Mapping the North Celestial Pole Loop

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Abstract

In this study our team used the 4.5m telescope at Leuschner Observatory to investigate the hydrogen clouds of the North Celestial Pole (NCP) loop, at l = 105° - 160°, b = 15° - 50°. We measured the region to be moving away from the observer at a rate of 29 ± 10 km/s, with the hydrogen-rich loop to be moving faster than the hydrogen-poor center. We present frequency and intensity maps of the region that compare well to the literature.

1 Introduction : The North Celestial Pole Loop

The 21cm line (1420.40575 MHz) is region of spectral emission of atomic hydrogen (HI). In our study, we use 21cm spectroscopy to map the hydrogen-based North Celestial Pole Loop. About 325 light-years away, this object features numerous filaments that knit together, forming small clouds that are connected via coarse arches of material hydrogen in the shape of a cylindrical cavity with an axis expanding along the line of sight, incl = 20° to the galactic HI disk (Meyerdierks, 1991) [1]. See Figure 1 for a diagram of their cylinder model. This structure may be formed through supernova, stellar winds, or in-falling high velocity clouds from the Milky Way. Heithausen (1987) called it the Polar loop because its circumference runs across the North celestial pole [2].

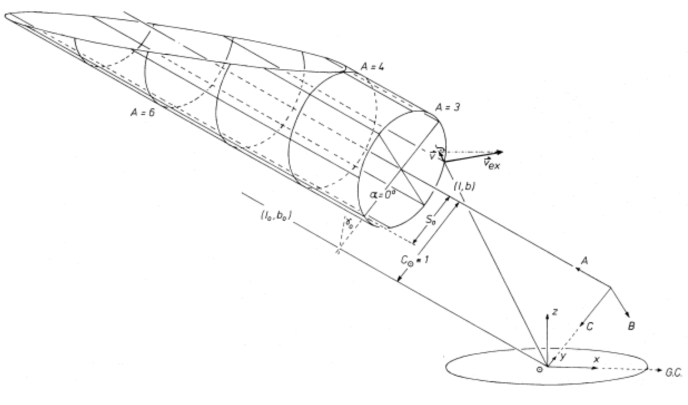

Figure 1: Cylinder Model of NCP Loop from Meyerdierks, H., A. Heithausen, and K. Reif. (1991). They propose that cylindrical expansion best matches the HI velocities, with expansion 20 km/s. The cylinder is directed toward the observer and inclined 17 ° to the galactic plane. Ring radius 30 pc.

In this report, Section 2 covers the experimental design and observing process for data retrieval. Section 3 provides a sample of our data analysis process and an overview of our results. Finally, Section 4 and 5 conclude the report and offer acknowledgements.

2 Experiment and Data

2.1 The Receiving System

Leuschner Observatory is home to a 4.5m radio telescope, located in Lafayette, California, approximately 10 miles east of the Berkeley campus. The telescope operates between 1320–1740 MHz and uses an 8192 element spectrometer with spectral resolution of about 1.5 kHz and a 12 MHz bandwidth.

