

NAME: _____

HUBBLE EXPANSION

What will you learn in this Lab?

In this lab, you will reproduce the 20th century discovery by Edwin Hubble that the Universe is expanding. You will determine the rate of this expansion using the Hubble Ultra Deep Field.

What do I need to bring to the Class with me to do this Lab?

For this lab you will need:

- A copy of this lab script
- A pencil
- A calculator

The Nature of Sound and Light

An interesting property of sound waves is that the pitch of a sound emitted from a source moving with respect to the observer, varies as a function of the moving object's velocity. This is a phenomena you are all familiar with, if you have ever noted the change in the sound of a firetruck's or police car's siren that occurs as the sound sources moves away or towards you at a high velocity. Christian Doppler first derived the mathematical formalism to describe this effect, so in honor of its discoverer, we refer to this phenomena as the Doppler Shift of Sound.

Light waves are a different physical phenomenon than sound waves, light waves are manifestations of oscillations in electro-magnetic fields, whereas sound waves are pressures disturbances in a dense medium. *But* both phenomena can be described as waves. A light wave can be described, like a sound wave, by its wavelength or frequency. You interpret light of different wavelengths as different colors:

REDDER light has LONGER Wavelengths or LOWER Frequencies

BLUER light has SHORTER wavelengths or HIGHER Frequencies

Because the Doppler Shift effect applies to all wave phenomena, there exists a Doppler Shift of Light effect as well. Scientists quantify the amount by which that the light is shifted “blue” or “red” away from its rest-frame wavelength is given by a ratio referred to as a “redshift”, or simply “z”. Use the table to below to understand this terminology:

<i>If the light is ...</i>	<i>...then the emitter is ...</i>	<i>...and we call the effect a</i>
“Bluer” than expected	Moving towards you	Blueshift
“Redder” than expected	Moving away from you	Redshift

In the above table, the “expected” wavelength of the light is measured in the “rest-frame”, usually in a laboratory on Earth. To see how this “expected” wavelength is useful consider the following. First, atoms and gases are the same here on Earth as they are anywhere in the Universe – Hydrogen in the Sun or here on Earth is the same Hydrogen that astronomers observe in galaxies hundreds of millions of lightyears away. So, if we know all of the transitions in a particular compound and the wavelength of light that each transition will produce, and we then measure any difference between the observed and expected wavelength from a distance object this indicates that the object has some relative velocity with respect to the observer.

The velocity of the object with respect to the rest-frame observer can be calculated with the following equation:

$$\frac{v}{c} = \frac{(1 + z)^2 - 1}{(1 + z)^2 + 1}$$

where z equals the redshift of the object and c is the speed of light, 2.99×10^8 m/s. When the redshift is small (much less than 1), then we can approximate the velocity of the moving object that is emitting light with the equation $v = cz$. For objects in the Milky Way, z is always much, much less than 1. This is because the velocity of the object is a true space velocity – the object is moving a distance x in a time t , and we all know that objects can’t travel faster than the speed of light.

But, things get interesting for distant galaxies where we commonly observe all objects with redshifts much greater than 1. But, this doesn’t mean that galaxies in the Universe are flying away from the observers at speeds greater than the speed of light. In fact, these galaxies are embedded in a Universe that is expanding! This discovery was made by Edwin Hubble in 1929, and is one of the primary arguments to support the “big bang theory.” In this lab, you will re-derive this expansion using a real scientific dataset.

