

ASTRONOMY 103: INTRODUCTION TO PLANETARY ASTRONOMY



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Astronomy 103: Introduction to Planetary Astronomy

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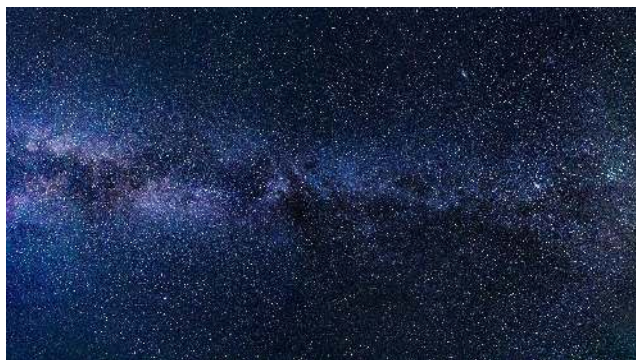
1: Introduction

Learning Objectives

- The basics of science and the scientific method
- Understanding our place in the universe.
- Able to locate major constellations and stars using the celestial sphere coordinate system of declination and right ascension
- Describe how the motion of the Earth affects the day/night cycle and the passage of the season.
- Understand how the motion of the Moon results in solar and lunar eclipses and the phases of the Moon.
- Using triangulation and parallax to measure the distance to far away objects.

Look up into the sky during a clear night and what do you see? You will see the Moon, most nights, and more stars than you can count. If you know where to look, you might even see a few of the planets that are visible from Earth. If you are lucky, maybe you will catch the glimpse of a meteor or “shooting star.” Certain times of the year, you may even see a whole meteor shower. Certain rare times, you might catch a lunar eclipse or even a comet.

Ever since the earliest humans looked up at the night sky, people have been fascinated by the lights above. They asked themselves, what are they? Where did they come from? How far away are they? As they looked at the sky night after night, they noticed certain patterns. Most stars appeared to rise and fall, much like the Sun and the Moon, but others appeared to rotate around a certain point in north (if they lived in the northern hemisphere) or the south (if they lived in the southern hemisphere). Regardless, most of the stars tended to move as a unit, staying together in groups that they named “**constellations**” (Greek for “stars together”). Some constellations only rose and fell during certain seasons throughout the year while those that rotated around the north or south appeared every night. A small number of stars, five to be precise, seemed to move of their own accord. Sometimes they would be in one constellation, sometimes in another. Sometimes they rose after sunset and while other times, they rose before sunrise. The ancient people called this apparently rootless stars “wanderers” or “**planets**” to distinguish them for the fixed stars that obeyed certain patterns.



The Milky Way Galaxy as seen on a clear night on Earth.

<https://wallpaperaccess.com/4k-star>

Of course, now we know that these planets are not stars at all. They are bodies that, like the Earth, orbit our Sun in regular, elliptical orbits. There are eight official planets in our Solar System along with a myriad of other bodies including moons, asteroids, comets, and **dwarf planets**. Four of the planets, including our Earth, are **terrestrial planets**, small, dense rocky bodies that orbit close to the Sun. The other four are **Jovian planets**, gaseous or icy giants that orbit beyond the main asteroid belt. Dwarf planets, a category created when Pluto was demoted from planetary status, are intermediate bodies. Too big to be asteroids and too small to be planets and having failed to clear out their orbital paths with similar bodies, dwarf planets occupy that middle niche.

But why did the ancient people take such an interest in the night sky? The answer lies with those patterns they noticed. The sky became both their calendar and their navigation chart. By noting which stars always appeared in certain locations at the same time every year, they could predict the coming of spring, letting people know when the river was about to flood its banks and deposit fresh nutrients or simply when it was the best time to plant their crops. Before the invention of the compass, the night sky was their own way to determine which direction was north, a crucial piece of knowledge to getting lost while traveling. Because the stars could tell people such useful information, people found that it made sense that they tell them other things as well. After, if the stars can us when to plant and harvest crops, why not assume it could tell you when it was a good time to get married or invade your

neighbors. People searched the sky for any telltale signs they could use to divine the future. They saw comets as heralds of doom and new stars were signs of an important birth.

Of course, today scientists do not look at the sky for portents of the future. They look at the sky to study the various bodies we see. This chapter will begin with a basics of the scientific method and then discuss the methods used by astronomers used to located objects in the sky. Then we will finish up with a discussion how the motions of the Earth and the Moon relate to our measurements of time and the phenomena of lunar and solar eclipses.

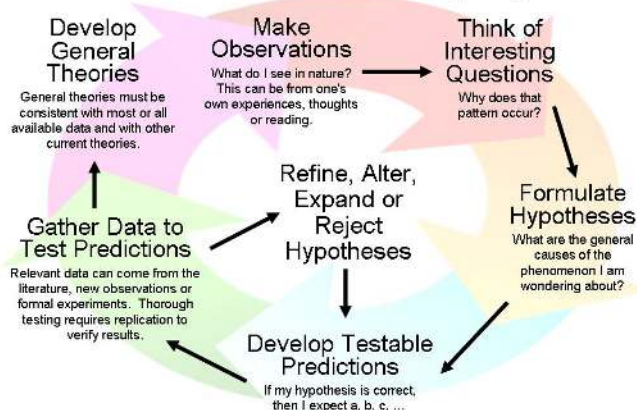
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1.1: The Scientific Method

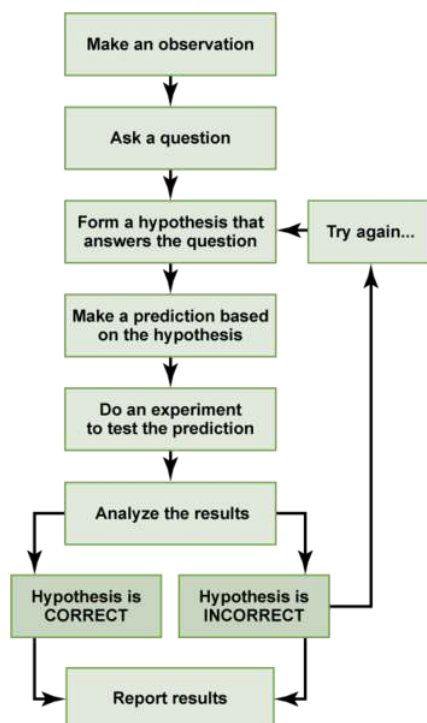
The most reliable way to gain being understanding of the world around is the **scientific method**, which is a formalized technique for testing ideas through observation, testing, and analysis.

