The Small Radio Telescope: Measuring Neutral Hydrogen in Our Galaxy

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Objective:

The objective for this lab is twofold. The first objective is simple – to become familiar with the (small) radio telescope (SRT) that is positioned on the roof of Olin. Though the telescope is small, the program used to operate the telescope is similar to what would be used for any other radio telescope. Simply becoming familiar with this and learning how to move the SRT and take the desired data for any location on the sky will be a valuable experience. The second is more specific. You will want to take data in order to produce a rotation curve for our galaxy (a plot of the rotation velocity vs. the distance from the center of the galaxy) and an L-v diagram (a plot showing the velocity distribution of the neutral hydrogen in our galaxy as a function of the galactic longitude.) From the rotation curve, you should have experimental evidence for dark matter.

Important Background Info & Astro Review:

Many of you may not have taken either of the Astrophysics classes offered, so this may be new to you, for others it may be useful review. The SRT is tuned to a wavelength of 21 cm (or a frequency of 1420.4 MHz). This wavelength corresponds neutral hydrogen. Much of the mass in our galaxy exists in clouds of hydrogen at a temperature of ~ 100 K. At this temperature, the hydrogen is in its ground state. The spin of the atoms is what is important here. The proton and the electron can be either parallel or anti-parallel. The parallel spin state is at a slightly higher energy than the anti-parallel, so when the spin state flips, a low energy photon is released. This light has a wavelength of 21 cm. (You probably saw much of the theory behind this in quantum.) Anywhere with a large amount of neutral hydrogen should emit a significant amount of this wavelength of light. Therefore, anywhere we observe a strong 21 cm signal, there should be a large amount of hydrogen.

Astronomers use the galactic coordinates L and b. L is galactic longitude. Zero is the direction straight towards the center of the galaxy, 180 is in the direction straight away from the center of the galaxy. b is the angle out of the galactic plane. If b is zero, you are looking straight into the plane of the galaxy.

When one observes a spot on the sky using the SRT, one often sees that the peak is not exactly at 1420.4 MHz. This is due to the Doppler shift. The hydrogen has motion that can be either towards or away from us. Thus, by measuring the frequency shift in the measured value, one can determine how fast the hydrogen is moving relative to us. Using these velocities, and some assumptions, the rotation velocity as a function of the distance from the center of the galaxy can be determined.

Procedure:

Go up on the roof, (with professorial guidance) and observe the SRT. The antenna is 2.3 meters in diameter and essentially looks like a satellite dish. It is mounted on top of the motor and the base. The motor allows the antenna to move radially in the vertical and the horizontal. The antenna reflects the radio waves to a focus at the receiver, also known as the feed horn. If you are interested in exactly how the feed horn works, visit
http://www.haystack.mit.edu/edu/undergrad/srt/index.html
and there should be a link that gives the information.
This website has all kinds of other information regarding this radio telescope.

Go to Olin 304 (the astro-computer lab); the computer you will need is on the right as you enter the room. Turn on the computer. It will take awhile to boot up, but eventually you will see a screen that wants a login. This is a linux system. Type in "radiotel" for the user and "m00nch33z3" for the password. open up a terminal. Type in "rt 0", this should load to telescope controls.

A screen should pop up that shows the limits of the telescope movement and some of the stellar object up in the sky at the present time. Across the bottom, the azimuth angle is measured. Zero is due east, 180 due west, etc. On the right, the elevation is measured. 90 is straight up. The telescope's position is marked by a red +. In the middle of the screen there should be a time-plot of the power counts being received. These counts correspond roughly to temperature. The counts should be a little greater than 100 in the stow position. It is possible to calibrate the SRT so that the do indeed correspond to the temperature of the object, but this does not aid us in any way, and is thus a waste of time.

Try clicking on one of those objects whose elevation is greater than 10. The SRT should move to the object. The counts will go down, probably to about 90. Why might this be? The telescope can be pointed to any azimuth and elevation by clicking on the "AzEl" button on the top right. After clicking this button, click on the text box on the bottom of the screen and type in the desired azimuth and elevation. Do this.

Now initiate a frequency scan. This can be done by clicking on the box marked "freq". Now type in the center frequency for the scan (1420.4) the number of frequencies to scan (do 50) and the step size in MHz (type 0.04). Two plots will pop up in the upperright. One shows the results of the last scan, one integrates all of the previous scans. The amount of time the detector has been active is also displayed. This will be much smaller than the actual time you have spent on the object, why?

If you wish to record a frequency scan, you have to be proactive and tell the computer to start recording. Do this by clicking the “record” button and then clicking the text box and then typing the name of the file you want to record. To stop the recording, click the record button again. Record two or three random locations for an integrated time of about a minute each. Double check that the files actually contain reasonable data.

Now we’re ready for the real guts of the lab. There should be a dotted line displayed on the screen. This line denotes where the galactic coordinate b is equal to zero. Each distance between each dot corresponds to a step in L of five degrees. Your task is to measure 10 longitudes with a b of 0 (+/- 1) that are each 10 degrees of L (+/-1) apart from each other. Preferably, these Ls will be between 0 and 90, but it is probable that not all of these longitudes will be observable at the time of your lab. Be sure that you mark the b, L, and also the velocity of the local standard of rest (vlsr) for each measurement. The vlsr is displayed on the right. Do two measurements with integrated time of about 1 minute for each L. The site
http://www.haystack.mit.edu/edu/undergrad/srt/SRT%20Projects/rotation.html
has more information about this galactic rotation experiment, and some geometric drawings that could be very helpful.

Analysis:

The data for this lab is best analyzed using excel. All of your recorded files can be opened in spreadsheet form using this program. You will simply have a list of numbers in columns that represent the frequency. For the velocity that corresponds to the frequency, simply use the non-relativistic Doppler formula and subtract the vlsr. Plot average power counts vs. L and velocity. This is called an L-v diagram. Comment on various features of the plot and what they might mean. Is there any sort of trend?

For all of the data collected for L <= 90, determine the “maximum velocity. This would be the maximum velocity for which one might consider the velocity to be part of the peak. This is somewhat arbitrary, so be sure to consider this in any error estimations. What might be special about the maximum velocity? Hint: think angles. Use this maximum velocity to create a rotation curve. How, you might ask? Think about velocities along the line of site and perpendicular to it. These combine for a total velocity. How might this change as a function of L? Helpful might be the fact that we are 8.5 kpc from the center of the galaxy, and we go around the galaxy at a speed of 220 km/s. How might the resulting rotation curve show the existence of dark matter? (Some of your classmates will certainly have take Astrophysics II, they will be a useful resource.)

In addition, address the following:

1. What Galactic mass distribution might fit your data?
2. On the basis of Keplerian motion what is an approximate estimate of the total mass of the Galaxy in solar masses ($M_{sun} \approx 2 \times 10^{30}$ kg) ?
3. How can you use your Galactic velocity dependence with distance to map the distribution of hydrogen?