# CLEA/VIREO

RADIO ASTRONOMY OF PULSARS

## 1. Starting up the program

Double click on the *Vireo* icon on the start screen.

Go to File ... Login. You don't need to enter names or a table number. Just press *OK* and press *OK* again when it says *You didn't Enter Anything.*

Go to File ... Run ... Exercise ... Radio Astronomy of Pulsars.

Go to Telescopes ... Radio. A picture of a radio telescope will appear in the center of the control screen when the telescope is ready.

Turn on the telescope and open the control panel by clicking the button in the lower right under *Telescope Control Panel* so that it is green and says *On*

A new window will pop up. This is the *Radio Telescope Control Screen.* You now have control of the telescope.

Turn on tracking by clicking the button *Tracking* in the lower left corner of the control screen. The telescope will now follow a set location as it moves across the sky due to Earth's rotation.

## 2. Observing the Pulsar 0628-28

To point the radio telescope to pulsar **0628-28**, click Slew ... Hotlist ... View/Select from List. Double click on *0628-08* (the name is in the leftmost column). Click *OK* on the window that pops up. When it asks to confirm, click *Yes.*

The telescope will begin to move. Don't click anything until the telescope is done moving and a window has popped up confirming that the telescope has reached the target coordinates.

**Question 1**: Write down, on your answer sheet, the Right Ascension and Declination you are pointing to. Hint: RA and Dec are on bottom of the window.

Click on the *Receiver* button in the upper right of the telescope control window to turn on the receiver. A rectangular window will open which has the controls for your receiver on the right, and a graphic display of the signal strength versus time on the left.

The frequency the receiver is set to is displayed in the window near the upper right. It is currently set to **600 MHz**. Keep it there for now. There are buttons next to it to tune the receiver to different frequencies. Fine tuning can be accomplished by changing the Freq. Incr. (frequency increment), button to its right in conjunction with the main tuning button.

Click on the *Mode* button to start the receiver. A graphical trace will begin at the left of the screen, tracing out the signal strength versus time on the graph. It looks like a random jiggle, which is the background static, with an occasional brief rise in signal strength, which is the pulsar signal. (If your computer is equipped with sound, you can also hear what the signal would sound like if you converted the signal to sound, like you do when listening to a radio station). Note how regularly the signal repeats.

Click on the *Mode* switch again to turn off the receiver. Note that it completes one scan of the screen before it stops.

Start the receiver again. While the receiver is running, change the vertical gain control by clicking on the up and down buttons next to *Vert. Gain*. The best setting is one where the pulses are high, but don't rise above the top of the display.

**Question 2**: Write down the best gain setting. The setting will vary from pulsar to pulsar, and also is dependent on how you have set the Horz Sec control. (It should be set at 4, right now).

Click the *Mode* switch off, and when the trace stops, reset **Horz Sec to 2** (horizatonal scale can only be changed when the receiver is off). This will make the graphic trace take 2 seconds to sweep across the screen. Note that the signal seems weaker, because the receiver is spending less time collecting radio waves before it displays them on the screen. (Astronomers would say the *integration time* is shorter). Note that if the horizontal scale changes, the vertical scale might also need to be adjusted so that the pulses are visible and fit on the screen.

Set the **vertical gain to 4** and the **horizontal seconds to 4**, and make sure the **frequency of the receiver is 600 MHz**. Start the receiver. Let it run for a few seconds to see the pulses, then turn it off again. When the trace stops moving, you can measure the time between pulses on the screen.

The computer has measuring cursors to aid in this. Holding down the left mouse button produces a vertical blue line on the screen which you can move as you hold down the button. Center it in the middle of one of the pulses near the left side of the screen. Note the blue numbers on the screen that tell you the time in seconds at which the pulse arrived.

**Question 3**: Time increases to the right. In order to measure the time of a second pusle, hold down the right mouse button. Position it over the next pulse. You can read this time from numbers on the screen, too. Record the time of arrival of both pulses. The difference between these is the period of the pulsar.

**Question 4**: A more precise way of measuring the period is to measure the time elapsed between several pulses and then divide by the number of periods that have elapsed. Set the **horizontal seconds control to 16**, turn down the gain a notch or two, and turn on the receiver again so that you can see many pulses on one scan. Measure the time it takes for **10 periods**, and use this to calculate the period of the pulsar. Record your measurements on your sheet.

**First Table**: Measure the period at different frequencies. Since the signal strength changes with frequency, you may have to adjust the vertical gain or the horizontal seconds controls to see the pulses clearly at each frequency. Fill in the first table on your sheet.

**Question 6**: How does the pulsar signal strength depend on frequency? To see how it changes in a more systematic fashion, keep those controls set, for example 4 for the vertical gain and 4 for the horizontal seconds. Then look at the signal at various frequencies from 1400 MHz back down to 400 MHz. On your sheet, state whether the pulsar signal is stronger at (lower/higher) frequencies.

Close the receiver window but not the telescope window.

## 3. The Periods of Different Pulsars

Now we will look at the periods of different pulsars. The short period of the pulsar we have just measured is remarkable, especially when you consider that the period is the length of time it takes for the star to rotate once. Imagine an object as massive as our sun rotating once a second! The pulses of each pulsar are distinctive, both in period and in strength.

