# 17.E: Analyzing Starlight (Exercises)

## For Further Exploration

### Articles

Berman, B. “Magnitude Cum Laude.” *Astronomy* (December 1998): 92. How we measure the apparent brightnesses of stars is discussed.

Dvorak, J. “The Women Who Created Modern Astronomy [including Annie Cannon].” *Sky & Telescope* (August 2013): 28.

Hearnshaw, J. “Origins of the Stellar Magnitude Scale.” *Sky & Telescope* (November 1992): 494. A good history of how we have come to have this cumbersome system is discussed.

Hirshfeld, A. “The Absolute Magnitude of Stars.” *Sky & Telescope* (September 1994): 35.

Kaler, J. “Stars in the Cellar: Classes Lost and Found.” *Sky & Telescope* (September 2000): 39. An introduction is provided for spectral types and the new classes L and T.

Kaler, J. “Origins of the Spectral Sequence.” *Sky & Telescope* (February 1986): 129.

Skrutskie, M. “2MASS: Unveiling the Infrared Universe.” *Sky & Telescope* (July 2001): 34. This article focuses on an all-sky survey at 2 microns.

Sneden, C. “Reading the Colors of the Stars.” *Astronomy* (April 1989): 36. This article includes a discussion of what we learn from spectroscopy.

Steffey, P. “The Truth about Star Colors.” *Sky & Telescope* (September 1992): 266. The color index and how the eye and film “see” colors are discussed.

Tomkins, J. “Once and Future Celestial Kings.” *Sky & Telescope* (April 1989): 59. Calculating the motion of stars and determining which stars were, are, and will be brightest in the sky are discussed.

### Websites

Discovery of Brown Dwarfs: http://w.astro.berkeley.edu/~basri/b...SciAm-book.pdf.

Listing of Nearby Brown Dwarfs: http://www.solstation.com/stars/pc10bd.htm.

Spectral Types of Stars: http://www.skyandtelescope.com/astro...ypes-of-stars/.

Stellar Velocities https://www.e-education.psu.edu/astr...ent/l4_p7.html.

Unheard Voices! The Contributions of Women to Astronomy: A Resource Guide: http://multiverse.ssl.berkeley.edu/women and http://www.astrosociety.org/educatio...esource-guide/.

### Videos

When You Are Just Too Small to be a Star: https://www.youtube.com/watch?v=zXCDsb4n4KU. 2013 Public Talk on Brown Dwarfs and Planets by Dr. Gibor Basri of the University of California–Berkeley (1:32:52).

## Collaborative Group Activities

1. The Voyagers in Astronomy feature on Annie Cannon: Classifier of the Stars in Section 17.3 discusses some of the difficulties women who wanted to do astronomy faced in the first half of the twentieth century. What does your group think about the situation for women today? Do men and women have an equal chance to become scientists? Discuss with your group whether, in your experience, boys and girls were equally encouraged to do science and math where you went to school.
2. In the section on magnitudes in The Brightness of Stars, we discussed how this old system of classifying how bright different stars appear to the eye first developed. Your authors complained about the fact that this old system still has to be taught to every generation of new students. Can your group think of any other traditional systems of doing things in science and measurement where tradition rules even though common sense says a better system could certainly be found. Explain. (Hint: Try Daylight Savings Time, or metric versus English units.)
3. Suppose you could observe a star that has only one spectral line. Could you tell what element that spectral line comes from? Make a list of reasons with your group about why you answered yes or no.

4. A wealthy alumnus of your college decides to give $50 million to the astronomy department to build a world-class observatory for learning more about the characteristics of stars. Have your group discuss what kind of equipment they would put in the observatory. Where should this observatory be located? Justify your answers. (You may want to refer back to the Astronomical Instruments chapter and to revisit this question as you learn more about the stars and equipment for observing them in future chapters.)
5. For some astronomers, introducing a new spectral type for the stars (like the types L, T, and Y discussed in the text) is similar to introducing a new area code for telephone calls. No one likes to disrupt the old system, but sometimes it is simply necessary. Have your group make a list of steps an astronomer would have to go through to persuade colleagues that a new spectral class is needed.

