Part 1. Looking at Spectra

Atoms emit and absorb light of fixed, standard wavelengths. An emission or absorption spectrum shows a specific pattern of lines that is a kind of "fingerprint," unique to the particular types of molecules. The emission spectrum of glowing hydrogen gas has one bright red line, a fainter blue line, and several other faint lines. The red line for hydrogen has a wavelength of 656 nanometers.

A spectrum of a galaxy is the pattern produced when the light from the galaxy is passed through a prism or similar device. The element hydrogen is the most common element in the universe, and it is plentiful in galaxies. Hydrogen is present in huge clouds of gas that fill some of the space between the stars in a galaxy. The bright red hydrogen line is an easily recognizable feature in many astronomical spectra.

Procedure

- Observe the spectrum of the Sun on the Student Worksheet.
- Observe the spectrum of the fluorescent lamp on the Student Worksheet. Have students record the colors they see and the wavelengths.
- Observe the spectrum of hydrogen gas. Have students record the colors they see and the wavelengths.
- Look again at the spectrum of the Sun and look for dark lines at these recorded wavelengths. Although these absorption lines are not as dramatic as the emission lines in the pure hydrogen spectrum, their presence tells us that the Sun contains hydrogen, and that this hydrogen is absorbing light.
- Observe the spectrum of the sample galaxy on the Student Worksheet. Determine the wavelength of the red hydrogen line in this spectrum. Note that the position of this peak is different from the laboratory sample of hydrogen.
- Discuss why the red hydrogen line would be in a different place.

Part 2. Analyzing Galactic Spectra, Calculating and Graphing Galactic Speed

As students observe the emission spectra from four different galaxies, they will observe that in each spectrum the bright red hydrogen line has shifted from its characteristic wavelength of 656 nanometers, as seen in the laboratory spectrum of hydrogen gas. This shift toward the longer wavelength part of the spectrum, which is the redder end of the spectrum, is called "redshift."

The observed redshift can be used to calculate the galaxy's velocity. 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, light from a galaxy moving away from us at 10% of the speed of light will be redshifted by 10%. The hydrogen line that was at 656 nanometers will be redshifted by about 65 nanometers to 721 nanometers. (As speeds approach the speed of light, the principles of relativity must be used to explain the relationship between an object's redshift and its speed. However, the speeds of the galaxies in this activity are much less than the speed of light, so the simple proportion described above can be used.)

Using the galactic spectra, students will calculate how fast Galaxies A, B, C, and D are receding from us, and graph that in relation to the galaxy's estimated distance from us.

Procedure

- Give each student or small group of students optical images of the four galaxies, A, B, C, and D.
- Tell students to assume that these four galaxies are all approximately the same actual size.
- Ask students to arrange the four galaxies in order of distance from the earth. Discuss what evidence they used for their choices.
- Label the graph on the student worksheet by writing the letters of the galaxies in order of their estimated distance along the x- axis.
- Give each student or small group of students the spectra of the four galaxies, A, B, C, and D.
- Determine the wavelength of the red hydrogen line in the spectra from galaxies, A, B, C and D. Record these on the worksheet.
- Compare the wavelength of the red hydrogen line in each galactic spectrum to the laboratory sample of hydrogen gas. By how much has the line been shifted? What fraction of the original wavelength is it? At what fraction of the speed of light is the galaxy moving?
- Calculate the recession velocity of the four galaxies using the Student Worksheet.
- Plot the velocity data on the y-axis of the graph on the Student Worksheet.

Discussion Notes

In the 1920s, Edwin Hubble measured redshifts to determine the velocities of galaxies. He found that there was a linear relationship between a galaxy's distance from us and how fast that galaxy is receding (its recession velocity). This simple relationship can be described in equation form, where the slope of the graph of distance vs. velocity represents the Hubble Constant for the universe.

$$v = H \times d$$

Recession velocity = Hubble's constant x distance from us

This equation, known as Hubble's Law, states that a galaxy at double the distance will have double the velocity; at triple the distance, it will have triple the velocity. Hubble's Law is important in understanding the age and size of the universe, and is described further in the background information for the previous activity, Modeling the Expanding Universe.

Suggested Answers

These notes provide answers to some of the questions on the Student Worksheets and can be used to help guide a class discussion.

In Part 1, when looking at the pure hydrogen spectrum, students should measure peaks at 656 nanometers, 486 nanometers, and 434 nanometers. Although this third line is not visible in the color image, it can be measured on the graph. All three of these lines appear in the spectrum of the Sun and may be easier to find in the graph than in the color image.

