Profiling the Milky Way Structure by Plotting Neutral Hydrogen onto a Velocity-Galactic Longitude Map

Richard A. Russel

Deep Space Exploration Society

Abstract

A 9-foot dish was outfitted with a 1420MHz feed and a Spectracyber 1 system was put together. A full sky survey was conducted, and the data collected. The Doppler measurements were converted to velocity and plotted onto a Velocity-Galactic Longitude map. The results show that the data maps very well to known structures of the Milky Way Galaxy. The dv/dl method was utilized to estimate the location of the Milky Way galactic arms. The results provided good results with three of the arms.

Introduction

Mapping the HI distance in the Milky Way using the tangent method becomes inaccurate near the 0° galactic longitude. A solution to this is called the dv/dl method and is described in reference (1).

The Deep Space Exploration Society (DSES) (2) maintains a 9-foot dish setup for 1420 MHZ in Colorado Springs, Colorado. The dish is fitted with 2 low-noise amplifiers at the feed leading to a Spectracyber 1 receiver. Details of the system is documented in Radio Astronomy, Sep-Oct 2019 (3).

The distance of the HI collected by the DSES antenna near the galactic center is calculated using the dv/dl method.

dv/dl Method

The dv/dl method described in (1) provides an analytical method to derive the range of the measured H1 clouds towards the galactic center. Figure 1 shows the geometry of the HI clouds dv/dl profile depending on their distance from the galactic center and the Sun.

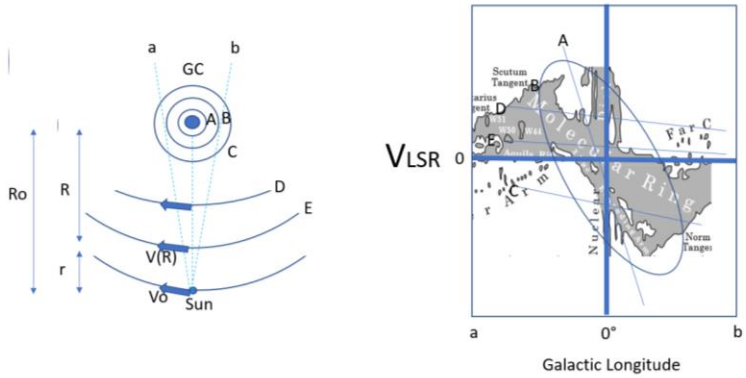

Figure 1:dv/dL Method Geometry (1)

The equation (1) that defines the range of the HI cloud to the galactic center (R) is:

$$R \cong 28\left(\frac{dv}{dl}\right)^{-1} \qquad (1)$$

The next steps are to obtain the HI velocity measurements using the DSES antenna system and then to convert the data to velocity and galactic latitude and longitude coordinates.

Obtaining Drift Scan Data

The output of the dish was hooked to a Spectracyber 1 receiver (4). An example output is shown in figure 2. The Doppler shift was measured for the highest peak. Future data reduction is planned to include all relevant Doppler shift peaks.

