Introduction

The late biologist J.B.S. Haldane once wrote: "The universe is not only queerer than we suppose, but queerer than we can suppose." One of the queerest things about the universe is that virtually all the galaxies in it (with the exception of a few nearby ones) are moving away from the Milky Way. This curious fact was first discovered in the early 20th century by astronomer Vesto Slipher, who noted that absorption lines in the spectra of most spiral galaxies had longer wavelengths (were "redder") than those observed from stationary objects. Assuming that the redshift was caused by the Doppler shift, Slipher concluded that the red-shifted galaxies were all moving away from us.

In the 1920's, Edwin Hubble measured the distances of the galaxies for the first time, and when he plotted these distances against the velocities for each galaxy he noted something even queerer: The further a galaxy was from the Milky Way, the faster it was moving away. Was there something special about our place in the universe that made us a center of cosmic repulsion?

Astrophysicists readily interpreted Hubble's relation as evidence of a universal expansion. The distance between all galaxies in the universe was getting bigger with time, like the distance between raisins in a rising loaf of bread. An observer on ***ANY*** galaxy, not just our own, would see all the other galaxies traveling away, with the furthest galaxies traveling the fastest.

This was a remarkable discovery. The expansion is believed today to be a result of a "Big Bang" which occurred between 10 and 20 billion years ago, a date which we can calculate by making measurements like those of Hubble. The rate of expansion of the universe tells us how long it has been expanding. We determine the rate by plotting the velocities of galaxies against their distances, and determining the slope of the graph, a number called the Hubble Parameter, $\mathbf{H_o}$, which tells us how fast a galaxy at a given distance is receding from us. So Hubble's discovery of the correlation between velocity and distance is fundamental in reckoning the history of the universe.

The software for the **CLEA** *Hubble Redshift Distance Relation* laboratory exercise puts you in control of a large optical telescope equipped with a TV camera and an electronic spectrometer. Using this equipment, you will determine the distance and velocity of several galaxies located in selected clusters around the sky. From these data you will plot a graph of velocity (the y-axis) versus distance (the x-axis).

How does the equipment work? The TV camera attached to the telescope allows you to see the galaxies, and "steer" the telescope so that light from a galaxy is focused into the slit of the spectrometer. You can then turn on the spectrometer, which will begin to collect photons from the galaxy. The screen will show the spectrum—a plot of the intensity of light collected versus wavelength. When a sufficient number of photons are collected, you will be able to see distinct spectral lines from the galaxy (the H and K lines of calcium), and you will measure their wavelength using the computer cursor. The wavelengths will be longer than the wavelengths of the H and K labs measured from a non-moving object (397.0 and 393.3 nanometers), because the galaxy is moving away. The spectrometer also measures the apparent magnitude of the galaxy from the rate at which it receives photons from the galaxy. So for each galaxy you will have recorded the wave-lengths of the H and K lines and the apparent magnitude.

From the data collected above, you can calculate the speed of the galaxy from the Doppler-shift formula. You will also estimate the distance to the galaxy by comparing its apparent brightness to an assumed value for its luminosity. (In a real experimental setup, we'd come up with some more complicated and more accurate method for determining distance.) The result is a velocity (in km/sec) and a distance (in megaparsecs, Mpc) for each galaxy. The galaxy clusters you will observe have been chosen to be at different distances from the Milky Way, giving you a suitable range to see the straight line relationship Hubble first determined. The slope of the straight line will give you the value of $\mathbf{H_o}$, the **Hubble Parameter**, which is a measure of the rate of expansion of the universe. Once you have H_o, you can use it to estimate the age of the universe.

The details of the measurements and calculations are described in the following sections.