GALAXIES AND THE HUBBLE LAW

Name:____________________ Date:_____

PROJECT GOALS:

1. **To measure the Hubble constant**
2. **To observe the relationship between velocity and distance for galaxies**

MATERIALS REQUIRED:

- **PC and downloaded computer program software Note: Mac-users can use on-campus computer labs. Computer lab hours are listed at** http://facility.berkeley.edu/labs/hours.html
- **a calculator**

INTORDUCTION

- **In the early 20th century, Vesto Slipher noted that absorption lines in the spectra of most spiral galaxies had longer wavelengths 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 directly measured the distances to these galaxies for the first time. When he plotted the distances versus the velocities, he noted something remarkable; the farther the galaxy from the Milky Way Galaxy, the faster it sped away from us! Hubble's relation is actually evidence of a universal expansion. The rate of the expansion of the universe tells us how long it has been expanding. In fact, the slope of Hubble's plot—velocity vs. distance—is the critical value to determine. Its reciprocal gives us the expansion age of the universe. You will repeat Hubble's experiment. First, you will measure the redshifts of absorption lines in five galaxy spectra to determine each galaxy's recession velocity. Then, given the distance to each galaxy, you will combine this information into Hubble's graph of velocity versus distance to determine Hubble's constant.**

ACCESSING THE SOFTWARE

- **Go to the website** http://www.gettysburg.edu/~marschal/clea/CLEAhome.html **Click on the green "Software" tab in the upper left corner. Then click on the project "Hubble Redshift-Distance Relation." Download "HubLab.EXE" Double click on HubLab.EXE to install the software.**

- Look on the computer for the folder called "CLEA" and the sub-folder called "Hublab." Double click the icon "Clea_hub.exe" to start the program. Click on "File" in the upper left corner and log in. Click on "File" again and choose "Run" to start.

  - The software puts you in control of a large optical telescope equipped with a TV camera and a spectrometer.

  - The telescope won't work until you open the dome, of course. Do that now by clicking "DOME". You will see galaxies and stars floating through your field of view. You need to turn on the telescope tracking so it will lock on the position you have pointed. Do that now by clicking "TRACKING". The field of view you see is about 2.5 degrees on a side. This is considered a "wide" field (5 full moons could fit across there!). When you actually take your measurements, the view will be zoomed.

  - For today's study, you are to choose *one* galaxy in each of five fields of view. To see the fields of interest, select "Field" in the menu bar. Choose any of the first five fields to start (do not choose Sagittarius). Next, you'll need to pick a galaxy to measure. To get a rough idea of the extent of the field and what's in it, you need to slew the telescope. To slew at a high rate of speed, click the "slew rate" button until the rate is 16 (that's 16 arcseconds per second). Then press and hold one of the directions NSEW. To slew at a slower rate, just click "slew rate" again until the desired rate appears.

  - Once you have found a galaxy to measure (a fuzzy object, not a star), move it to the center of the box. Then, click the "Change View" button to switch from the finder view to the instrument (zoomed) view. Fine tune your centering so that the brightest part of the galaxy shines through the slit of your spectrometer. If you don't, it will take forever to get a reading and you will also probably have a very ratty looking spectrum.

  - When you are satisfied with your centering, click "take reading." A new window will appear. Wavelength is plotted on the x-axis and intensity on the y-axis. The spectrometer will count photons one by one in this wavelength region. When you are ready to begin, click "start /resume count." Watch the signal-to-noise ratio that will appear at the bottom of your screen. Make sure to build a signal-to-noise ratio of at least 10.

  - The spectrum of the galaxy will exhibit the characteristic pair of calcium absorption lines which would normally appear at wavelengths 3933.67 angstroms (K, the line on the left) and 3968.847 angstroms (H, the line on the right). However, they will be redshifted due to the motion of the galaxy. Once you are satisfied with the spectrum, click "stop count." Click with your left mouse button on the deepest part of the absorption lines and the wavelengths will print on the screen. Record the measured wavelengths of both calcium lines in the table below. Repeat the measurements for 1 other galaxy in each of the 4 other fields.

Galaxy	calcium K	calcium H
in Ursa Major II		
in Ursa Major I		
in Coma Bernices		
in Bootes		
in Corona Borealis		

Calculating recession velocity from redshift

- Use the following definitions:

λ_H = rest wavelength of Calcium H line

λ_K = rest wavelength of Calcium K line

λ_{Hm} = measured Calcium H line

λ_{Km} = measured Calcium K line

v_H = velocity based on Calcium H line

v_K = velocity based on Calcium K line

c = speed of light = 3×10^5 km/s

$$V_H = c \times \frac{\left(\lambda_{Hm} - \lambda_H\right)}{\lambda_H} \qquad V_K = c \times \frac{\left(\lambda_{Km} - \lambda_K\right)}{\lambda_K}$$

- If you express c in km/s, then your velocity will emerge in km/s. Compute the recession velocity for each galaxy based on both wavelengths. Average the two velocities you compute and enter the value in the table below. If the computed velocity based on the H line is vastly different than what you compute based on the K line for some galaxy, *you need to repeat that measurement*!

galaxy	distance (Mpc)	K velocity	H velocity	avg velocity
in Ursa Major II	832			
in Ursa Major I	347			
in Coma Bernices	145			
in Bootes	794			
in CoronaBorealis	501			

- Plot a Hubble diagram by graphing the velocity of each galaxy in km/s (y-axis) versus the distance in megaparsecs (1 megaparsec = 1 million parsecs). Be sure to submit your graph with the rest of your assignment. Fit a straight line through the origin that best fits all the data points. The slope of the line is the *Hubble parameter*(some people call it "Hubble's constant"). What is the Hubble parameter you find?

______ km/s/Mpc