

Group Members:

Hubble Expansion Activity

This lab makes use of software from CLEA (Contemporary Laboratory Exercises in Astronomy) which is being developed by Gettysburg College in PA. The purpose is to familiarize you with the data that has convinced astronomers that the universe is expanding.

1) Background information

Beginning around the last turn of the century, scientists began to observe a redshift in the spectrum of most galaxies. Redshift is the term used by astronomers to refer to the change in the wavelength of light that results when the source of the light is receding away from the observer. According to the Doppler principle, the wavelength of a receding source will be longer than that of a stationary source and thus the color is shifted toward the red end of the spectrum. The fact that the spectrum of distant galaxies was red shifted meant that those galaxies were receding away from the earth.

In the 1920's, Edwin Hubble began to measure the distances to galaxies. When he plotted the distances to the galaxies against the velocities found from their redshift, he found that the farther a galaxy was from the Milky Way (our own galaxy) the faster it was receding away from us. To the scientist of the day, this was incredible. Since the 1920's, many more galaxies have been measured and the relationship between the distance to the galaxy and the recessional velocity has been found to be the same. That relationship we now call Hubble's Law and the constant is called the Hubble Constant (H).

$$(1) \quad H = \frac{v}{D}$$

where v is the recessional velocity, usually in kilometers per second, and D is the distance to the galaxy, measured in megaparsecs (Mpc). The value of the Hubble constant is related to the age of the universe by the simple formula:

$$(2) \quad \text{Age} = \frac{1}{H}$$

2) Collecting the spectrum of a galaxy.

The CLEA software simulates the taking of the spectrum of a galaxy with an astronomical telescope. The first thing you need to do is start the program. Click on the **START** button in the bottom left corner of the screen. Select **PROGRAMS**, then **CLEA Labs** and then double click on **Hubble Lab**. The CLEA introductory screen will come up and you should select **LOGIN** from the menu at the top of the screen. Enter the names of the members of your group and click OK. The screen shown now is the title screen, select **START**.

You are now looking at the simulated view from the dome of the Virtual Telescope. The controls are on the left and the door of the dome is in the middle. Open the doors by clicking on the **DOME** button. The doors will open and you will see the star field that is visible through the viewfinder of the telescope. You will note that the stars are slowly drifting to the right. This is due to the rotation of the earth. To “lock-on” to the star field, turn the tracking on by clicking on the **TRACKING** button.

Now you want to center the cross hairs in the box on one of the galaxies (any one will do) by holding the N, W, S or E buttons down. To get the galaxy centered exactly, zoom in by clicking on the **Change View** button, you now see a set of parallel lines. Center the lines on the middle of your chosen galaxy.

You are now ready to start taking measurements. Click on the **TAKE READING** button. What you see now is a plot of the relative intensity versus the wavelength in Angstroms. Since you haven't started the count yet, there is nothing in your plot. Select **START/RESUME COUNT** from the menu bar. Now you can see the data as it is being gathered.

Below and to the right of the graph is the **Signal/Noise** ratio of your spectrum. If you have a very bright galaxy, this number will get large very quickly but if your galaxy is faint, it may take several minutes before it reaches an acceptable value. Collect data until you get a signal-to-noise ratio of at least 15 then hit **STOP COUNT** in the menu bar.

Below and to the left of the graph are four pieces of data. The **Object** is the name of your galaxy, it may be a name or a catalogue number. Record the name of your galaxy in the data table. Below that is the **Apparent Magnitude**; this is the apparent brightness of your galaxy. Record this in your data table, it will be used to find the distance to your galaxy. The last two things are the **Photon Count** and **Integration**; these are how many photons of light were collected and how long you collected for.

Now look at the spectrum of your galaxy. It may have a somewhat jagged look to it but there are two prominent absorption “lines” in it. These are the K & H calcium lines that normally appear at 3933.7Å and 3968.8Å, respectively. Since the galaxy is receding away from you, the lines are shifted to longer wavelengths. Measure the actual wavelengths of the two lines by holding the left mouse button down and moving the crosshairs to the bottom of each line. The **Wavelength** (in Å) will appear above the plot. Record both wavelengths in the data table.

Once you have all the data collected for this galaxy you will need to repeat the procedure for other galaxies. Select **Return** from the menu bar (be sure you

have all the information recorded as it will be lost when you go back to the previous screen). Click the **Change View** to get back to the larger field of view. Go to the **Field** menu and select one of the other fields then click on OK. The telescope will slew over to the new field. Zoom in on a galaxy and repeat the procedure for gathering the spectrum. Do this for five different fields for a total of five galaxies. **DO NOT DO MORE THAN ONE GALAXY IN ANY FIELD.**

DATA TABLE

#	Galaxy Name	Apparent Magnitude	K Calcium Line (Å)	H Calcium Line (Å)
1				
2				
3				
4				
5				

3) Determining how far and how fast.

