Decoding Star Light
The Code for Temperature

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Introduction

Astronomy fundamentally changed after Henry Draper first photographed the spectrum of the star Vega in 1872. Soon thereafter, astronomers began surveying the stars and photographing their spectra. The resulting flood of stellar spectra was a blessing and a challenge. The bewildering variety of stellar spectra demanded a simple, adaptable, and meaningful organization system. By 1924, Annie Jump Cannon had revised the stellar spectra organization system and personally classified over two hundred thousand stars. Her basic system is still in use today.

In this activity, students begin their exploration by following in Cannon's footsteps to organize a few stellar spectra. Later they learn that the absorption features in the spectrum change according to the temperature of the star. Given this information, they may revise their organization scheme and order the stars by temperature. In this way, they come to understand the code for temperature in a star's spectrum. In the explanation section, students learn the history of how Cannon and others dealt with this same problem

Materials

- Star field overhead
- Scissors
- Sheet with seven photographic spectra
- Table of spectral features and wavelengths
- Spectrum key (absorption lines labeled by element)
- Line strength vs. temperature chart
- Evaluation sheet with unknown spectra

Standards

Science TEKS:

SCIENCE PROCESS SKILLS

- Organize, analyze, make inferences
- Communicate valid conclusions
- Construct graphs, examine, and evaluate data
- Research and describe the history of astronomy and contributions of scientists

SCIENCE CONCEPTS

- Matter and energy interactions (IPC 7c)
- Characteristics and life cycle of stars (Astronomy 6b)

Preparation

Students may not be aware of the Kelvin temperature that is based on the average kinetic energy per molecule of a perfect gas. All motion stops at absolute zero. Astronomers commonly refer to the temperature of stars in units of degrees Kelvin (K). Basically, Kelvin is degrees Celsius + 273. Before beginning the explore section, introduce this temperature scale to students.

Engage

Using an overhead projector, show the students the color transparency of the star field taken with an objective prism placed over a telescope. This is the Hyades cluster in the constellation Taurus. Point out that each spectrum represents a single star in the star field. Among the spectra are subtle differences in color intensity and spectral features. Ask students to compare and contrast the spectra.

Explore

1. Classification.

Break students up into groups of two to four. Tell them that each group will invent a system for organizing stellar spectra. Each group should write down how they chose to organize their spectra, the rules of their organization system, and why they chose the rules. Finally, pass out a spectra sheet to each group to cut into strips.

After students have organized their spectra, tell the class that their goal as scientists is to come up with a single organizational system for stellar spectra. The class must come to a consensus on an organization system that is clear, logical, and simple to use. Let each group present to the class how they organized the spectra and their spectra organization plan. You might record the results from the groups on the board or overhead projector. Encourage questions and discussion. The final solution will be a combination of features from the student groups that the class think best organizes the spectra.

2. Identify lines.

Using the table that lists the wavelengths of spectral lines in nanometers, ask students to write down which lines they believe they have observed within each spectrum. Do not distribute the teacher's key to all the students. They should interpolate the information to make their own identifications.

Wavelength (nanometers)	Element
379.8	H - theta
383.6	H - eta
388.9	H - zeta
393.4	Ca II
396.8	Ca II
397	H - epsilon
402.6	He II
410.2	H - delta
420	He II

434.1	H - gamma
447.1	He I
454.2	He II
468.6	He II
471.3	He I
486.1	H - beta
527	Fe I
589	Na I
656.3	H - alpha

3. Determine the star's temperature.

Tell the students that new observations and research of stars show trends between an element's line strength and the temperature of the star's photosphere. Pass out to each group the chart of line strengths verses temperature. Discuss with them what this chart means in terms of the appearance of their spectra. Note that roman numeral I refers to an element in its neutral state while roman numeral II refers to an atom missing one electron. The pattern of spectral lines is different for different ionization states.

