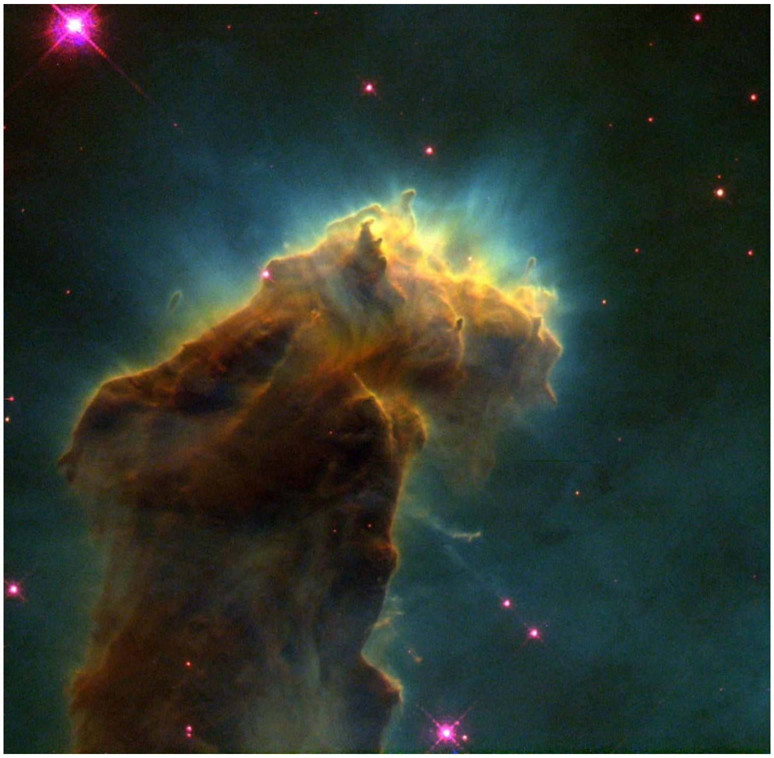
DENVER MUSEUM OF NATURE & SCIENCE

Space Odyssey Online Teacher's Guide

Deep Space

Science Information Background



Courtesy Jeff Hester & Paul Scowen (Arizona State University) and NASA

All Grades

The Sun and Other Stars

The Sun: Our Nearest Star

The Sun is the nearest star to Earth. It is therefore easier to study than other stars, so much of what we have learned about stars comes from studying the Sun. Fortunately, stars of all kinds have internal structures similar to our Sun's. Using the Sun as an archetypical star we can more easily illustrate the difference in other stars.

The Sun, a ball of gas with constant gravity and pressure in balance, has an unchanging structure, with the highest temperature and pressure in the center, getting progressively lower the farther out you go. This is a very stable arrangement. If the pressure were to drop, gravity would shrink the ball, increasing the temperature and pressure back to higher levels. Conversely, if the star expanded, internal pressure and temperature would drop, gravity would "win," and the star would shrink back to its stable configuration. The condition of pressure balanced by gravity in a gas or fluid is called hydrostatic equilibrium.

The Sun maintains its pressure by generating energy through fusion reactions in its central region. Fusion is the process where atoms combine to form other elements of higher atomic number. When the positively charged nuclei of hydrogen (protons) are pushed close enough together, nuclear forces take over to bind them in a nucleus. The massive gravity of stars provides enough weight so that protons in the core of the star are pushed together in just this way.

If you combine four hydrogen protons in this way, two of them turn into neutrons and the other two remain protons producing helium. If you carefully measure the weight of hydrogen atoms and helium atoms you will find that the sum of the parts is *less than* the whole: One helium atom weighs about one percent less than four hydrogen atoms. Where has this mass gone? Einstein's famous special relativity equation, $E=mc^2$, says that mass and energy are two different aspects of the same thing, related by the speed of light, c, squared. The speed of light is a large number, so a small amount of mass loss means a tremendous release of energy.

The Structure of the Sun

The amount of material in the Sun is so great that it takes hundreds of thousands of years for energy produced in the core to make its way to the surface. Most of this time elapses in the "radiative zone," where light scatters back and forth, but over time makes its way toward the surface. Above the radiative zone is the convective zone, where energy transport becomes a bit faster. Just as Earth's atmosphere on a summer day gets warmed by the heat from the surface, the Sun's gas becomes **much** warmer than the gas just above it and rises, to be replaced by descending cooler gas. This process of hot gas rising and cool gas falling is called convection and is quite similar to what happens in a pot of boiling water.

