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Edited from the online virtual version available at
http://www.cfa.harvard.edu/seuforum/galSpeed/

FROZEN IN TIME?
Galaxies are so large, and so far away, that you could never see them move just by looking -- even if you looked for a whole lifetime through the most powerful telescope!

Fortunately, there is a way to detect the motion of a galaxy: By examining the spectrum of light from a galaxy, you can determine whether the galaxy is moving towards or away from Earth, and how fast.

WELCOME TO THE VIRTUAL SPECTROSCOPY LAB
In this interactive laboratory, you'll investigate for yourself how fast several galaxies are moving. Here's what you'll need:
- This set of instructions to guide you.
- A notebook to record your measurements.
- Images of five galaxies and their spectra here:

STEP 1. "FINGERPRINTING" AN ELEMENT

Now select **Hydrogen** from the **Source** menu. Hydrogen is the simplest chemical element. The pattern you see was produced by taking the light from a glowing tube of hydrogen gas, and passing the light through a prism.

There is one bright red line, a fainter blue line, and several other very faint lines. This pattern is characteristic of the element hydrogen. If you see this unique pattern in the light from an unknown source, then you can conclude that the source must contain the element hydrogen.

For each color of light in the pattern, it's easy to read off the wavelength of that color: Just move the cursor along the **Emission Graph** and center the vertical line on the corresponding peak on the graph. The wavelength appears as number at the upper right of the graph. Note that the **red line** for hydrogen has a wavelength of **656 nanometers.** (A nanometer is one-billionth of a meter, or about one-thousandth the width of a single bacterium.)

The element hydrogen is the most common element in the universe, and it is plentiful in galaxies. That will help us as we investigate the speeds of galaxies.

STEP 2. UNDERSTANDING "REDSHIFT"

Examine **Galaxy 1** and its spectrum. This is the pattern produced when the light from this distant galaxy was passed through a prism.

Note that the spectrum includes a faint rainbow. What do you think is the source of this rainbow? (Hint: What's in a galaxy?)

In addition to the rainbow, there is a bright red line. You may also be able to make out a fainter blue line as well. These lines should be familiar from Step 1: They come from the element hydrogen, which is the most common element in the universe. Hydrogen is present in huge clouds of gas that fill some of the space between the stars in a galaxy.

But there's something unusual about these lines. Note that the **position** of this peak is no longer where it was in the laboratory sample of hydrogen. Instead, the peak has been **shifted towards the longer wavelength part** of the spectrum, which is the redder end of the spectrum. This phenomenon is called a "redshift."

Based on your experiments with the Doppler effect, would you conclude that Galaxy 1 is moving **away** from Earth or **towards** Earth?

STEP 3. "CLOCKING" A GALAXY

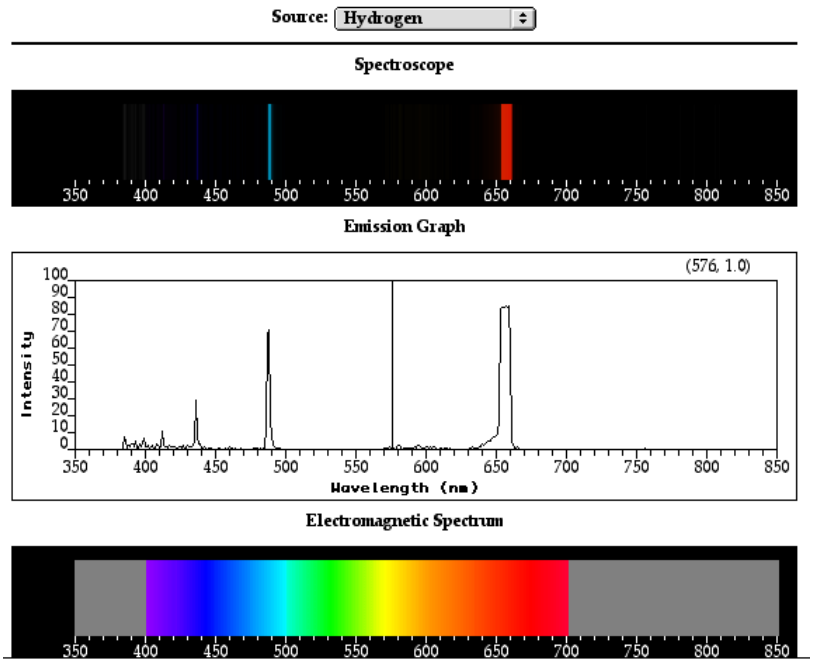
Now examine **Galaxy 3**. The lines are redshifted even more than for Galaxy 1. Based on your investigation of the Doppler effect, what does this tell you about the speed of Galaxy 3, compared to Galaxy 1?

