Smiley Radio Telescope

Lab 2

The Doppler Effect

Lab 2- The Doppler Effect

Objective: In this lab, students will determine how fast an astronomical radio source is traveling. They will observe the Doppler Effect by measuring the 1420 MHz frequency (21 cm wavelength) shift for several objects.

Background:

Next time you are at a lake, watch the boats speed by. As they approach you the water, waves are compressed in front of the boat and the waves behind the boat are spread out. In other words, as the boats approach, wavelengths of the water waves are short, but the wavelengths behind the boats are long.

Figure 1. Boats generating waves.

The same effect occurs with sound. Listen to a train go by. Blowing its whistle, the pitch is high as it approaches you. When it goes past, and away from you, the pitch is lower. Sound waves from the whistle are compressed as the train approaches and stretched out as the train recedes from you (Figure 2 and Figure 3). You hear the short, compressed wavelengths as a higher frequency and the stretched, longer wavelengths as a lower frequency.
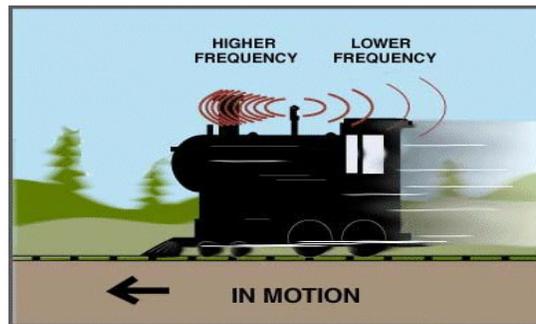

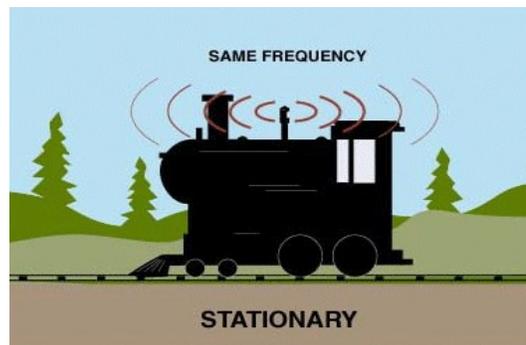**Figure 2. A train at rest sending out sound waves.**

Figure 3. A train in motion sending out sound waves.

Like water and sound, light can be described as waves. The same principle of compressed and stretched wavelengths of light from moving light sources applies. This principle is called the Doppler Effect. The Doppler Effect applies to objects that produce any type of wave (sound, water, light). In terms of light emitted by a moving object, the Doppler Effect states that the observed frequency of emitted light from a moving object depends on the speed of the moving object.

The equation for the Doppler Effect is:

$$f_{Dop}/f_{Rest} = v/c$$

where f_{Dop} is the Doppler shifted frequency, f_{Rest} is the rest frequency, v is the velocity of the source and c is the speed of light (3.00×10^8 m/s). After some algebra, the Doppler shift equation can be written as:

$$v = c(f_{Dop}/f_{Rest})$$

Now we have an equation that we can use to find the speed of a source if we know the Doppler and the rest frequencies of the light emitted from the source.

Radio waves and visible light waves are all part of the electromagnetic spectrum. Radio waves just happen to have a longer wavelength and lower frequency than visible light. Thus an object emitting radio waves will also produce the Doppler Effect, if that object (or the observer) is moving. In fact, many astronomical objects emitting radio waves show the Doppler Effect. For example, supernova remnants, relatively dense interstellar clouds of neutral hydrogen, and quasars, star-like objects, all exhibit the Doppler Effect. If we measure the Doppler shifted and rest frequencies, then we can find the speed of the source.

Procedure:

1. Login to Smiley. If you need any assistance with Smiley refer to the Smiley User's Guidesheet.

2. In **Map** mode, pick one of the objects. We suggest Cygnus A, Virgo A, the Crab Nebula, or the Galactic Center depending on which of these are above the horizon. Each of these sources is emitting 1.42 GHz radio waves, but when these objects are moving their 1.42 GHz radio waves are shifted when the arrive at the earth due to the Doppler Effect.

