Astronomy 103: Introduction to Planetary Astronomy

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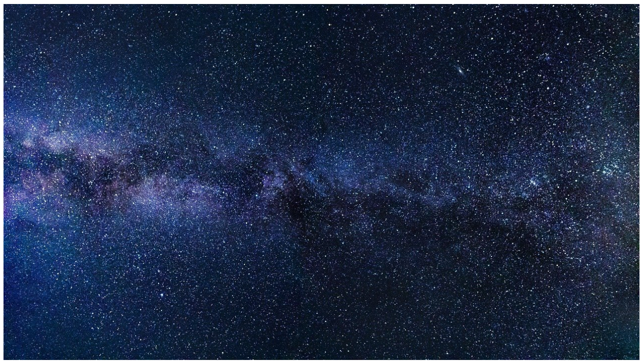
1: Introduction

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 norther 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.

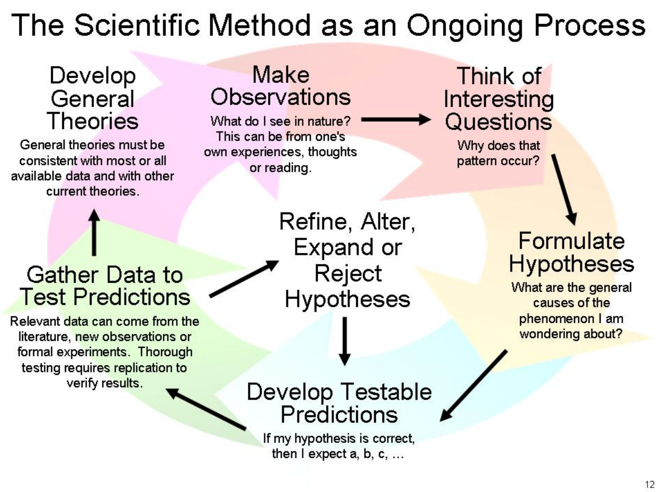
But why did the ancient people take such an interest in the night sky? The answer lies with those patterns they noticed. The sky became both their calendar and their navigation chart. By noting which stars always appeared in certain locations at the same time every year, they could predict the coming 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.

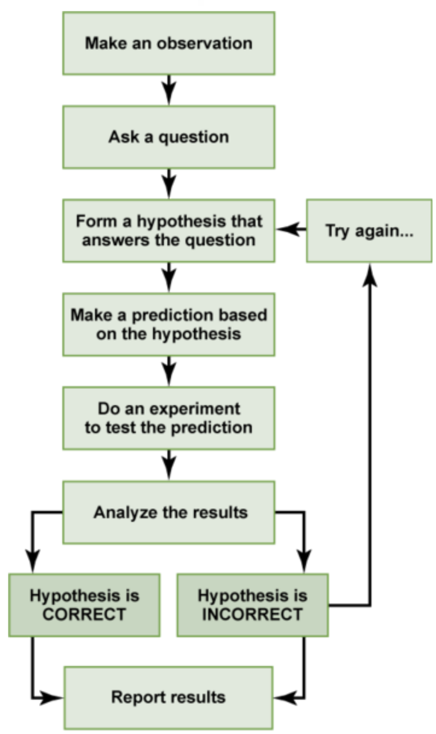
Of course, today scientists do not look at the sky for portents of the future. They look at the sky to study the various bodies we see. This chapter will begin with a basics of the scientific method and then discuss the methods used by astronomers used to located objects in the sky. Then we will finish 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.

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.





Scientific Method Flow Chart.

Image sources: https://commons.wikimedia.org/wiki/F...rparallax2.png, https://commons.wikimedia.org/wiki/F...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 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.orgCopy_of_Pas...e_L0057281.jpg

Erlemyer 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.

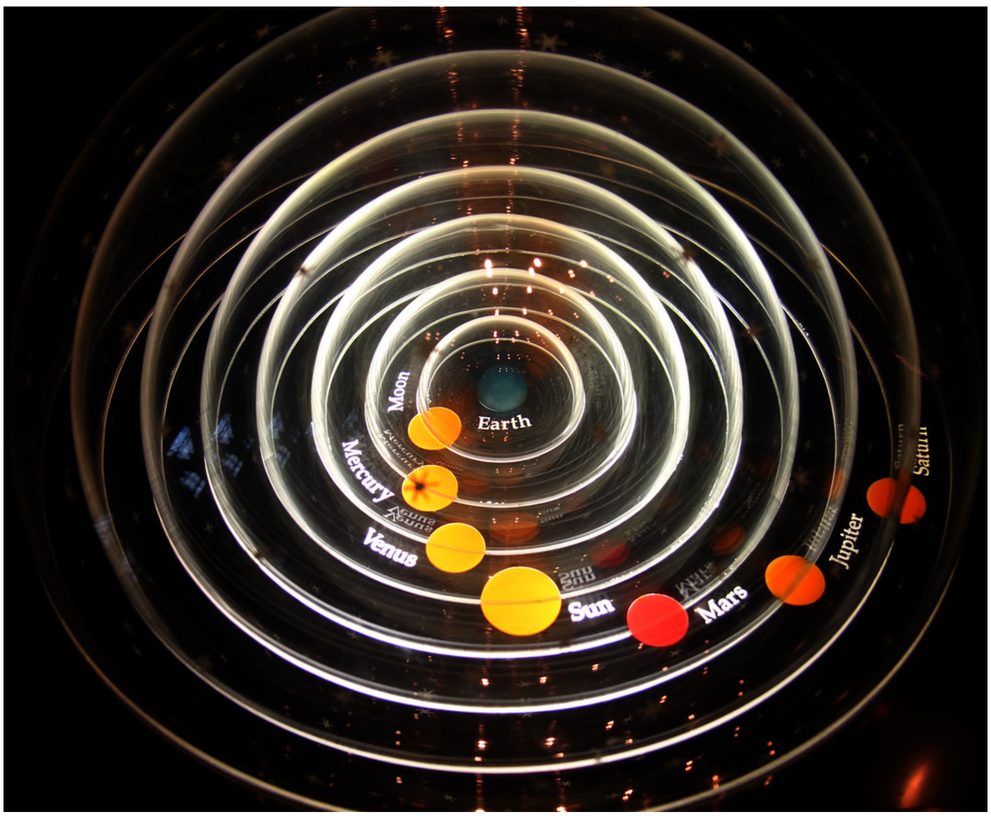
Today, few people dispute the fact that there is a strong link between smoking tobacco and certain forms of cancer. However, for decades, doubt was sown by an organization called the Tobacco Institute which published many convincing looking papers. All these papers came to the same conclusion: "Gosh, 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 in 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.

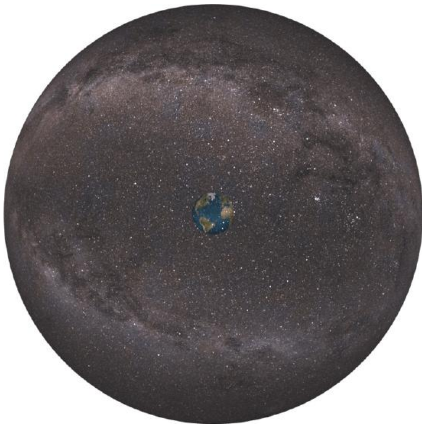
One final word on science and relates to how people use the word theory. Many non-scientists use the word to mean a guess or a hunch based on incomplete information. However, this is now how scientists use the term. In science, a theory is a broad explanation for a phenomenon that has been well-tested, shown to be supported repeatedly by experiment, and has gained wide acceptance. It is not a single hunch or guess. They 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 understand 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

1.2: The Celestial Sphere



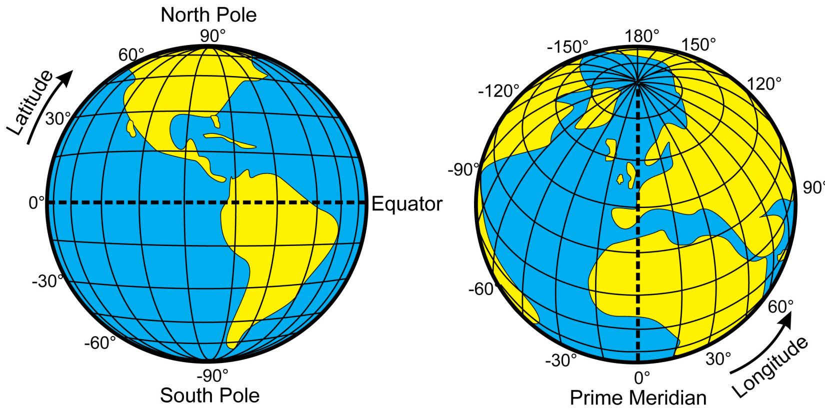
Celestial Sphere - Earth Stars.png; by ChristianReady is licensed under CC BY-SA 4.0

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;

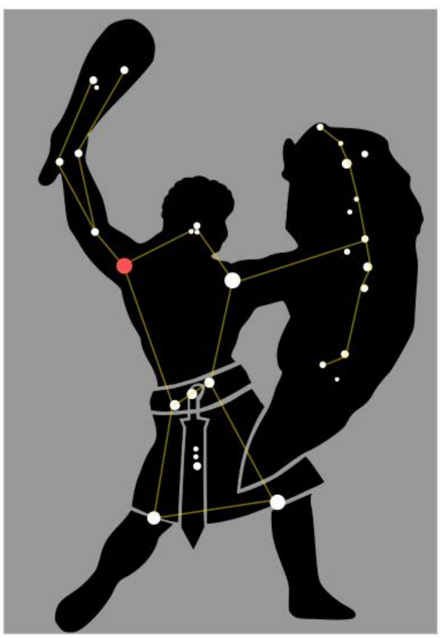
Even though there is no real celestial sphere with stars embedded on its inner surface, the celestial is still a useful model for a coordinate system to locate stars and planets that we want to study. After all, we cannot study an object if we cannot find it. On Earth, we use the system of latitude and 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**).

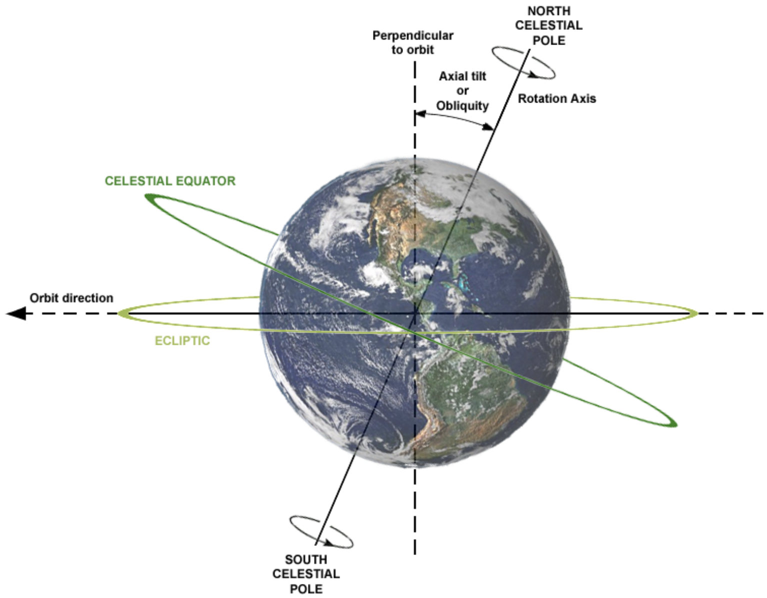
This is a very simple and useful method for locating objects and it is very intuitive for anyone familiar with the latitude and longitude system of coordinates. There is just one problem with it: the position of any object in the sky varies with the location of the observer. If you measure the altitude 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 seen during the winter months in the Northern Hemisphere.

The Celestial Sphere:
https://www.subpng.com/png-2mp4li/

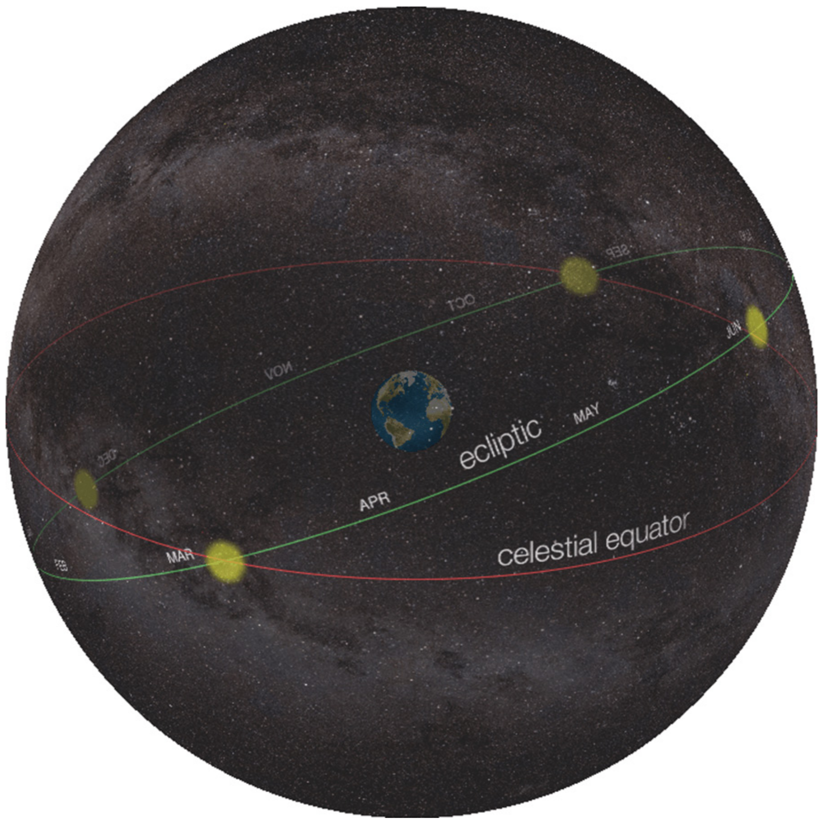
So, instead of using the horizon and the celestial meridian as our references, we are going to pick reference points that can be used no matter where the observer is on Earth. The first reference we are going to use it the **celestial equator**, which is the projection of the Earth's equator onto our 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 1/60th of a degree and an arcsecond is 1/60th 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.

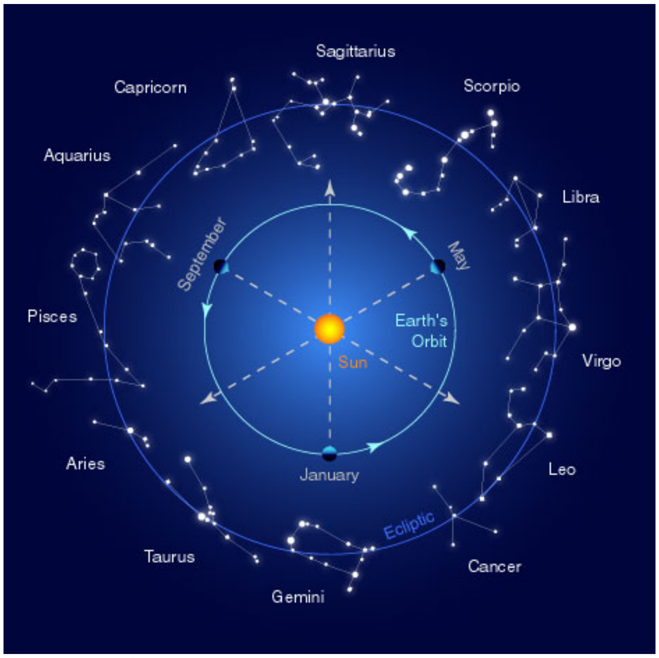
"File:Celestial Sphere - Eq Ecliptic.png" by ChristianReady is licensed under CC BY-SA 4.0

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 Earth, 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 Usra 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, the 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

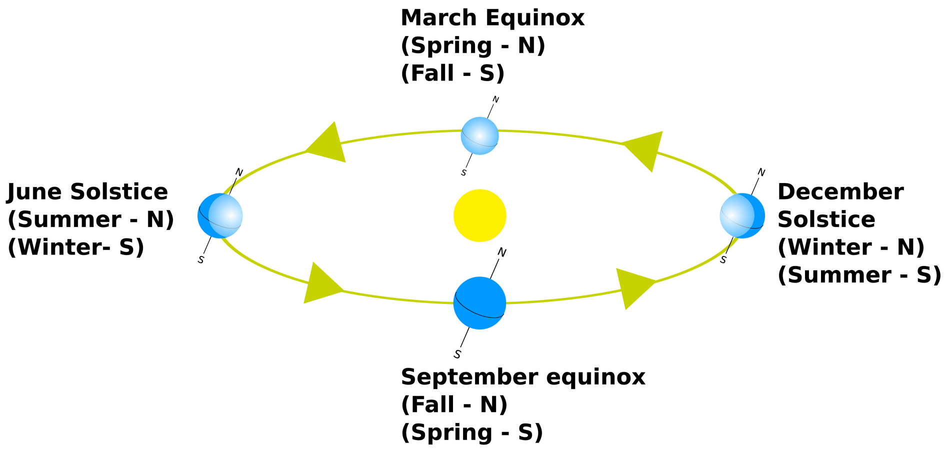
One group of constellations that many people find important are the twelve that lay right along the ecliptic. These are referred to as the **zodiac constellations**. Throughout the year, the Sun appears to "pass through" each of the constellations of zodiac. So, when someone says that are a "Libra," 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 as 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 norther 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.

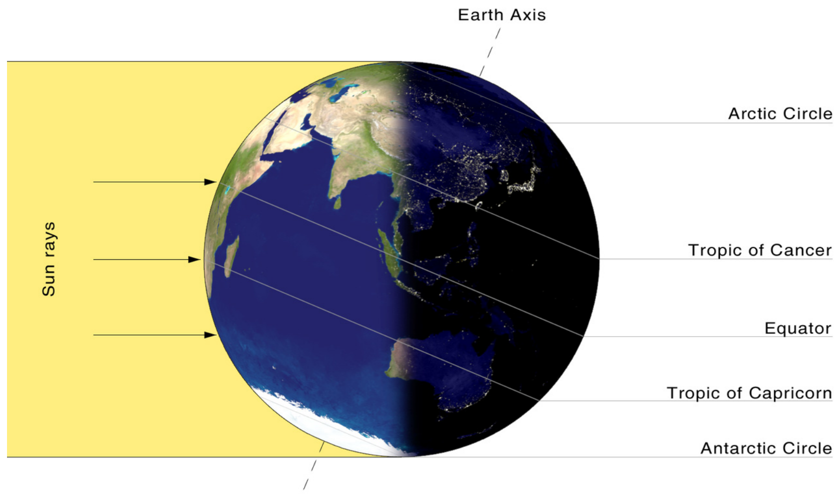


The solstices and equinoxes

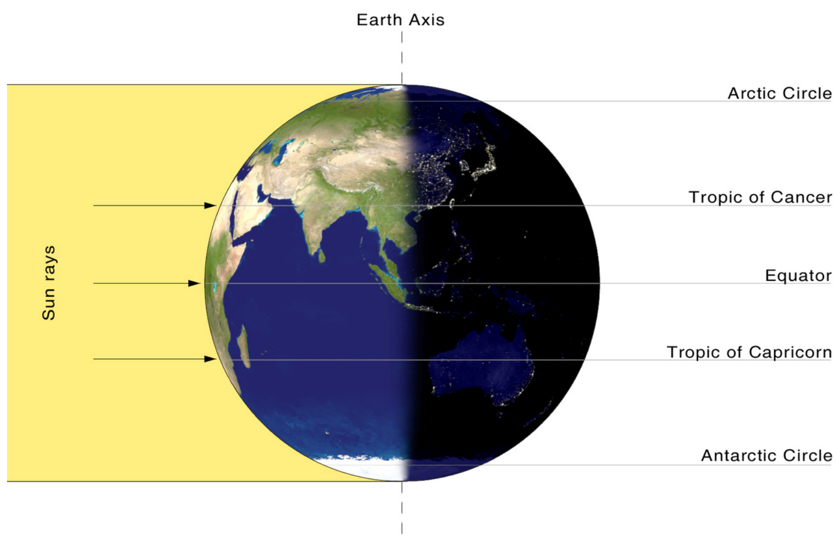
"File:Orbital relations of the Solstice, Equinox & Intervening Seasons.svg" by Colivine is licensed under CC0 1.0

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.

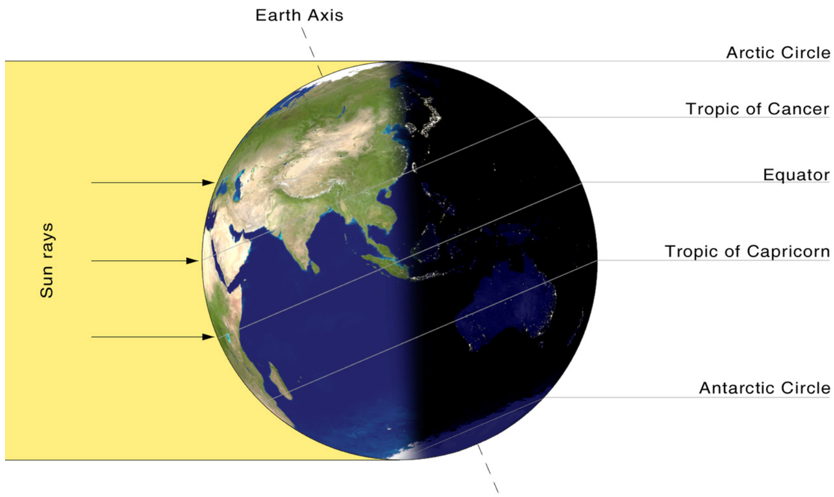
In between the winter solstice and the summer solstice are the equinoxes. The **vernal equinox** is the first official day of spring while the **autumnal equinox** is the first official day of fall. On both days, the Earth’s axis is pointed neither toward nor away from the Sun and the periods of daylight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



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

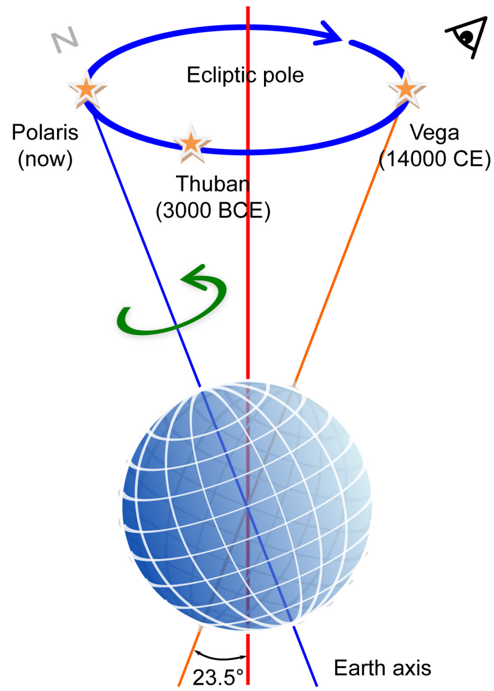


Axial Tilt During the Euquinoxes. Image by Przemyslaw "Blueshade" Idzkiewicz.



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.

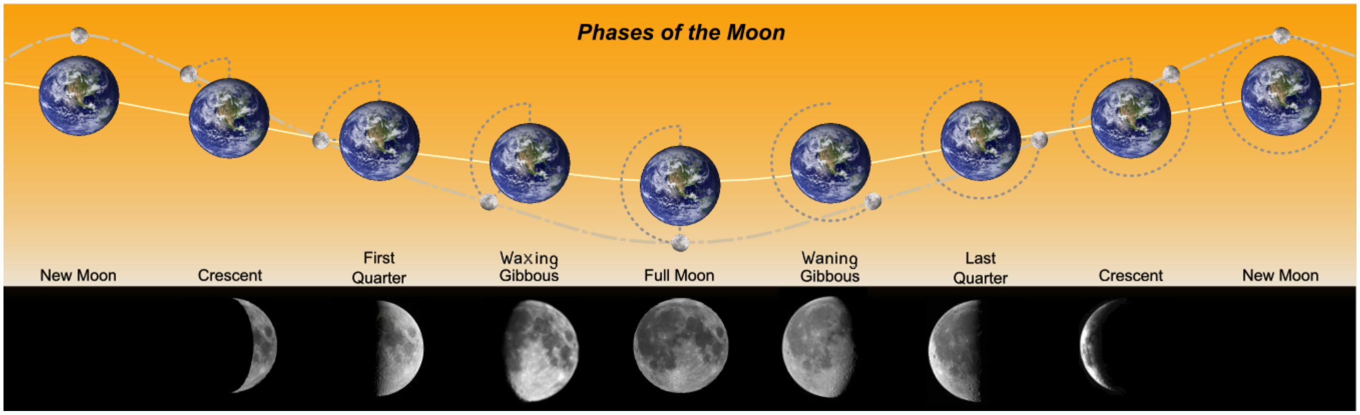
1.4: Motion of the Moon

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.



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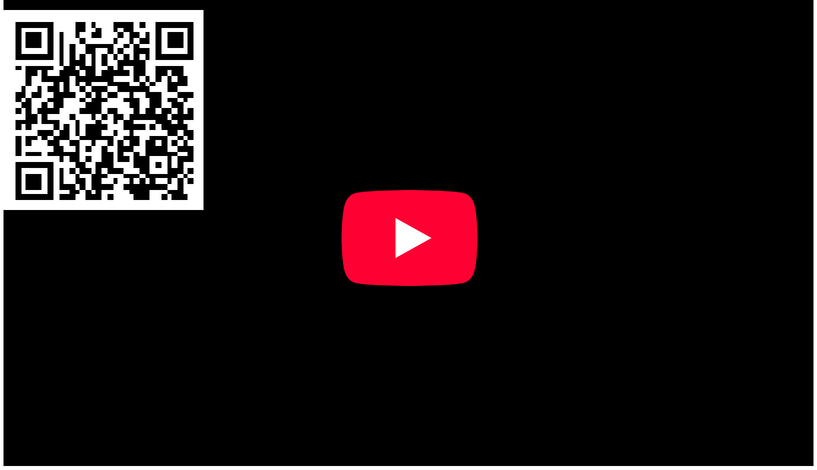
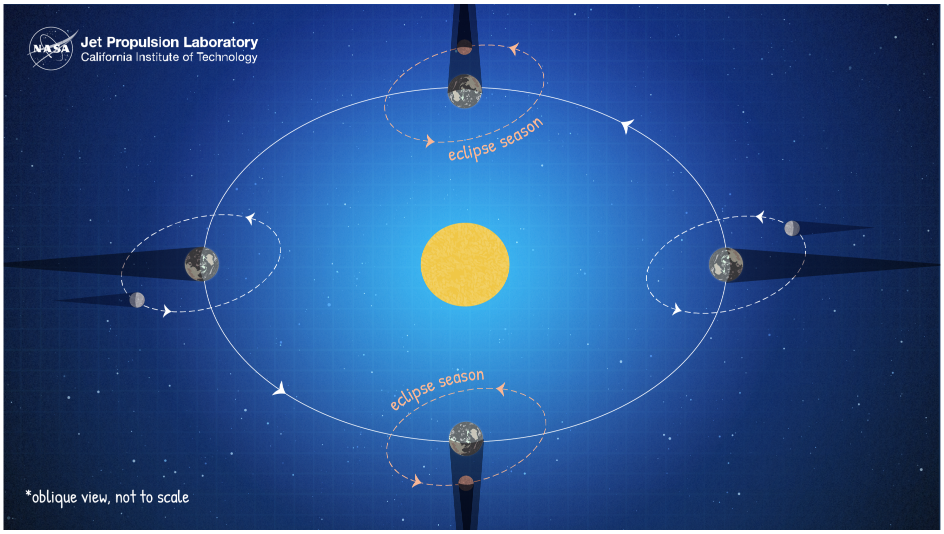


Sometimes, during full moon phase, the Moon passes through the Earth’s shadow, which blocks the Sun’s light. A **lunar eclipse**, where the Moon appears to disappear, can be either a **partial eclipse**, where only part of the Moon is in shadow or a **total eclipse**, when all of the Moon passes through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

Lunar Eclipse.

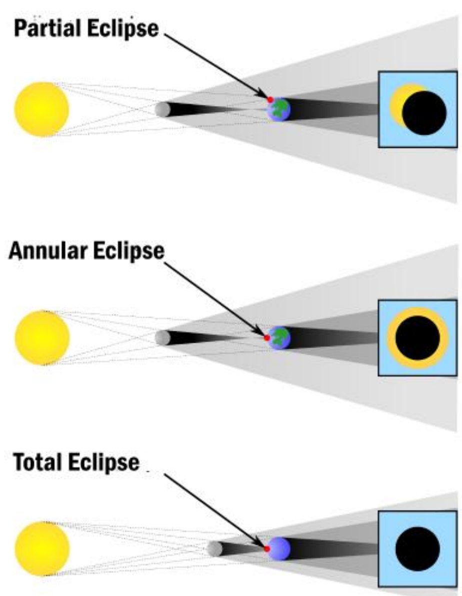
https://www.jpl.nasa.gov/edu/images/...nareclipse.gif



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 it blocked 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 is 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.

by Malingering is licensed under CC BY-NC-ND 2.0

Total Solar Eclipse with the Corona Visible.

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

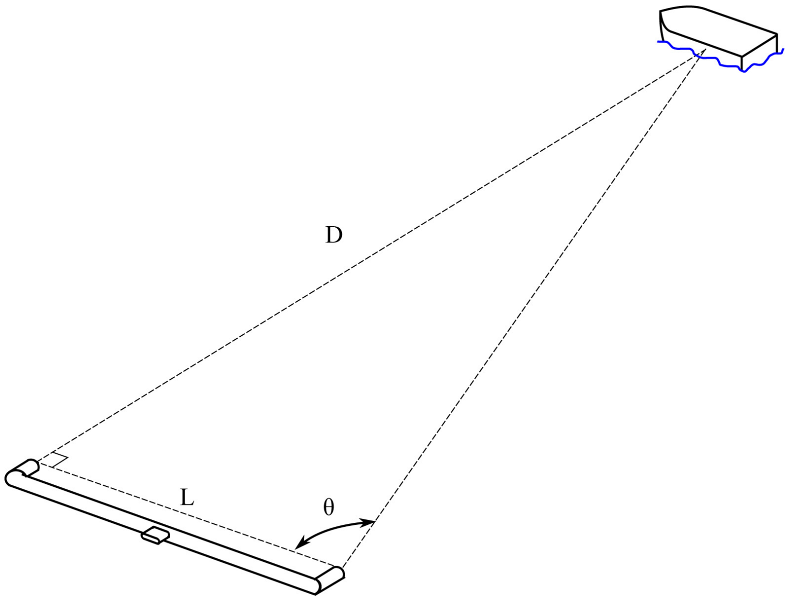
Annular Solar Eclipse

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.

1.5: Measuring Distances

How do we measure to the distances to distant objects like stars? After, we cannot take an infinitely long tape measure out to these stars. So, we need an indirect method to measure these distances. For distance objects, use a method called triangulation. For example, if you want to measure the distance to a boat at sea, you start by marking a point on the shore directly in line with the ship. Then, you walk down the edge of the shore at a right angle to the imagine line between the boat and the point you marked. Next, you measure the distance (L) from your initial point and a second point along the shore. Finally, you measure the angle (ɵ) from your second point to the ship. Now, you have two angles and one side of a right triangle. With a little trigonometry, you can then calculate the distance (D) from your first point and the ship.



Measuring distances using triangulation.

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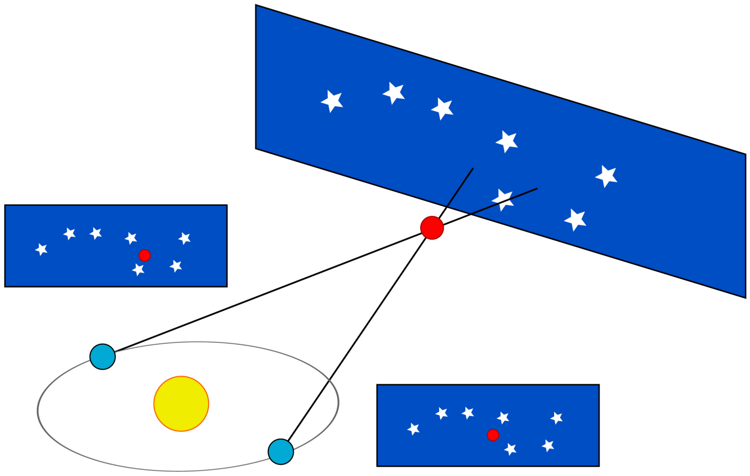
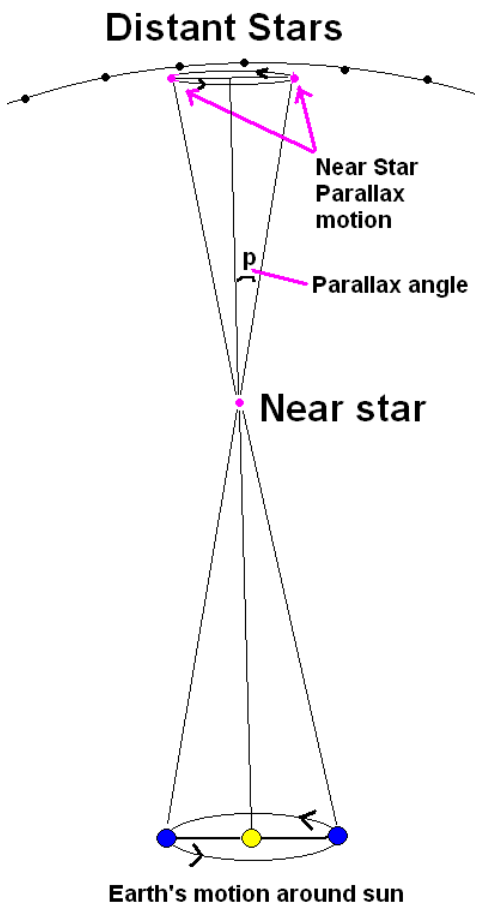
Techniques similar to this triangulation can be used to measure the distance to a star using a phenomenon called **parallax**, the apparent motion of objects against a more distance background. You can see a simple example of parallax by holding your thumb up against a distant object and closing one eye. Then, switch to the other eye. Your thumb will appear to change its position relative to the more distant object.



Positions of nearby stars appear to shift relative to the more distant stars as Earth revolves around the Sun.

Because stars are so far away, the parallax is very minute, usually a fraction of an arcsecond. These tiny deviations can be detected by taking very precise measurements of a star's position from different locations or different times of the year. In these case, we use the radius of the Earth or the radius of the Earth's orbit as the base of our triangle.



Using parallax to measure the distances to stars.

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2: Ancient Astronomy

Learning Objectives

- Understanding early cosmologies
- How Stone Age structures like Stonehenge were used as ancient astrological calendars.
- Able to describe the astronomical practices of ancient Babylon and Egypt
- Understanding how Greek philosophers and astronomy influenced Western ideas about the universe for centuries.
- Describing the astrological practices in other cultures, including China, Arabia, Africa, and the Americas.

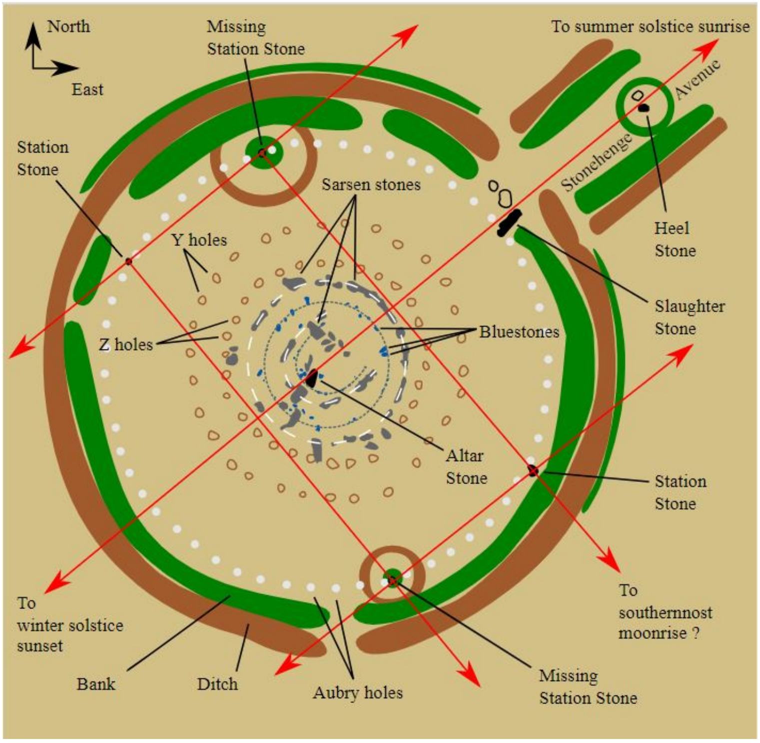
As we noted in Chapter 1, the ancient people took a keen interest in the night sky. They used it as their calendar to tell them when to plant their crops and when to harvest them, when the rainy season was about to begin, when rivers like the Nile would overflow, and when to hold specific religious festivals. They also used it navigation when they took long journeys for trade. People who could predict such important events naturally took on the air of mystery and power. Many closely guarded their secrets, sharing them only with trusted apprentices. These ancient astronomers very often were members of the priest class and wielded considerable influence. After, if you can predict the Nile would overflow, it made sense that you could predict other people. In ancient cultures, astronomy became intertwined with astrology. Even through the middle ages, many astronomers had to draw up astrological charts for their royal patrons in order to have the financing they needed to conduct their astronomical observations. Today, astronomers know that astrology has no legitimate scientific basis. However, that is a relatively recent separation. Astrology and astronomy really only began to part ways during the Copernican Revolution (Chapter 3). Eventually, astronomers like Copernicus and Galileo began to push against this marriage of astronomy and astrology, separating the science from the superstition.

In Chapter 3, we will discuss the birth of modern astronomy through the Copernican Revolution. In this chapter, we will talk about how various ancient cultures made observations about the night sky and how they put that information to use. We know from the structures they built and, in some cases, the records that they left behind, that ancient people took an interest in the movements of those “wandering stars” we call planets today. Often, they built observatories and other stone structures to mark the locations where the planets would appear at certain times of the year. They saw the stars and the planets as things moved by the gods. Until the Greeks, we have little evidence that ancient people had any models explaining the movements of the planets and stars. Their interest lay in knowing when the planets would come out and less in what forces were governing their motions.

2.1: Archeoastronomy

Researchers call the study of ancient astronomical practices **archeoastronomy**. The people of the Neolithic Period left no written records behind, so we have very little information about their **cosmologies**, their view of the universe. We know little about their creation myths or how they viewed their relationship to the cosmos. From cave paintings and the limited artifacts we have found, it appears that they had a rather small view of the universe, centered around individuals or small bands where the local environment was the entire world about which they knew. Thye likely believed the Earth was flat. Some cave paintings have included a disk with rays that archeologists have interpreted as representing the Sun and dots and crescents that could be the Moon. It appears that early hunter-gatherers had an interest in the stars, possibly to predict shifting of the season, such as the beginning of winter or when certain game animals usually migrated into the region. We do not have any information about whether they had a concept a celestial sphere as envisioned by later civilizations like the Greeks.

Stonehenge. "25AUG06 - Stonehenge 02" by AegirPhotography is licensed under CC BY-NC 2.0;



"Stonehenge plan v2 notex 2.svg" by Astroskiandhike is licensed under CC BY-SA 4.0;

With the rise of the earliest civilizations, people began to build the first **megalithic** (literally, “big rocks) structures, many of which served as calendars and observatories. One famous example is **Stonehenge**, the famous ring of standing stones in Southern

England. We know very little about the people who built Stonehenge or what kinds of rituals they held there, but archeologists believe they constructed in a series of stages over about 1,000 years. They likely completed it in the form we see it today around 1550 BCE. Taking measurements, archeologist have also determined that the people who used Stonehenge practice a form of horizon astronomy. They used the structure to mark the point of sunrise and sunset on the solstices. They also noted the points of extreme moonrise and moonset as well. We do not have any information about any cosmology associated with Stonehenge. It appears that the structure served mainly as a utilitarian tool.

2.2: Babylon and Egypt

2.2.1 The Babylonians

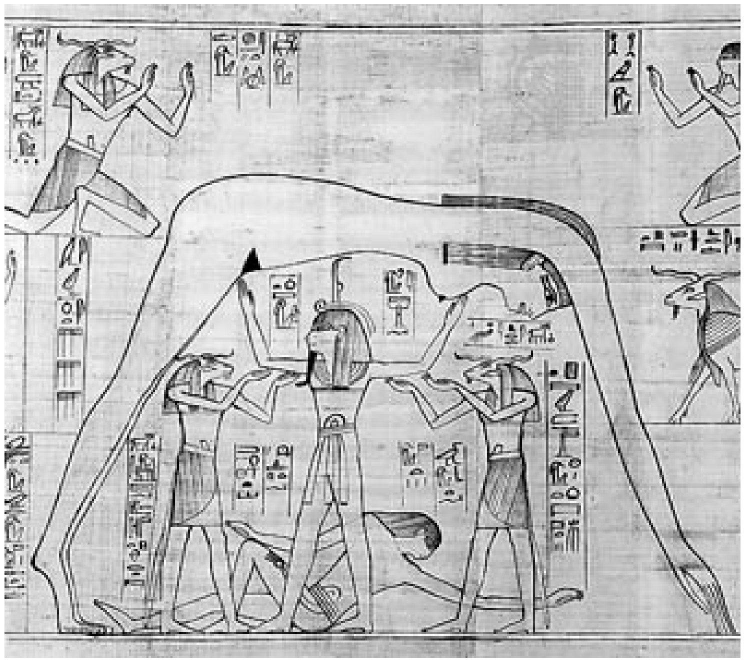
One of the earliest human civilizations to leave us records of their astronomical practices was the people of Babylon. The Babylonians developed a sophisticated calendar and had the ability to predict the positions of the planets. They kept records on clay tablets, the earliest of which date to earlier than 1500 BCE. They collected these records from copious observations and from these, we can see a subtle shift in cosmology from the earlier megalithic people. They still saw the Earth as flat, but their view of the world went beyond their immediate environment. The also viewed the sky as a gigantic vault or dome upon which contained the stars. The Sun and the Moon moved across the and they regarded these bodies as being unique and different from the stars. So, we can see the beginnings the celestial sphere model among the Babylonians.

For ancient people the sky was both their clock and their calendar.

The Babylonians also had a good enough understanding of the motions of the Sun and Moon to craft a lunar calendar. They also had a keen interest in planetary motions, which they used to make astrological predictions. To chart the motions of the planets, the Babylonians developed a sophisticated system of mathematics. Lacking any geometrical model, their mathematics were highly abstract. Also, unlike our modern system based on ten, the Babylonians based their mathematics on the number sixty. We still see remnants of this system in how we measure time, with sixty seconds in a minute and sixty minutes in an hour. This system is also where we get the measurement of 360 degrees in a circle, sixty arcminutes in a degree, and sixty arcseconds in an arcminute.

2.2.2 The Egyptians

The Egyptians had a similar cosmology to the Babylonians in which the sky consisted of the boy of the goddess Nut. The sun god, Ra, traveled across Nut's back in his boat and then descended into the underworld at night. The sky was attached to the Earth, which the Egyptians considered synonymous with the universe. The Egyptians used obelisks to tell time, much like a sundial uses the movement of its shadow to mark the passage of the hours during the day.



Egyptian god Geb and goddess Nut from the Greenfield papyrus Unknown author/Public domain;

Worship of Osiris. Amice M.Calverley, Alan Gardiner, 1935/CC BY-SA (https:/creativecommons.org/licenses/by-sa/3.0);


Obelisk of Thutmosis I in Karnak Hidden categories: CC-BY-SA-3.0-migratedLicense migration completedGFDLMedia missing infobox templateFiles with no machine-readable authorFiles with no machine-readable source;

Compared to the Babylonians, however, Egyptians had comparatively less interest in the mathematical measurements of celestial objects. The reasons for this are not quite clear, but it could be that they lacked the mathematical sophistication of the Babylonians. Records from 1100 BCE indicate the Egyptians had only five named constellations. Of particular importance to them was the constellation Orion, which they associated with the god Osiris. Osiris sat in judgment of the dead and determined what fate they received in the afterlife. Two airshafts in the Great Pyramid are aligned with the brightest stars in Orion's belt. One shaft points to where the bright star Thuban would have been 4,500 years ago.

The Great Pyramid at Giza. kallerna/CC BY-SA (https:/creativecommons.org/licenses/by-sa/3.0);

As you might expect in a desert culture, the Egyptians held the Sun in special regard, but they had practical concerns with the stars as well. They divided the night sky into 36 “decans” or star groups that they used to mark the passage of time at night. They also watched for the first appearance of the bright star Sirius; whose appearance coincided with the annual flooding of the Nile River. Every year, when the Nile flooded its banks, it left deposits of nutrient rich silt behind. The Egyptians depended on these deposits to grow their crops. Without these flood waters, Egypt would be a barren land incapable of supporting any agriculture. With the deposits left by the flood waters, however, Egypt became the breadbasket of the Mediterranean and could export grain to many of its neighbors. Knowing when those flood waters would come was therefore, crucial the prosperity of Egyptian civilization.

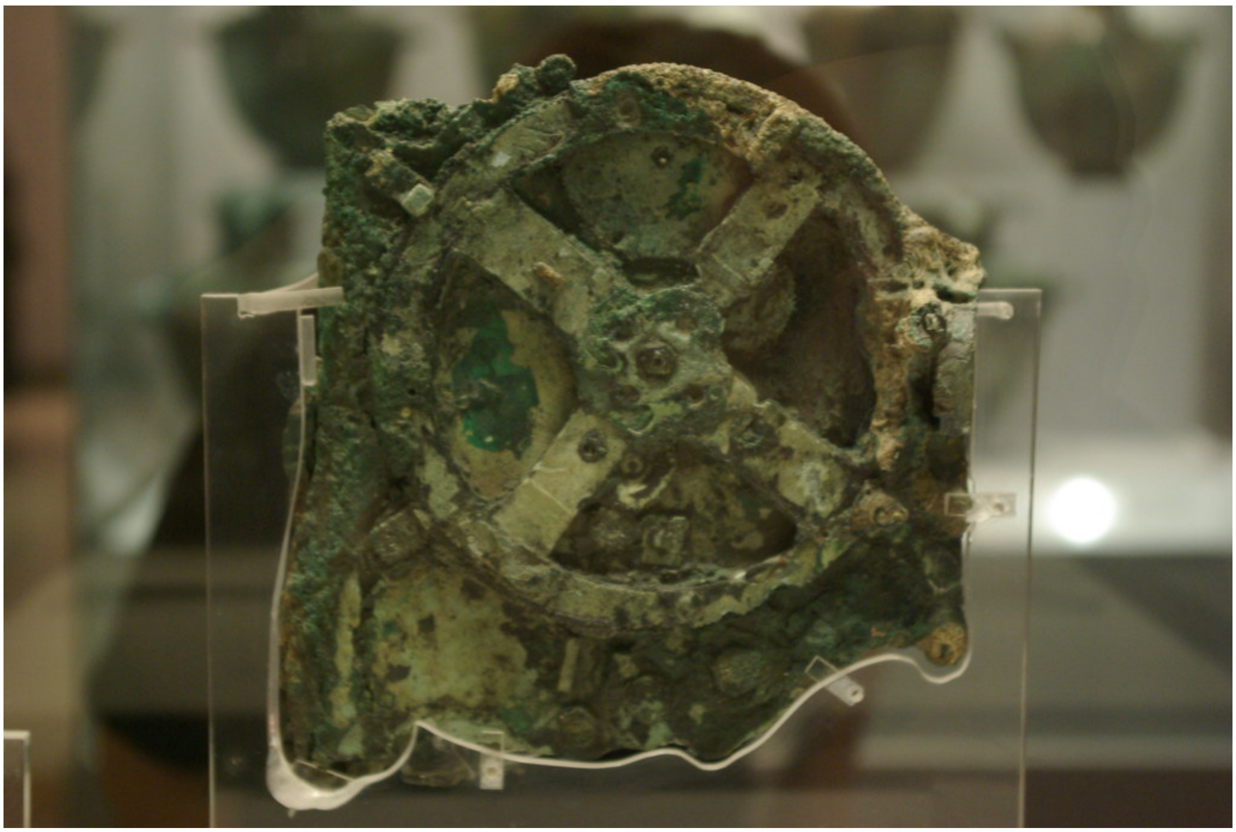
2.3: The Greeks

2.3.1 The Early Greeks

Until the fourth century BCE, ancient people mainly focused on documenting patterns in the sky and making predictions. Then the Greeks became the first people to devise a model that explained the motions of the Sun, the Moon, and the planets. Much of their models were guided by their belief that the Heavens were perfect, as opposed to the imperfect world around them. They saw the circle and the sphere as the most perfect shapes and therefore, assumed that the celestial bodies were perfect spheres and orbited in perfect circles. This philosophical assumption became so ingrained in Western thought that it was only until the late sixteenth/early seventh centuries that astronomers like Kepler and Galileo (See Chapter 3) began to question it.

The classical revolution in Greece became around 700 BCE. Much like the Babylonians and Egyptians, the Greeks were mainly using astronomy to make predictions, often using techniques imported from those countries. For example, in his writings, Hesiod describes using the appearance of the Pleiades star cluster as the time to harvest crops.

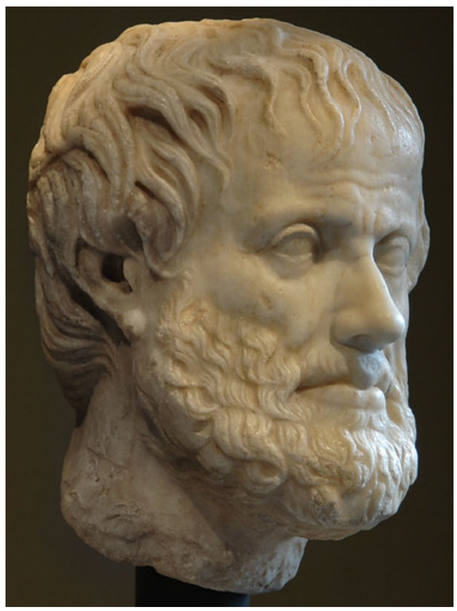
The Greeks also refined a lot of the mathematical techniques employed by the Babylonians. They even developed mechanical calendars and calculators for use in navigation and astrology. One example was the **Antikythera Mechanism**. This was discovered in 1901 in ancient shipwreck. Constructed sometime between 150-100 BCE, it could calculate the position of the Moon, planets, and stars for a given date.



This mechanical calculator was used for navigation and making astronomical observations by the Ancient Greeks.

By 500 BCE, the mathematician Pythagoras determined that the Earth was a sphere and that the Morning Star and the Evening Star were both the planet Venus. Later in the fifth century BCE, Anaxagoras of Clazomenae deduced the cause of lunar eclipses being the Moon passing through the Earth's shadow. Given the curved nature of the shadow as it moved across the face of the Moon, Anaxagoras was also able to determine that the Earth is a sphere. He also studied a meteorite and guessed that the Sun was an incandescent stone larger than all of Greece, which resulted in him being banished for impiety.

2.3.2 Aristotle



"Head of Aristotle. Vienna, Museum of Art History, Collection of Classical Antiquities." by Sergey Sosnovskiy is licensed under CC BY-SA 2.0;

In the fourth century BCE, Aristotle (382-322 BCE) published his philosophical writings that would become some of the most influential treatises in Western thought for centuries. Aristotle wrote that the Earth was a sphere at the center of the universe. He concluded the edge of the universe to be a literal sphere upon which held the "fixed" stars that revolved around the Earth. The Sun, the Moon, and the planets (wandering stars) each had their own spheres that also revolved around the Earth.

2.3.3 Heliocentrism v. Geocentrism

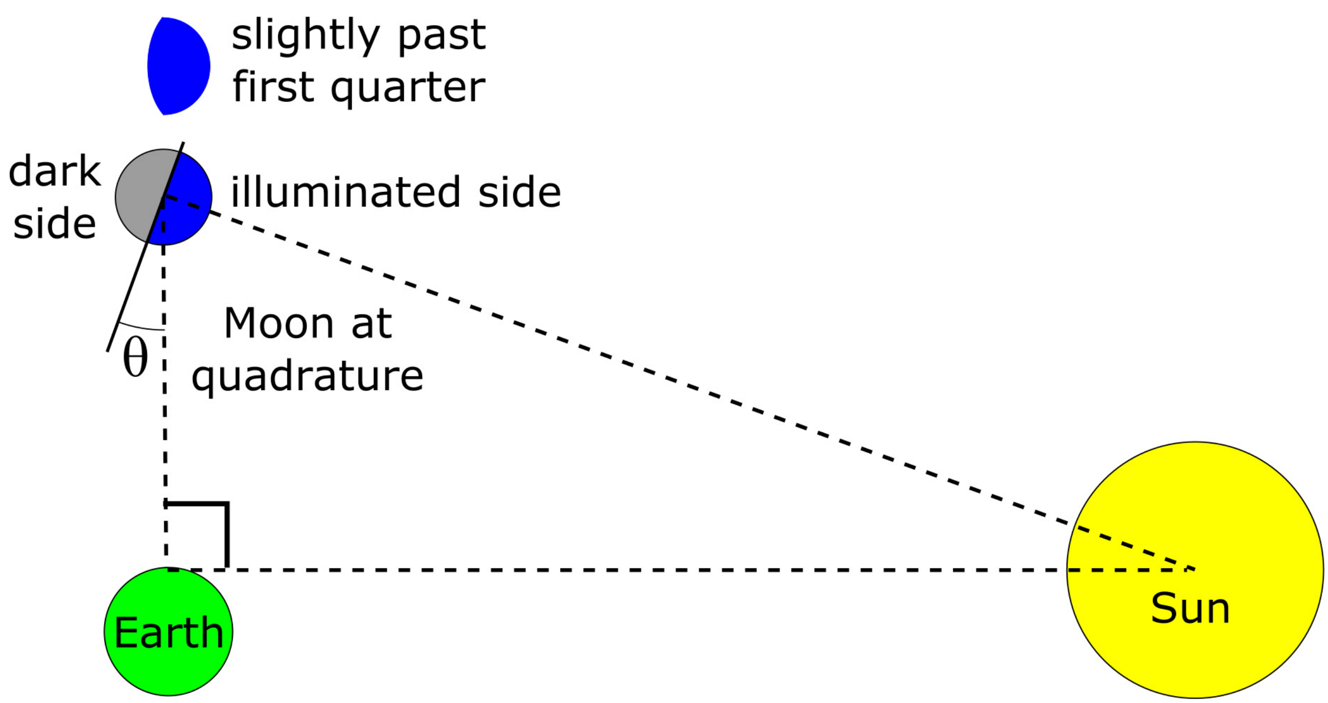
Around 360 BCE Eudoxus also described a model for the stars and planets. Like Aristotle, Eudoxus held to a **geocentric** (Earth-centered) model in which the complex motions of the planets could be explained as perfect circular motion consisting of 27 nested spheres, all revolving around the Earth.

Not all the Greeks held to a geocentric model. Aristarchus (310-230 BCE) took careful measurements to determine the relative distances and sizes of the Sun and the Moon. He determined that the Moon is about 1/3 the size of the Earth and that the Sun was at least 20 times farther away from the Earth than the Moon. He also estimated that the Sun was seven times larger than the Earth. He also deduced that the Moon shone because it reflected light from the Sun. Though his numbers were off, his insight that the Sun was larger than the Earth convinced Aristarchus that the Sun should be the center of universe. He viewed the Sun as the "king" sitting on its throne around which the planets, including the Earth, and all the stars revolved. This is the first known example of a **heliocentric** (sun-centered) cosmology.

A heliocentric model, however, predicts that the stars should exhibit parallax (Chapter 1) and Aristarchus could not detect any measurable parallax using the techniques available of his time. He therefore concluded that the stars had to be very far away, and that the universe was much bigger than assumed in Aristotle's geocentric cosmology. He wrote that the stars were distant suns like our own and that if we were able to view them up close, they would be as big and bright as the Sun.

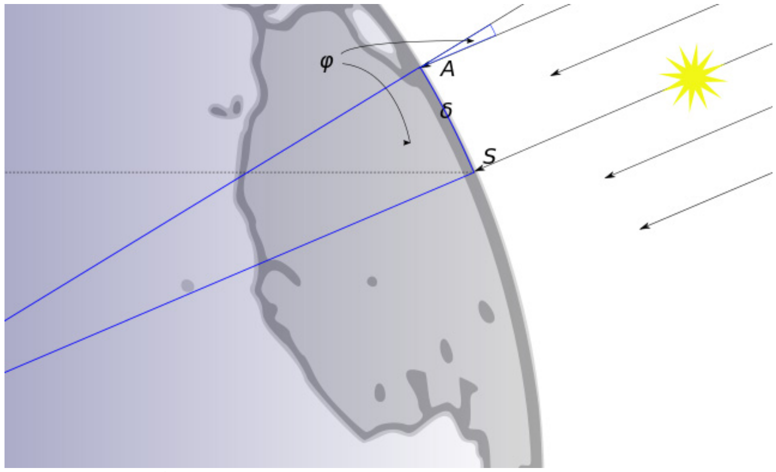
Most of his contemporaries, however, rejected Aristarchus' heliocentric model in favor of Aristotle's geocentric one. They had several objections, including the lack of parallax. If the Earth moves, why don't we perceive it? Why don't dropped objects fly off into the west? Why don't we fly off the surface? Why are tall buildings not being toppled by this motion? The most important objection, however, was that a heliocentric model based on perfect circles did not make any more accurate positions about the movement of the planets than a geocentric model did. It would take nearly a thousand years for people like Kepler, Galileo, and Newton to devise a better understanding of the motion and gravity before any of these objections could be overcome (Chapter 3).

Erastothenes (276-195 BCE) Was able to use measurements of shadows to calculate the circumference of the Earth. He noticed that the Sun was at his zenith in the city of Syene on the summer solstice. In Alexandria, the Sun was seven degrees from the zenith on the same day. From this, he deduced that the two cities were seven degrees apart on the spherical Earth. Knowing the distance between the cities, he calculated the circumference of the Earth as 42,000 km, which is fairly close to the actual figure of 40,000 km.



Aristarchus used triangulation to determine the Sun was much larger and much further away from the Earth than the Moon.

Guy vandegrift/CC BY-SA (https:/creativecommons.org/licenses/by-sa/4.0);

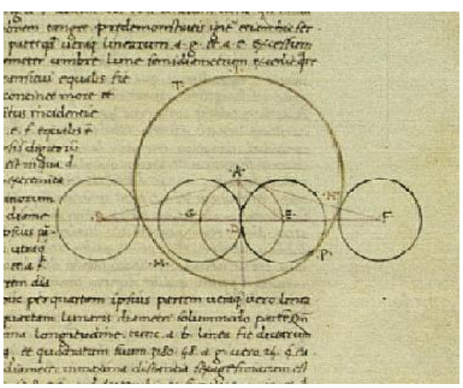


By measuring the differences in the angle of the Sun made on the Summer Solstice between Syene and Alexandria, Erastothenes was able to calculate the circumference of the Earth.

Erzbischof/CC BY-SA (https:/creativecommons.org/licenses/by-sa/3.0);

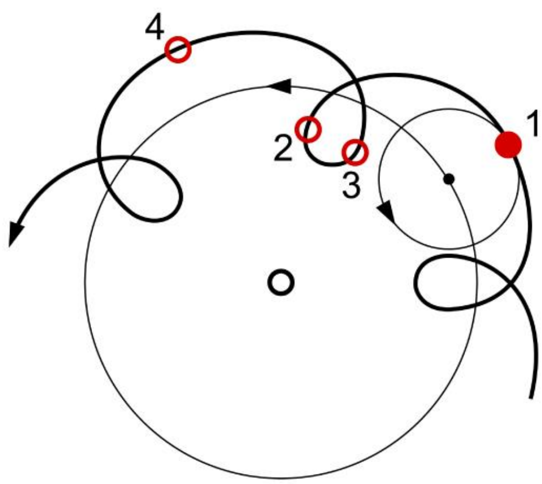
Sometime around 180 BCE, Hipparchus introduced a system of celestial coordinates and his star maps containing 850 stars. Using naked-eye sighting instruments to aid in his observations, Hipparchus created a magnitude system in which he described the brightest stars as first magnitude, the next brightest stars as second magnitude. His convention on brightness, with refinements from modern instruments, is still used by astronomers today. Hipparchus may also have been the first to use trigonometry in his studies of astronomy. Some scholars even credit him with inventing trigonometry. He also discovered the precession of the Earth's axis. Using the most precise measurements available in his time, Hipparchus tried to find evidence of stellar parallax. Not being able to detect any, he argued in favor of the geocentric model supported by Aristotle and Eudoxus.

Ptolemy (85-165 CE), the last great astronomer of the classical period, summarized all of the previous knowledge of Greek astronomy in his work, **Almagest** (Arabic for "The Greatest Work"). Ptolemy also refined the earlier epicycle/deferent model by introducing the **equant**. In Ptolemy's model, the planets, Sun, Moon, and stars all still revolved in perfect circles, but the Earth was move slightly off center. Instead, the celestial spheres all revolved around the equant, a point some distance away from the center of the Earth.



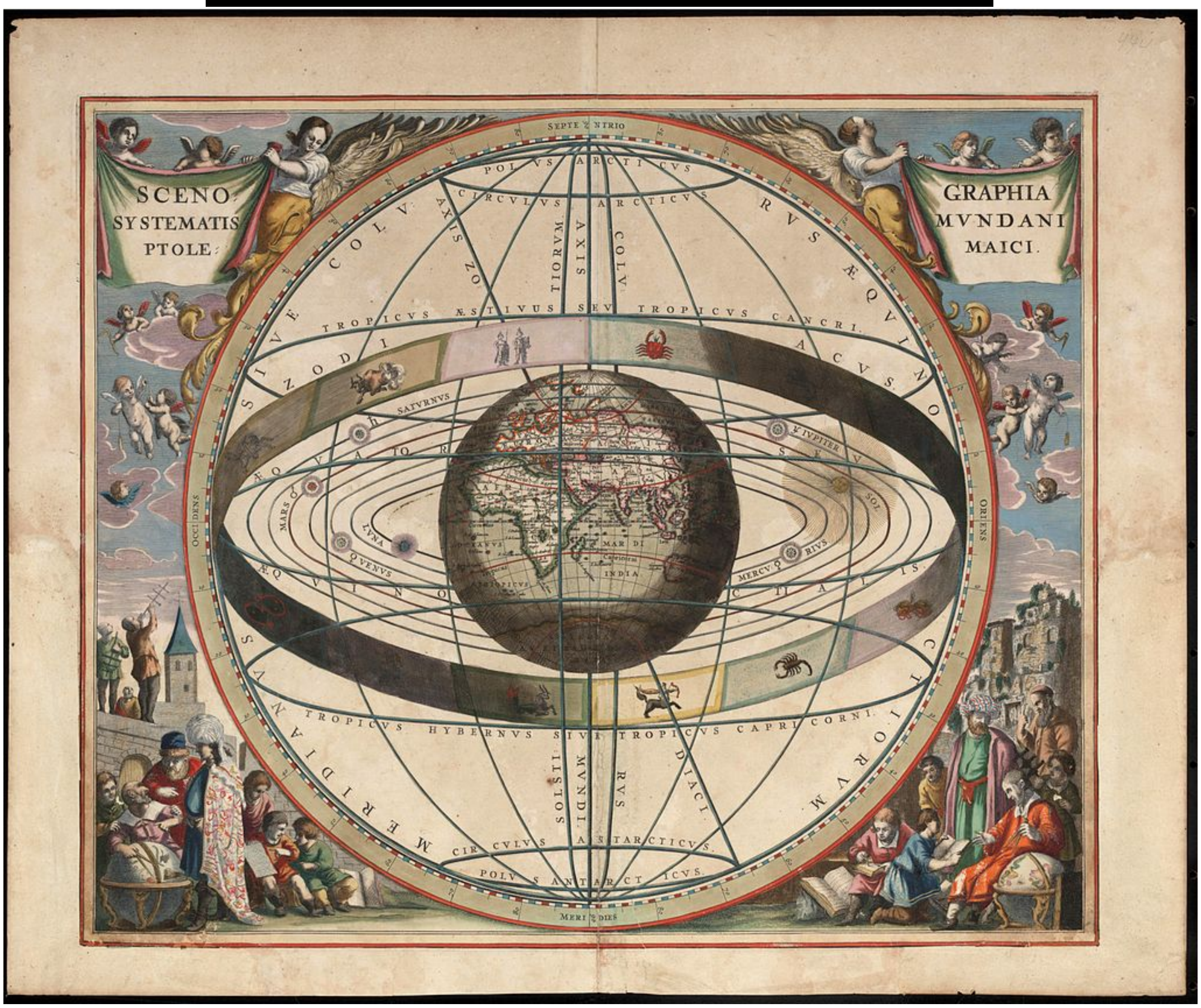
A Page from Ptolemy's Almagest.

Ptolemy/Public domain;



Epicycles were used to explain the retrograde motion of planets like Mars

Own work MLWatts/Public domain;



The Ptolemaic System. Jan van Loon/Public domain;

2.4: Astronomy in Asia, Africa, and Arabia.

2.4.1 Arabic Astronomers

By the end of the fifth century CE, the Western Roman Empire had fallen, plunging much of Europe into the Dark Ages. Like many other intellectual pursuits, astronomy in the West stagnated for centuries and many of the writings of the ancient Greeks were lost in the West. For example, we have no copies of Ptolemy's Almagest in the original Greek. However, the Arabic world managed to preserve many of these writings, which is why Ptolemy's work is mainly known by its Arabic name. These writings would be "rediscovered" in the West when the crusaders brought them back. In part, the reintroduction of these writings led to the Renaissance.

In the meantime, Arabic astronomers published their own observations. For example, al-Farghani published his own compendium in 850 CE that included correction of some of Ptolemy's errors. He also made improvements to the measurements of Earth's orbital tilt, the precession of furthest distances from the Earth to the Sun and the Moon, as well as the circumference of the Earth.

2.4.2 Indian Astronomers

Meanwhile, on the Indian subcontinent, other astronomers made some interesting observations. For example, around 600 CE, Aryabhata concluded the Moon reflects the Sun's light and that the Earth rotates. He even proposed a heliocentric model with elliptical orbits nearly a thousand years before Kepler. Varahamihira, contemporary of Ayabhata, proposed that the same force that causes objects to fall to the ground was the same that held the planets in their orbits, anticipating Newton's law of universal gravitation by a thousand years. The ideas of Ayabhata and Varahamihira, however, were not widely accepted outside their own circles and were forgotten for centuries.

By the twelfth century, invaders destroyed much of India's early astronomy, including their major observatory in Benares. The Mughal Empire did reestablish much of the early astronomy in later centuries. In particular, the rule Maharaja of Jaipur built five observatories across India. However, much of these were also destroyed by later invasions. Despite these setbacks, many Indian astronomers were able to exchange ideas with their counterparts in the Muslim world and in China.

2.4.3 Chinese Astronomers

With the benefit of a long, stable empire, astronomy in China thrived for thousands of years, predating many of the discoveries of the Greeks. For example, there is evidence that the Chinese were able to predict eclipses at far back as 2000-1000 BCE. In addition, the Emperor Wu Ding organized the sky into 28 mansions, their equivalent to constellations. China's stability enabled a long string of astronomers to maintain records of astronomical observations that spanned 2000 years. These records, which included observations of the Sun, comets, and novae, were more complete than any contemporary sources in the West. Some of these records are still studied today. During the Tang dynasty (610-910 CE) and the Yuan Dynasty (1270-1370 CE), Chinese astronomers were collaborating with those in India and with their Islamic counterparts. Chinese astronomy had little influence outside of Asia until the Renaissance because China avoided any direct contact with the West.

2.4.4 Astronomy in the South Pacific

In the South Pacific, the Polynesian people combined their knowledge of ocean currents with studies of astronomy as tools in navigation. They even constructed navigation aids and compasses out of natural materials.

A navigation compass used by Polynesian People in the South Pacific.

Newportm/CC BY-SA (https:/creativecommons.org/licenses/by-sa/3.0);

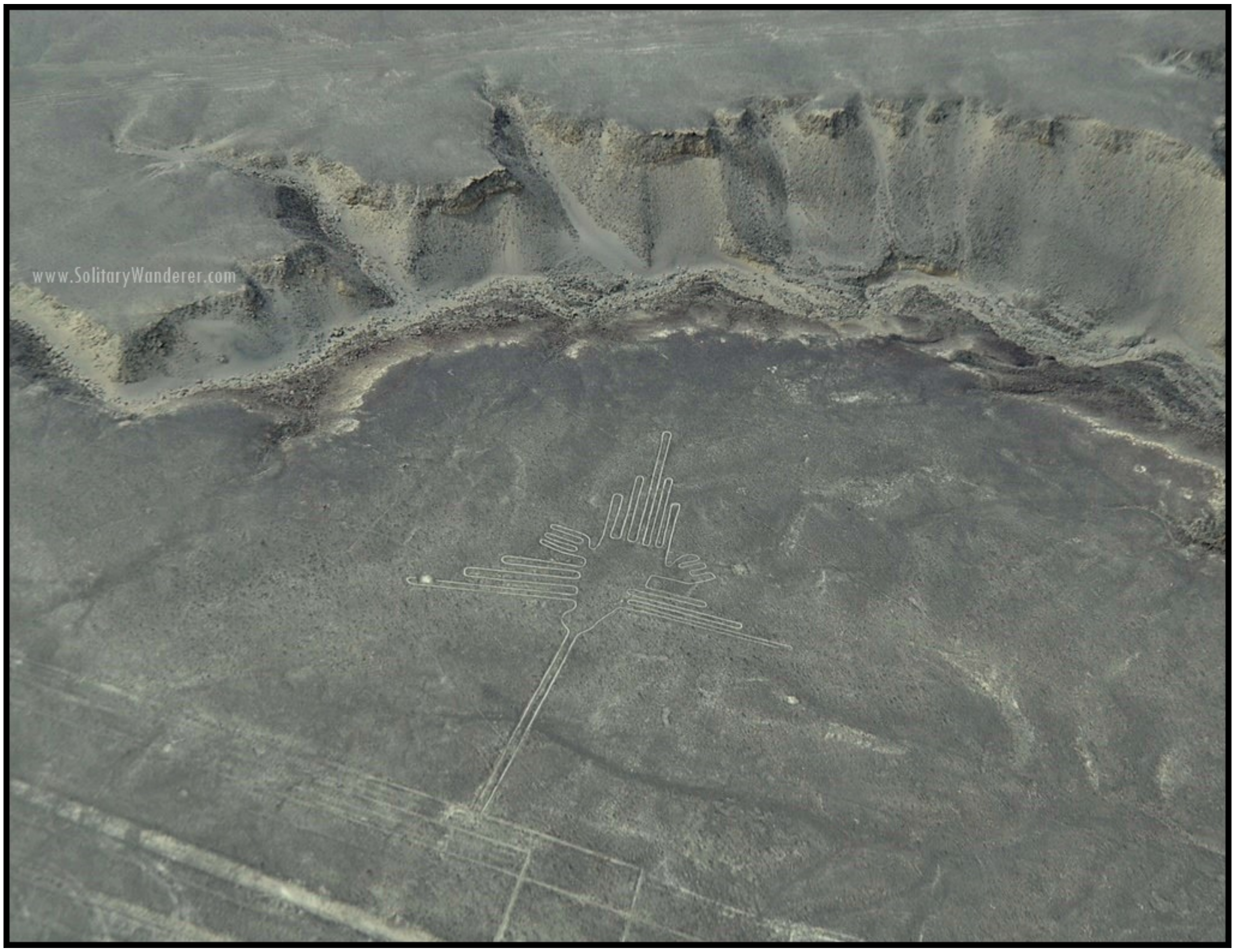
Less is known of astronomical practices in Sub-Saharan Africa, however, a number of ancient megalithic structures that were used for timekeeping have been studies. One is Ng'amoritung'a, structure on the shores of Lake Turkana in Kenya. This site includes a 2000-year-old calendar independent of any influence from the West. Researchers have also found evidence that ancient people in Africa were able to predict seasons from the orientation of the crescent moon as far back as 6500 BCE. Like other ancient people, the civilizations of Sub Saharan Africa made astronomical observations as one of their primary means of marking the passage of time and for navigation.

2.5: Ancient Astronomy in the Western Hemisphere.

2.5.1 The Nazca Lines of Peru

Archeologists have discovered a rich history of astronomy practices in the New World, especially in the construction of their temples and other major buildings. For example, the Incan city of Machu Pichu, which was probably the estate of the emperor. This site includes a solar observatory/sun temple that was used for marking the solstices. They also used sticks to mark days when the sun is directly overhead. Because they lived near the equator, the sticks would cast no shadow at noon on the summer solstice. The Javan people of Indonesia employed a similar method.

Prior to the Incans, the Nazca culture carved lines in the deserts of Peru. These Nazca lines are patterns in the ground that form images of animals and other figures. Many of these lines are aligned to certain stars. While the exact purpose of these lines is still subject to debate, many archaeologists have concluded that the stellar alignments point toward them being used as calendars.



"Nazca Lines" by Aleah Phils is licensed under CC BY-ND 2.0;

2.5.2 The Mayans

The Mayan culture flourished from 400-1200 CE. They accurately predicted eclipses. The planet Venus played an important role in their calendar and the Mayans associated it with their god of war. The Mayans built their city of Chichen Itza with several buildings aligned to the positions of Venus throughout the year. They even based their calendar on the cycles of Venus as well as the Sun. They even built observatories with Venus in mind. For example, El Caracol, a “crooked” observatory had windows aligned with Venus’ northernmost and southernmost settings. Completed sometime around 1000 CE, El Caracol also had alignments with the equinox setting of Venus, which indicates they used Venus to make the passage of the seasons.

Mayan Temple. Photo by Alex Azabache from Pexels

Ruins of Chichen Itza by John L is licensed under CC BY-NC-SA 2.0;

"El Carocal" by hmerinomx is licensed under CC BY-NC-SA 2.0


"2015-03-07 Piramides de Teotihuacán" by liaamancio is licensed under CC BY-NC-SA 2.0;

The Mayans also had a sophisticated system of mathematics based on the number 20 instead of our modern base 10 system. They also invented the concept of the number zero, which may not seem to significant, but western civilization did not have the number zero until they imported it from India/Arabia during the Crusades. While the Spanish burned many of the Mayans' manuscripts, destroying much of their astronomical knowledge, some of their records about Venus and eclipses did survive.

The Mayans also built their temples with the movements of the Sun. For example, their Temple to Kulkulkan aligned such that on the vernal equinox, the Sun cast a shadow along the steps creating the illusion that Quetzalcoalt's serpent body was descending from heaven.

2.5.3 Astronomy in Southwestern United States

The Anasazi lived in the "four corners" area of the southwestern United States. Like other cultures, they built structures marking the solstices and equinoxes. For example, in Chaco Canyon, they built (Cir. 1000 CE) the "Dagger of Light," which produces a projection of Sunlight onto a spiral pattern on opposing rock formations on both the solstices and equinoxes.

The Hohokam tribe built Casa Grande in Arizona around 1350 CE. Like the Dagger of Light, Casa Grande has holes on opposite sides of the building that align with the rising Sun on the summer solstice.


"Chaco Canyon Ruins" by carlo_mastrogiacomo is licensed under CC BY-NC-SA 2.0

"Alignment at Casa Grande" by zampano!!! is licensed under CC BY-NC-ND 2.0;

Finally, many of the plains tribes in North America drew star maps and sighting circles on the ground to mark rising points of the Sun on the solstice and the helical rising points of the stars. For example, the Big Horn Medicine Wheel in Wyoming, a large circular pattern of stones marks the solstices and other points of rising and setting.

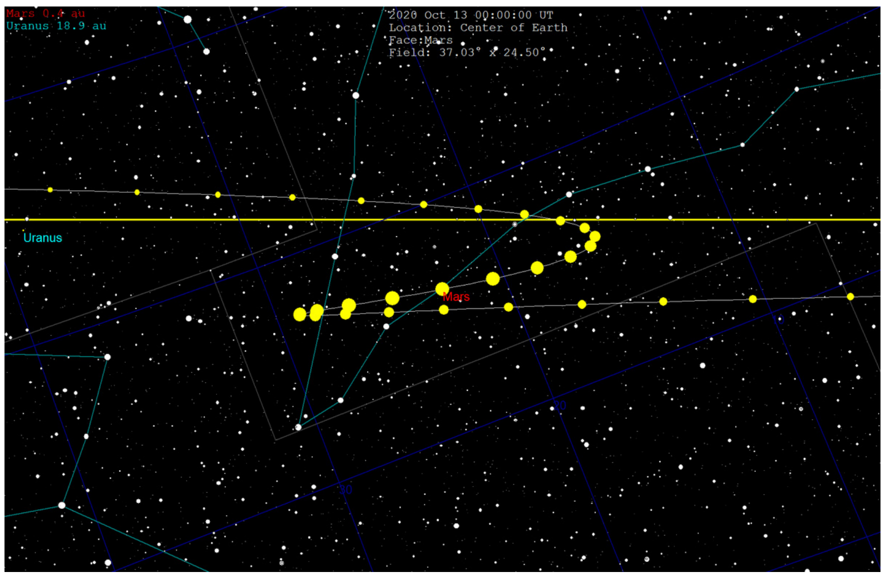
"Big Horn Medicine Wheel 01" by jaygannett is licensed under CC BY-SA 2.0;

3: The Copernican Revolution

Learning Objectives

- Describe the period leading up the Copernican Revolution.
- Understand the Copernican Model of a heliocentric universe.
- Describe the contributions of Tycho Brahe and Johannes Keple
- Understand Kepler's Laws of Planetary Motion.
- Describe Newton's Laws of Motion and Universal Gravitation.
- Understand Conservation of Energy and Momentum and describe how the explain the motion of planetary bodies.

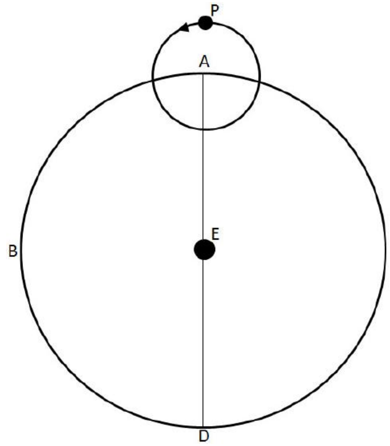
As the Medieval Period gave way to the Renaissance, western scholars began to rediscover the writings of Ptolemy and other ancient Greeks. By this point, errors from Ptolemy’s Almagest had crept into his calculations and his predictions no longer matched with contemporary observations. Some astronomers even noticed some observations that the Ptolemaic model could not explain, such as the changes in the apparent brightness of Mars throughout the year.



Retrograde Motion of Mars. https://commons.wikimedia.org/wiki/F...otion_2020.png

The five known planets had vexed astronomers for centuries. The Sun, the Moon, and the so-called “fixed stars” all moved in predictable patterns, but the planets did not. They shifted their positions with respect to the fixed stars. They changed in brightness and speed. The engaged in retrograde motion (Chapter 2). Ptolemy published his geocentric model around 140 CE. His included many **epicycles** to explain retrograde motion. In this model, there are two paths in a planet's orbit around the Earth. The **deferent** goes around the Earth while the epicycle makes a circle around the edge of the deferent. As a result, the planet moves along both the deferent and and the epicycle, explaining retrograde motion (figure below).

Ptolemy also included the use of an equant, putting the Earth off center from orbits of the planets. While Ptolemy’s model remained the most accurate predictor of planetary motion for centuries, by the 13th centuries, enough errors had crept in that his predictions were off by one or two degrees. This is bigger than the apparent size of the Moon. This discrepancy required more and more complex “corrections” to the Ptolemaic model.



Ptolemy used epicycles to explain retrograde motion of planets like Mars. According to Ptolemy, as a planet's orbit carried it around the Earth, it also made a smaller circle centered on the orbital path.

https:/commons.wikimedia.org/wiki/File:Epicycle-Ptolemy.png;

Still, Aristotle’s advocacy of the geocentric model carried tremendous weight among scholars and religious authorities. Aristotle’s words, combined with selected biblical passages that implied that the Sun, not the Earth, moves resulted in geocentrism becoming religious and church dogma throughout most of the Christian world. But there were observational reasons for some to object to heliocentrism. The most significant was the lack of measurable parallax among the stars. If the Earth moved, they asked, why don’t the stars shift their positions throughout the year? Also, the heliocentric model proposed by Aristarchus did not make any better predictions than Ptolemy’s geocentric model. This was because scholars were unwilling to abandon the assumption that the stars and planets were perfect spheres and moved in perfect circles.

Giordano Bruno was executed by the Catholic Church for his unconventional views on the universe.
https:/commons.wikimedia.org/wiki/File:Giordano_Bruno_BW_2.JPG;

The fifteenth through seventeenth centuries were also a time of political and religious upheaval. The Protestant Reformation had begun in earnest and was tearing the Holy Roman Empire (what we call Germany today) apart. The religious authorities could not afford to allow any dissent and clamped down on any perceived heresy as strictly and brutally as possible. For example, an Italian monk named Giordano Bruno proposed that the stars were distant suns that may have planets of their own. For this and other unorthodox beliefs, the Catholic Church had Bruno burned at the stake in 1600. Despite this oppressive atmosphere, the Renaissance was a time for challenging orthodoxy and considering new ideas. The time was ripe for an intellectual revolution. One that would, surprisingly, would be kicked off by a quiet clergyman from Poland.

3.1: Nicholas Copernicus (1473-1543)- The Quiet Revolutionary

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Nicholas Copernicus was born the youngers of four children in Torun, Poland. He studied mathematics and astronomy in Krakow and then medicine in Padua, Italy. After completing his studies, her returned home to the Prince-Bishopric of Warmia in Prussia (Poland) where he assumed several duties for the diocese. Eventually, he settled in Frauenburg and took charge of the bishopric's financial enterprises, including acting as sort of the landlord for the various tenant farmers living and working on church owned land. He also continued to practice medicine, but his true passion remained mathematics and astronomy.

Like many of his contemporaries, Copernicus noted the errors in Ptolemy's predictions and its failure to explain Mars' change in brightness. Soon, he realized that he could simplify the mathematics of planetary motion by putting the Sun at the center instead of the Earth. Following the principle of Occam's razor, in which the simplest explanation with the fewest unnecessary complications, is the better answer, Copernicus became convinced of the correctness of heliocentrism. Putting the Sun at the center also explained the change in brightness and retrograde motion of Mars. Mars and Earth both orbit the Sun, but Earth, being closer in, has a shorter path and moves faster than Mars. As a result, Mars appears to move backwards whenever Earth overtakes it in its orbit. Mars' brightness also changes because, as the planets orbit the Sun, their relative distance to one another changes. Mars therefore appears brighter when it is closer to the Earth and dimmer when they are further apart.

Despite his confidence in his theory, Copernicus was reluctant to publish. He feared not only church authorities but also ridicule from fellow astronomers. While his model better explained retrograde motion and changes in brightness, he could explain the lack of parallax among the fixed stars. Also, he still assumed the planets moved in perfect circles and could not make better predictions than Ptolemy's models. Also, most natural philosophers of his time argued that if the Earth moved, birds would fly backwards, and church steeples would topple as they resisted the motion.

Finally, his friends convinced Nicholas to publish. He received permission from a friendly bishop to publish and dedicated his work, *De Revolutionibus Orbium Coelestium* (On the Revolutions of the Celestial Spheres), to the Pope. He had hoped that these actions would insulate him from any charges of heresy. However, just as the printers were preparing his book, Nicholas Copernicus died in 1543 at the age of seventy. He, therefore, avoided the ridicule and censure he had feared in life. However, the authorities did not look kindly on his work and eventually put his book the Index of Forbidden Works.

NICOLAI COPERNICI

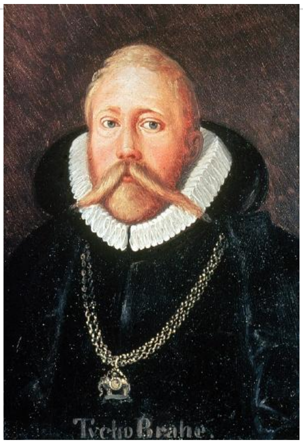
net, in quo terram cum orbe lunari tanquam epicyclo contineri diximus. Quinto loco Venus nono mense reducitur. Sextum denique locum Mercurius tenet, octuaginta dierum spacio circũ currens. In medio uero omnium residet Sol. Quis enim in hoc

pulcherrimo templo lampadem hanc in alio uel meliori loco poneret, quàm unde totum simul possit illuminare? Siquidem non inepte quidam lucernam mundi, alij mentem, alij rectorem uocant. Trimegistus uisibilem Deum, Sophoclis Electra intuentẽ omnia. Ita profecto tanquam in solio regali Sol residens circum agentem gubernat Astrorum familiam. Tellus quoque minime fraudatur lunari ministerio, sed ut Aristoteles de animalibus ait, maximã Luna cũ terra cognationẽ habet. Concipit interea à Sole terra, & impregnatur annuo partu. Inuenimus igitur sub hac

Excerpt from Copernicus' treatise on planetary motion.

Nicolaus Copernicu, De revolutionibus orbium coelestium (Norimbergae, 1543).

3.2: Tycho Brahe (1646-1601)- The Celebrated Collector of Planetary Data



Tycho Brahe by Eduard Ender (1822-1883)/Public domain;

A few years after the death of Copernicus, the man who would be celebrated as the greatest astronomer of his age was born in Denmark. Tycho Brahe came from a poor family and was raised by an uncle. However, his uncle rescued the King of Denmark from drowning and subsequently died of pneumonia. The grateful King Frederick II rewarded the young Tycho and made him a rich man.

With his newfound wealth, Tycho enrolled in the University of Copenhagen, initially to study law, but he also studied astronomy. Later, he attended the University of Rostock to study medicine. While at Rostock, his volatile temper got the better him and got into a duel with a fellow student over who was a better mathematician. The duel ended with his opponent slicing of Tycho's nose, requiring him to wear a prosthetic nose made of silver or gold.

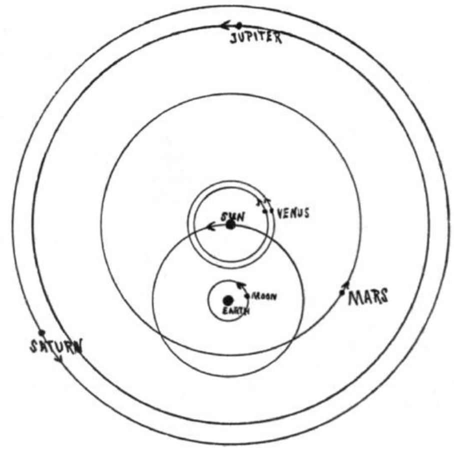
King Frederick II then granted Tycho the island of Hven as the site of his observatory, Uraniborg. There, Tycho designed and built many of his own instruments and began compiling what would become his celebrated and voluminous collection of observations of the stars and the planets. In 1572, he studies a "new star" (stellar nova), challenging the idea that the heavens were fixed and eternal. Now, we know that a nova is an old star that has exploded. His vast quantity of observational data led to Tycho Brahe being hailed as the "greatest astronomer of his age." Tycho also loved fine clothes and good food. He spent the money of his patron as fast as he could on his research and his lifestyle.

However, Frederick II died in 1588 and was succeed by his 11-year-old son, Christian IV. Until Christian came of age, a regency council ruled Denmark and the leader of this council was not friendly toward Tycho. Using Tycho's extravagant spending as a pretext, the council forced Tycho in exile. He eventually settled in Prague where he continued his research.

Unlike Copernicus, Tycho remained unconvinced about the validity of heliocentrism. In particular, he pointed to the lack of parallax as proof against it. However, he offered a compromise model in which the Sun, Moon, and stars still revolved around the Earth, but the five planets: Mercury, Venus, Mars, Jupiter, and Saturn, revolved around the Sun. He judged this model as adequate to explain retrograde motion and changes in planetary brightness.

Tycho's death was a colorful as his life. While attending a banquet held by the Holy Roman Emperor, Rudolf II in 1600, Tycho drank copiously and refused to leave the table, as that would have been a breach of etiquette. He developed a urinary ailment and died eleven days later of an infection or burst bladder.

During his life, Tycho jealously guarded his status as the most celebrated astronomer of his age, to the point where he was reluctant to share his copious data on planetary motion out of fear of being overshadowed. Unfortunately, he was indeed overshadowed by his young assistant, a young German astronomer who would use Tycho's stockpile of data to develop a model that better explained planetary motion than any previous one and laws that would become part of the foundation of modern understanding of motion.



Tycho Brahe's compromise system putting the planets orbiting the Sun while the Sun orbited the Earth.

Unknown author/Public domain;

3.3: Johannes Kepler (1571-1630) and his Laws of Planetary Motion

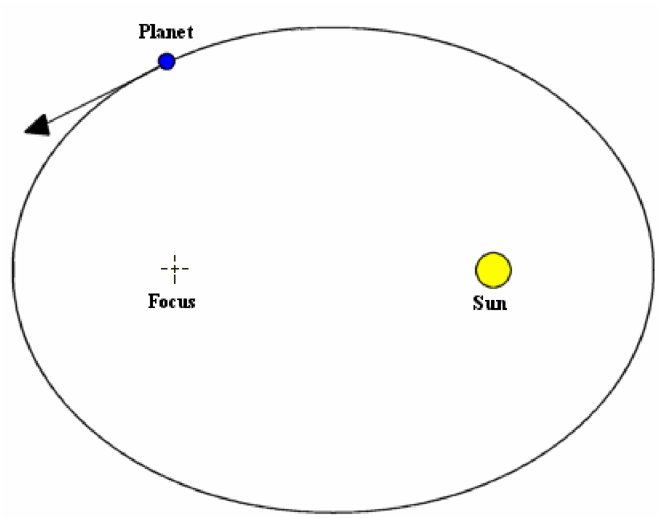
Johannes Kepler Unidentified painter/Public domain;

Johannes Kepler was born in Free Imperial City of Weil der Stadt, in what is now Stuttgart, Germany. Despite his early interest in astronomy, he contract smallpox as a child which left him with poor vision and weakened hands, limiting his ability to practice observational astronomy. He studied philosophy and theology at the University of Tubingen and became a teacher of mathematics at a grammar school in Graz. He impressed his fellow students with his skill in mathematics and astronomy by casting horoscopes for them (remember that, at this time, astronomy and astrology were considered one and the same). This led to an appointment as a professor of mathematics at the University of Tubingen. During this Kepler, also became a proponent of heliocentrism.

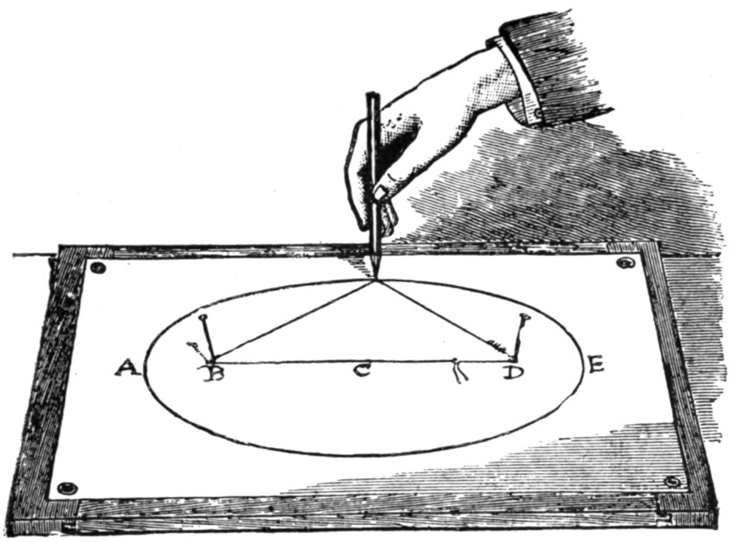
Religious and political difficulties eventually forced Kepler into exile from Graz. Not only did he refuse to convert to Catholicism, he also had to defend his mother from accusations of witchcraft. Fortunately, after some tense negotiations, he was able to secure a position in Prague as Tycho Brahe’s assistant in 1601. Kepler wanted access to Brahe’s collection of planetary data in order to work on the “Mars problem” that had set Copernicus on his course toward heliocentrism.

Fearing his new protégé might overshadow him, Tycho only shared a portion of his data with Kepler. Tycho assumed that this would keep his assistant busy. However, Tycho died shortly thereafter and Kepler inherited all of Tycho’s records. Using Tycho’s data, Kepler formulated his three laws of planetary motion.

Kepler’s First Law: Planets orbit in ellipses, with the Sun at one focus.



Kepler's first law This file is licensed under the Creative Commons Attribution-Share Alike 2.0 Austria license RJHall.

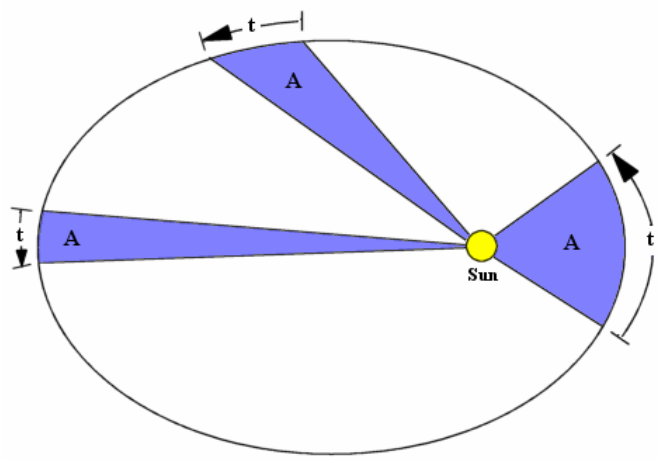


The construction of an Ellipse. George Frederick Chambers/Public domain;

An ellipse is a special curve in with the sum of the distance from two points, called foci, along the curve is a constant. You can draw an ellipse with a string and two thumbtacks. Put the thumbtacks into the paper and tie each end of the string to the thumbtacks. Using a pencil to stretch the string out, draw a curve. Since the length of the string never changes, the sum of the distances to each foci is a constant. Each ellipse has two axes. The major axis is the widest axis and the minor axis is the narrowest one. Half of the major axis is called the semimajor axis. An ellipse looks like a flattened circle and the degree of flattening is called the eccentricity. A circle can be thought of as a special case of an ellipse with zero eccentricity and both foci coinciding at the same point.

