Chapter 10

The Death of the Sun

In This Chapter

- The Sun will swell
- The Sun will be a beautiful nebula
- The Sun won't be a supernova
- The Sun will be a cinder

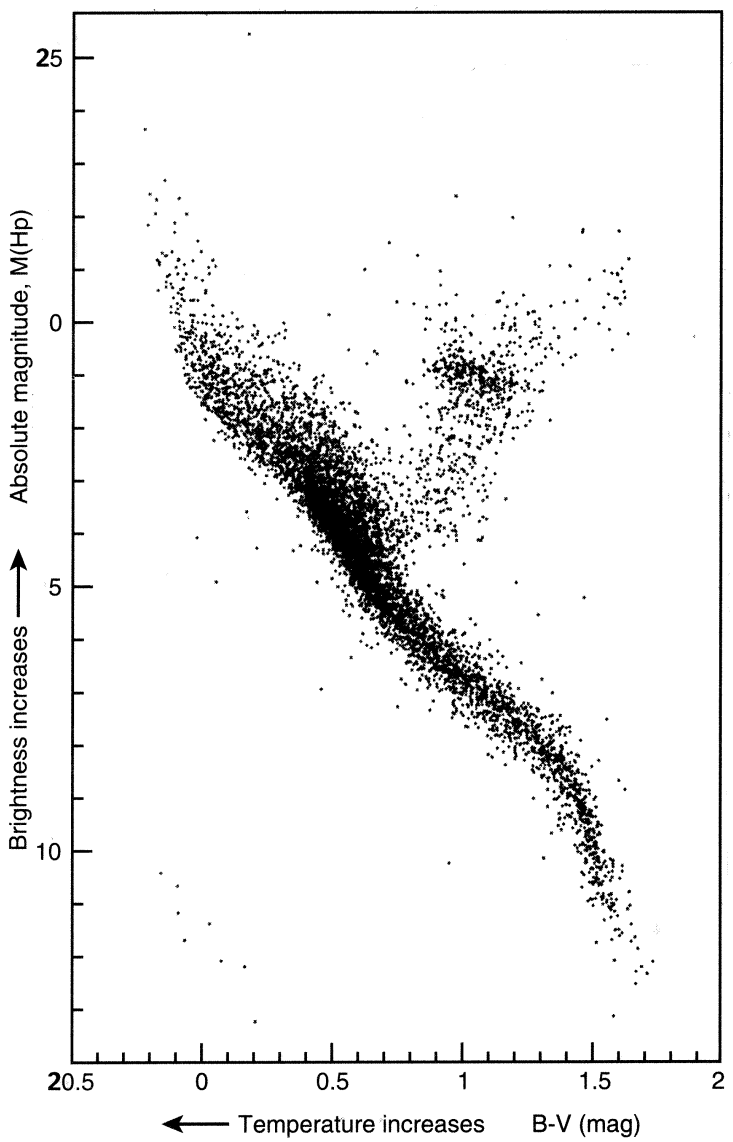
We live our lives on a planet orbiting a middle-aged star. The Sun has been shining for about five billion years, and we have about another five billion years to go. From watching other stars more advanced than ours, we can tell what will happen. It's like watching our future.

Red Giants and Yellow Dwarfs

About 90 years ago, two scientists independently plotted measures of temperature and brightness for a bunch of stars on a graph. One, Henry Norris Russell of Princeton University, corrected his values for brightness to take into account how far the individual stars were from us. After all, something can look bright either because it is really bright or because it is merely very close. The other, Ejnar Hertzsprung, a Danish astronomer

working in Germany, examined a lot of stars in star clusters, taking advantage of the fact that all those stars in each cluster were just about at the same distance from us as the others. Their result has dominated stellar astronomy ever since.

In particular, they discovered that stars weren't scattered all over their graph, which might have been the case. Instead, most stars formed a "main sequence," a fairly straight line diagonally across the graph. The horizontal axis of the graph in the following figure shows the stars' surface temperatures, which can be measured in various ways.