In Part 2, we have assumed all the galaxies are all the same actual size. Therefore, Galaxy B, which appears largest in the optical image, is presumed to be closest to us. Accordingly, the smallest image (C) is farthest away. In order from closest to farthest, the galaxies are B, D, A, and then C.

Galaxy B is about 210 Mly (million light years) from the Milky Way.

Spectrum B shows the hydrogen line at 666 nanometers. This is redshifted 10 nanometers, or 1.5 %, from its original location of 656 nanometers. Therefore, the velocity of Galaxy B is 0.015 times the speed of light (300,000 km/s), which equals about 4,500 km/s. Students may measure the redshift to be between 5 and 13 nanometers, which corresponds to a recession velocity between 4,350km/s and 6,000 km/s.

Astronomers calculate the recession velocity of Galaxy B to be 4350 km/s.

Galaxy D is about 750 Mly from the Milky Way.

Spectrum D shows the hydrogen line at 690 nanometers. This is redshifted 34 nanometers, or 5 %, from its original location of 656 nanometers. Therefore, the velocity of Galaxy D is 0.05 times the speed of light (300,000 km/s), which equals about 15,000 km/s. Students may measure the redshift to be between 29 and 39 nanometers, which corresponds to a recession velocity between 13,000 km/s and 18,000 km/s.

Astronomers calculate the recession velocity of Galaxy D to be 15,400 km/s.

Galaxy A is about 1,520 Mly from the Milky Way.

Spectrum A shows the hydrogen line at 724 nanometers. This is redshifted 68 nanometers, or 10 %, from its original location of 656 nanometers. Therefore, the velocity of Galaxy A is 0.10 times the speed of light (300,000 km/s), which equals about 30,000 km/s. Students may measure the redshift to be between 65 and 73 nanometers, which corresponds to a recession velocity between 29,000 km/s and 34,000 km/s.

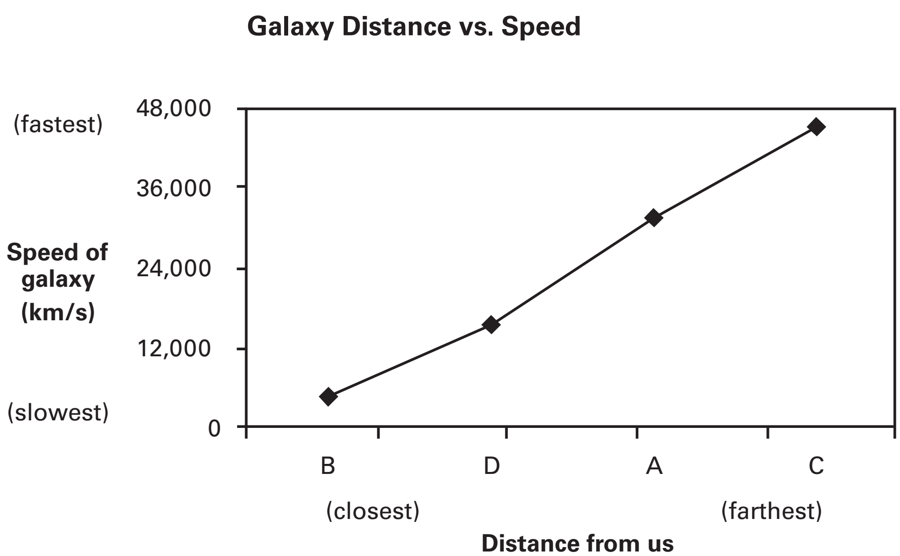
Astronomers calculate the recession velocity of Galaxy A to be 31,400 km/s.

Galaxy C is about 2,260 Mly from the Milky Way.