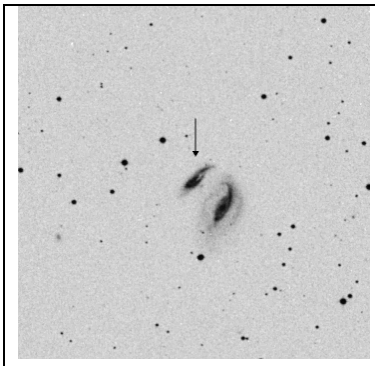
It turns out that the amount of the observed redshift is **proportional** to the speed of the source (for speeds that are not close to the speed of light). For example, for a galaxy moving away from us at 10% of the speed of light, its light will be redshifted by 10%. So, for this example, the hydrogen line that was at 656 nanometers will be redshifted by about 65 nanometers.

Can you tell how fast Galaxy 3 is receding from us? Use the spectroscope to measure the redshift of this galaxy. First determine the wavelength of the red hydrogen line, and then compare it to the wavelength of this line in the laboratory sample of hydrogen gas. By how much has the line been shifted? What fraction of the original wavelength is this? What fraction of the speed of light is the galaxy moving?

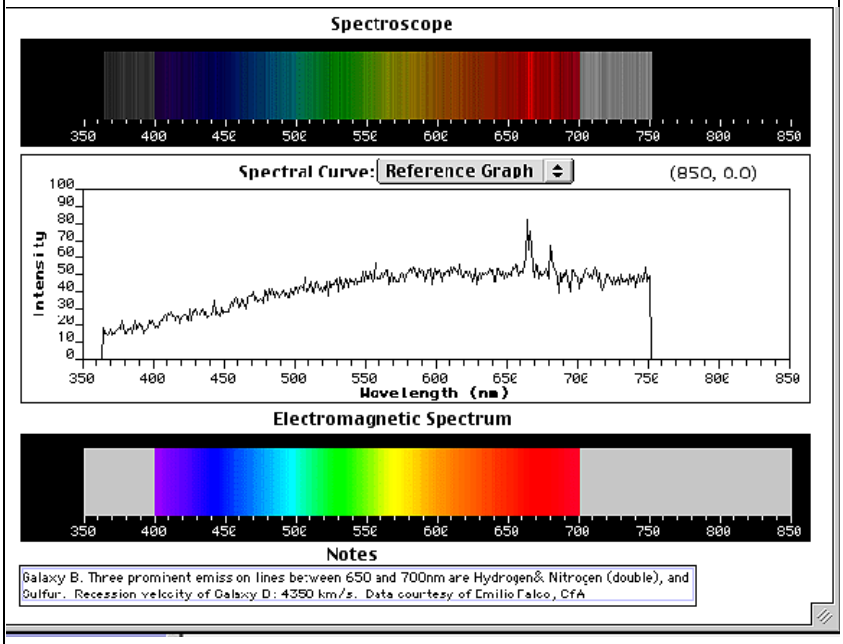
Congratulations! It's one thing to measure the speed of a car or a baseball pitch... but you've just measured the speed of a galaxy from millions of trillions of miles away!

