22.E: Stars from Adolescence to Old Age (Exercise)

For Further Exploration

Articles

Balick, B. & Frank, A. “The Extraordinary Deaths of Ordinary Stars.” *Scientific American* (July 2004): 50. About planetary nebulae, the last gasps of low-mass stars, and the future of our own Sun.

Djorgovsky, G. “The Dynamic Lives of Globular Clusters.” *Sky & Telescope* (October 1998): 38. Cluster evolution and blue straggler stars.

Frank, A. “Angry Giants of the Universe.” *Astronomy* (October 1997): 32. On luminous blue variables like Eta Carinae.

Garlick, M. “The Fate of the Earth.” *Sky & Telescope* (October 2002): 30. What will happen when our Sun becomes a red giant.

Harris, W. & Webb, J. “Life Inside a Globular Cluster.” *Astronomy* (July 2014): 18. What would night sky be like there?

Iben, I. & Tutokov, A. “The Lives of the Stars: From Birth to Death and Beyond.” *Sky & Telescope* (December 1997): 36.

Kaler, J. “The Largest Stars in the Galaxy.” *Astronomy* (October 1990): 30. On red supergiants.

Kalirai, J. “New Light on Our Sun’s Fate.” *Astronomy* (February 2014): 44. What will happen to stars like our Sun between the main sequence and the white dwarf stages.

Kwok, S. “What Is the Real Shape of the Ring Nebula?” *Sky & Telescope* (July 2000): 33. On seeing planetary nebulae from different angles.

Kwok, S. “Stellar Metamorphosis.” *Sky & Telescope* (October 1998): 30. How planetary nebulae form.

Stahler, S. “The Inner Life of Star Clusters.” *Scientific American* (March 2013): 44–49. How all stars are born in clusters, but different clusters evolve differently.

Subinsky, R. “All About 47 Tucanae.” *Astronomy* (September 2014): 66. What we know about this globular cluster and how to see it.

Websites

BBC Page on Giant Stars: www.bbc.co.uk/science/space/u...ts/giant_stars. Includes basic information and links to brief video excerpts.

Encylopedia Brittanica Article on Star Clusters: http://www.britannica.com/topic/star-cluster. Written by astronomer Helen Sawyer Hogg-Priestley.

Hubble Image Gallery: Planetary Nebulae: http://hubblesite.org/gallery/album/nebula/planetary/. Click on each image to go to a page with more information available. (See also a similar gallery at the National Optical Astronomy Observatories: www.noao.edu/image_gallery/p...y_nebulae.html).

Hubble Image Gallery: Star Clusters: http://hubblesite.org/gallery/album/.../star_cluster/. Each image comes with an explanatory caption when you click on it. (See also a similar European Southern Observatory Gallery at: www.eso.org/public/images/ar.../starclusters/).

Measuring the Age of a Star Cluster: www.e-education.psu.edu/astr...ent/l7_p6.html. From Penn State.

Videos

Life Cycle of Stars: https://www.youtube.com/watch?v=PM9CQDlQI0A. Short summary of stellar evolution from the Institute of Physics in Great Britain, with astronomer Tim O’Brien (4:58).

Missions Take an Unparalleled Look into Superstar Eta Carinae: https://www.youtube.com/watch?v=0rJQi6oaZf0. NASA Goddard video about observations in 2014 and what we know about the pair of stars in this complicated system (4:00).

Star Clusters: Open and Globular Clusters: https://www.youtube.com/watch?v=rGPRLxrYbYA. Three Short Hubblecast Videos from 2007–2008 on discoveries involving star clusters (12:24).

Tour of Planetary Nebula NGC 5189: https://www.youtube.com/watch?v=1D2cwiZld0o. Brief Hubblecast episode with Joe Liske, explaining planetary nebulae in general and one example in particular (5:22).

