Calculation of the Age of the Universe (II)

Calculation of Recession Velocity of a Galaxy

The wavelengths you have measured for the K and H lines in each galaxy are shifted toward a longer (redder) wavelength due to the galaxy's motion away from the Milky Way. To find the galaxy's velocity, we need to know how much the K and H lines are shifted from a standardized, stationary source. Thus we need to know the K and H wavelengths in a laboratory that is stationary in the frame of reference of an observer. These values are:

Unshifted K line: 3933.7Å

Unshifted H line: 3968.5Å

We can now calculate a *wavelength difference* ($\Delta\lambda$) for each K and H line, i.e.,

Wavelength Difference = Shifted Wavelength - Unshifted Wavelength

Perform this calculation for the data from each galaxy and record the results.

Next it is necessary to calculate the *fractional wavelength difference* ($F\Delta\lambda$) for each K and H line, i.e.,

Fractional Wavelength Difference = Wavelength Difference ÷ Unshifted Wavelength

Again, perform this calculation for each galaxy and record the results. The fractional wavelength difference is the fractional amount that the K or H line has been shifted from the laboratory wavelength and is related to the recession velocity of the galaxy.

Finally we can compute the *average fractional wavelength difference* as follows:

Average Fractional Wavelength Difference = (K FΔλ + H FΔλ)/2

This number, which is always less than 1.0, is the recession velocity of the galaxy in % of the speed of light. The speed of light (denoted by the symbol *c*) has a value of about 3×10^8 meters per second. Thus a galaxy with an average fractional wavelength difference of .75 would be moving at 75% of the speed of light away from us. What is implied by the fact that the average fractional wavelength difference is always less than 1.0?

The calculations for Hydra are done as an example on the next page. Note that the recession velocity for Hydra is roughly .2 or 20% of *c*.

Hydra K line: 4740Å Unshifted K line: 3933.7Å
Hydra H line: 4762Å Unshifted H line: 3968.5Å

Wavelength Difference ($\Delta\lambda$):

4740Å - 3933.7Å = **806.3Å** (K)
4762Å - 3968.5Å = **793.5Å** (H)

Fractional Wavelength Difference ($F\Delta\lambda$):

806.3Å ÷ 3933.7Å = **0.205Å** (K)
793.5Å ÷ 3968.5Å = **0.200Å** (H)

Average $F\Delta\lambda$:

(0.205 + 0.200) ÷ 2 = **0.202**

Hydra Recession Velocity:

= **20.2% of *c***

Compute recession velocities for each of the galaxies in Figure 1. You should see a pattern arising; i.e., the recession velocities increase as you move down the list of galaxies in Figure 1.

Calculation of the Distances to the Galaxies

We are now ready to calculate distances to the galaxies in Figure 1. This is the second set of values we need to construct a Hubble Plot. To begin, use the vernier calipers to measure the average diameter of each galaxy shown in the photographs on the left of Figure 1. Take two measurements for each galaxy, sum them up, and divide by 2. Next measure the length of the calibration bar at the lower left of Figure 1. Now for each galaxy perform the following calculation to find the angle that the galaxy subtends; i.e., the angular size of the galaxy:

$$\textbf{\textit{Angular Size}}\ \textbf{(radians)} = [\textbf{\textit{Average Diameter}} \times (7.27 \times 10^{-4})] \div \textbf{\textit{Length of Calibration Bar}}$$

For the galaxy in Hydra one should obtain a value of approximately 4.15×10^{-5} radians. Try this calculation before proceeding to the next step.

Finally, to get the distance to each galaxy in *light years* do the following calculation:

$$\textbf{\textit{Distance in Light Years}} = \textbf{100,000} \div \textbf{\textit{angular size}}$$

For the galaxy in Hydra, this distance is about 2.4×10^9 light years. It is important that you express these distances in billions (10^9) of light years. It may be necessary for you to convert some of your distances as in the following example:

$$\textbf{2.5} \times \textbf{10}^8\ \textbf{\textit{light years}} = \textbf{.25} \times \textbf{10}^9\ \textbf{\textit{light years}}$$

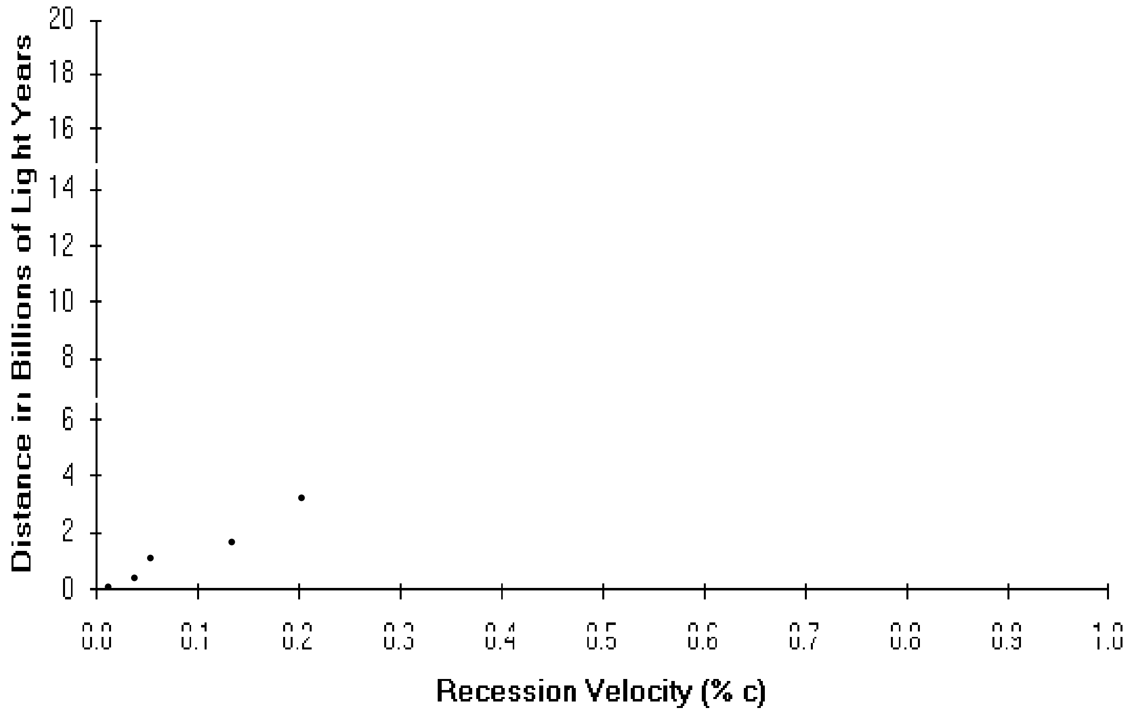
Record the distance in billions of light years to each galaxy in Figure 1.