- What do you think "line strength" means in terms of the appearance of absorption lines?
- "weak" lines are dim absorption features.
- "strong" lines are dark absorption features.
- As an element's line strength increases or decreases, what happens to that element's absorption feature in the spectrum?
- increasing line strength means that the absorption feature gets darker.
- decreasing line strength means that the absorption feature gets brighter.
- Ask for an example of a spectrum with strong hydrogen lines.
- Spectrum number 1 shows strong hydrogen absorption lines.
- Spectrum number 5 shows weak absorption lines.

Using the line strength vs. temperature chart, ask the student groups to rank their spectra in order of the star's temperature. Students should consider the line strengths of several elements when estimating the temperature. For instance, the hydrogen lines strength steadily increase up to a peak at about 9,000 degrees Kelvin, then drops off. In order to figure out which side of the peak the star's temperature lies, students should consider the presence or absence of other absorption features like calcium, iron, and helium lines.

- if the hydrogen lines are moderate, while calcium and iron lines strong, then the star is on the cool side of the 9,000 degree peak.
- if the hydrogen lines are moderate, but calcium and iron lines are weak or absent, then the star is on the hot side of the 9,000 degree peak.
- if helium appears in the spectrum, the star's photosphere is really hot, more than 10,000 degrees.

Once the spectra have been sorted according to temperature, ask students if this suggests refinements to their classification system. The goal of any refinement is to simplify the organization of spectra, yet be flexible and sophisticated enough to adapt to new knowledge about stars.

Explain

The set of spectra that the students organized represents the broad range of stellar spectra. Since 1860, astronomers have been refining an organizational method for stellar spectra. One of the first systems was offered by Father Angelo Secchi. He organized stellar spectra into five large groups according to the appearance of absorption and emission lines. But improving instrumentation revealed to astronomers more details in the stellar spectrum. Secchi's classifications were too broad, which inspired astronomers to develop several new more sophisticated organization schemes.

Henry Draper was first to photograph a star's spectrum in 1872. That lucky star was Vega. After Draper's death, his wife funded an ambitious telescopic observing plan led by Edward. C. Pickering at the Harvard College Observatory called the Henry Draper Memorial Survey. Between 1886 and 1897, this survey photographed hundreds of thousands of stellar spectra. Williamina Fleming analyzed these spectra and organized them by the strength of the hydrogen absorption lines. "A" designated spectra with the strongest hydrogen lines, then "B", "C", and so on down toward the spectra with the weakest lines, designated as "P".

Annie Jump Cannon was among many women working with Pickering and Fleming. She simplified the classification system by ordering spectra in a temperature sequence. Under this reorganization, she introduced the now familiar "O B A F G K M" spectral classification system with "O" stars being the hottest. She ensured smooth transitions between classes by adding digits 0 (hottest) to 9 (coolest) to the letter classifications. For instance, an B9 star was just a little hotter than a A0 star. But by far her greatest work was her personal classification of 225,300 stars by visual inspection of spectra on photographic plates. She and Pickering published these classifications in nine volumes between 1918 and 1924 called the Henry Draper Catalogue. The Henry Draper Extension increased the number of classified stars to 359,082 by 1948. This work is a cornerstone for astronomy.

Cannon's refinement of the Harvard Spectral Classification system is now the official system recognized by astronomers world-wide. The spectral types "O B A F

G K M" descend in temperature, with "O" type stars as the hottest and "M" stars the coolest. The photospheres of "O" type stars are so hot that they appear bluish-white with a temperature of over 30,000 degrees Kelvin. Our sun is much cooler. It is a "G2" type star with a photosphere temperature (effective temperature) of 5,770 degrees Kelvin. At the cool end of this sequence are the "M" stars. With an effective temperature of about 3,000 degrees Kelvin, these stars shine with a dim red light. Proxima Centauri, one of our closest stellar neighbors only 4 light-years away, is an "M" type star. Yet it is invisible to the unaided eye. At that same distance, our sun would appear as one of the brightest stars in the sky.

EXTEND:

Using the chart of line strengths versus temperature, note that letters appear at the top. Assign a stellar class to each of your spectra.