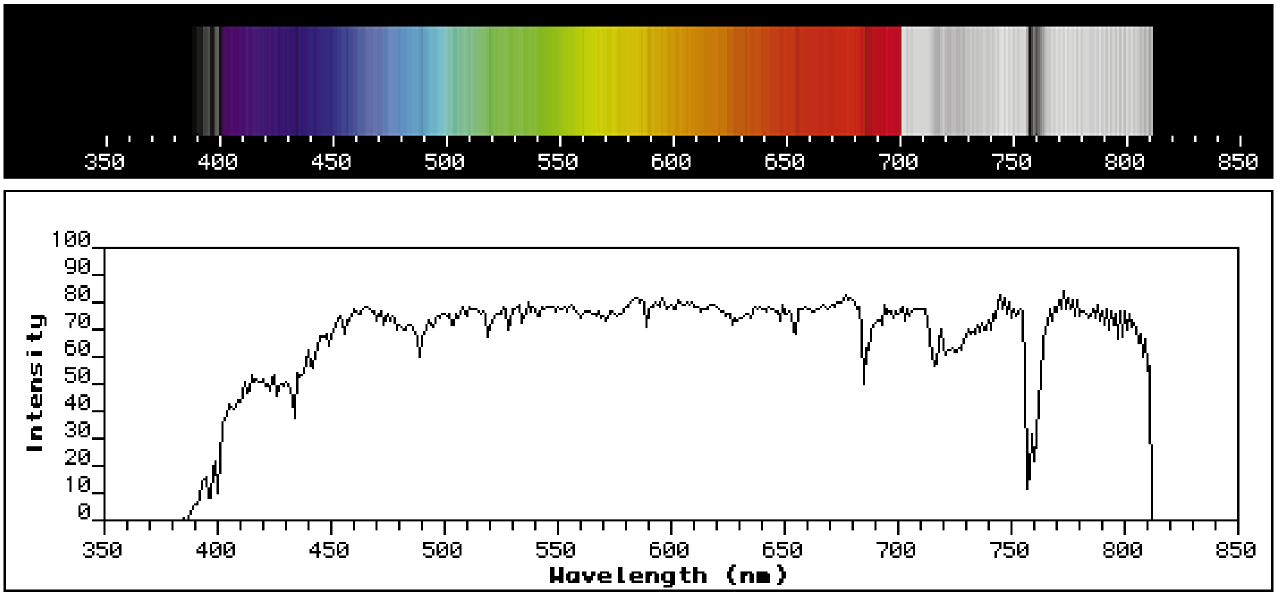
Spectrum C shows the hydrogen line at 752 nanometers. This is redshifted 96 nanometers, or 15 %, from its original location of 656 nanometers. Therefore, the velocity of Galaxy C is 0.15 times the speed of light (300,000 km/s), which equals about 45,000 km/s. Students may measure the redshift to be between 94 and 102 nanometers, which corresponds to a recession velocity between 42,000 km/s and 47,000 km/s.

Astronomers calculate the recession velocity of Galaxy C to be 44,700 km/s.