Kepler's replacement of the prefect circle with an ellipse was perhaps his most revolutionary idea, but it turned out to be mathematically and physically correct. Elliptical orbits solved the problem of both the Ptolemaic geocentric model and the Copernican heliocentric by making better predictions of planetary motion.

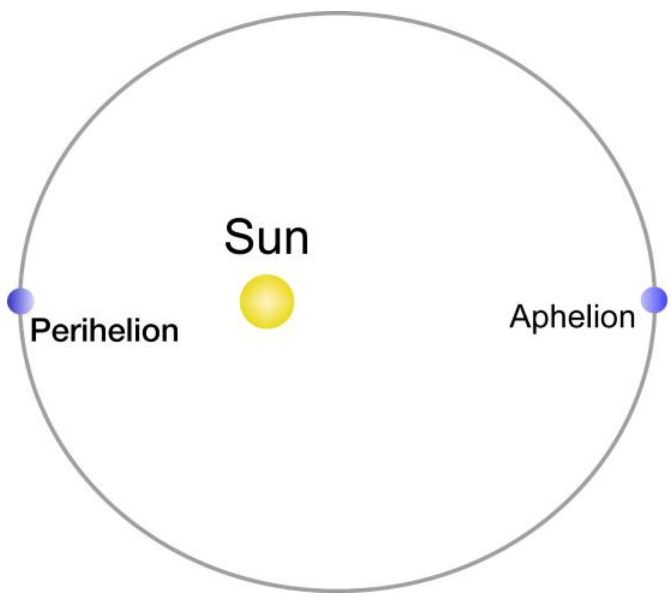
Kepler's Second Law: An imaginary line connecting Sun and planet sweeps out equal areas in equal times.



Kepler's second law; This file is licensed under the Creative Commons Attribution-Share Alike 2.0 Austria license RJHall.

Because planets orbit the Sun in ellipses, their distance from the Sun changes. We call the point of closest approach to the Sun **perihelion** and the point of furthest distance from the Sun **aphelion**. Kepler's Second Law shows that the orbital speed of a planet changes as it moves along its path. In order to cover equal areas in equal periods of times, the planet must travel its fastest during perihelion and slowest during aphelion.

Kepler's Third Law: Square of period of planet's orbital motion is proportional to cube of semimajor axis.



Perihelion-Aphelion. https:/commons.wikimedia.org/wiki/File:Perihelion-Aphelion.svg;)

Kepler developed his third law empirically but crunching the numbers, but we can demonstrate that this relationship holds with all eight planets. Also, if we use AUs (length of Earth's semimajor axis) as the unit for the planet's semimajor axis (a) and Earth years as the unit for the planet's orbital period (p), the relationship simplifies to:

$$a^2 = p^3.$$

Kepler's third law, however, can only tell us the relative distances of planets from the Sun in AUs. We were unable to convert AUs into kilometers until we could use radar signals to measure the distance between Earth and Venus at their closest approach. Once we had that distance, we could describe the semimajor axes of all the planets in terrestrial units.

3.4: Galileo Galilei (1564-1642)- The Man Who Saw Further than Anyone

Galileo Galilei

"Justus_Sustermans_-_Portrait_of_Galileo_Galilei,_1636" by VLN Physics 12 is licensed under CC BY 2.0;

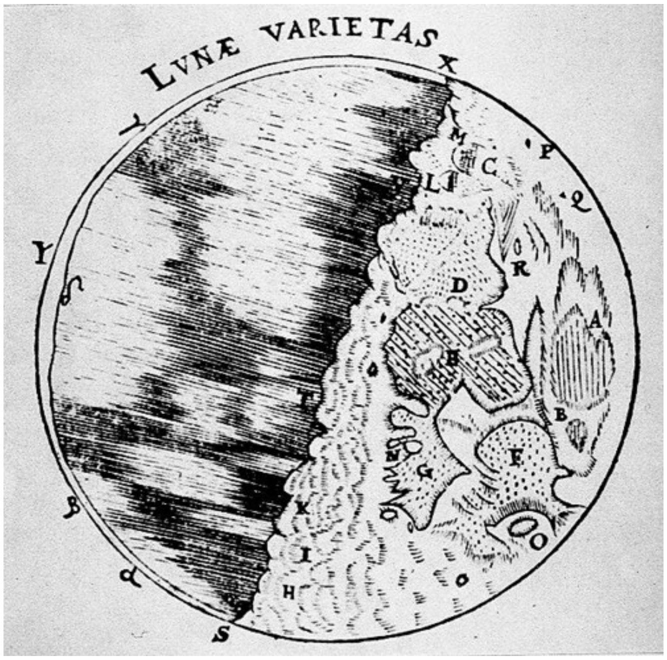
"Galileo telescopes" by Bruce Stokes is licensed under CC BY-NC-SA 2.0;

If anyone can be considered the father of the modern scientific method, it would be Galileo Galilei. Galileo's observations changed the way we view our place in the universe. His studies of motion paved the way for Isaac Newton's laws of motion. He was the first astronomer to use a telescope to study the night sky and the first to discover moons orbiting another planet. Through he posthumously vindicated in his advocacy of heliocentrism, his zealous (some might say, arrogant) defense of the Copernican model cost him dearly.

Born in the Duchy of Florence, Galileo initially studied medicine at the University of Pisa, but later switched to mathematics and natural philosophy. While working as a professor of mathematics and astronomy at the University of Padua, Galileo heard of a party novelty invented by a pair of Dutch eyeglass makers that could make distant objects appear closer. Glass makers at the time kept their techniques secret, so Galileo had to teach himself how to grind lenses, using an artillery ball to shape the convex lens.

Eventually, he produced a telescope with several improvements compared to the Dutch invention. He presented his telescope to the leaders of Florence, who immediately saw the military advantage of being able to see incoming ships hours before the arrived at the harbor. They rewarded they with a generous stipend for life.

Galileo next turned his telescope toward the sky. He examined the Moon and, contrary to the conventional wisdom, was not a perfect, smoother sphere, but contained numerous mountains, valleys, and craters. He then studied Jupiter and found four tiny "stars," too faint for the naked eye to see, orbiting Jupiter. He quickly concluded that these were moons that went around Jupiter much like our own moon orbits the Earth. He published his findings in his work *Sidereus Nuncius* (Starry Messenger), which created a sensation. Capitalizing on his newfound fame, Galileo maintained to secure patronage from the powerful Medicci family and returned to live in Florence.

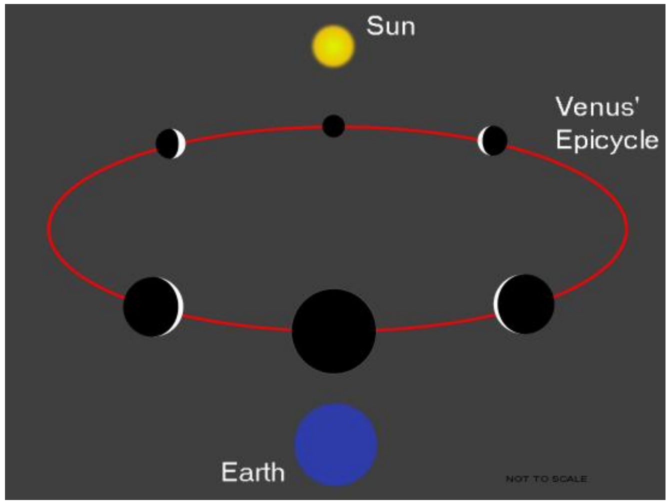


One of Galileo's drawings of the surface of the Moon.

"Galileo_scheinermoon.bmp" by scead is licensed under CC BY 2.0;)

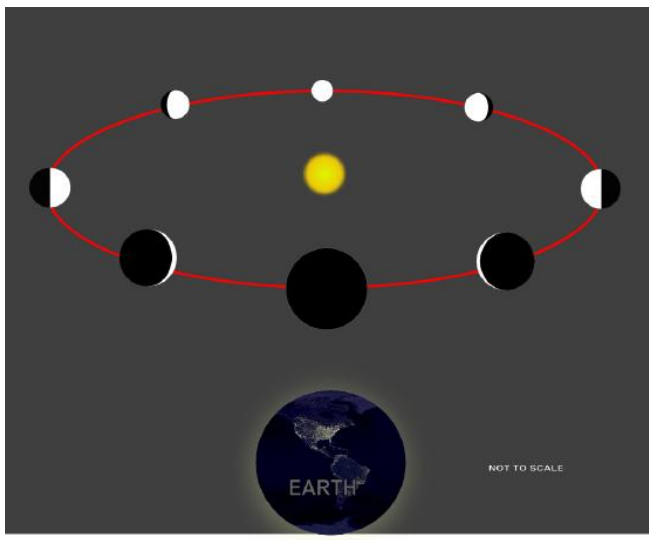
"Jupiter with Galilean moons" by DangerBarrow is licensed under CC BY-NC-ND 2.0;

Galileo continued to gather evidence in favor of the Copernican model, including discovering that the planet Venus exhibited phases much like the Moon did and that the Sun had tiny blemishes or sunspots on its surface. The phases of Venus could not be explained by a geocentric model. In Ptolemy's model, Venus could only have two phases: New and Crescent, not the full set of phases Galileo observe. Also, the existence of sunspots challenged the assumption that the Sun and other heavenly bodies were perfect and unblemished. When asked by the Grand Duchess of the Medicci family if his findings conflicted with scripture, Galileo simply replied that scripture had been misinterpreted and that the Bible was never intended to be an astronomy textbook.



In a geocentric model, Venus would only appear with two phases: Crescent and New.

https:/commons.wikimedia.org/wiki/File:Phases-of-Venus-Geocentric.svg;



In a heliocentric model, Venus exhibits the same range of phases as the Moon.

Nichalp 09:56, 11 June 2006 (UTC) modified by Sagredo/Public domain;)

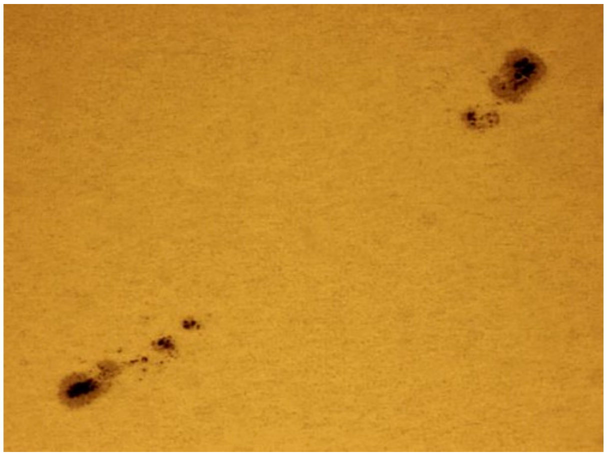
These statements came to the attention of the Grand Inquisitor Cardinal Bellimine, who informed that heliocentrism ran counter to church doctrine and he was forbidden to publish arguments in favor of it without real evidence. Bellimine and the other church leaders pointed to several arguments (besides scriptural) against heliocentrism, including the following:

1. The lack of perception of movement. Why did dropped objects not fly off to the west if the Earth moved?
2. The lack of stellar parallax.
3. Aristotle's view that the heavens were perfect, constant, and circular.

Galileo answered each of those objections. Aristotle believed that all objects tended to go to rest, which is why many assumed that a dropped object would appear to fly off to the West as the Earth movement away from it. Galileo countered with the analogy of a horse rider carrying a ball. If the rider tossed the ball in the air while the horse was at full gallop, the ball continued to travel with the horse and rider as it fell back into his hand. From the rider's perspective, the ball did not fly backwards as Aristotle would have assumed. While Galileo's explanation would later become the foundation for Isaac Newton's First Law of Motion, it failed to convince the inquisitors.

To explain the lack of parallax, Galileo pointed his telescope at the Milky Way. What looked like a whitish cloud stretched across the sky turned out to be made up of countless stars. They only looked like a cloud because they were so far away. While Tycho had believed he had measured the distances to the stars, Galileo demonstrated that many of them were much, much further away than the “greatest astronomer of his age” had though.

To counter Aristotle’s view that the heavens were perfect and constant, Galileo pointed to Tycho Brahe’s study of a supernova to argue that the heavens were not constant. He also argued that mountains and valleys on the Moon and sunspots showed the heavens were not the perfect spheres people had assumed they were for centuries. Also, the fact that Jupiter had moons proved that not everything could orbit the Earth.



The existence of sunspots challenged the assumption that the Sun and other celestial objects were perfect and unblemished.

"Sunspots" by David St. Louis is licensed under CC BY 2.0;

Despite these points and the phases of Venus, the Churches declared heliocentrism a foolish superstition and Cardinal Bellimine ordered Galileo to cease his advocacy of the heliocentric model. Unable to publish, Galileo continued his observations in hopes of uncovering more evidence to persuade the authorities to reverse their decision.

In 1623, an event occurred that gave Galileo the opportunity he had hoped for. Urban VIII ascended to the papacy. Galileo had known Urban VIII, born Maffeo Barberini, for years and considered him a friend. Urban VIII did admire much of Galileo’s work, though he still held to the church doctrine favoring geocentrism. However, Galileo approached Urban to see if he could obtain permission to publish. The two discussed the issue at length and while Galileo failed to convert Urban to heliocentrism, Urban did tell Galileo that the heliocentric view could be discussed hypothetically, if presented as one of many possible views for the cosmos.

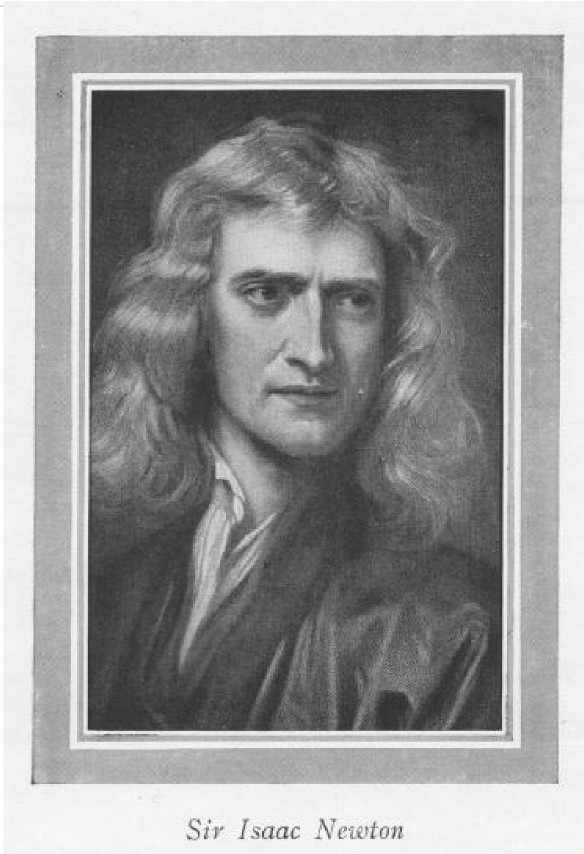
Cover to Galileo's Dialogues. "Dialogues" by Rhubarble is licensed under CC BY-NC 2.0;

Seizing on this, Galileo published his arguments for heliocentrism in the form of a dialogue. In his work, *Dialogue Concerning the Two Chief World Systems,* three Italian gentlemen discuss the cosmos over dinner. Sagredo, the host, is initially neutral while Salviati argues in favor of the Copernican model. Meanwhile, Simplicio (the fool), argued for Aristotle and Ptolemy's geocentric view. Salviati clearly had the stronger argument of the two while Simplicio made only simplistic points. Galileo made a tactical error, however, when he incorporated some of the statements Urban VIII had made in their earlier discussions. Believing Galileo had deliberately satirized him, Urban VIII turned his back on Galileo. The inquisitor put Galileo on trial. Knowing the fate of Giordano Bruno, Galileo recanted his support for heliocentrism rather than face torture and execution. The inquisition put him under house arrest for the rest of his life and forbade him from every publishing about astronomy again.

Instead, Galileo returned to some of his earlier studies on motion. Using an inclined plane, he studied the motion of balls as they rolled downhill. From his timing of these balls, Galileo determined that all falling objects experienced that same acceleration from

Earth’s gravity, regardless of their weight. His final work on motion would be refined by Isaac Newton as he formulated his laws of motion and law of gravity.

3.5: Isaac Newton (1642-1724) and the Laws of Motion



"Isaac Newton" by paukrus is licensed under CC BY-SA 2.0;

Few people have made as many contributions to science as Sir Isaac Newton. He experimented with optics to determine that white light could be separated in the colors of the rainbow. He invented the reflecting telescope and the mathematics of calculus. But it is his studies of motion and gravity for which he most remembered. Newton studied natural philosophy at Trinity College, Cambridge and later became a professor at Cambridge, becoming the Lucasian Chair of Mathematics at Cambridge, one of the most prestigious positions at the university.

Newton's great insight was that the same laws that govern the motion of objects on Earth also govern objects in the Solar System and beyond. No longer would the heavens be regarded as mysterious bodies moved by unseen hands, but as real objects that obey the same laws of physics we do here on Earth. In 1687, Newton published his *Philosophiæ Naturalis Principia Mathematica* (Mathematical Principles of Natural Philosophy) which became the foundation of classical mathematics. Newton's Principia outlined his three laws of motion, which in modern terminology, are as follows:

Newton's First Law of Motion: An object at rest will remain at rest while an object in motion will continue in motion with a constant velocity unless acted on by outside force.

Place a ball on a flat, level table. It will not move unless you give it a nudge. This much was consistent with Aristotle's idea that objects naturally come to rest. But Newton figured that a moving object would continue moving so long as an outside force does not interfere with its motion. If we had an infinite, frictionless surface and gave the ball a push, it would roll forever. In the real world, a rolling ball slows down, not because its nature is to come to rest, but because friction with the table's surface acts as a force to slow it down. Newton's first law is sometimes referred to as the Law of Inertia, where inertia is an object's resistance to changes in its motion.

Newton's Second Law of Motion: When a force acts on an object, its acceleration is inversely proportional to its mass.

This gives the classic equation of $a = F/m$ or $F = ma$, where F is the force acting on the object, a is the acceleration or the rate of the change in motion of the object, and m is the object's mass. The unit of force is therefore the $kg{\cdot}m/s^2$ or the newton (N), in honor of Isaac Newton.

Newton’s Third Law of Motion: When object A exerts a force on object B, object B exerts an equal and opposite force on object A. For every force, there is always an equal and opposite reaction force.

It is through the Third Law that rockets can function. A rocket does not launch itself by pushing against the ground. It launches by burning a fuel, which produces, hot expanding gases. The force of the gas escaping the nozzle produces a reaction force in the opposite direction that pushes the rocket upwards.

Newton's laws state that the ball will remain motionless until attacked on by a force from the kicker. Also, as the soccer player exerts a force on the ball, the ball will exert an equal and opposite force on the soccer player.

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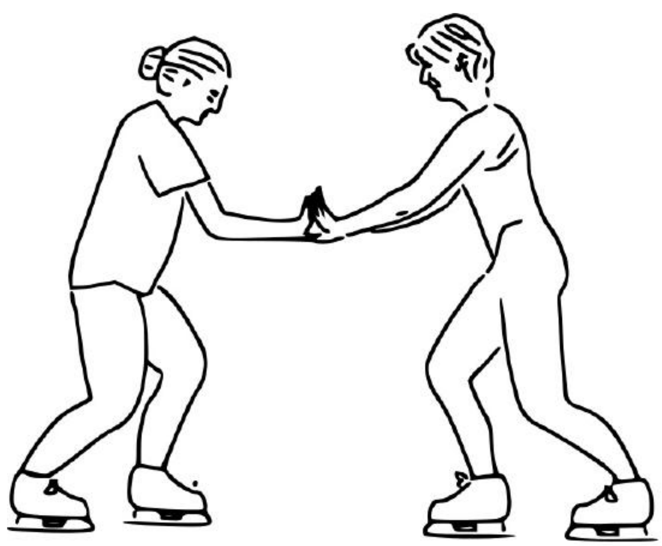

Two skaters pushing against each other will exert equal and opposite forces on each other.

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Newton's Third Law explains how rockets move without having a surface to "push off" of.

https://www.nasa.gov/audience/foredu...-rocketry.html

We use several terms to describe an object's motion. For example, **speed** is defined as the rate at which an object moves. In metric units, speed is often given in units of meters per second (m/s) or kilometers per second (km/s). On the other hand, **velocity** is defined as both the magnitude of the speed with a specific direction. So, if we describe an object as moving 10 m/s, we are saying its speed is 10 m/s with information about which direction it is moving. If we say the object moving 10 m/s, due north, now we are describing its velocity with both a magnitude (10 m/s) and a direction (north). Velocity is a vector, which is a quantity that has bother magnitude and direction.

Acceleration is the rate change of velocity. Like velocity, acceleration is a vector and can describe any change in an objects rate of motion, whether in magnitude, direction, or both. Physicists also use acceleration to describe the slowing down of an object (negative acceleration). In metric units, acceleration is often given in meters per second squared (m/s^2).

Earth's gravity accelerates all objects toward the center of the planet. This acceleration of gravity, g, is the same for all objects, not counting friction or air resistance. Near the surface of the Earth, the value of $g = 9.8\ m/s^2$. Galileo's experiments with the inclined plane demonstrated that g is the same for all objects, regardless of their mass and Newton later expanded on this principle with his law of universal gravity.

Another important term is **momentum**, or a measure of an object's motion. Mathematically, momentum is equal to an object's mass times its velocity. A net force, then, will act on an object to change its momentum, resulting in an acceleration or change in velocity.

A rotating object or an orbiting object has the property known as **angular momentum**. Angular momentum describes the motion of all spinning or revolving objects. For an orbiting object like a planet, its angular momentum is equal to its mass times its velocity times the radius of its orbit. Changing angular momentum requires a **torque**, which is equal to the force times its distance from the axis of rotation.

Before a collision, the system has a certain amount of momentum, based on the masses and speeds of the two objects.

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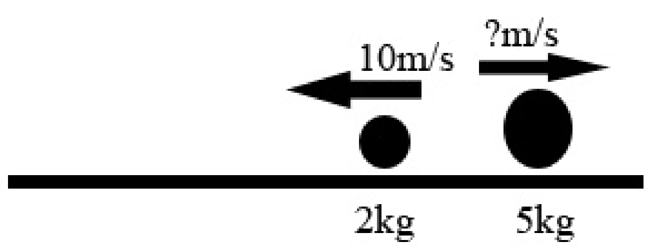

After the collision, the total momentum of the system remains the same.

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As a skater pulls her arms closer to her body, her moment of inertia decreases and her rotational speed increases.

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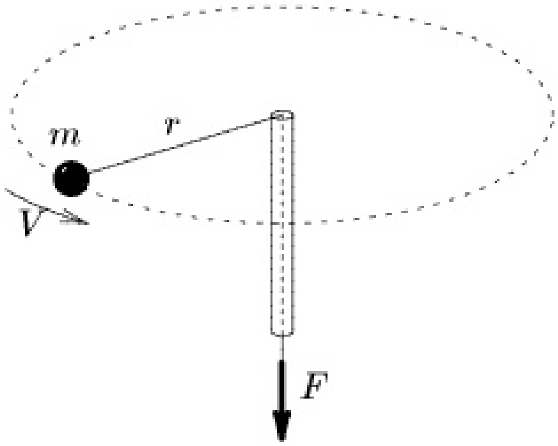

A rotating object has angular momentum and centripetal force that holds it in its path.

LP~commonswiki; MomAng2.jpg

Another important principle is the difference between **mass** and **weight**. Mass is defined as the amount of material "stuff" an object contains, whereas weight is the force of gravity acting on the object. Mass is generally a constant. An object with a mass of 1 kg will be 1 kg whether its on the Earth, on the Moon, or in space. However, an object with a weight of 1 N on the Earth will only weigh 1/6 N on the Moon. In space, it would weightless. Note however, that there is gravity in space. Object in orbit around the Earth is still subject to the Earth's gravity, however, it is said to be in **free fall**. An object in free fall is weightless.

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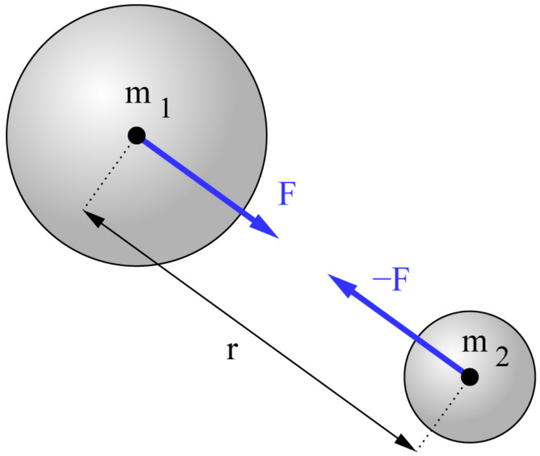
Objects and people in freefall, such as on board the International Space Station, are weightless.



Newton's Law of Universal Gravitation states that the attractive force between two objects is proportional to the product of their masses and inversely proportional to the square of the distance between them.

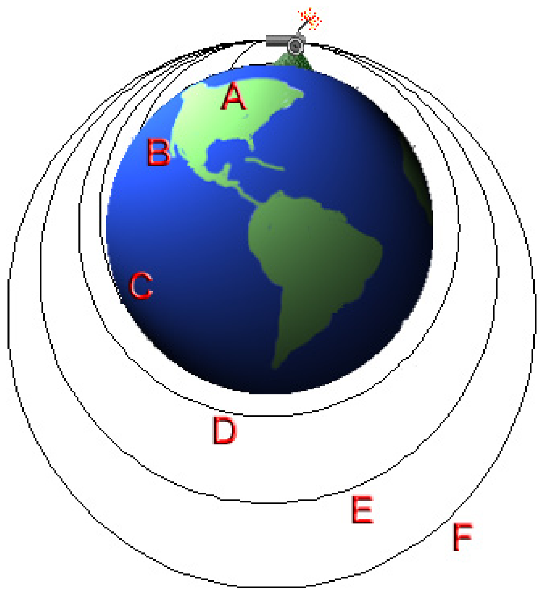
On Earth, the acceleration of gravity becomes readily apparent. Throw a ball and it will travel in a curved path. It will continue moving with the horizontal velocity you gave it, but it will first move vertically if you gave it an upward velocity. The vertical component of its velocity will slow down as the acceleration of gravity acts on it. At the pinnacle of its arc, its vertical velocity reaches zero and then it begins accelerating down until it reaches the ground. This curved path of throw objects and falling objects inspired Newton to formulate his Law of Universal Gravity. The equation for his law of gravity is:

$$F = GM_1M_2/r^2$$

Where F is the force of gravity between two objects. M_1 and M_2 are the respective masses of the two objects. The value r is the distance between their centers and G is the Universal Gravitational constant where $G = 6.67408 \times 10^{-11}\ m^3\ kg^{-1}\ s^{-2}$.

Apply the law of gravity, a planet stays in orbit based on two factors. The force of gravity between the Sun and planet pull on each other. Since the Sun is many times more massive than the planet, the planet is pulled towards the Sun’s center. Meanwhile, the inertia from the planet’s motion keeps it moving forward. The combination of these two factors creates a centripetal acceleration, or an acceleration towards the center. The planet therefore moves around the Sun. We can think of an orbit as a form of free fall, where the object is continuously “falling” toward the Sun, but its forward motion causes it to also “miss” it. A planetary orbit is therefore just like the curved path of the thrown ball where the radius of the curve of its motion is greater than the radius of the Sun.

Newton proposed a model using a cannon. Firing a cannon causes the cannon ball to travel in a curved path. The more powerful a cannon, the further the ball traveled before it hit the ground. Newton imagined that if he had a cannon powerful enough, the curve of the ball’s path would become greater than the radius of the Earth. This would put the ball in orbit, an object in free fall that never reaches the ground as its momentum carried along its orbital path.



Newton's cannon: A ball fired from a cannon travels in a curved path. If you could give a cannonball a high enough velocity, its curved path would carrying around the world, putting it into orbit.

FrankH at English Wikipedia/Public domain; OrbitingCannonBalls.jpg

Newton's law of gravity describes orbits a little differently than Kepler's laws do. Recall that Kepler's First Law stated that planets orbit in ellipses with the Sun at one focus. Kepler derived his law empirically. The elliptical path fit the data he inherited from Tycho, but he did not have any idea what forces governed this motion. Because Newton's law describes the force between two objects at the product of their masses, both objects orbit around their common **center of mass**.

Put two objects of equal mass on a balance. The two will perfectly balance each other at a point equidistant from each other. This point is called the center of the mass of the system. If you add more mass to one side of the balance, the center of mass will shift, moving closer to end with more mass. The Sun and Earth are balanced by their mutual attraction. Because the Sun is much more massive than the Earth, the center of mass of the Earth-Sun system is very closer the center of the Sun. So, while the Earth makes a wide orbit around the center of mass, the Sun only makes a tiny "wobble" around this same point. This wobble also accounts for the slight change in distance between the Earth and the Sun between aphelion and perihelion while Kepler's law assumes a stationary Sun.

While Kepler discovered his third law of planetary motion empirically, we can derive it from Newton's laws mathematically. First, we start with the second law and put in the value of centripetal acceleration:

$$F = ma = mv^2/r$$

Where F is the net force on the planet, m is its mass, v is its average speed, and r is its average distance from the Sun. Next, we set it equal to the force of gravity:

$$GmM/r^2 = mv^2/r$$

Where G is the universal gravitational constant and M is the mass of the Sun. The m's cancel out, as well as one r, leaving:

$$GM/r = v^2$$

Next, using the definition of period, P, being the time for one complete orbit, we find that the average speed, v, is equal to the circumference divided by the period (we're assuming a circular orbit since we're following Newton's law of gravity in which the planet and Sun revolve around their common center of mass).

$$v = 2\pi r/P$$

Substituting this value for v in the equation above yields:

$$GM/r = 4\pi^2 r^2/P^2$$

Solving for P and replacing r with a, the semimajor axis, as we are now considering an elliptical orbit, gives us:

$$P^2 = 4\pi^2 a^3/GM$$

Since 4, π, G, and M are all constants, we have a relationship in which the square of the period is proportional to the cube of the semimajor axis, just as predicted by Kepler's third law.

Newton's law of gravitation and Kepler's laws do not just predict elliptical orbits. An elliptical orbit is simply a bound orbit, where the planet orbits the star indefinitely. There can also be unbound orbits that follow parabolic or hyperbolic paths as they make a close approach to a strong source of gravity. Such unbound orbits can be used to accelerate a satellite to higher or lower velocities by dipping into a planet's gravity to "borrow" a little bit of energy.

We can also use Newton's law of gravity to demonstrate the principle discovered by Galileo that all objects experience the same acceleration, regardless of their math. For example, a falling object will experience an acceleration as defined by Netwon's second law:

$$a = F/m_1$$

Where $m_1$is the object's mass. The force of gravity is given again as:

$$F = GM_e m_1/r^2$$

Where M_e is the mass of the Earth Putting this value for force into the second law equation gives us:

$$a = F/m_1 = GM_e m_1/r^2 m_1$$

Note that the value for the mass of the object cancels out, leaving a value for acceleration as:

$$a = GM_e/r^2$$

Thus, the acceleration due to gravity is independent of a body's mass.

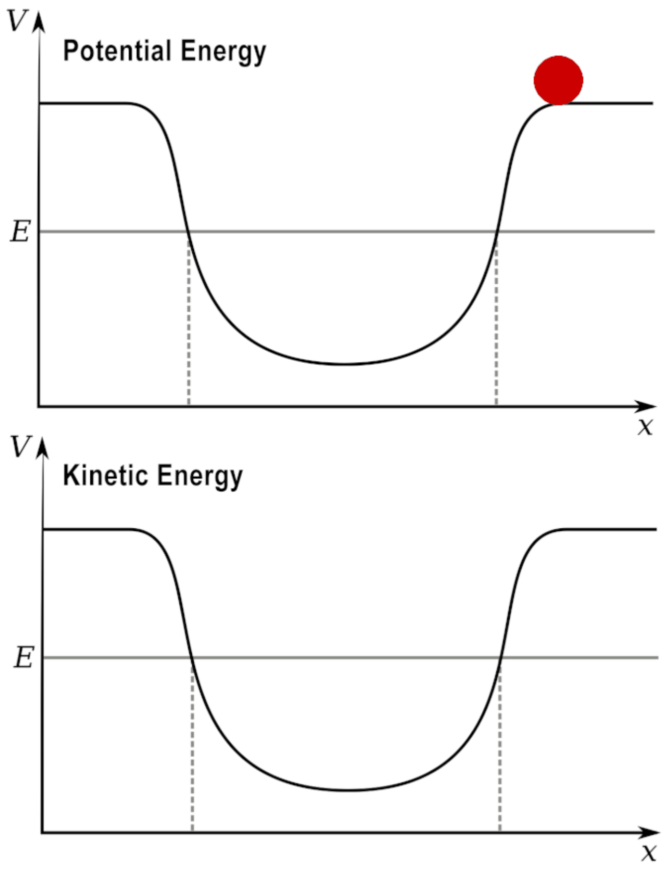
Of course, the Solar System does not contain just two bodies. The planets pull on each other and their respective moons also pull on the planets. These actions may cause perturbations as they tug on each other. This can cause deviations from paths predicted by Kepler's third law. In fact, it was the perturbations on Uranus' orbit from Neptune's gravity that led to its discovery.

3.6: Conservation Laws

3.6.1 Potential and Kinetic Energy

One fundamental principle of physics is that momentum is always conserved in any interaction. When two objects interact, according to Newton's third law, they exert equal and opposite forces on each other. Changes in the motion of the objects occur through conservation of momentum. If one object gains velocity, the other must lose velocity. The same applies to angular momentum, in which a rotating object cannot change its momentum unless an external twisting force (torque) acts upon it. Since the Earth experiences no such twisting force as it orbits the Sun, its revolution and orbit will continue indefinitely. However, friction from the tides is slowing the Earth's rotation down. The tides are governed by the Moon's gravity and since angular momentum must be conserved, as the Earth's rotation loses angular momentum, the Moon's orbit gains angular momentum. This results in the Moon moving further away from the Earth in its orbit by about a centimeter a year.

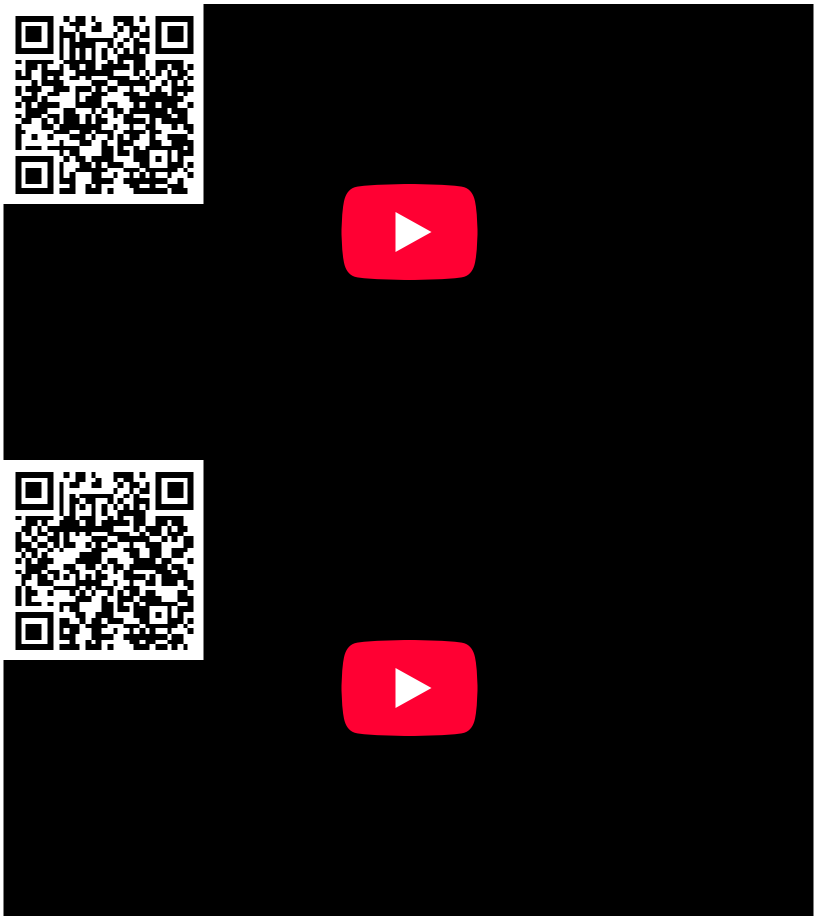
Like momentum, **energy** is also conserved. We define energy as the intangible phenomenon that can cause changes in an object's motion, temperature, or chemical phase. For our discussion, we are going to divide energy into three categories. **Kinetic energy** is energy of motion. All moving objects have kinetic energy. **Potential energy** is energy that is stored, either by the object's position (such as raising it to a higher elevation) or in the chemical bonds of a fuel like gasoline or sugars. Finally, **radiative energy** is all forms of light or electromagnetic radiation.



Potential and Kinetic energy: A ball at a high elevation has maximum potential energy by zero kinetic energy.

As it rolls down the hill, the potential energy is converted into kinetic energy.

Benjamin J. Burger / CC BY-SA (https://creativecommons.org/licenses/by-sa/4.0)



3.6.2 Measuring Temperature

Energy can make matter move or change form. It is always conserved, but it can be transformed from one form to another or transferred from one object to another. On the microscopic level, the atoms in matter, whether a solid, liquid, or gas, have kinetic energy. The collective kinetic energy of all the atoms and molecules in an object like a rock or a tank of water is called **thermal energy**. Usually, when we speak of thermal energy, we refer to an object's **temperature**, which is defined as the average kinetic energy of all of particles in an object. Two objects can have the same temperature, but if Object A is twice as dense as Object B, then Object A also has twice as much thermal energy as Object B.

We use three different scales for measuring temperature. The Fahrenheit scale, the one most familiar to Americans, sets the freezing point of water at 32 degrees and the sea-level boiling point of water at 212 degrees. Note that these designations are arbitrary, and we can set any value to these to points. For example, the Celsius scale was designed to be simpler than the Fahrenheit scale. The Celsius scale sets the freezing point at zero degrees and the boiling point of water at 100 degrees.

However, neither of these scales are really useful in astronomy where we often study objects that are cooler than the freezing point of water. As we will see in Chapter 4, there are some equations for which negative values for temperature do not work. Therefore, we need a scale that begins at the absolute coldest point possible. At -273.15 degrees Celsius, matter (theoretically) loses all thermal energy. This point is called absolute zero is as cold as anything could possibly get in this universe. The Kelvin scale, therefore, begins at absolute zero. The increments on the Kelvin scale (scientists do not generally use the term "degrees" in the Kelvin scale) are the same size as the degrees in the Celsius scale. As a result, -273.15 degrees Celsius is equal to 0 K and 0 degrees Celsius is equal to 273.15 K. We can easily convert from Celsius to Kelvin simply by adding 273.15. For example, the sea level boiling point of water, 100 degrees Celsius is equal to 373.15 K.

3.6.3 Gravitational Potential Energy

Recall that the force of gravity an object experiences on Earth is equal to its mass times the acceleration of gravity, g. The gravitational potential energy demands on the mass, g, and how far it could fall, such as its height, h, above the ground.

$$PE = mgh$$

As an object falls, the potential energy is converted into in kinetic energy as it gathers speed, v. Kinetic energy can therefore be given with the equation:

$$KE = \frac{1}{2} mv^2$$

For objects in space, such as a gas cloud, the gravitational potential energy depends on how it spread out its mass is. Therefore, when a cloud contracts, the gravitational potential energy is converted into thermal energy and the temperature rises.

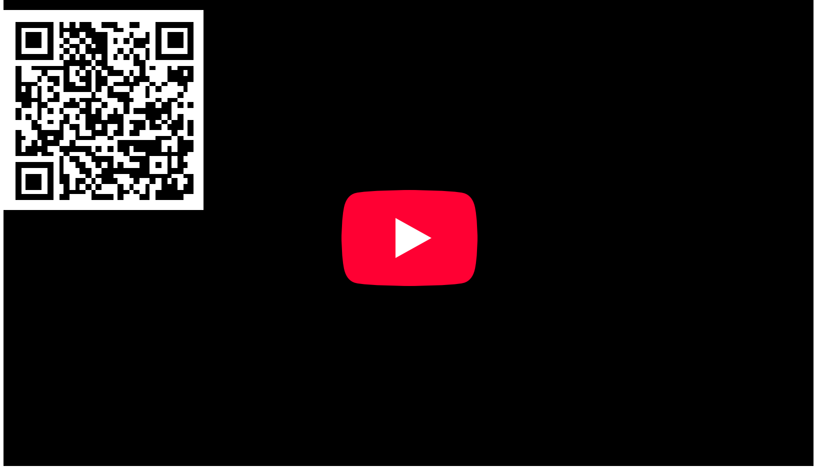
Albert Einstein demonstrated that mass itself is a form of potential energy through his equation:

$$E = mc^2$$

Where c is the speed of light. With this relationship, a small amount of mass can be converted into a large amount of kinetic or radiative energy, such as in nuclear bomb or in the core of a star. Likewise, concentrated energy in a particle accelerator can be turned into particles with mass.

Together, we use matter and energy to understand orbits. The total orbital energy, including gravitational and kinetic energy, stays constant if the orbiting object experiences no external force. Thus, orbits cannot change spontaneously. An object can gain or lose orbital energy through forces like friction. Most satellites are launched into Near Earth Orbit (NEO). NEO is not a perfect vacuum, so these satellites do experience some friction that will eventually slow them down and cause them to reenter the atmosphere. A gravitational encounter can also cause an object to gain or lose orbital energy by tugging on it.

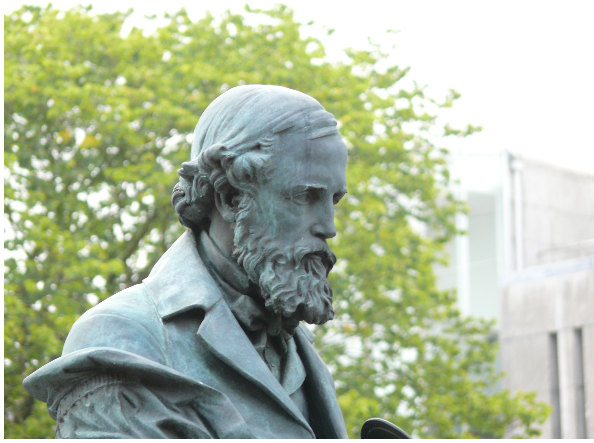
To launch an object into out of an orbit, it must gain enough orbital energy to reach the escape velocity. For Earth, the escape velocity ≈ 11 km/s from sea level. An object launched with this speed will escape the Earth and will no longer be held in orbit around it. This is not, however, enough energy to escape the Sun’s gravity, so an object that escapes the Earth is still in orbit around the Sun.



4: Electromagnetic Radiation

Learning Objectives

- Describe the basics of wave motion, including wavelength, frequency, diffraction, and interference.
- Describe the nature of electromagnetic waves.
- Describe the basics of atomic theory and how it relates to spectroscopy.
- Describe Wien and Kirchoff's Laws and how they are used to study plants and stars.
- Describe how the Doppler Effect can be used to determine the motion of objects in space.



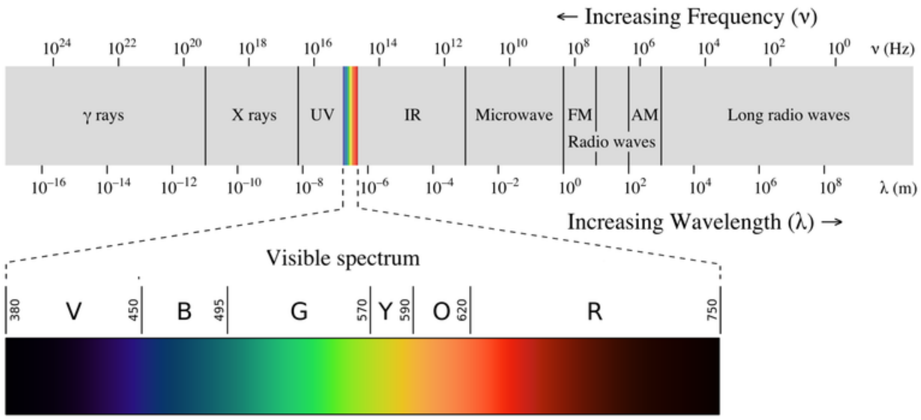
James Clerk Maxwell

https:/commons.wikimedia.org/wiki/File:James_Clerk_Maxwell_statue_in_George_Street,_Edinburgh_04.jpg

What is light? Is it a wave? Is it particle? Does it travel instantaneously?

These questions puzzled scientists for centuries. Over time and with extensive observations and study, researchers have found some answers. What we call light is just a small subset of the **electromagnetic radiation**, which is the transmission of energy through space by varying electric and magnetic fields. The entire electromagnetic spectrum ranges from the very long wavelength radio waves to the short wavelength, high energy X-rays and gamma rays.

The question of whether electromagnetic radiation is a particle or a wave proved to be a major enigma for scientists. When they conducted experiments to see if it was a particle, they discovered it have many properties of particles. On the other hand, when they tested for wavelike properties, they found light could also behave as a wave. It seemed that light was both. It is wave of electric and magnetic fields oscillating through space as well as a particle as a **photon**. While it may be hard to picture a phenomenon being both a wave and a particle, modern quantum theory tells us that is indeed how matter and energy behave at the subatomic level. But before we can discuss this wave-particle duality, we need to understand a few properties of waves.



The Electromagnetic Spectrum

https://upload.wikimedia.org/wikiped...rumrevised.png

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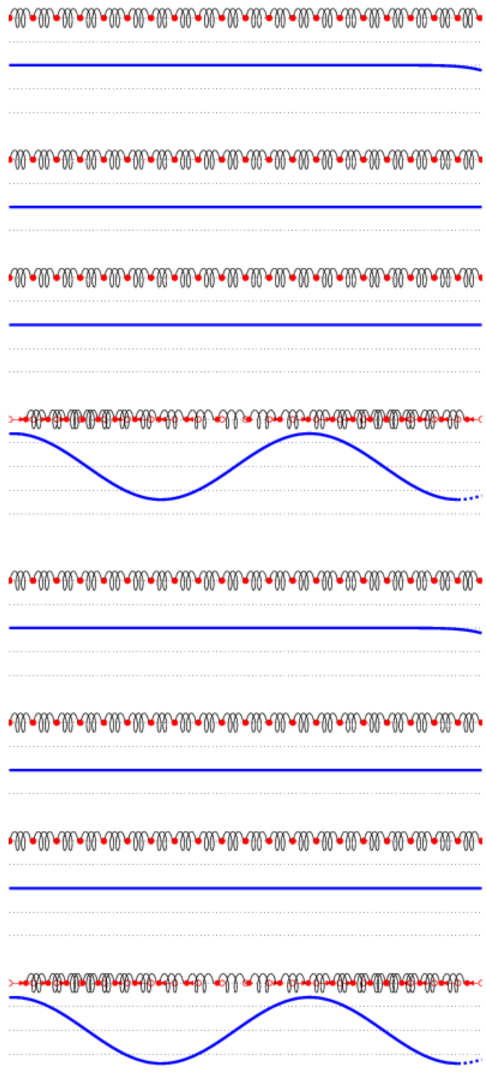
4.1: Wave Properties

4.1.1 Wave Properties

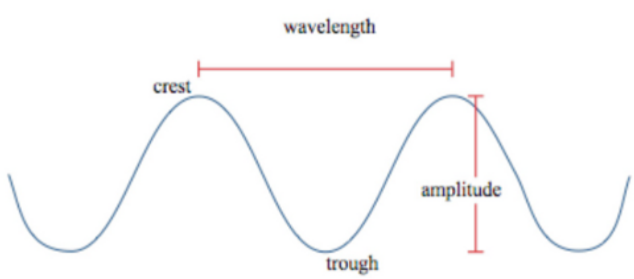
A **wave** is defined as the transmission of energy through a medium without the transport of matter. Picture waves in a pond as you through a rock into water. Ripples of water waves spread outward in concentric circles from the point of impact. The water itself is not traveling outwards. It is only moving up and down, but the energy from the impact travels through the water. Water waves are an example of **transverse waves**. In such a wave, motion of the medium is perpendicular to the direction of motion of the wave fronts. In contrast, sound waves are **longitudinal waves**, in which the medium compresses and expands in the same direction as the movement of the wave energy. Excessive wave consists of a series of **crests**, the point of highest displacement, and **troughs**, the points of lowest displacement. The **amplitude** of a wave is the maximum height of a crest. Waves are defined by their **frequency**, the number of wave crests that pass a point in a specific amount of time. The unit of frequency is generally given in cycles per second or Hertz. Waves also have a **period**, defined as the amount of time between successive crests. The relationship between frequency (f) and period (P) is given by the equation:

$$f = 1/P$$



Waves can either be transverse or longitudinal

https://commons.wikimedia.org/wiki/F...ngitudinal.gif



A wave consists of an oscillating medium with maximums (crests) and minimums (troughs).

https://commons.wikimedia.org/wiki/F..._amplitude.png

Wavelength, the distance between two successive crests, is another important property in waves. Waves also travel a specific velocity and the relationship between velocity (v), frequency (f), and wavelength (λ) is given by the equation:

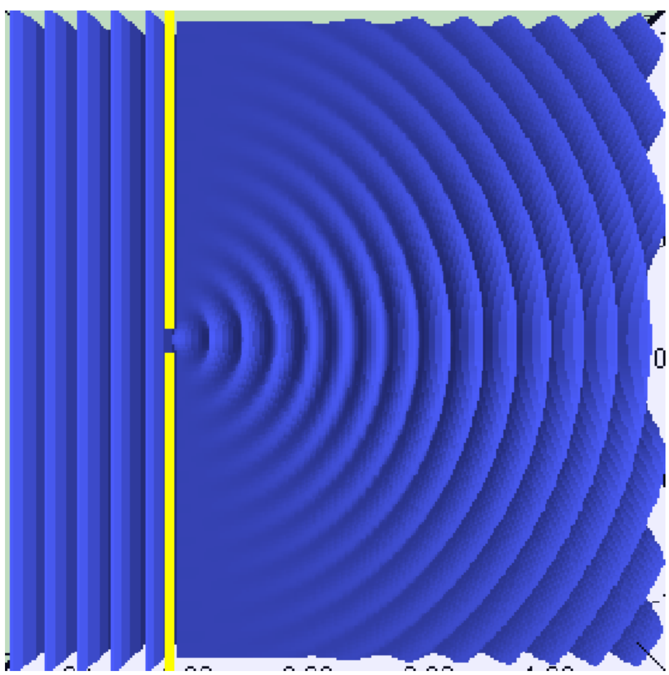
$$v = \lambda f$$

We know that the speed of electromagnetic radiation is a constant, c = $3.0X10^8$ m/s. This means that wavelength and frequency of electromagnetic radiation are inversely proportion to each other. The higher the frequency, the shorter the wavelength. The energy of electromagnetic radiation is also related to frequency by:

$$E = h \times f = \text{photon energy}$$

Where h = 6.626×10^{-34} joule × s and is known as Planck's Constant.

Waves have two additional properties that are important. The first is **diffraction**, or the bending of the wave front around a barrier. Again, we can use the analogy of water waters. As the wave hits a breakwater, part of the wave front is blocked, but part of it continues and propagates around the breakwater. The other key property is **interference**. Interference occurs when two or more waves interact with each other and they can interfere with each other destructively or constructively. **Destructive interference** happens when a crest and a trough coincide together, resulting in a dampening of the resulting wave's amplitude. In contrast, **constructive interference** occurs when two crests or two troughs coincide with each other, producing higher crests or deeper troughs.



Waves passing through a slit experience diffraction, in which the waves spread out in all directions.

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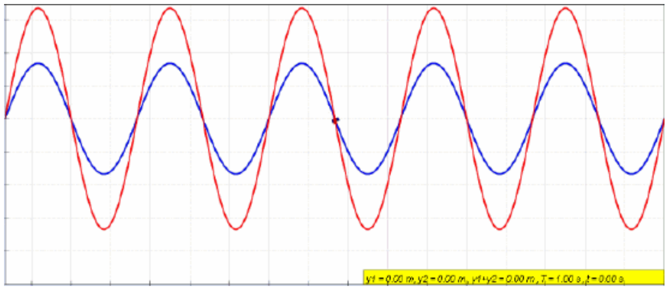


Two waves interacting will interfere with each other.

https://commons.wikimedia.org/wiki/F...terference.gif

Studies of light have found that electromagnetic radiation has both properties of diffraction and interference, giving evidence its wave properties. But other studies have indicated that electromagnetic radiation also exists as discrete particles called **photons**. Every photo, however, has a specific wavelength and frequency associated with it and the energy of the photon is found by multiply its frequency by Planck's constant.

4.1.2 Electromagnetic Waves

But if electromagnetic radiation is a wave, what it is traveling through? Water waves travel through wave and sound waves travel through the air and other mediums. Neither can travel through the vacuum of space because it lacks a physical medium. Scientists searched hard for a universal medium, which they called the Ether, through which electromagnetic waves travel. After repeated tests failed to find any evidence for the Ether, scientists had to conclude that it does not exist. Electromagnetic waves travel through nothing!

But what are they then?

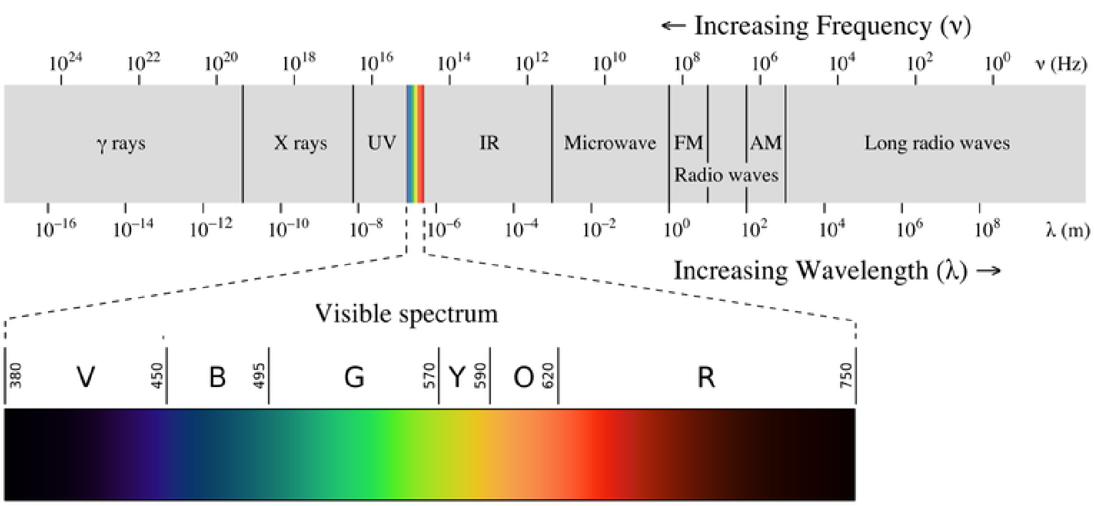
Scientists had long known of the strong relationship between electric and magnetic fields. A charged particle placed in a magnetic field will accelerate along the magnetic field lines. Likewise, an electric field can induce a magnetic field in a conductor. Work by James Clerk Maxwell and other researchers soon found that an accelerated electric charge produces a fluctuation of both electric and magnetic fields. They determined that the electromagnetic wave is a combination of a fluctuating electric field and a fluctuating magnetic field, oscillating at right angles to each other and travel in a direction perpendicular to both.

As noted above, visible light is just a small portion of the entire electromagnetic spectrum. What we perceive as different colors is determined by different frequencies of light. Red has the lowest frequency and the longest wavelength while violet has the highest frequency and the shortest wavelength. A photo of violet light, therefore, has more energy than a photon of red light. Infrared radiation consists of wavelengths longer than red. Even longer wavelengths make up microwave and radio waves, which are used to cook food and for various communication systems, respectively. Ultraviolet rays have a higher frequency than violet light and Gamma and X-rays have even higher frequencies.

An electromagnetic wave consists of an oscillating electric fields (E) and magnetic fields (B).

https://commons.wikimedia.org/wiki/File:EM-Wave.gif

It is not a coincidence that our eyes are sensitive to the frequencies that make up the visible portion of the spectrum. These are the frequencies of light that the Earth’s atmosphere is most transparent to. There are also other frequencies that can pass through the atmosphere, such as the near-infrared and parts of the radio spectrum with frequencies higher than the AM radio band. The Earth’s atmosphere blocks out most other forms of infrared radiation, as well as the high frequency ultraviolet, gamma, and X-ray ranges. This is good, as photons in these upper frequencies are the most damaging to our cells and can induce various from of cancer, including skin cancer.



The Electromagnetic Spectrum.

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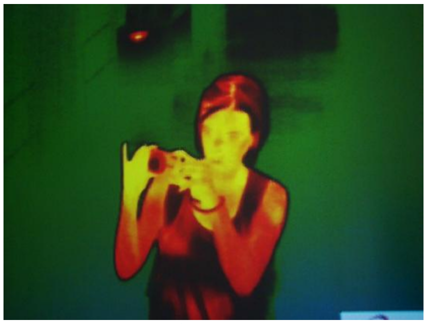
4.2: Thermal Radiation

4.2.1 Introduction to Thermal Radiation

All objects, regardless of temperature, have some internal motion of their molecules. The molecules in fluids such as liquids and gases freely move around and collide with one another. In solids, the molecules are held in place, but still vibrate. As a result, all objects emit some form of thermal radiation. Temperature also determines the average speed of gas molecules, which has a big impact on the composition of a planet's atmosphere. Tiny Mercury's weak gravity is not strong enough to retain any gases as they heat up from the Sun's rays, same with the Moon. Earth, on the other hand, has a strong enough gravity to retain many gases, including oxygen, nitrogen, carbon dioxide and water vapor, but not lighter ones like hydrogen and helium. These gases were likely the main components of Earth's atmosphere, but they quickly escaped into space. In contrast, Mars has a weaker gravity and has lost much of its early atmosphere, leaving only a thin layer of mostly the heavier gas, carbon dioxide. Even to this day, Mars is still losing its atmosphere to space.

At temperatures found on Earth, the thermal radiation emitted is in the infrared range of the spectrum and is, of course, invisible to the naked eye. This radiation can, however, be detected by infrared cameras. Firefighters can use such cameras to find unconscious victims inside a smoke-filled room where visible light is scattered by the smoke, but the infrared radiation is not.



 At typical Earth temperatures, all objects emit infrared radiation that can be detected with special cameras.

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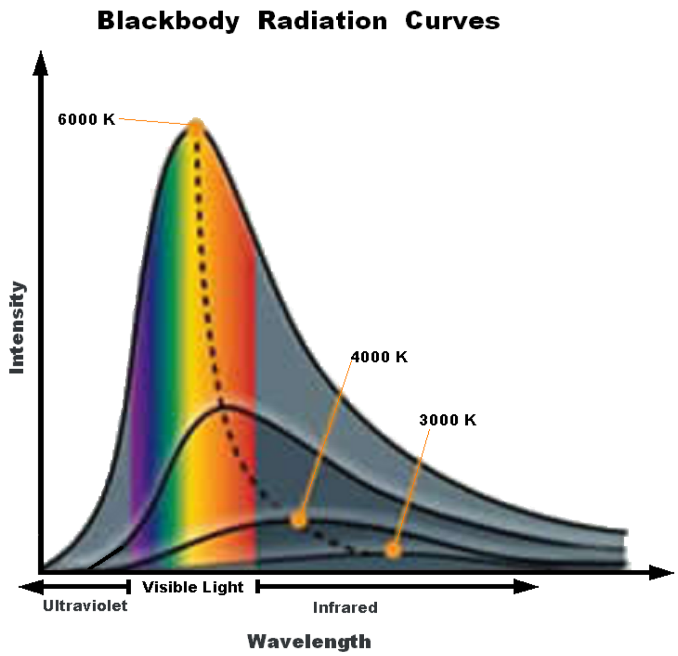
Recall in Chapter 3 that absolute zero on the Kelvin scale is the point where are motion ceases. An object that temperature would not emit any thermal radiation. In practice, however, we cannot reach absolute zero. We have been able to cool things to very close to absolute zero, even within a billionth of a degree, but it is not possible to get all the way down to absolute zero.

4.2.2 Blackbody Radiation

Physicists use a model called a **blackbody**, which a body whose radiation emitted is dependent only on its temperature. While a blackbody spectrum is an idealized model, many objects, including planets and stars, behave enough like a blackbody that it is a useful approximation of their spectra. An object's thermal radiation spectrum depends on its temperature, with hotter objects emitting more light at all wavelengths per unit area and hotter objects emit photons with a higher average energy. The emission of thermal energy is governed by two key laws:

1. Peak wavelength is inversely proportional to temperature.
2. Total energy emitted is proportional to fourth power of temperature. $E \alpha T^4$



Blackbody spectrum has a continuous spectrum with a peak wavelength based on its temperature.

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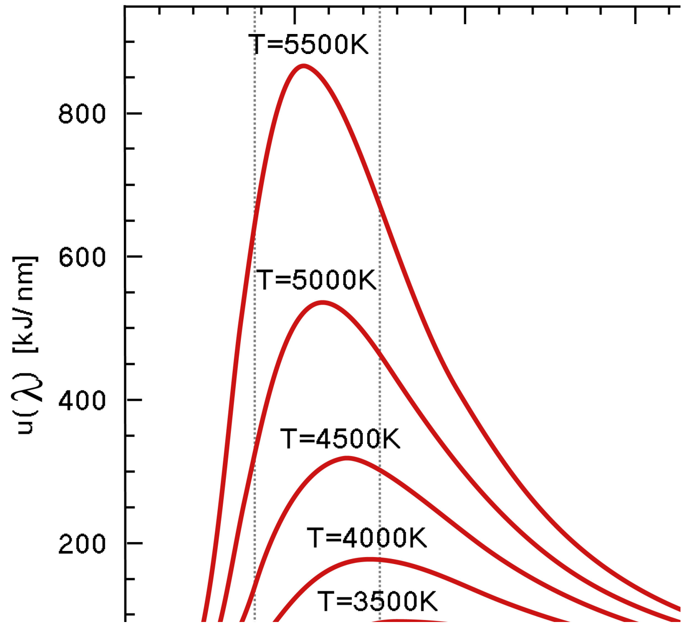
Note that this is one of these instances where the relationship between energy and temperature in which energy most be given on the absolute (Kelvin) scale since negative temperature values would through these calculations off.

Wilhelm Wien studied the spectrum of objects as their temperatures increased. For example, a piece of metal at room temperature emits only infrared radiation and therefore, does not glow in visible light. If you heat it up, it will start to glow red, as the peak wavelength of the light emitted gets short. Heat it up even more, and it will glow blueish-white, showing that ite peak wavelength has shifter to even shorter (bluer) wavelengths. Wien's Law describes how the peak wavelength of the radiation emitted by an object varies with temperature. All bodies emit thermal radiation spanning a broad range of wavelengths. The amount and peak wavelength of the radiation depends on the temperature of the body, but not on its composition. It is independent of what the material is made of. The higher the temperature, the more radiation is emitted and the shorter (or bluer) the peak wavelength of the radiation. The peak wavelength (color) of an object (in nanometers) is related to temperature:

$$\lambda = 2.9X10^6 / T$$

Again, temperature must be expressed on the Kelvin scale. Wien's Law therefore states that as an object gets hotter, it will glow brighter and, as its peak wavelength shortens, its color will shift toward the blue end of the spectrum and the average energy of the photons emitted increases. Very hot objects, such as the gases being pulled into the gravity well of a black hole, are heated to the point where their peak emissions are in the X-ray portion of the spectrum!



Wien's Law states that the peak wavelength emitted by a blackbody varies with Temperature.

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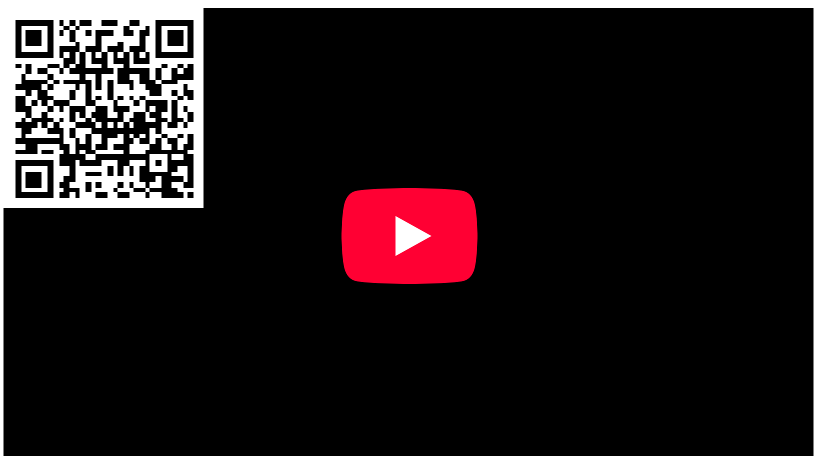


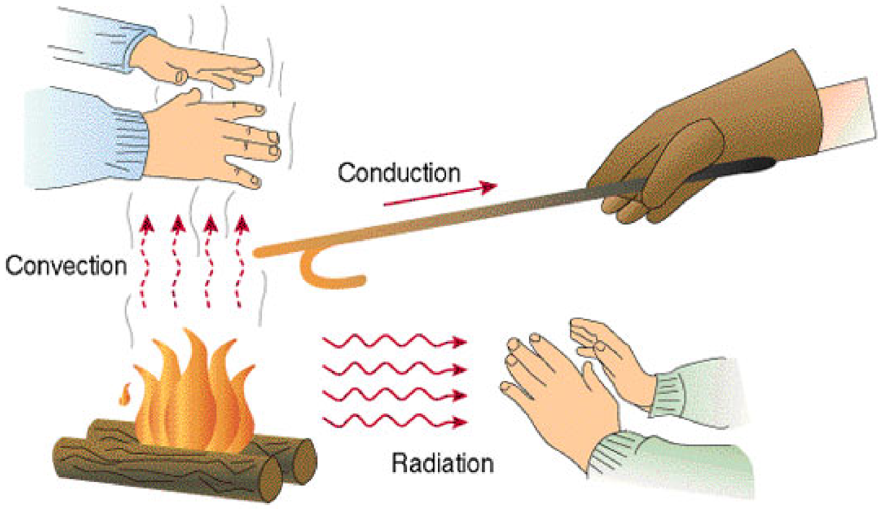
4.2.3 Thermodynamics

The laws of thermodynamics govern the transfer of heat from one system to another. Heat tends to move from hotter objects to cooler ones, until both systems are in thermal equilibrium, in which their temperatures are equal. The **First Law of**

Thermodynamics, also known as **the Law of Conservation of Energy** states that the total amount of energy in a closed system is always conserved. These means we can never get free energy. In order to perform any work, such moving an object or moving objects around, requires energy. We can change the from of energy, such as from potential energy to kinetic energy (Chapter 3) or we can transfer energy from one system to another, but it can never be created or destroyed. We can never get more energy out of a system than we put into it.

The **Second Law of Thermodynamics** or, the **Law of Entropy**, states that the entropy, or disorder of a system, always increases, so as energy changes forms, the amount of heat energy tends to increase. This means that in any energy system, some energy will be lost to waste heat. So, the amount of energy or useful work we can get out of a system will always be less than amount we put into it. The Law Entropy is universal in that the amount of entropy in the universe is steadily increasing. We can decrease entropy locally, as living organisms do when they use energy from the Sun to build complex molecules, but only by increasing the overall entropy. Eventually, everything runs down. Any energy conversion system, whether a living organism or a car's engine, can only continue running so long as additional energy is put into it. Even so, parts wear out and need to be replaced over time. Likewise, even the Sun will run out usable hydrogen to fuse into helium and die. Even the entire universe, assuming it does not collapse into a "Big Crunch" (the opposite of a Big Bang), will eventually reach a state of maximum entropy where all usable energy will be dispersed and no systems will be able to function. Astronomers call this the **Heat Death of the Universe**. Do not get too worried about it. Scientists predict the Sun will not run out of hydrogen for another four or five billion years and the Heath Death is hundreds of trillions of years after that. In the meantime, the Second Law also dictates that it is impossible to remove all the heat energy from a system and therefore, it is impossible to reach absolute zero.

Heat can be transferred from one system to another by one of three ways. The first is **conduction**, which heat is transferred from direct contact between two systems, such as placing a pot on top of a stove burner. The movement of liquids or gases can also transfer heat through **convection**, such as air currents absorbing heat from Earth's surface. Since warm air is less dense than cooler air, it rises (this is how a hot air balloon rises). As the warm air rises, the heat is dispersed into the upper troposphere. The air cools, becomes denser, and sinks back down to the surface. **Radiation** is the transfer of heat through electromagnetic radiation without any contact between materials. This is how energy from the Sun travels to the Earth.



Heat is transmitted by three methods: Radiation, conduction, and convection.

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4.3: Atomic Theory

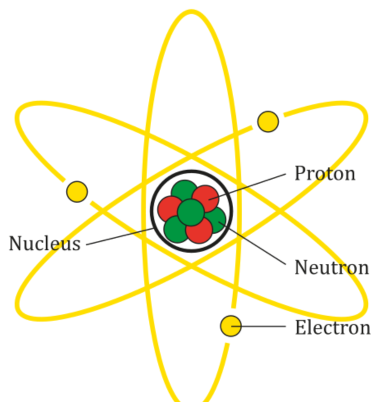
4.3.1 Early Atomic Theory

Ancient philosophers pondered the nature of matter for thousands of years. Many held that all matter was made up of four primal substances or elements, such as air, earth, fire, and water. Under this model, all matter was made up of different combinations of these four elements. In contrast, the Greek philosopher Democritus, held that matter was made up of tiny particles. He called these particles **atoms**, from the Greek word for "inseparable." Democritus argued that any object could be cut into smaller parts but eventually, if we kept cutting, we would reach a tiny particle that could no longer split into smaller parts. This fundamental particle was thus, inseparable.

For thousands of years, philosophers favored the idea of primal elements over Democritus' atomic theory, but by the late nineteenth century, physicists had concluded from observation that Democritus had been right all along. Matter was indeed made of tiny, inseparable particles.

But then, in 1900, Joseph John Thompson discovered the **electron**, a particle with a negative charge and that was lighter than the lightest known atom. Suddenly, atoms no longer seemed so "inseparable" at all, as there appeared to be a particle smaller and more fundamental than the atom. At first, physicists modeled atom as a mass of positive charges with negatively charged electrons embedded in it, like plums embedded in a pudding.

Eventually, however, other particles were discovered, such as the alpha particle, which we now know is a helium nucleus, containing two **protons** and two **neutrons**. Ernest Rutherford's experiments with alpha particles revealed that, instead a "plum pudding" model, most of the atom's mass was concentrated in a tiny point in the center, a nucleus containing protons and neutrons. Most of the atom, in fact, was empty space! Rutherford concluded that electrons must orbit the nucleus much like planets orbit the Sun.



Rutherford's Atomic Model

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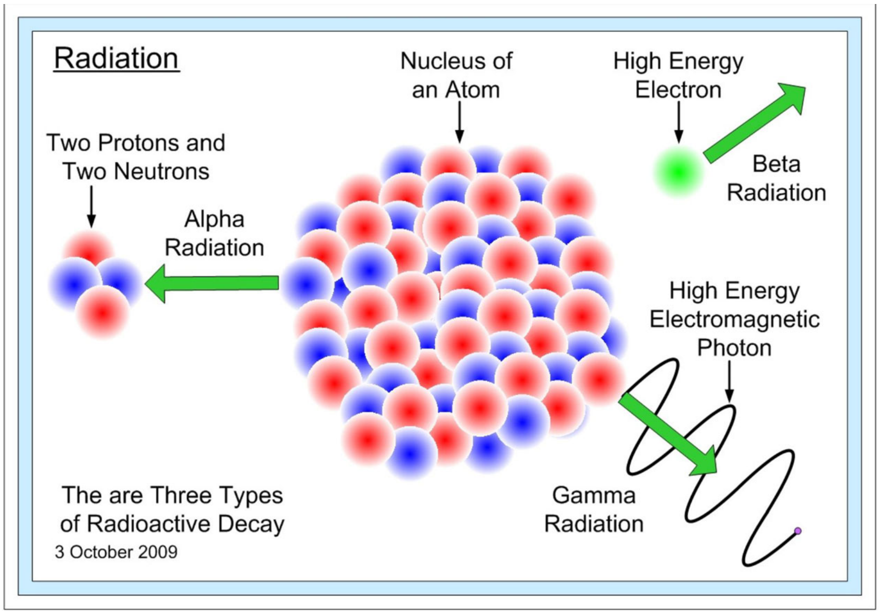
In Rutherford's model, the nucleus of an atom contains two particles: positively charge protons and neutrons, which lack any charge. The number of protons in the nucleus, known as the **atomic number**, determines what element the atom is. The lightest atom, hydrogen, has an atomic number of one and therefore, only has one proton in the nucleus. The heaviest naturally occurring element, uranium has ninety-two protons in its nucleus, giving it an atomic number of ninety-two. Today, an **element** is defined as a substance that cannot be chemically broken down into any other substances. Instead of just four elements, the modern periodic table contains ninety-two naturally occurring elements and over twenty-five elements that have been produced artificially in nuclear reactors and particle accelerators. The total number of protons and neutrons in the atom is the **atomic mass**. Some atoms of the same element may have differing numbers of neutrons, and therefore, have different atomic masses. Such atoms, called **isotopes**, have slightly different masses and some are unstable, undergoing **radioactive decay** into lighter, most stable atoms. Isotopes of the same element are designated with a superscript of their respective atomic mass, for example, ^{12}C and ^{14}C, being two isotopes of carbon. Atoms can form bonds with each other by exchanging or sharing one or more orbital electrons. Two or more atoms bound together form a **molecule**. Molecules made of two or more different elements, such as water (H_2O) or carbon dioxide (CO_2) are called **compounds**.



Radioactive atoms emit three kinds of radiation: Alpha, Beta, and Gamma.

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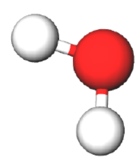
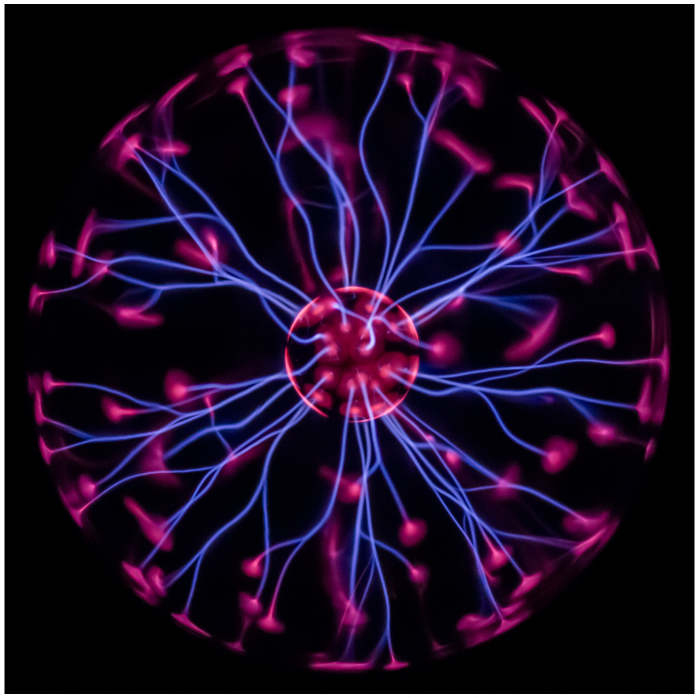


A water molecule is an example of a compound.

https://commons.wikimedia.org/wiki/F...r_Molecule.png

Matter can exist in of four physical states. Three of those states are familiar to us: solid, liquid, and gas. The fourth state, **plasma**, consists of ionized gases, that is, gaseous atoms that have been stripped of their electrons. The state a substance exists in depends on the nature of the substance, its temperature, and pressure. For example, the atmospheric pressure on Mars is too low to keep water in a liquid state. A bottle of liquid water on Mars would quickly freeze solid, although solar radiation may cause some of the ice to sublimate, that is, turn directly from solid to the vapor phase. On the other hand, Venus has an atmospheric pressure on the surface that is ninety times that of Earth at sea level, more than enough to keep water in a liquid form. However, the temperature on Venus is far too high for liquid water and any water on the surface would boil away in an instant. Of the terrestrial planets, only the Earth has the right combination of temperature and pressure for liquid water to exist on the surface.



A plasma globe produces a plasma, fluid of charged particles.

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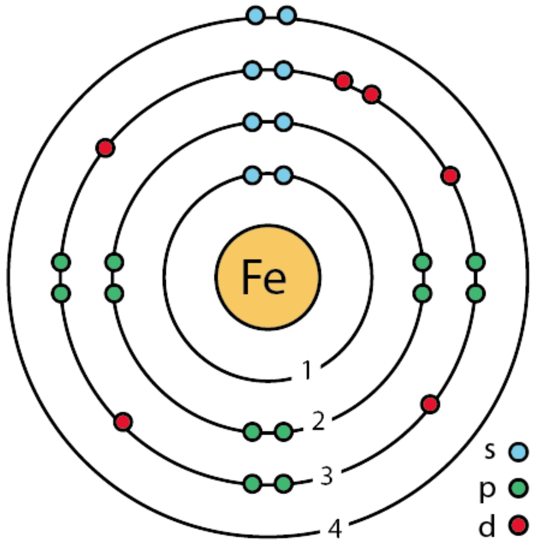
At very high temperatures, such as those found on the Sun, gases may undergo **ionization**, in which their atoms are stripped of their electrons, becoming plasma. Another change in matter of interest to planetary astronomers is **dissociation**, in which radiation breaks the chemical bonds in molecules, separating them into their individual atoms. Dissociation often occurs in the upper atmospheres of the terrestrial planets.

4.3.2 Bohr Atomic Model

Able to explain how atoms behave and form bonds, **Rutherford's planetary model** seemed to explain the observed behavior of atoms.

However, Niels Bohr soon discovered a problem with the standard planetary model. He knew that an accelerating charge, such as an electron moving in a circular orbit, emits electromagnetic radiation. As it did, it would lose energy and spiral into the nucleus. It seemed Rutherford's planetary model was unstable and could not explain how electrons remained in their orbits. Bohr also noted that electrons could only exist in certain energy states as they orbited an atom. For example, an electron could exist at the lowest energy state, the ground state, and at certain excited states, but it could never exist in an orbit in between these states. The electron remained in the ground state until it absorbed a photon of exactly the amount of energy needed to excite it to one of the higher states. It could then fall back to the ground state by emitting a photon of the exact same energy. However, if a photon with an intermediate energy, such as between the energy of the ground state and the first excited state, nothing happened. The electron could not absorb any photon except those whose energies were an exact match of the difference between its current state and an upper, excited state. Likewise, it would only emit a photon of energy equal to the difference between its current state and the lower state. Electrons in an excited state can fall back to the ground state directly, such as from the third excited state to the ground state, or as a cascade, dropping from the third excited state, to the second, to the first, and finally back to the ground state.

It is important to note that electrons do not move up or down from one state to another as a smooth transition, like a ball rolling down a ramp. Instead, they behave more like steps on a ladder. The electron can be on the bottom state or any of the higher states, but it cannot exist in any space in between two states, just as your foot could not rest in any space between two rungs on a ladder. The **Bohr Model** of the atom thus defines electron orbits as specific, **quantized** energy states instead of any of a spectrum of orbits like planets. The energy states that electrons can occupy depend on the number of protons in the nucleus and the number of electrons orbiting it. As a result, the wavelengths of light that the electrons can emit or absorb are unique to each element.



Bohr model of an iron atom.

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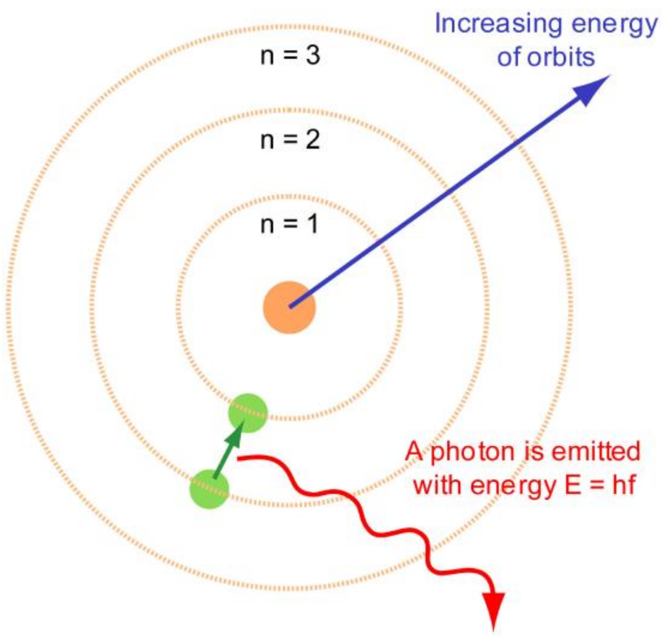

In the Bohr model, a photon of a specific energy is absorbed by an electron, causing it to jump to a higher energy state. As the electron falls to a lower energy state, a photon of the same energy is emitted.

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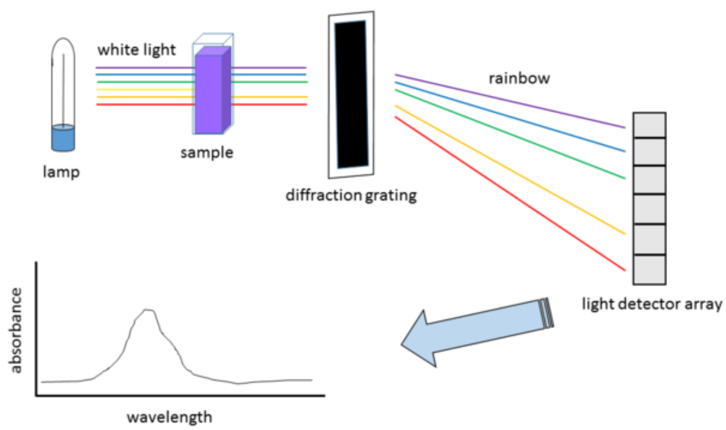
4.4: Kirchhoff's Laws

4.4.1 Spectroscopy

Isaac Newton demonstrated that white light can be separated into its component colors. Pure white light contains the six colors of the visible spectrum: red, orange, yellow, green, blue, and violet. A **spectroscope** consists of a prism to separate colors and then projects them onto a screen or detector for analysis. Astronomers use spectroscopes to examine the light coming from stars and other bodies. A curious thing happens, though, when we examine the light coming from, say, a cloud of thin, hot gas. Instead of seeing a continuous spectrum, we see a series of discrete lines. These **emission lines** are produced by electrons dropping from an excited state to a lower state. The wavelengths emitted, as explained by the Bohr Model, are unique for each element. As a result, by examining the emission lines, we can determine what elements the cloud of is made.



A spectroscope analyzes light by using a prism to split it into its various colors.

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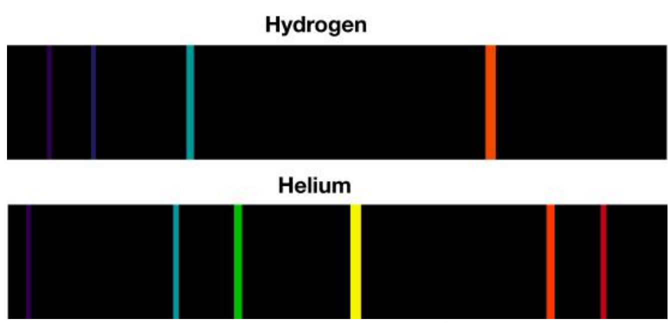

Atomic emission spectrum of helium.

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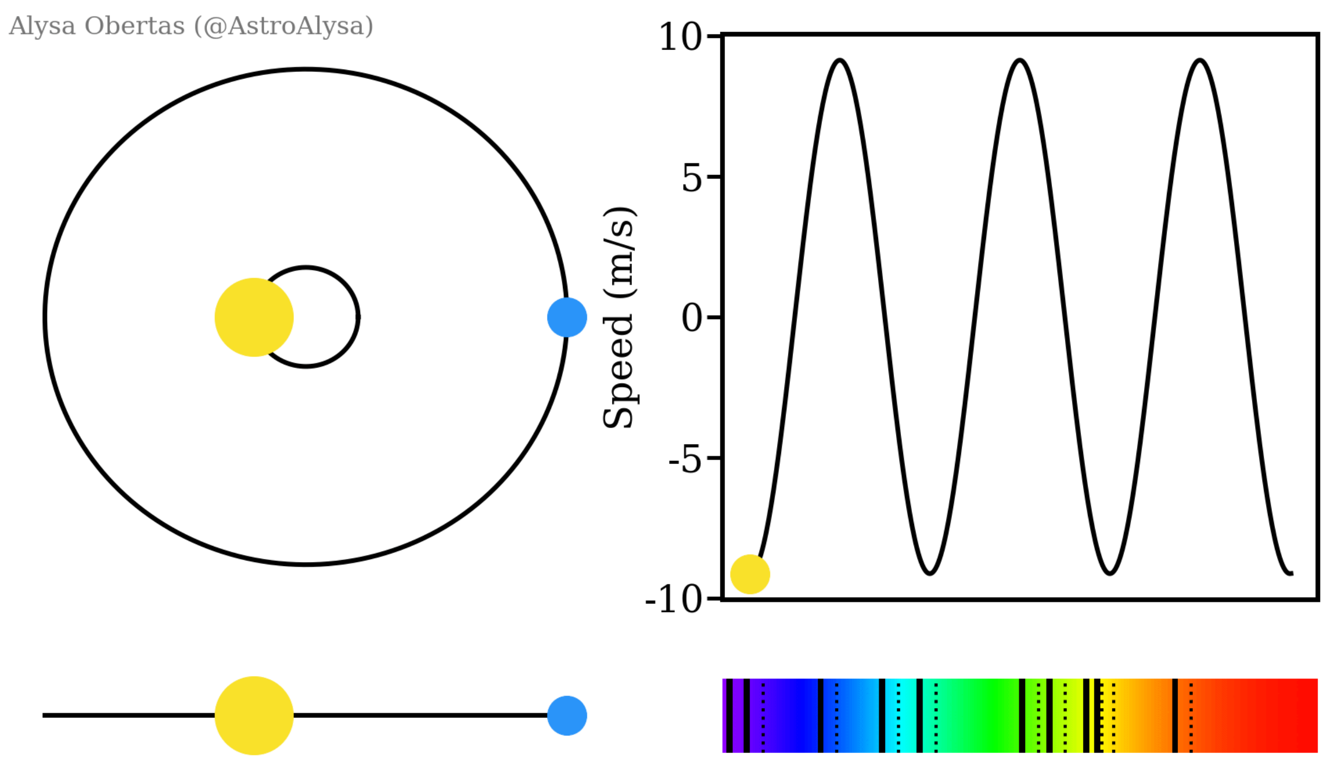
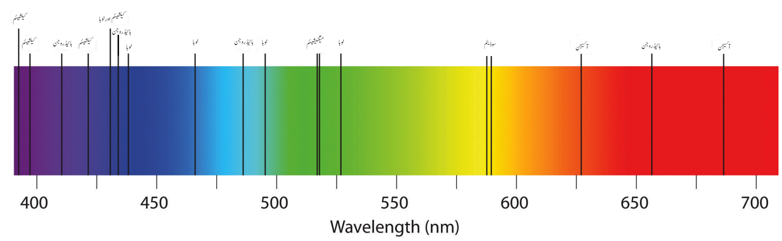
If we examine the light after it passes through a cool gas, we see what appears to be a near-continuous spectrum, but with several blank lines in which specific wavelengths of light have disappeared. These **absorption lines** are the result of electrons absorbing light and jumping from a lower state to a higher energy state. The specific wavelengths in the absorption lines of an element are the same as the wavelengths in the emission lines of the same element. Thus, we can identify elements by either their emission or absorption spectra.



We can see how the spectrum of an object shifts as an object moves toward or away from us. https://commons.wikimedia.org/wiki/F...ectroscopy.gif



The absorption spectrum of a few elements.

https://commons.wikimedia.org/wiki/F...w_elements.PNG

4.4.2 Kirchhoff's Laws of Radiation

Bohr developed his model of the atom in part by examining the emission and absorption spectra of hydrogen. Hydrogen is the simplest of the atoms as it has only one electron orbit the nucleus. Multielectron atoms have more complex spectra. Molecules have even more complex spectra, such as the spectra for molecular hydrogen, consisting of two hydrogen atoms bonded together, are more complex than that of a single hydrogen atom. However, all these various spectra behave in predictable fashion, so each acts a definitive “fingerprint” that can be used to identify the element or compound present.

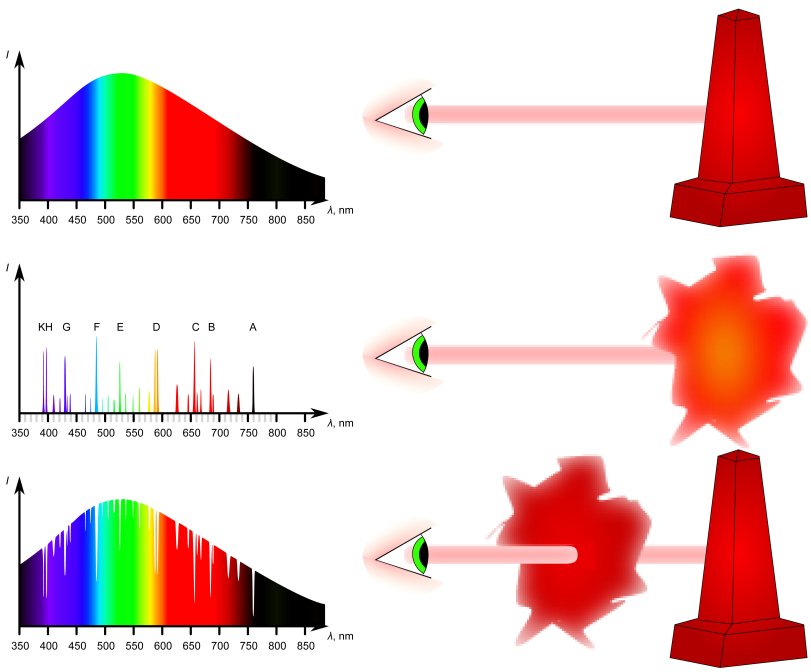
As noted above, whether a substance produces an emission or an absorption spectrum depends in part on its temperature as well as its state and density. Kirchhoff’s Laws formally describe what kinds of spectra emitted as follows:

1. A hot solid, liquid or gas, under high pressure, gives off a continuous spectrum.

2. A hot gas under low pressure produces a bright-line or emission line spectrum.

3. A dark line or absorption line spectrum is seen when a source of a continuous spectrum is viewed behind a cool gas under pressure.

Kirchhoff’s Laws have proven to be useful in identifying the composition and temperature of everything from planetary atmospheres, stars, and interstellar nebula. But they do not tell us anything about the motion of these objects. For that, we will need to consider another property of electromagnetic waves, the Doppler effect.



Kirchhoff's Laws describe light emitted from a luminous solid, a hot gas, and a cool, diffuse gas.

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4.5: The Doppler Effect

The Doppler Effect.

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Ever listen to an ambulance siren as it goes by? The pitch will appear to go higher as the ambulance approaches you and then falls as it heads away from you. This is known as the Doppler effect and we experience it with any waves in which the source is moving towards or away relative to the observer, including electromagnetic waves. When the source is moving toward the observer, the successive wave fronts "bunch up" as they get emitted. This results in the wavelengths getting shorter. For light waves, this means the light waves are "**blueshifted**" as the color shifts towards the blue end of the spectrum. If the source is moving away from the observer, the successive wave fronts are stretched out, resulting longer wavelengths. For light, the waves are "**redshifted**" as the color shifts toward the red end of the spectrum. For electromagnetic waves in general, we use the terms blue shift and red shift to describe shortening or lengthening of EM waves, respectively, regardless of the original wavelength.

It does not matter whether the source of the observer is moving, the effect remains the same. Only the relative motion between source and observer matters.

The relationship between the degree of shift in wavelength to the speed of the object is found by:

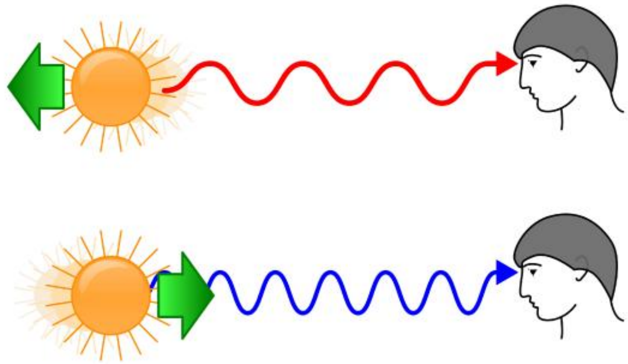
Apparent wavelength/true frequency = true wavelength/apparent frequency = 1 + recession velocity/wave speed.

Since the speed of light in a vacuum, c, is a constant, the speed of the object can be found with the following equation:

$$\Delta\lambda/\lambda = v/c$$

Where $\Delta\lambda$ is the change in wavelength, λ is the normal or laboratory wavelength of the light, and v is the relative speed of the source toward or away from the observer.

