AmplifyScience

Earth, Moon, and Sun:

An Astrophotographer’s Challenge

Article Compilation

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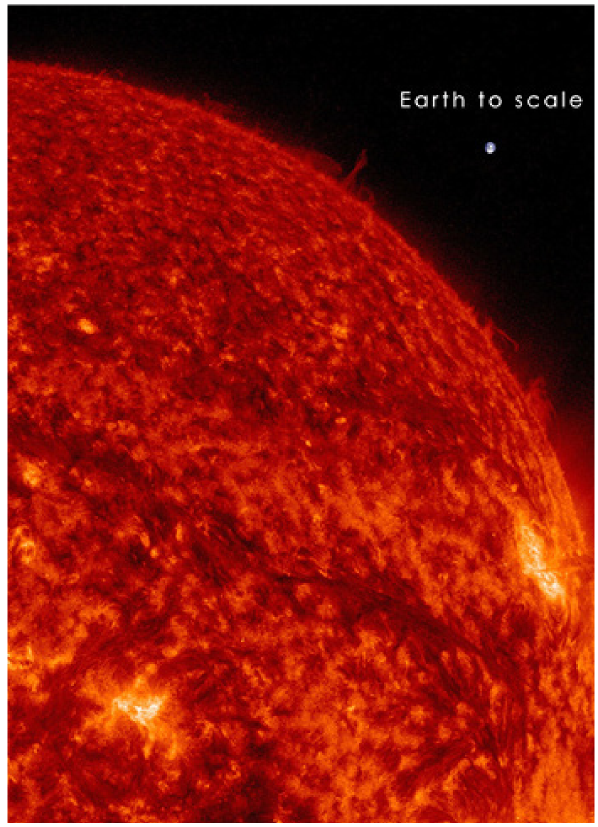
The Solar System Is Huge

When people think of our solar system, they think of the sun, planets, moons, comets, and other objects. Actually, the solar system is mostly empty space. The biggest object in the solar system is the sun. The diameter of the sun is 1,400,000 (1.4 million) kilometers. In comparison, about 58,000,000 (58 million) km of empty space separate the sun from its closest planet, Mercury. The whole solar system takes up a vast area of space: it's about 9,000,000,000 (9 billion) km in diameter. That's more than 6,000 times wider than the sun! As big as it is, the sun is tiny in scale compared to the scale of the empty spaces in the solar system.

All the other objects in the solar system fill up even less of this empty space. Imagine gathering all eight planets (Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune) and all their moons, plus all the asteroids, comets, and other objects in the solar system. Even added all together, these objects aren't as big as the sun. Compared to all the empty space in the solar system, the objects in it are very small in scale.

Since the solar system is so big and the objects in it are so small in comparison, making a model of the solar system can be difficult. Most solar system models can either show the sizes of the different objects in the solar system or the distances between them. If the sizes and the distances were both shown accurately, the model would not fit on a page or a computer screen!

To address this problem, scientists use two different types of models: models that are to scale and models that are not to scale.



This image shows the size of the sun compared to the size of Earth. The sun is many times bigger than any of the planets, but it is still tiny in scale compared to the whole solar system.

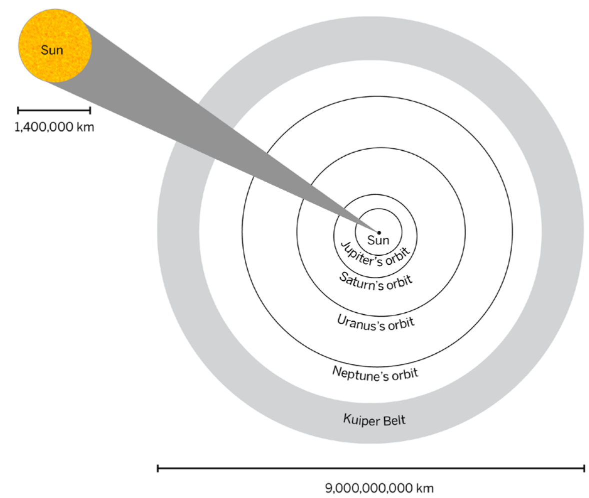
In models that are to scale, everything—the sizes of the objects and the distances between them—has been shrunk or enlarged by the same percentage. Because of that, you can use scale models to compare size relationships. In models that are not to scale, the sizes of the objects and the distances between them may not have been changed by the same percentage. You can learn many things from models that are not to scale, but you can't necessarily use them to compare the size of objects or the distances between them.

Both kinds of models can be useful, depending on what the model is for. Models that are to scale are most useful for showing the relationships between the sizes of things and the distances between them. The model at the top of page 2 is to scale. It shows the sizes of the orbits of the four outer planets of the solar system and gives you an idea of how far apart they are. However, because the outer planets' orbits are so large and so far away from the sun, this model can't show things that are smaller in scale. For example, you can't see any of the actual planets, just the paths of their orbits. The model doesn't even show the orbits of the inner planets, such as Earth—they're too small. Even the sun itself, which is very large, has to be magnified in order to be visible in this scale model!

