Educator Background

All sessions provide educators with a script to use to help accurately explain scientific concepts to learners. This document provides additional background information for the educator.

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Anatomy of the Sun

[Text adapted from NASA Sun]

The Sun is a 4.5-billion-year-old star – a hot glowing ball of hydrogen and helium at the center of our Solar System. The Sun is about 93 million miles (150 million kilometers) from Earth, and without its energy, life as we know it could not exist here on our home planet.

The Sun is the largest object in our Solar System. The Sun's volume would need 1.3 million Earths to fill it. Its gravity holds the Solar System together, keeping everything from the biggest planets to the smallest bits of debris in orbit around it. The hottest part of the Sun is its core, where temperatures top 27 million degrees Fahrenheit (15 million degrees Celsius). The Sun's activity, from its powerful eruptions to the steady stream of charged particles it sends out, influences the nature of space throughout the Solar System. The Sun is only an average star in terms of its size. Stars up to 100 times larger have been found. Many star systems have more than one star.

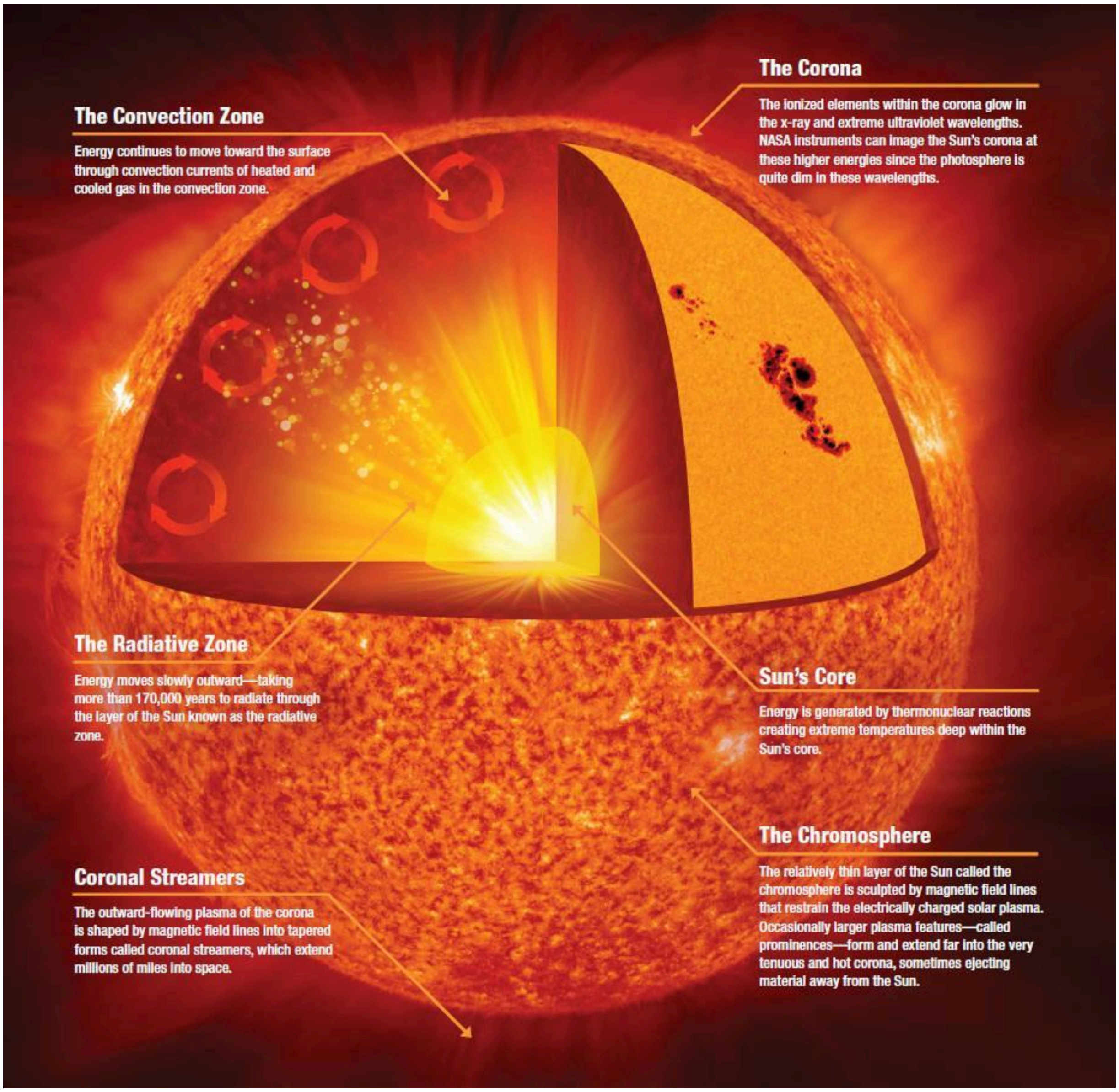
Because of the enormous mass of the Sun, its gravity heats and compresses the hydrogen and helium atoms so that at the core it is about the same density as solid lead, while at the surface the gas density is less than Earth's atmosphere at sea level. Detailed models based on the behavior of matter allow astronomers to make detailed predictions about the mass, density, temperature, and energy flows inside the Sun.

The Sun is composed of a superheated state of matter called **plasma**. To become a plasma, ordinary gas has to become **ionized**. This means that the atoms that make up the gas have released one or more of their electrons. The atom is then said to be ionized. An ordinary gas contains a mixture of neutral (no net charge) atoms and molecules traveling at speeds that depend on the temperature of the gas. When the collisions carry enough energy, they can ionize the particles. At room temperature, the nitrogen and oxygen molecules that make up our atmosphere travel at only 500 m/s (1,000 mph). In contrast, hydrogen atoms have to be traveling at about 10 km/s corresponding to a temperature of 10,000 K for each impact to cause the single hydrogen electron to be ejected.

Common examples of plasma on Earth include some types of flames, lightning, and neon signs. Plasma is actually the most common state of matter in the universe, making up the billions and billions of stars.

Another important thing about plasmas is that there is no net motion, or pattern, of a heated plasma because the particles are just randomly buzzing around in space. However, if for some reason a flow develops among some of the ions and electrons, this produces an organized electrical current. But just like any electrical current, it will also generate a magnetic field. This is why the surface of the Sun, with its convecting plasma flows and other large-scale currents, is such a complex mixture of magnetic fields of all shapes and sizes. The complex interactions of the magnetic fields on the Sun create **sunspots, solar flares, coronal mass ejections (CMEs),** and other eruptions on the surface of the Sun. These eruptions of plasma are what cause **space weather**. But not all eruptions from the solar surface cause matter to be ejected into space. The plasma needs to achieve escape velocity, which determines if a cloud of plasma ejected from the surface will escape the Sun and travel through interplanetary space.

The Sun has several regions. The interior regions include the **core, the radiative zone, and the convection zone**. Moving outward – the visible surface or **photosphere** is next, then the **chromosphere**, followed by the transition zone, and then the **corona** – the Sun's expansive outer atmosphere.



Anatomy of the Sun. *Credits: NASA/Jenny Mottar*

Once material leaves the corona at supersonic speeds, it becomes the **solar wind**, which forms a huge magnetic "bubble" around the Sun, called the **heliosphere**. The heliosphere extends beyond the orbit of the planets in our Solar System. Thus, Earth exists *inside* the Sun's atmosphere. Outside the heliosphere is **interstellar space**.

The core is the hottest part of the Sun. Nuclear reactions here – where the **fusion** of hydrogen into helium – power the Sun's heat and light. Temperatures top 27 million °F (15 million °C) and it's about 86,000 miles (138,000 kilometers) thick. The density of the Sun's core is about 150 grams per cubic centimeter (g/cm^3). That is approximately eight times the density of gold (19.3 g/cm^3) or 13 times the density of lead (11.3 g/cm^3).

Energy from the core is carried outward by **radiation**. This radiation bounces around the radiative zone, taking about 170,000 years to get from the core to the top of the convection zone. Moving outward, in the convection zone, the temperature drops below 3.5 million °F (2 million °C). Here, large bubbles of hot plasma (a soup of ionized atoms) move upward toward the photosphere, which is the layer we think of as the Sun's surface.

