## Name:

## Lab Partner:

# The Hubble Redshift Distance Relation Student Manual

A Manual to Accompany Software for the Introductory Astronomy Lab Exercise Edited by Lucy Kulbago, John Carroll University 11/24/2008



Department of Physics Gettysburg College Gettysburg, PA

Telephone: (717) 337-6019 Email: clea@gettysburg.edu



Contemporary Laboratory Experiences in Astronomy

## Contents

Goal
Objectives
Equipment4
Introduction4
Background: The Large-Scale Distribution of Matter5
Technique7
Using the Hubble Redshift Program7
Calculating the Hubble Parameter11
Determining the Age of the Universe13
Data Sheet15

## Goal

You should be able to find the relationship between the redshift in spectra of distant galaxies and the rate of the expansion of the universe. You should be able to use observations of the redshifts of galaxies, along with their coordinates in the sky, to produce a three-dimensional map of a nearby region of the sky. You should understand how matter is distributed on the largest scales in the universe. You should appreciate some of the difficulties involved in making and interpreting large-scale maps of the universe.

## Objectives

#### If you learn to.....

- Use a simulated spectrometer to acquire spectra and apparent magnitudes.
- Determine distances using apparent and absolute magnitudes.
- Measure Doppler shifted H & K lines to determine velocities.
- Plot radial velocities and positions on a wedge diagram.
- Interpret the distributions of galaxies you see on the wedge diagram.

#### You should be able to.....

- Calculate the rate of expansion of the universe.
- Calculate the age of the universe.
- Produce a map of the three-dimensional distribution of galaxies in a small part of the universe near our own Milky Way galaxy.
- Develop an understanding of the typical sizes of large-scale features (super clusters and voids) in universe.
- Appreciate some of the difficulties and limitations of such measurements.

absolute magnitude	Declination	Hubble Constant	radial velocity	superclusters
absorption lines	distance modulus	Hubble relation	redshift	wavelength
Angstrom (Å)	Doppler Shift	local group	Right Ascension	wedge diagram
apparent magnitude	elliptical galaxy	megaparsec	spectrometer	Z
Ca H and K	galaxy	parsec	spectrum	
Coma cluster	galaxy cluster	photon	spiral galaxy	

#### Useful Terms you should review using your textbook

#### Equipment

You will need a scientific pocket calculator, graph paper, ruler, PC compatible computer running Windows 3.1 (VGA graphics) or better, and the **CLEA** Program *Hubble Redshift Distance Relation*. Share the use of the computer and program with your partner to collect data. All calculations and graphing, as well as your narratives, must be your own original work.

#### Introduction

The late biologist J.B.S. Haldane once wrote: "The universe is not only queerer than we suppose, but queerer than we can suppose." One of the queerest things about the universe is that virtually all the galaxies in it (with the exception of a few nearby ones) are moving away from the Milky Way. This curious fact was first discovered in the early 20th century by astronomer Vesto Slipher, who noted that absorption lines in the spectra of most spiral galaxies had longer wavelengths (were "redder") than those observed from stationary objects. Assuming that the redshift was caused by the Doppler shift, Slipher concluded that the red-shifted galaxies were all moving away from us.

In the 1920's, Edwin Hubble measured the distances of the galaxies for the first time, and when he plotted these distances against the velocities for each galaxy he noted something even queerer: The further a galaxy was from the Milky Way, the faster it was moving away. Was there something special about our place in the universe that made us a center of cosmic repulsion?

Astrophysicists readily interpreted Hubble's relation as evidence of a universal expansion. The distance between all galaxies in the universe was getting bigger with time, like the distance between raisins in a rising loaf of bread. An observer on *ANY* galaxy, not just our own, would see all the other galaxies traveling away, with the furthest galaxies traveling the fastest.