First we need to find out how far away the galaxies are. We will assume that all galaxies have the same luminosity so, the farther away it is, the dimmer it appears to be. If all galaxies have an absolute magnitude of -22 , we can find the distance to the galaxy by using the formula

$$(3) \quad D = 10^{\frac{m-M+5}{5}}$$

(Read "10 to the power $\frac{m-M+5}{5}$ ")

m is the measured apparent magnitude

M is the absolute magnitude ($M = -22$)

D is the distance in parsecs

Since M is -22 for all the galaxies equation (3) simplifies to

$$(4) \quad D = 10^{\frac{m+27}{5}}$$

Calculate D for each of your galaxies. Divide by 1,000,000 to get the value in Megaparsec and record the result in the Calculated Values table.

Now we want to find out how fast the galaxies are receding away from us. To do this, we will use how much the wavelengths have been redshifted. The recessional velocity can be calculated using the redshift formula

$$v = c \times \frac{\lambda_{measured} - \lambda_{actual}}{\lambda_{actual}}$$

$\lambda_{measured}$ is the measured wavelength

λ_{actual} is the actual wavelength (3933.7Å for the K-line or 3968.8Å for the H-line)

c is the speed of light (300,000 km/s)

Calculate the recessional velocity for each galaxy using **both** the H and K lines as well as the average of the two and record the results in the table.

CALCULATED VALUES TABLE

Galaxy Name	Distance (Megaparsec)	K Recessional Velocity (km/s)	H Recessional Velocity (km/s)	Average Recessional Velocity (km/s)

4) Finding the value of H

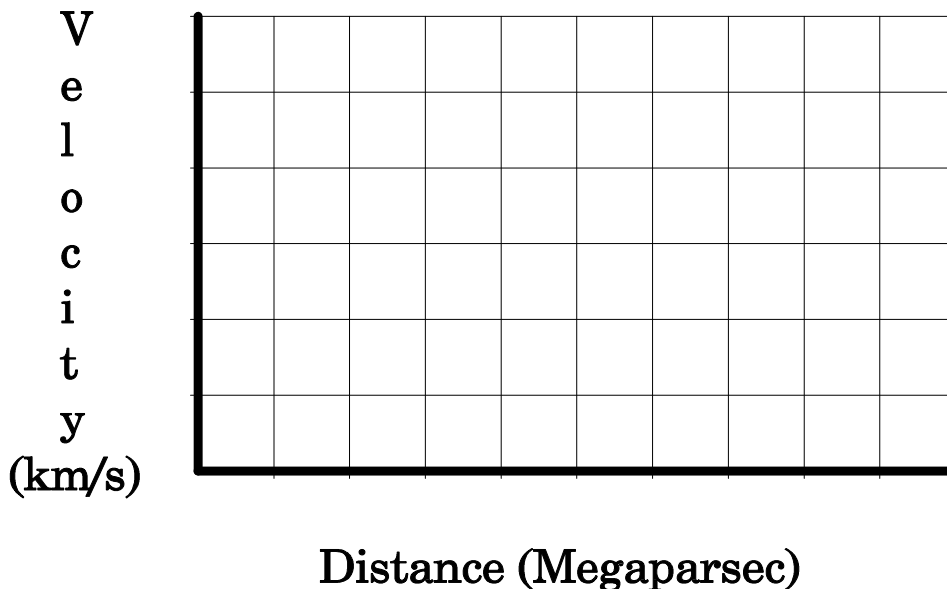
To find the value of H, we will do the same thing that Hubble did in the 1920's: plot the recessional velocity against the distance to the galaxy. The value of H is then simply the slope of the plot. Plot the five galaxies in the graph on the next page and draw the best straight line through them. Determine the slope of that line using the formula

$$\text{slope} = \frac{\text{rise}}{\text{run}} = \frac{y_2 - y_1}{x_2 - x_1}$$

where y_1 and y_2 are the values of the velocity at the bottom and top of the graph, respectively, and x_1 and x_2 are the corresponding values of the distances. Be sure to label the scale you are using on the axis of your graph. Choose a scale that uses as much of the space of the graph as possible.

The slope is your value for the Hubble constant. Record that value below

My Value for H _____ ^{km}/_s per Megaparsec



5) Determining the age of the universe.

As we saw in the background at the beginning of this activity, the age of the universe is simply $\frac{1}{H}$. The units of the Hubble constant you have calculated are km/s per megaparsec. To get the age of the universe in units we can understand, we will need to convert H into units of time. First, divide your H by the number of kilometers in a megaparsec (3.086×10^{19}). This will give H in units of per second.

H (in km/s per megaparsec) _____ $\div 3.086 \times 10^{19} =$ _____ (in /sec)

Now you can calculate the age of the universe in seconds.

Age (in seconds) = $\frac{1}{H} =$ _____ where H is in /sec.

Now convert seconds into billions of years (Gyr) by dividing by the number of seconds in a billion years (3.158×10^{16})

Age (in sec) _____ $\div 3.158 \times 10^{16} =$ _____ (in Gyr)

Does the value for the age of the universe you get seem reasonable? The most widely accepted value for the age of the universe is 13.8 Gyr. Find your percent difference using the formula below.

$$\% \text{ Diff} = \frac{\text{Your Value} - \text{Accepted Value}}{\text{Accepted Value}} \times 100$$

Your % Difference = _____