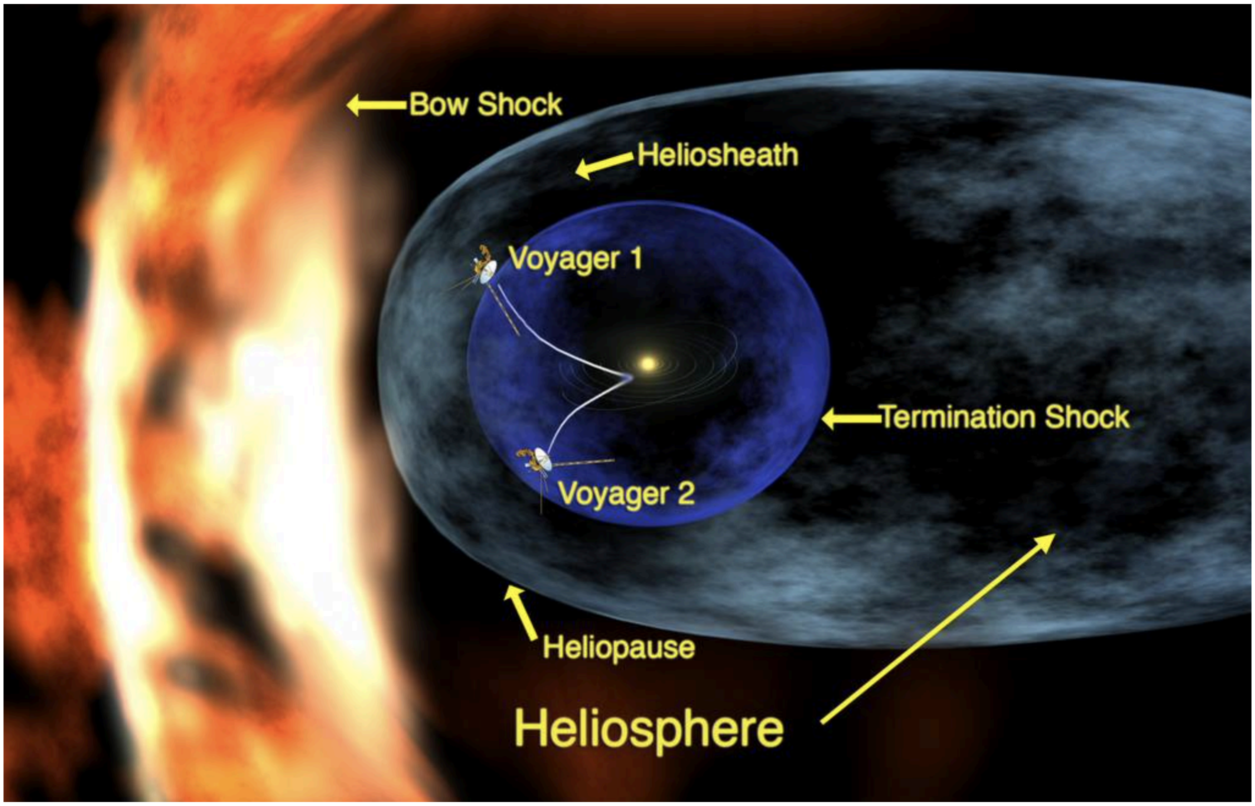
What is Heliophysics?

[Text adapted from NASA Sun and NASA Heliosphere]

Heliophysics is the study of the nature of the Sun, how it influences the very nature of space – and, in turn, the atmospheres of planets and the technology that exists there. This includes an understanding of the Sun and its interactions with Earth and the Solar System. Space is not, as is often believed, completely empty; instead, we live in the extended atmosphere of an active star. Our Sun sends out a steady outpouring of particles and energy – the **solar wind** – as well as a constantly writhing magnetic system. This extensive, dynamic solar atmosphere surrounds the Sun, Earth, and the planets, and extends far out into the Solar System.

Studying the Sun not only helps us understand fundamental information about how the universe works, but also helps protect our technology and astronauts in space. NASA seeks knowledge of near-Earth space, because – when extreme – **space weather** can interfere with our communication systems, satellites, and power grids. The study of the Sun and space can also teach us more about how stars contribute to the habitability of planets throughout the universe.

The Sun sends out a constant flow of charged particles called the solar wind, which ultimately travels past all the planets to some three times the distance to Pluto before being impeded by the **interstellar medium** (the space between stars). This forms a giant bubble around the Sun and its planets, known as the **heliosphere**. NASA studies the heliosphere to better understand the fundamental physics of the space surrounding us – which, in turn, provides information regarding space throughout the rest of the universe, as well as what makes planets habitable.



An artist's concept of our heliosphere as it travels through our galaxy with the major features labeled. *Credit: NASA*

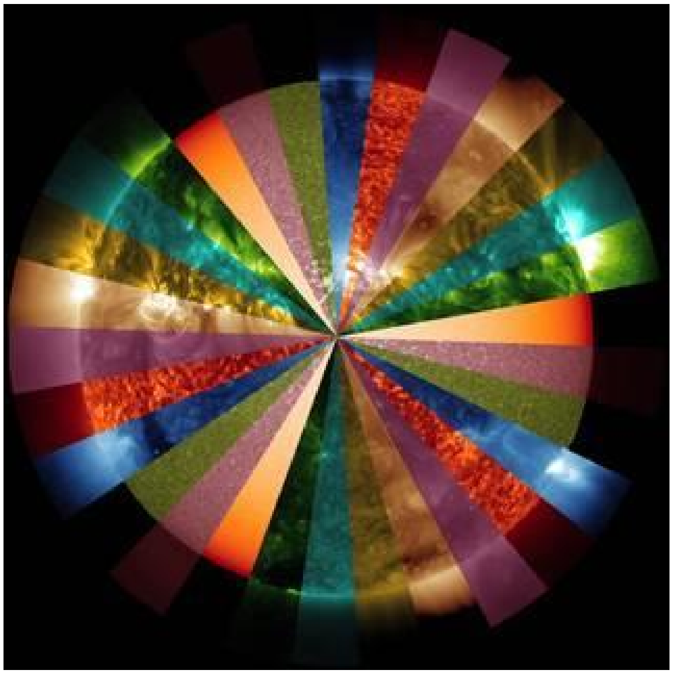
The solar wind is a gas of charged particles known as plasma, a state of matter governed by its own set of physical laws just as the more common solids, liquids, and gases are. As the solar wind sweeps out into space, it creates a space environment filled with radiation as well as magnetic fields that trail all the way back to the Sun. This space environment is augmented by interstellar cosmic rays and occasional concentrated clouds of solar material that burst off the Sun, known as **coronal mass ejections (CMEs)**.

This complex environment surrounds the planets and ultimately has a crucial effect on the formation, evolution, and destiny of planetary systems. For one thing, our heliosphere acts as a giant shield, protecting the planets from galactic cosmic radiation. Earth is additionally shielded by its own magnetic field, the **magnetosphere**, which protects us not only from solar and cosmic particle radiation but also from erosion of the atmosphere by the solar wind. Planets without a shielding magnetic field, such as Mars and Venus, are exposed to such processes and have evolved differently.

NASA's studies of the heliosphere include research into how the solar wind behaves near Earth, what causes and sustains magnetic and electric fields around other planets, how the heliosphere interacts with the interstellar medium, what the boundaries of the heliosphere look like, the origin and evolution of the solar wind and the interstellar cosmic rays, and what contributes to the habitability of exoplanets.

The field is, therefore, intensely cross-disciplinary. Heliospheric research often works hand in hand with planetary scientists, astrophysicists, astrobiologists, and space weather researchers.

Mapping out this interconnected system requires a holistic study of the Sun's influence on space, Earth, and other planets. NASA has a fleet of spacecraft strategically placed throughout our heliosphere – from **Parker Solar Probe** at the Sun observing the very start of the solar wind; to satellites around Earth; to the farthest human-made object, **Voyager**, which is sending back observations on **interstellar space**. Each mission is positioned at a critical, well-thought-out vantage point to observe and understand the flow of energy and particles throughout the Solar System – all helping us understand the effects of the star we live with.



This composite image from NASA's Solar Dynamics Observatory (SDO) shows different slices of the Sun viewed in different wavelengths. Normally invisible to the naked eye, images from each wavelength are colorized. The image clearly shows how different wavelengths can highlight different features on the Sun. *Credit: NASA's Scientific Visualization Studio*

Space Weather

[Text adapted from NASA Sun and NASA Sun: Facts]

Everyone is familiar with changes in the weather on Earth, but "weather" also occurs in space. Much like terrestrial weather, **space weather** results from a complex system driven both by the Sun and events much closer to Earth.