Sample Graph

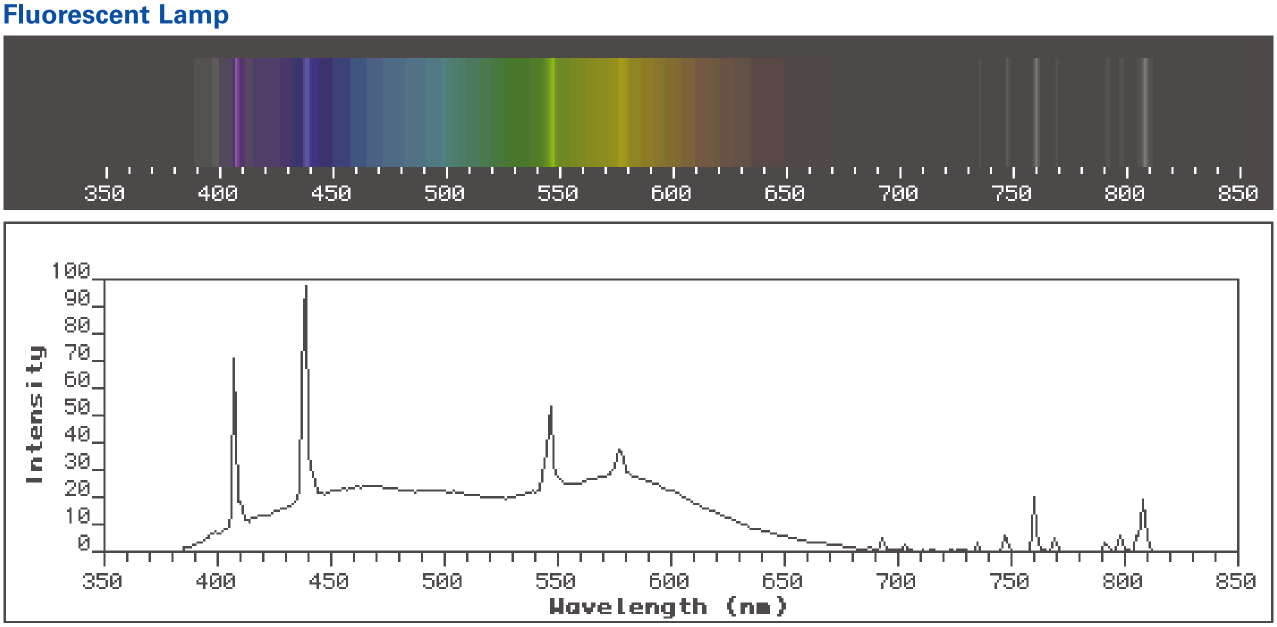


The Sun



This is the spectrum of the Sun. The pattern is created by passing light from the Sun through a glass prism, which separates the light into its component colors. In addition to the familiar rainbow of colors, notice the dark lines. These lines are produced by atoms in the Sun's atmosphere that absorb certain wavelengths of light. This dark-line pattern is called an absorption spectrum. Note that the pattern extends past the red, into the infrared region. Infrared light is not visible to our eyes. It is colored grey in this image. The grey area to the left of the blue is part of the ultraviolet region of the spectrum.

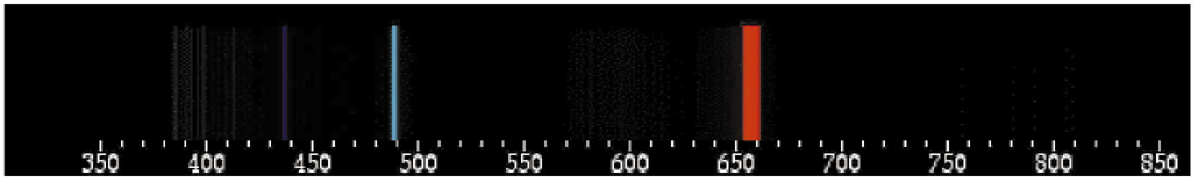
Fluorescent Lamp

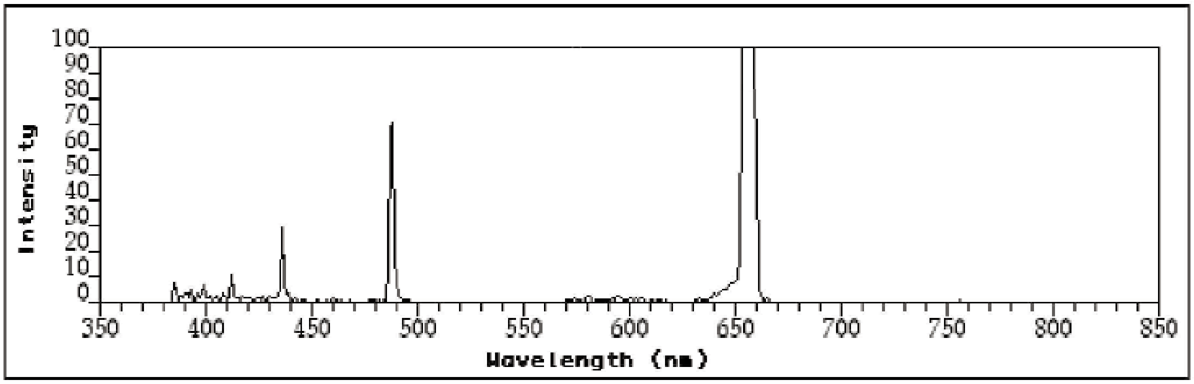


This is the spectrum of a Fluorescent Lamp. Instead of a complete rainbow, we see only certain colors of light. This bright-line pattern is called an emission spectrum. We don't see a full rainbow because rainbows are produced only by light sources that are very hot.

What colors do you see in the Fluorescent Lamp spectrum, and what are their wavelengths?