The Hubble Plot

Begin by creating a table similar to the one shown below.

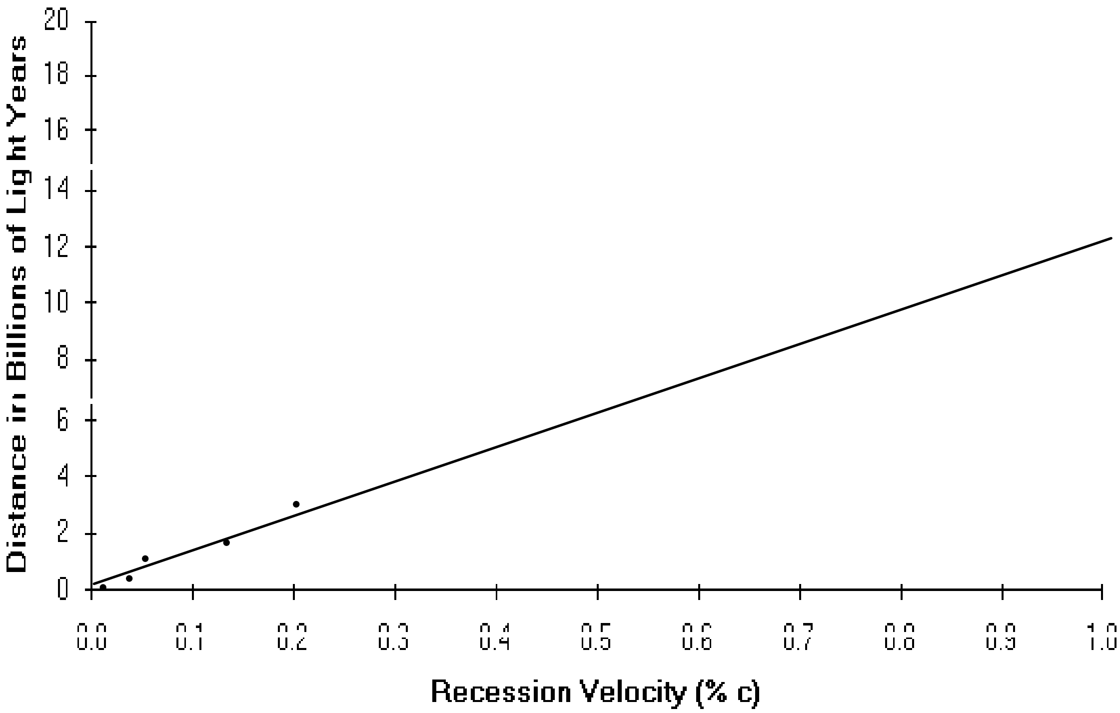
Galaxy in	recession velocity (% c)	distance
Virgo		
Ursa Major		
Corona Borealis		
Bootes		
Hydra	.202	2.4×10^9 light years

After you have developed a table like the one above you will be ready to create a graph of distance vs recession velocity, i.e., a Hubble Plot. Recession velocity values will be measured on the horizontal axis of your plot and distance values on the vertical axis. You should obtain a plot of five points similar to the one shown below:



You will have to estimate the position of your first point since both values will be very close to zero. Do the best job that you can. The outcome of this plot does not depend critically upon this point so as long as you are close everything will be OK. As before, be sure to make your axes as large as possible.

This will greatly enhance your ability to estimate distances between tic marks on the axes. After you have plotted all of your points, draw the best ***straight line*** that fits all of the points as shown below:



Be sure to extend your straight line so that it will intersect a vertical line drawn up from 1.0 *c* on the horizontal axis.

Calculation of the Age of the Universe

To estimate the age of the universe from the Hubble Plot simply draw a horizontal line from the intersection of the straight line through your points and a vertical line from 1.0 *c* on the horizontal axis.

The age is given in years because we are assuming that the light from the farthest visible objects has traveled so many billions of years at the speed of light, thus giving us the units of years instead of light years. The accepted age of the universe is between 10 - 20 billion years.

The reason we extended our straight line from the horizontal axis at 1.0 *c* is that we assume that the earliest created material in the universe will be moving away with a velocity of *c*. Thus, the total elapsed time since the creation of the material is the total distance traveled divided by the speed of light.

Exercises

1. Why is the recession velocity of a galaxy always less than the speed of light?

2. What is a red shift?

3. What spectral lines are the measurements in this exercise based on?

4. Why are the spectral lines in different places in the spectra of the different galaxies?

5. A galaxy is observed to have a K line at 4740Å and a H line at 4762Å. Compute its recession velocity.

6. How are the last four exercises that we have done related?