Observation of Atomic Hydrogen Hyperfine Transitions within the Milky Way galaxy

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Abstract

For this paper we discuss our measurements and analysis of hyperfine lines of hydrogen at distinct places within the galactic plane of our Milky Way. We found that the average column density of neutral hydrogen was $N(n) = 1.59 \times 10^{22}$ cm^{-2} $\pm$ 1.91×10^{21} cm^{-2} and that the related average brightness temperature was equal to $T_{B_{Avg}} = 18.84$ K $\pm$ 1.02 K. From the experiment we deduced that not only is neutral hydrogen far more abundant within the galactic plane but it is also rotating around our galactic center, leading us to believe neutral hydrogen is concentrated in the spiral arms of our galaxy.

1 Introduction

Hydrogen is the most abundant element in the universe, more specifically neutral hydrogen is the most abundant element in the interstellar medium (ISM) The ISM is the space between the star systems in a galaxy. The study of neutral hydrogen allows us to better understand the arrangement of galaxies.[2]

This paper looks to better describe the structure of neutral hydrogen within our own galaxy, more specifically it's movement and abundance within the Milky Way.

2 Procedure

2.1 Setup

To begin, an extension cord was connected from an outlet to the antenna, and then from the antenna to the dome. A feed horn was then attached to the antenna bracket. The opening of the feed horn was set to a distance of .0684 meters (26.6 inches) with respect to the bracket, this distance is the focal length of the antenna. The low noise amplifier (LNA) was then connected to the feed horn. Next, a coaxial signal cable was used to attach the LNA to the input of the Agilent Spectrum Analyzer. Finally, the LNA was plugged into a 12 volt regulated power supply that was then connected to the initially mentioned extension cord.

We adjusted the antenna to point along the meridian. The altitude was then set to 90° longitude and $-37.0°$ latitude. The telescope was set so that about an hour through our observation the Milky Way's disc would cross our meridian.

2.2 Observations

Observations were taken on the morning of December 18, 2019 from 9:50am to 11:42am. Using the the setup outlined above, 19 scans of the hydrogen hyperfine lines were captured at a galactic longitude $-30°$ from the center of the galaxy. The galactic disk would align with the meridian at a celestial right ascension of about 18 hours and 46 minutes. Each scan before and after this was taken over a period of 5 minute intervals and contained a total of 461 data points.

3 Results

To begin, we found the wavelength of our spectra by solving for λ in Equation 1:

$$v = -\lambda \Delta f = -\lambda (f - f_0) \tag{1}$$

From this we found that $\lambda = 2.112 \times 10^{-4}$ km.

3.1 Conversion of Spectrum Analyzer Power to Brightness Temperature

The spectrum analyzer registers power at it's own input. To determine the power received from the antenna we had to work backwards by converting the power from the analyzer to the power from the antenna as a function of the analyzer. To do this we first converted the power from the analyzer in dBm to Watts via Equation 2.

$$dBm = 10 \cdot \log \frac{P(milliwatts)}{1000} \tag{2}$$

After having converted dBm to Watts, we then followed the outlined steps 4-8 in the Observational instructions given to us from George Brown [1]. With these steps we were able to correct for cable attenuation, Low Noise Amplifier (LNA) gain, reflected power, polarization and system inefficiencies. This final quantity, which we called $\frac{dP}{df}$, is the value of total power received from the antenna.

Armed with the values of $\frac{dP}{df}$ and λ, we were finally able to solve for the the spectral brightness by using Equation 3 and the brightness temperature via Equation 4.

$$B(f, \hat{n}) = \frac{1}{\lambda^2}\frac{dP}{df} \tag{3}$$

$$T_B(f, \hat{n}) = \frac{\lambda^2}{2k_B}B(f, \hat{n}) = \frac{1}{2k_B}\frac{dP}{df} \tag{4}$$

By plotting T_B and a function of v, we were able to find the background brightness temperature by fitting the data to a third order polynomial with the form seen in Equation 5. .

$$T_{B_{Background}}(v) = (N_1)v^3 + (N_2)v^2 + (N_3)v + N_4 \tag{5}$$

We then subtracted this background function from the brightness temperature and found the average brightness temperature to be $T_{B_{Avg}} = 18.84$ K $\pm$ 1.02 K. Plots of the brightness temperature as a function of velocity can be found in Figure 2 and Figure 3 of the Appendix.

