

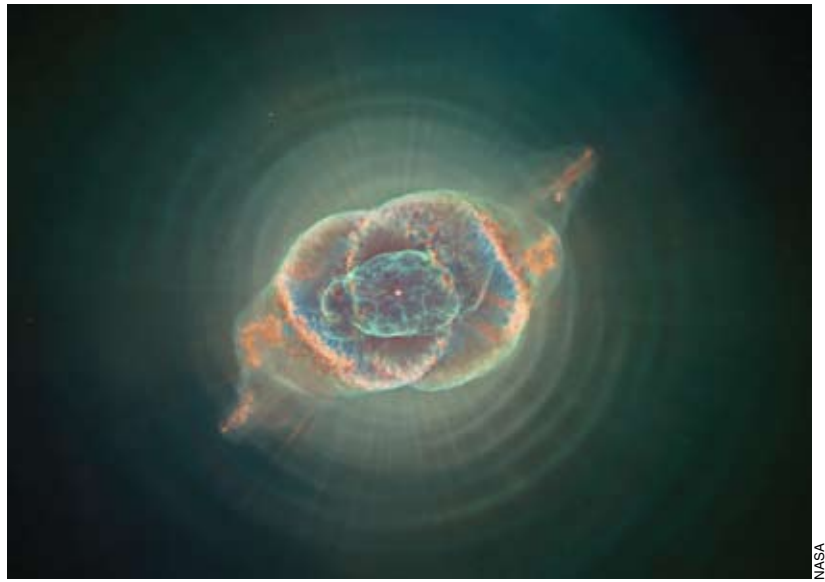
End of the line for a star like ours

by Bob Riddle

Stars of different masses have varying life spans, with the more massive stars “burning out” more quickly than stars of lower masses. How or what they do when they burn out also varies, depending on the mass of the star. All stars are called *main sequence stars* as long as they continue fusing hydrogen and staying in a state of equilibrium—a balance between gravity and thermal pressure. However, when stars stop fusing hydrogen, they undergo changes that will lead to their eventual death. Once again, a star’s mass determines how long it will last.

Our Sun is considered to be a low-mass star and is used as the reference mass—1 solar mass—for comparing other stars. With regard to star mass, the smallest star is about 0.08 solar mass, while the upper limit for a star is estimated to be around 150 solar masses. Regardless of size, stars will continue fusing elements until they can no longer do so. The greater the mass, the more quickly a star will fuse through its components. If a star were to form at 150 solar masses, it might “switch on” (begin the fusion process and “officially” be a star) and then, in a relatively short period of time compared to stars of less mass, blow apart because the rate of fusion and energy production is too great to be contained by gravity.

A relatively low-mass star such as the Sun will steadily fuse hydrogen into helium while slowly increasing its core temperature and brightness. These increase over time because as the star fuses hydrogen in the core, there is less and less hydrogen in the core pushing back against the inward force of gravity. The core begins to shrink from the additional pressure, which then increases the temperature and fusion rate. However, while the core may be shrinking, the diameter of the star is increasing, hence the increase in brightness. Fortunately, as long as there is core fusion, the star is more or less self-regulating in that the expansion of the star causes cooling, which allows



The Cat's Eye Hubble Remix

the Sun to contract, but not back to its previous size. This continues steadily during the main sequence phase of the Sun’s life, but overall it is slowly and steadily increasing in luminosity, size, and brightness.

At some point in the future, the supply of hydrogen in the Sun’s core will be exhausted, and nuclear fusion in the core will end the equilibrium between gravity and thermal pressure. The core, now composed of helium, will begin to shrink as it is being compressed under the weight from the overlying hydrogen making up the rest of the mass of the star. From this point on in the Sun’s life, things will get a bit strange.

As the core is compressed, it will heat up; however, while the core is shrinking, the outer layers of the Sun will be expanding, because nuclear fusion will begin in the hydrogen shell surrounding the shrinking helium core. The unfused hydrogen surrounding the core will be compressed and will eventually reach the necessary temperature to begin hydrogen fusion. The Sun will then have a “burning” shell of hydrogen around an inert core of helium. The hydrogen shell will fuse at a higher

temperature than its core predecessor, so the Sun will continue to increase in luminosity and size, becoming a red giant star.

Temperatures within the core region of the Sun will continue to increase as the amount of helium produced by the fusion in the hydrogen shell adds to the mass of the core, causing it to shrink further and increasing its gravitational pull on the surrounding hydrogen shell. The temperature in the hydrogen shell will increase even further, causing the rate of fusion to increase and the Sun to expand while the core contracts. The Sun will continue what seems like an endless cycle, alternating between equilibrium and not being in equilibrium. This erratic imbalance will continue until the core temperature reaches around 100 million K and helium fusion is able to begin. At the same time, while the Sun is increasing in size (diameter), the outer layers of the Sun will move further away from the core and the gravitational attraction from the core. In effect, the outer layers will not be held that tightly by the Sun's gravity, so the Sun's outer layers of gases will be able to drift away as part of a solar wind.