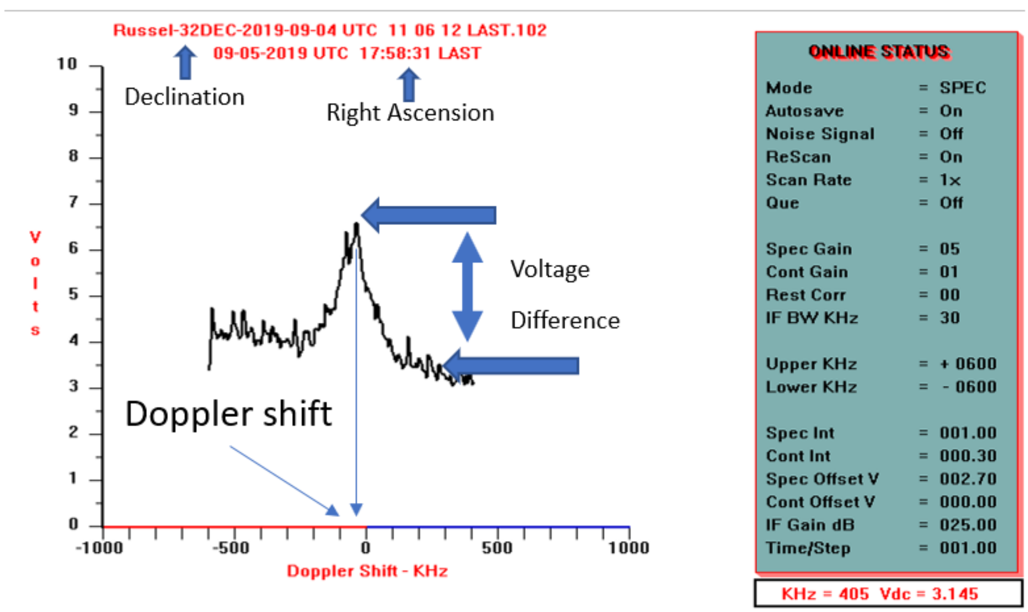

Figure 2: Measuring Peak Hydrogen above Background Noise

The peak signal strength was plotted on a right ascension-declination plot. This was detailed in reference (3). (figure 3). This figure showed good sensitivity to detect the Milk Way H1 signal.

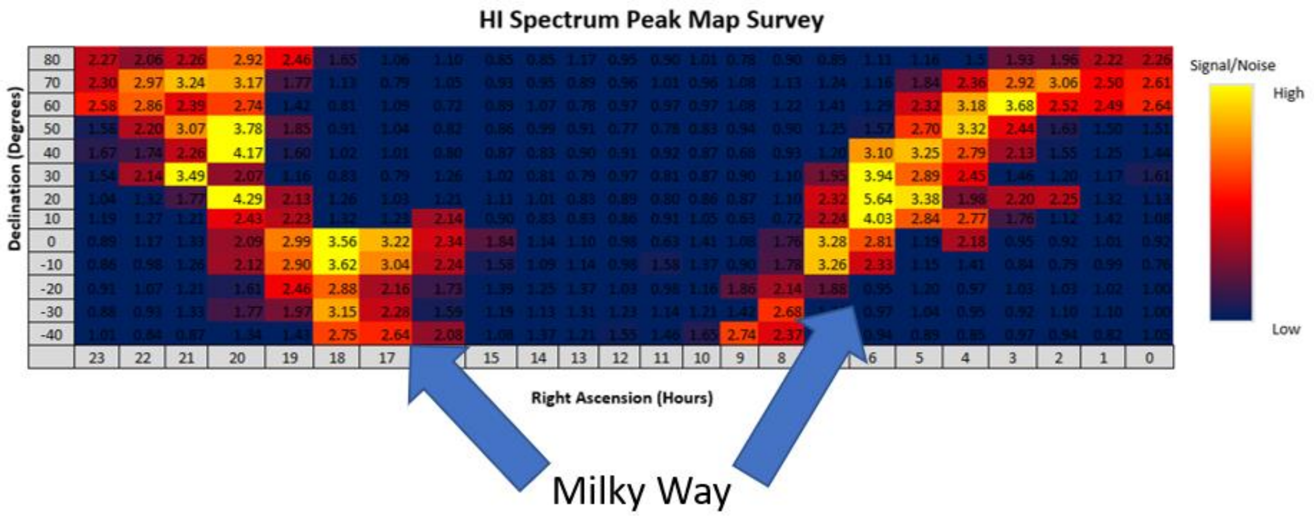

Figure 3: HI Spectrum All Sky Survey

The next step was to convert the celestial coordinates to galactic latitude and longitude coordinates. This was done by using SIMBAD (5) website and to convert Right Ascension and Declination to Galactic Latitude and Longitude. The data was documented and plotted using Microsoft Excel (figure 4).