The scientific method begins with making initial observations, which will lead the scientist to develop an initial explanation for the phenomena call a **hypothesis**. A good hypothesis will make predictions that can be tested. The results of the testing can then be compared to the predictions. Though it may seem counterintuitive, when scientists run experiments, they are trying to disprove their own hypothesis. So, the results they get will either indicate that the hypothesis is false and therefore the hypothesis will be rejected. Or, the results will align with the predictions made by the hypothesis in which case, it fails to reject the hypothesis. No hypothesis is ever considered “proven” with 100% certainty because any hypothesis could possibly be disproved by a later experiment. Instead, scientists speak in terms of their confidence level that the data support the hypothesis.

The Scientific Method as an Ongoing Process



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Scientific Method Flow Chart.

Image sources: <https://commons.wikimedia.org/wiki/File:rparallax2.png>, https://commons.wikimedia.org/wiki/File:e_01_01_05.png

Many fields of science involve a controlled experiment in the laboratory. Any experiment involves the use of two kinds of variables: independent and dependent variables. The **independent variable** is the condition that is changed to test the hypothesis

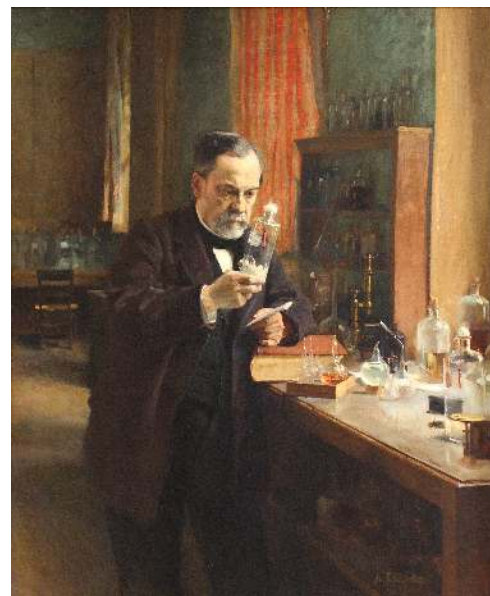
while the **dependent variable** is the that is measured as the result of the changes in the dependent variable. In the experiment, there will be a control group and treatment group. The **control group** is one in which the independent variable is not changed. Scientists use the control group as a point of comparison to the **treatment group** where the independent variable is manipulated. Often, there may be multiple treatment groups with different values of the independent variable have been applied to each group. After running the experiment, the scientist will collect his or her **data**, or the numerical information collected, and plot it in a graph or table so that they can analyze the data. If the hypothesis has any validity, the data should indicate a relationship between the independent variable and the independent variable.



One famous example is the experiment conducted by Louis Pasteur to test the hypothesis of **spontaneous generation**. This was the once popular idea that non-living material can spontaneously transform into living organisms. For example, if meat were left out too long, people would find that it was infested with maggots. Many people assumed that the meat was transforming into live maggots. After the discovery of microorganisms like bacteria, people questioned where they came from. Were they being spontaneously generated or were they reproducing? In other words, did microorganisms produce new microorganisms.

To test the hypothesis of spontaneous generation, Pasteur devised a simple but ingenious experiment. He filled two flasks

with chicken broth. One was an open-necked flask and the other was a swan-necked flask. The open-necked flask would allow bacteria from the air to enter the broth. On the other hand, the swan-necked flask would trap any bacteria in the elbow of the neck, thus preventing the bacteria from reaching the broth. He then boiled both broths to sterilize them. If spontaneous generation was valid, it should not have mattered whether bacteria from the outside was able to enter the broth. There should be bacteria growing in both flasks. On the other hand, if bacteria only came from the outside, then only the open-necked flask should have bacteria growing in it. After a few days, Pasteur examined the broth in both flasks and found only new bacteria growing in the open-necked flask. Since the swan-neck flask did not show any bacteria growing in it, the hypothesis of spontaneous generation was rejected and we now know that for maggots to grow on meat, flies must first lay their eggs on the meat. The maggots then hatch out of the eggs and feed on the rotting meat. The meat itself did not spontaneously generate the maggots.



Albert_Edelfelt_-_Louis_Pasteur_-_1885.jpg Photo from Wikimedia Commons

To put Pasteur's experiment into the above terms, the shape of the flask's neck was the independent variable and the amount of bacterial growing in each flask was the dependent variable that Pasteur tested for. The open-neck flask was the control group used to compare the swan-neck flask that was used for the treatment group.



Wikimedia commons L0057281 Copy of Pasteur's flask used in his experiments on spontaneous generation Credit: Science Museum, London. Wellcome Images images@wellcome.ac.uk http://wellcomeimages.org/Copy_of_Pas...e_L0057281.jpg



Erlenmeyer flask By Hannes Grobe 19:04, 3 September 2006 (UTC) - Own work, CC BY-SA 2.5, <https://commons.wikimedia.org/w/index.php>

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The above is an example of a **manipulative experiment**, in which a single variable to changed under controlled conditions. Many people think that manipulative experiments are the only way in which science is done, but there are many cases in which the phenomena being studied are too big or too distant in space or time to be studied by a controlled experiment in the lab. In these cases, scientists learn by doing **observational science**. For example, we cannot build a star in a lab and study it up close. Fortunately, our galaxy is filled with billions of stars of different sizes, ages, and temperatures. By collecting data from many stars in various stages of stellar evolution, astronomers can build a model for how stars form and change over time. Astronomy is therefore, largely an observational science.

A scientific experiment must be repeatable, that is, you or someone else conducting the same study should get similar results. One case might be a fluke, but if several repeats of the experiment yield similar results, then the hypothesis is better supported.

Once the scientist has completed her study, the usual practice is for her to write a paper and submit it to a peer reviewed journal. Peer review is the process by which scientists in the same field evaluate each other's work. When a journal receives a proposed paper, it sends it out to several other scientists (the "peers") who review it and recommend whether to publish it. If the peers conclude that the researched followed good scientific methodology and the conclusions are supported by the data, they recommend publication. Otherwise, the paper is rejected, and the scientist has to do more work before resubmitting.

Unfortunately, there are many places where "scientific" papers can be published without peer review. Many of these are pay-for-publishing journals that will publish almost any paper if the researcher pays a fee. Also, some organizations with a political agenda may self-publish what looks like legitimate research that is slanted to reach a predetermined conclusion.