The beginning of helium fusion will cause a sudden increase in energy that will be released in a helium flash. Helium fusion requires three helium nuclei to convert into one carbon nuclei and a release of energy. The helium flash will push the fusing hydrogen shell further out from the now-fusing helium core, causing the temperature and fusion rate within the hydrogen shell to decrease. This relative cooling will allow the outer layers of the Sun to contract, which will then cause an increase in temperature. The Sun, when it becomes a helium-fusing star, will have changed from a cooler surface temperature and a larger "red giant" size to a smaller and hotter surface temperature yellow star. However, as a helium fuser, it will be hotter and more luminous than when it was a hydrogen-fusing star on the main sequence. However, even with fusion occurring in the core and the hydrogen shell, the rate of energy production and temperature will be held in check by the inward pull of gravity. The Sun will be in equilibrium once again—at least for a while.

The end is here

Helium fusion in the core of the Sun can only be sustained for a span of time that is determined by its mass. When helium fusion ends, the Sun will be once again out of equilibrium, and the carbon core will begin to be compressed under the now greater force of gravity. As the force of increasing gravity raises the temperature, the helium surrounding the inert carbon core will begin to fuse. The Sun will now have an inert, nonfusing, carbon core under increasing pressure surrounded by

Questions for students

1. What is meant by the luminosity of a star? (*The luminosity of a star is a measure of the total energy output of a star and is measured in watts or stars and compared with the Sun as a standard reference.*)
2. Where did the carbon dust come from? (*The carbon dust within the planetary nebula comes from the carbon produced during helium fusion. Toward the end of the Sun's life, carbon will be brought to the surface by the more energetic convection currents. This will be expelled with the solar wind; as the gases drift away from the Sun, they will begin to cool and condense into carbon dust grains.*)
3. What do you think will happen to the Earth and other planets in the solar system as the Sun grows to red-giant-star size with a diameter many times that of the Sun's present size? (*This could be part of an exercise in creative writing as students research the effects of an expanding Sun. For example, students could describe what we could do to prepare for the effects of an expanding Sun.*)

a fusing helium shell and a fusing hydrogen shell. The Sun will also expand in size and luminosity and will possibly reach a radius the size of the Earth's orbit. However, the core will never reach the temperature needed for carbon fusion. Consequently, after perhaps several million years, fusion will end in both shells.

Throughout the dying stages of the Sun, the expansion will allow much of its outer layers, in increasing amounts, to be lost to an ever-expanding bubble of carbon dust and gas. We can see examples of what our Sun may look like at that stage in its life when we see the colorful clouds of gases in many images taken by the Hubble Space Telescope. They are known as planetary nebula because of their disk-shaped, planetlike appearance, as seen through the lower-powered telescopes used during the early days of telescope-based astronomy (see opening photo and Astronomy Picture of the Day in Resources)

At the end, our Sun will have gone through several changes, beginning with its humble beginnings as a protostar. What will remain of our Sun after all of the fusion ends will be a slowly cooling core, a white dwarf star, surrounded by an expanding nebula—perhaps like the colorful planetary nebula shown in the opening photo. Most nebulae left from stars such as our Sun glow in ultraviolet as their particles are ionized by the white dwarf star they surround. However, eventually the white dwarf star cools, and the nebula disperses. ■

February

- 2 Waning gibbous Moon near Saturn
- 5 Last quarter
- 12 Moon near Mercury
- 13 Moon at apogee: 406,542 km
Cassini spacecraft flyby of Mimas
- 14 New Moon
Neptune in conjunction with Sun
- 16 Venus and Jupiter conjunction
- 18 Clyde Tombaugh discovers Pluto (1930)
- 22 First quarter Moon near the Pleiades
- 25 Waxing gibbous Moon near Mars
- 27 Moon at perigee: 357,832 km
- 28 Jupiter in conjunction with the Sun
Full Moon

Visible planets

Mercury will be visible before sunrise. However, it will not be very high above the eastern horizon.

Venus will start to become more visible over the west-

ern horizon after sunset. Venus and Jupiter will pair up in a close conjunction on February 16.

Mars will rise shortly after sunset and will be in retrograde motion, moving west past the Beehive open star cluster during the first week of the month.

Jupiter will be visible over the western horizon at sunset, but it will be low and near the Sun.

Saturn will rise around sunset and will be visible all night during February.

Resources

Astronomy Picture of the Day—http://antwrp.gsfc.nasa.gov/apod/image/0803/NGC6543HST_peris.jpg
Sun-Earth Day 2010—<http://sunearthday.nasa.gov/2010>

Bob Riddle (briddle@kcmsd.net) is the planetarium director for the Kansas City, Missouri, school district. Visit his astronomy website at www.currentsky.com.