Name: ______________________________

Partner(s): ___________________________

LAB #12 THE HUBBLE LAW

Objectives

In this lab you will use simple observational evidence to recreate the most profound discovery in cosmology. By calculating the distance to other galaxies and finding the velocity they are moving relative to us, you will be able to show that the universe is expanding. For more details, you may want to take a second look at Chapter 20 of the textbook.

Data

The galaxy images and corresponding spectra are at
http://www.astro.washington.edu/users/solontoi/HubbleLaw/galaxies.html
This is linked from the course web-page.

Outline

A brief outline of the lab procedure, the steps will be walked through later on.

- Find the distance to each galaxy
  - Find the angular width of each galaxy
  - Assuming spiral galaxies are all the same size, use the standard rod method to calculate the distance to each galaxy
- Find the velocity of each galaxy
  - Find the wavelength of 2-3 emission/absorption lines in the spectra of each galaxy
  - Calculate the redshift of each galaxy, using the observed wavelength and the emitted wavelength
  - Calculate the velocity each galaxy is moving relative to us based on the redshift
- Find the rate of expansion of the Universe
  - Graph the velocity of each galaxy against the distance
  - Determine a best-fit line for your data
  - Calculate the slope of the best-fit line and know this to be H – the rate of expansion and the Hubble constant

Procedure

Finding the Distances

NOTE - for this lab you will measure distances and redshifts for many galaxies. The data presented in the lab cover a broad range in image and spectral quality. It is important to use as many galaxies as possible but if you feel a galaxy's image or spectrum is bad or strange enough that it will severely skew your results you can opt not to use that galaxy's data in your final calculations. If you opt to throw out any galaxy you **must** indicate what your justification was for throwing it out somewhere in the lab.

• You will need a data table to hold the following values for each galaxy containing the angular size, three wavelength measurements, and the calculated distance, a redshift for each wavelength, an average redshift and the velocity. You may use the sheet provided or make your own. If you are comfortable with Excel, this would be a good time to use it.

• For each galaxy in your sample you will need to measure the angular size. Use the **image** link to bring up a centered image of the galaxy. Identify the long axis of the galaxy and then measure the angular size by clicking on each side of the image. After each click the web-page will report the x,y pixel coordinate that you clicked on. After you click the second point it will report the angular size of the galaxy in milliradians. If you make an error, make sure to click the **try again** link to reset the page.

It is up to you to determine criteria for what defines the edge of the galaxy. Just be consistent from galaxy to galaxy! This may be a source of error in your lab.

(5 pts) Record the angular size of each galaxy in your data table.

• To get the distance, we will assume that every galaxy is the same size in real life (this is a standard rod assumption and is pretty good for galaxies of the same type) - namely **22 kilo-parsecs (kpc) across** – this corresponds to about 71,000 light years. Since the angle subtended by distant galaxies is very small, we can use the small angle approximation from trigonometry:

$$\text{distance} = \frac{\text{actual size}}{\text{angular size}}$$

Find the distance for each galaxy in your sample. **NOTE** - if you keep the angle in units of milliradians and the size in units of kpc, then your distance will come out in units of mega-parsecs (Mpc). These are the units that you want for this lab. While we typically use light years, using Mpc is better for larger distances and makes the distance calculation easier. For reference, 1 Mpc = 1,000,000 parsecs = 3,260,000 light years.

(5 pts) Record the distance to each galaxy in your data table.

Finding the Velocity

• Measure the shift in wavelength for three different lines for each galaxy. You should use the **Calcium H and K** lines as well as the **H-alpha** line.

The spectra link will take you to a page containing zoomed in sections of the galaxy's spectra. On the left hand side you can find the Calcium K and H lines.

The absorption lines due to calcium will be some of the strongest (deepest) of the spectral lines. At the bottom of the image are two black lines that show the actual position of where the calcium lines show up in the lab. The wavelengths of these two black lines are listed at the top of the spectra image. You will need to click on each of the absorption lines in order to measure the wavelength at which these lines are observed in the galaxy.

You will also do the same thing on the right hand size in measure the Hydrogen α emission line. Generally there are two strong emission lines to the right of H-α's laboratory wavelength. H-α is the bluer of them (the one with smaller wavelength). Sometimes it has a small "hump" on the blue side of the emission feature.

(5 pts) Record your three observed wavelengths of the lines in each galaxy your data table.

• To get the velocity, use your shifted wavelengths and the Doppler formula:

$$\frac{(\lambda_{\text{shifted}} - \lambda_{\text{rest}})}{\lambda_{\text{rest}}} = \frac{v}{c} = z$$

where λ_{shifted} is your *measured* wavelength, and λ_{rest} is the *known* wavelength of the line if it were not moving, and z is the redshift.

• Find the redshift for ALL of the lines you measured (this means doing this calculation **three times** for every galaxy).

(5 pts) Record your three redshifts for each galaxy in your data table.

•Average the redshifts and multiply the average times the speed of light (3×10^5 km/s) to get the velocity of the galaxy:

$$z_{\text{average}} \times \left(3 \times 10^5\right) = v\,(\text{km/s})$$

(5 pts) Record your average redshift and the velocity of each galaxy in your data table.