

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 Slipher, 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.

Making Observations

Step 1: Setting up the Telescope

1. Click on the **VIREO** link on the desktop
2. Log in by going to **File** → **Log in** → **Enter** (no need to fill in the form)
3. Go to **File** → **Run Exercise** → **The Hubble Redshift-Distance Relation**.
It may take a moment to come up. When the center is black and menus are accessible:
4. Select a telescope with the menu **Telescope** → **Optical** → **Access 4.0 meter** (bigger is better! *Think about why.*)
5. The program will tell you that you have control of the simulated telescope. Click "OK."
6. Open the dome by clicking on the **switch** under where it says **Dome** on the right.
7. When the Dome is open, turn the **Telescope Control Panel** by clicking the button that currently says "off". This will bring up a new window.
8. If you watch the stars in the view for a moment, you will see that they shift over time. This is due to the Earth's rotation. We want the telescope to correct for that, and follow the stars. On the left side there is a button called **Tracking**. Click this button so that the telescope field of view does not drift. A green light should come on next to the button to show that tracking is on.

You are now almost ready to take observations!

Step 2: Taking Spectra

You will observe several galaxies. To do this, we need to think about what a galaxy looks like in the telescope.

STARS are perfectly round, in our own galaxy, and relatively bright. They don't look fuzzy at all. If they are *really* bright, they will have cross-hair type spikes. This is **not** because they *actually* have spikes, but instead is due to the telescope's shape. If you see something with regular spikes, it is not a galaxy!

GALAXIES are fuzzy. They may look round, but they will not be as bright as stars. They may also have shapes which are not round, or which have funny things sticking off them (different from the diffraction spikes on stars).

Fortunately for you, we have set up an observation list, which will point the telescope right to the galaxy, so you don't have to guess at all. However, do take the time to look at the field so you get a feel for “galaxy” vs. “star”.

1. Your group will be assigned several galaxies to observe. In the menu at the top click **Slew** → **Observation hot list**, and select one of the galaxies assigned to your group.
2. Once the telescope has stopped slewing (moving to) that galaxy, zoom in by clicking the switch to **Telescope** (It is currently on **finder scope**)
3. Make sure the two lines in the middle of the field of view are centered on your galaxy (remember: galaxies are fuzzy). If it is not you can use the **N,S,E,W** buttons to move it a little. (Moving the 'scope is called *slewing*)
4. Check that your instrument says Spectrometer then click the Access button. This brings up yet another window, which is where you will collect the data.
5. Click “GO” to take the data and “stop” when you think you have a good spectrum. Take data so you have a signal-to-noise of about 50. **Write down how long it takes you to get to 50 in Table 1.** Notice how long it takes to increase S/N early in an observation vs. when you get close to 50.
6. Write down the **name** of your object, its **Apparent Magnitude**, the **time** it took and your precise **signal-to-noise** in Table 1 of your Answer Packet, and any **comments** you have (galaxy's appearance/about the observation).
7. Save the spectrum by going to **File** → **Data** → **Save Spectrum**. Close the spectrum window and go back to the Telescope.
8. Repeat steps 1-7 for the other galaxies assigned to your group.