The Hertzsprung-Russell diagram, the plot of some measure of stars' temperature vs. some measure of their intrinsic brightness.

(The Hipparcos Project and ESA/M.A.C. Perryman)

If you draw a vertical line on the preceding graph showing a color-magnitude diagram, that line hits a lot of points, each of which represents a star. Going upward

from the bottom axis (that is, going to brighter stars), the line hits the curved band that represents the main sequence at some point. Most of the stars that the line hits, especially when you draw that vertical line for some red color, are on the main sequence. But a few of the points that are hit by the line are above the main sequence on the graph. That is, the stars are brighter than main-sequence stars at the same color.

The Solar Scoop

The diagrams that have descended from the work of Hertzsprung and Russell are known as H-R diagrams or color-magnitude diagrams, since color is a measure of temperature, and magnitude is a measure of how bright a star is. Harking back to the spectral types of stars, which are given the order OBAFGKM, the O stars, the hotter stars, are at the left. Therefore, temperature increases going leftward, which is opposite the usual sense of increase for that axis in most graphs. Also, the fainter a star, the higher its magnitude. When first called that thousands of years ago, the brightest stars were "of the first magnitude." So the magnitude scale on the vertical axis increases downward. In some sense, that is backward, too. So both axes, for historical reasons, are opposite of how most graphs are drawn.

In Chapter 8, we discussed black-body curves. Whenever gas has an overall smooth spectrum with a peak of intensity at some particular color (such as that shown in the first figure in Chapter 8), we say that the gas is acting like a black body and that all that gas is at the same temperature. Let us use this concept to compare two stars on the same vertical line (that is, of the same temperature), with one star higher (brighter) than the other on the graph. So both stars—the fainter one on the main sequence and the brighter one above it—have surfaces at the same temperature. That means that each bit of surface (let's say, each square inch) gives off the same amount of energy. So how can one star be brighter? It must be larger, since then it has more surface area. That makes the star a giant. By looking at how diffuse their spectral lines were, Hertzsprung had already noticed that these stars were very large (since larger stars have lower gravity at their surfaces, which allows the atoms there to move around faster, making their spectral lines less sharp).

In comparison with the *giant* stars, the stars on the main sequence are known as *dwarfs*.

Sun Words

Giant stars are bloated; their surfaces are larger than those of dwarf stars of the same temperature, giving them more surface area and making them brighter. **Dwarf stars** are normal stars; they are in the prime of life, not yet having gone through the death throes that transform stars to giants, supergiants, or even later stages of stellar evolution.

Though the name—chosen by Hertzsprung—may be odd, dwarf stars are normal stars, and they include the Sun. Hertzsprung just noticed that at a given color, some stars were smaller than the giants he had already studied, so he called them dwarfs.

In about five billion years, the Sun will have used up much of the hydrogen in its core, which takes up about 10 percent of its size. The hydrogen will be transformed into helium, and hydrogen will continue to fuse to helium in a shell around the core. But a stable star is in a constant battle between the force of gravity pulling everything inward and some pressure pushing it outward. When the pressure of hydrogen fusion in the core disappears, the star collapses a bit. The energy released from the collapse heats it up, and the core gives off more energy. That energy goes to heat the swollen outer layers, which have expanded outward. These outer layers are large and cool. When this process happens to our star, the Sun will then be a red giant.

Not a Planet After All

After the Sun or stars like it swell to become red giants, the outer layers continue to drift out. A wind of matter flows out of the inner part of the star, blowing the outer layers outward. This wind may come in fits and starts, making various shells of matter around the star's core.