Finally the energy reaches a point in the Sun that is transparent enough for the energy to escape into space. This layer is called the "photosphere" and it is the "surface" we see when we look at the Sun through a telescope. Above the photosphere, the temperature actually rises (up to 20,000 degrees), and is hot enough that hydrogen emits bright spectral lines. This region is known as the chromosphere. Beyond the chromosphere is the large extended corona. Here temperatures can reach one million degrees. The heating mechanism is not well understood, but is currently believed to be due to the release of large amounts of energy in magnetic events.

Mass Matters

Stars differ from one another. Some are small and relatively cool at their surfaces, perhaps one-tenth the radius of the Sun and 3,000 degrees. Others are large and much, much hotter, perhaps 10 times the size of the Sun and as hot as 30,000–50,000 degrees.

If a star is bigger and hotter, it is giving off more energy. To maintain stable equilibrium it must produce energy more quickly than a smaller star. Likewise, a star that is smaller and cooler than the Sun must be producing energy more slowly or it will become unstable. The amount of fusion that goes on in a star is very sensitive to the temperature in the core. A more massive star has a hotter core and much higher fusion rates. In fact, a star that is 10 times the mass of our Sun is about 3,000 times brighter even though it only has 10 times as much fuel. As a consequence, the star survives a much shorter amount of time. The most massive stable stars (about 20–30 times the mass of the Sun) only live a few million years. A massive star has a hotter photosphere. Hotter objects glow bluer like the metal under an arc-welder's spark. The most massive stars are so hot that most of their energy is emitted beyond blue in the ultraviolet. You'll need SPF 10,000 if you ever visit Sirius, the bright blue star in the summer sky!

Less-massive stars fuse more slowly, live longer, and are cooler. Stars with cooler surfaces glow redder and fainter than warmer stars. The smallest stars have about .08 times (1/12th) the mass of the Sun. Computer models show us that gas balls smaller than this never attain high enough core temperatures to sustain fusion. This produces what is called a brown dwarf: a slowly cooling ball of gas that fades from a dull red glow into the infrared as it cools in a few tens of millions of years.

A graph of the luminosity versus temperature (called a Hertzsprung-Russell diagram) of all stars show that most of the stars in the sky, about 90 percent, fall in a line called the Main Sequence, where the brightest stars are also the bluest. Stars spend most of their lifetimes on the Main Sequence. All the rest of the stars in the graph are stars that are getting old and are in the process of dying.

Pediatrics and Geriatrics

Stars are born from the gas and dust in the Interstellar Medium. When stars die, they return their material to the Interstellar Medium, making the lives and deaths of stars a cycle of evolution: Gas and dust become stars, and stars return much of their material to gas and dust. With each turn of the cycle, elements such as hydrogen are fused into heavier elements.

Stars start to die when the hydrogen in their cores is completely consumed, at which point the core shrinks and heats up, This heating allows helium to "burn" to form carbon, generating energy up to 10,000 times faster. The extra energy causes the star's outer layers expand outward, where they then cool; the star becomes a **red giant**.

The ultimate fate of a star depends on its initial mass: **The most massive stars (60 times the mass of the Sun or more)** shed much of their mass during the main sequence phase as powerful stellar winds, including all of their hydrogen. In the cores of such massive stars most of the matter is converted into heavier elements. Near the end of a massive star's life, it swells, first forming a blue supergiant, then a red supergiant, even oscillating between the two as processes cause the star to heat and cool, expand and contract. The very most massive stars, called Wolf-Rayet stars, are so luminous they blow off their outer layers and are recognizable by their strange spectra.

Once the material at the core is burned to iron, the star faces the ultimate energy crisis, since iron cannot be fused to gain energy. In a flash, the iron core collapses and the star releases more energy than the star produced during its entire lifetime! This is a supernova explosion that expels material at 10 percent the speed of light and leaves behind a black hole.

Stars with initial masses between eight and 50 times that of the Sun do not evolve to the Wolf-Rayet stage; they never completely lose the hydrogen in their outer layers. Such stars also become blue and red supergiants. As they build up an iron core, they too explode as supernovae. The remaining core collapses until neutrons cannot be squeezed any closer, and the core becomes a neutron star. If the core is larger than five solar masses, collapse continues until it becomes a black hole. If the core is less than five solar masses, the collapse is stopped when electrons are squeezed into protons by the extreme pressure to form an ocean of neutrons. These neutron stars have giant magnetic fields that produce powerful beams of electrons. If, like a lighthouse light, the neutron star's spin sweeps the beams past Earth, we see pulses of radio energy—a pulsar.

