STUDENT ACTIVITY GUIDE

How can starlight reveal the elements in a star?

The challenge

When you look at the night sky, you see a dazzling display of stars, each shining as a distant point of light. To your eyes, these stars may all seem similar, appearing as tiny white dots. But by analyzing the light from these stars, astronomers can uncover detailed information about their composition.

Image credit: "The binary star system Alpha Centauri, as seen through the Hubble Telescope" by NASA and ESA, Public domain

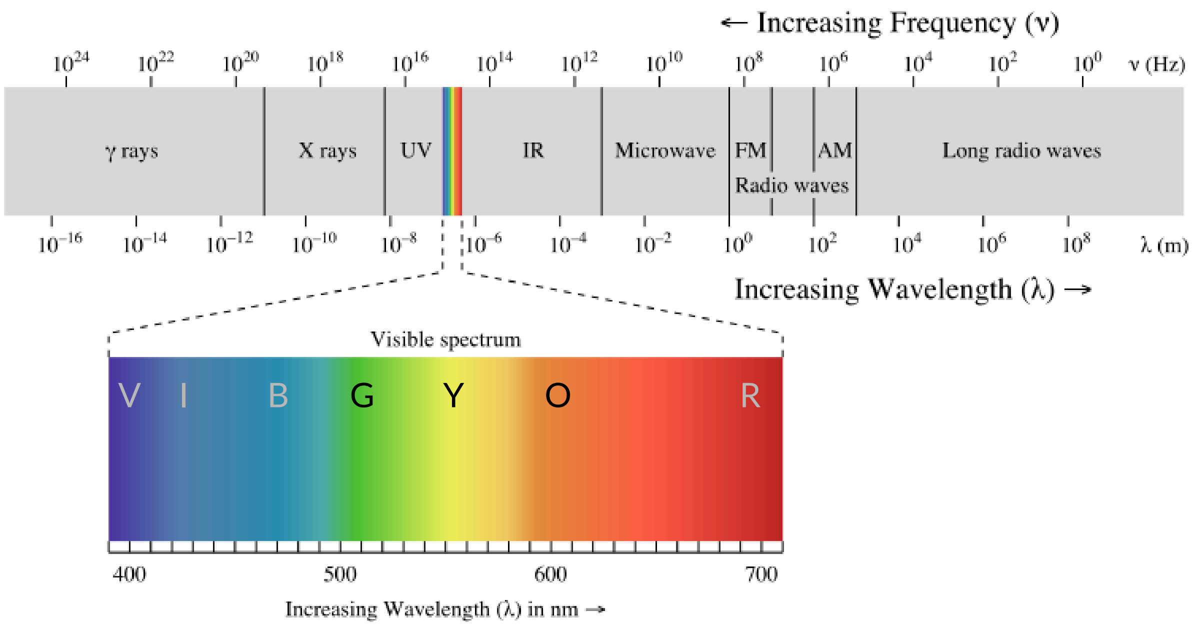
In this activity, you'll construct a device called a spectroscope, which will allow you to examine the spectra of different light sources. Then, you'll analyze the spectra of various stars to determine the elements found within them.

By the end of this activity, I will be able to…

- explain why the spectra of various light sources may appear different.
- explain how emission and absorption lines are formed.
- explain how astronomers use spectral analysis to determine the elements present in stars.

Setting the stage

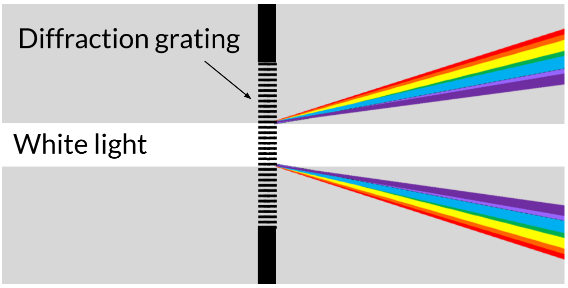
Electromagnetic radiation consists of oscillating electric and magnetic fields. The different bands of electromagnetic radiation are organized by wavelength on the **electromagnetic spectrum**. Visible light is only a small portion of the entire electromagnetic spectrum. It ranges from wavelengths of about 400 nanometers to about 700 nanometers, as shown on the following diagram.