The Doppler effect shifts an object's entire spectrum either toward the red or toward the blue. Thus, all the electromagnetic waves are either shortened or lengthened. For example, an object emitting radio that is moving toward us would have the radio waves shifted toward shorter wavelengths whereas an object emitting ultraviolet radiation moving away from is would have its wavelengths lengthened, perhaps into the violet or blue portions of the spectrum.



Objects approaching the observer are blue shifted while objects moving away are red shifted.

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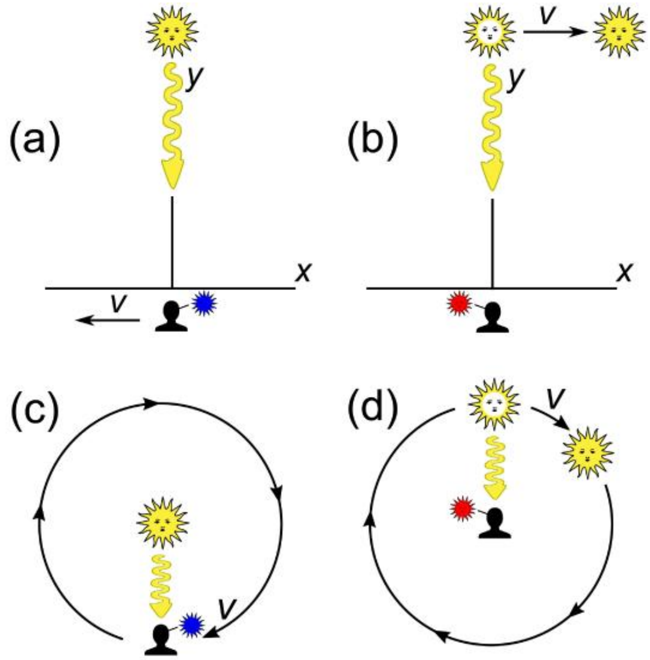
This includes the emission or absorption spectral lines. Each spectral line would be shifted by the same amount, depending on the relative speed of the source. Therefore, they will still have the same relative differences in wavelength with respective to each other. As a result, we can identify the spectral lines, calculate their degree of shifting, and use that to determine the relative speed of the source.

The Doppler effect can also be used to determine the speed of rotation of a star. When a star is rotating, part of is moving toward us and part is moving away. As a result, light from one "limb" of the sphere will be blueshifted and light from the other "limb" will be redshifted. The degree of blue and red shifting depends on the rotational speed of the star, cause the spectral lines to become more spread out over a range of frequencies. The wider the spread of frequencies in the spectral lines, the faster the star's rotation.

Finally, it is important to note that the Doppler effect only tells us how fast an object is moving toward or away from us. It tells us nothing about its motion across our field of view. If the object is moving directly toward or away from us, the Doppler effect will tell its full speed. If the object is moving across our field of view, it will tell us nothing about its motion. Finally, if the object is moving diagonally, it will only tell us the portion of the motion toward or away from us and nothing about its lateral motion.



The Doppler Effect does not tell us any information about an objects transverse motion relative to the observer.

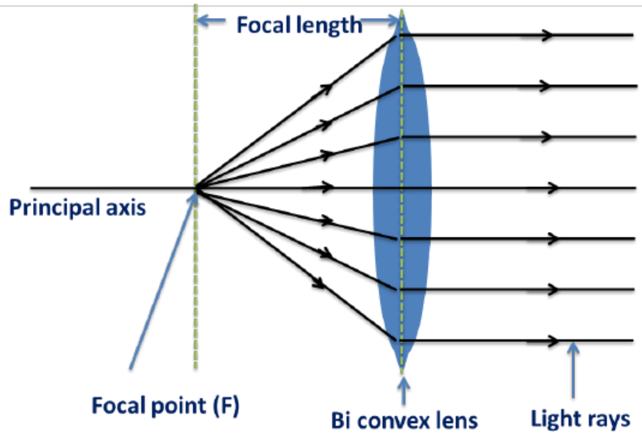
https://commons.m.wikimedia.org/wiki...cenarios_2.svg

5: Telescopes

Learning Objectives

- Describe the principles of optics used in telescopes.
- Explain the differences between refracting and reflecting telescopes.
- Understand how radio telescopes work and how they are used.
- Explain uses of telescopes in space.
- Explain how other wavelengths, such as infrared, ultraviolet, x-rays, and gamma rays are used in astronomy.
- Explain other methods for studying the universe, such as gravity wave and neutrino detection.

5.1: Optical Telescopes

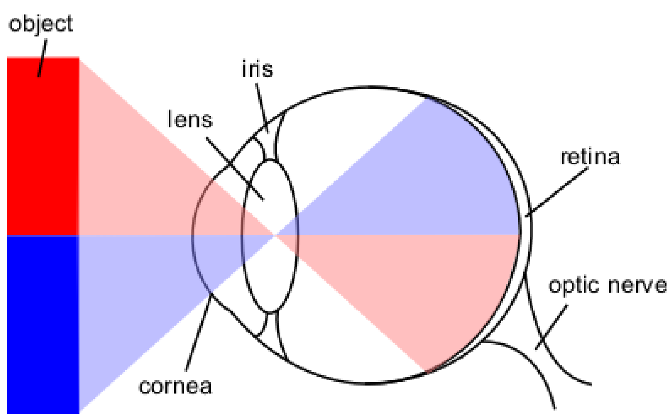


Biconvex Lens used to focus light rays onto a focal point.

https://commons.wikimedia.org/wiki/F...ocal_point.png

Since the time of Galileo (Chapter 3), astronomers have used telescopes to examine the planets and stars. While Galileo did not invent the telescope, he made significant improvements in the original design and was the first to use to study the night sky. Galileo used a **refracting telescope**, one that uses a curved lens to focus light rays to a focal point. Refraction results from the bending of light waves as it travels from one medium to another. So, as light waves travel from air to a curved lens, the waves become bent. The shape of the lens then focuses the light waves by causing the parallel rays to a single point. Also, the Sun appears distorted at sunset as the Sun's rays pass through a thicker layer of atmosphere, causing additional refraction.

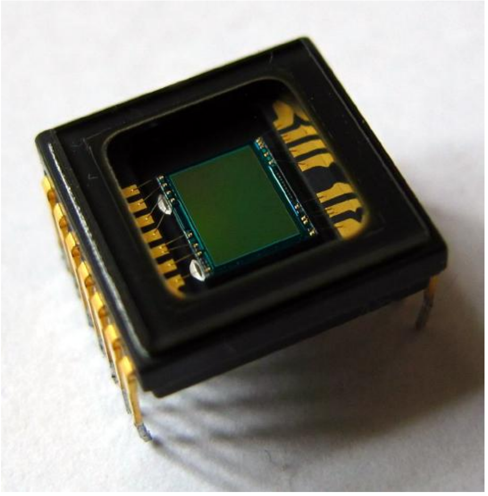
The lens of your eye works the same way. It bends the light entering you eye to focus it onto your retina. The retina is located at the focal plane, the plane where light from different directions comes into focus. Using a single convex lens (a lens that bulges outward), images appear upside on the focal plane. Fortunately, our brain can interpret the signals from the retina to put things right side up. For telescopes, additional lenses or a compound lenses can be used to turn images right side up for many spyglasses, although this is not a serious problem in astronomy, as there is not defined up or down in space.



Eye Diagram

https://commons.wikimedia.org/wiki/F...ye-diagram.png

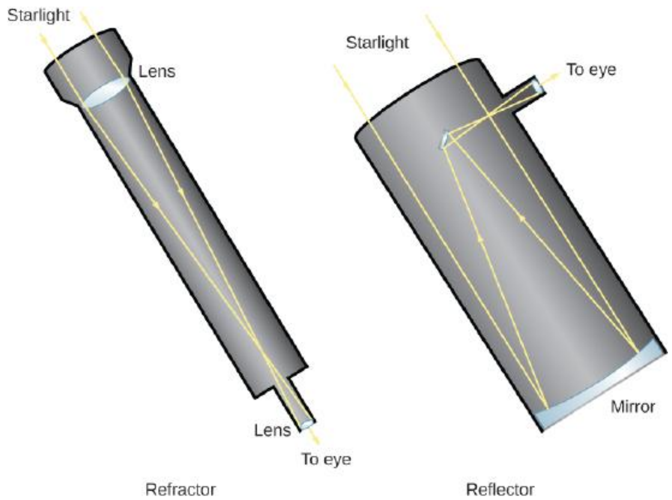
You may be familiar with the popular image of an astronomer squinting into an eyepiece to look at distant objects. However, modern professional astronomers do not really spend much time looking through eyepieces. They spend most of their time in front of a computer, looking at images or data on a screen. Modern observatories are computerized. Astronomers will book time for observations and enter the coordinates of the object(s) they want to view and the computer then positions the telescope where they want to look. Instead of an eyepiece, the images are focused onto a **charged couple device** (CCD) that converts the light waves into an electronic signal that computer processes. The CCDs used in telescopes are like those used in digital cameras and operate on the same principle.



A charged couple device.

https:/commons.wikimedia.org/wiki/File:CCD_Sensor_Sony_Video_Camera.jpg;

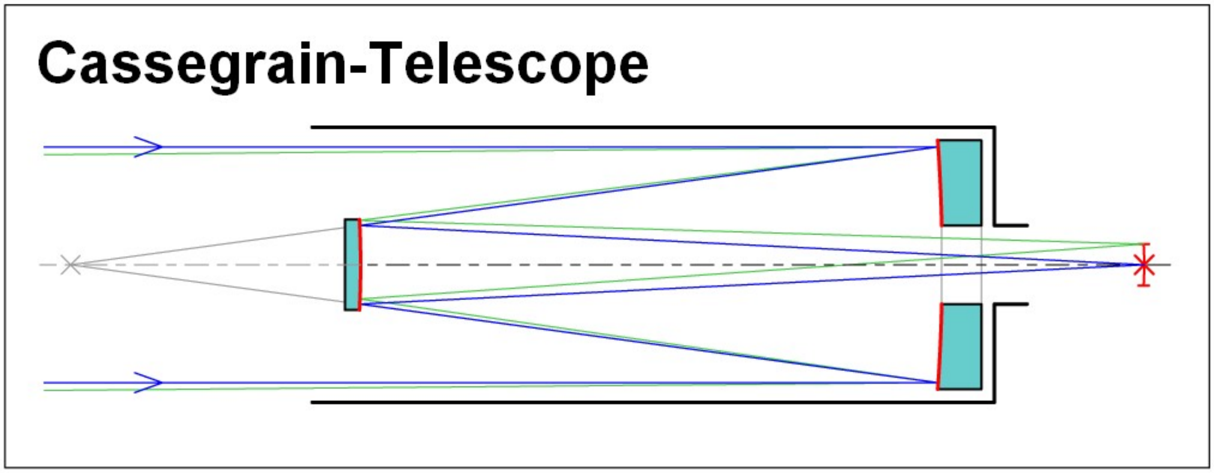
Isaac Newton invented the other major category of telescope, the **reflecting telescope**. Newton replaced the primary lens with a curved mirror made of metal. In a Newtonian reflector, light reflects off the mirror and is converged to the focal plane. However, before it reaches the focal plane, it encounters a second mirror at a forty-five-degree angle. This redirects the light into an eyepiece on the side of the telescope. The second mirror does limit some of the light that can reach the primary mirror, but this is compensated with a greater **light-gathering power** or "light bucket."



A refracting (right) and reflecting (left) telescopes.

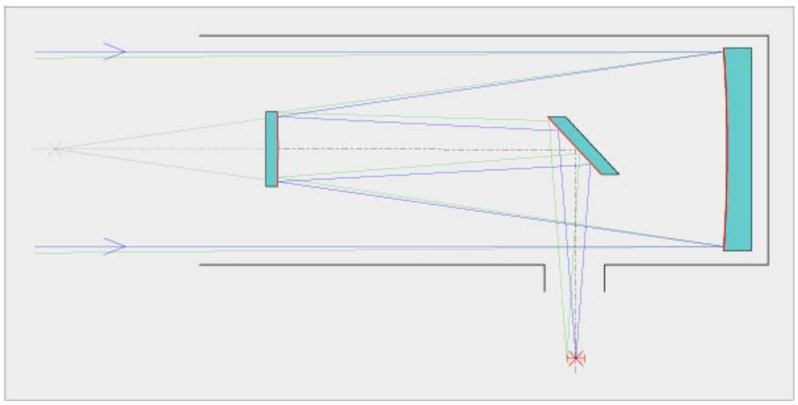
https:/commons.wikimedia.org/wiki/File:OpenStax_Astronomy_refracting_and_reflecting_telescopes.jpg;

Because many people found the side mounted eyepiece awkward, an alternative to the Newtonian reflector, the Cassegrain reflector. Instead of reflecting the image off to the side, the secondary mirror in a Cassegrain telescope focuses the light back down through a hole in the primary mirror. A third reflecting telescope design, the Nasmyth, using three mirrors to refocus the light and divert out the side to an image processing or coudé room. Some large telescopes may include both a Cassegrain and Nasmyth configuration.



A Cassegrain Telescope.

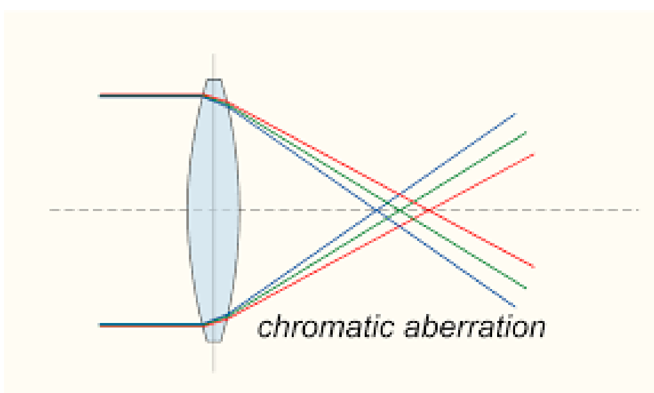
https:/commons.wikimedia.org/wiki/File:Cassegrain-Telescope.jpg;



A Nasmyth Telescope.

https://commons.wikimedia.org/wiki/F...-Telescope.svg

All modern large telescopes are reflectors, either Cassegrain, Nasmyth, or a combination. This is because of several limitations of refracting telescopes. One is chromatic aberration, which is caused by the fact that light of different wavelengths is bent at slightly different angles. This is how a prism separates white light into its component colors. **Chromatic aberration** results in a rainbow-colored halo around certain objects. Another limitation with refractors is spherical aberration, which creates distortions in the shape of the object. Newton's desire to eliminate chromatic and spherical aberration led to his invention of the Newtonian reflector.



https://en.wikipedia.org/wiki/Chroma...ns_diagram.svg

However, the biggest limitations of refractors result from the glass of the lens itself. Glass absorbs some of the light passing through it, which limits its light bucket. In contrast, reflector focuses nearly all the incident light. A glass lens must have two perfectly polished sides, while a mirror only requires one. Most importantly, however, is the fact that a lens can only be supported around the edges. This causes “lens sag” in which the lens sags under its own weight. This puts an upper limit on how large a lens can be and thus limits its light bucket. A mirror can be supported across its entire back, giving it a much larger light-gathering power. Many major observatories even employ a primary mirror made up of several circular or hexagonal mirrors, enabling an even larger light-gathering power.

The larger the lens or mirror diameter, the greater the light gathering area. The largest optical telescopes today have a mirror with a diameter of about 10 meters, though some can increase its overall light gathering area by employing multiple mirrors of up to 10 meters.

The two important properties of a telescope are light-gathering power (light bucket) and **resolving power**. Light bucket improves out ability to see distant or faint objects and is proportional to the square of the radius of the primary mirror. Resolving power measures the ability of a telescope to distinguish objects that are close together. Most commonly, it is expressed as angular resolution, which is the minimum angular separation that the telescope can distinguish. The smaller the resolution, the better it can distinguish between close objects. Resolution is proportional to wavelength and inversely proportional to the size of the mirror. Larger telescopes have better resolution because of less interference of the light waves. Too much interference can produce rings around an image of a star. The limit on resolution is also referred to as the telescope’s **diffraction limit**. Thus, but light-gather power and resolution improve with the size of the telescope.

What may surprise some people is that magnification is the least important property of a telescope. Computer processing can enlarge and sharpen image, reducing the need for the image to be made larger on the telescope’s focal plane.

So, what do astronomers use telescopes for? Obviously, they use them for imaging, takin pictures of objects in the sky. Because the images processed by computers, they are filtered through detectors the record only one color of light at a time. The computer then combines several images to make a full-color images. Astronomical detectors can also record forms of light that is invisible to our eyes, such as infrared. In such images, the computer produces a false-color image where it assigns different colors of visible light to represent invisible wavelength.

Astronomers also use telescopes for spectroscopy (Chapter 4). By breaking light into spectrum, astronomers can identify absorption and emissions lines as well use the peak brightness to determine the temperature of the object. By graphing the relative brightness of light at differing wavelengths, astronomers can study details of the spectrum. Using the Doppler effect, astronomers can measure the movement of an object and its rotational velocity.

Finally, astronomers can also perform time monitoring to measure how the light output of an object can vary with time. By plotting brightness measurements over a period, astronomers can study the behavior of stars and even detect exoplanets (Chapter 16) by looking for dips in brightness or subtle Doppler shifts in its light output.

5.2: High-Resolution Astronomy

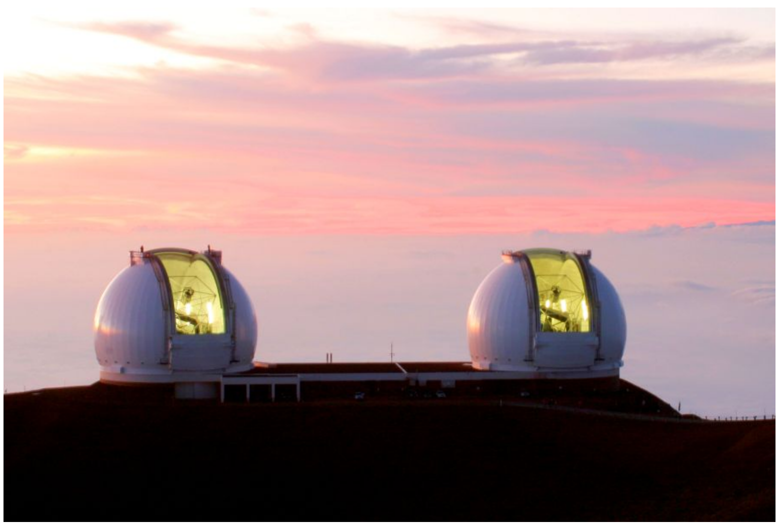
The atmosphere is the bane of astronomers. Cloudy nights, temperature variations, and wind currents create distortions that limit the overall resolution of a telescope. On top of that, they must contend with light pollution from nearby cities which limit their light-gathering power.

One solution is to put telescopes in space. Indeed, for wavelengths that do not penetrate the atmosphere, such as ultraviolet, x-rays, and some infrared frequencies, that is the only way to make observations in those bands. However, launching a telescope is expensive and subject to delays. Also, with the retirement of the space shuttle, servicing and maintaining space-based telescopes is difficult. We will talk about space-based telescopes in Section 5.3, but for now, we will talk about ways to improve resolution for ground-based astronomy.

Following the old real estate maxim of "location, location, location," one way to improve telescope resolution is by choosing a good location. The ideal location should be a place that is:

1. calm (not too windy)
2. high (less atmosphere to see through)
3. dark (far from city lights)
4. dry (few cloudy nights)

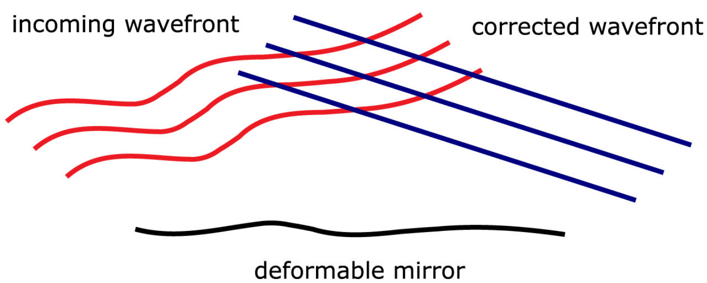
The best observing sites are atop remote mountains, especially in desert regions. In the Northern Hemisphere, one popular location is Mount Mauna Kea, the tallest mountain in Hawaii. High above the cloud layer Mauna Kea affords an excellent location for seeing and researchers from several countries have built observatories there. In the Southern hemisphere, several nations have built observatories in the Atacama Desert in Chile, a mountainous region and one of the driest places on Earth.



The Keck Observatory in Hawaii

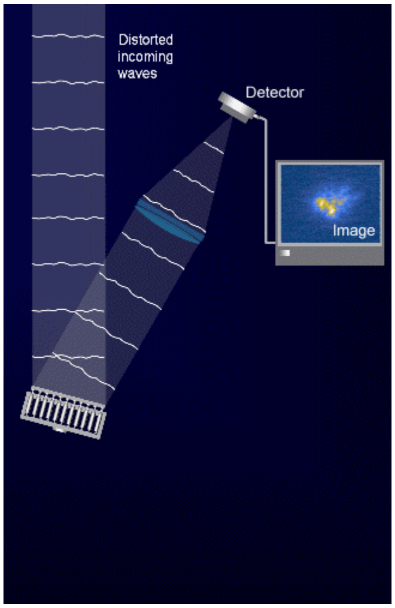
https:/commons.wikimedia.org/wiki/File:KeckObservatory20071020.jpg;

Even at these elevations, some atmospheric distortion is still inevitable. To contend with this, astronomers at the Keck Observatory in Mauna Kea have perfected the use of **adaptive optics**. By focusing on a bright star close to the object they wish to observe, computers operating tiny motors distort the mirror to perform real-time corrections to compensate for atmospheric distortion. If no convenient bright can be found near the object of interest, astronomers can use lasers to excite sodium atoms in the upper atmosphere to create artificial guide stars to calibrate their mirror distortions. Modern adaptive optics techniques have been able to produce resolutions equal to or even greater than that achieved by the orbiting Hubble Telescope.



A Deformable mirror can be used to correct for atmospheric distortion.

https://commons.wikimedia.org/wiki/F...correction.svg

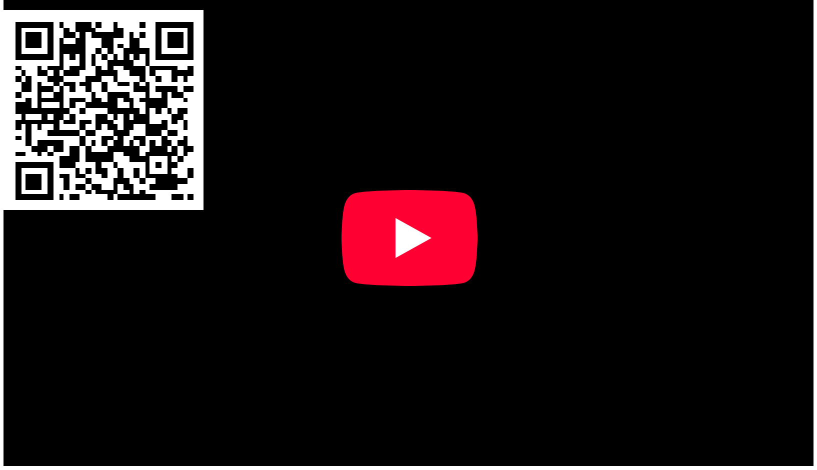


Principle of Adaptive Optics.

https://www.eso.org/sci/facilities/eelt/owl/FAQs.html


The Extremely Large Telescope is designed to use adaptive optics.

https:/commons.wikimedia.org/wiki/File:ELT_adaptive_optics_(34873921940).jpg;



5.3: Radio Astronomy

National Radio Astronomy Observatory Very Large Array Telescope (VLA).

https:/commons.wikimedia.org/wiki/File:National_Radio_Astronomy_Observatory_Very_Large_Array_Telescope_(VLA)_-_panoramio_(1).jpg;

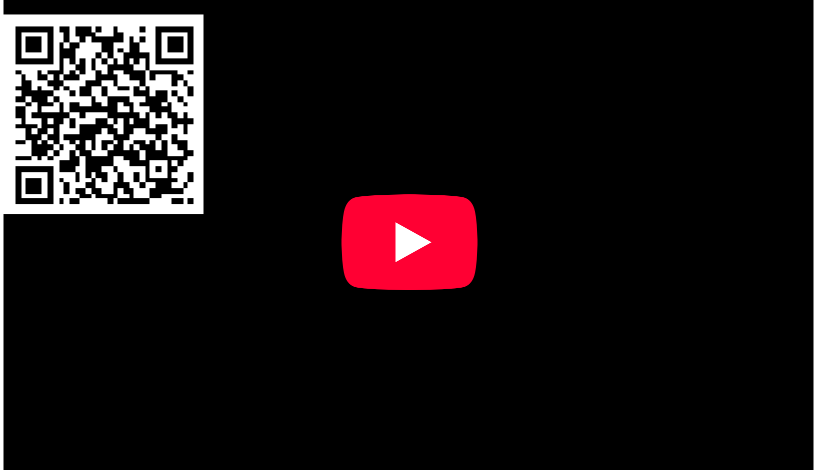
In 1930, Karl Jansky, an engineer working for Bell Labs, built the first radio telescope. Jansky used his invention to study radio emissions from the Milky Way Galaxy. His original telescope had wheels taken from a Model T Ford to make it mobile.

In many ways, a radio telescope operates on a similar principle as a reflecting telescope. It uses a curved dish to focus radio waves on to central point where a radio wave detector can convert those radio waves into an electronic signal. However, because of the longer wave lengths, radio dishes are more tolerant of imperfections and do not have to be polished to near perfection. Radio astronomy has a few advantages over optical telescopes. For example, radio telescopes can operate day and night, rain or shine. Clouds, rain, and snow do not interfere with the seeing of a radio telescope the way they do with optical telescopes. Observations on a different set of wavelengths also enables us to see features that would otherwise be invisible. Many objects emit radio signals but either do not emit visible light or their light is scattered by interstellar clouds of dust.

The longer wavelengths, however, do result in lower quality in resolution combined to visible light. This can be overcome by using **interferometry**, which involves using multiple radio telescopes examining the same signals. By combing the information from several widely separated radio telescopes, scientists can achieve a resolution equal to that of a telescope with a diameter equal to the largest separation between two dishes. Interferometry works by preserving the phase difference between the waves based on the separation of two or more dishes. This technique can achieve resolution close to that of optical telescopes. We can perform interferometry using optical telescopes, but the shorter wavelengths make it more difficult.

ALMA: The Atacama Large Millimeter/Submillimeter Array uses multiple radio dishes to improve resolution through interferometry.

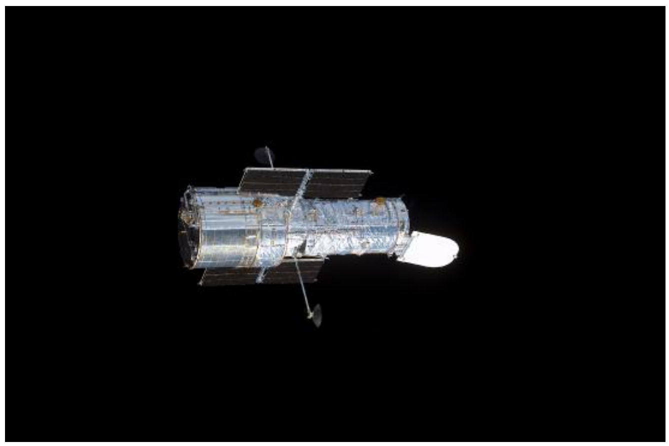
https:/commons.wikimedia.org/wiki/File:ALMA_-_Antennas_in_compact_configuration.jpg;



5.4: Space-Based Telescopes

5.4.1 The Hubble Space Telescope

By far, the most famous space-based telescope is the Hubble Space Telescope (HST). Launched in 1990, HST has given us some of the most memorable images of our universe. However, HST had a rocky start. After it was deployed, astronomers noticed that its primary mirror had a tiny flaw, about the width of a paint chip. This was enough to produce blurry images making what was at the time the most expensive satellite every launched, into a laughingstock. A servicing mission in 1993 enabled astronauts to fix this problem by installing some tiny mirrors to correct flaw, effectively giving HST glasses. HST has cameras on board that enable it to study in the visible, infrared, and ultraviolet areas of the spectrum. Between 1993 and 2011, several more servicing missions replaced worn out equipment and upgrade the telescope's systems. However, with the retirement of the space shuttle fleet in 2011, no further servicing missions are planned and eventually, it will be retired. While Hubble will be missed when it finally ceases to function, adaptive optics have enabled ground-based telescoped to match or even exceed the resolution of HST.



The Hubble Space Telescope

https://commons.wikimedia.org/wiki/F...e_in_space.jpg

5.4.2 The Kepler Telescope

In 2009, NASA launched the Kepler Telescope. Unlike the HST, which can be positioned to view almost any region of space, Kepler's initial mission kept it focused on a single region. During this mission, Kepler continuously monitored over five hundred thousand stars, collecting data and looking for the tell-tale drop in brightness in a star indicating an exoplanet transitioning across the face of the star. Over the course of its mission, Kepler helped detect nearly three thousand exoplanets. In 2013, the second of four flywheels that helped keep Kepler focused on its region of space failed, ending its primary mission. A secondary mission, dubbed K2, began and Kepler continued aiding in the search for exoplanets until the telescope was finally retired in 2018.

The Kepler Telescope.

https://picryl.com/media/arc-2006-ac...131-013-92885e

5.4.3 The Spitzer Space Telescope

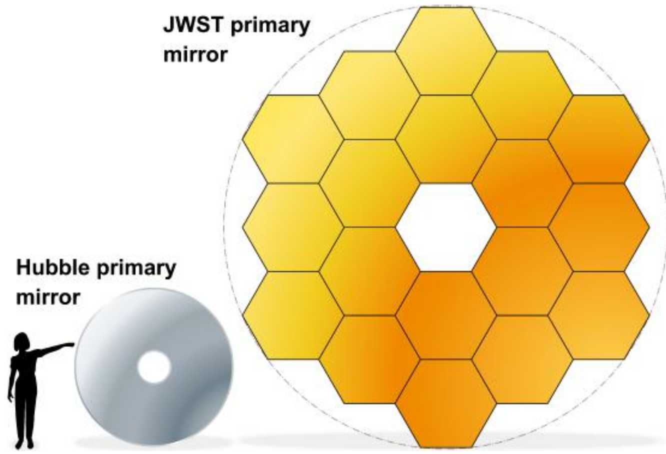
The Spitzer Space Telescope, launched in 2003, made observations in the infrared spectrum. Spitzer made numerous contributions to science. However, in May 2009, it ran out of liquid helium, which kept the telescope cold enough to operate. Without the coolant, the telescope's own infrared emissions (Section 4.2) interfered with most of its instruments. That was not the end of Spitzer's mission, however, as scientist were still able to make observations in two short-wavelength areas that its detectors could utilize without interference. Spitzer continued operation until it was finally retired in January 2020.

5.4.4 The Gaia Space Telescope

In 2013, the European Space Agency launched the Gaia Telescope. Gaia’s mission is to measure the positions of stars, nebula, and other objects in our galaxy to create the most comprehensive 3-dimensional map of the Milky Way. It is expected to continue operation until 2022.

5.4.5 The James Webb Telescope

The James Webb Telescope, the much-anticipated successor to the HST, will be the largest telescope ever put into space. An infrared telescope, James Webb will use a 9.5-meter, gold-plated composite hexagonal mirror. In contrast, HST has a 2.4-meter primary mirror. Unfortunately, James Webb has experienced several launch delays. After years of delay, the James Webb was launched in early 2022 and promises to open up a new era in space exploration.



Comparison of the HST mirror (left) and the James Webb mirror (right)

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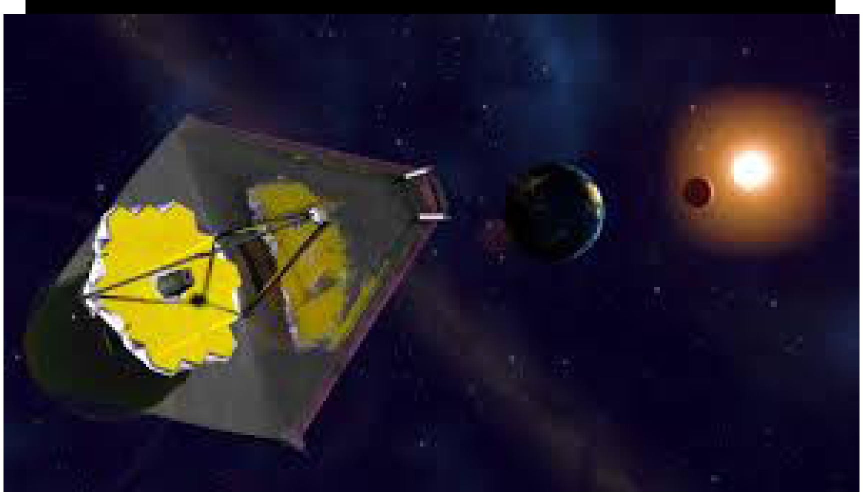


Artist's conception of the James Webb Space Telescope.

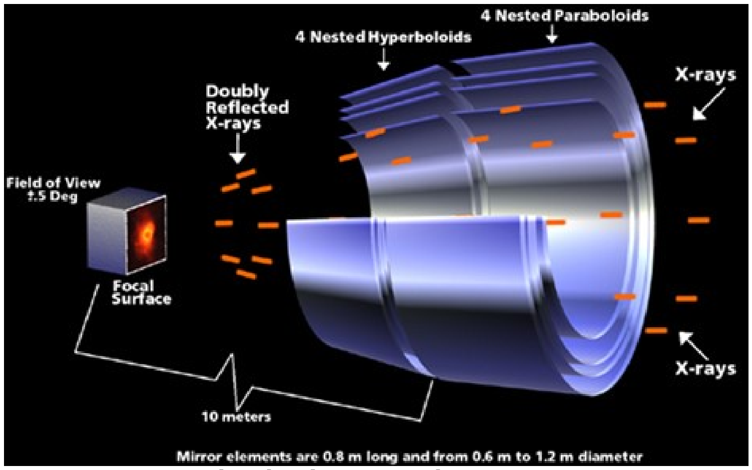
https://commons.wikimedia.org/wiki/F...742910940).jpg

5.4.6 The Nancy Grace Roman Space Telescope

Originally dubbed, the Wide Field Infrared Survey Telescope. (WFIRST) was renamed the Nancy Grace Roman Space Telescope on May 20, 2020, after the “mother of the Hubble.” With a 2.4-meter primary mirror, Roman will study dark energy and continue the search and study of exoplanets. Once operational, Roman will conduct a census of exoplanets around nearby stars and perform direct imaging of them. NASA plans to launch Roman in 2025.

5.4.7 X-ray and Gamma Ray Astronomy

X-ray and gamma ray astronomy provides an additional challenge as these high-frequency photons do not reflect off mirrors the way other wavelengths due. Instead, satellites like the Chandra X-ray observatory and the Fermi Gamma Ray Observatory focus these photons using a series of highly polished concentric conical mirrors. The incoming photons impact the inside of these cylinders at a shallow angle, which deflects them closer together. By passing through a series of narrowing cylinders, the x-rays and gammas rays can be focused. Scientists use these telescopes to study high energy sources of radiation, such as supernova remnants, neutron stars, and the accretion disks of black holes. NASA deployed the Chandra using the space shuttle Columbia in 1999 and the Fermi in 2008 using a Delta II rocket. Both continue operation today.



The Chandra X-Ray Observatory.

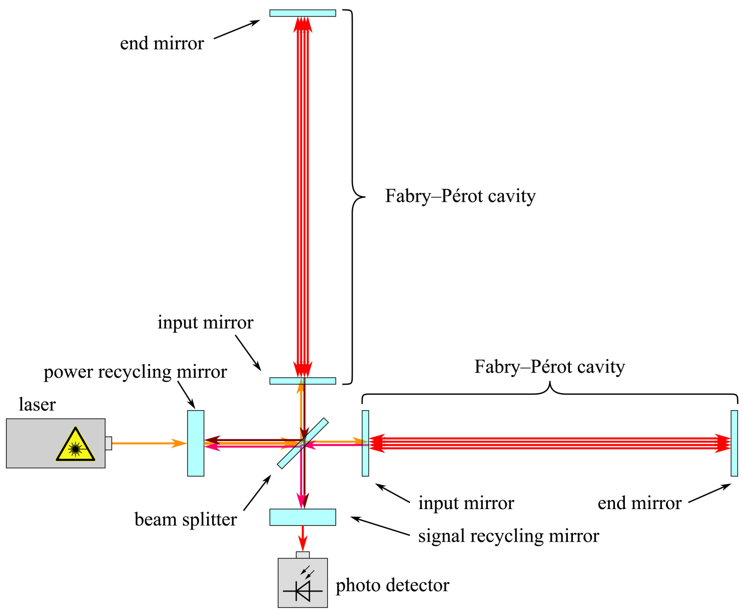
https://chandra.harvard.edu/resource...teleSchem.html

5.5: Other Methods of Studying Space

While electromagnetic radiation remains the most important tools for study planets and stars, scientists have additional tools that use other means to study space.

5.5.1 LIGO

The Laser-Interferometer Gravitational Wave Observatory (LIGO) uses to two lasers fired into an L-shaped configuration. Originally designed and built by Caltech and MIT, the two LIGO observatories are in Hanford, Washington and Livingston, Louisiana. By looking for minute deviations in the alignment of the two lasers at each site, LIGO can detect gravity waves. On February 11, 2016, the operators of LIGO published a paper reporting their first successful detection of gravity waves caused by the merger of two black holes 1.3 billion light years away.



LIGO uses two laser beams to detect gravity waves.

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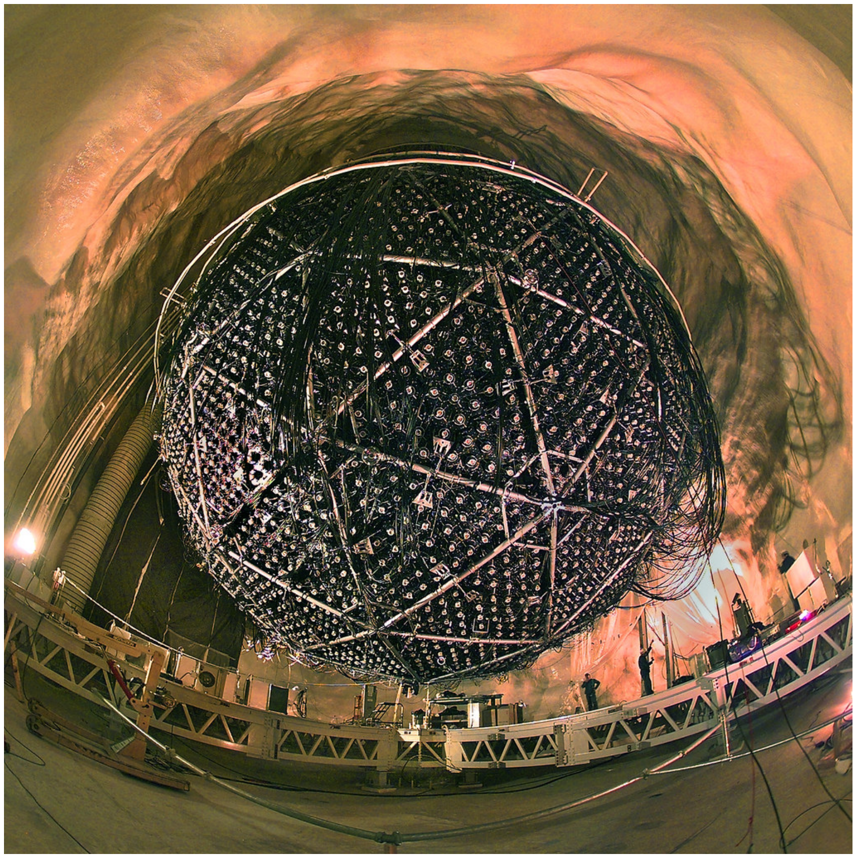
5.5.2 Neutrino Detectors

Nuclear fusion and other reactions produce tiny particles called neutrinos. Neutrinos, however, interact very weakly with matter. Billions pass through the Earth every second without interacting with a single atom. This weak interaction makes them hard to detect and neutrino detectors require a large field to detect even a single particle. A typical neutrino detector contains 1,000 tonnes of water or a fluid containing chlorine that must be continuously monitored for tiny flashes that could indicate a neutrino detection.

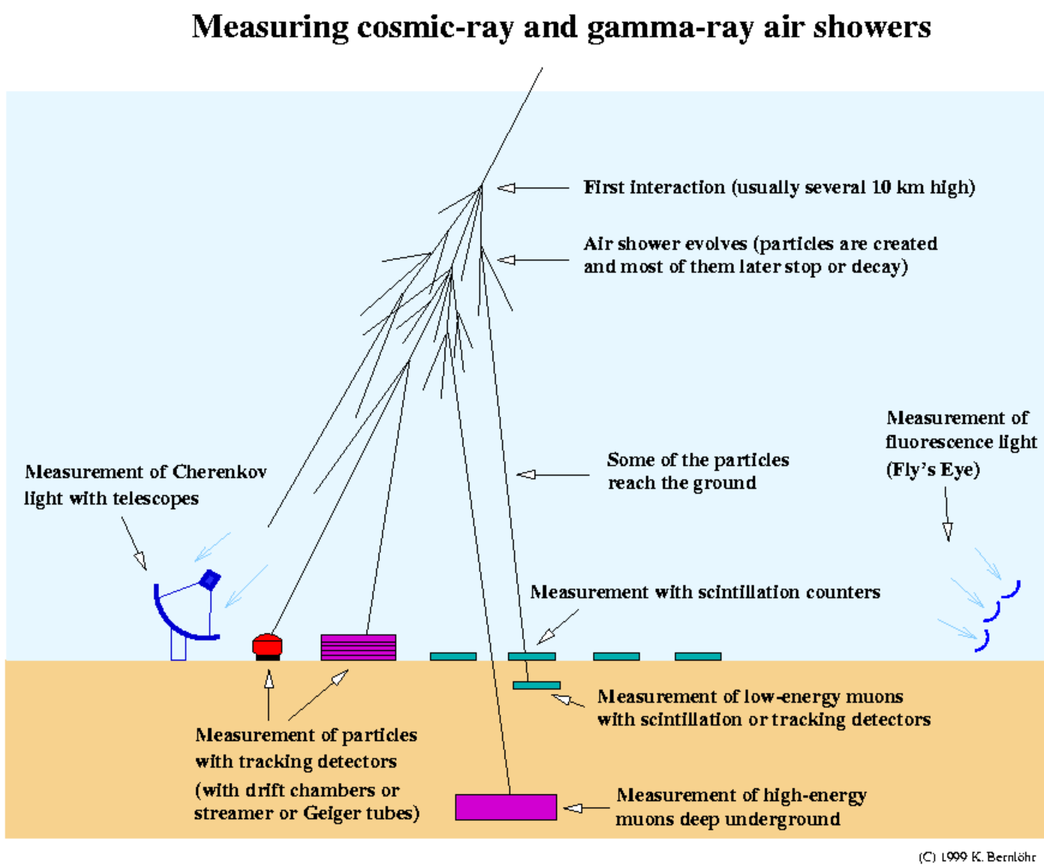


Sudbury Neutrino detector.

https:/www.flickr.com/photos/berkeleylab/2826495494;

5.5.3 Cosmic Rays

Cosmic rays, charged particles from deep space, can also be studied. Most cosmic ray detectors look for the “showers” of radiation that come from cosmic rays interacting with the upper atmosphere. Scientists also use space-based detectors, such as those on board the International Space Station, to study cosmic rays.



Cosmic Radiation Detection.

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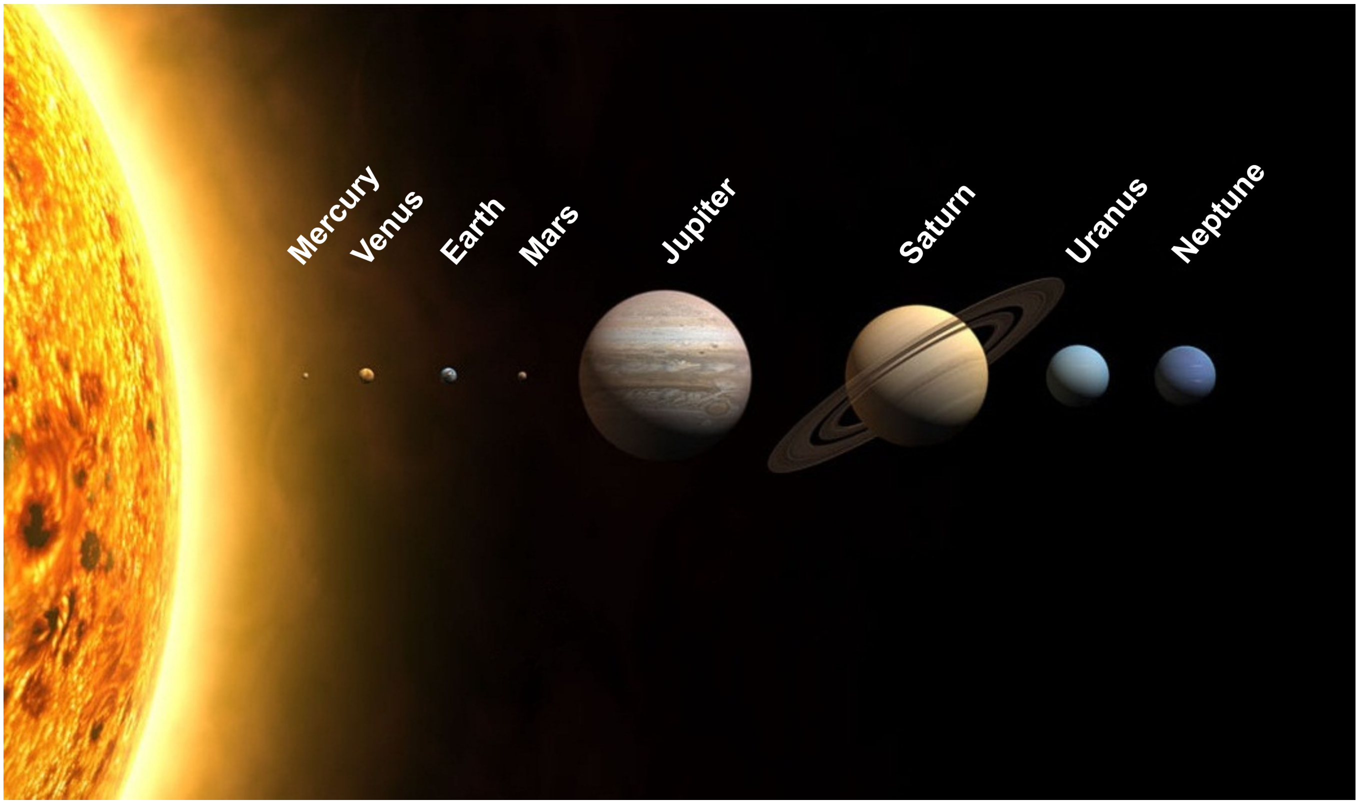
6: Solar System- Origin and Basics

Learning Objectives

- Take an inventory of the Solar System and its major bodies.
- Examine smaller bodies in the Solar System, including asteroids, meteoroids, and comets.
- Examine the Kuiper Belt and Beyond.
- Describe the origin and evolution of the Solar System.



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So far, we have discussed several ways we can study and learn about objects in our solar system.

1. We can determine the distance from Sun by Kepler's laws.
2. The orbital period can be observed by tracking its position in the sky.
3. The planet's radius can be determined from distance and from angular size.
4. We can use Newton's laws to determine a planet's mass.
5. Rotational period can also be known from observations.
6. Knowing radius and mass, we can calculate a planet's volume therefore, density.

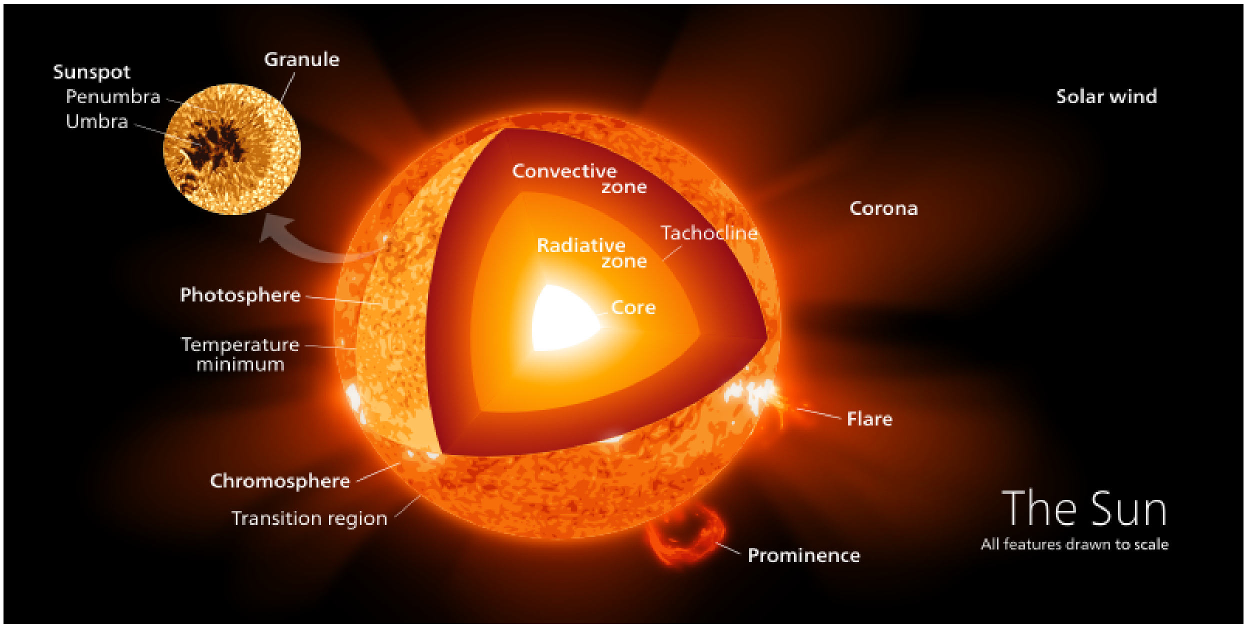
With this information, can start taking an inventory of the solar system. It contains one star, eight planets, over 200 moons, at least five dwarf planets, and numerous smaller bodies such as asteroids, meteoroids, Kuiper Belt objects, and comets. Of the eight planets, we can separate them into two categories, **Terrestrial (Earth-like) planets** and **Jovian (Jupiter-like) planets**. The solar system has four Terrestrial planets (Mercury, Venus, Earth, and Mars) and four Jovian planets (Jupiter, Saturn, Uranus, and Neptune). The table below compares several properties of Terrestrial and Jovian planets.

Terrestrial Planets	Jovian Planets

Orbit close to the Sun	Orbit further away from the Sun
Orbits are closely spaced	Orbits are farther apart
Predominantly rocky	Predominantly gaseous
Have small mass	Have large mass
Have small radii	Have large radii
Have high density	Have low density
Have few moons	Have numerous moons
Solid surface	No solid surface
Slow rotation	Fast rotation
Weak or no detectable magnetic fields	Strong magnetic fields
No rings	Several rings

6.1: A Tour of the Sun and the Planets

At the heart of the solar is the Sun, which contains over 99.9% of the solar system's mass. Though the Sun dominates our solar system, compared to many other stars in our galaxy, the Sun is rather small, a yellow dwarf among blue-white giants. The Sun is made mostly of hydrogen and helium in the form of ionized gas or plasma. Each second, as it fuses hydrogen into helium, the Sun converts over 4 million tons of its mass into energy.



The Sun and its interior.

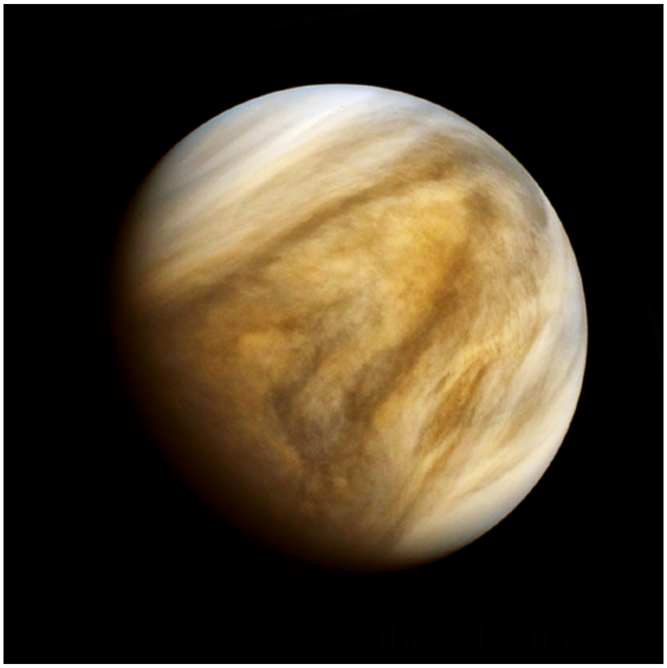
https://commons.wikimedia.org/wiki/F...Sun_poster.svg)

Tiny Mercury orbits closest to the Sun. The smallest of the eight planets, Mercury nonetheless has the largest core relative to its size. Mercury is also the most metallic of the Terrestrial planets. Billions of years ago, Mercury suffered numerous impacts from asteroids, giving it a heavily cratered surface like that of our Moon. Because it lacks a significant atmosphere, Mercury has a huge range in surface temperature, heating up from 425ºC during the day and then dropping to –150ºC at night.

Mercury.

https:/www.flickr.com/photos/ugordan/2231456684;

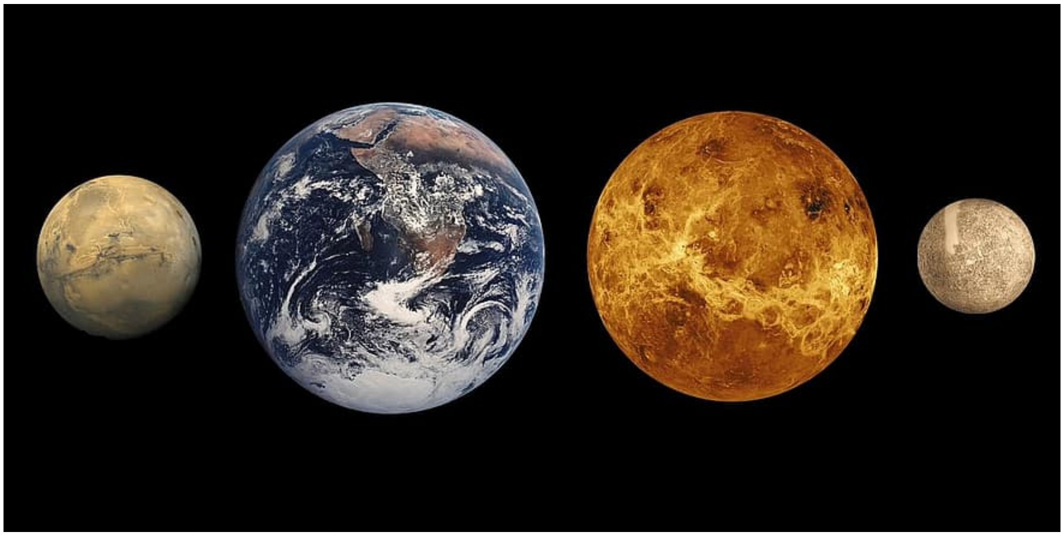
Second in orbit from the Sun, Venus initially appears to the most Earth-like planet in the solar system, being almost the same size and mass as the Earth. Its surface, though, remained hidden under a thick cloud layer giving it a high reflectivity, making it the third brightest object in our sky after the Sun and Moon. Despite its Earth-like size, however, Venus has a much different. With a super- dense atmosphere, the pressures on the surface of Venus are ninety times the atmospheric pressure at sea level on Earth. Its monstrously think atmosphere mostly contains carbon dioxide, giving it a runaway greenhouse effect, producing surface temperature high enough to melt lead. To make matters worse, it rains sulfuric acid. Named after the Roman goddess of love and beauty, Venus comes closest to our conception of Hell.



Venus.

https://commons.wikimedia.org/wiki/F...background.png

Third from the Sun is our own world. The Earth is often called the "Goldilocks planet." Not too hot and not too cold, the Earth serves as an oasis of life. Of the Terrestrial planet, only the Earth has the right conditions for liquid water on its surface. The oceans cover about seventy percent of Earth's surface and the planet's poles are topped with ice caps. Earth also has the strongest magnetic field of the Terrestrial planets and has a unique atmosphere consisting mostly of nitrogen and oxygen. The Earth's most unique feature, however, may be its moon. No other planet has such a large moon in relation to its size.



The four planets of the inner Solar System: Mercury, Venus, Earth, and Mar.

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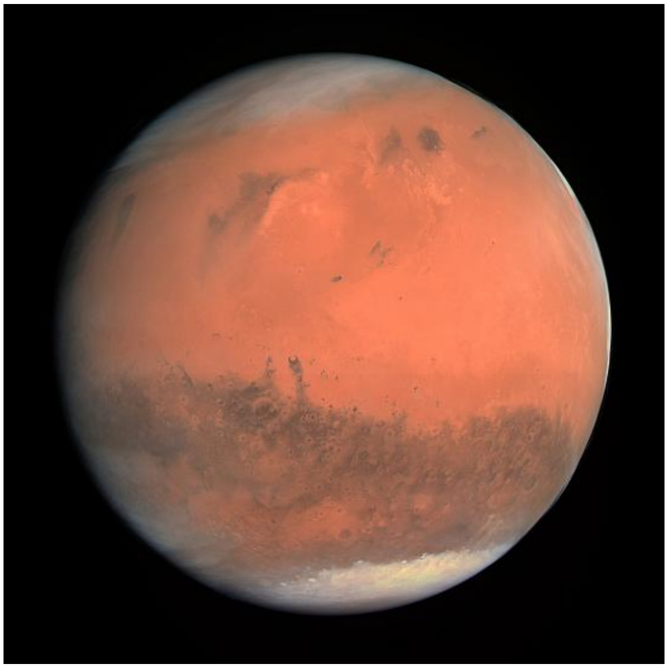
Mars, the red planet, may also appear Earth-like, however, it is a cold desert with an atmosphere too thin for liquid water to exist on the surface. Any water released onto its surface with either freeze or vaporize. A planet of extremes, Mars has the longest canyon and the tallest volcano in the solar system. Scientists have found evidence that Mars looked much different early in its history, when its atmosphere was thicker, liquid water may have flowed on its surface. This raises the question, could life have existed on Mars in the distant past.



Mars.

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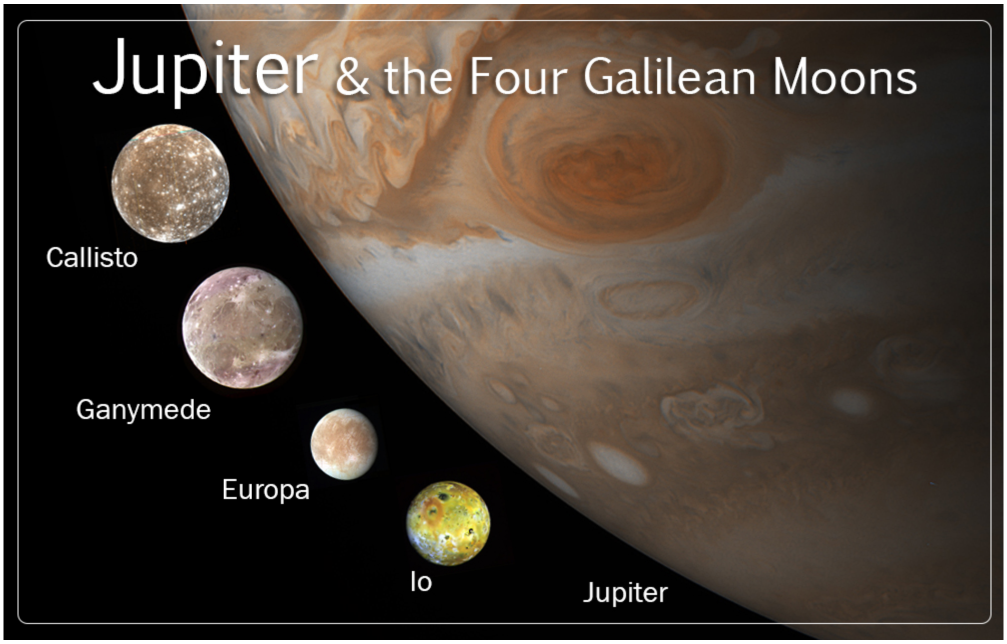
After Mars, we leave the Terrestrial planets behind and meet the largest of the Jovian worlds, Jupiter. Named after the king of the Roman gods, Jupiter is truly the king of the planets. Made mostly of hydrogen and helium and 300 times as massive as the Earth, Jupiter has numerous moons and several faint rings. The Galilean moons, named after their discoverer, Galileo, are the four largest of Jupiter's moons and each is a fascinating world its own right:

1. Io: the volcanically active body in the solar system

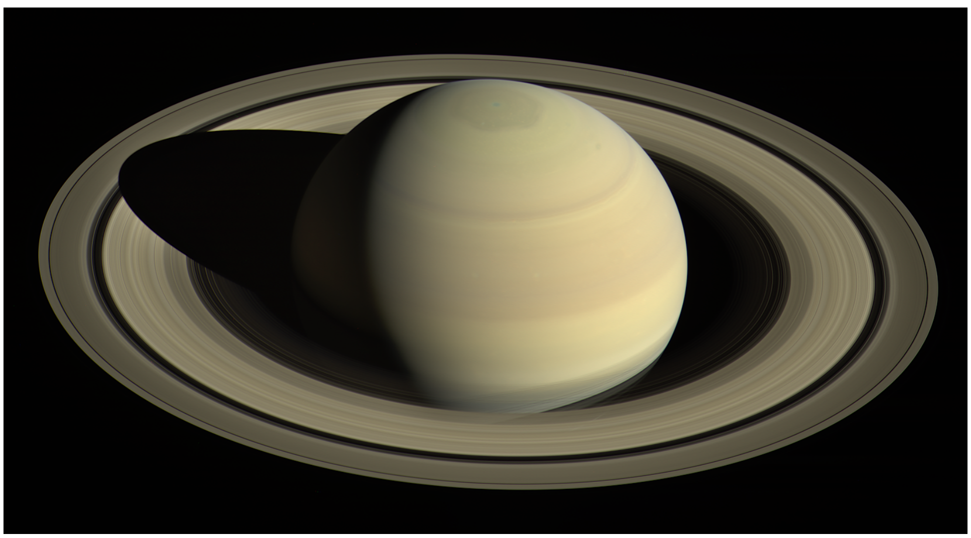
2. Europa: An ice ball that may have an ocean of liquid water beneath its surface.
3. Ganymede: The larges moon in the solar system.
4. Callisto: A big, cratered slush ball.



Jupiter and the Four Galilean Moons.

https:/commons.wikimedia.org/wiki/File:Galilean_Moons_Infographic_(16459663809).jpg;

People recognized Saturn instantly because of its brilliant ring system. Made of up particles of ice and rock, Saturn's rings orbit a planet a little smaller but similar in composition to Jupiter. Like Jupiter, Saturn has numerous moons, including Titan, the only moon with a thick atmosphere. Beneath Titan's hazy atmosphere lie lakes of liquid methane and cryovolcanoes, volcanoes that would freeze your hand if you stuck it into their flow.

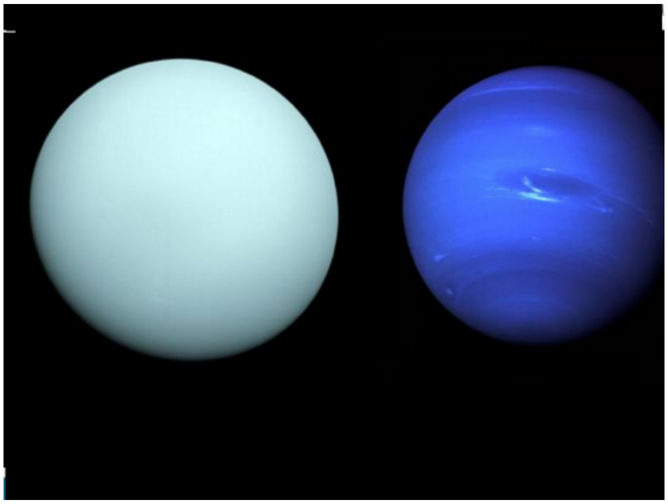


Saturn.

https://commons.wikimedia.org/wiki/F...612580000).png

Passing Saturn, we leave behind all the planets known to the ancient people and that are visible to the naked. Astronomers only discovered the final two planets in relatively modern times. Uranus has the most extreme axial tilt of more than ninety degrees. It rolls along its orbit like a ball rolling around an ice rink. Like Jupiter and Saturn, Uranus contains mostly hydrogen and helium, but it also contains hydrogen compounds like methane, ammonia, and water. Astronomers call these compounds “ices” and sometimes refer to Uranus and Neptune “ice giants” to differentiate them from the larger gas giants, Jupiter and Saturn.

Other than its axial tilt, Neptune appears like Uranus in many ways. Both Uranus and Neptune have faint systems and numerous moons, the largest of which is Neptune’s Triton.



Uranus and Neptune.

https://commons.wikimedia.org/wiki/F...%26Neptune.png

Neptune marks the end of our known planets, but it is not the end of our solar system. Beyond Neptune orbits tiny Pluto and its five moons. Once classified as a planet, this ball of ice and frozen nitrogen received a demotion when astronomers discover that it did not orbit the Sun alone. Today, we know Pluto is one of numerous objects orbiting the Kuiper Belt. In 2006, astronomers reclassified Pluto as a dwarf planet. Other bodies they have labeled dwarf planets include fellow Kuiper belt objects with names like Makemake, Haumea, and Eris, as well as the asteroid Ceres.

Pluto.

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Dwarf Planet Candidates.

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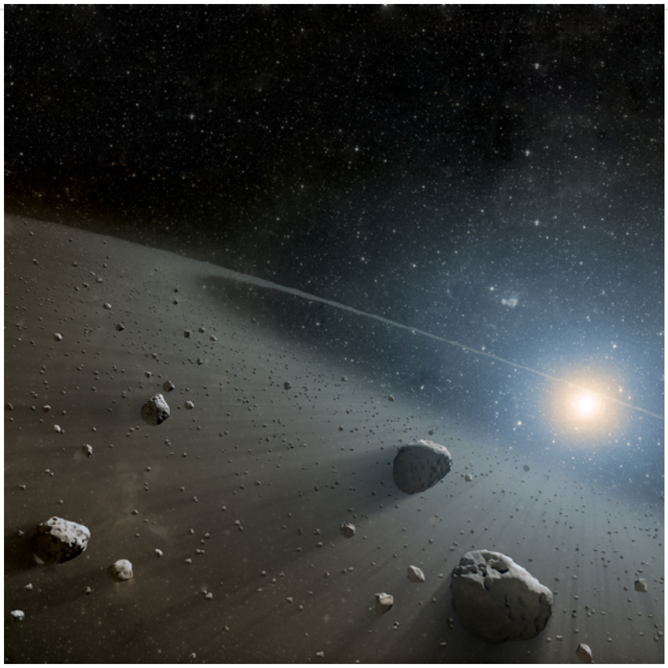
6.2: Asteroids and Meteoroids

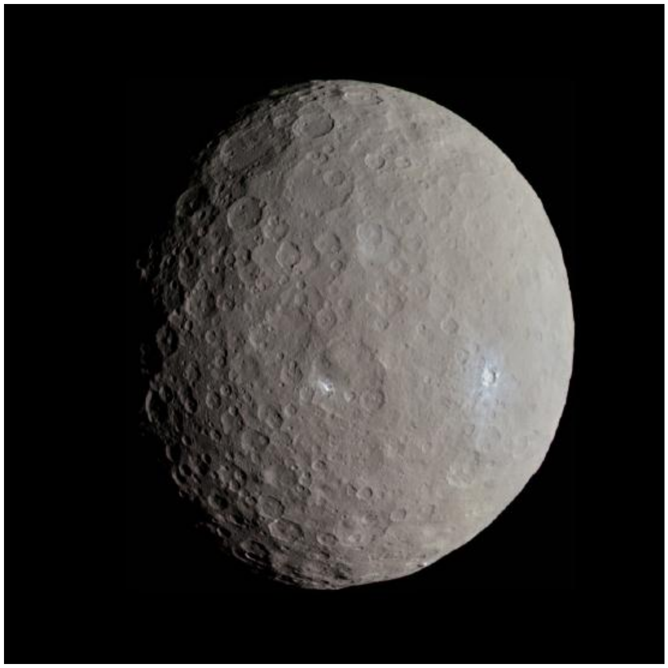


The Asteroid Belt.

https://commons.wikimedia.org/wiki/F..._landscape.png

6.2.1 Asteroids

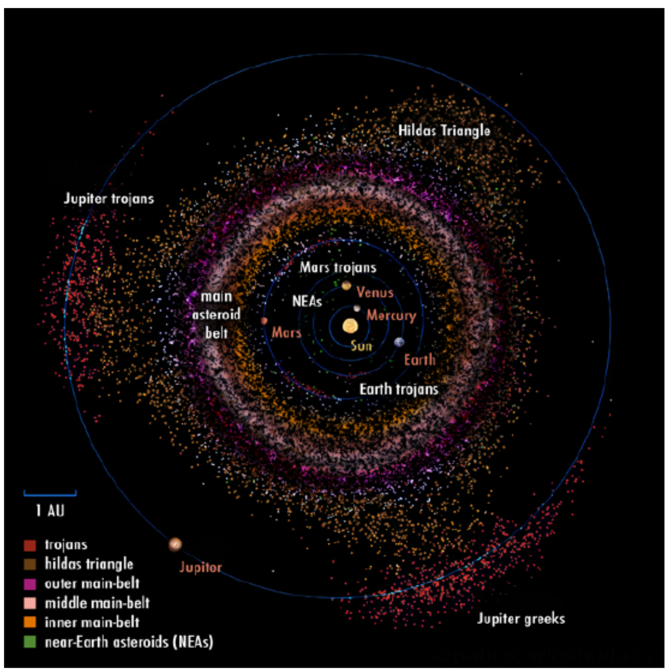
The average distance between planetary orbits gets bigger as we move out into the solar system. The distance between Mercury and Venus is less than the distance between Venus and Earth, which is less than the distance between Earth and Mars, and so on. However, astronomers noticed a gap in between the orbits of Mars and Jupiter that did not fit the pattern. Many were sure a planet must occupy this region. In 1801, Italian astronomer Giuseppe Piazzi discovered Ceres. Too small to be a planet, Ceres nonetheless fit the location where astronomers expected to find one. Eventually, astronomers found more and more small, rocky bodies, which they named **asteroids**, in what is now called the Asteroid Belt.



Ceres. Note the white patch on the right that could be exposed ice.

https:/commons.wikimedia.org/wiki/File:Ceres_-_RC3_-_Haulani_Crater_(22381131691).jpg;

The origin of the asteroid belt puzzled astronomers. Where they the remnants of a planet that had explode or was torn apart by Jupiter's massive gravity? It turns out, no. If you took all the asteroids and put them together into a single body, they would be smaller than our Moon. There just is not enough mass in the Asteroid belt to make up a planet. Instead, astronomers have concluded that, in the early days of the solar system, as the planets were forming, there was a race to gather as much as mass as possible. Jupiter got a head start and gobbled up much of the mass in that vicinity. Asteroids, then, are simply leftover debris that lacked enough mass to gather together into a single body.



The Asteroid Belt.

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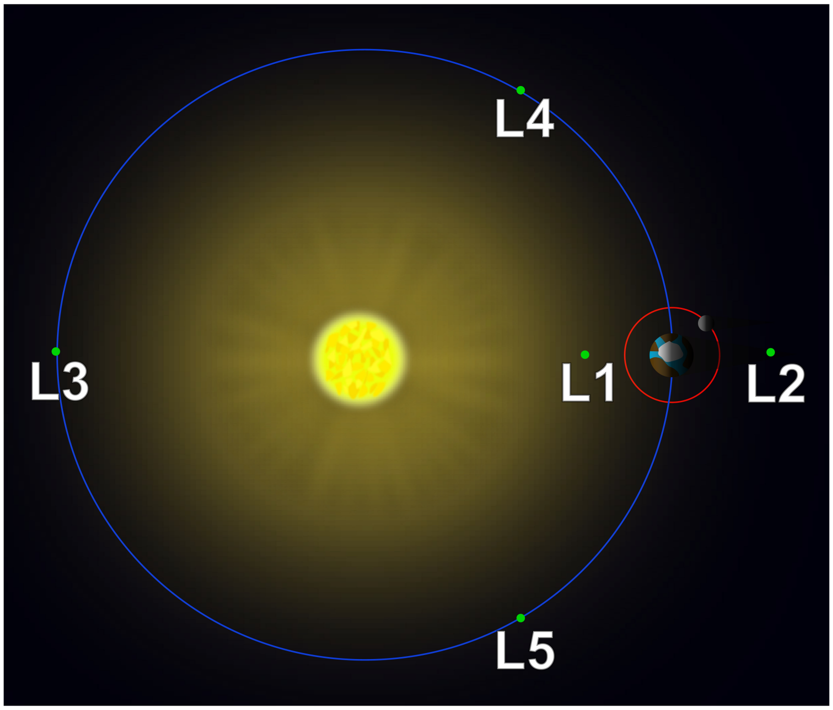


The Lagrange Points are islands of stability between the Sun and a planet where the gravitational forces are in balance.

https://commons.wikimedia.org/wiki/F...nts_simple.svg

You may have seen science fiction movies flying through an asteroid field, dodging rocks, right and left. This makes for exciting drama, but it is not an accurate reflection of the Asteroid Belt. If asteroids really orbited as close together as depicted in the movies, they would either collide and knock each other further apart or be pulled together into a single body. In reality, you could fly through the Asteroid Belt and never even see a single asteroid as the average distance between them is millions of kilometers.

Asteroids are classified by their composition as follows:

1. The C-type (chondrite) asteroids are most common, probably consist of clay and silicate rocks, and are dark in appearance. They are among the most ancient objects in the solar system.

2. The S-types ("stony") are made up of silicate materials and nickel-iron.

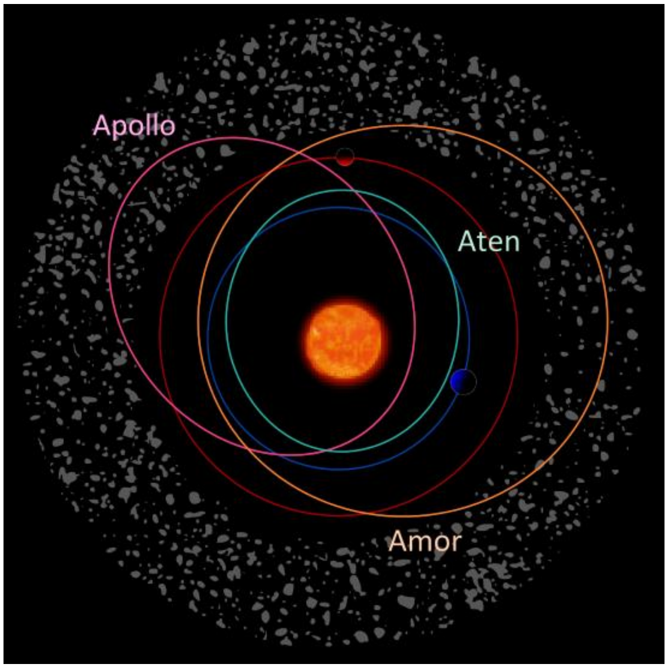
3. The M-types are metallic (nickel-iron). These were probably formed by impacts that heated the rocks and separated the metals into a core.

Many asteroids are known to contain ice and some, like Ceres, are large enough to self-gravitate into a sphere like planets. Many have also differentiated into a metallic core and a rocky crust, indicated that during formation, they had heated up to become molten. Others are fragments of larger bodies, that broke apart during collisions, such as metallic asteroids being former cores of much larger bodies. Some asteroids are solid while others little more than piles of rubble held together by their mutual gravity. Some asteroids even have moons, small asteroids bond to their gravitational pull.

Astronomers also discovered asteroids sharing Jupiter's orbit, both ahead and trailing behind the gas giant. These asteroids occupy the L4 and L5 **Lagrange points**. In any system in which a planet orbits a star (or a moon orbits a planet), there are certain points where the gravity of the two bodies balance out. Lagrange points form zones of stability. Place an object in a Lagrange point and it will orbit in such a way that it will maintain the same relative position with respect to the planet and the star. The L4 Lagrange point is in the planet's orbital path 60˚ ahead of planet and the L5 Lagrange point is located 60˚ behind the planet. The German astronomer Max Wolf discovered the first asteroid in Jupiter's L5 point and named it Achilles, after the hero of the Trojan War in Homer's Iliad. As a result, astronomers called these asteroids **Trojan Asteroids**. By convention, astronomers named asteroids in the L5 point after the Greek fighters and the asteroids in the L4 point after Trojan warriors. Often, astronomers refer to these asteroids as the Greek and Trojan camps, respectively.

Since the discovery of Jupiter's Trojan asteroids, astronomers have found similar asteroids in orbit in the L4 and L5 points of other planetary orbits, including the Sun-Mars Lagrange points and the Sun-Earth Lagrange points.

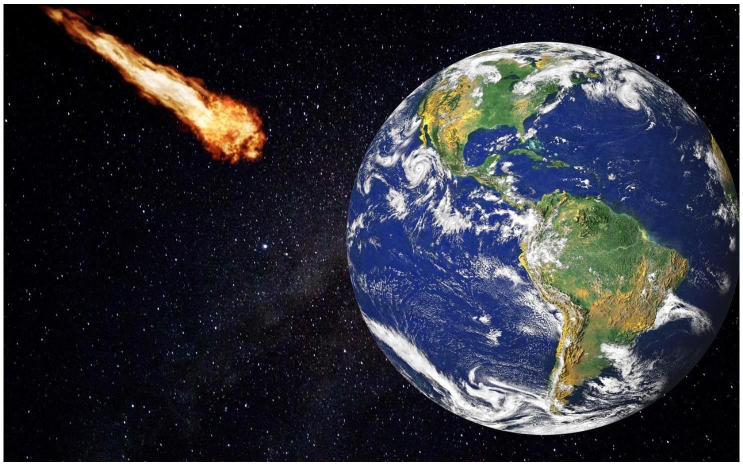
Other asteroids have more irregular orbits that take them into the inner solar system. Some cross Earth's orbit and astronomers refer to them as Earth-crossing or **Apollo asteroids**. One such asteroid hit the Earth 65 million years ago, ending the era of the dinosaurs. Because a similar collision today would cause a civilization-ending catastrophe, astronomers have begun searching for and tracking Apollo asteroids to determine if any have the potential of hitting the Earth any time in the near future.



Apollo and other Earth crossing asteroids.

https://commons.wikimedia.org/wiki/File:Neas.svg

If we do find an asteroid heading our way, what could we do? Again, Hollywood gives us the impression that perhaps blowing up the asteroid might work. Even an exploded asteroid could be devastating as all the debris would still be heading toward Earth. Indeed, it might make matters worse as the devastation would be spread out over a wider area. Instead, some scientists have suggested giving the asteroid a push to divert it away from the Earth. This could be done by hitting it with a projectile that would not blow up the asteroid, just give it a little nudge. Alternatively, laser could be used to ablate (vaporize) a side of the asteroid, using the escaping gasses to push the asteroid away, just like escaping gases use Newton's laws to propel a rocket (Section 3.5).



Asteroid approaching Earth.

https:/www.needpix.com/photo/1682066/asteroid-comet;

6.2.2 Meteoroids

Astronomers often call smaller rocky bodies **meteoroids**, although there is no hard rule on the difference between a small asteroid and a large meteoroid. If a meteoroid enters our atmosphere, it heats up, producing a streak of light we call a shooting star or a **meteor**. Any part of a meteor that does not burn up and impacts the ground is called a **meteorite**. Since meteorites are leftover rocky debris from the earliest days of our solar system's history, scientists often study them for clues about the origin of the solar system. Like asteroids, we classify meteorites by the composition:

1. Irons: "pure" iron-nickel
2. Stones: silicate or rocky material
3. Stoney-irons: mixture of metallic iron and rocky material

A meteor.

https:/commons.wikimedia.org/wiki/File:Leonid_Meteor.jpg;

A meteorite.

https:/commons.wikimedia.org/wiki/File:Murnpeowie_meteorite.jpg;

In contrast, a **meteor shower** occurs when numerous meteors fall through the sky at once. These come from comets have broken apart. As the Earth orbits the Sun, it passes through some of the debris fields leftover from the cometary remains, producing annual meteor showers. We name meteor showers after the constellation the meteors appear to radiate from. For example, the Leonid meteor shower appears in the constellation Leo and occurs in November while the Perseids (in the constellation Perseus) occur in late July-early August.

Gemind Meteor Shower.

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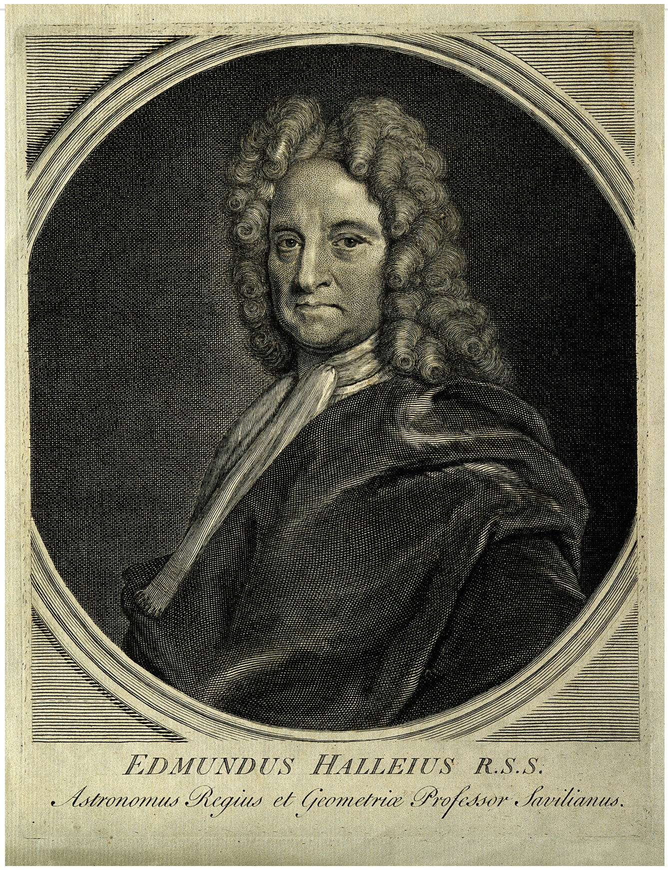
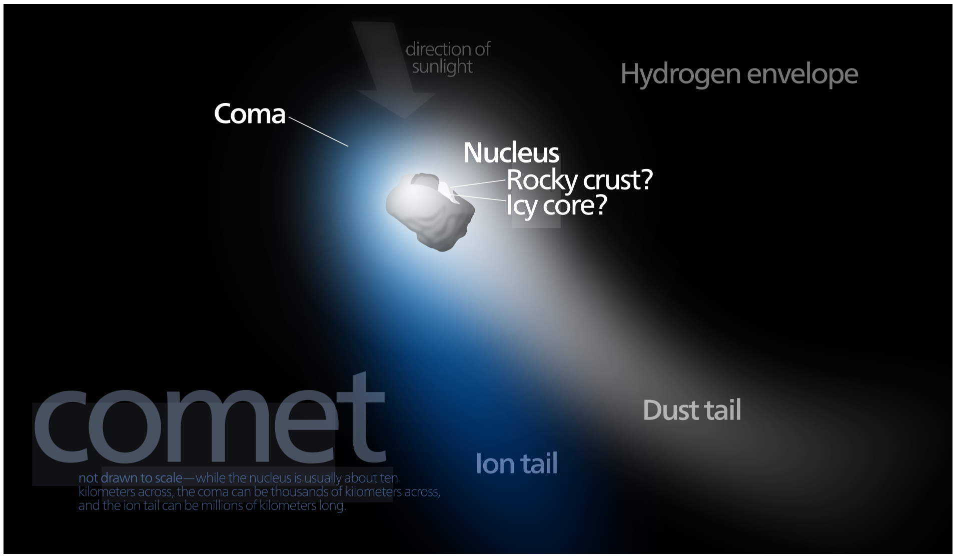
6.3: Comets



Edmund Halley.

https:/commons.wikimedia.org/wiki/File:Edmund_Halley._Line_engraving_after_R._Phillips._Wellcome_V0002535.jpg;)

Philosophers have debated the nature of comets for thousands of years. Some argued that they were an atmospheric phenomenon and were heavenly bodies like stars and planets. Many saw them as harbingers of doom or change. A comet appears in the First century, BCE just before the assassination of Julius Caesar. Another appears in 1066 before the Battle of Hastings where William the Conqueror defeated King Harold for the throne of England. China had records of cometary predictions going back millennia, but not until Edmond Halley successfully predicted the coming of the comet that now bears his name in the 18th century did astronomers in the West understand that comets return at regular intervals.



Comet.

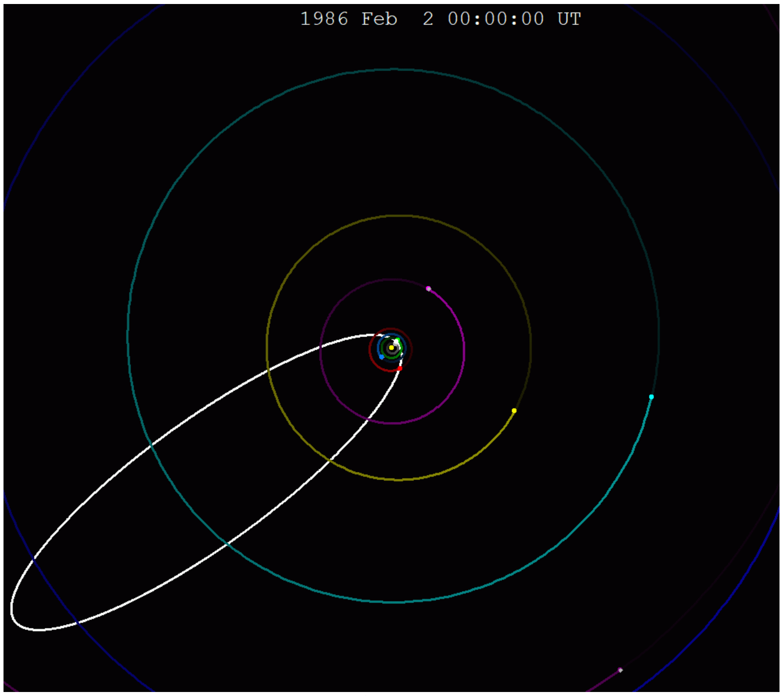
https://commons.wikimedia.org/wiki/File:Comet.svg

Astronomers sometimes call comets “dirty snowballs” because they are made of mostly ice and rock. They orbit the Sun in highly eccentric orbits. Astronomers classify comets short-period and long-period comets. Short-period comets have an orbital period of less than two hundred years while long-period comets have a period of greater than two hundred years.

Spending most of their time in the outer solar system, comets only acquire their signature tails as they approach perihelion. As comets approach the Sun, the Sun’s rays ablate the ice, creating a wispy atmosphere called a coma. Jets erupt from the surface, carrying the dust and gas away. The steady stream of charge particles and the pressure from sunlight push the gas and dust in the coma, giving the comet its characteristic tail. Comets actually have two tails, one of ionized gas and one of dust. The solar wind pushes out from the Sun, so the tails always point away from the Sun. However, the more massive dust particles resist the push of the solar wind, so the dust tail behind the ionized tail.

Since comets loss mass to ablation every perihelion, they eventually fade away. Some do not even last that long, such as Comet Shoemaker-Levy 9, which died spectacularly in 1994 by crashing into Jupiter. But if comets disappear over time, how can we still have comets over 4 billion years after the formation of the Solar System? The answer lay in the **Oort Cloud**, a swarm of cometary bodies in interstellar space that surrounds the Solar System between 2,000 and 200,000 AU from the Sun. Oort Cloud comets rarely enter the inner solar system. Gravitational encounters occasionally nudge a comet, causing it to fall into an elliptical orbit taking it closer to the Sun. Because the Oort Cloud surrounds the Solar System in a spherical swarm, cometary orbits can vary a lot in their size, shape, and orientation once they get nudged into an elliptical orbit.

As noted in the previous section, comets that break up in the inner Solar System are responsible for the meteor showers we see at different times throughout the year.



The orbit of Halley's Comet.

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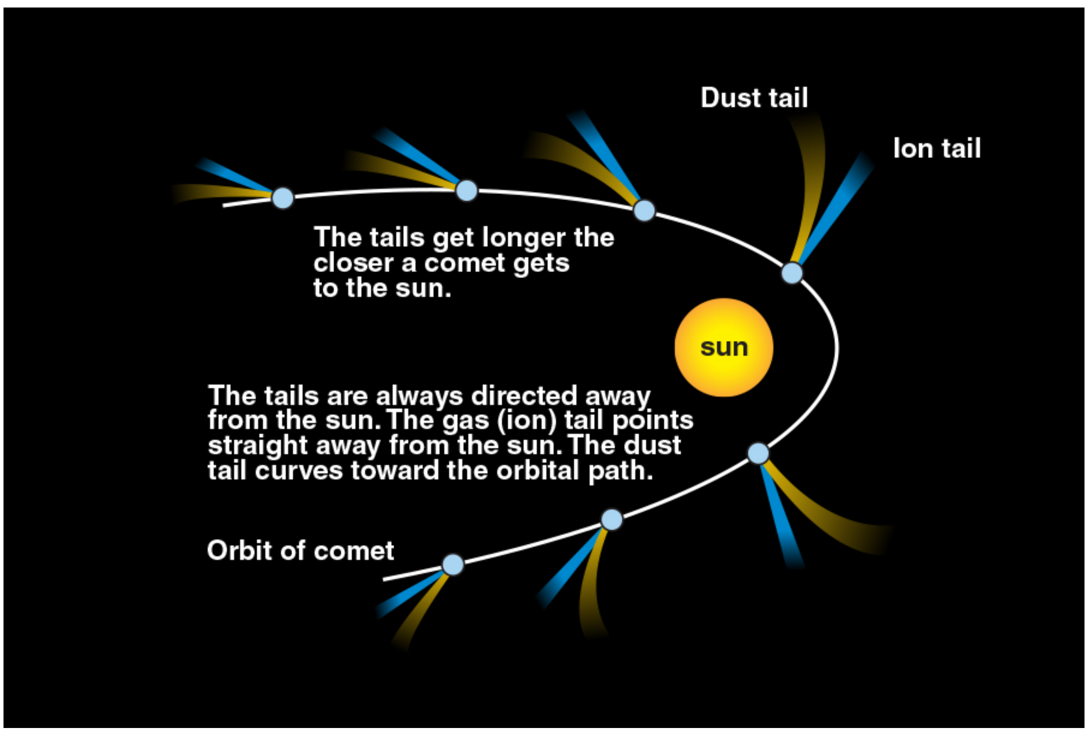

Comet tail diagram.

https:/commons.wikimedia.org/wiki/File:Comet_tail_diagram.jpg;

6.4: Origin of the Solar System

A young star with a disk of gas and dust that may form into a planetary system one day.

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Where did it all come from? That is a question that philosophers and astronomers have pondered for thousands of years. While cannot rewind time and watch the formation of the Solar System form the beginning, we can look at the Solar System as it is today for clues as to its origins. From that, we can develop a model to describe how it may have gotten that way. Any model for the origin of the Solar System must be consistent with the laws of physics as first described by Isaac Newton and later expanded by Albert Einstein with his theory of general and special relativity.

A theory on the origin of the Solar System must also be able to account for what we can observe today. Some observations that we can make about the Solar System include the following:

Mass

The Sun contains over 99% of the Solar System's mass while the planets contribute only about 0.2%

Angular Momentum

In contracts, planets have most of the Solar System's angular momentum.

Patterns of Motion

All the planets orbit the Sun in the same direction and in roughly the same plane. All of them are inclined less than 10 degrees from the ecliptic with Mercury having the greatest inclination. In contrast, the dwarf planets like Pluto and Eris have much more tilted orbits, at 17 and 44 degrees to the ecliptic, respectively. Also, the Sun's rotational equator lies very close the ecliptic. The planets all orbit the Sun in the same west-to-east direction, called prograde revolution and the Sun also rotates in the same prograde direction. Also, except for Venus and Uranus, the planets also rotate in the prograde direction. The planets also have small obliquity, the tilt between equatorial and orbital planes, with Uranus again being the exception. The planetary orbits are also nearly circular.

Two Types of Planets

As we noted, planets are either rocky terrestrial bodies or gaseous Jovian worlds. Their distribution varies roughly with their distance from the Sun with the dense-metal-rich terrestrial planets in the inner system and the giant, hydrogen-right planets in the outer system. The distances between the planets roughly conform to a simple rule, called **Bode's Rule**, which states the planets have a geometry spacing between their orbits. Mercury, the inner-most planet, has the highest metal composition, followed by the three more rocky planets, Venus, Earth, and Mars. Then, asteroids occupy a strange gap in the planetary distribution. After the asteroids, come Jupiter and Saturn, two planets made mostly of hydrogen and helium. Next come Uranus and Neptune, similar to the other Jovian planets, but with more hydrogen compounds like methane and ammonia, giving them a blue or greenish blue hue. Beyond Neptune, we have the Kuiper belt full of small icy bodies and even more such bodies beyond until we head into interstellar space and the Oort cloud beyond.

