AMERICAN MUSEUM OF NATURAL HISTORY

JOURNEY TO THE STARS

EDUCATOR'S GUIDE

amnh.org/education/stars

INSIDE:

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- **Essential Questions** for Student Inquiry
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ESSENTIAL QUESTIONS

Journey to the Stars explores the birth, life, and death of stars, and why they are important to us. Use the Essential Questions below to connect the show's themes to your curriculum. (Bolded terms are found in the glossary.)

What is a star?

A **star** is a huge glowing ball of hot gas, mainly hydrogen and helium. The temperature is so high in its **core** that **nuclear fusion** occurs, producing energy. The outward pressure of gas heated by fusion is balanced by the inward pull of **gravity**, leaving the star in **hydrostatic equilibrium**. This balance of forces lasts for most of a star's life, maintaining its steady temperature. **Radiation** and **convection** carry the energy from the core out through a star's atmosphere. When the energy gets high enough in the atmosphere that the region above it is transparent, it escapes out into space as light of all wavelengths, as well as **stellar wind**. Though stars may appear static, they rotate and vary in **luminosity**. There are hundreds of billions of stars in the Milky Way Galaxy alone. Among them is our Sun, the closest star to Earth.

Where do stars come from?

Every star forms in a huge cloud of gas and dust. Over time, gravity causes the cloud to contract, drawing the gas closer and closer together. As more gas accumulates at the center, it becomes denser and pressure increases. This causes it to heat up and begin to glow. Its gravity continues to pull in gas and dust, further increasing its **mass**, and thus its pressure and temperature. Eventually, the center reaches millions of degrees Celsius—hot enough to fuse hydrogen nuclei and generate intense energy. The heat generated by nuclear fusion causes the gas at the center of the star to expand, exerting an outward pressure. When hydrostatic equilibrium is reached, a star is born. Nuclear fusion powers the star until it eventually runs out of fuel and dies. Most stars form in tightly packed groups called **star clusters**, from which the majority are eventually ejected.

How do stars differ?

Though stars may look like similar points of light from our perspective on Earth, they actually differ from each other in many ways. Stars vary in their mass, size, temperature, color, luminosity, and age. They differ in their distance from Earth, and some orbit one or more other stars. They also change over the course of their lives. A star's mass determines its temperature and luminosity, and how it will live and die. The more massive a star is, the hotter it burns, the faster it uses up its fuel, and the shorter its life is. The hottest and most massive stars are blue and bright, while the coolest and least massive stars are red and dim.

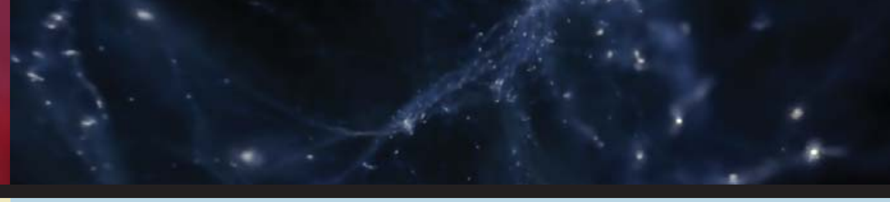
Why are stars important?

Without stars, we wouldn't be here at all. At the beginning of the universe, the only **elements** that existed were hydrogen, some helium, and trace amounts of lithium. All other naturally occurring elements were formed during the life and death of stars. At the end of a star's life, much of its matter is blown into space, where it provides the gas and dust for building new stars, planets, and everything on them including our bodies. Closer to home, when our Sun was born, its gravitational force held gas and dust in orbit, allowing for Earth's formation. Now the Sun holds the planets in their orbits, heats the surface of Earth, drives Earth's dynamic climate, and fuels photosynthesis.

Stars are factories for new elements. As they live and die, they form almost all of the elements on the periodic table. These elements make up Earth—and us.

How do scientists study stars?

We can see stars with the naked eye. But to observe them in detail, we depend on technology on the ground and in space. Ground-based telescopes enable scientists to see visible light, radio waves, and some infrared light. Satellites that orbit Earth, orbit the Sun, or journey through space allow scientists to observe light at all wavelengths, free from the blurring and obscuring effects of Earth's atmosphere, and also enable them to sample the solar wind. In the lab, scientists conduct experiments to infer atomic and molecular properties of stars, and to investigate how nuclear fusion works. Finally, scientists use theoretical modeling and computer simulations to compute how the properties of stars (such as density, pressure, velocity, or composition) change over time.



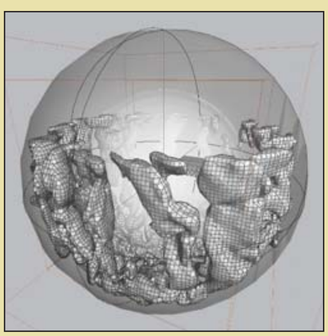
HOW DO WE KNOW?

Observations

Aside from **dark matter**, all objects in the universe emit light. Almost everything we know about these objects—from their chemical composition to their temperature to their age—comes from studying this light, only a fraction of which is visible to the human eye. Sophisticated telescopes capture different wavelengths of light, like X-rays and microwaves. This enables **astrophysicists** to investigate distant celestial objects. For example, they use cutting-edge observational techniques to see small, dim objects like **brown dwarfs**. On Earth and in space, these telescopes are our eyes to the universe.

Models & Simulations

Telescopes can provide snapshots of celestial objects in different stages of development. However the time scales are often just too long to see them in action. So, to help them understand billions of years of stellar history, astrophysicists create mathematical models that are based on the laws of physics to describe how nature behaves across the cosmos. They sometimes use powerful computers to make vast numbers of complex calculations to simulate the life of stars. Astrophysicists compare these models and simulations to observational data for verification. The visualizations in *Journey to the Stars* are based on both numerical models and observational data.