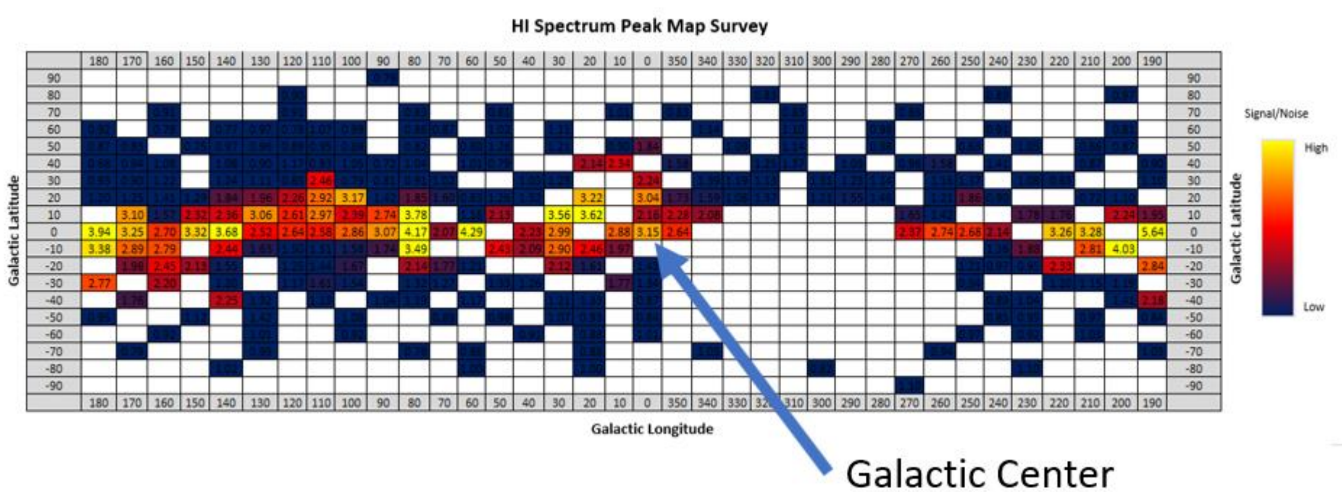

Figure 4: Sky Survey Converted to Galactic Latitude and Longitude Coordinates

Velocity-Galactic Longitude Map

A velocity-galactic longitude map was developed by the Harvard -Smithsonian Center for Astrophysics (6). This plot mapped the emission of carbon dioxide in molecular clouds. (7) The vertical axis is the velocity measurements and the horizontal axis is the galactic longitude. (figure 5)

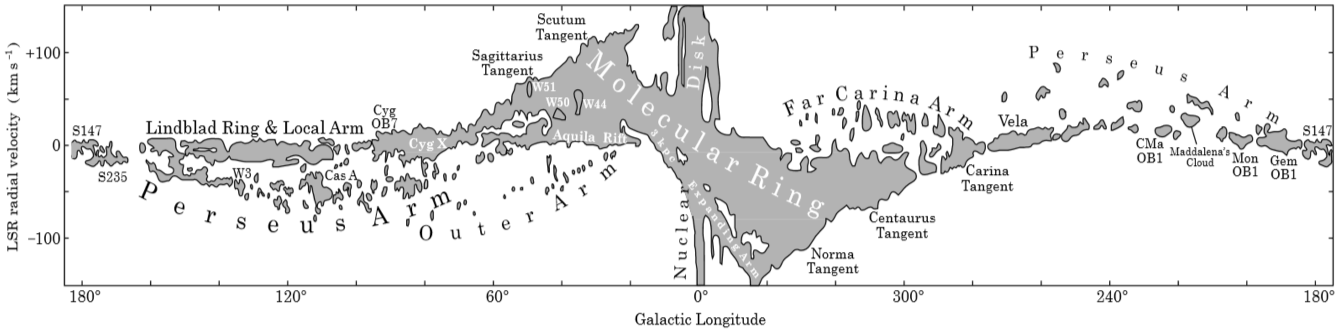

Figure 5: Velocity - Galactic Longitude map (7)

Another map was found that used H1 measurements (figure 6). (8)

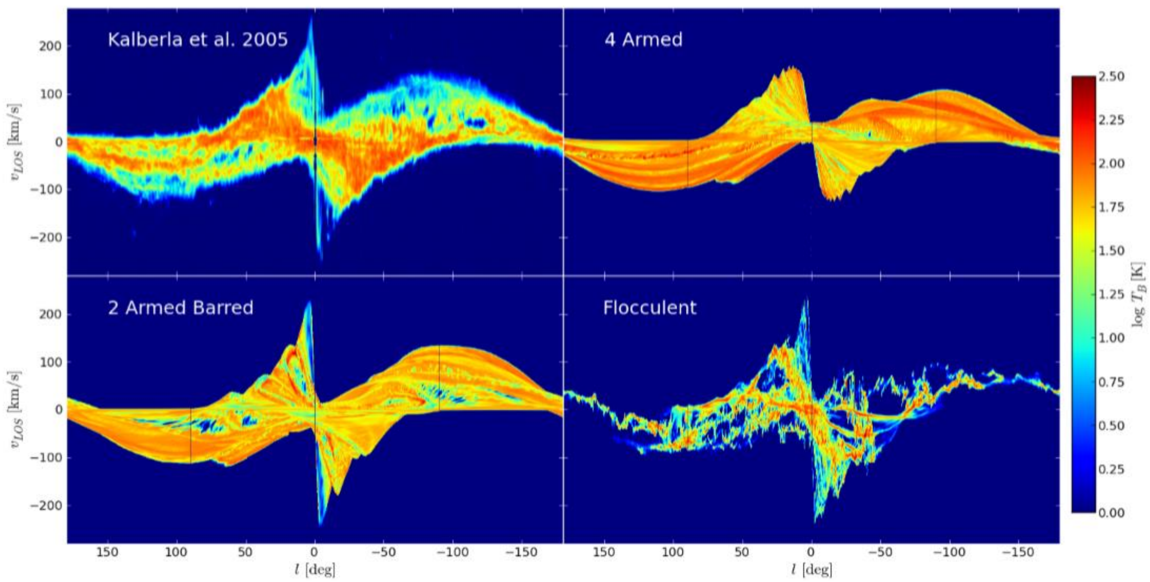

Figure 6: HI (21-cm line) velocity-Galactic Longitude map (8)