The Jovian planets also have numerous moons, making them appear to be miniature versions of the Solar System while the terrestrial planets have relatively few moons.

Craters

Many bodies, especially those that have little or no erosion or plate tectonics, like Mercury and the Moon, show evidence of numerous impacts. These impacts have left craters behind and our dating of the craters of the Moon indicate that the majority of these impacts occurred within the first few hundred million years of the Solar System's history.

Asteroids and Comets

Examination of meteorites show that they differ in geological properties from all known planetary and lunar rocks. As for comets, most of them orbit in a large, almost spherical swarm around the Solar System called the Oort cloud. Kuiper belt objects resemble comets in their composition.

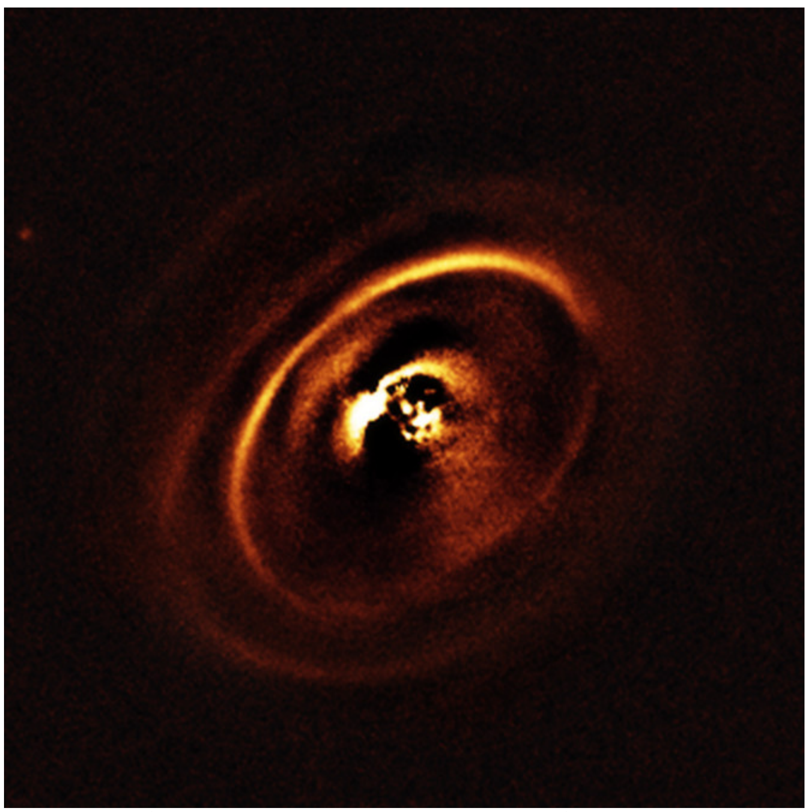
The Exceptions

Finally, our model of the Solar System must also account for the anomalies that we observe, such as Earth's large Moon, Venus' retrograde motion, and Uranus' extreme axial tilt.

Overall, the universe is mostly hydrogen and helium, however, the terrestrial planets, including the Earth, are mostly made of heavier elements. Where did those heavier elements come from? Massive stars can fuse hydrogen and helium in heavier elements such as oxygen, carbon, nitrogen, silicon, etc. However, even the most massive stars cannot fuse atoms inside their cores into elements heavier than iron. Those elements can only be formed in the supernova explosions that mark the death of the most massive stars. These elements where then hurled into space by the force of the supernovae. Eventually, they coalesced into **nebulae** (Latin for clouds) made up of hydrogen, helium, and dust particles.

6.5.1 Nebular Theory

According to **nebular theory**, one of these clouds began to contract. The cause of this contraction is unclear, but perhaps it was force of a dying star going supernova that pushed the cloud into contracting. Kant and Laplace first proposed the nebular collapse theory over two centuries ago and since then, astronomers have found a great deal of evidence to support it. For example, we can see young stars forming in massive nebulae like such as the Eagle Nebula. In addition, we can see that the star Beta Pictoris has a disc of warm matter surrounding it, which may indicate early planetary formation.



This image of the star Beta Pictoris shows evidence of a protoplanetary disk.

https:/commons.wikimedia.org/wiki/File:Protoplanetary_disk_of_RX_J1615_(eso1640b).jpg;

As the cloud collapses, it must speed up due to conservation of angular momentum (Chapter 3). Just as a skate can start herself rotating slowly with her arms fully extended and then speed herself up by bringing her arms into her body, a cloud will contract as it contracts further. Meanwhile, collisions between particles will cause cloud to flatten and form a disc around the early star. Collisions between gas particles will reduce random motions and up and down motions, resulting in flattening as the particles eventually settle into motions that orbit around the forming star. The material in the disc eventually forms into the planets. Initially, the early Sun rotated much faster than it does now, however, friction between its magnetic field and the nebula slowed it down.

Note that some astronomers had propose a rival theory to the nebular theory in which the planets formed from material torn off the surface of the Sun as it made a close encounter with another massive object. However, this encounter theory could not explain the motions of the planets and their distribution.

6.5.2 Formation of the Planets

The planets formed through condensation, which occurs when gas cools and forms tiny solid particles. These dust grains act as condensation nuclei. Temperature governs where particular materials condense out. Astronomers mark a boundary in the between where rocky particles condense and where icy particles condense the **frost line** or the **snow line**. Inside the snow line, where it is too hot for hydrogen compounds to form ices, the terrestrial planets form, with metals condense closer in, making Mercury the most metallic planet. Outside the frost line, the Jovian planets form from ice particles.

The small particles of rock and metal inside the snow line eventually start to clump together. Initially, friction between the particles creates electrostatic charges which cause the particles to stick together. Over time, some of these particles form larger bodies called planetesimals, which are large enough for gravity to take over the accretion process. Gravity also reshapes the bodies, forming them into spheres. Gravity pulls all matter toward an objects center of mass, so above a certain mass, all bodies take on a spherical shape. More smaller objects collect into a few large ones. As the planetesimal collided, their energy converted thermal energy, causing them melt. These hot molten bodies continue to gather the remaining mass in their orbital path, becoming the four terrestrial planets. As they become molten, the denser elements like iron and nickel sink into the center, forming the planetary cores.

Artist conception of a planet forming from the collision of smaller planetesimals.

https:/www.pikist.com/free-photo-iykto;

Meanwhile, outside the snow line, ices form the basis of the particles that accrete into planetesimals. A combination of photos and the solar wind (charged particles flowing out from the Sun) blew the lighter gases into the outer Solar system. The gravity of these larger planets pulled the hydrogen and helium together. Meanwhile, these large gas giants formed discs of their own which condensed into the moons of the Jovian planets.

Early in its history, the Earth was probably a ball of hot magma.

https:/www.pikist.com/search?q=Magma;

Like the terrestrial planets, the Jovian planets also underwent differentiation, forming rocky cores surrounded by gases ices. Jupiter won the race to gobble up the most matter, leaving only a small amount of debris in the asteroid belt marking the boundary between the inner and outer solar system. Uranus and Neptune, being further out and colder, could gather more ices than Jupiter and Saturn, giving them higher methane, ammonia, and water contents.

Leftover debris then formed into the asteroids and comets. Asteroids being closer in than the Jovian planets, could form out of both dust and ice. Some of them formed large enough bodies to undergo differentiation. Larger asteroids like Ceres, are spherical with metallic cores surrounded by ice and rock layers. Comets and the Kuiper Belt objects like Pluto, formed mostly from ices and frozen nitrogen, which smaller amounts of rock compared to the asteroids.

The early few million years of the Solar System had a lot more planetesimals that are present today. Perturbations from Jupiter's gravity disrupted them from their ordinary orbits and flung them into the inner solar system. Others were flung into the outer solar system, colliding with the moons of the Jovian planets or being gobbled up by the gas giants themselves. This **Late Heavy**

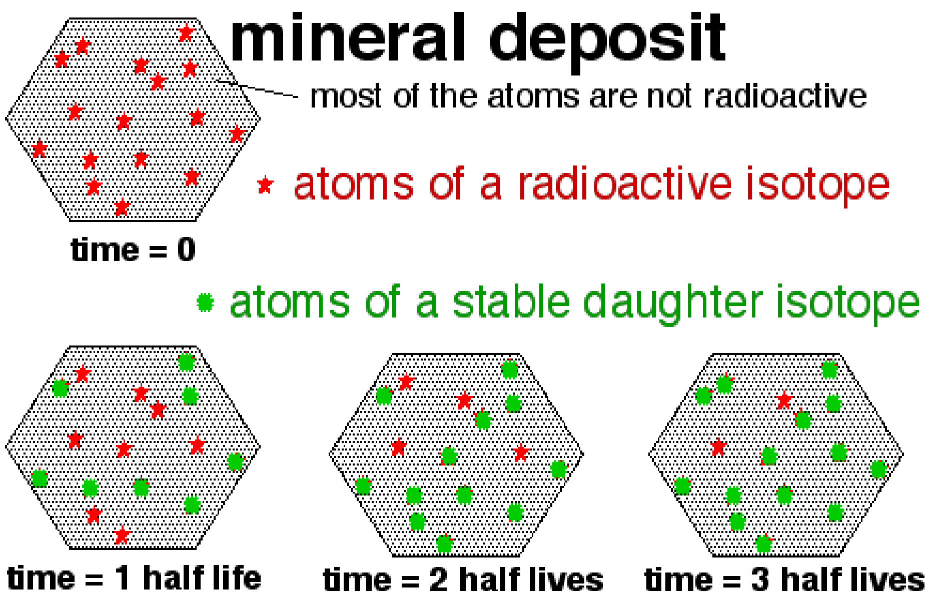
Bombardment period lasted between 4.1 and 3. 8 billion years ago and turned much of the solar system into a shooting gallery. Massive collisions left many of the Moons and planets like Mercury heavily cratered. One major collision probably led to the formation of the Moon (Chapter 8). Icy planetesimals from beyond the snow line likely brought water to the Earth. Mars' two moons, Phobos and Deimos, may be captured planetesimals leftover from the Late Heavy Bombardment. Other large collisions may have caused the odd rotation of planets like Venus and Uranus.

The Moon was likely formed from a collision between the Earth and a Mars-sized body astronomers have named Theia.

https:/commons.wikimedia.org/wiki/File:Lunar_cataclysm.jpg;

6.4.3 Measuring the age of rocks

How do we know how old the Solar System is? It turns out, the rocks we find on Earth do not help us answer this question much. Because the Earth has the most active surface of the terrestrial planets, there are few places on Earth where the crust is very old. As the various tectonic plates (Chapter 8) move, old crust disappears into the mantle while new crust forms as magma forces it way to the surface. The movement of plates raise up mountains and then wind and water wear them down. As a result, the Earth likely has the youngest surface of the terrestrial planets.



Radioactive dating of a mineral sample.

https://en.wikiversity.org/wiki/File...ingmineral.png

The main way we date rock is through **radiometric dating**. Some isotopes are radioactive and decay into more stable atoms over time. Radioactive decay is a random process and we can never predict when a single atom may decay. As result, the decay rate is governed by a statistical model based on an exponential decay curve. Radioactive isotopes decay according to their respective **half-life**, the amount of time it takes for half of the atoms present to decay. When a rock forms from the cooling of magma, the quantity of certain isotopes becomes fixed. By measuring the ratio of the radioactive isotopes to their decay product, we can calculate how many half-lives have passed since the rock formed.

The isotope most people may be familiar with is Carbon-14. However, its half-live is only about 5700 years, which is too short to be useful for dating ancient rocks. Carbon-14 dating is mostly used in archeology to date artifacts made of wood, bone or some other organic material.

Some dating methods that are useful for dating rocks include:

- rubidium-87 decays to strontium-87 with a half-life of 49 billion years.
- uranium-238 decays (in a series of steps) to lead-206 with a half-life of 4.5 billion years.
- potassium-40 decays to argon-40 with a half-life of 1.25 billion years.

Potassium-40 decays into argon-40 with a half-life of 1.25 billion years. This is a much more useful half-life for rock dating. The table below summarizes the potassium/argon ratio over a period of a few half-lives, giving the approximate age of a rock as the ratio is measured.

For example, say a rock contains potassium-40 when it forms. After one half-life (1.25 billion years), half of the potassium-40 will have decayed into argon-40, giving a potassium-40/argon-40 ratio of 1:1. After two half-lives (2.5 billion years), the ratio will become 1:3. After three half-lives (3.75 billion years), the ratio will become 1: 7. After four half-lives (5 billion years), the ratio will be down to 1:15.

Number of half-lives	**Potassium/Argon ratio**	**Age**
1	1:1	1.25 billion years
2	1:3	2.5 billion years
3	1:7	3.75 billion years
4	1:15	5 billion years

Using radiometric dating techniques such as potassium-argon dating, scientists have determined that the oldest rocks ever found on the surface of the Earth have an age of about 4.28 billion years, meaning the Earth must be at least than old. But since the Earth's surface has been under a constant reformation, we cannot be certain that the oldest rocks on the surface are the same age as the Earth itself or the Solar System. Fortunately, we have other rocks besides those found on Earth that we can date. One group has been falling onto the Earth since the earliest days of the Solar System. The other group, we can go and bring back. These are meteorites and the lunar rocks from the Apollo program.

Radiometric dating of lunar rocks has found that the oldest of them are about 4.4 billion years old. This gives us a minimum age for the Moon and given that the Moon likely formed from a collision with the Earth, the Earth must be even older. However, the Moon does not have active plate tectonics, so its surface must be older than the Earth's surface. Most lunar craters date from between 4.1 and 3.8 billion years ago, giving us a time frame for the Late Heavy Bombardment. Finally, we have found that the oldest meteorites are 4.55 billion years old. Given that these meteorites formed out of the same disc debris that the planets formed from, the planets likely formed sometime around 4.5 billion years ago. Calculations then indicate that to give enough time for the Sun and the planetary disc to form, the nebula contraction probably began around 4.6 billion years ago.

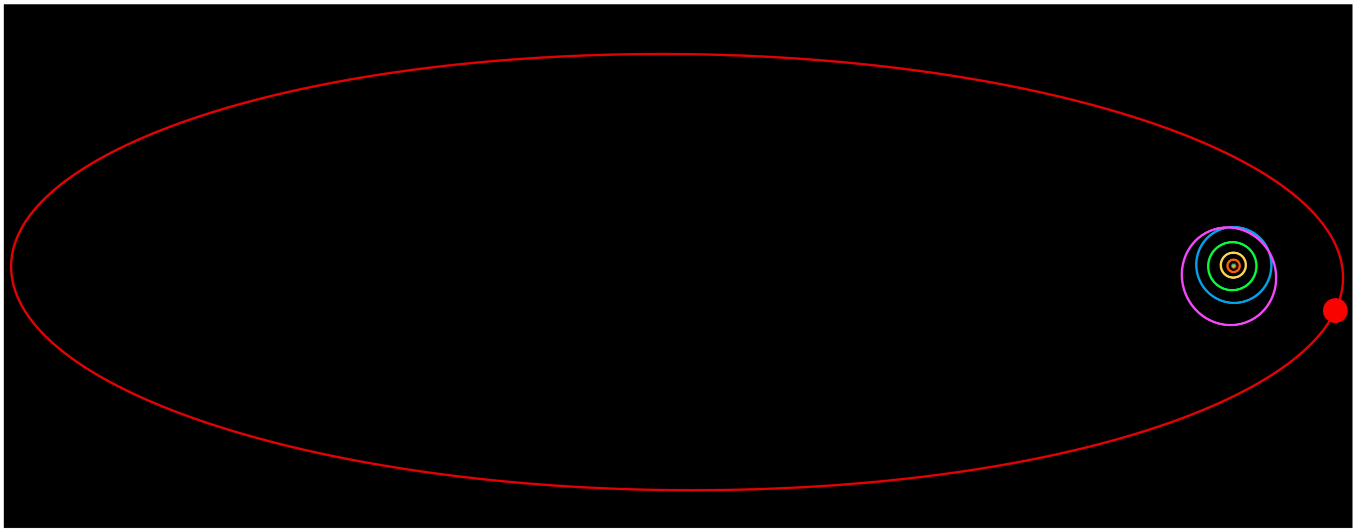
Lunar rock samples like this one from the Apollo 11 mission have enabled us to calculate the age of the Earth-Moon system through radiometric dating.

https:/commons.wikimedia.org/wiki/File:Apollo_11_moon_rock,_sample_10072,80.jpg;

6.5: Beyond the Kuiper Belt.

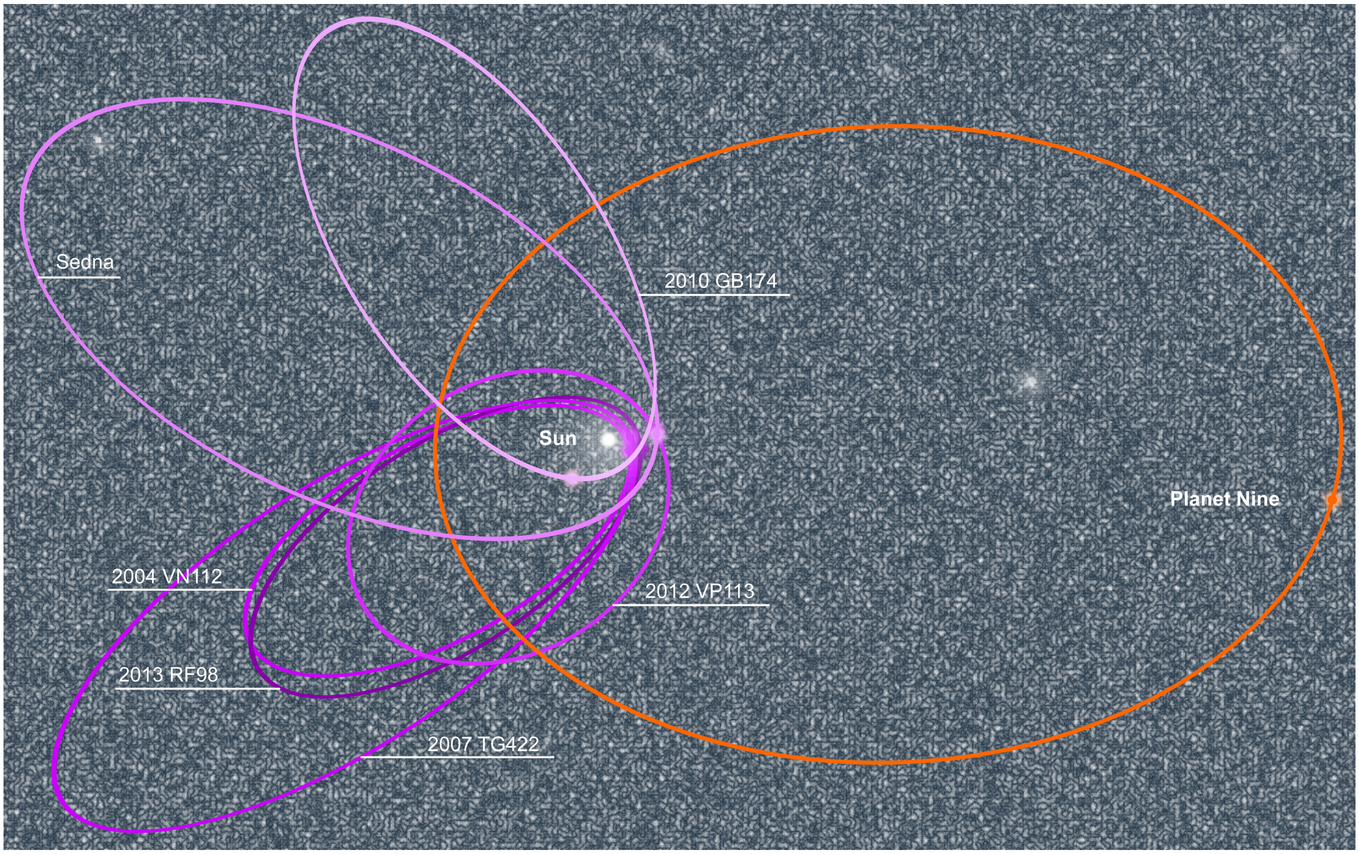
Recently, astronomers have discovered some dwarf planets on highly eccentric orbits beyond the Kuiper Belt. For example, astronomers discovered Sedna in 2003. Sedna has a wildly eccentric orbit that varies from 76 AU at perihelion only to swing out to 936 AU at aphelion. More recently, astronomers discovered another icy body in October of 2018, which they nicknamed “the Goblin.” Its orbital varies even more that Sedna’s, coming closest to the Sun at 65 AU at perihelion only to swing out to 2300 AU during aphelion.

These newly discovered bodies not only have high eccentricity, they also have extreme orbital tilts that seem to point in the same general direction. This has led many astronomers to conclude that their orbits are being shepherded by a large, unknown planet. According to their calculations, this mysterious “Planet 9” would be a Jovian world smaller than Neptune orbiting in an eccentric orbit beyond the Kuiper Belt. It likely formed closer in but was ejected past the Kuiper Belt by gravitational encounters with the other four Jovian worlds. Astronomers have a general idea where Planet 9 might be, but so far, they have not been able to spot it. Until an actual sighting of Planet 9 or some other explanation for the eccentric and tilted orbits of bodies like Sedna and the Goblin is found, the reasons for these anomalies remains a mystery.



Sedna orbit.

https://commons.wikimedia.org/wiki/F...edna_orbit.svg



Planet Nine may occupy an orbit far from the other planets.

https://commons.wikimedia.org/wiki/F...Nine_Orbit.svg

7: Rocketry and Exploring the Solar System

Learning Objectives

- Describe the principles of rocketry and the history of rockets.
- Explore the concept of transfer orbits and gravity assist maneuvers.
- Describe newer propulsion systems.
- Review the history of space exploration, including missions to the Moon, the terrestrial planets, and the out solar system.

3. . . 2 . . . 1 . . . Blast off!

There is something about a rocket launch that excites the imagination. The idea of leaving the bounds of Earth to travel to other worlds fascinates us. While people have used rockets in in warfare for thousands of years, we have only been using them to send people and payloads into space since the mid-twentieth century. Today, they remain the way we send probes to explore other planets and get people and supplies to the International Space Station (ISS).

7.1: Rocketry Basics

Rockets work according to Newton's Laws of Motion. Recall from Chapter 3 that Newton's Laws state as follows:

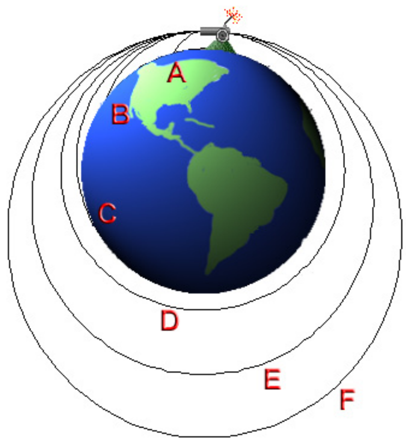
1. **First law:** In an inertial frame of reference, an object either remains at rest or continues to move at a constant velocity, unless acted upon by a force.
2. **Second law:** In an inertial frame of reference, the vector sum of the forces F on an object is equal to the mass m of that object multiplied by the acceleration a of the object: F = ma.
3. **Third law:** When one body exerts a force on a second body, the second body simultaneously exerts a force equal in magnitude and opposite in direction on the first body.

https://www.nasa.gov/audience/foreducators/rocketry/relatedsites/basics-of-rocketry.html

You can easily model a rocket by blowing up a balloon and hold the nozzle closed. The air inside the balloon exerts pressure throughout the entire interior of the balloon. So long as the nozzle is closed, the internal forces balance each other, and the balloon will not accelerate. However, if you release the balloon and allow air to escape the nozzle. Now those internal forces are no longer balanced. The air opposite the nozzle still exerts a force on the inside of the balloon but that force is not canceled out by a force in the opposite direction as the air escapes through the nozzle. This creates an action-reaction force pair and a net force in the direction opposite of the nozzle. Thus, the balloon flies though the air.

Rockets work by burning a fuel that produces a rapidly expanding gas. As with a balloon, the gas exerts a force on all sides of the rocket, except the nozzle, where the gas can escape. Thus, the force in the direction of the nose cone is not canceled out by a force on the nozzle, as there is nothing there for it push against. Therefore, the rocket rises.

Newton noted that any projectile travels in a curved path as it travels horizontally and down toward the ground simultaneously. Examining projectiles fired from canons, he noted that, the more powerful the canon, the further the projectile traveled and the greater the radius of its curve. He postulated that if he had powerful enough canon, he could launch a projectile on a curved path with a radius greater than the radius of the Earth. Such a projectile would be in orbit around the Earth. In a sense, if would continue to “fall” toward the Earth but its horizontal motion would keep it moving fast enough so that it continued to “miss” the Earth. An orbiting satellite is in **free fall**, forever falling toward the Earth and forever missing it. It could return to Earth only if a drag force slowed its forward motion down enough to cause it to fall down to Earth.



FrankH at English Wikipedia/Public domain;

Jules Verne, in his classic story, *From Earth to the Moon*, imagined a group of scientists fired themselves out of a canon to launch themselves to the Moon. As exciting as the idea of a giant canon firing people into space, in practice, the unfortunate astronauts would be crushed to jelly by the acceleration before their capsule excited the barrel of the canon. Hence, why we use rockets, which can accelerate us up to orbital velocity in a more gradual manner, without crushing its passengers.

Jules Verne. https:/commons.wikimedia.org/wiki/File:Jules_Verne_2.jpg;

To reach orbit, a rocket must accelerate to **orbital velocity**, which is given by the following formula:

$$v = \sqrt{\frac{Gm_E}{r}}$$

Where:

G = the universal gravitational constant, $G = 6.673 \times 10^{-11}\ N \cdot m^2/kg^2$

m_E = the mass of the Earth (5.98×10^{24} kg)

r = the distance from the object to the center of the Earth

For Earth, the orbital velocity comes out to about 8 km/s.

Rockets can maximize efficiency by launching near the equator on an eastward trajectory. This adds the Earth's rotational velocity (465 m/s at the equator, 410 m/s in Florida) to the rocket's velocity. This why American rockets launch from Florida as it is the closest part of the continental United States to the equator.

Orbital velocity pulls a satellite into orbit. To leave Earth entirely and travel to other planets, our craft must reach **escape velocity**. This is given by the following formula:

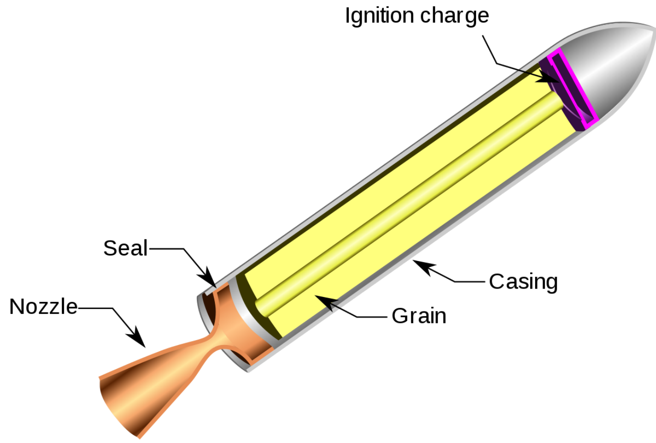
$$v_{escape} = \sqrt{\frac{2GM}{r}}$$

For Earth, the escape velocity comes out to 11.2 km/s.

Rockets can be powered by either solid or liquid fuel rockets. In order to work in space, rockets must also carry an oxidizer to ignite the fuel. As they burn fuel and oxidizer, rockets lose mass as gases escape from the nozzle. Rocket scientists must take this change in mass into their account when calculating a rocket's thrust and trajectory.

Schematic of the liquid fuel rocket. https:/commons.wikimedia.org/wiki/File:LiquidFuelRocketSchematic.jpg;

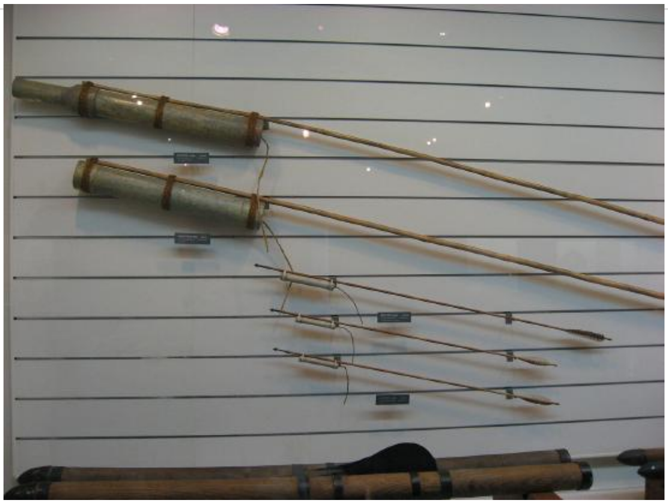
Liquid rockets inject both the fuel and the oxidizer (liquid oxygen) into the thrust chamber and ignite them. Because the fuel and oxidizer are liquid, these rockets have shifting centers of mass as they launch. This makes liquid fuel rockets vulnerable to "slosh" that may throw it off balance unless they are properly stabilized. Robert Goddard developed the first liquid fuel rockets in the 1930s.



chematic of a solid fuel rocket. https://commons.wikimedia.org/wiki/F...ocketMotor.svg

In contrast, solid fuel rockets date back to ancient China, making them the oldest form of rockets. Modern solid fuel rockets combine both the fuel and the oxidizer in a rubbery mixture. These rockets have low cost to thrust ratio. However, solid fuel rockets cannot be turned off. Once ignited, they burn until all the fuel is consumed. As a result, they make cheap boosters to launch payloads into space, but they cannot be used for maneuvering or course corrections as these require being able to fire rockets in short, controlled bursts.

7.2: History of Rockets



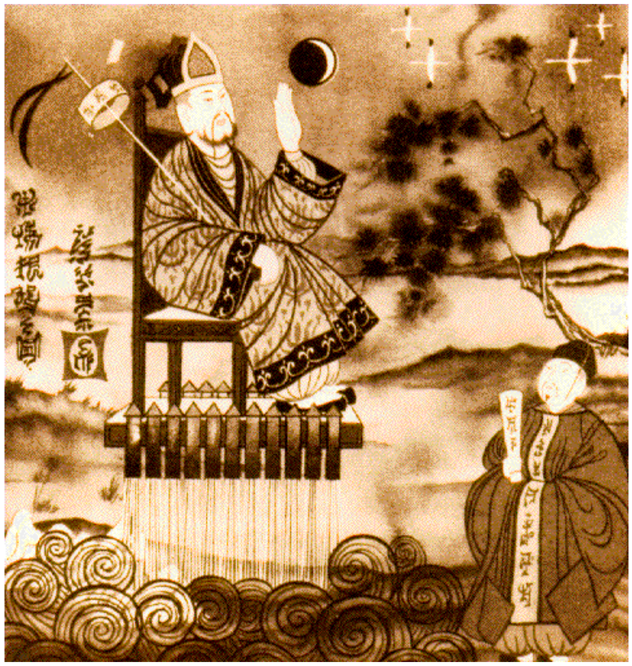
Korean rocket arrows.

https:/upload.wikimedia.org/wikipedia/commons/e/e7/Korean_rocket_arrows.jpg;

7.2.1 Origins of Rocketry

The earliest rockets consisted of bamboo tubes filled with gunpowder, a mixture of sulfur, charcoal, and saltpeter. The first recorded use of gunpowder dates to the 3rd century BCE in China. By 1045 CE, the Chinese were routinely using rockets in their military tactics. In 1232 AD, the Sung Dynasty used rockets to repel Mongol invaders. The Mongols saw a good idea and adopted rockets. By 1245, they used rockets to attack the Magyars in what is now Hungary. Arab records show the Mongols also used rockets to attack Baghdad in 1258. Soon, the Arabs also adopted rockets and in 1268 they used rockets against the French forces of Louis IX during the Seventh Crusade. By 1300, Europeans were using rockets in warfare. Then, the French used rockets against the English during the siege of Orleans in the Hundred Years War. Rockets continue to be used as tool of war in the coming centuries, improving in both power and accuracy. In the Nineteenth Century, Sir William Congreve designed rockets that were used against Napoleon.

While rockets remained primarily a weapon of war, there is at least one legend of an attempt to use rockets to travel into space from the 16th century. Wan Hu attached 47 fire-arrow rockets to two large kites and a wicker chair. Thinking it would propel him into space, he sat in the chair, while his 47 assistants each lit a rocket. The rockets fired with a huge bang and, after the smoke clear, Wan Hu and his chair were gone! Assuming the legend of Wan Hu is not just a myth, it is, unfortunately, unlikely that he survived his attempted space journey.



Wan Hu: According to legend, Wan Hu attempted to journey into space with 47 rockets attached to his chair.

https://upload.wikimedia.org/wikiped...n_Hu_large.png

As immortalized in the lyrics of the Star-Spangled Banner, rockets played a role in warfare almost from the founding of the United States of America. Rockets came to the New World during the War of 1812. Later, Captain Robert E. Lee used rockets at the Battle of Telegraph Hill during the Mexican American War. The first recorded use of rockets in the Civil War came on July 3, 1862, when Maj. Gen. J.E.B. Stuart's Confederate cavalry fired rockets at Maj. Gen. George B. McClellan's Union troops at Harrison's Landing, Virginia. Later in 1862, an attempt was made by the Union Army's New York Rocket Battalion -- 160 men under the command of British-born Major Thomas W. Lion -- to use rockets against Confederates defending Richmond and Yorktown, Virginia. The first attempt did not go well. When ignited, the rockets skittered wildly across the ground, passing between the legs of several mules. One detonated harmlessly under a mule, lifting the animal several feet off the ground and, according to written accounts of the incident, prompted the mule's immediate defection the Confederacy. Nonetheless, rockets continued to play a role in warfare through the 20th century.

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7.2.2 Robert Goddard

Up until the early 20th century, rockets still used only solid fuel (mostly gunpowder) and were pretty "dumb" and inaccurate. Armies would fire a multitude of rockets at a target in the hope at a few with hit. Given the devastating potential of rockets, this proved to be an effective strategy. Still, some rocket scientist began to experiment with liquid fuel rockets and methods to them more accurate, both for warfare and for the potential use for traveling into the space.

Robert Goddard was the one the first American pioneers in experimental rocketry.

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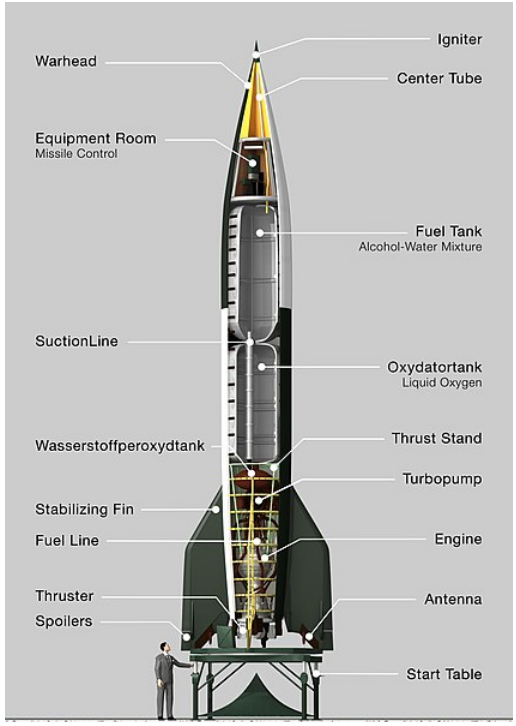
In 1914, Robert Goddard received two U.S. patents, one for a rocket using liquid fuel. The other involved a two- or three-stage rocket using solid fuel. In 1920, Goddard proposed using rockets to travel to the moon, for which he was ridiculed in the New York Times for it. The Times editorial board, apparently not understanding Newton's Laws of Motion, could not work in space because there was nothing to "push against." Undeterred, Goddard explored the practicality of using rocket propulsion to reach high altitudes, even the moon. He eventually proved that a rocket will work in a vacuum and that it needs no air to push against. He also developed and fired a liquid fuel rocket on March 16, 1926 in Auburn, Massachusetts. He later shot a scientific payload in a rocket flight in 1929. In addition, in 1932 in New Mexico, he used vanes in the rocket motor blast for guidance and provide for a more stable flight. Other advances Goddard pioneered in 1932 included a gyro control apparatus for rocket flight and developed pumps suitable for rocket fuels. In 1937, he launched a rocket with a motor pivoted on gimbals under the influence of his gyro mechanism. With this research, Goddard helped make rockets more reliable and stable and he became known as the "Father of American Rocketry."

7.2.3 Wernher von Braun

Meanwhile, as war brewed across Europe, another rocket scientist conducted research on building more powerful and reliable rockets for the Germans. Wernher von Braun developed the A-4 rocket for the Germans. Renamed the Vengeance Rocket Number Two, or the V-2, it became the first successful, long-range ballistic missile. Toward the end of WW II, the Nazis feared von Braun might fall into the hands of the allies and marked von Braun and his team for death. Von Braun considered his options and decided to defect to the Americans. Through what became known as Operation Paperclip, von Braun and his team the Allies recruited von Braun and his team and brought to White Sands, NM. The Soviets were more aggressive, having recruited over 2,200 German scientists and specialists.

After building rockets as weapons for the Germans in WW II, Wernher von Braun defected to the United States and helped build rockets for America's early space program.

https:/commons.wikimedia.org/wiki/File:Bundesarchiv_Bild_183-64549-0022,_Wernher_von_Braun.jpg;



An early ICBM rocket design. Rockets such as these were adapted for use in the Mercury program.

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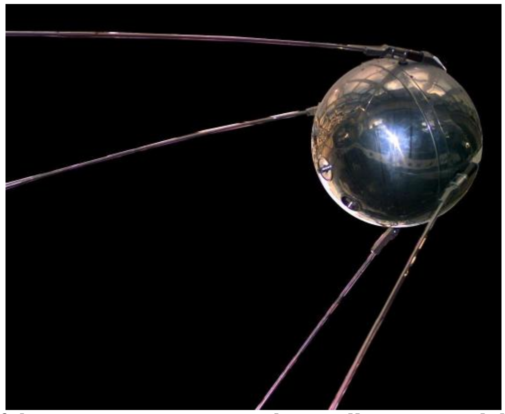
Goddard died in 1945, leaving von Braun as America's principle rocket scientist. Despite his work developing weapons of war for the Nazis, von Braun shared Goddard's dream of using rockets to travel to other planets. Over the coming decades, von Braun would publish papers describing his theories using 1950s and 1960s technology to travel to Mars and beyond. Initially, though, von Braun and his team worked on ballistic missiles for the U. S. military, including missiles to deliver the fledgling nuclear weapons as the Cold War began in earnest. Eventually, the space race began, and von Braun and his team developed early American rockets like the Bumper, Redstone, and the Jupiter C that were based on his V-2 designs.

7.2.4 The Space Race Begins

Then, in 1957, the Soviet Union launched Sputnik I, the first human-made satellite. The space race was on and America established the National Aeronautics and Space Administration (NASA) in 1958. The federal government transferred von Braun and his team to NASA to work on rockets for space.



The launch of the Soviet Union's Sputnik I satellite triggered the space race.

https:/www.needpix.com/photo/934/sputnik-satellite-astronautics-nasa-cosmonautics-space-flight-space-travel-aerospace-technology;

On April 12, 1961, Yuri Gagarin became the first human in space, flying a complete orbit around the Earth. A few weeks later, on May 5, 1961, Alan Shepherd rode a Redstone rocket to become the first American in space in a suborbital launch as part of the Mercury Program.

Yuri Gagarin, the first man in space.

https:/commons.wikimedia.org/wiki/File:Gagarin_(cropped).jpg;

Alan Shepard, the first American launched into space.

https:/www.nasa.gov/sites/default/files/alanshepard_1.jpg;

The Mercury Program had 20 unmanned launches and six manned missions; each involved a capsule designed for a single occupant. Highlights of the Mercury Program include:

- January 21, 1961: Mercury-Redstone-2 launched with Ham the chimp on board.

- February 21, 1961: The improved Atlas-2 rocket was the first successful Atlas launch.
- May 5, 1961: Mercury-3 is launched with Alan Shepard on board.
- November 29, 1961: The Atlas-5 is launched with Enos the chimp on board.
- July 24, 1961: Mercury-Redstone-4 launched with Gus Grissom on board.
- February 20, 1962: The Mercury-Atlas-6 is launched. John Glenn becomes the first American to orbit the Earth.

The Redstone rocket consisted of a single-stage vehicle. It used ethyl alcohol and liquid oxygen for fuel. All the suborbital flights of the Mercury Program used the Redstone while the orbital flights used the Atlas. The Atlas-D came from a modified ballistic missile and used RP-1 (refined form of kerosene) and liquid oxygen (LOX) with a first stage and a booster.

The Mercury Redstone Rocket was used in several early space missions.

https:/commons.wikimedia.org/wiki/File:Mercury-Redstone_Rocket_%E2%80%93_Johnson_Space_Center._20-3-2017_(40673408212).jpg;

After Mercury, NASA switched to the Gemini Program, which used a two-man capsule. The Gemini program had two uncrewed launches and ten crewed missions using the Titan II launch vehicle, a modified intercontinental ballistic missile (ICBM). The Titan family used two stages fueled by RP-1 and LOX (liquid oxygen). NASA used Gemini to practice EVA activities and docking maneuvers.

Cold War politics played a major role in the development of America’s space program. The Soviets had beaten America to launching the first man-made satellite (Sputnik I), first living organism in space (Laika, the dog on board Sputnik II), and the first man in space (Gagarin). In 1961, President Kennedy decided America needed a mission that would show up the Soviets and put America ahead in the space race. So, he issued his famous challenged for putting a man on the Moon by the end of the 1960s. Thus, the Apollo Program was born.

President Kennedy challenged Americans to reach the Moon.

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For the Apollo Program, NASA needed a more powerful rocket, so von Braun and his team developed the Saturn rocket family. For all the manned Apollo missions, NASA used the Saturn V rocket. The Saturn V consisted of a three-stage rocket. Stage 1 used RP-1/LOX while stages 2 and 3 used liquid hydrogen (LH2) and LOX. The last use of the Saturn V was to launch Skylab, America's first orbiting space station. With the close of the Apollo Program, NASA retired the Saturn V to focus on developing the space shuttle.

The Saturn V, the most powerful rocket ever built, was used for the Apollo missions

https:/pixabay.com/photos/rocket-nasa-saturn-v-forward-space-3776927;

NASA developed the space shuttle in the 1970s as a reusable launch vehicle and low orbital spacecraft. It consisted of an orbiter with an external LH2/LOX and two solid fuel boosters using ammonium perchlorate composite (APCP) solid fuel. APCP is a rubbery mixture that contains both the fuel and the oxidizer. While the boosters parachuted and were recovered after launch, the fuel tank was expendable. As a result, the shuttle never truly achieved its initial goal of total reusability. After a write in campaign from fans of Star Trek, NASA named shuttle built the Enterprise, a test vehicle with no orbital capabilities. NASA used the Enterprise to test the shuttle’s flight and landing systems before launching one into space. NASA initially produced four orbital space shuttles: Columbia, Challenger, Discovery, and Atlantis. Each was used to conduct experiments in space and launch satellites and interplanetary probes. Challenger exploded during launch in 1986 and NASA built the Endeavor to replace Challenger in 1991. Then, Columbia broke apart during reentry in 2003. Both accidents resulted in the loss of their respective crews. After 133 successful missions, NASA retired the shuttle program with the final launch of Atlantis in 2011.

The Space Shuttle was NASA's primary launch vehicle and sole crewed vehicle from 1980 until 2011.

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7.2.5 Twenty-First Century Space Travel

While NASA had proposed several potential replacements for the shuttle, none of them survived budget cuts by 2011. This left the United States without a manned launch vehicle for nine years. So, the United States was dependent on purchasing rides on the Russian Soyuz capsule to reach the International Space Station. To meet the need for a crewed launch vehicle, NASA began the Commercial Crew Program with two corporate partners, Boeing and SpaceX. Under the Commercial Crew Program, Boeing developed its Starliner capsule while SpaceX developed its Crew Dragon capsule. Both projects, however, were plagued with delays and missed deadlines. This ended on May 27, 2020 when SpaceX launched two astronauts on board the Crew Dragon on board the Falcon 9 vehicle, making it the manned first launch from US soil since the shuttle was retired. Boeing still hopes to launch a crewed mission with the Starliner capsule on board an Atlas V sometime in 2022. NASA has also developed the Orion crew capsule for use in future missions to the Moon and Mars.

Inside the SpaceX Crew Dragon capsule.

https:/commons.wikimedia.org/wiki/File:Crew_Dragon_Interior_(21119686299).jpg;

Testing Boeing's Starliner capsule.

https:/commons.wikimedia.org/wiki/File:Crew_Dragon_Interior_(21119686299).jpg;

NASA continues to use a variety of rockets to launch satellites and planetary probes, some of these modern rockets include:

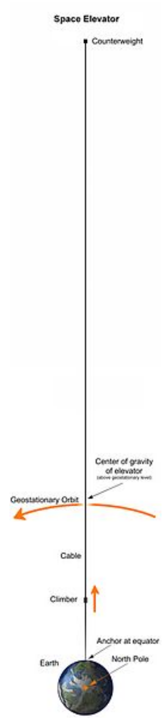
Rocket	**Developer**	**Stages**	**Maximum Payload**	**First Successful Launch Date**
Minotaur	Northrop Grummon	4	1,735 kilograms	September 7, 2013
Falcon 9	SpaceX	2	22,800 kilograms	October 8, 2012
New Shepard	Blue Origin	1	11.3 kg	November 23, 2015
Antares	Northrop Grummon	2	8,000+ kg	April 21, 2013

Space Launch System (SLS)	NASA	2, +2 boosters	70 tonnes	Planned for November 2021
Electron	Rocket Lab	2-3	225 kg	25 May 2017
Falcon Heavy	SpaceX	2, +2 boosters	63,800 kg	February 6, 2018
Atlas V	Lockheed Martin	2, + 0-5 boosters	8,250–20,520 kg	August 21, 2002
Delta IV	United Launch Alliance	2, + 2 boosters	11,470–28,790 kg	November 20, 2002
Pegasus	Orbital Sciences Corporation	1, launched from aircraft	443 kg	April 5, 1990
Starship	SpaceX	2	> 100,000 kg	Under development
New Glenn	Blue Origin	2	45,000 kg	Under development
Vulcan Centaur	United Launch Alliance	2, +0-6 boosters	27,200 kg	Under development

7.3: Other Propulsion Systems

7.3.1 Space Elevator

Rockets remain the only way we can get people and payloads into space. In theory, we could use a space elevator. Long a staple of science fiction, a space elevator would involve a long tether. We could anchor one end of the tether to a point on the surface of the Earth while connecting the other end to a space station in **geostationary equatorial orbit** (GEO), an orbit in which the satellite remains over a fixed point above the equator. Theoretically, an elevator running up the tether could lift payloads into the space at a lower cost than rockets. However, there is one problem: We do not have any material strong enough to run the 35,786 kilometers (22,236 miles) between the surface and GEO. Carbon nanotubes are one possibility, but so far, we can only make them a few centimeters in length. So, until we can solve this and a few other engineering issues, a space elevator will have to remain science fiction.

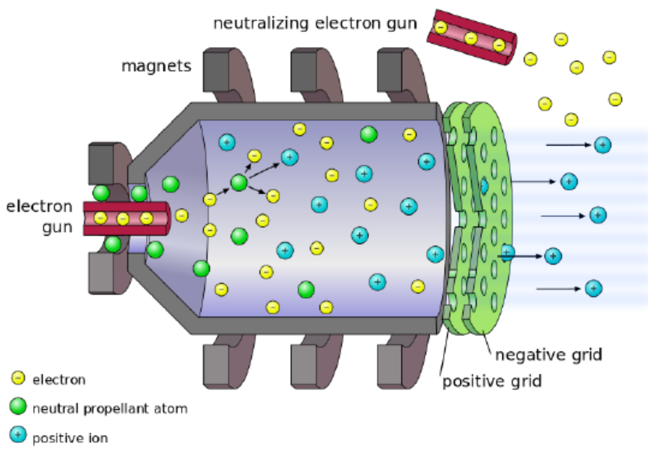


A space elevator may one provide a cheap means of transporting people and cargo into orbit.

https:/upload.wikimedia.org/wikipedia/commons/5/50/Space_elevator_structural_diagram--corrected_for_scale%2BCM%2BGEO%2Betc.jpg;

7.3.2 Ion Engines

Another limitation for rockets is that they require a large amount of fuel and fuel is mass. There is a point of diminishing returns where the mass of additional fuel outweighs the added thrust it can produce. To provide alternatives to using rockets to send probes out into the Solar System, researchers have explored some alternatives to rockets, such as ion drives, solar sails, laser sails, and magnetic sails.



Electric or ion thrusters can provide continuous thrust with minimal mass.

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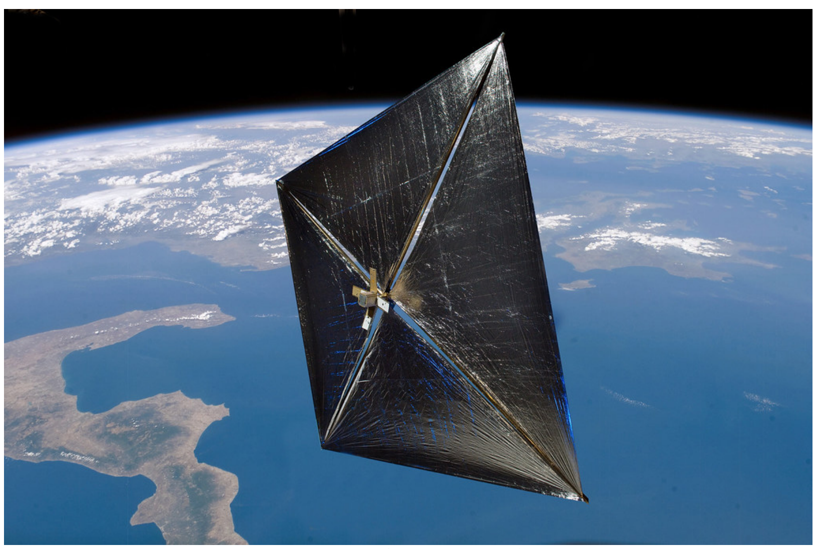
An ion drive, sometimes called a plasma drive, is one kind of an electric propulsion system. In an electric drive, source of electricity, such as solar or nuclear, heats up a gas such as hydrogen. The hydrogen would expand as it heats up and the drive could use that expansion to generate thrust. A plasma drive takes things step further and uses electricity to strip a gas of its electrons, converting it into a plasma. Then, it expels the plasma to generate thrust. While this would only generate a small thrust, a plasma drive could run continuously with much less mass than a rocket would require. Over time, the thrust would accelerate, pushing the craft to very high velocities. NASA first tested an ion drive in its Deep Space I and has used them on a few other missions.

7.3.3 Solar Sails

Solar sails use a thin sheet of material with a very high surface area to mass ratio. Light from the Sun exerts a tiny amount of pressure which produces thrust. With a large area, a solar sail could capture a lot light pressure and use to gradually reach high velocities. The Planetary Society just recently successfully deployed Light Sail 2 using cube sats. Japan’s space agency, JAXA, has also tested a solar sail. This proof-of-concept could be scaled up to reach the outer solar system.

Like a solar sail, a laser sail uses light pressure. Instead of capturing light from the Sun, a laser sail would use light from a laser. A station in Earth orbit or on the Moon could fire the laser continuously to provide thrust and accelerate the probe to high velocities. Some proposals for laser sails estimate they could reach Mars in three days, as opposed to six months using conventional rockets. Variations of a laser sail include using a laser to ablate (convert from solid to gas) the surface of a craft to generate thrust or use a maser (microwave laser) to push a metal mesh. Another variation proposes firing a steady stream of pellets at a craft to push it.



Solar sails have been tested as a means of propulsion for traveling in the Solar System.

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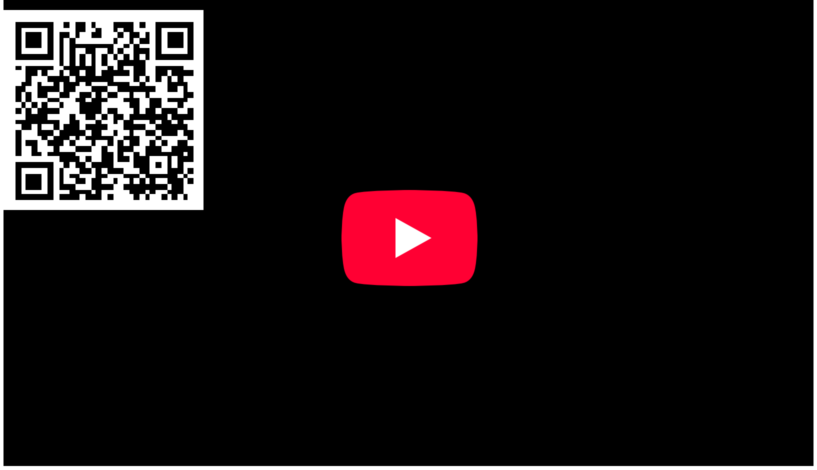


7.3.4 Magnetic/Electric Sails

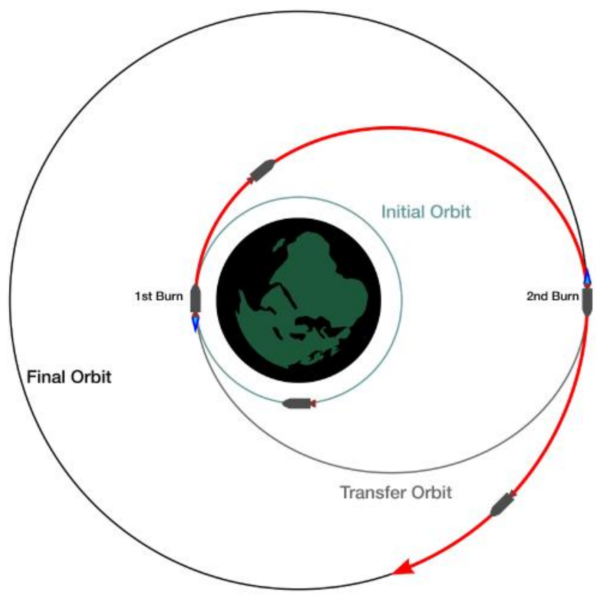
Finally, a magnetic sail would create a “sail” out of a magnetic field around a metal mesh. Instead of sunlight, this magnetic field would gain thrust from the solar wind.

7.4: Exploring the Solar System

7.4.1 Hohman Transfer Orbits

You are in space, now what? Leaving Earth's gravity means the spacecraft is still in orbit around the Sun. Traveling to another planet is not as simple as flying in a straight line. The planets are all in motion and Sun's gravity will work to slow the probe down. The most fuel-efficient way to get to another planet would be to accelerate and put the spacecraft into a **Hohman transfer orbit.** A Hohman transfer orbit is an elliptical orbit that carries a craft from the orbital path of one planet to the orbital path of another. To get to Mars, the craft would have to accelerate by firing thrusters in the direction of Earth's orbital path. This increases the craft's velocity relative to the Sun and pushes it into a transfer orbit. Once in such a transfer orbit, the craft will orbit the Sun in a path that crosses both the orbit of the Earth and Mars. To get to Venus, the craft will accelerate against the Earth's revolution around the sun, slowing its orbital velocity relative to the Sun. This causes it to "fall" into a lower orbit that carries it into similar orbit that cross both the orbits of the Earth and Venus.

Of course, once your craft reaches Mars orbit, Mars might not be at the point in it orbit. If the craft arrives at Mars orbit and Mars is not there, it will continue on its transfer orbit and return to the Earth's orbit. To ensure that the planet is there to meet the problem when it arrives, the launch must be properly timed. The time when the planets make their closest approach, enabling the shortest transfer orbit is known as the **launch window**. For Mars, the launch window happens every 25 months while for Venus it happens every 19 months. Every launch window last for only a few weeks. Therefore, delays in launch could add years onto the mission and increase the cost by millions of dollars.



Hohmann Transfer orbits are used to efficiently transport a spacecraft to planets such as Mars or Venus.

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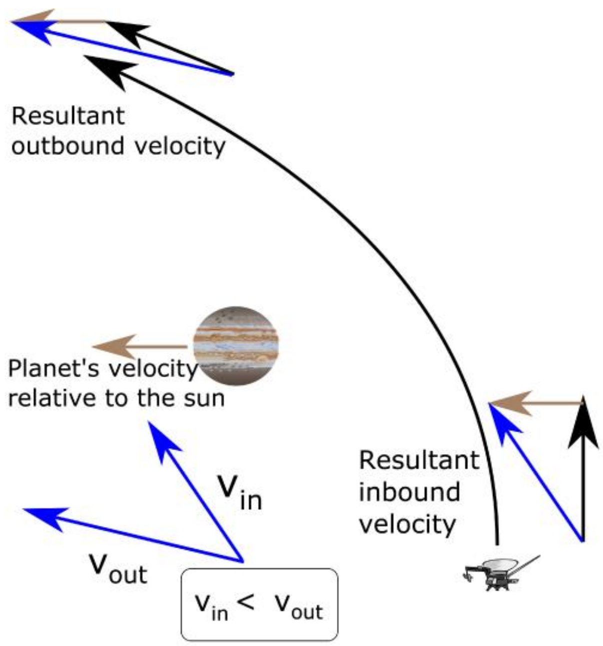
7.4.2 Gravity Assist

Another issue for traveling in the Solar System is that current propulsion technology limits us to getting out as far out as Jupiter or as far in as Venus. To get to Mercury or Saturn (and beyond), we need to use a **gravity assist** to get to speeds fast enough to counter the Sun's gravity. A gravity assist involves coming up behind a planet an "stealing" a bit of its angular momentum to gather speed. This creates a slingshot effective can fling a craft to higher velocities. Many missions to the outer solar system have involved multiple gravity assists, sometimes bouncing between Venus and the Earth, gathering speed with each pass, until the craft reaches a velocity high enough to make to the outer solar system. A planet's gravity can also be used to slow the craft down by passing in front of the planet. Planetary missions often use gravity deceleration to help put the probe into orbit around the planet.



Gravity assist maneuvers are used to reach the outer solar system by "borrowing" some momentum by making a close approach to another planet.

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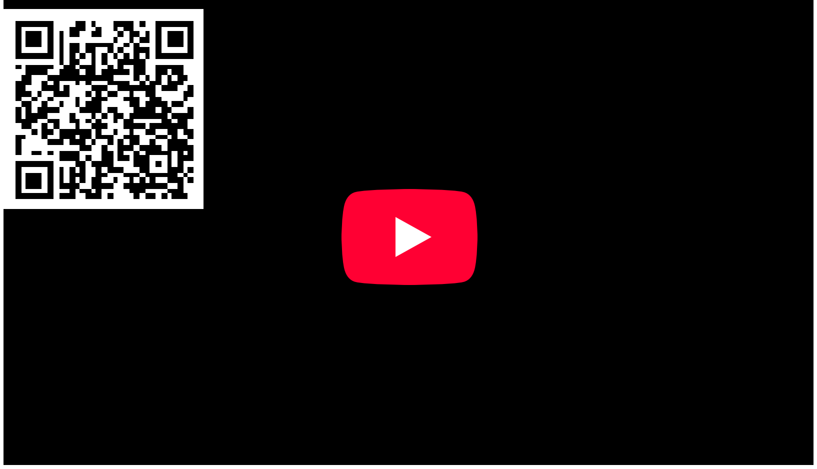

7.4.3 Types of Planetary Probes

NASA and other space agencies have launch different kinds of planetary probes. These include the following.

- **Flyby:** The probe makes a close approach to a body and then travels further on, not stopping. Many early planetary missions involved flybys, especially the Pioneer and Voyager missions to the outer solar system.
- **Orbiter:** The probe parks itself in orbit around an object for extended observations. Orbiters can be used to map the surface of a planet or take measures of its surface temperature, magnetosphere, and atmosphere.
- **Impactor:** A probe that is deliberately crashed into the surface of an object as it gathers data. Impactors are disposable probes which are meant only to collect data during its approach to the surface and cannot be used for extended missions. Several orbiters have been “retired” by crashing them onto the surface or burning up into the atmosphere of planets.
- **Atmospheric:** A probe designed to enter the atmosphere and take measurements, usually crashing on the surface or burning up in the atmosphere. The Soviet Union sent several atmospheric probes to Venus in the 60s and 70s. The Galileo probe also dropped an atmospheric problem into Jupiter’s atmosphere.
- **Lander:** A probe that makes a “soft” landing and starts collecting samples and/or data. Landers can operate for extended periods on the surface.
- **Rover**: A lander with wheels or trends that can move across the surface of a planet or moon. Unlike landers, which are limited to collecting samples in their immediate landing area, rovers can travel around the surface, collecting data and samples over a wider area.

7.5: Missions to the Moon

7.5.1 Early Lunar Missions

The first missions to the Moon began in 1958 as both the United States and the Soviet Union raced to one up each other. Many of the early missions ended in failure or partial success, but over time, both nations records improved. By the 1990s, other players, including Japan, ESA, China, and India began sending their own missions to the Moon as well. The table below summarizes the missions to the Moon from 1958 until the present.

Spacecraft	Launch Date	Carrier	Mission Type	Result
Pioneer 0	8/17/58	USAF	Orbiter	Launch failure
Luna E-1 No. 1	9/23/58	USSR	Impactor	Launch failure
Pioneer 1	10/11/58	NASA	Orbiter	Launch failure
Luna E-1 No. 2	10/11/58	USSR	Impactor	Launch failure
Pioneer 2	11/8/58	NASA	Orbiter	Launch failure
Luna E-1 No. 3	12/4/58	USSR	Impactor	Launch failure
Pioneer 3	12/6/58	NASA	Flyby	Launch failure
Mechta (E-1 No. 4)	1/2/59	USSR	Impactor	Launch failure
Pioneer 4	3/3/59	NASA	Flyby	Partial failure (first U. S. spacecraft to leave Earth orbit)
E-1A No. 1	6/18/59	USSR	Impactor	Launch failure
Luna 2	9/12/59	USSR	Impactor	Successful (first spacecraft to reach the lunar surface
Luna 3	10/4/59	USSR	Flyby	Successful (returned first images of the far side of the Moon)
Pioneer P-3	11/26/59	NASA	Orbiter	Launch failure
Luna E-3 No. 1	4/15/60	USSR	Flyby	Launch failure
Luna E-3 No. 2	4/16/60	USSR	Flyby	Launch failure
Pioneer P-30	9/25/60	NASA	Orbiter	Launch failure
Pioneer P-31	12/15/60	NASA	Orbiter	Launch failure
Ranger 3	1/26/62	NASA	Impactor	Spacecraft failure
Ranger 4	4/23/62	NASA	Impactor	Spacecraft failure
Ranger 5	10/18/62	NASA	Impactor	Spacecraft failure
Luna E-6 No. 2	1/4/63	USSR	Lander	Launch failure
Luna E-6 No. 3	2/3/63	USSR	Lander	Launch failure

Luna 4	4/2/63	USSR	Lander	Spacecraft failure
Ranger 6	1/30/64	NASA	Impactor	Spacecraft failure
Luna E-6 No. 6	3/21/64	USSR	Lander	Launch failure
Luna E-6 No. 5	4/20/64	USSR	Lander	Launch failure
Ranger 7	7/28/64	NASA	Impactor	Successful (Impacted on 7/30/64)
Ranger 8	2/17/65	NASA	Impactor	Successful (Impacted on 2/20/65)
Kosmos 60	3/12/65	USSR	Lander	Launch failure
Ranger 9	3/21/65	NASA	Impactor	Successful (Impacted on 3/24/65)
Luna E-6 No. 8	4/19/65	USSR	Lander	Launch failure
Luna 5	5/9/65	USSR	Lander	Spacecraft failure
Luna 6	6/8/65	USSR	Lander	Spacecraft failure
Zond 3	7/8/65	USSR	Flyby	Successful
Luna 7	10/4/65	USSR	Lander	Spacecraft failure
Luna 8	12/3/65	USSR	Lander	Spacecraft failure
Luna 9	1/31/66	USSR	Lander	Successful (first spacecraft to successfully land on the Moon. Landed on 2/3/66 and returned data until 2/6/66
Kosmos 111	3/1/66	USSR	Orbiter	Launch failure
Luna 10	3/31/66	USSR	Orbiter	Successful (first spacecraft to orbit the Moon)
Surveyor 1	5/30/66	NASA	Lander	Successful (landed on 6/2/66 and returned data until 7.13.66
Explorer 33	7/1/66	NASA	Orbiter	Launch failure
Lunar Orbiter 1	8/10/66	NASA	Orbiter	Partial failure (deorbited early due to lack of fuel)
Luna 11	8/21/66	USSR	Orbiter	Partial failure (Entered orbit but failed to return images)
Surveyor 2	9/20/66	NASA	Lander	Spacecraft failure
Luna 12	10/22/66	USSR	Orbiter	Successful
Lunar Orbiter 2	11/6/66	NASA	Orbiter	Successful
Luna 13	12/21/66	USSR	Lander	Successful
Lunar Orbiter 3	2/5/67	NASA	Orbiter	Successful

Surveyor 3	4/17/67	NASA	Lander	Successful (Landed on 4/20/67 and returned data until 5/3/67)
Lunar Orbiter 4	5/4/67	NASA	Orbiter	Successful
Surveyor 4	7/14/67	NASA	Lander	Spacecraft failure
Explorer 35	7/19/67	NASA	Orbiter	Successful
Lunar Orbiter 5	8/1/67	NASA	Orbiter	Successful
Surveyor 5	9/8/67	NASA	Lander	Successful
Soyuz 7K-L1 No. 4L	9/27/67	USSR	Flyby	Launch failure
Surveyor 6	11/7/67	NASA	Lander	Successful
Soyuz 7K-L1 No.5L	11/22/67	USSR	Flyby	Launch failure
Surveyor 7	1/7/68	NASA	Lander	Successful
Luna E-6LS No. 112	2/7/68	USSR	Orbiter	Launch failure
Luna 14	4/7/68	USSR	Orbiter	Successful
Soyuz 7K-L1 No. 7L	4/22/68	USSR	Flyby	Launch failure
Zond 5	8/14/68	USSR	Flyboy	Successful
Zond 6	11/10/68	USSR	Flyby	Spacecraft failure
Soyuz 7K-Li No. 13L	1/20/69	USSR	Flyby	Launch failure
Luna E-8 No. 201	2/19/69	USSR	Lander/rover	Launch failure
Soyuz 7K-L1S No. 3	2/21/69	USSR	Orbiter	Launch failure
Luna E-8-5 No. 402	6/14/69	USSR	Lander, Sample return	Launch failure
Soyuz 7K-L1S No. 5	7/3/69	USSR	Orbiter	Launch failure
Luna 15	7/13/69	USSR	Lander, Sample return	Spacecraft failure
Zond 7	8/7/69	USSR	Flyby	Successful
Kosmos 300	9/23/69	USSR	Lander, Sample return	Launch failure
Kosmos 305	10/22/69	USSR	Lander, Sample return	Launch failure
Luna E-8-5 No. 405	2/6/70	USSR	Lander, Sample return	Launch failure
Luna 16	9/12/70	USSR	Lander, Sample return	Successful

Zond 8	10/20/70	USSR	Flyby	Successful
Luna 17	11/10/70	USSR	Lander/rover	Successful
PFS-1	7/26/71	NASA	Orbiter	Successful
Luna 18	9/2/71	USSR	Lander, Sample return	Spacecraft failure
Luna 19	9/28/71	USSR	Orbiter	Successful
Luna 20	2/14/72	USSR	Lander, Sample return	Successful
PFS-2	4/16/72	NASA	Orbiter	Successful
Soyuz 7K-LOK No. 1	7/3/72	USSR	Orbiter	Launch failure
Luna 21	1/8/73	USSR	Lander/rover	Successful
Explorer 49	6/10/73	NASA	Orbiter	Successful
Mariner 10	11/3/73	NASA	Flyby	Successful
Luna 22	5/29/74	USSR	Orbiter	Successful
Luna 23	10/28/74	USSR	Lander/Sample return	Spacecraft failure
Luna E-8-5M No. 412	10/16.75	USSR	Lander/Sample return	Launch failure
Luna 24	8/9/74	USSR	Lander/Sample returen	Successful
ISEE-3	8/12/78	NASA	Gravity Assist en route to Comet 21P/Giacobini–Zinner.	Successful
Hiten	1/24/90	ISAS (Japan)	Flyby/Orbiter	Successful
Hagoromo	1/24/90	ISAS	Orbiter	Spacecraft failure (Deployed from Hiten)
Geotail	7/24/92	ISAS/NASA	Gravity assist	Successful
WIND	11/1/94	NASA	Gravity assist to reach Earth-Sun L1 point	Successful
Clementine	1/25/94	USAF/NASA	Orbiter	Successful
Lunar Prospector	1/7/98	NASA	Orbiter	Successful, confirmed ice in one of Moon's polar craters
Nozomi	7/3/98	ISAS	Gravity assist	Spacecraft failure

WMAP	6/30/01	NASA	Gravity assist to reach Earth-Sun L2 point	Successful
SMART-1	9/27/03	ESA (European Space Agency)	Orbiter	Successful
STEREO A	10/25/06	NASA	Gravity Assist to reach heliocentric orbit	Successful
STEREO B	10/25/06	NASA	Gravity Assist to reach heliocentric orbit	Successful
ARTEMIS P1	2/17/07	NASA	Orbiter	Successful, still operational
ARTEMIS P2	2/17/07	NASA	Orbiter	Successful, still operational
SELENE	9/14/07	JAXA (Japan)	Orbiter	Successful
Chang'e 1	10/24/07	China	Orbiter	Successful
Chandrayaan-1	10/28/08	India	Orbiter	Successful
Moon Impact Probe	10/22/08	India	Impactor	Successful
Lunar Reconnaissance Orbiter	6/8/09	NASA	Orbiter	Successful, still operational
LCROSS	6/8/09	NASA	Impactor	Successful
Chang'e 2	10/1/10	China	Orbiter	Successful
Ebb (GRAIL-A)	9/10/11	NASA	Orbiter	Successful
Flow (GRAIL-B)	9/10/11	NASA	Orbiter	Successful
LADEE	9/7/13	NASA	Orbiter	Successful
Chang'e 3	12/1/13	China	Lander	Successful, still operational
Yutu	12/1/13	China	Rover	Mostly successful, deployed from Chang'e 3
Chang'e 5-T1	10/23/14	China	Flyby	Successful
Manfred Memorial Moon Mission	10/23/14	LuxSpace (private European agency)	Flyby	Successful
TESS	4/18/18	NASA	Gravity assist into high Earth orbit	Successful

Quegiao	5/21/18	China	Gravity assist to L5 orbiter	Successful, still operational
Longjiang-1	5/21/18	China	Orbiter	Spacecraft failure
Longjiang-2	5/21/18	China	Orbiter	Successful
Chang'e 4	12/7/18	China	Lander	Successful, still operational
Yutu-2	12/7/18	China	Rover	Successful, still operational, deployed from Chang'e 4
Beresheet	2/19/19	Isreal	Lander	Spacecraft landing failure
Chandrayaan-2	7/22/19	Indi	Orbiter	Successful, still operational
Vikram/Pragyan	7/22/19	India	Lander/rover	Lander failure

Throughout the 1960s and 1970s, both NASA and the USSR often followed a policy of launching missions in pairs, launching two probes within a few weeks of each other. This doubled the chances of success in the case one of the probes failed. A launch failure meant a malfunction in the one of the stages of the launch vehicle, resulting the probe failing to reach orbit. A spacecraft failure meant a malfunction in the probe itself, usually resulting in craft failing to achieve orbit, crashing on the surface, or otherwise not being able to complete its mission. The peculiar naming convention of many of the USSR's lunar missions stems in part from the Soviet policy of restarting numbering or renaming missions to "erase" their failures.

Note the gap in between 1978 and 1990 when no country launched any lunar missions as both the Soviets and America focused their resources on other projects.

Some highlights of the early days of lunar exploration include:

- The Luna 1 Impactor (USSR) was the first successful flyby of the Moon and demonstrated that the Moon had no magnetic field. It was supposed to impact the Moon, but a malfunction caused it to miss.
- Pioneer 4 (NASA) made a partial successful flyby of the Moon at 60,000 km.
- Luna 3 Flyby (USSR) transmitted the first pictures of the far side of the Moon.
- NASA's Ranger 3 was supposed to be an impactor but made a flyby instead while Ranger 4 crashed on the far side without returning any data.
- Luna 9 (USSR) became the first successful lander on the Moon.
- Zond 5 contained the first "Earthlings" to flyby the Moon: Two tortoises, some mealworms, wine flies, and plants
- Zond 6 carried a similar payload of organisms, but a depressurization accident killed the biologicals.
- Mariner 10 also took pictures of the Moon on its way to Venus and Mercury.
- While NASA focused on the manned Apollo missions, the Soviets performed robotic sample return missions, the last one being Luna 24 in 1974.

7.5.2 Apollo Missions

Of course, the Apollo landings were the main attraction of the lunar missions of the late 1960s and early 1970s. Following Kennedy’s 1961 challenge, NASA threw considerable resources toward meeting his deadline of the end of the 1960s. Unfortunately, the program began with some serious problems. Apollo 1 caught fire on the launch pad during an engine test, killing all three astronauts on board: Gus Grissom, Ed White, and Roger Chaffee. A post-accident review found several design flaws. In future missions, the 100% oxygen atmosphere inside the cabin was replaced with normal breathing air. NASA also redesigned the spacesuits to be fire resistant and made the hatch easier to open in the event of an abort. Because of these changes, NASA scrapped Apollo 2 and 3. They tested the Saturn V rocket with an unmanned capsule for Apollo 4. NASA used Apollo 5 as an unmanned test of the Saturn IB rocket. Apollo 5 was also the first to carry the **lunar module (LM)**, the vehicle that eventually landed on the Moon. Apollo 6 used the Saturn V rocket to test the **Command/Service Module (CSM)** which would orbit the Moon while the LM was on the surface.

Apollo 7 was the first manned flight and performed an 11-day Earth orbit to test the CSM systems. Apollo 8, crewed by Jim Lovell, Frank Borman, and William Anders became the first manned vehicle to orbit the Moon. NASA used Apollo 9 to test the full lunar EVA suit and its portable life systems. Then, Apollo 10 took the LM within 50,000 feet of the Lunar surface.

Finally, on July 20, 1969, Apollo 11 landed on the Moon! Neil Armstrong and Buzz Aldrin took the LM to the surface while Michael Collins remained in the CSM in orbit.

The Apollo 11 landing module.

https://pixabay.com/photos/moon-land...-aldrin-60543/

The official crew portrait of the Apollo 11 astronauts from left to right are: Neil A. Armstrong, Commander; Michael Collins, Module Pilot; Edwin E. "Buzz" Aldrin, Lunar Module Pilot

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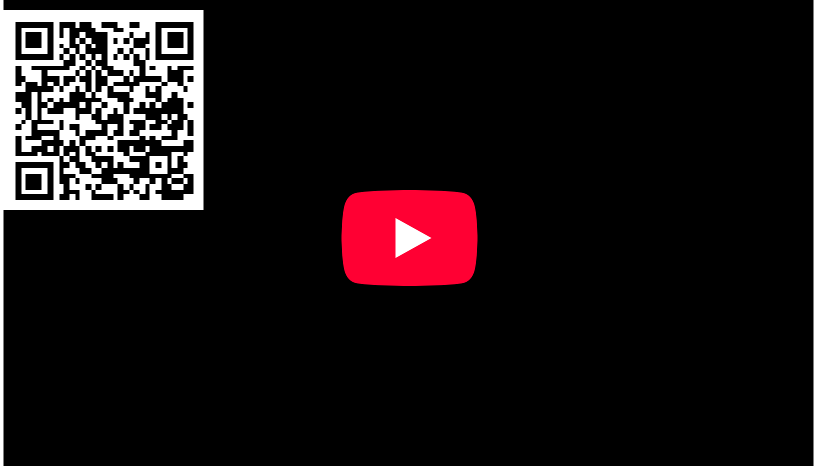
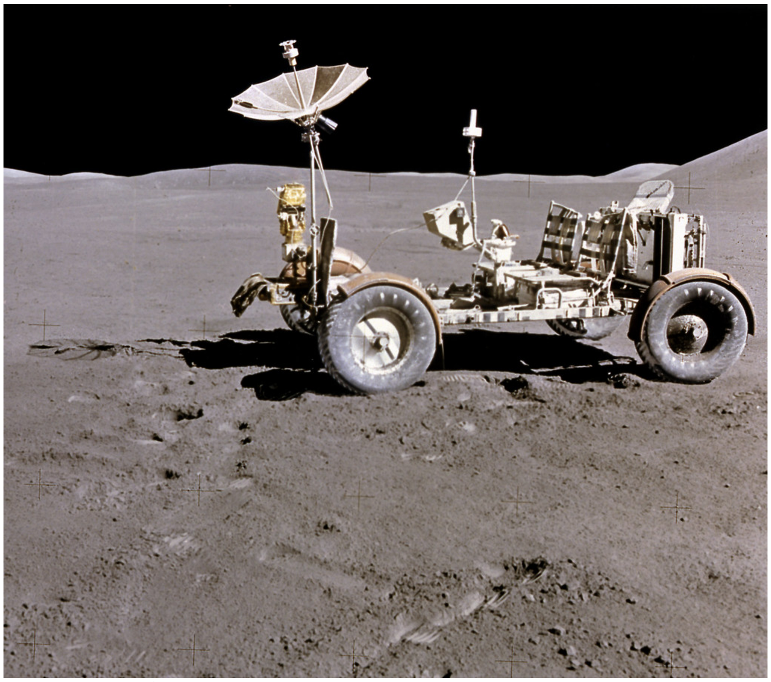


Apollo 12 landed within walking distance of Surveyor 3’s landing site and returned with some parts from it.

Apollo 13 became known as the “successful failure.” A mechanical failure prevented them from landing on the Moon and only performed a flyby before returning to Earth. All three astronauts, Jim Lovell, Jack Swigert, and Fred Haise all returned to Earth safely.

Apollo 14-17 were all successful with Apollo 15-17 being the missions that used the Lunar Rover to explore the surface. Apollo 17 landed on the Moon on December, 1972 and became the last Apollo mission. Indeed, it was the last time any human has traveled beyond Low Earth Orbit (LEO). Originally, at least two more Apollo missions had been planned. Nixon decided the costs of the remaining missions outweighed the benefits and scrapped the program to focus on the shuttle and other programs.



One of the lunar rovers used in the Apollo 14-17 missions.

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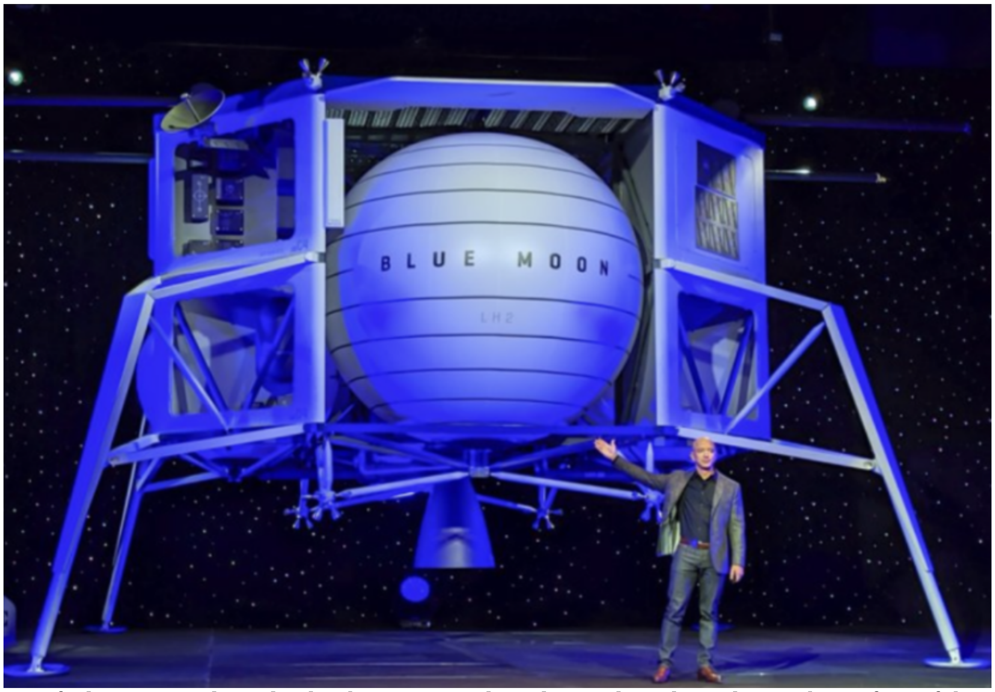
7.5.3 Post-Apollo Moon Missions

Since the Golden Age of space travel, NASA and other organizations resumed lunar missions in the 1990s. Some recent highlights include:

- 1990: Japan launches the Hiten orbiter/impactor (above), making it the first Asian object to land on the moon.
- 1998: NASA launched the Lunar Prospector and in January 1999, the Lunar Prospector was deliberately crashed in the Moon's south pole, where it detected ice in one of its craters.
- 2014: LuxSpace launched the first private commercial probe of the Moon.
- Some orbiters and landers, including NASA's Lunar Reconnaissance Orbiter (LRO, China's Chang'e 4 and Yutu-2 lander/rover probes, and India's Chandrayaan-2 orbiter continue to operate today.



Mock up of Blue Origin's lunar lander that may one day tale people and supplies to the surface of the Moon.

https://commons.wikimedia.org/wiki/F...Spacecraft.png

Even since the end of the Apollo missions, many have asked the question, when are we going back to the Moon? After many false starts, NASA is once again preparing for a return to the Moon with the Artemis program. With a target data for a human landing on the Moon in 2024, Artemis will be substantially different from Apollo. Instead of single missions, NASA intends to establish long-term missions on the Moon and in orbit around it. Private contractors will deliver robots and other materials to the Moon while NASA will use its SLS and Orion capsule to send astronauts to Gateway, a platform to be placed in orbit around the Moon. NASA has chosen three contractors, SpaceX, Blue Origin, and Dynetics to develop reusable landers to take astronauts to the surface. Research conducted on the surface of the Moon and on-board Gateway will help prepare NASA for crewed missions to Mars and beyond. More than fifty years after the last Apollo landing, we may be going back to the Moon very soon.


NASA is developing the Orion capsule to carry astronauts to the Moon and possibly Mars.

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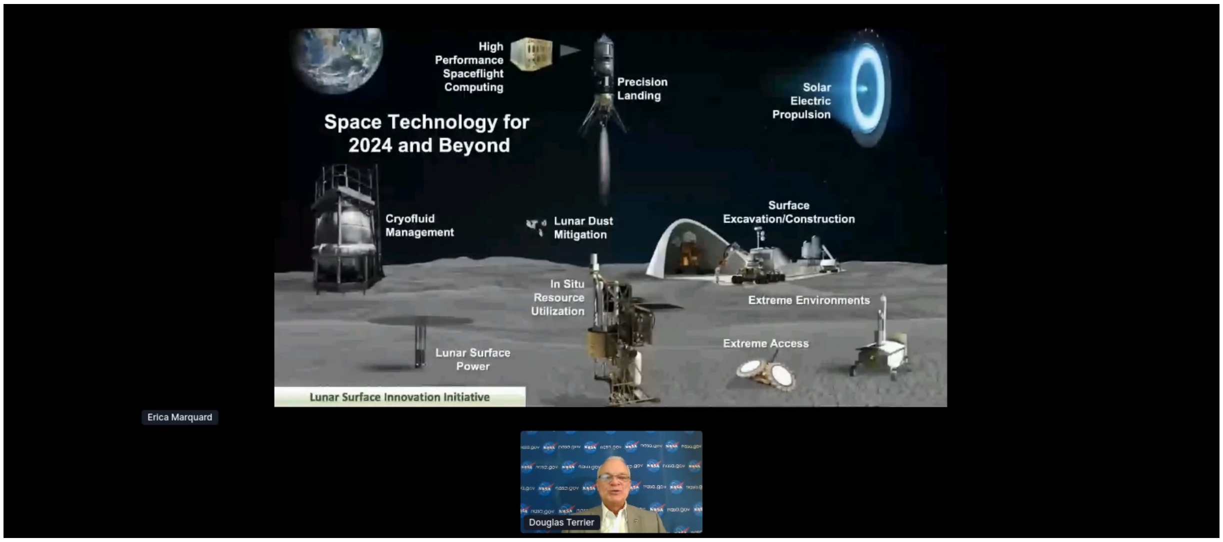


NASA's plans to return to the Moon in the 2020s.

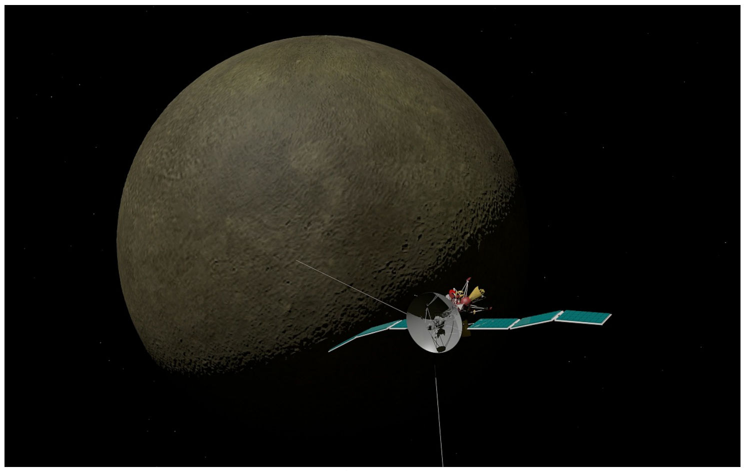
https:/www.nasa.gov/sites/default/files/thumbnails/image/dt_wt20_4_0.jpg;

7.6: Missions to Mercury and Venus.

7.6.1 Missions to Mercury

Getting to Mercury is not easy. That close to the Sun, a probe must contend with the high temperatures and the gravity of the Sun, either of which could jeopardize a mission to the smallest of the planets.

To date, only two probes have visited Mercury. Launched on November 3, 1973, Mariner 10 made its first flyby of Mercury on March 24, 1974. Later, it made two more passes on September 21, 1974 and March 16, 1974. Because the same side of Mercury was illuminated by the Sun on each flyby, however, Mariner 10 only mapped about 45% of the planet's surface. Mariner 10 also detected a magnetic field around Mercury.



Artist's conception of the MESSENGER probe.

https:/www.needpix.com/photo/269915/mercury-planet-solar-system-space-travel-landing-technology-target-vision-brown;

The MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) was launched on August 4, 2004 and made several passes around Earth, Venus, and Mercury from 2005-2008. MESSENGER entered orbit of Mercury in 2011. It made the first detailed observations of Mercury and exceeded its initial plans. MESSANGER managed to map the entire surface of Mercury. Then in 2015, after two mission extensions, it ran out of propellant was allowed to crash into the planet.

As of this writing, a third probe is en route to Mercury. BepiColombo, Joint ESA-JAXA mission to Mercury was launched on October 20, 2018. After making several passes around Venus and Earth, it is due to arrive in 2025. The mission comprises two spacecraft: The Mercury Planetary Orbiter (MPO) and the Mercury Magnetospheric Orbiter (MMO). BepiColombo will orbit Mercury as it attempts to determine if its core is solid or liquid, whether planet has any active plate tectonics, and learn more about Mercury's composition.

7.6.2 Missions to Venus

Venus has posed other challenges to observers on Earth. Because of its extensive cloud cover, the surface of Venus cannot be mapped using visible light. In the 1960s, NASA's Goldstone and the Arecibo telescope began using radar to map the planet This enabled us to determine the planet's rotational period, axis of rotation, and planetary radius for the first time. From the sixties until the mid-eighties, the Soviet Union sent numerous probes to study Venus, most of which failed. While the Soviets were determined to land a probe on Venus, NASA launched relatively few probes to Venus, all of which were either flyby or orbiter missions.

Spacecraft	**Launch Date**	**Operator**	**Mission Type**	**Result**
Tyazhely Sputnik	2/4/61	USSR	Impactor	Launch failure
Venera 1	2/12/61	USSR	Impactor	Spacecraft failure
Mariner 1	7/22/62	NASA	Flyby	Launch failure
2MV-1 No.1	8/25/62	USSR	Lander	Launch failure
Mariner 2	8/27/62	NASA	Flyby	Successful
2MV-1 No.2	9/1/62	USSR	Lander	Launch failure
2MV-2 No. 1	9/12/62	USSR	Flyby	Launch failure
2MV-2 No. 1	2/19/64	USSR	Flyby	Launch failure
Kosmos 27	3/27/64	USSR	Flyby	Launch failure
Zond-1	4/2/64	USSR	Flyby/lander	Spacecraft failure
Venera 2	11/12/65	USSR	Flyby	Spacecraft failure
Venera 3	11/16/65	USSR	Lander	Spacecraft failure
Kosmo 96	11/23/65	USSR	Flyby	Launch failure
Venera 4	6/12/67	USSR	Atmospheric	Successful (First manmade enter the atmosphere of Venus)
Mariner 5	6/14/67	MASA	Flyby	Successful
Kosmos 167	6/17/67	USSR	Lander	Launch failure

Venera 5	1/5/69	USSR	Atmospheric	Successful
Venera 6	1/10/69	USSR	Atmospheric	Successful
Venera 7	8/17/70	USSR	Lander	Partially successful (Landed on its side, making it the first soft landing on another planet. Only returned partial data)
Kosmos 359	8/22/70	USSR	Lander	Launch failure
Venera 8	3/27/72	USSR	Lander	Successful
Kosmos 482	3/31/72	USSR	Lander	Launch failure
Mariner 10	11/3/73	NASA	Flyby	Successful
Venera 9	6/8/75	USSR	Orbiter/lander	Successful
Venera 10	6/14/75	USSR	Orbiter/lander	Successful
Venera 11	9/9/78	USSR	Flyby/lander	Partially successful (some instruments failed)
Venera 12	9/14/78	USSR	Flyby/lander	Partially successful (Both cameras on lander failed)
Pioneer Venus 1	5/20/78	NASA	Orbiter	Successful
Pioneer Venus 2	8/8/78	NASA	Atmospheric	Successful
Venera 13	10/30/81	USSR	Flyby/lander	Successful
Venera 14	11/4/81	USSR	Flyby/lander	Successful
Venera 15	6/2/83	USSR	Orbiter	Successful
Venera 16	6/7/83	USSR	Orbiter	Successful
Vega 1	12/15/84	USSR	Flyby/atmospheric/lander	Successful
Vega 2	12/21/84	USSR	Flyby/atmosphere/lander	Successful (last Soviet mission to Venus)
Magellan	5/4/89	NASA	Orbiter	Successful (Used Radar to map the planet)
Galileo	10/18/89	NASA	Gravity assist	Successful (gravity assist en route to Jupiter)
Cassini	10/15/97	NASA/ESA	Gravity assist	Successful (gravity assist en route to Saturn)
MESSENGER	8/4/04	NASA	Gravity assist	Successful (gravity assist en route to Mercury)
Venus Express	11/9/05	ESA	Orbiter	Successful
Akatsuki	5/20/10	JAXA	Orbiter	Successful (still operation)
IKAROS	5/20/10	JAXA	Flyby	Successful (experimental solar sail deployed by Akatsuki)

Shin'en	5/20/10	JAXA	Flyby	Spacecraft failure (communication lost and past Venus
BepiColombo	10/20/18	ESA/JAXA	Gravity assist	Successful (made two flybys for gravity assist en route to Mercury)

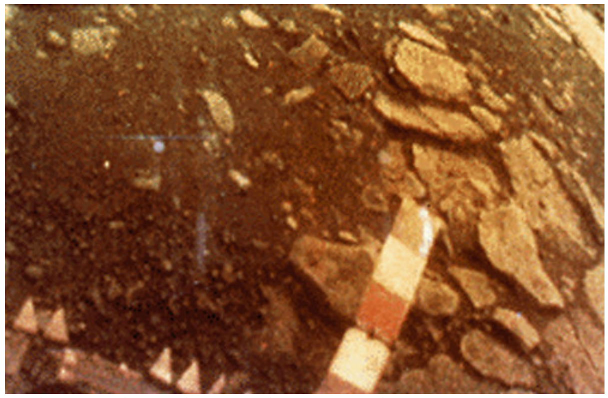


Image of the surface of Venus from one of the Soviet Venera landers.

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Cloud cities on Venus?

Several agencies around the world have future missions planned or proposed for Venus. Some scientists have suggested that Venus might be the place to establish a cloud city, like the one portrayed in *Star War: The Empire Strikes Back*. Because carbon dioxide is heavier than breathable air, you could fill a balloon with a nitrogen/oxygen mix and it will float at that level. At about 30 miles about the surface, the pressure is close to that on Earth and the temperatures are more bearable than the hellish conditions on the surface. A 1-km diameter spherical balloon could lift 700,000 tons (about two Empire State Buildings) while a balloon 2-km in diameter could life 6 million tons! Colonists could (theoretically) live inside these balloon cities and use robots to mine the surface.

NASA has a proposal called HAVOC (High Altitude Venus Orbital Concept). This would involve sending astronauts to Venus with a dirigible that they could fill with ordinary air. They could then pilot this airship 30 miles above the surface where the pressure is close to that of the Earth.

7.7: Missions to Mars.

7.7.1 Early Missions to Mars

Mars has long fascinated humanity. From H. G. Wells' War of the Worlds to Percival Lowell's claims of a Martian society digging canals to move water from the poles to the equator, the possibility of Mars having life has been a topic of speculation for well over a century. Since 1960, we have sent numerous probes to the Red Planet. Unfortunately, about half of the spacecraft we sent to Mars have failed in their mission. The Table below summarizes the Martian missions to date.