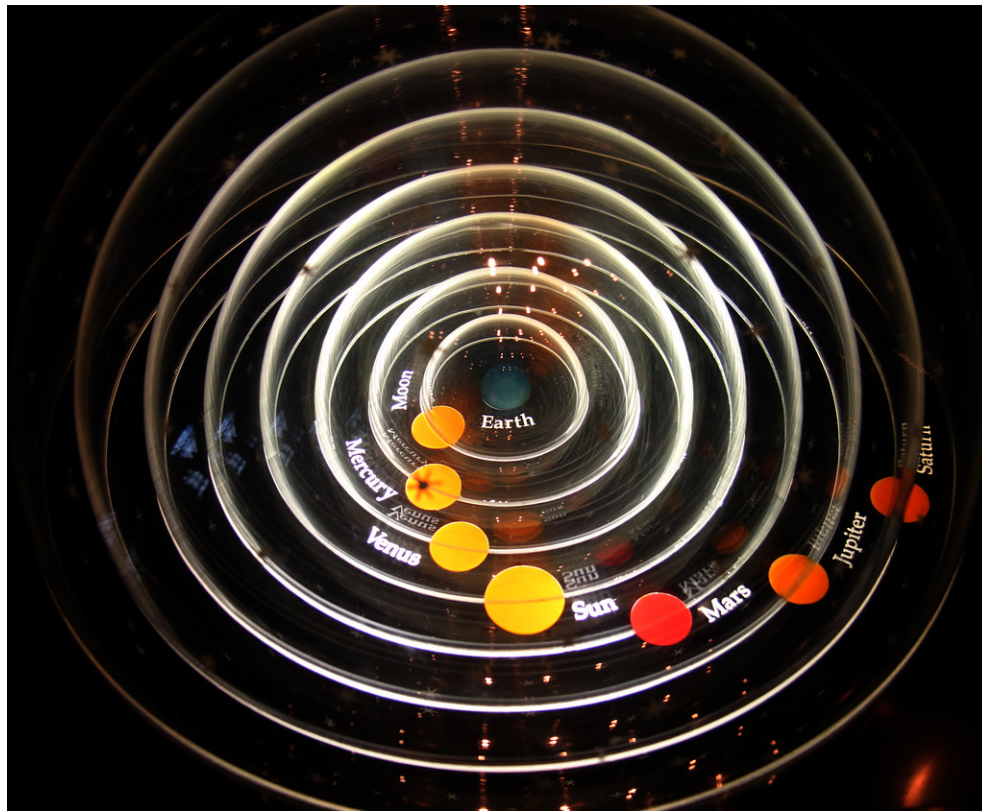
Today, few people dispute the fact that there is a strong link between smoking tobacco and certain forms of cancer. However, for decades, doubt was sown by an organization called the Tobacco Institute which published many convincing looking papers. All these papers came to the same conclusion: "Gosh, we just can't find any link between tobacco and cancer." This was the opposite of what nearly every other researcher in the field concluded. How were the able to come to different results? Well, the Tobacco Institute was funded by the tobacco industry and we now know that they were under orders by their sponsors to come to predetermined conclusions no matter what the data said.

More recently, a research paper in a pay-to-publish journal created a sensation in the news media by announcing that you can lose weight by eating chocolate. Wouldn't that be great? Sounds too good to be true, right? Well, it was. The researcher behind it came forward to admit that the entire paper was a hoax. He did it to highlight how easy it is to get bogus studies published and how readily the media can hype what seem like sensational results. Sadly, most journalists are not trained to discern the difference between sound science and what we can label "junk science."

Science plays a big role in our understanding of the world around us. It is therefore imperative that we have a scientifically literate society that is capable of discerning good science from junk science, especially when making decisions relating to their health and well-being.

One final word on science and relates to how people use the word theory. Many non-scientists use the word to mean a guess or a hunch based on incomplete information. However, this is not how scientists use the term. In science, a theory is a broad explanation for a phenomenon that has been well-tested, shown to be supported repeatedly by experiment, and has gained wide acceptance. It is not a single hunch or guess. The way non-scientists use the term theory is more akin to how scientists use the word theory. Another misconception is that if a hypothesis is validated by experiment, it may be “promoted” to become a theory. That is not accurate either. A theory is a broader explanation while a hypothesis is generally narrower in scope. Indeed, a single theory may encompass several hypotheses into it.

Keep that in mind when someone dismiss a scientific principle as “just a theory.” Nearly everything you are taught in a science class is based on theory. Of course, just because a theory has gained broad acceptance does not always mean it is true, but it takes a lot of evidence to overturn a theory that has been repeatedly validated by observations. Probably the best-known example of such a major shift in our understanding was the Copernican Revolution, when the geocentric (Earth-centered) model for our solar system eventually gave way to the heliocentric (sun-centered) model. We will discuss the debates surrounding the Copernican Revolution in Chapter 3.



Geocentric Model of Solar System by Mr.TinDC is licensed under CC BY-ND 2.0

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1.2: The Celestial Sphere



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Celestial Sphere - Earth Stars.png; by ChristianReady is licensed under CC BY-SA

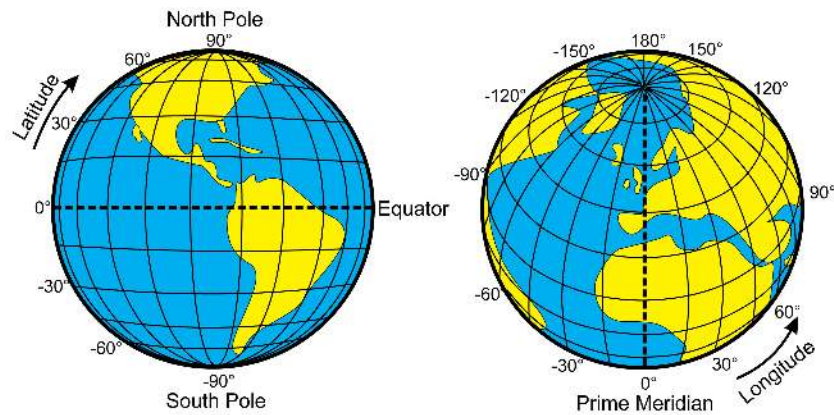
Looking up at the sky and watching the Sun, the Moon, and the stars go by, it's easy to think that we are at the center of the universe, that everything revolves around our little world. Indeed, that is how most people throughout human history thought things were. They saw the Earth as the center of all things. Being the center of all creation made Earth a special place. The Sun, the Moon, and the five known planets all revolved around the world. Somewhere beyond Saturn, was the Firmament or Vault or Heaven where the stars resided. Some people saw the Firmament as a literal dome or sphere where the stars hung. They considered this **celestial sphere** to be a real, physical structure and all the stars were more or less the same distance from Earth.

Of course, today we know there is not physical celestial sphere and that the stars are much further away from us than ancient thought. In fact, they are not all equidistant from us. Stars that appear to be close together in the sky may in fact be hundreds or thousands of light-years away when we consider them in three dimensions. They only appear to be close together because they happen to be in roughly the same line of sight from our vantage point. Think of an optical illusion that makes two objects look close together even when they are in fact, far apart.



