Mapping the North Celestial Pole

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ABSTRACT

This experiment uses the 4.5m diameter Leuschner dish in order to map the hydrogen in the North Celestial Pole (NCP). In galactic longitude and latitude, the region that was observed covered roughly l =105° to 160° and b =15° to 50°, covering approximately 1600 square degrees, requiring $\sim$ 350 profiles. 1D images of the NCP were created in order to represent the velocity, intensity and column density of the hydrogen within the region while a 2D image was created combining the intensity and velocity. These images show a low velocity region with a low intensity and density of hydrogen atoms centred at $(l, b) = (135°, 40°)$ surrounded by a large shell of high intensity hydrogen with a velocity between -5 km/s and -10 km/s.

Contents

1. Introduction

1.1. About the North Celestial Pole

The celestial equatorial coordinate system is based on the concept of the *celestial sphere* which is an imaginary sphere of infinite radius surrounding the Earth. Locations of objects in the sky are given by projecting their location onto this sphere. The celestial sphere is fixed with respect to the universe and since the earth rotates from west to east the celestial sphere appears to rotate from east to west according to an observer on Earth. The North Celestial Pole (NCP) is the point in the sky about which all the stars seen from the Northern Hemisphere rotate. The North Star, Polaris, is located almost exactly at this point in the sky. The NCP is directly above the Earth's north pole and has a declination of $+90°$ with respect to the celestial equator, as shown in figure 1.

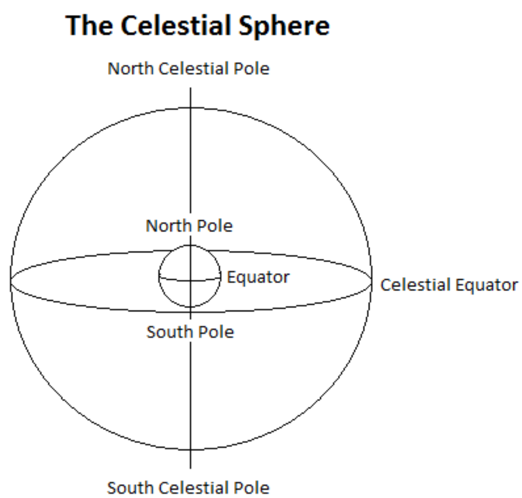

Fig. 1.— Illustration of the North Celestial Pole at a declination of $+90°$ from the celestial equator and directly above the Earth's north pole.

The North Celestial Pole consists of large expanding shells of hydrogen. These shells are the interstellar material that is swept up by shock waves produced predominantly by supernovae. By observing the NCP using 21-cm radio astronomy, the density and intensity of the hydrogen sources can be determined and the velocity of these H1 shells can be calculated.

1.2. The Receiving System

The telescope used in this experiment is a 4.5m diameter radio dish located at the Leuschner Observatory. The signal passes through a series of amplifiers and band pass filters and a mixer before being passed into the digital spectrometer, as shown in the block diagram in figure 2. The signal is sampled at 24 MHz despite the signal having frequency of 150 MHz $\pm$ 6 MHz. This is allowed since the signal can be brought down to baseband frequency of (min, max)=(-12, +12) MHz since it has a replicating property due to the Fourier transform. Thus sampling at 24 MHz satisfies the Nyquist criterion.