Spacecraft	Launch Date	Operator	Mission	Outcome
1M No.1	10 October 1960	USSR	Flyby	Launch failure
1M No.2	14 October 1960	USSR	Flyby	Launch failure
2MV-4 No.1	24 October 1962	USSR	Flyby	Launch failure
Mars 1 (2MV-4 No.2)	1 November 1962	USSR	Flyby	Spacecraft failure
2MV-3 No.1	4 November 1962	USSR	Lander	Launch failure
Mariner 3	5 November 1964	NASA	Flyby	Launch failure
Mariner 4	28 November 1964	NASA	Flyby	Successful
Zond 2 (3MV-4A No.2)	30 November 1964	USSR	Flyby	Spacecraft failure
Mariner 6	25 February 1969	NASA	Flyby	Successful
2M No.521	27 March 1969	USSR	Orbiter	Launch failure
Mariner 7	27 March 1969	NASA	Flyby	Successful
2M No.522	2 April 1969	USSR	Orbiter	Launch failure
Mariner 8	9 May 1971	NASA	Orbiter	Launch failure
Kosmos 419	10 May 1971	USSR	Orbiter	Launch failure
Mars 2	19 May 1971	USSR	Orbiter	Successful
Mars 2 lander	19 May 1971	USSR	Lander	Spacecraft failure
Mars 3	28 May 1971	USSR	Orbiter	Successful
Mars 3	28 May 1971	USSR	Lander	Successful
Prop-M Rover	28 May 1971	USSR	Rover	Partial failure
Mariner 9	30 May 1971	NASA	Orbiter	Successful
Mars 4	21 July 1973	USSR	Orbiter	Spacecraft failure
Mars 5	25 July 1973	USSR	Orbiter	Partial failure
Mars 6	5 August 1973	USSR	Lander Flyby	Spacecraft failure

Mars 7	9 August 1973	USSR	Lander Flyby	Spacecraft failure
Viking 1 orbiter	20 August 1975	NASA	Orbiter	Successful
Viking 1 lander	20 August 1975	NASA	Lander	Successful
Viking 2 orbiter	9 September 1975	NASA	Orbiter	Successful
Viking 2 lander	9 September 1975	NASA	Lander	Successful
Phobos 1 *(1F No.101)*	7 July 1988	USSR	Orbiter Phobos lander	Spacecraft failure
Phobos 2 *(1F No.102)*	12 July 1988	USSR	Orbiter Phobos lander	Partial failure
Mars Observer	25 September 1992	NASA	Orbiter	Spacecraft failure
Mars Global Surveyor	7 November 1996	NASA	Orbiter	Successful
Mars 96	16 November 1996	Russia	Orbiter Penetrators	Launch failure
Mars Pathfinder	4 December 1996	NASA	Lander	Successful
Sojourner	4 December 1996	NASA	Rover	Successful
Nozomi *(PLANET-B)*	3 July 1998	ISAS	Orbiter	Spacecraft failure
Mars Climate Orbiter	11 December 1998	NASA	Orbiter	Spacecraft failure
Mars Polar Lander	3 January 1999	NASA	Lander	Spacecraft failure
Deep Space 2	3 January 1999	NASA	Penetrator	Spacecraft failure
Mars Odyssey	7 April 2001	NASA	Orbiter	Operational
Mars Express	2 June 2003	ESA	Orbiter	Operational
Beagle 2	2 June 2003	ESA	Lander	Lander failure
Spirit	10 June 2003	NASA	Rover	Successful
Opportunity	8 July 2003	NASA	Rover	Successful
Rosetta	2 March 2004	ESA	Gravity assist	Successful
Mars Reconnaissance Orbiter	12 August 2005	NASA	Orbiter	Operational
Phoenix	4 August 2007	NASA	Lander	Successful
Dawn	27 September 2007	NASA	Gravity assist	Successful
Fobos-Grunt	8 November 2011	Russia	Orbiter Phobos sample	Spacecraft failure

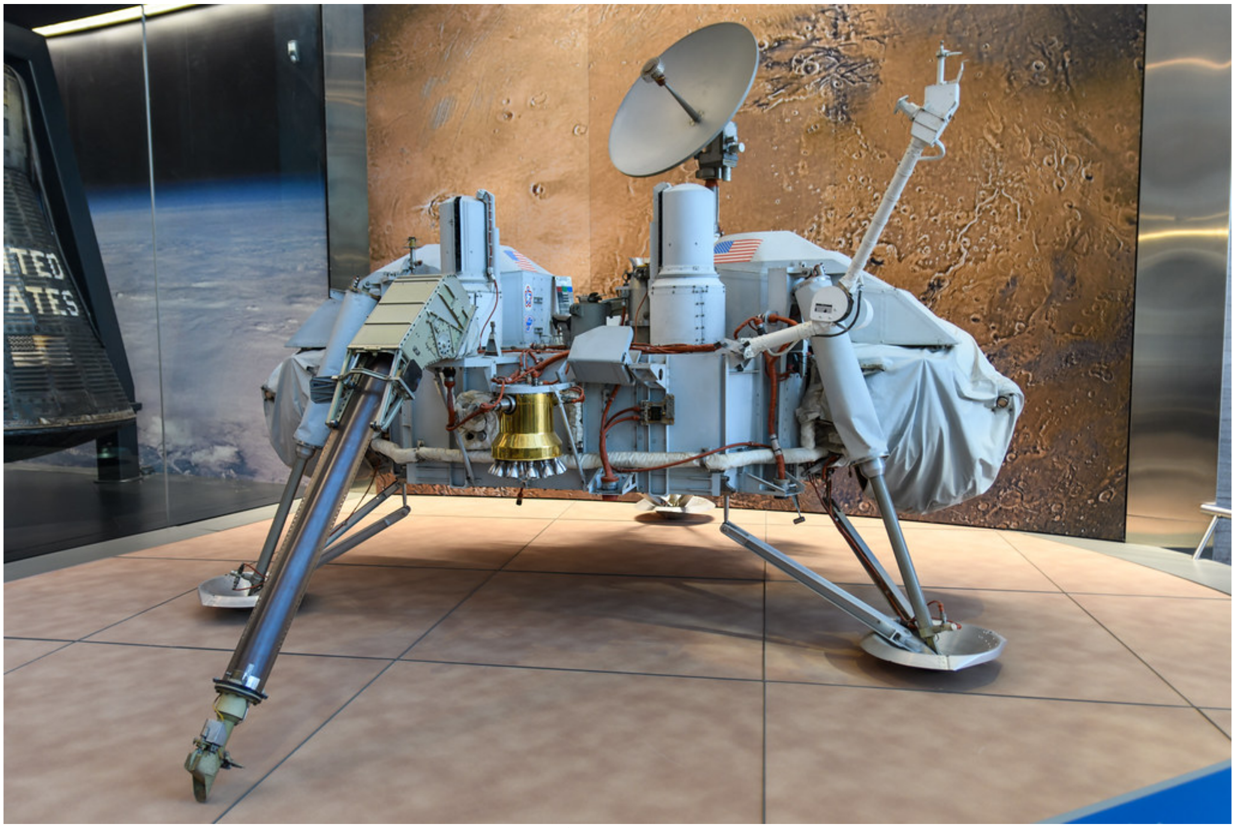
Yinghuo-1	8 November 2011	China	Orbiter	Failure Lost with Fobos-Grunt
Curiosity (Mars Science Laboratory)	26 November 2011	NASA	Rover	Operational
Mars Orbiter Mission (Mangalyaan)	5 November 2013	India	Orbiter	Operational
MAVEN	18 November 2013	NASA	Orbiter	Operational
ExoMars Trace Gas Orbiter	14 March 2016	ESA/Russia	Orbiter	Operational
Schiaparelli EDM lander	14 March 2016	ESA	Lander	Spacecraft failure
InSight	5 May 2018	NASA	Lander	Operational
MarCO	5 May 2018	NASA	Two CubeSats flyby supporting InSight	Successful
Emirates Mars Mission	19 July 2020	UAE	Orbiter	En route
Tianwen-1 orbiter	23 July 2020	China	Orbiter	En route
Tianwen-1 lander/rover	23 July 2020	China	Lander/rover	En route
Perseverance rover	30 July 2020	NASA	Rover	En route
Ingenuity helicopter	30 July 2020	NASA	Helicopter	En route

In May of 1971, following the policy of duel missions, the Soviets launched the Mars 2 and Mars 3 orbiter/lander missions. Both Mars 2 and 3 orbiters reached orbit, but they could not map the surface due to dust storms. The Soviets did not design these orbiters to be reprogrammed after launch, so they were unable to tell the orbiters to hold off until the dust storms abated. Mars is notorious for dust storms that can cover the entire planet and last for months. Meanwhile, the Mars 2 lander failed to land. The Mars 3 did land, but contact was lost 14.3 seconds after landing.

Meanwhile, NASA also launched Mariner 9 the same month as Mars 2 and Mars 3. Mariner 9 became first satellite to orbit another planet, just barely beating Mars 2 and Mars 3. Unlike the Soviets, NASA was able to reprogram Mariner 9, telling to wait out the dust storms. After months of waiting, Mariner 9 sent back images of the surface.

7.7.2 The Viking Missions

In 1975, NASA launched the twin Viking orbiter/lander probes. Both proved to be successful with Viking 1 orbiter orbiting for 1386 orbits while the Viking 2 orbiter orbited for 700 orbits. Both the landers also operated successful. Viking 1 landed successfully and operated for 2245 Earth days while Viking 2 landed successfully and operated for 1281 Earth days. Both landers performed the first chemical tests to look for the presence of life. These test involved taking samples of the Martian regolith and subjecting them to chemical tests to look for gases that could be produced by biological life. The results found some chemicals that could indicate life, but were more likely to have been formed inorganically. At best then, the Viking results were considered inconclusive.



Model of the Viking lander.

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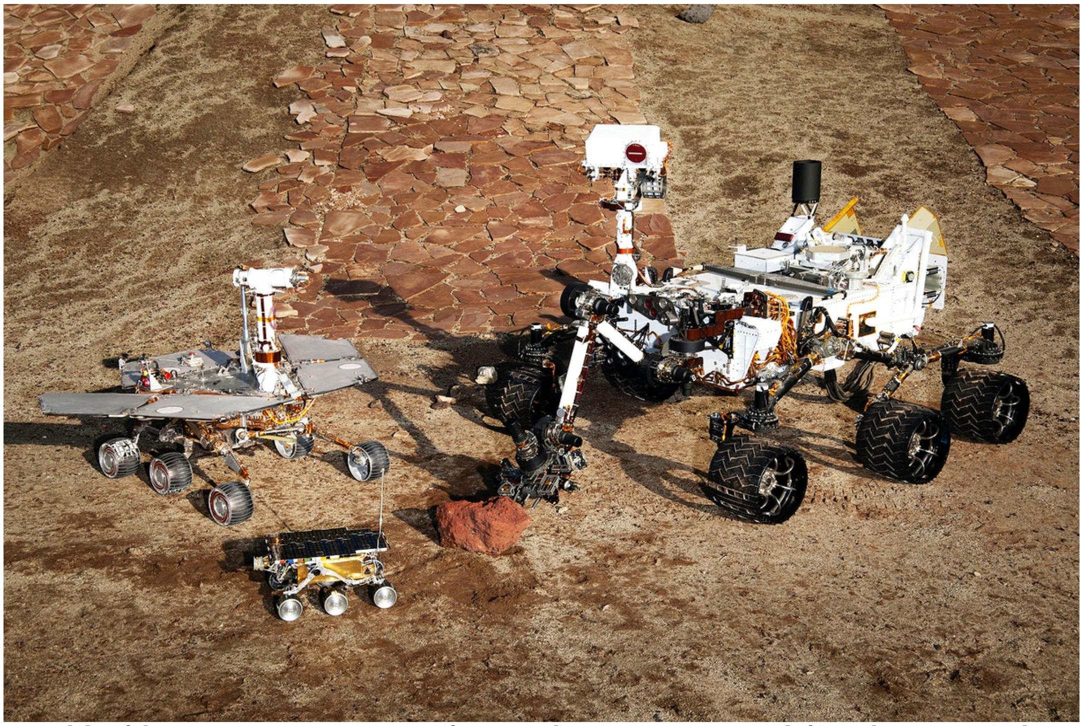
7.7.3 Sojourner, Spirit, and Opportunity: the First Rovers on Mars

There were no further Mars missions until 1988, which time, both the Soviet Union and NASA had numerous failures. Then in 1996, NASA's Mars Global Surveyor succeeded in getting into orbit and operated for seven Earth years. 1996 also saw the landing of the Pathfinder mission, which included the Sojourner. Named after the abolitionist and women's right activist Sojourner Truth, Sojourner became the first successful rover on Mars and operated for 84 days. The Pathfinder lander was formally named the Carl Sagan Memorial Station after its touchdown. Pathfinder was also the first lander to use the "airbag" system in which inflated bags to cushion its landing. After bouncing several times on the Martian surface, Pathfinder rolled to a stop, opened, and allowed Sojourner to roll out.

However, in 1998, NASA suffered what was probably its most embarrassing failure. The Mars Climate Observer approached Mars too closely during orbit insertion attempt because one of the contractors failed to convert their units from Imperial to metrics. Then in 1999, NASA's Mars Polar Lander failed to land and its Deep Space 2 lost communication after landing.

These got better at the beginning of the 21st century. For example, in 2001, NASA's Mars Odyssey successfully entered orbit and is expected to remain operational until 2025. Then in 2003, NASA's Mars Express also entered orbit and is expected to remain operational until 2026. Meanwhile, in 2003, Europe's Beagle 2 was deployed by Mars Express, landed successfully, but two solar panels failed to deploy and lost communication with Earth.

However, in 2003, NASA successfully deployed the Spirit and Opportunity rovers using the airbag landing system. Spirit landed on January 4, 2004. It was originally intended to last for 90 days. However, Spirit exceeded expectations and continued to collect geologic and meteorological data for years. On May 1, 2009, 21.9 times planned its original mission duration, Spirit became stuck in soft soil. The last communication with Earth was March 22, 2010. Meanwhile, Opportunity also performed better that its designers had hoped. It landed on January 25, 2004, three weeks after Spirit in Meridiani Planum. Opportunity's original mission was also for 90 days. It remained in operation until Feb 2019, collecting data on the rocks and atmosphere of Mars. Opportunity found first confirmed meteorite on the surface of Mars. Spirit and Opportunity both found evidence water once flowed on Mars. In 2018, Opportunity went into hibernation mode due to a dust storm which blocked sunlight for its solar panels. Attempts to revive the rover after the storm failed and in February 2019, NASA declared Opportunity’s mission complete, fifteen years after its landing.



Models of three Mars rovers: Sojourner (foreground), Spirit/Opportunity (left), and Curiosity (right).

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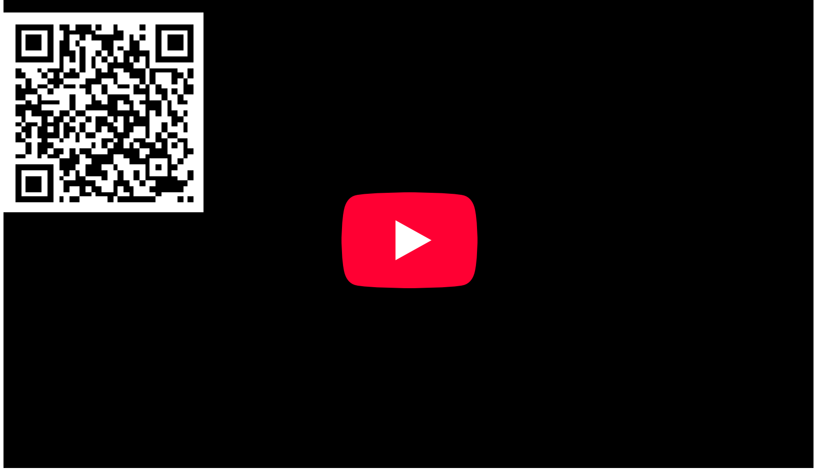
In 2005, NASA’s Mars Reconnaissance Orbiter was successful and continues to map the surface today. Then in 2007, NASA launched the Phoenix lander. Built from spare parts and modifications from the failed polar lander, Phoenix rose from the ashes of that failure. Successfully landing on Mars, ts mission lasted until November 2, 2008. Phoenix found evidence of perchlorates, chlorine containing compounds that might indicate life once existed on Mars.

Curiosity, the next rover from NASA landed in Gale Crater on August 6, 2012. Unlike the previous rovers, Curiosity was too large for the airbag system. Instead, NASA employed the “sky crane” system. Rockets slowed the spacecraft’s descent while a cable lowered Curiosity onto the surface. Once Curiosity touched down, the cable detached, and the sky crane component crashed onto the surface. Curiosity’s initial 2-year mission has been extended indefinitely. It is looking for any evidence of biological life in Mars’ past. Recently Curiosity detected methane in the atmosphere and other organic chemicals that could be the “precursors” of life.

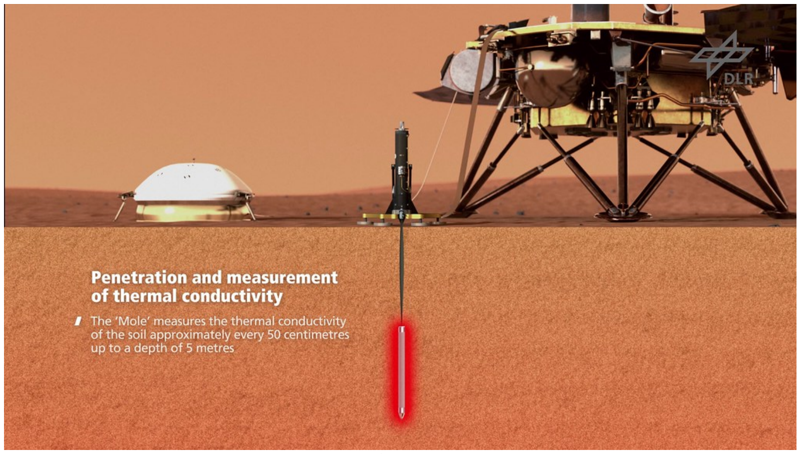


7.7.4 Insight, Maven, and Perseverence

Other recent missions to Mars include:

- India’s Mars Orbiter Mission which is expected to continue operation until 2020.
- NASA’s Maven (Mars Atmosphere and Volatile Evolution) orbiter continues to study the Martian atmosphere and how Mars lost so much of it over time.
- The joint ESA/Russian ExoMars Trace Gas Orbiter (TGO) is also studying the Martian atmosphere, particularly how it has so much methane.

- NASA’s InSight landed on November 26, 2018 in the Elysium Planitia. Its primary objective is to study the crust, core, and mantle of Mars. It uses a seismometer and has recently detected some seismic activity on Mars and includes the “mole” which digs 16 feet below the surface to measure temperatures. InSight also includes to CubeSats, MarCO-A and MarCO-B, nicknamed Wall-E and Eve. They were deployed as communication relay satellites to keep InSight in communication even when it is out of line of sight with Earth. Wall-E and Eve are first CubeSats deployed beyond Earth orbit. each weighs about 13.5 Kg (30 lb) and are an example of small, lightweight satellites that are increasingly being used for low-cost missions.
- Perseverance was launched in 2020 and landed on Mars in February 2021.
- Perseverance included the helicopter Ingenious, which is now the first successful powered flight on another planet.



Artist's conception of the Mars InSight lander.

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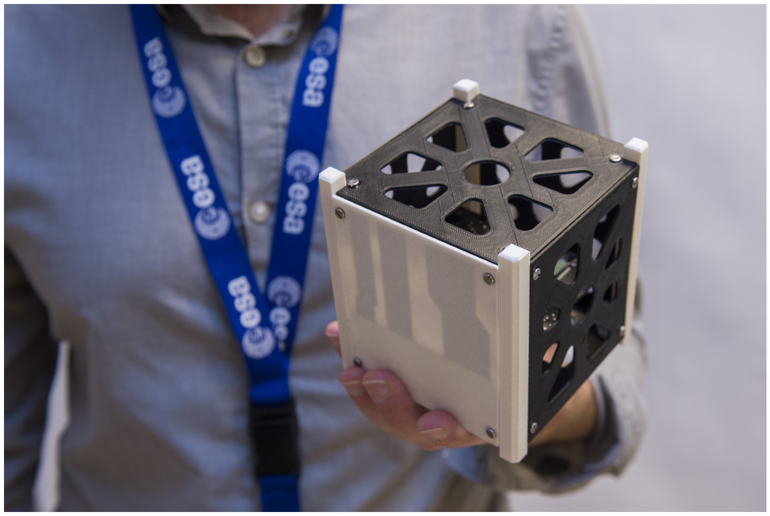

Small, lightweight cubesats are being used for low cost orbital missions around Earth and Mars.

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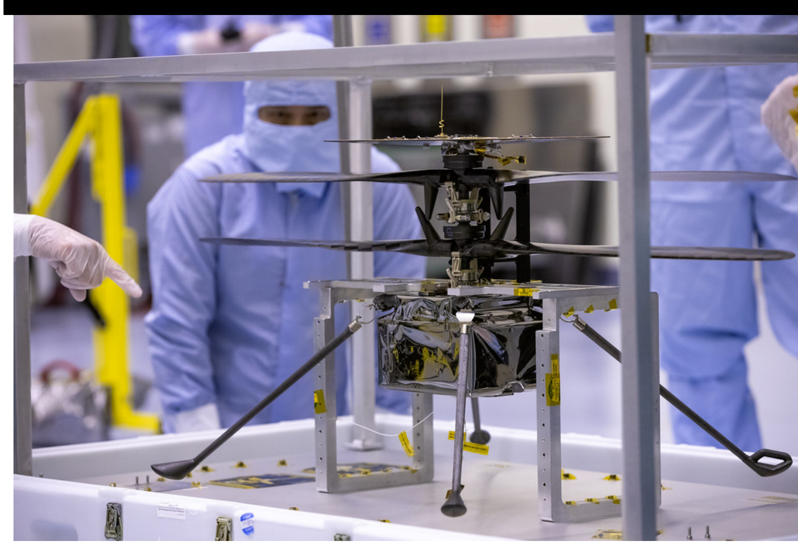

This helicopter was deployed remotely by NASA's Perseverance rover in 2021.

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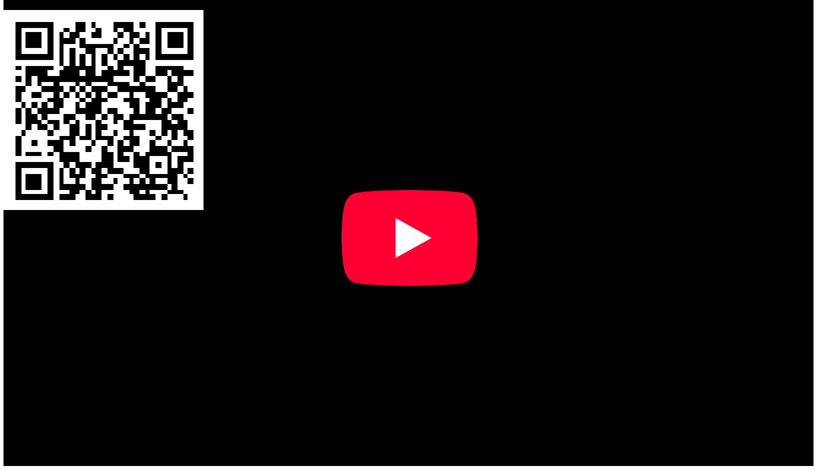


Planned missions to Mars over the next few years include:

- Hope Mars Mission, which is an orbiter planned by the United Arab Emirates
- In 2020, NASA launched Perseverance a combined rover/helicopter mission This will be the first helicopter deployed on another planet.
- ESA and Russia will launch the joint mission, Rosalind Franklin (Formally ExoMars) rover.
- China will launch the Mars Global Remote Sensing Orbiter and a Small Rover (HX-1).
- Japan with launch the Mars Terahertz Microsatellite, a combined orbiter/rover mission and the Martian Moons Exploration, which includes an orbiter and a Phobos lander.
- India will launch Mars Orbiter Mission 2.

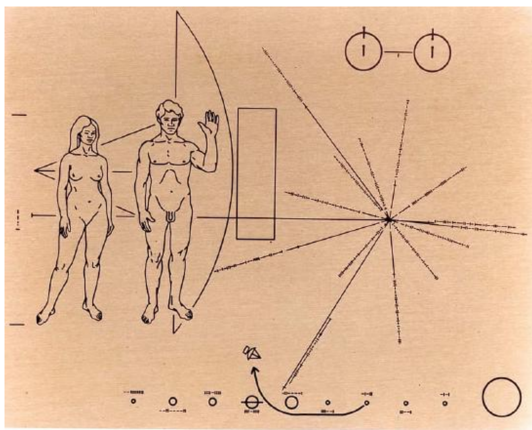
7.8: Missions to the Outer Solar System

7.8.1 Pioneer and Voyager

Because of the difficulty and expense involved, we have not sent as many missions to study the Jovian planets and their moons. NASA launched Pioneer 10 in March of 1972 and it became the first probe to cross the asteroid belt. On November 6, 1973, Pioneer 10 began taking pictures of Jupiter. After its flyby of Jupiter, it continued out to head out to the edge of the solar system, studying the solar wind and cosmic rays. We lost radio contact on January 23, 2003.

Following its policy of duel missions, NASA launched Pioneer 11 on April 6, 1973. Like its twin, Pioneer 11 studied the asteroid belt, Jupiter, cosmic rays, and the solar wind. It also became the first probe to study Saturn and its rings in a flyby. Like Pioneer 10, Pioneer II is now on course to leave the solar system. NASA reported its last radio contact with Pioneer 11 November 24, 1995.

Both Pioneer 10 and 11 carried a gold plaque showing our relative position, a hydrogen molecule, and images of a man and a woman. Though it will be many thousands of years before either Pioneer probe passes near another star, the hope was that this message of piece might one day be found by an alien civilization.



Both Pioneer probes carried this plaque as a message to any future alien civilization.

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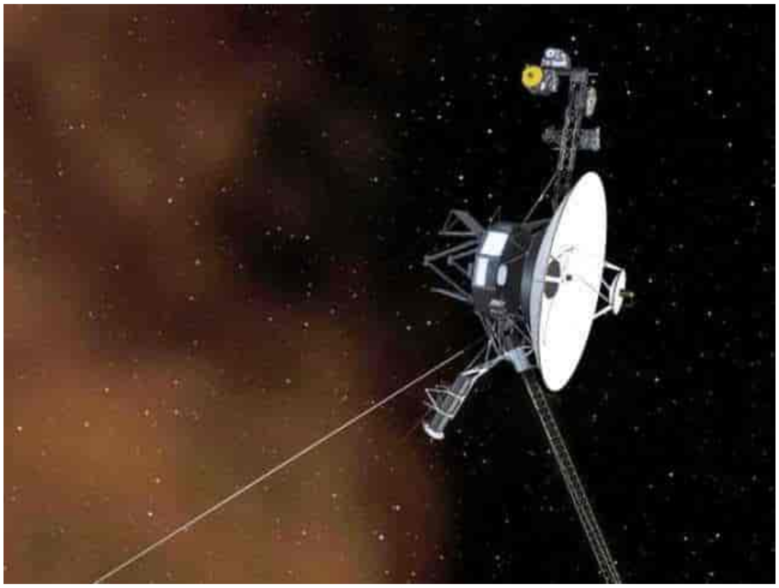
NASA decided to build on the success of Pioneer 10 and 11 by taking advantage of a once in a lifetime alignment of the Jovian planets with would enable them to send a probe to all four of them. Such an alignment only occurs every 160 years and NASA was determined not to miss it. Redesigning the Pioneer probes, NASA created the two Voyager probes. NASA launched Voyager 1 on September 5, 1977 and Voyager 2 on August 20, 1977. Even though they launched Voyager 2 first, NASA sent Voyage 1 on a faster trajectory so that it reached Jupiter first. Voyager 1 conducted flybys of Jupiter, Saturn, and Saturn's moon Titan. Voyager 1 discovered three new moons of Jupiter, which were named Adrastea, Metis, and Thebe. It also discovered active volcanoes on Jupiter's moon Io and that Europa's ice crust is "cracked" due to tidal heating and may have a liquid water interior. After its flyby of Saturn, Voyager 1 headed "north" in the solar system. On August 25, 2012, Voyager 1 became the first satellite to reach **heliopause**, the boundary between the Sun's magnetosphere and the magnetosphere of the Milky Way Galaxy. This made it the first probe to enter what many astronomers consider interstellar space, although it will be many more years before it reaches the Oort Cloud of comets that surround our Solar System.

Voyager 2 made flybys of Jupiter, Saturn, Uranus, and Neptune and to date, is the only probe to visit Uranus and Neptune. Voyager 2 transmitted high-resolution photos of Europa, confirming the findings of Voyager 1. Like Voyage 1, Voyager 2 has also reached heliopause and is traveling through interstellar space. Just as the Pioneer probes carried a gold plate as a message to any alien civilization, both Voyager 1 and Voyager 2 carried a golden record that included sounds of Earth, including greetings in various languages and music from Mozart and Chuck Berry. Both Voyager probes continue to transmit data and their radioactive power supplies are expected to run out sometime in 2024-2025.



The Voyager probes sent back our first images of the Jovian planets.

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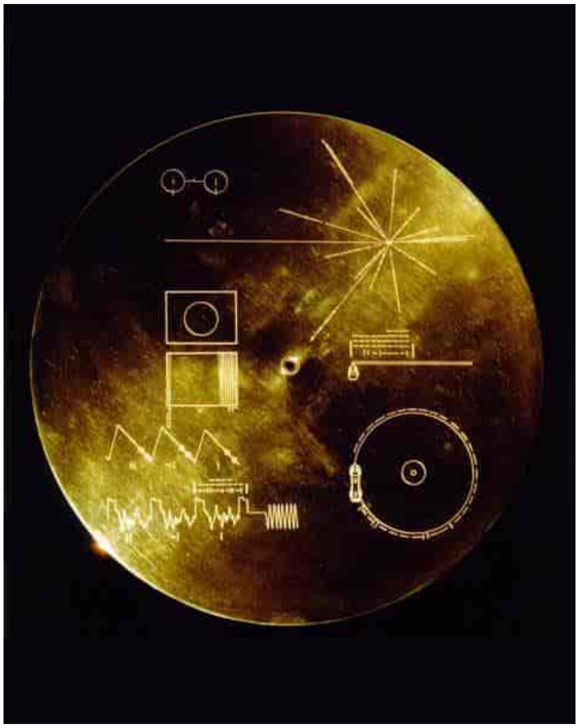

Both of the Voyager probes carried a gold record with recordings of music and greetings from Earth.

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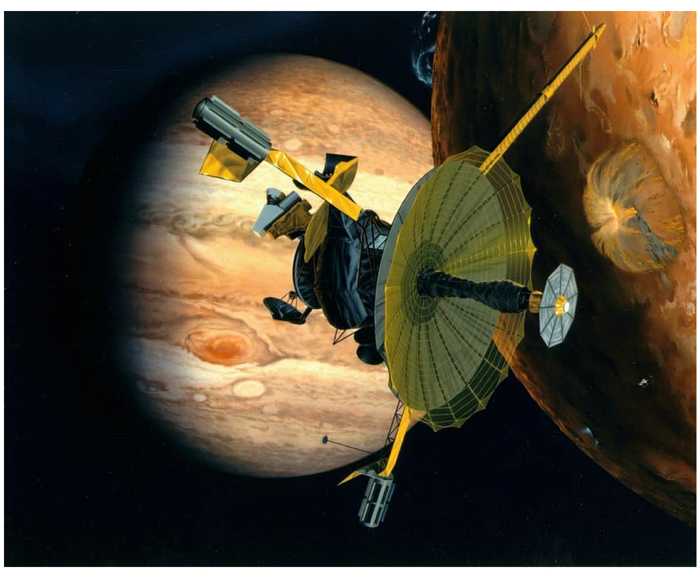
7.8.2 Ulysses and Galileo

In 1990, NASA and ESA launched Ulysses, a join mission to study the Sun. In February 1992, it made a gravity assist maneuver with Jupiter to fly above the orbital plane of the solar system. As Ulysses flew over Jupiter's north pole and made measurements of its magnetic field.

In October 1988, NASA launched Galileo by the Atlantis shuttle. NASA had planned to launch Galileo earlier, but the Challenger disaster delayed several missions, including Galileo. This proved to be a problem as when scientists attempted to open its high gain antenna, it failed to deploy. Apparently, while Galileo had been in storage waiting for its rescheduled launch, the lubricant for its antenna had degraded and failed to work. After several attempts to open the high gain antenna failed, NASA had to resort to send all of Galileo's data through its low gain antenna. The low gain antenna was designed only for maneuvering and course corrections and could not handle all the data planned for Galileo. However, through compression techniques and other efforts, NASA was able to salvage much of Galileo's mission.

As it passed through the Asteroid Belt, Galileo, made a flyby of the asteroid Gaspra and discovered the first asteroid moon. Galileo also captured images of the comet Shoemaker-Levy-9's crash into Jupiter's atmosphere in 1994. Then, it reached Jupiter on December 7, 1995. In July 1995, it dropped a probe into Jupiter's atmosphere which collected data for 57 minutes. Galileo also found more evidence that Europa has liquid water under its surface and found that Ganymede has a strong magnetic field, making it unique among moons. In September 2003, NASA allowed Galileo to burn up in Jupiter's atmosphere to prevent its moons from being contaminated with Earth bacteria.



The Galileo probe dropped the first atmospheric probe into one of the Jovian planets, Jupiter.

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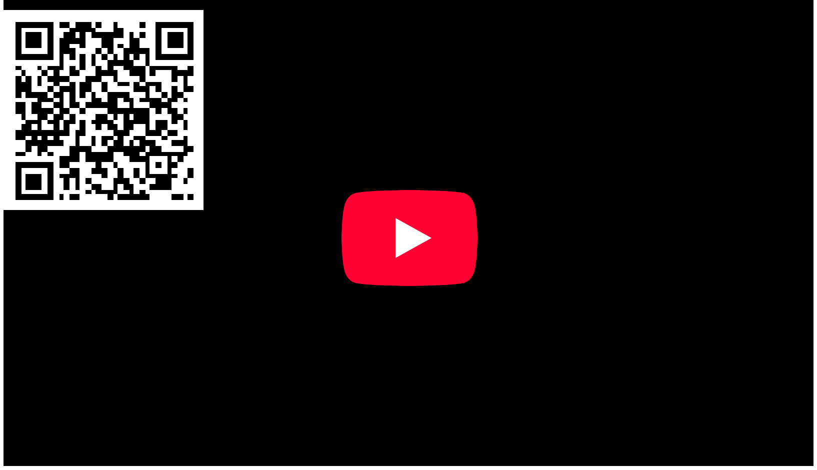
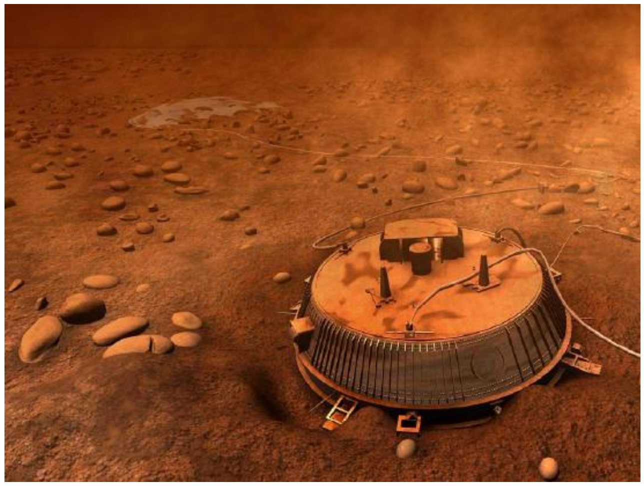


7.8.3 Cassini-Huygens

The next mission to the outer solar system was another joint NASA-ESA mission. Cassini-Huygens was launched on October 15, 1997. This mission consisted of two components the Cassini orbiter and the Huygens lander. It made a flyby of Jupiter on March 5, 2003 and made detailed study of Jupiter's atmosphere, the Great Red Spot, and Jupiter's rings. Its primary target, though, was Saturn and on January 14, 2005, the Huygens module parachuted into Titan's atmosphere and transmitted data for 90 minutes, making it the first successful landing on a moon other than Earth's and first landing in the outer solar system. Cassini made important discoveries about Saturn's rings and moons while Huygens gave us our first glimpse of the atmosphere and surface of Titan. In September 2017, NASA allowed Cassini to enter Saturn's atmosphere and burned up.



Released by the Cassini orbiter, the Huygens became the first successful lander on a moon in the outer solar system.

https:/www.nasa.gov/directorates/heo/scan/images/history/December2004.html;

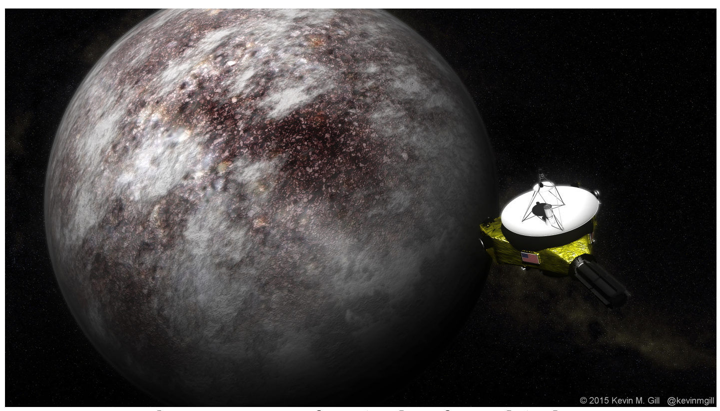
7.8.4 Juno

On August 5, 2011 by NASA launched Juno, which entered a polar orbit of Jupiter on July 5, 2016.

The spacecraft is studying the planet's composition, gravity field, magnetic field, and polar magnetosphere and is looking for evidence that Jupiter has a rocky core. Juno’s mission was originally scheduled to end on July 30, 2021, where, like its predecessor Galileo, it would burn up in Jupiter’s atmosphere. However, NASA has extended its mission until 2025.

7.8.5 New Horizons

Finally, NASA launched New Horizons on January 19, 2006. On February 28, 2007 it made a flyby gravity assist around Jupiter. Then, on January 15, 2015, the spacecraft began its approach phase to Pluto. In August 2016, New Horizons was reported to have traveled at speeds of more than 84,000 km/h (52,000 mph). On October 25, 2016, at 21:48 UTC, the last of the recorded data from the Pluto flyby was received from New Horizons. Having completed its flyby of Pluto, New Horizons then maneuvered for a flyby of Kuiper belt object 486958 Arrokoth (then nicknamed Ultima Thule), which occurred on January 1, 2019. It is now the fifth man-made object to reach escape velocity of the Solar System after Pioneers 10 and 11 and Voyagers 1 and 2.



The New Horizons probe gave us our first (and so far, only) close up images of Pluto.

https:/commons.wikimedia.org/wiki/File:New_Horizons_over_Pluto_(17620333413).jpg;

8: The Earth-Moon System

Learning Objectives

- Describe the layers of the Earth and the geologic forces that shape the Earth's surface.
- Describe the composition and properties of the Earth's atmosphere.
- Explain the origin of the Moon.
- Describe the surface and interior of the Moon.

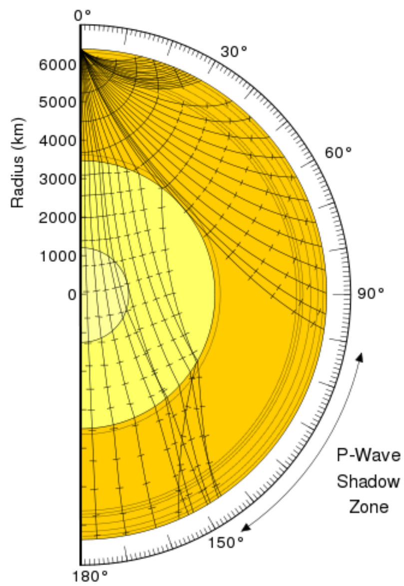
Our Solar System has four terrestrial planets. Of those, the most unique is the one most familiar to us. Earth is the largest of the terrestrial planets and the only one with ample liquid water on its surface. It is also the only one with an atmosphere made primarily of nitrogen and oxygen. It has the strongest magnetic field and the largest Moon. Indeed, the Earth-Moon system has the largest moon relative to the size of its primary. All of the other planets with moons, including Mars, have moons that are much smaller than their bodies.

8.1: Structure of the Earth

8.1.1 The Earth's Layers

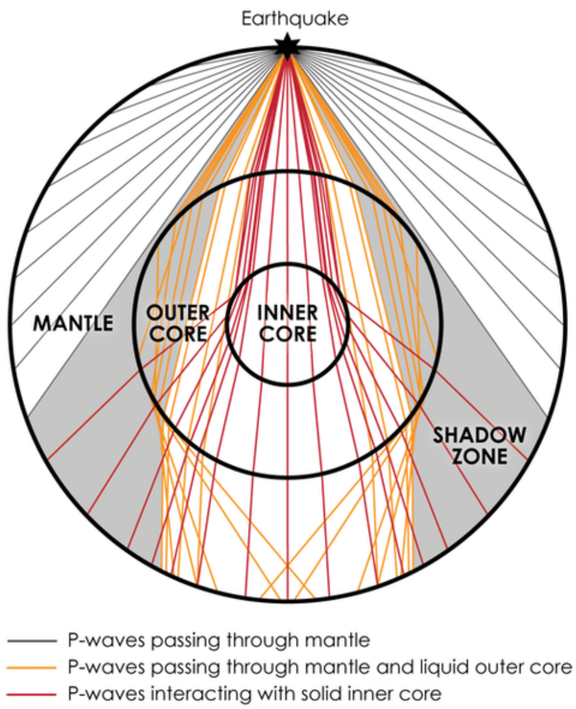
We do not have any way to explore the Earth's interior directly. Instead, we infer its structure by measuring how **seismic waves** travel through the interior. Earthquakes produce two kinds of seismic waves: pressure waves and shear waves. **Pressure waves** can travel through both liquids and solids while shear waves will not travel through liquids, as liquids do not resist shear forces. The pressure wave is a longitudinal wave, whereas the shear wave is a transverse wave. A **shear wave** cannot propagate within a liquid. In addition, the speed of seismic waves depends on density of material. Therefore, we can use the pattern of waves measured by seismometers during earthquakes to deduce the interior structure of Earth.

From our analysis of seismic waves, we have determined that the Earth consists of several layers. The **core** sits at the center of the Earth and consists of two parts: a solid iron and nickel inner core in the center and a molten iron and nickel outer core.



Earthquake waves create a shadow zone because the P-waves cannot travel through liquid.

https://commons.wikimedia.org/wiki/F...hadow_zone.svg



Different kinds of waves travel can be used to model the Earth's interior.

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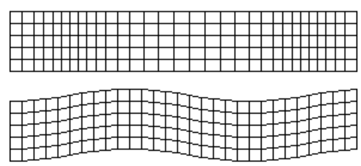
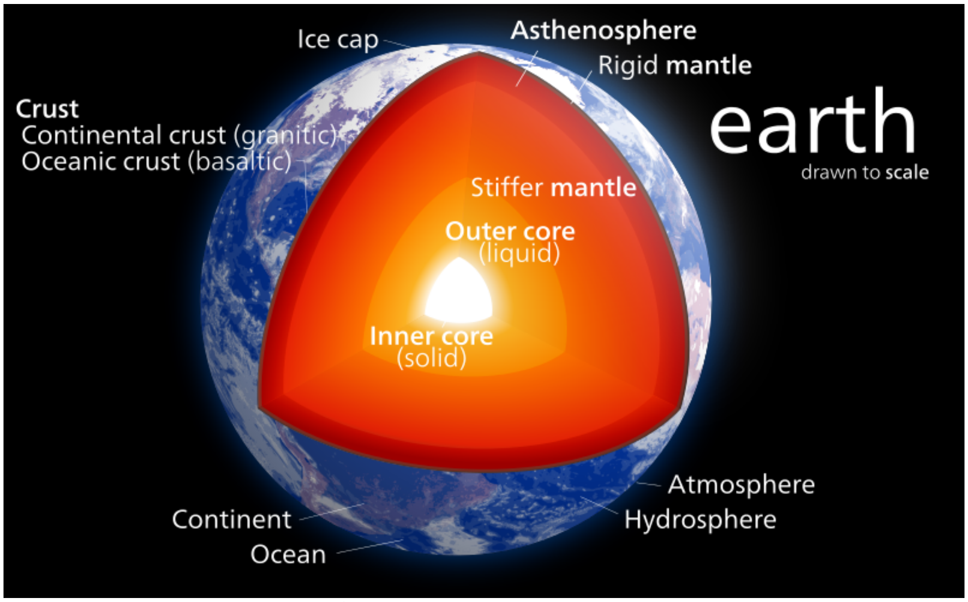


Pressure wave (above) travel through compressions in the medium while transverse waves (below) move through an up and down motion of the medium.

https://commons.wikimedia.org/wiki/File:Wavess.gif

The **Mantle** surrounds the core and consists of a thick layer of less dense, elastic rock. The **asthenosphere**, one of the outer portions of the mantle, contains very soft or melted rock. Above the mantle, the **crust**, a thin layer of brittle, low-density rock, forms the outermost layer of the Earth. Often, geologists refer the uppermost portion of the mantle combined with the crust as the **lithosphere**.



The Earth's interior consists of several layers: Inner core, Outer core, Mantle, and Crust.

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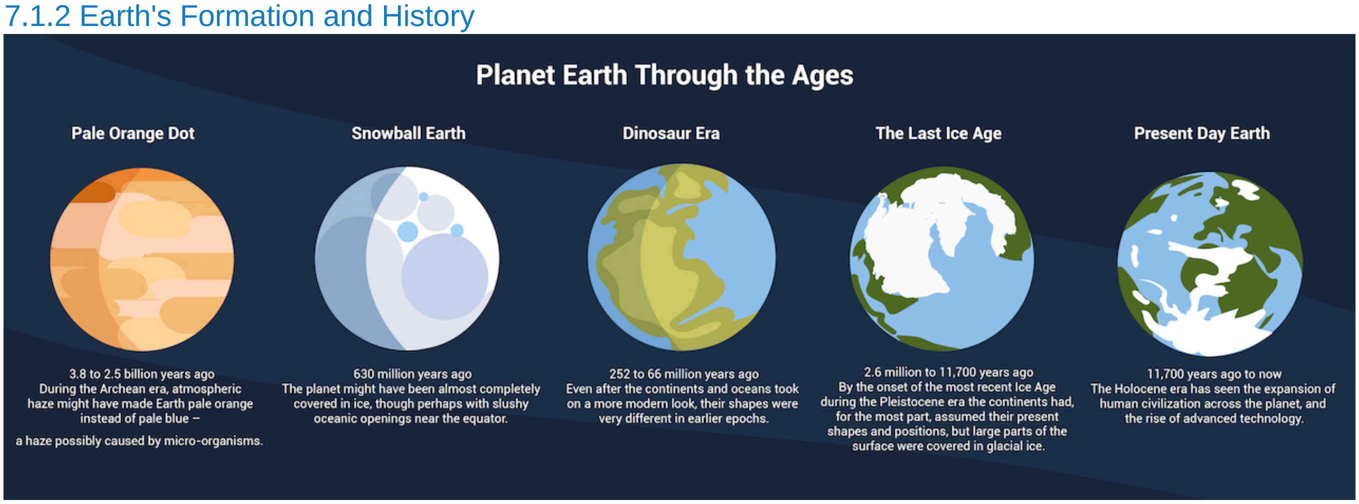
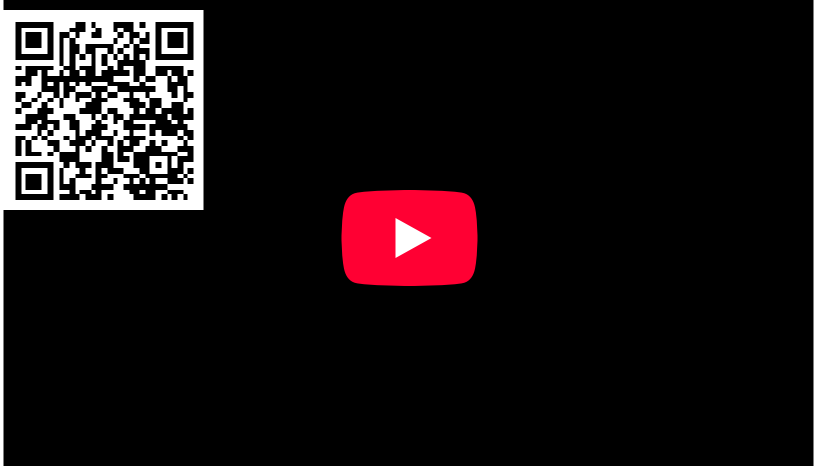
7.1.2 Earth's Formation and History



The stages of the Earth's history.

https:/exoplanets.nasa.gov/resources/2245/planet-earth-through-the-ages;

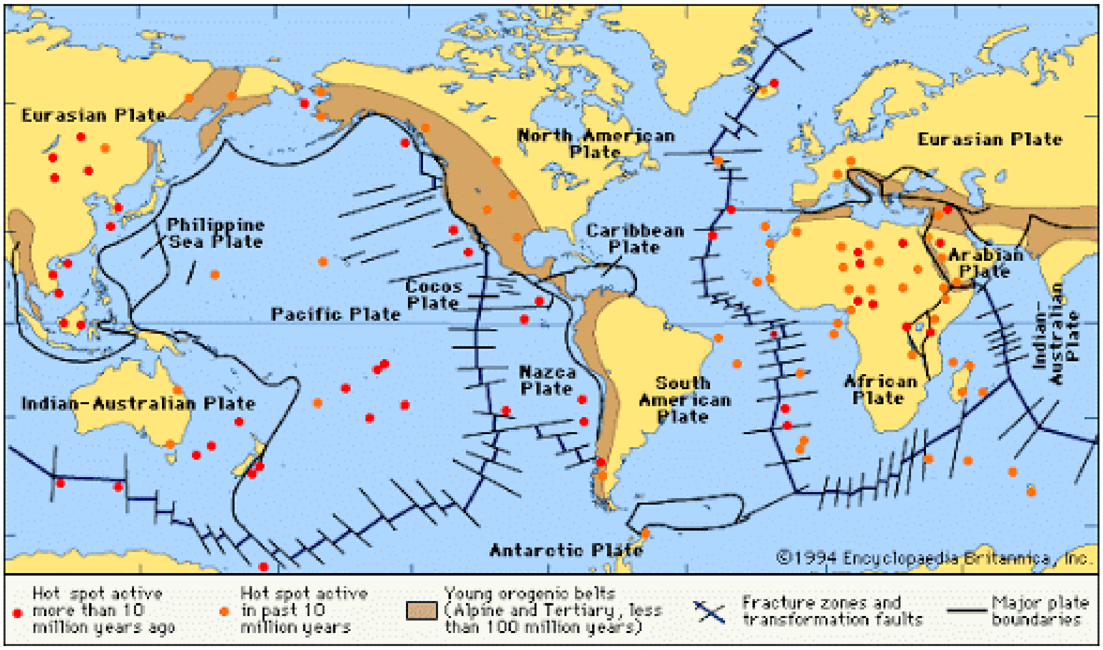


7.1.3 Plate Tectonics

Compared the core, the mantle is much less dense. The mantle is rocky while the core is metallic, consisting of denser material such as iron and nickel that sank to the center when the entire Earth was molten. As noted above, portions of the are molten and volcanic lava comes from mantle, allowing us to analyze of the mantle's composition.

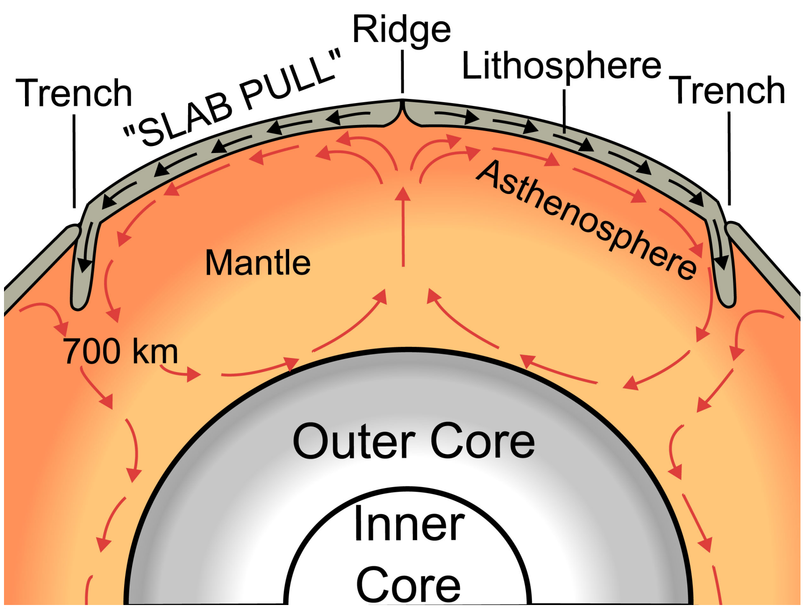
The Earth's crust does not consist of a single piece. Instead, it is broken up pieces called **plates**, which can move independently at a rate of a few centimeters a year. **Plate tectonics**, the movement of the lithospheric plates, causes earthquakes and volcanoes to occur at the boundaries between the plates.

Heat from the inner mantle drives convection currents which push the mantle's soft up as it warms and down as it cools. The movement of these convection currents drive plate tectonics as it drags the plates around. Over hundreds of millions of years, the continents have moved around the surface of the Earth, sometimes combining, separating, and recombining. About 225 million years ago, all the Earth's major lands were joined into one supercontinent called **Pangaea**. The movement of these plates has a major influence of climate and biological evolution.



The major tectonic plates of the Earth.

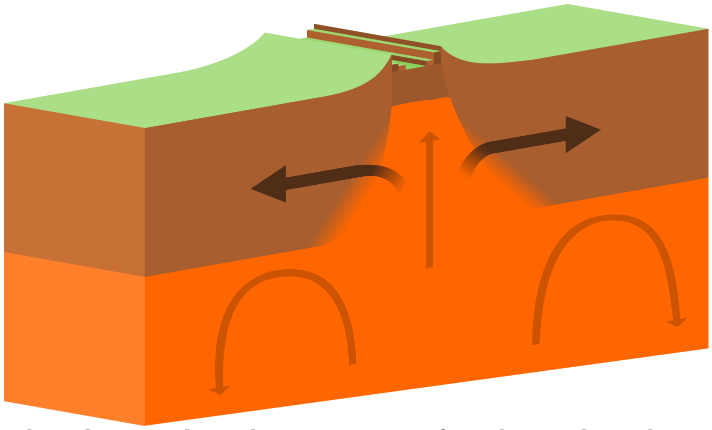
http://enfo.agt.bme.hu/drupal/en/node/10034



Convective forces in the mantle create a conveyor belt movement that drags the tectonic plates around.

https://commons.wikimedia.org/wiki/F..._spreading.svg

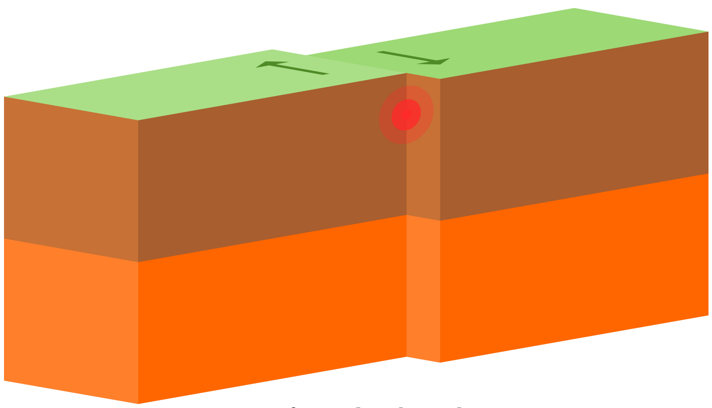
There are three major kinds of plate boundaries. **Divergent plate boundaries** occur where rising **magma** (molten rock) pushes plates apart, creating new crust. Divergent plate boundaries tend to occur under the ocean and new crust tends to form along rifts along the sea floor. These rifts produce long chains of underwater mountains, such as the Mid-Atlantic Ridge, the longest mountain chain on Earth. Ocean crust is therefore younger than continental crust. New crust pushes older crust away from the rift. As the magma cools, certain minerals align themselves with the Earth's magnetosphere. Different alignments of minerals in the ocean crust indicate the Earth's magnetic field has reversed several times.



A divergent plate boundary is a place where magma rises from the mantle, pushing two plates apart.

https://commons.wikimedia.org/wiki/F...e_boundary.svg

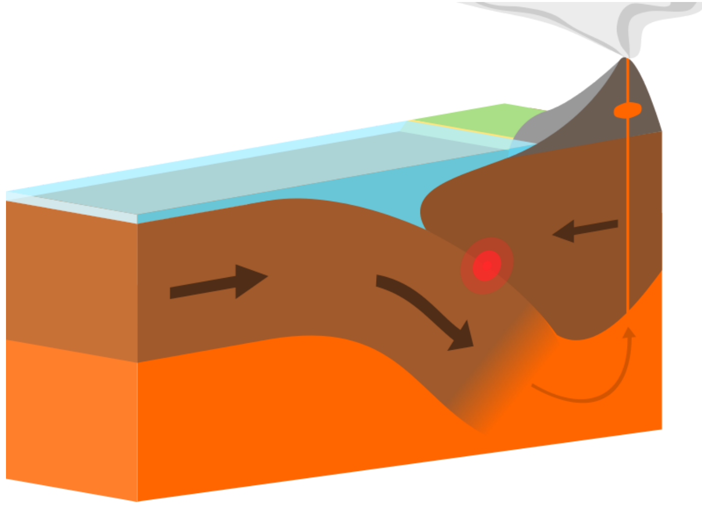
At **transform plate boundaries**, two plates meet, slipping and grinding. As the plates grind against each other, they build up frictional forces. Occasionally, these forces trigger a release of energy, producing an earthquake. Transform plate boundaries are often referred to as **strike-slip faults.**



A transform plate boundary.

https://commons.wikimedia.org/wiki/F...directions.svg

At **convergent plate boundaries**, plates collide with each other. Underwater convergent plate boundaries cause **subduction** where a section of ocean crust slides beneath a continental crust. At a subduction zone, molten rock erupts through the surface in volcanoes, creating chains of volcanic islands like Japan or Philippines. When two continents collide, they produce **uplift.** This raises up mountain ranges like the Himalayas in Asia and the Andes in South America.



Oceanic crust subducting into the mantle at a convergent plate boundary.

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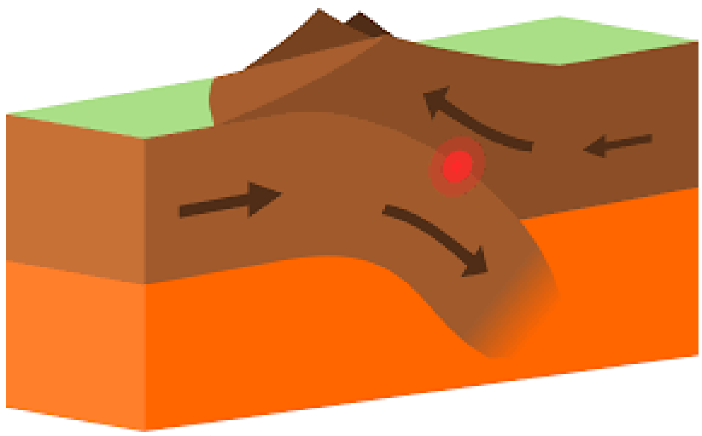
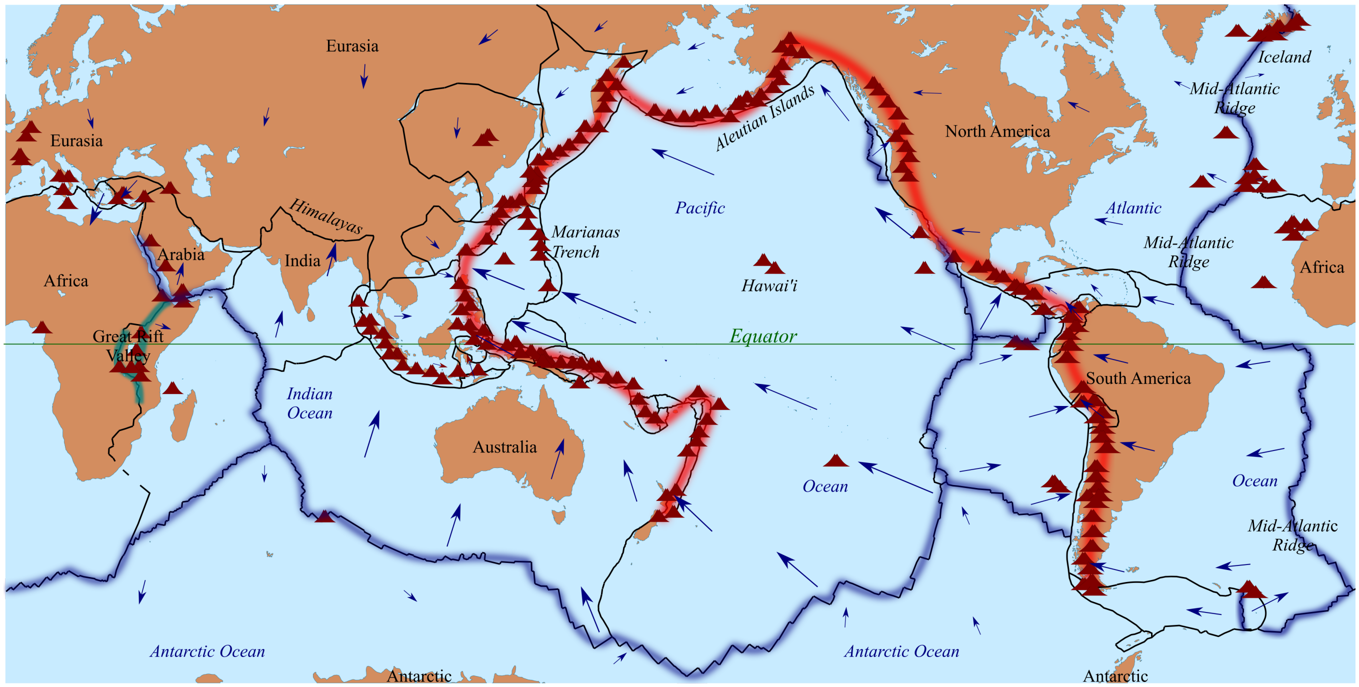


Uplift at a convergent plate boundary.

https://commons.wikimedia.org/wiki/F...e_boundary.svg

As we can see, plate tectonics build mountains, shape the geography of oceans, islands, and continents. some large lakes formed in immense valley floors. The topography created by tectonics shapes climate by altering patterns of rain, wind, currents, heating, cooling, which, affect rates of weathering and erosion and the location of biomes. These in turn, affect evolution and extinction.

The most active portion of the Earth's surface is the **Circum-Pacific Belt or "Ring of Fire."** This is an arc of subduction zones and fault systems that circle around the Pacific Ocean. over 90% of Earth's active volcanoes and earthquakes occur along the "ring of fire."

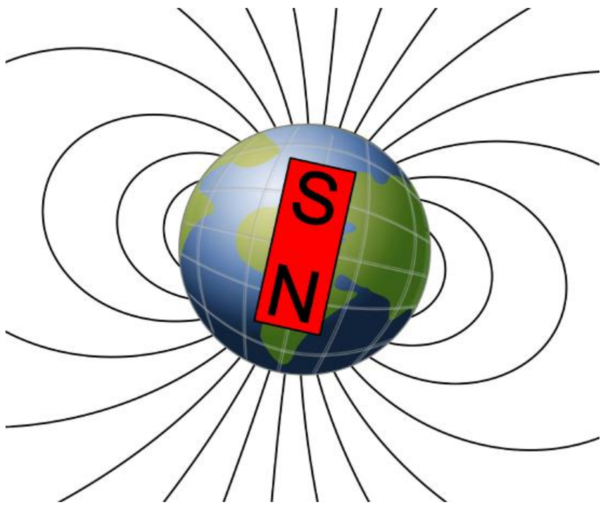


The Ring of Fire, where 90% of Earth's active volcanoes and earthquakes are found.

https://commons.wikimedia.org/wiki/F...ng_of_fire.png

7.1.4 The Magnetosphere

Another produce of the Earth’s internal heat is the **magnetosphere**, the region around Earth where charged particles from the solar wind are trapped. As the Earth rotates, the molten metals in the core produce a **dynamo effect**, in which a rotating liquid conductor induces a powerful magnetic field. As the solar wind interact with the field lines of the magnetosphere, they are trapped in areas called the **Van Allen belts**, where they spiral around the magnetic field lines. The field lines drag the charged particles toward the poles. near the poles, the Van Allen belts intersect the atmosphere. There, the charged particles can collide with atoms in the atmosphere. When they do, they excite electrons, producing the glowing light called an **aurora**, also known as the **Northern and Southern Lights**.



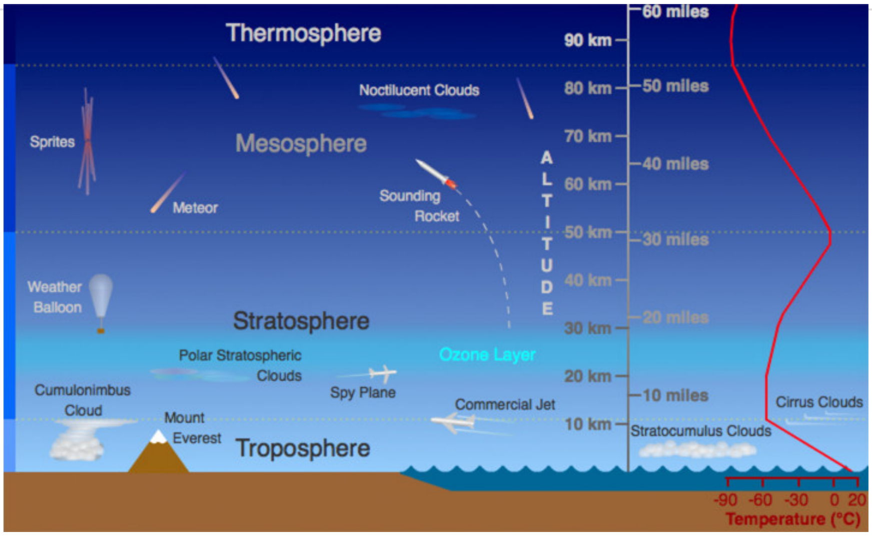
Earth's magnetic field.

https://commons.wikimedia.org/wiki/F..._schematic.svg

The Northern Lights.

https://commons.wikimedia.org/wiki/F...997815384).jpg

8.2: Atmosphere of the Earth



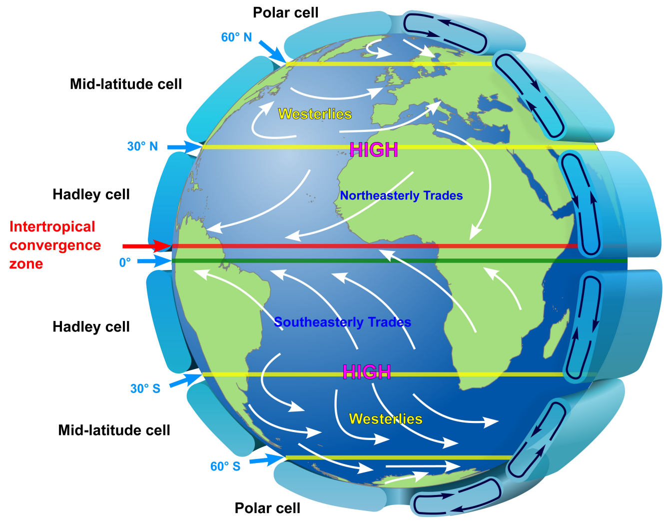
The Earth's atmospheric layers.

https://commons.wikimedia.org/wiki/F...ere_layers.jpg

8.2.1 Troposphere

Like the interior of the Earth, its atmosphere also has several layers. The lowest level, the **troposphere** contains the air we breathe and where our weather patterns occur. **Surface heating** produces convection currents in the troposphere. As the Sun's rays warms the Earth's surface, the air near surface absorbs heat and rises, creating convection currents. As the air rises in the troposphere, it cools, becomes denser, and sinks back toward the surface.

Three major **convection cells** drive the prevailing weather patterns, climate, and ocean currents. The **Hadley cells** consist of warm, moist air rising at the equator. As it rises, the air cools. Since cool air cannot hold as much moisture as warm air, it brings high levels of on the equator, giving its wet, warm tropical climate. The dry, cool air then sinks at 30 degrees latitude north and south, creating dry, desert climates at those latitudes. The **Ferrell cells** operate because the north and south latitudes of 30 and 60 degrees, creating regions of heavy rainfall as 60 degrees latitude. Finally, the **polar cells** operate inside the Arctic and Antarctic circles, creating regions of very little rainfall at the poles. While it may seem strange to think of Antarctica as being a region of low rainfall since it is covered in ice, it receives so little annual rainfall that it is technically a desert.

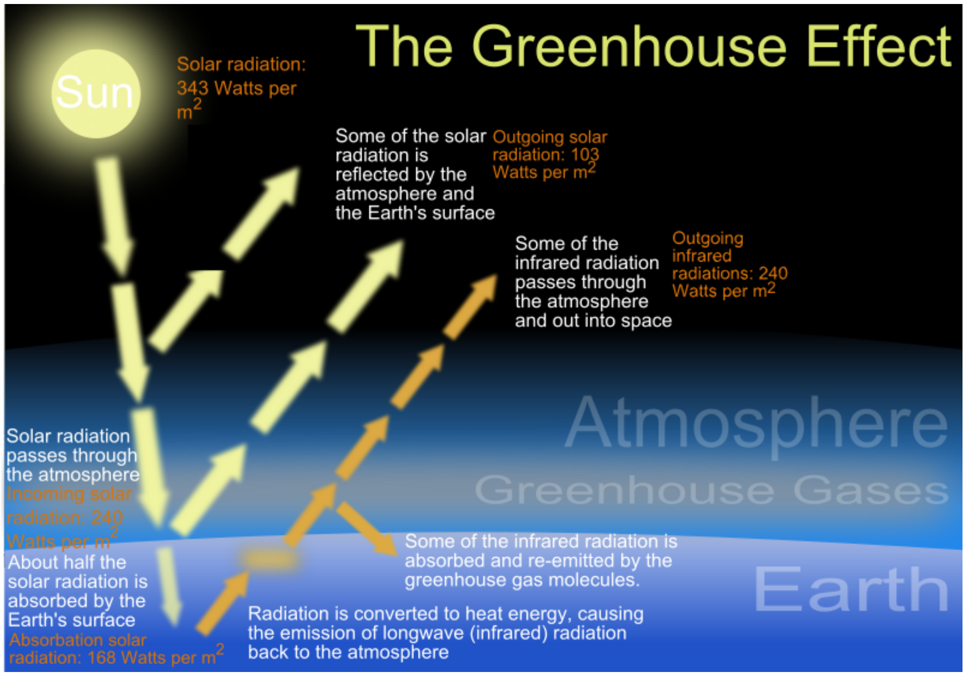


The convection cells of the atmosphere.

https://commons.wikimedia.org/wiki/F...ation_-_en.svg

8.2.2 The Greenhouse Effect

Sunlight that is not reflected is absorbed by Earth's surface, warming it. The surface re-radiates as infrared thermal radiation. While most gases in the atmosphere are transparent to both visible light and infrared radiation, gases with three or more atoms in their molecules will absorb some of the infrared radiation. This produces the **greenhouse effect**, so named because the atmosphere traps heat much like a greenhouse does. Overall, the greenhouse effect benefits life on Earth. Without it, the temperature on the Earth would be much colder than it is and life as we know it would be impossible. However, in recent decades, atmospheric scientists have found extremely strong evidence that Earth is getting warmer. This warmer corresponds with the increase in certain gases in the atmosphere, such as carbon dioxide, a gas that is known to contribute to the greenhouse effect. The atmospheric levels of carbon dioxide have been rising since the industrial revolution in the mid-19th century. The effects of this warming is still a subject of debate, but most climatologists have concluded that it will result in continued melting of the glaciers and rising sea levels, as well as increases in intense storms in some regions and increasing droughts in others.



The Greenhouse Effect.

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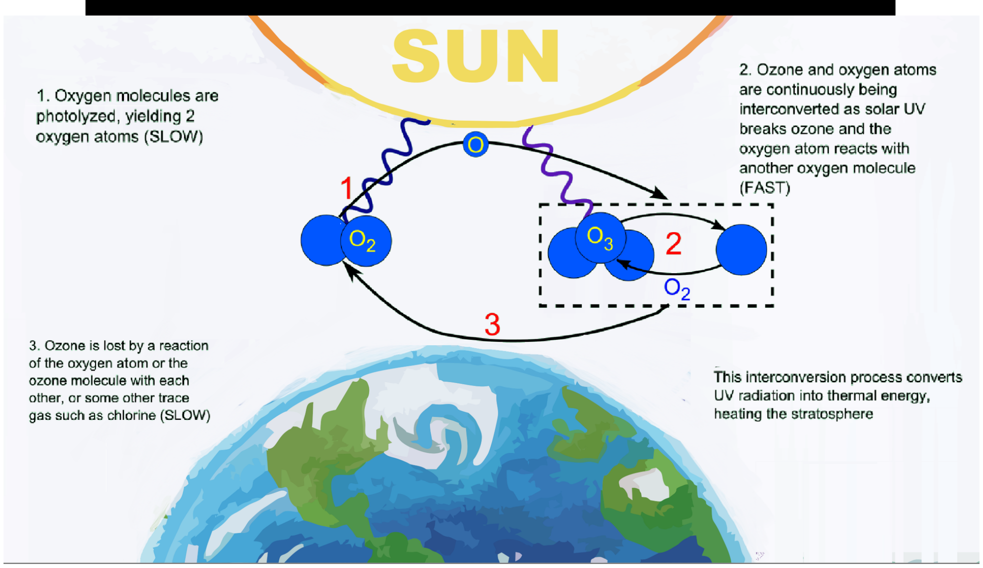

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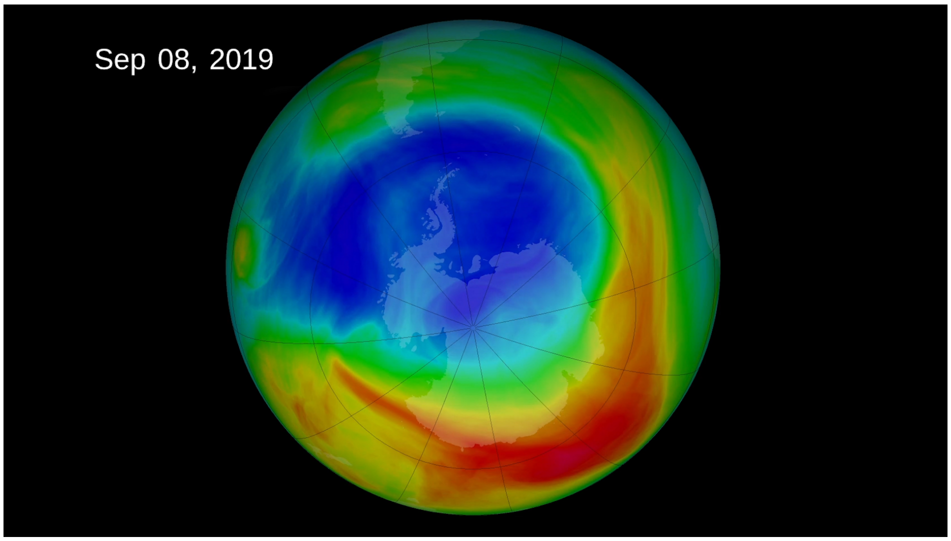
8.2.3 The Upper Layers of the Atmosphere

The layer above the troposphere, the **stratosphere**, contains the **ozone layer**. Since the 1970s, scientists have known that certain chemicals, such as **Chlorofluorocarbons** (CFCs), have been damaging the ozone layer, resulting in an **ozone hole**. The ozone hole is a region of reduced ozone concentration in the stratosphere above Antarctica. The ozone layer absorbs much of the Sun's ultraviolet radiation and without it, humans would be at risk for higher levels of skin cancer and other ailments. In response to concerns about the loss of stratospheric ozone, nations signed the **Montreal Protocol** in 1987, pledging to phase out production of CFCs and other ozone depleting chemicals.



The hole in the ozone layer about Antarctica.

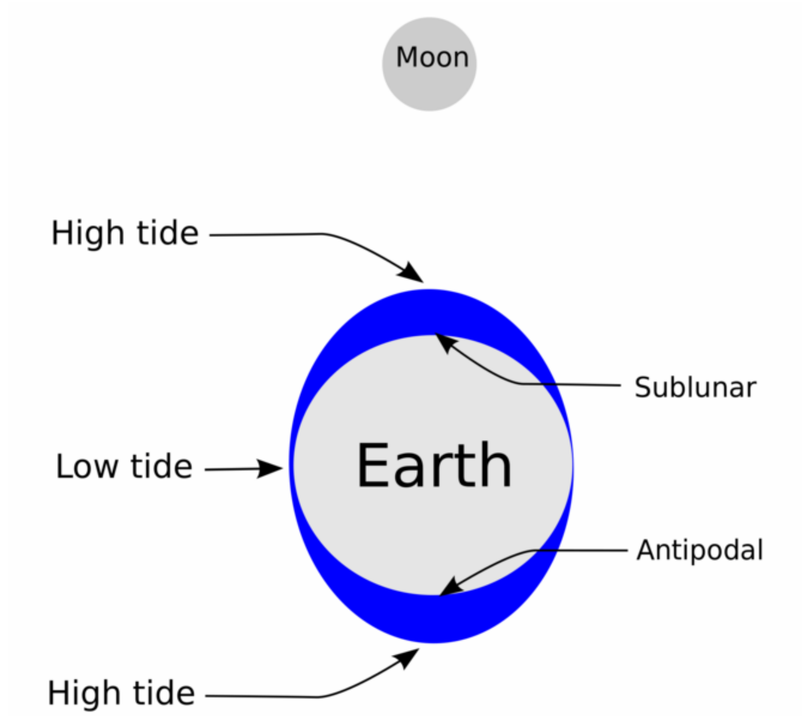
https://commons.wikimedia.org/wiki/F..._depletion.jpg

The two layers about the stratosphere are the **mesosphere** and the **ionosphere**. The ionosphere gets its name because it is ionized by solar radiation and is good conductor. This causes it to reflect waves in the AM range, though it is transparent to radio frequencies used for FM bands and TV.

8.2.4 The Oceans and the Tides

The Earth formed inside the frost line (Section 6.5), so water could not have condensed on its surface during accretion. Astronomers had once assumed that Earth's water can been delivered by comets during the Late Heavy Bombardment period. To confirm this, astronomers studied at least four well-known comets: Halley's Comet and Comets Hyakutake, Hale-Bopp, and 67P/Churyumov-Gerasimenko. In these comets, however, they found that the percentage of deuterium (a form of hydrogen with double the mass of normal hydrogen) is twice that of what we find in average seawater. As a result, astronomers have concluded that comets probably contributed no more than 10% of Earth’s water. The current best bet is that asteroids delivered most of the Earth's water within the first 100 million years after it formed. The majority probably came from asteroids containing water ice. Jupiter’s gravity perturbed the orbits of the asteroids, sending into the inner solar system where they eventually impacted the Earth.

Once important property of the oceans is the daily rising and falling of the **tides**. The Moon’s gravity is the primary force that governs the motion of the tides, although the Sun’s gravity can modify the lunar tides. Tides result from the fact that the gravitational force on Earth from the Moon is unequal. The force on near side of Earth is greater than force on far side. This causes tidal “bulges” of rising water on both the near side and the far side of the Earth and low tides at 90 degrees in between as water flows out of these regions. Tides exert a “drag” force on Earth, which is slowing its rotation. As the Earth’s rotation slows, its angular momentum is transferred to the Moon, causing it to recede further away from the Earth. This will continue until Earth rotates synchronously with the Moon so that the same side of Earth always points toward the Moon. When that comes, the people on one side of the Earth will see the Moon in the sky 24 hours a day while the people on the opposite will never see the Moon again. This has already happened with the Moon, whose near side is always toward Earth.



The Moon's gravity influences the tides.

https://commons.wikimedia.org/wiki/F...s_overview.png

8.3: The Surface and Structure of the Moon.

8.3.1 The Lunar Surface

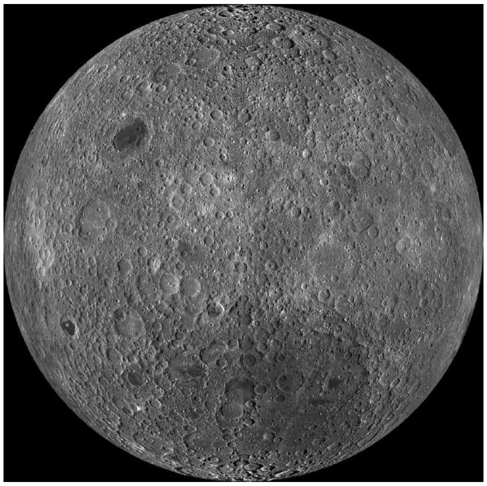
The surface of the Moon consists of large dark flat areas, called **maria** (early observers thought they were oceans and thus gave them the Latin name for seas), due to lava flow. In addition to the maria, the Moon has numerous **craters** and mountain ranges. Compared to the near side of the Moon, the far side is more heavily cratered with fewer maria.

Craters form when a meteoroid strikes the Moon; explosion ejects material, leaving a crater. Craters are typically about 10 times as wide as the meteoroid creating them, and twice as deep. The impact pulverizes rock to a much greater depth. Most lunar craters date to at least 3.9 billion years ago, which is the period of the Late Heavy Bombardment. Since then, there has been much less bombardment since then. What bombardment the Moon receives is mostly from very small “micrometeoroids.” These tiny impacts slowly erode and soften features. Since the Moon lacks an atmosphere, it does not experience any erosion from wind or water as the Earth does. The surface of the Moon is also covered with **regolith**, a thick layer of dust left by meteorite impacts

Four billion years ago, the Moon had many craters but no maria. Heavy impacts on the near side produced lava flows from the Moon’s mantle covered portions of the Moon, creating the maria. By 3 billion years ago, Moon’s internal temperature had cooled to the point where no further lava flows occurred. Since then, many of the Maria have received occasional impacts, covering them in younger craters.

The near side of the Moon that always faces the Earth.

https://commons.wikimedia.org/wiki/F...llMoon2010.jpg



The far side of the Moon shows more impact craters compared to the near side.

https://www.pikrepo.com/fcjdb/far-side-of-the-moon

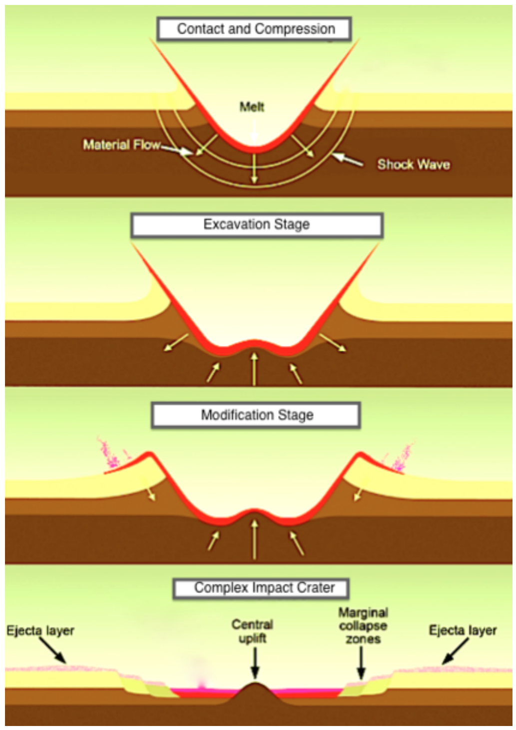
Craters near the poles of the Moon are in permanent shadow. Recent probes from NASA and India have found evidence of water ice inside these craters. Asteroids containing ice probably delivered this ice and since these craters receive no sunlight, the ice has never sublimated (turned from solid to vapor phase).

During the Moon's early formation. the Earth's gravity pulled more magma to the surface on the near side. This resulted in less magma welling up to the surface on the far side, so impacts just built up craters and mountains. This made the Moon's crust thicker on the far side.

Apollo astronauts installed the first lunar seismic detectors to study the Moon’s interior. The instruments registered some meteorite impacts and a very few moonquakes, showing the Moon to be much less geologically active than the Earth. Using the sparse data, scientists found that the interior of the Moon is essentially the same material as the Earth's mantle, with perhaps a very small iron core. The Moon's lithosphere is about 1,000 kilometers deep — much thicker than the Earth's lithosphere. Because the Moon is smaller than the Earth, it cooled more quickly and completely, creating a relatively thicker lithosphere.

Based on radiometric dating of lunar rocks, astronomers divide the surface of the Moon into different periods:

Surfaces that formed during the Pre-Nectarian Period are between 4.5 to 3.9 Billion years in age. Rocks from the Nectarian Period run from 3.9 to 3.8 Billion years in age. The Imbrian Period consists of surfaces from 3.8 to 3.2 billion years in age. The Eratosthenian Period follows, from 3.2 to 1.1 billion years ago. Finally, the youngest surfaces date from the Copernican Period, with ages from 1.1 billion years ago until today.



Craters on the Moon formed mostly through impacts from meteoroids.

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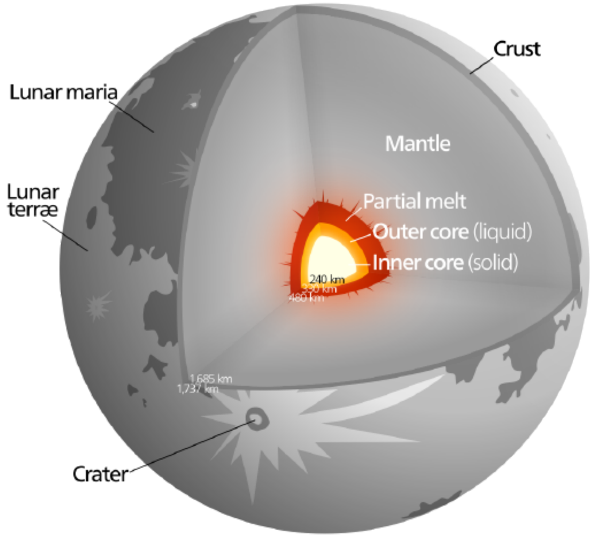


The Moon's internal structure

https://www.freepik.com/premium-vect...rs_4455684.htm

8.3.2 Origin of the Moon

Before we analyzed the composition of the moon rocks brought back by the Apollo missions, there were several theories about the origin of the Moon. The first was the fission theory, in which the Moon was once part of Earth, but somehow separated from it early in their history. The other theory was known as the sister theory, in which the Moon formed together with but independent of Earth, as we believe many moons of the outer planets formed. A third theory, the capture theory posited that the Moon formed elsewhere in the solar system and was captured by Earth.

However, analysis of the lunar rocks found that none of theories matched the data. Geologists found that the Moon is deficient in iron compared to the Earth and is made from material like the Earth's mantle. The lunar surface is also deficient in water and other volatile compounds, compared to the Earth. In short, the Moon was like the Earth in all the wrong ways as predicted by any of the previous theories. The proportions of different oxygen isotopes in lunar rocks (e.g. O16, O18, etc.) are the same as in terrestrial minerals, but different from those in other parts of the Solar System.

We know that very large bodies hit the Moon early in its history and even though the evidence is masked by erosion and geological upheaval, very large bodies also hit the Earth. The current theory of the Moon's origin posits a Mars-sized body (Which astronomers have named Theia), impacted the still-liquid Earth with a glancing blow. This caused enough material, mostly from the mantle, to be ejected. This material remained in orbit around the Earth and eventually coalesced to form the Moon.

The Moon likely formed by an impact of the Earth by a Mars-sized object.

https://www.pxfuel.com/en/free-photo-qpmid

9: Planetary Geology

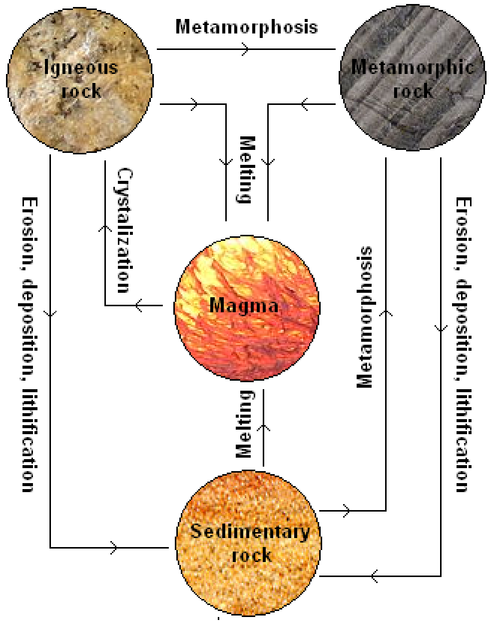
Learning Objectives

- Understand the rock cycle.
- Describe three main categories of rocks.
- Describe the surfaces of the four terrestrial planets.
- Describe the origin and properties of planetary magnetospheres.
- Compare and contrast the atmospheres of Earth, Venus, and Mars.

We can take what we have learned about the Earth's interior and combine it with what our probes have told us about the size and densities of these planets, we can construct models about their interiors as well. Mercury, Venus, and Mars formed in much the same way as Earth did, with planetesimals colliding. These collisions would convert the gravitational potential energy of the planetesimals into thermal energy, heating the planets up until they became molten.

These early molten worlds would have undergone differentiation, in which gravity would pull the high-density, material, such as metals, to center. Meanwhile, the lower-density materials such as silicate rocks, would rise to the surface. As the material separated by density, we would expect the other three planets to form similar layers as the Earth, with a core, mantle, and a crust. Since all evidence indicates that the terrestrial planets are all made of similar rocky materials, we can expect them all to behave the same when subjected to the same forces.

9.1: The Rock Cycle



The Rock Cycle.

https://commons.wikimedia.org/wiki/F...lustration.PNG

A **rock** is defined as any solid aggregation of minerals. In turn, a **mineral** is any element or inorganic compound that consists of a crystal structure, a specific chemical composition, and a set of distinct physical properties. Over time, rocks experience a variety of forces, including heating, melting, cooling, weathering, and reassembling through the process we call the **rock cycle.** As rocks go through various transformations and alterations, their physical properties undergo a variety of changes.

We classify rocks into three main categories based on how the rocks formed. **Igneous Rocks** formed when **magma**, the hot, molten, liquid form of rock, cools and solidifies. Magma underground cools slowly, forming large crystals. **Intrusive or plutonic rocks**, such as granite, form from the slow cooling of underground magma. **Lava**, magma released by a volcano, can flow along the surface and cools more quickly. Lava on the surface cools faster than underground magma, forming **extrusive or volcanic rocks** such as basalts. Because they solidify faster than plutonic rocks, volcanic rocks have smaller crystals. Large, smooth areas such as the lunar maria, which formed from surface lava flows, are mostly made of basalts, as are many of the younger, smooth areas on Mars.

Magma and lava, the molten form of rock, cool to form igneous rocks.

https:/www.needpix.com/photo/226234/magma-lava-volcano-volcanism-guatemala-liquid-stone-heat-hot;

Sedimentary rocks formed as sediments are pressed together and bound by dissolved materials. **Sediments** are rock particles formed by physical erosion or chemically from precipitation of substances. Wind and water action on rocks weather away tiny particles from rocks through fiction. As sediments pile up over time, their mass can compact the lower levels of sediments, solidifying them into rocks. Sedimentary rocks can also form dissolved minerals precipitating out of solution and becoming cemented together.

Sometimes, on Earth, dead organisms become buried under sediments before they decompose or are eaten by scavengers. Compaction and transformation can then create imprints of the remains of once living fossils in stone called **fossils**.

Sedimentary rocks form in layers as sediments accumulate on top of each other.

https:/commons.wikimedia.org/wiki/File:Layers_of_sedimentary_rock_in_Makhtesh_Ramon_(50754).jpg;

Some sedimentary rocks form through biological processes. For example, a particularly important sedimentary rock for life on Earth is limestone. Limestone is produced in two ways, by a chemical process and as the result of biological activity. The chemical process, the Urey weathering reaction, occurs when carbon dioxide dissolved in water reacts with silicates in rocks. Also, limestone and chalk are also produced by biological processes. The shells of many tiny marine organisms are made of calcium carbonate. When they die, these creatures sink to the bottom of the oceans, and most limestone is probably the result of the gradual compression of the deposits of these shells. Limestone and chalk formation create one of the major reservoirs of carbon dioxide on Earth.

Since sedimentary rocks require weathering as part of their formation, we would not expect to find much evidence of sedimentary rocks on the Moon or Mercury, as these bodies lack a significant atmosphere. On the other hand, Venus and Mars have atmospheres, that can produce wind weather. Since some sedimentary rocks form in the presence of water, these rocks are indicators of liquid water on the surface in the past. So, even though the surface of Mars is very dry today, the presence of rocks and minerals that form in the presences of water would indicate that liquid water once did flow on its surface. Moreover, if we were to find minerals on another planet that require biological activity to form, such as chalk, this would indicate not only the presence of life but also more complex, multicellular life.

The third category of rocks, **metamorphic rocks**, form deep underground as rocks of other types are subjected to great heat or pressure, changing its form. Rocks such as gneiss (pronounced “nice”) form when rocks like marble are transformed due to these underground forces.

Metamorphic rocks form as other rocks are subject to heat and pressure, changing them forms.