This was a remarkable discovery. The expansion is believed today to be a result of a "Big Bang" which occurred between 10 and 20 billion years ago, a date which we can calculate by making measurements like those of Hubble. The rate of expansion of the universe tells us how long it has been expanding. We determine the rate by plotting the velocities of galaxies against their distances, and determining the slope



of the graph, a number called the Hubble Parameter,  $H_0$ , which tells us how fast a galaxy at a given distance is receding from us. So Hubble's discovery of the correlation between velocity and distance is fundamental in reckoning the history of the universe.

Using modern techniques of digital astronomy, we will repeat Hubble's experiment.

Figure 1: Hubble's Constant

The technique we will use is fundamental to cosmological research these days. Even though Hubble's first measurements were made three-quarters of a century ago, we have still only measured the velocities and distances of a small fraction of the galaxies we can see,

and so we have only small amount of data on whether the rate of expansion is the same in all places and in all directions in the universe. The redshift distance relation thus continues to help us map the universe in space and time.

#### **Background: The Large-Scale Distribution of Matter**

Drawing a map of the universe is not an easy task. Understanding why it is difficult, however, is rather simple. Consider how hard it is to determine the shape and extent of a forest when one is standing in the middle of it. Trees are visible in all directions, but how far do they extend? Where are the boundaries of the forest, if any? Are there any clearings or any denser groves, or are the trees just scattered uniformly about at random? A terrestrial surveyor might answer these questions by walking around the forest with a compass and transit (or, more recently, a Global Positioning System or GPS receiver), mapping carefully where everything was located on a piece of ruled paper. But consider how much more difficult it would be if the surveyor were tied to a tree, unable to budge from a single spot. That's the problem we earthbound observers face when surveying the universe. We have to do all our mapping (of galaxies, of course, not trees), from a single spot,—our solar system—located about 2/3 of the way between the center of the Milky Way galaxy and its edge.

Two of the three dimensions required to make a 3-dimensional map of the positions of the galaxies in universe are actually fairly easy to determine. Those two dimensions are the two celestial coordinates, Right Ascension and declination, that tell us the location of a galaxy on the celestial sphere. Over the years, by examining photographs of the heavens, astronomers have compiled extensive catalogs that contain the coordinates of hundreds of thousands of galaxies. They estimate that there are hundreds of billions of galaxies that lie within the range of our best telescopes.

More is needed, however. The two celestial coordinates just tell us in what direction to look to see a galaxy. A third number—the distance of the galaxy—is necessary in order to produce a reliable map. Unfortunately the distance of galaxies is not immediately obvious. A small, faint galaxy nearby can appear much the same as a large, luminous galaxy much further away. Except in the very nearest galaxies, we can't see individual stars whose luminosity we can use to estimate distance. How then can we determine galaxy distances reliably?

The solution to this problem is to make use of the *expansion of the universe* to give us a measure of distance. By the expansion of the universe we mean the fact that the overall distance between the galaxies is getting larger all the time, like the distance between raisins in a rising loaf of bread. An observer on any galaxy notes that all the galaxies are traveling away, with the most distant galaxies traveling the fastest.

The increase of galaxy speed with distance was first noted by astronomer Edwin Hubble in the 1920's who measured the distances of nearby galaxies from the brightness of the Cepheid variable stars he could see in them. He measured the speeds (technically called the *radial velocities*) of the galaxies by measuring the wavelengths of absorption lines in their spectra. Due to the Doppler effect, the wavelengths of absorption lines are longer (shifted in toward the red end of the spectrum), the faster the galaxy is moving away from the observer. One of Hubble's first graphs, showing the increase of radial velocity with distance, is shown below.

Hubble's redshift-distance relation gives us the key to the third dimension. Since the radial velocity of a galaxy is proportional to its distance, we can simply take a spectrum of it, measure the amount the spectral lines are redshifted, and use that as a measure of distance. We plot the position of galaxies in three dimensions, two being the Right ascension and declination of the star,



Figure 1 Radial Velocity vs. Distance

and the third being the redshift (or velocity, or distance), to create a three-dimensional map of the universe which, hopefully, will reveal the size and scope of its major structures.