The 9-foot dish HI data was converted to velocity-galactic longitude and plotted on figure 5. This figure was used because of its detailed labeling of galactic structures. Figure 7 shows all of the measured data points in red, while figure 8 plotted only the highest signal strength points (> 50% relative signal strength peak).

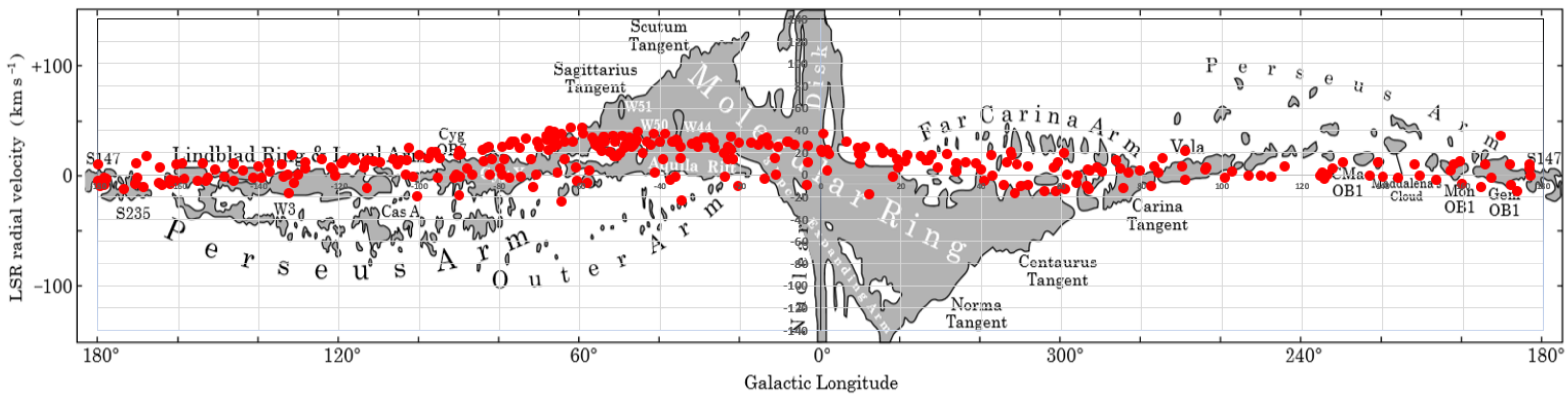

Figure 7: All HI Data plotted

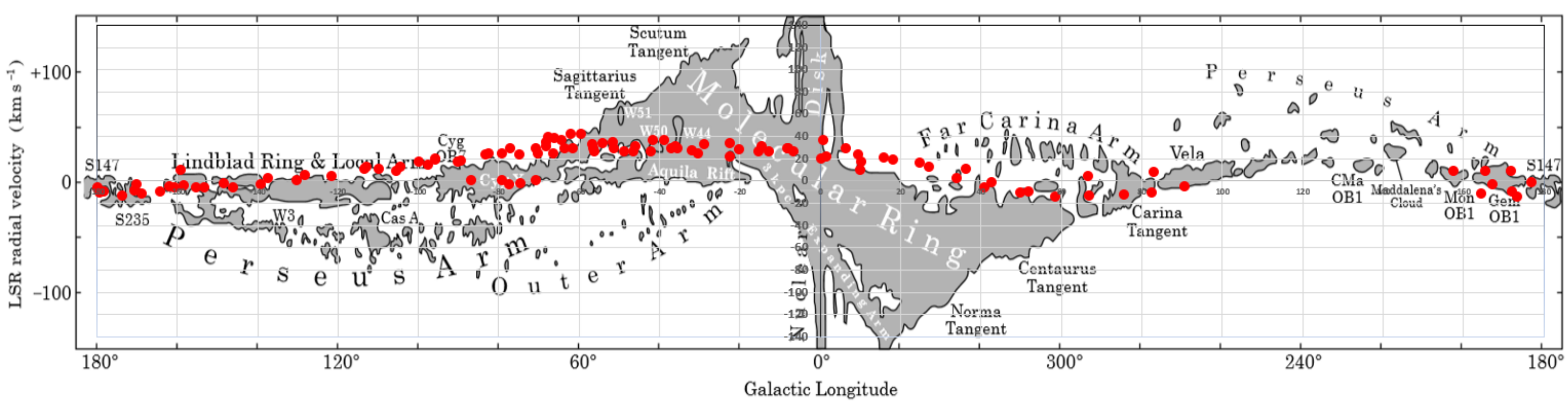

Figure 8: High Signal Strength HI Data Plotted