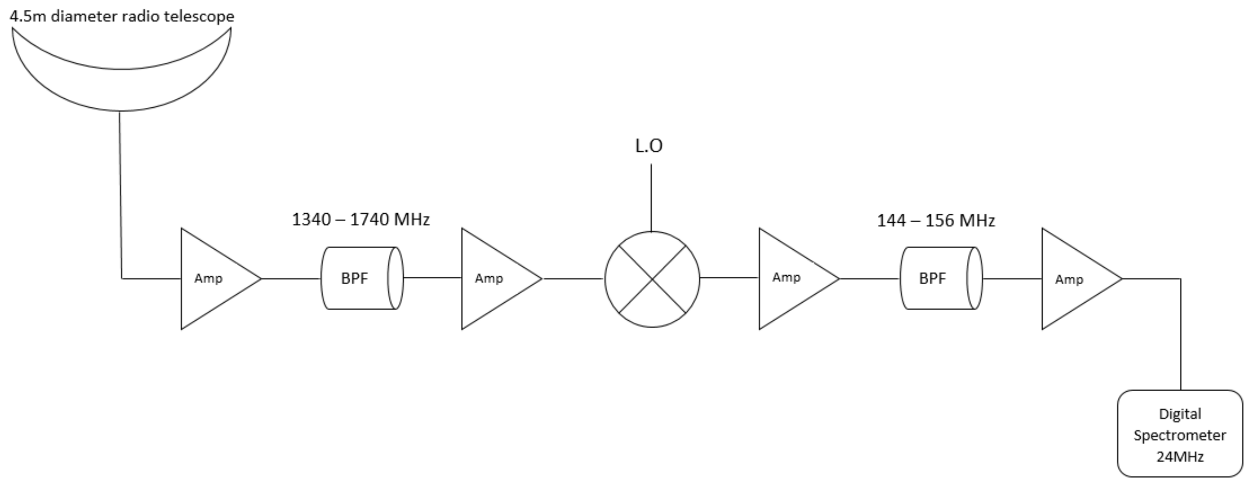

Fig. 2.— Block diagram of the 4.5m diameter radio dish at Leuschner used during this experiment. Set-up shows a series of band pass filters and amplifiers through which the signal travels before being passed through a digital spectrometer to be sampled at 24 MHz.

2. Experimental Procedure and Analysis

2.1. Observing the NCP

In this experiment, the HI signals from the NCP are detected using the Leuchsner Telescope. The signal from the NCP is strong and so only a short integration time of 70 seconds per observation point was required during which 100 spectra are obtained and averaged. Since the NCP is always visible in the sky, no priority map of observation times was required. Constraints were placed on the altitude of the observation points to ensure that no points were observed below 20° as this would be below the horizon and the telescope cannot operate below 14°. After observation, the azimuth and altitude of observing points were checked to ensure no points were behind the hill during observation. The power spectra for each pointing were checked to ensure no spectra has an unusually high intensity, suggesting that the telescope was pointed at the ground, hill or a stray turkey.

In galactic longitude and latitude, the region that was observed covered roughly l =105° to 160° and b =15° to 50°, covering approximately 1600 square degrees. Using a 2° spacing for the b coordinates, there were 18 values of b to be mapped. Since the region mapped is on a sphere, observation time was saved by using increments of $\Delta l = \frac{2^\circ}{cos(b)}$. The observation code contained a nested loop so that all l values were observed for a given b. This resulted in 347 profiles which were obtained by pointing the telescope at the required position and then using the `getspect` procedure to take and record the data. Observation of all 347 pointings took approximately 17 hours of data taking.

2.2. Analyzing the Data

In order to perform an intensity calibration on the spectra an online and offline spectrum for each point of (l, b) was taken. This was done by using two L.O frequencies of 1420 MHz and 1422 MHz for online and offline, respectively. In addition to that, the noise diode was turned on every tenth pointing and a spectrum was taken. This noise diode spectrum was used to calibrate the previous ten spectrum taken. The calibration was done using the same method carried out in lab 2, where the ratio between the online and offline spectrum and the ratio between the offline and online spectrum were calculated. The peaks from these ratios were then combined and averaged. This was done for both the x- and y-polarizations. Assuming a noise diode temperature of 145 K for the x-polarization and 30 K for the y-polarization, the intensity could be calculated. Using the doppler velocity formula, $v = -c\frac{\Delta\nu}{\nu}$, the frequencies, ν, could be converted into velocity, where $\Delta\nu$ is the frequency shift of the 21-cm line. The `ugdoppler` information was extracted from the output structure of each spectrum in order to obtain the LSR velocity of the source.

