Activity 7 Our Community's Place Among the Stars

Goals

In this activity you will:

- Understand the place of our solar system in the Milky Way galaxy.
- Study stellar structure and the stellar evolution (the life histories of stars).
- Understand the relationship between the brightness of an object (its luminosity) and its magnitude.
- Estimate the chances of another star affecting the Earth in some way.

Think about It

When you look at the nighttime sky, you are looking across vast distances of space.

- **As you stargaze, what do you notice about the stars?**
- **Do some stars appear brighter than others? Larger or smaller? What about their colors?**

What do you think? Record your impressions and sketch some of the stars in your *EarthComm* notebook. Be prepared to discuss your thoughts with your small group and the class.

Investigate

Part A: Brightness versus Distance from the Source

1. Set a series of lamps with 40-, 60-, and 100-W bulbs (of the same size and all with frosted glass envelopes) up at one end of a room (at least 10 m away). Use the other end of the room for your observing site. Turn all the lamps on. Close all of the shades in the room.
   a) Can you tell the differences in brightness between the lamps?
2. Move the lamp with the 40-W bulb forward 5 m toward you.
   a) Does the light look brighter than the 60-W lamp?
   b) Does it look brighter than the 100-W lamp?
3. Shift the positions of the lamps so that the 40-W lamp and the 100-W lamp are in the back of the room and the 60-W lamp is halfway between you and the other lamps.
   a) How do the brightnesses compare?
4. Using a light meter, test one bulb at a time. If you do not have a light meter, you will have to construct a qualitative scale for brightness.
   a) Record the brightness of each bulb at different distances.
5. Graph the brightness versus the distance from the source for each bulb (wattage).
   a) Plot distance on the horizontal axis of the graph and brightness on the vertical axis. Leave room on the graph so that you can extrapolate the graph beyond the data you have collected. Plot the data for each bulb and connect the points with lines.
   b) Extrapolate the data by extending the lines on the graph using dashes.
6. Use your graph to answer the following questions:
   a) Explain the general relationship between wattage and brightness (as measured by your light meter).
   b) What is the general relationship between distance and brightness?
   c) Do all bulbs follow the same pattern? Why or why not?
   d) Draw a light horizontal line across your graph so that it crosses several of the lines you have graphed.
   e) Does a low-wattage bulb ever have the same brightness as a high-wattage bulb? Describe one or two such cases in your data.
   f) The easiest way to determine the absolute brightness of objects of different brightness and distance is to move all objects to the same distance. How do you think astronomers handle this problem when trying to determine the brightness and distances to stars?
7. When you have completed this activity, spend some time outside stargazing. Think about the relationship between brightness and distance as it applies to stars.
   a) Write your thoughts down in your *EarthComm* notebook.

Do not stare at the light bulbs for extended periods of time.

Part B: Luminosity and Temperature of Stars

1. An important synthesis of understanding in the study of stars is the Hertzsprung-Russell (HR) diagram. Obtain a copy of the figure below. Examine the figure and answer the following questions:

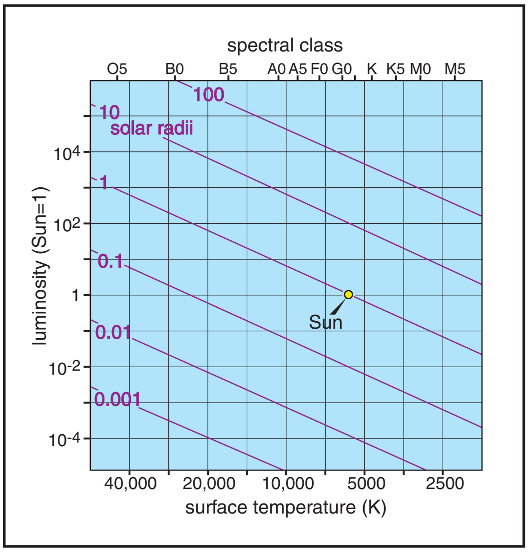
   a) What does the vertical axis represent?

   b) What does the horizontal axis represent?

   c) The yellow dot on the figure is the Sun. What is its temperature and luminosity?

   d) Put four more dots on the diagram labeled A through D to show the locations of stars that are:

   A. hot and bright
   B. hot and dim
   C. cool and dim
   D. cool and bright



2. Obtain a copy of the *Table 1* and the HR diagram that shows the locations of main sequence stars, supergiants, red giants, and white dwarfs.

   a) Using the luminosity of the stars, and their surface temperatures, plot the locations of stars shown in *Table 1* on a second HR diagram.