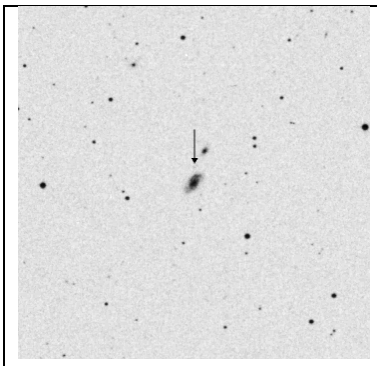
Images for How Fast Do Galaxies Move?



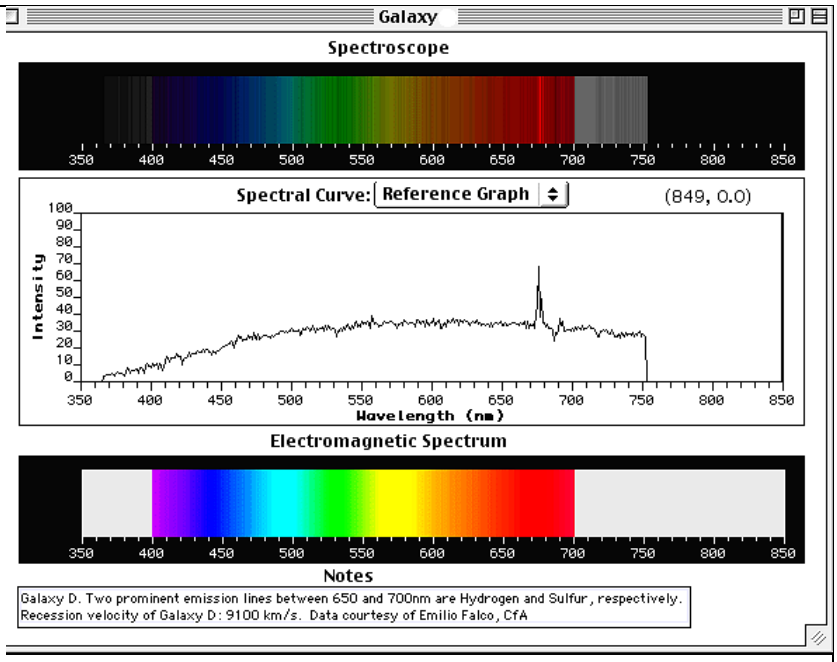


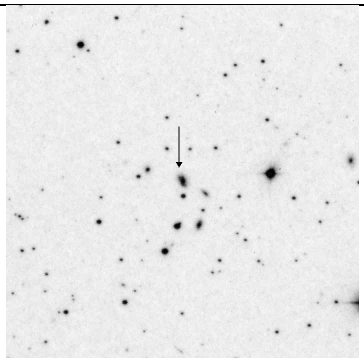
Galaxy 1