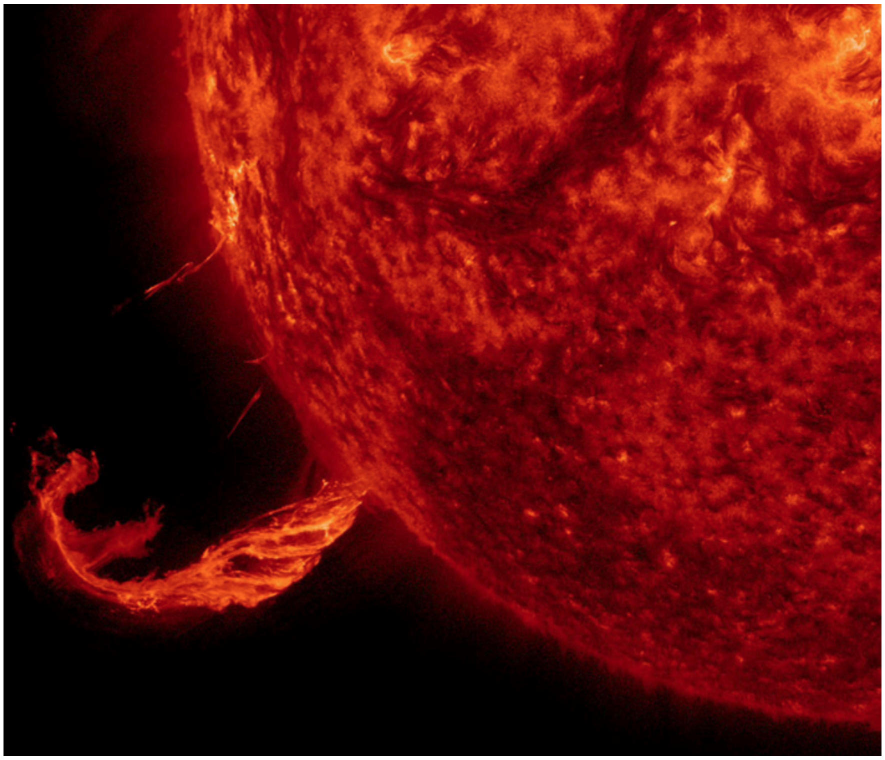
Though space is about a thousand times emptier than even the best laboratory vacuums on Earth, it's not completely devoid of matter – the Sun's constant outflow of **solar wind** fills space with a thin and tenuous wash of particles, fields, and **plasma**. This solar wind, along with other solar events like giant explosions called **coronal mass ejections (CMEs)**, influences the very nature of space and can interact with the magnetic systems of Earth and other worlds. Such effects also change the radiation environment through which our spacecraft – and, one day, our astronauts headed to Mars – travel. Close to Earth, such space weather can interfere with satellite electronics, communications, and GPS signals, and even – when extreme – utility grids on Earth.

The National Oceanic and Atmospheric Administration (NOAA) Space Weather Prediction Center is the U.S. Government's official source for space weather forecasts on how such events may affect Earth. NASA heliophysics works as the research arm of the Nation's space weather effort, coordinating with NOAA as well as other U.S. Government Agencies.

To support space weather research, NASA observes the Sun and our space environment 24-7 with a fleet of solar observatories studying everything from the dynamics of the Sun, to the solar atmosphere, to the particles and magnetic fields in the space surrounding our home planet. Collectively, such observations help us understand the physical processes driving the space environment, which, in turn, helps to create better simulations and predictive models of this complex system – and ultimately better protect our technology and astronauts from space weather.

The Sun is the main source of **space weather**. Solar activity can release huge amounts of energy and particles, some of which impact us here on Earth. Much like weather on Earth, conditions in space – known as space weather – are always changing with the Sun's activity.

When the solar wind interacts with Earth's magnetic field, a **geomagnetic storm** occurs. The strongest **geomagnetic storm** on record is the **Carrington Event**, named for British astronomer Richard Carrington who observed the Sept. 1, 1859, **solar flare** that triggered the event. Telegraph systems worldwide went haywire. Spark discharges shocked telegraph operators and set their telegraph paper on fire. Just before dawn the next day, skies all over Earth erupted in red, green, and purple auroras – the result of energy and particles from the Sun interacting with Earth's atmosphere. Reportedly, the auroras were so brilliant that newspapers could be read as easily as in daylight. The auroras, or Northern Lights, were visible as far south as Cuba, the Bahamas, Jamaica, El Salvador, and Hawaii.



The Sun blew out a coronal mass ejection along with part of a solar filament over a 3-hour period (Feb. 24, 2015). While some of the strands fell back into the Sun, a substantial part raced into space in a bright cloud of particles (as observed by the Solar and Heliospheric Observatory [SOHO] spacecraft). The activity was captured in a wavelength of extreme ultraviolet light. Because this occurred way over near the edge of the Sun, it was unlikely to have any effect on Earth. *Credits: NASA/Solar Dynamics Observatory*

The Sun doesn't behave the same way all the time. It goes through phases of high and low activity, which make up the **solar cycle**. Approximately every 11 years, the Sun's geographic poles change their magnetic polarity – that is, the north and south magnetic poles swap. During this cycle, the Sun's photosphere, chromosphere, and corona change from quiet and calm to violently active.

The height of the Sun's activity cycle, known as **solar maximum**, is a time of greatly increased solar activity. **Solar radiation storms** occur when large quantities of charged particles, protons, and electrons are accelerated by processes at or near the Sun – usually from large eruptive events such as **solar flares** and/or **coronal mass ejections**. When these processes occur, the near-Earth satellite environment is bathed with high-energy particles. The latest solar cycle – Solar Cycle 25 –

started in December 2019 when **solar minimum** occurred, according to the Solar Cycle 25 Prediction Panel, an international group of experts co-sponsored by NASA and NOAA. In cooperation with NASA, NOAA is the U.S. Government's official source for space weather predictions. Scientists now expect the Sun's activity to ramp up toward the next predicted maximum in July 2025.

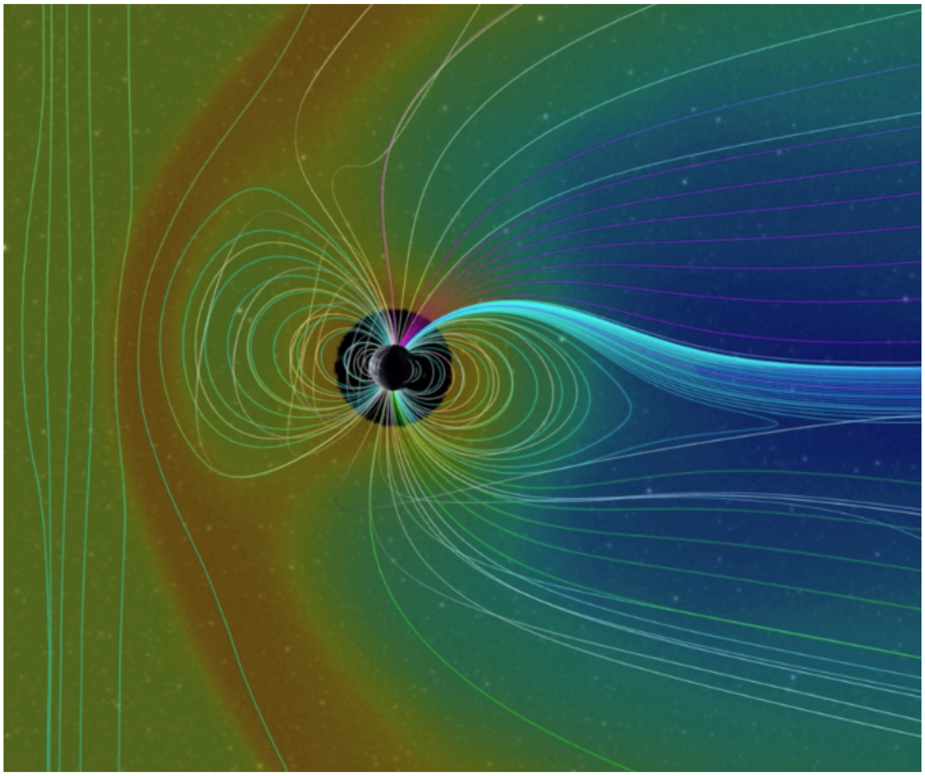
Earth's Magnetosphere

[Text adapted from NASA: Magnetospheres]

Earth's internal magnetism creates a region around the planet known as the **magnetosphere**. While several planets in our Solar System have magnetospheres, Earth has the strongest one of all the rocky planets. Our magnetosphere is a vast, comet-shaped bubble, and it has played a crucial role in our planet's habitability.

Life on Earth initially developed, and continues to be sustained, under the protection of this magnetic environment. The magnetosphere shields our home planet from harmful solar and **cosmic particle radiation**, as well as erosion of the atmosphere by the **solar wind** – the constant flow of charged particles streaming off the Sun. Additionally, **space weather** within the magnetosphere – where many of our spacecraft reside – can sometimes have adverse effects on space technology as well as communications systems like radio and GPS. So, a better understanding of the magnetosphere also helps improve our space weather models and protect our assets in space.