Below is a key to match spectral type with spectrum number.

O5	B5	A5	F5	G5	K5	M5
5	2	1	4	7	6	3

One surprising fact about stars is that despite the variety of spectra, their composition varies only slightly from star to star. They are mostly hydrogen and helium. All other naturally occurring elements, from Lithium up to Uranium, make up just 2 to 3 percent of a star's recipe. Astronomers refer to these as "metals." 68 of the 92 naturally occurring elements have been identified in stellar spectra. The remaining are probably there, but their spectral signatures are too faint.

The array of spectral types is really the result of the range in effective temperature, not stellar composition. Follow the hydrogen curve on the line strength vs. temperature chart. The amount of hydrogen doesn't change, but the electron state of the hydrogen atoms is sensitive to temperature. When electrons change energy states, they emit or absorb discrete wavelengths of light, which corresponds to discrete amounts of energy in the form of photons. The energy of the photon emitted or absorbed is equal to the energy associated with the electron's change of state. At about 9,400 Kelvin, the electrons in most hydrogen atoms are in the right state to absorb or emit light at several wavelengths in the visible spectrum. As a result, these hydrogen lines (Balmer line series) are strongest in "A" type stars, which have effective temperatures around 9,400 Kelvin. Compare that to lower temperatures, at about 4,000 Kelvin in the realm of "M" stars. Here, few hydrogen atoms are in the right state to emit or absorb light at the Balmer series wavelengths. Thus, these hydrogen lines are weak in the spectra of "M" stars.

EVALUATE

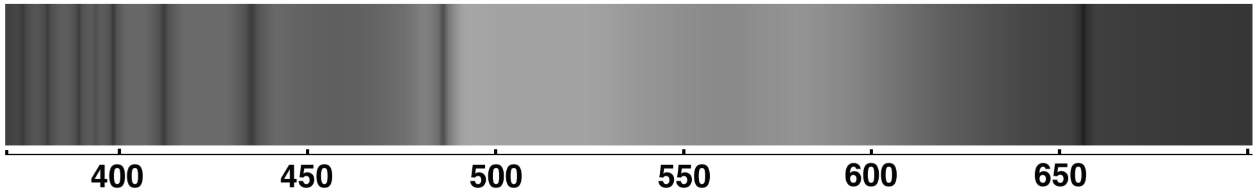
Ask students to classify the unknown spectra on the special sheet and to explain how they did it.

The key is:

B3	A2	F0	F8	K5	M5
10	8	11	9	12	13

Classifying these stellar spectra may be a challenge. If students are able to properly place the spectra in the right class (B, A, F, K, M) they are doing well. Students show mastery if they are able to justify temperature differences of stars within the same class. For instance, students may argue that spectrum #10 (B3 star) is hotter than spectrum #2 (B5 star). They can point out that the hydrogen alpha line (656.3 nm) has nearly disappeared, as well as the Ca II line (396.8 nm). These together indicate a higher temperature, but still within the B class.