Objects that are really far apart can appear close together if they are along the same line of sight. "WTF?" by BillKasman is licensed under CC0 1.0;

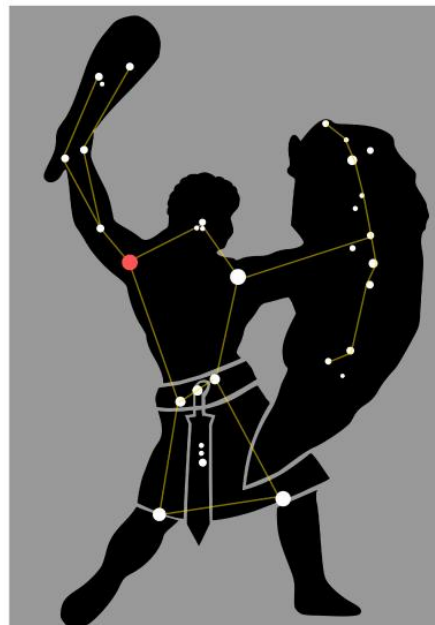
Even though there is no real celestial sphere with stars embedded on its inner surface, the celestial is still a useful model for a coordinate system to locate stars and planets that we want to study. After all, we cannot study an object if we cannot find it. On Earth, we use the system of latitude and longitude to mark a position on the surface of the planet. As with any coordinate system, we need to define a few points of reference from which we can measure our relative position. **Latitude** is measured in terms of degrees north or south of the equator. On the other hand, **longitude** is measured in terms of degrees east or west of the **prime meridian**, an imaginary line that passes through Greenwich, England.



"File:Latitude and Longitude of the Earth.svg" by Djexplo is licensed under CC0 1.0

For our celestial sphere model, we need a similar set of coordinates, but one that is placed on the inside of our sphere. But before we examine our stellar coordinate system, let's ask ourselves, are there any short cuts we can use to help us find objects in the sky? If we were looking for New York City on a globe, we might have start at the equator or prime meridian if we know that New York is on the continent of North America. That would help narrow down our search.

There are no continents in the sky, but there are groups of stars that appear to belong together. Ancient people put stars into groupings they called **constellations** (Greek for "stars together"). They gave the constellations various names based on mythic heroes and beasts of legend. Often, they told stories about the characters the constellations represented. Today, astronomers still use constellations, but define them a little differently. In the modern terminology, the constellations represent 88 defined regions in the sky that are often used to help us find objects we want to study. For example, if you want to study the Crab Nebula, it helps to know that it is in the constellation Cancer.



"File:Orion (constellation) Art.svg" by Sanu N is licensed under CC BY-SA 4.0;

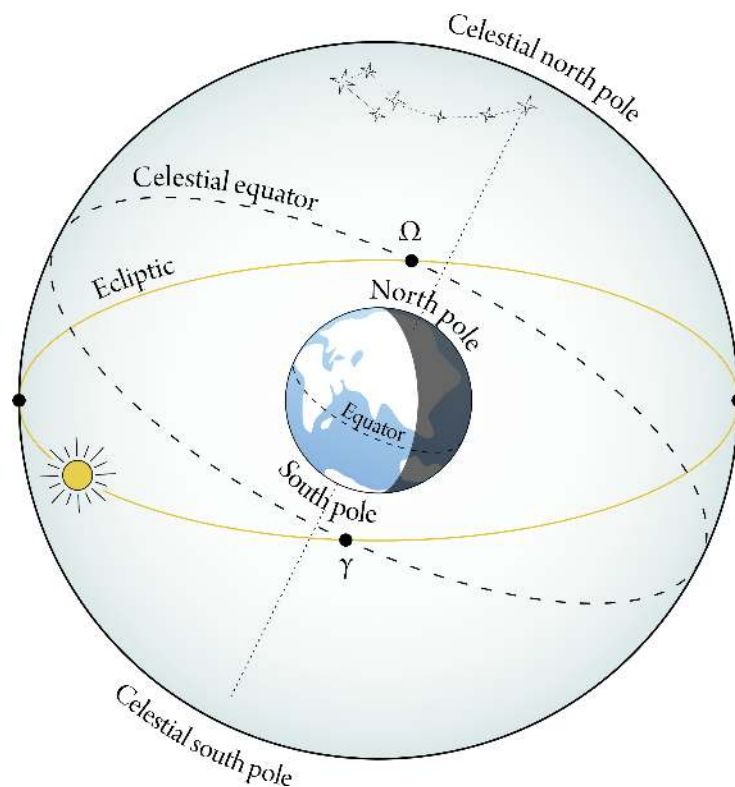


"The Prime Meridian" by chrismetcalf is licensed under CC BY-NC-SA 2.0

What sort of coordinate system can we use on our imaginary celestial sphere? An easy starting point might be using the **zenith**, or point directly overhead of our observer, and define the **horizon** as all the points on a circle that are 90 degrees down from the zenith. The horizon can then serve as our "latitude." We can then draw an imaginary arc connecting the cardinal north and south directions and passing through the zenith. We can call this arc the celestial meridian and use it as our starting point for our celestial "longitude." Therefore, we can define the location of any object in the sky as a certain number of degrees above the horizon (**altitude**) and a certain number of degrees east or west of the meridian (**azimuth**).

This is a very simple and useful method for locating objects and it is very intuitive for anyone familiar with the latitude and longitude system of coordinates. There is just one problem with it: the position of any object in the sky varies with the location of the observer. If you measure the altitude and azimuth of an object in the sky from say, Arizona, and then call a friend in Seattle and give them your coordinates, they won't find that same object at those coordinates!

Look at something simple as the Zenith. If you were standing on the North Pole and looked straight up, you would see the **North Star**, Polaris, right near your zenith. That is because you would be standing directly underneath the **North Celestial Pole**, the point in the sky above the North Pole. However, for an observer on the equator, they would not see Polaris right above their head. Instead, Polaris would be down at the horizon if it were visible at all. That is because they are 90 degrees south of the North Pole, so the North Celestial Pole would be 90 degrees away from their zenith. Worse, an observer in the southern hemisphere cannot see Polaris at all, as it would be below their horizon. Note that there is also a **South Celestial Pole**, which is defined as the point in the sky that is directly above the South Pole and can only be defined for observers in the southern hemisphere. Therefore, what constellations we see depend on our location, the number of degrees north or south of the equator we are and the time of year. For example, Orion is considered a winter constellation because it is seen during the winter months in the Northern Hemisphere.