Hydrogen Gas



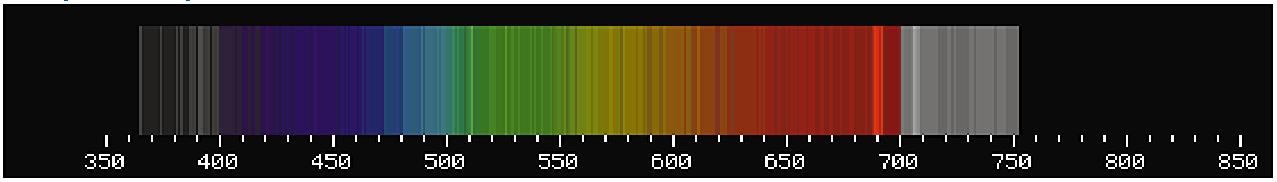


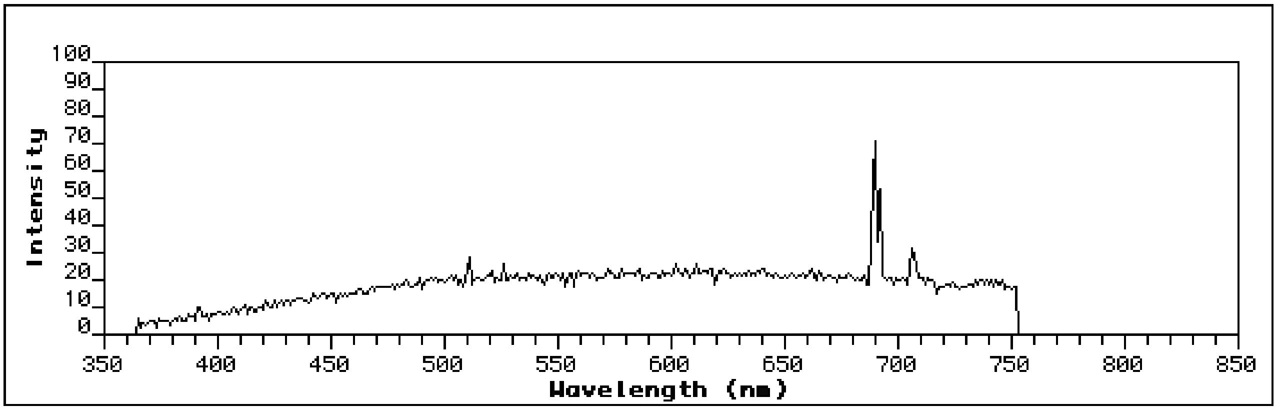
This is the emission spectrum of the element hydrogen. Hydrogen is the simplest chemical element. The pattern was produced by taking the light from a glowing tube of hydrogen gas, and passing the light through a prism.

What colors do you see in the hydrogen spectrum, and what are their wavelengths?

Look for lines at these same wavelengths in the spectrum of the Sun. Which lines can you see?

Sample Galaxy





This is the spectrum of a galaxy. The pattern was produced when the light from this distant galaxy was passed through a device similar to a prism. In addition to the rainbow, there is a bright red line. This line comes from the element hydrogen. Determine the wavelength of the red hydrogen line in the spectrum of the sample galaxy. The peak has been shifted from its characteristic wavelength (as measured above in the hydrogen spectrum) toward the longer wavelength part of the spectrum, which is the redder end of the spectrum. This phenomenon is called a "redshift."

In the sample galaxy, the red hydrogen peak is at __________________ nanometers.

STUDENT WORKSHEET Calculating and Graphing Galactic Speed

Look at the optical images of the four galaxies A, B, C, and D. These galaxies, are all approximately the same actual size. Which galaxy do you think is closest to us? Farthest?

_________	_________	_________	_________
Closest			farthest

What evidence did you use in these choices?

Label the x-axis of the graph on page 2 with the letter of the galaxies, in order from closest to farthest.

Look at the spectra of the four galaxies A, B, C, and D. Determine the wavelength of the red hydrogen line in each spectra.

Galaxy A: _____________ nanometers

Galaxy B: _____________ nanometers

Galaxy C: _____________ nanometers

Galaxy D: _____________ nanometers

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, the light will be redshifted by 10%. The hydrogen line that was at 656 nanometers in the laboratory sample of hydrogen gas will be redshifted by about 65 nanometers, and will be observed at 721 nanometers.

By how much has the red hydrogen line been shifted in the spectra of galaxies A, B, C, and D? What fraction of the original wavelength is this? At what fraction of the speed of light is the galaxy moving?

Galaxy A: redshifted ____ nanometers =____ %

Galaxy B redshifted ____ nanometers =____ %

Galaxy C: redshifted ____ nanometers =____ %

Galaxy D redshifted ____ nanometers =____ %

Calculate the speed of each galaxy as it is receding from us, using the percentages from your answer above. The speed of light is approximately 300,000 kilometers per second (186,000 miles per second).