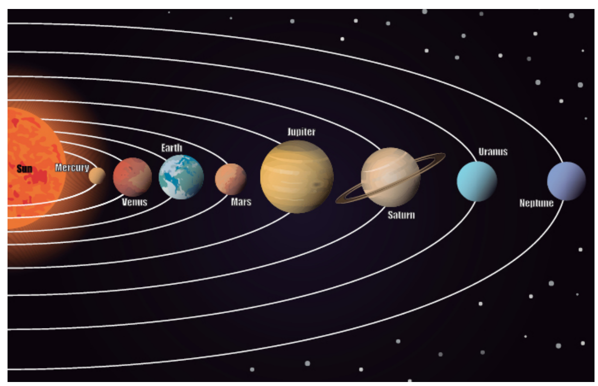
Models that are NOT to scale can still be useful. Models that are not to scale are most useful when seeing size and distance relationships isn't as important. If you wanted a model that included all the objects in the solar system, but didn't need it to show how far apart they are, a model that is not to scale would work well. The model to the lower right is not to scale. It doesn't give a good idea of the relative sizes of the planets and how far apart they are, but it does include all eight planets and the sun, and the order the planets are in relative to the sun. In many cases, scientists use models that are not to scale to get their ideas across.

As you can see, it is possible for a model to show the size of the solar system or the sizes of the planets inside it, but a model that showed both to scale at the same time would be so large that it wouldn't be useful at all.

Solar System



In this diagram of the solar system, the orbits of Earth, Mercury, Venus, and Mars are too small to see. Compared to the whole solar system, they are very close to the sun.

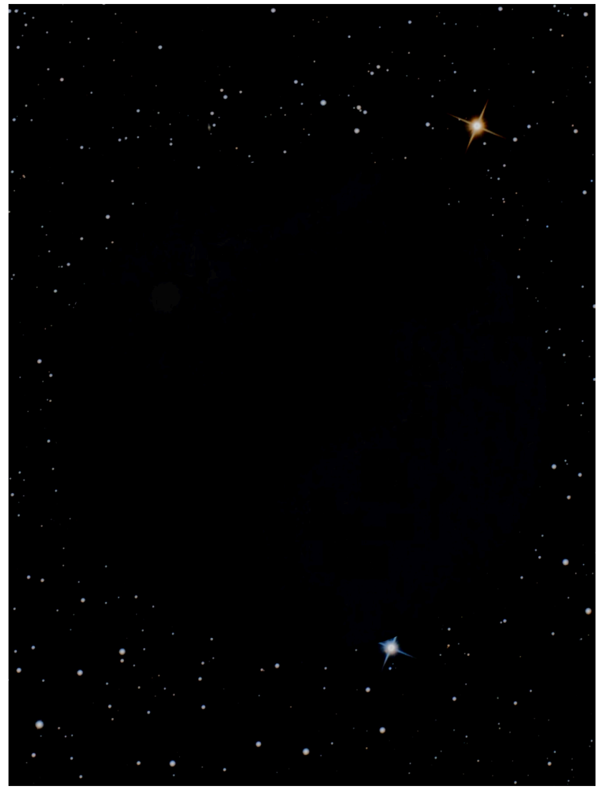


This diagram shows the sun and planets in our solar system. The diagram is not to scale.

The Dark Side of the Moon

In 1968, as part of NASA's Apollo 8 mission, astronauts from the United States became the first humans to travel all the way around the Moon in a spacecraft. When they were flying by the half of the Moon that was facing the sun, they could see the Moon well—the direct light of the sun made everything visible. But when they were flying by the half of the Moon that was facing away from the sun, they could see very little. Without light from the sun, the surface of the Moon was so dark that the astronauts couldn't see it, even though it was large and they were flying near it. The Moon was so dark that the astronauts could only see a circle of darkness blocking the stars.

How can one side of the Moon be so bright and the other so dark? It's because the Moon does not make its own light. The moonlight you see from Earth is actually light from the sun. The sun is the main source of light in our solar system. Light from the sun travels in a straight line, so the sun can only illuminate the side of the Moon that's facing it. The side of the Moon that faces the sun is very bright. The side of the Moon that faces away from the sun, however, is in almost complete darkness. A small amount of light travels into our solar system from other stars, but because the stars are so far away, it isn't much.



When the astronauts on the Apollo 8 mission flew by the side of the Moon that was not illuminated by the sun, it was so dark that they couldn't see the Moon. They could only see an area where the stars were blocked.

Which side of the Moon is the bright side and which is the dark side? It depends. As Earth and the Moon move through space, different parts of the Moon move into the path of the sun's light—so half of the Moon is always illuminated by the sun, but it isn't always the same half. Every part of the Moon is sometimes illuminated by the sun and sometimes in almost total darkness.

The sun illuminates the half of the Moon that faces it, leaving the other half in darkness.

Phases of the Moon

Have you ever looked at the Moon and seen a face looking back at you? So have lots of other people—many cultures have myths about a face or other shapes on the surface of the Moon. Of course, the face on the Moon isn't really a face. It's an arrangement of large flat areas called *maria* (that's Latin for seas, because early astronomers thought these areas were oceans) that were formed by volcanic eruptions. Whether the *maria* look like a face or something else to you, they are always facing Earth, even when they aren't illuminated by light from the sun. The side of the Moon that faces Earth is always the same.

However, that doesn't mean that the Moon always looks the same when we see it in the sky. When we look up at the Moon, what we see depends on where the Moon is in its orbit, the nearly circular path that it travels around Earth. You may know that the sun always illuminates half of the Moon, but because the Moon is constantly moving and changing position along its orbit, the half of the Moon that faces the sun doesn't always face toward Earth. As the Moon moves around Earth, different parts of the Moon are illuminated by the sun. This makes the Moon look different from night to night. These changes in the Moon's appearance are called the phases of the Moon, and you've probably seen them before. In the sections below, you'll read about five phases of the Moon: the new moon, the crescent moon, the quarter moon, the gibbous moon, and the full moon.

The photograph above shows a full moon as seen from Earth.