1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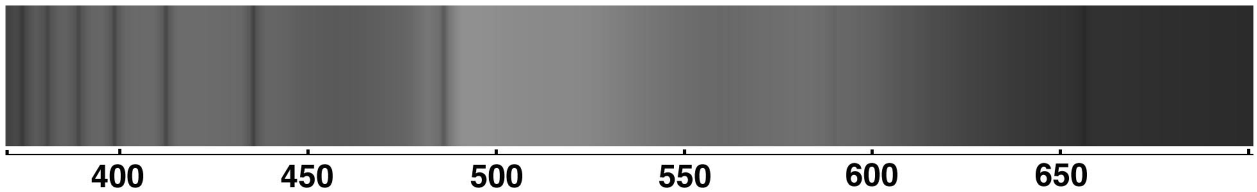
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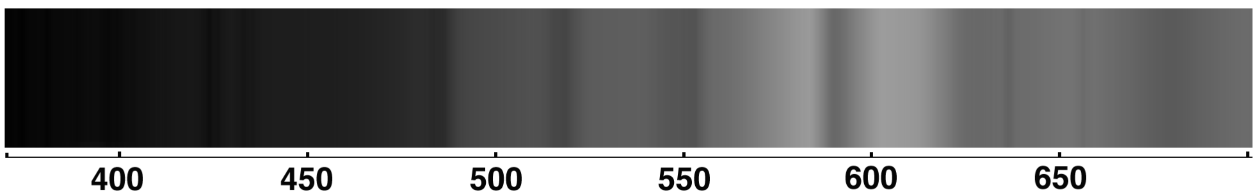
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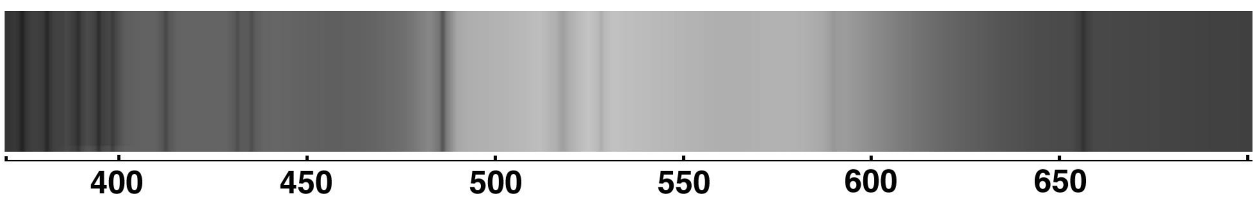
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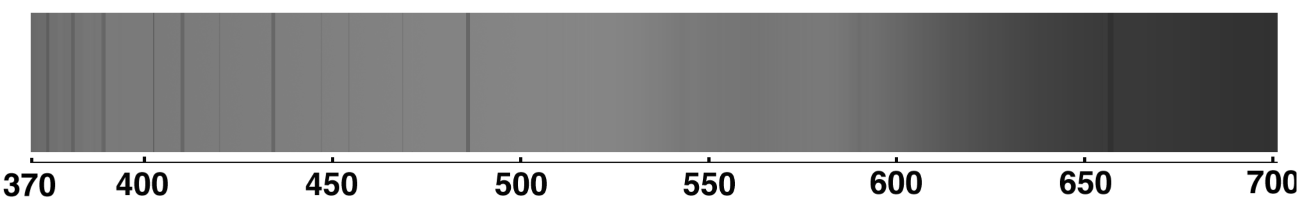