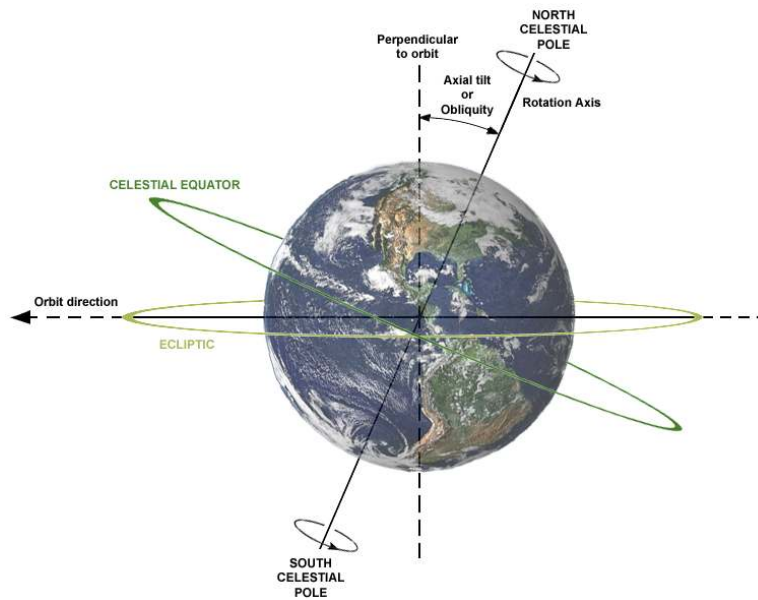
The Celestial Sphere:

<https://www.subpng.com/png-2mp4li/>

So, instead of using the horizon and the celestial meridian as our references, we are going to pick reference points that can be used no matter where the observer is on Earth. The first reference we are going to use is the **celestial equator**, which is the projection of the Earth's equator onto our celestial sphere. We use the term **declination** to mean the number of degrees north or south of the celestial equator. The advantage of using the celestial equator is that it moves with the relative position of the stars from one location on Earth to another. This makes it a portable reference that can be applied anywhere on Earth. For more precise measurements, declination is given in degrees, arcminutes, and arcseconds, where an arcminute is $1/60^{\text{th}}$ of a degree and an arcsecond is $1/60^{\text{th}}$ of an arcminute. Degrees, arcminutes, and arcseconds are also used to measure the apparent size of an object. For example, viewed from Earth, the Moon has an apparent size of 31 arcminutes or roughly half a degree.

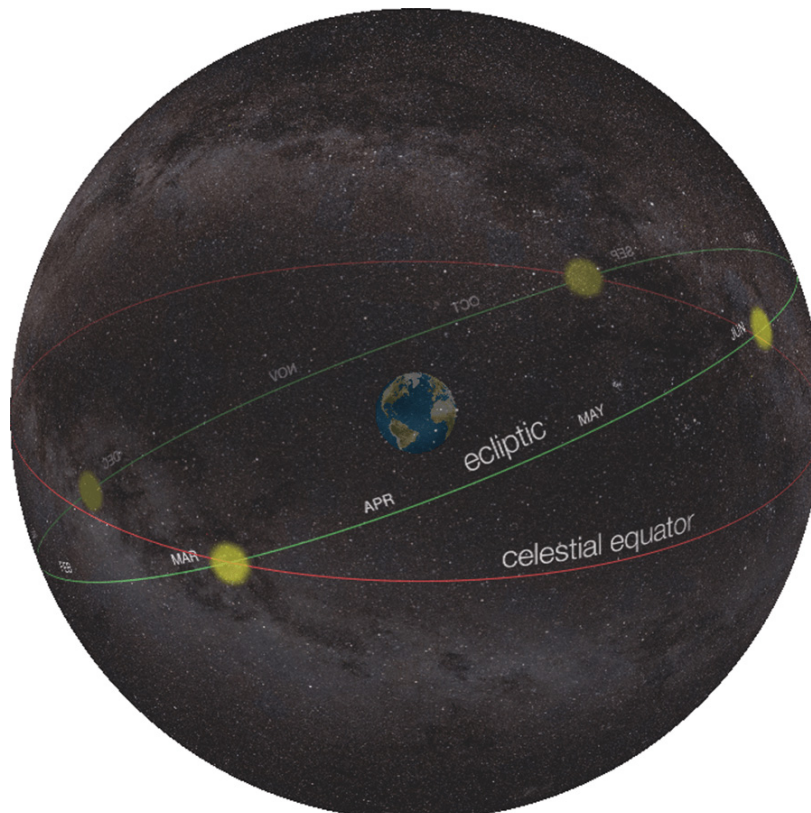
The other reference in our celestial coordinate system uses the **ecliptic**, which is defined as the apparent path the Sun makes as it moves across the sky during the day (Astronomers also use the term ecliptic to mean the plane of the Earth's orbit as it revolves around the Sun). This measurement is called **right ascension** and is defined not using degrees but in the number of hours, minutes,

and seconds from the Sun's position on the vernal equinox. Using declination and right ascension, we can then pinpoint the location of an object on our celestial sphere than can be translated in any local altitude and azimuth.



The Celestial Equator, Ecliptic, and Celestial Poles.

https://en.wikipedia.org/wiki/Celestial_equator



The Celestial Sphere with the ecliptic and celestial equator.

"File:Celestial Sphere - Eq Ecliptic.png" by ChristianReady is licensed under CC BY-SA 4.0



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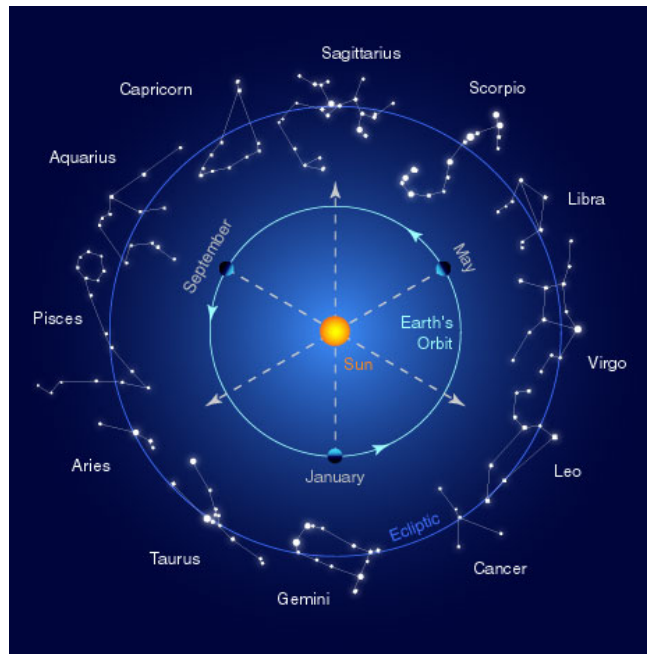
1.3: Motion of the Earth

As noted above, the constellations we see depend on the time of the year. As the Earth revolves around the Sun, it faces different directions in our galaxy. That is why we cannot see Orion in the northern hemispheric summer. The Northern Hemisphere is facing in the opposite direction of our celestial sphere. However, some constellations, most notably Ursa Major and Ursa Minor, also known as the Big Dipper and the Little Dipper, appear to revolve around the celestial north pole, because their apparent location on the celestial sphere is close to that point. Likewise, in the Southern Hemisphere, there are constellations such as the Southern Cross that appear to revolve around the South Celestial Pole for the same reason.



