(Astro)Physics 343 – Spring 2010
Lab # 1: Measuring the Telescope Beamwidth with the Sun

Observations: week of 1 February 2010

Reports due: 15 February 2010

Purpose: The *antenna pattern* or *beam pattern* of a radio telescope describes its response as a function of direction. This pattern will be the same whether the telescope is being used to transmit or detect radio waves. If θ and ϕ are polar coordinates describing the location of a source relative to the telescope's axis (i.e., the direction in which the telescope is pointing), then we can define the *normalized beam pattern* $P_{\rm n}(\theta, \phi)$ to have a value of unity at $\theta = 0$. Radio telescopes with perfect circular symmetry have beam patterns that do not depend on ϕ. In this case, we define the *beam width* as $2 \times \theta_{1/2}$, where $\theta_{1/2}$ is the angle at which

$$P_{\rm n}(\theta_{1/2}, \phi) = 0.5 \quad (1)$$

We refer to $2 \times \theta_{1/2}$ as the *full width at half–maximum* (FWHM) of the beam pattern, or simply as the *half–power beamwidth* (HPBW). Note that in addition to the *main lobe* of the beam pattern, within which the HPBW is measured, we can also have *sidelobes*– directions far from the telescope's axis in which there is still a nonzero response. If a strong source happens to fall in a sidelobe when you are trying to detect a weak source in the main lobe, you may be in trouble!

To measure a telescope's HPBW, we need to move it in very short steps across a bright radio source. Although certain radio–bright binary stars (e.g., Cygnus X–1) and geosynchronous satellites can be used to do this for the SRT, the best strategy is to use the Sun.

Before the lab period: You should have read the "Small Radio Telescope Operator's Manual". You should also already have written a command file to (1) point at the Sun (2) set the observing frequency to 1415 MHz (3) move 30° in azimuth away from the sun (4) pause for 60 s (5) return to the Sun and do an "npoint" scan. You will be able to hit the ground running in lab if you also prepare a command file that can obtain the 51–point horizontal scan of the Sun described in Step 5 below. If possible, leave your command file on a computer from which we can transfer it via the internet (the alternative is to type it in during lab).

Procedure:

1. Log onto the computer that controls the telescope using your account and password (in fact, you'll need to log onto "obsastro" rather than "blanco"). Open a "Command Prompt" window by clicking, successively, on Startup → Programs → Accessories → Command Prompt. When this opens, type
   ```
   cd c:\srt
   java srt 0
   ```
   which will launch the control program.

2. Once the SRT control window is running, point the telesope at the Sun and do a 25–point raster scan (using the `npoint` button). Record the time, the azimuth and elevation of the Sun at the time of the observation, the azimuth and elevation offsets

of the maximum of the antenna temperature, and the value of the maximum antenna temperature.

3. Near the beginning of the lab period, you and your lab partners should work out a "consensus" command file to measure the radio signal at 51 points spaced by 1 degree, starting at a $-25°$ offset from the Sun and going to a $+25°$ offset. The procedure should open a file with a unique name, store your results in that file, and close it when the measurement is done. Do this for two scans:

   - one along a line of constant azimuth, and
   - one along a line of constant elevation.

   Use a frequency of 1419.0 MHz with 10 samples at each point, and a frequency step of 0 MHz. (The poorly-documented frequency mode 5 of the digital receiver accepts a central frequency, mode – 5, number of samples, and a frequency step.) With ten samples at each point, you can improve your precision in measuring the signal–to–noise ratio, and you can get a decent estimate of the uncertainty in the result.

4. Repeat your azimuth and elevation scans until each member of your lab team has a dataset of his/her own. Remember to edit the procedure to change the name of the output file each time (for clarity, including each person's name or initials in his/her filename would be helpful). You should store the command file and the output in a subdirectory off `c:\srt`, and email yourself the output file (with the help of your instructor if needed).

Analysis:

1. The data analysis should take place in two phases:

   - Each individual student should analyze his/her own data set and prepare it for comparison with results from the other members of his/her lab group.
   - Once the above is done, the three members of each lab group should get together and compare results.

2. You may analyze your data file using the software package of your choice; Excel is one possibility, but you are welcome to write your own short programs (in FORTRAN, C++, or another language) if you prefer.

3. Find the average of your ten measurement at each scan position and the uncertainty in the average. (Excel has a "Function" to do this.)

4. Plot the average values (with error bars) for your elevation scan on one plot and those for your azimuth scan on another.

5. Estimate the half-power beam width (HPBW) in both azimuth and elevation. A complication with the azimuth scan is that each change of 1 degree in azimuth is really only $(1\,\text{deg})\cos(\text{elevation})$ on the sky. Correct your azimuth HPBW for this effect to get the true beamwidth in that direction. Is the HPBW the same in the elevation and azimuth directions?

6. Overplot on your two plots the beam pattern expected for a uniformly illuminated circular aperture with the width of your antenna dish:

$$P(\theta) = \left(\frac{2J_1(x)}{x} \right)^2, \tag{2}$$

where $x = \pi\theta/(\lambda/D)$ and θ is the angular offset from the center of the beam in radians. Here $J_1(x)$ is the spherical Bessel function of the first kind with order 1. Look in your favorite math reference book for tables of values or convenient polynomial approximations if you are not able to implement this in Excel. Multiply $P(\theta)$ by a constant and then add another constant so that the theoretical beam pattern has the same peak value and value at large offsets as your real profile. Comment on any difference in shape between the theoretical and observed beam pattern.

7. Get together with your lab partners and share your results. How well do the several scans agree with each other? As well as you expect from the uncertainties? Cooperate in making a "consensus" plot that shows each of the three data sets on the same graph.

8. Each of you must prepare an individual lab report giving your results and conclusions. Your writeup and conclusions should be your own, not the results of a group effort. However, some parts (e.g., plots combining results from everyone in a group) are group efforts and should be clearly labelled as such.