Of course one needs to observe the spectra of a lot of galaxies in order to trace out the contours of the universe. This was a time-consuming process in the beginning; Hubble sometimes had to expose his photographic plates for several hours in order to get data on just one galaxy. But by the 1980's techniques of spectroscopy made it possible to obtain galaxy spectra in a matter of minutes, not hours, and several teams of astronomers began undertaking large map making surveys of the galaxies. One of the most important of these pioneering surveys was undertaken by John Huchra and Margaret Geller at the Harvard-Smithsonian Center for Astrophysics in Cambridge, MA. The CfA Redshift Survey (which provides much of the data for this exercise), surveyed all the brighter galaxies in a limited region of space, in the direction of the constellation Coma.

The maps produced by the CfA Redshift Survey and other groups revealed that the galaxies were not distributed at random, but rather were concentrated in large sheets and clumps, separated by vast expanses, or voids, in which few, if any, galaxies were found. One large sheet of galaxies, called the "Great Wall", seemed to span the entire survey volume.

Even with modern techniques, surveying thousands of galaxies takes a great deal of time, and the task is far from complete. Only a tiny fraction, about 1/100 of 1%, of the visible universe has been mapped so far. Describing the large scale structure of the universe on the basis of what we currently know may be a bit like describing our planet on the basis of a map of the state of Rhode Island. But some of the major conclusions are probably quite sound.

In the exercise that follows, you will conduct a survey of all the bright galaxies in a catalog covering the same region of the sky as the original CfA redshift survey. We've reduced the number of galaxies in our catalog, and made the operation of the instrument a bit simpler, but the fundamental process is the same as that used today to gauge the overall structure of the universe we live in.

#### Technique

The software for the **CLEA** *Hubble Redshift Distance Relation* laboratory exercise puts you in control of a large optical telescope equipped with a TV camera and an electronic spectrometer. Using this equipment, you will determine the distance and velocity of several galaxies located in selected clusters around the sky. From these data you will plot a graph of velocity (the y-axis) versus distance (the x-axis).

How does the equipment work? The TV camera attached to the telescope allows you to see the galaxies, and "steer" the telescope so that light from a galaxy is focused into the slit of the spectrometer. You can then turn on the spectrometer, which will begin to collect photons from the galaxy. The screen will show the spectrum—a plot of the intensity of light collected versus wavelength. When a sufficient number of photons are collected, you will be able to see distinct spectral lines from the galaxy (the H and K lines of calcium), and you will measure their wavelength using the computer cursor. The wavelengths will be longer than the wavelengths of the H and K labs measured from a non-moving object (397.0 and 393.3 nanometers), because the galaxy is moving away. The spectrometer also measures the apparent magnitude of the galaxy from the rate at which it receives photons from the galaxy. So for each galaxy you will have recorded the wave-lengths of the H and K lines and the apparent magnitude.

From the data collected above, you can calculate both the speed of the galaxy from the Doppler-shift formula, and the distance of the galaxy by comparing its known absolute magnitude (assumed to be (-22) for a typical galaxy) to its apparent magnitude. The result is a velocity (in km/sec) and a distance (in mega parsecs, Mpc) for each galaxy. The galaxy clusters you will observe have been chosen to be at different distances from the Milky Way, giving you a suitable range to see the straight line relationship Hubble first determined. The slope of the straight line will give you the value of  $H_0$ , the **Hubble Parameter**, which is a measure of the rate of expansion of the universe. Once you have  $H_0$ , you can take its reciprocal to find the age of the universe.

The details of the measurements and calculations are described in the following sections.

#### Using the Hubble Redshift Program

Welcome to the observatory! We will simulate an evening's observation during which we will collect data and draw conclusions on the rate of expansion of the universe. We will gain a proficiency in using the telescope to collect data by working together on the first object. Collecting data for the other four objects will be left to you to complete the evening's observing session. Then you will analyze the data, draw your conclusions, and use the information to predict the age of the universe.

