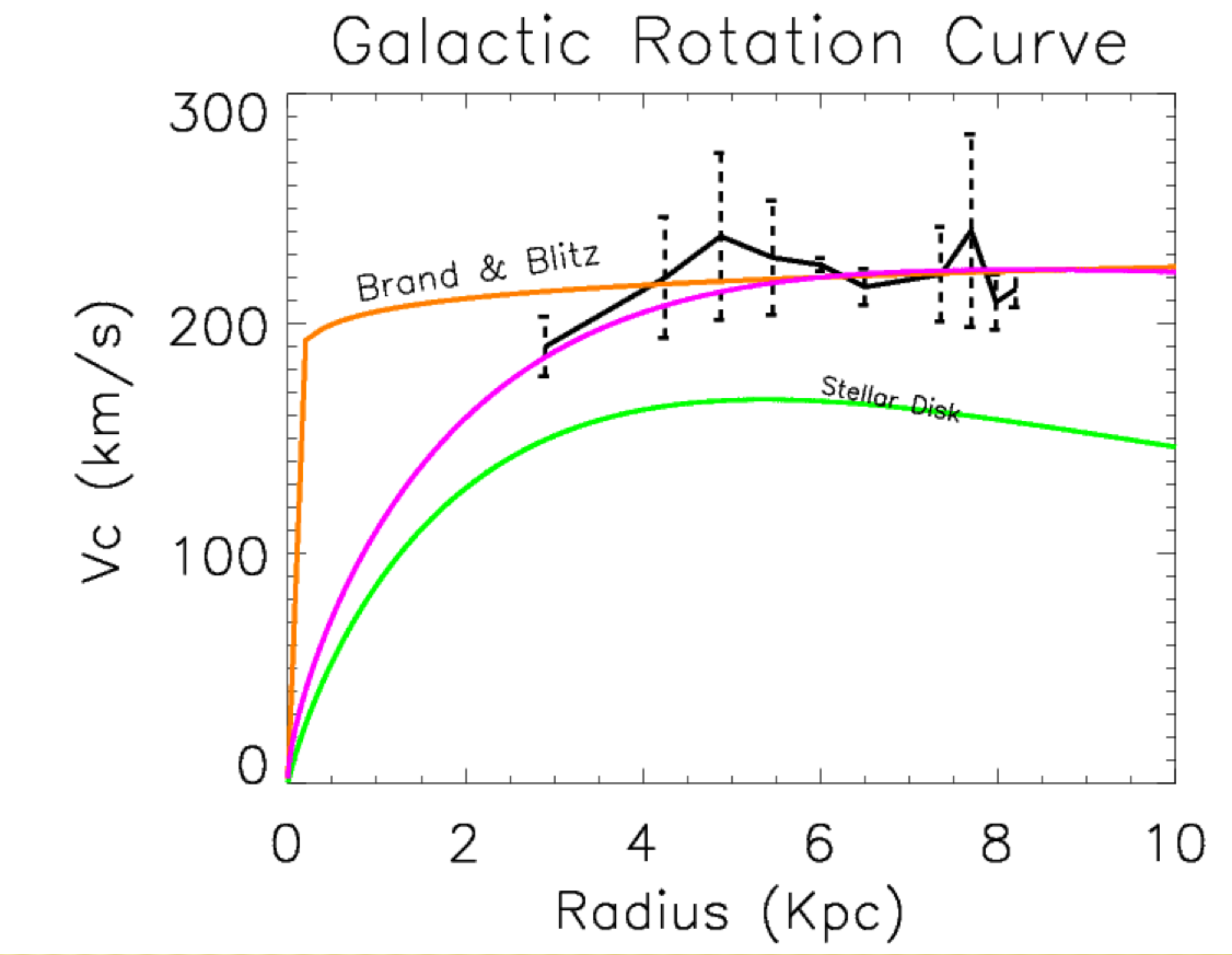
Overall, our graph shows that our findings hover between 200-240 km/s over increasing radii, depicting a generally constant rotation curve for the Milky Way galaxy. These values match well with published data and widespread astronomical consensus. This shows that the Sterling SRT can produce accurate data when compared with much larger, better-calibrated telescopes.