## Review Questions

1. What two factors determine how bright a star appears to be in the sky?
2. Explain why color is a measure of a star's temperature.
3. What is the main reason that the spectra of all stars are not identical? Explain.
4. What elements are stars mostly made of? How do we know this?
5. What did Annie Cannon contribute to the understanding of stellar spectra?
6. Name five characteristics of a star that can be determined by measuring its spectrum. Explain how you would use a spectrum to determine these characteristics.
7. How do objects of spectral types L, T, and Y differ from those of the other spectral types?
8. Do stars that look brighter in the sky have larger or smaller magnitudes than fainter stars?
9. The star Antares has an apparent magnitude of 1.0, whereas the star Procyon has an apparent magnitude of 0.4. Which star appears brighter in the sky?
10. Based on their colors, which of the following stars is hottest? Which is coolest? Archenar (blue), Betelgeuse (red), Capella (yellow).
11. Order the seven basic spectral types from hottest to coldest.
12. What is the defining difference between a brown dwarf and a true star?

## Thought Questions

1. If the star Sirius emits 23 times more energy than the Sun, why does the Sun appear brighter in the sky?
2. How would two stars of equal luminosity—one blue and the other red—appear in an image taken through a filter that passes mainly blue light? How would their appearance change in an image taken through a filter that transmits mainly red light?
3. Table $17.3.1$ in Section 17.3 lists the temperature ranges that correspond to the different spectral types. What part of the star do these temperatures refer to? Why?
4. Suppose you are given the task of measuring the colors of the brightest stars, listed in Appendix J, through three filters: the first transmits blue light, the second transmits yellow light, and the third transmits red light. If you observe the star Vega, it will appear equally bright through each of the three filters. Which stars will appear brighter through the blue filter than through the red filter? Which stars will appear brighter through the red filter? Which star is likely to have colors most nearly like those of Vega?
5. Star X has lines of ionized helium in its spectrum, and star Y has bands of titanium oxide. Which is hotter? Why? The spectrum of star Z shows lines of ionized helium and also molecular bands of titanium oxide. What is strange about this spectrum? Can you suggest an explanation?
6. The spectrum of the Sun has hundreds of strong lines of nonionized iron but only a few, very weak lines of helium. A star of spectral type B has very strong lines of helium but very weak iron lines. Do these differences mean that the Sun contains more iron and less helium than the B star? Explain.
7. What are the approximate spectral classes of stars with the following characteristics?
   1. Balmer lines of hydrogen are very strong; some lines of ionized metals are present.
   2. The strongest lines are those of ionized helium.
   3. Lines of ionized calcium are the strongest in the spectrum; hydrogen lines show only moderate strength; lines of neutral and metals are present.
   4. The strongest lines are those of neutral metals and bands of titanium oxide.
8. Look at the chemical elements in Appendix K. Can you identify any relationship between the abundance of an element and its atomic weight? Are there any obvious exceptions to this relationship?

9. Appendix I lists some of the nearest stars. Are most of these stars hotter or cooler than the Sun? Do any of them emit more energy than the Sun? If so, which ones?
10. Appendix J lists the stars that appear brightest in our sky. Are most of these hotter or cooler than the Sun? Can you suggest a reason for the difference between this answer and the answer to the previous question? (Hint: Look at the luminosities.) Is there any tendency for a correlation between temperature and luminosity? Are there exceptions to the correlation?
11. What star appears the brightest in the sky (other than the Sun)? The second brightest? What color is Betelgeuse? Use Appendix J to find the answers.
12. Suppose hominids one million years ago had left behind maps of the night sky. Would these maps represent accurately the sky that we see today? Why or why not?
13. Why can only a lower limit to the rate of stellar rotation be determined from line broadening rather than the actual rotation rate? (Refer to Figure $17.4.6$ in Section 17.4.)
14. Why do you think astronomers have suggested three different spectral types (L, T, and Y) for the brown dwarfs instead of M? Why was one not enough?
15. Sam, a college student, just bought a new car. Sam's friend Adam, a graduate student in astronomy, asks Sam for a ride. In the car, Adam remarks that the colors on the temperature control are wrong. Why did he say that?


