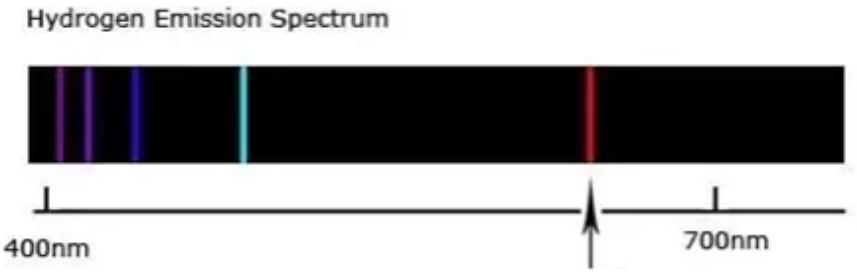
Cosmic Expansion

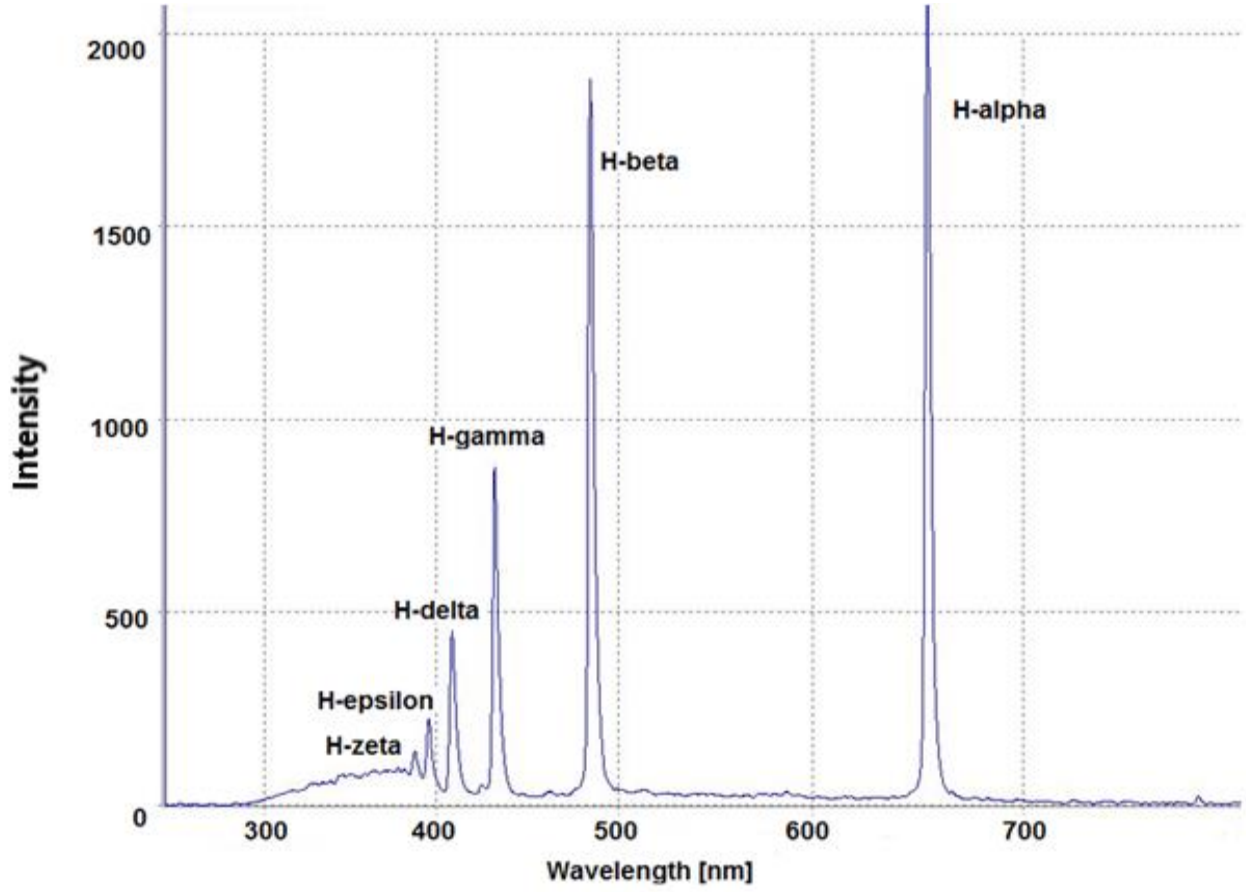
(aka The Hubble-Lemaître Law)

Learning Goal: Identify the relationship between a galaxy's distance to Earth and the observed wavelengths of light, in order to cite evidence for the expanding universe.