The electromagnetic spectrum by Phillip Ronan, CC-BY-NC-SA 3.0.

The color of visible light we observe depends on its _________________________. Some light sources, such as lasers, emit specific wavelengths of visible light. The light from a laser emitting a wavelength of 650 nanometers would appear to us as (circle one) **blue / green / red** light. On the other hand, a source like a flashlight emits many wavelengths of light at once, and we observe the light as _______________________.

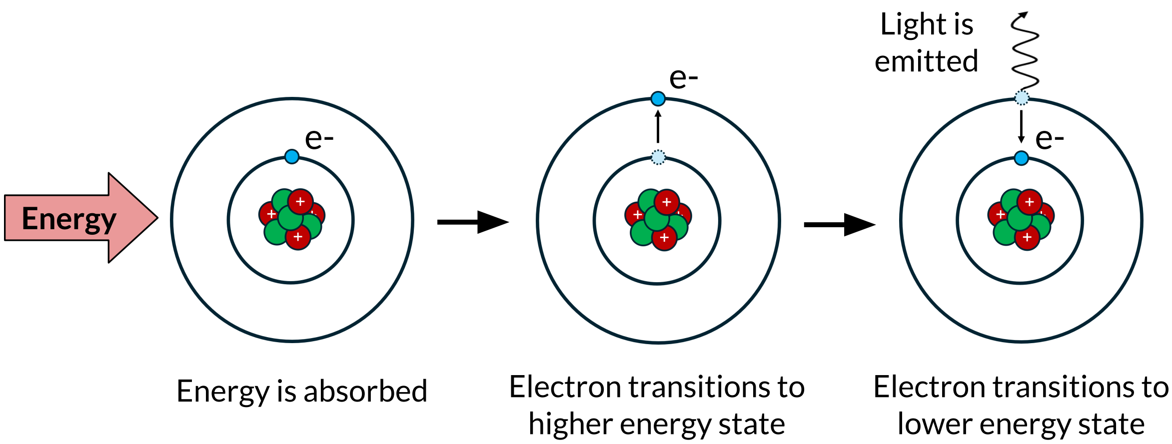
Like all waves, when light passes through an opening similar in size to its wavelength, it experiences ______________________________ and spreads out. A **diffraction grating** is a material that contains many tiny openings. When white light passes through a diffraction grating, it spreads out and separates into the visible spectrum. A **spectroscope** is a device that uses a diffraction grating to analyze the spectrum of a light source. The wavelengths observed from a light source can give important information about the source.



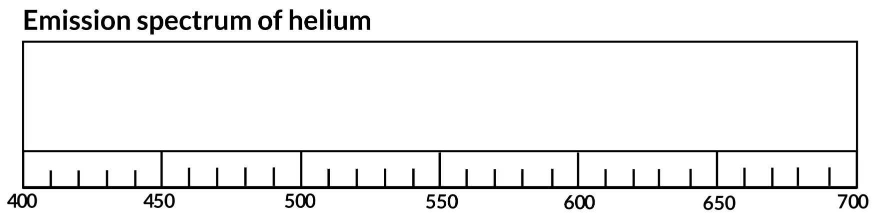
A **blackbody** is an ideal object that absorbs all electromagnetic radiation it receives, and emits a continuous spectrum through **thermal radiation**. The maximum wavelength emitted depends only on the ______________________________ of the blackbody. As the temperature of the blackbody increases, it emits (circle one) **shorter / longer** wavelengths of radiation. There are no gaps in the EM spectrum emitted by a blackbody, so it is called a **continuous spectrum**. When observed through a spectroscope, a blackbody's visible spectrum will appear as a continuous band of color.

