# Hubble's Law and the Age of the Universe

Procedure: Name:________________________

1. Login into the network using your user ID and your password.

2. Double click on the Astronomy shortcuts folder on the desktop.

3. Double click on the Clea_Hub shortcut.

4. Click on Login on the MENU BAR and enter your name. Click OK when you are done.

5. Click on START from the MENU BAR.

The expansion of the universe program simulates the operation of a computer controlled spectroscope attached to a telescope at a large mountain top observatory. It is realistic in all important ways, and is designed to give you a good feeling for how astronomers collect and analyze data for research.

The screen shows the control panel and view window as found in the "warm room" at the observatory. Notice the **Dome status** and **Tracking status** is off.

6. To begin our evenings work, first open the dome by clicking on the **Dome status** button.

The dome is open and the **Monitor** we see is from the finder scope. The finder scope is mounted on the side of the main telescope and points in the same direction. It is used to locate the objects we want to measure, because the field of view is much larger than the view in the main instrument. It is displayed on-screen by a CCD camera attached on the finder scope. (Note that it is not necessary for astronomers to view objects through an eyepiece.) Locate the **Monitor** button on the control panel and note its status, i.e. finder scope. Also note the stars are drifting in the view window. This is due to the rotation of the earth and is very noticeable due to the high magnification of the finder telescope. It is even more noticeable in the main instrument which has even a higher magnification. In order to have the telescope keep an object centered over the spec trometer opening (slit) to collect data, we need to turn on the drive control motors on the telescope.

7. We do this by clicking on the **Tracking** button.

The telescope will now track in sync with the stars.  Before we can collect data we will need to do the following:

(a) Select a field of view (one is currently selected).

(b) Select an object to study (one from each field of view).

8. To see the fields of study for tonight's observing session.

Click once on the **Change field** item in the MENU BAR at the top of the control panel.

The items you see are the fields that contain the objects we have selected for study tonight. An astronomer would have selected these fields in advance of going to the telescope by:

(a) Selecting the objects that will be well placed for observing during the time we will be at the telescope.

(b) Looking up the RA and DEC of each object field in a catalog such as Uranometria 2000, Norton's Atlas, etc.

This list contains 5 fields for study tonight.  You will need to select one galaxy from **each** field of view and collect data with the spectrometer (a total of 5 galaxies).

To see how the telescope works, change the field of view to Ursa Major II at RA 11 hour 0 minutes and Dec. 56 degrees 48 min.

9. Click on Ursa Major I in the selected **Galaxy Field** to highlight the field.  Then click the **OK** button.

Notice the telescope "slews" (moves rapidly) to the RA and DEC coordinates we have se lected.  The view window will show a portion of the sky that was electronically captured by the charge coupled device (CCD) camera attached to the telescope.

The view window has two magnifications:

**Finder View**: is the view from the small finder scope that gives a wide field of view and has a cross hairs and outline of the instrument field of view.

**Instrument View**: is the view from the main telescope with red lines that show the position of the slit of the spectrograph.

As in any image of the night sky, stars and galaxies are visible in the view window. It is easy to recognize bright galaxies in this lab simulation, since the shapes of the brighter galaxies are clearly different from the dot-like images of stars. But faint, distant galaxies can look a lot like stars, since we can't see their shape.

10. Using the **Instrument View** (if you are NOT on **Instrument View**, click on the **Monitor** button), carefully position the slit directly over the object you are intend to use to collect data. Any of the galaxies will be fine. Do this by "slewing", or moving, the telescope with the mouse and the **N**, **S**, **E** or **W** buttons. Place the arrow on the N button and press the left mouse button. Notice the red light comes on to indicate the telescope is "slewing" in that direction. Click again will cause the telescope to stop slewing as is noted by the light going off.

**NOTE**: One click is enough. The computer will store your click so at first it may appear that your action was not accepted. But some computers are very slow in their response.