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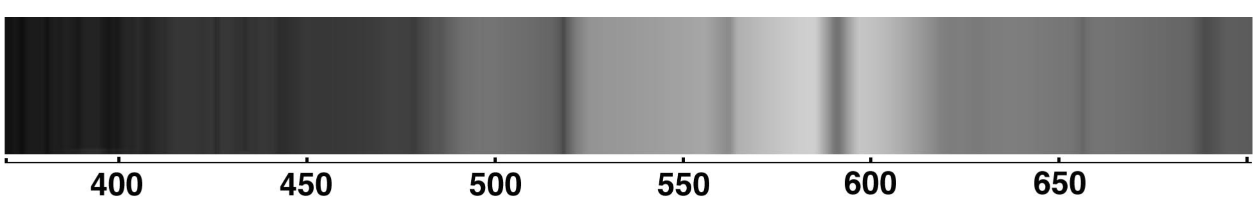
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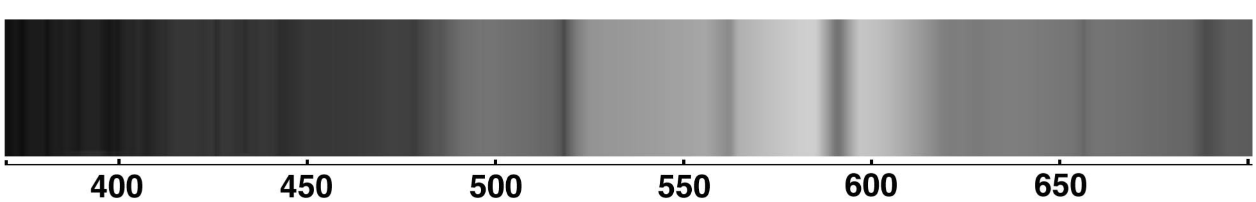
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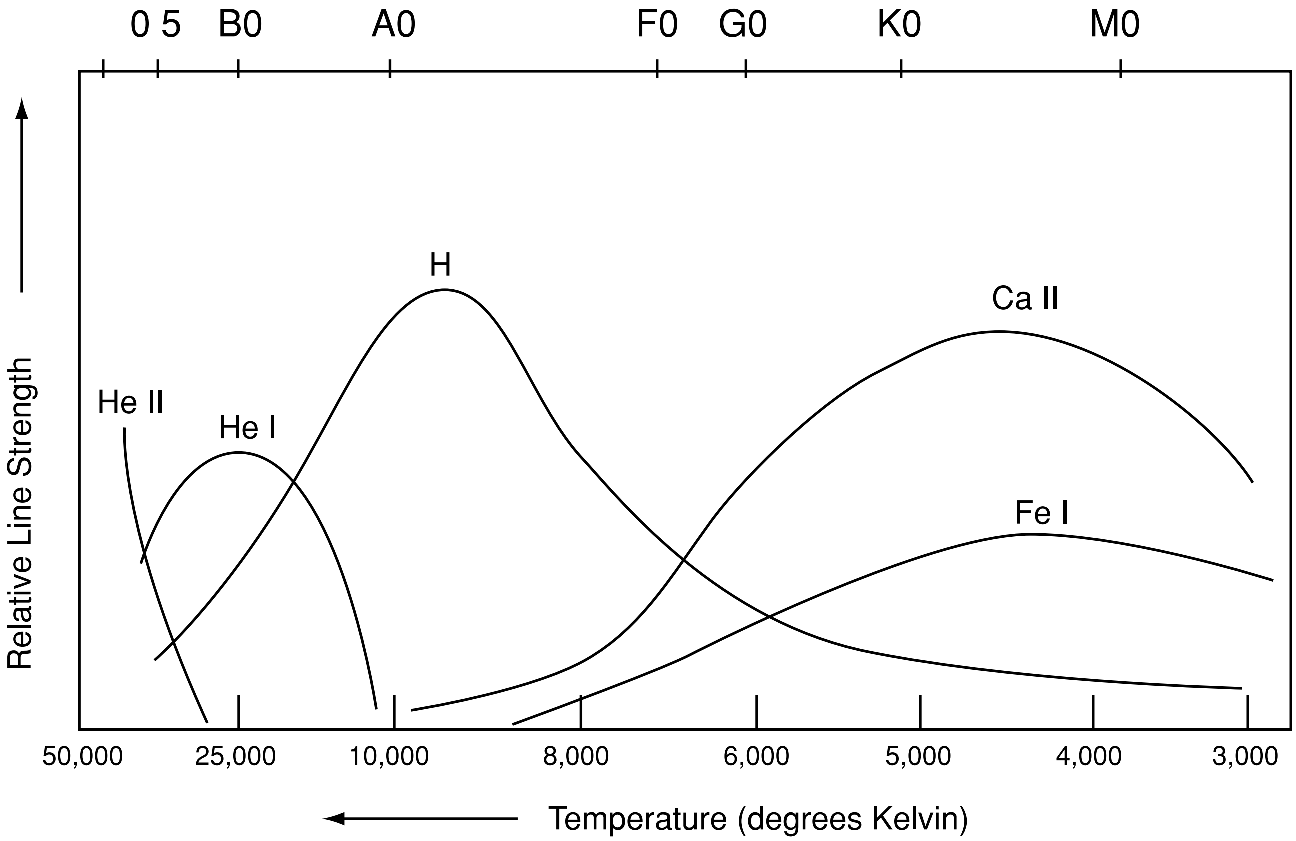
KEY

