18.E: The Stars - A Celestial Census (Exercises)

For Further Exploration

Articles

Croswell, K. “The Periodic Table of the Cosmos.” *Scientific American* (July 2011):45–49. A brief introduction to the history and uses of the H–R diagram.

Davis, J. “Measuring the Stars.” *Sky & Telescope* (October 1991): 361. The article explains direct measurements of stellar diameters.

DeVorkin, D. “Henry Norris Russell.” *Scientific American* (May 1989): 126.

Kaler, J. “Journeys on the H–R Diagram.” *Sky & Telescope* (May 1988): 483.

McAllister, H. “Twenty Years of Seeing Double.” *Sky & Telescope* (November 1996): 28. An update on modern studies of binary stars.

Parker, B. “Those Amazing White Dwarfs.” *Astronomy* (July 1984): 15. The article focuses on the history of their discovery.

Pasachoff, J. “The H–R Diagram’s 100th Anniversary.” *Sky & Telescope* (June 2014): 32.

Roth, J., and Sinnott, R. “Our Studies of Celestial Neighbors.” *Sky & Telescope* (October 1996): 32. A discussion is provided on finding the nearest stars.

Websites

Eclipsing Binary Stars: www.midnightkite.com/index.aspx?URL=Binary. Dan Bruton at Austin State University has created this collection of animations, articles, and links showing how astronomers use eclipsing binary light curves.

Henry Norris Russell: http://www.nasonline.org/publication...ll-henry-n.pdf. A biographic memoir by Harlow Shapley.

Henry Norris Russell: http://www.phys-astro.sonoma.edu/bru...RussellBio.pdf. A Bruce Medal profile of Russell.

Hertzsprung–Russell Diagram: http://skyserver.sdss.org/dr1/en/proj/advanced/hr/. This site from the Sloan Digital Sky Survey introduces the H–R diagram and gives you information for making your own. You can go step by step by using the menu at the left. Note that in the project instructions, the word “here” is a link and takes you to the data you need.

Stars of the Week: http://stars.astro.illinois.edu/sow/sowlist.html. Astronomer James Kaler does “biographical summaries” of famous stars—not the Hollywood type, but ones in the real sky.

Videos

WISE Mission Surveys Nearby Stars: http://www.jpl.nasa.gov/video/details.php?id=1089. Short video about the WISE telescope survey of brown dwarfs and M dwarfs in our immediate neighborhood (1:21).

Collaborative Group Activities

1. Two stars are seen close together in the sky, and your group is given the task of determining whether they are a visual binary or whether they just happen to be seen in nearly the same direction. You have access to a good observatory. Make a list of the types of measurements you would make to determine whether they orbit each other.
2. Your group is given information about five main sequence stars that are among the brightest-appearing stars in the sky and yet are pretty far away. Where would these stars be on the H–R diagram and why? Next, your group is given information about five main-sequence stars that are typical of the stars closest to us. Where would these stars be on the H–R diagram and why?
3. A very wealthy (but eccentric) alumnus of your college donates a lot of money for a fund that will help in the search for more brown dwarfs. Your group is the committee in charge of this fund. How would you spend the money? (Be as specific as you can, listing instruments and observing programs.)
4. Use the internet to search for information about the stars with the largest known diameter. What star is considered the record holder (this changes as new measurements are made)? Read about some of the largest stars on the web. Can your group list some reasons why it might be hard to know which star is the largest?
5. Use the internet to search for information about stars with the largest mass. What star is the current “mass champion” among stars? Try to research how the mass of one or more of the most massive stars was measured, and report to the group or the

whole class.

Review Questions

1. How does the mass of the Sun compare with that of other stars in our local neighborhood?
2. Name and describe the three types of binary systems.
3. Describe two ways of determining the diameter of a star.
4. What are the largest- and smallest-known values of the mass, luminosity, surface temperature, and diameter of stars (roughly)?
5. You are able to take spectra of both stars in an eclipsing binary system. List all properties of the stars that can be measured from their spectra and light curves.
6. Sketch an H–R diagram. Label the axes. Show where cool supergiants, white dwarfs, the Sun, and main-sequence stars are found.
7. Describe what a typical star in the Galaxy would be like compared to the Sun.
8. How do we distinguish stars from brown dwarfs? How do we distinguish brown dwarfs from planets?
9. Describe how the mass, luminosity, surface temperature, and radius of main-sequence stars change in value going from the "bottom" to the "top" of the main sequence.
10. One method to measure the diameter of a star is to use an object like the Moon or a planet to block out its light and to measure the time it takes to cover up the object. Why is this method used more often with the Moon rather than the planets, even though there are more planets?
11. We discussed in the chapter that about half of stars come in pairs, or multiple star systems, yet the first eclipsing binary was not discovered until the eighteenth century. Why?

