INSIDE LAB 10: The Hubble Redshift-Distance Relation

OBJECTIVE: *To become familiar with Hubble's law.*

DISCUSSION:

In the early 20th century, astronomers discovered that the light from most galaxies is redshifted. If the redshift is caused by the Doppler effect, then almost all galaxies are moving away from us at significant speeds. In the late 1920's Edwin Hubble discovered that, although the light from some nearby galaxies is blueshifted, the light from all distant galaxies is redshifted and the farther away a galaxy is the more redshifted its light is. By interpreting the redshift to be due to the motions of the galaxies, Hubble came up with his famous law $v = H_0 d$ with v the speed the galaxy appears to be moving away from us, d its distance and H a constant called Hubble's constant.

These facts suggest that the universe is expanding. Galaxies move away from us in the same way that dots on a balloon that is being blown up move away from each other. Observers in any other galaxy (or dot) would also see the other galaxies (dots) racing away from them as well. As for dots on a balloon, the expansion isn't really due to the motion of individual galaxies. Instead it is due to the creation of space in between the galaxies. Going backwards in time, one would observe that there is less space between the galaxies and therefore that the universe is smaller. Going backwards far enough in time would result in there being no space between points (galaxies weren't around at the beginning). This is the beginning of the universe or the Big Bang.

So what is the cause of the redshift from the distant galaxies? It is due to the fact that light is a wave and, as space expands, light must expand with it. Thus the wavelengths of the light must get longer. The more the universe expands the more space is created and the longer the wavelengths get. The more distant a galaxy is the longer it takes the light it emits to get to us. The longer it takes for the light to get to us the more the universe expands and, hence, the greater the redshift.

Exercises:

Navigate to the following website:

www.astro.washington.edu/courses/labs/clearinghouse/labs/HubbleLaw/galaxies.html .

On this page, you will see a list of distant galaxies (NGC objects) with sample images and emission spectra. Select the spectra for the galaxies listed below, and determine the wavelength of the K and H lines of Calcium.

Galaxy	λ_K (Å)	λ_H (Å)	v_K (km/s)	v_H (km/s)	v_{avg} (km/s)
NGC1832					
NGC2775					
NGC2903					
NGC3627					
NGC5548					
NGC6181					

To determine the velocity at which each object is moving away, we use the Doppler shift formula,

$$\frac{v}{c} = \frac{\lambda - \lambda_0}{\lambda_0}, \quad \text{or} \quad v = \frac{\lambda - \lambda_0}{\lambda_0}\left(300{,}000 \text{ km/s}\right).$$

where λ is the measured value and λ_0 is the laboratory value. Compute this value for both the K and H lines, then take the average. The lab value for the K line is 3934 Angstroms, and the lab value for the H line is 3969 Angstroms.

Galaxy	b (L_{Sun}/Mly^2)	L (L_{Sun})	d (Mly)	v/d
NGC1832	1.93×10^5	2.5×10^{10}		
NGC2775	5.83×10^5	2.5×10^{10}		
NGC2903	1.61×10^6	2.5×10^{10}		
NGC3627	1.76×10^6	2.5×10^{10}		
NGC5548	5.83×10^4	2.5×10^{10}		
NGC6181	1.11×10^5	2.5×10^{10}		

We know that most galaxies have a luminosity of about $L = 2.5\times10^{10}\ L_{Sun}$. We can then find the distance to the galaxies using the formula:

$$L = 4\pi b d^2.$$

This formula can be rearranged to solve for the distance, namely,

$$d = \sqrt{\frac{L}{4\pi b}}.$$

Use this formula to fill in the distances in the table above.

It is straightforward to calculate the value v/d for each of the galaxies. This is the Hubble constant H_0; take an average of these six values and write it below. What are the units of this value?

$H_0 =$ ______________________ ____________

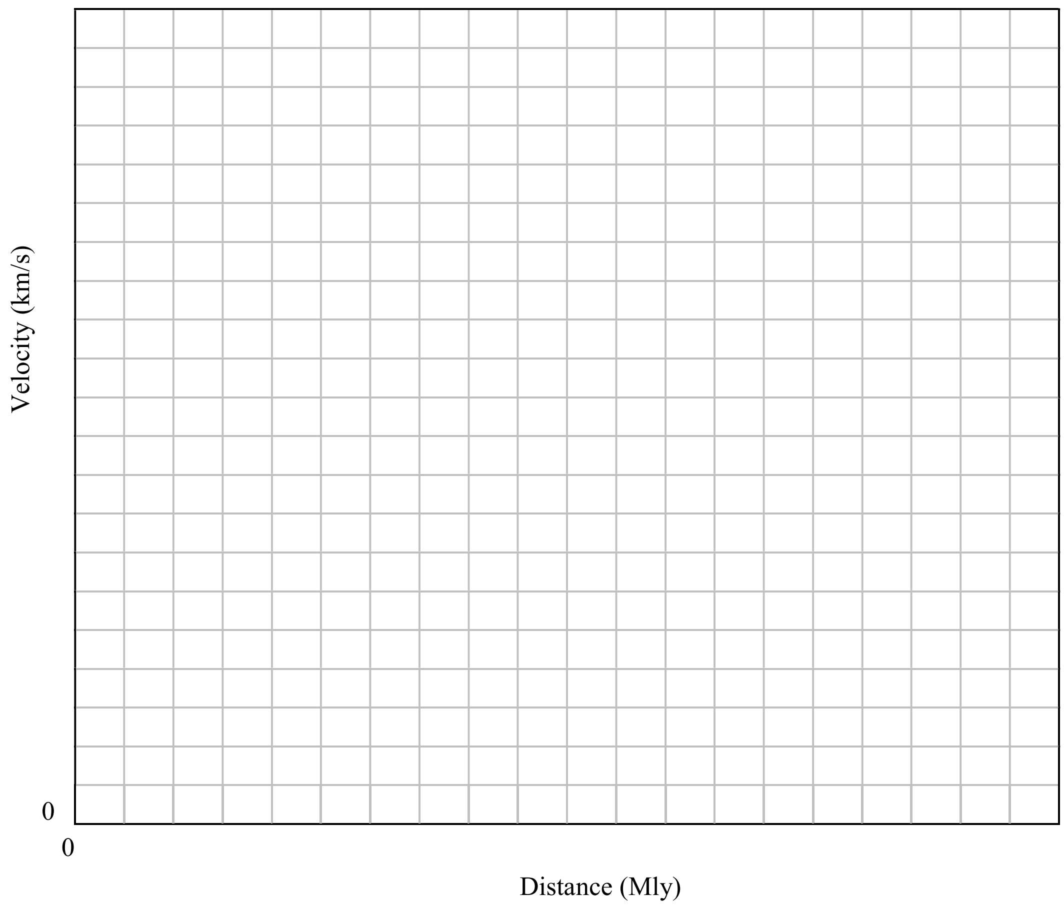
Given that 1 Mly = 9.461×10^{18} km, write the Hubble constant in units of 1/s.

$H_0 =$ ______________________ /s

As mentioned earlier, the Hubble constant tells us about the expansion of the universe, and can be used to find a rough estimate of the age of the universe. Invert the Hubble constant to determine the age of the universe:

$\frac{1}{H_0} =$ ___________________________ s = ______________________ years

Plot your data by graphing the velocity of the galaxy along the y-axis, and the distance along the x-axis. According to Hubble's Law, these points should all lie approximately on a straight line passing through the origin. Draw the line.



Suppose an astronomer detects a previously unobserved galaxy that is moving away from us at 10,000 km/s. Use your value of Hubble's constant to determine how far away the galaxy is in Mly.

d = ________________