The mapping shows good correlation with the CO mapping. This is shown in figure 9.

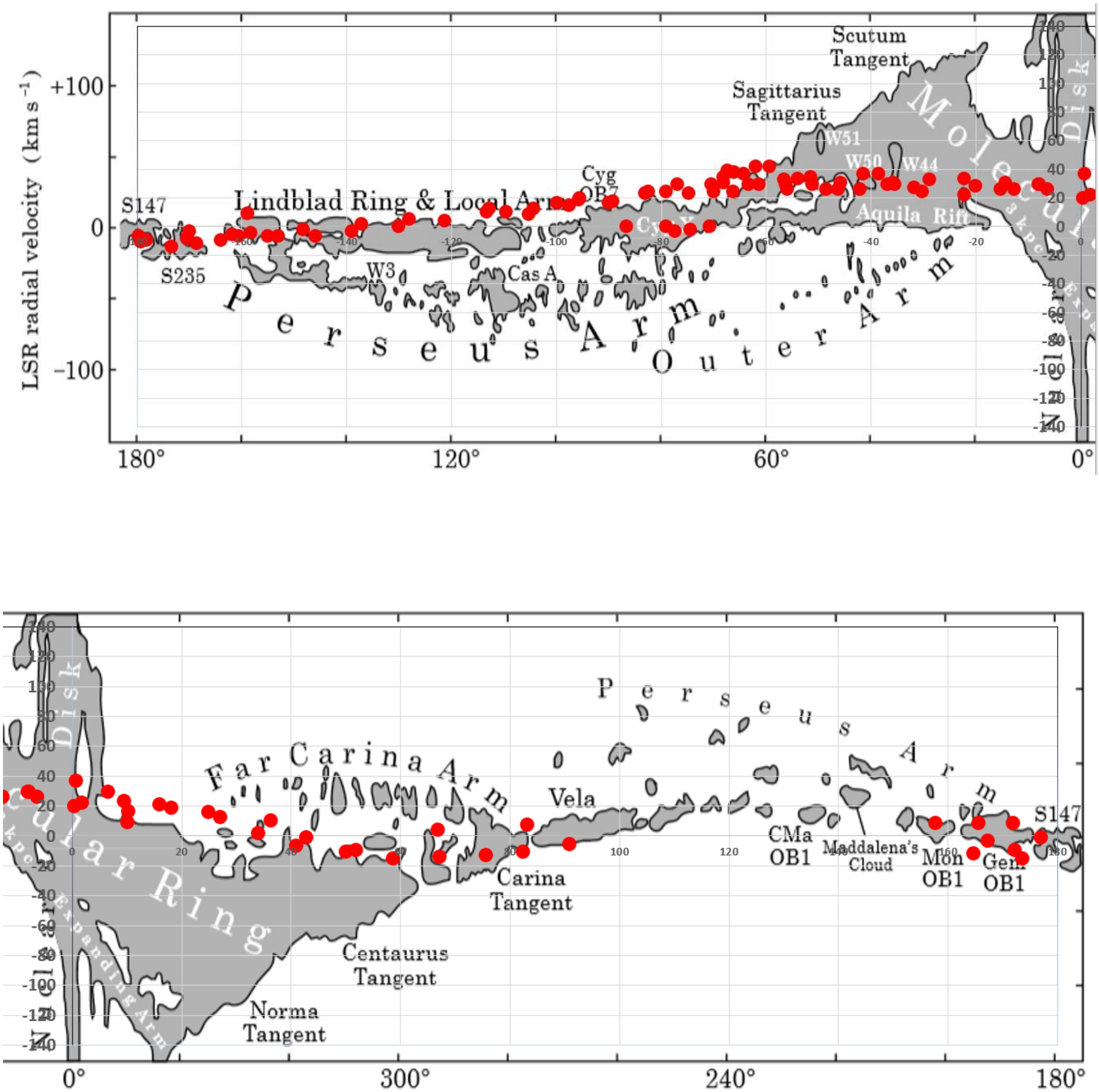

Figure 9: Magnified view of plotted data

Note that the red data points are sample points of the dish data. There is only the highest signal point (velocity) per scan and only one scan per right ascension was plotted. This was only due to the manual data reduction approach used to map the data into Excel. Work is being done to automatically process and plot the data. This will lead to significantly higher quality mappings.