Our magnetosphere is part of a dynamic, interconnected system that responds to solar, planetary, and interstellar conditions – and it all starts deep inside Earth. As electrically charged, molten iron churns far below Earth's surface, within the planet's outer core, it generates a magnetic field large enough to extend far out into space. On the Sun-facing side of Earth – where the magnetic field is compressed by the constant bombardment of the solar wind – the magnetosphere extends some 6 to 10 times the radius of Earth. The side of the magnetosphere facing away from the Sun – the nightside – stretches out into an immense **magnetotail**, which fluctuates in length and can measure hundreds of Earth radii, extending far past the Moon's orbit at 60 Earth radii.



Earth is surrounded by a system of magnetic fields, called the magnetosphere. The magnetosphere shields our home planet from harmful solar and cosmic particle radiation, but it can change shape in response to incoming space weather from the Sun. *Credit: NASA's Scientific Visualization Studio*

NASA studies the magnetosphere to better understand its role in our space environment. Such research helps unravel the fundamental physics of space, which is dominated by complex electromagnetic interactions quite different from what we experience day-to-day on Earth. By studying this space environment close to home, we can better understand the nature of space throughout the universe.

Aurora

[Text adapted from NASA: Aurora]

The **aurora** is a captivating display of light in the night sky. The aurora borealis and aurora australis – also called the northern lights and southern lights – occur at the northern and southern poles. Occasionally, **space weather** interacting with Earth can cause auroras to extend even further away from the poles. These colorful lights are constantly changing shape and intensity, from dim and scattered to bright enough to read by.

The dancing lights of the aurora provide spectacular views from the ground, and also capture the imaginations of scientists who study incoming energy and particles from the Sun. NASA studies auroras to better understand this complex space environment, which in turn can help us predict and mitigate its effects on communication signals and human technology.

The Sun continuously produces a **solar wind**, made of charged particles, that flows outward into the Solar System. When the solar wind reaches Earth's magnetic field, it can cause **magnetic reconnection**, an explosive process that allows charged particles from space to accelerate into the atmosphere.

Earth's tear-shaped magnetic field – called the **magnetosphere** – continuously oscillates and responds to the changing intensity of the solar wind. The solar wind particles funnel around to the long tail of the magnetosphere, where they become trapped. When magnetic reconnection occurs, the particles are accelerated toward Earth's poles. Along the way, particles can collide with atoms and molecules in Earth's upper atmosphere, an interaction that provides the atoms with extra energy that is released as a burst of light. These interactions continue at lower and lower altitudes until all the incoming energy is lost. When we see the glowing aurora, we are watching a billion individual collisions, lighting up the magnetic field lines of Earth.

Auroral beads seen from the International Space Station (ISS) on Sept. 17, 2011. NASA studies auroras as they are visible markers of space weather processes around Earth. *Credit: NASA*

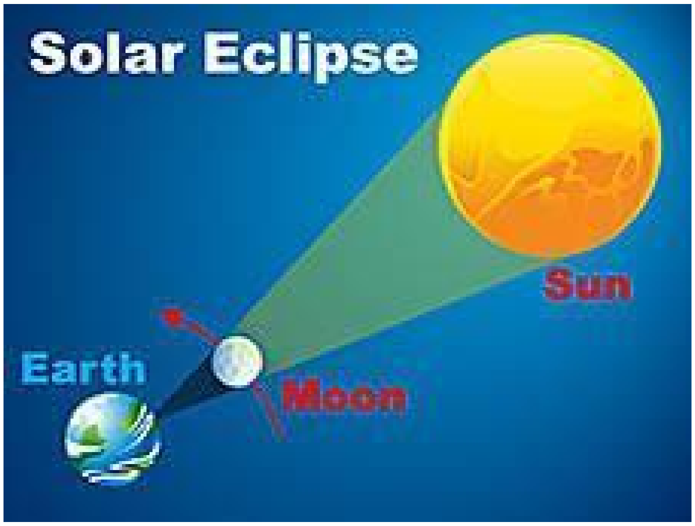
Observing auroras – and discovering what causes them to change over time – gives scientists insight into how our planet's magnetosphere reacts to the space weather near Earth. Scientists study auroras from a variety of vantage points: below, above, and within. From below, ground-based telescopes and radar look upward to track what's happening in the sky. From above, NASA missions such as THEMIS (Time History of Events and Macroscale Interactions during Substorms) investigate what causes auroras to dramatically shift from slowly shimmering waves of light to wildly shifting streaks of color. To gather observations from within an aurora, NASA uses **sounding rockets** – rockets that take a quick trip through space for 5 to 20 minutes at a time – to fly right up into auroras as they happen in real time.

Eclipses, Transits, Lunar Phases, and Seasons

Solar Eclipse

[Text adapted from NASA: Eclipses]

Sometimes when the Moon orbits Earth, it moves between the Sun and Earth. This doesn't happen every month, because the Moon doesn't orbit in the exact same plane that the Sun and Earth do – but it does happen occasionally. When it happens, the Moon blocks the light of the Sun from reaching Earth. This causes an eclipse of the Sun, or **solar eclipse**. During a solar eclipse, the Moon casts a shadow onto Earth.



During a solar eclipse, the Moon casts two shadows. One is called the umbra; the other is called the penumbra. *Credit: NASA*

There are three types of solar eclipses. The first is a **total solar eclipse**. A total solar eclipse is only visible from a small area on Earth. The people who see the total eclipse are in the center of the Moon's shadow when it hits Earth. The sky becomes very dark, as if it were night. For a total eclipse to take place, the Sun, Moon, and Earth must be in a direct line.

The second type of solar eclipse is a **partial solar eclipse**. This happens when the Sun, Moon, and Earth are not exactly lined up. The Sun appears to have a dark shadow on only a small part of its surface.

The third type is an **annular solar eclipse**. An annular eclipse happens when the Moon is farthest from Earth. Because the Moon is farther away from Earth, it seems smaller. It does not block the entire view of the Sun. The Moon in front of the Sun looks like a dark disk on top of a larger Sun-colored disk. This creates what looks like a ring around the Moon.

During a solar eclipse, the Moon casts two shadows on Earth. The first shadow is called the umbra. This shadow gets smaller as it reaches Earth. It is the dark center of the Moon's shadow. The second shadow is called the penumbra. The penumbra gets larger as it reaches Earth. People standing in the penumbra will see a partial eclipse. People standing in the umbra will see a total eclipse.

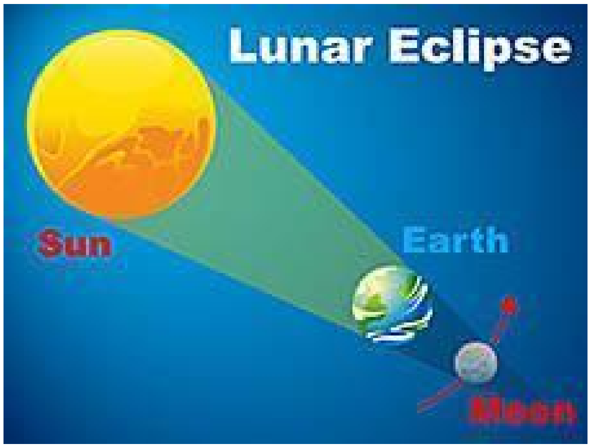
Unlike lunar eclipses, solar eclipses only last for a few minutes. Wear eclipse glasses to protect your eyes from solar radiation any time you look directly at the everyday Sun or its reflection. When viewing a solar eclipse, use these glasses whenever ANY PART of the Sun's bright face is visible.

Staring at the Sun for a long period of time can damage your eyes. Do not use a telescope or binoculars without proper solar filters or you could cause permanent damage to your eyes.

Lunar Eclipse

[Text adapted from NASA: Eclipses]]

The Moon moves in an orbit around Earth, and at the same time, Earth orbits the Sun. Sometimes Earth moves between the Sun and the Moon. When this happens, Earth blocks the sunlight that normally is reflected by the Moon. Instead of light hitting the Moon's surface, Earth's shadow falls on it. This is an eclipse of the Moon – a **lunar eclipse**. A lunar eclipse can occur only when the Moon is full.



An eclipse takes place when Earth or the Moon passes through a shadow. *Credit: NASA*

A lunar eclipse can be seen from Earth at night. There are two types of lunar eclipses: total lunar eclipses and partial lunar eclipses.

A **total lunar eclipse** occurs when the Moon and the Sun are on exact opposite sides of Earth. Although the Moon is in Earth's shadow, some sunlight reaches the Moon. The sunlight passes through Earth's atmosphere, which causes Earth's atmosphere to filter out most of the blue light. This makes the Moon appear red to people on Earth.

A **partial lunar eclipse** happens when only a part of the Moon enters Earth's shadow. In a partial eclipse, Earth's shadow appears very dark on the side of the Moon facing Earth. What people see from Earth during a partial lunar eclipse depends on how the Sun, Earth, and Moon are lined up.

A lunar eclipse usually lasts for a few hours. At least two partial lunar eclipses happen every year, but total lunar eclipses are rare. It is safe to look at a lunar eclipse.

