HUBBLES LAW ELMS LABKEY

1. **(essay)** It's true that we have telescopes on Earth and telescopes in space, so *technically* we can look at the same galaxy from two different places. But in this context, why is that basically the same as not being allowed to move while you make a map of the forest? **Distance between Earth and satellite is very tiny compared to distance between Earth and another galaxy--it's as if you aren't moving at all.**

2. **(essay)** A) We've already discussed several ways we measure astronomical distances. Think of two different ways we've already learned about, and list them, please. **radar, stellar parallax, main sequence fitting, Cepheid variables, Type Ia SN**

B) Can we make a map of the entire (known) universe using only those methods? Why or why not? **All of these methods are limited by distance, and some of them take considerable time to make an observation. One can't measure distances to the entire universe this way.**

3. **(essay)** Does it make sense that galaxies would also have absorption lines? Why or why not? (Hint: galaxies are assemblages of. . . ?) **Yes. Stars have absorption lines; galaxies are composed of stars. So galaxies should have absorption lines as well.**

4. **(MC)** If Slipher's absorption lines were at a lower energy than expected, were the lines at longer or shorter wavelengths than expected? **longer**

5. **(MC)** Your spreadsheet should be entirely filled in. Your graph at the bottom should have five data points and a black line. This type of graph is called a **Hubble Diagram**.

Let's think about what it says. Choose which option best completes the following sentence: If I know the average velocity of the galaxy (from its spectrum), I can figure out… **its distance**

6. **(essay)** Before, our trend line was what fit our data points best. We just told Excel that its automatic line was *ok*, but we wanted to force the trend line to go through the point (0,0). This point is interpreted as follows:

if the distance to the galaxy is 0 Mly, the velocity should be 0 km/s.

Why should our trend line pass through the point (0,0)? Please explain your reasoning. **Observer is at distance 0 from self--and is certainly not moving away from self! So, v = 0 as well: (0,0)**

7. **(essay)** The second equation you recorded is known as **The Hubble-Lemaitre Law** (or often simply **Hubble's Law**) and is typically written as:

$$v = H_0 \times D$$

H_0 is called Hubble's Constant and is the slope of the trend line in the Hubble Diagram. *Your value for Hubble's Constant is the slope of your trendline in units of km/s/Mly!*

Below is a list of different measurements of Hubble's Constant. Look at these two measurements and compare them to your value.

Hubble's 1929 measurement	153 km/s/Mly
Today's best measurement	20.8 km/s/Mly
Your value	**~13.36 km/s/Mly**

1) explicitly write out your value of Hubble's Constant.

2) Does your value match the ones above? **shouldn't!**

3) If it doesn't, what could cause your measurement to be different? (There are multiple reasonable possibilities.) **small sample size, accuracy of measuring spectral lines, Hubble distances were in error, assumed constant expansion rate when rate is not constant, etc.**

8. **(MC)** For the next three questions, complete the sentence using the choices given:

The further a galaxy is from us, the **faster** it is moving. (While this may not seem very exciting, this was Hubble's great discovery which revolutionized astronomy.)

9. **(MC)** It may not have been obvious from your spreadsheet, but all of the absorption lines are redshifted. This means that galaxies are moving **away from us**.

10. **(MC)** Consider your answer to the previous question. Assuming your answer is true, that means that at some point in the past, all galaxies must have been: **closer to us** **(essay)** The conclusion you made above

11. provides direct observational evidence for what major theory in astronomy? Please explain: **Big Bang. If everything is moving away from us, everything must have been MUCH closer in the past. At some time we must have all been in the same spot and expanded from there.**

12. **(essay)** 1) Returning to our spreadsheet one last time: what do you notice about the integration time (column C) and the distance to the galaxy? (The relationship may not be a perfect fit.) **Roughly, the more distant the galaxy, the longer it took to get the desired S/NR—the simulation isn't perfect at this, for unknown reasons, but you can get 3-4 points to work of the 5.**

2) Photons are always arriving from each galaxy every second; you are always able to obtain a spectrum. So why would the relationship you noticed exist? **Inverse square law again: distant objects are fainter, so it takes longer to collect enough photons.**

13. **(essay)** Using Hubble's Law and the value of H_0 you found with your Hubble Diagram, calculate the velocity of a galaxy that is 2000 Mly away. **answers vary but should be close to:**

$V = H_0D$, $D = 2000$ Mly, $H_0 = 13.36$ km/(s*Mly)

V = (13.36 km/(s*Mly))*2000 Mly = 26,720 km/s or 2.67*10^4 km/s

14. **(essay)** You now know the distance to the galaxy and how fast it's moving away from you. In order to understand how we're going to calculate the age of the universe, consider this example: You tell a friend that you are currently 120 miles away from your house and that you've been driving at 60 miles/hour since you left your house. By using the appropriate equation relating distance, velocity, and time:

$$v = \frac{d}{t}$$

your friend could figure out that you have been driving for two hours.

Let's apply this same concept to figure out when the universe "started its trip". First, convert to the distance (2000 Mly) to km so that it will match the units of velocity (km/s). As we might expect, this will be a fairly large number of kilometers. Enter your answer in scientific notation. ***Use the***

values provided at the end of the lab for your calculation.

2000 Mly*10^6 ly/Mly*9.45*10^12 km = 1.89*10^22 km

15. **(essay)** Now that you have distance and velocity in the appropriate units, determine how many seconds ago the universe started.

V = d/t, so t = d/V
1.89*10^22 km/(2.67*10^4 km/s) = 7.08*10^17 s

16. **(essay)** The age of the universe in seconds isn't very helpful! Convert your previous answer to *years*. (Hint: remember the value for seconds/yr you calculated in the very first lab? Think pi and 10E7! Or, of course, just check the appendix to this lab!)

7.08*10^17 s * 1 yr/3.15*10^7 s = 2.25*10^10 yr

17. **(essay)** Even the age of the universe in years is quite a large number to understand. Astronomers typically talk about the age of the universe in terms of billions of years. The universe is how many *billions* of years old?

2.25*10^10 yr * 1 billion yr/10^9 yr = 22.5 billion yr

18. **(essay)** Our current estimate for the age of the universe is about 13.8 Gyr (billion years). Does your answer match this? If not, what could cause the discrepancy? **No, our measurements could be off, or our calculations. [More subtle & they probably won't get this] Our method assumes the universe has been expanding at a constant rate—it hasn't (inflation, dark energy if they know about it).**