Computer simulations can follow the motion of gas in three dimensions to represent the interior of the Sun.

The results of such simulations can be visualized to reveal what happens beneath the Sun's surface. Here we can see swirling currents of gas that carry the Sun's energy outward.

COME PREPARED

Before you visit, review the **Essential Questions** to see how the show's educational themes connect to your curriculum. Consider what you would like your students to learn before, during, and after your trip.

Visit **amnh.org/education/stars** to:

1. **Download activities.** You may wish to use these activities before, during, and after your Museum visit to focus your experience around an educational theme:
    - Ecosystems and food webs (grades 3-5)
    - Sizes and distances of celestial objects (grades 6-8)
    - Life cycle of stars and the light stars emit (grades 9-12)

    You and your class chaperones can use some of the activities to guide you through suggested exhibitions after the show.

2. **Plan your visit.** Find important information on reservations, logistics, and lunchrooms.

NOTE: Please plan to arrive at the planetarium show boarding area, located on the 1st floor of the Rose Center, 15 minutes before the show starts.

CORRELATION TO STANDARDS

Your viewing of *Journey to the Stars* can be correlated to the standards below. Visit **amnh.org/resources/rfl/web/starsguide/standards.html** for a full listing of relevant NYS Science Core Curriculum Standards and NYC Scope & Sequence topics.

National Science Education Standards

All Grades • A1: Abilities necessary to do scientific inquiry • A2: Understanding about scientific inquiry • E1: Abilities of technological design • E2: Understanding about science and technology • G1: Science as a human endeavor • G2: Nature of science

Grades K-4 • B1: Properties of objects and materials • B2: Position and motion of objects • B3: Light, heat, electricity, and magnetism • C3: Organisms and environments • D2: Objects in the sky • D3: Changes in Earth and sky

Grades 5-8 • B1: Properties and changes of properties in matter • B2: Motions and forces • B3: Transfer of energy • D3: Earth in the Solar System

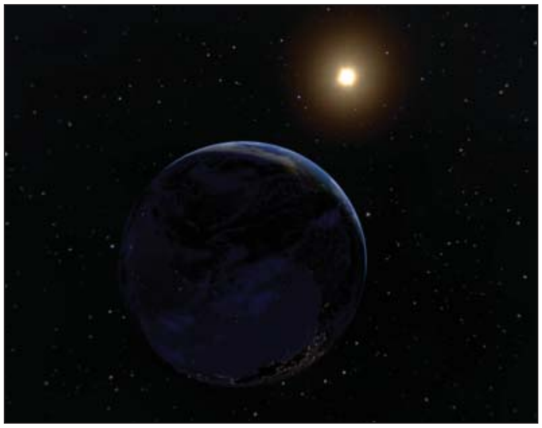
Grades 9-12 • B1: Structure of atoms • B2: Structure and properties of matter • B4: Motions and forces • B5: Conservation of energy and increase in disorder • B6: Interactions of energy and matter • D1: Energy in the Earth system • D4: Origin and evolution of the universe

TEACHING WITH THE SHOW

To support a class discussion after viewing *Journey to the Stars*, you may wish to review the main content points from each section of the show (bolded terms are found in the glossary) and then use the Guiding Questions (answers available at amnh.org/resources/rfl/web/starsguide/questions.html).

1. Introduction

- We live on a planet that orbits a **star** that is one of hundreds of billions in our galaxy.
- Our star, the Sun, is a middle-aged yellow star of somewhat above average **mass**.
- Without nurturing light that carries energy from our Sun, life as we know it would not exist.
- And without the **elements** formed by stars that lived and died billions of years ago, we—and everything around us—would not exist.



Visualizations of the Sun and Earth are created from observations made by scientists using both ground-based and space-based telescopes.

GUIDING QUESTIONS

All Grades

- What have you learned about stars?
- Why are stars important to us?
- How do scientists study stars? How do they study the Sun?

Grades 3–5

- What is the Sun?
- How is the Sun important?
- How are stars the same? How are they different?

Grades 6–8

- How does the Sun affect Earth?
- How is our Sun similar to or different from other stars?
- What are star clusters?
- What is mass? How does mass relate to gravity?
- What are the stages of the life of a star?

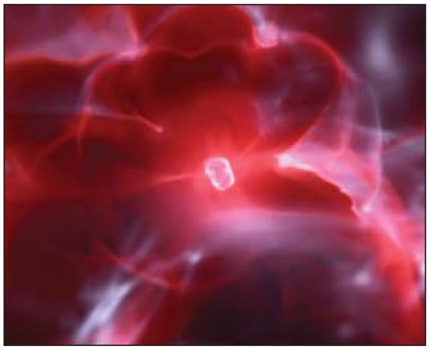
Grades 9–12

- What does the Sun emit?
- How do stars form?
- Why do stars shine?
- What does the color of a star indicate?
- How does life depend on ancient stars?
- How might the Sun impact future stars?
- How does the discovery of brown dwarfs expand our understanding of stellar objects?