Transits

[Text adapted from NASA: What is a transit?]

A **transit** occurs when a planet passes between a star and its observer. Transits within our Solar System can be observed from Earth when Venus or Mercury travel between us and the Sun. Solar eclipses are a special type of planetary transit.

Transits are somewhat similar to a solar eclipse; both include an object passing in front of the Sun. So what's the difference? During a solar eclipse, the Moon passes between Earth and the Sun. Due to its close proximity to Earth, it obscures the Sun, casting the Earth into a shadow. This obscuration is key in defining an eclipse. During a planetary transit, objects much larger than the Moon pass in front of the Sun, but because they are considerably more distant, they appear to be much smaller. Mercury is 230 times farther away from Earth than the Moon and Venus is 100 times farther away (on average). Mercury and Venus do not obscure the Sun; therefore, they don't cast Earth into a shadow. The seemingly small planets just appear as dark spots that seem to crawl across the surface of the Sun.

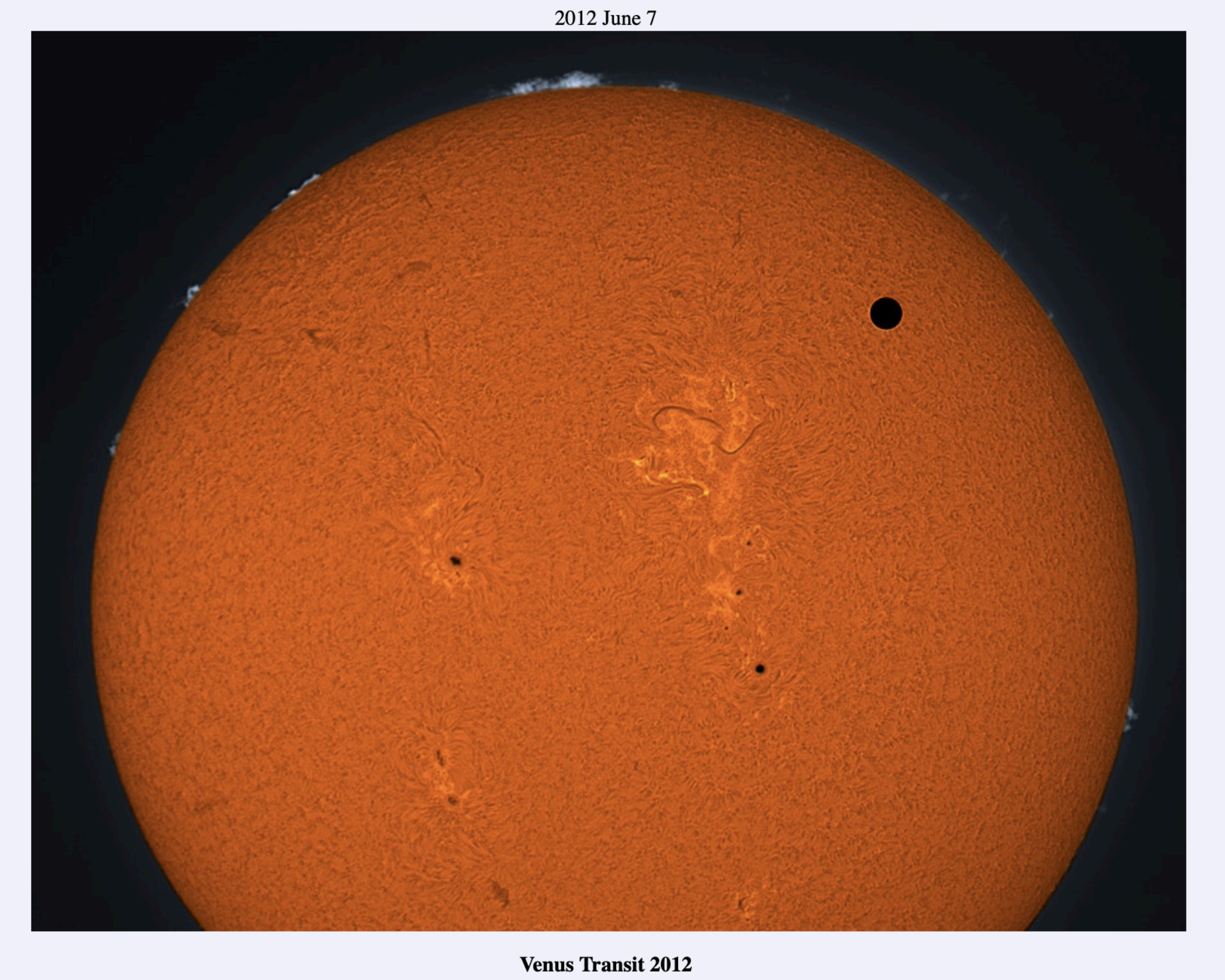


Image Credits: Chris Hetlage/NASA APOD

The image above is of the Venus Transit on June 7, 2012. The next solar transit of Venus will not occur for another century — December 11, 2117.

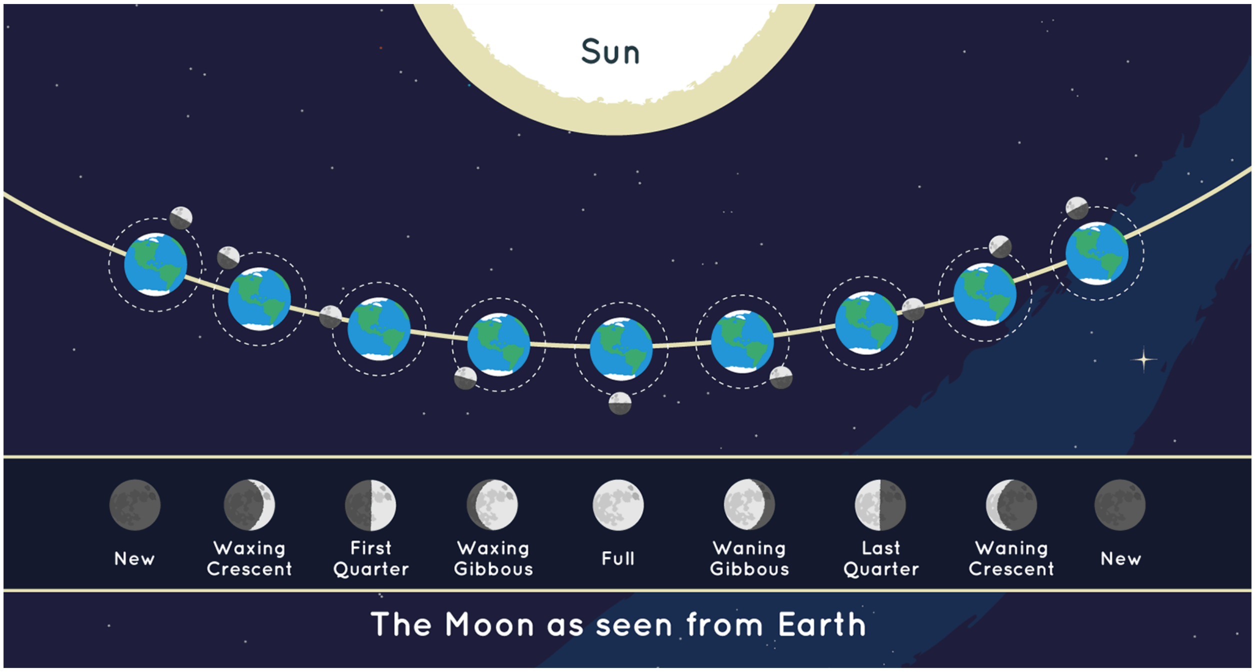
Can Mercury and Venus ever transit the Sun at the same time? Or can a transit occur during an eclipse? Yes, it can happen. However, these events are exceedingly rare and the next time they occur will be so far into the future that it seems unthinkable. Astronomers have calculated that Mercury and Venus will transit simultaneously in the year 69,163; Mercury will transit the Sun during a partial eclipse in 6757; and in 15,232 Venus will transit the Sun during a total eclipse.

Lunar Phases

[Text adapted from NASA: Earth's Moon]

In our entire Solar System, the only object that shines with its own light is the Sun. That light always beams onto the Earth and Moon from the direction of the Sun, illuminating half of our planet in its orbit and reflecting off the surface of the Moon to create moonlight. The Sun always illuminates half of the Moon while the other half remains dark, but how much we are able to see of that illuminated half changes as the Moon travels through its orbit.

Because the Moon's orbit is tilted about 5 degrees with respect to Earth's orbit, we do not experience eclipses every month, but rather only when the alignment is just right.