Stars that are approximately the size of the Sun stop fusing elements after they form a core of helium or carbon. Their cores collapse until they are about the size of Earth and electrons can't be squeezed any closer, resulting in a white dwarf star. As the white dwarf forms, it gently expels the outer layers of the progenitor red giant star out into space, which it then lights up with UV radiation from the hot white dwarf core. This whole object is called a planetary nebula.

Sometimes a supernova can occur when a white dwarf accretes matter from a companion star that is evolving to its red giant phase. When the mass of the white dwarf reaches 1.4 solar masses, the electrons can't support the star against the inward pull of gravity, and it collapses. But since most white dwarfs contain lots of helium and carbon, the collapse triggers rapid nuclear burning, and within seconds blows up the star. This type of supernova—Type Ia—does not leave behind a collapsed remnant.

Stars and their descendants aren't the only objects to be seen in the night sky. Stars are just a tiny building block in a larger picture—they are the components of galaxies.

What Is a Galaxy?

Galaxies are isolated cities of stars. Our own galaxy, the Milky Way, is made up of more than a hundred billion stars all orbiting around a common center. All the stars we see at night—and a lot more that we can't see—make up our home galaxy, the Milky Way.

But galaxies are much more than collections of stars. To an astronomer, a galaxy is a gravitational potential well filled with fluid matter—plasma, gas, and particles of dust—that is held together by gravity, threaded by magnetic fields, and stirred up by the actions of stars imbedded in this interstellar medium. Always at work, gravity pulls together pockets of gas even further into stars that are born from the fluid; through life and upon death they return much of their material to the medium, leaving behind small compact remnants. So over its lifetime, a galaxy will evolve from a big puddle of gas to a collection of burnt-out cinders. Only traces of interstellar gases will be left—gases that are too hot or too diffuse to collapse into stars.

The Milky Way: Our Home

The Milky Way—our home galaxy—is a spiral, star-forming galaxy, much like the Andromeda Galaxy. The name comes from the bright band of stars that we see with the naked eye that comprises the main disk of the galaxy. But stars in other directions are also part of our galaxy: All of the stars we see at night are in the Milky Way, even if they are not in the visible feature we call the band of the Milky Way.

We cannot see our galaxy from the outside, but we live in a fairly run-of-the-mill star-forming disk galaxy; our Sun is about halfway out to the edge of the visible disk of stars. Most astronomers believe there is a black hole in the center of the Milky Way, but ours is only about a thousandth of the mass of the ones found in most other galaxies that host black holes at their centers.

Beyond its spheroidal bulge and the star-forming disk, the Milky Way is enshrouded by an extended halo of stars and gas. The stars are found mainly in beautiful jewel-like objects called globular clusters, which, as homes to the oldest stars in the galaxy, are likely to have been some of the first objects formed when our galaxy was born.

Like most objects in the universe, our galaxy is not in isolation. Much like the Earth has a satellite moon and stars have orbiting planets, our Milky Way has several satellite galaxies orbiting the galaxy in its outer reaches. Our nearest neighbor satellite galaxies are called the Large and Small Magellanic Clouds and are easily visible with the naked eye from the Southern Hemisphere, as they were to Magellan when he circumnavigated the globe. Our galaxy and its satellites, along with the spiral galaxies M31 and M33 and their attendant satellites, are all bound together in a small group with the imaginative name the Local Group.

Calculations tell us that the Magellanic Clouds won't stay in orbit around us forever. In about a hundred million years they will come crashing down on the Milky Way, pulled in by the relentless force of our galaxy's gravitational field. Data suggest that this is not an isolated incident. We believe that another satellite called the Sagittarius Dwarf Galaxy is crashing into us right now on the far side of the galaxy. And data suggest that many other such crashes took place in the past. In what will surely be the most spectacular crash for our Local Group, the Milky Way and the Andromeda Galaxy are scheduled to collide about 4 billion years from now, right about the time our Sun runs out of fuel. This time, however, we will not be the galactic cannibals; since the Andromeda is bigger than we are, it is the Milky Way that will be served up for Andromeda's lunch.

The universe is littered with galaxies. The Hubble Deep Field image shows tens of thousands of them all concentrated in a small patch of sky no larger than the head of a pin held at arms length. The most recent estimates suggest that there are more than 150 billion galaxies, each containing another 100 billion stars. That's a lot of stars!