more steadily. Finally, massive blue-giant stars are the largest and hottest so they burn their fuel very quickly. Late in its life, an average star like the Sun uses up its fuel and swells into a cool red giant star. After time, it blows off its outer layers and forms a planetary nebula, a kind of cosmic smoke ring. The nebula floats away, leaving behind a white dwarf—a small, faint star—that eventually fades completely into a cold black orb. When a much more massive star uses up its fuel and reaches the end of its life, it undergoes a supernova explosion. The remaining stellar core is a very small, ultra-dense neutron star. In the death of the most massive of all stars, the central core collapses completely under its own gravity, forming a black hole, an object so dense that nothing — not even light— can escape from it.

Things to Think About

• What beneficial things do we get from the Sun, and what dangers does it pose? How can the Sun's effects be lethal?

• Research the many ancient cultures that worshiped the Sun and had Sun gods. Why do you think people worshiped the Sun and other celestial objects?

• How do stars give birth to planets and solar systems?

• Research astronomers' work on the birth and death of stars. At what stage in the life cycle is our own Sun? What is its likely fate, and what will happen at that time to Earth and the other planets in our solar system?

• Explore the theories that mass extinctions on Earth millions of years ago were caused by the death of stars.

• Exactly what happens during a total solar eclipse? What makes it such an awesome event that some people travel great distances to experience it? How did ancient peoples view eclipses, and why?

• What safety tips should one take when observing a solar eclipse? What could happen if someone did not take such precautions?

• A new public issue is "light pollution," to stop the glare from growing urban centers that is encroaching upon mountaintop telescopes, as well as preventing people from simply seeing the stars with the naked eye. Research recent efforts in some states to restrict outdoor lights. Do you thing such laws are a good idea?

• Consider Walt Whitman's poem "*When I Heard the Learn'd Astronomer*":

When I heard the learn'd astronomer,
When the proofs, the figures, were ranged in columns before me,
When I was shown the charts and diagrams, to add, divide,and measure them,
When I sitting heard the astronomer where he lectured with much applause in the lecture-room,
How soon unaccountable I became tired and sick,
Till rising and gliding out I wander'd off by myself,
In the mystical night-air, and from time to time,
Look'd up in perfect silence at the stars.

What do you think Whitman's point is? How does it make you feel about seeing the stars?

Internet Resources

cfpa.berkeley.edu/BHfaq.html — The Black Holes FAQ page, maintained by the Center for Particle Astrophysics.
http://starchild.gsfc.nasa.gov/docs/StarChild/StarChild.html -- StarChild, a site for young astronomers maintained by the High Energy Astrophysics Science Archive Research Center, with learning activities, films, links, and more.
www.geocities.com/CapeCanaveral/3001— The Black Holes and Mysteries of the Cosmos website.

Other Resources

For students:
Couper, Heather and Nigel Henbest. ***Black Holes.*** Dorling Kindersley, 1996.
Newton, David E. ***Black Holes and Supernovae.*** Twenty-First Century Books, 1997.
For adults:
Friedman, Herbert. ***The Astronomer's Universe: Stars, Galaxies, and Cosmos.*** W. W. Norton, 1998.
Merrifield, Michael and James Binney. ***Galactic Astronomy.*** Princeton University Press, 1998.

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THE EXPANDING UNIVERSE

THE SUN AND OTHER STARS

The really bright ball in the skies above the Earth is the Sun — a huge, turbulent ball of very hot gas that provides us with light which is both nurturing and potentially lethal. The Sun is but one of billions of stars in the Milky Way galaxy. All these stars have been born from interstellar dust and gas, only to die eventually. Stars can die violently, in a massive supernova explosion, or quietly, by shedding their outer atmospheres, which then form a planetary nebula. Learn how stars form, the fascinating stages they pass through during their life cycles, and how they ultimately die, turning from fledgling protostars to planetary nebulae, supernovae, neutron stars, and even black holes. Discover how some of the active stages of stars affect both them and the objects around them. And learn what the eventual death of our own Sun means for Earth and our solar system.