3. After you have picked an object click on **GO**.

4. Once Smiley has reached the target make sure Smiley is close to the target by comparing the **TARGET Coordinates** with the **CURRENT Coordinates** and using **HandPaddle**.

5. Go into **Spectrum** mode to begin measuring intensity.

6. Set your **PLOT RATE** to 1x, your **IF GAIN** to around 19, your **Base Frequency** to 1.42 GHz and click on **Begin Scan**.

7. Watch the scan. The x-axis is the frequency and the y-axis is the intensity. The center of the x-axis is the 1.42 GHz frequency (right click on the graph and click on "show grid" to see the x and y axes). Lower frequencies are left of the center and higher frequencies are to the right of the center. Notice that the peak in intensity does not occur at exactly 1.42 GHz, because of the Doppler Effect!

8. Click on **Save Scan** and name the scan. Then click on **Open Data File,** find the scan you saved and list the data points.

9. Record the Doppler shifted frequency of your scan and calculate the velocity of the source in the table below.

10. Repeat procedures #2 –8 for two more objects.

Object	Rest Frequency	Peak Intensity	Doppler shifted frequency	Velocity

Here is an example of a spectrum scan showing a Doppler shifted frequency from 1.42 GHz.
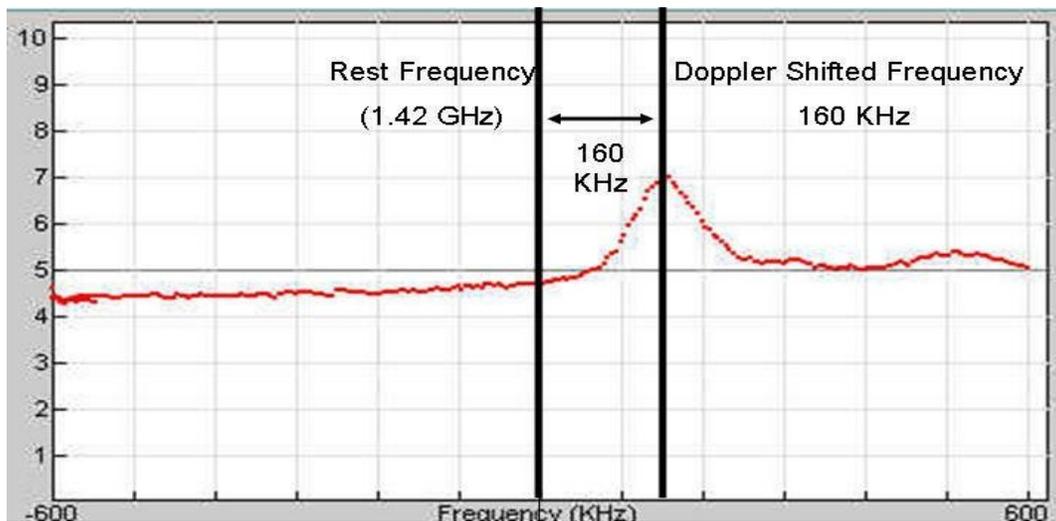
The rest frequency is 1.42 GHz (1.42 x 10^9 Hz) and the Doppler shifted frequency is 160 KHz (160 x 10^3 Hz).

Below is a screenshot of the listed points for the graph above showing the value of the peak intensity.

120.0000	6.2137
125.0000	6.3364
130.0000	6.5552
135.0000	6.7191
140.0000	6.7993
145.0000	6.8735
150.0000	6.8832
155.0000	6.9390
160.0000	7.0023
165.0000	6.9128
170.0000	6.8256
175.0000	6.6781
180.0000	6.6062
185.0000	6.4724
190.0000	6.3894
195.0000	6.2364
200.0000	6.0666

To calculate the Doppler shift from the above scan we use the equation:

$$v = c(f_{Dop}/f_{Rest})$$

or

$$v = (3.00 \times 10^8 \text{ m/s})[(160 \times 10^3 \text{ Hz})/(1.42 \times 10^9 \text{ Hz})]$$

Thus $v = 3.38 \times 10^4$ m/s

Discussion questions:

1. Convert the velocity of the objects you observed from m/s to km/hr and compare them to the speed limit on a typical highway (100 km/hr).

2. Are the objects you observed moving towards or away from us? How do you know?