Astronomy 4 Term Project

Measuring the Age of the Universe

Introduction: In 1912, the American astronomer Vesto Slipher discovered that the spectral lines in light reaching the Earth from most galaxies are shifted toward the red end of the spectrum. These redshifts imply that these galaxies are receding from our galaxy. In the 1920s, another American astronomer, Edwin Hubble, found ways to measure distances to galaxies, and discovered that the further away a galaxy is from ours, the faster is it receding from us. This discovery, that the greater the distance, the greater the redshift, became known as Hubble's Law. Plotting recessional velocity of galaxies against their distance on a graph will thus yield a straight line. The slope of this line gives a value that is known as Hubble's Constant (H_0). For more details, see the course textbook, *Astronomy today*, 5th ed., pp. 644-48.

Task: The goal of this project is to estimate the age of the universe, i.e., the length of time that the universe has been expanding since the Big Bang. You will do this by collecting the data required to plot Hubble's Law. First, you will measure the distances to several clusters of galaxies. Using provided radial velocities of recession (i.e., the velocity of a galaxy along the line of sight between the galaxy and us) for several galaxies in these clusters, information derived from their measured redshifts, you can then plot your data on a Hubble diagram. Given Hubble's Law, a line through these points and the origin of your graph (why should the line pass through the origin?) should be straight. Recall that on an x-y graph, any line through the origin is specified by y = mx, where m is the slope of the line. On a Hubble diagram:

recessional velocity (km/s) = $\mathbf{H_0}$ (km/s/Mpc) x **distance** (Mpc),

where H_0 is the slope of the line. The units of distance here are megaparsecs (Mpc), or 10^6 parsecs. You will recall that a parsec is the approximately 3.3 light years.

Once you have determined a value for the Hubble Constant (the slope of the line of your graph), you can then find the time elapsed since the Hubble expansion began, if you assume that the expansion has not slowed down or sped up over time (is this a reasonable assumption?). In such cases of a constant velocity of recession,

V = D/T,

so that in our case, $T = 1/ H_0$, where T is the time since the expansion began. Thus, the inverse of the slope of the line of your graph will yield the "Hubble age" of the universe.

Procedures: First, you will measure the distances to seven clusters of galaxies (see the table below). Using a single "camera," astronomers some decades ago prepared the Palomar Sky Survey, a complete map of the heavens, with each photographic print covering a 6° square patch of the sky and with each plate exposed the same length of time. The goal was to create a complete sky map at a uniform scale. Objects down to magnitude 21 can be seen, including literally millions of galaxies (the naked eye can see objects only down to magnitude 6). In 1994, the Palomar prints were scanned at by the Digitized Sky Survey.

Rather than using the "standard candle" photometric method to measure distances to the galaxy clusters, you will use a "standard size" method. You will assume that the largest spiral galaxy in each cluster each has the same intrinsic linear diameter (is this a good assumption?). That is, if placed at a standard distance from us, all these largest spirals would appear to have the same angular width in the sky. By measuring the apparent diameters (θ, in mm) of the largest spirals in each of the clusters, you will then be able to compute their distances (**D**), if you already know the distance to, say, the closest cluster. Since it is important to keep the scale constant in the photographs of the various clusters, you should try to measure the apparent diameters directly on your computer screen; printing the digitized images might alter these scales as the printer automatically adjusts the image size to fit the page size.

Beyond our Local Group cluster (where our Milky Way comprises one of about 45 galaxies), the nearest neighbor is the Virgo Cluster, at a distance of about 18 Mpc. If you measure the apparent diameter of Virgo's largest spiral on the Palomar plates and the apparent diameter of the largest spirals in the other seven clusters, you can determine distances to the latter by means of the following relation:

$$\mathbf{D_{cluster} = D_{Virgo} \times \theta_{Virgo's\ largest\ spiral} / \theta_{cluster's\ largest\ spiral}}$$

Can you show why this relation gives the distance to the cluster for the "standard size" method?

You may access the Digital Sky Survey at http://archive.stsci.edu/cgi-bin/dss_form. Enter the object name (e.g., "Fornax Cluster") to look up its coordinates in right ascension and declination (using SIMBAD), the grid for locating items in the sky. Retrieve the scan from the POSS2/UKSTU. Set the Height and Width to 30 arcmins to extract from the survey a one-half degree square scan of the sky, centered on the cluster in question. For some of the larger clusters, you may need to view a larger scan, say 60 x 60 arcmins. Set the file format for GIF, and hit RETRIEVE IMAGE to bring the scan into your web browser. Scroll around to locate the largest spiral galaxy in the cluster. Using a ruler, measure the apparent diameter of that spiral in mm.

Note that many of the galaxies in these clusters are not spiral but elliptical galaxies (see *Astronomy Today*, 5th ed., pp. 634-40 for Hubble's classification of galaxies by their shape). Be sure to focus your attention on the largest spirals, not the ellipticals. Why do you think our "standard size" method of determining distances uses spirals rather than ellipticals?

We suggest that you measure the distances to the following galaxy clusters. To determine the radial velocity of each cluster, the redshifts of the lines in spectra taken from many of its constituent galaxies have been measured. Not every galaxy in a cluster is receding from us at the same speed. Hence the radial velocities in the following table represent the average speed of the galaxies in the cluster. These radial velocities are thus "cluster values," just as are the distances you determine. That is, we must assume that both these velocities and your distances represent the cluster as a whole, not any particular galaxy in the cluster. Is this a good assumption?

Cluster[1]	Redshift	Radial velocity (km/s)
Cancer	0.016	4,800
Coma	0.022	6,700
Corona Borealis	0.072	21,600
Fornax	0.005	1,400
Hercules	0.034	10,300
Leo	0.065	19,500
Pegasus I	0.013	3,700
Ursa Major II	0.137	41,000

Using the radial velocities in the table above, plot points on a Hubble diagram, with appropriate scales, for each of the galaxies listed above.

You are now ready to compute the Hubble age of the universe. From the slope of the line drawn from the origin through the points on your graph, you can read off a value for H_0 in km/s/Mpc. With this value, you can compute the age of the universe in years. Note that there are about 3×10^{13} km/pc, and about 3.1×10^{7} s/yr.

Turn in your Hubble diagram, calculations, and a brief discussion of the various questions raised above.

PS: For an interesting comparison with the spirals in the clusters listed above, take a look at the Andromeda Galaxy (also known as M31), a large spiral in our Local Group.

[1] Data taken from John D. Fix, *Astronomy: Journey to the Cosmic Frontier*, 2d ed (Boston, 1999), Appendix 15.