**Second Table**: Observe pulsars **2154+40, 0740-28, and 0531+21 (the Crab Nebula Pulsar)**. You can find each of them on the Hot List and can automatically slew to them just as you did with the previous pulsar. You will need to select which ever combination of frequency, vertical gain, and horizontal seconds you think is best. It may not be the same for each pulsar (or it may be the same). Fill out the second table on your sheet with your observations.

**Question 8**: Generally speaking, the rotation of a pulsar slows down as it ages. Using this fact and what you have observed rank the pulsars you have observed (the first pulsar you observed, named 0628-28, and the three in the table you just observed) from youngest to oldest on your sheet.

## 4. Measuring the Distance of a Pulsar Using Dispersion

Most pulsars can't be seen with optical telescopes, so we can't use their absolute magnitudes to determine distance. Instead, one powerful method is to use the phenomenon of *dispersion*.

All forms of electromagnetic radiation, including radio waves, travel at the speed of light. However, interstellar space is not quite a vacuum. On the average the interstellar medium consists of a few atoms and a few free electrons in each cubic centimeter. This slows down electromagnetic waves slightly. In general, the velocity of electromagnetic radiation is proportional to the square of the frequency divided by the electron density. Using the assumption that the interstellar electron density is 0.03 electrons/cm$^3$, the relationship between new velocity and frequency is:

$$v = \frac{f^2}{124.5} \tag{1}$$

This means that the lower the frequency, the slower the radiation travels. Thus, higher frequency pulses from a pulsar arrive a fraction of a second earlier than lower frequencies. In fact, we can use this fact to determine the distance to a pulsar. The relation is:

$$D = \frac{T_2 - T_1}{124.5((\frac{1}{f_2})^2 - (\frac{1}{f_1})^2)} \tag{2}$$

In this equation $T$ stands for the the arrival time of a pulse, just as it did previously, and $f$ once more stands for frequency.

If you are curious about the origin of equation, check out the appendix at the end of this lab.

Go to pulsar **0628-28**, set the **vertical gain to 4**, the **horizontal secs to 4** and tune to **400 MHz**. Start the receiver for one cycle to check the strength of the signal.

After the receiver is stopped, add a second receiver by using the **Add Channel** button. Set the vertical, horizontal, and frequency controls the same values as the first receiver. Change the **Freq Inrc.** value on the lower receiver to **10 MHz**.

**Question 9 and 10**: Turn on the receivers. The traces in each receiver should be the same. Now increase the frequency on the lower receiver to **410 MHz**. Is there a difference in arrival times between the two receivers? If it's not clear, slowly increase the frequency on the lower receiver in increments of 10, up to **600 MHz**. Use your observations to answer question 9 on your sheet and then write in answer 10 the reason for this relationship (**Hint: Read the introduction to this section**).

Turn off the receivers and open a third channel. Tun the second receiver to **600 MHz** and the third receiver to **800 MHz**. Set the **vertical gain to 4** and **horizontal gain to 4**.

Run the receiver for one cycle. At higher frequencies, the pulses arrive earlier. Thus the right most pulse on the top trace will be to the left on the second and even further to the left on the third (they may not be the right most pulses in these latter two). If this isn't clear, run the receiver for more cycles and watch. It is important that you are able to identify the same pulse in each receiver.

**Question 11**: Measure the arrival time of the pulses by clicking on the top most trace and dragging the white line (by holding down the white button) until it crosses the middle of a pulse. Do the same for each receiver. Make sure you measure the same pulse in each case. Remember that this pulse will be further to the left in each of the higher frequencies. That is your arrival times should be earlier at higher frequencies. Fill in your observations on the sheet.

**Third Table**: Using the dispersion equation fill at the third table on your sheet. Note that the subscript numbers for time and frequency should correspond. That is if $f_1$ is **600 MHz**, $T_1$ is the arrival time of that pulse. **Show your work on the bottom of the last page or on the back of the last page**.

Each distance you calculate in this table should be fairly similar. This pulsar is about 1000 pc away. Hopefully, the values you calculated are close to this. If not, go back and check your math.

**Fourth Table** Move to pulsar **2154+40** and fill out the forth table on your sheet using the same method as above. Again **show your work**.

## 5. Appendix

Consider two objects moving the same distance ($D$) but at different speeds ($V$). The amount of time ($T$) it takes each object to cover that distance will differ.

$$T_A = \frac{D}{V_A} \tag{3}$$

$$T_B = \frac{D}{V_B} \tag{4}$$

The difference in these times is

$$T_B - T_A = \frac{D}{V_B} - \frac{D}{V_A} = D * (\frac{1}{V_B} - \frac{1}{V_A}) \tag{5}$$

If we solve for D we get

$$D = \frac{T_B - T_A}{\frac{1}{V_B} - \frac{1}{V_A}} \tag{6}$$

Recall that the velocity of an electromagnetic wave going through interstellar space with electron density ($n_e$) of 0.03 electrons/cm$^3$ is dependent on frequency ($f$)

$$v = \frac{f^2}{124.5} \tag{7}$$

In case you're wondering this comes from the equation

$$v = \frac{f^2}{4150 * n_e} \tag{8}$$

Plugging this value into the distance equation above yields the dispersion equation.

$$D = \frac{T_2 - T_1}{124.5((\frac{1}{f_2})^2 - (\frac{1}{f_1})^2)} \tag{9}$$