Galaxy A: ____ % x 300,000 km/s = ________

Galaxy B: ____ % x 300,000 km/s = ________

Galaxy C: ____ % x 300,000 km/s = ________

Galaxy D: ____ % x 300,000 km/s = ________

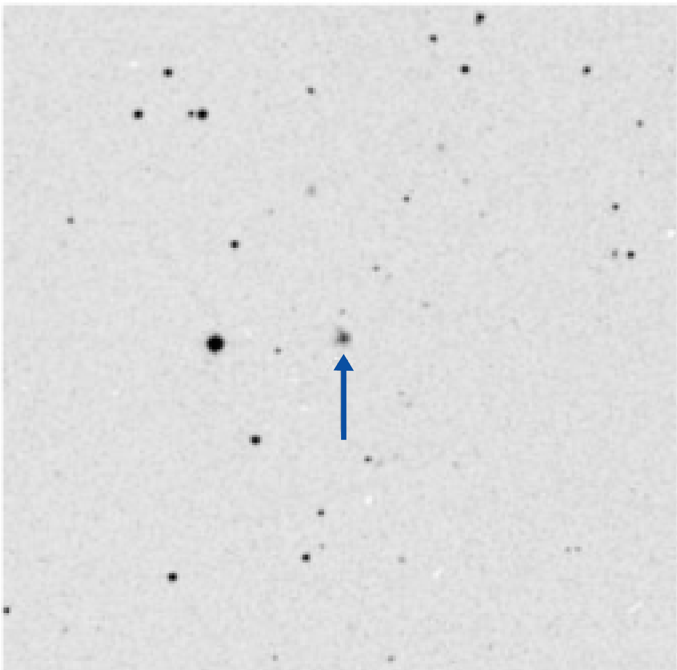
Plot the speeds of Galaxies A, B, C and D on the y-axis of the graph.

Galaxy Distance vs. Speed

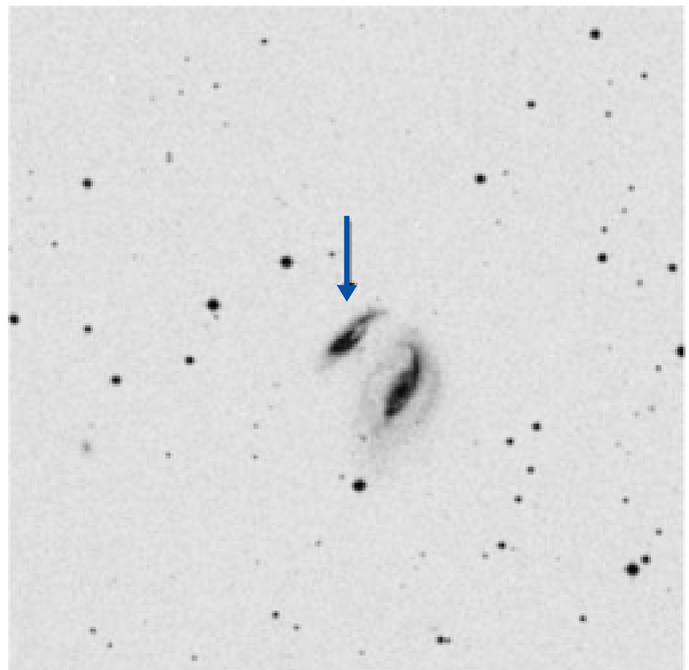
What can you conclude about the relationship between galaxy distance and redshift?

How does this evidence support the theory of an expanding universe?