3. Classify each of the stars into one of the following four categories, and record the name in your copy of the table:

   — Main sequence
   — Red giants
   — Supergiants
   — White dwarfs

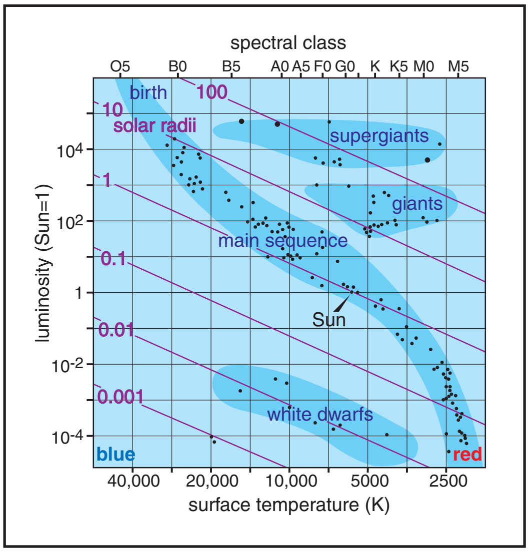


Table 1 Selected Properties of Fourteen Stars							
Star	**Surface Temperature (K)**	**Luminosity (Relative to Sun)**	**Distance (Light-Years)**	**Mass (Solar Masses)**	**Diameter (Solar Diameters)**	**Color**	**Type of Star**
Sirius A	9100	22.6	8.6	2.3	2.03	Blue	
Arcturus	4300	115	36.7	4.5	31.5	Red	
Vega	10300	50.8	25.3	3.07	3.1	Blue	
Capella	5300	75.8	42.2	3	10.8	Red	
Rigel	11000	38,679	733	20	62	Blue	
Procyon A	6500	7.5	11.4	1.78	1.4	Yellow	
Betelgeuse	2300	4520–14,968 (variable)	427	20	662	Red	
Altair	7800	11.3	65.1	2	1.6	Yellow	
Aldebaran	4300	156–171 (variable)	65	25	51.5	Red	
Spica	25300	2121	262	10.9	7.3	Blue	
Pollux	4500	31	33	4	8	Red	
Deneb	10500	66,500	1600	25	116	Yellow	
Procyon B	8700	0.0006	11.2	0.65	0.02	White	
Sirius B	24000	0.00255	13.2	0.98	0.008	Blue-white	

Note: Mass, diameter, and luminosity are given in solar units. For example, Sirius A has 2.3 solar masses, has a diameter 2.03 that of the Sun, and has luminosity 22.6 times brighter than the Sun.
1 solar mass = 2×10^{30} kg = 330,000 Earth masses; 1 solar diameter = 700,000 km = 110 Earth diameters.

Reflecting on the Activity and the Challenge

Measuring the apparent differences in brightness of the light bulbs at different distances helps you to see that distance and brightness are important factors in helping you understand the objects in our universe. When you look at the stars at night, you are seeing stars at different distances and brightnesses. In your **Chapter Challenge** you will be telling people about the effects of distant objects on the Earth. When you assess danger from space, it is important to understand that stars in and of themselves don't pose a danger unless they are both relatively nearby and doing something that could affect Earth. The spectral characteristics of stars help you to understand their temperature, size, and other characteristics. In turn, that helps you to understand if a given star is or could be a threat to Earth. The light from distant stars can also be used to understand our own star, and our own solar system's makeup and evolution.