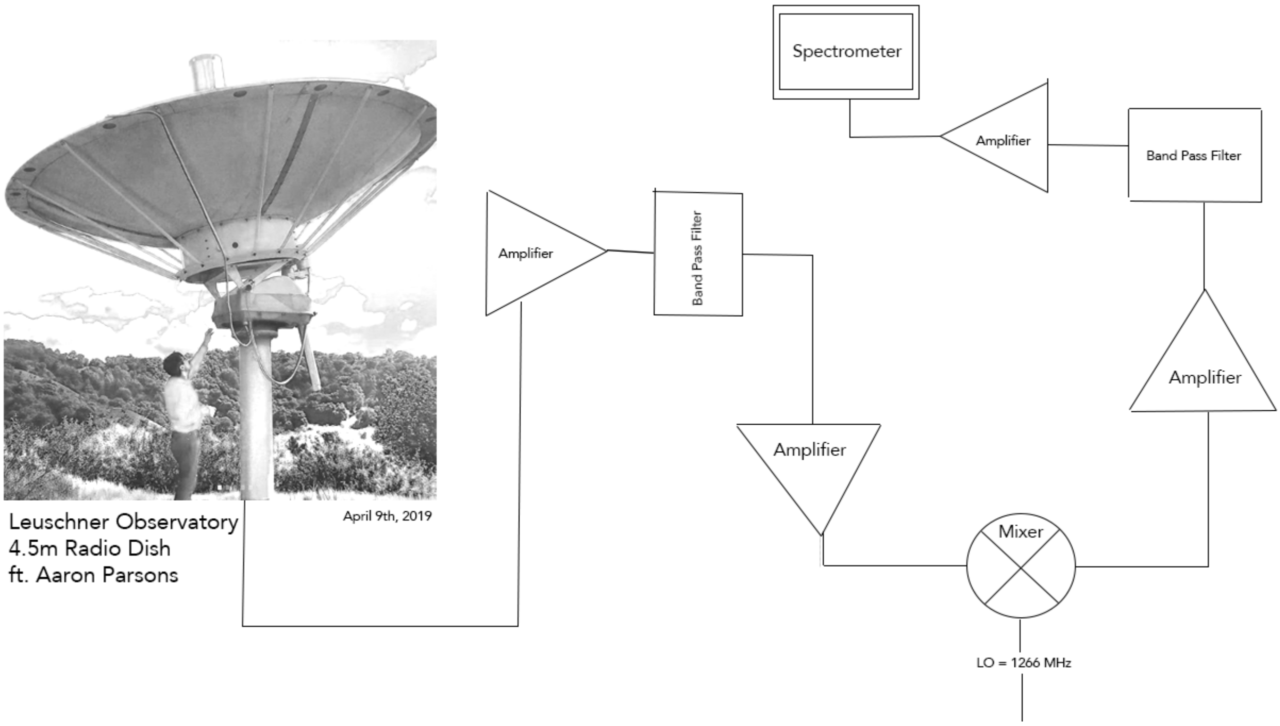

Figure 2: Generalized signal diagram of the Leuschner dish receiving system. The telescope operates at 1320–1740 MHz and the circuitry system reduces these signals to pass through the spectrometer at lower levels. Pictured with the telescope is Professor Aaron Parsons, taken on the field trip on April 9th 2019.

After an observation is taken, the signal passes through a series of amplifiers and bandpass filters and a mixer before being passed into a digital spectrometer, see Figure 2. The Nyquist window for our observations was 144-196 MHz, so we measured our signal using an LO of (633 * 2) = 1266 MHz (the signal is doubled for legacy purposes), to bring our signal down to 154 MHz, within the Nyquist range.

2.2 Telescope Pointing

This survey project observed in the region of the sky from (l = 105° - 160°, b = 15° - 50°). The conversion from (ra, dec) earth-based coordinate systems to galactic (l,b) is shown in Figure 3.

We obtained and averaged 15 spectra per pointing at 10 seconds per pointing, and used 450 pointings to map the 1600 sq-degree area. Because the NCP Loop is located at the North Celestial Pole, the observations had to account for the curvature of the Earth and the limitations of the telescope range. Because the North Celestial Pole is always in the sky in the Northern Hemisphere, we originally anticipated that most hours would be prime for observations. However we discovered that we needed to carefully maneuver the telescope around its boundary limits, which unfortunately map through several regions of our object. Not only did it require several observation runs so as to prevent the telescope from slewing between extremes, but we also ended up with a hole in our map, which ended up larger than originally predicted due to symmetrical mirroring across the pole from projection effects (foreshadowing).

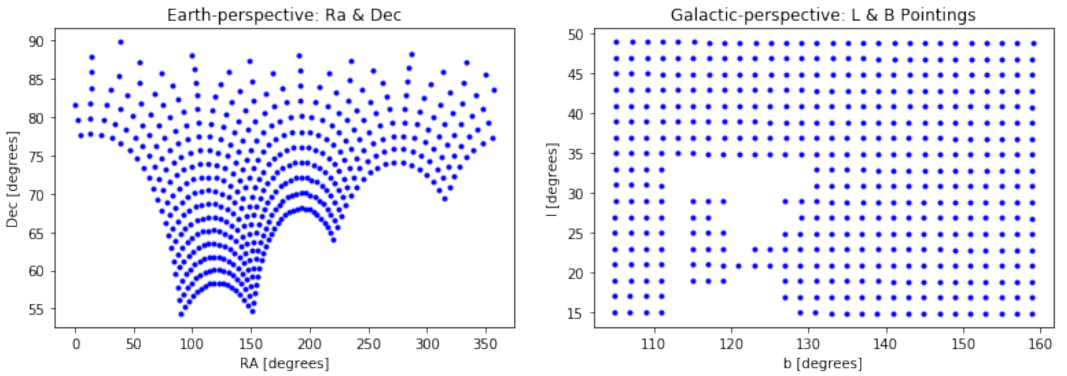

Figure 3: Telescope pointings, converted from (ra, dec) coordinate system to galactic longitude and latitude (l, b)