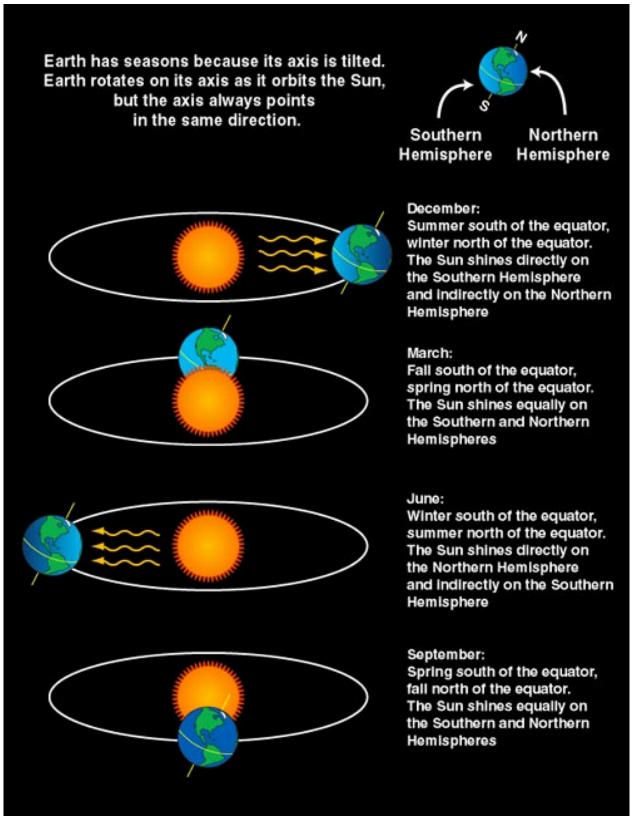
This graphic shows the position of the Moon and the Sun during each of the Moon's phases and the Moon as it appears from Earth during each phase. Not to scale. *Credits: NASA/JPL-Caltech*

Seasons

[Text adapted from NASA Space Place: What causes the seasons?]

Along with eclipses and phases of the Moon, the position of the Sun and Earth create the seasons. A common misconception is that Earth is closer to the Sun in the summer and that is why it is hotter. And, likewise, that Earth is farthest from the Sun in the winter. Although this idea seems logical, it is incorrect. It is true that during part of the year, Earth is closer to the Sun than at other times. This is because Earth's orbit is not a perfect circle; it is in the shape of an **ellipse**, or an oval. However, in the Northern Hemisphere, we are actually experiencing winter when Earth is closest to the Sun and summer when it is farthest away. Compared with how far away the Sun is, this change in Earth's distance throughout the year is irrelevant. Earth's **perihelion** is the point on Earth's orbit where it is closest to the Sun (91,400,000 miles from the Sun). Perihelion occurs in January. Earth's **aphelion** is the point farthest from the Sun (94,500,000 miles from the Sun). Aphelion occurs in July. The difference of 3 million miles, relative to the entire distance, is negligible.

Earth's seasons are caused by the tilted axis of the Earth. Scientists hypothesize that when the Earth was young, a large object hit the Earth and knocked it off-kilter. So instead of rotating with its axis straight up and down, it leans over a bit. As Earth orbits the Sun, its tilted axis always points in the same direction. So, throughout the year, different parts of Earth get the Sun's direct rays. Sometimes it is the North Pole tilting toward the Sun (around June) and sometimes it is the South Pole tilting toward the Sun (around December).



Earth has seasons because its axis is tilted. Earth rotates on its axis as it orbits the Sun, but the axis always points in the same direction.

December: Summer south of the equator, winter north of the equator. The Sun shines directly on the Southern Hemisphere and indirectly on the Northern Hemisphere

March: Fall south of the equator, spring north of the equator. The Sun shines equally on the Southern and Northern Hemispheres

June: Winter south of the equator, summer north of the equator. The Sun shines directly on the Northern Hemisphere and indirectly on the Southern Hemisphere

September: Spring south of the equator, fall north of the equator. The Sun shines equally on the Southern and Northern Hemispheres

Earth's seasons are caused by the tilt of the Earth. *Credit: NASA Space Place*

Stars

[Text adapted from NASA Star Basics]

By studying the Sun, scientists can better understand the workings of distant stars. Just like the Sun, all stars are fueled by the **nuclear fusion** of hydrogen to form helium deep in their interiors. While the Sun can only fuse mainly hydrogen, larger stars can fuse heavier elements, all the way up to iron on the periodic table. The outflow of energy from the central regions of the star provides the pressure necessary to keep the star from collapsing under its own weight, and the energy by which it shines.

The Sun is a G2 V, yellow dwarf **main-sequence star**. (G2 stands for the second hottest stars of the yellow G class, and the V represents a main-sequence, or dwarf star.) The Sun is only an average star in terms of its size. Stars up to 100 times larger have been found. And many star systems have more than one star. A star the size of our Sun requires about 50 million years to mature from the beginning of the collapse to adulthood. Our Sun will stay in this mature phase (known as the main-sequence phase in its life cycle) for approximately 10 billion years.

The smallest stars, known as **red dwarfs**, may contain as little as 10% the mass of the Sun and emit only 0.01% as much energy, glowing feebly at temperatures between 3,000 to 4,000 K. Despite their diminutive nature, red dwarfs are by far the most numerous stars in the universe and have lifespans of tens of billions of years.

On the other hand, the most massive stars, known as **hypergiants**, may be 100 or more times more massive than the Sun, and have surface temperatures of more than 30,000 K. Hypergiants emit hundreds of thousands of times more energy than the Sun, but have lifetimes of only a few million years. Although extreme stars such as these are believed to have been common in the early universe, today they are extremely rare – the entire Milky Way Galaxy contains only a handful of hypergiants.

The Sun formed about 4.6 billion years ago in a giant, spinning cloud of gas and dust called a **nebula**. As the nebula collapsed under its own gravity, it spun faster and flattened into a disk. Most of the nebula's material was pulled toward the center to form our Sun, which accounts for 99.8% of the Solar System’s mass. Much of the remaining material formed the planets and other objects that now orbit the Sun. The rest of the leftover gas and dust was blown away by the young Sun's early **solar wind**.

Like all stars, our Sun will eventually run out of energy. When it starts to die, the Sun will expand into a **red giant**, becoming so large that it will engulf Mercury and Venus, and possibly Earth as well. Scientists predict the Sun is a little less than halfway through its lifetime and will last another for a billion years or so before it becomes a **white dwarf**.

Average stars become white dwarfs. For average stars like the Sun, the process of ejecting its outer layers continues until the stellar core is exposed. This dead but still ferociously hot stellar cinder is called a white dwarf; white dwarfs are roughly the size of our Earth despite containing the mass of a star.

Large-mass stars have a different life cycle. In general, the larger a star, the shorter its life, although all but the most massive stars live for billions of years. When a star has fused all the hydrogen in its core, nuclear reactions cease. Deprived of the energy production needed to support it, the core begins to collapse into itself and becomes much hotter. Hydrogen is still available outside the core, so hydrogen fusion continues in a shell surrounding the core. The increasingly hot core also pushes the outer layers of the star outward, causing them to expand and cool, transforming the star into a red giant.

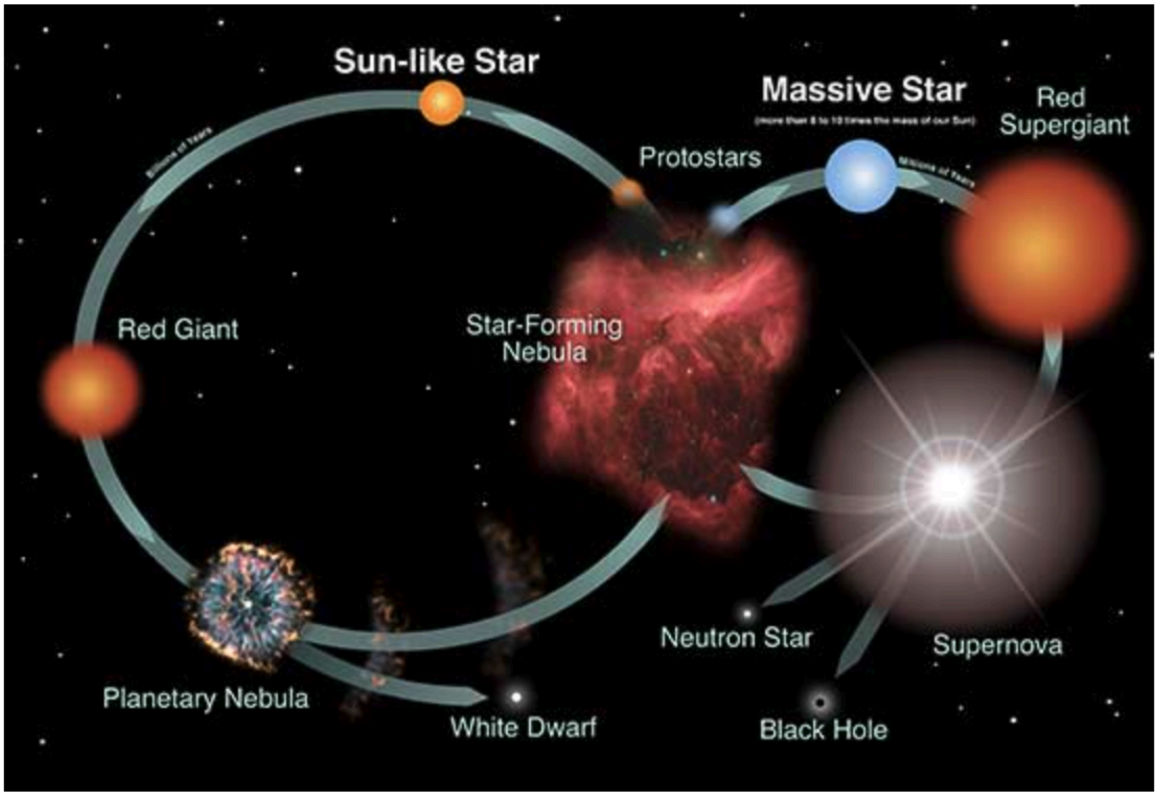


Diagram showing the life cycle of both an average, Sun-like star and a massive star. *Credits: NASA/Night Sky Network*