2. Stellar History

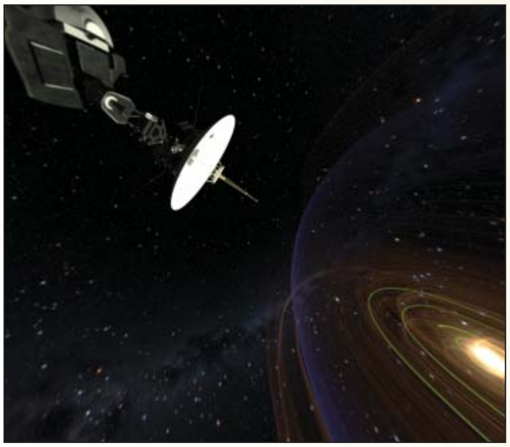
- Over 13 billion years ago (300 million years after the **Big Bang**), all that existed in the universe was **dark matter** and the elements hydrogen, helium, and trace amounts of lithium. Dark matter's **gravity** gathered the gas to form the first stars. Over the next few billion years, stars were born more rapidly than at any other period in the history of the universe. Stars now form at a rate one-tenth as high.
- About 4.5 billion years ago, within the Milky Way Galaxy, our Sun was born from a dense cloud of gas and dust, along with hundreds to thousands of other stars in a **star cluster**. As happens with many young stars, our Sun was ejected from its cluster. Since then it has traveled, along with its planets, in orbit around the center of the Milky Way.
- Except for hydrogen and helium, all the naturally occurring elements come from the life and death of stars. Together, they make up all the matter of daily life.
- Stars are different masses, temperatures, and colors. More massive stars are hotter and bluer, while less massive stars are cooler and redder. Yellow stars are in between.

Scientists use supercomputer models to understand star formation and star clusters. The first stars were massive—they burned hot and heated the surrounding gas (red, purple, white filaments). They lived fast and died young in supernova explosions (white region in center).



3. The Life of Stars: Our Sun as an Example

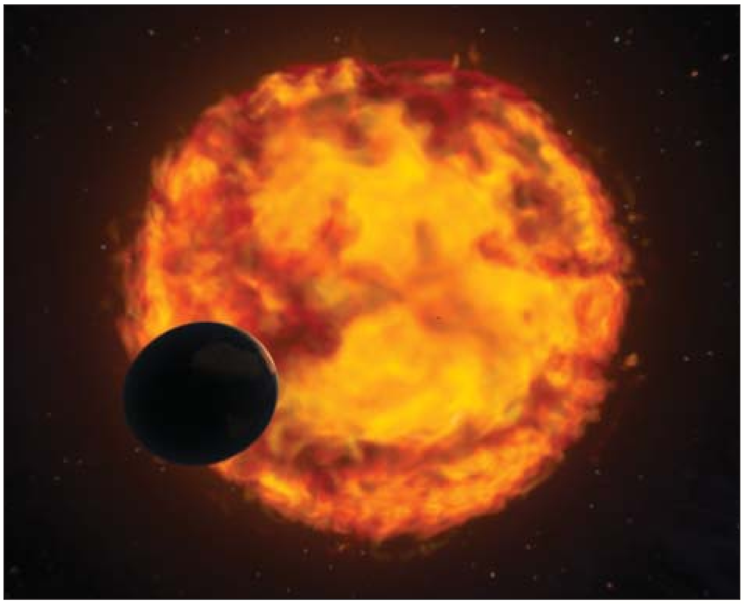
- **Nuclear fusion** in the **core** of the Sun generates energy (light of all wavelengths) that diffuses partway out as **radiation**. Energy is then carried the rest of the way to the surface by **convection**.
- The Sun, like all stars, performs a balancing act to keep itself together: the enormous outward pressure of hot gas is balanced by the inward pull of the Sun's own gravity. This is called **hydrostatic equilibrium**.
- The Sun continuously blasts a **solar wind** made up of charged particles (protons, electrons, and heavier ions). Magnetic explosions called **solar flares** produce storms in the solar wind and generate radiation. In rare cases, such storms can disrupt radio, cell phones, and GPS, or even cause blackouts on Earth.



The Voyager Space Probe has detected the outer edge of the Sun's solar wind and magnetic field, where they encounter the surrounding interstellar gas. This mission has extended the human footprint to the edge of the Solar System—it has traveled the farthest from Earth of any human-made objects.

4. Death of a Star: Our Sun

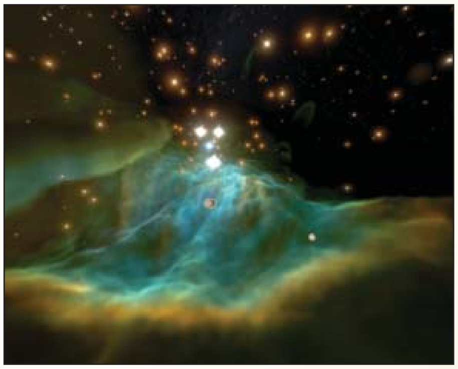
- In 5 billion years, our Sun will run out of fuel. Nuclear fusion in the core will cease, generating less energy, the pressure pushing outward will dwindle, and gravity will win. The outer layers will swell into a **red giant**, and ultimately blow out into the universe ejecting matter that may someday form other stars and planets. The core will collapse into a **white dwarf**.
- It will take tens of billions of years for the white dwarf, the remnant of our Sun, to cool and fade away. This is the way that nearly all stars end their lives.



Towards the end of its life, the Sun will become a red giant. Its outer layers will swell towards Earth.

5. Our Solar Neighborhood

- The stellar life cycle continues today. Stars still form, live, and die. The young Orion Nebula contains one of many clusters of newborn stars in the Milky Way. Some of them are just forming planets. The Pleiades, a mature star cluster, is ejecting stars. The Helix Nebula was expelled by a star at the end of its life.
- A **brown dwarf** shares properties of both stars and planets, having a mass that's in between. For every star like our Sun, there are hundreds of brown dwarfs. Scientists do not fully understand these objects or how they relate to planets and stars.
- On Earth, the stars that we see in the night sky—and the one that we see during the day—each tell a story.



Scientists find huge stellar nurseries like the Orion Nebula throughout the Milky Way Galaxy and the universe today.

Scientists also observe the remains of stars, like the Helix Nebula, within which the star's core has already contracted into an extremely dense white dwarf.