#### Let's begin.

1. Open the Hubble Redshift program by double clicking on the **CLEA\_hub icon**. Select **File...Log in** from the menu bar, and enter student names and the lab table number. Click **OK** when ready. The title screen appears.

2. Select **File...Run** from the menu bar to begin the exercise. The screen shows the control panel and view window as found in the "warm room" at the observatory.

The **Hubble Redshift Distance Relation** program simulates the operation of a computer-controlled spectrometer attached to a telescope at a large mountain-top observatory. It is realistic in appearance, and is designed to give you a "hands-on" approach of how astronomers collect and analyze data for research.

Notice that the **dome** is closed and **tracking status** is off. Before you can access the telescope controls, a message appears notifying you that you have control of the telescope. Click **OK** to continue.

3. To begin our evening's work, first open the dome by clicking on the **dome** button.

The dome opens and the view 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. Because the field of view of the finder scope is much larger than the field of view of the main instrument, it is used to *locate* the objects we want to measure. The field of view 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 **Change View** button on the control panel and note its status, i.e. finder scope. Also note that the stars are drifting in the view window. This is due to the rotation of the earth and is very noticeable under 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 in the spectrometer opening (slit) to collect data, we need to turn on the drive control motors on the telescope.

4. We do this by clicking on the **tracking** button. The telescope will now track in sync with the stars. However, before we can collect data we 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).

5. To review the fields of study for tonight's observing session, select **Field...** from the menu bar at the top of the control panel. The items you see listed are the fields that contain the objects we have selected to 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 in the **select star field dialog box** contains 6 fields for study tonight. You will need to select two galaxies from **each** field of view and collect data with the spectrometer (a total of 12 galaxies).

To see how the telescope works, change the field of view to Coma Berenices at RA 12 hr 59 min and Dec. 27 deg 41 min. Press **OK** to move the telescope to the correct position.

Notice the telescope "slews" (moves rapidly) to the RA and DEC coordinates we have selected. 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 (see Figure 2 on next page):

**Finder View** is the view through the finder scope that gives a wide field of view and has a red square which outlines the instrument field of view.

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

6. 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 similar to like stars, since we can't see their shape.

Find a galaxy and slew the telescope so that the galaxy is inside the red finder window.



Figure 2: Field of View from the Finder Scope

7. Locate the **Change View** button in the lower left hand portion of the screen. **Click** on this button to change the view from the **Finder Scope** to the **Instrument**. The field of view is now smaller so that you can accurately position the galaxy in the slit of the spectrometer. Use the directional buttons (**N**, **S**, **E** or W), to "slew", or move, the telescope to carefully position, in the slit, the object you intend to use to collect data—any of the galaxies are suitable. To move continuously, **press and hold down** the left mouse button. Notice the red light comes on to indicate the telescope is "slewing" in that direction.

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). When you have positioned the galaxy accurately in the slit, click on the **take reading** button to the right of the view screen.

The more light you get into your spectrometer, the stronger the signal it will detect, and the shorter the time required to get a usable spectrum. Try to position the spectrometer 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.

As we collect data from the object. We will be looking at the spectrum from the galaxy in the slit of the spectrometer. The spectrum of the galaxy will exhibit the characteristic H & K calcium lines which would normally appear at wavelengths 3968.5 Å and 3933.7 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. To initiate the data collection, press **start/resume count**.

8. To check the progress of the spectrum, click the **stop count** button. The computer will plot the spectrum with the available data. Clicking the **stop 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 a cross hair and the wavelength data appears at the top of the display. 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.



Information that appears in the lower left hand portion of the window

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

Apparent magnitude: the visual magnitude of the object

**Right Ascension:** Displays the celestial coordinates of the center of the field of view. Right Ascension is displayed in hours, minutes and seconds.