If the star is sufficiently massive, the collapsing core may become hot enough to support more exotic nuclear reactions that consume helium and produce a variety of heavier elements up to iron. However, such reactions offer only a temporary reprieve. Gradually, the star's internal nuclear fires become increasingly unstable – sometimes burning furiously, other times dying down. These variations cause the star to pulsate and throw off its outer layers, enshrouding itself in a cocoon of gas and dust. What happens next depends on the size of the core.

Main-sequence stars over eight solar masses are destined to die in a titanic explosion called a **supernova**. In a supernova, the star's core collapses and then explodes. In massive stars, a complex series of nuclear reactions leads to the production of iron in the core. Having achieved iron, the star has wrung all the energy it can out of nuclear fusion – fusion reactions that form elements heavier than iron actually consume energy rather than producing it. The star no longer has any way to support its own mass, and the iron core collapses. In just a matter of seconds the core shrinks from roughly 5,000 miles across to just a dozen, and the temperature spikes 100 billion degrees or more. The outer layers of the star initially begin to collapse along with the core, but then rebound with the enormous release of energy and are thrown violently outward. Supernovae release an almost unimaginable amount of energy.

For a period of days to weeks, a supernova may outshine an entire galaxy. Likewise, all the naturally occurring elements and a rich array of subatomic particles are produced in these explosions. Our Solar System would not exist without supernovae explosions, which produce the key elements that make up Earth and all of the organisms living on the planet. We are literally “made of star stuff,” as Carl Sagan has pointed out.

On average, a supernova explosion occurs about once every hundred years in the typical galaxy. About 25 to 50 supernovae are discovered each year in other galaxies, but most are too far away to be seen without a telescope. The Sun will not go supernova.

If the collapsing stellar core at the center of a supernova contains between about 1.4 and 3 solar masses, the collapse continues until electrons and protons combine to form neutrons, producing a **neutron star**. Neutron stars are incredibly dense – similar to the density of an atomic nucleus. Because a neutron star contains so much mass packed into such a small volume, the gravitation at its surface is immense.

Neutron stars also have powerful magnetic fields that can accelerate atomic particles around its magnetic poles, producing powerful beams of radiation. Those beams sweep around like massive searchlight beams as the star rotates. If such a beam is oriented so that it periodically points toward

Earth, we observe it as regular pulses of radiation that occur whenever the magnetic pole sweeps past the line of sight. In this case, the neutron star is known as a **pulsar**.

If the collapsed stellar core is larger than three solar masses, it collapses completely to form a **black hole**: an infinitely dense object whose gravity is so strong that nothing can escape its immediate proximity, not even light. Since light is what our instruments are designed to see, black holes can only be detected indirectly. Indirect observations are possible because the gravitational field of a black hole is so powerful that any nearby material – often the outer layers of a companion star – is caught up and dragged in. As matter spirals into a black hole, it forms a disk that is heated to enormous temperatures, emitting copious quantities of X-rays and gamma-rays that indicate the presence of the underlying hidden companion.

The dust and debris left behind by a supernovae eventually blend with the surrounding interstellar gas and dust, enriching it with the heavy elements and chemical compounds produced during stellar death. Eventually, those materials are recycled, providing the building blocks for a new generation of stars and accompanying planetary systems.

The Sun can teach us many things about other star systems. Just like the Sun has planets revolving around it, many stars have planetary systems. These planets are called extrasolar planets, or **exoplanets**.

Finding exoplanets can be pretty hard because stars are gigantic and bright and, comparatively, planets are small and dim. Stars are also very far away. In most cases, scientists can't just point a telescope at a star and see planets orbiting it. But there are other methods that scientists can use to find them.

The Transiting Exoplanet Survey Satellite (TESS) Mission uses a specific method to discover exoplanets by looking for transits. A **transit** is when an object passes between a star and its observer. We can experience transits here on Earth. One example of a transit is a solar eclipse, when the Moon passes between Earth and the Sun. We can also view transits of Venus and Mercury, during the right time, when these inner planets pass between the Earth and the Sun. But just like a solar eclipse, all of the participating parts (Earth, Sun, and Moon) need to be lined up in just the right way.

However, the planet has to be exactly between the view of the telescope and the star for the scientist to be able to measure the light from the transit, so not all exoplanets can be detected this way. If the telescope was viewing the star from "above" or "below," the exoplanet would not be detected. That is why NASA uses multiple methods to detect exoplanets and doesn’t confirm a discovery unless it has been verified by at least two methods.

In addition to classifying stars by size, stars can also be classified by temperature, brightness, and color. Missions looking for exoplanets are very interested in looking at G, K, and M stars, because these types of stars are the best candidates for hosting exoplanets with biological life.

The Sun is a G-type star; K and M stars are similar in size to the Sun. The size of these stars is conducive to hosting planets where there could be potential for biological life. These conditions include long life cycles (enough time for life to evolve on the exoplanet) and temperatures similar to the Sun (to allow for liquid water on the surface of the planet).

When scientists find G, K, and M stars, they look around the star in an area called the **habitable zone**, or the Goldilocks Zone, which is the distance from a star that a planet could exist with liquid water on the surface. The planets in this zone aren't too hot, or too cold, they are just right! Planets in the habitable zone are the best places to look for life.

Another interesting discipline of science, called **astrobiology**, is dedicated to the study of the origins, evolution, distribution, and future of life in the universe. Although life has yet to be discovered anywhere else in the universe, astrobiologists are looking within our own Solar System and beyond.

Heliophysics Missions

[Text adapted from NASA mission pages]

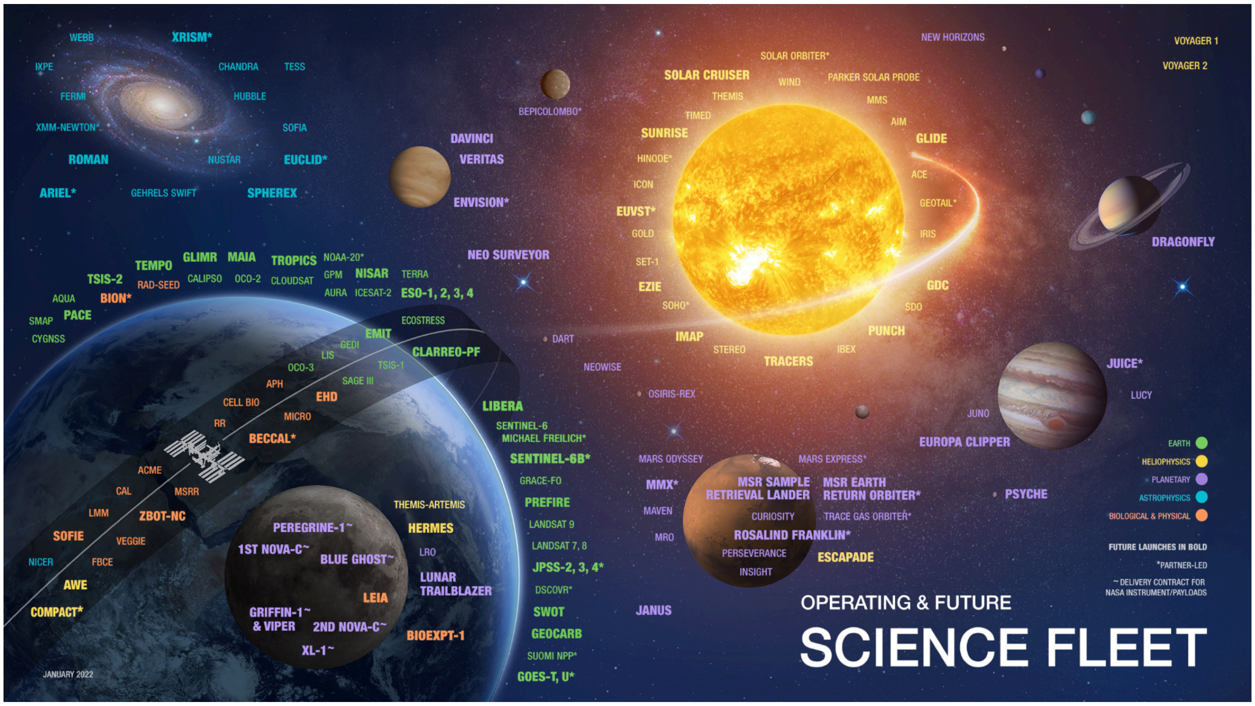


Diagram showing NASA's mission fleet. *Credit: NASA*

The graphic above shows the fleet of current and future NASA missions. The missions are categorized as Earth Science, Planetary Science, Astrophysics, or Heliophysics missions. All of these missions work together to create a deeper understanding of the universe.

