Expansion of the Universe

As our telescopes get more sensitive, we can find fainter and fainter objects – and we find that the universe is filled with galaxies. Not even 100 years ago, we thought that the whole universe was filled with stars, and that all of the fuzzy blobs we saw were objects between the stars.

In 1920, a big debate between Shapley and Curtis tried to "solve" the question of what those fuzzy nebulae were. Shapley thought that the Milky Way was the entire universe; Curtis on the other hand thought that some of those fuzzy blobs were "island universes" in their own right. Shapley handily won the debate – but in the end it turned out he was wrong. A few years after the debate, Hubble made observations using Henrietta Swan Leavitt's period-luminosity relation for Cepheids. His observations showed that they were much too distant to be within the Milky Way.

Hubble combined his observations with those of Vesto Silpher, who had discovered that the galaxies' spectra were Doppler shifted relative to spectra observed in the laboratory. Recall that for objects moving away from us the wavelengths of emitted light are stretched so that we observe longer redder wavelengths. Similarly, objects moving toward us compress the wavelengths so that they appear bluer. By measuring the amount of wavelength shift we can determine the speed and direction the galaxies are moving. Hubble compared the velocities of the galaxies to their distance and discovered that the further the galaxy was, the faster it was moving away from us!

The distance-velocity relation discovered by Hubble arises naturally in a universe that is expanding. If the space between any two points in space is getting larger, the velocity of their separation will be proportional to their distance. If we run the clock backwards, we find that at some point in the distant past all the galaxies we see in the universe were all in the same place – Big Bang. In today's lab, you are going to follow in Hubble's footsteps to determine how long ago the Big Bang occurred.

Procedure

In order to explore the idea of Doppler shifted spectra we are going to use a computer program to simulate observing galaxies. Modern images and spectra of galaxies are obtained on electronic devices and computer processed. In this lab we will simulate such observations to determine galaxy distances and velocities.

Part 1: Making Observations

Step 1: Setting up the Telescope

1. Click on the **CLEA** folder on the desktop
2. Start the program **Hubble Redshift**
3. Log in, using initials for each group member and your group number
4. Go to **File → Run**
5. The program will tell you that you have control of the simulated telescope. Click "OK."
6. Open the dome by clicking on the **Dome** button.
7. Click **Tracking** to make the telescope correct for the Earth's rotation.

Step 2: Taking Spectra

The telescope is already pointed at a cluster of galaxies, called **Coma I**. You should see three galaxies in your field of view. You will observe **two** of these galaxies.

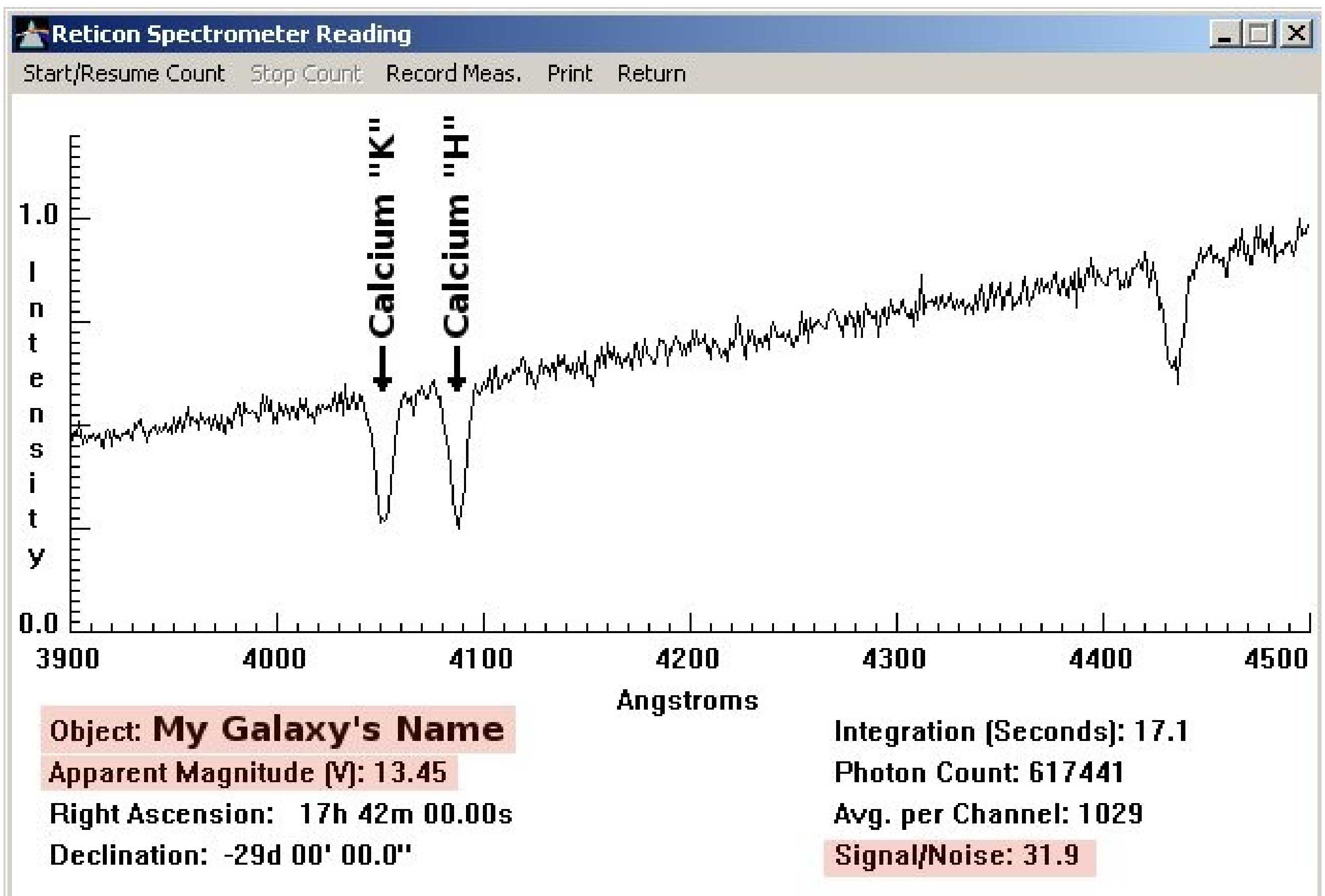
8. Use the **N,S,E,W** buttons to move the telescope to one of the galaxies. You can change how fast you move by clicking the **slew rate** button.
9. When your galaxy is centered, click the **Change View** button to zoom in.
10. Center the **brightest** part of the galaxy in between the two lines. (If you use a dim part it will take a long time). The lines are the spectrograph, which will take the data and turn it into a spectrum.
11. Click **Take Reading** to bring up the spectrograph window.
12. Click **Start/Resume Count** in the menu at the top to start taking data. You will see the spectrum "build up" as you collect photons. You want a