Some light sources, like incandescent light bulbs and stars, can be approximated as blackbodies.

However, not all light sources produce a continuous spectrum through thermal radiation. Instead, some involve quantized electron transitions between energy levels. When an atom absorbs energy, an electron can become excited and transition to a (circle one) **lower / higher** energy state. Afterwards, the electron transitions to a (circle one) **lower / higher** energy state, releasing energy as light. The process is modeled below.



This process emits electromagnetic radiation in **discrete** wavelengths. For example, when the light from excited helium atoms is observed through a spectroscope, the strongest visible wavelengths are **447**, **471**, **492**, **502**, **588**, and **668** nanometers. Use colored pencils or markers to draw lines at each wavelength to represent the **emission spectrum** of helium.



This emission spectrum is unique to helium. It is like a fingerprint for detecting the presence of helium. Each element has its own unique emission spectrum that can be used to identify its presence.

Let's get started!

Materials

- Black foam board (four 5 cm x 30 cm strips)
- Black foam square (6.5 cm x 6.5 cm with a 3 cm x 3 cm window cut from the center)
- Aluminum foil (two 6 cm x 4 cm rectangles).
- Note card
- Scissors
- Wedge of a CD, with reflective coating removed
- Duct tape, masking tape, and electrical tape
- Multiple light sources
- Colored pencils or markers
- Smartphone camera (optional)

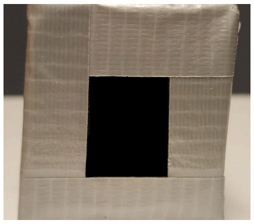
Investigation

Let's construct a **spectroscope**.

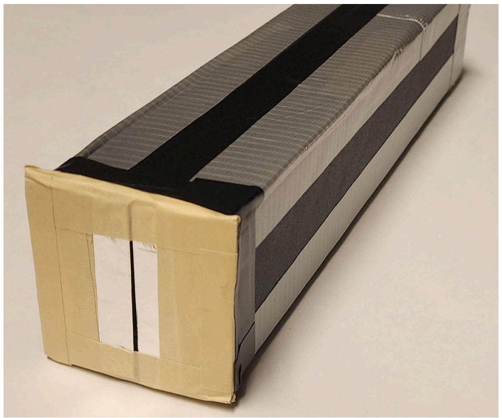
1. Use masking tape to loosely assemble a rectangular tube with the four foam board strips. Reinforce the corners with duct tape. The tube should be sturdy when finished.
2. Place strips of black electrical tape along the corners. The electrical tape will block light from entering through any gaps in the edges.
3. Cut a note card in half, then trim each piece to about 3.5 cm x 6.0 cm. The 6.0 cm edge should be the original edge of the card so that it is perfectly straight.
4. Fold the aluminum foil pieces in half along the length. Place the 6.0 cm edge of each note card into a piece of foil. Use masking tape to secure the foil to each note card to create two opaque "screens".
5. Use a straight edge or your fingernail to flatten the aluminum foil against the edge of each note card. The foil should have a sharp, straight edge.
6. Use masking tape to attach one of the screens to the square so that its aluminum edge covers half of the window.

7. Place the other screen onto the square so that its aluminum edge leaves a small slit between the other screen's edge. The slit should only be a couple of millimeters wide. Use masking to secure the screen.
8. Use duct tape to attach the window to the tube.
9. Place the CD wedge over the other end of the tube. Line up the curve of the CD with the orientation of the slit.
10. Use duct tape to securely fasten the CD over the opening. You may trim off any parts of the CD that overhang. Use more duct tape to create a square viewing port, about 3 cm x 3 cm.
11. Look through the viewing port for areas inside the tube where light is coming in. Apply electrical tape as necessary to cover any gaps.

