1 The Hubble Constant

1.1 Introduction

Soon after telescopes were invented surveys of the sky showed many fuzzy patches of light among the stars. In 1771 Messier published a catalog of over 100 such objects. Until the beginning of the 20^{th} century there was little agreement as to what these objects might be. We now know that many of them are galaxies like our own Milky Way galaxy.

During the 1920's Edwin Hubble, using the 200-inch diameter Hale telescope at the Palomar Observatory in California, began a systematic study of these objects. As part of his study he measured the spectra of several galaxies and noted that they showed varying amounts of displacement of the known spectral lines of Hydrogen. The displacements were all towards longer wavelengths. He took this as an indication of the doppler shift caused by the galaxy moving away from Earth. Using newly discovered techniques for distance estimates he correlated the velocity values of several galaxies with their apparent distance and discovered a linear relationship, now known as Hubble's Law:

$$V = H_0 * D \tag{1}$$

where V is the galaxy's velocity (in km/sec) and D is the distance to the galaxy measured in Mpc.[1]

The value of the Hubble constant has been a subject of serious debate since that time and, in fact, modern estimates using data from the Hubble telescope show a wide variation. Current values range between 60 and 80 km/sec/Mpc. The reason that the Hubble constant is of such interest is that it gives a time scale for the age of the Universe. In this lab you will be able to estimate a value for the Hubble constant and infer your own value for the age of the Universe.

1.2 Apparatus

- A set of images of various galaxies[2]
- A set of spectra for the galaxies

[1] 1 Mpc = 10^6 parsecs; 1 parsec = $3.08568025 \times 10^{16}$ meters.
[2] Adapted from the University of Arizona Department of Astronomy Lab

1.3 Procedure

1.3.1 Galaxy size estimates

The images of the galaxies you have were taken from a single image, shown in Figure 1, which means the size scale is the same for all images. In the master image the angular size of galaxy #2 is known to be 31 arcseconds.

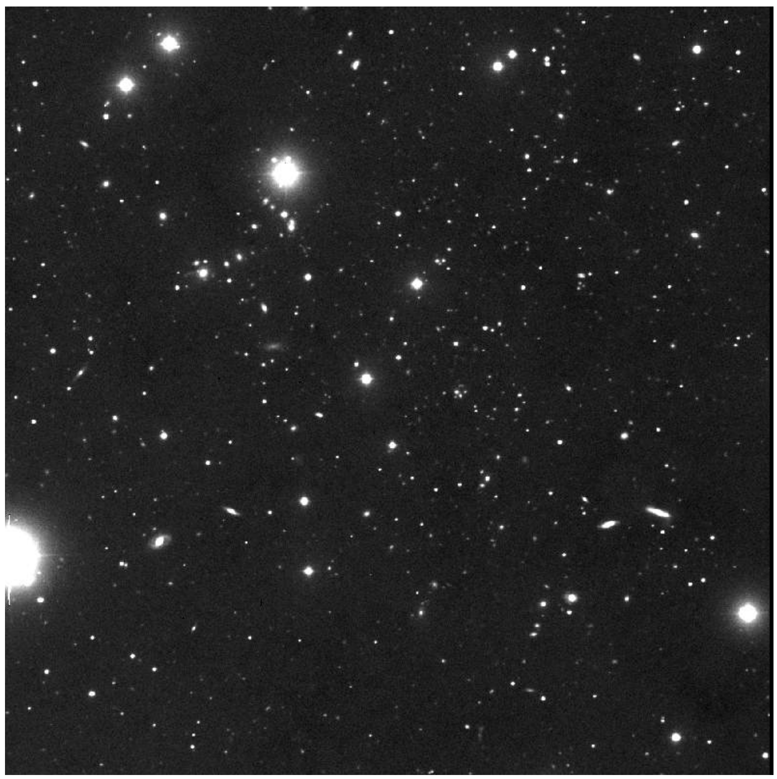

Figure 1: http://ngala.as.arizona.edu/dennis/instruct/dzimages/scan2.jpg

- Download the image of each galaxy from the UAF P213 web site.[3]
- Measure the size of all the galaxies and use the size of galaxy #2 to find the angular size of each galaxy. These galaxies are disks of stars. Since the disk may lie at an arbitrary angle you should measure the largest dimension.
- Assuming all galaxies have the same diameter and that galaxy #2 is lies at a distance 67 Mpc, convert the angular measurements above to distances in Mpc.

[3]see the instructions from your instructor.

1.3.2 Recession velocity estimate

If a distant source is moving away from us the light from the source will be red-shifted by an amount proportional to the speed along the line of recession. The relation between wavelength shift and speed is

$$\frac{\lambda - \lambda_0}{\lambda_0} = \frac{v}{c} \tag{2}$$

- Download the calibration spectrum 'hcalib1.jpg' from the UAF P213 web site. This spectrum shows the location of the three principal spectral peaks you should use in this experiment. The wavelengths are 3727Å, 4861Å, and 5007Å.
- Download the spectrum of each galaxy from the UAF P213 web site.
- Locate and measure the wavelength of the peaks. The plots have different sizes so the scales may be different. You should measure the distance between two major wavelength marks on the abcissa, for example 4000Åand 4500Åand then, using a ruler, scale this distance so that you can measure the offsets to the lines of interest.
- Average the values of v/c obtained for the three peaks and calculate the recession velocity in km/sec for each galaxy according to equation (2) above.

1.4 The Hubble constant, H_0, and the age of the Universe

- Plot the velocity of each galaxy in km/sec versus its distance in Mpc.
- Find the best-fit straight line through the plotted points and measure its slope. The slope is he Hubble constant, H_0, measured in $(km/sec)/Mpc$.

If we assume that the galaxies have been moving outward at the same speed since the 'Big Bang', then Hubble's constant can be used to estimate how long it has been since the bang. Note the units of Hubble's constant are essentially $(sec)^{-1}$; thus, it's reciprocal is an estimate of the time since the big bang. Use your value of H_0 to estimate the age of the Universe.

You may wish to fill your table with more estimates. A convenient way to accomplish this is to refer to the detailed lists of galaxies and their spectra that are available on the world-wide web. For example, a very nice set of data is present at the University of Washington web site.[4]

[4] http://www.astro.washington.edu/courses/labs/clearinghouse/labs/HubbleLaw/galaxies.html