Determining Range (R) of HI Cloud to the Galactic Center

Figure 10 represents the geometry of equation (1). This equation only works at a small angle away from the line from the Sun to the galactic center. This distance was not well defined in (1) so an assumption was made to use ±20° longitude (20°=> 340°) as shown in figure 10.

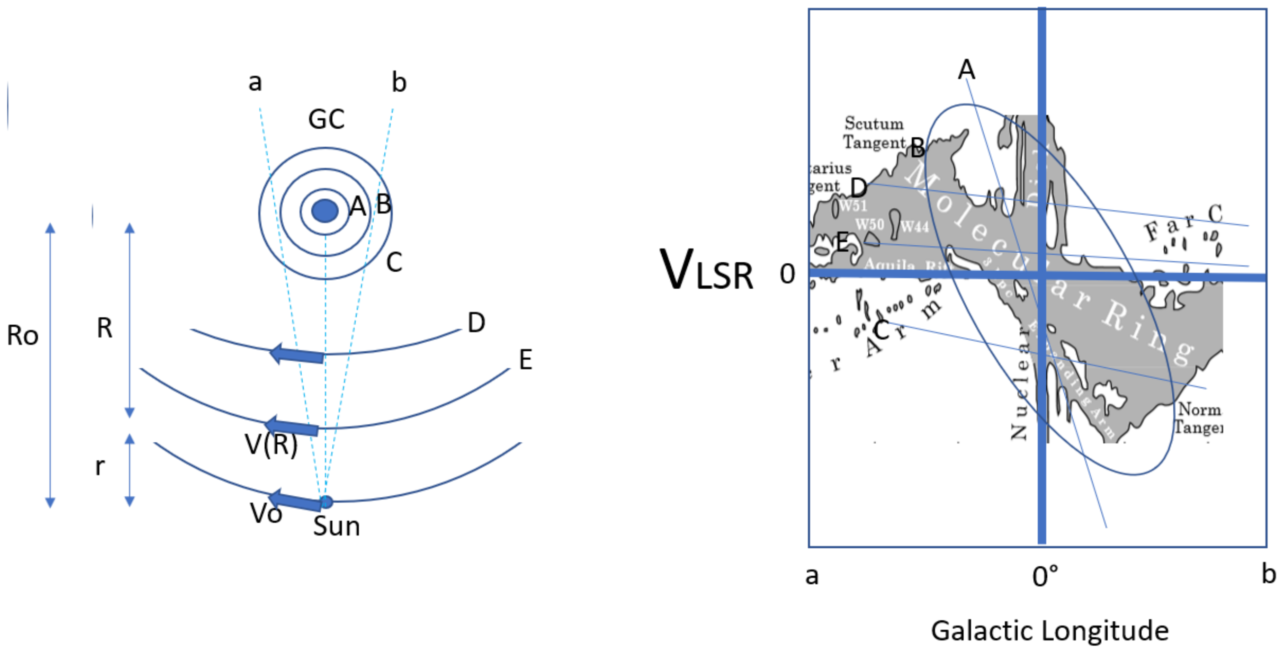

Figure 10: dv/dl method

The HI data near the galactic center was evaluated for use with the dv/dL method. There was not a clear slope to use for dv/dl so the author developed an approach to calculate the sloe between and 2 of the data points in the galactic laongitude range. The range was calculated for each matched pair. This resulted in a large set of range values that did not make sense, so the following assumptions were used to filter out the results that made physical sense:

- The range needed to be < 8.5kpc (inside the Sun galactic radius)
- The absolute value of the ranges were taken

This resulted in 6 combinations of data points that met these assumptions. The data is documented in figure 11 as well as a scale value to plot on a NASA Galaxy map.