Pre-Lab Review: Read the information and graphs, then answer the questions below each.

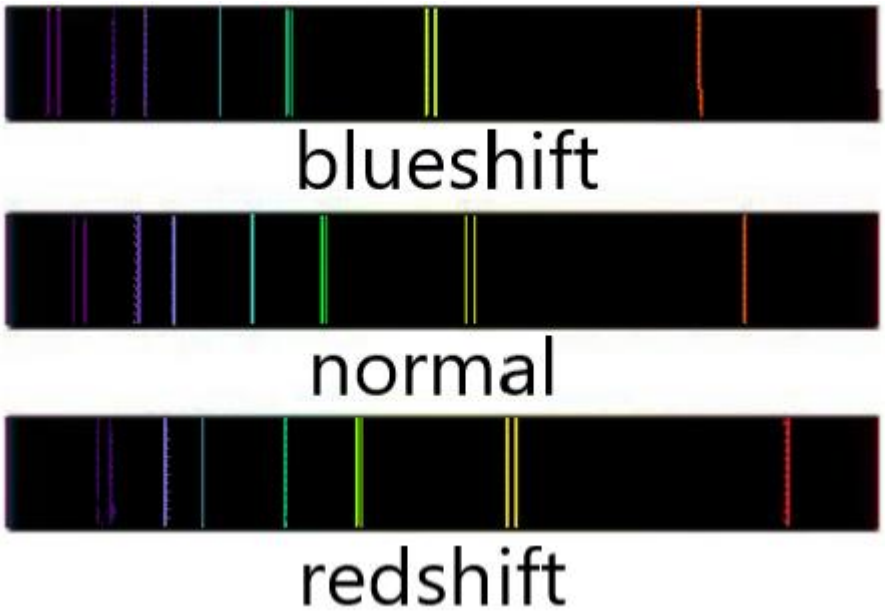
In a previous class, you looked at a tube filled with hydrogen gas, and when the tube was turned on it glowed a pinkish-red color. When you looked at the tube with a handheld spectrometer, it looked like this:





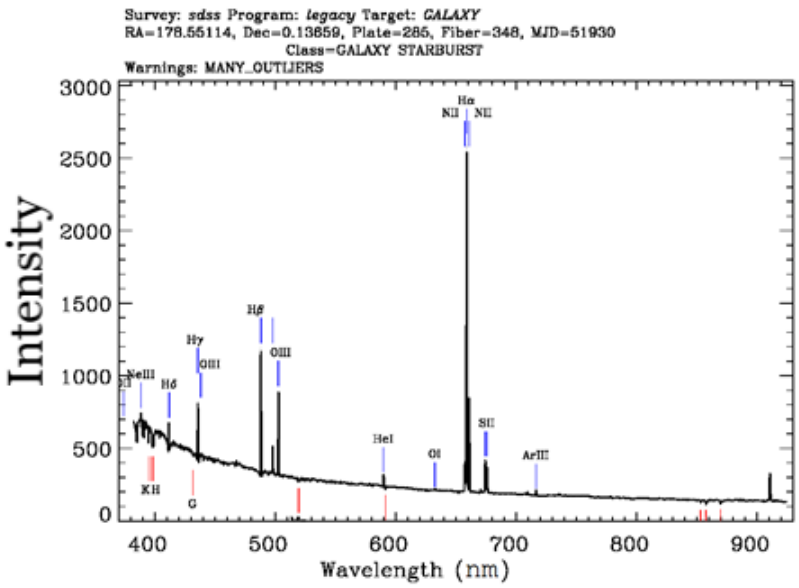
- Explain how the spectrum is similar to the colors you observe with a handheld spectrometer.
- Search for spectra for elements other than hydrogen (such as oxygen, mercury, helium, etc.). Why does it make sense that some people call these spectra "chemical fingerprints?"
- The spike labeled "H-alpha" is the brightest color emitted by hydrogen gas. Use the graph to estimate its wavelength in nanometers (nm).

In another previous lesson, you learned about the Doppler Effect, which explains why sounds seem to change pitch (frequency) when you are moving towards or away from a loud object.



- For sounds waves, the ***frequency*** of the wave is called the "***pitch***" (bass notes are low pitch, for example). What do we usually call the frequency of a light wave?
- The image above shows the spectra for 3 identical clouds of gas. If the middle spectrum in the image above represents a gas that is not moving towards us, then what do you conclude about the top and bottom spectra in the image?