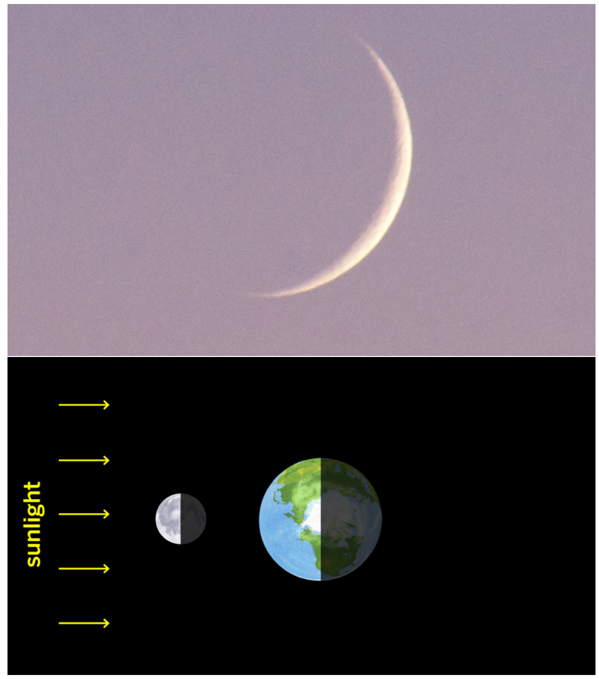
The photograph above shows a crescent moon as seen from Earth.

New Moon

Sometimes, it's hard to see the Moon from Earth at all. When the side of the Moon that faces Earth doesn't get any light from the sun, we call it a new moon. During a new moon, the Moon is between Earth and the sun. As always, the sun illuminates half the Moon—but during a new moon, the half that's illuminated is the half that faces away from Earth. Therefore, the side of the Moon that faces Earth is dark during a new moon.

The exact moment of a new moon, when the Earth-facing side of the Moon isn't illuminated by the sun at all, always happens during the day. The new moon is not easily visible from Earth because the side of the Moon that faces us is dark at the same time that the sky is bright with daylight. This is because the Moon and the sun are always on the same side of Earth during a new moon.

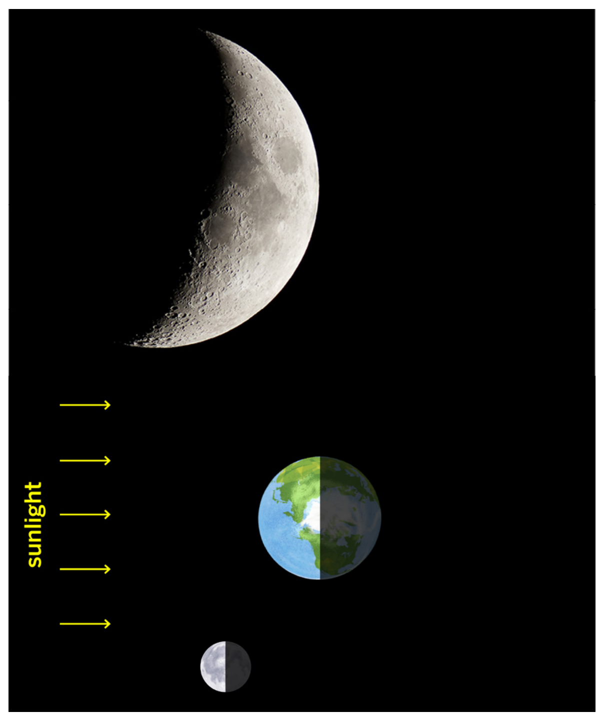
Many cultures use calendars that are based on the phases of the Moon. Those calendars often use the new moon to mark the beginning of each month.



The photograph above shows the Moon just after the new moon phase, when it first becomes visible again. The diagram below it shows the position of the Moon during a new moon phase.

Crescent Moon

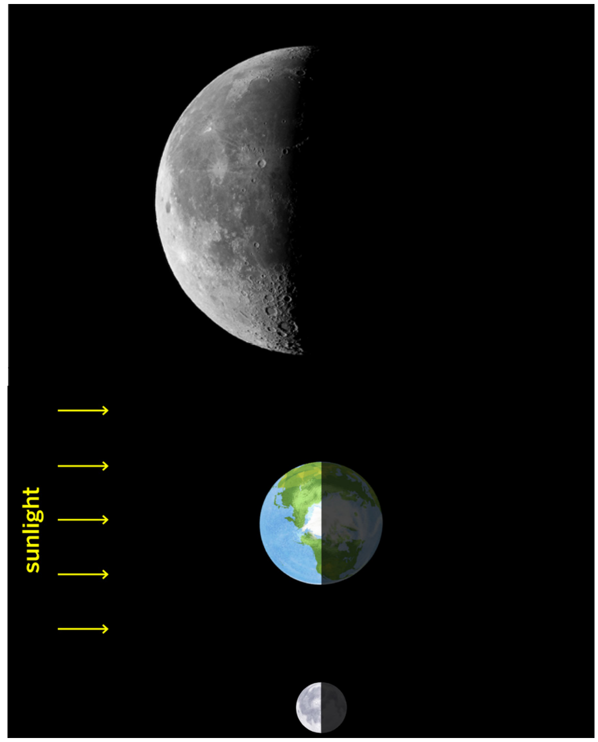
During the crescent moon phase, only a small section of the part of the Moon that faces Earth is illuminated. Half of the Moon is still illuminated by the sun, but we only see a small part of the illuminated portion. This means we see the Moon as a small sliver, or crescent.



The photograph above shows a crescent moon as seen from Earth. The diagram below it shows one position the Moon can be in during a crescent moon phase.