Decoding Star Light

Stellar Temperature vs. Line Strength



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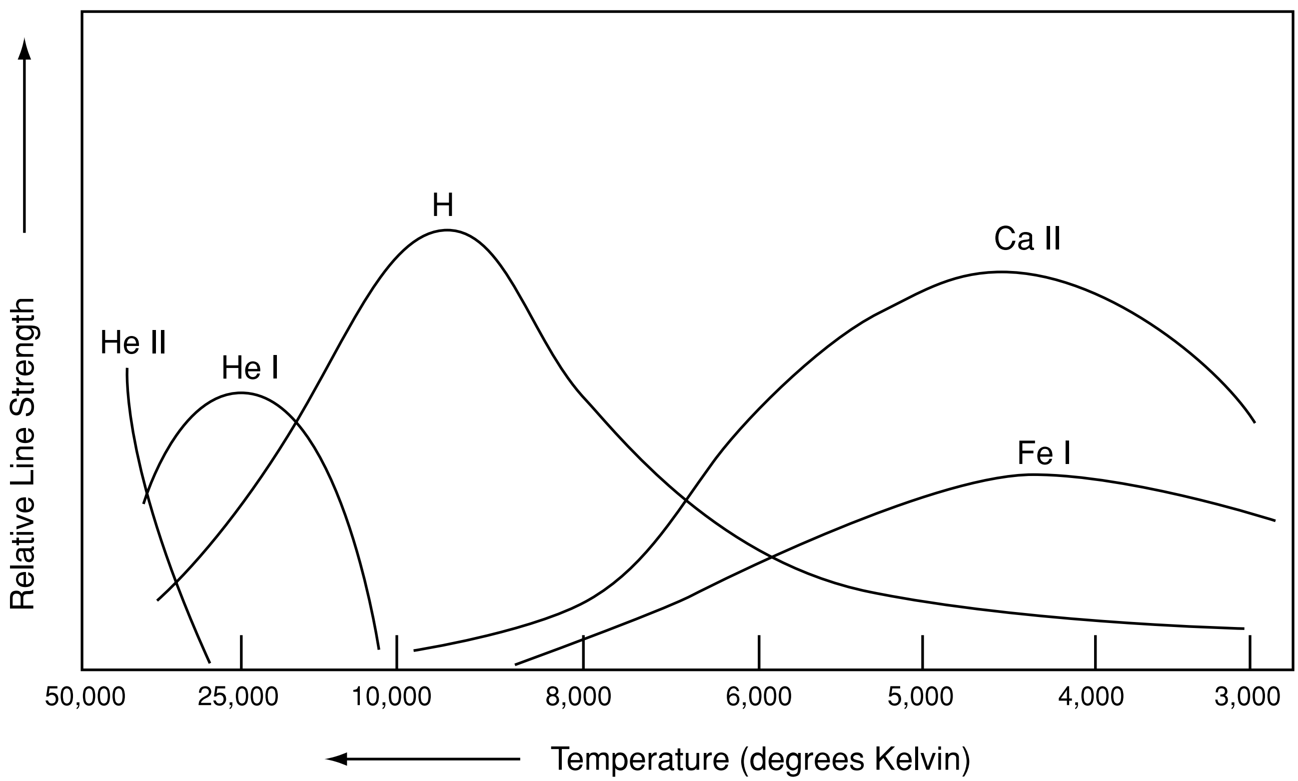
Stellar Temperature vs. Line Strength



