Ph 343 Lab 5 The Thickness of the Galactic Hydrogen Disk

Due: Monday, April 21, 2003

Purpose: Measure the angular width of the Galactic hydrogen disk at one galactic longitude.

Procedure:
Log onto Greenbank and start the SRT control window. Calibrate with the noise diode at an altitude of at least 30 degrees. Use a frequency 1419.4 MHz, 50 frequency bins, and zero frequency step. This frequency is at the lower boundary of the scan range of the observations for the rest of the lab and is far enough from 1420.4 MHz (the laboratory wavelength of the Hydrogen spin-flip line) to avoid contamination of the calibration by hydrogen emission — which occurs almost everywhere on the sky.

To measure the width of the H I disk, use a central frequency of 1420.4 MHz and 50 frequency bins with the default spacing of 0.04 MHz. Point the telescope to the galactic longitude of 180 deg and record 500 s of data at galactic latitudes of 0 deg, ±2.5 deg, ±5.0 deg, ±10.0 deg, and ±15.0 deg.

Analysis:
1. For each of your pointings, calculate the average system temperature at each observed frequency and its uncertainty. Also calculate a row in your spreadsheet that contains the frequencies at which you observed. The system temperature *versus* frequency is your observed spectrum at each latitude.

2. At each frequency, the observed system temperature is the sum of the receiver temperature, the spill temperature, and the antenna temperature from the hydrogen emission. In order to study the Galactic disk, we need to subtract the first two terms from the system temperature to leave just the hydrogen emission. The usual procedure is to estimate the "baseline" of the receiver temperature plus spill temperature from the measurements at frequencies far enough away from 1420.4 MHz that they contain no hydrogen emission. In other words, where the system temperature is not changing with frequency at the two ends of each of your spectra. The baseline actually appears to change roughly linearly with frequency in a spectrum. So, you need fit a line to the temperature measurements in the baseline and subtract that from your system temperatures to produce antenna temperatures for the HI emission.

The simplest way that I have found to fit a line to (frequency, temperature) points in Excel is the following. Feel free to use your own procedure, if you wish. In either case, your lab report should briefly describe what you have done. a) Copy the *values* of your average temperatures (*i.e.*, use "paste special") into a new row. b) Clear the temperature values in this new row that contain HI emission – in other words, leave only the baseline values. This is necessary because the Excel functions which calculate the intercept and slope of the line only accept single ranges of cell values, but will ignore blank values. You will need to experiment with just what temperature values to include in the baseline before you are satisfied that you have the best set. c) Use the Excel functions SLOPE and INTERCEPT with your row of frequencies and row of censored temperatures to calculate the slope and intercept of the line that best fits the baseline. Put these values in their own cells. Unfortunately, these functions do not return the uncertainties in their values. c) Calculate the value of the fitted line at each frequency point and subtract this from the average system temperature at that point to get the antenna temperature at each frequency.

Find the antenna temperature (the baseline-subtracted temperature) as a function of frequency for each pointing. Your report should include a printout of the lines from the spreadsheet that show your calculations, but it does not have to include a printout of the raw data.

3. For each pointing, find and report the maximum antenna temperature and the frequency of the bin at which the largest temperature occurs. Also estimate the frequency on either side of the maximum at which the antenna temperature has fallen to half the maximum value. The hydrogen emission occurs over a range of frequencies because of the motion of the gas in the interstellar medium. At the Galactic anticenter, we are seeing primarily the turbulent motions of the gas, since the Galactic orbital velocities are all across our line of sight. Estimate the size of these turbulent velocities using the Doppler formula with your measured frequencies at which the antenna temperature has fallen to half of the peak value. Express the velocities in kilometers per second. Do these velocities show any dependence on galactic latitude, b?

4. Plot antenna temperature *versus* frequency for your nine pointings. Put all of these baseline-subtracted spectra on one plot. Discuss how the shape of the spectrum varies with b. At a minimum, discuss whether the spectra at different b's are or are not the same except for a vertical (multiplicative) scaling.

5. Plot your peak antenna temperatures from part 3 *versus* b. Is the plot symmetric about $b = 0$? Make a simple estimate of the galactic latitudes (plus and minus) at which the peak temperature has fallen to half the value observed at $b = 0$.

6. For each of your pointings, sum the antenna temperature over all of the frequency bins for which you judge that it is significantly different from zero. This produces a number that is proportional to the the total amount of hydrogen emission along that line of sight. Plot this total hydrogen emission *versus* b. Is this plot symmetric about $b = 0$? If the plot is not symmetric, discuss possible reasons why. Estimate (again, simply) the galactic latitudes at which the total emission drops to half its value at $b = 0$. Is the plane thicker or narrower as measured with the total emission as compared to the peak emission?

7. Calculate the column density, N_H, of neutral hydrogen (in atoms per square centimeter) along your $b = 0$ line of sight using the formula

$$\begin{aligned} N_H &= (3.88 \times 10^{17} \text{ atoms/cm}^2\text{/kHz/K}) \int_0^\infty T_b d\nu \\ &\simeq (3.88 \times 10^{17} \text{ atoms/cm}^2\text{/kHz/K}) \sum T_b \Delta\nu. \end{aligned}$$

Here T_b is the observed brightness temperature of the hydrogen emission, so the sum is the same one as calculated in part 6, and $\Delta\nu$ is the width of the frequency bins in kilohertz (kHz). This formula assumes that the gas is optically thin (*i.e.*., transparent) to 21-cm radiation, which is reasonable for most lines of sight.