3 Data Analysis

3.1 Line Shape and Frequency

Once each pointing spectra was obtained and averaged, we used spectral calibration techniques to remove systematic structures from the spectrum. To do this, we frequency shifted the LO from 1266MHz to 1332MHz, and divided the averaged 1332MHz spectrum from each of our averaged pointings. The data product of the telescope output produces dual-polarizations, which we combined to increase our signal strength. We then isolated the region containing the hydrogen line, and found that the peak of the HI line averages around 1336.335 MHz ± 0.131, although the frequency of the peak is location-dependent within our map, see Figure 4. This is because frequency of the line changes with the velocity of the cloud. Because the the 1336.335 MHz line is "red-shifted" from the expected 1420.40575 MHz, we can tell that this cloud is moving away from the observer.

The relative cloud velocities can be interpreted from Figure 5a, which plots galactic longitude and latitude against color-coded peak frequencies. Warm tones (red and yellows) represent regions of high red-shifting, which are observed around the outskirts of the object, while cool tones (green, blue, black) are regions of low red-shifting and are observed centrally within the object. This representation (while low-tech) is compliant with characteristic observations of the NCP Loop in the literature, Figure 5b, where the HI clouds in the loop are moving away faster than the low velocity regions in the center of the circle.

The intensity of the 21cm line hydrogen spectrum in each pointing is directly proportional to the column density of H atoms along the line of sight (as long as opacity is small). Intensity is related to the brightness temperature (T_B)and the line frequency shift (δv) from the expected 1420.40575 MHz, shown in Equation 1.

$$N_{HI}(\delta v) = 1.8x10^{18} T_B(v) cm^{-2} \tag{1}$$

We subtracted the median value of each spectra from itself to remove noise (from the noise diode that was left on occasionally), then applied this function to each spectra in our map to calibrate the intensity. Figure 6 shows an image of the relative temperatures of the hydrogen in the NCP Loop. Although HI filaments exist in the loop, the filament-like circle pictured is due to projection effects, which stretch the object. Unfortunately the Basemap package which graphs stereographic projects did not work on my available facilities, so the cylindrical equidistant projection is shown.