Declination: Declination is displayed in degrees, minutes and seconds.

Information that appears in the lower right hand portion of the window

Integration (seconds): The number of seconds it took to collect data

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

**Avg. per Channel:** The number of photons averaged from the total number of the channels of the spectrometer.

**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.

Information that appears in the top portion of the window

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

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

9. Click **start/resume count** from the menu bar in 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 Å apart; the K line is first, followed by the H line. They should stand out from 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 is -22
- (b) The laboratory wavelength of the K line of calcium is 3933.7 Å.
- (c) The laboratory wavelength of the H line of calcium is 3968.5 Å.

10. Record the object name, apparent magnitude, and the measured wavelength of the H & K lines of calcium on the data sheet located at the end of this exercise. The H & K lines measured should be red shifted from the laboratory values depending on the galaxies motion.

NOTE: At higher radial velocities the spectral features at longer wavelengths may be redshifted out of the recorded spectral range. Measure only those lines for which you can accurately determine the line center.

When you have finished recording the line measurements, you should choose a second galaxy in the same galaxy field and repeat steps 6 through 10. You should record data for two galaxies in each of the 6 galaxy fields. You do not need to save any data on the computer.

11. To collect data for additional galaxies, press **Return**. Change the Monitor to display **Finder**, then follow steps 6 through 10.

#### **Calculating the Hubble Parameter**

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

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

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

(B) 
$$\mathbf{v}_{\mathbf{H}} = \mathbf{c} * \underline{\Delta \lambda_{\mathbf{H}}}$$
 and  $\mathbf{v}_{\mathbf{K}} = \mathbf{c} * \underline{\Delta \lambda_{\mathbf{K}}}$   
 $\lambda_{\mathbf{H}}$   $\lambda_{\mathbf{K}}$ 

*Note that we measure*  $\lambda$  *(wavelength) in order to calculate* v*.* 

(C) 
$$\Delta \lambda_{\rm H} = \lambda_{\rm H \, measured} - \lambda_{\rm H}$$
 and  $\Delta \lambda_{\rm K} = \lambda_{\rm K \, measured} - \lambda_{\rm K}$ 

(D)  $\mathbf{H} = \mathbf{v} / \mathbf{D}$ , where **H** is the Hubble Parameter in km/sec/Mpc, **v** is the velocity, and **D** is the distance.

1. Using the computer simulated telescope, measure and record on your data sheet the wavelengths of the calcium H and K lines for *two* 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 mega parsecs 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.

$$D = 10^{\log D} = 10^{(m-M+5)/5}$$

3. Use your measured wavelengths to calculate the redshifts for each line,  $\Delta \lambda_{\rm H}$  and  $\Delta \lambda_{\rm K}$ . 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:

$$\mathbf{v}_{\mathbf{H}} = \mathbf{c} * \underline{\Delta \lambda_{\mathbf{H}}} \qquad and \qquad \mathbf{v}_{\mathbf{K}} = \mathbf{c} * \underline{\Delta \lambda_{\mathbf{K}}} \\ \lambda_{\mathbf{H}} \qquad \lambda_{\mathbf{K}}$$

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 average velocity of a galaxy in km/sec (y-axis) vs. the distance in mega parsecs (x-axis) on a sheet of graph paper, or by using Excel. Use the data in your data table.