"BASELINE" galaxy: When we look at nearby galaxies that are not moving towards or away from us, we see a spectrum graph that looks like this:



- Refresh your memory: what are the wavelengths of blue and red light, using units of nm?

- An astronomer would look at the image above and immediately identify it as the spectrum of a bluish galaxy. How could she determine the galaxy's color by looking at this graph?
- The same astronomer would also say that this galaxy contains a lot of free hydrogen gas that is not "locked up" inside stars. What is her evidence?
- Look for the hydrogen-alpha peak, labeled Hα, on the spectrum. How does the position of the Hα peak show us that the galaxy is not moving towards or away from us?

Instructions

1. Below are 10 pictures of galaxies from the Hubble Space Telescope. To the right of each picture is the emission spectrum for the galaxy, which also lists distances and an image size scale.
2. You and your partners should work to identify some relationship based on the information given, and justify this relationship using a graph. Use the data table below to help organize your findings, and add new column(s) if you need to.

Galaxy		
A		
B		
C		
D		
E		
F		
G		
H		
I		
J		

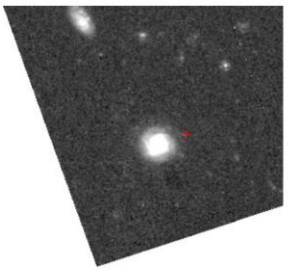
3. Clearly label your X and Y axes and scale on the graph.
4. Share your results with another group and compare graphs. Did the other group choose a different relationship than yours? If so, what did they discover?

Analysis

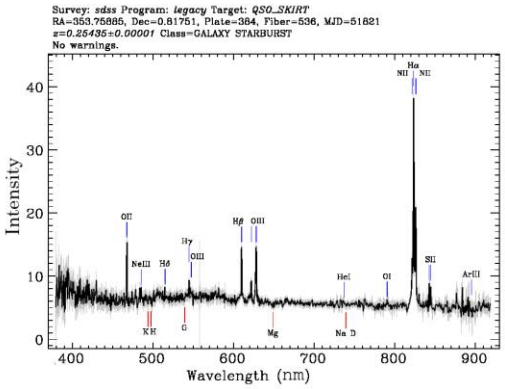
1. What conclusion(s) would you make about these galaxies; based on the pattern discovered or graph you've produced? Justify your answer with evidence from the investigation.
2. In previous activities, you discovered that light waves can become redshifted or blueshifted if they are moving towards or away from us. Was this fact useful in your investigation or perhaps another group's investigation?
3. This NASA article summarizes important findings made in the 1920s by Edwin Hubble and Henrietta Leavitt. Read the article and discuss with your partner. Do your results provide evidence to support the information in the article?
4. The Big Bang model of the universe includes the idea that the universe is expanding. Explain how the results of your investigation could be used as **evidence** for an expanding universe.

Extensions

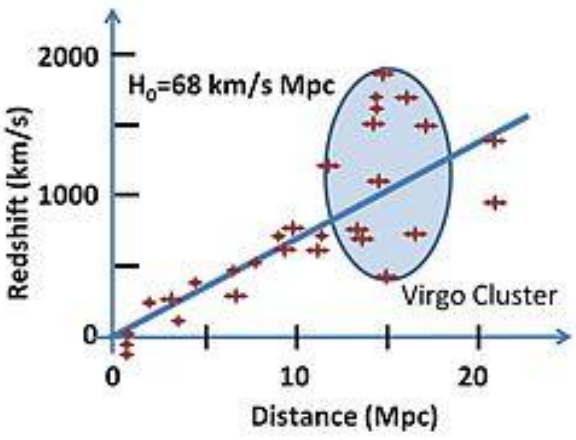
1. The image below is of a very distant galaxy. Based on the information given in the image, how far away would you expect this galaxy to be? Justify your answer.



