Decoding Star Light

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Introduction

Unlike other scientists, astronomers never get to touch the objects they are curious about. All they can do is explore the light from the object. Since stars are so faint, astronomers use large telescopes to collect starlight, and they use complex instruments to analyze the light. This unit will show you some tools they use to decode starlight. We'll tease the information a spectrum offers in ways similar to those used by professional astronomers and learn the secrets of stars. Astronomers use computers to make models and compare these to actual data to find out the relative sizes, temperatures, and compositions of stars — and eventually, their life histories. Students with prior knowledge of chemistry and physics will be able to explore these activities on a deeper level.

Prior Knowledge

When light is dispersed into its component colors (i.e., wavelengths) it forms a spectrum.

Different circumstances produce emission, absorption, or continuous spectra.

Stars give off light.

Materials

- ***Required***: Overhead projector, blank transparencies, pens, and one penny and a "star field" (make this by poking pinholes in a sheet of black construction paper. Big holes indicate bright stars, little holes dim stars.)
- ***Spectrum Sheet #1***: Spectral Transparency (color, gray-scale, tracing, and star map of Vega/Deneb)
- ***Spectrum Sheet #2***: Vega spectrogram and empty graph (for each student group.)
- ***Spectrum Sheet #3 and #4***: Intensity verses wavelength graph of the stars Vega and Deneb.

Objectives

Students will decode stellar spectra and extract data that they can relate to properties of stars. The following TEKS will be met for Grade 8, Astronomy, Integrated Physics and Chemistry, and Physics:

Science Process Skills

- Collect data, measure, and observe
- Organize, analyze, make inferences
- Communicate valid conclusions
- Construct graphs, examine, and evaluate data

Science Concepts

- Matter and energy interactions (IPC 7c)
- Characteristics of the universe (8.13a, 8.13c)
- Characteristics and life cycle of stars (Astronomy 6b)

Reading the Code

In the following activities, students draw their own intensity versus wavelength graph ($I(\lambda)$ graph) of stellar spectra. They discuss the advantage this graph offers the astronomer over using "naked-eye" visual spectra.

Activity

Using an overhead projector, display the transparency of the color spectrum of the star Vega (covering up the other segments of the transparency).

Ask students:
What features do you see? [E.g., colors of the rainbow, dark lines, shapes...] How does this compare to other spectra you have seen? [E.g., rainbow, spectroscope activity, other demonstrations]

Explore: Ask students to imagine what this color spectrum might look like as a gray-scale image, as in a black and white movie or photograph. With this in mind, ask each student to use the information contained in the color image on the transparency to sketch a black and white version on his or her papers.

Discuss: Reveal the gray scale image as well as the color image (leaving the other information covered) of Vega's spectrum and ask them to compare their sketches to it. Ask them how they decided to assign levels of gray to their sketches. Explain that this is how they assigned their own relative intensity values for each color. The color information is encoded as the wavelength, or position along the spectrum. They created an intensity versus wavelength representation of a color spectrum.

Explore: Ask students if these are suitable for data analysis - how could they quantify (numerically represent) the information in the spectra.

What quantities are necessary? [Intensity and wavelength]

Pass out the activity sheet of Vega's gray scale spectrum and graph below. As an example, one of the prominent spectral lines has already been drawn on the graph. Tell students to complete the $I(\lambda)$ graph on their own activity sheets.

Explain: Reveal the graph as well as the color and gray-scale images on the transparency. Explain that astronomers have written computer programs that convert the spectral information into $I(\lambda)$ graphs. The spectrogram is digital information because the CCD camera used by the astronomer is like a digital camera that converts photons into pixel-count readings. Point out faint details that may escape your eye's contrast detection, but which easily show up on the $I(\lambda)$ graph. Point out the continuum and shapes of the absorption features. (The continuum is the smooth curve that follows the shape of maximum light at each wavelength. If there were no absorption lines formed by the star's photosphere, all that would be left is the continuum. For those with more physics, the shape of the continuum is due to the star acting like a perfect radiator, also known as a "black body." It will be different for different temperature stars.) The continuum and absorption lines are clues to the temperature and pressure of the star's atmosphere.

Discuss: Ask students why they think this $I(\lambda)$ is useful to an astronomer. Astronomers use $I(\lambda)$ graphs in several ways:

To analyze the spectrum visually and mathematically.
To facilitate comparison of different stellar spectra in a common format.
To enhance determining the physical properties of a celestial object.

Cracking the Code and Reading the Message

Now that students know how to represent the spectrum mathematically, they can learn how these tracings reveal information about the star's photosphere. (The photosphere is the star's outer layer where most of the light comes out. For instance, when you safely view the Sun, you are seeing the photosphere.) The appearance of these features is clues to the temperature and relative diameter of the star.

Activity

Students will compare the spectra of two stars.

Engage: Lay the starfield on an overhead projector and project it on a screen. [Tell them that stars' apparent size differences are due to distortions of Earth's atmosphere and the optics of the telescope, not the actual sizes of the stars.] Look at the screen. Which stars are large and which are small? Invite discussion. Ask students to define large versus small. Most students will compare bright to dim. Explain that just as streetlights look fainter when they are distant, so do stars. Just looking at the apparent brightness doesn't offer clues to a starís physical diameter.