- a. To manually plot a Hubble Diagram:
  - i. Plot each data point on your graph, the x-coordinate is the distance in Mpc, the ycoordinate is the average velocity.
  - ii. Draw a straight line through the origin that best fits all the data points.
  - iii. The slope of the line is the Hubble Parameter (**H**).
  - iv. 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, but a point on the line drawn).
  - v. Determine **H** using the following equation:  $\mathbf{H} = \mathbf{v} / \mathbf{D}$ , where **H** is the Hubble Parameter in km/sec/Mpc, **v** is the velocity measured from your line, **D** is the distance measured from your line.
- b. To use Excel to plot a Hubble Diagram:
  - i. Enter the data in 2 columns, Distance in Mpc in column 1 for x-axis, and Average Velocity in column 2 for y-axis
  - ii. Highlight the data and click on Chart
  - iii. Choose XY scatter for Chart Type, Click on Next
  - iv. Data Range is already selected, Click on Next
  - v. Enter Chart Title and label the axes, Click on Next
  - vi. Put Chart on a new sheet, Click on Finish
  - vii. Right Click on a data point
  - viii. Click on Add Trendline, Select Linear
  - ix. Click on the Options Tab, and Check Select Intercept at Zero, and Check Display Equation on Chart, Click OK
  - x. Print a copy of the graph for each person
  - xi. The Hubble Parameter **H** is the slope, shown in the equation as the coefficient of x.

c. Record your value for the Hubble Parameter on the line below.

Using the Graph: Average Value of  $H = \___km/sec/Mpc$  (70 – 80)

#### **Determining the Age of the Universe**

Show all your work! Note: For your guidance in these calculations, approximate values for the answers are given in parenthesis beside each answer. These values are given as ballpark figures, and you should record your calculated answer even if it is not exactly the same.

1. The Hubble Law, equation (D), can be used to determine the age of the universe. Using *your* average value of  $\mathbf{H}$  determined from your graph, calculate the recessional velocity of a galaxy which is 800 Mpc away.

 $V = \____km/sec$  (60,000)

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

- 1. How far away is the galaxy.
- 2. How fast it is moving 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 from 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) 
$$\mathbf{D} = \mathbf{V} * \mathbf{T}$$
 or  $\mathbf{T} = \frac{\mathbf{D}}{\mathbf{V}}$ 

Thus,

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

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

$$\mathbf{D} =$$
\_\_\_\_km (2 x 10<sup>22</sup>)

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

 $\mathbf{T} = \underline{\qquad} \operatorname{secs} (4 \times 10^{17})$ 

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

 $\mathbf{T}$  = \_\_\_\_\_ years (1.2 x 10<sup>10</sup>)

6. Therefore, the age of the universe is approximately \_\_\_\_\_ billion years old. (12 billion years)

#### **Useful Equations and Quantities**

$\mathbf{M} = \mathbf{m} + 5 - 5 * \log \mathbf{D}$	$\mathbf{v}_{\mathbf{K}} = \mathbf{c} * \frac{\Delta \lambda_{\mathbf{K}}}{\lambda_{\mathbf{K}}}$	$1 \text{ pc} = 3.09 \text{ x} 10^{13} \text{ km}$
$D = 10^{(m-M+5)/5}$	$\Delta \lambda_{\rm H} = \lambda_{\rm H \ measured} \ - \ \lambda_{\rm H}$	$1 \text{ Mpc} = 1 \times 10^6 \text{ pc}$
$\mathbf{v}_{\mathbf{H}} = \mathbf{c} * \frac{\Delta \lambda_{\mathbf{H}}}{\lambda_{\mathbf{H}}}$	$\Delta \lambda_{\rm K} = \lambda_{\rm Kmeasured}  \textbf{-}  \lambda_{\rm K}$	1pc = 3.26 light years
Wavelength of K Line: $\lambda_{\rm K} = 3933.67$	Wavelength of H Line: $\lambda_{\rm H} = 3968.47$	$c = 3 \times 10^5 \text{ km/sec}$

### **Data Sheet**

Object Name	Abs Mag M	App Mag m	Distance in pc	Distance in Mpc	$\lambda_{\mathrm{K\ measured}}$	$\lambda_{ m H\ measured}$	$\Delta \lambda_{\mathrm{K}}$	$\Delta \lambda_{ m H}$	Velocity K	Velocity I
	-22									
	-22									
	-22									
	-22									
	-22									
	-22									
	-22									
	-22									
	-22									
	-22									
	-22									
	-22									