Slit between aluminum screens



Viewing port



Completed spectroscope

12. Aim the slit at a light source. You should see a spectrum appear on each side of the spectroscope tube. If no spectrum is visible, slowly move the spectroscope to one side until you see it appear. If the spectra appear very dim, try adjusting the width of the slit. When viewing a light source, make sure that light from other sources does not enter the spectroscope.

13. Use your spectroscope to view the spectrum of each light source listed below. Estimate the wavelengths of light observed, and sketch what you see on the scales. Provide a description for each spectrum, and note any missing wavelengths. *(Note: **When viewing sunlight, do not aim the spectroscope directly at the Sun!** To view its spectrum safely, place a sheet of white paper into the sunlight and use the spectroscope to observe the light reflected from the paper.)*

Incandescent light

400 450 500 550 600 650 700

Description:

Fluorescent light

400 450 500 550 600 650 700

Description:

Sunlight

400 450 500 550 600 650 700

Description:

Follow-up questions

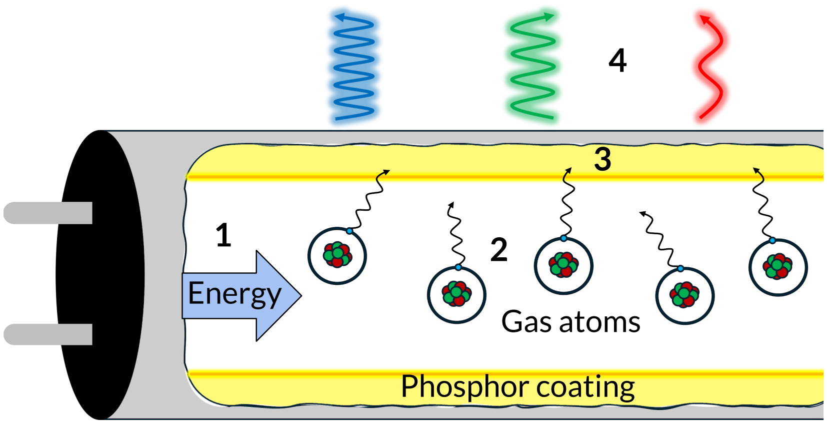
1. Why is it important to block out other light sources when viewing a light source with the spectroscope?

2. Which of the spectra observed were most similar? Describe the similarities you observe.

3. Which of the spectra observed were noticeably different? Describe the differences you observe.

4. The incandescent bulb produces light through **thermal radiation**. Current flows through the metal filament of the bulb and the filament's temperature increases. The random vibrations of the charged particles in the filament produce a **continuous spectrum** that includes visible light.

   The fluorescent bulb uses a different process to produce light. Analyze the numbered steps on the diagram below and answer the questions.



   Step 1: Electrical energy enters the tube, exciting the gas atoms inside. Electrons in the gas atoms transition to (circle one) **lower / higher** energy states.

   Step 2: When the electrons transition to (circle one) **lower / higher** energy states, energy is emitted as electromagnetic radiation. Much of the radiation is emitted in the ultraviolet range, outside the visible spectrum.

   Step 3: The inside of the fluorescent bulb is coated with a material called *phosphor.* The ultraviolet radiation is (circle one) **reflected / absorbed** by the phosphor atoms. Its electrons become excited, and transition to higher energy states.

   Step 4: When the phosphor electrons transition to lower energy states, they emit electromagnetic radiation at longer wavelengths that we see as visible light. Phosphor atoms only emit light at certain wavelengths, so the fluorescent bulb produces a (circle one) **continuous / discrete** spectrum.

5. The gas inside the fluorescent bulb emits *mostly* ultraviolet radiation that is absorbed by the phosphor. However, it *also* emits some wavelengths of visible light. The specific wavelengths emitted by the gas can be used to identify it.

   The four brightest visible wavelengths emitted by various elements are shown below. Compare the values to your observation of the fluorescent bulb's spectrum to determine which gas is contained in the fluorescent bulb. Support your reasoning with evidence.