ONLINE RESOURCES

All Grades

Journey to the Stars for Educators
amnh.org/education/stars
Free online resources and fieldtrip information.

Cullman Hall of the Universe
amnh.org/rose/universe.html
Vivid animations of stellar life cycles in the "Stars Zone" include a high mass star that swells into a red giant and a low mass star that becomes a white dwarf.

Solar & Heliospheric Observatory (SOHO)
soho.nascom.nasa.gov
Nearly up-to-the-minute images of the Sun and a full range of educational resources, including a very informative "Sun 101" resource and access to solar physicists.

StarGazers
stargazers.gsfc.nasa.gov
Lesson plans, activities, and information about the structure and workings of the Sun.

Elementary & Middle School

Astronomy OLogy
amnh.org/ology/astronomy
Hands-on activities and articles related to astronomy, such as a Stargazing Sky Journal, Build the Big Dipper Mobile, One-on-One with the Sun, and Planetary Mysteries.

Solar System Exploration
solarsystem.nasa.gov/educ/lessons.cfm
Lesson plans and activities related to NASA missions throughout the Solar System, as well as profiles of the men and women involved in NASA's space exploration.

Middle & High School

Sun-Earth Day
sunearthday.nasa.gov
Extensive educational guides, activities, and images related to the Sun, as well as information about the Sun-Earth Day program, which celebrates a different aspect of NASA Sun-Earth Connection research each year.

Discovering the Universe
amnh.org/resources/moveable_astro
Curriculum materials that explore stars and other celestial bodies, and demonstrate how astrophysicists analyze their distant light for clues to their physical and chemical properties.

Science Bulletins
amnh.org/sciencebulletins
Videos, interactives, and essays that introduce students to current research in astrophysics. Check out the Astro features and snapshots, including "SALT: Imaging the Southern Sky," "Sloan Digital Sky Survey: Mapping the Universe," and "Earth's Magnetic Shield."

Chandra X-Ray Observatory
chandra.harvard.edu/edu/
Information and activities related to the Chandra X-Ray Observatory, which scientists use to study high-energy regions of space, such as the remnants of supernovas.

How Stars Work
howstuffworks.com/star.htm
Information about the properties and life cycles of stars.
See also: howstuffworks.com/sun.htm

CREDITS

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Photo Credits

Sun insert: Layers of the Sun diagram and the Sun in three wavelengths, © NASA.
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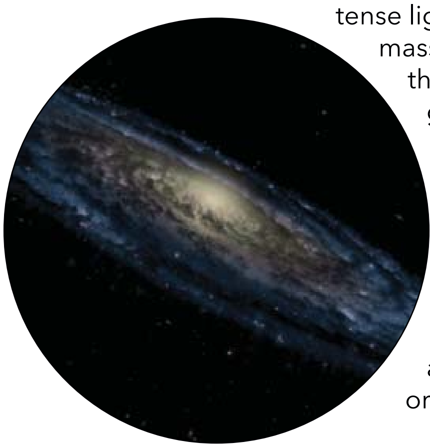
AMERICAN MUSEUM OF NATURAL HISTORY

ABOUT THE SHOW

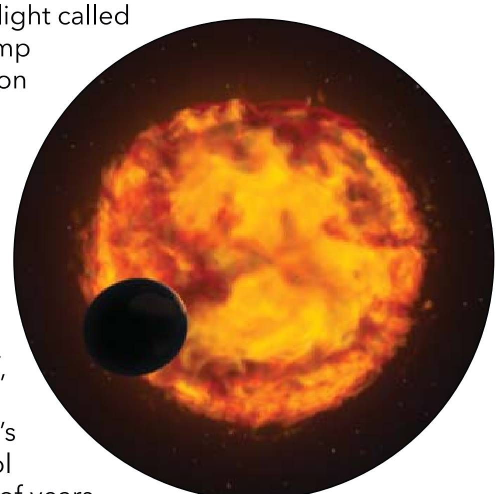
The journey begins on Earth, where we bask in the warm rays of the setting Sun. We lift off and travel out beyond our Solar System, and even beyond the edge of our galaxy.

We then jump over 13 billion years into the past, to a time when there were no stars at all. In this primeval state, there was only an invisible substance called dark matter, along with hydrogen and helium gas. But soon, the first shining stars appeared. They burned hot, lived fast, and exploded in incredible supernovas that blasted new elements out into space. These new elements provided the essential raw materials for building new stars, planets, and, eventually, even life. The gravity of dark matter collected gas into galaxies—more and more galaxies formed, along with more and more stars within them. One of the galaxies was our own Milky Way.

Our journey brings us forward in time to about 4.5 billion years ago, when our very own Sun was born. A cloud of gas and dust, somewhere in the Milky Way, formed stars of many different masses and colors. Within this tightly packed group of stars, called a star cluster, was our young Sun. The intense light and heat of the massive bright stars dispersed the surrounding cloud of gas and dust. The most massive stars lived only briefly and exploded in gigantic supernovas. Eventually, the less massive stars were flung out of the cluster—some, like our Sun, with planets already formed and orbiting around them.



We travel to the present day, zooming in on our Sun, to see how stars work. The Sun's layers are revealed from the outside in: the million-degree corona blasting out a solar wind, the photosphere with its darker sunspots, and, below that, the tumultuous currents of hot gas churning above the radiant interior. The Sun's core is where nuclear fusion happens: atomic nuclei fuse together, releasing immense amounts of energy. Pulling back from the Sun, we see how its churning outer layers generate a vast magnetic field, and a stunning visualization then reveals how the Sun's magnetic field and solar wind extend across the Solar System. Earth's own magnetic field almost always shields it from the dangerous blast of charged particles—only a trickle of solar wind gets through, sliding down to the poles and producing radiant displays of light called auroras. A quick jump to the future, 5 billion years from now, reveals our Sun at the end of its life, as it expands into a red giant and then sheds its outer layers into space. All that is left is a white dwarf, the hot dense remnant of the Sun's core, which will cool down over billions of years.