2.3. Creating the Image

A Gaussian fit was fitted to the 21-cm line peaks of the power spectra for each pointing of the telescope in order to find the peak velocity of the line in the LSR frame. The intensity of the 21-cm line at the peak velocity was also recorded.

The galactic coordinates (l, b) were projected onto a stereographic projection using the equations:

$$R = tan(0.5 \times (90^\circ - b)) \tag{1}$$

$$x = Rcos(l) \tag{2}$$

$$y = Rsin(l) \tag{3}$$

where (x, y) defines the pixel values of the new system. These pixels were then populated with the observed velocity and intensity data from the Gaussian fit for each (l, b) coordinate using a 'nearest neighbour' approach. This is where the nearest observed position is found for each pixel and this pixel is then populated with the observed data. This allowed two separate 1-D images to be created for both the velocity, v, and intensity, I, of the hydrogen in the NCP in (l, b, v) and (l, b, I) space, respectively. These images were then combined into a single 2-D image that represents both the velocity and intensity of a H1 source in the NCP in (l, b, v, I) space, shown in figure 5.

The 2-D color table was chosen carefully in order to visually represent the velocity and intensity of hydrogen by ensuring that all colors could be clearly seen. The color represents the velocity while the shade of the color, dark or light, represents the intensity or density of the hydrogen with a darker shade corresponding to a low intensity, and thus density, of hydrogen at a particular galactic coordinate and a brighter shade corresponding to a high intensity or density.

3. Mapping the NCP

3.1. 1D Images of the NCP

The intensity of the 21-cm line is directly proportional to the column density of hydrogen atoms. The density of hydrogen atoms per centimetre squared, N_{HI}, can be calculated using by:

$$N_{HI} = 1.8 \times 10^{18} \int T_B(v)dv \tag{4}$$

where T_B is the brightness temperature of the beam and v is the velocity. This integral was carried out by summing the intensity under the 21-cm line in the power spectrum over a range of velocities. This allowed a 1D image of the column density of hydrogen in the NCP to be created, as shown in figure 3. The image shows an area of low density surrounded by a shell of high density. The center of the area of low density occurs at projected coordinates of $(x, y) \sim (-0.4, 0.35)$. This corresponds to galactic coordinates of $(l, b) \sim (137°, 37°)$. This means that an intensity map would show the same features since density and intensity are directly proportional.

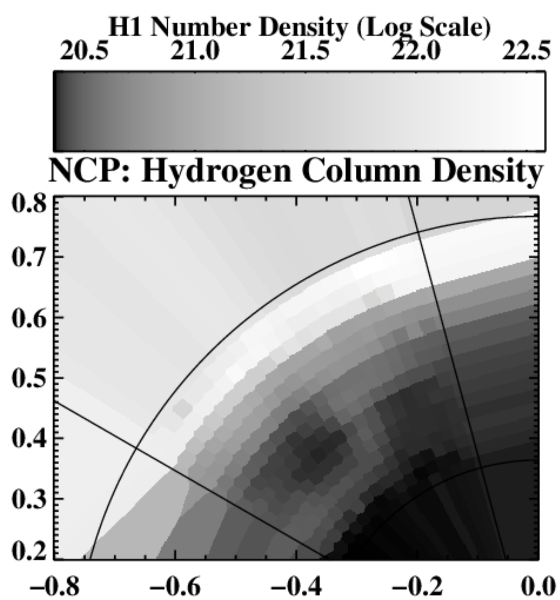

Fig. 3.— Column density of hydrogen in the NCP. The contour lines on the graph refer to the galactic longitude and latitude while the axis are the projected points from equation 2 and 3. The image shows a region of low density located at $(l, b) \sim (137°, 37°)$.