signal-to-noise of at least 15. Take note how long it takes you to get to 15, as it will help you answer the questions later. (You do not need to stop at 15 – remember that a higher signal-to-noise means a better measurement.)

13. When you are satisfied with your measurement, click **Stop Count**.

There are a few things to notice about your observation. As usual for a spectrum, the graph is intensity vs. wavelength. You see a continuum, which generally slopes upward. This is because a galaxy is made up of stars, and there are many more red stars than blue ones, so you see more red light than blue.

You also see a few absorption lines. Sometimes you will see three and sometimes only two. **The lines we are interested in are the two that are close together.** You will take measurements of the **Calcium H** line – the right-hand one – for this lab.



14. Click and hold to get a cross-hairs, then move the mouse to the center of the Calcium “H” line. Try to get as centered as possible! Release the mouse button. A vertical line will appear. If you are satisfied that you got it centered, write down the wavelength that appears at the top in Table 1.
15. Write the galaxy name (listed after **Object:**) in the information below the graph) and its **Apparent Magnitude** in Table 1.
16. When you have finished writing down all the information you need, click on Return and then Yes to return to the main controls.
17. Click **Change View** to zoom out again, then repeat steps 8-16 for a second galaxy in the Coma galaxy cluster.

We know that these are Calcium lines because every atom has its own fingerprint, a special spacing of spectral lines. The *actual* wavelength (at rest) of the Calcium “H” line is 3969 Angstroms.

18. Calculate the Doppler Shift of the line using the following formula and write it in Table 1.

$$\Delta\lambda = \lambda_{observed} - \lambda_{rest}$$

19. Click on **Change View** to zoom out again, if you haven't already. Take a look at the appearance of the galaxies in the Coma cluster. Then go to **Field...** in the menu. A box will pop up with several other clusters. Choose one of the other clusters and double-click on its name. Good choices are Ursa Major 1, Bootes, or Corona Borealis.

20. Choose one of the galaxies. Take a measurement, and fill in Table 1 for that galaxy.

21. Answer questions 1-3 in the packet.

22. Click on **Change View**, then **Field...** and choose one of the other recommended clusters, making an observation of one more galaxy.

Part 2: Finding Distance and Velocity

We now know that the light from the galaxies is Doppler shifted. We want to know how fast they are moving. We also can estimate how far away the galaxies are, by making a few assumptions. The biggest assumption we'll make is that all galaxies are roughly the same intrinsic brightness.

1. Calculate the galaxy distances by using the following equation:

   $$\text{distance (pc)} = 10^{((V-Mv+5)/5)}$$

   using an absolute magnitude of **M_v = -22** for all of the galaxies. Divide by 10^6 to get Mpc, and write your answer in column 2 of Table 2. **Check your answers with your lab instructor before continuing!**

2. Calculate the velocity of the galaxies by using the Doppler shift formula, and write your answer in column 3 of Table 2:

   $$\text{Velocity} = \Delta\lambda^* c \,/\, \lambda_{rest}$$

   where ***c*** is the speed of light, 3×10^5 km/s.

3. Convert your velocities from km/s to Mpc/Gyr (mega-parsecs per billion years) by dividing by 980. Write this in column 4 of Table 2.

   $$V\ (\text{Mpc/Gyr}) = V\ (\text{km/s}) \,/\, 980$$

Part 3: The Hubble Law

Take a look at the last column of Table 2. You will see a number, “H”, which has units of (Mpc/year) / Mpc. In other words,

H = Velocity / Distance

1. Calculate H by dividing your velocity in Mpc/year by the distance to the galaxy. Write this in column 5 of Table 2.

But what does it mean?

Take a look at your values for H. They're all pretty similar – in other words, H is a constant. If you think about the equation (and your data!), it means that the FARTHER something is, the FASTER it is moving away from us. Weird!!!

2. Calculate the average value of H, and write it in question 4.

3. Plot your galaxies on a piece of graph paper, using your velocity in Mpc/year as the y-axis and the distance as the x-axis. Draw a best fit line, making sure it passes through (0,0). Calculate the slope of the line. This slope is also H. Write your slope in question 4.

4. Answer questions 5-8.