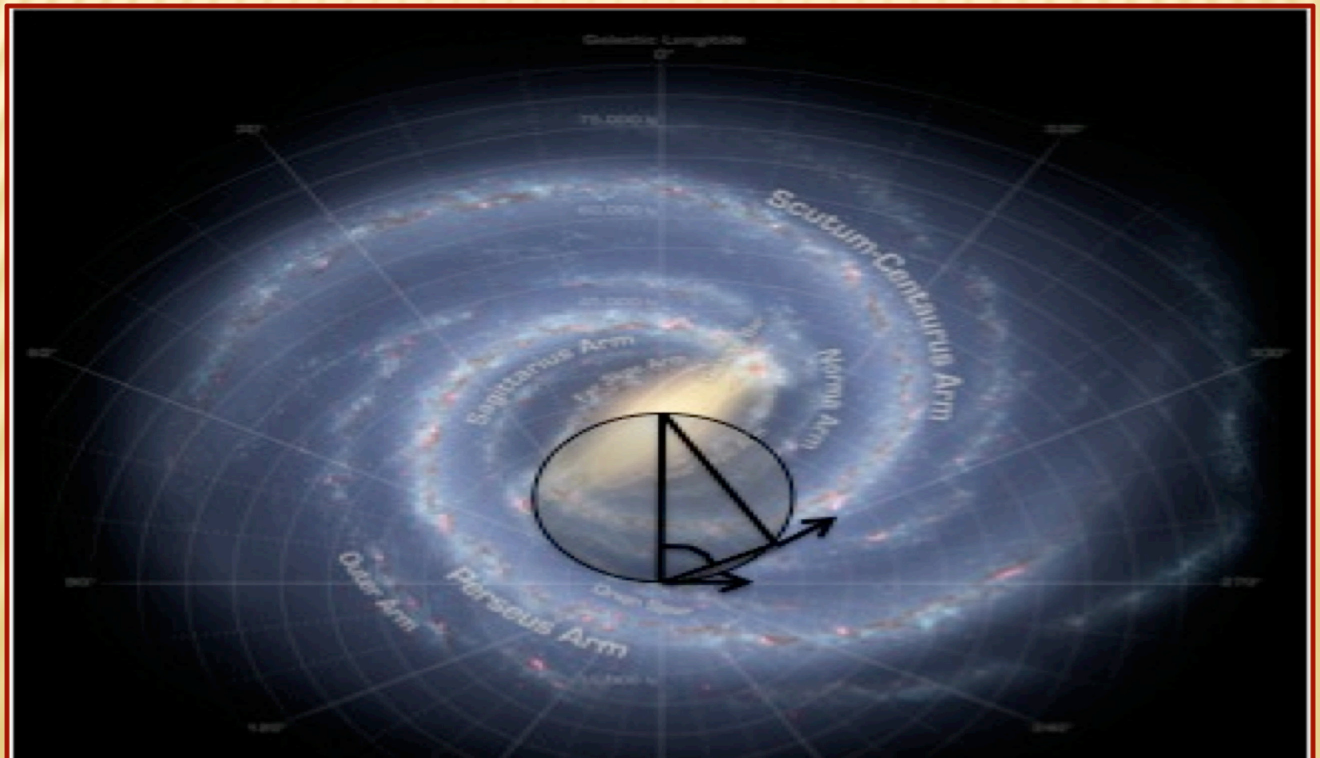
# RESULTS: DARK MATTER PROFILE AND MASS

Based on this we measure galactic mass of ~10^11 s masses within 8.2 kpc. Cor to dark matter.