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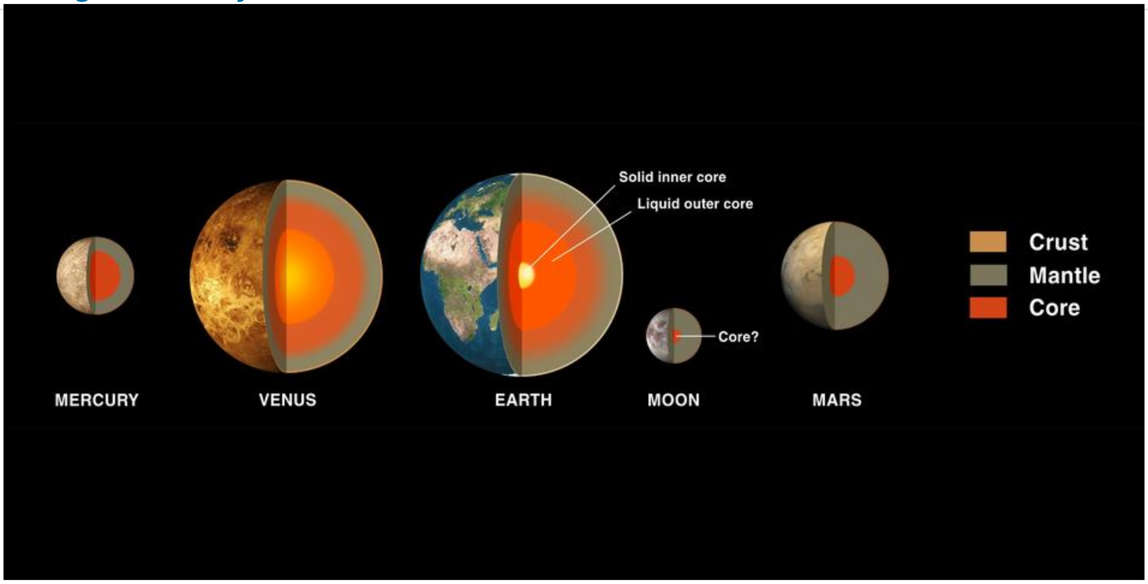
9.2: Heating Planetary Interiors



Of the four terrestrial planets plus the Moon, only the Earth is believed to have enough internal heat to keep the planet warm.

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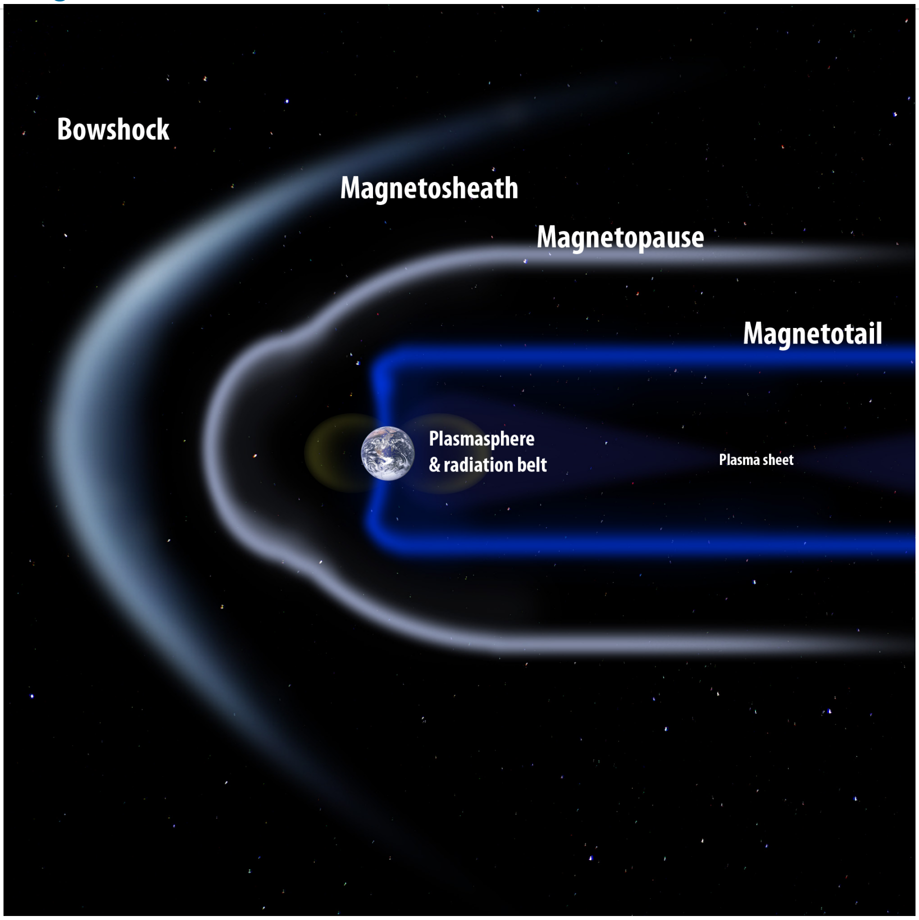
As we noted in Section 91, accretion and differentiation occur when planets were young. Initially, planets have a lot of internal heat from their formation. Depending on the size of the planetary body, the heat from formation dissipates. Smaller bodies like the Moon or Mercury have lesser internal heat than the Earth. Convection transports heat as hot material rises and cool material falls. This transfer heat from the mantle to the crust. The heat then escapes into space through radiation. The rate at which a planetary interior cools off depends on its surface-to-volume ratio. Heat content depends on volume. Loss of heat through radiation depends on surface area. The time it takes for the planetary interior to cool depends on surface area divided by volume. Larger objects have a smaller ratio and cool more slowly. Smaller worlds cool off faster and harden earlier. As a result, the Moon and Mercury are now geologically "dead," having lost most of their internal heat from formation hundreds of millions of years ago.

While it has cooled of more slowly than the smaller terrestrial planets, the Earth also has another source of internal heat. Much of Earth's internal heat today comes from decay of radioactive isotopes. This has kept much of the Earth's interior molten and continues to drive the plate tectonics that shape and reshape the Earth's surface to this day.

9.3: Origin of Magnetic Fields



Only two terrestrial planets, Earth and Mercury have strong magnetospheres.

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Since motions of charged particles create magnetic fields, a world can have a magnetic field if charged particles are moving inside. To generate a magnetic field, a planet must meet three requirements: 1) A molten, electrically conducting interior; 2) Convection in the interior and 3) A moderately rapid rotation.

Of the four terrestrial planets, Earth has the strongest magnetic field. Geologists believe that Earth's rotating molten core produces a **dynamo effect** that in turn, generates its magnetic field. Earth's core comprises about 33% of the planet's mass. As noted in the previous section, the core is molten because of the heat leftover from its formation and the presence of radioactive isotopes.

After Earth, Mercury has the second strongest magnetic field. It is also the most metallic and its core makes up about 60% of its mass, giving it the largest ratio of a planet's core to its size in the Solar system. However, Mercury is also the smallest planet and therefore has the highest surface area to mass ratio. As a result, its core likely lost most of the heat from its formation. The presence of a relatively strong magnetic field raises the question as to whether it is still molten despite losing most of its heat of formation. One hypothesis posits that the core contains sulfur, which would lower the melting point of the iron core. Another possibility is that Mercury's magnetic field is somehow produced by charged particles from the solar wind.

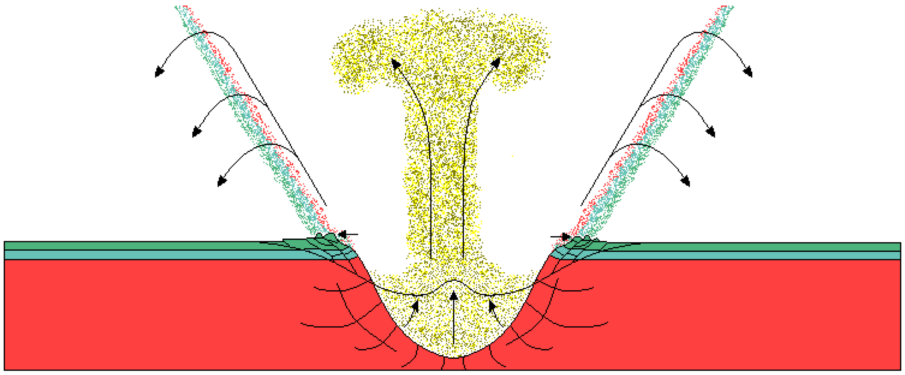
Venus is close to the Earth in size but does not have a strong magnetic field. This has puzzled planetary scientists. The lack of plate tectonics on Venus may indicate a lack of convective forces in the mantle. This would indicate that is core may not be molten. Also, its slow rotation may not be sufficient to generate a dynamo.

In contrast, Mars has a rotation period that is close to the Earth's. Data indicates it has an iron core about half the planet's radius in size. Like Venus, however, Mars lacks any convective currents in its interior. Data from the oldest rocks indicate that Mars once did have a strong magnetic field. So, what could have shut it down? Mars' small size might have caused the core to cool down and solidify. Also, there might be hydrogen in the core, which could shut down convection. The Mars InSight lander landed on Mars on November 26, 2018 to explore the interior and may answer some of these questions.

9.4: Surface of Terrestrial Planets

Several factors have shaped the surfaces of the terrestrial planets. For example, impacts by asteroids or comets have created **impact cratering.** In addition, **Volcanism**, the eruption of molten rock on the surface have created new crust material. **Plate tectonics**, the movement of crustal plates due to convective forces in the mantle have built up mountain ranges and pushed older crust back into the mantle. Finally, **erosion** from wind, water, or ice have worn away surface features.

9.4.1 Cratering



Craters are formed by impacts.

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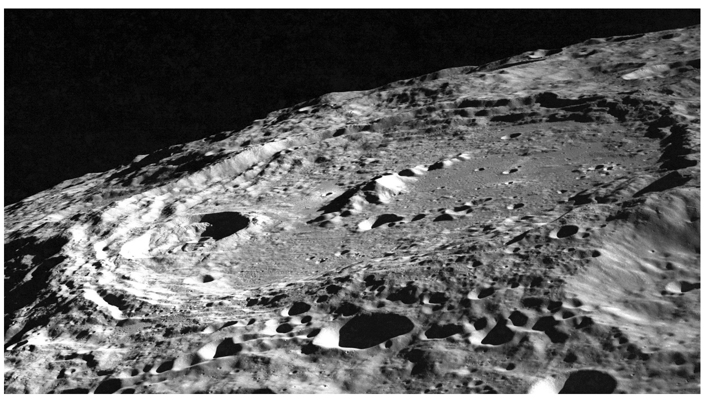

Keeler crater on the Moon.

https://commons.wikimedia.org/wiki/F...10-32-4823.jpg

Most cratering happened soon after the solar system formed during the Late Heavy Bombardment period, in the first billion years after the formation of the planets. Craters formed by impacts tend to be about 10 times wider than the object that made them. As a rule, small craters greatly outnumber large ones. Because most cratering happened in the first billion years, we can generally conclude that a surface with many craters has not changed much in 3 billion years. For example, some areas of Moon are more heavily cratered than others while younger regions were flooded by lava after most cratering.

9.4.2 Volcanism

Volcanic eruptions have shaped the surfaces of all four terrestrial planets.

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Volcanism happens when molten rock (magma) finds a path through lithosphere to the surface. There are three major types of volcanoes: cinder cone volcanoes, composite/stratovolcanoes, and shield volcanoes. The thickest lava makes steep stratovolcanoes while cinder cones tend to produce more ash and dust than lava. Slightly runnier lava makes broad shield volcanoes. Runny also lava makes flat lava plains. Bodies like the Moon and Mars, with lower gravity, tend to have runnier lave, producing the giant shield volcanoes on Mars or the wide maria on the Moon. Volcanism also releases gases from the planet's interior into the atmosphere, particularly carbon dioxide.

9.4.3 Tectonics

Convection of the mantle creates stresses in the crust called tectonic forces. Compression of crust creates mountain ranges while valleys can form where crust is pulled apart. Earth's continents slide around on separate plates of crust. The other terrestrial planets appear to lack any active plate tectonics. It is likely that liquid water on the surface is necessary to provide lubrication to keep subduction, the sliding of one plate beneath another, going. On Earth, subduction occurs on the ocean floor. On the other terrestrial planets, any water on the surface boiled away or frozen a long time ago. Without liquid water, subduction may have ceased, shutting down all the plate tectonics on planets like Mars and Venus. Also, smaller worlds cool off faster and harden earlier. Larger worlds (like Earth) remain warm inside, promoting volcanism and tectonics.

9.4.4 Erosion

Erosion by wind and other forces can shape the surface of planets.

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Erosion is a blanket term for weather-driven processes that break down or transport rock. Processes that cause erosion include glaciers, rivers, and wind. For example. the Colorado River continues to carve Grand Canyon while glaciers carved the Yosemite

Valley. In addition, wind wears away rock and builds up sand dunes in the deserts. Erosion can create new features such as deltas by depositing debris.

Larger worlds tend to have more erosion because their gravity retains an atmosphere. In addition, planets close to the Sun are too hot for rain, snow, ice and so have less erosion. Hot planets have more difficulty retaining an atmosphere while planets far from the Sun are too cold for rain, limiting erosion. We can then conclude that planets with liquid water have the most erosion. Also, planets with slower rotation have less weather, less erosion, and a weak magnetic field while planets with faster rotation have more weather, more erosion, and a stronger magnetic field.

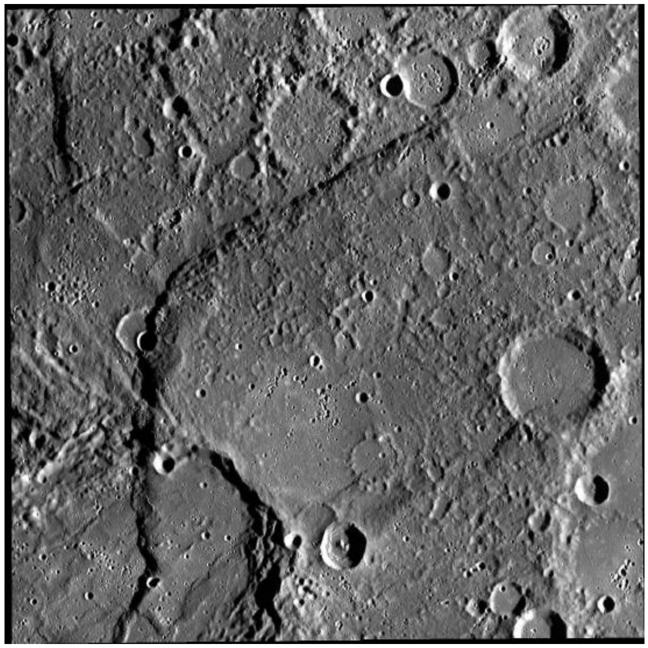
Comparing the four terrestrial planets we can see their relative rates of erosion in the table below.

Planet	**Distance from the Sun**	**Rotation**	**Atmosphere**	**Liquid water on the surface?**	**Rate of Erosion**
Mercury	Very close	Slow	None	None	None
Venus	Close	Slowest	Very thick	None	Little
Earth	Moderate	Fastest	Medium	Yes	Highest
Mars	Furthest	Fast	Very thin	None	Little

9.4.5 Dating the Surfaces of planetary bodies

Since in many cases, the only information we have about the surface of planets and moons is images, astronomers date the surfaces of the terrestrial planets by counting craters. Astronomers assume that smoother areas, such as lunar maria, are younger because they were covered by relatively recent lava flows. Therefore, the more heavily cratered an area, the older it is. Crater counting, however, only gives us relative ages. Aside from the Earth, the only body that we have been able to date using radiometric techniques is the Moon. We, therefore, have been able to conclude that the lunar surface is much older than the Earth's.

In comparison, all we know about Mercury is from the Mariner and Messenger probes. These images have shown that Mercury is heavily cratered and lacks large maria. This indicates that the surface of Mercury is likely as old as the oldest areas of the Moon.



The surface of Mercury is heavily cratered, much like the Moon, indicating its surface may be as old as the Moon's.

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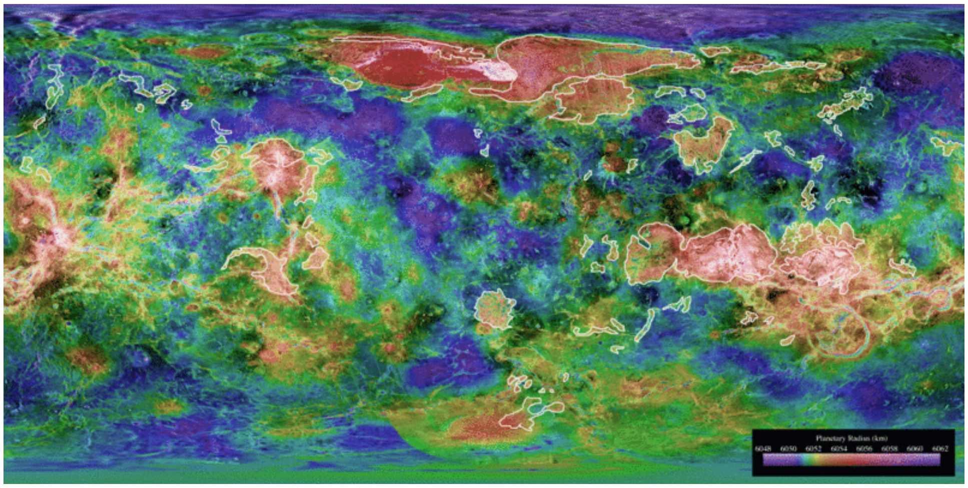
The cloudy atmosphere of Venus has made it difficult to map its surface. Since visible light cannot penetrate Venus' thick cloud layers, we have used radar give us a picture of what the surface of Venus looks like. One thing the Magellan probe found was that the force of gravity is stronger over highlands and mountains. This is due to there being more mass concentrated there. Earth does not have this variation in gravity due to the Archimedes Principle. This states that mass of any object is equal to the mass of the fluid it displaces. The continents displace an equal mass of fluid in the mantle, keeping the overall mass balanced, as a result, gravity remains uniform. The fact that on Venus, the mass of the highlands does not appear to displace any fluid beneath it indicates its mantle is more solid. This is probably why Venus lacks plate tectonics.



The surface of Venus as mapped by radar from orbit.

https://commons.wikimedia.org/wiki/F..._Venus_gif.gif

Compared to Venus, we have a much more complete map of the surface of Mars thanks to the several orbiters that have taken images of the red planet since the 1970s as well as the numerous landers and rovers that have explored its surface. Using crater counts and other methods, planetary scientists divide the surface of Mars into three epochs.

- The Noachian epoch (4.3–3.5 billion years ago)
- The Hesperian epoch (3.5–1.8 billion years ago)
- The Amazonian epoch (1.8 billion years ago until the present).

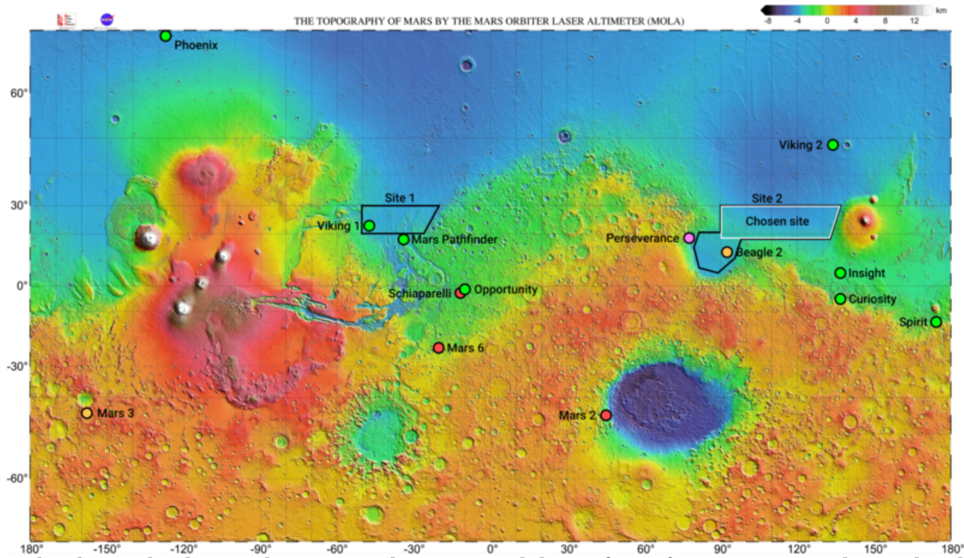
There is quite a bit of uncertainty in these dates for two main reasons. First, we do not have the independent ages from radioactive dating that we do for the Moon. Second, we cannot be sure that Mars received the same bombardment as the Moon did.

Examination of the surface of Mars has found features that indicate past river flows are found in the oldest (Noachian) areas of Mars. This tells us Mars was wetter in the past. Also, the northern hemisphere is also 6 km lower than the southern hemisphere, which many planetary scientists could it have been home to an ocean back in the Noachian epoch.

The surface of the northern hemisphere is also younger, having mostly formed during the Amazonian epoch (2 billion years ago). Radar images, however, indicate that there is an older, crater-filled surface beneath the current surface of the northern hemisphere. The elevation difference between north and south must have occurred early in the history of the Mars.

Spectroscopic analysis of the Martian surface has found that the older (Noachian and Hesperian) regions of Mars are mostly basalt. The Amazonian region is mostly iron oxide, which gives Mars is characteristic red color. There is no evidence of hydrated minerals in the Amazonian regions, indicating Mars has been dry for at least 2 billion years. Opportunity first discovered sandstone, sulfates, and salts in Endurance Crater. These are minerals that form in the presence of water, indicating the presence of water at one time. Opportunity also found rocks that contain hematite that scientists have nicknamed “blueberries” due to their size and the color they appear on the images. On Earth, hematite only forms in the presence of water. Rovers have also found phyllosilicates (simple clays) on the Martian surface.

The Martian lithosphere is thicker than Earth's due to its smaller size, which has promoted more rapid cooling. This allows Martian mountains to grow higher than on Earth because they have more support. Thick lithospheres also partially explain the lack of plate tectonics in the rest of the Solar System — a planet's lithosphere must be thin enough to break into separate plates.



With orbiters, landers, and rovers, we have mapped the surface of Mars in extraordinary detail.

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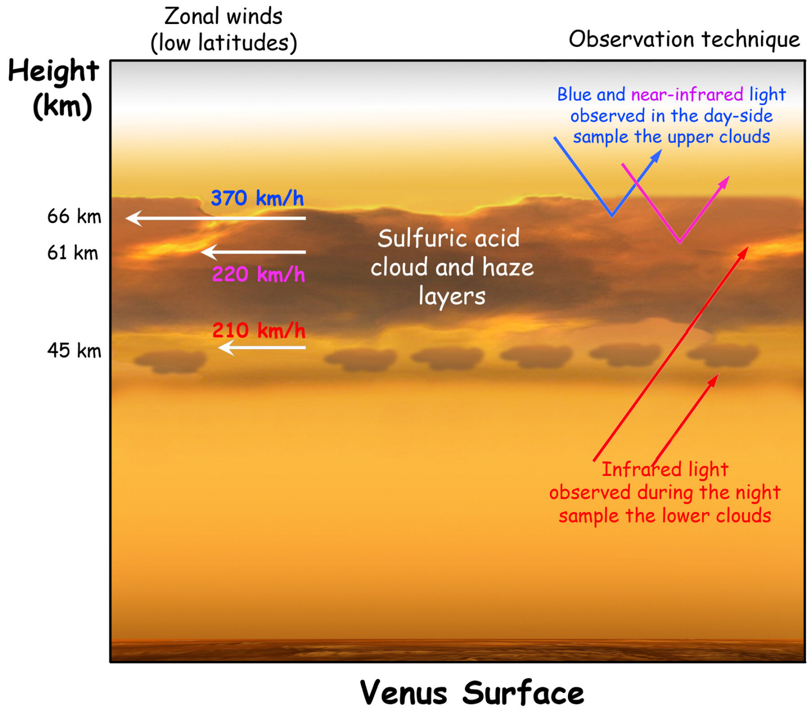


The atmosphere of Venus.

https:/www.esa.int/ESA_Multimedia/Images/2008/09/Studying_the_winds_on_Venus;

9.5.1 Atmosphere of Venus

Mercury has no detectable atmosphere; it is too hot, too small, and too close to the Sun. In contract, Venus has an extremely dense atmosphere. The outer clouds are similar in temperature to Earth, and it was once thought that Venus was a “jungle” planet. We now know that its surface is hotter than Mercury’s; hot enough to melt lead. The atmosphere of Mars is similar to Venus in composition, but very thin. The Earth is the only terrestrial planet with atmosphere consisting mostly of nitrogen and oxygen.

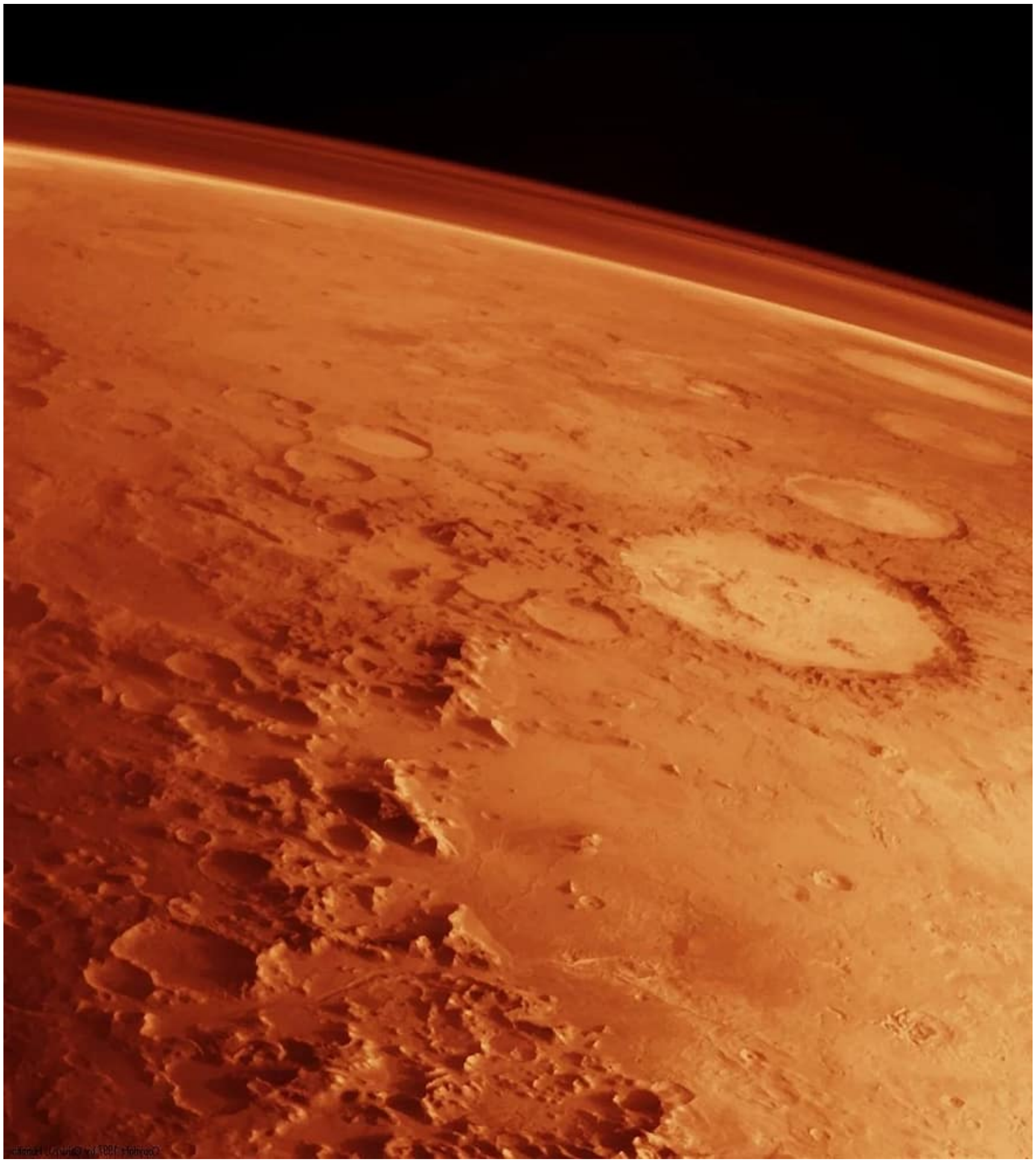
At formation, planets had primary atmosphere—hydrogen, helium, methane, ammonia, water vapor—which was quickly lost due to the high temperatures and the fact that most of these gases are very light. Over time, Venus, Earth, and Mars developed secondary atmospheres containing water vapor, carbon dioxide, sulfur dioxide, nitrogen. Secondary atmospheres come from volcanic activity releasing these gases from the planet’s interior.

Earth now has a tertiary atmosphere, 20 percent oxygen, due to the presence of life. Oxygen is a highly reactive gas. It reacts with other elements to compounds such as water, carbon dioxide, iron oxides, and silicates. Without photosynthetic organisms releasing oxygen into the atmosphere, Earth’s atmosphere would eventually lose its oxygen.

Earth has a small greenhouse effect. Gases such as carbon dioxide and water vapor trap some of the Sun’s energy near the surface, giving the Earth a comfortable (for us) surface temperature. Venus has a much thicker and denser atmosphere that gives it a runaway greenhouse effect has resulted in its present surface temperature of 730 K, the highest surface temperature of any planet in the Solar System. On Earth, much of the carbon dioxide was dissolved in the oceans and then incorporated into the crust while photosynthetic organisms released oxygen, creating the atmosphere we have today. On Venus, the oceans evaporated, releasing the carbon dioxide back into the atmosphere. Without any significant sink for carbon dioxide, Venus’ atmosphere became thicker and its greenhouse effect increased dramatically.

9.5.2 Atmosphere of Mars

In contrast, Mars, lacking a magnetic field, had no protection from the solar wind. Combined with Mars’ low gravity, the solar wind caused Mars to lose much of its atmosphere. Mars continues to lose gas from its atmosphere to this day. As a result, even those Mars’ atmosphere, like that of Venus, is mostly carbon dioxide, it has a very small greenhouse effect, making a cold, dry world.



Compared to Earth and Venus, Mars has a very thin atmosphere.

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10: The Terrestrial Planets

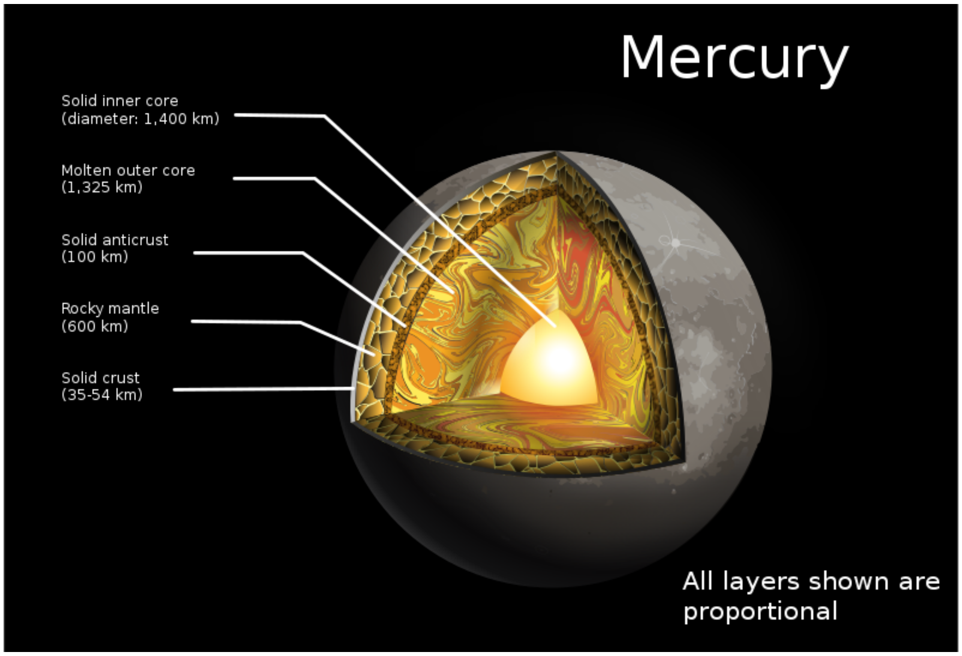
Learning Objectives.

- Compare and contrast the features of Mercury, Venus, and Mars.

10.1: Mercury and Venus

As the inner most planets, the orbits of Venus and Mercury show that these planets never appear far from the Sun. Venus has been known as both the Morning Star and the Dawn Star as it appears either just after sunset or right before sunrise.

10.1.1 Mercury



Mercury and its interior.

https://commons.wikimedia.org/wiki/F...y_(planet).svg

Because of its closeness to the Sun, Mercury can be difficult to image from Earth. In fact, Mercury orbits so close to the Sun that the Hubble Space Telescope might damage its optics if it attempted to photograph it.

Instead, its rotation rate had to be measured use radar from Earth. Because of difficulty in measuring its rotation, astronomers had long thought that Mercury was tidally locked to the Sun. Just as the same side of the Moon always faces the Earth, astronomers believed that the same side of Mercury always faced the Sun. However, radar measurements in 1965 showed this to be false. Instead, Mercury's day and year are in a 3:2 resonance. In other words, Mercury rotates on its axis three times for every two orbits it makes around the Sun. Its rotational period is 59 Earth days while its orbital period is 88 Earth days. Because it lacks a substantial atmosphere, Mercury does not retain the Sun's heat during its nighttime period. This gives Mercury the most extreme differences in temperature. Temperatures reach about 700 K during Mercury's day and plunge down to 100 K during its night.

Of all the planets, Mercury has the greatest inclination. Its orbit is tilted 7° to the ecliptic. Its orbit is also very elliptical, with an eccentricity of 0.21.

Mercury is also the most metallic of the planets, being 70% metallic and only 30% silicate.

The dimensions of Mercury are given as follows:

- Mean Radius: 2,440 km or 0.3829 Earths
- Density: 5.427 grams/cubic centimeter
- Surface Gravity: 0.38 Earths
- Atmosphere: none detectable
- Atmospheric Pressure: trace
- Surface Temperature: 100-700 K
- Magnetic field: yes
- Moons: None

Because of the difficulty in reaching Mercury, the MESSENGER mission in the early 21st century gave us the first complete mapping of the planet. MESSENGER showed us a world similar to the Moon, with numerous craters but fewer smooth maria compared to the Moon. Like the Moon, Mercury received numerous impacts during the Heavy Bombardment. One distinctive feature on Mercury is the **scarps** (cliffs), which are several hundred kilometers long and up to 3 km high. These cliffs are thought to be formed as the planet cooled and shrank, much like a hot glass container might crack if cold water is poured into it.

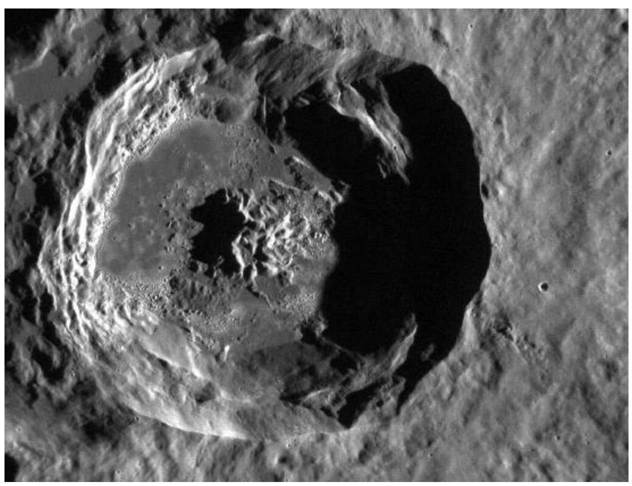
The most likely models for Mercury's interior suggest a metallic iron-nickel core amounting to 60% of the total mass and 75% of its radius, giving it the largest core relative to its size among the planets. The core has a diameter of 3500 kilometers and extends out to within 700 kilometers of the surface. The large core may of the result of a major impact, which tore away a lot of Mercury's original crust and mantle, leaving a planet that is mostly core.

Most of the Mercurian features have been named in honor of artists, writers, composers, and other contributors to the arts and humanities, in contrast with the scientists commemorated on the Moon. Among the named craters are Bach, Shakespeare, Tolstoy, Van Gogh, and Scott Joplin.

Today, Mercury appears to be a quiet world, with no evidence of current plate tectonics on Mercury. It likely lost most of its internal heat a long time ago due to its small size.

Mercury has no detectable atmosphere. Being so small, it lacked the gravity to hold onto many gases, especially given how close it is to the Sun. The high temperatures gave gas molecules the energy to escape the planet early in the Solar System's history. Without an atmosphere or plate tectonic, Mercury's surface is very old, probably as old as the Moon's surface.

Despite being close to Sun, Mercury has polar craters whose floors are in permanent shadow. The MESSENGER probe has confirmed that these craters contain ice. As with similar craters on the Moon, asteroid or comet impacts probably delivered this ice to Mercury and the shaded craters have kept it frozen for billions of years.



Caloris Basin, a major crater on Mercury.

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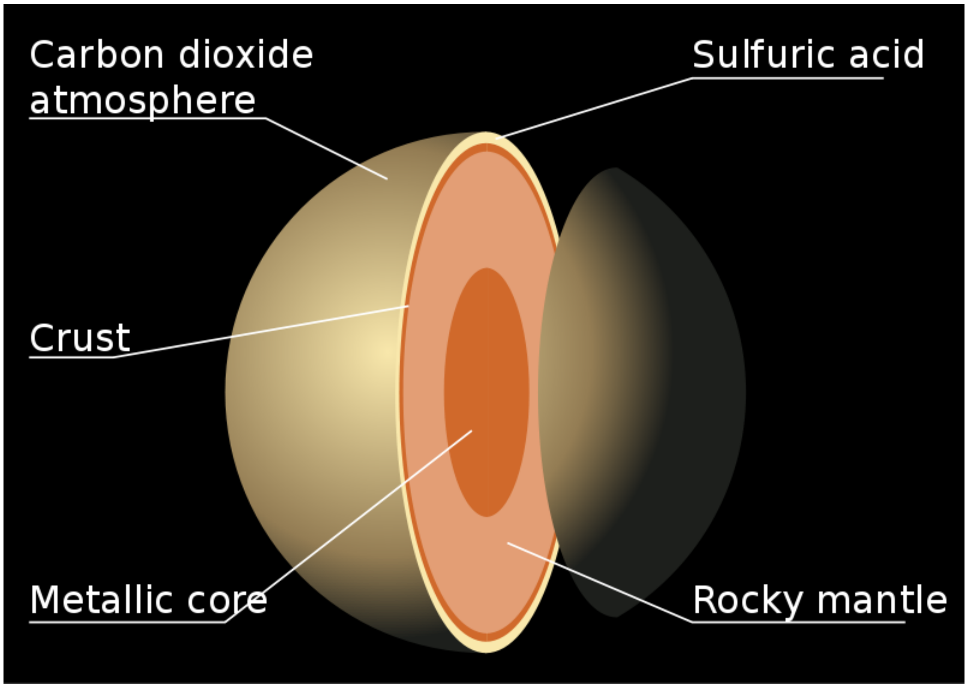


Venus and its interior.

https://commons.wikimedia.org/wiki/F...iorOfVenus.svg

Like Mercury, Venus is a difficult world to observe from Earth. The phenomenon that makes Venus just a bright object in our sky also makes it impossible to see the surface in visible light. The cloud cover reflects so much of the Sun's light, keeping the surface hidden behind a permanent shroud. The thick atmosphere also traps so much heat that Venus has the highest surface temperature of all the planets with a uniform temperature of 735 K. The clouds are not water vapor, but sulfuric acid.

Because of its cloud cover and being closer to the Sun, science fiction writers often pictured Venus as a steamy, jungle world. Once we gain more information about its surface conditions, the picture changed dramatically. Instead of rainforests populated by prehistoric monsters, Venus is a barren, dry world where liquid water is impossible with temperatures hot enough to melt lead. The surface atmospheric pressure is 90 times that of Earth. At those crushing pressures, carbon dioxide behaves almost like a dense liquid. To make matters even more hellish, the clouds bring rains of sulfuric acid.

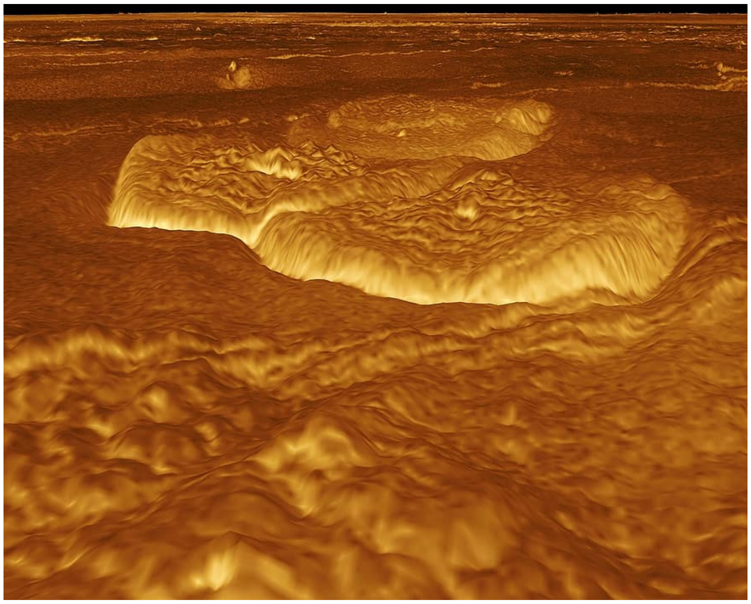
The rotational period of Venus is 243 Earth days and its orbital period is 225 Earth days. This means a day on Venus is longer than its year. Even more curious, Venus rotates retrograde, meaning the Sun rises in the West and sets in the East. The reasons for this slow rotation are unknown. Perhaps Venus experienced a collision that flipped it over and slowed its rotation down during the Heavy Bombardment.

The physical characteristics of Venus are as follows:

- Eccentricity: 0.007
- Inclination: 3.4°
- Composition: Mostly silicates
- Mean Radius: 12,103.6 km (0.94 Earths)
- Density: 5.243 g/cm3
- Surface Gravity: 0.904 Earths
- Atmosphere: 96.5% Carbon dioxide, 3.5% Nitrogen
- Atmospheric Pressure: 90.8 atm
- Surface Temperature: 735 K (hotter than Mercury)
- Magnetic field: very weak
- Moons: None

In terms of size, density, and composition, Venus is much like the Earth, which is why it is sometimes referred to as Earth's twin. However, the atmospheres of the two planets could not be more different. While Earth's atmosphere is a mixture of nitrogen and oxygen, Venus has an ultra-dense atmosphere mostly of carbon dioxide. This has given Venus a runaway greenhouse effect, trapping in nearly all the heat it receives from the Sun.

Venus has numerous **lava domes**, also known as pancake domes, on its surface. This were probably caused by magma flows that caused the surface to distend. When the magma retreated, the domes then collapsed. Venus also has areas of parallel ridges and troughs where the crust has been pulled apart.



Venus has several lava domes caused by magma flows that have since retreated.

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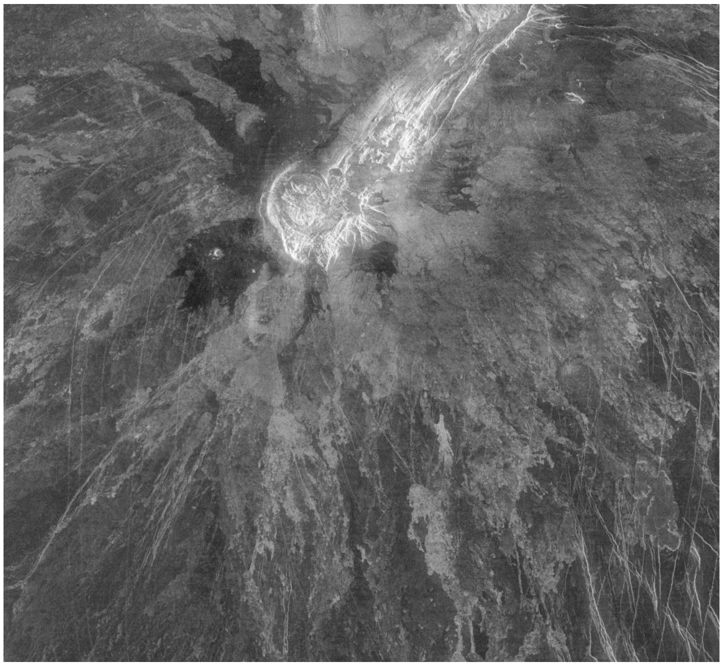


Gula Mons is a large volcano on Venus.

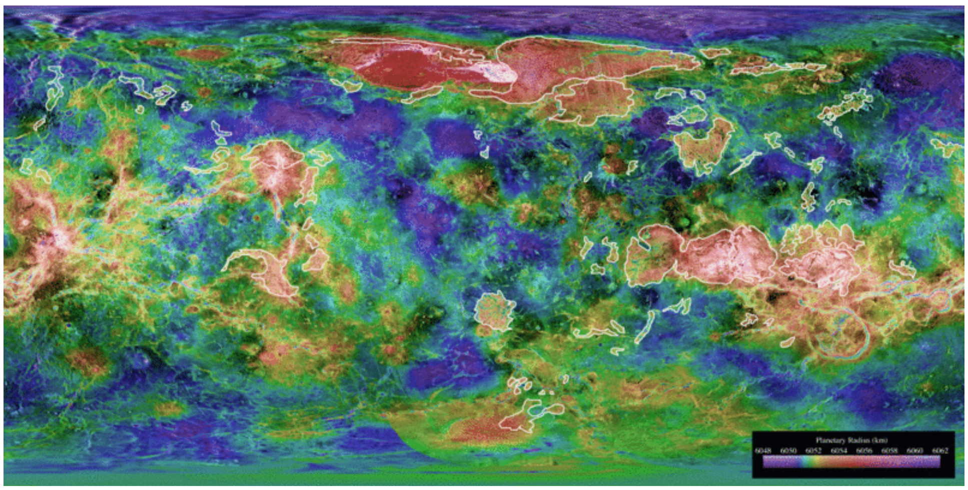
https:/commons.wikimedia.org/wiki/File:Gula_Mons_plan_view,_779-,663,-116.jpg;

Scientists have identified other mysterious Venusian features such as “arachnoids” (Greek for spider), “anemones” and “ticks.” The formation of these distinctive patterns remains a mystery.

It is unclear if Venus has any active volcanoes. Some recent data indicates that there may be some volcanic activity. However, Venus appears to lack any kind of plate tectonics. This may be the result of its lack of water may explain why. On Earth, water helps “soften” or “lubricate” the mantle rocks, enabling them to move. Once any water on Venus boiled away, the tectonics may have shut down completely.

Radar surveys of Venus, have revealed that most of the planet is covered by low, rolling plains, with only about a kilometer of relief in these areas. These plains may be analogous to the low elevation, basaltic sea-floor crust of Earth. Were liquid water possible on Venus, these lowlands might oceans. The other 40% of Venus is covered by highlands, including a few Australia-sized, continent-like plateaus standing a few kilometers above the surface. The largest of these are Ishtar Terra and Aphrodite Terra, named after the Babylonian and Greek goddesses of love and beauty.

These highlands contain a few huge volcanic peaks like Maxwell Montes (the only Venusian feature named after a man). Maxwell towers 10.6 kilometers (35,000 feet) above the average elevation — higher than our Mount Everest rises above sea level.



The terrain on Venus consists of lowlands and several highlands.

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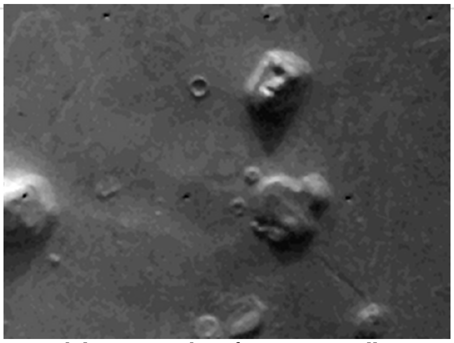
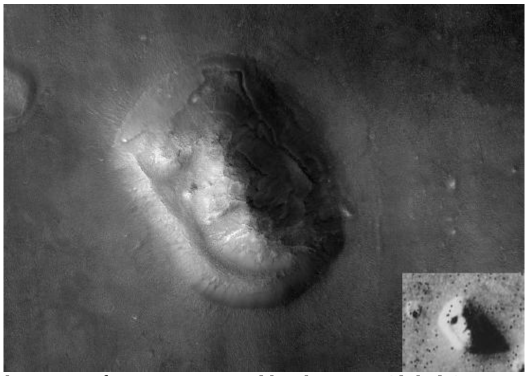
10.2: Mars



Viking orbiter photo the "Face of Mars." While it may to be a face, it is actually an artifact of poor resolution and shadows.

https://commons.wikimedia.org/wiki/F...d-enhanced.png

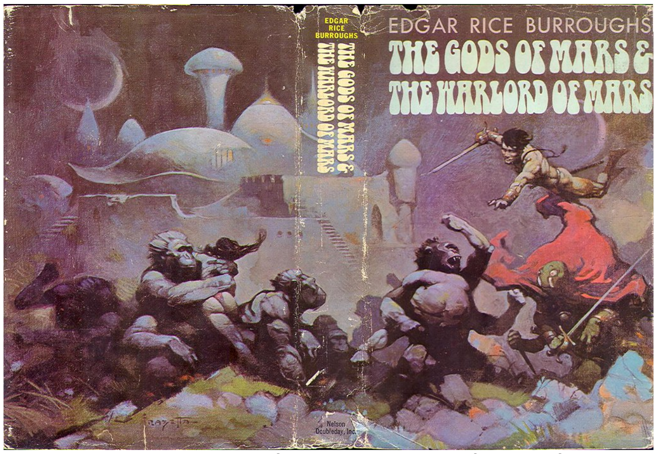


The "Face of Mars" as imaged by the Mars Global Surveyor.

https:/pixabay.com/photos/mars-face-on-mars-cydonia-mensae-63034;

No planet has been visited by more probes than Mars. From Schiaparelli and Percival Lowell's "canals" to conspiracy theories about the imaginary "face" of Mars, Mars has been the subject of wild speculation and fascination. We have long wondered if Mars has life. No planet in our solar system has been the subject of science fiction stories either. Mars has served as a source of inspiration for fiction since the 19th century. Examples of Mars featured in our popular culture include:

- H. G. Wells' novel War of the Worlds and the 1938 radio adaption of the story by Orson Wells that aired on Halloween night.
- Edgar Rice Boroughs' John Carter of Mars series.
- The cartoon character Marvin the Martian.
- The My Favorite Martian television series.
- The Martian Manhunter, a superhero from comic books and television.
- Movies like Mars Attacks and the Martian.

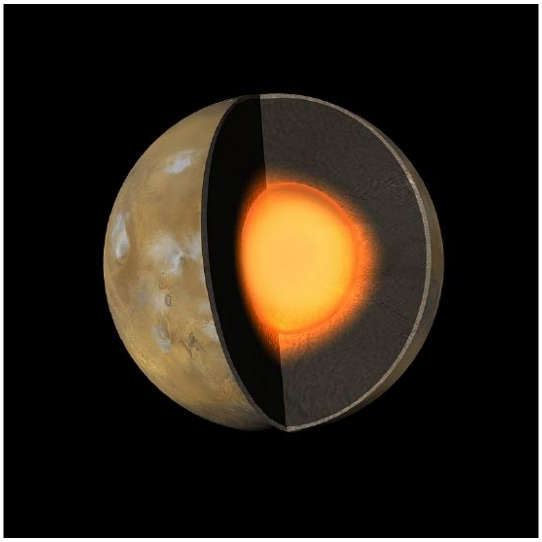


Mars has been the setting for numerous works of science fiction.

https:/www.flickr.com/photos/sdobie/3381466841;

10.2.1 Physical Characteristics of Mars

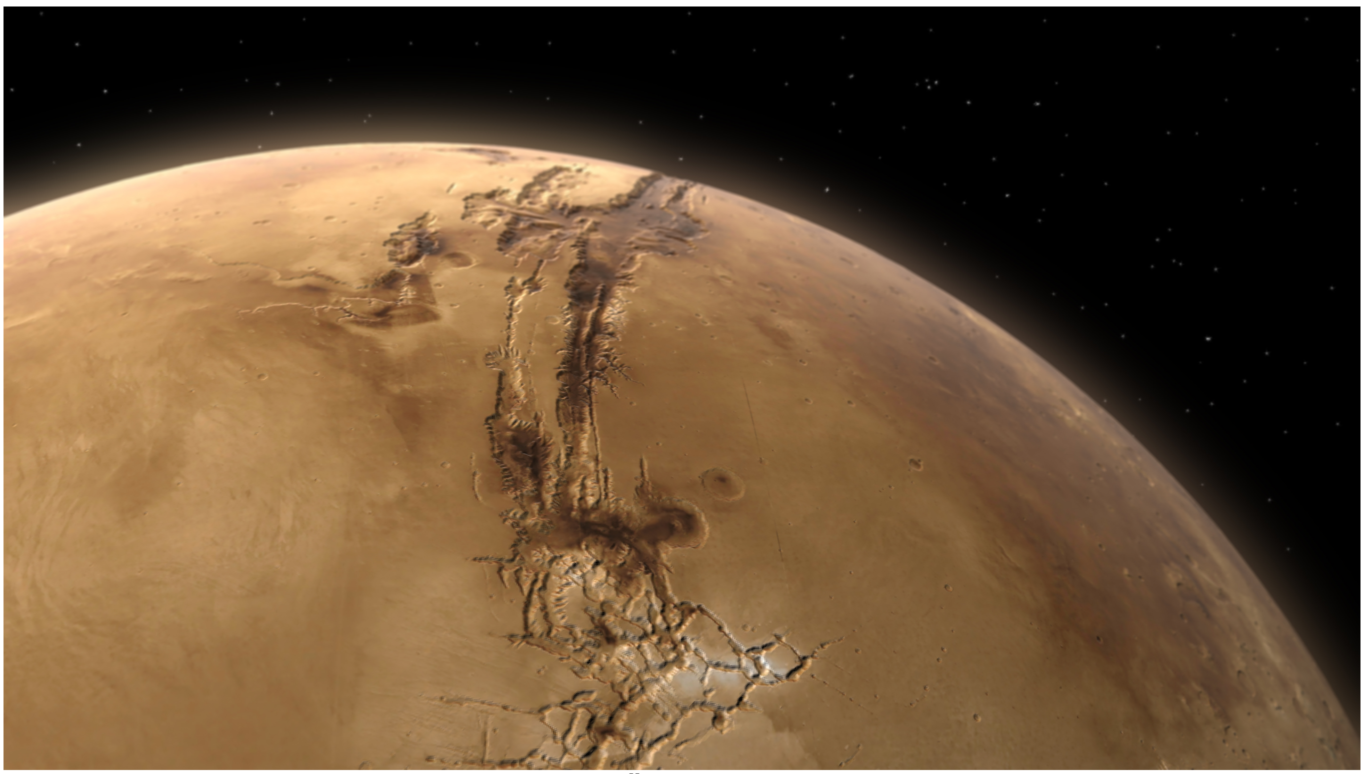
- The physical characteristics of Mars are:
- Rotation Period: 24 hours, 39 minutes
- Orbital Period (Earth days): 687
- Eccentricity: 0. 09
- Inclination: 1.85°
- Composition: Silicon, Oxygen, and metals
- Mean Radius: 3,389.5 km (0.53 Earths)
- Density: 3.9335 g/cm3
- Surface Gravity: 0.376 Earths
- Atmosphere: 96% Carbon dioxide, 1.3% Argon 1.89% Nitrogen
- Atmospheric Pressure: 0.00628 atm
- Surface Temperature: 180-270 K
- Magnetic field: none
- Moons: 2 (Phobos and Deimos)


Mars Interior.

https:/commons.wikimedia.org/wiki/File:Mars_interior.jpg;

By the end of the 1700s, astronomers had observed even more features that resemble Earth's. Though about half the size of the Earth, Mars has a rotational period only about 39 minutes longer. It bright, white polar caps, which shrink in the summer and grow in the winter, giving the appearance of seasons like those on Earth. The Italian astronomer Cassini notices that the surface markings underwent seasonal changes, growing darker in the summer and changing shape from year to year. Some observers speculated they might be patches of vegetation. From the 18th through the early 20th century, many speculated that Mars might be habitable, with rolling deserts. Some, like Percival Lowell, imagined entire civilizations that built elaborate canals to transport water from the poles to dry regions near the equator.

Though we now know the idea that Mars could be home to an advanced civilization to be nothing more than ideal speculation, Mars still has many features that have fascinated scientists. For example, the Tharsis Bulge, a region the size of North America that rises 10 km above its surroundings due a large upwelling in the crust. This bulge has minimal cratering, indicating it is the youngest surface on Mars. The Tharsis Bugle has some of the largest volcanoes in the solar system sitting on top.

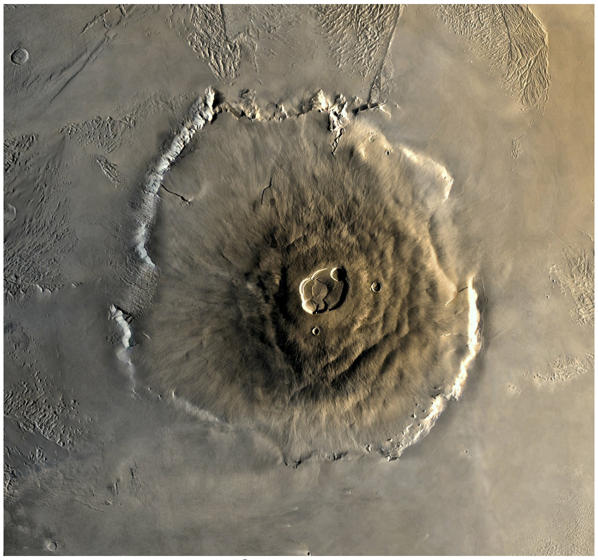


Valles Marineris.

https:/commons.wikimedia.org/wiki/File:Mars_-_Valles_Marineris_(16715969092).jpg;

Mars is also home to Valles Marineris, the largest canyon in the solar system and Olympus Mons, the tallest mountain in the solar system. Planetary scientists suspect that Valles Marineris formed because of Mars having a lack of plate tectonics. With the movement of tectonic plates to relieve stress, convection in the mantle could have stretched the crust, forming a giant crack. Weathering by wind and perhaps water early in Mars' history could have widened this crack into its current size. The formation of Valles Marineris may also be related to the Tharsis Bulge nearby.

Olympus Mons is 700 km in diameter at its base and 25 km high with a caldera 80 km in diameter. Mars' low gravity has enabled large flows of lave to spread out, creating this gigantic shield volcano. In addition to Olympus Mons, Mars has four other volcanoes that are only slightly smaller.



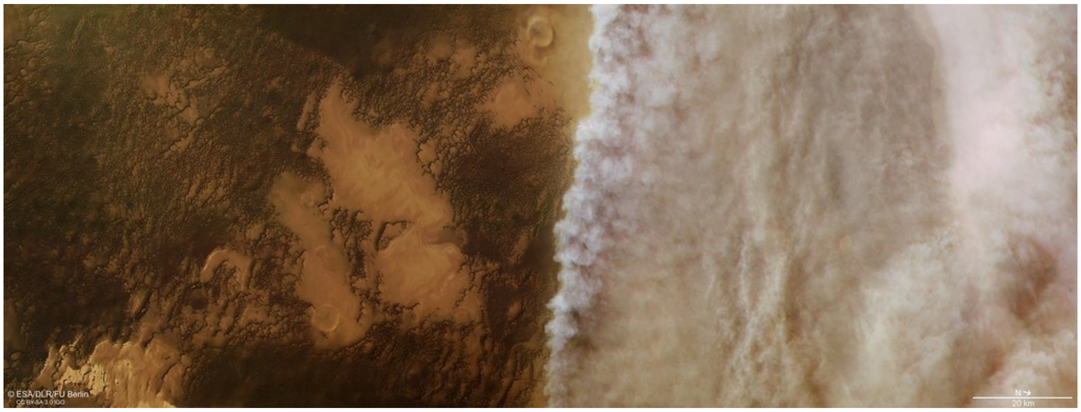
Olympus Mons.

https:/www.needpix.com/photo/8174/mars-planet-olympus-mons-volcano-mountain-highest-mountains-space-space-travel;

Mars is also knowns for its gigantic dust storms that occasionally sweep the planet, sometimes for weeks or even months at a time.

The southern hemisphere of Mars is heavily cratered highlands with an average altitude is 5 km above the northern. Why the northern hemisphere is lower in elevation is still a mystery. Because it has fewer craters, the assumption is that the northern hemisphere is younger than the southern hemisphere. Though it is currently very smooth, radar surveys of the northern hemisphere have found evidence of an older, cratered surface beneath.

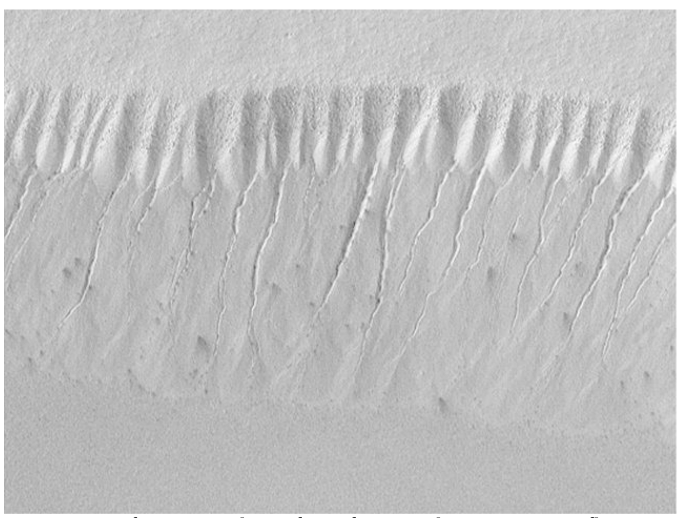
This means the northern hemisphere must have become lower than the southern early in Mars' history and was then covered by a lava flow, obscuring its craters from the Heavy Bombardment. Its low elevation has also led to speculation that it may have been home to an ocean during Mars' early, wetter history.



Dust storms on Mars.

https://commons.wikimedia.org/wiki/File:SiGe_RTG.png

10.2.2 Water on Mars



Numerous features on the surface of Mars indicate past water flows.

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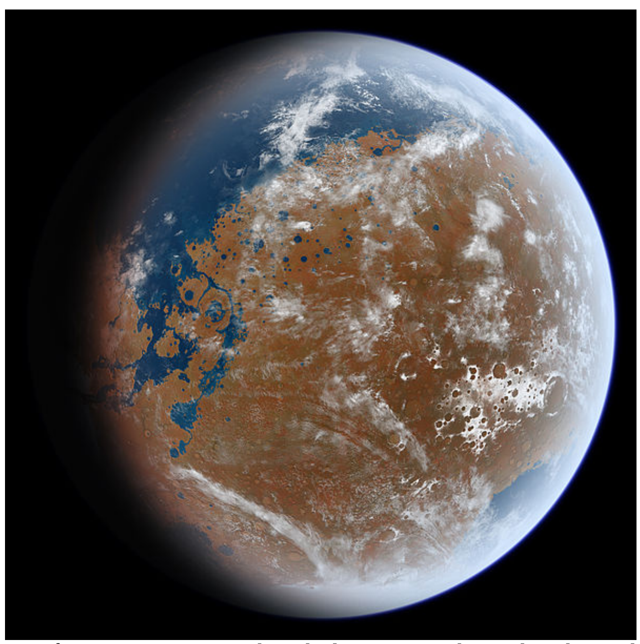
Nanedi Valles valley system on Mars.

https://commons.wikimedia.org/wiki/F..._ESA199848.jpg

Though Mars today is a frozen, dry world, there is evidence that earlier in its history, liquid water may have existed on its surface. Satellite surveys of Mars have found runoff channels resembling those on Earth. No evidence of a connected river system has been found, indicating the features are probably due to flash floods occurring during heavy rain storms. Other evidence of early water on the surface of Mars includes the fac that impact craters less than 5 km across have mostly been eroded away.

As noted in Chapter 9, planetary scientists have used analysis of craters to estimate of the age of the surface. Features that indicate past river flows date to the oldest (Noachian) areas of Mars. Further indicating that Mars was wetter in the past. The smoother surface of the northern hemisphere is younger, having mostly formed during the Amazonian Epoch (2 billion years ago). If this region was once home to an ocean, it indicates that Mars probably dried up around 2 billion years ago.


Billions of years ago, Mars may have had an ocean in the northern hemisphere.

https:/commons.wikimedia.org/wiki/File:AncientMars.jpg;

Could there be liquid water on Mars today? The atmosphere is too thin to allow for any bodies f liquid water to accumulate on the surface today. Recently however, gullies have been seen that probably indicate the occasional presence of liquid water. These appear to be seasonal appearances of possibly briny water that appear for very brief periods before freezing or evaporating.

Scientists once thought the southern polar cap is composed of mostly frozen carbon dioxide (dry ice), but recent measurements of the polar temperatures indicate both permanent caps are mostly H_2O ice, with some CO_2 ice mixed in. In the winter, the polar weather is so cold that CO_2 freezes out of the atmosphere and makes much larger seasonal caps of dry ice deposits a few meters thick.

In 2010, radar on the Mars Reconnaissance Orbiter measured 820,000 cubic kilometers (200,000 cubic miles) of ice in the northern polar cap. But the red planet's eccentric orbit brings it a lot closer to the Sun during the southern hemisphere's summer. This makes the southern summers warmer, so the southern polar cap shrinks more than the northern one does. However, because of Kepler's second law of orbital motion, Mars also moves a lot faster in its orbit during the southern summer. The warmest part of the Martian year is brief, and the southern ice cap never completely melts. If the ice in Mars' polar caps melted, it would cover Mars to a depth of 5.6 meters.

There is some possibility that there are "seas" of liquid water under these ice deposits. In July 2018, scientists announced the discovery of an underground lake near Mars' southern polar ice cap. Radar data from ESA's Mars Express orbiter found this lake about 1 mile beneath the surface. This lake may be 12 miles long. What keeps it liquid is still unknown. It may be loaded with salts (perchlorates) that lower the melting temperature.

Could this be an ancient water basin on Mars?

https:/www.flickr.com/photos/europeanspaceagency/6995559030;

A crater on Mars showing erosion features.

https:/www.pxfuel.com/en/search?q=mars;

10.2.3 Martian Moons

Mars' moon Phobos.

https:/commons.wikimedia.org/wiki/File:Phobos_seen_by_Mars_Express_(4437606433).jpg;

Mars has two small, potato-shaped satellites which are probably captured asteroids or early planetesimals. The Martian moons are named after the two sons of the Roman god of war, Phobos (Fear) and Deimos (Terror). Their black surfaces indicate that they may be rich in carbonaceous material, similar to that found on some asteroids.

Phobos is the larger of the two moons, have dimensions of 27 by 19 kilometers (17 by 12 miles). In about 100 million years, however, a Martian observer would have quite a show. Phobos's orbit is quite close to the planet, and tidal forces are bringing it even closer. Eventually, it will either crash onto the Martian surface or get torn apart by those tidal forces, forming a ring of debris around Mars.

Deimos is the smaller of the moons, having dimensions of 15 by 11 kilometers (9 by 7 miles).

10.2.4 Martian meteorites

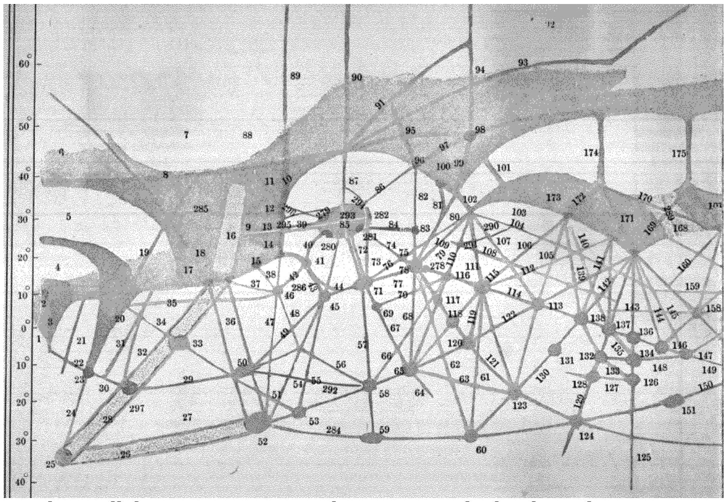
This meteorite originated from Mars.

https:/commons.wikimedia.org/wiki/File:Los_Angeles_meteorite,_martian_basalt,_UCLA.jpg;

The heavily cratered surface of Mars show that the red planet has seen many impacts. Because Mars has a surface gravity that is only 38% of Earth's, fragments blasted from large impacts can escape from Mars. Sometime later (typically a few million years), a very small fraction of these fragments has collided with Earth and survived their passage through our atmosphere, just like other meteorites. Most of the Martian meteorites are volcanic basalts; most of them are also relatively young—about 1.3 billion years old. Analyzing the details of their composition can show us that they are not from Earth or the Moon. Besides, there was no volcanic activity on the Moon to form them as recently as 1.3 billon years ago. Also, it would be very difficult for ejecta from impacts on Venus to escape through its thick atmosphere. So, by the process of elimination, the only reasonable origin seems to be Mars, where the Tharsis volcanoes were active at that time.

The Martian origin of these meteorites was confirmed by the analysis of tiny gas bubbles trapped inside several of them. These bubbles match the atmospheric properties of Mars as first measured directly by Viking. It appears that some atmospheric gas was trapped in the rock by the shock of the impact that ejected it from Mars and started it on its way toward Earth. One of the most exciting results from analysis of these Martian samples has been the discovery of both water and organic (carbon-based) compounds in them, which suggests that Mars may once have had oceans and perhaps even life on its surface.

10.2.5 Martian Canals?



Percival Lowell drew numerous maps depicting "canals" he claimed to see on Mars.

https://commons.wikimedia.org/wiki/F...Mars_Map_1.gif

In 1877, Giovanni Schiaparelli observes “channels” on Mars, which he called “canali” in Italian. In English, the word “channel” implies a natural feature while “canals” are artificially dug waterways. The similarity of the Italian word “canali” with the English “canal” had led many to think Mars had a series of canals on its surface. Wealthy amateur astronomer Percival Lowell was among those who imagined Mars as a dying world, whose inhabitants dug canals to transport water from the poles. Lowell drew detailed maps of the canals he claimed to have observed through his telescopes and published speculative works about a dying Martian civilization, desperately digging aqueducts to transport water from the poles. Later observations by robotic probes, however, found that much of Lowell’s “canals” were the result of wishful thinking. Some people suspect that what Lowell was drawing was the reflection in the eyepiece of the blood vessels in his own eye.

10.2.6 Life on Mars?

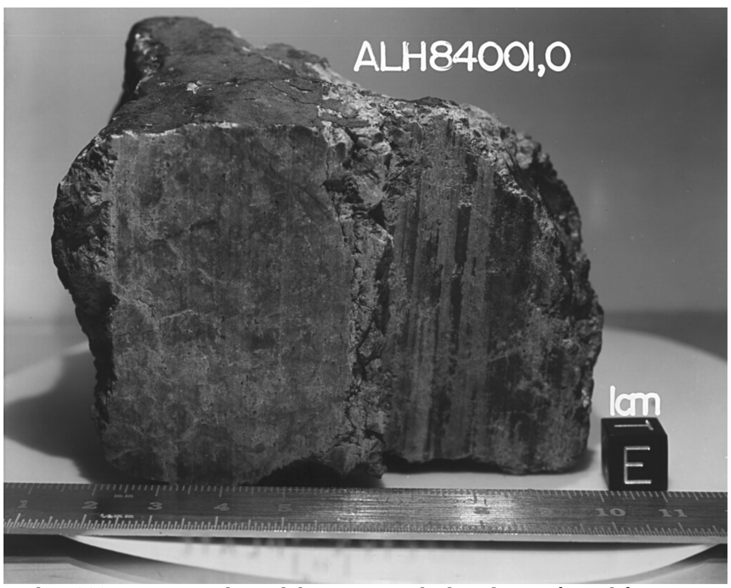
Viking Lander Arm.

https:/commons.wikimedia.org/wiki/File:Viking_Lander_Arm_(170938835).jpg;

Despite the discrediting of Lowell's canals, many scientists still held out hope that Mars could be home to life today. The Viking probes of the 1970s found no conclusive evidence of life on Mars. However, one of the Viking orbiters took a photograph that renewed speculation about a Martian civilization among some people. The photograph was of a rock formation that some people interpreted as looking like a human face. The so-called "Face of Mars" fueled conspiracy theories. Some accused NASA of covering up "evidence" of a Martian civilization. In 1997, NASA's Mars Global Surveyor took photographs of the same rock formation with 20 years improvements in resolution. Like the canals draw by Lowell, the "face" proved to be an optical illusion, a trick of poor resolution, shadows, and wishful thinking.

In 1996, scientists another event fueled speculation about Martian life. A group of scientists claimed that they found fossilized evidence of microbial life in the meteorite ALH84001. This four-billion-year-old meteorite was found in Antarctica in 1984 and analysis confirmed that it originated from Mars. The claims that the meteorite contained evidence of ancient Martian life, however, are controversial and many other scientists believe the features found in ALH84001 could have formed from inorganic (nonliving) processes. It is also possible ALH84001 was contaminated with organic material from Earth. Today, few scientists credit ALH84001 shows evidence of past Martian life.

Even though the evidence of life on Mars has long eluded us, many scientists still believe that Mars may have supported life during its earlier, wetter period. Perhaps one day, conclusive evidence of past microbial life on Mars may be found.



In the 1990s, scientists claimed this meteorite had evidence of past life on Mars.

https:/www.flickr.com/photos/nasa2explore/9350187371;

10.2.6 Colonizing Mars

In recent years, there has been renewed interest in sending humans to Mars, not only as a short-term scientific mission but also to establish a permanent colony. Not only has NASA begun planning for a crewed mission to Mars, but private corporations such as Elon Musk’s SpaceX have also announced intentions to send people to Mars.

But why Mars?

Humans may soon travel to Mars.

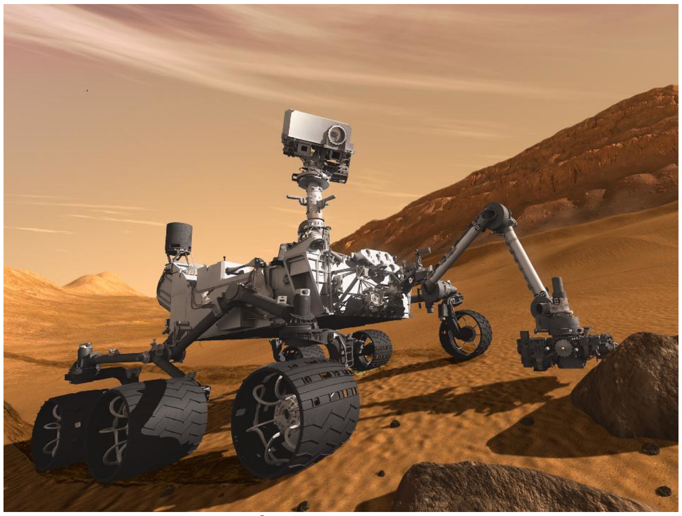
https:/commons.wikimedia.org/wiki/File:Terraforming_of_Mars.jpg;

For one thing, it is the planet in our Solar System that is most like Earth. Many people, such as Elon Musk, Amazon’s Jeff Bezos, and the physicist Stephen Hawking have argued that humanity’s survival may depend on spreading our species out to multiple worlds. Keeping our entire species on a single planet makes us vulnerable to an extinction level event such as the asteroid that wiped out the non-avian dinosaurs. Humans on Mars also offer the opportunity to conduct more direct scientific research that cannot be done with robots. Finally, just like the people who first climbed Mount Everest or traveled to the South Pole might has said, it is there. Humanity has long been explorers with a yearning to see new things and be the first to arrive at a new location.

When planning a mission to Mars, we must select a crew. Most proposals suggest a first mission with a crew of about five or six people. Who should they be? The first and most important rule should be: No one should be indispensable. Members of the crew should be cross trained in various skills. You do not want your crew to be six months into a two and half year journey away from Earth and discover that the only person with medical training needs emergency surgery or that the only person who can fix the engine has met with an accident.

The second rule would be: They should get along. In a theoretical mission, they could spend six months to get to Mars, a year and a half on the surface, and six months to get back. That is two and a half years together in a confined spaced. There have been numerous experiments involving keeping a small group of people isolated in a remote location like Antarctic, Siberia, or the Atacama Desert to study the psychological effects of prolonged living in tight quarters. Personal disputes can put the entire crew at risk, especially when sending one or more of them back to Earth mid-missions is not even an option.

In terms of the skills our Martian crew would need, they would need a mechanic or engineer. Members of the crew will need to know how to fix nearly any problem on their craft and their surface habitat that may arise. Obviously, they will need a pilot, someone who can fly the craft that will take them to and from Earth. Someone with medical training would also be indispensable. Since they will likely have to grow their own food, a botanist will be needed to tend the hydroponics garden. Other skills will be needed depending on the kind of research to be conducted on the surface, including chemistry, chemical engineering, geology, atmospheric science, and astronomy.



The Curiosity Rover.

https:/www.flickr.com/photos/nasablueshift/7753901656;

Over the past few decades, we have done quite a bit of successful research using robotic probes on Mars. Robot landers and rovers have sent back invaluable data that have expanded our understanding of the red planet more than we could have possibly imagine. Robots do have several advantages over a crewed mission. They do not need air, food, or water. They also do not need to be shielded from the radiation in space. All those things mean added mass and complications to the mission. Life support systems are additional things can break down and jeopardize the mission. Without life support the need for the added mass of life support, a robotic mission requires less fuel to get to Mars.

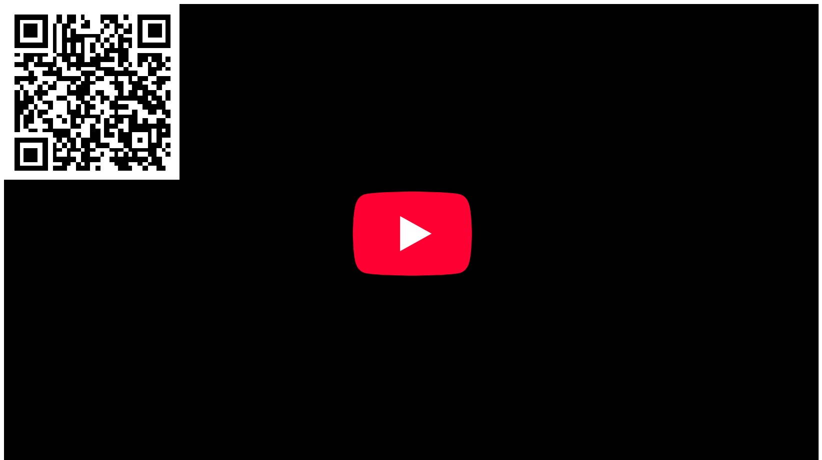
We also do not need to bring the robots back home, unless they intend to conduct a sample return mission. This also reduces the required amount of fuel for the mission and eliminates the need for a return vehicle. Robotic missions, being one way, can discard their transport vehicles, heat shields, and parachutes once they are no longer needed. Those systems do not need to be designed to bring the probe back. Unless the humans intend to become permanent colonists on Mars, they will require some means of returning to Earth.

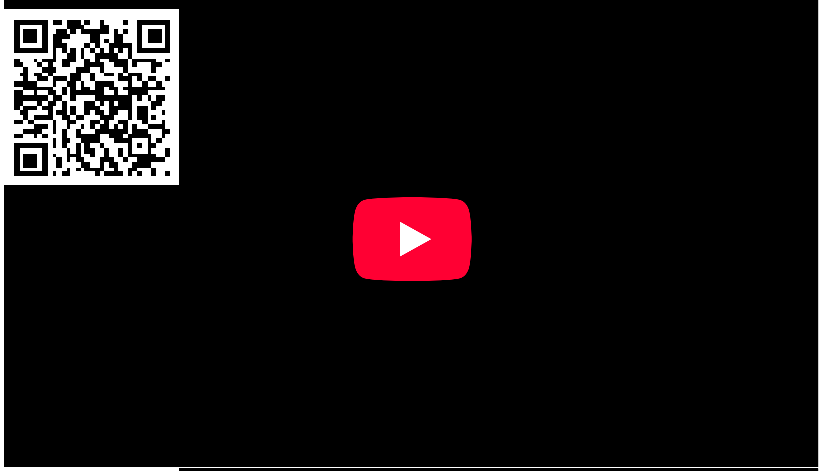
Robots are also more robust than humans. They can be designed to withstand landing techniques that would kill a human being. The airbag landing system used the Pathfinder, Spirit, and Opportunity missions would not work for a capsule containing humans. Humans would require a softer landing with fewer margins for error.

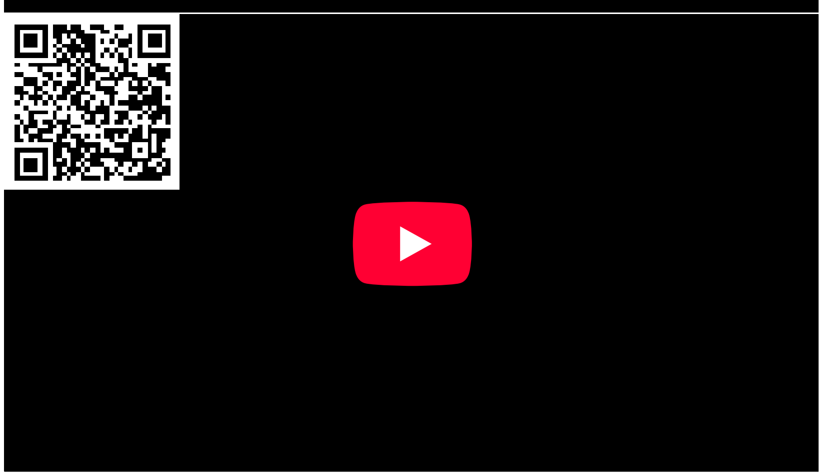
On the other hand, robotic probes still need to be operated remotely. Artificial intelligence research has not yet reached the point where landers and rovers cannot operate independently. They cannot make decisions on their own to react with unexpected conditions. For example, some of the rover missions ended when the probes got stuck in soft regolith or because their solar panels failed to deploy. Being unable to act independently means robotic probes need to receive constant commands from Earth. These commands are limited by the speed limit. The time it takes a signal from Earth to Mars varies depending on where the two planets are in their respective orbits. At their closest approach, the time delay is fifteen minutes. That means, when a technician on Earth sends a command, it takes at least fifteen minutes for the probe on Mars to receive it and then another fifteen minutes or more for the probe to send a signal back to Earth confirming that the command has been received. This makes robotic missions to Mars slow and tedious.

Humans on the surface can make independent decisions, decide what samples to collect, and what data to record without constantly waiting for updates from Earth. They can also react to the unexpected or mission threatening emergencies on their own. This affords greater mission flexibility.

Sending humans to Mars poses several technical and safety challenges. One of the biggest problems is radiation. Once humans leave Earth's magnetic field, they have no protection from the solar wind and cosmic rays. Occasionally, there may be solar flares, which could be deadly. A mission to Mars could result in an exposure twenty times what the average American receives in a year. Mars also lacks a strong magnetic field, so the crew would continue to face radiation exposure while on the surface of the red planet.

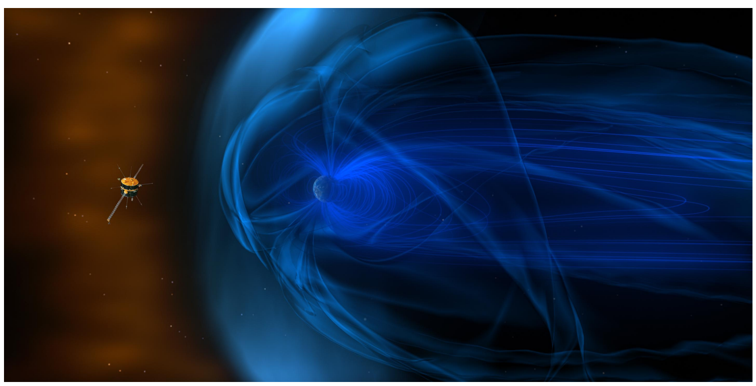







An artist's conception of a Mars colony.

https:/www.flickr.com/photos/nasa2explore/9516300839;


e leave the Earth's magnetosphere, humans will have no protection from radiation.
ɔmmons.wikimedia.org/wiki/File:NASA_mission_Wind_(Solar_Wind_Workhorse_Marks_20_Years_of_Science_Discoveri

To survive, humans will need shielding. In popular imagination, lead is often described as a good shielding for radiation. While a layer of lead can block most radiation, lead is a very dense and heavy metal. It is also very soft. A spacecraft needs to be sturdy and light, so lead is unsuitable. Fortunately, there is another material that makes a good radiation shield and astronauts will require large quantities of it anyway: water. To protect astronauts from radiation, we can pack water tanks around the outside of the habitat. Toward the interior, there can be a more heavily shielded “storm shelter” for solar flare events.

Another challenge for astronauts is microgravity. Astronauts traveling to Mars would spend a year in a near weightless environment. NASA and other space agencies have studied the effects of microgravity for decades on board the space shuttle and the ISS. The known health effects include muscle atrophy as they do not work as hard as they do on Earth. Also, the heart does not have to pump as hard, so it weakens as well. Astronauts on prolonged space mission also experience a loss of bone density. In addition to weakened bones, the calcium that leaves the bones can accumulate in the blood, increasing the risk of kidney stones.

Microgravity poses a significant health risk to humans.

https:/www.flickr.com/photos/nasafo/8167821805;

While the effects of microgravity are well-known, there are not many options to prevent them. Astronauts on the ISS engage in regular exercise on a treadmill. This can slow muscle atrophy, but it does not prevent it entirely. One possible solution would be to use centrifugal force of rotation would simulate the effect of gravity. As the craft travels to and from Mars, it would be attached to cable with a counterweight attached to the other end. The two would then rotate around their common center of mass. The centrifugal force of the rotation would simulate the gravity of Earth. The technical challenges in making this practical are daunting and it has never been done before.

Humans will also need food to eat and food is added mass. The Apollo missions lasted less than a week and could pack enough food for the journey. The ISS receives regular supply shipments from Earth. Food is added mass and for a mission of 5-6 people over 2.5 years, packing enough freeze-dried or vacuum-sealed food is not practical. The astronauts will have to grow their own food. Growing food in soil would be too difficult on a mission in Mars, so **hydroponics**, growing plants in water without soil would be the only practical solution. Hydroponics is still experimental but could theoretically produce enough food for a mission if maintained. Astronauts would have to get used to a vegetarian diet, as bringing animals for meat, milk, eggs would not be possible. Not only would they take up space, but they would also require their own air, water, and food, increasing the demands for life support. Even a hydroponics garden would take up a considerable amount of space and water.

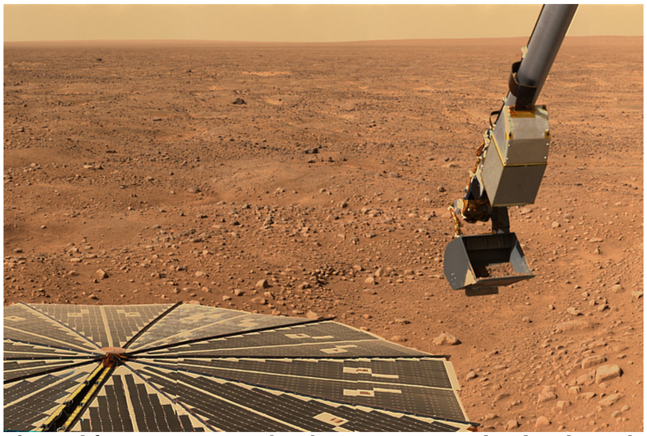
Hydroponics may enable people to grow food in space.

https:/commons.wikimedia.org/wiki/File:Hydroponics_(33185459271).jpg;

Humans also need to breathe, so they will require air. Specifically, they will require a means to convert the carbon dioxide they exhale back into oxygen. Again, simply packing the ship with tanks of oxygen is not practical for a long-term mission, but that adds more mass to the mission. As astronauts breathe, the amount of available oxygen in the capsule is depleted and replaced with carbon dioxide. Too much carbon dioxide leads to fatigue, light-headedness, and eventually suffocation. Hydroponic plants can help but may not be enough. Oxygen production will probably also have to be done chemically.

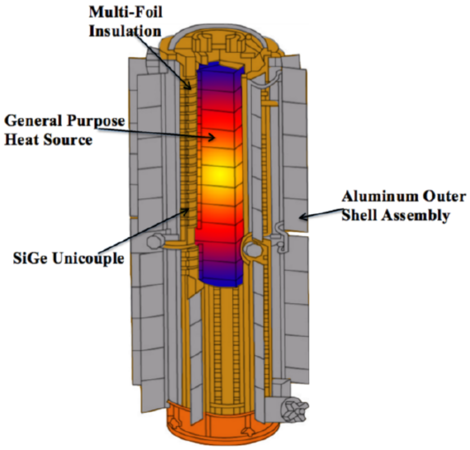
As we have noted, one of the biggest limiting factors for a mission to Mars is mass. More mass requires more fuel. In fact, fuel itself is added mass. The fuel demands for a mission can be divided into the following parts: 1) Launching from the Earth's surface; 2)Setting the ship onto a course to Mars; 3) Landing on Mars; 4) Launching from the Martian surface; 5) Setting the ship onto a return course; and 6) Returning to the surface of the Earth. Each of these six steps have their own fuel needs and packing enough fuel for all them may be cost prohibitive. Mars Direct, a proposal from the private organization, the Mars Society, has offered a possible solution. Instead of sending everything needed for the entire mission in a single launch, two separate vehicles would be sent. The first would be the Earth Return Vehicle (ERV). The ERV would have an automated chemical factory which would produce fuel for the return trip out of the Martian Atmosphere. Once the ERV signaled to Earth that its fuel tanks were fuel, mission control would launch the crewed habitat vehicle. The crewed habitat would land near the ERV and once the mission was complete, the astronauts would board the ERV and pilot it home.

A Martian landing site will also need electricity. Solar panels may be an obvious solution, but Mars' many dust storms will reduce their capabilities. The crew may have to spend a lot of their time cleaning them off to keep them operational. Some alternatives, such as a plutonium powered thermocouple system may be needed as a backup. Such systems have been routinely used in probes to the outer solar system where the Sun's light is too dim for solar panels to work.



Solar panels can be used for power on Mars, but they can get covered in dust due to the many storms.

https:/www.pickpik.com/mars-planet-red-planet-surface-mars-rover-space-probe-149576;



A nuclear thermocouple generator can be used to produce power.

https://commons.wikimedia.org/wiki/File:SiGe_RTG.png

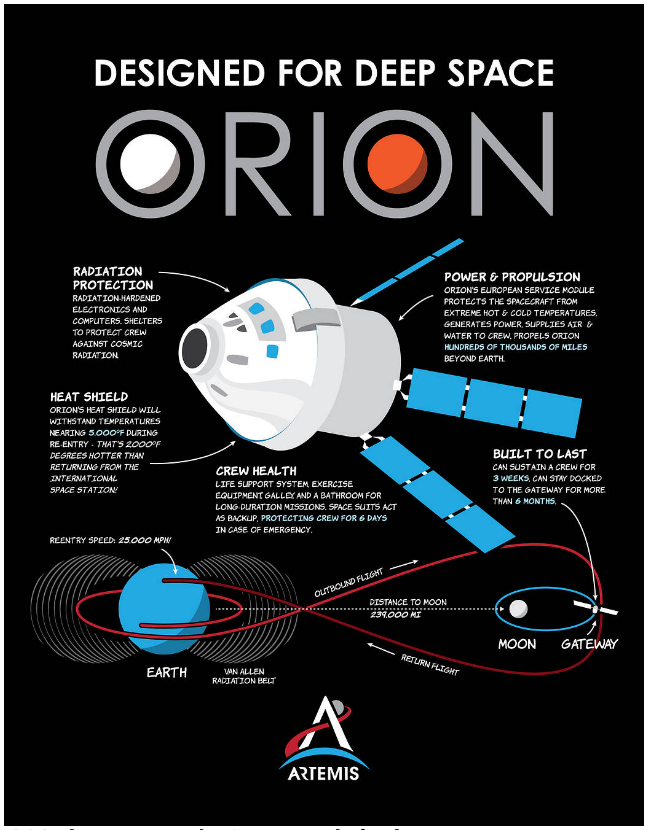
While on the Martian surface, the astronauts will also need an airtight structure that is shielded from radiation. One proposal is to use underground lava tubes. These are natural caverns that were hollowed out when Mars still had active lava flows. The thick rock above the lava tubes would provide adequate shielding. Astronauts could set up inflatable habitats for living quarters inside the lava tubes.

Another proposal would be to use 3D printed habitats. NASA has held annual competitions in which various university or private teams compete to design a habit that can be printed using materials made from the Martian regolith.

NASA has held competitions for 3D printed habitats on Mars.

https:/www.flickr.com/photos/nasahqphoto/35999286213;

So, looking at the challenges ahead, what is NASA's plan to get to Mars? Given its historic aversion to unnecessary risk, it is perhaps not surprising that NASA intends to test out many of the systems needed for a Mars mission closer to Earth before sending them on a two and a half year journey where turning around and aborting will not be an option. So, NASA's current plan is to first go back to the Moon in a program named Artemis, after the twin sister of the Roman god Apollo. Unlike the Apollo program of the 1960s and 1970s, Artemis will involve more long-term missions on the surface and in orbit around the Moon. A spaceship called Gateway will orbit the Moon. Using Gateway, astronauts will engage in months-long missions in orbit around and on the Moon. They will study how the human responds to prolonged deep space conditions and how to keep a crew alive. These missions may begin as early as the mid-2020. Then, in the 2030s, NASA will attach an Orion capsule to Gateway and send it on a manned mission to Mars.