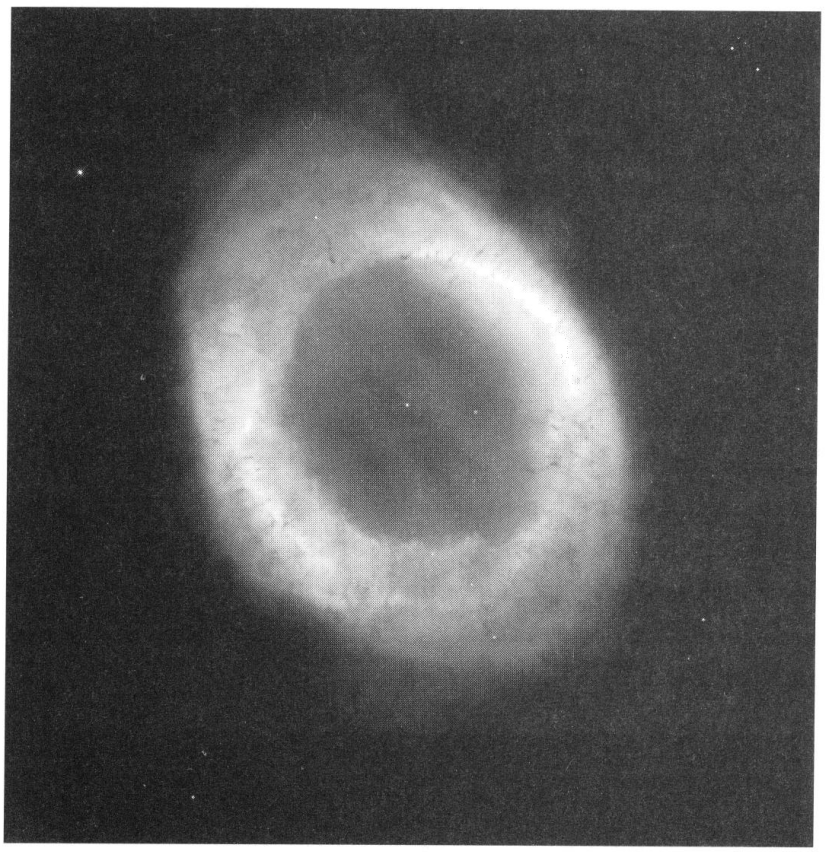
Can we see any such objects? Indeed, several have been known for hundreds of years. Already in a catalog of nonstellar objects from the 1770s put together by Charles Messier, at least the 27th object (we now call it M27), the 57th object (M57), the 76th object (M76), and the 97th object (M97) turn out to be bloated outer layers of stars. The first was discovered by Messier in 1764. In 1784, William Herschel, famous already for his discovery of the planet Uranus, thought the objects looked like tiny, hazy, greenish disks, much as the planet Uranus appeared to him. So he called them planetary nebulae.

Much later, these planetary nebulae turned out to be shells around dying sunlike stars and have nothing to do with planets. But the name has stuck. The most famous objects are these:

- M27, the Dumbbell Nebula
- M57, the Ring Nebula
- M97, the Owl Nebula

The Ring, in the constellation Lyra, is a favorite object for amateur astronomers, in part because it is high in the sky on summer nights. It looks like a tiny, hazy smoke

ring to the eye peering through today's amateur telescopes. It takes an image with an electronic camera, or a long image with a film camera, to bring out the colors.



The Ring Nebula, a planetary nebula in the constellation Lyra. The Hubble Space Telescope has revealed in this image that we are really looking down a cylinder of gas. The gas was thrown off by the dying star in the center. Note that planetary nebulae do not have anything to do with planets in our solar system or in others.

(Hubble Heritage Team [AURA/STScI/NASA])

Fun Sun Facts

Planetary nebulae glow faintly greenish because of the strange conditions in them—almost a vacuum; oxygen that has lost two of its electrons contributes most of the radiation in a greenish emission line. For decades in the late nineteenth and early twentieth centuries, the green emission line was known, but its true source was not. It had been given the name nebulium, since it was found only in nebulae. The name wasn't as successful a guess as the similar name helium given to whatever caused a certain yellow line in the Sun's spectrum at eclipses. Helium, of course, turned out to be one of the basic chemical elements, while both nebulium from nebulae and coronium from the Sun's corona turned out to be from highly ionized gases.