Distant Galaxy

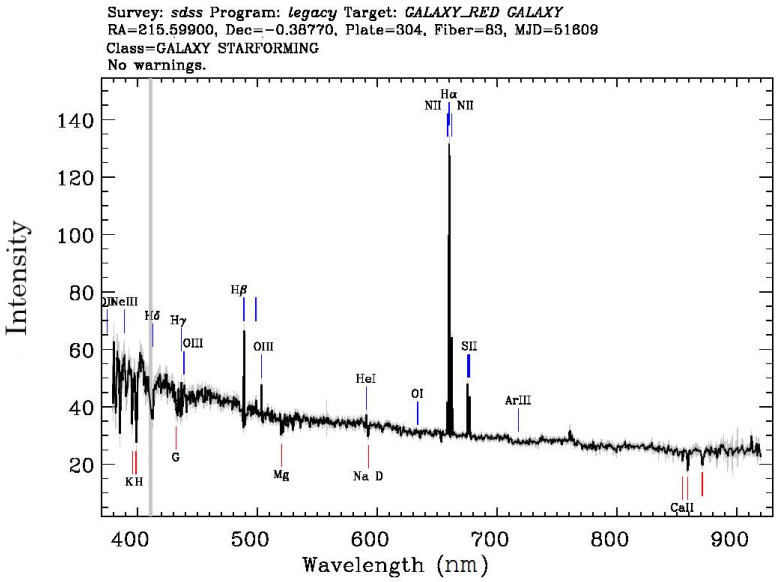


2. Cut a rubber band in half. Use this rubber "string" along with some paper clips and a ruler to make a model for an expanding universe. Justify with measurements.
3. Electronic activity: There are two images on the final page- one is a larger version of the other. They have been configured to be mostly transparent, so that you can overlay them and move the small one around in front of the large one. Use these two images to explain the following statement: "***Everyone in an expanding universe believes they live at the center of it***."
4. You were provided a list of distances to the galaxies, without any explanation of how these distances were measured. Try to find out how this was done! (hint: for nearby galaxies we use "Cepheid variable stars" and for distant galaxies we use "supernovae.")
5. Suppose you graph the speed of galaxies on the Y-axis of a graph and their distance on the X-axis, as shown in the article you read and shown below. The slope of this line is called the "Hubble Constant" and written H_0 like on the graph, with units of $\frac{\frac{km}{s}}{Mpc}$. The unit "Mpc" stands for *megaparsec* and is equivalent to 3.26 million light years. A light year is a unit of distance equivalent to 9.46 x 10^{12} km.

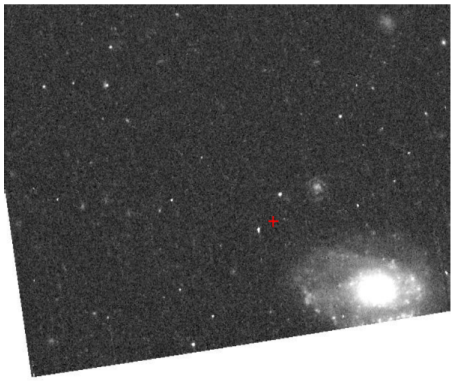


   a. You can convert the Hubble constant to units of $\frac{\frac{km}{s}}{km}$ by first dividing H_0 by the Mpc/light year conversion factor, then dividing by the light year/km conversion factor. What value do you obtain?
   b. What are the units of this new value for H_0? What would be the units of its reciprocal?
   c. Suppose that at some time long ago, all the galaxies were so close together that they were essentially at the same location. How could we use the Hubble Constant to estimate how long ago this was?
   d. Estimate the age of the universe in units of years, using the Hubble Constant. Compare this value to the "commonly accepted" value of 13.7 billion years.