Quarter Moon

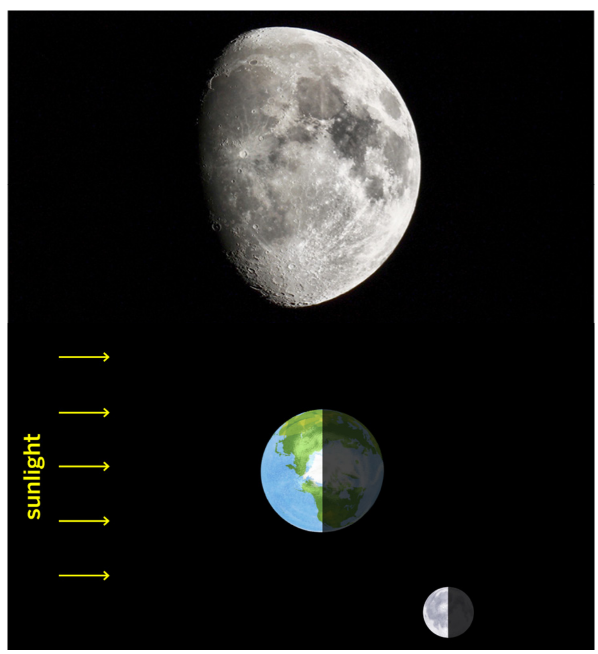
In the quarter moon phase, the Moon looks like a half-circle from Earth. Half of the side that faces Earth is in sunlight, and half is in darkness. Just as always, sunlight illuminates the half of the Moon that faces toward the sun, and from Earth we see half of that illuminated half. Half of a half is a quarter, and that's why this phase is called a "quarter moon."



The photograph above shows a quarter moon as seen from Earth. The diagram below it shows one position the Moon can be in during a quarter moon phase.

Gibbous Moon

During a gibbous moon phase, the side of the Moon facing Earth is almost, but not quite, completely illuminated. Half of the Moon is still illuminated by the sun, and we see almost all of the illuminated half.

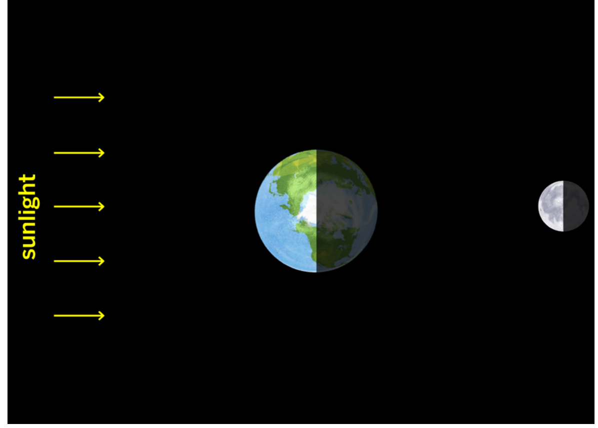


The photograph above shows a gibbous moon as seen from Earth. The diagram below it shows one position the Moon can be in during a gibbous moon phase.

Full Moon

During a full moon, the Moon is on the opposite side of Earth from the sun. As always, the sun illuminates half of the Moon—and during a full moon, the side that's being lit is the side we see! That also means the side of the Moon we don't see is totally dark during a full moon. During a full moon, the entire side of the Moon that faces Earth is illuminated and easy to see.

No matter what phase the Moon is in, one thing is the same: half of the Moon is illuminated by the sun. What changes from night to night is how much of that half we can see from Earth. When the entire illuminated half of the Moon is facing Earth, we see a full circle of light, which we call a full moon. Then, as the Moon continues in its orbit around Earth, we see less and less of it until the illuminated half is facing directly away from Earth, and it seems to disappear. This happens when the illuminated half faces entirely away from Earth, and we call this a new moon. But don't worry—the Moon is never out of sight for very long. As its orbit around Earth continues, the illuminated half of the Moon moves back into our view—just a little at first, but more and more each night until, about a month after the last full moon, it is finally full again.



The photograph above shows a full moon as seen from Earth. The diagram below it shows the position of the Moon during a full moon phase.

Meet a Scientist Who Studies the Early Solar System

Kaveh Pahlevan is an astronomy researcher in France.

Astronomer Kaveh Pahlevan studies Earth, the Moon, and the sun, but his goal isn't to learn about how they are today. Instead, he's trying to find out what they were like long, long ago—so long ago that our solar system had not yet formed. "There was a time before the sun, the Moon, and Earth and other planets even existed," says Pahlevan. "In my work, I look at what these objects look like today and try to use clues to figure out how they came to be the way they are."