As in real observatories, it takes a bit of practice to move the telescope to an object. You can adjust the speed or "slew rate" of the telescope by using the mouse to press the **Slew rate** button. (1 is the slowest and 16 is the fastest). If you have positioned the cursor accurately over the galaxy, click on the **Take reading** button to the right of the view screen.

The more light you get into your spectrograph, the stronger the signal it will detect, and the shorter twill be the time required to get a usable spectrum. Try to position the spectroscope slit on the brightest portion of the galaxy. If you position it on the fainter parts of the galaxy, you are still able to obtain a good spectrum but the time required will be much longer. If you position the slit completely off the galaxy, you will just get a spectrum of the sky, which will be mostly random noise.

We are about to collect data from the object.  We will be looking at the spectrum from the galaxy in the slit of the spectrograph.  The  spectrum of the galaxy will exhibit the characteristic H & K calcium lines which would normally appear at wavelengths 3968.847 Å and 3933.67 Å, respectively, if the galaxies were not moving.  However, the H & K lines will be red shifted to longer wavelengths depending on how fast the galaxy is receding.

Photons are collected one by one.  We must collect a sufficient number of photons to allow identification  of the wavelength.  Since an incoming photon could be of any wavelength, we need to integrate for some time before we can accurately measure the spectrum and draw conclusions.  The more photons collected, the less the noise in the spectrum, making the absorption lines easier to pick out.

11. To check the progress of the spectrum, click the **Stop/resume count** button. The computer will plot the spectrum with the available data.  Clicking the **Stop/resume count** button also places the cursor in the measurement mode.  Using the mouse, place the arrow anywhere on the spectrum, press and hold the left mouse button.  Notice the arrow changes to cross hair and wavelength data appears in the lower right area of the window.  As you hold the left mouse button, move the mouse along the spectrum.  You are able to measure the wavelength and intensity at the position of the mouse pointer.

Also notice other information that appears in the window:

**Object**:  the name of the object being studied.

**Apparent magnitude**:  the visual magnitude of the object.

**Photon count**:  the total number of photons collected so far, and the average number per pixel.

**Integration** (seconds):  the number of seconds it took to collect data.

**Wavelength** (angstroms):  wavelength as read by the cursor in the measurement mode.

**Intensity**:  relative intensity of of light from the galaxy at the position marked by the cursor in the measurement mode.

**Signal-to-noise Ratio**: A measurement of the quality of the data taken to distinguish the H and K lines of calcium from the noise. Try to get a signal-to-noise ratio of 10 to 1. For faint galaxies, this may take some time.

12. Click **Stop/resume count** from the menu bar of the Spectrometer Reading Window. Continue to collect photons until a clear spectrum of the H & K lines of calcium is displayed. These lines are approximately 40 angstroms apart. They should stand out form the noise. If not, continue to count photons. If you are not sure about the data, check with a lab instructor to help you interpret the data.

Additional information is needed to complete the analysis of the information that is not displayed in the spectrometer reading window. They are the following:

(a) The absolute magnitude (M) for all galaxies in this experiment.

(b) The laboratory wavelength of the K line of calcium is 3933.67 Å.

(c) The laboratory wavelength of the H line of calcium is 3968.847 Å.

13. Record the object, photon count, apparent magnitude, and the measured wavelength of the H & K lines of calcium on the data sheet. The H & K lines measured should be red shifted from the laboratory values depending on the galaxies motion.

## METHOD

Now that we see how to use our instrument to collect data, we can use this information to determine for each galaxy, its distance and its velocity, using the following relationships:

**(A)**

$$M = m + 5 - 5 * \log D$$

**OR**

$$\log D = \frac{m - M + 5}{5}$$

Note that we measure m and assume a value for M in order to calculate D (distance), where D is in parsecs.

**(B)** $v_H = c * \frac{\Delta\lambda_H}{\lambda_H}$ **AND** $v_K = c * \frac{\Delta\lambda_K}{\lambda_K}$

Note that we measure l (wavelength) in order to calculate v.