NASA plans on using the Orion capsule for deep space missions to Mars.

https:/www.nasa.gov/image-feature/orion-capabilities-for-deep-space-enable-crewed-artemis-moon-missions;

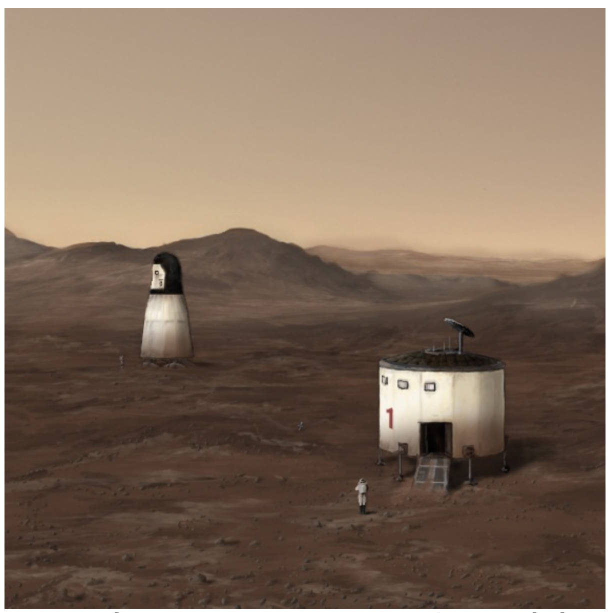
There have been several privately funded Martian missions in the early stages. One example is Mars One, in which a private organization based in Holland set the goal of sending people to Mars to establish a permanent colony there (no return trip). Mars One, however, has been criticized for having unrealistic goals. Despite this, hundreds of people applied to part of this colonization effect. As of this writing, Mars One has lost its source of funding. Its founder has promised to find a new source of funding, but for now, Mars One appears to be dead.

Meanwhile, SpaceX, the private launch company owned by Elon Musk has been moving forward with plans of an unmanned Mars landing in 2022 and a manned mission by 2024. The company has begun testing its Starship design for a vehicle that may one day take people to Mars.

Elon Musk, the CEO of SpaceX is among the people who advocate for colonizing Mars.

https:/commons.wikimedia.org/wiki/File:Elon_Musk_and_Chris_Anderson_at_TED_2017_(33486317634).jpg;

There is also Mars Direct, which is proposal written by Dr. Robert Zubrin of the Mars Society to send manned missions to Mars in a series of stages. First launch would an unmanned mission that includes the Earth Return Vehicle (ERV), a nuclear reactor, and a chemical plant. The chemical plant would manufacture fuel for the ERV from the Martian atmosphere. Once the fuel tanks in the ERV were full, the second launch would include a habitat unit and a crew of four. There may also be a second ERV launched during this time to serve as a backup or for use in a future mission. Once their mission was over, the crew would take the ERV home. Future launches would send additional ERVs and habitats, always ensuring that the crew had an ERV ready to take them home before they left Earth. Although the Mars Direct plan has no funding or support from a space agency or company with the resources to implement it, it did have a big influence on the plot of The Martian novel and movie.



Mars Direct proposes sending missions to Mars in two parts: A return vehicle and crew lander.

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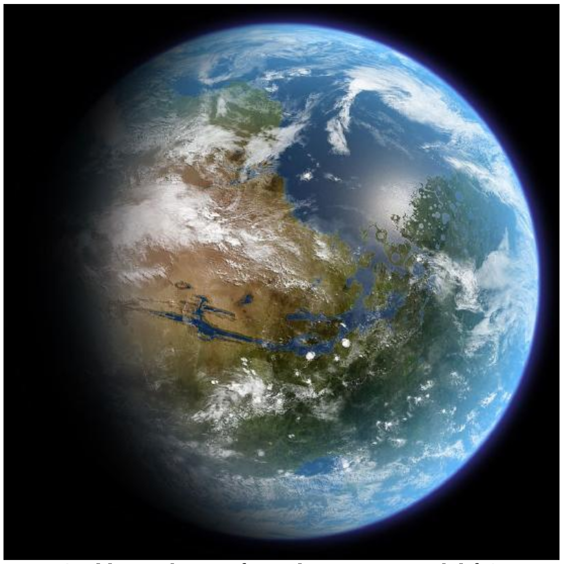
10.2.7 Terraforming Mars



Could Mars be terraformed to support Earth life?

https:/commons.wikimedia.org/wiki/File:TerraformedMarsGlobeRealistic.jpg;

Mars is cold and dry. Its atmosphere is thin and mostly carbon dioxide and it has no significant magnetic field. However, Mars may have had a thicker atmosphere in the past but lost it due to its weak gravity and lack of a magnetosphere. Which raises the question, can we **terraform** Mars, that is, can we alter the environment on Mars so that it can support life as we know it?

The first challenge would be to warm planet. Mars could be made warmer by building factories to pump out greenhouse gases. An MIT undergraduate named Margarita Marinova came up with an idea for how to do this. With astrobiologist Chris McKay, she proposed using artificially created perflurocarbons or PFCs to initiate the warming. PFCs are super-effective greenhouse gases that last a long time. They also have no effect on living organisms or the ozone layer. Marinova did rough calculations and found that a hundred factories making PFCs, each with the energy of a typical nuclear reactor, would raise the Martian temperature by a degree every fifteen years. With an assist from evaporating carbon dioxide it would take 500 to 600 years to bring the entire planet above the freezing point of water.

Other methods might include orbiting mirrors or diverting asteroids that are rich in ammonia and water. Warming could also be achieved with a mirror the size of Texas aiming light at the South Pole. The 200,000 tons of aluminum that are required is only five days' worth of Earth production. Mining and manufacturing could be done in space, using mineral mined from asteroids. With the pole raised in temperature by only 5 °C, the CO_2 would start to evaporate and take Mars to the tipping point of global warming.

As the temperature rises by about 10 C, the frozen carbon dioxide (dry ice) in the poles will completely thaw, releasing more greenhouse gases into the atmosphere. Eventually, the atmosphere would be thick and warm enough to support liquid water on the surface.

Once this point is reached, people would not need space suits on the surface, but would still need some form breathing mask for oxygen.

Next, we would need to provide a breathable atmosphere. We could seed the planet with algae or build oxygen factories to pump out oxygen. Nitrogen could be released from the Martian regolith. One type of cyanobacterium with the unmanageable name Chroococcidiopsis is found at such extremes of cold, dryness and salinity on Earth that it is often the sole survivor. The cyanobacterium called Matteia can dissolve and bore through rock, fixing nitrogen and liberating carbon dioxide. There is also Deinococcus radiodurans. This microbe can survive a hundred times the radiation dose that would kill a human in minutes; it keeps multiple stacked copies of its DNA so it can repair damage quickly. Naturally occurring microbes could be augmented with genetically engineered varieties. The goal would be to establish the biosphere and release enough oxygen, nitrogen, and carbon dioxide to raise the atmospheric pressure from its current 0.7% of Earth to about 2% or 3% of Earth's sea level pressure.

Then, we could introduce plants and boost the atmosphere to a breathable level. Many of these changes will occur simultaneously. Once the atmosphere is thick enough to support liquid water on the surface, water will carve out rivers and cause erosion. Soil will begin to form, transforming the surface from meteorite-pulverized regolith to something that could support plant life. Eventually, the climate on Mars would be much like high latitudes on Earth, such as parts of Alaska or Scandinavia.

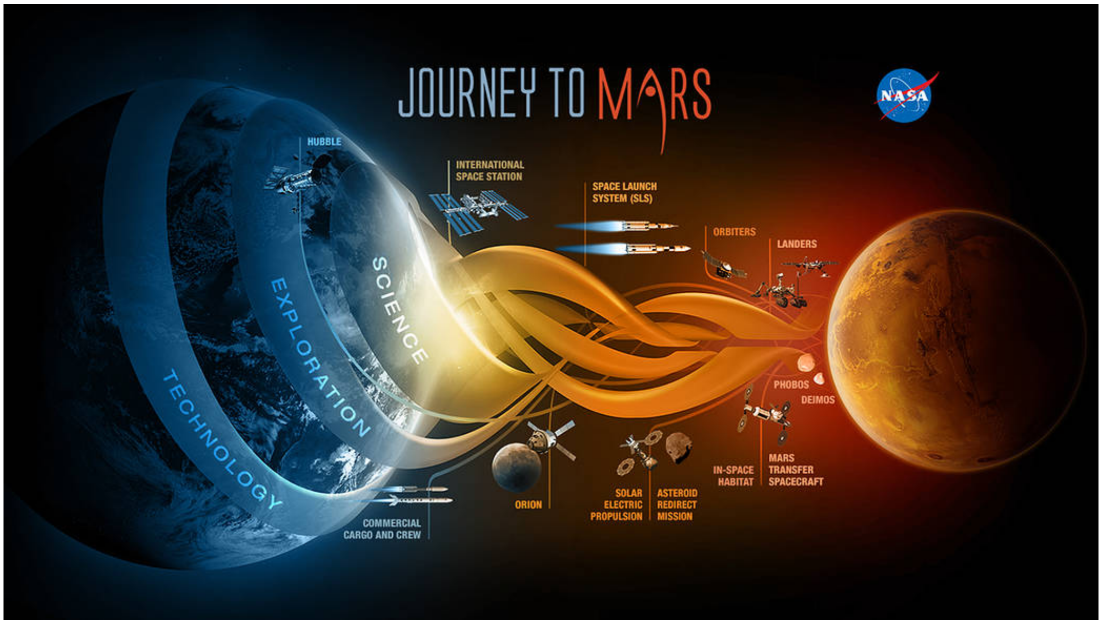
Mars may one day have a climate similar to that of the northern latitudes on Earth.

https:/commons.wikimedia.org/wiki/File:Almost_terraformed_Mars.jpg;

This is all still theoretical and once Mars has a new and complex set of biological chemical cycles in play, different from those on Earth, it would be difficult to predict the actual conditions. The process could take between 100 and 1,000 years, depending on the techniques used. Once established, it might remain stable for 100,000,000 years before the atmosphere would bleed into space.

One final thing Mars still lacks is a magnetosphere. For humans to live openly on the surface, we would need an artificial magnetosphere. Not only would it protect people from radiation, but a magnetosphere would slow the loss of atmosphere by deflecting the solar wind away from the planet. Some models propose placing a spacecraft in the L1 Lagrange point in between Mars and the Sun. This satellite would generate a permanent magnetic “shield” that would surround the red planet.

Colonizing and terraforming Mars are still the stuff of science fiction. There may be technical and economic complications that may make turning Mars into an Earth-like home for humanity an impossibility. Or perhaps we will discover new technologies that will make it even easier to achieve than we can imagine today. Time will tell if the future of humanity includes living on the red planet.



https:/www.nasa.gov/content/nasas-journey-to-mars;

11: The Jovian Planets

Learning Objectives

- Describe the properties and composition of the four Jovian planets.
- Compare the atmospheres of Jupiter, Saturn, Uranus, and Neptune.
- Compare the magnetospheres of Jupiter, Saturn, Uranus, and Neptune.
- Compare the internal properties of the four Jovian planets.

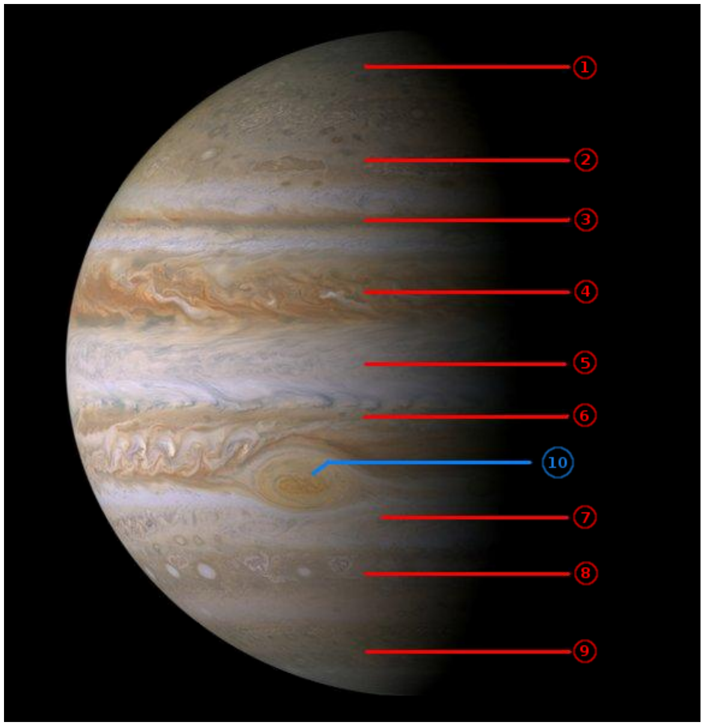
Beyond the asteroid belt, orbit the Jovian planets. the Jovian planets are very different than the inner terrestrial planets. While the terrestrial planets are small, rocky bodies, the Jovian planets are gaseous without a solid surface. The two largest, Jupiter and Saturn, are mostly hydrogen and helium and are referred to as the **gas giants**. Uranus and Neptune also contain some hydrogen and helium, but also contain a lot of hydrogen compounds like water (H_2O), methane (CH_4), ammonia (NH_3). Astronomers refer to these compounds collectively as “ices” and refer to Uranus and Neptune as **ice giants**.

All the Jovian planets are much larger and much less dense than the terrestrial planets. In fact, Saturn is less dense than water, which means, if you could find a bathtub big enough to fit it, it would float. Uranus and Neptune are denser than Saturn because they have less H/He, proportionately, and more ices. Though similar in composition to Saturn, Jupiter is denser because of compression. Its large mass causes more pressure on the hydrogen and helium, squeezing them into a denser configuration. In fact, Jupiter may be at the upper limit for how large a Jovian planet can get. Adding more mass to it would cause more compression, further squeezing the planet into a smaller radius.

Being large balls of gas gives the Jovian planets mean they do not rotate uniformly. They spin faster at the equator than at the poles. They are also are not quite spherical because of their rapid rotation, being flattened at the poles. In addition, all the Jovian planets have strong winds and storms caused by convection and rotation. All the Jovian planets have substantial magnetospheres, but Jupiter's is the largest by far.

11.1: Jupiter's Atmosphere

Jupiter is known for its multi-colored bands. The atmosphere of Jupiter has **bright zones** and **dark belts**. The zones are cooler and are higher than belts. A stable flow of gases underlies the zones and bands, called **zonal flow**. Cooler gases sink in the atmosphere, creating the dark belts while warmer gases rise, creating the lighter zones. Different compounds in atmosphere produce clouds of different colors. For example, ammonium sulfide clouds (NH_4SH) reflect red/brown while ammonia in the highest, coldest layer, reflects white. Because Jupiter does not have a solid surface, when modeling its atmosphere, astronomers take the top of the troposphere as the 0 km mark and then map all positives based on how far above or below that mark they are.



Jupiter's belts and zones.

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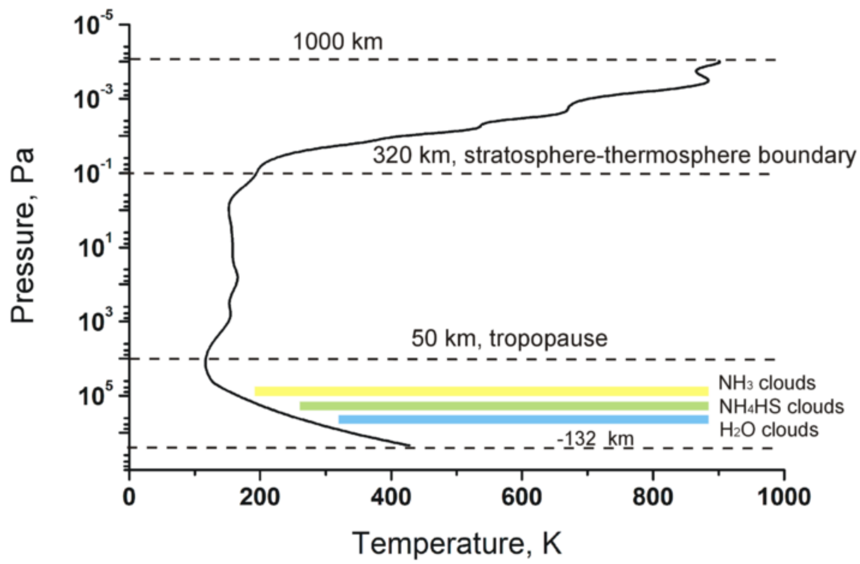


Structure of Jupiter's atmosphere.

https://commons.wikimedia.org/wiki/F...atmosphere.png

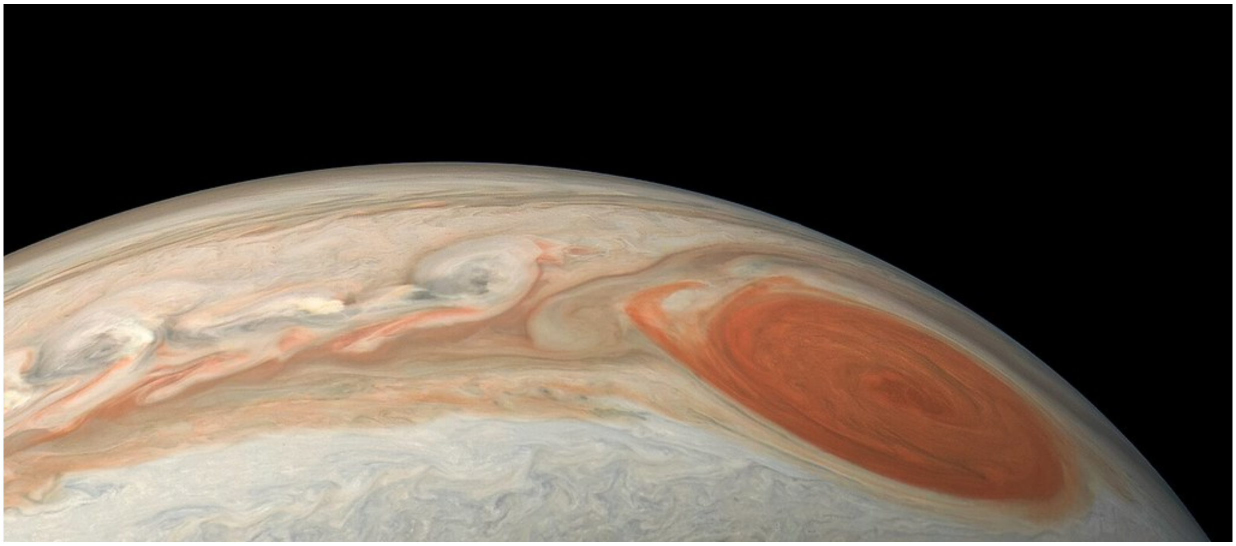
The composition of Jupiter's atmosphere is as follows:

- 89.8% Hydrogen (H_2)
- 10.2% Helium
- ~0.3% Methane
- ~0.026% Ammonia
- ~0.003% Hydrogen deuteride (HD)
- 0.0006% Ethane
- 0.0004% water
- Ices on Jupiter include ammonia, water, ammonium, hydrosulfide(NH_4SH)

In December of 1995, the Galileo probe entered Jupiter's atmosphere and collected data for 57 minutes. The data from the probe revealed Jupiter's atmosphere had roughly the same percentage of hydrogen and helium as the Sun. The Galileo probe also found that Jupiter appears to have more carbon, nitrogen, sulfur, and other heavy elements, than the Sun. It is likely that these elements may come from interplanetary bodies like comets and asteroids that strike Jupiter. The Galileo probe found few organic molecules.

Hydrogen compounds in Jupiter form clouds. Different cloud layers correspond to freezing points of different hydrogen compounds. These cloud layers include, in descending order, ammonia (40-50 km below the top of the troposphere), ammonium hydrosulfide (60-70 km below the top of the troposphere), and water (~100 km below the top of the troposphere). Jupiter's lowest cloud layer cannot be seen by optical telescopes. Measurements taken by *Galileo* probe show high wind speeds even at great depth. These are likely due to heating from the interior of the planet instead of from the Sun.

Jupiter’s most striking feature is the Great Red Spot. This storm system is twice as wide as Earth. It is at least three centuries old as astronomers first noted its existence three hundred years ago and it is still there. Unlike on Earth, where hurricanes lose energy as they pass over colder water or make landfall, Jupiter’s lake of a solid surface produces instabilities that can last for centuries.



The Great Red Spot.

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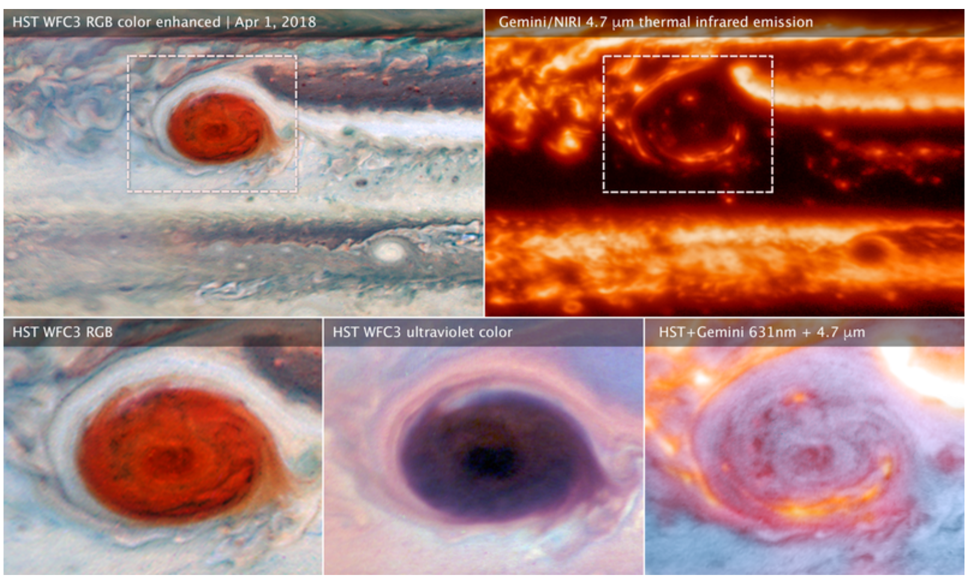
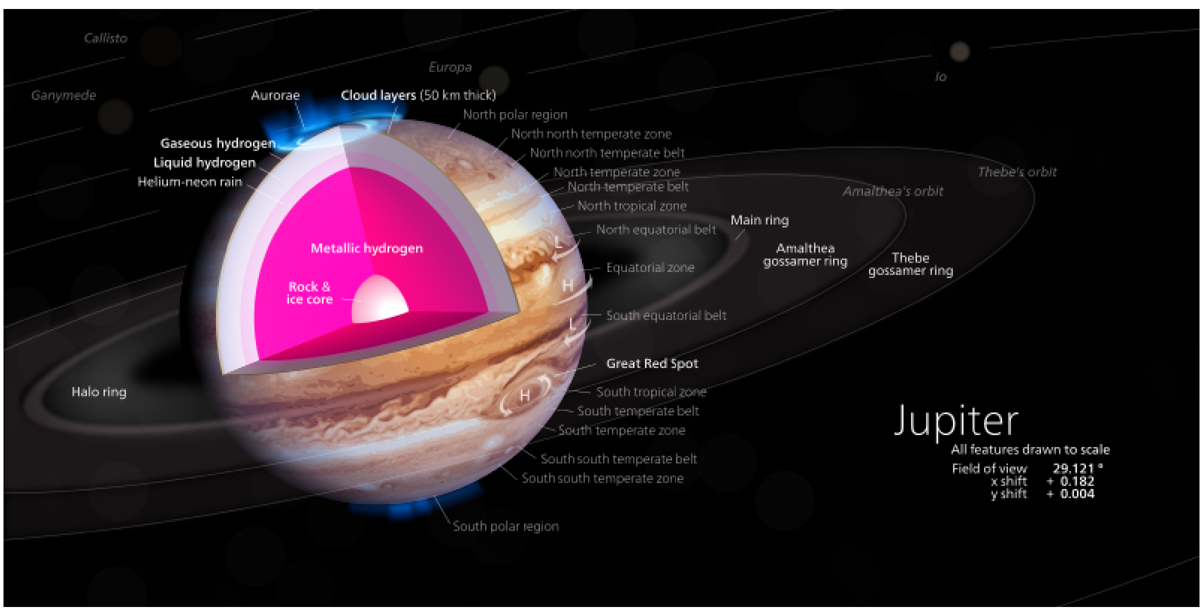


The Great Red Spot in various wavelengths.

https://commons.wikimedia.org/wiki/F...892941386).png

11.2: Jupiter's Interior

There is no direct information is available about Jupiter's interior, but scientist have a good understanding of the behavior and properties of its main components: hydrogen and helium. The interior of Jupiter consists of layers under high pressure and temperatures. Models suggest that at a depth of 100 km, the temperature reaches 300 K and a pressure of 10 atmospheres. Under those conditions, hydrogen exists as liquid molecular hydrogen. The molecular hydrogen layer continues to a depth of 20,000 km. At that depth, the temperature reaches 11,000 K and the pressure is $3X10^6$ atmospheres. Below that level, the electrons in hydrogen become released from their atoms and freely move about. Under these conditions, hydrogen takes on the properties of metal, such as being a good conductor of heat and electricity. As a result, scientists refer to this state as **metallic hydrogen**. The metallic hydrogen layer rangers from a depth of 20,000 km to 60,000 km where the temperature reaches 18,000 K and the pressure is $4X10^7$ atmospheres. Below the metallic hydrogen layer, Jupiter may have a solid core of approximately 10 Earth masses mostly made of hydrogen compounds, metals, and rock.

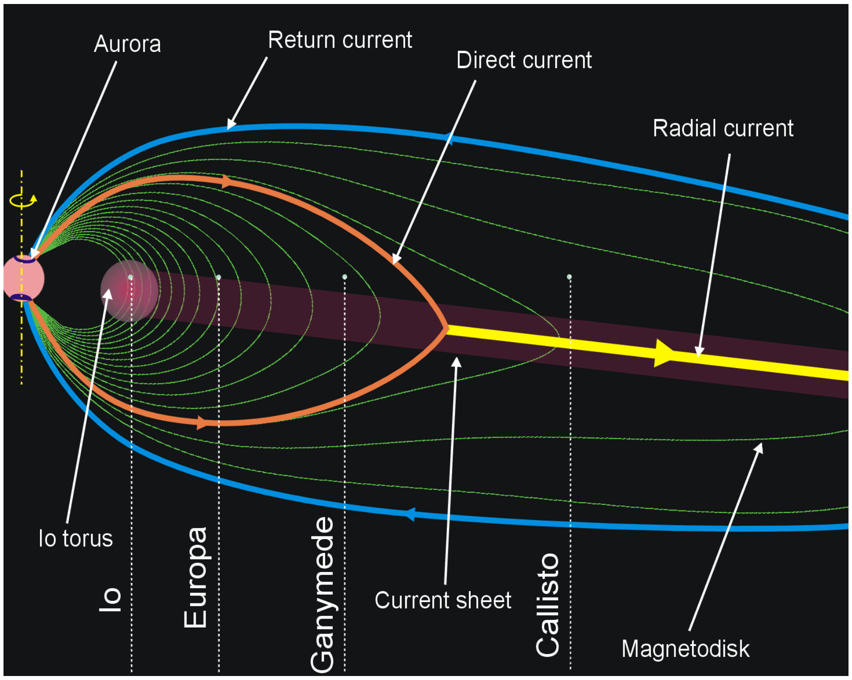


Jupiter and its interior

https://commons.wikimedia.org/wiki/F...er_diagram.svg

Jupiter radiates 1.5-2 times as much energy as it receives from the Sun. This energy probably comes from slow contraction of interior (releasing potential energy).

Jupiter has the strongest magnetosphere of all the planets. Its field has an intrinsic field strength 20,000 times that of Earth. As Jupiter magnetosphere interacts with the solar wind, the magnetic field lines are stretched out into a tail that can extend beyond the orbit of Saturn. Like Earth, Jupiter has aurorae that are produced by the interaction of solar wind particles with the magnetosphere.



Jupiter's Magnetosphere

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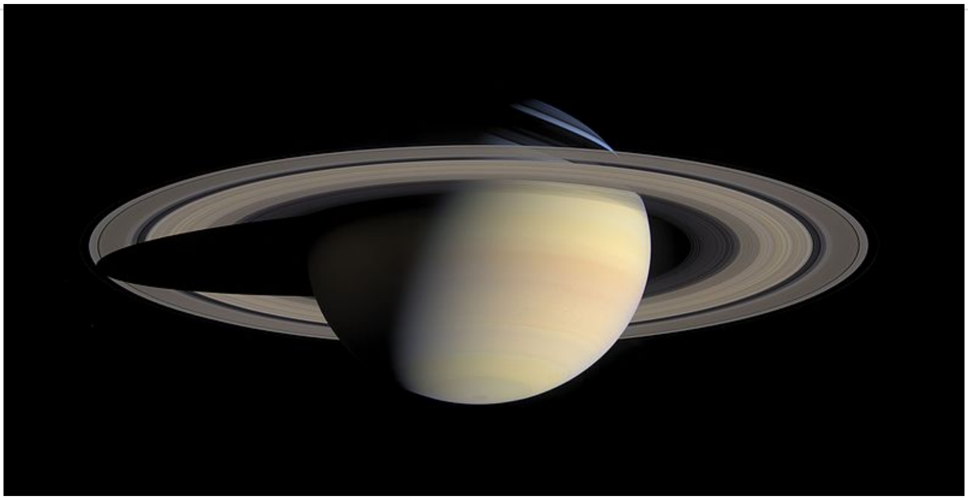
11.3: Saturn



Saturn from Cassini Orbiter.

https:/commons.wikimedia.org/wiki/File:Saturn_from_Cassini_Orbiter_(2004-10-06).jpg;

Saturn is somewhat colder than Jupiter. Compared to Jupiter, its atmosphere is thicker and its bands are fainter. Saturn's bands are fainter and less prominent than those of Jupiter. Saturn's atmosphere is much like Jupiter's in composition, but its pressure is lower.

The composition of Saturn is as follows:

- ~96% Hydrogen (H_2)
- ~3% Helium
- ~0.4% Methane
- ~0.01% Ammonia
- ~0.01% Hydrogen deuteride (HD)
- 0.0007% Ethane.
- Ices in Saturn include: Ammonia, water, ammonium, hydrosulfide(NH_4SH).

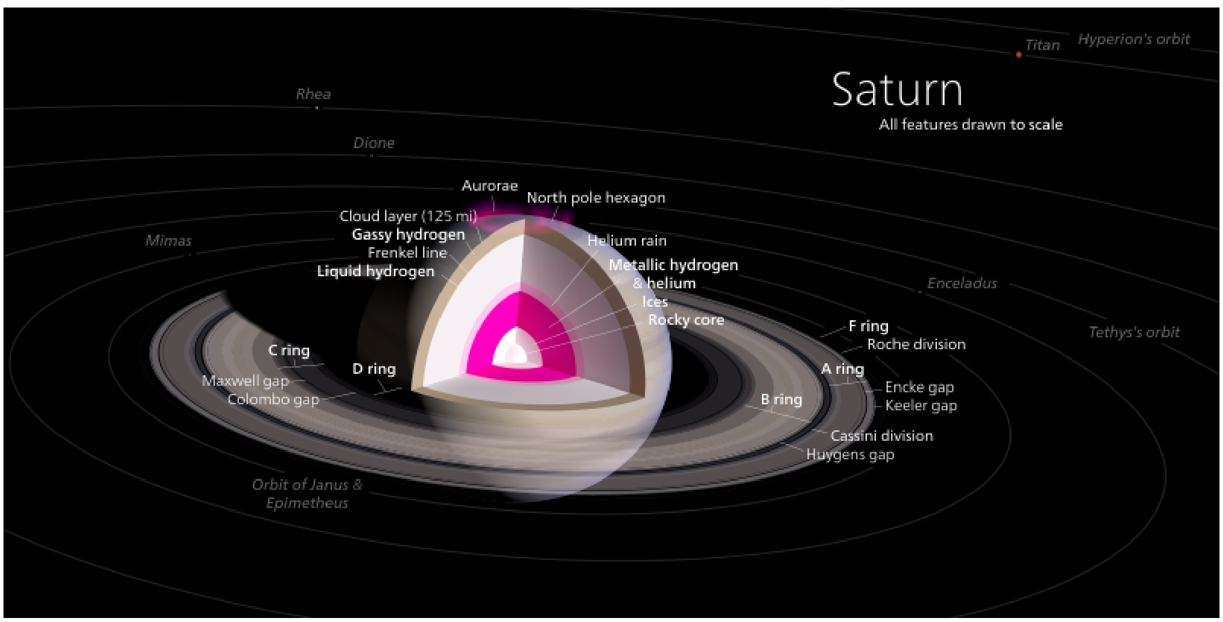
Saturn has three cloud layers, which are deeper inside Saturn compared to Jupiter's. The ammonia ice layer is approximately 50-100 km below the top of the troposphere. The ammonia hydrosulfide ice layer is around 200 km below the top of the troposphere. Finally, the water ice layer is approximately 250-300 km below the troposphere. A layer of haze exists above the ammonia ice layer, obscure much of what is below. Cloud layers on Saturn are thicker than Jupiter's so we see only the top layer.

Like Jupiter, Saturn also has large storms. One storm was observed by the *Cassini* spacecraft in 2011, though it faded after several months.

Like Earth and Venus, Saturn has enormous polar vortices that resemble huge storm systems. One peculiar feature of these vortices is that the southern vortex forms a hexagon. Compared to Jupiter, Saturn's atmosphere has less lightning and less auroral activity.

Like Jupiter, Saturn radiates more energy that receives from the Sun, about 2-3 times as much. Rather than from heat of from the interior, Saturn's excess energy probably comes from differentiation from helium rain that falls in its lower atmosphere.

Saturn's interior also consists of liquid and metallic hydrogen layers, though its metallic hydrogen layer is not as deep as Jupiter's due to its smaller size. Scientists also believe Saturn has a solid core made of rock and ices that may be 9-20 Earth masses in size.



Saturn and its interior

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Saturn, like all the Jovian planets, rotates faster at the equator than at the poles. It also has a strong magnetic field.

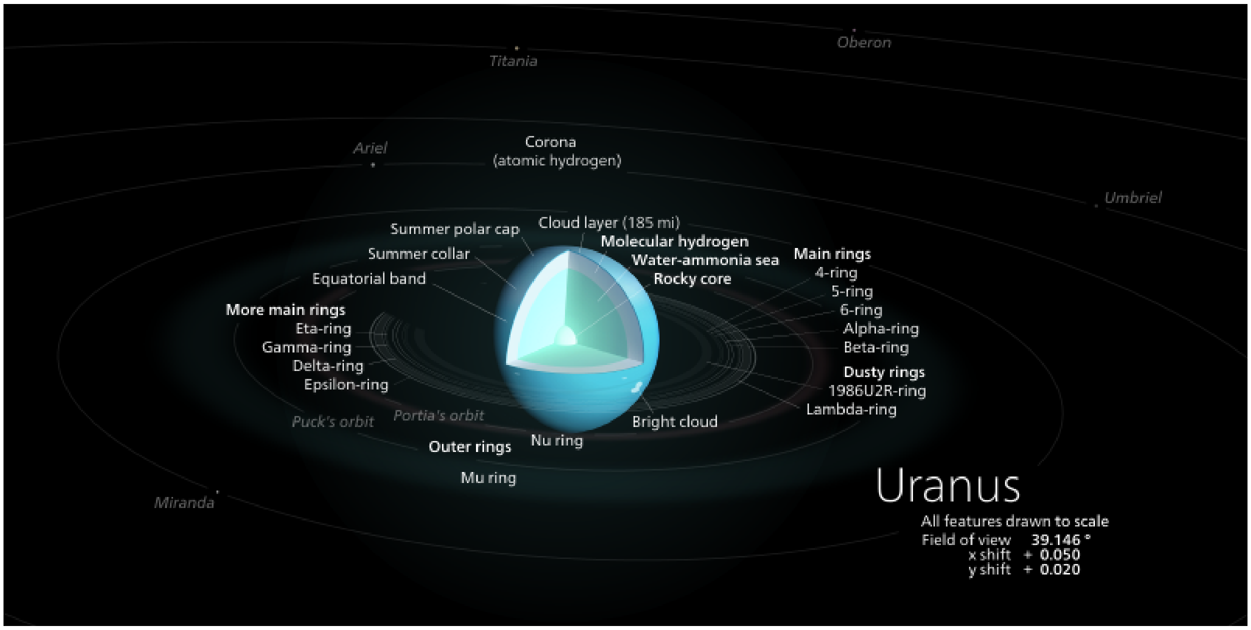
11.4: Uranus and Neptune

The two largest Jovian planets were known to ancient people. In contrast, the **ice giant**s, Uranus and Neptune were only discovered in recent centuries. Uranus was discovered by William Herschel in 1781 as he was surveying the sky with a telescope he made himself. Neptune was discovered in 1846 using mathematical observations of Uranus' orbit which indicated it was being influenced by the gravity of a fourth Jovian world. Three men worked independently to calculate Neptune's orbit and locate it: Johann Gottfried Galle, Urbain Jean Joseph Le Verrier, and John Couch Adams. There is dispute over who discovered it first, so Neptune has no single official discoverer. Le Verrier, in France, worked out the mathematics of where Uranus could be found and asked Galle in Germany to look for it. Using coordinates supplied by LeVerrier, Galle quickly spotted the Uranus. However, the English astronomer Adams also claimed to have spotted Uranus before Galle, so the three have had to share credit for its discovery.

Because they are smaller than Jupiter and Saturn, both Uranus and Neptune have lower internal pressures. These pressures are not extreme enough to convert hydrogen into metallic hydrogen. Both planets vast oceans of liquid molecular ammonia, methane, and hydrogen extend from the base of the atmosphere down to what may be ice/rock core. These oceans are at very high pressure, and they reach temperatures of several thousand Kelvin.

Uranus and Neptune differ in composition compared to Jupiter and Saturn. Both have a higher proportion of silicates, metals, and impurities.

11.5.1 Uranus



Uranus and its interior.

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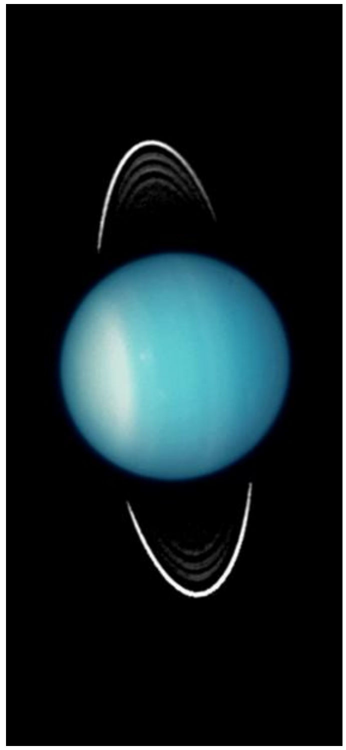
Uranus is best known for its unusual axial tilt. Its axis of rotation lies almost in the plane of its orbit. This gives Uranus extreme seasonal variations. Astronomers have been able to measure its rotation by watching storms.

Uranus has an atmosphere composition as follows:

- 83 ± 3% Hydrogen (H_2)
- 15 ± 3% Helium
- 2.3% Methane
- 0.009% Hydrogen
- (0.007–0.015%) deuteride (HD)
- Ices in Uranus' atmosphere include: Ammonia, water, ammonium, hydrosulfide (NH_4SH), methane (CH_4).

The high concentrations of ices such as methane give it a bluish green color. Methane absorbs red light. Also, the same scattering of blue light that exists in Earth's atmosphere also occurs in Uranus. These two factors work together to give Uranus its distinctive color. The blue color is less prominent for Jupiter and Saturn because their uppermost clouds have less methane haze above them.



Uranus with its rings, showing its unusual axial tilt.

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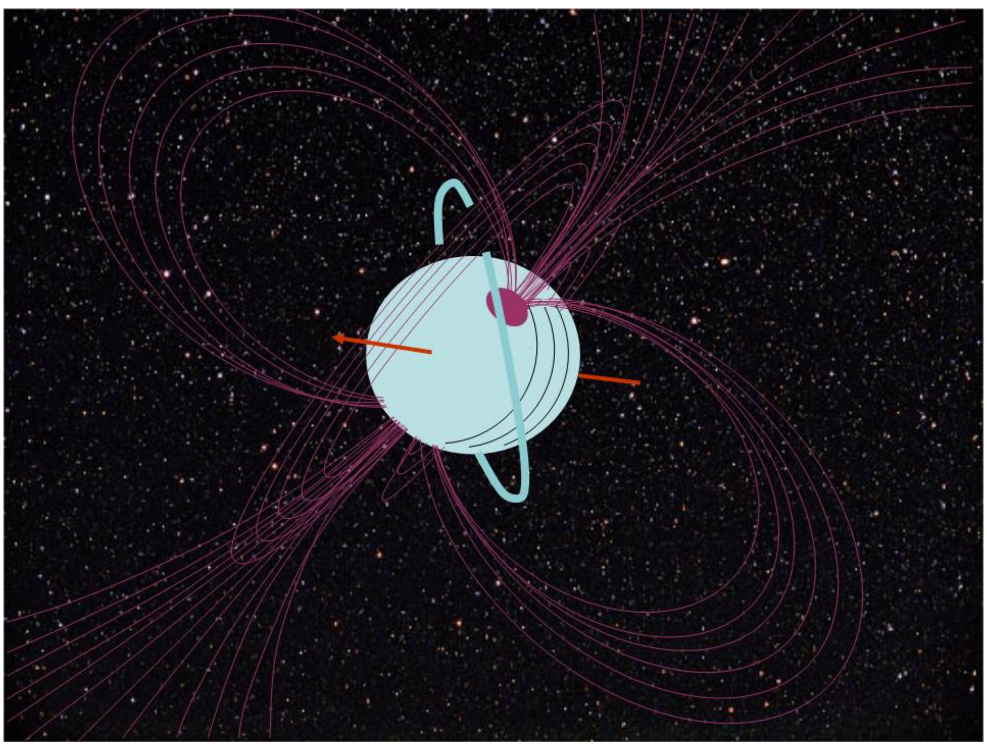


Magnetic field of Uranus.

https:/commons.wikimedia.org/wiki/File:Magnetic_field_of_Uranus.jpg;

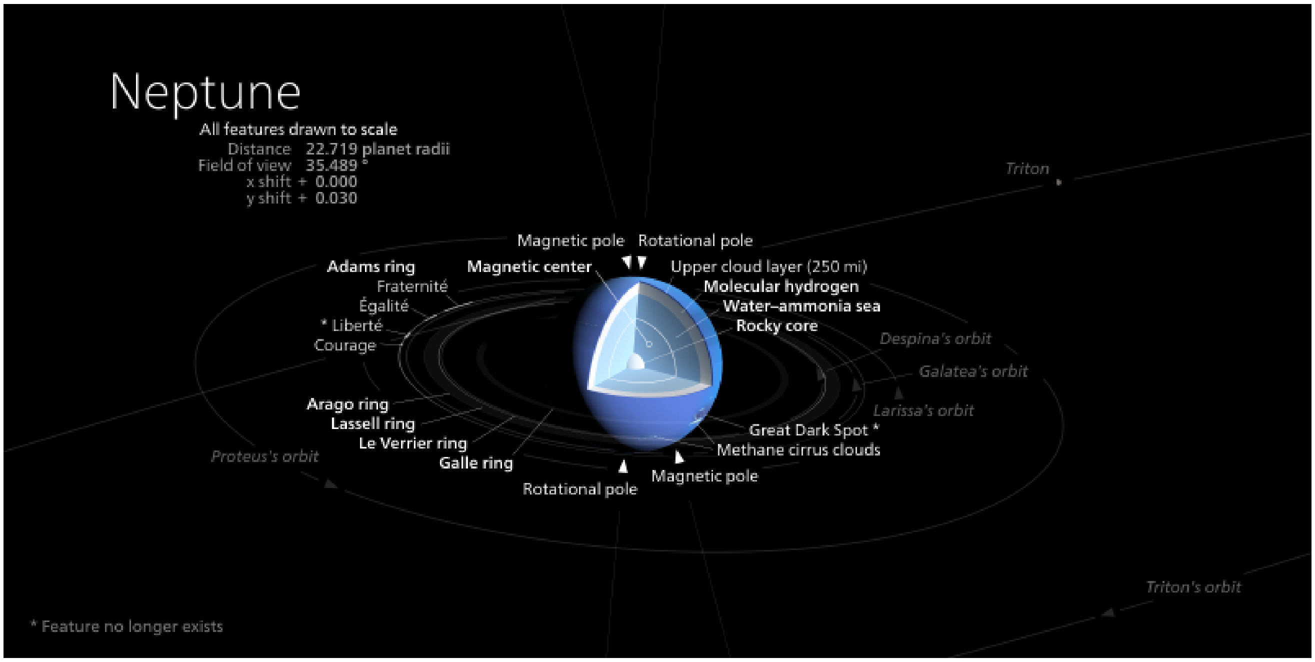
The atmospheres of Uranus and Neptune are still less active than Jupiter and Saturn and both planets lack the obvious bands of convective motion. Uranus’ clouds indistinct because they are hidden beneath a thick layer of haze. This makes the planet appear almost featureless.

Beneath the troposphere, Uranus' layers include a layer of molecular hydrogen followed by a layer of "slush" consisting of water, methane, and hydrogen. Below the slush layer may be a rocky core.

Uranus has a substantial magnetic field, but the axis of is magnetic field is oddly off-center and tilted 60 degrees from its axis of rotation. In contrast, Earth's magnetic field axis is tilted by 11 degrees from its axis of rotation.

Uranus: radiates 1.06 times the energy it receives from the Sun. Like Jupiter, is it believed that this is excess energy from its formation as the planet contracted.

11.5.2 Neptune



Neptune and its interior

https://commons.wikimedia.org/wiki/F...ne_diagram.svg

Neptune has storm systems like those on Jupiter, but fewer.

Neptune’s atmosphere composition is as follows:

- 80±3.2% Hydrogen (H_2)
- 19±3.2% Helium
- 1.5±0.5% Methane
- ~0.019% Hydrogen deuteride (HD)
- ~0.00015% Ethane.
- Ices on Neptune include ammonia, Water, Ammonium hydrosulfide(NH_4SH), Methane (CH_4).

The layers below the troposphere on Neptune are about the same as those on Neptune: Molecular hydrogen, followed by a “slush” layer of water, methane, and hydrogen, and then a rocky core.

Neptune also has strangely tilted magnetic field that is angled at 46 degrees from the axis of rotation.

Neptune emits nearly 2.6 times as much energy as it receives, but the source of that energy is not well understood. Two different situations are possible: either Neptune suffered a great many collisions with comets and other debris early in its life or it is actually raining diamonds on Neptune. In the first scenario, these materials that Neptune absorbed are currently undergoing gravitational contraction and has these former comets comprise, they're radiating heat. Alternatively, according to work done by Raymond Jeanloz and Laura Benedetti, liquid methane in Neptune's atmosphere may be condensing into diamonds, or at least diamond dust, and as this material falls through Neptune's atmosphere it is causing frictional heating much like the liquid helium on Saturn.

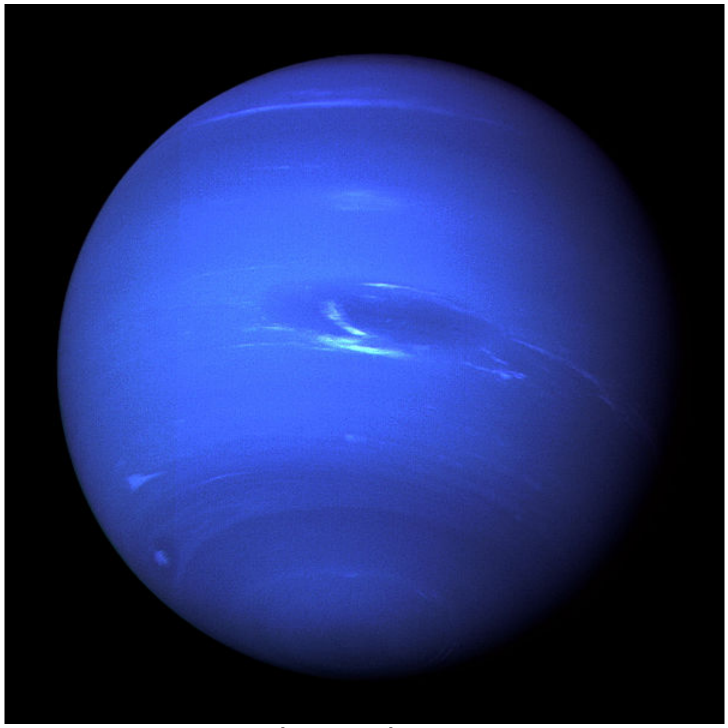


Image of Neptune from Voyage 2

https:/commons.wikimedia.org/wiki/File:Neptune_Full.jpg;

Unlike Uranus, Neptune has an atmosphere in which convection currents, vertical drafts of gas, rise from the interior and fall back down These currents are powered by the planet's internal heat source. The currents carry warm gas above the 1.5-bar cloud level, forming additional clouds at elevations about 75 kilometers higher. Despite Neptune's smaller size and different cloud composition, Voyager showed that it had an atmospheric feature much like Jupiter's Great Red Spot. Called Neptune's Great Dark Spot, this storm was measured at nearly 10,000 kilometers long. Like Jupiter, giant storms formed at latitude 20° S, had the same shape, and took up about the same fraction of the planet's diameter. Data from Voyager 2 found the Great Dark Spot rotated with a period of 17 days, versus about 6 days for the Great Red Spot. However, when the Hubble Space Telescope examined Neptune in the mid-1990s, astronomers could find no trace of the Great Dark Spot on their images. It appears that the Great Dark Spot has faded away.

12: Moons, Rings, and Kuiper Belt Objects

Learning Objectives

- Study the properties of the Galilean Moons, the larger moons of Saturn and Neptune.
- Study the properties of the medium-sized moons.
- Explain why so many Jovian moons are geologically active.
- Describe the properties, composition, and nature of the rings of the Jovian planets.
- Describe Pluto and the orther Kuiper Belt objects and explain why Pluto was demoted from planet to dwarf planet.

The outer solar system has over 200 moons orbiting the four Jovian planets. These moons contain more ices than the moons of Earth and Mars. Many of them are more like comets in composition than asteroids. They range in size from the larger Galilean moons of Jupiter to numerous small, irregular bodies.

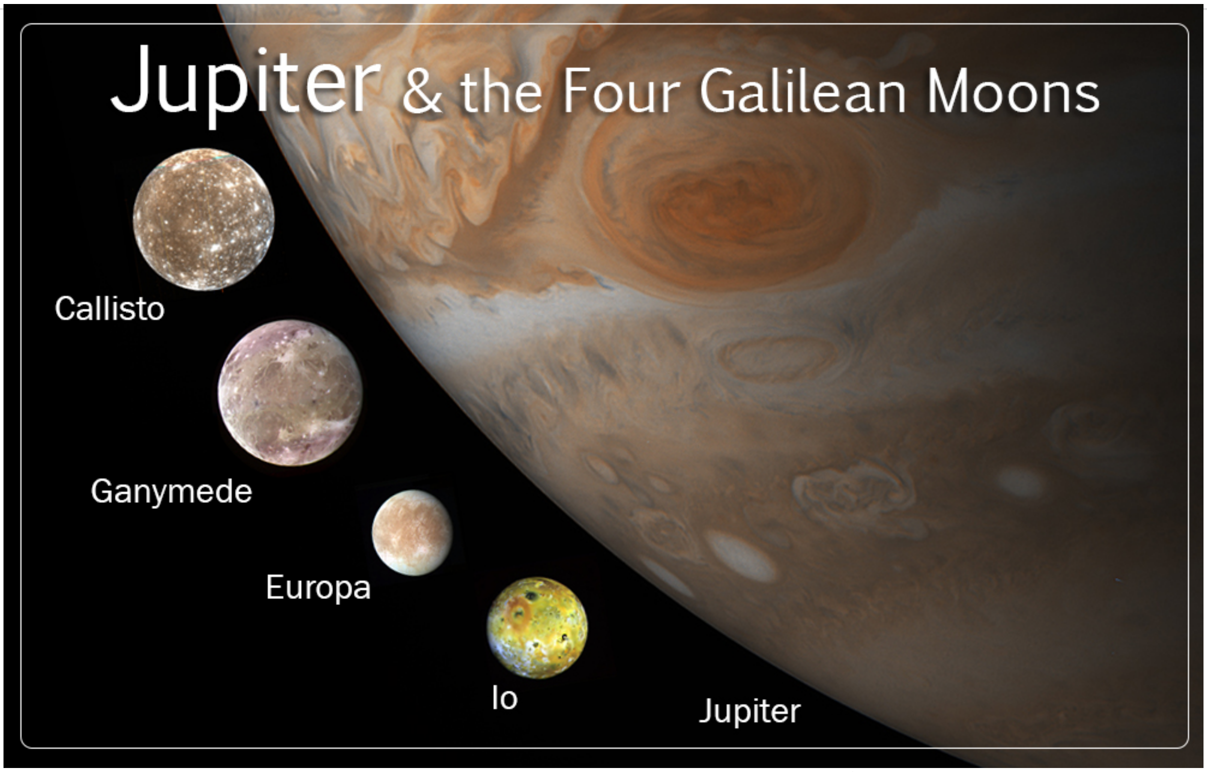
We can divide the outer moons into three size categories. Small moons are those less than 300 km in diameter. These are by far the most numerous moons. They do not have enough mass for their gravity to shape them into a sphere. Most of them are irregular or "potato" shaped. Many of them are likely captured asteroids or comets. As a result, their orbits do not follow the usual patterns into terms of direct and distance from the planet.

Medium-sized moons are between 300 and 1500 km in diameter. They are large enough to be spherical and have substantial amounts of ice. Unlike the smaller moons, they formed in orbit around the Jovian planets and have circular orbits in the same direction as the planet's rotation. Medium moons many have had geological activity in the past but have lost the internal heat of their formation. Because of this, they are no longer geological active.

The large moons are those greater than 1500 km in diameter. Like the medium moons, they are spherical, formed in orbit around the Jovian planets, and orbit in the same direction as their planet's rotation. Due to tidal stresses, the large moons are still geologically active.

Image credit: https:/www.flickr.com/photos/kevinmgill/49724716636;

12.1: The Galilean Moons



Galilean Moons. https:/commons.wikimedia.org/wiki/File:Galilean_Moons_Infographic_(16459663809).jpg;

Figure 12.1.1: Copy and Paste Caption here. (Copyright; author via source)

The Galilean moons of Jupiter are so named because they were discovered by Galileo in 1610. All four are named after romantic conquests of the Roman god Jupiter. The inner three of these moons are locked in orbits that form a 1:2:4 orbital resonance. This resonance increases the amount of tidal stresses the moons experience, further driving internal activity. Every seven days, the three moons line up, creating a series of tugs that add up, making all three orbits elliptical.

12.1.1 Io

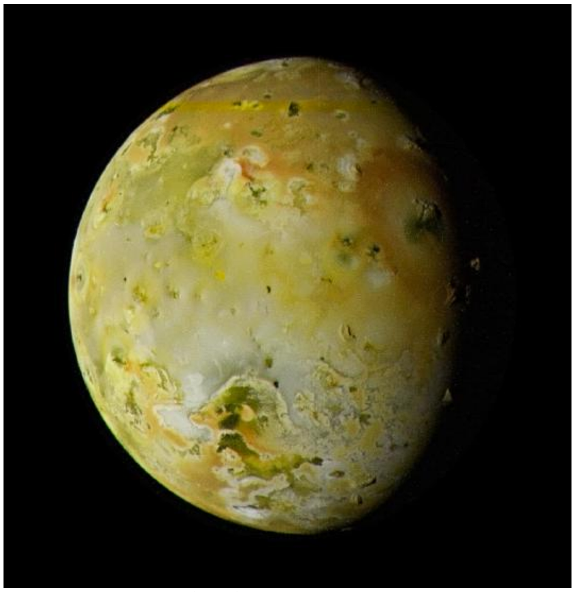
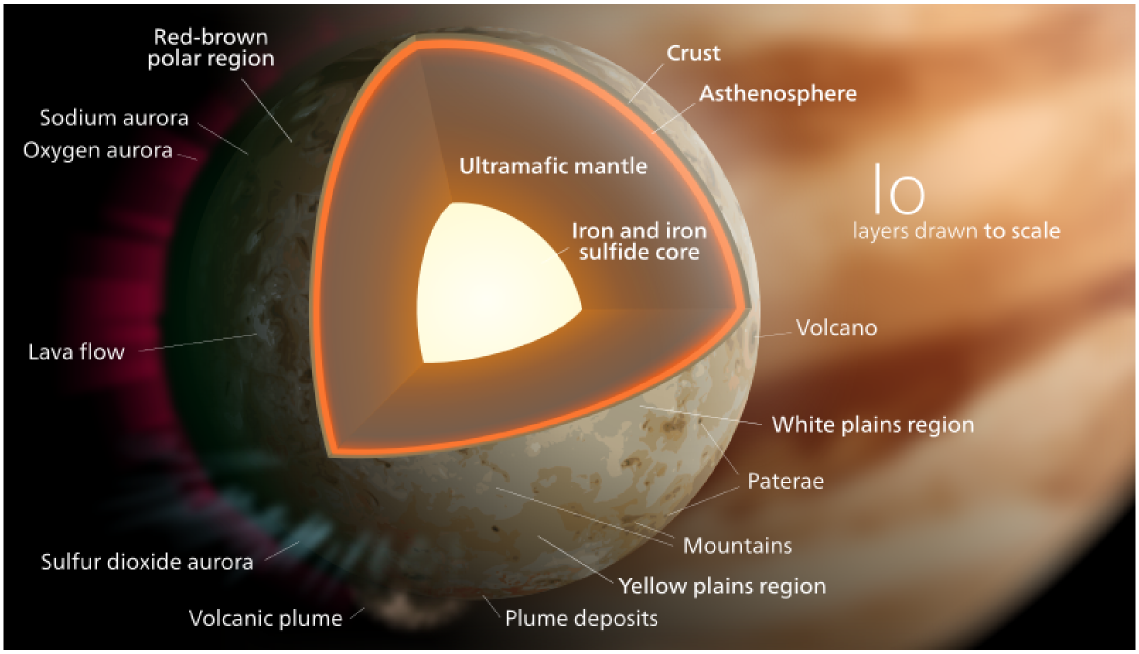


Image of Io from the Galileo probe.

https:/commons.wikimedia.org/wiki/File:Io_-_October_16_2001_(28120329089).jpg;

Io is the innermost moon and is the densest of Jupiter's moons. Io is also the most geologically active object in the Solar System, with many active volcanoes. When the Voyager probes first returned photographs of Io, scientists were amazed that Io appeared to have an ever-changing surface. It never looks the same way twice. In fact, Io can change surface features in a few weeks. It has no craters as they fill in too fast, giving Io the youngest surface of any solar system object. Gravity from Jupiter as well as from Europa subjects Io to tremendous tidal forces. The tides are so strong on Io that they left the crust itself. During a single 41-hour orbit, the surface of Io can rise as much as 300 feet. These tidal forces power the volcanoes on Io.

Io's interior include three main layers: a curst, a rocky mantle, and a core made of iron and iron sulfide.



Io and its interior

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12.1.2 Europa

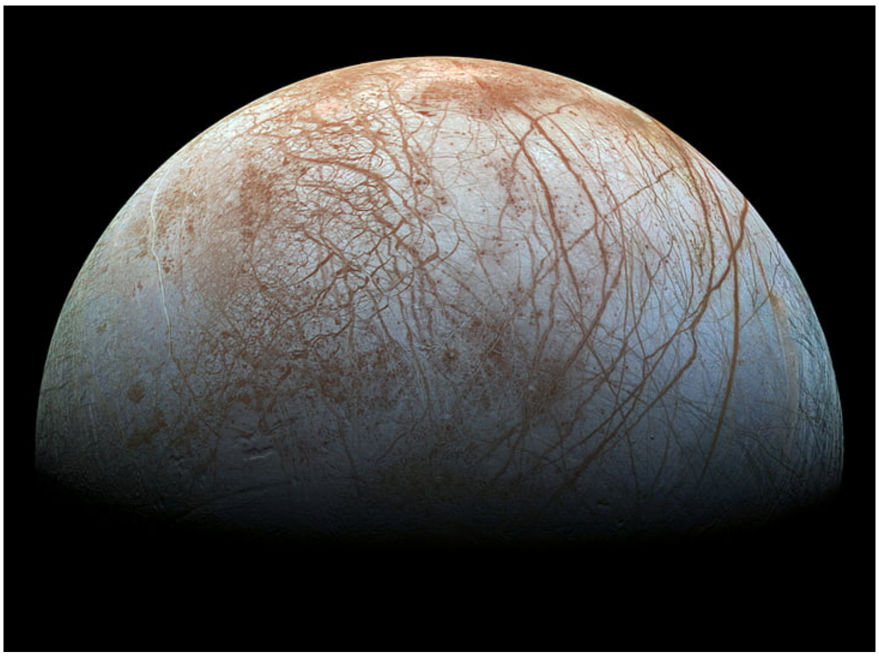
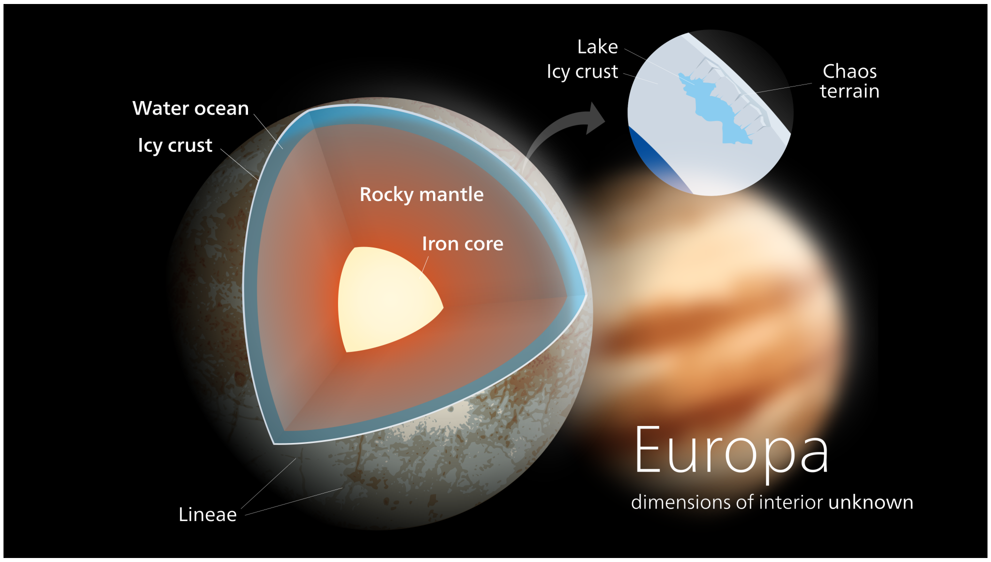


Image of Europa from the Galileo probe.

https:/www.pickpik.com/jupiter-moon-europa-icy-space-cosmos-astronomy-137142;

Europa, like Io, has no craters. Its surface is covered with water ice. Tidal forces stress and crack ice. This creates water flows that keep surface relatively flat with many ridges across its surface. Europa's interior also warmed by tidal heating and there is substantial evidence that there is a layer of liquid water beneath the surface. There may be more liquid water on Europa than in all of Earth’s oceans. The friction from tidal action may also be a source of energy that could be utilized by living organisms, much like microbes use heat from dent undersea volcanic vents a source of energy. We have no evidence that Europa has life, but the potential is there. Planetary scientists hope to one day land a probe on Europa and drill through the ice in order to see if there what really is under that crust.

Underneath the icy crust and possible water layer, Europa has a rocky mantle and an iron/iron sulfide core.



Europa and its interior

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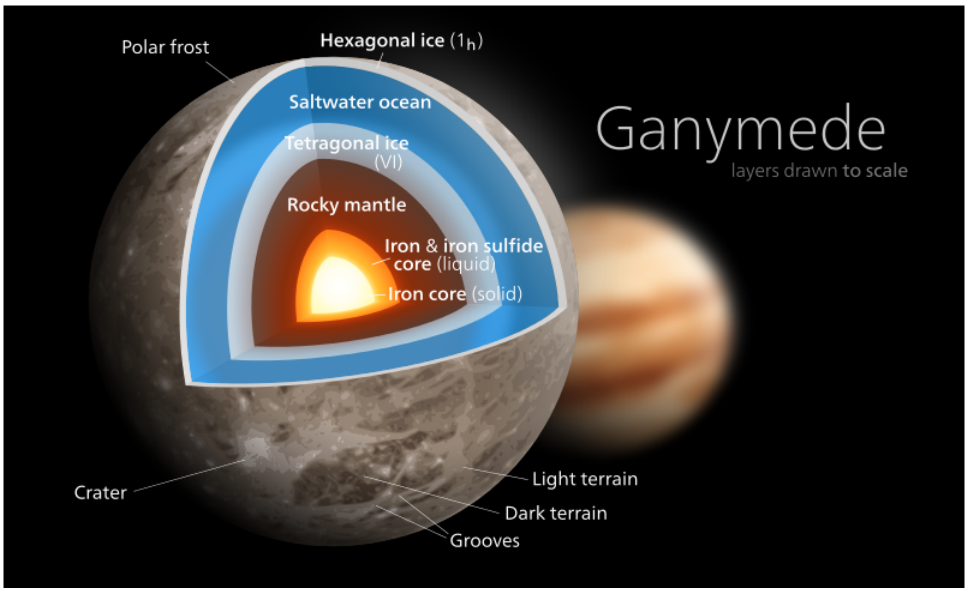
12.1.3 Ganymede



Ganymede and its interior

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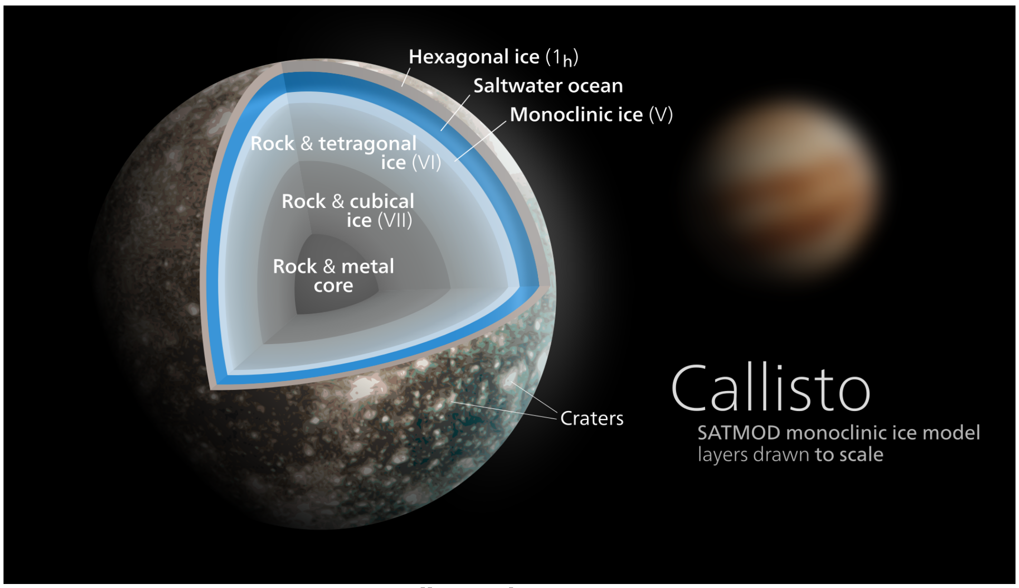
Next out from Jupiter is Ganymede, the largest moon in the Solar System. In fact, Ganymede is larger than Pluto and Mercury. If it orbited the Sun alone, Ganymede would be considered a planet. Ganymede's surface and history looks similar to that of Earth's Moon, but with a surface of water ice instead of lunar rock. Ganymede has few craters, giving evidence of resurfacing. Curiously, Ganymede has a magnetic field, which is unusual for moons.

Beneath Ganymede's icy crust may also be a water layer. Beneath that, Ganymede has a rocky mantle and an iron/iron sulfide core.

12.1.4 Callisto



Callisto and its interior

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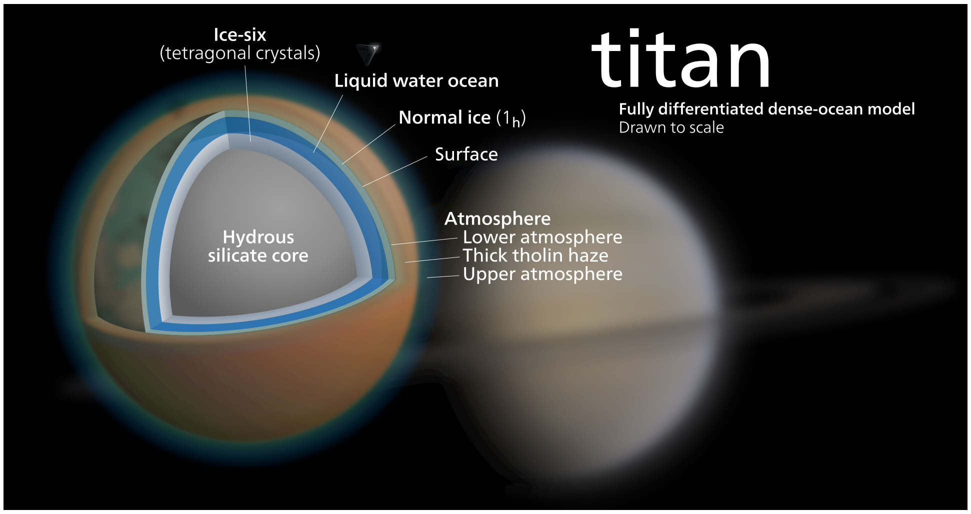
The fourth Galilean moon is Callisto, which looks similar to Ganymede but with heavy cratering and no evidence of resurfacing activity. Another strange feature of Callisto is that it appears to be an undifferentiated mixture of rock and icy material Callisto's low density (only twice that of water ice) can only be explained by a composition of roughly equal parts ice and rock, with no metallic core like Ganymede's. Evidence for its lack of a dense core was found my measuring its gravitational pull on the Galileo spacecraft. We would expect that all the big icy moons would be differentiated. The heat released from the collisions from its formation should have melted it, causing the dense, metallic materials to sink to the core. In fact, it should be easier for an icy body to differentiate than for a rocky one because the melting temperature of ice is so low. It would take only a little heating will soften the ice and get the process started, allowing the rock and metal to sink to the center while the slushy ice floats to the surface. Yet Callisto seems to have frozen solid before the process of differentiation was complete. How this happened is still a mystery.

12.2: Titan and Triton

12.2.1 Titan



Titan and its interior

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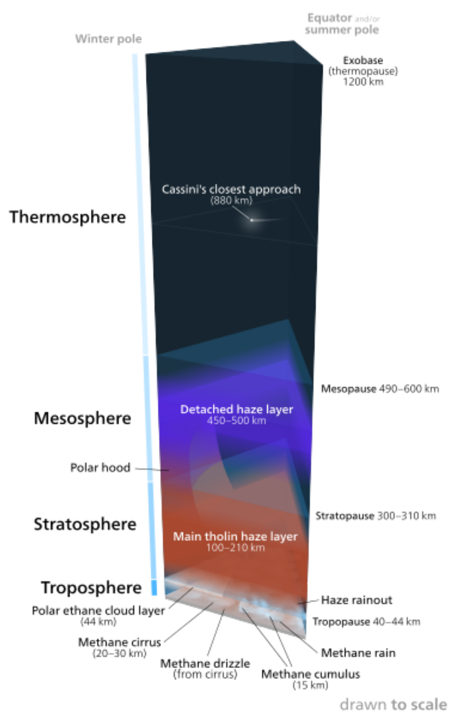
Titan is Saturn’s largest moon. Titan is unique in that it is the only moon with a thick atmosphere. In fact, Titan’s atmosphere is thicker and denser than Earth’s and consists mostly nitrogen and argon. Titan’s cloudy atmosphere makes it impossible to see the surface. Infrared images Titan have shown details including a possible icy volcano. Titan has few craters, consistent with active surface. Actively on Titan consists of cryovolcanoes of flowing ices instead of lava. Complex chemical interactions occur in Titan’s atmosphere, forming hydrocarbons and other organic molecules.



The layers of Titan's atmosphere.

https://commons.wikimedia.org/wiki/F...atmosphere.svg

The surface of Titan has lakes of liquid hydrocarbons and "rocks" made of ice.

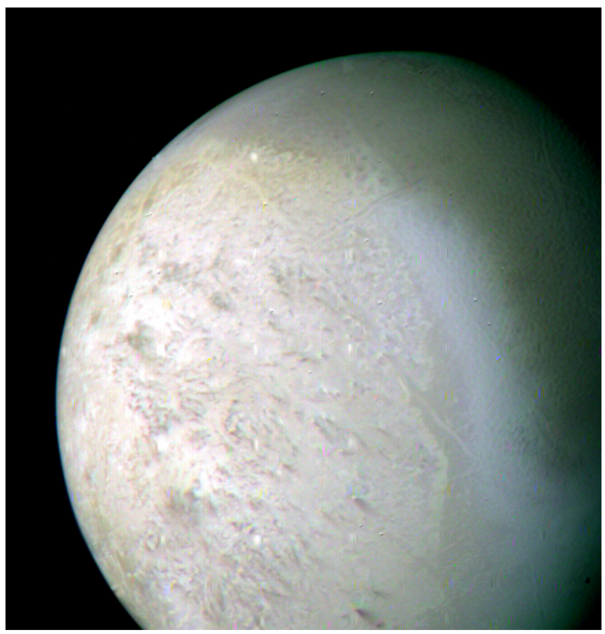
https:/commons.wikimedia.org/wiki/File:Viewfromtitan.jpg;

The Huygens probe passed through the atmosphere and provided us the first look at Titan’s surface in early 2005. Huygens found lakes of liquid methane and “rocks” made of ice. Analysis of Titan’s atmosphere found it had several layers found at the following elevations:

- Ultraviolet-absorbing haze: 400 km
- Ultraviolet/optical haze layer: 300 km
- Main haze layer 100-200 km, includes aerosol haze
- Methane clouds and rain at <20 km

12.2.2 Triton

Triton is Neptune’s largest moon. Unlike other large moons, it orbits in a retrograde orbit. Its surface has few craters, indicating an active surface. Voyager 2 found liquid nitrogen geysers observed on Triton, which probably contribute to its resurfacing. Because of its retrograde orbit, planet scientist believe Triton is likely captured Kuiper belt object. Models used to calculate its orbit indicate that Triton may be a doomed moon that will one day crash into the icy deeps of Neptune.



Triton image from Voyage 2.

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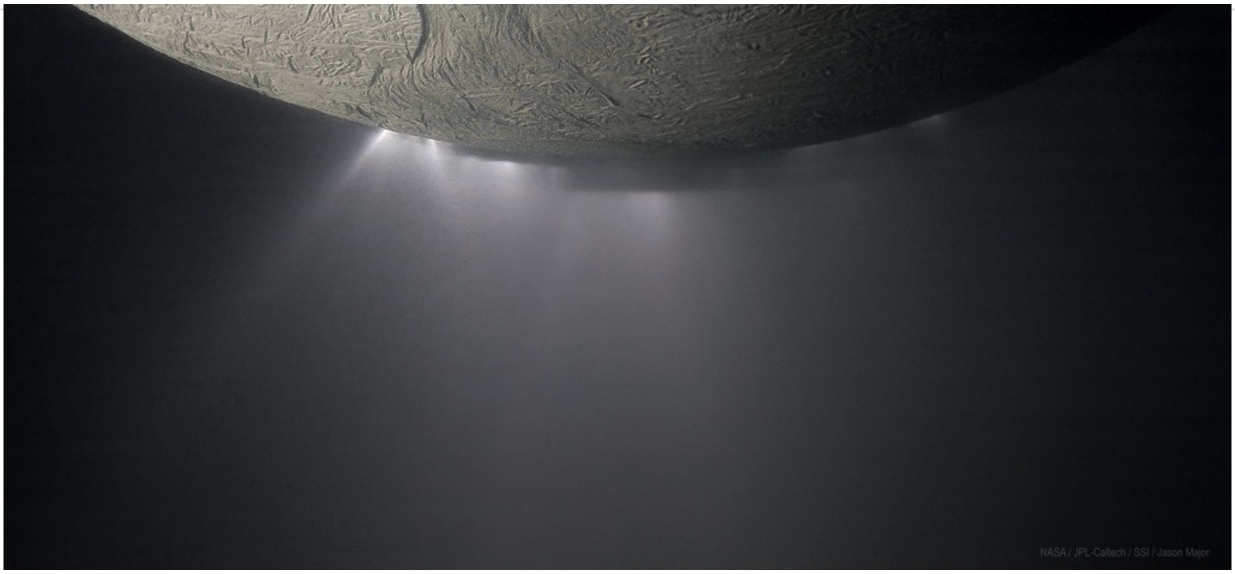
12.3: Medium-Sized Moons



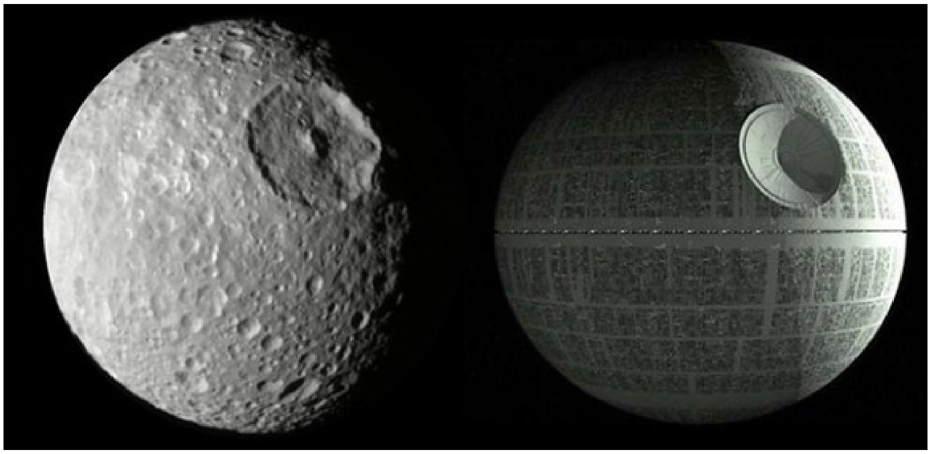
Geysers of water have been detected erupting from the south polar region of Iapetus.

https:/www.flickr.com/photos/lightsinthedark/41100060804;

There are many more medium-sized moons than large ones. The measurements of the densities of these moons suggest that they are rock and water ice. Saturn has several medium moons including Enceladus. Like Europa, Enceladus is an icy world with a possible liquid ocean underneath. The Cassini probe found geysers of water erupting from the surface in the south polar region, giving evidence for a water interior.

Saturn's moon Iapetus is 907 miles (1,460 km) in diameter and has a dual personality. One hemisphere is covered with bright ice, the other with darker material possibly ejected by impacts on the more distant moon Phoebe. The icy side is five times as bright as the darker side. Iapetus also has a curious ridge around much of its equator.

Mimas has a huge crater Herschel named after the discoverer of the moon. The crater's diameter is 130 km, which is almost a third of the moon's own diameter. Herschel's walls are over 5 km high and its central peak rises to up to 6 km. Some parts of the crater go as deep as 10 km. Mimas is sometimes called the "Death Star Moon" because its huge crater resembles the laser dish on the space station from the Star Wars movies.



Mimas and its large crater, Herschel.

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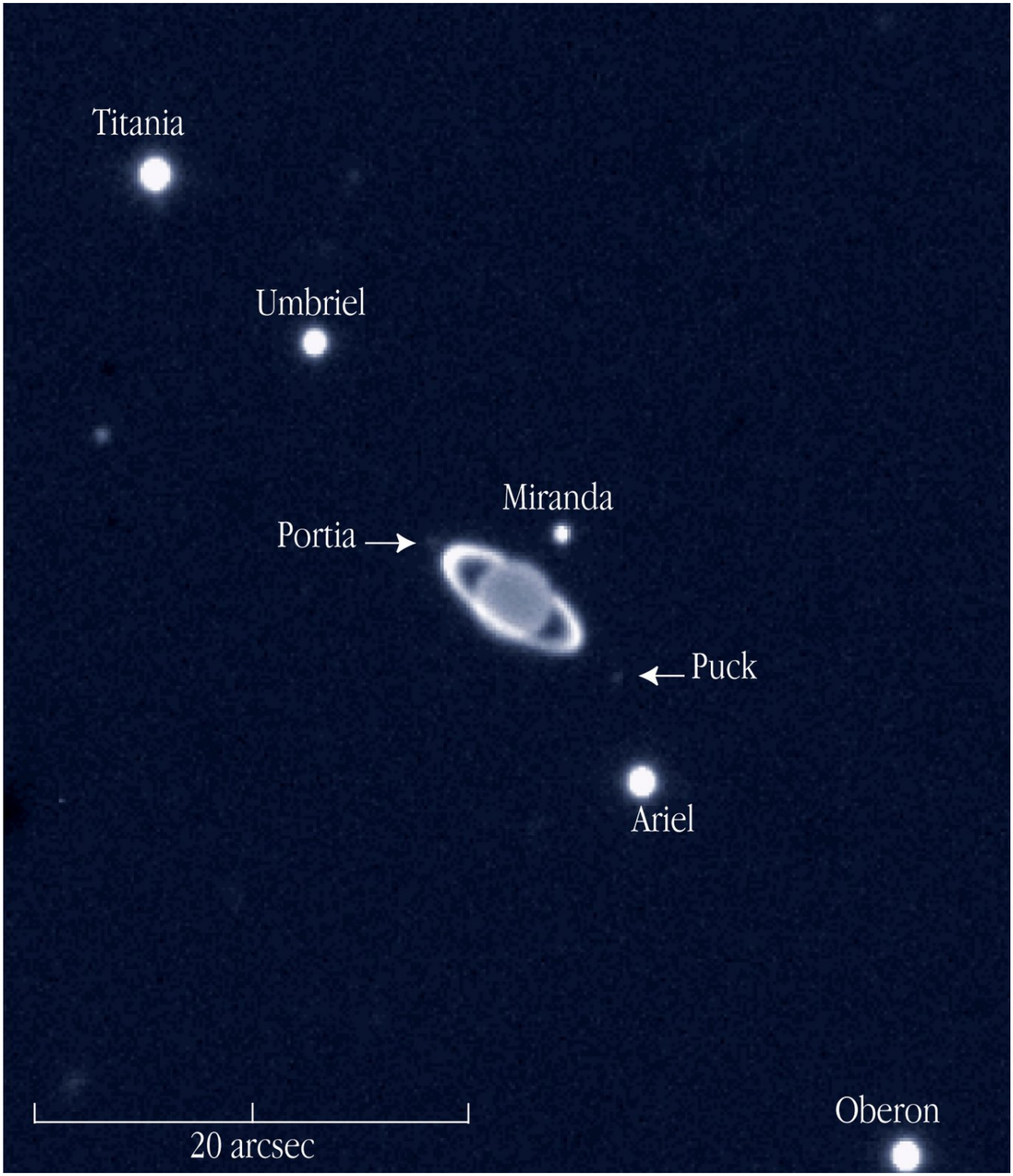
Many of Uranus' moons are named after characters from Shakespeare's plays. One, Miranda, shows evidence of a violent past, although the origin of the surface features is unknown. Miranda has large tectonic features and few craters, possibly indicating an episode of tidal heating in past.

Why are the icy moons more active that larger rocky planets like Mars or Mercury? One might think being further away from the Sun would give them quieter interiors. However, rock melts at higher temperatures than ice. Only large rocky planets have enough heat for activity, which in the Solar System means Earth and possibly Venus. Since ice melts at lower temperatures, tidal heating can melt internal ice, driving activity.



Uranus and several of its moons.

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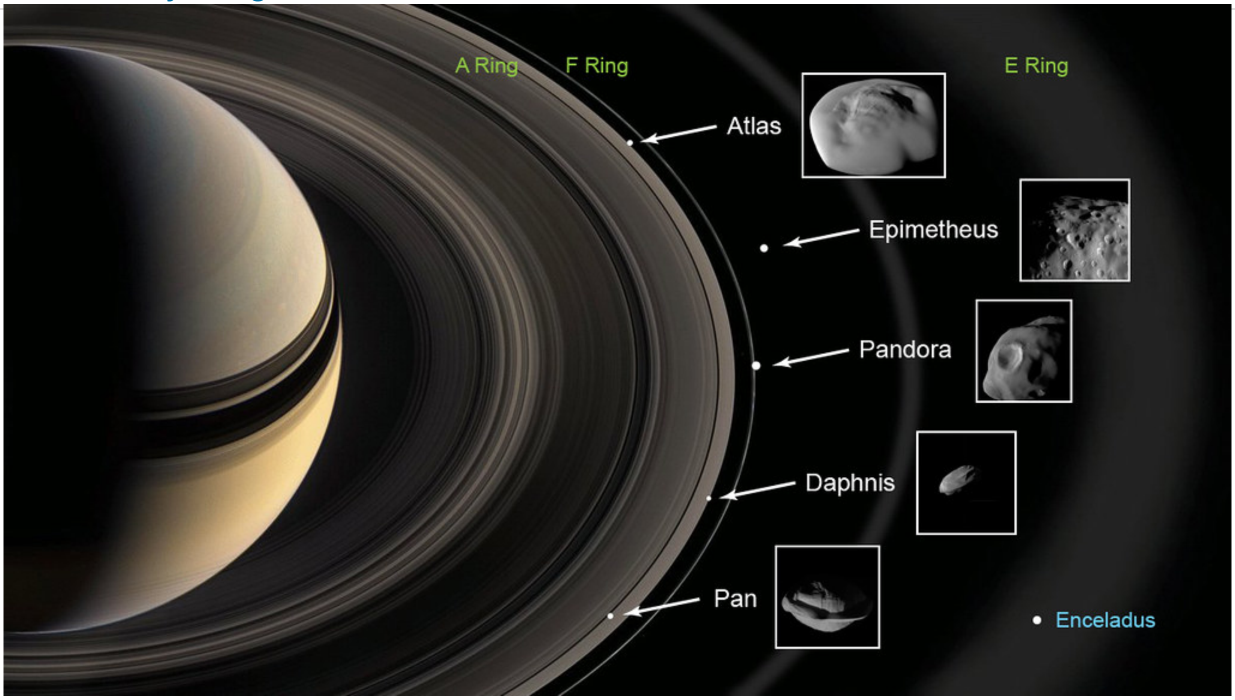
12.4: Planetary Rings



Saturn's rings are guided by several "shepherd moons."

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12.4.1 Saturn's Rings

The rings are not solid structures. They are composed of small rocky and icy particles. These particles range in size from dust grains to boulders the size of houses. Saturn's rings consist of six main rings, given the letters A, B, C, D, E, and F. The letters were assigned in order of discovery, so are not alphabetically from inner to outer rings. The largest division, the Cassini Division, lays between the A and B rings. The Cassini Division is named after its discoverer, Italian astronomer Giovanni Domenico Cassini, who also discovered four of Saturn's moons in the 17th century. This ring system is 274,000 kilometers (171,000 miles) from tip to tip but dynamical forces keep the rings less than about 100 meters thick.

The Voyager probes showed Saturn's rings to be much more complex than originally thought. Each of the named rings consist of numerous smaller rings bunched together. The Cassini probe passed through a gap in the rings in 2004 at 50,000 mph, giving us the closest view of the rings to date. Cassini suffered 100,000 particle hits in just five minutes, but the density and size of the particles were like that of cigarette smoke, so no damage was done. The gaps can be formed when a pair of small moons force particles into a narrow ring or orbital resonance with a larger moon herds the particles out of gap.

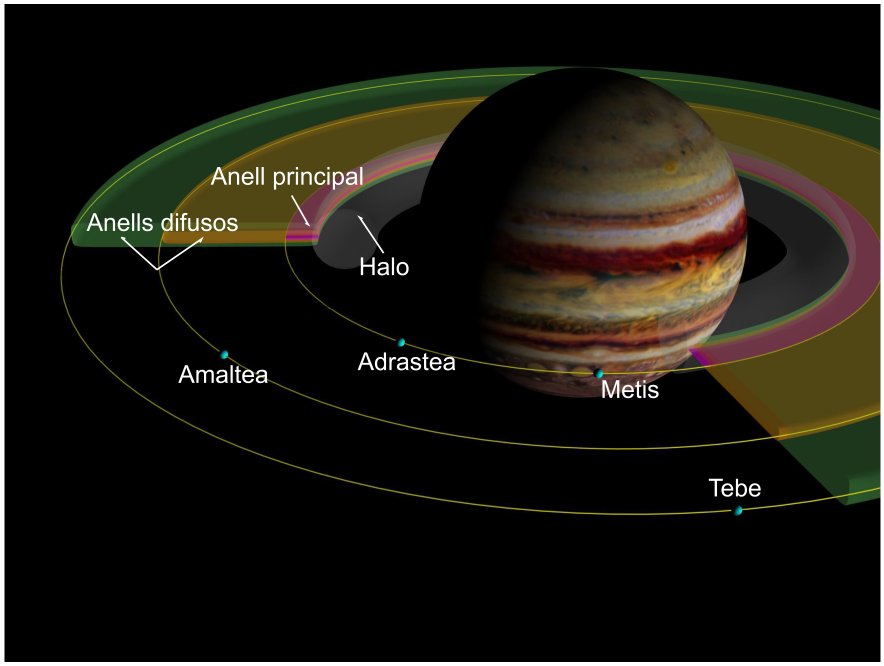
The Cassini spacecraft also revealed many concentric rings. It also found that some small moons create gaps within rings. These moons act as **"shepherd" moons** define the edges of some of the rings. Saturn has several shepherd moons, including Prometheus (F ring), Daphnis (Keeler Gap), Pan (Encke Gap), Janus, and Epimetheus (both A ring). Likewise, some of Jupiter's small innermost moons, namely Metis and Adrastea, may act as shepherds. Uranus' moons Cordelia and Ophelia, also act shepherd moons on its ε ring.

Neptune's shepherd moon Galatea and possibly other as-yet undiscovered shepherd moons are responsible for clumpiness of its ring system. Shepherd moons get their names because their gravitational attraction nudges particles into their orbits, keeping the rings relative stable, much like a shepherd dog keeps a flock of sheep from wandering away.

All the observed ring systems occur within what is known as the Roche limit. The Roche limit is the distance from the planet where tidal forces are too strong for a moon to survive. Surveys of the Jovian ring systems do not support the idea that they were once moons that were torn apart from tidal forces. Instead, the tidal forces prevented moons from forming within the Roche limit in the first place. The rings receive new particles to replenish them as particles are knocked off the surface of their icy moons. Impacts on the moons free particles that are then shepherded into the rings. Collisions on the moons are random, so rings may grow or shrink over time. Evidence indicates that Saturn’s rings are relatively young. It is likely then, the Saturn’s large, brilliant ring system is simply the result of recent impacts.

12.4.2 Rings of the Other Jovian Planets.

While Saturn has spectacular rings that are visible from Earth, all four Jovian planets have ring systems. The other three ring systems are so faint. They were not confirmed until the 1970s and 1980s by the two Voyager space probes. Jupiter has a small, thin ring system. Its main ring has a sharp outer edge and a diffuse inner edge. It is much fainter and narrower than Saturn’s rings. Inside the main ring is another component of the ring system, called the “halo.” The halo is a broad, diffuse, donut-shaped ring of particles. Outside the main ring, there are two additional “gossamer rings,” that are fainter than the main ring. Jupiter’s rings are bound by the orbits of two of Jupiter’s small satellites, Amalthea and Thebe. While Saturn’s rings are bright, icy particles, Jupiter’s rings contain dark, microscopic dust particles. These darker particles have a lower albedo and partially explains why they cannot be seen from Earth.



Jupiter's Rings.

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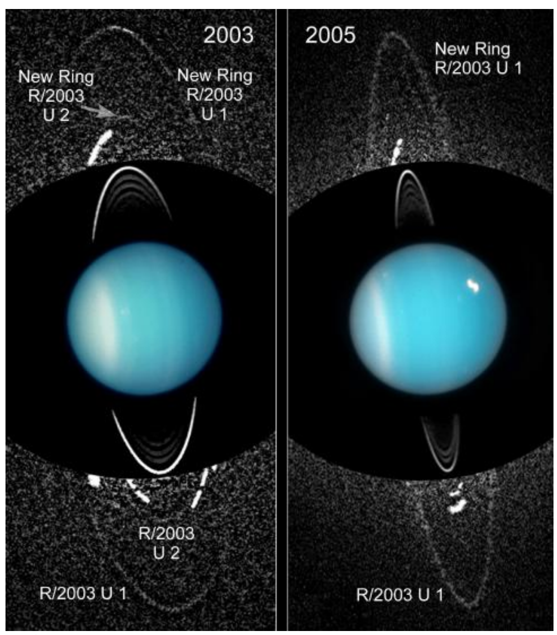
Uranus has nine thin rings, which are labeled using Greek letter. Two shepherd moons keep the Epsilon ring of Uranus from diffusing away. Uranus's rings appear to be different than those of Saturn or Jupiter. Instead of broad ring systems, Uranus' ring particles are concentrated into nine or more separate string-like rings, separated by large gaps.