L1	V1	L2	V2	R	R kpc
0	20.06	1	36.96	1.7	1.7
0	20.06	2	22.18	26.4	
0	20.06	7	29.57	20.6	
0	20.06	9	23.23	79.5	
0	20.06	10	16.9	-88.6	
0	20.06	10	9.5	-26.5	
0	20.06	-7	26.4	-30.9	
0	20.06	-8	29.57	-23.6	
0	20.06	-13	26.4	-57.4	
1	36.96	2	22.18	-1.9	1.9
1	36.96	7	29.57	-22.7	
1	36.96	9	23.23	-16.3	
1	36.96	10	16.9	-12.6	
1	36.96	10	9.5	-9.2	
1	36.96	-7	26.4	21.2	
1	36.96	-8	29.57	34.1	
1	36.96	-13	26.4	37.1	
2	22.18	7	29.57	18.9	
2	22.18	9	23.23	186.7	
2	22.18	10	16.9	-42.4	
2	22.18	10	9.5	-17.7	
2	22.18	-7	26.4	-59.7	
2	22.18	-8	29.57	-37.9	
2	22.18	-13	26.4	-99.5	
7	29.57	9	23.23	-8.8	
7	29.57	10	16.9	-6.6	6.6
7	29.57	10	9.5	-4.2	4.2
7	29.57	-7	26.4	123.7	
7	29.57	-8	29.57	#DIV/0!	
7	29.57	-13	26.4	176.7	
9	23.23	10	16.9	-4.4	4.4
9	23.23	10	9.5	-2.0	2.0
9	23.23	-7	26.4	-141.3	
9	23.23	-8	29.57	-75.1	
9	23.23	-13	26.4	-194.3	
10	16.9	10	9.5	0.0	
10	16.9	-7	26.4	-50.1	
10	16.9	-8	29.57	-39.8	
10	16.9	-13	26.4	-67.8	
10	9.5	-7	26.4	-28.2	
10	9.5	-8	29.57	-25.1	
10	9.5	-13	26.4	-38.1	
-7	26.4	-8	29.57	-8.8	
-7	26.4	-13	26.4	#DIV/0!	
-8	29.57	-13	26.4	44.2	

G-Long	R (KPC)	Scale (Inches)
0	1.7	0.3
1	1.7	0.3
1	1.9	0.3
2	1.9	0.3
7	2.0	0.4
7	2.0	0.4
9	4.2	0.7
9	4.2	0.7
10	4.4	0.8
10	4.4	0.8
7	6.6	1.2
10	6.6	1.2

Figure 11: Data Reduction of HI Data revealing possible arms

The data from figure 11 is plotted on figure 12. Note that there appears to be three distinct distances from the galactic center. It is possible that these distances may be related to the galactic arms.

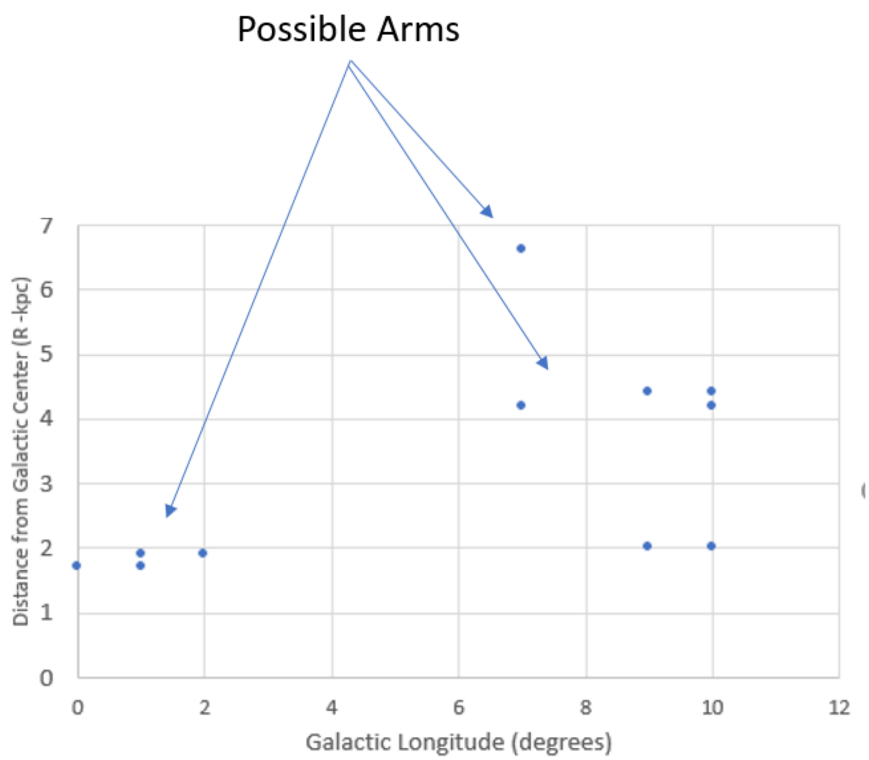

Figure 12: H1 data plotted showing distance to galactic center

Comparison with Known Arm Positions

The results indicate that the H1 measured by the dish appear to be at 2 kpc, 4.2 kpc and 6.6 kpc from the galactic center.