Figure $17.E.1$ (credit: modification of work by Michael Sheehan)

16. Would a red star have a smaller or larger magnitude in a red filter than in a blue filter?
17. Two stars have proper motions of one arcsecond per year. Star A is 20 light-years from Earth, and Star B is 10 light-years away from Earth. Which one has the faster velocity in space?
18. Suppose there are three stars in space, each moving at 100 km/s. Star A is moving across (i.e., perpendicular to) our line of sight, Star B is moving directly away from Earth, and Star C is moving away from Earth, but at a 30° angle to the line of sight. From which star will you observe the greatest Doppler shift? From which star will you observe the smallest Doppler shift?
19. What would you say to a friend who made this statement, "The visible-light spectrum of the Sun shows weak hydrogen lines and strong calcium lines. The Sun must therefore contain more calcium than hydrogen."?

## Figuring for Yourself

1. In Appendix J, how much more luminous is the most luminous of the stars than the least luminous?

> For Exercise 2 through Exercise 7 below, use the equations relating magnitude and apparent brightness given in the section on the magnitude scale in The Brightness of Stars and Example $17.1.1$ in that section.

2. Verify that if two stars have a difference of five magnitudes, this corresponds to a factor of 100 in the ratio $\left(\frac{b_2}{b_1}\right)$; that 2.5 magnitudes corresponds to a factor of 10; and that 0.75 magnitudes corresponds to a factor of 2.
3. As seen from Earth, the Sun has an apparent magnitude of about −26.7. What is the apparent magnitude of the Sun as seen from Saturn, about 10 AU away? (Remember that one AU is the distance from Earth to the Sun and that the brightness decreases as the inverse square of the distance.) Would the Sun still be the brightest star in the sky?
4. An astronomer is investigating a faint star that has recently been discovered in very sensitive surveys of the sky. The star has a magnitude of 16. How much less bright is it than Antares, a star with magnitude roughly equal to 1?

5. The center of a faint but active galaxy has magnitude 26. How much less bright does it look than the very faintest star that our eyes can see, roughly magnitude 6?
6. You have enough information from this chapter to estimate the distance to Alpha Centauri, the second nearest star, which has an apparent magnitude of 0. Since it is a G2 star, like the Sun, assume it has the same luminosity as the Sun and the difference in magnitudes is a result only of the difference in distance. Estimate how far away Alpha Centauri is. Describe the necessary steps in words and then do the calculation. (As we will learn in the Celestial Distances chapter, this method—namely, assuming that stars with identical spectral types emit the same amount of energy—is actually used to estimate distances to stars.) If you assume the distance to the Sun is in AU, your answer will come out in AU.
7. Do the previous problem again, this time using the information that the Sun is 150,000,000 km away. You will get a very large number of km as your answer. To get a better feeling for how the distances compare, try calculating the time it takes light at a speed of 299,338 km/s to travel from the Sun to Earth and from Alpha Centauri to Earth. For Alpha Centauri, figure out how long the trip will take in years as well as in seconds.
8. Star A and Star B have different apparent brightnesses but identical luminosities. If Star A is 20 light-years away from Earth and Star B is 40 light-years away from Earth, which star appears brighter and by what factor?
9. Star A and Star B have different apparent brightnesses but identical luminosities. Star A is 10 light-years away from Earth and appears 36 times brighter than Star B. How far away is Star B?
10. The star Sirius A has an apparent magnitude of −1.5. Sirius A has a dim companion, Sirius B, which is 10,000 times less bright than Sirius A. What is the apparent magnitude of Sirius B? Can Sirius B be seen with the naked eye?
11. Our Sun, a type G star, has a surface temperature of 5800 K. We know, therefore, that it is cooler than a type O star and hotter than a type M star. Given what you learned about the temperature ranges of these types of stars, how many times hotter than our Sun is the hottest type O star? How many times cooler than our Sun is the coolest type M star?

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