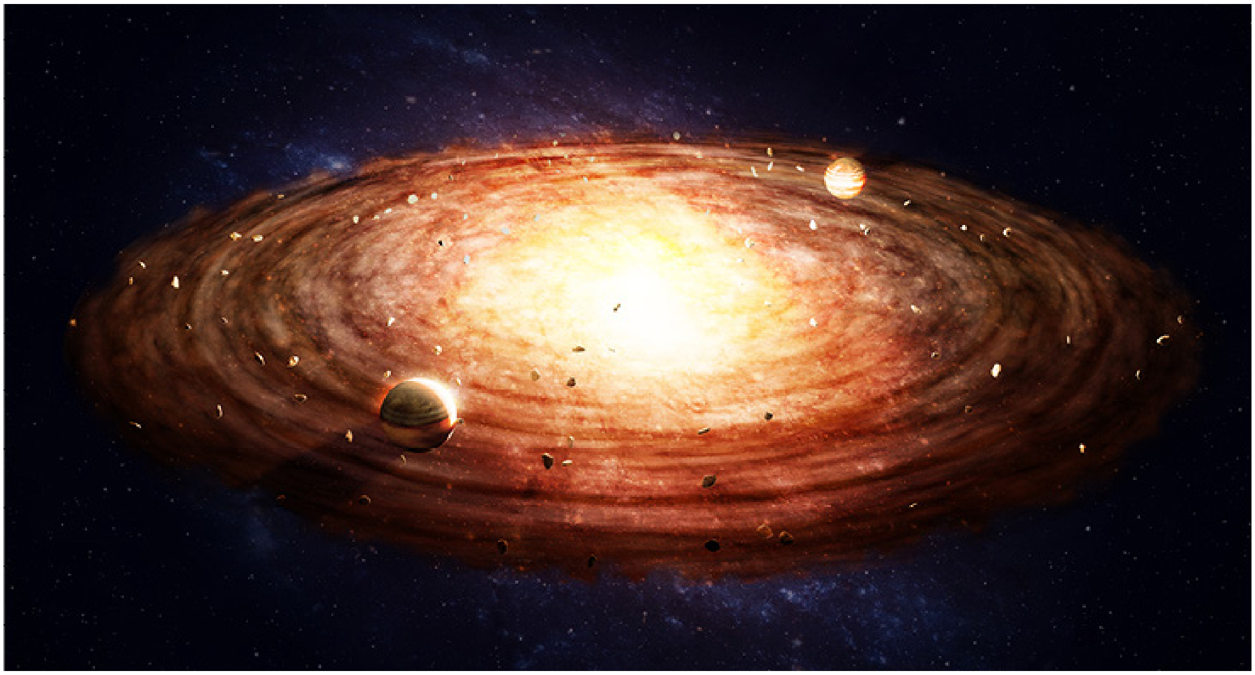
"Scientists are pretty sure that the Moon formed in a collision between Earth and another planet, but the details of that collision are not well known," he says. Pahlevan is trying to answer questions like how large the planet was that crashed into Earth and how fast it was going before the crash. How can scientists get evidence about something that happened so long ago? There are many different ways of gathering this kind of evidence. Some scientists use computer models to help them figure out what happened. Pahlevan looks for clues from the objects themselves using rocks collected by astronauts during trips to the Moon. "I am working to relate some of these scenarios to something that we can measure in the Moon rocks returned by the astronauts," he says. Together, evidence from this kind of hands-on observation and evidence from computer models can help scientists understand what happened during the collision that formed the Moon.

Pahlevan looks for clues that can tell him how the Moon formed.

It’s not surprising to Pahlevan that he became a scientist—he’s always been interested in the natural world. “As a child, I had a ‘science box’ where I would collect rocks, feathers, and eggshells that were worthy of collection,” he says. In school, his teachers introduced him to the formal study of science: how to ask and investigate questions. And then, in college, he found the subject that would be his career. “I took an introductory course on astronomy, and I immediately knew that I wanted to be in this world,” he says. “Scientists had discovered that the sun was an ordinary star, that the atoms in our bodies were forged inside of dying stars?! I had to be a part of this.” Today he works as a researcher at an observatory (a place where telescopes are used to observe objects in space) in Nice (NEES), a city in southern France.

To Pahlevan, being a scientist is exciting because he can learn things that are new to him—and things that are new to everybody. “As a researcher, you are always learning new things about the universe that you didn’t know before, and sometimes learning new things that no one has ever known,” he says.

However, Pahlevan says he doesn’t spend all his time doing experiments and making exciting discoveries. Designing and preparing experiments, analyzing and communicating what he’s learned, writing reports, and working with other scientists can be a lot of work! “Doing the research and making discoveries is the fun part,” he says. “But as a researcher, you also have to write up and publish your work in scientific articles to get credit for them, and to share your results with other researchers. This is an arduous and time-consuming process, which can be a challenge, especially if you’re already thinking about the next discovery.” Still, it’s all worth it. “When you make a new discovery, you are the first person to know something,” he says. “There’s a certain quiet exhilaration in that.”



Our solar system formed billions of years ago from a huge disk of dust and gases. This illustration shows what the early solar system may have looked like.

Gravity in the Solar System

Have you ever wondered where our solar system—the sun, the planets, and all the other objects nearby—came from? Here's a hint: the same force that keeps you close to Earth's surface also began the process that formed the solar system. Gravity, or gravitational force, is an attractive force between all objects that have mass. The more mass an object has, the more strongly it pulls other objects toward it through the force of gravity. So how did this force help produce the sun and all the objects that move around it?

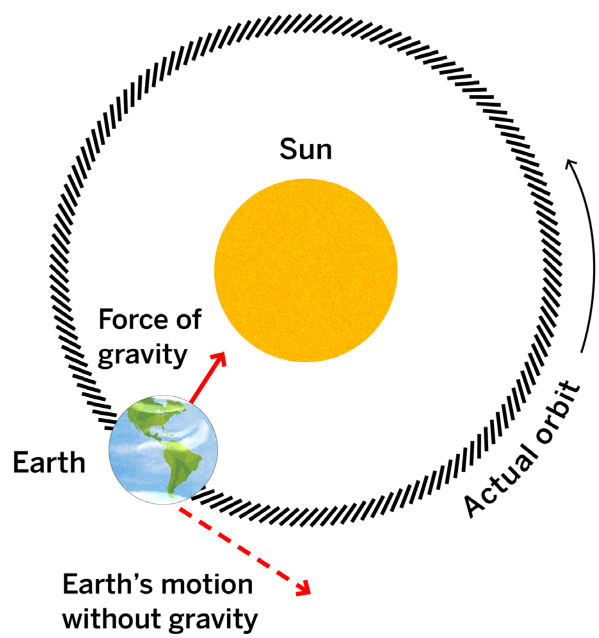
About 4.6 billion years ago, our area of space was a huge cloud of dust and gases. Then something changed: a small part of the cloud collapsed in on itself. The collapse brought many particles in that area of the cloud very close together. In other words, many particles with tiny masses stuck together to form one big clump with a lot of mass. Since a lot of mass means a lot of gravitational force, that area began to attract more and more particles from the cloud and got bigger and bigger. As this cloud collapsed, the whole thing began to rotate around its center. The spinning cloud flattened into a disk of particles and gases circling the spot where the collapse took place. The strong force of gravity from the large clump of dust and gas eventually caused atoms inside it to combine and release energy as light and heat, allowing our sun to form. That was the beginning of our solar system.