CHOICES

Vocabulary

Aurora borealis — The Northern Lights, a display of light in the northern skies at night, caused when charged particles from the Sun are trapped by the Earth's magnetic field and collide with the Earth's upper atmosphere, making gases in the air glow.
black hole — A point-like, massive object, whose gravity is so strong that nothing—including light—can escape from it. Black holes are formed from collapsed massive stars, at the centers of galaxies and in the early universe.
corona — The Sun's outer atmosphere, visible only during a total solar eclipse.
cosmic rays — High-energy particles that travel close to the speed of light. They are produced by both supernova and solar flares.
Crab Nebula — The remains of a supernova explosion that Chinese astronomers observed in 1054. The neutron star at its center is all that remains of the collapsed core of the original star.
eclipse — An event in which one object moves in front of another object, blocking its light as observed from the Earth. Eclipses, can be solar (of the Sun) or lunar (of the Moon) and can be partial or total.
galaxy — A collection of hundreds of billions of stars, as well as gas and dust, held together by gravity. The Milky Way is an example.
helium — The second-simplest type of atom after hydrogen, and a major component of stars.
hydrogen — The simplest type of a atom, composed of an electron and proton; a major component of stars.
implosion — The act of undergoing a violent collapse of material.
Lagoon Nebula — A nebula in the constellation Sagittarius, visible to the naked eye, which is the birthplace hundreds of new stars.
Milky Way — The galaxy in which our solar system is located.
nebula — A cloud of gas and dust in space.
neutron star — the remnant of a supernova explosion composed primarily of ultra-condensed neutrons.
photon — Particle without mass or charge that travels at the speed of light. Photons can be considered particles of light.
planet — A large body that orbits a star. Earth is an example.
protostar — The earliest stage in the life of a star, before it becomes hot enough to begin nuclear reactions.
red giant star — A star in its later stages of life, which has expanded and cooled as a result of changes in its energy source.
singularity — A point in space where there is an infinitely strong gravitational field. Singularities are believed to exist in the center of black holes.
SOHO — The Solar and Heliospheric Observatory satellite, launched in December 1995 to orbit and study the Sun.
solar maximum — The period every 11 years when there is a maximum in the number of sunspots and the amount of solar activity.
solar system — A star and the bodies orbiting it—planets, moons, etc. In our solar system, nine planets circle the Sun: Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune, and Pluto.
spiral arms — The characteristic swirling arms of a spiral-shaped galaxy, where star formation and supernovae are most likely to occur.
spiral galaxy — A type of galaxy that has arms in a spiral shape. The Milky Way is an example.
star — A large ball of primarily very hot hydrogen and helium gas that produces copious amounts of light. The Sun is an example.
Sun — The star at the center of our solar system. It is an average star which is middle-aged at 5 billion years old.
sunspots — Darker markings on the Sun, produced at the site of the Sun's magnetic fields. The magnetic fields prevent hot gases from reaching the surface, so the spots are relatively cooler and less bright.
supernova — A large explosion in which a star much more massive than the Sun end its life.
total solar eclipse — An event in which the Moon is directly in front of the Sun, so that the Sun's corona can be seen.
ultraviolet radiation — A high-energy component of sunlight that can cause sunburn and skin cancer. Other stars also emit ultraviolet radiation.

The Life Cycle of a Star

A nebula is a cloud of gas and dust which is often the birthplace of hundreds of stars. As a star-forming nebula collapses under its own gravity, the center heats up and clumps together to form a protostar — the initial stage in a star's life. Continuing to collapse, the young star becomes even hotter and denser until the material begins nuclear reactions, resulting in a violent wind that blows away the remaining protostellar cloud. At the center is then a newly formed, brightly burning young star.
The difference in the initial masses of stars causes them to burn their hydrogen fuel at different rates. This also determines their size and how long they live. Low mass, red-dwarf stars, like Proxima Centauri, are smaller, cooler, and burn their fuel very slowly. However, those stars with the same mass as the Sun are of average size and temperature and burn their fuel