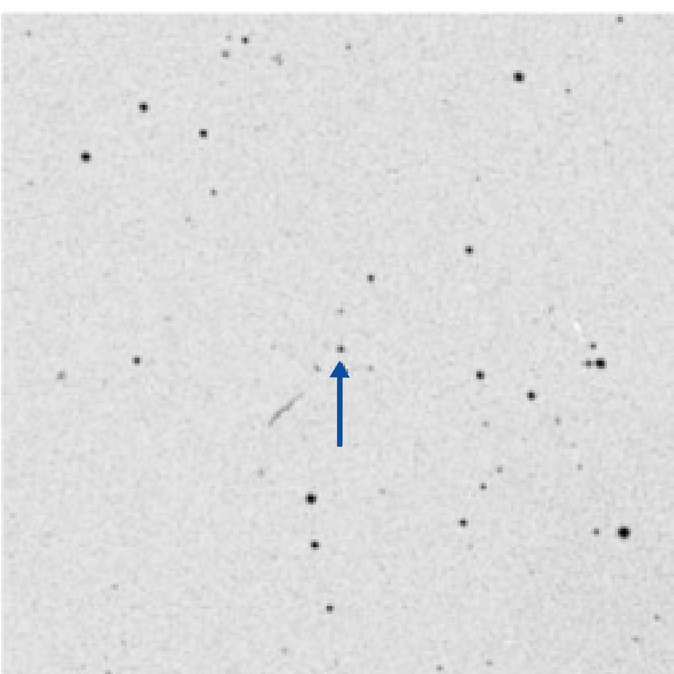
Galaxy A



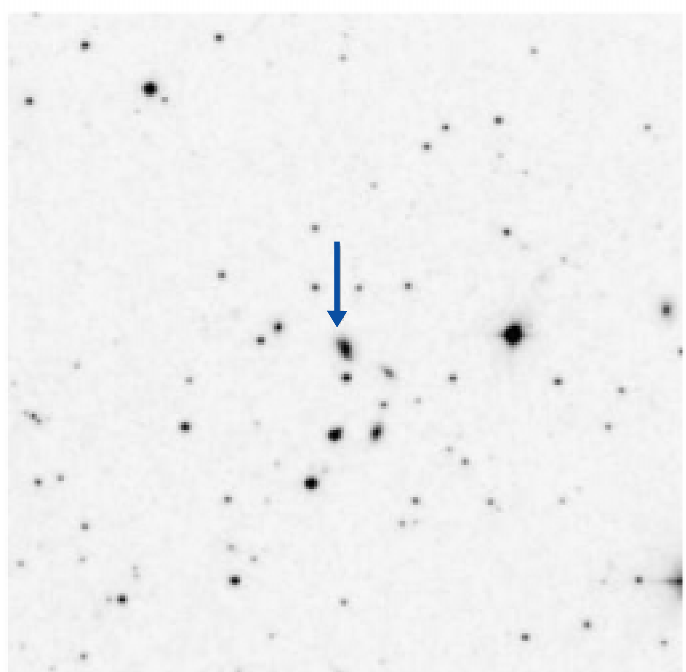
Galaxy B



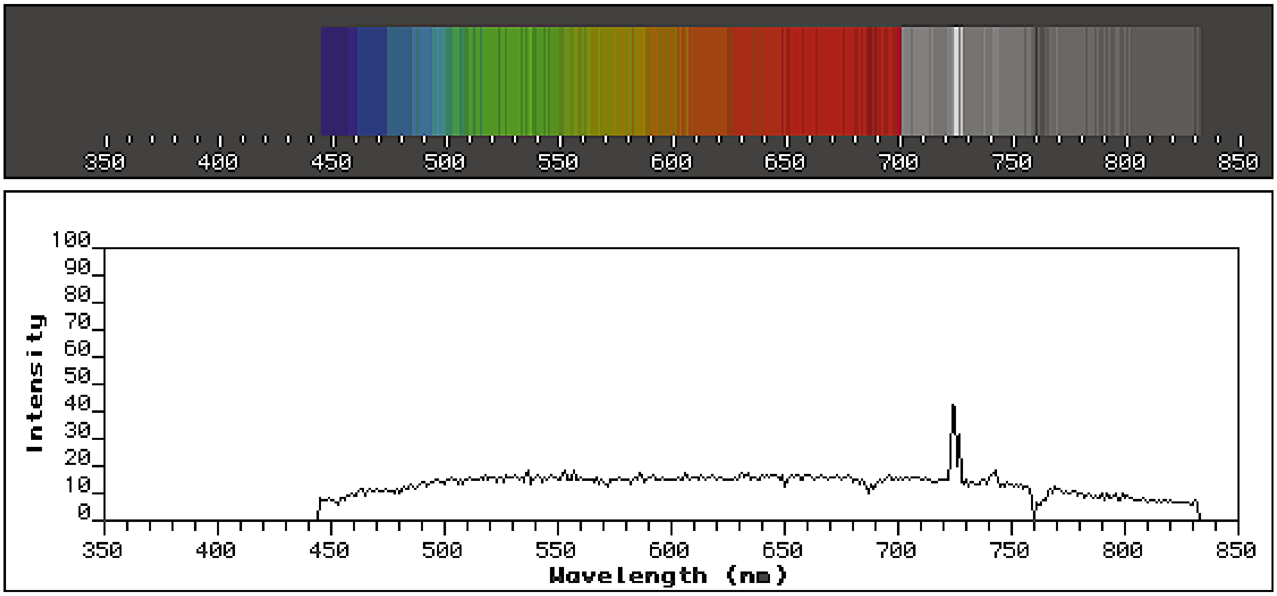
Galaxy C



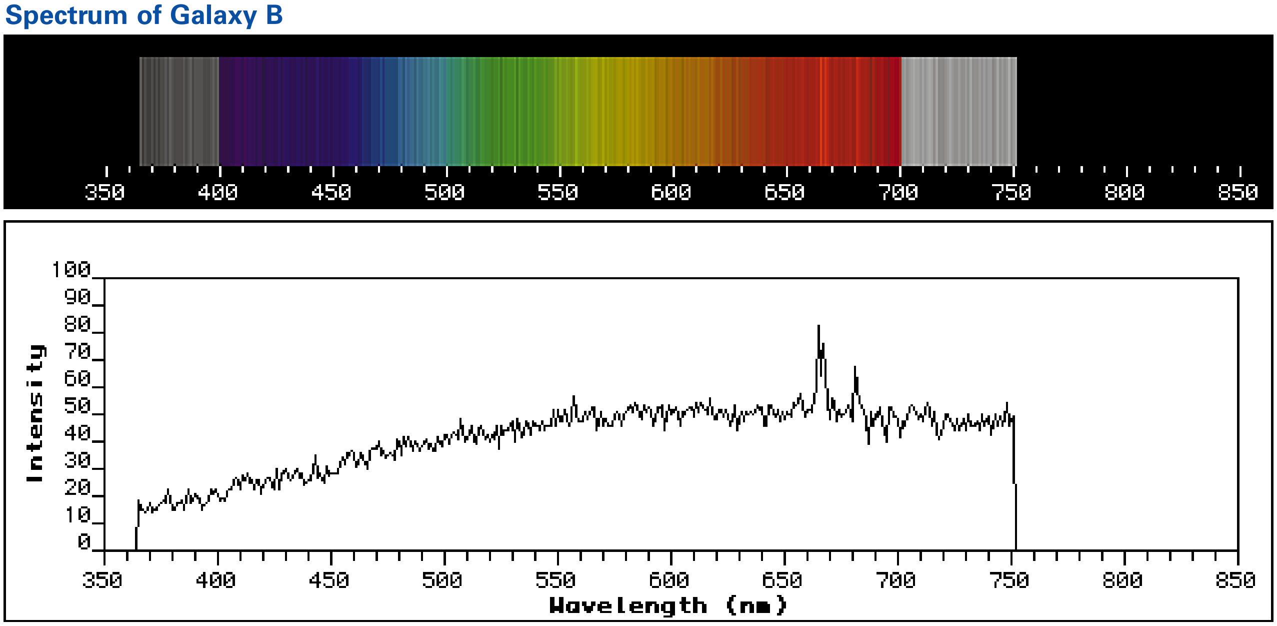