Constellations like the Big Dipper, the Little Dipper, and Draco appear in the sky all year round and appear to revolve around the celestial north pole. "Draco" by JeaMY_Lee is licensed under CC BY-NC-SA 2.0

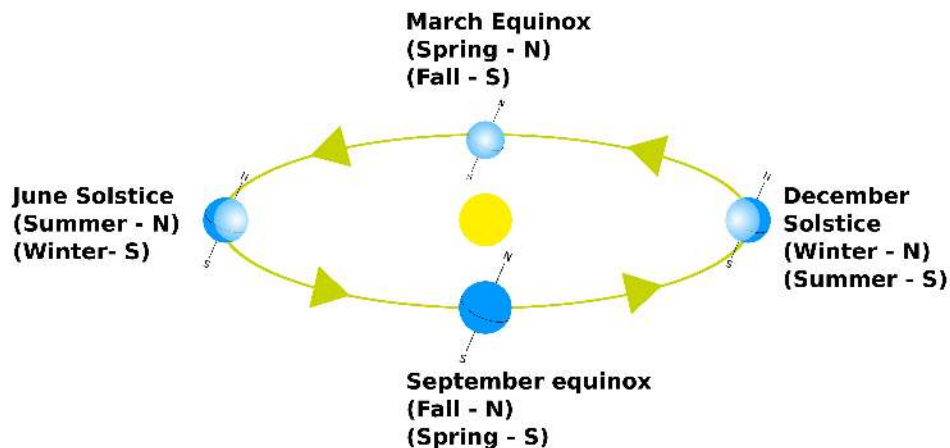
One group of constellations that many people find important are the twelve that lay right along the ecliptic. These are referred to as the **zodiac constellations**. Throughout the year, the Sun appears to “pass through” each of the constellations of zodiac. So, when someone says that they are a “Libra,” that means they were born during the period of time when the Sun passes through the constellation of Libra. Note that when the Sun passes through a constellation, you cannot actually see it because it is “behind” the Sun and its light washes out the light from the stars of that constellation. The signs of the zodiac are used in astrology, the superstition that believes the stars can influence people’s personalities and fates.



The Constellations of the Zodiac are twelve constellations that lie on the ecliptic.

<https://pixy.org/src/168/thumbs350/1689836.jpg>

The Earth's motion around the Sun determines the seasons, but not in the way many people many assume. While the Earth's distance from the Sun does vary throughout the year, this is not what determines the seasons. Note that when it is summer in the Northern Hemisphere, it is winter in the Southern Hemisphere. In fact, during the northern hemispheric winter, the Earth is actually closer to the Sun than during the northern hemispheric summer. What determines the season is the 23.5 degree tilt in the Earth's axis of rotation with respect to the ecliptic. When the Northern point of the axial tilt is pointed toward the Sun, that hemisphere experiences summer while the Southern Hemisphere experiences winter and vice versa. Compared to when the axis is titled toward the Sun, when it is tilted away, that hemisphere receives less direct sunlight, the Sun's rays pas through a thicker portion of the Earth's atmosphere and the Sun's rays are also "spread out" over a wider surface area. For these reasons, that hemisphere that is currently titled away from the Sun receives less solar radiation per square meter. This results in colder temperatures compared to the summer months.



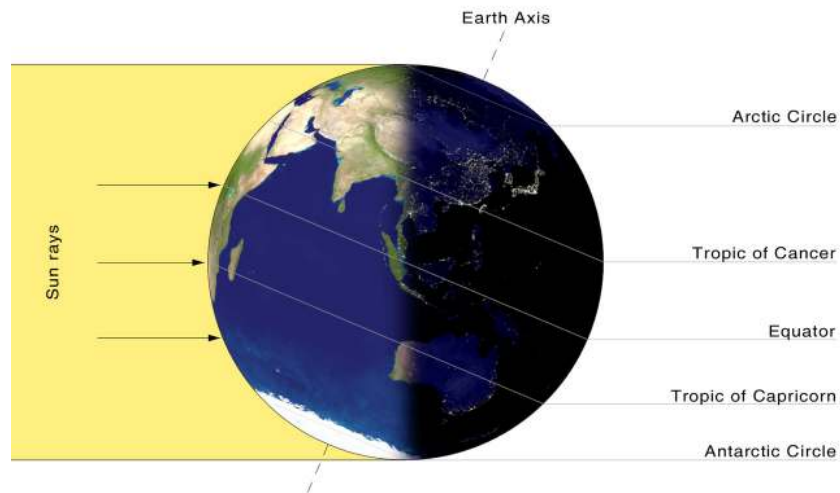
The solstices and equinoxes

"File:Orbital relations of the Solstice, Equinox & Intervening Seasons.svg" by Colivine is licensed under CC0 1.0

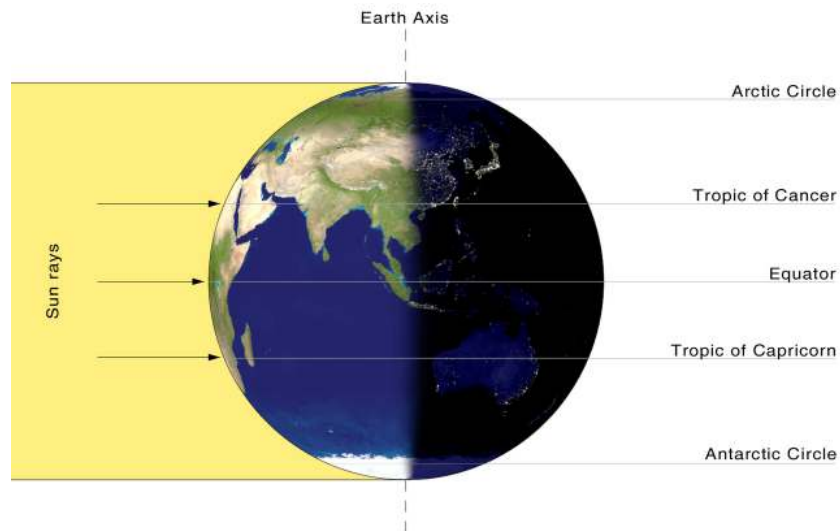
There are four important dates throughout the year with respect to the seasons. The first is the **winter solstice**. As the first official day of winter, the winter solstice is the point where the Sun stops moving lower in the sky. It is also the day with the shortest period

of daylight hours and the longest period of nighttime hours. The word “solstice” literally means “sun stops,” as in the Sun stops moving lower. After the winter solstice, the Sun starts reaching higher altitudes at noon each day and the amount of daylight time gets steadily longer until the **summer solstice**. This is the time when the Sun stops moving higher in the sky and starts reaching lower and lower maximum altitudes each day. The summer solstice is also the first official day of summer and marks the day with the longest period of daylight hours and the shortest period of nighttime hours. After the summer solstice, the daylight period gets short and shorter until the next winter solstice.