Digging Deeper

EARTH'S STELLAR NEIGHBORS

Classifying Stars

You already know that our solar system is part of the Milky Way galaxy. Our stellar neighborhood is about two-thirds of the way out on a spiral arm that stretches from the core of the galaxy. The galaxy contains hundreds of billions of stars. Astronomers use a magnitude scale to describe the brightness of objects they see in the sky. A star's brightness decreases with the square of the distance. Thus, a star twice as far from the Earth as an identical star would be one-fourth as bright as the closer star. The first magnitude scales were quite simple—the brightest stars were described as first magnitude, the next brightest stars were second magnitude, and so on down to magnitude 6, which described stars barely visible to the naked eye. The smaller the number, the brighter the star; the larger the number, the dimmer the star.

Today, scientists use a more precise system of magnitudes to describe brightness. The brightest star in the sky is called Sirius A, and its magnitude is –1.4. Of course, the Sun is brighter at –27 and the Moon is –12.6! The dimmest naked-eye stars are still sixth magnitude. To see anything dimmer than that, you have to magnify your view with binoculars or telescopes. The best ground-based telescopes can detect objects as faint as 25th magnitude. To get a better view of very faint, very distant objects, you have to get above the Earth's atmosphere. The Hubble Space Telescope, for example can detect things as dim as 30th magnitude!

Figure 1 This NASA Hubble Space Telescope near-infrared image of newborn binary stars reveals a long thin nebula pointing toward a faint companion object which could be the first extrasolar planet to be imaged directly.

Perhaps you have seen a star described as a G-type star or an O-type star. These are stellar classifications that depend on the color and temperature of the stars. They also help astronomers understand where a given star is in its evolutionary history. To get such information, astronomers study stars with spectrographs to determine their temperature and chemical makeup. As you can see in the table below, there are seven main categories of stars:

Stellar Classification	Temperature (kelvins)
O	25,000 K and higher
B	11,000–25,000 K
A	7500–11,000 K
F	6000–7500 K
G	5000–6000 K
K	3500–5000 K
M	less than 3500 K

Geo Words

luminosity: the total amount of energy radiated by an object every second.

molecular cloud: a large, cold cloud made up mostly of molecular hydrogen and helium, but with some other gases, too, like carbon monoxide. It is in these clouds that new stars are born.

The Lives of Stars

Astronomers use the term **luminosity** for the total rate at which a star emits radiation energy. Unlike apparent brightness (how bright the star appears to be) luminosity is an intrinsic property. It doesn't depend on how far away the star is. In the early 1900s Ejnar Hertzsprung and Henry Norris Russell independently made the discovery that the luminosity of a star was related to its surface temperature. In the second part of this activity, you worked with a graph that shows this relationship. It is called the Hertzsprung-Russell (HR) diagram in honor of the astronomers who discovered this relationship. The HR diagram alone does not tell you how stars change. By analogy, if you were to plot the IQ versus the weight of everyone in your school, you would probably find a very poor relationship between these two variables. Your graph would resemble a scatter plot more than it would a line. However, if you plotted the height versus weight for the same people, you are more likely to find a strong relationship (data would be distributed along a trend or line). The graph doesn't tell you why this relationship exists — that's up to you to determine. Similarly, the HR diagram shows that stars don't just appear randomly on a plot of luminosity versus temperature, but fall into classes of luminosity (red giants, white dwarfs, and so on).

The life cycle of a star begins with its formation in a cloud of gas and dust called a **molecular cloud**. The material in the cloud begins to clump together, mixing and swirling. Eventually the core begins to heat as more material is drawn in by gravitational attraction. When the temperature in the center of the cloud reaches 15 million kelvins, the stellar fusion reaction starts up and a star is born. Such stars are called main-sequence stars. Many stars spend 90% of their lifetimes on the main sequence.