Our journey returns us to the present, to explore stars in our galactic backyard that are going through all these processes now. We visit the dazzling Orion Nebula, Pleiades, and Helix Nebula to observe stars being born, being ejected from star clusters, slowly dying, and shedding matter that may someday form other stars and planets. Finally, a short flight back home lets us experience the familiar night sky as seen on Earth. When morning arrives, the light of the rising Sun clearly reveals what stars have made possible.

The Hayden Planetarium at the Rose Center for Earth and Space uses state-of-the-art technology to communicate the excitement of cutting-edge science. A digital video system projects across the theater's 67-foot-wide hemispheric dome, and every seat has an amazing view.

Based on authentic scientific observations, data, and models, the planetarium show takes us deep into space and through billions of years to witness the birth, life, and death of stars. Along the journey, we discover how and why stars are important to us—indeed, how and why they make all life possible.

CONTINUE YOUR JOURNEY TO THE STARS

AT THE MUSEUM

Rose Center for Earth & Space

- **Scales of the Universe** (2nd floor)
  Investigate the vast range of sizes in the universe using the Hayden Sphere as a basis for comparison.
- **Heilbrunn Cosmic Pathway** (entrance on 2nd floor)
  Walk down this gently sloping 360-foot walkway to explore 13 billion years of cosmic evolution.
- **Cullman Hall of the Universe** (lower level)
  Examine how the universe evolved into galaxies, stars, and planets.

Gottesman Hall of Planet Earth

(1st floor)

Explore how our own Earth took shape over 4.5 billion years ago.

Arthur Ross Hall of Meteorites

(1st floor)

Discover how our Solar System evolved into the Sun and planets of today.

EXPLORE ONLINE

Journey to the Stars
amnh.org/stars
Visit the planetarium show website.

Astronomy OLogy
amnh.org/ology/astronomy
Kids can find out how to keep a stargazing sky journal, read an interview with the Sun, and more!

Science Bulletins
amnh.org/sciencebulletins
Videos, interactives, and essays bring you current research in astrophysics.

Cullman Hall of the Universe
amnh.org/rose/universe.html
Click on the "Stars Zone" to watch animations of stellar life cycles, including a high mass star that swells into a red giant.

FUN FACTS

- Our Sun has lots of company: it is one of more than 200 billion stars in the Milky Way Galaxy alone. Every individual star that you can see with the naked eye is in the Milky Way.
- But there are many more stars than that. There are perhaps 40,000,000,000,000,000,000,000 stars or more!
- Stars are factories for new elements. As they live and die, they convert their hydrogen gas into all the rest of the elements on the periodic table. These elements make up Earth and you.
- A star's mass—how much matter it contains—determines its temperature, luminosity, color, and how it will live and die.
- Our Sun is more massive than the average star. Nearly 90% of stars are less massive, making them cooler and dimmer.
- The hottest and most massive stars are bright and blue, while the coolest and least massive stars are dim and red. Yellow stars like our Sun are in-between.
- About 99% of stars, including our Sun, will end their lives as white dwarfs. Only about 1% of stars are massive enough to explode as a supernova.

LIFE CYCLE OF STARS

All stars are born, mature, and eventually die. A star's mass is the most important factor that determines how it will live and die.

Stars are Born

Throughout the universe, **dense clouds of gas and dust** are the birthplaces of stars. Gravity pulls the gas and dust into clumps. If the clump is massive enough, a star forms—increased pressure and temperature cause its core to ignite, initiating nuclear fusion. Lower mass objects such as brown dwarfs, planets, and asteroids form along with stars.

Stars Live and Die

After billions of years of hydrostatic equilibrium, a star will run out of fuel in its core and begin to die. What happens next depends on the mass of the star.