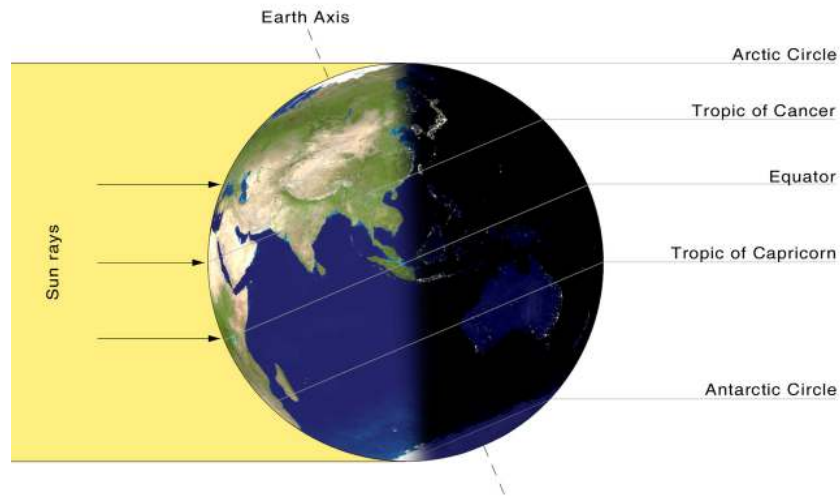
In between the winter solstice and the summer solstice are the equinoxes. The **vernal equinox** is the first official day of spring while the **autumnal equinox** is the first official day of fall. On both days, the Earth’s axis is pointed neither toward nor away from the Sun and the periods of daylight and nighttime are equal.



Axial Tilt During the Northern Winter Solstice. Image by Przemyslaw "Blueshade" Idzkiewicz.



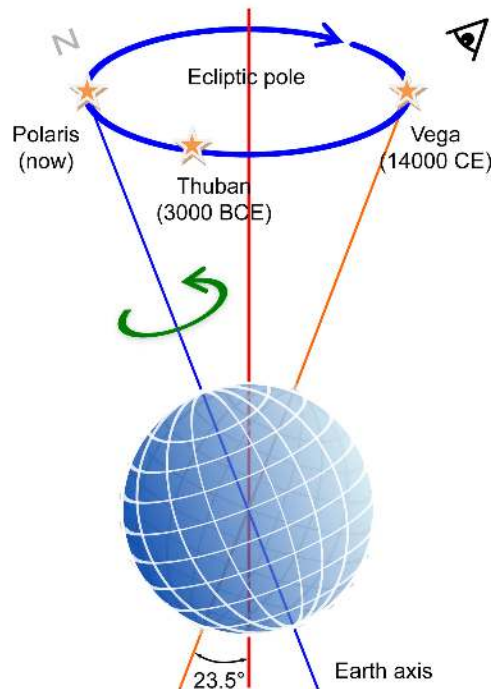
Axial Tilt During the Equinoxes. Image by Przemyslaw "Blueshade" Idzkiewicz.



Axial Tilt During the Northern Summer Solstice. Image by Przemyslaw "Blueshade" Idzkiewicz.

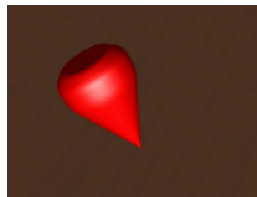


Another important movement of the Earth is the precession of its axis. Over a period of about 26,000 years, the Earth's axis makes a complete circle, much like how the axis of a spinning top makes a circle as it slows down. As a result of precession, the direction of the axis shifts over time. Currently, the northern axis points in the general direct of the star Polaris, which is why it is always near the celestial north pole. This has made Polaris a handy tool for navigation and why it is called the North Star. However, 5,000 years ago, when the Egyptians were building the pyramids, the north axis was pointing toward a different star, Thuban. In the future, it will point toward other stars or toward no star at all. Currently, the southern axis is not pointing to any star, so there is no "South Star" that can be used for navigation below the equator.



□ The Precession of the Earth's Axis

"File:Precession-sphere-EN.svg" by Markus Nielbock is licensed under CC0 1.0;



The Precession of the Earth's Axis is like a slowly spinning top.

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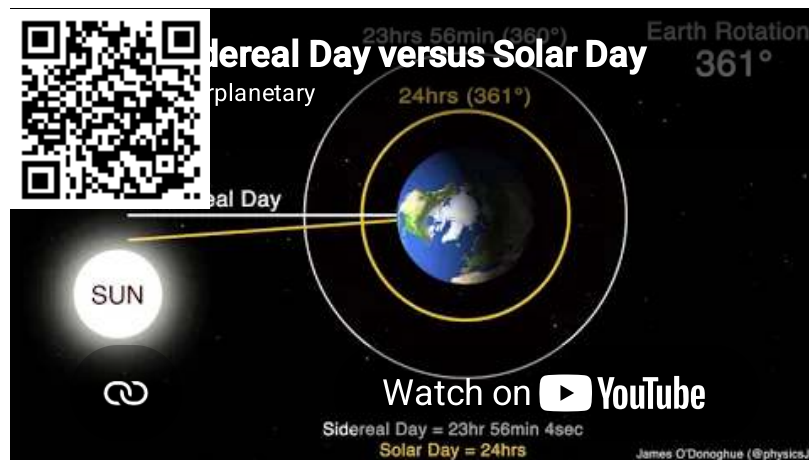


Recall that ancient people used the sky to mark the passage of time, particularly from one year to the next. But is a year? That is harder to define as you might think and there are actually two different ways to define a year. A **sidereal year** measures one orbit of the Earth around the Sun relative to the constellations. On the other hand, a **tropical year** is measured using the seasons, such as from one vernal equinox to the next. Because of some slight differences in the Earth's motion relative to each measurement, a sidereal year is about 20 minutes longer than a tropical year. This means that the appearances of the constellations are slowing

shifting over time. Currently, Orion is a winter constellation, but in 13,000 years, it will be a summer constellation, appearing in July and August even though those months, according the tropical year, will still be the northern summer.



Likewise, we have two different ways to measure a day. For example, we define a **solar day** as from noon to noon. However, because the Earth moves partially along its orbit, the stars are not in the same position in sky as they were at the same time as the previous day. Therefore, a **sidereal day**, which is measured from the position of the stars from night to night, is about 3.9 minutes shorter than a solar day.