Collaborative Group Activities

1. Have your group take a look at the list of the brightest stars in the sky in Appendix J. What fraction of them are past the main-sequence phase of evolution? The text says that stars spend 90% of their lifetimes in the main-sequence phase of evolution. This suggests that if we have a fair (or representative) sample of stars, 90% of them should be main-sequence stars. Your group should brainstorm why 90% of the brightest stars are not in the main-sequence phase of evolution.
2. Reading an H–R diagram can be tricky. Suppose your group is given the H–R diagram of a star cluster. Stars above and to the right of the main sequence could be either red giants that had evolved away from the main sequence or very young stars that are still evolving toward the main sequence. Discuss how you would decide which they are.
3. In the chapter on Life in the Universe, we discuss some of the efforts now underway to search for radio signals from possible intelligent civilizations around other stars. Our present resources for carrying out such searches are very limited and there are many stars in our Galaxy. Your group is a committee set up by the International Astronomical Union to come up with a list of the best possible stars with which such a search should begin. Make a list of criteria for choosing the stars on the list, and explain the reasons behind each entry (keeping in mind some of the ideas about the life story of stars and timescales that we discuss in the present chapter.)
4. Have your group make a list of the reasons why a star that formed at the very beginning of the universe (soon after the Big Bang) could not have a planet with astronomy students reading astronomy textbooks (even if the star has the same mass as that of our Sun).
5. Since we are pretty sure that when the Sun becomes a giant star, all life on Earth will be wiped out, does your group think that we should start making preparations of any kind? Let's suppose that a political leader who fell asleep during large parts of his astronomy class suddenly hears about this problem from a large donor and appoints your group as a task force to make suggestions on how to prepare for the end of Earth. Make a list of arguments for why such a task force is not really necessary.
6. Use star charts to identify at least one open cluster visible at this time of the year. (Such charts can be found in *Sky & Telescope* and *Astronomy* magazines each month and their websites; see Appendix B.) The Pleiades and Hyades are good autumn subjects, and Praesepe is good for springtime viewing. Go out and look at these clusters with binoculars and describe what you see.
7. Many astronomers think that planetary nebulae are among the most attractive and interesting objects we can see in the Galaxy. In this chapter, we could only show you a few examples of the pictures of these objects taken with the Hubble or large telescopes on the ground. Have members of your group search further for planetary nebula images online, and make a "top ten" list of your favorite ones (do not include more than three that were featured in this chapter.) Make a report (with images) for the whole class and explain why you found your top five especially interesting. (You may want to check Figure $22.4.4$ in Section 22.4 in the process.)

Review Questions

1. Compare the following stages in the lives of a human being and a star: prenatal, birth, adolescence/adulthood, middle age, old age, and death. What does a star with the mass of our Sun do in each of these stages?
2. What is the first event that happens to a star with roughly the mass of our Sun that exhausts the hydrogen in its core and stops the generation of energy by the nuclear fusion of hydrogen to helium? Describe the sequence of events that the star undergoes.
3. Astronomers find that 90% of the stars observed in the sky are on the main sequence of an H–R diagram; why does this make sense? Why are there far fewer stars in the giant and supergiant region?
4. Describe the evolution of a star with a mass similar to that of the Sun, from the protostar stage to the time it first becomes a red giant. Give the description in words and then sketch the evolution on an H–R diagram.
5. Describe the evolution of a star with a mass similar to that of the Sun, from just after it first becomes a red giant to the time it exhausts the last type of fuel its core is capable of fusing.
6. A star is often described as "moving" on an H–R diagram; why is this description used and what is actually happening with the star?
7. On which edge of the main sequence band on an H–R diagram would the zero-age main sequence be?
8. How do stars typically "move" through the main sequence band on an H–R diagram? Why?
9. Certain stars, like Betelgeuse, have a lower surface temperature than the Sun and yet are more luminous. How do these stars produce so much more energy than the Sun?

10. Gravity always tries to collapse the mass of a star toward its center. What mechanism can oppose this gravitational collapse for a star? During what stages of a star's life would there be a "balance" between them?
11. Why are star clusters so useful for astronomers who want to study the evolution of stars?
12. Would the Sun more likely have been a member of a globular cluster or open cluster in the past?
13. Suppose you were handed two H–R diagrams for two different clusters: diagram A has a majority of its stars plotted on the upper left part of the main sequence with the rest of the stars off the main sequence; and diagram B has a majority of its stars plotted on the lower right part of the main sequence with the rest of the stars off the main sequence. Which diagram would be for the older cluster? Why?
14. Referring to the H–R diagrams in the previous exercise, which diagram would more likely be the H–R diagram for an association?
15. The nuclear process for fusing helium into carbon is often called the "triple-alpha process." Why is it called as such, and why must it occur at a much higher temperature than the nuclear process for fusing hydrogen into helium?
16. Pictures of various planetary nebulae show a variety of shapes, but astronomers believe a majority of planetary nebulae have the same basic shape. How can this paradox be explained?
17. Describe the two "recycling" mechanisms that are associated with stars (one during each star's life and the other connecting generations of stars).
18. In which of these star groups would you mostly likely find the least heavy-element abundance for the stars within them: open clusters, globular clusters, or associations?
19. Explain how an H–R diagram of the stars in a cluster can be used to determine the age of the cluster.
20. Where did the carbon atoms in the trunk of a tree on your college campus come from originally? Where did the neon in the fabled "neon lights of Broadway" come from originally?
21. What is a planetary nebula? Will we have one around the Sun?