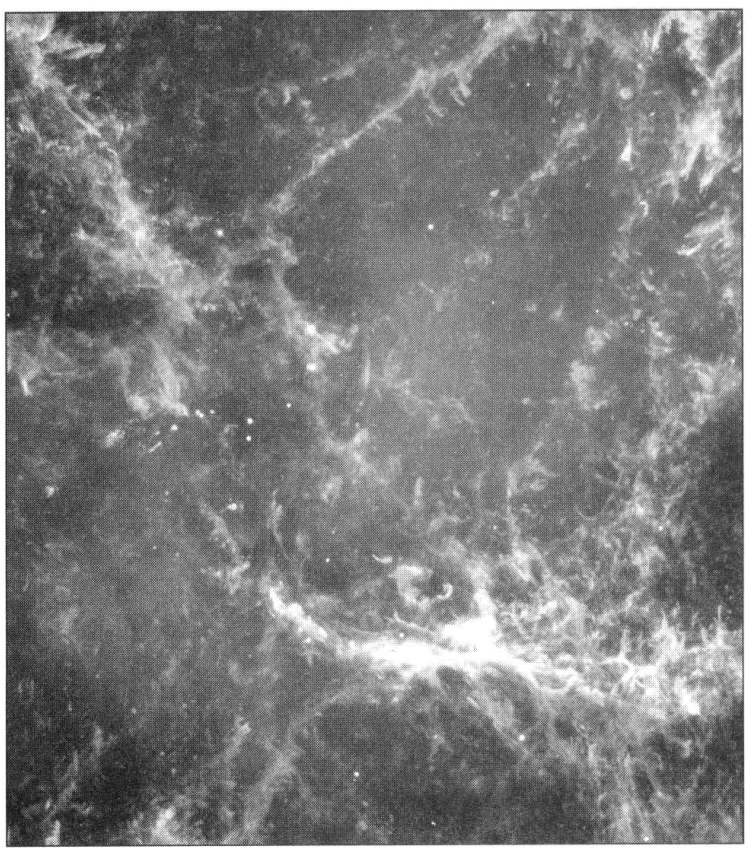
Planetary nebulae are favorite objects for the Hubble Space Telescope's high-resolution cameras to observe because of the wonderful detail that can be seen in these relatively close objects. Hubble's images, improved over those from ground-based telescopes,

have brought to prominence the various shells and other details that were smeared out previously. As a result, we now appreciate how important the episodic nature of the ejection of the gaseous shells is. And we see nonround shapes that indicate that the original stars were giving off their outer layers preferentially in certain directions.

The duration of the planetary nebula stage of a star's life is just a twinkle in the eye of the cosmos. Planetary nebulae last only about 50,000 years before they are so spread out that they are invisible. That span is only $^{50,000}/_{5,000,000,000}$, or $^{1}/_{100,000}$ (0.001 percent) of the remaining lifetime of the Sun.

We Won't Blow Up

Stars that have the mass of the Sun, or approximately its mass, see their outer layers become planetary nebulas, while their inner layers stabilize as white dwarfs. More massive stars grow hotter and denser deep inside, and the force of gravity pulling inward fuses even massive nuclei like iron into still more massive forms. That fusion of iron steals energy from the system rather than adding it, and these massive stars explode as supernovae. But the Sun doesn't have enough mass to reach that stage, so our star will never be a supernova like that.



The Crab Nebula, the remnant of a star that blew itself to shreds and whose explosion's light reached us in the year 1054 C.E.

(Hubble Heritage Team [AURA/STScI/NASA])

Fun Sun Facts

We do benefit from supernovae, however, even if the Sun will never be one. When they explode, they form the heaviest elements in the universe (silver, gold, and uranium, for example). The explosion spews these elements into space. When our Sun formed some five billion years ago, it formed out of a cloud of gas and dust that incorporated these elements from earlier supernova explosions. Thus each of us has within us the star stuff, to use Carl Sagan's phrase, that came from these spectacular events.

Our Ultimate Resting Place

We have already said that the outer layers of the Sun will be ejected in about five billion years and that they will fade into invisibility. That means that we will then be able to see the inner part of the Sun, the part that is left. As gravity pulls it inward, it will shrink and heat up. Eventually, the electrons will press in on each other so hard that they won't get closer together anymore. This effect is known as electron degeneracy. The pressure formed by this degeneracy counterbalances the force of gravity pulling inward. At that point, the Sun will be stable again.