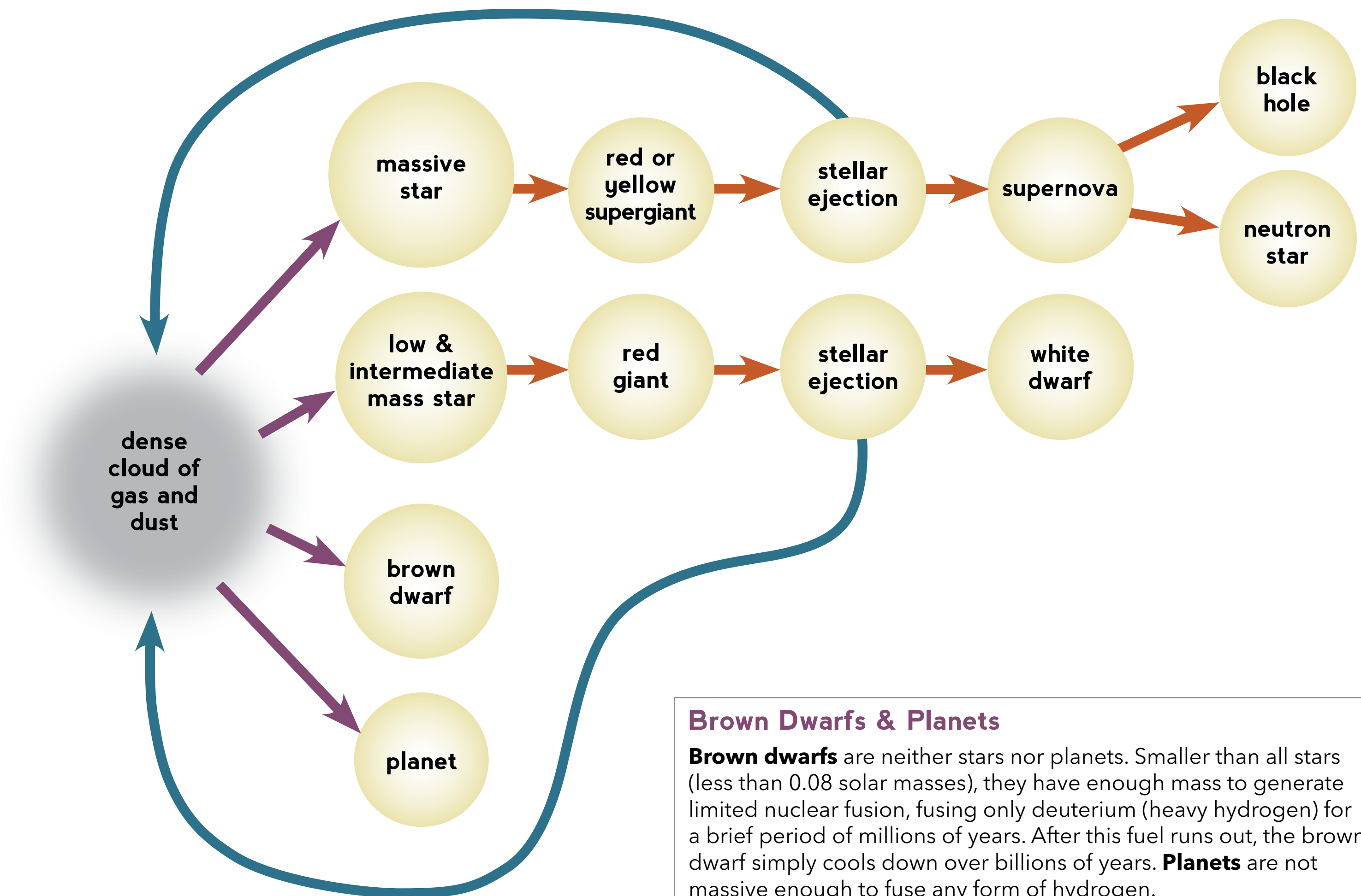
For **low and intermediate mass stars** (up to 8 solar masses), the outer layers swell into a **red giant**. The star then ejects its outer layers, while the interior collapses into a **white dwarf**. It takes billions of years for the white dwarf to cool down. Ninety-nine percent of stars end their lives like this.

A **high mass star** (between 8 and 20 solar masses) becomes a **red supergiant** and begins to shed stellar matter. The star collapses in on itself, causing it to explode as a **supernova**, ejecting even more matter. Its core becomes a **neutron star**, which takes millions of years to cool down.

The **most massive stars** (over 20 solar masses) form **red** or **yellow supergiants**, and then explode in **supernovas**, forming **black holes** in their centers. Black holes are so dense that not even light can escape their gravity.

The Cycle Continues

As a star dies, it **ejects matter** out into space that provides raw material for new stars, planets, and other celestial objects.



Brown Dwarfs & Planets

Brown dwarfs are neither stars nor planets. Smaller than all stars (less than 0.08 solar masses), they have enough mass to generate limited nuclear fusion, fusing only deuterium (heavy hydrogen) for a brief period of millions of years. After this fuel runs out, the brown dwarf simply cools down over billions of years. **Planets** are not massive enough to fuse any form of hydrogen.

GLOSSARY

Big Bang: The moment, over 13 billion years ago, when the universe began to expand from an almost infinitely dense and hot state.

Big Bang nucleosynthesis: The fusion of hydrogen into helium when temperatures were high enough throughout the universe, from three seconds to twenty minutes after the Big Bang.

black hole: An object so dense that nothing can escape its gravity, not even light. Black holes are formed by the most massive stars at the ends of their lives.

brown dwarf: An object less massive than a star but more massive than a planet. Nuclear fusion of deuterium (heavy hydrogen) occurs within its core for a brief period of millions of years after its birth.

chromosphere: A hot outer layer present in many stars, lying between the photosphere and the corona.

convection: The rising of heated material and falling of cooled material in a region simultaneously heated from below and cooled from above, such as a pot of water about to boil or the interior of a star.

convective zone: A layer of a star, where convection occurs, producing turbulence. This turbulence generates the Sun's magnetic field.

core: The center of a star, where nuclear fusion generates intense energy.

corona: The million-degree outermost layer of many stars, which is so hot that gas escapes the star's gravity and flows out into space as a stellar wind.

dark matter: An invisible substance making up most of the mass in the universe that is detected by its gravitational influence. It has existed since the Big Bang.

element: A substance containing only atoms that all have the same number of protons.

gravity: The force of attraction between any two masses.

heliosphere: The extent of space affected by the Sun's magnetic field, which reaches past Pluto.

hydrostatic equilibrium: In a star, the balance achieved between the enormous outward pressure of gas heated by fusion and the inward pull of its own gravity.

luminosity: The total amount of light that a star emits. Luminosity is not the same as brightness, which drops off with distance.

magnetic field: The forces produced by moving, charged material, such as the turbulent, ionized gas in a star's convective zone.

mass: The amount of matter contained within a given object.

neutron star: A stellar remnant formed by a massive star when it explodes as a supernova at the end of its life. They are extremely dense and about the size of a city.

nuclear fusion: The combination of light atoms such as hydrogen and helium into heavier ones, such as helium, carbon, and oxygen. This process releases intense energy.

photosphere: The layer of a star where it becomes transparent, and where light escapes into space.

radiation: Energy that travels in the form of rays or waves (e.g. electromagnetic waves such as light, radio, X-rays, and gamma rays), or in the form of subatomic particles.