Thought Questions

1. Is the Sun on the zero-age main sequence? Explain your answer.
2. How are planetary nebulae comparable to a fluorescent light bulb in your classroom?
3. Which of the planets in our solar system have orbits that are smaller than the photospheric radius of Betelgeuse listed in Table $22.1.2$ in Section 22.1?
4. Would you expect to find an earthlike planet (with a solid surface) around a very low-mass star that formed right at the beginning of a globular cluster's life? Explain.
5. In the H–R diagrams for some young clusters, stars of both very low and very high luminosity are off to the right of the main sequence, whereas those of intermediate luminosity are on the main sequence. Can you offer an explanation for that? Sketch an H–R diagram for such a cluster.
6. If the Sun were a member of the cluster NGC 2264, would it be on the main sequence yet? Why or why not?
7. If all the stars in a cluster have nearly the same age, why are clusters useful in studying evolutionary effects (different stages in the lives of stars)?
8. Suppose a star cluster were at such a large distance that it appeared as an unresolved spot of light through the telescope. What would you expect the overall color of the spot to be if it were the image of the cluster immediately after it was formed? How would the color differ after 10^{10} years? Why?
9. Suppose an astronomer known for joking around told you she had found a type-O main-sequence star in our Milky Way Galaxy that contained no elements heavier than helium. Would you believe her? Why?
10. Stars that have masses approximately 0.8 times the mass of the Sun take about 18 billion years to turn into red giants. How does this compare to the current age of the universe? Would you expect to find a globular cluster with a main-sequence turnoff for stars of 0.8 solar mass or less? Why or why not?
11. Automobiles are often used as an analogy to help people better understand how more massive stars have much shorter main-sequence lifetimes compared to less massive stars. Can you explain such an analogy using automobiles?

Figuring for Yourself

1. The text says a star does not change its mass very much during the course of its main-sequence lifetime. While it is on the main sequence, a star converts about 10% of the hydrogen initially present into helium (remember it's only the core of the star that is hot enough for fusion). Look in earlier chapters to find out what percentage of the hydrogen mass involved in fusion is lost

because it is converted to energy. By how much does the mass of the whole star change as a result of fusion? Were we correct to say that the mass of a star does not change significantly while it is on the main sequence?

2. The text explains that massive stars have shorter lifetimes than low-mass stars. Even though massive stars have more fuel to burn, they use it up faster than low-mass stars. You can check and see whether this statement is true. The lifetime of a star is directly proportional to the amount of mass (fuel) it contains and inversely proportional to the rate at which it uses up that fuel (i.e., to its luminosity). Since the lifetime of the Sun is about 10^{10} y, we have the following relationship:

$$T = 10^{10} \frac{M}{L} \text{ y} \tag{22.E.1}$$

where T is the lifetime of a main-sequence star, M is its mass measured in terms of the mass of the Sun, and L is its luminosity measured in terms of the Sun's luminosity.

   1. Explain in words why this equation works.
   2. Use the data in Table $18.4.2$ in Section 18.4 to calculate the ages of the main-sequence stars listed.
   3. Do low-mass stars have longer main-sequence lifetimes?
   4. Do you get the same answers as those in Table $22.1.1$ in Section 22.1?

3. You can use Equation $22.E.1$ in the previous exercise to estimate the approximate ages of the clusters in Figure $22.3.3$, Figure $22.3.5$, and Figure $22.3.6$, all in Section 22.3. Use the information in the figures to determine the luminosity of the most massive star still on the main sequence. Now use the data in Table $18.4.2$ in Section 18.4 to estimate the mass of this star. Then calculate the age of the cluster. This method is similar to the procedure used by astronomers to obtain the ages of clusters, except that they use actual data and model calculations rather than simply making estimates from a drawing. How do your ages compare with the ages in the text?
4. You can estimate the age of the planetary nebula in image (c) in Figure $22.4.3$ in Section 22.4. The diameter of the nebula is 600 times the diameter of our own solar system, or about 0.8 light-year. The gas is expanding away from the star at a rate of about 25 mi/s. Considering that distance = velocity × time, calculate how long ago the gas left the star if its speed has been constant the whole time. Make sure you use consistent units for time, speed, and distance.
5. If star A has a core temperature T, and star B has a core temperature $3T$, how does the rate of fusion of star A compare to the rate of fusion of star B?