Explore: Pass out spectrum sheets #3 and #4 of the stars Vega and Deneb. Tell students that these spectra come from two stars with the same temperature. Place the entire transparency on the overhead. Show the locations of Vega and Deneb on the star map. Ask students to compare and contrast the spectra.

Point out that these tracings are only a portion of the earlier spectrum they examined. If students need hints of how to compare, suggest seeing what wavelength the features appear on each sheet and how they are the same or different. They may wish to number or label these features. Do not suggest a scheme to them. Some of the students may realize they can hold the sheets together up to the light to compare features.

Discuss: Ask them what was the same and what was different in the two tracings? They should note that the positions of most lines are the same, but the shapes and depths of the individual lines are different. Now tell them Vega is 25 light years away, but Deneb is 1467 light-years. What does this say about Deneb's intrinsic brightness (luminosity)? It must be much brighter. If Deneb and Vega were exactly the same brightness in the sky, then we could do the following calculation. Relative brightness is proportional to distance squared. Deneb would be about $(1467/25)^2$ or 3325 times brighter. Scientists know that the luminosity of a star depends on its diameter and temperature. Luminosity is proportional to a star's diameter squared times its photosphere temperature raised to the fourth power.

$$\textbf{L is proportioned to } \mathbf{D^2 \times T^4}$$

But Deneb and Vega are the same temperature, so if one was 3325 times brighter, how much bigger is it? [58 times bigger].

For Physics teachers: Actually, Vega is brighter than Deneb so that the ratio of luminosity is 1318, not 3325. So, the actual ratio in diameter is only 36. The actual relationships involve the use of logarithms that are not commonly used in lower level classes. The following chart may be useful for those who wish to use more math in this activity and have prior knowledge of apparent and absolute magnitudes:

	Vega	Deneb
m_V apparent magnitude	0.03	1.25
M_V absolute magnitude	0.6	-7.2
L Luminosity	1	1318
d Distance (light years)	25 ly	1467 ly

$$m_1 - m_2 = -2.5 \log (F_1/F_2) = -2.5 \log (L_1/L_2 \times [d_2/d_1]^2)$$

$$\text{but if } m_1 - m_2 \sim 0, \text{ then } L_1/L_2 = [d_1/d_2]^2$$

$$L_{Deneb} / L_{Vega} = 100^{(M_{Vega} - M_{Deneb})/5} = 1318$$

Explain: This supergiant star has a very low density photosphere in which the atoms don't interact with each other as frequently as in the smaller, denser atmosphere star. The shape of the line indicates its relative diameter. Whenever an astronomer sees very narrow spectral lines, she knows it is a giant star.

A star's photosphere pressure (number of gas particle collisions per second) affects the shape of the absorption line. These stars are both the same temperature, so changes are not due to temperature. The high pressure inside the photosphere of a star like our Sun produces wide absorption lines — they look "smudged." The photosphere pressure of the largest stars, called super-giants, is the lowest. These stars show spectral lines that are razor sharp.

Extend: Even with a large telescope, images of stars appear as points. This indicates that their distance from our solar system is far greater than their size. But stars dramatically differ in size. Relative to the size of own sun, the range begins at one tenth the Sun's diameter (just a little bigger than Jupiter) and extends to thousands of solar diameters. There are stars, like Antares in the constellation Scorpius that would extend to the orbit of Venus if they were at the center of our solar system. Supergiant stars like Betelgeuse in the constellation Orion would engulf our solar system out to Saturn.

Using a combination of the overhead projector and a penny, you can demonstrate the relative size difference between our sun and a giant star. Both stars have the same effective temperature.

On transparency film, draw a circle. The diameter should be almost as wide the transparency sheet.

Use the overhead projector to project the circle on the screen.

On the screen, the circle should look huge — about 1.5 meters or 150 centimeters wide depending on how far away the projector is from the screen. The penny is 2 cm wide.

Compare the penny and the projected circle. The penny itself is our star, the sun. On the screen, the large circle represents a giant star about 75 times the size of our sun.

Meaning of the Message

Pressure information is related to some of the "big ideas" in stellar astronomy. Stars come in a variety of sizes, despite their appearance to the eye through a telescope. Stars have lives and change as they age in regular patterns. In the end, what stellar astronomers have come to realize is that a star's appearance, destiny, and fate are related to one property — the star's mass.

A star whose spectrum indicates much lower photosphere pressure (compared with that of our sun) is enormous, either a giant or a supergiant. But giants and supergiants were not born this way. These are stages in a star's life. In their younger days, they used to be much smaller.

Stars like our sun are in the prime of their lives. They regularly fuse hydrogen into helium inside their core to generate energy and light. But once the hydrogen fuel dwindles, the star makes adjustments as it struggles to continue shining. A giant star is evidence of such a struggle. Its photosphere expands due to a dramatic increase in the amount of energy generated in the star's core. As the star becomes bloated, its photosphere thins out. Super giant stars run the same course, except that the increase in energy, or luminosity, is even greater. As a result the bloating is more pronounced. Ultimately the star's mass will determine its characteristics and future.

Ask a stellar astronomer what the most important property of a star is and he or she will emphatically reply: "the star's mass". Mass shapes the properties, life, and fate of every star. Stars with a mass greater than our sun live fast, are hotter, grow into supergiants, and then explode into supernovae. More massive stars finally collapse into black holes. Our sun and less massive stars live long slow lives, balloon into giants, expel their outer layers as planetary nebulae, and then fade away as white dwarfs.