**(C)**

$$\Delta\lambda_H = \lambda_{H\,measured} - \lambda_H$$

**AND**

$$\Delta\lambda_K = \lambda_{K\,measured} - \lambda_K$$

1. Using the computer simulated telescope, measure and record on your data sheet the wave lengths of the calcium H and K lines for **ONE** galaxy in **EACH** of the fields selected for the evenings observation. Also, be sure to record the object name, apparent magnitude, and photon count. Round off numbers to two decimal places. Collect enough photons (usually around 40,000) to determine the wavelength of the line accurately.

2. Use your measured magnitudes and the assumed absolute magnitude for each galaxy and derive the distance (D) to each galaxy using equation (**A**). Express your answer in both parsecs and megaparsecs in the appropriate places on your data table. Note that equation (**A**) tells you how to find the log of the distance. To find the distance (D), you must take the anti log, i.e.

$$D = 10^{\log D}$$

If your calculator cannot calculate powers of 10, use the calculator in Windows in the Accesories folder.

3. Use your measured wavelengths given above to calculate the redshifts for each line, $\Delta\lambda_H$ and $\Delta\lambda_K$ Record each on your data table.

4. Use the doppler shift formula, to determine the velocities as determined by both the H and K lines. There is a place on the data table for each of these figures:

$V_H = c * \frac{\Delta\lambda_H}{\lambda_H}$ **AND** $V_K = c * \frac{\Delta\lambda_K}{\lambda_K}$

5. Calculate and record the velocity of the galaxy. It is the average of the velocities determined from the H and K lines.

6. Now plot a Hubble diagram by graphing the velocity of a galaxy in km/sec (y-axis) vs. the distance in megaparsecs (x-axis) on a sheet of graph paper. Draw a straight line through the origin that best fits all the data points. The slope of the line is the Hubble Parameter (H). To calculate the slope of the line, measure a value of D and v from a point near the **upper right** end of the line you drew (do not use one of the points that you plotted, just use a data point). Determine H using the following equation:

**(D)** $$H = \frac{V}{D}$$

where H is the Hubble Parameter in km/sec/Mpc v is the velocity measured from your line D is the distance measured form your line.