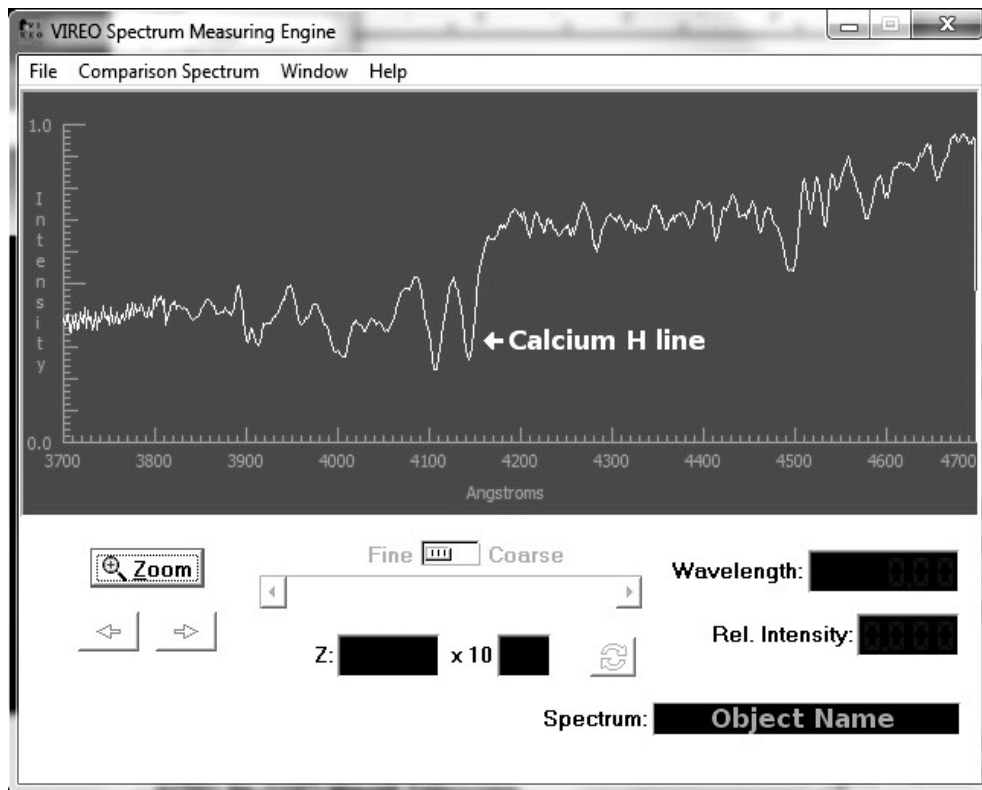
Step 3: Making Measurements

Once you have this data saved, return to the Observatory Main Control Panel (not the telescope one). Go to **Tools** → **Spectrum Measuring**. A new window will pop up (looks a lot like the take a spectrum window but it is different). Load one of your saved spectra by going to **File** → **Data** → **Load Saved Spectrum**.

You will need to measure the wavelength of the right-most line of the pair of lines. This is the “H” line of Calcium (see the other packet for more details). Write the measured wavelength in your table.

There are a few things to notice about your observation. As usual for a spectrum, the graph is intensity vs. wavelength (in Angstroms here, or 10^{-10} m). 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. **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.



1. 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 (not necessarily on the peak)! Release the mouse button. A vertical line will appear. If you are satisfied that you got it centered, write down the wavelength in Table 2. You can zoom a little if the shape of the line is tricky, but don't zoom too much or you will have a hard time finding the line you want.
2. Write the galaxy name (listed after **Spectrum:** in the information below the graph) and **your measurement of the Calcium H line** in Table 2.
3. When you are done with this galaxy, load a new spectrum (in the same window) once again with **File** → **Data** → **Load Saved Spectrum**. Repeat the measurements for your remaining galaxies.
4. Write up your data on the board for the rest of the class to use.
5. **Answer questions 1-3 in the packet.** Once you are done, continue on with the data analysis.

Part 2: Data Analysis

There are two things we can figure out from our observations. One thing astronomers always want to know is how far away things are. We can estimate the distance each galaxy is by making an assumption: that all galaxies are roughly the same intrinsic brightness. This may sound like a bad assumption, but measurements using independent methods suggest it's not too terrible.

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

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

using an absolute magnitude of $M_V = -21.4$ for all of the galaxies.

2. Divide by 10^6 to get Mpc, and write your answer in Table 2. **Check your answers with your lab instructor before continuing!**

The second thing we can measure is how fast the galaxies are moving toward or away from us using the Doppler shift. We know that the line we measured is a Calcium line because every atom has its own fingerprint, a special spacing of spectral lines. The *actual* wavelength (at rest) of the Calcium H line is

$$\lambda_{\text{rest}} = 3968.50 \text{ Angstroms.}$$

3. Calculate the Doppler Shift of the Calcium H line using the following formula and write it in Table 2.

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

4. Calculate the velocity of the galaxies by using the Doppler shift formula, and write your answer in column 5 of Table 2:

$$\text{velocity} = \Delta\lambda * c / \lambda_{\text{rest}}$$

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

3. A more useful measure of velocity for our analysis is mega-parsecs (Mpc) per billion years (Giga-year, or Gyr). Convert your velocities from km/s to Mpc/Gyr by dividing by 980. Write this in column 6 of Table 2.

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

Part 3: The Hubble Law

Hubble had these two quantities, and like any good astronomer, decided to graph one versus the other. Since he wanted to find out if there was any consistent thing he could see as the galaxies got further away, he graphed velocity vs. distance.

1. Plot your galaxies on a piece of graph paper, using your velocity in Mpc/Gyr as the y-axis and the distance as the x-axis. Draw a best fit line, making sure it passes through (0,0).

Hubble then wrote the equation of that line as

$$\text{velocity} = (\text{a constant}) * \text{distance, or}$$
$$v = H D$$

Where H is the slope of the line.

2. Calculate the slope of the line. This slope is also H. Write your slope in question 5.

We can also find H from each individual galaxy. Solving the equation above for H, we find that

$$H = \text{velocity}/\text{distance}$$
$$H = v/D$$

3. Calculate H by dividing your velocity in Mpc/Gyr by the distance to the galaxy. Write this in column 7 of Table 2
4. Take the average and write this in question 5.

But what does it mean?

Remember that velocity = distance/time

...so H must have units of 1/time

What “time” might that be?

5. Answer the remaining questions in the packet to find out!