3.2 Calculation of Column Density

Using Equation 6, we found the the average column density over every trace to be $N(n) = 1.59 \times 10^{22}$ cm^{-2} $\pm$ 1.91×10^{21} cm^{-2}. Where T_B is in kelvins and Δv is the step size in km/s.

$$N(n) = 1.8224 \cdot 10^{18} \int T_B(v; \mathbf{n})dv = 1.8224 \cdot 10^{18} \sum T_B(v; \mathbf{n})\Delta v \tag{6}$$

Plots of the column density versus trace number can be found in Figure 1 of the Appendix. The Plot found in Figure 1 represents how the column density falls off the further away we observe from the galactic plane.

4 Discussion

NASA's HEASARC website gives an average column density of $N(n) = 1.12 \times 10^{22}$ cm^{-2}, which is in very good agreement with our data. Any difference could be attributed to our machinery versus that of NASA's which is likely to be far more sophisticated than our own tools. Because brightness temperature peaks closer to the plane of the galaxy (where the rotating spiral arms are located), we can deduct from Figures 2 and 3 that the brightness temperature changes as the galactic plane rotates; meaning the neutral hydrogen clouds rotate around the galactic center. Further more, from the peak in Figure 1 we can say that as we approach the galactic plane we find more neutral hydrogen. This and the fact that the brightness temperature increases the closer we are to the galactic plane leads us to believe that neutral hydrogen must be optically thicker within the spiral arms of the galactic plane than it would be outside of it.

5 Conclusion

In conclusion, We found that the average column density of neutral hydrogen was $N(n) = 1.59 \times 10^{22}$ cm^{-2} $\pm$ 1.91×10^{21} cm^{-2} and that the average brightness temperature is equal to $T_{B_{Avg}} = 18.84$ K $\pm$ 1.02 K. From the experiment we deduced that not only is neutral hydrogen far more abundant within the galactic plane and even more specifically the spiral arms of the Milky Way, but that it neutral hydrogen is also rotating around our galactic center.

References

[1] George Brown. *Radio Lab Write-up*. 2018.

[2] Westerhout. *A Summary of Our Knowledge of the Neutral Hydrogen in Galaxies*. 1962.

6 Appendix

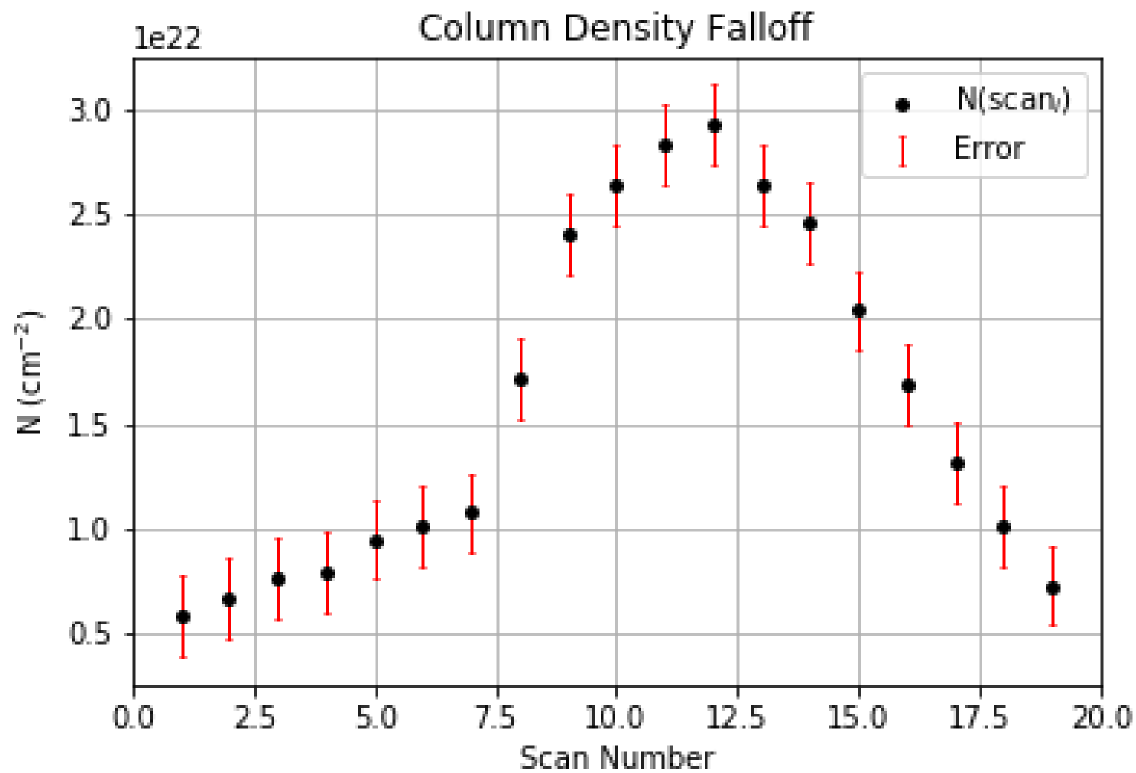
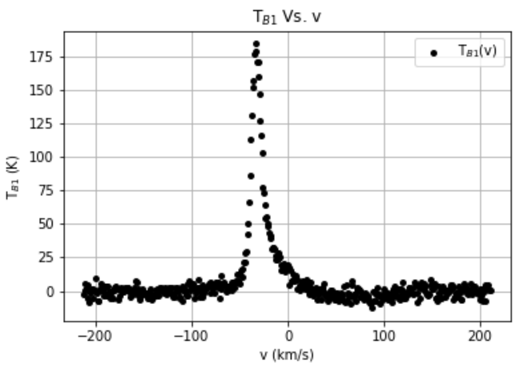
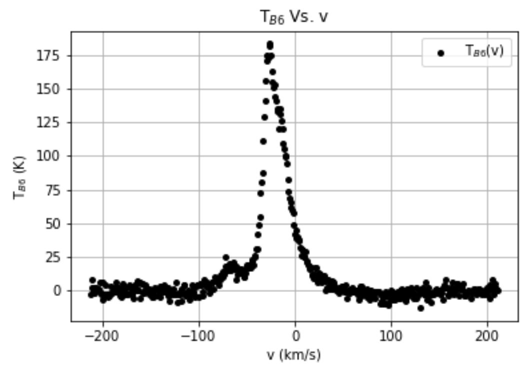