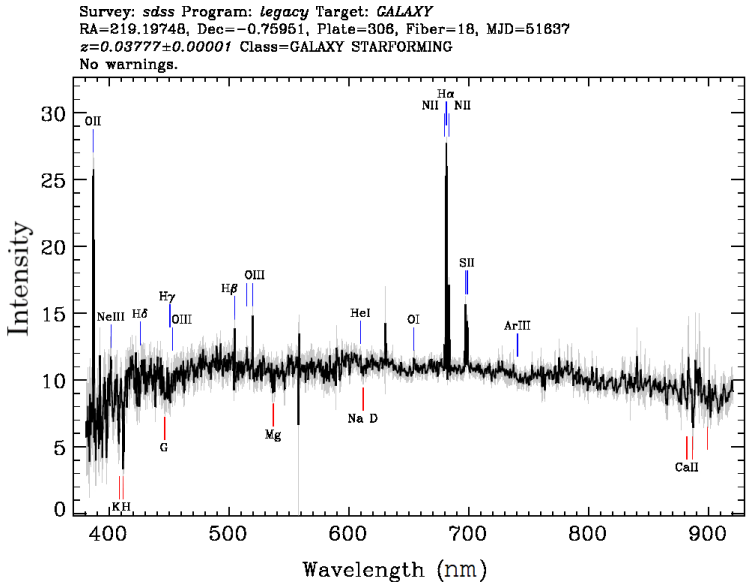
Galaxy A



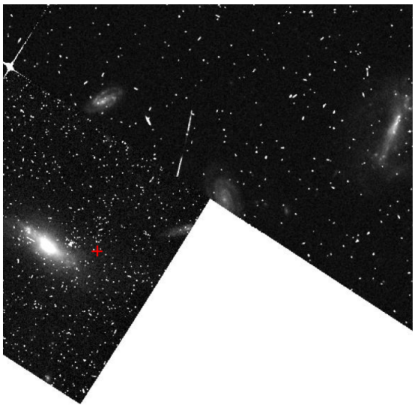
Above: Galaxy A, distance 72 Million Light Years



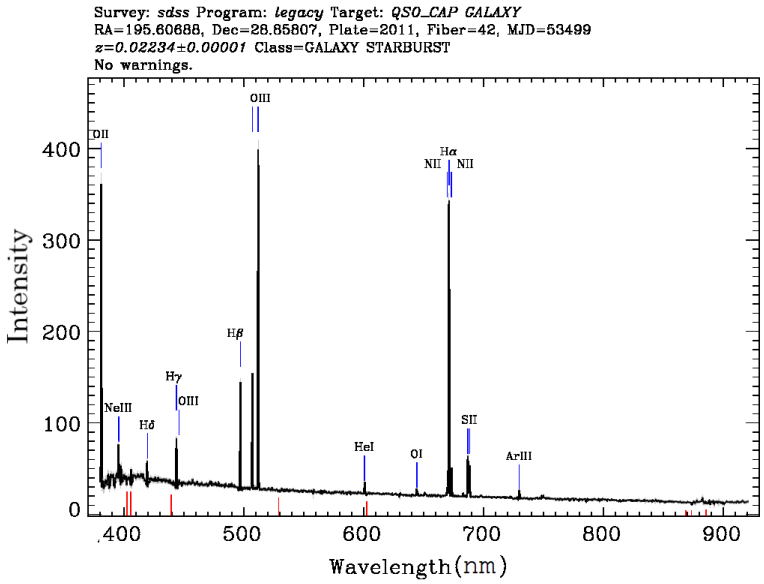
Galaxy B



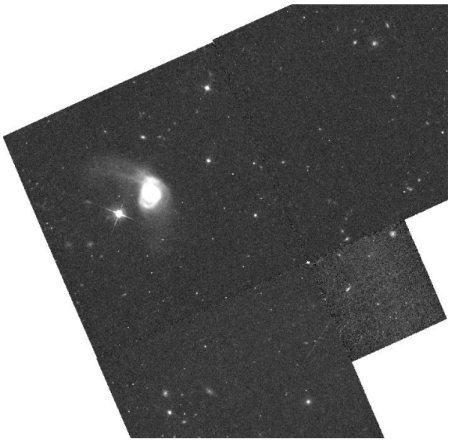
Above: Galaxy B, Distance 557 Million Light Years