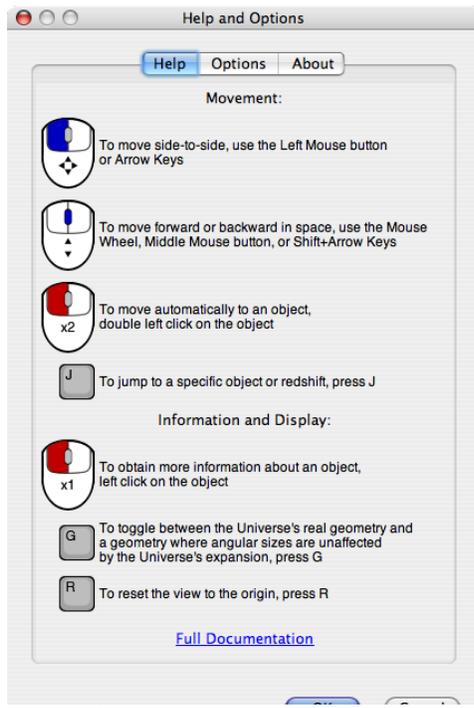


Figure 1: Instructions for using AHaH

Introduction to AHaH

In this lab you will use the Hubble Ultra Deep Field, a very long (~1 Million seconds) exposure of a “dark” part of the southern sky taken with the Hubble Space Telescope. In this image, thousands of galaxies were observed; some of these galaxies emitted their light more than 12 billion years ago. Arizona State researchers prepared this image so that a user of the “Appreciating Hubble at Hyperspeed” software could zoom through the image and inspect the images of the individual galaxies in the Field.

You will use this software to measure the redshifts and distances to a number of galaxies in the Field and derive the Hubble Law. The AHaH software is intuitive but the controls are provided in Fig. 1.

Follow-up Questions:

- Q1.** What is the slope of your line? Don't forget to add the units of the slope. The units of the slope are the units of the y-axis divided by the units of the x-axis.
- Q2.** Consider the movement of the galaxies.
- a. On your graph, as you move to larger and larger distances what happens to the velocity of the galaxies?

 - b. Are these galaxies moving away from us or towards us?

 - c. Do you always see galaxies moving in this way, regardless of direction? That is, are all galaxies moving in the same way, regardless of which direction in the sky we look?
- Q3.** There are 2 reasons why we might see the results discovered by Hubble: (1) we are the center of the universe, and all galaxies move from this point in space or (2) space itself is expanding, carrying the galaxies with it. Science has shown that Earth is not the center of the Solar System, and similarly, it is unlikely that our galaxy is the center of the Universe. Explain how the expansion of space itself could explain the movement of the galaxies.

Q4. If space is expanding, that tell us something about how the universe began. What would happen if wind the clock backwards? How would the distance between objects today compare with the distances in the early universe?

Q5. If the accepted value of Hubble's Constant is 73.8 km/s/Mpc, what is the percent difference in your measurement?

$$\% \text{ Difference} = \left| \frac{\text{measured} - \text{accepted}}{\text{accepted}} \right| \times 100\%$$

Q6. If the universe has been expanding at the Hubble rate since its beginning, we can calculate the age of the universe!

a. Notice the units of the Hubble constant. Both *km* and *Mpc* are units of distance. With a little work, we see that Hubble's Constant is a "rate" with units 1/s. Convert *Mpc* to *km*, cancel out these distance units, and put the constant in units of 1/s units. *Hint: Divide your value of Hubble's constant by 3.08×10^{19} km/Mpc. Watch your units!*

b. Multiply your answer from part a by the number of seconds in one year (3.15×10^7 s/yr) and invert your answer (1 divided by your answer) to get age of the universe in years.

- Q7.** Now, let's consider possible sources of error in the measurement of the Hubble Constant. "We could have messed up our measurements" is not a scientific measurement error. Instead, we consider what measurements are most *uncertain*.

Hubble's Constant is found using distance and velocity measurements. If a distance or velocity is not well known, how would it affect the Hubble constant? In what way? As always, be specific! (*Hint: Think about previous labs we have had in the semester – for example, Color-Magnitude Diagrams and Cepheids labs.*)

CONCLUSION:

Summarize the concepts you learned about in tonight's lab. What did you learn about each of these concept? Summarize the experiment. How did this experiment help you understanding of the concepts?