radiative zone: The layer of a star just above the core, where energy produced by nuclear fusion in the core is diffused outward by radiation.

red giant: The form that most stars take near the end of their lives, after they use up their fuel and their outer layers swell. High mass stars become red supergiants, or even yellow supergiants.

solar flare: A magnetic explosion on the Sun that produces storms in the solar wind and generates dangerous radiation.

star: A huge luminous ball of hot gas in hydrostatic equilibrium.

star cluster: A group of many stars orbiting each other tightly.

stellar wind: A flow of high-speed gas ejected by stars. It is called the **solar wind** when referring to our Sun.

sunspots: Darker, cooler areas on the Sun's photosphere that form where the magnetic field is strongest.

supernova: An explosion that occurs when a high mass star uses up its fuel and is unable to maintain hydrostatic equilibrium.

white dwarf: The final state of 99% of all stars after they evolve into red giants. White dwarfs are very dense and about the size of Earth.

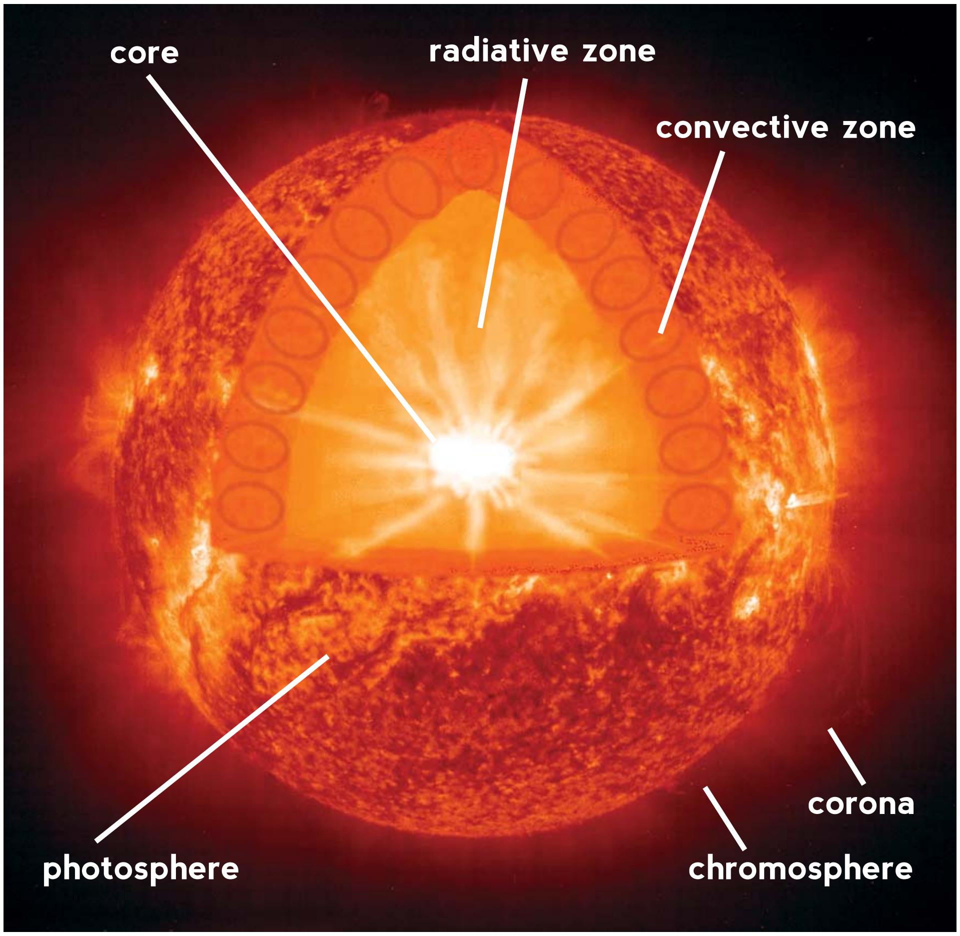
"STELLAR" CAREERS

astrophysicist or **astronomer:** A scientist who studies the physical laws of the universe and the physical properties of celestial objects such as stars and galaxies. Today these titles are used interchangeably.

heliophysicist: A scientist who studies the Sun. Also called a solar physicist.

OUR STAR: THE SUN

Our star, the Sun, is a middle-aged yellow star that is more massive than the average star. It is a star that nurtures and supports life on Earth. Its heat and light warm Earth's surface, drive phenomena such as weather and ocean currents, and fuel photosynthesis. We experience the Sun's energy every time we feel its warmth on our skin or see with the aid of its light. (Bolded terms are found in the glossary.)



CORE

The Sun's energy is generated deep within its **core** by one of the most powerful processes in the universe: **nuclear fusion**. Hydrogen nuclei smash together, forming helium and releasing huge amounts of energy. This is why a star shines. It burns its fuel through nuclear fusion (unlike fire, which burns through oxidation). The balance between the outward push of gas heated by fusion and the inward pull of gravity is called **hydrostatic equilibrium**.

RADIATIVE & CONVECTIVE ZONES

In the **radiative zone**, closest to the core, the gas is smooth and static, and the energy (light of all wavelengths) diffuses through it as **radiation**. Above this layer is the **convective zone**, where swirling currents of gas carry the Sun's energy outward in a process called **convection**: gas is simultaneously heated from below by fusion, and cooled from above as energy is released into space. Convection causes the gas to churn, like water just before it boils.