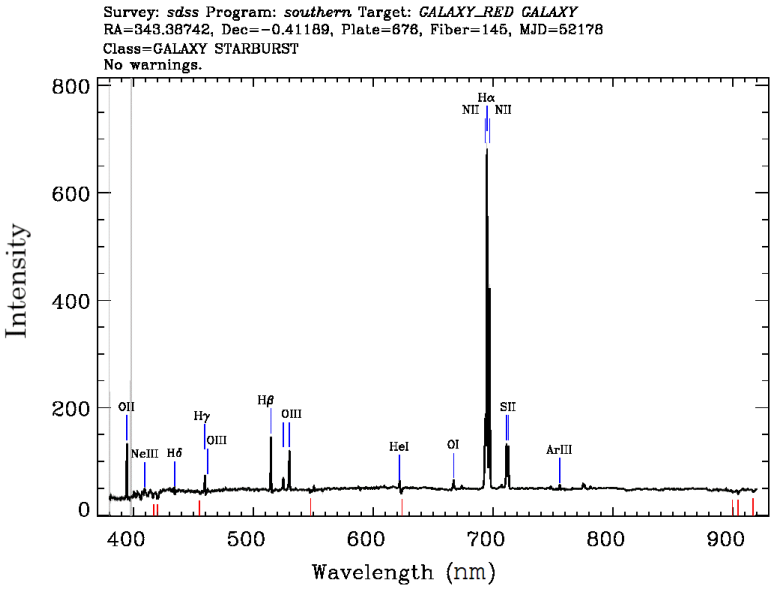
Galaxy C



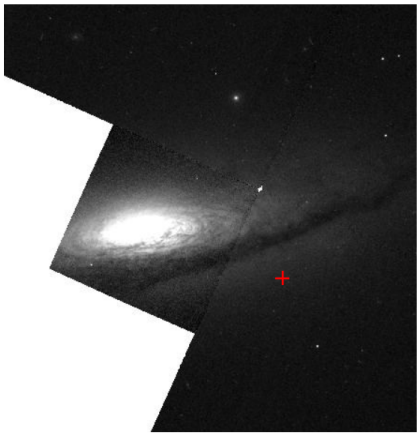
Above: Galaxy C, distance 340 Million Light Years



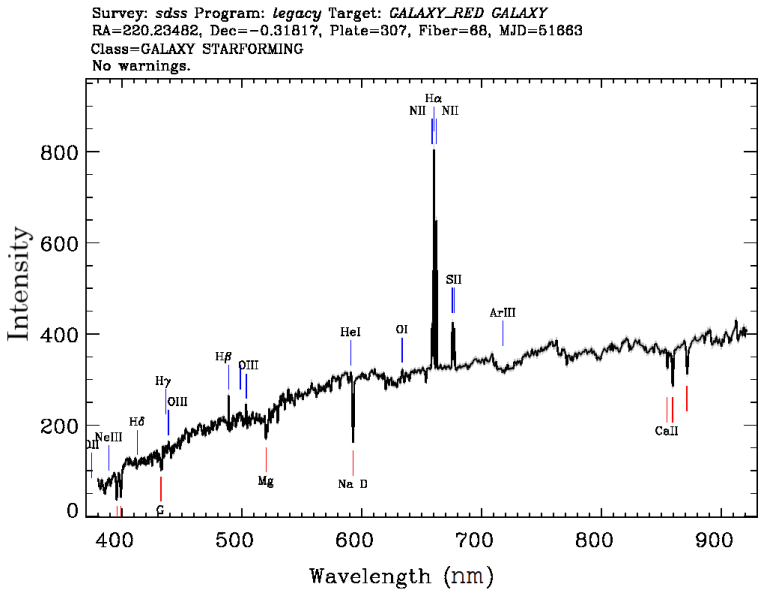
Galaxy D



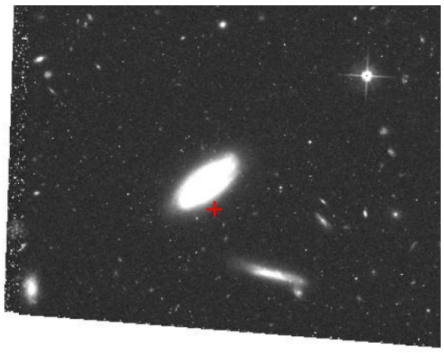
Above: Galaxy D, distance 811 Million Light Years



