The Small Radio Telescope that Could: the Milky Way Radial Velocity Diagram at 21cm

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Abstract: Using the 21-cm atomic hydrogen line from interstellar gas, we measure emission intensity across various lines of sight over the Milky Way disk with the 2.3-meter Small Radio Telescope (SRT). Our goal is to produce the l - V diagram which shows the overall rotation pattern of the Milky Way, as well as its large scale spiral-arm structures. We measured hydrogen spectra every three degrees along the Milky Way plane. For each spectrum, the observed frequency was converted to radial velocity using the Doppler equation. We used the calibration diode to estimate the spectral filter shape. We find that our observations are in agreement with previous l-Vr works using larger, more robust observing systems. This shows that the SRT system produces reliable and consistent observations.

Motivation: The journey to unravel the history of the Milky Way's evolution has inspired many astronomers to learn more about our galaxy's spiral structure. Most of the Milky Way's gas is located in a disk which rotates around the Galactic center. Galactic rotation provides an imprint on radial velocity (V_r) of stars and gas clouds. For a simple circular rotation of clouds around the Galactic center we expect:

$$V_r = R_\odot sin\{l * (\frac{V}{R} - \frac{V_\odot}{R_\odot})\}$$

Where V is cloud orbital velocity, R is its distance from the Galactic center, l is Galactic longitude (angular separation between the Sun and observed direction), and Rs and Vs are the corresponding distance and orbital velocity of the Sun. Figure 1 shows observations of the 21-cm line of atomic hydrogen along different directions in the Milky Way disk. The characteristic shape of this diagram, the l-Vr diagram, results from Milky Way's rotation. In addition, coherent large-scale features correspond to spiral arms.

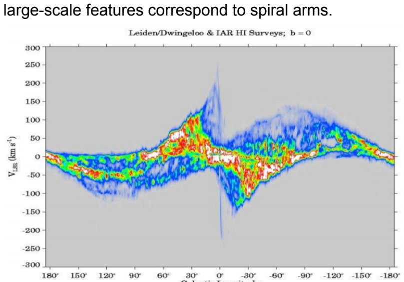

Figure 1: Neutral hydrogen along the galactic plane. This l-Vr diagram was obtained from the Leiden/Dwingeloo Survey of HI in our Galaxy[1], which has an angular resolution of 36'.

Observations:

At UW-Madison, the Astronomy 460 team has attempted to observe the influence of Milky Way's rotation on the radial velocity of interstellar clouds by using the Small Radio Telescope on top of Sterling Hall. This telescope has at least 10 times lower angular resolution then the professional telescope used to make Figure 1. We observed the 21-cm emission of neutral hydrogen as this transition is not absorbed by Earth's atmosphere.

Figure 2: The Small Radio Telescope (SRT) on the roof of Sterling Hall at UW Madison. Second SRT is located in Pine Bluff.

To conduct observations with the SRT, we wrote observing scripts. Each team member observed seven positions (from l = 0 to l=213 degrees, every 7 degrees). We integrated for 300 seconds on each position and run a noise calibration diode. Observations were centered at 1420.405 GHz, frequency of the hyperfine transition of hydrogen.

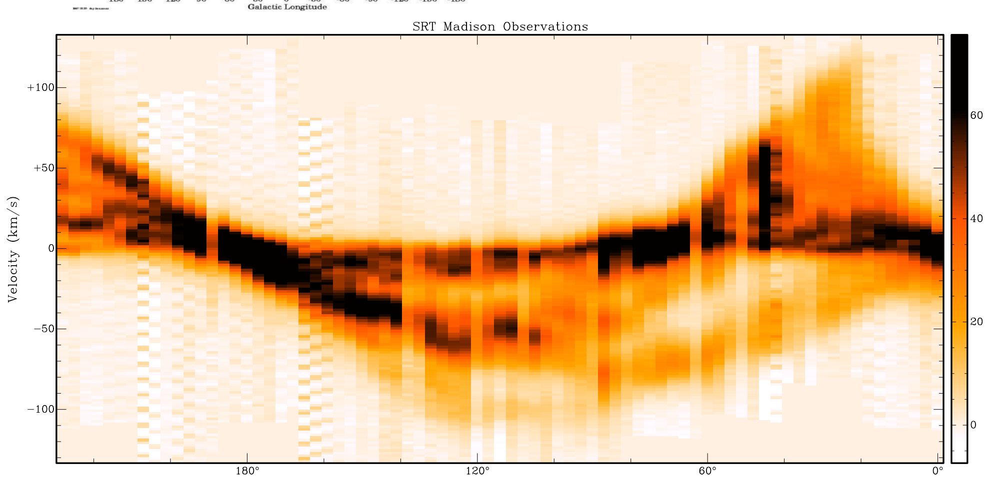

Figure 3: The l − Vr diagram, at b = 0 degrees and increment l from l = 0 to l = 231 degrees, obtained with the Small Radio Telescope.

Analysis: The SRT has a calibration dipole which is essentially an antenna that is attached to a noise diode of a known signal equal to a brightness temperature of 103 K. Since the level of the noise diode is known, the difference in signal between the two measurements must be 103 K, which is then used to convert from digital number to brightness temperature. Then, the spectra from each individual exposure were averaged together to help minimize the noise. Once averaged, the x-axis was converted from units of frequency to units of radial velocity via the Doppler equation. Also, by taking the difference between the two calibration spectra and then fitting a linear polynomial to the resulting spectra, we subtracted a filter shape function from each spectrum. Next, the data were averaged to account for any outliers that may skew results.

Results and Conclusions: Figure 3 shows the final result of our work. All spectra were aligned according to their Galactic longitude. It can be seen that hydrogen clouds past l=190 degrees is coming toward us and from 80<l<190 clouds are moving away from us. From 0<l<80 there is some HI moving towards and away from us. Our l-Vr diagram has a sinusoidal shape as expected from Equation (1) due to Milky Way's rotation.

We successfully recreated the l − Vr diagram for the portion of the galaxy visible from the SRT at Madison although our resolution is at least 10 times lower than that of Figure 1. In addition, we clearly detect the Perseus spiral arm. Overall, the project was a successful exercise in observing and data reduction, as well as studying galactic rotation. We have also demonstrated for the first time that SRT provides reliable calibration over days to weeks long observations.

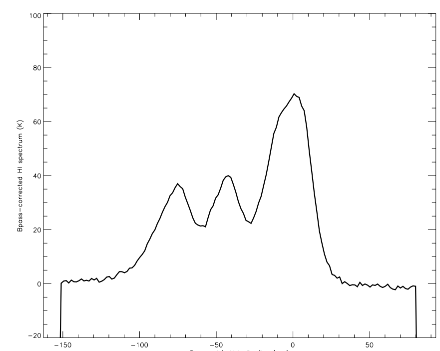

Figure 4: An example HI spectrum at l =87 degrees.

References:

[1] W. B. Burton and D.A.P. Hartmann. The Leiden/Dwingeloo survey of HI in our galaxy. ASP Conference Series, 67, 1994.

[2]Dustin Johnson and A. E. Rogers. Developing a new generation small radio telescope. AAS, 2013.