# Ph 343 Lab 6 The Galactic Rotation Curve

## This part due: Tuesday, November 26, 2002

**Purpose:** Measure the rotation curve of our Galaxy interior to the Sun's distance from the Galactic center. Also, place limits on the circular velocity at the Sun's distance from the Galactic center. The measured rotation curve will yield the amount and distribution of mass in our Galaxy from the center out to the Sun's location.

We will determine the Galactic rotation curve using the standard method of measuring the radial velocities of HI gas along lines of sight with galactic longitudes $0° < \ell < 90°$ ($1^{st}$ quadrant – which is best observed from the northern hemisphere) and $270° < \ell < 360°$ ($4^{th}$ quadrant – best observed from the south). In these quadrants, the most positive ($1^{st}$) or negative ($4^{th}$) radial velocity occurs for gas at the point where the line of sight penetrates closest to the galactic center. This point is called the tangent point and occurs at a distance from the Galactic center of

$$R_{min} = R_0 \sin(\ell), \tag{1}$$

where $R_0$ is the Sun's distance from the center. The radial velocity of the gas at the tangent point is

$$v_{r,max} = \Theta(R_{min}) - \Theta_0 \sin(\ell), \tag{2}$$

which implies

$$\Theta(R_{min}) = v_{r,max} + \Theta_0 \sin(\ell). \tag{3}$$

Here $\Theta_0$ is the circular velocity at $R_0$. Observations at a series of galactic longitudes in the range $0° < \ell < 90°$ will map out the circular velocity for $0 < R < R_0$.

One problem with Equation 3 is the presence of $\Theta_0$, which the observations do not yield. One approach to determining $\Theta_0$ is to measure the spectrum of HI emission at $\ell = 90°$. At that longitude,

$$v_r = \Theta(R)(R_0/R) - \Theta_0. \tag{4}$$

If the disk of our Galaxy extends to sufficiently large radii and $\Theta(R)$ does not increase faster than $R$, then the most negative observed radial velocity will be $-\Theta_0$.

**Procedure:**
Log onto JodrellBank and start the SRT control window. Use a central frequency of 1420.4 MHz (the laboratory wavelength of the hydrogen spin-flip line) and 50 frequency bins with the default spacing of 0.04 MHz.

Point the telescope to an altitude of 30 degrees and calibrate the receiver using the noise diode.

Point the telescope to the galactic longitude selected by myself or the TA and record 600 s of data at a galactic latitude of 0 deg. Our goal is to observe all galactic longitudes greater than 0° and smaller than 90° in steps of 5°.

Point the telescope to $\ell = 90°$, $b = 0°$ and record 1500 s of data. Repeat at $\ell = 90°$, $b = +15°$. This second observation is to check for the effects of the warp of the galactic disk.

**Analysis:**
The goals for this first stage of the analysis are to produce HI spectra with a sloping baseline

subtracted and to measure the most positive velocity with HI emission in your spectra from $0 < \ell < 90$ deg (both from this lab and the one from lab 5). In the last week of the class you will use the maximum positive velocities to calculate the rotation curve and the sum of all of our $\ell = 90$ deg spectra to estimate $\Theta_0$.

1. For each of your three pointings, calculate the average system temperature at each observed frequency. Also calculate the uncertainty in that temperature.

2. In lab 5 we noticed that the baseline seemed to increase from left to right across the 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. Start with your spectrum measured at a longitude between 0 and 90 degrees.

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) Create a row in the spreadsheet containing the value of the frequency at each point. b) Copy the *values* of your average temperature (*i.e.*, use "paste special") into a new row. c) 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 may need to experiment with just what temperature values to include in the baseline before you are satisfied that you have the best set. d) Use the Excel functions SLOPE and INTERCEPT 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. e) 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.

Your report should include a printout of the lines from the spreadsheet that show your calculations, but it does not have to have a printout of the raw data.

3. Similarly, find and subtract a linear baseline from your $b = 0$ deg spectrum from lab 5 to produce a value for the antenna temperature at each frequency.

4. Plot antenna temperature *vs.* frequency for the results of parts 2 and 3. Include error bars. Assume that the uncertainty in each antenna temperature is the uncertainty in the original average system temperature. This neglects the uncertainty in the fitted baseline, but that is probably not too bad an assumption since that line is the result of a fit to a number of points. Discuss how good a job the linear baselines did at producing a subtracted spectrum with temperatures constant at 0 for frequencies outside of the range with HI emission.

5. For each of your two plots, find the lowest frequency bin with an antenna temperature significantly different from zero. Use the Doppler formula, $v = c(\nu_0 - \nu)/\nu_0$, to calculate the radial velocity that corresponds to each of the lowest frequencies. The laboratory frequency for the HI emission is $\nu_0 = 1420$ MHz. Use your judgment to estimate the uncertainties in these radial velocities and justify your values.

6. Find and subtract a linear baseline from your $\ell = 90$, $b = 0$ and $\ell = 90$, $b = 15$ spectra. Leave the results in an Excel file in your "My Documents" folder. All your lab report needs to contain is the name of the file. I will take all of the individual spectra and sum them for you to use in the next part of the lab.