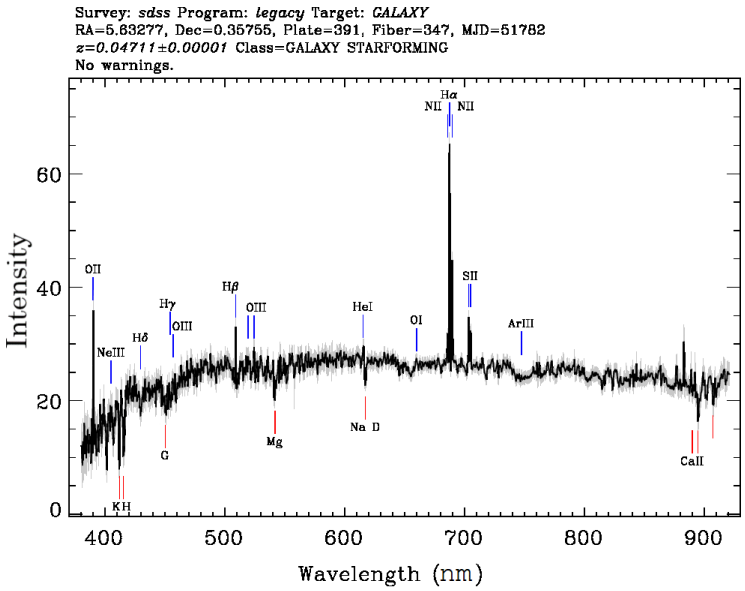
Galaxy E



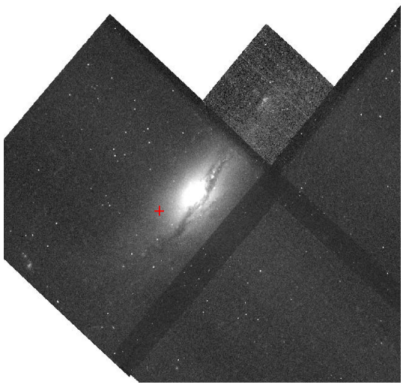
Above: Galaxy E, distance 88 Million Light Years



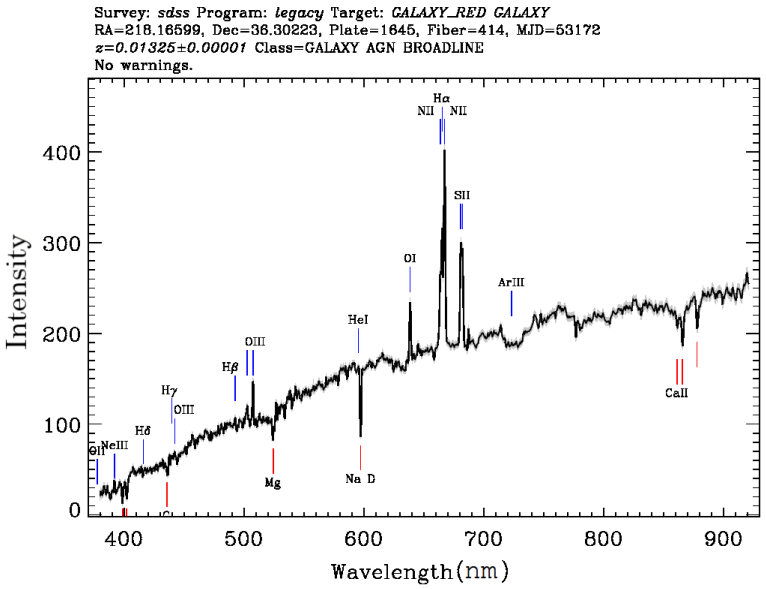
Galaxy F



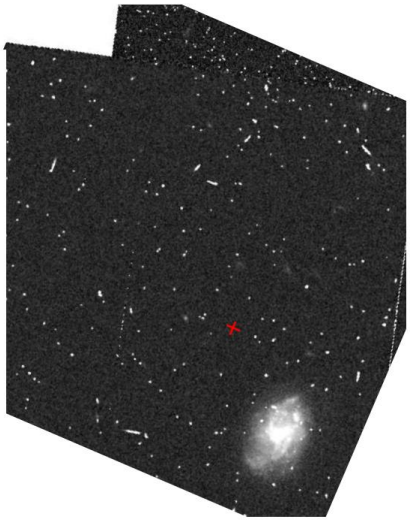
Above: Galaxy F, distance 715 Million Light Years



