Name: ____________________

Date: ____________________

Section: ____________________

Astron 104 Laboratory #12
Hubble's Law
Section 15.3

In this lab, you investigate Hubble's Law, an empirical law which relates the speed with which galaxies recede from us to their distance from us. You obtain a value for the Hubble Constant, and from that measurement get an estimate of the age of the universe.

Procedure

1. **Determine the distance to the galaxy**
   Select *Galactic Speeds and the Hubble Law* from the *Start Lab* menu. You are given a view of the sky which contains a cluster of ten galaxies. Both spiral galaxies and elliptical galaxies can be observed, with some spiral galaxies seen from a face-on perspective, and others edge-on. For the purpose of this exercise, the estimated distances are given to you when you position the cursor over a galaxy, or when you click on a galaxy.

2. **Measure recession speed from the Doppler shift**
   Most of the billions of galaxies in the universe are receding away from us. The recession speed can be measured using the Doppler effect, which leads to a change in the observed wavelength of the light detected from a galaxy relative to the reference wavelength which we know must have been emitted by the stars in that galaxy, λ_0. Since the galaxies are moving away from us, the light is shifted towards longer wavelengths, or is red-shifted. By measuring the Doppler shift of the wavelength, $\Delta\lambda$, the recession speed, v, can be calculated using the formula:

   $$v = \frac{\Delta\lambda}{\lambda_0} c \tag{1}$$

   where the speed of light, c, is 3×10^8 m/s or 300,000 km/s.

   By positioning the cursor directly over a galaxy, you see two hydrogen spectra: one from the galaxy and one from the lab (for reference). Click on one of the spectral lines, and a grid is superimposed on the spectrum to help you make the measurement of the wavelength shift, $\Delta\lambda$ between the wavelength of the galaxy's line and the reference wavelength.

NOTE: The major lines on this grid correspond to a wavelength change of 2.5 nanometers (nm), and the finer divisions to a wavelength change of 0.5 nm. The screen incorrectly states that the larger divisions are 0.5 nm wide!

After you measure the wavelength shift, then click anywhere in the expanded spectrum view to be returned to the full spectrum. Repeat this procedure for all four lines and record your measurements in the table provided.

CALCULATING THE SPEEDS
Once you have determined the average Doppler shift ratio ($\Delta\lambda/\lambda_0$) for each galaxy with a precision of 3 significant figures, you can calculate each recessional speed using equation (1).

CHECKING YOUR DATA
Select *Check Galactic Data* from the overhead menu. In the window which appears, enter the identification number of the galaxy, one or more Doppler shifts for the spectral lines, and the recessional speed which you have determined for this galaxy. Correct results will be indicated with a check mark, incorrect results should be corrected before proceeding.

When you have completed making measurements on all four spectral lines, click on the galaxy a final time to "unlock" its spectrum from the display. Move on to the other galaxies and repeat the above measurements. Be sure to record the distance and the identifying number for each galaxy in the tables provided.

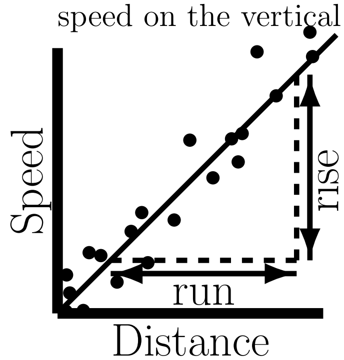
10 galaxies, 5 points each

3. **Determine the Hubble Constant [10 pts]**

Edwin Hubble discovered that when a plot is made of the recession speed versus distance to a galaxy, there is an unmistakable trend which is expressed by Hubble's Law:

$$v = Hd \tag{2}$$

where H is the Hubble constant. The first step in determining the Hubble constant is to plot on a sheet of graph paper the distance on the horizontal axis and recessional speed on the vertical axis.



Take a ruler and draw on your graph the best straight line which goes through all of the data points. From the Hubble Law, the Hubble Constant (H) is just the slope of this line. To get a numerical value, draw a large triangle (see figure) from which you can calculate the rise and run for this line. The slope is then the ratio:

$$H = \frac{\text{rise}}{\text{run}}$$

Since the distances are measured in millions of light years (Mlyr), and the recessional speeds in km/s, the Hubble Constant has units of km/s/Mlyr.

4. **Calculate the Age of the Universe [10 pts]**
The age of the universe can be calculated directly from the Hubble constant:

$$\text{Age} = \frac{300.0}{H}$$

where the age is measured in billions of years (assuming a constant rate of expansion).

CHECKING YOUR RESULT
Once you have a value for an estimate for the age of the universe, you can check your results by selecting *Check Your Hubble Constant* from the overhead menu. *SHOW YOUR INSTRUCTOR!*

(Note: The value you obtain for the Hubble Constant is not necessarily equal to that which you might find given in your textbook, although it should be approximately the same.)