   Hint: The phosphor emits light around 460 nm (blue), 550 nm (green), and 620 nm (red). Check the fluorescent light spectra for ***other*** *wavelengths that stand out.*

Krypton: 511, 541, 585, 647 nm	**Neon:** 585, 598, 614, 627 nm
Mercury: 405, 436, 546, 577 nm	**Europium**: 579, 585, 593, 612 nm

6. Unlike the incandescent and fluorescent lights, sunlight is not from a manmade source. It's starlight! The Sun can be approximated as a blackbody that emits a continuous spectrum based on its temperature.
   However, you *may* have noticed vertical dark lines scattered throughout the Sun's spectrum. These lines would be very apparent with sensitive equipment. What do you think is happening at the specific wavelengths where dark lines appear?

Star spectral analysis

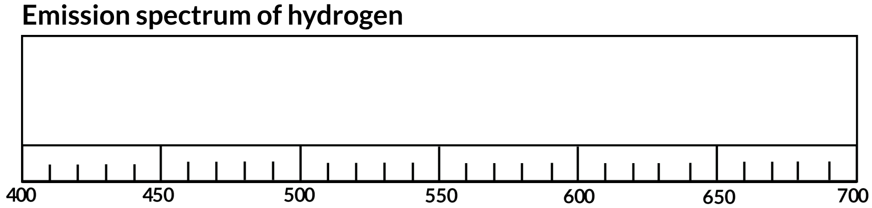
Let’s dig deeper to figure out why a star’s spectrum contains dark lines, and what they can tell us about the star.

The hot core of a star produces a continuous spectrum of light. This spectrum passes through the star’s cooler, outer gas layers on its way out. The elements in those gases absorb specific wavelengths (the same wavelengths which they later emit in all directions). This absorption dims the outgoing spectrum of the star at those particular wavelengths, allowing astronomers to identify which elements are present.

Consider hydrogen as an example. Excited hydrogen atoms absorb *and* emit visible light at wavelengths of **410**, **434**, **486**, and **656** nanometers.

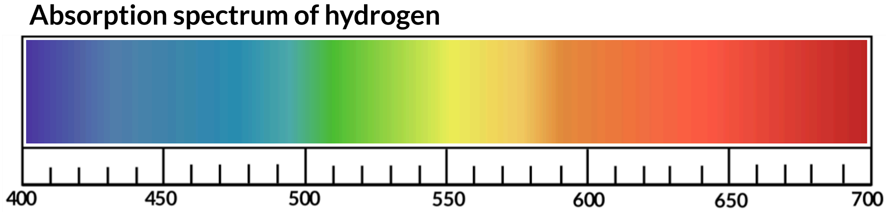
When hydrogen gas is energized, the gas *emits* hydrogen’s characteristic wavelengths. On the scale, draw a properly colored line at each of the wavelengths emitted by hydrogen to represent its **emission spectrum**.

Emission spectrum of hydrogen

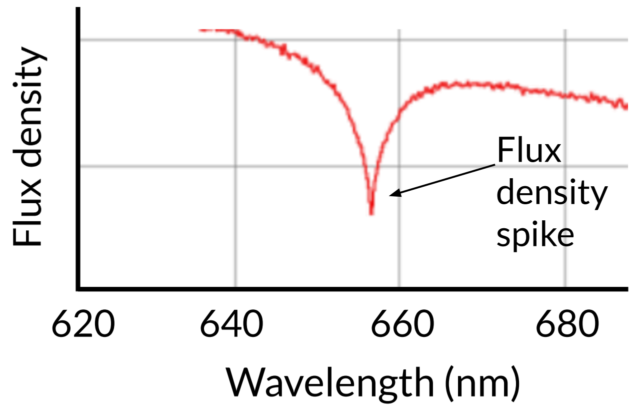


When a continuous spectrum shines through hydrogen gas, the gas *absorbs* hydrogen’s characteristic wavelengths, producing hydrogen’s **absorption spectrum**. On the continuous spectrum below, draw **black lines** to show where hydrogen gas would cause the spectrum to darken.