Galaxy D



Spectrum of Galaxy A

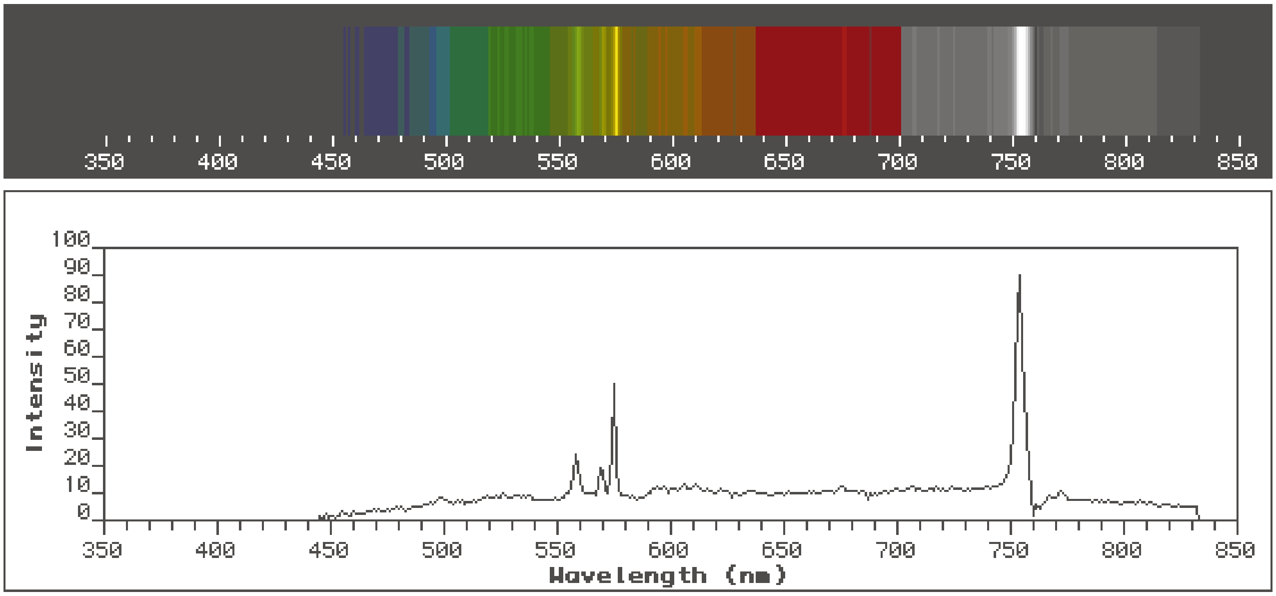


Spectrum of Galaxy B



Galaxy data courtesy of Emilio Falco, Center for Astrophysics

Spectrum of Galaxy C



Spectrum of Galaxy D