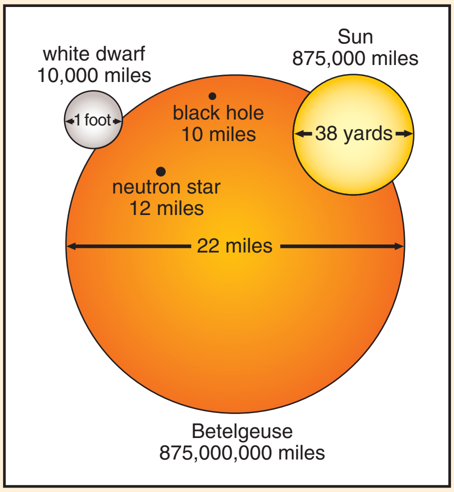


Figure 2 Scaling stars to 10,000 miles to one foot reveals the relative sizes of various stars.

Newborn stars are like baby chickens pecking their way out of a shell. As these infant stars grow, they bathe the cloud surrounding them in strong ultraviolet radiation. This vaporizes the cloud, creating beautiful sculpted shapes in the cloud. In the photograph in *Figure 3*, the Hubble Space Telescope studied a region of starbirth called NGC 604. Notice the cluster of bright white stars in the center "cavern" of the cloud of gas and dust. Their ultraviolet light has carved out a shell of gas and dust around the stellar newborns.

Figure 3 The starforming region NGC 604 in the galaxy M33.

Figure 4 The Orion Nebula is an example of a molecular cloud, from which new stars are born.

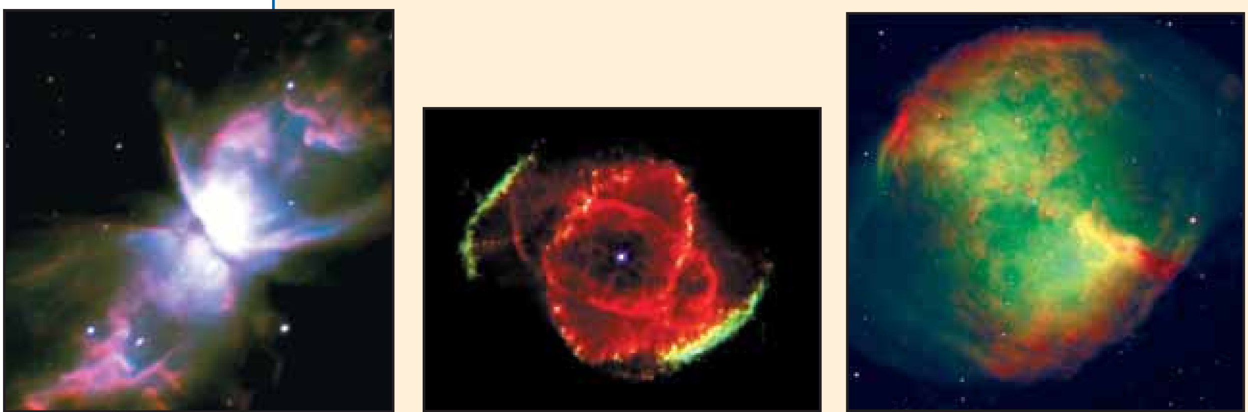
How long a star lives depends on its mass (masses of selected stars are shown in *Table 1* in the **Investigate** section of the activity). Stars like our Sun will live about 10 billion years. Smaller, cooler stars might go on twice that long, slowly burning their fuel. Massive supergiant stars consume their mass much more quickly, living a star's life only a few tens of millions of years. Very hot stars also go through their fuel very quickly, existing perhaps only a few hundred thousand years. The time a star spends on the main sequence can be determined using the following formula:

$$\text{Time on main sequence} = \frac{1}{M^{2.5}} \times \textbf{10 billion years}$$

where M is the mass of the star in units of solar masses.

Even though high-mass stars have more mass, they burn it much more quickly and end up having very short lives.

In the end, however, stars of all types must die. Throughout its life a star loses mass in the form of a stellar wind. In the case of the Sun this is called the solar wind. As a star ages, it loses more and more mass. Stars about the size of the Sun and smaller end their days as tiny, shrunken remnants of their former selves, surrounded by beautiful shells of gas and dust. These are called planetary nebulae. In about five billion years the Sun will start to resemble one of these ghostly nebulae, ending its days surrounded by the shell of its former self.