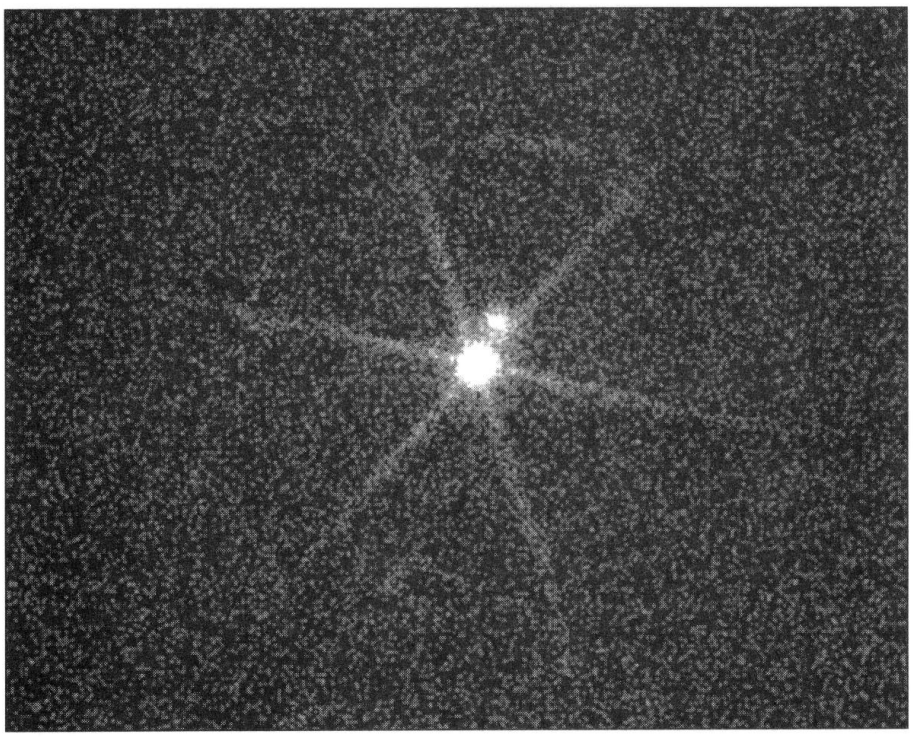
When a star stabilizes, with electron degeneracy pressure balancing gravity, it is only the size of the Earth. It has just shrunk by a factor of about 100 in diameter, which is by a factor of about 1 million in volume. The object has shrunk from being a central star of a planetary nebula, which is very hot, so it starts out very hot. That makes it blue-white hot, and the resulting objects are called *white dwarfs*.

Sun Words

Do not confuse the term **white dwarfs** with ordinary dwarfs like the Sun or a wide variety of stars on the main sequence of Hertzsprung's and Russell's diagram (which are yellow dwarfs or red dwarfs or, in general, dwarfs). White dwarfs have their own part of the diagram, to the lower left.

Fun Sun Facts

In 1930, a young Indian graduate student took a steamer for London. His thinking during that long voyage changed our conception of the universe. During the voyage, Subrahmanyan Chandrasekhar (Chandra, for short) figured out that there would be a limit to the mass that a dying star could support. We now name that limit after him and realize that his work led to our conceptions of white dwarfs and other end products of stellar evolution, such as black holes.



In x-rays, as in the Chandra X-ray Observatory image shown here, Sirius B is the brighter of the pair since the hotter star, the white dwarf, radiates more x-rays. In fact, the faint light from Sirius A in this image may merely be from a leak in the filter that is supposed to pass only x-rays.

(CXC/SAO/NASA)

The Least You Need to Know

- In five billion years, the Sun's outer layers will swell to make it a red giant.
- The Sun will puff off a beautiful cloud of gas and dust.
- The Sun doesn't have enough mass to explode as a supernova.
- The Sun will wind up as a cold, dense cinder known as a white dwarf.