Gravity formed the planets, too: when the sun formed, it consumed almost all of the particles in the center of the disk. However, there were some particles left over in the outer regions of the disk, circling and circling around the sun. As they moved, they crashed into each other and formed clumps with larger masses. With larger masses, gravity from these clumps pulled on nearby objects with even more force. Over time, those clumps grew large enough to become planets, moons, asteroids, and other objects in our solar system.

Since then, the solar system hasn't changed much. It's still a disk with objects circling the sun at the center. The sun's gravity plays a role in keeping those objects circling. In our solar system, each planet's orbit is pretty stable, never getting much closer to or farther from the sun. If the sun's gravity is so strong, how can that be?

The planets don't all collapse into the sun because they are moving too fast, and there is no force, like friction, to slow them down. The planets are moving sideways past the sun and have momentum in that direction. One way of thinking of momentum is to call it "mass in motion," and because planets have lots of mass and are moving very fast, they have lots of momentum. Although the planets' momentum is aimed in a straight line sideways past the sun, gravity from the sun pulls on the planets and causes them to move in a circle instead. The force of gravity from the sun can't stop the planets' sideways motion—it can only pull them toward the sun. If the sun disappeared and its gravitational pull suddenly stopped, all the planets would shoot off in the direction they were moving at that moment, leaving the solar system and moving far away into space. Luckily for us, gravity IS acting on the planets, and the gravitational pull of the sun combines with planets' momentum to keep them circling the sun.

Gravity isn't just an important force inside our solar system. Gravity is just as important in other star systems everywhere in the universe. Our solar system is part of a giant collection of more than 100 billion other stars called the Milky Way galaxy. The Milky Way galaxy is just one of many galaxies in the universe. Just as Earth orbits in a giant circle around the sun, our solar system orbits in an even larger circle around the center of the Milky Way galaxy. You might be thinking that there needs to be an object with a huge mass at the center of the galaxy to be able to exert enough gravitational pull to hold our entire solar system and 100 billion stars in orbit around it. You'd be right. In fact, scientists have evidence that there is a supermassive object known as a black hole at the center of the Milky Way galaxy that is 4 million times more massive than the sun.

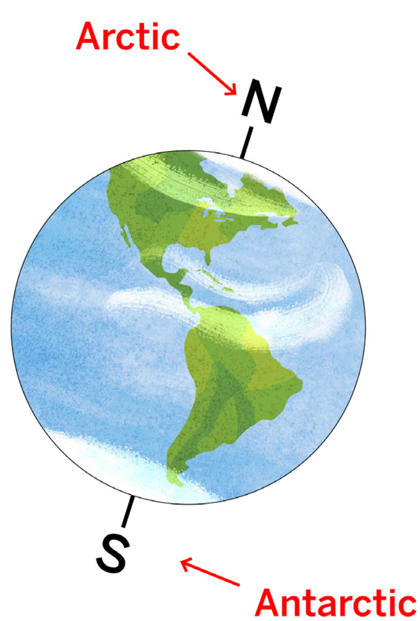


The planets have momentum in the sideways direction, but the sun pulls the planets toward its center with the force of gravity. This combination keeps the planets moving around the sun.

The Endless Summer of the Arctic Tern

Arctic terns fly about 2.4 million km (1.5 million mi) over the course of their lives.

The Arctic tern is a species of bird that lives in the Arctic—but only for part of the year. These terns fly very long distances to stay in parts of the planet that are experiencing summer. Every year, Arctic terns fly from the Arctic all the way to the Antarctic and back. Arctic terns live an average of 30 years and migrate about 2.4 million kilometers (1.5 million miles) during their lives! Why would these birds fly so far? It's all about sunlight.



The Arctic is the area around Earth's North Pole, while the Antarctic is the area around Earth's South Pole.

All Arctic terns are born in the far north, near the Arctic Circle. During the northern summer, the Arctic gets 24 hours of sunlight each day. At the same time, the Antarctic experiences a dark, dark winter—for months, the sun never rises at all. When the seasons change, conditions at the two poles switch: when the darkness of winter comes to the Arctic, the South Pole gets 24-hour sunlight. All that sunlight means plants and other producers are able to perform lots of photosynthesis and provide food for animals and other organisms. Warmer temperatures can also mean better conditions for reproducing and raising baby terns. Arctic terns fly back and forth between the Arctic and Antarctic as the seasons change so they have enough food to eat.