1. What do you get for your Hubble Constant? [10 pts]

2. What do you get for the Age of the Universe? [10 pts]

3. An astronomer measures a Balmer line at a wavelength of 499.1 nm from a distance galaxy while his colleague measures the same line in her laboratory to be at 486.13 nm. What is the Doppler shift? What is the recessional velocity (in km/s)? Assuming a Hubble constant of $H = 23\,\text{km/s/Mly}$, what is the distance to the galaxy? Show your work for full credit. [10 pts]

Galaxy ID:		
Rest Wavelength λ_0	**Doppler Shift** $\Delta\lambda$	$\Delta\lambda/\lambda$ (divide column 2 by column 1)
Violet line: 410 nm		
Indigo line: 434 nm		
Green line: 486 nm		
Red line: 656 nm		
	Average value=	
	Recession speed=	
	Distance=	

Galaxy ID:		
Rest Wavelength λ_0	**Doppler Shift** $\Delta\lambda$	$\Delta\lambda/\lambda$ (divide column 2 by column 1)
Violet line: 410 nm		
Indigo line: 434 nm		
Green line: 486 nm		
Red line: 656 nm		
	Average value=	
	Recession speed=	
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Rest Wavelength λ_0	**Doppler Shift** $\Delta\lambda$	$\Delta\lambda/\lambda$ (divide column 2 by column 1)
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Red line: 656 nm		
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	Distance=	

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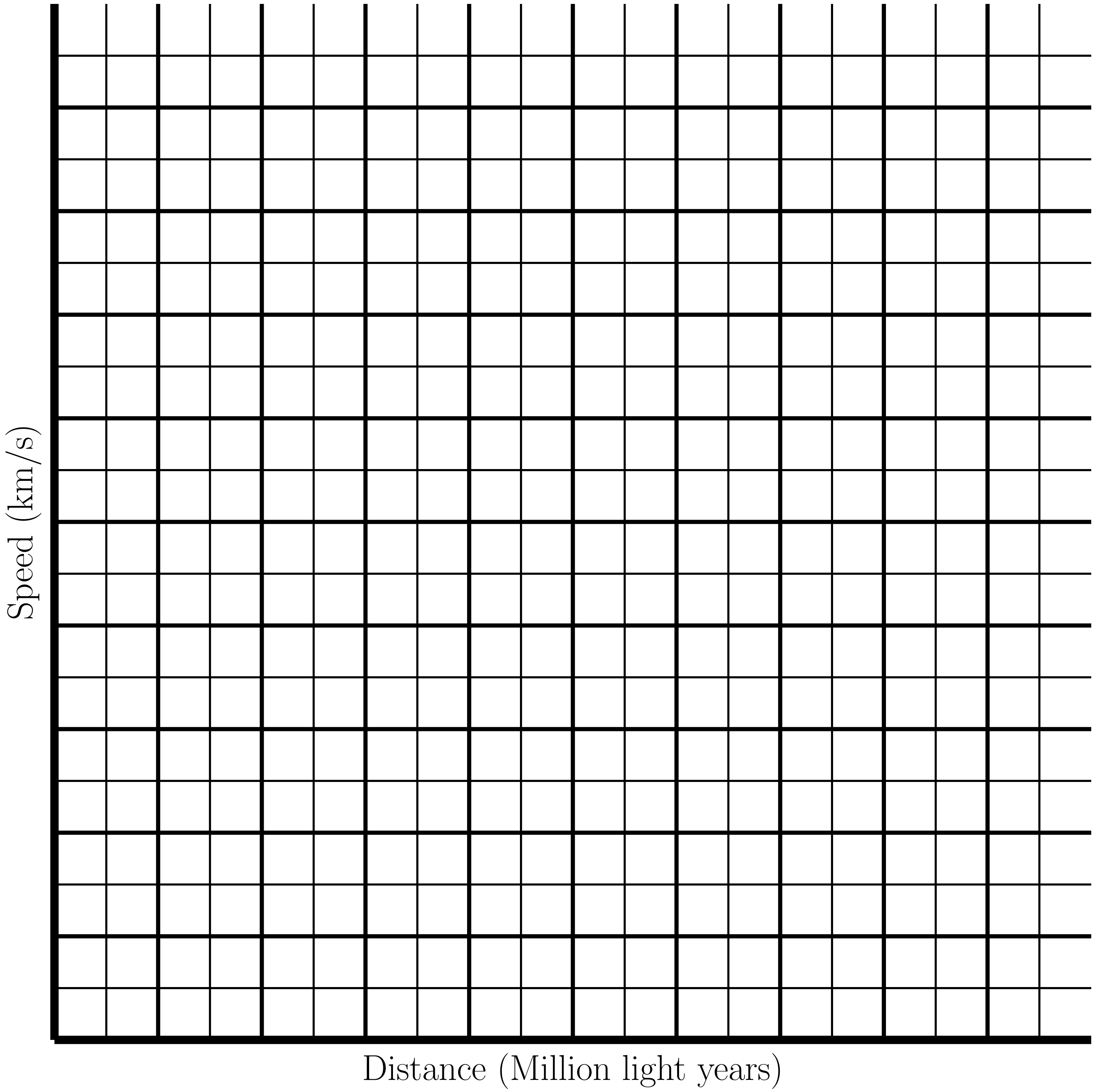
Speed (km/s)
Distance (Million light years)