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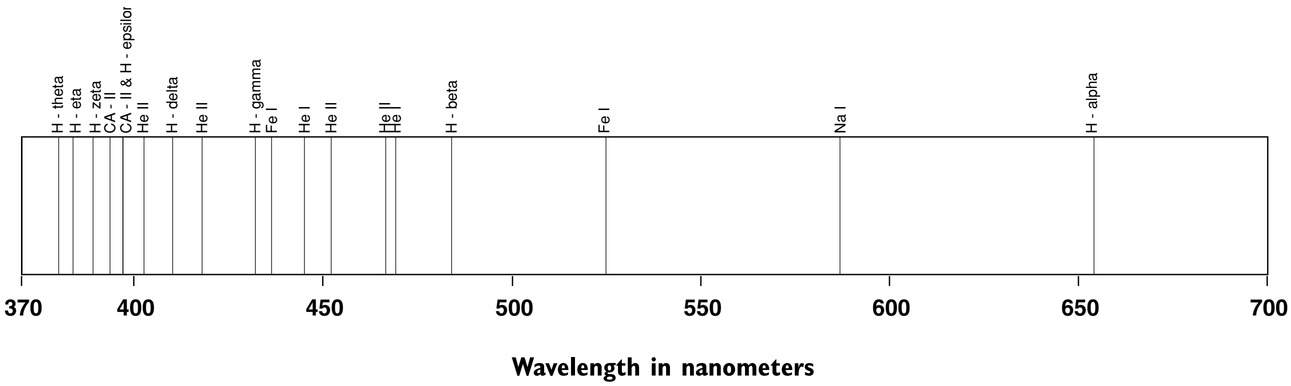
Teacher Spectrum Key



These are the major spectra features found in the Decoding Star Light spectrum sets. Below is a table listing the elements and absorption wavelengths.

Wavelength (nanometers)	Element	Notes
379.8	H - theta	
383.6	H - eta	
388.9	H - zeta	
393.4	Ca II	
396.8	Ca II	blends with H - epsilon
397	H - epsilon	
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410.2	H - delta	
420.0	He II	
434.1	H - gamma	
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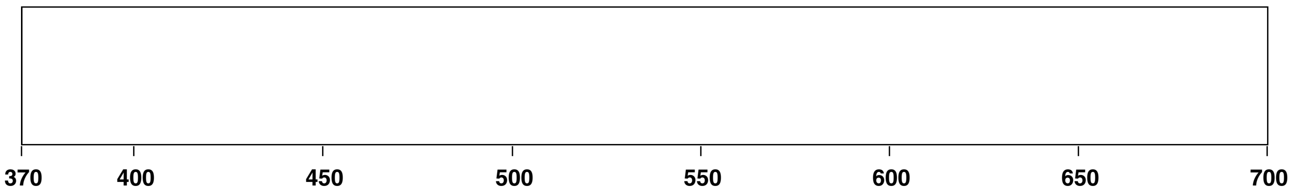
447.1	He I	
454.2	He II	
468.6	He II	
471.3	He I	
486.1	H - beta	
527	Fe I	
589	Na I	blend of two Na I lines: 598 and 598.6
656.3	H - alpha	

Decoding Star Light

Student Spectral Line Chart



Wavelength in nanometers

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Stellar Types and Spectral Features

Spectral Type	Primary Spectral Features	Main Sequence Temperature (K)	Notes
O	He II*, some emission features. H fading. Few III, IV, and V ionized metals.	50,000 – 28,000	Weak H alpha. Most energy radiated in ultraviolet.
B	He I, H strong but fading. Metal lines fading.	28,000 — 9,900	Many of the brightest stars are B type. Most energy radiated in ultraviolet.
A	H, few metals	9,900 — 7,400	Strong H Balmer lines. Simplest spectra
F	H and metals	7,400 — 6,000	Singly ionized metals disappearing
G	Ca II and metals	6,000 — 4,900	Strong Ca II lines in the violet end.
K	Ca II, Ca I, some molecular lines	4,900 — 3,500	Ca II lines in the violet end
M	Molecular lines: TiO, MgH, H_2 Numerous metal lines	3,500 — 2,000	Many absorption features. Banded appearance. Complex

*Ionization states are represented by Roman numerals:
I neutral atom
II singly ionized – one electron ejected
III doubly ionized – two electrons ejected
IV triply ionized – three electrons ejected
…and so on.