Earth has seasons because of the way the northern hemisphere (northern half) and the southern hemisphere (southern half) of Earth are oriented toward the sun. At certain times of year, as Earth moves in its orbit around the sun, one hemisphere of Earth is tilted toward the sun. While it's tilted toward the sun, that hemisphere receives more hours of sunlight each day than it does during other times of year, and the sunlight it receives is more intense than at other times of year. It is summer for that half of Earth. At the same time, the other hemisphere, or half, of Earth is tilted away from the sun and gets less intense sunlight for fewer hours each day—that's winter for that half of Earth. Earth's tilt does not change as Earth orbits the sun over the course of a year. As Earth travels, the hemisphere that starts out tilted toward the sun is eventually tilted away from it. Earth takes one year to orbit all the way around the sun, so each hemisphere of Earth experiences one summer and one winter each year.

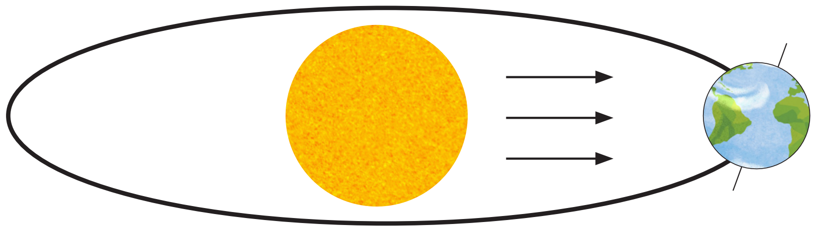
Just because it's summer in the Arctic when the Northern Hemisphere is tilted toward the sun, that doesn't mean it is very warm there. Summer temperatures in the Arctic average 0°C (32°F). These chilly summers happen because the Arctic never directly faces the sun, like locations closer to the equator do—the sun is never directly overhead at the Arctic. The same is true about the Antarctic. It is warmer at the South Pole when the Southern Hemisphere is tilted toward sun, but the average summer temperature is still below freezing!

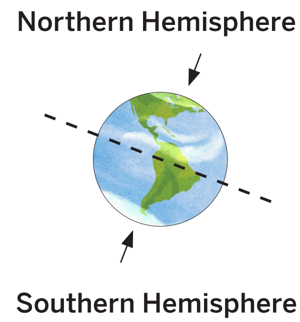
Arctic terns fly back and forth between the North Pole and the South Pole.

The Arctic tern's migration ensures the terns are always living where there's plenty of sunlight. When the Arctic is tilted toward the sun and experiences summer, the terns live there. When the seasons begin to change, the terns leave the Arctic and fly south. By the time the Antarctic is tilted all the way toward the sun, the terns have arrived at the Antarctic. They live there until the seasons change again, and fly north again. That way, they always live where it's summer.

Since Earth's seasons are all about how our planet is tilted, that means our seasons don't depend on how far Earth is from the sun. In fact, Earth's distance from the sun doesn't change very much as it orbits. One way we know this is true is because the whole planet doesn't experience the same season at the same time. For example, if summer were caused by Earth moving closer to the sun, you would expect the whole planet to have summer at the same time. But we know that only half of Earth experiences summer at the same time—it's when that hemisphere is tilted toward the sun.

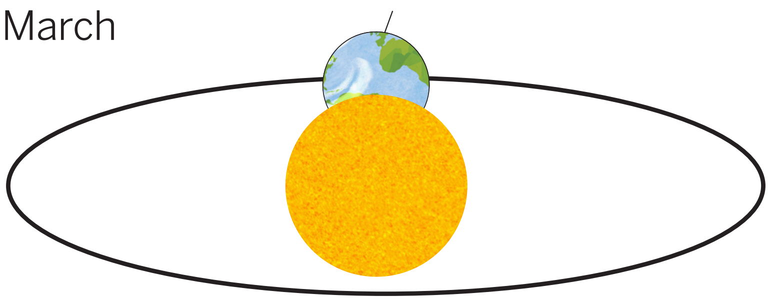
December





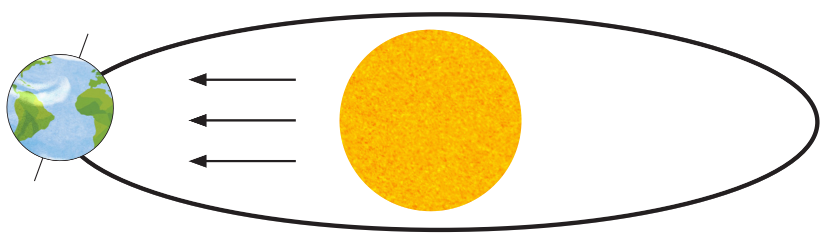
- Winter in the Northern Hemisphere, summer in the Southern Hemisphere
- Less intense sunlight and fewer hours of sunlight in the Northern Hemisphere

March



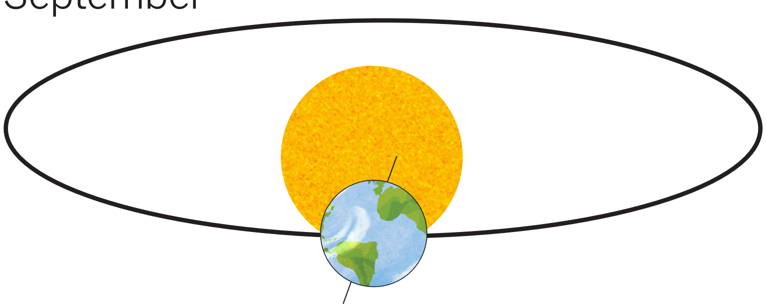
- Spring in the Northern Hemisphere, fall in the Southern Hemisphere
- The sun shines equally on both hemispheres

June



- Summer in the Northern Hemisphere, winter in the Southern Hemisphere
- More intense sunlight and more hours of sunlight in the Northern Hemisphere

September



- Fall in the Northern Hemisphere, spring in the Southern Hemisphere
- The sun shines equally on both hemispheres

An Ancient Machine for Predicting Eclipses

The Antikythera mechanism is a set of metal gears that predicted patterns in the position of the sun, the Moon, and the planets. The gears were found in the remains of an ancient sunken ship in the Mediterranean Sea.

