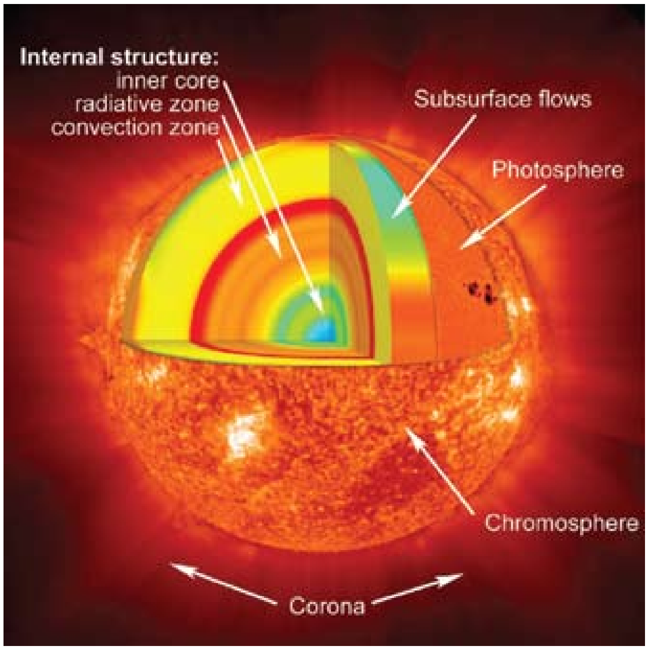
Living with a star

by Bob Riddle



WWW.RISE.ORG.AU/INFO/RES/SUN/IMAGE004.JPG

There is an old joke about an astronomy lecturer who, having just completed a lecture about the fate of our Sun, was approached by a very nervous student. "How long did you say the Sun would last?" the student blurted. "About 5 billion more years," replied the lecturer. "Man, that's a relief. I thought you said 5 million!"

Currently, our Sun is a content, middle-aged main sequence star steadily fusing hydrogen atoms into helium atoms and releasing radiation in many of the wavelengths making up the electromagnetic spectrum. So what happens between now and when the Sun runs out of hydrogen? And what happens after that? Before we can answer these questions, we need to take a look at what goes on within a star's hot interior and how that energy reaches the surface of the Sun and then onward out into the surrounding space.

"The Sun is a mass of incandescent gas," the song "Why Does the Sun Shine" states, "a gigantic nuclear furnace" (see Resources). More correctly, the Sun is a mass of plasma, a gas at extremely high temperatures containing positive ions and electrons. Because of the tremendous pressures and temperatures that increase inward, the structure of the Sun suggests distinct layers of differing properties. The innermost layer is the core, where the temperature and density from the overlying layers push the thermometer to temperatures of approximately 15,000,000°C. At these temperatures, atoms cannot exist; they are broken into their component parts of neutrons, protons, and electrons. Because neutrons are electrically neutral, they do not interact in the core. On the other hand, the electrons move freely through the hot, dense plasma while the positively charged protons, the atom's nuclei, collide with other positive nuclei. Because protons are positive, they normally would repel each other. However, under the conditions within the core, there is enough pressure to overcome the electromagnetic repulsion and force these nuclei together, fusing them into larger nuclei of helium.

The fusion process that converts hydrogen to helium involves six hydrogen nuclei or protons, of which four of the nuclei are actually fused together, forming just one helium nucleus composed of two protons and two neutrons. Fusion of protons into helium nuclei at the Sun's core is called the *proton-proton chain*, a three-step process involving two protons during each of the three steps.

In the first step of the proton-proton chain, two protons are fused together, forming a nucleus with one proton and one neutron. This is *deuterium*, an isotope version of hydrogen. During this step, when a proton is converted to a neutron, a very tiny bit of matter called a *neutrino* is formed. In addition, the conversion of a positively charged proton to a neutral neutron also forms a particle called a *positron* to carry away the no-longer-needed positive charge from the proton. A positron, or an anti-electron, is antimatter and, as such, ceases to exist when it collides with a freely moving electron forming two gamma-ray photons of energy.

In the second step of the proton-proton chain process, a deuterium nucleus collides and fuses with a proton-forming helium-3, a helium nucleus with two protons and one neutron, and releases a gamma-ray photon.

The third and final step in the proton-proton chain is the collision and fusing together of two of the helium-3 nuclei into a single helium nucleus containing two protons and two neutrons. Two excess protons are also released.

Because one helium nucleus has less mass than the four hydrogen nuclei that went into forming it, the remaining mass becomes kinetic energy in the form of photons that slowly work their way through the overlying layers to the surface of the Sun. This is not an easy path to follow, given the extreme density of the core; however, by following photons as they make their way outward from the core, we can learn something about the structure of the Sun (see photo on the opening page).