Figures 5A, 5B, 5C Three examples of the deaths of stars about the size of the Sun. **A:** The Butterfly Nebula. **B:** The Cat's-Eye Nebula. In both cases at least the dying star lies embedded in a cloud of material exhaled by the star, as it grew older. **C:** The Dumbbell Nebula. European Southern Observatory.

Massive stars (supergiants tens of times more massive than the Sun) also lose mass as they age, but at some point their cores collapse catastrophically. The end of a supergiant's life is a cataclysmic explosion called a **supernova**. In an instant of time, most of the star's mass is hurled out into space, leaving behind a tiny remnant called a **neutron star**. If the star is massive enough, the force of the explosion can be so strong that the remnant is imploded into a **stellar black hole**—a place where the gravity is so strong that not even light can escape.

The material that is shed from dying stars (whether they end their days as slowly fading dwarf stars, or planetary nebulae, or supernovae) makes its way into the space between the stars. There it mixes and waits for a slow gravitational contraction down to a new episode of starbirth and ultimately star death. Because humans evolved on a planet that was born from a recycled cloud of stellar mass, they are very much star "stuff"—part of a long cycle of life, death, and rebirth.

Astronomers search the universe to study the mechanics of star formation. Star nurseries and star graveyards are scattered through all the galaxies. In some cases, starbirth is triggered when one galaxy collides with (actually passes through) another. The clouds of gas and dust get the push they need to start the process.

Scientists also search for examples of planetary nebulae. They want to understand when and how these events occur. Not only are these nebulae interesting, but also they show scientists what the fate of our solar system will be billions of years from now.

What would happen if there were a supernova explosion in our stellar neighborhood sometime in the future? Depending on how close it was, you could be bombarded with strong radiation and shock waves from the explosion. The chances of this happening are extremely small—although some astronomers think that a supernova some five billion years ago may have provided the gravitational kick that started our own proto–solar nebula on the road to stardom and planetary formation.

Figure 6 The Crab Nebula is the remnant of a supernova explosion first observed in the year AD 1054.

Geo Words

supernova: the death explosion of a massive star whose core has completely burned out. Supernova explosions can temporarily outshine a galaxy.

neutron star: the imploded core of a massive star produced by a supernova explosion.

stellar black hole: the leftover core of a massive single star after a supernova. Black holes exert such large gravitational pull that not even light can escape.

Check Your Understanding

1. How do astronomers classify stars?
2. Write a brief outline of how stars are born.
3. What determines the way a star dies?