Biological and Physical Sciences (BPS) missions use the spaceflight environment to study phenomena in ways that cannot be done on Earth. The International Space Station (ISS) is a BPS mission.

Earth Science missions are critical for monitoring the health of the Earth, including gathering data on global temperatures, precipitation, ocean currents, forest health, wildfires, and the effects of climate change.

Planetary Science missions include missions to other planets and their moons, and even to asteroids and comets. Scientists are very interested in our neighbors, Venus and Mars, which hold clues about how Earth was formed.

Astrophysics missions study everything beyond the heliosphere. This includes other stars, exoplanets, galaxies, black holes, and the hidden dark energy of interstellar space.

Heliophysics missions study the Sun and its interactions with Earth and the Solar System.

The **heliophysics missions** that learners explore in club sessions include **IBEX, Voyager, MMS, Artemis, ICON, SDO, STEREO,** and **Parker Solar Probe.** Learners also explore a variety of **astrophysics missions**, including **Hubble Space Telescope, James Webb Space Telescope, TESS, Kepler,** and **Spitzer.**

Artemis: With the Artemis Missions, NASA will land the first woman and first person of color on the Moon, using innovative technologies to explore more of the lunar surface than ever before. We will collaborate with commercial and international partners and establish the first long-term presence on the Moon. Then, we will use what we learn on and around the Moon to take the next giant leap: sending the first astronauts to Mars.

Hubble Space Telescope: Hubble sees primarily visible light, as well as some infrared and ultraviolet radiation. Far above rain clouds, light pollution, and atmospheric distortions, Hubble has a crystal-clear view of the universe. Scientists have used Hubble to observe some of the most distant stars and galaxies yet seen, as well as the planets in our Solar System.

ICON: The Ionospheric Connection Explorer (ICON) studies the frontier of space: the dynamic zone high in our atmosphere where Earth weather and space weather meet.

IBEX: The focused science objective of the Interstellar Boundary EXplorer (IBEX) is to discover the global interaction at the boundary between interplanetary space – largely dominated by solar wind streaming from the Sun – and the interstellar medium.

James Webb Space Telescope: JWST is an infrared telescope. It will be the premier observatory of the next decade, serving thousands of astronomers worldwide. It will study every phase in the history of our universe, ranging from the first luminous glows after the Big Bang, to the formation of Solar Systems capable of supporting life on planets like Earth, to the evolution of our own Solar System.

Kepler: The Kepler Mission is specifically designed to survey our region of the Milky Way Galaxy to discover hundreds of Earth-size and smaller planets in or near the habitable zone and determine the fraction of the hundreds of billions of stars in our galaxy that might have such planets.

MMS: The Magnetospheric Multiscale Mission (MMS) orbits through near-Earth space to observe a little-understood process called magnetic reconnection. This process occurs in many places throughout the universe and powers a wide variety of events, including giant explosions on the Sun and green-blue auroras shimmering in the night sky.

SDO: The Solar Dynamics Observatory (SDO) is designed to help us understand the Sun's influence on Earth and Near-Earth space by studying the solar atmosphere on small scales of space and time and in many wavelengths simultaneously.

STEREO: The Solar Terrestrial Relations Observatory, or STEREO, has provided scientists a unique and revolutionary view of the Sun-Earth System. Composed of two nearly identical observatories – one ahead of Earth in its orbit, the other trailing behind – STEREO has traced the flow of energy and matter from the Sun to Earth.

Parker Solar Probe: The primary science goals for the mission are to trace how energy and heat move through the solar corona and to explore what accelerates the solar wind as well as solar energetic particles. Parker has traveled closer to the Sun than any mission before it, actually entering the Sun’s atmosphere.

Spitzer Space Telescope: Spitzer is an infrared telescope that allows us to peer into regions of space that are hidden from optical telescopes.

TESS: The Transiting Exoplanet Survey Satellite (TESS) is an all-sky survey mission that will discover thousands of exoplanets around nearby bright stars.

Voyager: The mission objective of the Voyager Interstellar Mission (VIM) is to extend NASA’s exploration of the Solar System beyond the neighborhood of the outer planets to the outer limits of the Sun's sphere of influence, and possibly beyond.

There are a variety of different kinds of missions, depending on what scientists are interested in learning about and the kind of data they can collect.

MISSIONS with PHYSICAL SAMPLES: We have collected physical samples from the Moon, and even an Asteroid (Bennu) from the OSIRIS-REx Mission (Origins, Spectral Interpretation, Resource Identification, Security-Regolith Explorer), samples returning to Earth in 2023. The Stardust Mission was the first mission to return samples from a comet to Earth. We even have samples of the solar wind from NASA’s Genesis Mission. Physical samples give scientists a lot of information about the object they are studying.

MISSIONS with SURFACE EXPLORATION: We currently have several missions studying the surface of Mars, including rovers like Curiosity and Perseverance. The Huygens Mission landed on Saturn’s largest moon, Titan. Rovers and other probes that land on the surface of an object have instruments that can be used to conduct experiments and collect valuable data. Some missions have been able to return samples to Earth, including the Apollo 11 Mission, which was the first mission to send humans to the Moon. NASA’s Artemis Mission is a program with multiple exciting upcoming missions, which will send the next generation of astronauts to the Moon and Mars. Mars Sample Return (MSR) Missions are already underway and will return the first Mars samples to Earth, anticipated for 2031.

ORBITING MISSIONS: There are also satellites orbiting planets, taking pictures and collecting data, like the Mars Reconnaissance Orbiter (MRO), one of many missions orbiting Mars. The Juno Mission orbits around Jupiter. The Messenger Mission orbited Mercury for 4 years. Cassini orbited Saturn for 13 years. The Galileo Mission orbited Jupiter for 8 years. The Magellan Mission orbited around Venus. Orbiting a planet many times allows scientists to collect lots of information about the planet. Some of the missions gathering data on Earth include Landsat-9, which monitors land resources and Global Precipitation Measurement (GPM), which monitors rain and snow. The International Space Station is a unique orbiting mission that studies multiple disciplines of science to demonstrate new technologies and makes research breakthroughs not possible on Earth.

FLYBY MISSIONS: We have more limited data collected from missions that just had a flyby of a planet, dwarf planet, or a moon, like the New Horizons Mission that passed by Pluto and its moons in 2015. A flyby gives scientists less time to gather data than the missions that orbit an object for many years. The Voyager Missions, launched in 1977, have gone farther than any other mission ever has – leaving our Solar System in 2012, gathering data from its flybys of the Jupiter and Saturn systems, and discovering new moons in both systems. Launched in 1973, the Mariner 10 Mission had the first flybys of Mercury and Venus.

OTHER MISSIONS: There are lots of other missions, just orbiting Earth, that are equipped with powerful telescopes that can see really far out into the universe. Scientists can use the light captured by telescopes to learn about distant objects. The NASA Hubble Space Telescope, the James Webb Space Telescope, the Spitzer Space Telescope, the Kepler and K2 Missions, and the TESS Mission are examples of missions with powerful telescopes looking out into the distance. Heliophysics missions that orbit the Earth and collect data on the Sun-Earth environment include MMS, IBEX, ICON, and STEREO.

All of NASA’s missions work together to increase our understanding of the universe.

If you have any questions about the background information, NASA resources, or details about how to run the NASA Helio Club, or activities in the club, contact the NASA HEAT education specialist, christina.h.milotte@nasa.gov.

Every question leads to more questions, and new discoveries are made every day that change our perception of the way the universe works. Remember that it is okay to say to a student, “I don’t know.” This is hard stuff! Tell them, “I have a connection at NASA, and I will find out.” This is an important part of modeling the scientific process for your students.