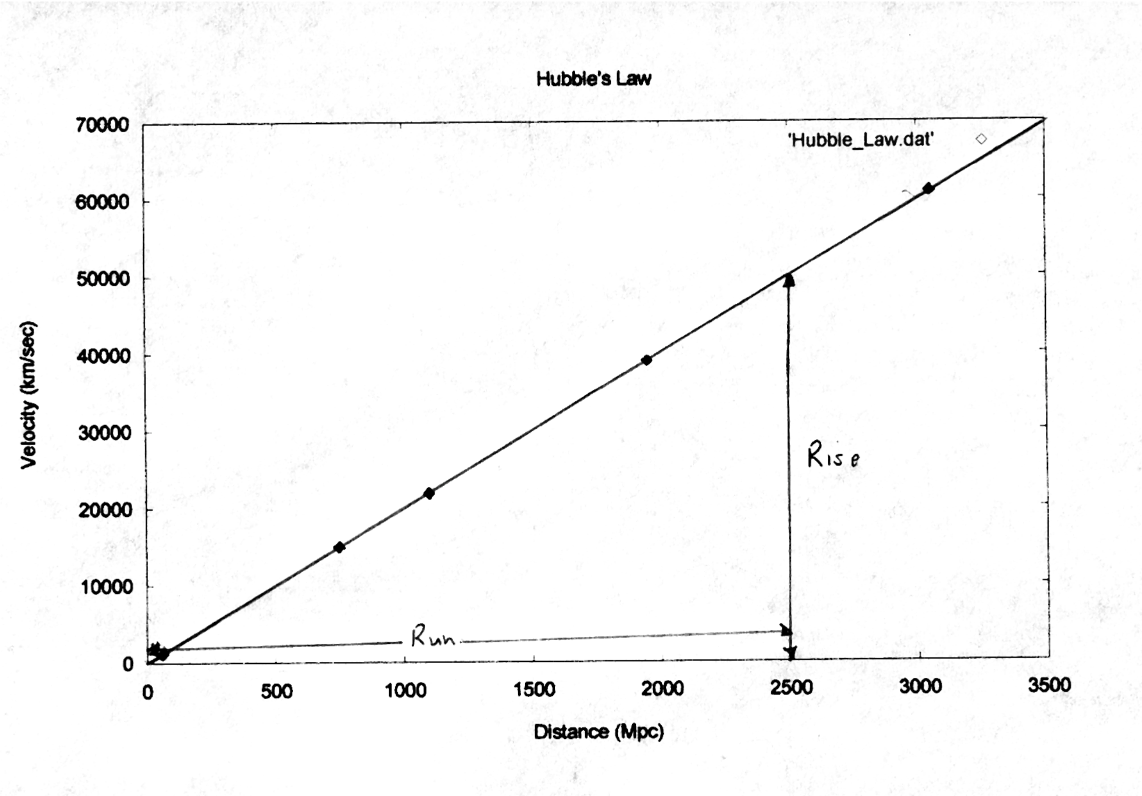


Figure 1: Example plot. The slope is determinred from the Rise/Run. In this example the Rise is 50,000 km/sec and the Run is 2,500 Mpc.

a) Record your value for the Hubble Parameter on your data table on the line called the **Average Value of H**.

b) Mark the point you used on your graph.

c) Label the axis of your graph, and give it a meaningful title.

## DETERMINING THE AGE OF THE UNIVERSE

The Hubble Law, equation (D), can be used to determine the age of the universe. Using your average value of H, calculate the recessional velocity of a galaxy which is 800 Mpc away.

Velocity of a galaxy 800 Mpc away: __________________________km/sec

Verify your velocity by looking it up on your Hubble diagram. You now have two important pieces of information:

1. How far away the galaxy is. 2. How fast it is going away from us.

You can visualize the process if you think about a trip in your car. If you tell a friend that you are 120 miles away form your starting point and that you traveled 60 miles per hour, your friend would know you had been traveling TWO hours. That is your trip started two hours ago. You know this from the relationship:

Distance equals Rate ( or velocity ) * Time

which we can write as

**(E)** $D = R * T$ **OR** $T = \frac{D}{R}$

Thus, $$2\ hrs = \frac{120\ mi}{60\ mi/hr}$$

Now let's determine when the universe "started its trip". The distance is 800 Mpc, but first convert Mpc into km because the rate, or velocity, is in km/sec.

800 Mpc = ______________________km

Use equation (**E**) to determine how many seconds ago the universe started:

______________________secs

There are about $3.15 \times 10^7$ seconds in one year. Convert your answer into years:

______________________years

The age of the universe is _____________________ years.

**SHOW MATH HERE IN AN ORGANIZED FASHION**.

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# Data Tables

| Cluster | Object Name | RA | Dec | Apparent Magnitude | Intensity K line | Intensity H line | Observed Wavelength | Photon Count |
|---|---|---|---|---|---|---|---|---|
| Ursa Major II | | | | | | | | |
| Ursa Major I | | | | | | | | |
| Coma Berenices | | | | | | | | |
| Corona Borealis | | | | | | | | |
| Bootes | | | | | | | | |
| | | | | | | | | |

| Object | Absolute Magnitude |
|---|---|
| | |
| | |
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| | |

# Calculations

## Distances

| **Object Name** | **Distance (pc)** | **Distance (Mpc)** |
|---|---|---|
| | | |
| | | |
| | | |
| | | |
| | | |

## Velocities

| **Object Name** | Wavelength Shifts $\Delta\lambda$ (Å) | | Velocities (km/sec) | | Average Velocity (km/sec) |
|---|---|---|---|---|---|
| | K line | H line | K line | H line | |
| | | | | | |
| | | | | | |
| | | | | | |
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| | | | | | |
| | | | | | |

## Graph

Average Value of H = __________km/s/Mpc