SUN AND STARS DATELINE

1967 — Jocelyn Bell records the first signals from a pulsar.
December 1970 — NASA launches Uhuru, a satellite to look for objects emitting X rays in space; in 1971 it discovers what is apparently the first black hole ever observed, Cygnus X-1.
February 1987 — SN1987A, a supernova visible to the naked eye, is discovered at the edge of the Large Magellanic Cloud galaxy.
August 1989 — The European Space Agency launches satellite Hipparcos, which for almost four years measures the position and motion of stars.
April 1990 — The shuttle *Discovery* launches the Hubble Space Telescope, which will collect many beautiful images of celestial phenomena ranging from young stars to interacting galaxies to the structure of the early universe.
October 1990 — The shuttle *Discovery* launches the spacecraft Ulysses to investigate differences in light and magnetism at the Sun's equator and poles.
December 1990 — The shuttle *Columbia* carries the Broad Band X-ray Telescope (BBXRT), which made important discoveries about galaxy clusters, active galaxies, X-ray binary stars and other objects.
1991 — British astronomers conclude that V404 Cygni has an unseen companion massive enough to be one of the best candidates for a stellar black hole in our own galaxy.
April 1991 — The shuttle *Atlantis* launches the Compton Gamma Ray Observatory to measure gamma rays produced by solar flares, pulsars, supernova explosions, and other phenomena. It functioned for nine years and was the first great gamma ray observatory.
August 1991 — The Japanese observatory Yohkoh is launched to study X rays and gamma rays from the Sun
January 1992 — The first planetary system surrounding a pulsar is discovered by radio astronomer Alex Wolszczan.
June 1992 — The Extreme Ultraviolet Explorer (EUVE) is launched to gather data about stellar evolution.
November 1994 — The spacecraft Wind is launched to study the impact of solar wind on the Earth's atmosphere.
December 1995 — SOHO (Solar and Heliospheric Observatory) is launched to orbit the Sun and study the structure of the solar atmosphere and the location of solar disturbances.
— The Rossi X-ray Timing Explorer (XTE) is launched to study the variability in X-ray emissions from such things as white dwarf stars, neutron stars, pulsars, and black holes.
August 1996 — FAST (Fast Auroral Snapshot Explorer) is launched to study Earth's auroras, caused by interaction of solar wind and our magnetosphere.
November 1996 — The shuttle *Columbia* launches the Orbiting Retrievable Far and Extreme Ultraviolet Spectrometerer, a high-tech observatory that lets astronomers probe stars, galaxies, quasars (small, highly luminous, active young galaxies), and planets in ultraviolet light.
August 1997 — ACE (Advanced Composition Explorer) is launched to collect observations of particles of solar, interstellar, and other origins.
October 1997 — Scientists announce that with the Hubble Space Telescope, they have found one of the most massive stars ever seen, the Pistol Star, near a dense nebula at the center of the Milky Way.
April 1998 — TRACE (Transition Region and Coronal Explorer) is launched to observe effects of magnetic flux from Sun's interior to corona.
May 1998 — Astronomers report evidence of an energetic explosion that occurred 12 billion light years away at the far edge of the universe, possibly caused when two black holes, two neutron stars or a black hole and a neutron star collided.
October-November 1998 — The shuttle *Discovery* deploys and retrieves the Spartan 201 satellite to study the Sun.
March 1999 — Scientists say that the appearance of S-shaped formations on Sun's surface predicts coronal mass ejections (violent magnetic solar storms).
June 1999 — FUSE (Far Ultraviolet Spectroscopic Explorer) is launched to study high energy emission from active galaxies and quasars, massive stars, supernovae, and planetary nebulae
July 1999 — The shuttle *Columbia* launches the Chandra X-ray Observatory — the largest and most sensitive X-ray telescope ever built — to detect radiation from black holes, quasars, gas clouds, and exploding stars
November 1999 — Telescopes for the first time record direct observations confirming the existence of planets around stars outside our solar system when they observe the light from star dims as the planet orbits in front of it.
March 2000 — Scientists announce that observations from the Compton Gamma Ray Observatory suggest that many gamma rays bursts observed to be from within the Milky Way from unknown class of objects.
— IMAGE (Imager for Magnetopause-to-Aurora Global Exploration) is launched to study how changes in solar wind affect the Earth's magnetosphere.
April 2000 — Astronomers with the Sloan Sky Survey announce they have discovered the most distant object ever detected, a quasar — an active galaxy.