Imagine diving 150 feet beneath the sea. You are looking for sponges, which is not very exciting, but it's your job. Now imagine coming across the wreck of an ancient ship! That's what happened to some divers off the island of Antikythera (an-tee-KITH-er-ah) in the Mediterranean Sea. The ship had been on the seafloor for almost 2000 years. Divers found coins, statues, musical instruments, and many other precious items in the shipwreck. The greatest treasure of all, however, was a collection of corroded metal gears. Nothing like them had ever been found before or has ever been found since. They seem to fit together in a complicated way. They are part of a machine that scientists call the Antikythera mechanism.

It took scientists many years to figure out what the mysterious machine was for. Eventually, scientists used x-rays to view the gears and other parts inside the machine. They were also able to read ancient Greek writing on some of the parts. Using this new information, scientists realized the Antikythera mechanism was built by ancient astronomers to predict patterns in the appearance of the sun, the planets that people were able to observe, and especially the Moon.

Ancient Greek astronomers had been observing the Moon and keeping track of its appearance for hundreds of years. Looking over all their observations, they noticed patterns. The astronomers assumed the same patterns that had been going on for hundreds of years would keep going into the future. They built the Antikythera mechanism to predict events in the future based on the patterns they had observed.

A user of the Antikythera mechanism could turn a dial on one side of the mechanism to choose a date and time, either in the past or in the future. The gears would spin into place, predicting the appearance and position of the Moon and other bodies at that time. The machine had pointers and other displays to show its predictions. For example, ancient astronomers knew there would be a full moon every 29 and a half days. There was a ball on the Antikythera mechanism that traced the phases of the moon. The ball was white on one side (representing the side of the moon illuminated by the sun) and black on the other (representing the dark side of the moon). As the user turned the date dial of the machine, the little moon ball would spin to show what phase the moon would be in on that date.

The Antikythera mechanism also traced patterns that took much longer to repeat.

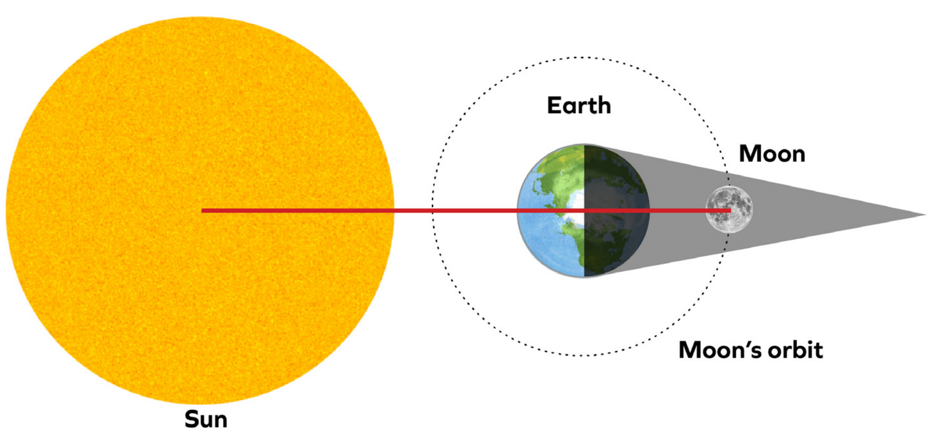
For instance, ancient astronomers knew that occasionally, on the night of a full moon, a lunar eclipse happens. During a lunar eclipse, the fully illuminated face of the full moon goes dark for a time. However, they noticed that this didn't happen every full moon—in fact, over a year would sometimes pass between their observations of lunar eclipses. Through careful record-keeping, the ancient astronomers realized that eclipses, although rare, happened in patterns. They kept track of the patterns and recorded that knowledge in the workings of the Antikythera mechanism. As a user turned the date dial of the Antikythera mechanism, the mechanism counted the days and displayed exactly when people in Greece could expect to observe a lunar eclipse.

The mechanism showed WHEN an eclipse would happen, but it didn't show WHY an eclipse would happen. The astronomers who made the Antikythera mechanism knew that the Moon seems to shine because it is illuminated by light from the sun. They also knew that an eclipse of the Moon happens when Earth blocks the sunlight and makes a shadow on the Moon. They did not know exactly why this happened at some times and not others.

Today astronomers can explain why lunar eclipses happen when they do. Lunar eclipses are caused by Earth blocking sunlight from reaching the Moon. For Earth to block the sunlight, it has to be between the sun and the Moon. Not only that, but the sun, Earth, and the Moon have to line up exactly, with Earth in the middle. When they line up in this way, Earth blocks the sunlight and the Moon goes dark. Eclipses only happen on the night of a full moon, because the full moon is the phase when the sun, Earth, and the Moon line up with Earth in the middle.

If this is true, why don't lunar eclipses happen every time the Moon is full? Why did the ancient astronomers have to wait so long between observations of eclipses? It's because the Moon's orbit around Earth is slightly tilted out of alignment. During most full moons, the sun, Earth, and the Moon are lined up, but they are not lined up EXACTLY. For the three bodies to line up exactly, the Moon has to be exactly in the right spot on its tilted orbit. That happens very infrequently. The makers of the Antikythera mechanism knew how unusual this was, but they didn't understand the reason—now you do!

Lunar Eclipse



During lunar eclipses, the sun, Earth, and the Moon are arranged in a straight line. Light from the sun is blocked by Earth and cannot reach the Moon.