Figure 1: Column density per trace (observation). With the shift in latitude per trace, we can see that the peak column density coincides with a latitude of 0° (along the galactic plane).



(a)



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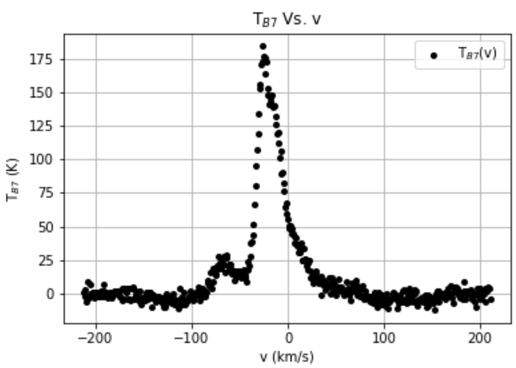

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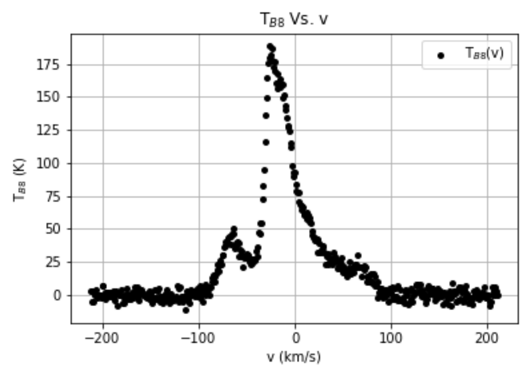

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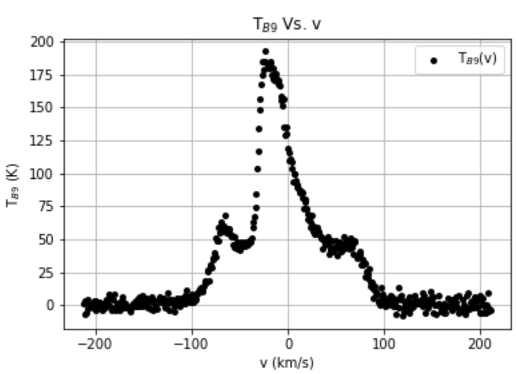

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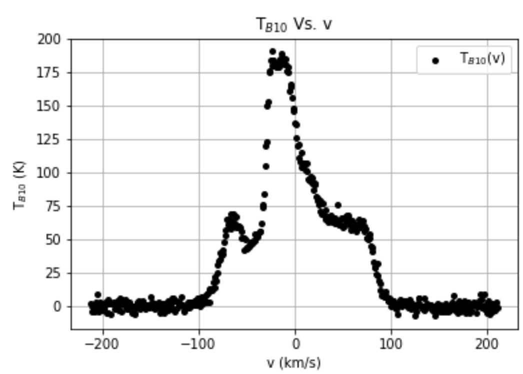