Absorption spectrum of hydrogen



Now, let's apply this knowledge to analyze real star spectra. Each star's spectrum is represented as a graph of **flux density vs. wavelength**. Flux density is a way of measuring the intensity of a star's electromagnetic radiation at every wavelength. A sharp decrease in the flux density occurs when a specific wavelength of light is absorbed by an element in the star's atmosphere.



In the example above, a portion of a star's spectral graph shows a sharp decrease in the flux density at about 656 nanometers. Hydrogen gas absorbs light with a wavelength of 656 nanometers! This is evidence that the star's atmosphere contains hydrogen.

The spectral graphs of three stars are shown on the following pages. Spikes in the flux density are marked with arrows. Record the wavelength where a spike occurs.

Then, use the table of characteristic wavelengths shown here to determine which element caused the spike.

Note: Not all of an element's absorption lines may not appear in a star's spectrum. Only the spikes most useful for classifying the star are marked with a line on the following graphs.

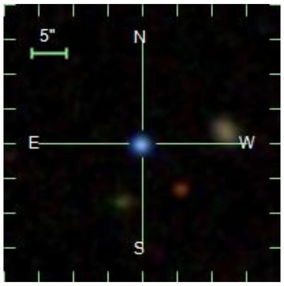
Element	**Wavelengths (nm)**
Hydrogen (H)	410, 434, 486, 656
Helium (He)	403, 447, 492
Oxygen (O)	630, 636
Sodium (Na)	589
Magnesium (Mg)	517
Calcium (Ca)	610
Titanium (Ti)	453, 465, 482
Chromium (Cr)	521
Iron (Fe)	483, 527, 640

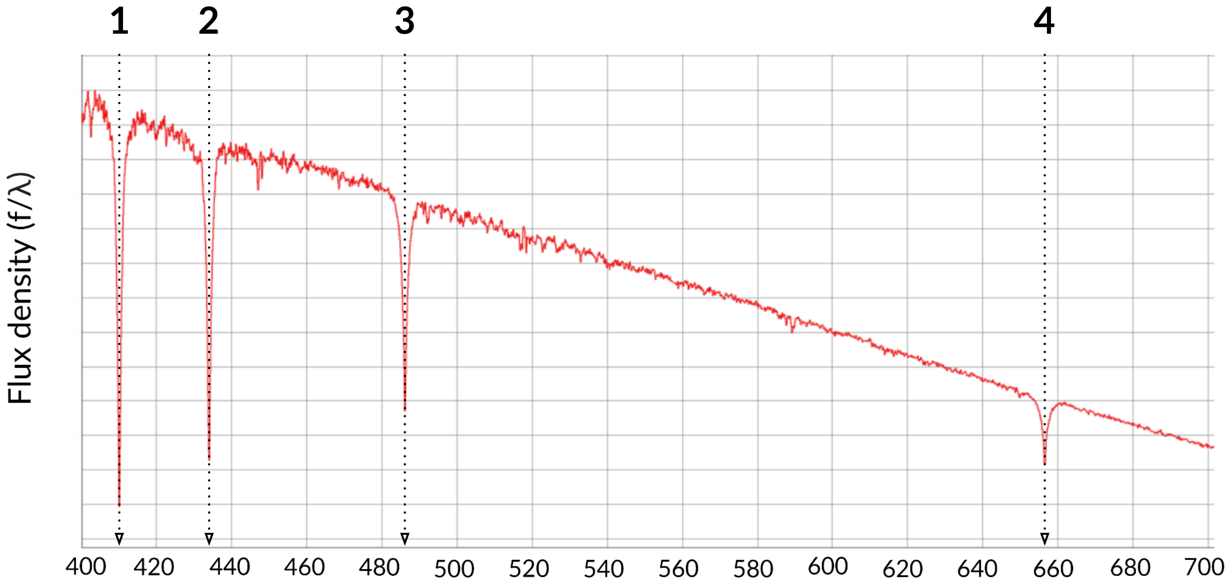
Spectral analysis of star 1

International Astronomical Union ID

J103540.95-004228.5

Image of object J103540.95-004228.5 by the Sloan Digital Sky Survey, CC BY 4.0





Flux density vs wavelength for object J103540.95-004228.5 by the Sloan Digital Sky Survey, CC BY 4.0. Cropped from original.