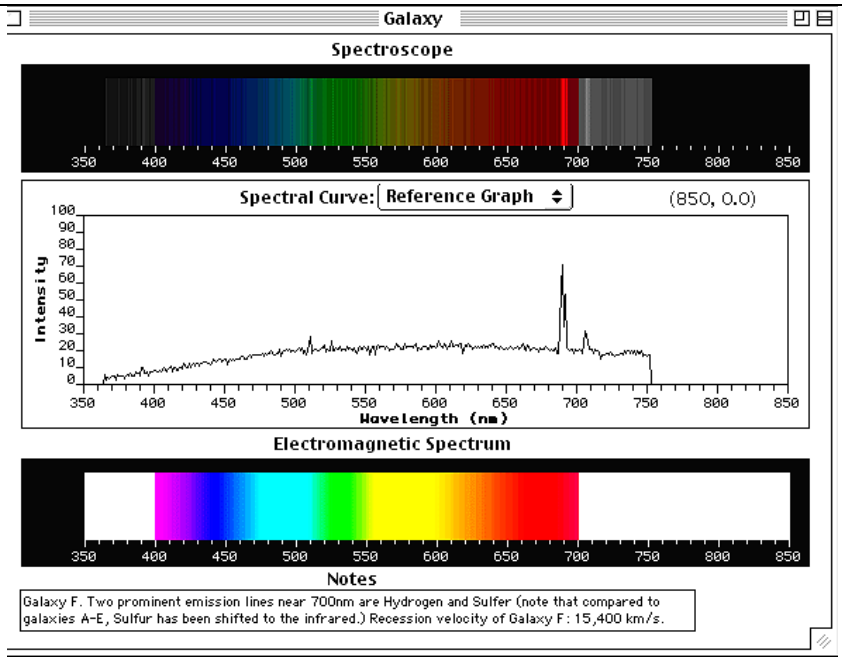


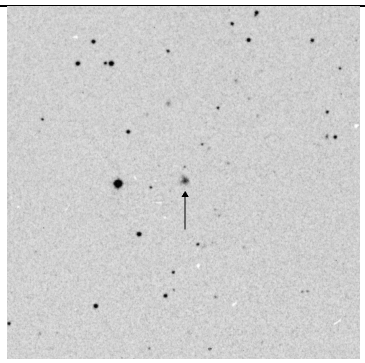
Galaxy 2



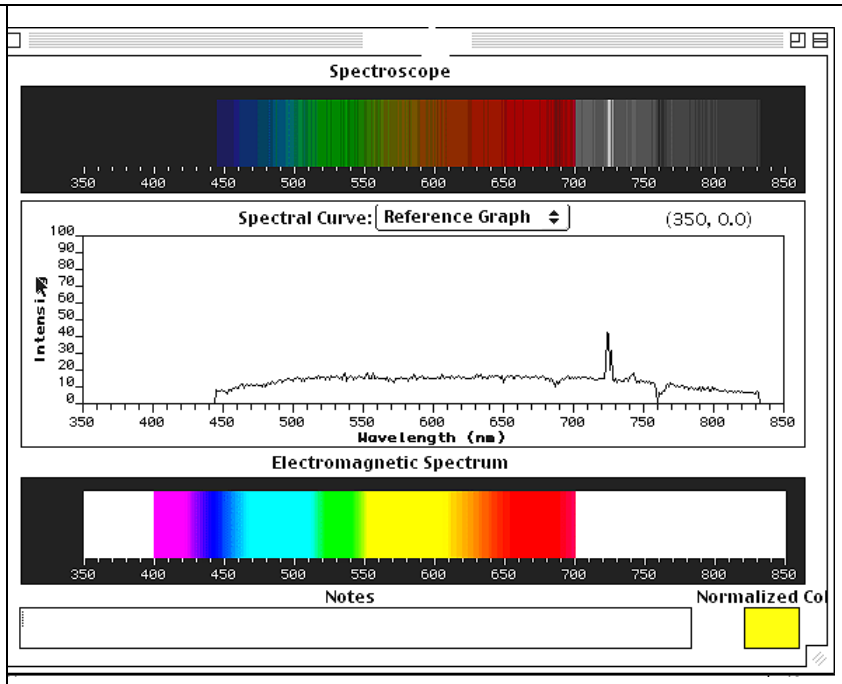


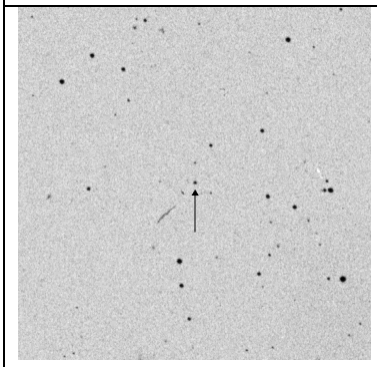
Galaxy 3





Galaxy 4





Galaxy 5