Using the map of the galaxy from NASA (9), the closest associations from the results are:

- the 2 kpc result being the Near 3 KPC Arm
- the 4.2 kpc result being the Norma Arm
- and the 6.6 kpc result being the Sagittarius Arm.

The plot is shown on figure 13.

HI Results
Scaled to Galaxy Map

G-Long	R (KPC)	Scale (Inches)	Galactic Arm
0	1.7	0.3	3 KPC Arm
1	1.7	0.3	3 KPC Arm
1	1.9	0.3	3 KPC Arm
2	1.9	0.3	3 KPC Arm
7	2.0	0.4	3 KPC Arm
7	2.0	0.4	3 KPC Arm
9	4.2	0.7	Norma Arm
9	4.2	0.7	Norma Arm
10	4.4	0.8	Norma Arm
10	4.4	0.8	Norma Arm
7	6.6	1.2	Sagittarius Arm
10	6.6	1.2	Sagittarius Arm

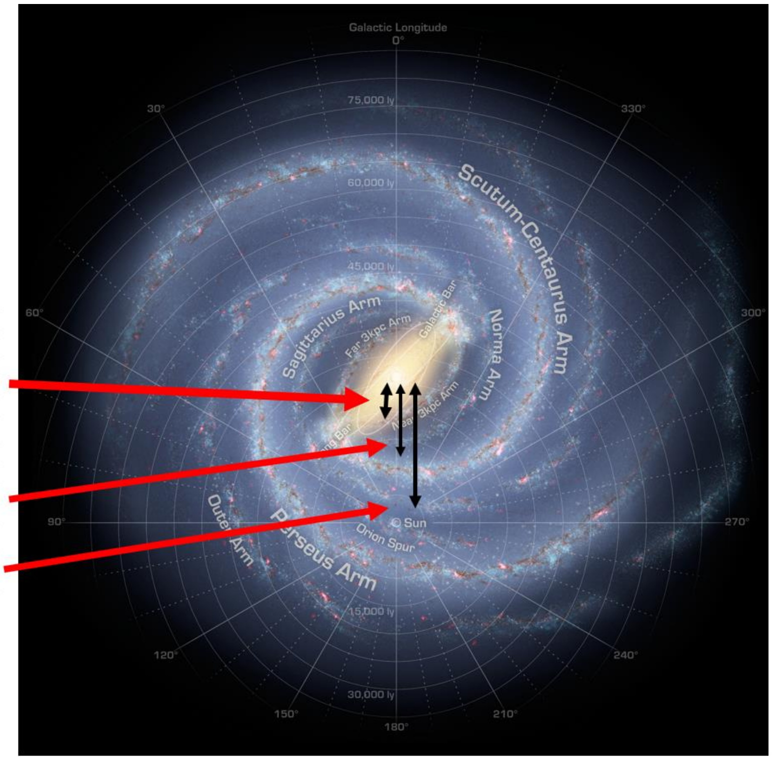

Figure 13: HI Results Plotted on NASA Galaxy Map

The basic results show a fair correlation to the Milky Way Arms. The results, however, are not precise enough to verify that the dish is measuring H1 data at the Milky Way Arm crossings. More precise measurements need to be taken to help substantiate that the dish data is detecting the galactic arms.

Summary

The detection and collection of HI data using a radio astronomy dish is one of the advanced skills for an amateur radio astronomer. Once the data is collected, however, the next skill is to derive insight into astrophysics the data represents.

The plotting of HI data onto a velocity-galactic longitude map provides an excellent opportunity to use the amateur radio data to map the Milky Way. It provides an excellent correlation of H1 data measurements to the Milky Way astronomy map.

The use of the dv/dl method to estimate the Milky Way Arm locations is a promising technique to derive the Milk Way arm positions using amateur radio astronomy. This will provide an excellent challenge for the current and future radio astronomy amateurs and students.

The techniques used in this paper provide exciting experiments that can be conducted using amateur low-cost radio astronomy equipment. This allows the amateur astronomer to move from the technology of collecting data to deriving the physical structure of the Milky Way with the data.

Special Thanks

- The Deep Space Exploration Society (www.dses.science)
- Dr. Dayton Jones, Ralph Boyd, and Tony Bigbee for their excellent inputs on this article.
- Steve Plock and Jeffrey Lichtman for their continued support.

For more information

Dr. Richard Russel DrRichRussel@netscape.net

Deep Space Exploration Society: www.DSES.science

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