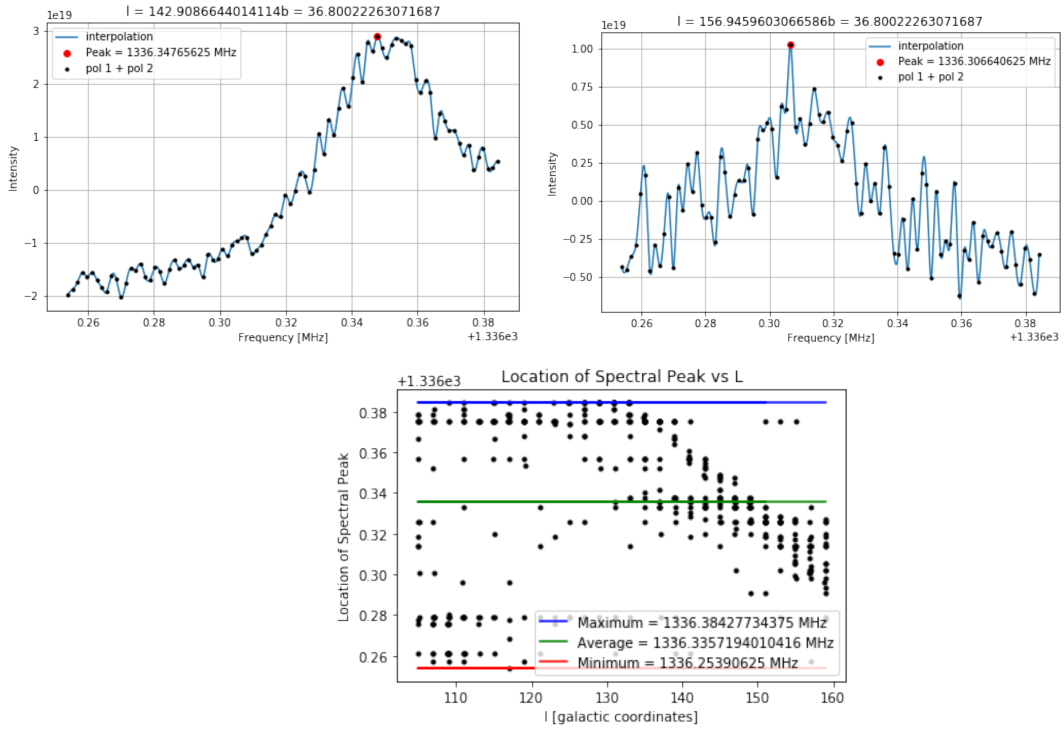

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Figure 4: The peak intensity of each averaged spectrum is calculated by finding the peak value of the scipy.interpolation of the peak region in the spectrum. The frequency of the maximum peak is location-dependant, and the average peak location is 1336.335 MHz ± 0.131. Figures (a) and (b) are two sample spectra that demonstrate the peak frequency range, and Figure (c) is a plot of the peak frequencies plotted against the Galactic Longitude, which shows that frequency red-shifts along the latitude axis.

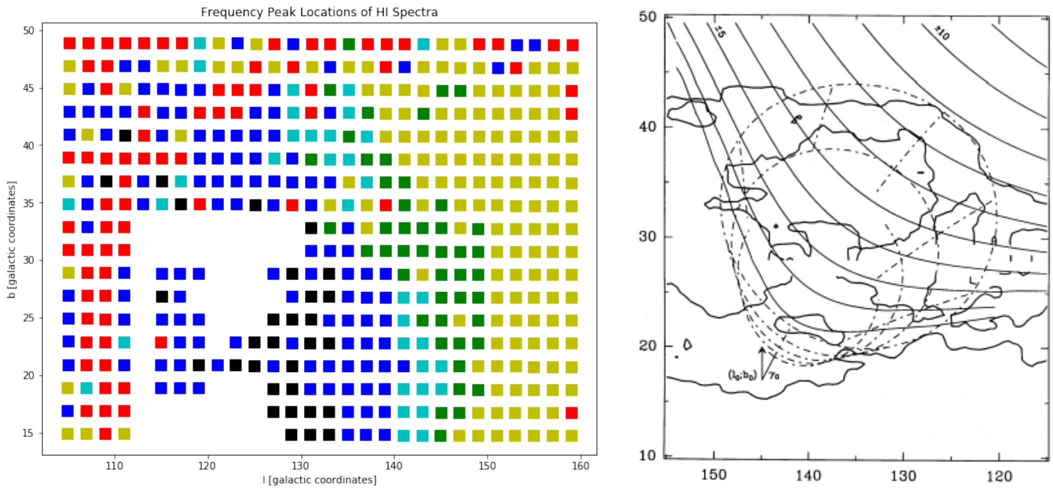

Figure 5: Side-by-side comparison of our observed NCP Loop that from the literature. Figure (a) is a map of galactic longitude and latitude colored by peak frequencies (velocities) found in Fig 4. Red and yellow colors indicate regions of maximum red-shift, in which the hydrogen clouds are moving away from the observer the fastest. Green is average motion. Blue and black colors are regions of the least movement. Figure (b) is a cloud velocity map from Meyerdierks (1991) [1], which overlays the cylinder model over their mapped cloud velocity regions. Note that their galactic latitude is plotted in reverse order.