(f)

Figure 2: Set of six Traces: (a) Trace 1; (b) Trace 6; (c) Trace 7; (d) Trace 8; (e) Trace 9; (f) Trace 10

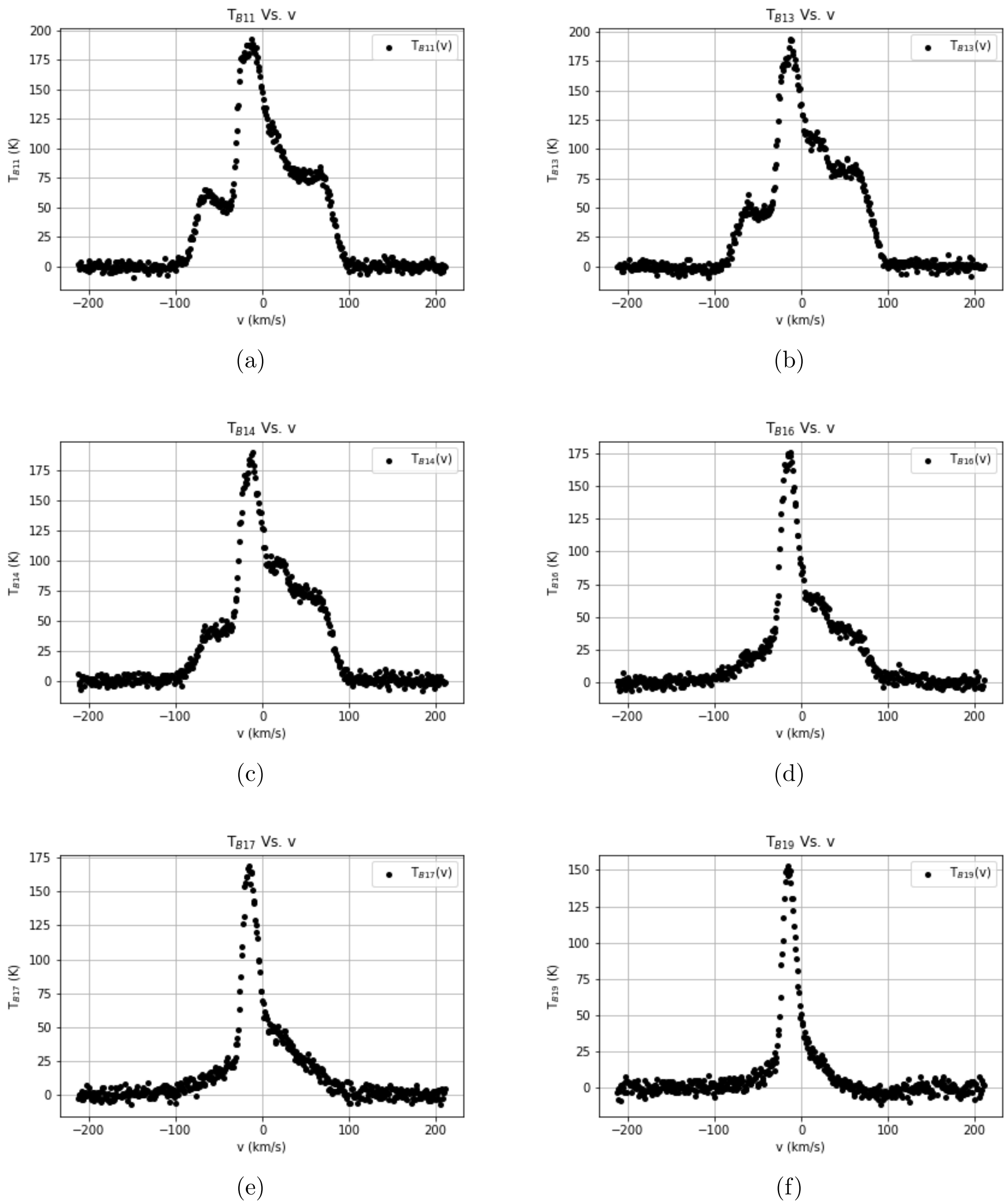

Figure 3: Set of six Traces: (a) Trace 11; (b) Trace 13; (c) Trace 14; (d) Trace 16; (e) Trace 17; (f) Trace 19