3.2. 2D Image of the NCP

Figures 4 and 5 show 2D images of the North Celestial Pole. These images were created by combining a 1D image of the velocity with a 1D image of the intensity. The LSR velocities range from approximately

+5 km/s to -25 km/s while the intensity ranges from 0 K to 190 K. Figure 4 shows the 2D image in terms of the projected coordinates (x, y). This image has a region of low velocity and intensity centred at $(x, y) \sim (-0.35, 0.3)$ and galactic coordinates $(l, b) \sim (135, 40)$. This region is surrounded by a hydrogen shell of high intensity moving with speeds between -5 km/s and -10 km/s.

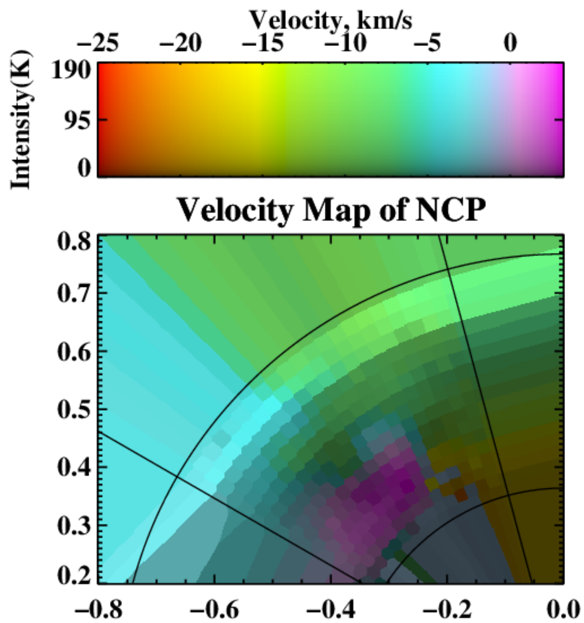

Fig. 4.— Velocity of hydrogen sources in the NCP expressed in km/s in the LSR frame of reference. The contour lines on the graph refer to the Galactic longitude and latitude while the axis are the projected points from equation 2 and 3. The image shows a region of low velocity, almost stationary, centred at $(l, b) \sim (135°, 40°)$.

Figure 5 shows the 2D velocity/intensity image of the NCP graphed in galactic coordinates. Since these points lie on a celestial sphere and are graphed on a rectangular grid, the projection is not perfect. Regions of high latitude are less conformal and are stretched since there are less values of l for values of higher b.

This image shows a region of low velocity (almost stationary) and low intensity, as in figure 4, centred at $(l, b) = (135°, 40°)$. The intensity of hydrogen increases outside of this region, indicating a moving shell of hydrogen with intensity increasing with decreasing latitudes as the galactic plane is approached.