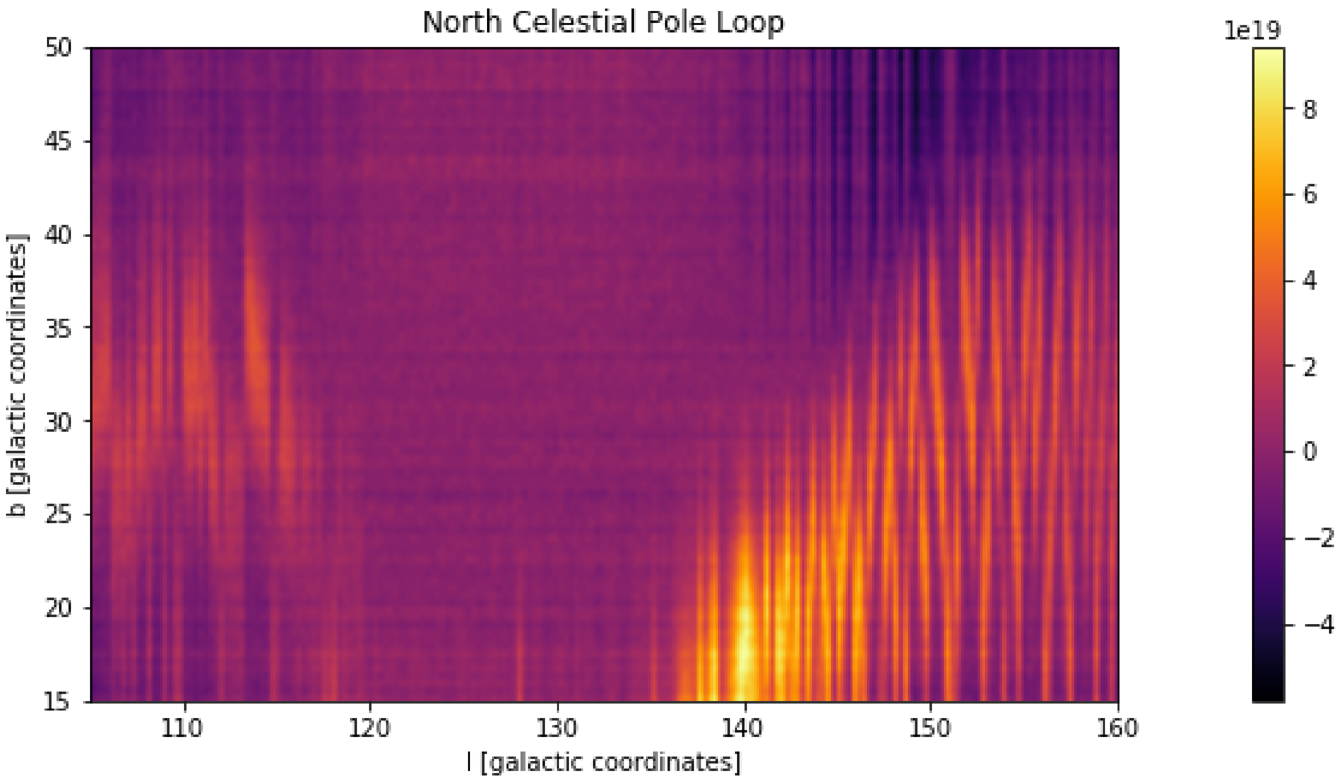

Figure 6: Plotted using Matplotlib.pyplot's Imshow feature, this is an image of the relative temperatures of the hydrogen in the NCP Loop. The "loop" is visible as a ring around the frame, noting that cloud densities throughout the ring are not uniform. The center of the loop does not contain HI, making it darker.

4 Conclusions

Large scale survey projects can be completed with automated telescopes given sufficient time allocation and resource availability, and the data products from those surveys can be used to extract structural information about the world around us. In this report we observed the neutral hydrogen in the North Celestial Pole Loop, and found that velocities of the hydrogen-rich ring, 29 $\pm$ 10 km/s, are close but comparable to those found by Meyerdierks (1991) which found HI velocities of 20 km/s. Our value could be constrained with a more careful consideration of Galactic rotation. The maps presented in this paper could be expanded in future labs to account for projection effects, since our object covers the pole, cylindrical equidistant projection will present a warped view of the object due to foreshadowing.

5 Acknowledgements

I would like to all my lab mates, Scout, Grace, and Adam, pictured in Fig 7, for all the hard work we've put into Radio lab this semester. I originally wasn't going to take this class at all because I heard it was "hard", but together the skill set, determination, and camaraderie with these lovely Anoising folks made every lab enjoyable. I would also like to thank Dr. Parsons for teaching this class and making radio astronomy accessible to folks without extensive circuitry or physics backgrounds, and for his passion and pedagogy for hands-on learning. The labs from this class allowed me to apply the concepts I have studied throughout my undergraduate career, perfectly wrapping up my time as a graduating astronomy student as well as giving me marketable skills to approach the big-data world.

Figure 7: Team Anoising, pictured on the roof of Campbell Hall with the Big Horn from Lab 2.

References

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