Wavelength (nm)

Line	Wavelength	Element
1		
2		
3		
4		

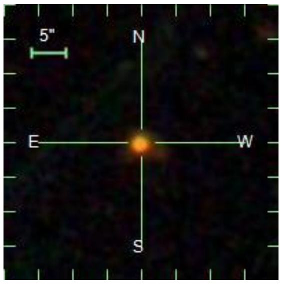
Khan Academy

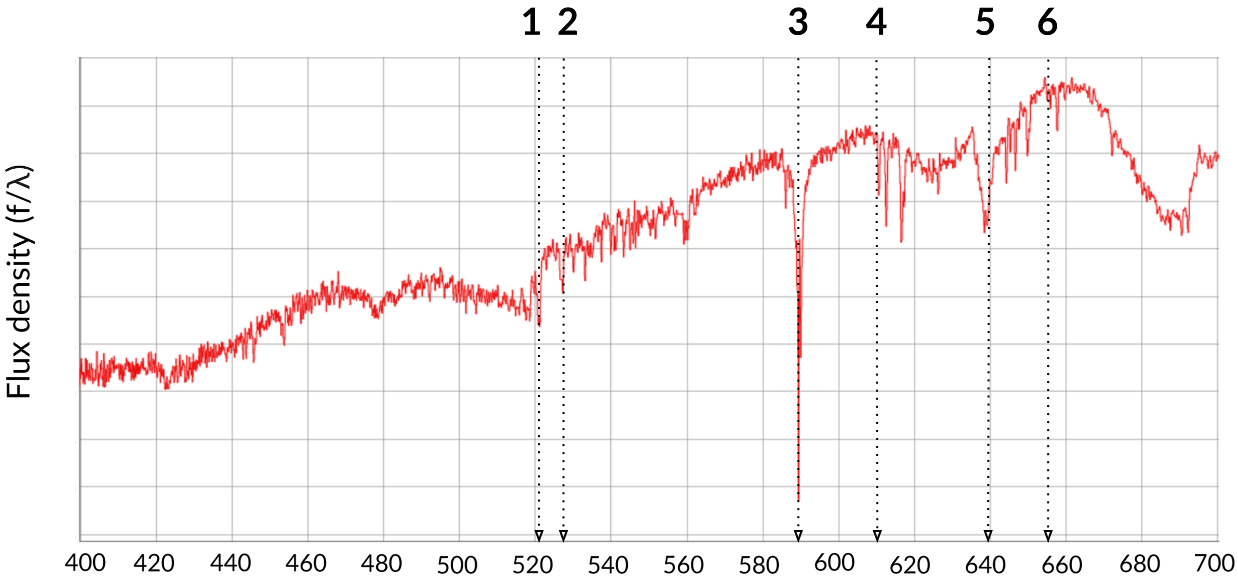
Spectral analysis of star 2

International Astronomical Union ID

J112753.82-005139.4

Image of object J112753.82-005139.4 by the Sloan Digital Sky Survey, CC BY 4.0

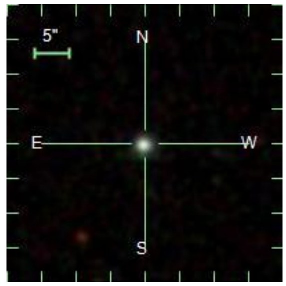


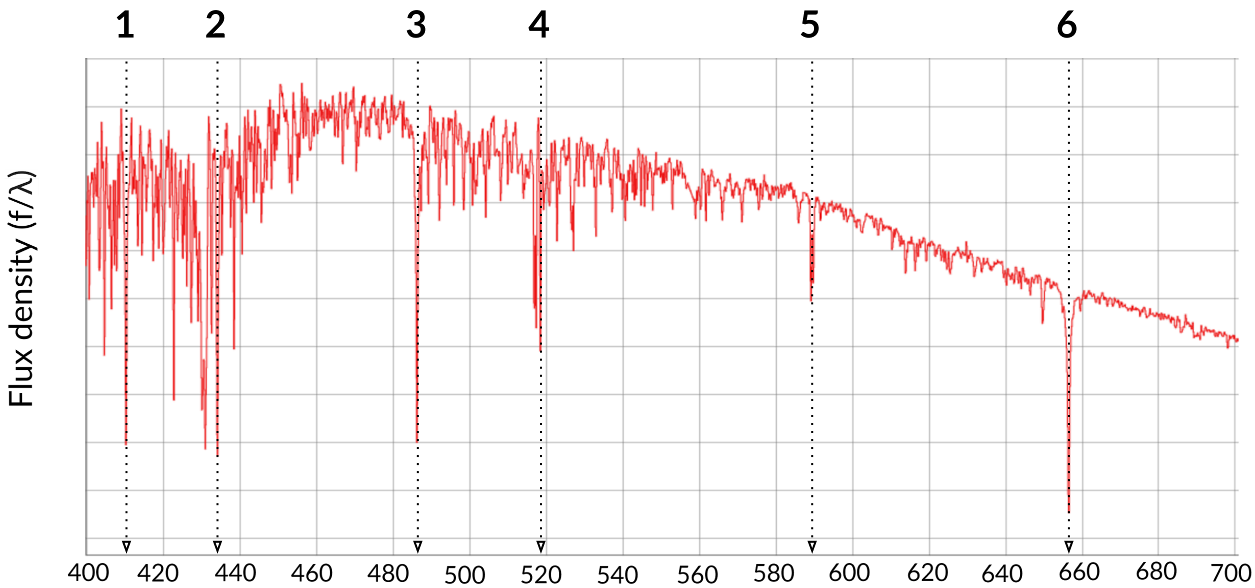


Flux density vs wavelength for object J112753.82-005139.4 by the Sloan Digital Sky Survey, CC BY 4.0. Cropped from original.

Line	Wavelength	Element
1		
2		
3		
4		
5		
6		

Spectral analysis of star 3	
International Astronomical Union ID *J103558.08+001738.4*	*Image of object J103558.08+001738.4 by the Sloan Digital Sky Survey, CC BY 4.0*





Flux density vs wavelength for object J103558.08+001738.4 by the Sloan Digital Sky Survey, CC BY 4.0. Cropped from original.

Line	**Wavelength**	**Element**
1		
2		
3		
4		
5		
6		

Keep creating!

Astronomers categorize stars into seven different **classes**, each with its own unique set of absorption spectra. Use the internet to research these star classifications and create a short presentation that explains each one, including star temperature and color. Give examples of stars from each class that can be seen in the night sky without a telescope.

The table below lists the elements that produce strong absorption lines used to classify stars in each class. Use the table below to classify each star you analyzed in this activity.

Class	**Strongest absorption lines**
O	Helium
B	Hydrogen, helium
A	Hydrogen
F	Hydrogen, sodium, magnesium, iron
G	Oxygen
K	Titanium, iron
M	Magnesium, chromium, iron

More creative ideas!

Astronomers analyze the light from distant stars to detect the presence of exoplanets orbiting them. When an exoplanet is identified, starlight can also reveal details about the planet's atmospheric composition!

Explore the methods astronomers use to find exoplanets and understand their atmospheres. Develop a model to illustrate these processes, and use Adobe Express to create a video that clearly explains the techniques involved.