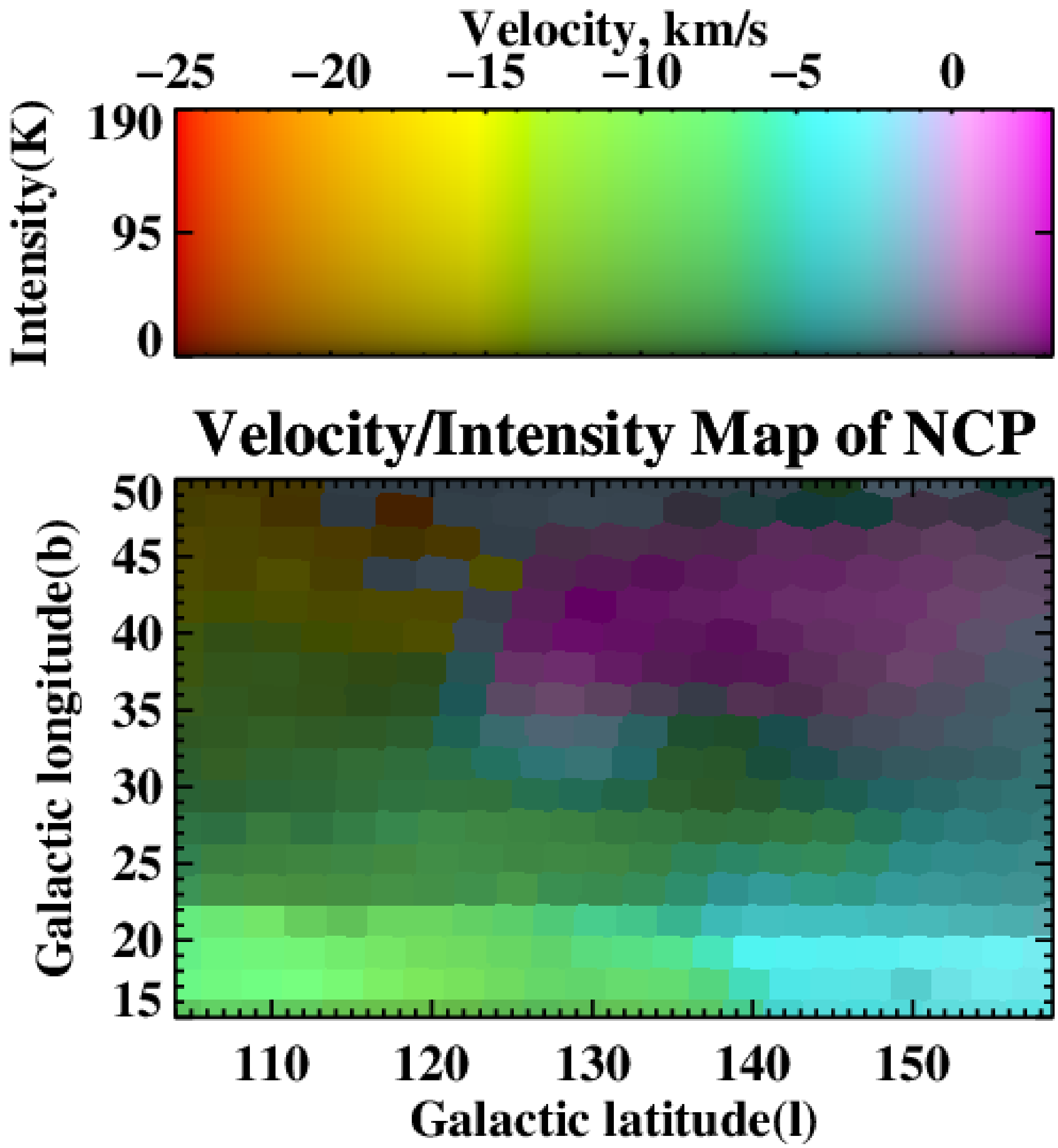

Fig. 5.— Velocity of hydrogen sources in the NCP expressed in km/s in the LSR frame of reference. This image is graphed with the galatic coordinates on a rectangular grid, thus regions of higher latitude are more stretched and less conformal. The image shows a region of low velocity and intensity centred at $(l, b) \sim (135°, 40°)$.

4. Conclusion

From observations of the North Celestial Pole using the radio dish at Leuschner, velocity, density and intensity images were created, as shown in figures 3, 4 and 5. All images produced of the NCP in this experiment show a region of low density and intensity with a low LSR velocity, in fact almost stationary, centred at approximately $(l, b) \sim (135°, 40°)$. This region is surrounded by a large shell of high intensity and density of hydrogen with velocities ranging between -5 km/s and -10 km/s. This indicates that the shell is moving towards the Earth. Intensity of hydrogen increases with decreasing galactic latitudes as the galactic plane is approached. Resolution in the images could be improved by decreasing the spacing between observations points from $\Delta b = 2°$ to $\Delta b = 1°$.

Fig. 6.— Temple Bars at the 4.5m diameter radio dish at Leuschner.