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1.4: Motion of the Moon

While we can use the timing and position of the Sun to mark the days and the years, early people used the motion of the Moon to define the month. Also, as with the day and the year, we have two ways to define a month. A **synodic month** marks the amount of time it takes for the Moon to go through a complete set of phases, from full moon to full moon, about 29.5 days. On other hand, a **sidereal month** marks one complete orbit of the Moon 360 degrees around the Earth. Because the Earth moves along its orbit around the Sun, a sidereal month is about two days longer than a synodic month.

Days, months, and years make up the basic units of our calendar. However, neither the day nor the month make a convenient fraction of a year. At roughly thirty days long, a month does divide evenly into the 365.25 days of a year. Five extra days need to be added to the calendar to fill out a standard year and an extra day needs to be added every four years (called a leap year) to keep the calendar standard. The ancient Romans used to tack the extra days at arbitrary times throughout the year until Julius Caesar standardized the length of each month, scattering the extra days throughout the year. To this day, we still use the months defined in the Julian calendar, with some modifications.

People often refer to the “Dark Side of the Moon,” but in reality, all areas of the Moon receive illumination from the Sun throughout the month. The Moon is tidally locked to the Earth, which means the same side of Moon always faces the Earth. Instead, we will refer to the two hemispheres of the Moon as the **near side** and the **far side**. We have been familiar with the near side of the Moon since the first people looked up and saw it in the sky hundreds of thousands of years ago. However, we had no idea what the far side looked up until the 1960s, when we sent probes around to the far side that transmitted pictures of its surface back to Earth.

The phases of the Moon refer to how much of the near side is illuminated by the Sun and therefore visible from Earth. During full moon, the entire near side is reflecting light from the Sun toward Earth and we can see its entire surface. After full moon, the Moon is said to be **waning**, as less and less of the near side receives light from the Sun. The Moon moves from gibbous phase to quarter phase to crescent phase. At new moon, none of the near side is receiving light from the Sun and none of it is visible from the Earth. After new moon, we say the Moon is **waxing** through crescent phase, quarter phase, and gibbous phase as more and more of the near side receives sunlight until the next full moon phase.



https://commons.wikimedia.org/wiki/File:F...f_the_Moon.png

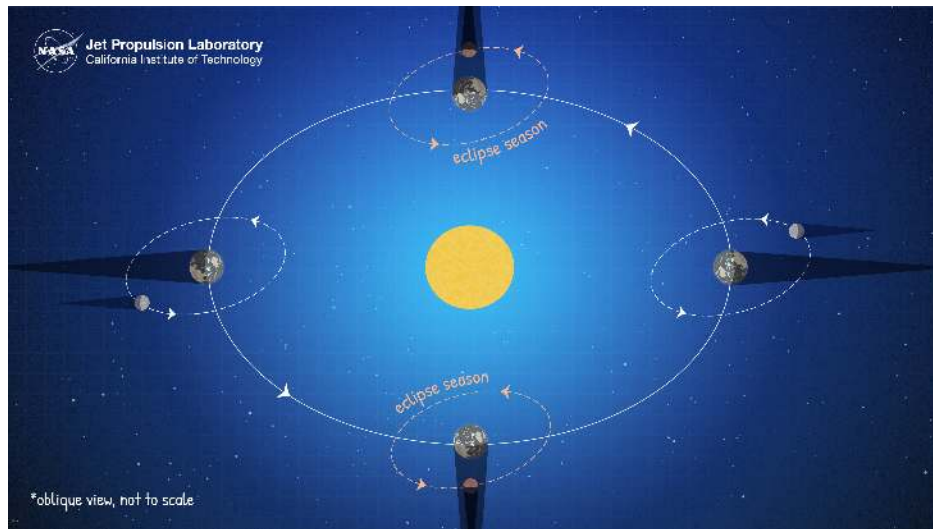


Sometimes, during full moon phase, the Moon passes through the Earth's shadow, which blocks the Sun's light. A **lunar eclipse**, where the Moon appears to disappear, can be either a **partial eclipse**, where only part of the Moon is in shadow or a **total eclipse**, when all of the Moon passes through the Earth's shadow.



Lunar Eclipse.

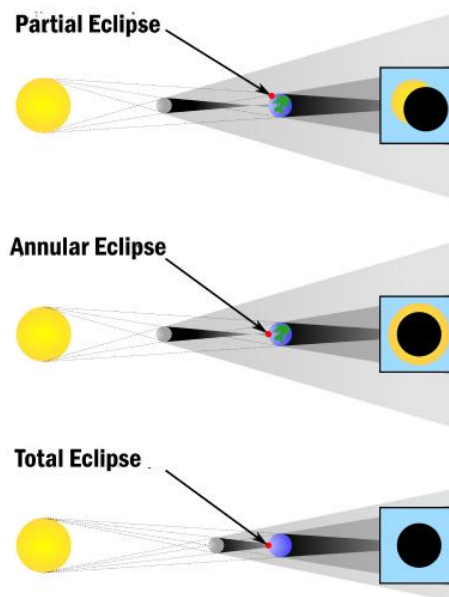
<https://www.jpl.nasa.gov/edu/images/...nareclipse.gif>



Lunar Eclipse.

Credit: NASA/JPL-Caltech

Likewise, during new moon phase, the Moon sometimes casts its shadow across the Earth's surface, causing a solar eclipse. During a **solar eclipse**, the Moon's shadow has two parts, the outer, light part **penumbra** and the darker central **umbra**. Areas of the Earth covered by the Moon's umbra experience a total eclipse, where all the Sun's disk is blocked by the Moon. During a total solar eclipse, we can see the Sun's **corona**, or outer atmosphere. Normally, the light from the Sun's surface is too bright for us to see the corona, but during a total eclipse, the Moon's shadow blocks all of the light from the Sun's surface, allowing us to see the corona. Areas of the Earth touched by the penumbra of the Moon's shadow experience a partial eclipse. During a partial solar eclipse, only a portion of the Sun's disk is blocked and the corona is not visible. When the Moon is at apogee, its furthest distance from the Earth, its apparent size can be too small to cover the entire disk of the Sun. When this occurs, we can have an **annular eclipse**, where a ring of the Sun can be seen around the Moon's shadow.



Partial, Annular, and Total Solar Eclipses

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Partial Solar Eclipse.

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Total Solar Eclipse with the Corona Visible.

<https://spaceplace.nasa.gov/eclipses/en/>



Annular Solar Eclipse

Photo by Drew Rae from Pexels;

Why do we not see an eclipse every new moon and every full moon? The Moon's orbit is tilted with respect to the ecliptic. Therefore, eclipses only occur when the positions of the Sun, the Earth, and Moon form a straight line.



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