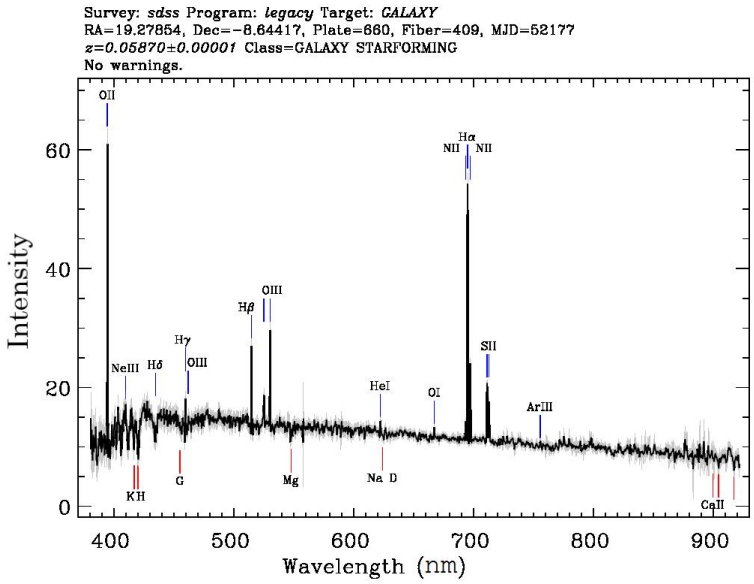
Galaxy G



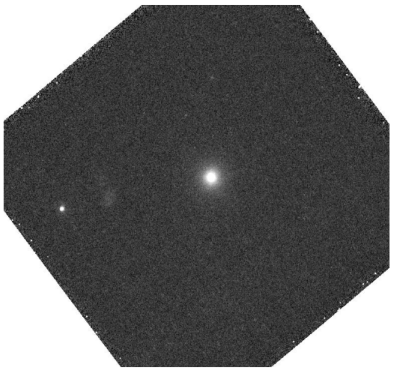
Above: Galaxy G, distance 205 Million Light Years



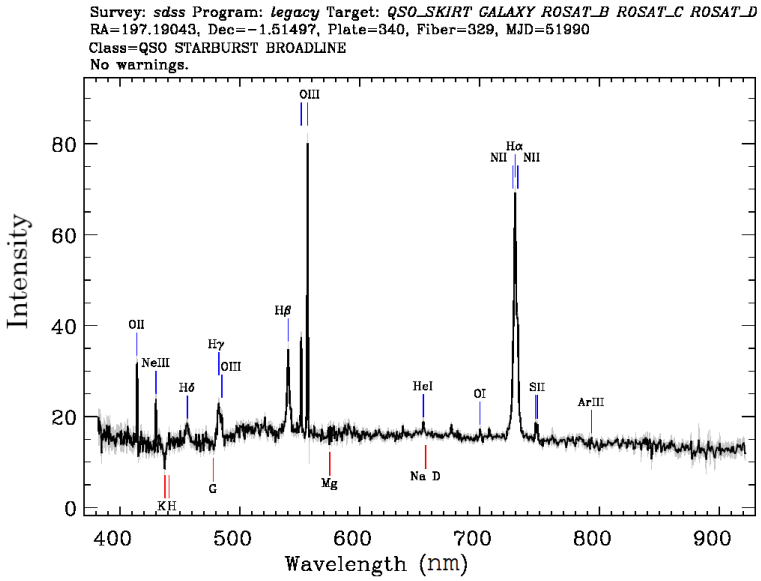
Galaxy H



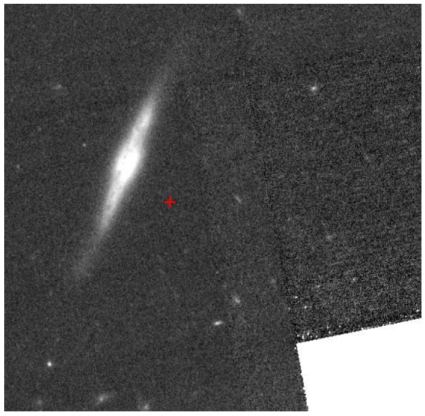
Above: Galaxy H, distance 896 Million Light Years



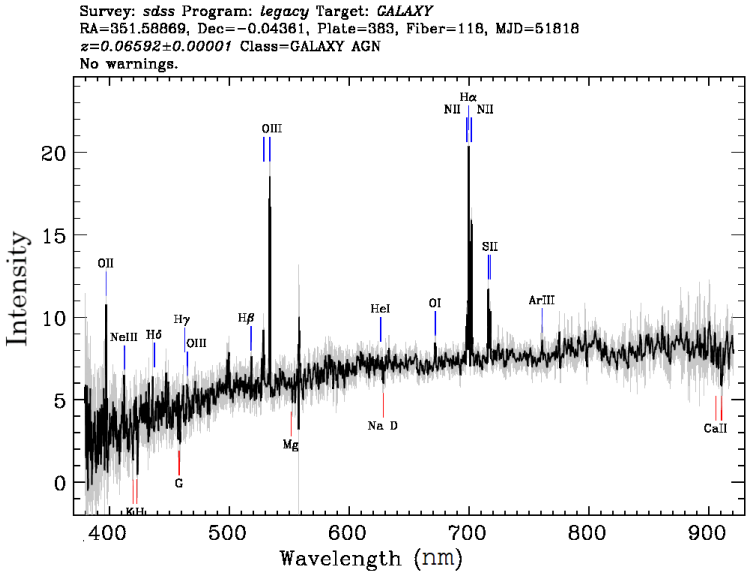
Galaxy I



Above: Galaxy I, distance 1526 Million Light Years



Galaxy J



Above: Galaxy J, distance 996 Million Light Years