Future work with the Sterling will utilize longer integr times and wider bandwidth order to produce more reli spectra



# METHOD (NATE): HOW DO WE MEASURE MILKY WAY'S ROTATION



# ASSUMPTIONS

- When expressing the radial velocity of stars and neutral hydrogen clouds we assumed they move in circular orbits around the Galactic Center, so we could easily write it as :

$$V_r = R_\theta \sin(l)(V/R - V_\theta/R_\theta)$$

l = galactic longitude, V = orbital velocity of star/cloud

R = Distance from galactic center to star/cloud

$V_\theta$ = orbital velocity of the sun

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# THE TELES

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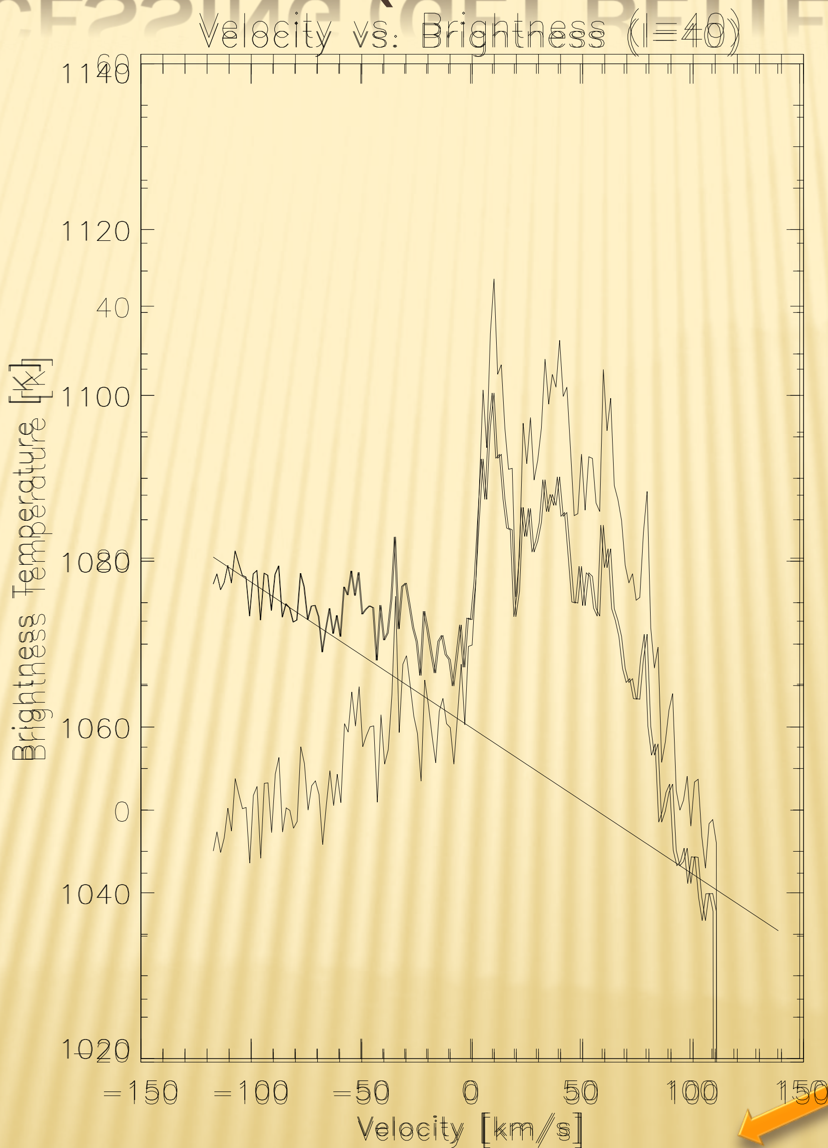
# DATA PROCESSING (GET BETTER FIGURES)

Multiply the Intrinsic Intensity Units by 0.1 to get Brightness Temperature

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