Thought Questions

1. Is the Sun an average star? Why or why not?
2. Suppose you want to determine the average educational level of people throughout the nation. Since it would be a great deal of work to survey every citizen, you decide to make your task easier by asking only the people on your campus. Will you get an accurate answer? Will your survey be distorted by a selection effect? Explain.
3. Why do most known visual binaries have relatively long periods and most spectroscopic binaries have relatively short periods?
4. Figure $18.3.2$ in Section 18.3 shows the light curve of a hypothetical eclipsing binary star in which the light of one star is completely blocked by another. What would the light curve look like for a system in which the light of the smaller star is only partially blocked by the larger one? Assume the smaller star is the hotter one. Sketch the relative positions of the two stars that correspond to various portions of the light curve.
5. There are fewer eclipsing binaries than spectroscopic binaries. Explain why.
6. Within 50 light-years of the Sun, visual binaries outnumber eclipsing binaries. Why?
7. Which is easier to observe at large distances—a spectroscopic binary or a visual binary?
8. The eclipsing binary Algol drops from maximum to minimum brightness in about 4 hours, remains at minimum brightness for 20 minutes, and then takes another 4 hours to return to maximum brightness. Assume that we view this system exactly edge-on, so that one star crosses directly in front of the other. Is one star much larger than the other, or are they fairly similar in size? (Hint: Refer to the diagrams of eclipsing binary light curves.)
9. Review this spectral data for five stars.

   Table A

Star	Spectrum
1	G, main sequence
2	K, giant
3	K, main sequence
4	O, main sequence
5	M, main sequence

   Which is the hottest? Coolest? Most luminous? Least luminous? In each case, give your reasoning.
10. Which changes by the largest factor along the main sequence from spectral types O to M—mass or luminosity?

11. Suppose you want to search for brown dwarfs using a space telescope. Will you design your telescope to detect light in the ultraviolet or the infrared part of the spectrum? Why?
12. An astronomer discovers a type-M star with a large luminosity. How is this possible? What kind of star is it?
13. Approximately 9000 stars are bright enough to be seen without a telescope. Are any of these white dwarfs? Use the information given in this chapter to explain your reasoning.
14. Use the data in Appendix J to plot an H–R diagram for the brightest stars. Use the data from Table 18.4.2 in Section 18.4 to show where the main sequence lies. Do 90% of the brightest stars lie on or near the main sequence? Explain why or why not.
15. Use the diagram you have drawn for the previous exercise to answer the following questions: Which star is more massive—Sirius or Alpha Centauri? Rigel and Regulus have nearly the same spectral type. Which is larger? Rigel and Betelgeuse have nearly the same luminosity. Which is larger? Which is redder?
16. Use the data in Appendix I to plot an H–R diagram for this sample of nearby stars. How does this plot differ from the one for the brightest stars in Exercise 14? Why?
17. If a visual binary system were to have two equal-mass stars, how would they be located relative to the center of the mass of the system? What would you observe as you watched these stars as they orbited the center of mass, assuming very circular orbits, and assuming the orbit was face on to your view?
18. Two stars are in a visual binary star system that we see face on. One star is very massive whereas the other is much less massive. Assuming circular orbits, describe their relative orbits in terms of orbit size, period, and orbital velocity.
19. Describe the spectra for a spectroscopic binary for a system comprised of an F-type and L-type star. Assume that the system is too far away to be able to easily observe the L-type star.
20. Figure 18.2.4 in Section 18.2 shows the velocity of two stars in a spectroscopic binary system. Which star is the most massive? Explain your reasoning.
21. You go out stargazing one night, and someone asks you how far away the brightest stars we see in the sky without a telescope are. What would be a good, general response? (Use Appendix J for more information.)
22. If you were to compare three stars with the same surface temperature, with one star being a giant, another a supergiant, and the third a main-sequence star, how would their radii compare to one another?
23. Are supergiant stars also extremely massive? Explain the reasoning behind your answer.
24. Consider the following data on four stars:

Table B

Star	Luminosity (in L_{Sun})	Type
1	100	B, main sequence
2	1/100	B, white dwarf
3	1/100	M, main sequence
4	100	M, giant

Which star would have the largest radius? Which star would have the smallest radius? Which star is the most common in our area of the Galaxy? Which star is the least common?