The core of the Sun is at the center of mass where the pressure is the greatest, as is the density and temperature on the plasma. As a result, photons, even traveling at the speed of light, take many thousands of years to move through the dense, hot plasma. Electrons move more freely through the plasma than the photons; as a result, there are many collisions between photons and electrons. Each collision redirects the photon so that it follows a very random path as it makes its way outward. This process of constant collisions and changes of direction is known as *radiative diffusion,* and the region of the Sun around the core where this occurs is logically called the *radiation zone.*

Temperature and pressure decrease moving outward from the Sun's core; at some point in the radiation zone the temperatures and pressures have decreased enough so that photons can actually be absorbed by the cooler, less-dense plasma rather than ricocheting off electrons. This area marks a transition from energy transfer through radiation to a flow of energy known as convection. This is the *convection zone* of the Sun. Just as a pan of water heats up, bubbles of relatively hot plasma rise upward and away through increasingly cooler and less-dense plasma while at the same time passing cooler and denser plasma flowing downward to be rewarmed and rise again. At temperatures around 6,000°C, the density has decreased enough that the photons are able to leave the Sun and travel outward into space. This area is at a temperature that radiates energy in the visible light part of the electromagnetic spectrum, and we refer to this part of the Sun's structure as the *photosphere,* or the Sun's surface. It is not truly a surface, and upon closer examination you would see that the photosphere has a granular appearance caused by the rising bubbles of plasma. The region of the photosphere is where the Sun's magnetic field winds and twists, interacting with the photosphere and sunspots. It is also the lower layer of the Sun's atmosphere. The middle layer, the *chromosphere,* is warmer: nearly twice the temperature of the photosphere. At these temperatures and from within this region, we receive much of the ultraviolet radiation from the Sun.

Surrounding the chromosphere is the outermost layer of the Sun's atmosphere, the *corona.* The density of the corona is very low; however, the temperature of the corona is about 1,000,000°C, and this is where most of the x-rays radiated from the Sun come from. The photons of energy radiated from the Sun do not stop at the corona, but continue traveling outward as the solar wind, bathing the solar system in radiation and interacting with the planets.

November

1	Daylight Saving Time ends
	WISE launch
2	Full Moon
	Mars crosses the Beehive Cluster
	Cassini flyby of Enceladus
4	Neptune ends retrograde motion
5	Mercury at superior conjunction
7	Moon at perigee: 368,903 km
9	Moon near Mars
	Last quarter Moon
10	Jupiter at east quadrature
12	*STS-129* to International Space Station
13	*Rosetta's* third Earth flyby
15	Neptune at east quadrature
16	New Moon
17	Leonid meteor shower peak
21	*Cassini* flyby of Enceladus and Rhea
22	Moon at apogee: 404,733 km
23	Moon near Jupiter
24	First quarter Moon
30	Sylacauga meteorite

Visible planets

Mercury will be on the opposite side of the Sun at superior conjunction. Watch for it as an evening planet toward the end of the month.

Venus will be visible, but low over the eastern horizon before sunrise. This is the last month to see Venus as a morning planet.

Mars will rise before midnight and will be visible the rest of the night.

Jupiter will rise during the afternoon and will be visible over the south to southeastern horizon at sunset.

Saturn will rise several hours before sunrise and will be visible over the southeastern horizon.

Resources

Cassini mission—*http://saturn.jpl.nasa.gov*
International Year of Astronomy—*http://iya09.org*
LCROSS—*www.nasa.gov/lcross*
Leonid meteor shower—*http://meteorshowersonline.*

com/leonids.html
Living with a star—*http://ds9.ssl.berkeley.edu/LWS_GEMS*
Rosetta—*http://sci.esa.int/science-e/www/area/index.cfm?fareaid=13*
STS-129—*www.nasa.gov/mission_pages/shuttle/shuttlemissions/sts129*
Sun-Earth connection—*http://sunearth.gsfc.nasa.gov*
Sun Song on YouTube—*www.youtube.com/watch?v=Zbgul1NpEA8&feature=related*
Sylacauga meteorite—*http://articles.adsabs.harvard.edu/full/1954Metic...1..125S*
Why does the sun shine?—*http://kids.niehs.nih.gov/lyrics/whysunshine.htm*
WISE—*http://wise.ssl.berkeley.edu*

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

Questions for students

1. What is the difference between an atom of an element and the isotope version of an element? (An atom has a specific number of protons and neutrons in the nucleus, but under certain conditions can have a different number of neutrons: an isotope.)
2. What is meant by radiative diffusion? (Radiative diffusion means to spread out or diffuse the radiation or photons of energy. Demonstrate diffusion by dropping a drop of dark ink in a beaker of water. The ink diffuses into the water as the ink molecules bounce off the water molecules.)
3. What is meant by visible light, or the visible portion of the electromagnetic spectrum? (Visible light, sometimes called white light, is the part of the electromagnetic spectrum that our eyes are able to see based on the temperature of the source of radiation.)