Understanding and Applying What You Have Learned

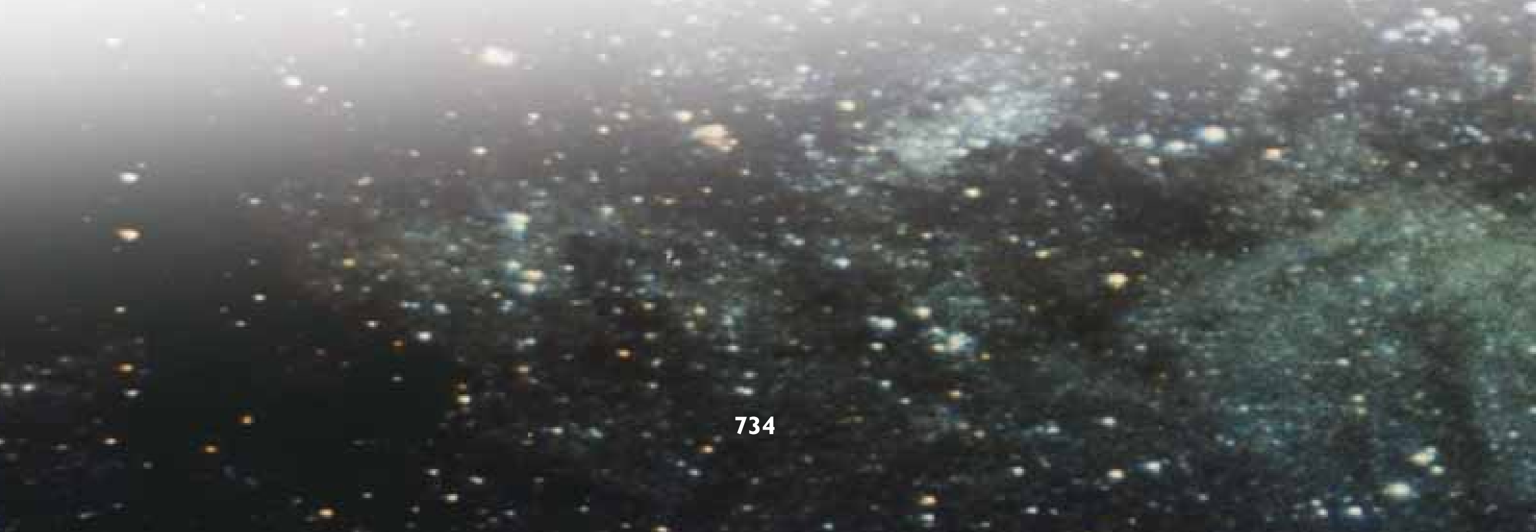
1. Using an astronomy computer program or a guidebook to the stars, make a list of the 10 nearest stars, and their distances, magnitudes, and spectral classes. What do their classes tell you about them?
2. What is mass loss and how does it figure in the death of a star? Is the Sun undergoing mass loss?
3. What happens to the material left over from the death of a star?
4. Two identical stars have different apparent brightnesses. One star is 10 light-years away, and the other is 30 light-years away from us. Which star is brighter, and by how much?
5. Refer to *Table 1* to answer the questions below:
   a) Calculate how long the Sun will spend on the main sequence.
   b) Calculate how long Spica will spend on the main sequence.
   c) Relate your results to the statement that the more massive the star, the shorter they live.
6. Explain the relationships between temperature, luminosity, mass, and lifetime of stars.

Preparing for the Chapter Challenge

You are about to complete your **Chapter Challenge**. In the beginning you were directed to learn as much as you could about how extraterrestrial objects and events could affect the Earth and your community. In order to do this you have explored the stars and planets, looking at all the possibilities. By now you have a good idea about how frequently certain kinds of events occur that affect Earth. The Sun is a constant source of energy and radiation.

In this final activity you learned our solar system's place in the galaxy, and you read about how stars are born and die. Because the birth of our solar system led directly to our planet, and the evolution of life here, it's important to know something about stars and how they come into existence.

You now know that the solar system is populated with comets and asteroids, some of which pose a threat to Earth over long periods of time.



The evolution of the Earth's orbit and its gravitational relationship with the Moon make changes to the Earth's climate, length of year, and length of day. The solar system is part of a galaxy of other stars, with the nearest star being only 4.21 light-years away. The Sun itself is going through a ten-billion-year-long period of evolution and will end as a planetary nebula some five billion years in the future. Finally, our Milky Way galaxy is wheeling toward a meeting with another galaxy in the very, very distant future. Your challenge now that you know and understand these things is to explain them to your fellow citizens and help them understand the risks and benefits of life on this planet, in this solar system, and in this galaxy.

Inquiring Further

1. **Evolution of the Milky Way galaxy**

   The Milky Way galaxy formed some 10 billion years ago, when the universe itself was only a fraction of its current age. Research the formation of our galaxy and find out how its ongoing evolution influenced the formation of our solar system.

2. **Starburst knots in other galaxies**

   Other galaxies show signs of star birth and star death. You read about a starbirth region called NGC 604 in the **Digging Deeper** reading section of this activity. Astronomers have found evidence of colliding galaxies elsewhere in the universe. In nearly every case, such collisions have spurred the formation of new stars. In the very distant future the Milky Way will collide with another galaxy, and it's likely that starburst knots will be formed. Look for examples of starbirth nurseries and starburst knots in other galaxies and write a short report on your findings. How do you think such a collision would affect Earth (assuming that anyone is around to experience it)?