Figuring for Yourself

1. If two stars are in a binary system with a combined mass of 5.5 solar masses and an orbital period of 12 years, what is the average distance between the two stars?
2. It is possible that stars as much as 200 times the Sun’s mass or more exist. What is the luminosity of such a star based upon the mass-luminosity relation?
3. The lowest mass for a true star is 1/12 the mass of the Sun. What is the luminosity of such a star based upon the mass-luminosity relationship?
4. Spectral types are an indicator of temperature. For the first 10 stars in Appendix J, the list of the brightest stars in our skies, estimate their temperatures from their spectral types. Use information in the figures and/or tables in this chapter and describe how you made the estimates.
5. We can estimate the masses of most of the stars in Appendix J from the mass-luminosity relationship in Figure 18.2.6 in Section 18.2. However, remember this relationship works only for main sequence stars. Determine which of the first 10 stars in

Appendix J are main sequence stars. Use one of the figures in this chapter. Make a table of stars' masses.

6. In Diameters of Stars, the relative diameters of the two stars in the Sirius system were determined. Let's use this value to explore other aspects of this system. This will be done through several steps, each in its own exercise. Assume the temperature of the Sun is 5800 K, and the temperature of Sirius A, the larger star of the binary, is 10,000 K. The luminosity of Sirius A can be found in Appendix J, and is given as about 23 times that of the Sun. Using the values provided, calculate the radius of Sirius A relative to that of the Sun.
7. Now calculate the radius of Sirius' white dwarf companion, Sirius B, to the Sun.
8. How does this radius of Sirius B compare with that of Earth?
9. From the previous calculations and the results from Diameters of Stars, it is possible to calculate the density of Sirius B relative to the Sun. It is worth noting that the radius of the companion is very similar to that of Earth, whereas the mass is very similar to the Sun's. How does the companion's density compare to that of the Sun? Recall that density = mass/volume, and the volume of a sphere = $(4/3)\pi R^3$. How does this density compare with that of water and other materials discussed in this text? Can you see why astronomers were so surprised and puzzled when they first determined the orbit of the companion to Sirius?
10. How much would you weigh if you were suddenly transported to the white dwarf Sirius B? You may use your own weight (or if don't want to own up to what it is, assume you weigh 70 kg or 150 lb). In this case, assume that the companion to Sirius has a mass equal to that of the Sun and a radius equal to that of Earth. Remember Newton's law of gravity: $F = GM_1M_2/R^2$ and that your weight is proportional to the force that you feel. What kind of star should you travel to if you want to *lose* weight (and not gain it)?
11. The star Betelgeuse has a temperature of 3400 K and a luminosity of 13,200 LSun. Calculate the radius of Betelgeuse relative to the Sun.
12. Using the information provided in Table $18.1.1$ in Section 18.1, what is the average stellar density in our part of the Galaxy? Use only the true stars (types O–M) and assume a spherical distribution with radius of 26 light-years.
13. Confirm that the angular diameter of the Sun of 1/2° corresponds to a linear diameter of 1.39 million km. Use the average distance of the Sun and Earth to derive the answer. (Hint: This can be solved using a trigonometric function.)
14. An eclipsing binary star system is observed with the following contact times for the main eclipse:

Table C

Contact	Time	Date
First contact	12:00 p.m.	March 12
Second contact	4:00 p.m.	March 13
Third contact	9:00 a.m.	March 18
Fourth contact	1:00 p.m.	March 19

The orbital velocity of the smaller star relative to the larger is 62,000 km/h. Determine the diameters for each star in the system.

15. If a 100 solar mass star were to have a luminosity of 107 times the Sun's luminosity, how would such a star's density compare when it is on the main sequence as an O-type star, and when it is a cool supergiant (M-type)? Use values of temperature from Figures $18.4.3$ or $18.4.4$ in Section 18.4 and the relationship between luminosity, radius, and temperature as given in Exercise 12.
16. If Betelgeuse had a mass that was 25 times that of the Sun, how would its average density compare to that of the Sun? Use the definition of density $= \frac{\text{mass}}{\text{volume}}$, where the volume is that of a sphere.