PHOTOSPHERE, CHROMOSPHERE, & CORONA

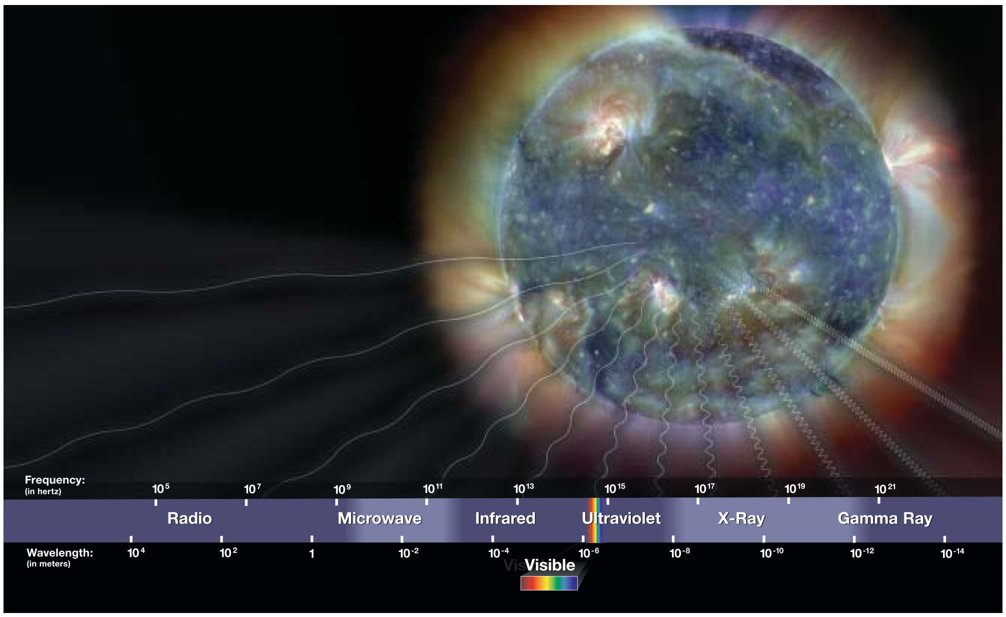
The **photosphere** is the Sun's visible surface, where the atmosphere of the Sun becomes transparent to visible light. **Sunspots** are cooler regions of the photosphere. The chromosphere and corona are the outermost layers of the Sun. The **chromosphere** is ten times hotter than the photosphere, but the **corona** is still hotter—a million degrees—so hot that it escapes the star's gravity and flows out into space as solar wind.

THE SUN MAKES MORE THAN LIGHT

Understanding Sunshine

What we see as sunshine is the visible light that reaches Earth and lights our day. But the Sun also gives off energy in invisible wavelengths of light, such as gamma rays, X-rays, ultraviolet, infrared, microwave, and radio.

Spacecraft that orbit Earth and the Sun provide dramatic, close-up images of the Sun in different wavelengths of light. **Heliophysicists** color code the images to make them easier to interpret: they use artificial color to visualize the Sun in different wavelengths.



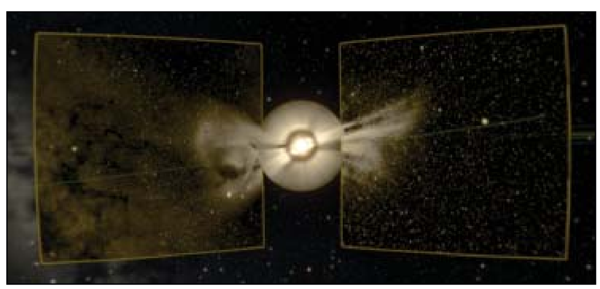
The Sun and the Electromagnetic Spectrum

The electromagnetic spectrum is the entire range of electromagnetic **radiation** (light). As wavelength increases, frequency and energy decrease.

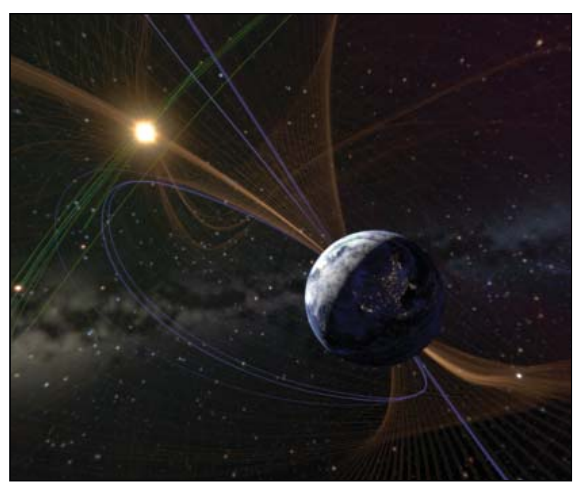
This image of the Sun is actually three images merged into one. Heliophysicists took images of the solar corona at three wavelengths within the invisible UV range. They assigned a color code (red, yellow, blue) to each image, revealing what solar features, like flares, look like at the different wavelengths.

Solar Wind and Radiation

The **solar wind** is a constant flow of hot gas that blasts out from the Sun's corona at a million miles an hour. Fortunately, Earth's **magnetic field** and atmosphere almost always protect us: typically, only a trickle of solar wind gets through, sliding down to the North and South Poles and producing radiant displays of light called auroras. Earth's magnetic field also protects us from the constant flow of dangerous radiation emitted by the Sun. However, sometimes magnetic explosions on the Sun, called **solar flares**, create storms in the solar wind. Under rare conditions, they can disrupt radio, cell phones, and GPS, or even cause blackouts on Earth. The Sun, the Sun's magnetic field, and the solar wind together form a dynamic, interconnected system called the **heliosphere**, which extends across our Solar System to beyond the Kuiper Belt.



Satellite images reveal gusts in the solar wind.



Solar wind drags the Sun's magnetic field along with it. Earth is almost always protected from the solar wind by its own magnetic field and atmosphere.