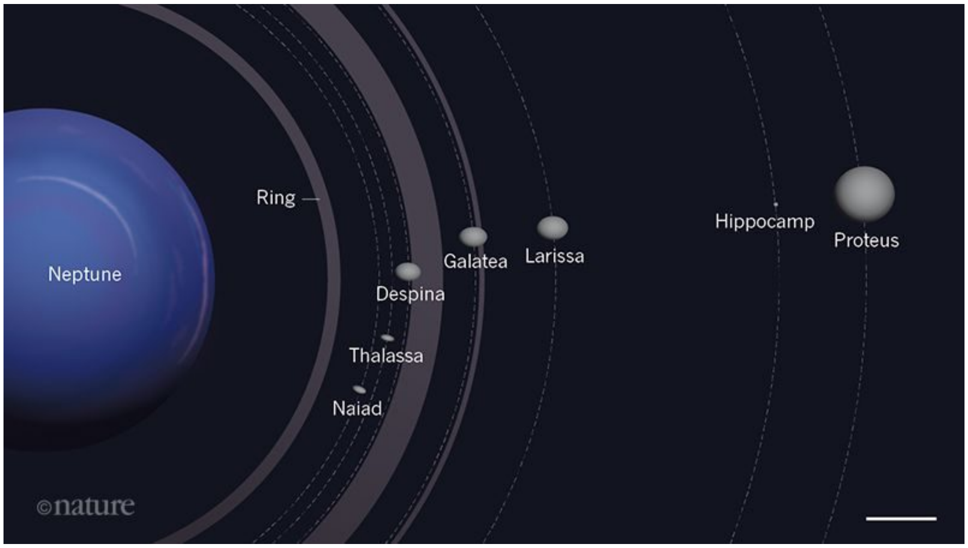


Moon and Rings of Uranus. Note how its rings and moons are oriented to its axial tilt.

https:/commons.m.wikimedia.org/wiki/File:Moon_and_Rings_of_Uranus.jpg;

Five rings have been discovered around Neptune has five rings, three narrow and two wide. These rings are like Uranus's rings. Voyager 2 found that the rings of Neptune have clumps of particles that form distinct arcs. Voyager 2, also returned images of several new rings around these planets, along with satellites "shepherding" them.

Besides direct imaging, we can also use occultations to study rings. When a star passes behind the rings, its light dims momentarily, giving information about the location and thickness of the rings.

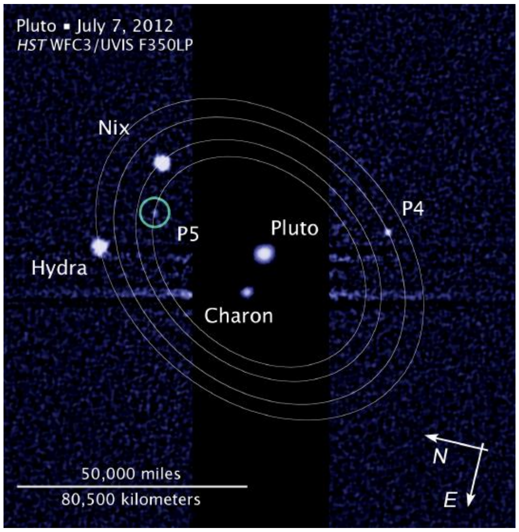


Neptune and its inner moons and rings.

https:/earthsky.org/space/hubble-solves-mystery-neptune-moon-hippocamp;

12.5: Kuiper Belt Objects

Pluto was discovered in 1930 by Clyde Tombaugh. Amateur astronomer Percival Lowell measured some irregularities in Neptune's orbit and predicted that there must be a fifth Jovian planet perturbing its orbit, much like the way Neptune perturbing Uranus' orbit. Tombaugh looked in the direct Lowell expected this world to be and found Pluto. Initially, the discovery of Pluto was hailed as confirmation of Lowell's idea. However, it soon became apparent that Pluto was much smaller than Lowell had predicted. In fact, it is a tiny world, smaller than Mercury. Even Earth's moon is larger.



Pluto and its moons.

https://commons.wikimedia.org/wiki/F...s_in_Orbit.jpg

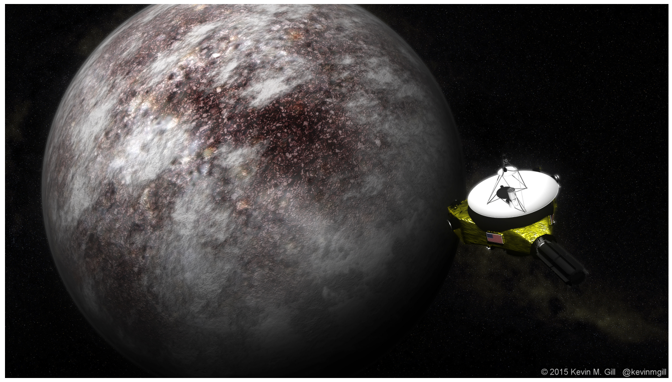
In the 1980s, when the Voyager 2 probe made better measurements of the masses of Uranus and Neptune, scientists determined that Lowell had been working on erroneous data. With more accurate measurements, the irregularities Lowell noted disappeared.

Pluto has five moons, the largest of which, Charon, was discovered in 1978. Charon orbits at an angle of 118º to the plane of Pluto's orbit. It is rotationally locked to Pluto, and about a sixth as large. Pluto is also locked to Charon, forming an almost double planetary system where both bodies always face the same sides to each other. The other four smaller moons of Pluto are named Nix, Hydra, Styx, and Kerberos.

Despite its small size and being different than any of the outer Jovian planets, astronomers accepted Pluto as the ninth planet for decades. Pluto has an icy composition like a comet or one of the medium-sized moons of the Jovian planets. It also has a very elliptical, inclined orbit. Overall, Pluto has more in common with comets than with the eight major planets. Pluto could be considered a double-planet system as Charon is nearly as large as Pluto itself and was probably made by a major impact.

The temperature on Pluto is very cold, around 40 K. Pluto has a thin nitrogen atmosphere that will refreeze onto the surface as Pluto's orbit takes it farther from the Sun.

New Horizons has revealed a surprisingly active geology. Pluto's surface consists of large areas of water ice and slushy regions of frozen nitrogen.

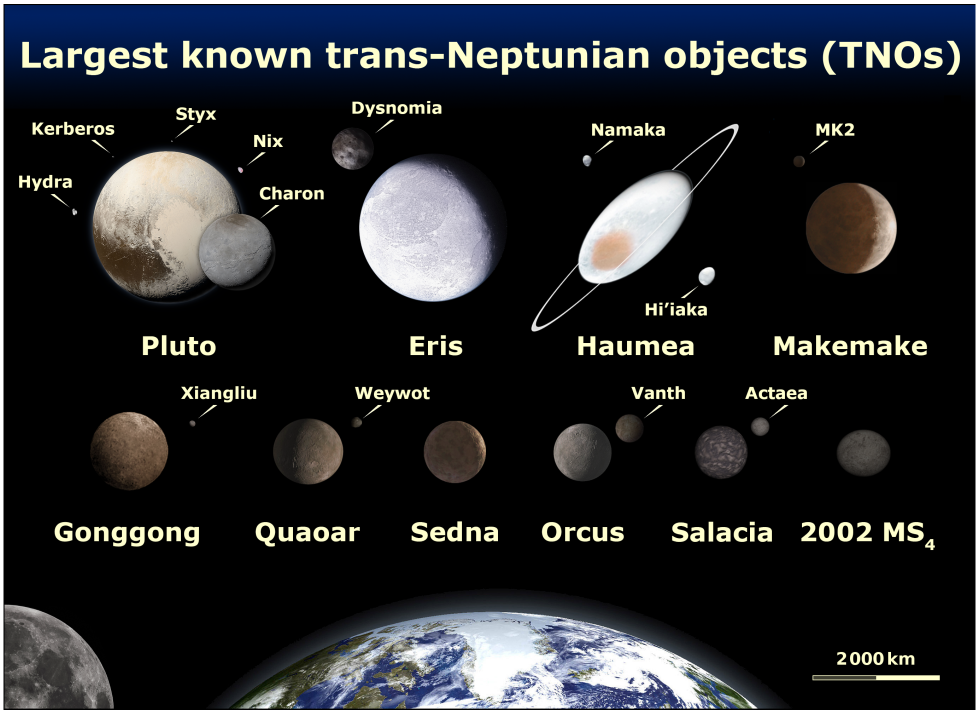


New Horizons over Pluto.

https:/commons.wikimedia.org/wiki/File:New_Horizons_over_Pluto_(17620333413).jpg;

For decades, astronomers assumed that Pluto orbited the Sun alone, just like the other planets. Then, starting the 1990s, astronomers discovered other objects orbiting in the region now known as the Kuiper Belt. Eris, a body slightly larger than Pluto, was discovered in 2005. Now, more 1200 have been found. Eris even has a moon named Dysnomia. Others include Makemake and Haumea.

Facing the dilemma of whether we should call are 1200 Kuiper Belt objects as planets, the The International Astronomical Union (IAU) created a new classification called dwarf planets. Unlike true planets, dwarf planets have not cleared most other objects from their orbital paths. Pluto received a demotion from planet to dwarf planet. Scientists also refer to Kuiper Belt objects as trans-Neptunian objects or plutoids.



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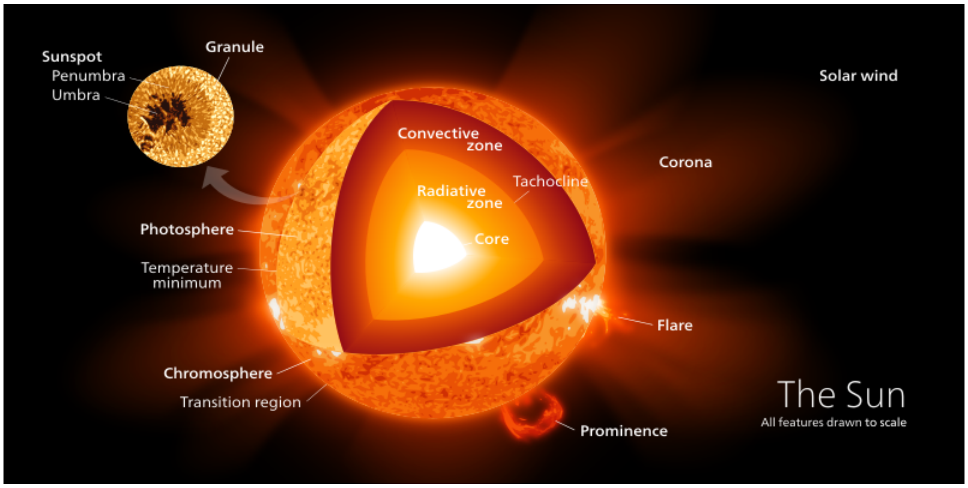
13: The Sun

Learning Objectives

- Describe the properties and composition of the Sun.
- Describe the layers of the solar interior.
- Describe the solar atmosphere.
- Understand the various times of solar weather, including sunspots, solar flares, prominences, and coronal mass ejections.
- Understand the process of nuclear fusion and how it produces the energy emitted from the Sun.



The Sun lies at the heart of the Solar System, containing over 99.9% of the total mass. It is also by far the largest object in the Solar System, with a radius of 6.9×10^8 m, about 109 times that of the Earth. The Sun is the source of the energy that makes life possible on Earth. But how much energy does it radiate?

We can measure the **luminosity**, the total energy radiated by the Sun, by measuring the fraction of that energy that reaches Earth. Imagine a sphere with a radius of 1 AU centered on Sun. The amount of energy per unit area the Earth receives would be one fraction of the total energy. Total surface area of this imaginary sphere can be found using the formula $4\pi r^2$. Using this area, we can find that the total luminosity is of the Sun is about 3.8×10^{26} W. This is the equivalent of 10 billion 1-megaton nuclear bombs being detonated every second.

Based on our models on the formation of the Solar System, the Sun is about 4.6 billion years old. Based on its mass of 2×10^{30} kg (300,000 times the mass of the Earth) and its current rate of converting hydrogen into helium, the Sun is about halfway through its life cycle.

By measuring the motion of sunspots, we have determined that the Sun rotates at its equator once every 25.4 days relative to the stars. Since the Earth's orbital motion is in the same direction as the solar rotation, the Sun rotates every 27.3 days relative to the Earth. Like the Jovian planets, the Sun is a gaseous body without a solid surface, so it rotates differentially. Its equatorial region rotates faster (25 days) than the polar regions (33 days).

The light that reaches the Earth originates in the Sun's photosphere. Using spectral analysis of this light, we have been able to determine the temperature and composition of the outer layers of the Sun. However, we have no direct means of measuring the Sun's interior. So, we have to rely on mathematical models. Fortunately, the behavior gases like hydrogen and helium at high temperatures and pressures is well understood by scientists, so by combing modeling with experimentation, we can be confident about the behavior and nature of the solar interior.

Based on analysis and calculations, scientists have determined that the Sun's composition is as follows:

- Helium - 8.7% of atoms, 27.1% of mass
- Oxygen - 0.078% of atoms, 0.97% of mass
- Carbon - 0.043% of atoms, 0.40% of mass
- Nitrogen - 0.0088% of atoms, 0.096% of mass
- Silicon - 0.0045% of atoms, 0.099% of mass

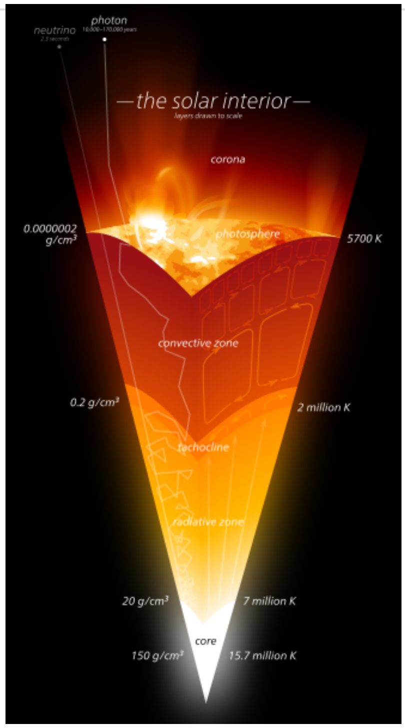
- Magnesium - 0.0038% of atoms, 0.076% of mass
- Neon - 0.0035% of atoms, 0.058% of mass
- Iron - 0.0030% of atoms, 0.14% of mass
- Sulfur - 0.0015% of atoms, 0.040% of mass

The high temperatures of the Sun free the electrons from their atoms, converting the gas into plasma, the fourth state of matter. Plasma is a lot like gas but is a mixture of charged particles at high temperatures where electrons and nuclei are free to move about.

Two forces act on the Sun. One is the inward gravitational pressure of the Sun's mass. The other is the outward pressure from heat generated in its interior. The Sun remains stable because these two forces are in gravitational equilibrium. The energy supplied by fusion maintains the pressure that balances the inward crush of gravity. So long as these forces are balance, the Sun will neither shrink nor expand. Should one become stronger than the other, the Sun would become out of balance and its size would change. To maintain the proper energy balance, the rate at which energy radiates from the surface of the Sun must be the same as the rate at which it is released by fusion in the core.

During the early formation of the Solar System, the energy that heated the core came from gravitational contraction. Once the pressures inside the core became high energy to trigger fusion, contraction stopped, and the Sun stabilized.

13.1: The Solar Interior



The solar interior.

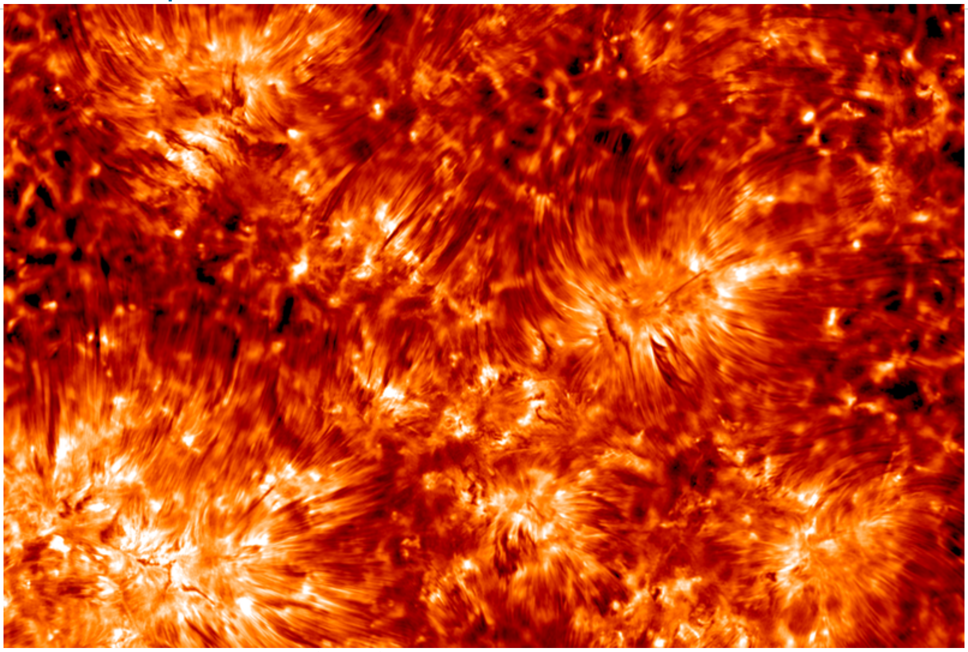
https://commons.wikimedia.org/wiki/F...r_interior.svg

Temperatures at the **core** of the Sun reach 15 million K. The heat is generated by the fusion of hydrogen into helium. The core extends to a radius of about 200,000 km.

Between 200,000 km and 500,000 km from the center, energy from the core is transported primarily through radiation. The **radiation zone** has a temperature of about 7 million K at its closest to the core to about 2 million K at its outer edge. At these temperatures, the plasma is transparent to the radiation from the core, so radiation is the primary means of energy transport. Despite traveling at the speed of light, photons bounce around inside the radiation zone, colliding from one atom to another like pinballs. Because of this meandering path, it can take millions of years for a single photon to travel through to radiation zone to reach convection zone above.

The **convection zone** extends from 500,000 km to 700,000 from the center of the Sun. With a temperature of about 2 million K, the plasma in this zone absorbs heat from the core and then bubbles upward, transferring the heat to the surface through a series of convection cells. The gas heats up, expands and rises to a higher level, where it transfers its heat, cools, and sinks back down to pick up more heat. The visible top layer of the convection zone is granulated, with areas of upwelling material surrounded by areas of sinking material. Doppler shifts of spectral lines indicate complex patterns of rising and falling currents transporting feature to photosphere. Helioseismology, the study of surface fluctuations of the Sun's surface, can enable scientist to map out how variations in the Sun's surface can affect solar weather.

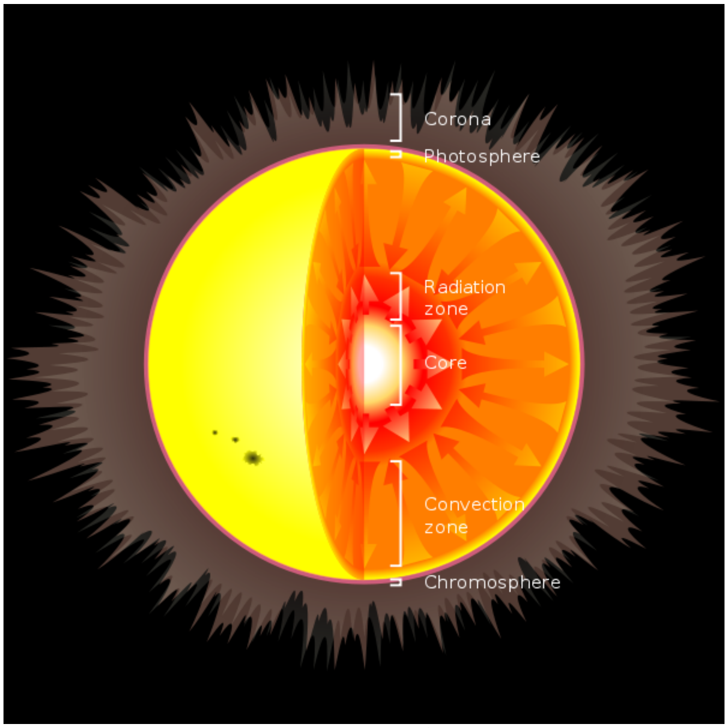
13.2: The Solar Atmosphere



The surface of the Sun exhibits constant activity.

https://commons.wikimedia.org/wiki/F...resolution.png

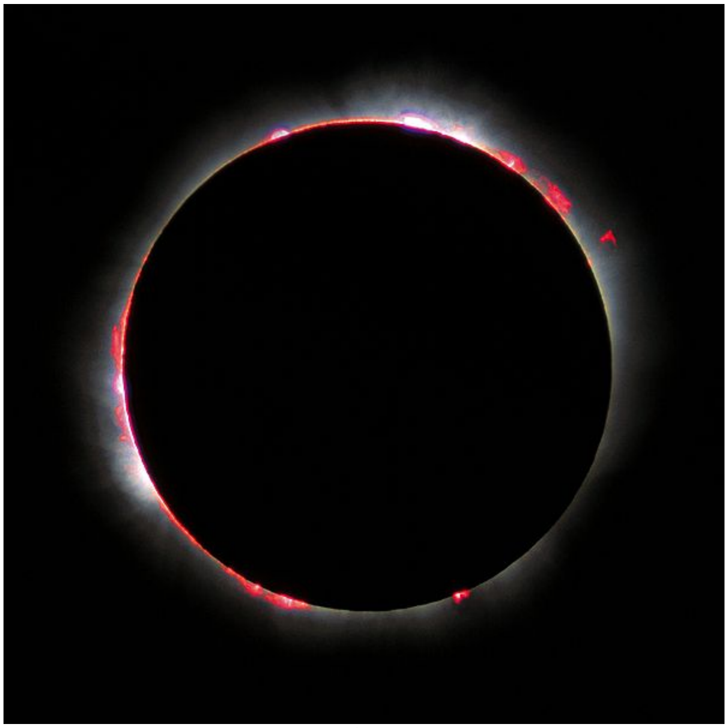
The Sun lacks a solid surface, but if it can be said to have a surface of any kind, it would be the **photosphere**, the visible, granulated region that sits on top of the convection zone. The photosphere is about 500 km thick and has a temperature about 6000 K. It is the light from the photosphere that we detect on Earth as visible light. Sunspots also occur on the photosphere.



The various layers of the Sun

https://commons.wikimedia.org/wiki/F..._structure.svg

From the top of the photosphere, at about 1500 km thick and a temperature of about 5000 K in temperature is the **chromosphere**. Slightly cooler than the photosphere, the chromosphere is only visible during a total solar eclipse when the Moon blocks all the light from the photosphere. Spectral analysis can tell us what elements are present in the chromosphere and photosphere. Because the radiation from the solar interior is absorbed and then re-emitted by the photosphere, we cannot use spectral analysis to analyze the Sun's interior.



The chromosphere can only be seen from Earth during a total solar eclipse.

https:/commons.wikimedia.org/wiki/File:Solar_eclips_1999_5.jpg;

The outermost layer of the solar atmosphere is the **corona**. With a temperature of about 1 million K, the corona is significantly hotter than the chromosphere, indicating that it must have a source of heat other than energy released from the lower regions. This heat source is probably from electromagnetic interactions of its atoms. Like the chromosphere, the corona is not visible from Earth except during a total solar eclipse where the Moon covers both the photosphere and the chromosphere. The corona appears bright in X-ray photos in places where magnetic fields trap hot gas.

The corona can only be seen during a total solar eclipse that covers both the photosphere and the chromosphere.

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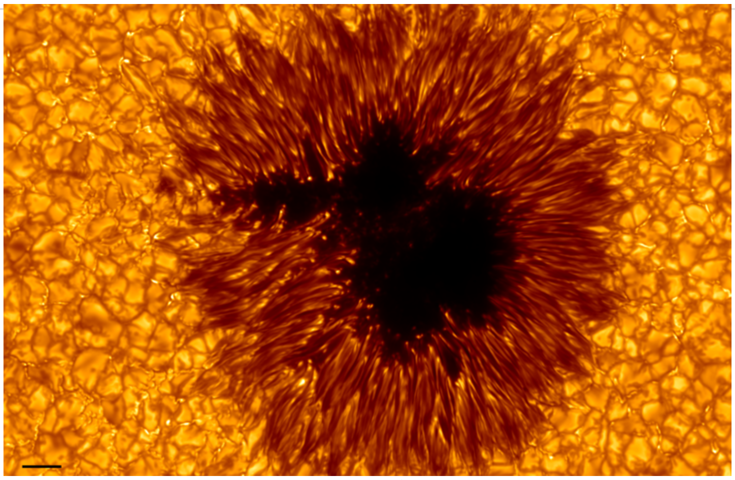
13.3: Solar Weather



A closeup view of a sunspot.

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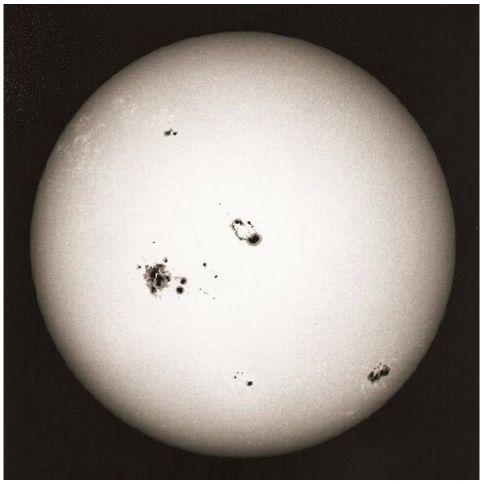
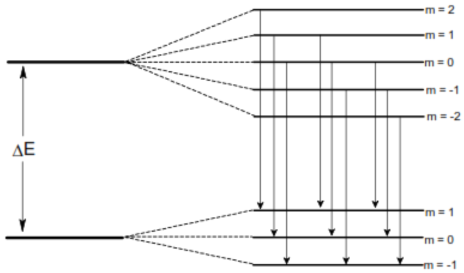


Sunspots appear as dark blemishes on the surface of the Sun.

https://commons.wikimedia.org/wiki/F...1000_years.svg)

13.3.1 Sunspots

Galileo was one of the first scientists to notice dark blemishes on the surface of the sun. These **sunspots** appear dark because they are slightly cooler than their surroundings. By Earth standards, they are actually very hot, with temperatures about 4000 K. Sunspots are regions with strong magnetic fields. We can measure magnetic fields in sunspots by observing the splitting of spectral lines. Known as the **Zeeman Effect**, it is the result of strong magnetic fields splitting a single spectral line into three separate lines.



The intense magnetic fields of a sunspot causes spectral lines to split into three separate lines.

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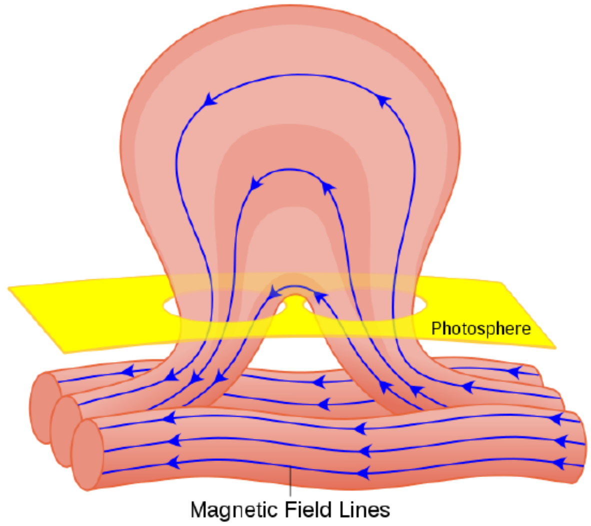
Sunspots occur in pairs that are linked by magnetic field lines. In a sunspot pair, one spot has a north pole and the other acts as a south pole. Charged particles spiral around the magnetic field lines connected the two spots. These particles emit radiation, making the field lines detectable as loops of bright gas travel along the lines. Sunspot come and go over a period of a few days as they appear, move across the face of the Sun, and then disappear.



Sunspot flares produce magnetic field lines that can be seen through their affect on ionized gases.

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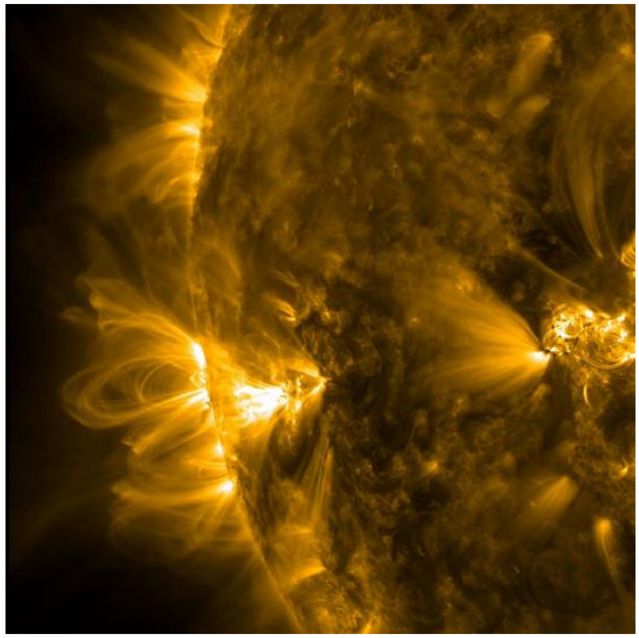
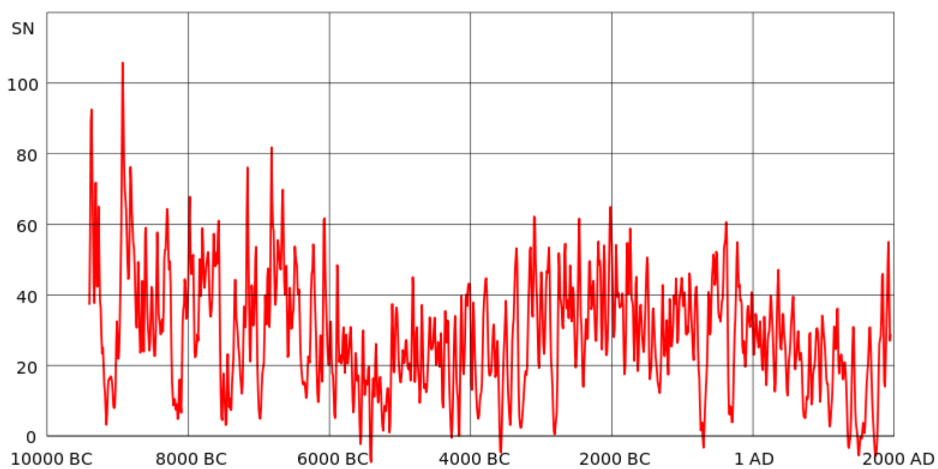


Solar Flares

https:/www.flickr.com/photos/sdomission/12525560223;

Sunspots are produced by distortions in the Sun's magnetic field. As the Sun rotates, it drags magnetic field lines around with it, causing kinks in which the lines twist up, creating magnetic storms on the surface.

The Sun has an 11-year sunspot cycle, during which sunspot numbers rise, fall, and then rise again. The cycle is really a 22-year cycle because the spots switch polarities between the Northern and Southern Hemispheres every 11 years. The solar corona also changes with the sunspot cycle. It is much larger and more irregular at sunspot peak.



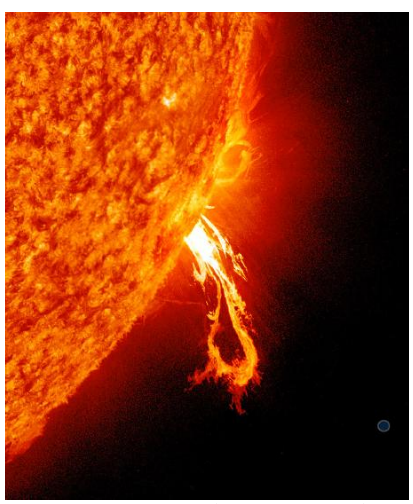
The Solar cycles over the past 1000 years.

https://commons.wikimedia.org/wiki/F...1000_years.svg

Curiously, during the late 1600s and 1700s, the Sun went through a period of relatively low sunspot activity. During this **Maunder minimum,** there were few, if any, sunspots.

13.3.2 Solar Storms

Areas around sunspots are active and may be associated with large eruptions in the photosphere. Sunspots and other magnetic activity on the Sun's surface can create **solar prominences**, large sheets of ejected gas that erupt high about the Sun's surface. Prominences can last for several days or weeks.

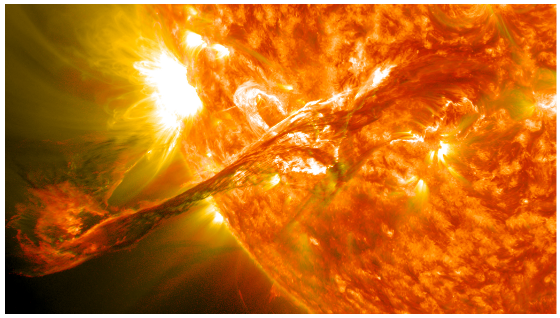


A solar prominence is a plume of gas erupting from the surface.

https:/www.flickr.com/photos/lightsinthedark/5821379923;

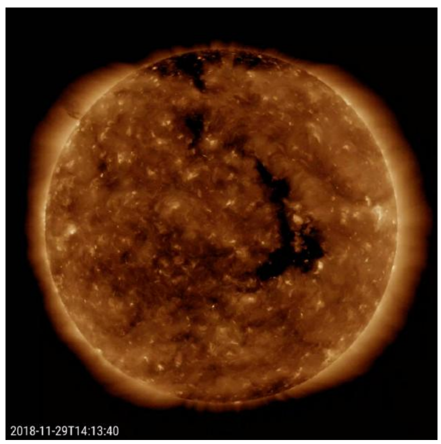
Magnetic activity can also cause **solar flares** that send bursts of X-rays and charged particles into space. A solar flare is a large explosion on the Sun’s surface, emitting an amount of energy. Flares appear similar to prominences but last for seconds or minutes rather than days or weeks.

Occasionally, the Sun will emit are large blob of hot plasma. This **coronal mass ejection** emits charged particles out through the Solar System and has a strong magnetic field that can affect Earth. If a coronal mass ejection interacts with the Earth’s magnetic field, it can disrupt satellite communications or even damage the electric grid, causal a global blackout.



A coronal mass ejection is a mass of ionized gas released from the Sun.

https:/commons.wikimedia.org/wiki/File:Magnificent_CME_Erupts_on_the_Sun_-_August_31.jpg;



The solar wind originates from coronal holes, which are dark, V-shaped regions as pictured here.

https:/www.flickr.com/photos/sdomission/32307510758;

13.4: Nuclear Fusion

13.4.1 The Four Fundamental Forces in Nature

The energy of the Sun comes from the fusion of hydrogen into helium. **Nuclear fusion** requires that like-charged nuclei get close enough to each other to fuse. Under normal conditions, the electromagnetic repulsion between two protons keeps them from coming close enough to stick together. Overcoming this repulsion requires extremely high temperatures of over 10 million kelvins.

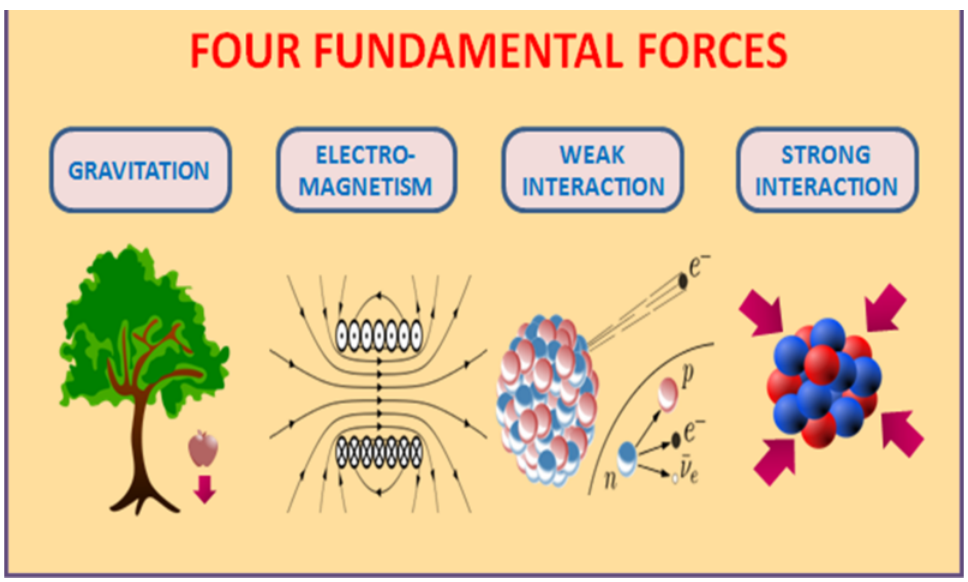
Fusion in the sun involves the interaction of all four fundamental forces of nature.

The first force is **gravity**. While gravity dominates on the scale of planets and stars, in fact it is the weakest of the four forces. The reasons for its dominance on the large scale are that its always attractive (there is no "anti-gravity" force that has ever been found), its range is unlimited, and it increases with mass. Thus, the more massive objects are, the stronger the attraction due to gravity. The pressure from the gravitational collapse that formed the Sun generated the original heat that produced temperatures where fusion was possible. Today, the gravitation pressure of the Sun's mass is in balance from the electromagnetic forces released by fusion in the core.

Electromagnetism is the other force we can recognize on the large scale. Unlike gravity, electromagnetism can either be attractive or repulsive. For example, opposite electric charges attract each other while opposite changes repel. Fluctuating electromagnetic fields produce all the forms of radiation from radio waves to visible light to high energy X-rays. Like gravity, the range of electromagnetism is unlimited, falling off with the inverse square of distance.

The final two forces have very short ranges and only operate at distances inside the radius of an atomic nuclear. As a result, they are called **strong nuclear force** and the **weak nuclear force**, respectively. The strong force holds tiny particles called quarks together to form the protons and neutrons in the nucleus. The weak force governs certain forms of radioactive decay, such as beta decay.

Each of the forces has a carrier particle associated with it. Electromagnetism has the photon while the strong nuclear force has the gluon (because they act as "glue" to hold the quarks together). The weak force is carried by W^+, W^-, and Z particles. The particle associated with gravity has been called the graviton, however, it has yet to be observed in nature.



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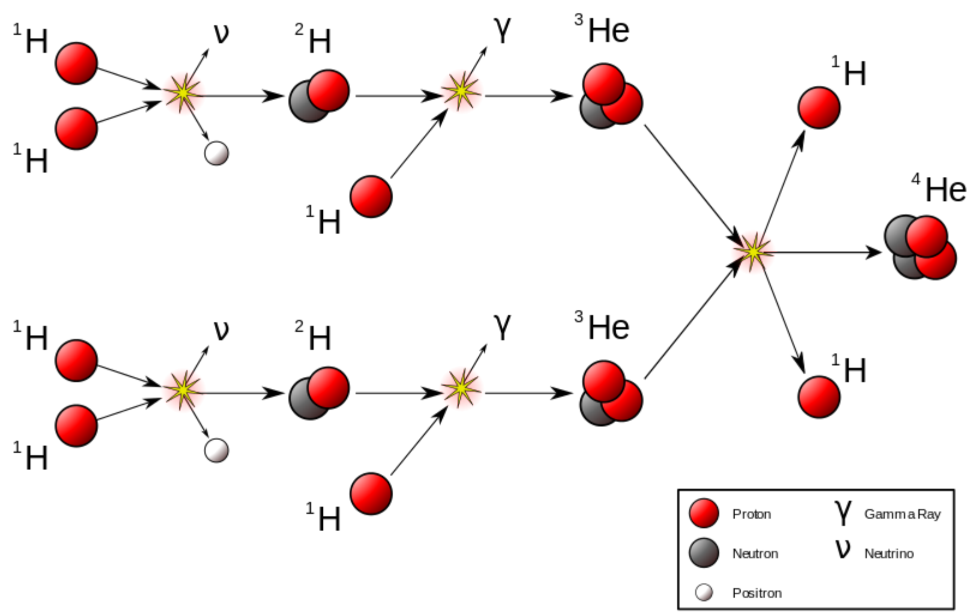
13.4.2 Proton-Proton Chain

The process that powers most stars is a three-step fusion process called the **proton–proton chain.** The result of this chain is the fusing hydrogen nuclei (protons) in a single helium nucleus. The first step in the proton-proton chain involves two protons coming together to form a particle called a **deuteron**. As the two protons come together, the strong force causes them to stick while the weak force converts one of them into a neutron. To balance the charges, the deuteron emits a **positron**, the antimatter form of an electron that carries a positive charge. Fusing the two protons into a deuteron emits energy while the positron eventually encounters an election. When the matter and antimatter particles come together, they destroy each other, converting all their mass into a gamma photon. Another particle is also emitted from the formation of a deuteron, the neutrino. More about them later.



The proton-proton chain.

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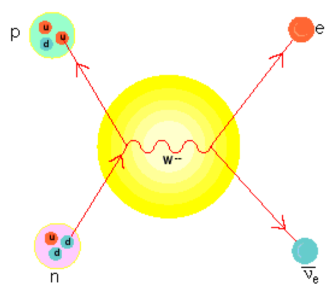
The second step involves the deuteron fusing with another proton, forming a helium-3 nucleus that contains two protons and one neutron. This also releases a burst of energy. Finally, two helium-3 nuclei will come together to form a helium-4 nucleus while ejecting two protons and releasing yet another burst of energy. The two free protons may fuse with other protons to continue the cycle.

In summary, the proton-proton chain requires a total input of four protons and produces an output of one helium-4 nucleus, 2 gamma rays, 2 positrons, and 2 neutrinos. The total mass of the output particles is 0.7% lower than the mass of the original four protons. This missing mass is converted into the energy that is emitted by the Sun.

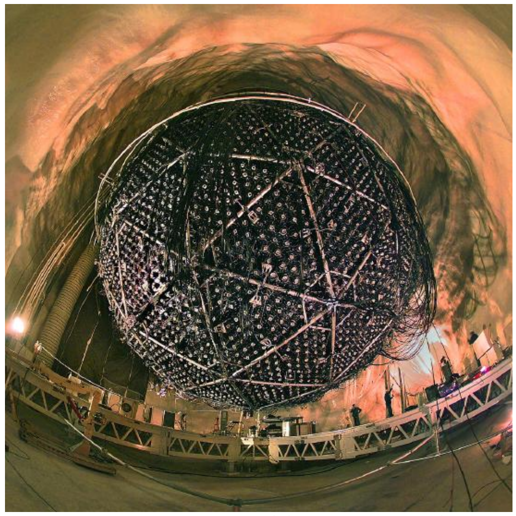
Neutrinos are small, weakly interacting particles that are emitted directly from the core of the Sun and escape. Because they do not interact strongly interact with matter, neutrinos do not take a meandering path out of the core the way photons do. Instead, they travel straight out into space. Being able to observe these neutrinos gives us a direct picture of what is happening in the core. However, because they interact with matter so weakly, neutrinos are almost impossible to detect. Millions of neutrinos pass through the entire Earth every second without interacting with a single atom. They are no more likely to interact with Earth-based detectors than they are with the Sun. the only way to spot them is to have a huge detector volume and to be able to observe single interaction events. Neutrino detectors often employ 1,000 tonnes of water or other fluid deep underground where sensors look for a single flash of radiation indicating a neutrino detection.



Neutrinos are small, nearly massless particles that are produced during nuclear fusion.

https://upload.wikimedia.org/wikiped.../Neutrino4.gif

Early searches for solar neutrinos, however, failed to find the predicted number. This created a problem for scientists, who either had to revise their models for the Sun's interior or explain why their detectors were not finding the correct amount. Eventually, scientists realized that some of the neutrinos were changing form en route from the Sun and their detectors where only looking for the kind of neutrinos produced from the fusion itself. More recent observations find the right number of neutrinos by searching for different types of neutrinos.



Neutrino detectors use large volumes of fluid to search for tiny interactions.

https:/www.flickr.com/photos/berkeleylab/2826495494;

14: Exoplanets

Learning Objectives

- Describe the methods of detecting exoplanets including the transit and Doppler methods.
- Describe how exoplanets can be detected through direct imaging.
- Describe the sizes, orbits, and properties of many exoplanets that have been detected.
- Understand how future detection methods may find more Earth-like exoplanets.

Astronomers have wondered whether other worlds existed beyond our own. Giovanni Bruno, a Dominican friar and astronomer, theorized in the 16th century that the stars could be suns like our own with planets orbiting. However, Bruno was the exception for centuries. Most ancient and medieval observers did not think stars were like the Sun because Sun is so much brighter. Most assumed that they were just points of light and had no idea how big or distant they were.

Giordano_Bruno_BW_2.jpg

Christian Huygens (1629–1695) used holes drilled in a brass plate to estimate the angular sizes of stars. His results demonstrated that, if stars were the same size as the Sun, they must be at great distances. Galileo also argued that the stars must be much further away that assumed due to the lack of observed parallax.

Even after the fact that the stars are like the Sun, the question of whether they had planetary systems of their own remained an open question for generations. The computer models of nebular contraction supported the belief that planetary systems should be common. As a cloud contracted and its rotation rate increased, protoplanetary discs appeared an inevitable result. Despite their best efforts, repeated observations failed to uncover evidence of extrasolar planetary systems.

The problem came down to a question of brightness and distance. A Sun-like star is about a billion times brighter than the light reflected from its planets. Planets orbit close to their stars, relative to the distance from us to the star. Trying to pick out the light reflected off a planet is akin to trying to find a firefly next to a searchlight. Discerning the tiny angular separation between a star and a planet orbit it is like being in San Francisco and trying to see a pinhead 15 meters from a grapefruit in Washington, D.C.

All of this changed in 1995 when two astronomers, Didier Queloz and Michel Mayor, announced the discovery of 51 Pegasi b, the first confirmed planet orbiting a star other than our soon. Soon, astronomers found other exoplanets and over the past few decades, the search for exoplanets have become one of the most vibrant and exciting fields of astronomy. The International Astronomical Union has established a naming convention by adding a letter after the name of the parent star. The letter “a” is reserved for the brightest object in the stellar system, i.e., the star. The first planet discovered is assigned the letter “b”, the second “c”, and so on.

Since the discovery of 51 Pegasi b, thousands of exoplanets have been confirmed, with thousands of more candidates awaiting confirmation. The Kepler mission, an orbiting infrared telescope dedicated to searching for exoplanets found over 2600 exoplanets during its nine-and-a-half-year operation. Initially, the first exoplanets were “**hot Jupiters**,” that is, large gas giants with orbits close to their host star. These planets were the easiest to detect given the techniques and data available at the time. Since then, planets ranging from smaller than the Earth to more massive than Jupiter have been found. Most planets detected to date fall in a range of masses between the of Earth and Neptune. Astronomer have labeled these worlds “**superearths**.”

Image credit: https:/commons.wikimedia.org/wiki/File:Clear_to_cloudy_hot_Jupiters.jpg;

14.1: Detection Methods

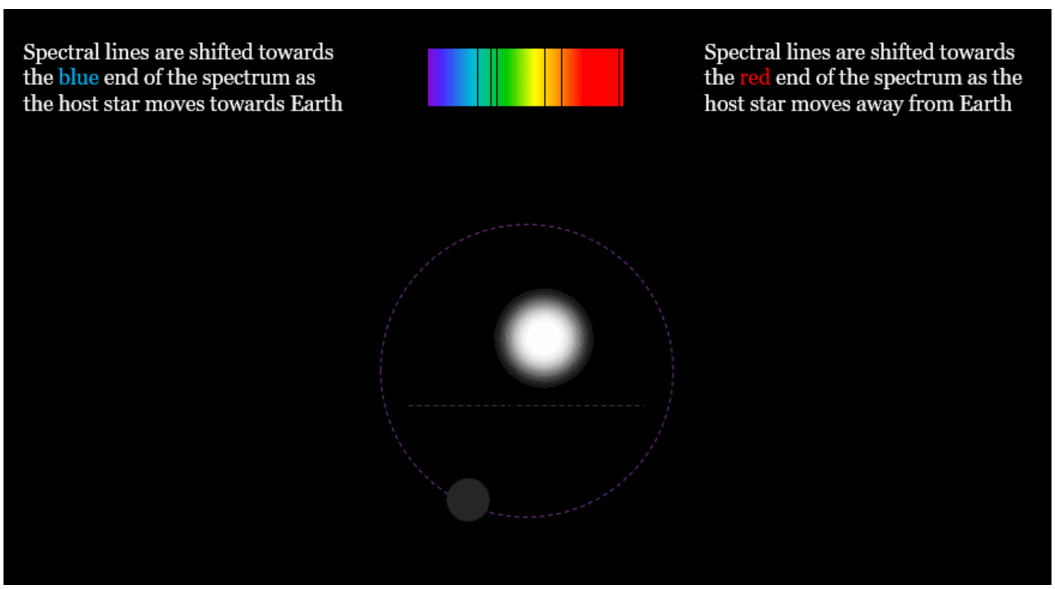
14.1.1 Doppler and Transit Methods

Searches for exoplanets fall into two categories. In **direct** methods, astronomers find images or spectra of the planets themselves. In contrast, **indirect** involve making measurements of stellar properties revealing the effects of orbiting planets on the motion of parent star.

The first successful methods in exoplanet detection involved looking for signs of the planets exerting gravitational tugs on their host stars. A Newton demonstrated, planets and their host stars orbit around their common center of mass. Because stars are much more massive than planets, a star will only make a tiny "wobble" around the center of mass while the planets make large orbits. The more massive the planet, the larger the stellar wobble. For example, as the Sun and Jupiter orbit around their common center of mass, the Sun wobbles around that center of mass with same period as Jupiter. Since the Jupiter is the most massive planet in our solar system, it exerts the largest wobble on the Sun of the planets. The Sun's total motion around the solar system's center of mass depends on tugs from all the planets. Looking at the solar system from a great distance, however, the motion caused by the orbit of Jupiter would be most detectable.

Astronomers looking at other stars searched for means to measure this motion to both infer the existence of exoplanets as well as determine their masses and orbit. One technique to detect this motion is the astrometric technique, which we detect exoplanets by measuring the change in a star's position on sky. However, these tiny motions are very difficult to measure (~ 0.001 arcsecond). As a result, few exoplanets have been detected using the astrometric technique. Date from the GAIA spacecraft as it makes precise measurements of the location and motion of the stars in our galaxy may help. There is hope that astrometric techniques can find more exoplanets in the future.

Meanwhile, numerous exoplanets, including 51 Pegasi b, have been found using the Doppler technique. This involves measuring a star's Doppler shift can tell us its motion toward and away from us. As the star wobbles around the center of mass of the system, it will alternatively move toward the Earth and away from the Earth in regular intervals. This will cause periodic red and blue shifts in the star's light output. Current techniques can measure motions as small as 1 m/s (walking speed!).



The Doppler shift can be used to detect an exoplanet based on its influence on the star's motion.

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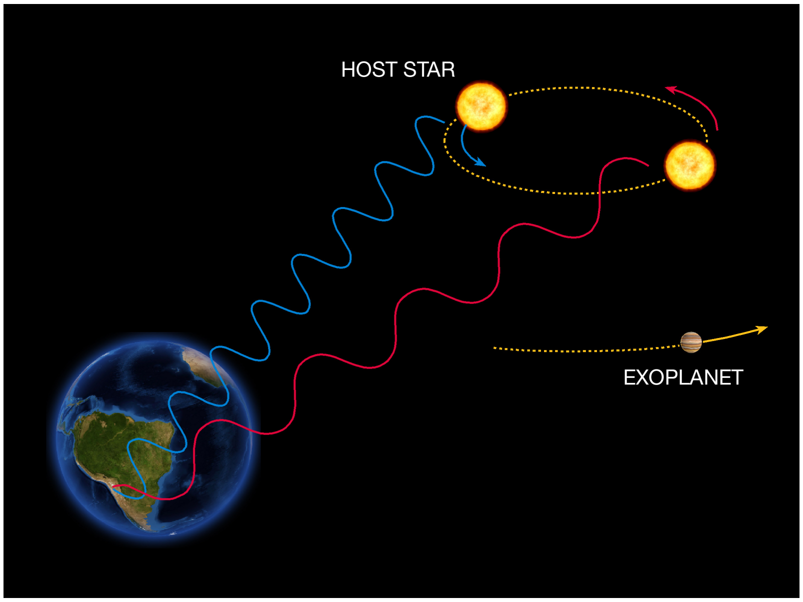
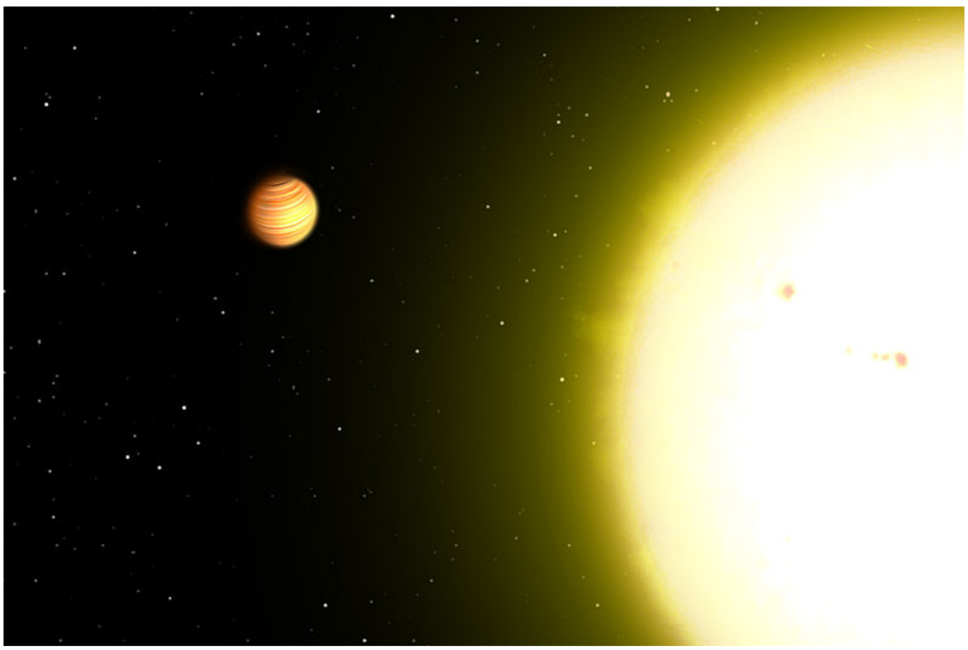


The Doppler Method.

https:/commons.wikimedia.org/wiki/File:The_radial_velocity_method_(artist%E2%80%99s_impression).jpg;

Doppler shifts of the star 51 Pegasi indirectly revealed a planet with 4-day orbital period. Such a short period means that the planet has a small orbital distance. Calculations determined that 51 Pegasi b has a mass like Jupiter's, despite its small orbital distance. Its large mass and closeness to it host star led astronomers to coin the phrase “Hot Jupiter” to describe this class of exoplanet.

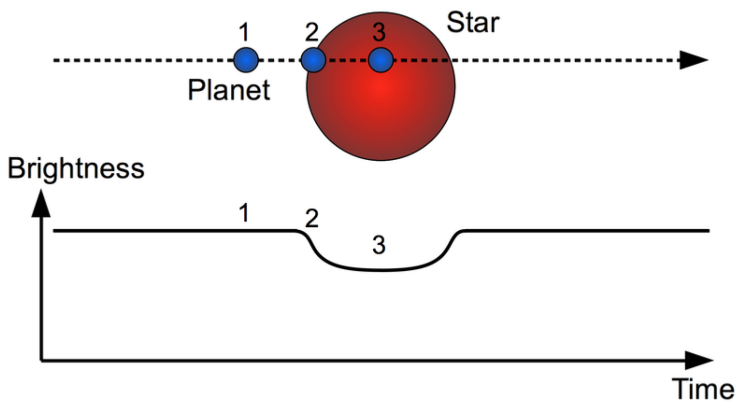

Artist's conception of 51 Pegasi b.

https:/commons.wikimedia.org/wiki/File:51_Pegasi_b_v1.jpg;

Since the discovery of the 51 Pegasi b, astronomers have found numerous other hot Jupiters. Because of their large masses and short orbital periods, hot Jupiters produce Doppler shifts that are relatively easy to detect. Their short orbital periods also mean we do not need to sift through years of data to find the patterns of shifts. For these reasons, nearly all of the early exoplanets discovered fall into the category of hot Jupiters.

Date from Doppler shift can tell us about a planet's mass and the shape of its orbit. However, we cannot measure an exact mass for a planet without knowing the tilt of its orbit, because Doppler shift tells us only the velocity toward or away from us. It gives us no information about any lateral (left to right) motion resulting from the exoplanet's orbit. As a result, Doppler data only give us lower limits on masses.

Other exoplanets have been found using the brightness or transit technique. This involves the periodic dimming of the parent star's brightness. A **transit** is when a planet crosses in front of a star. Whenever a planet transit, it produces a dip in the star's brightness. An **eclipse**, when the planet passes behind the star, can also be sometimes observed. The changes in brightness from transits and eclipses are very minute and require precise and care measures.



The transit method can be used to detect an exoplanet by the periodic dimming of a star.

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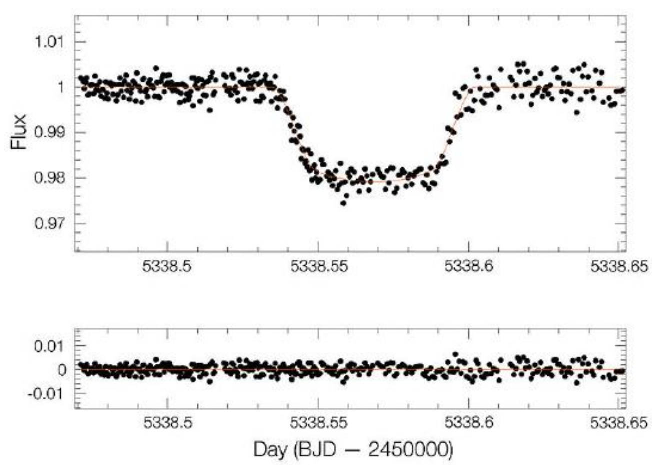


This data curve shows the dimming of light from a star.

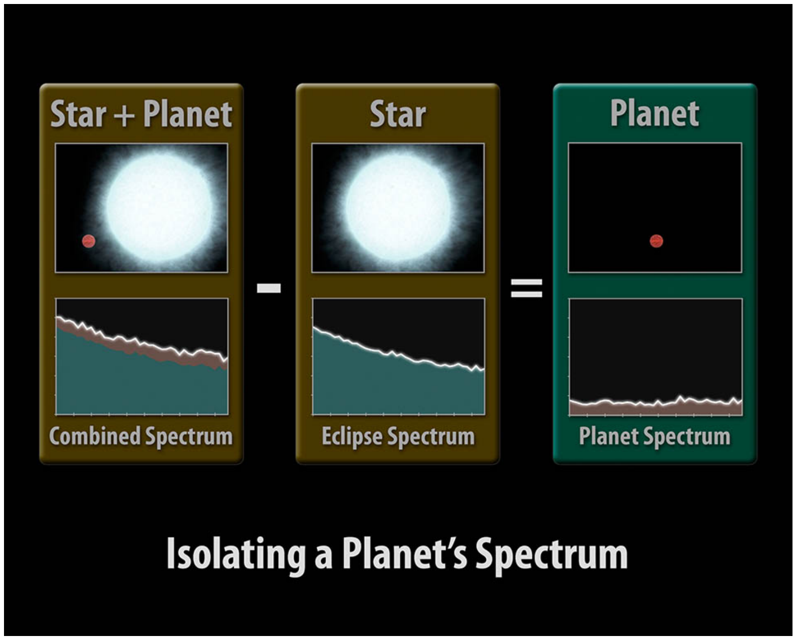
https://commons.wikimedia.org/wiki/F...t_WASP-19b.jpg)

As astronomers look for periodic changes in brightness, they can divide the planet's motion into six phases.

1. Before transit when the star is at full visible light brightness.
2. Transit begins and a noticeable drop in brightness begins.
3. During transit, the planet blocks a small percentage of the star's visible light.
4. Before eclipse, at this point, the planet emits infrared radiation, and the total infrared spectrum includes that of both the star and the planet.
5. Eclipse begins, and the infrared spectrum dips as the planet's infrared radiation is blocked by the star.
6. During eclipse when the planet's infrared spectrum is blocked until the planet emerges on the other side the star.

By measuring the time it takes for the electromagnetic spectrum to go through the cycle of both visible and infrared dimming, astronomers can determine the exoplanet's orbital period. In addition, the amount of dimming that occurs as transit begins enable astronomers to infer the size of the planet. Also, the planet's atmosphere may dim additional light and produce an absorption spectrum, enabling astronomers to identify the composition of the atmosphere. Finally, measuring changes in the infrared spectrum during eclipse enable scientist to infer the planet's temperature.

Unlike the Doppler technique, the brightness technique is not limited by orbital tilt, enabling more accurate measurement of planet mass.



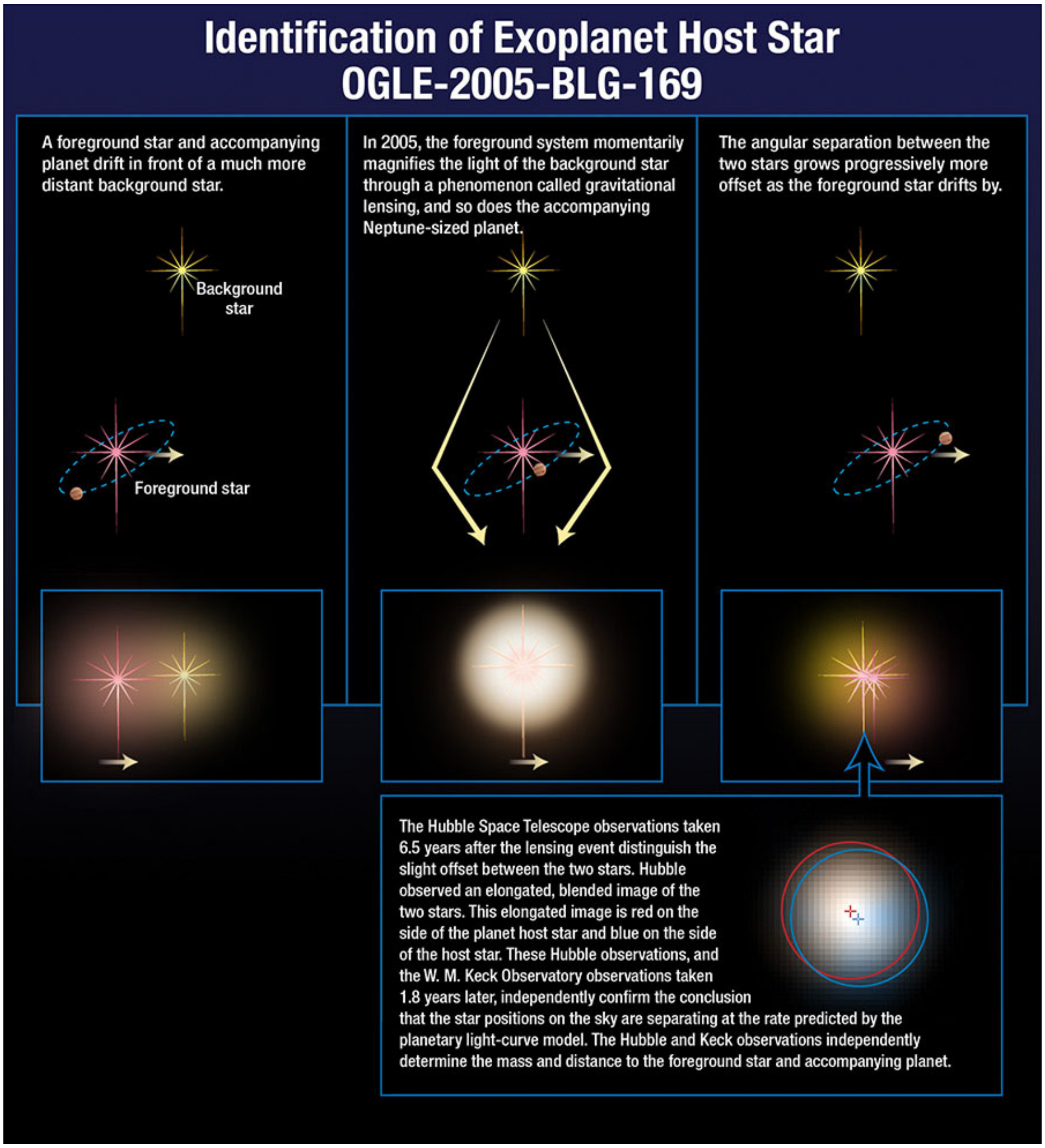
Isolating a planet's spectrum.

https:/exoplanets.nasa.gov/resources/58/isolating-a-planets-spectrum;

The Kepler Mission used the brightness technique to find thousands of planet candidates. Launched in 2008 it began looking for transiting planets. Unlike the Hubble Space Telescope, which can be pointed into almost any direction, Keppler remained focused on a single region of space during its initial mission. During this time, it gathered date from thousands of stars. Keppler was designed to measure a 0.008% decline in brightness when an Earth-mass planet eclipses a Sun-like star.

14.1.2 Gravitational Microlensing

Other techniques include **gravitational lensing.** Einstein's theory of general relativity states that gravity is the result of the warping of spacetime due to the mass of a large object. A electromagnetic waves pass through the warped spacetime, its path bends in response. The gravitational lensing method depends on how mass bends light when a star with planets passes in front of another star. Because it requires two stars to line in one behind the other at just the right time, gravitational lensing is a more difficult method. Scientists must find a star at just the right moment to spot the lensing effect.



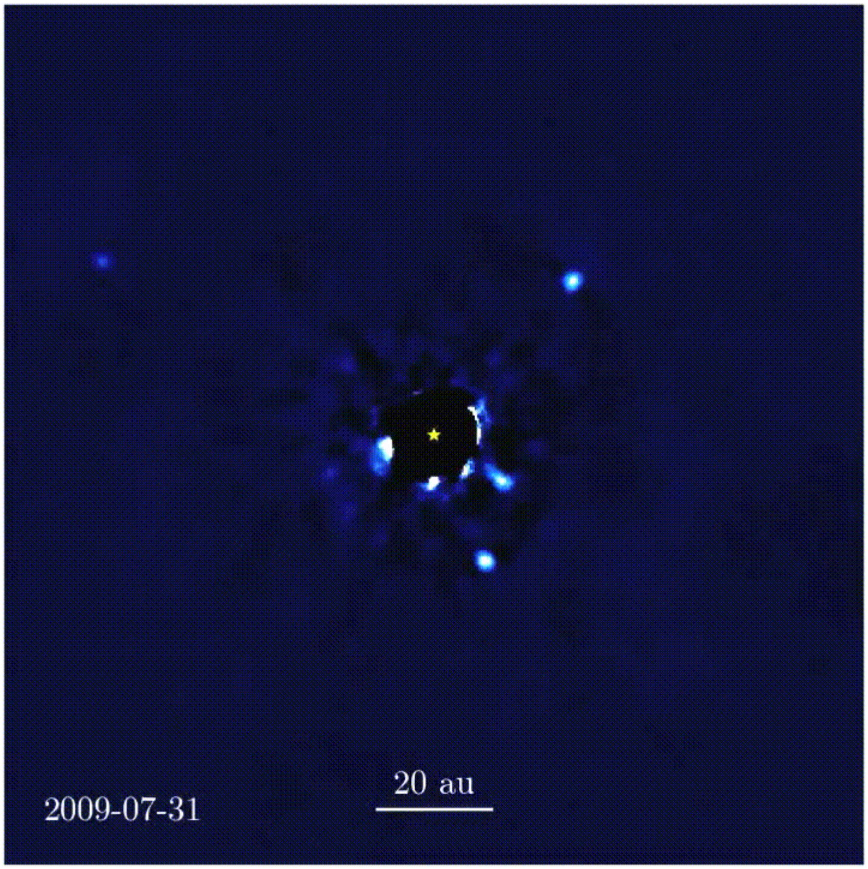
Gravitational microlensing can be used to detect exoplanets.

https://exoplanets.nasa.gov/resource...-2005-blg-169/

Astronomers can also find the presence of exoplanets by looking at gaps, waves, or ripples in disks of dusty and gas around newly forming stars.

14.1.2 Direct Imaging

Most recently, advances in image resolution through adaptive optics have enabled us to make **direct detection** of exoplanets possible. Unlike other methods, which only detect the affects exoplanets have on brightness or motion of stars, direct detection enables us to image the exoplanets directly. Direct detection. Techniques using coronagraphs to block the bright light from stars can also aid in detecting planets around them. Once the James Webb Space Telescope is launched, data collected from it will help astronomers perform more direct detection of exoplanets.



Direct imaging of exoplanets.

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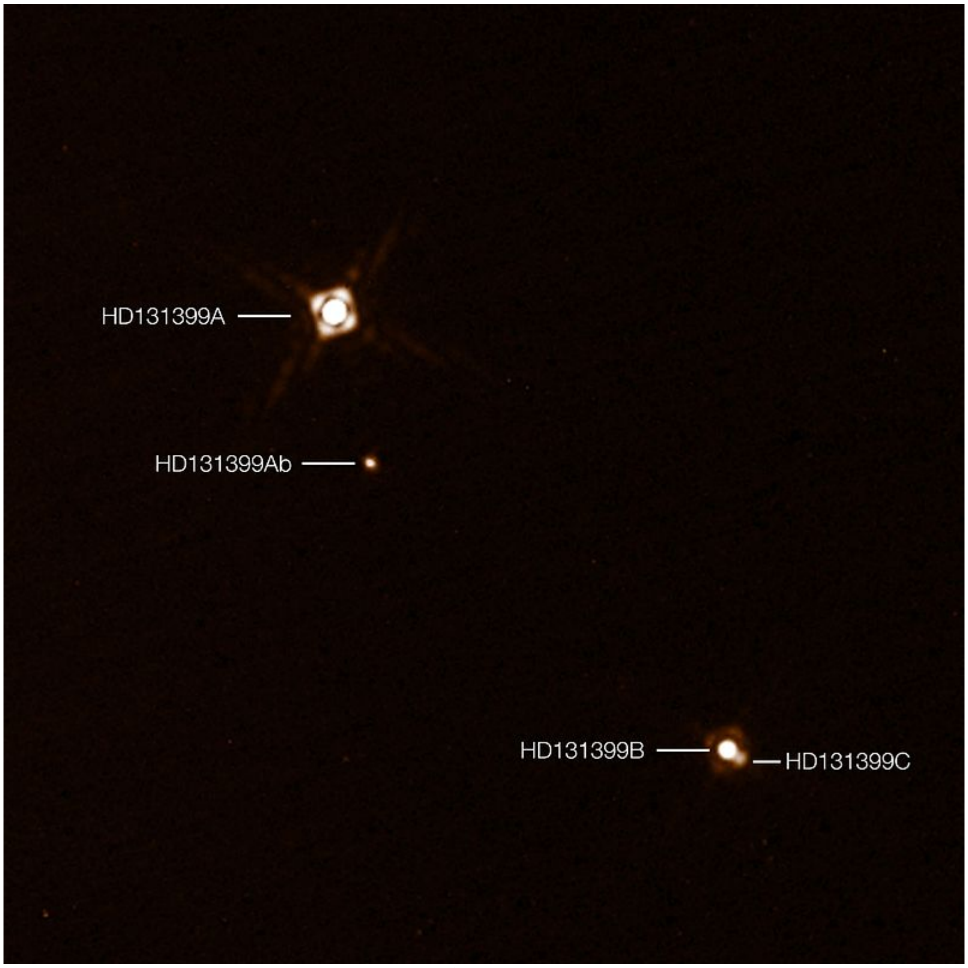

Direct image of orbiting exoplanets.

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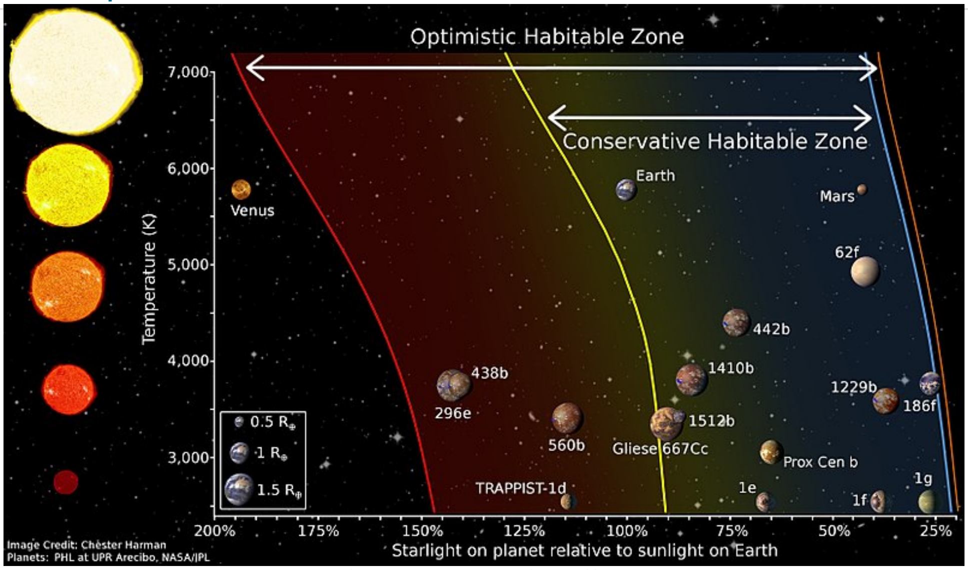
14.2: Orbits of Exoplanets



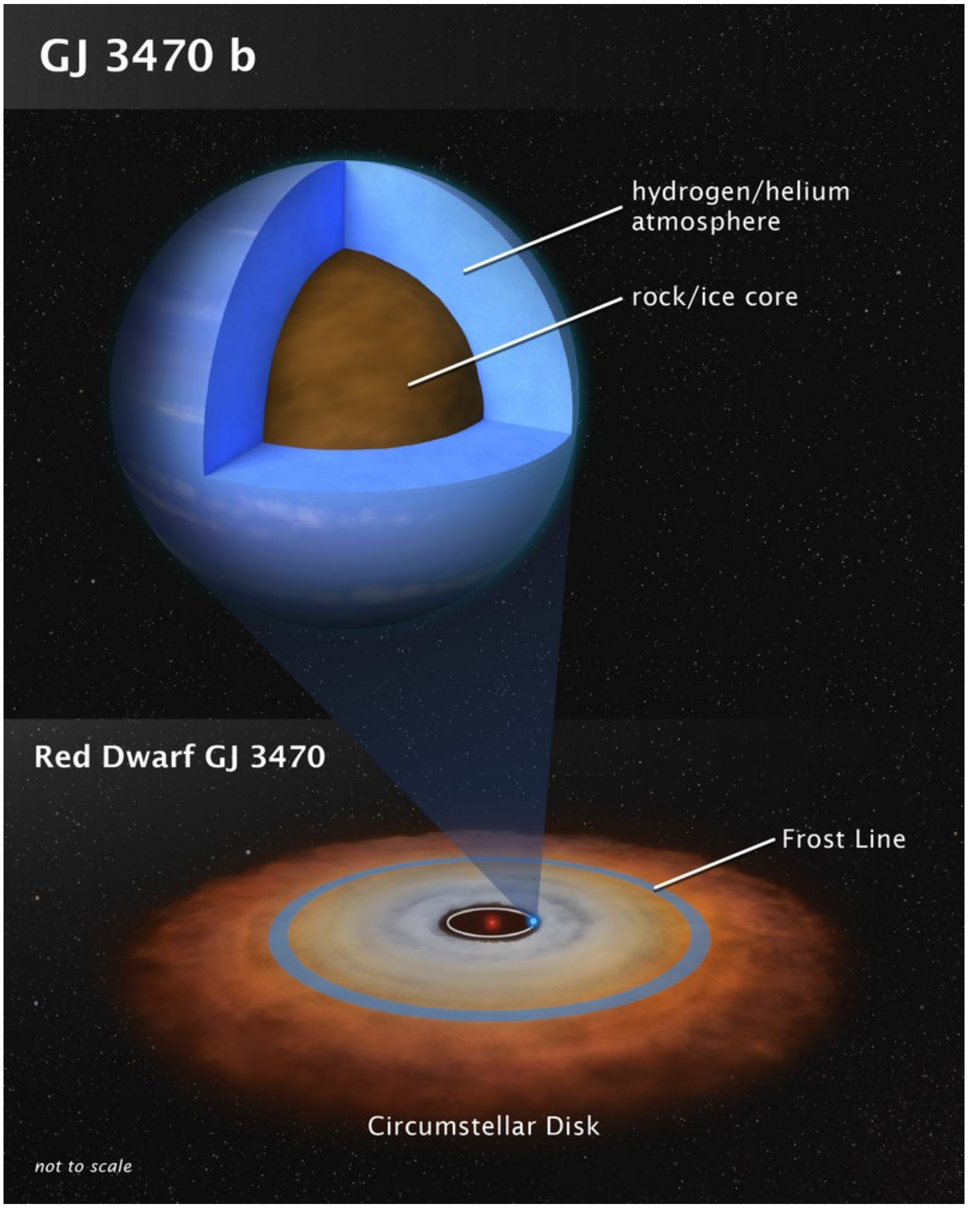
Comparison of habitable zones for different sized stars.

https:/commons.wikimedia.org/wiki/File:Diagram_of_different_habitable_zone_regions_by_Chester_Harman.jpg;

To date, most of the detected planets have orbits smaller than Jupiter's, closer to Neptune than that of Earth. Planets that orbit at greater distances are harder to detect with the Doppler technique. Kepler has enabled us to find many planets with masses lower than that of Jupiter. Orbits of some extrasolar planets have a greater eccentricity than those in our solar system. As techniques for finding planets with longer periods, it is likely, we find more of those.

About 20% of stars surveyed may have Earth-like planets in their respective habitable zones. While some Earth-analogs have been found, there is a gap in our detection consisting mainly of smaller planets with long (100 days or more) orbital periods As we collect and analyze more data and our techniques for finding long period exoplanets improve, we can expect that this gap will be filled in.

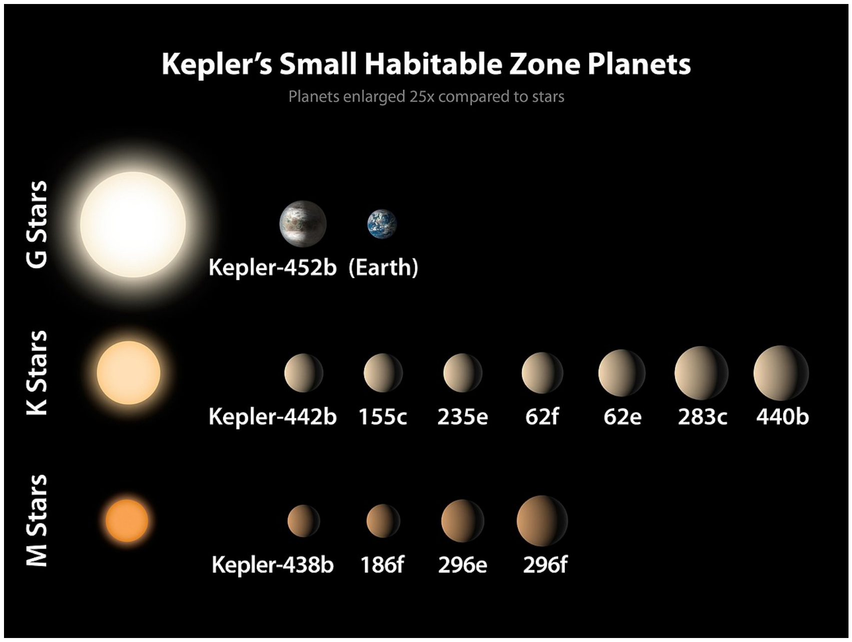
We know have enough confirmed exoplanets to conclude that planetary systems are likely the norm. Most stars are expected to have at least one planet orbiting them. We have, however, found some surprises in these studies. For example, many extrasolar planets have highly elliptical orbits, unlike the nearly circular orbits in our solar system. Planets also show great diversity in size and density, including numerous exoplanets intermediate between Neptune and Earth, even though no such planet exists in our solar system.



Orbit of Gleise 3470.

https:/commons.wikimedia.org/wiki/File:Structure_of_Exoplanet_GJ_3470_b.tif;

The detection of hot Jupiters has required us to revisit some of the assumptions in nebular theory. The earlier nebular model predicts that massive Jupiter-like planets should not form inside the frost line (at << 5 AU of our Sun). Despite this, we have found numerous Jovian-type planets very close to their host stars. While part of this is to due the bias of early techniques, the large number of hot Jupiters requires some explanation. This may be explained by planetary migration, in which planet forms further away from the star and then moves in closer. For example, a young planet's motion can create waves in a planet-forming disk. Models suggest that matter in these waves can tug on a planet, causing its orbit to migrate inward. Also, a close gravitational encounter between two massive planets could eject one planet while flinging the other into a highly elliptical orbit. Multiple close encounters with smaller planetesimals may also cause inward migration. Orbital resonances between large planets with a 2:1 ratio in their orbital periods may also contribute to inward migration.



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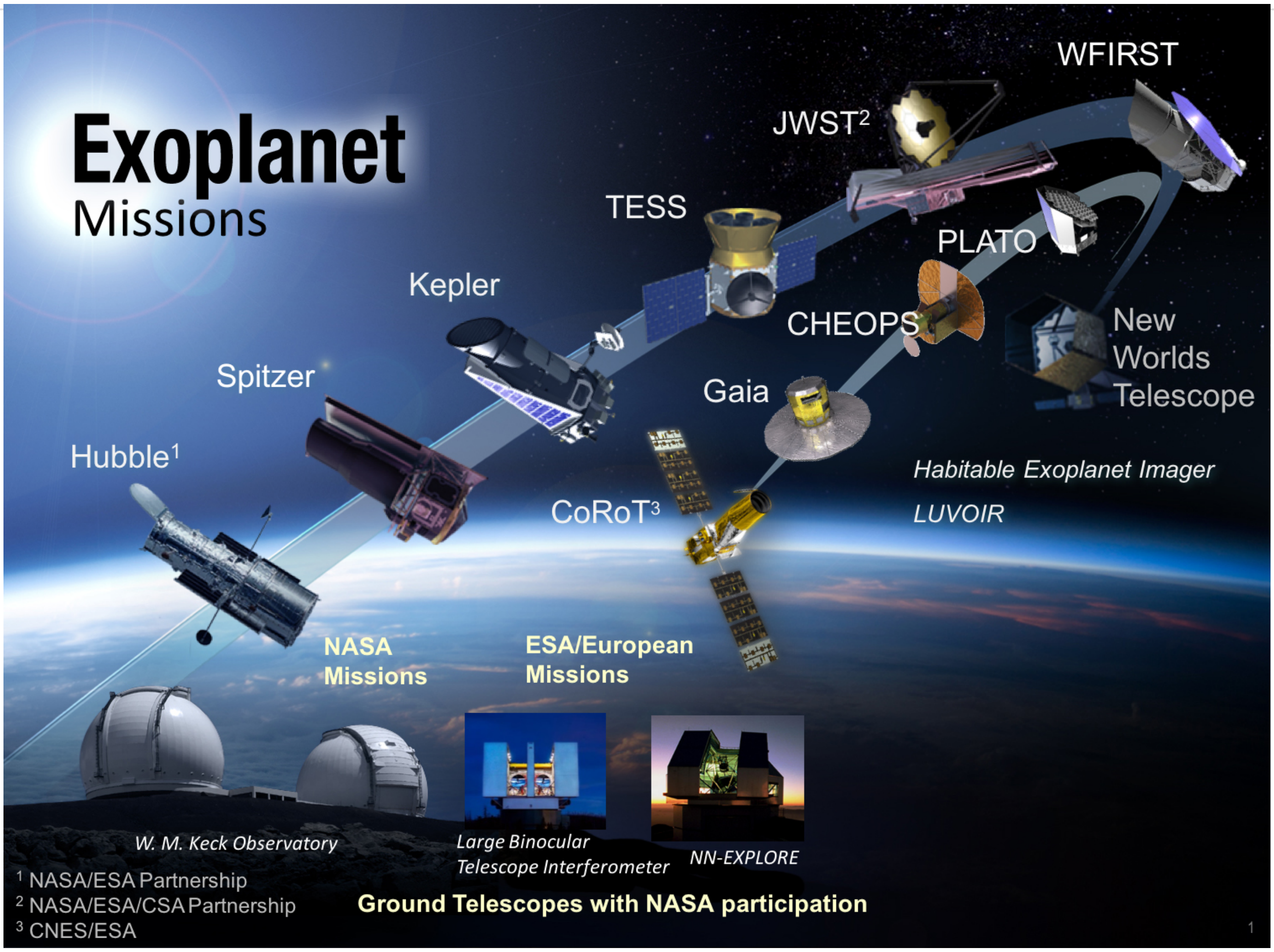
14.3: Future Studies

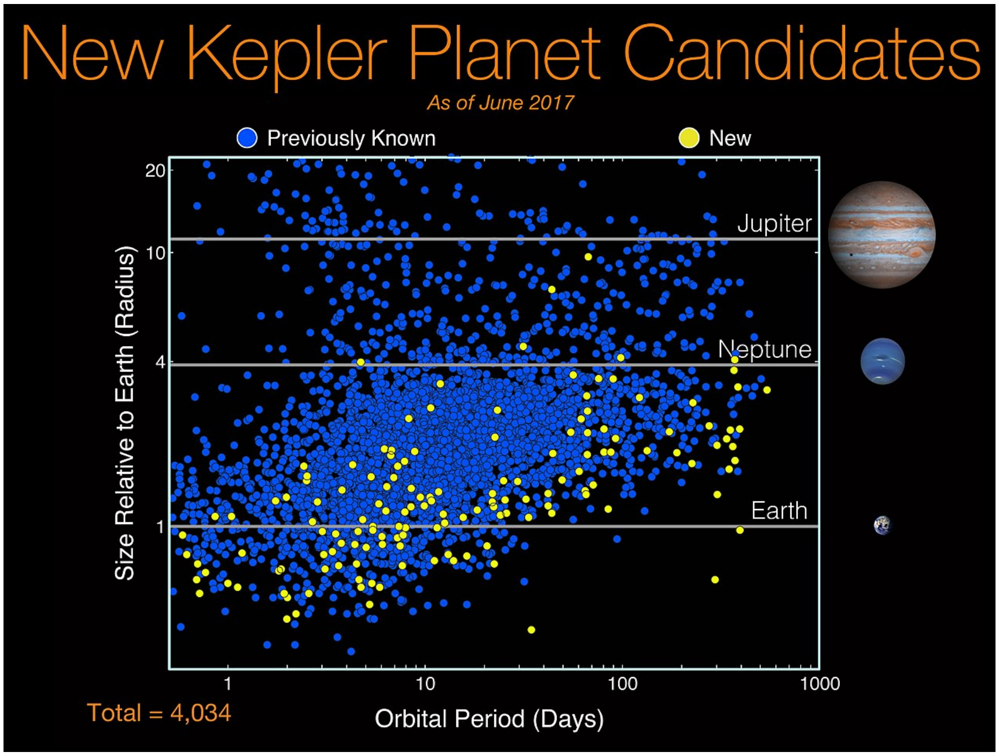


https:/exoplanets.nasa.gov/resources/280/light-curve-of-a-planet-transiting-its-star;

GAIA is a European mission launched by ESA in 2013 that will use interferometry to measure precise motions of a billion stars. In addition, TESS is a NASA mission that will use the same strategy as Kepler. ESA also plans to launch the CHEOPS mission that will carefully measure properties of known planets using transits. Finally, the James Webb is expected to open new avenues of planetary detection, including improvements in direct detection.

Transit missions will continue the search for Earth-like planets that cross in front of their stars and find more smaller worlds in the habitable zones. Direction of Earth-like planets will require the use of interferometry and techniques for blocking starlight. Also, astrometric missions will be capable of measuring the "wobble" of a star caused by an orbiting Earth-like planet through precise angular measurements.

We have only begun to study the planets in our galaxy and can expect more surprises and discoveries in the coming years.



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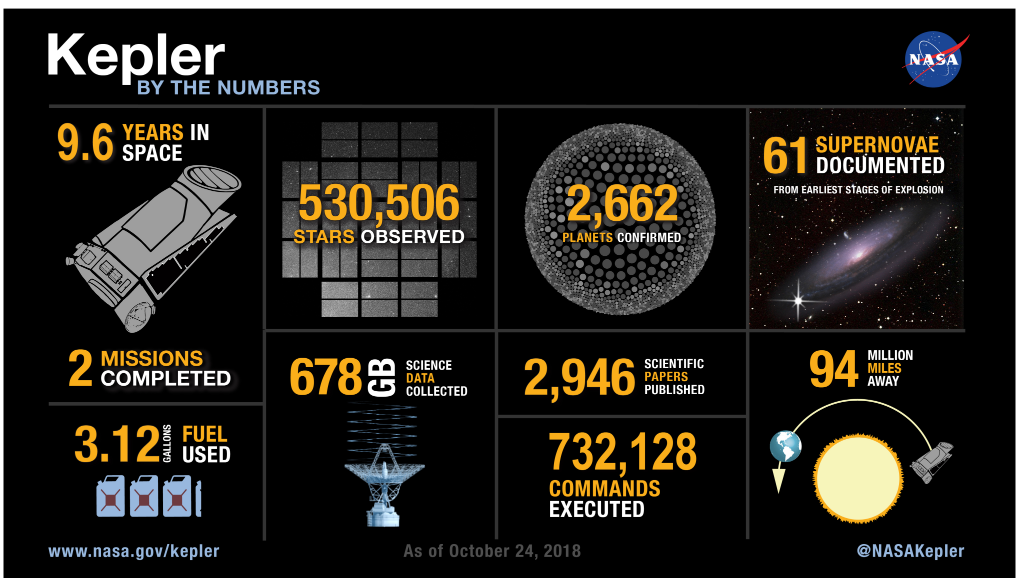

https:/exoplanets.nasa.gov/resources/2192/
nasas-kepler-mission-by-the-numbers
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15: Astrobiology and the Search for Extraterrestrial Intelligence

Learning Objectives

- Explore the various hypotheses about abiogenesis.
- Describe the field of astrobiology.
- Explore various examples of extremophiles and how they can be used in the search for extraterrestrial life.
- Describe the conditions that a habitable world is expected to have and where in the galaxy they may be found.
- Discuss the search for extraterrestrial intelligence, the probability of another intelligent civilization existing in the galaxy, and ask why we haven’t seen any signs of one.

Where did life come from?

Is there life on other worlds?

Could there be intelligent aliens with which we may be able to communicate?

There are probably no questions more profound about our own existence that these. To understand if life exist on other worlds, we need a greater understanding of life and how it many have begun here on Earth.

But what is life?

This is one of those questions that seems easy at first, but it is more difficult that initially thought. Are bacteria alive? What about viruses? If we found life on another world, would be able to even identify it? There are some agreed upon characteristics that something must have to be considered alive:

Order: organisms have some form of organism. This may consist of multiple, specialized cells working together. But even single-cell organisms have complex internal structures which can carry out complex chemical reactions in a controlled environment.

Response to the environment: Organism respond and grow together stimuli. Mobile animals travel toward resources and away from danger. Planets grow in response to sunlight, water, and available nutrients. Even bacteria can move toward certain chemicals or light.

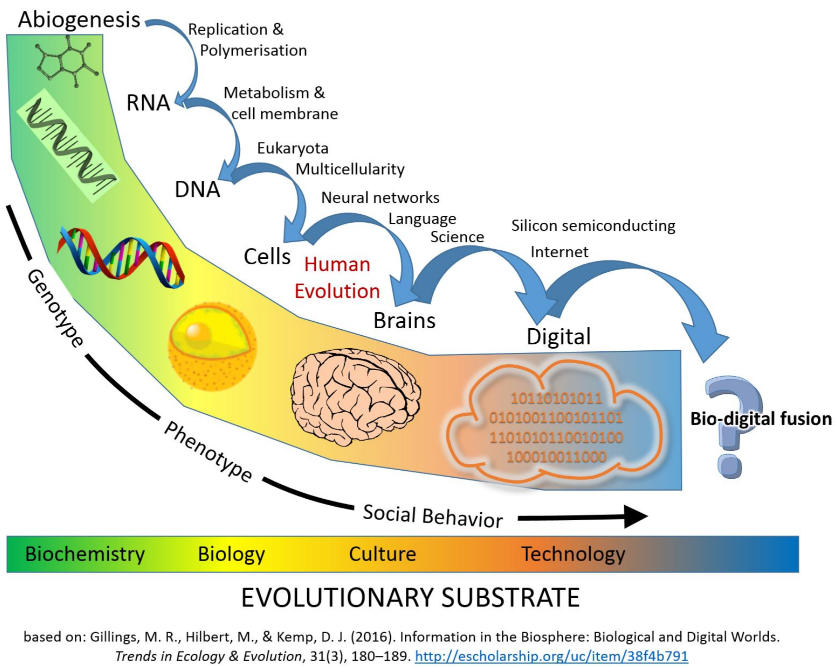
Reproduction: Cells divide and reproduce. Multicellular organisms reproduce either sexually or asexually. All life as we know it uses the self-replicating molecules of DNA to produce offspring that have similar traits as the parent.

Growth: All organisms grow occurring to predictable patterns governed by their inherited DNA.

Homeostasis: Organisms absorb nutrients and expel wastes. This helps them maintain homeostasis, or stable internal conditions, which is necessary to carry out the chemical reactions and molecular machinery to keep the organism functioning.

Energy processing: Organisms make use of sources of energy to power their metabolism and maintain homeostasis. This energy may come from sources like the sun for photosynthesis or by taking in energy by consuming other organisms.

Evolution: Populations of organisms can respond to changes in the environment by adapting. Traits that enhance survival and reproduction are more likely to be passed onto future generations. They will therefore become more prevalent in the population over succeeding generations. As a result, the average characteristics of members of the population will change over time.



Evolution of life.

https:/commons.wikimedia.org/wiki/File:Major_Evolutionary_Transitions_digital.jpg;

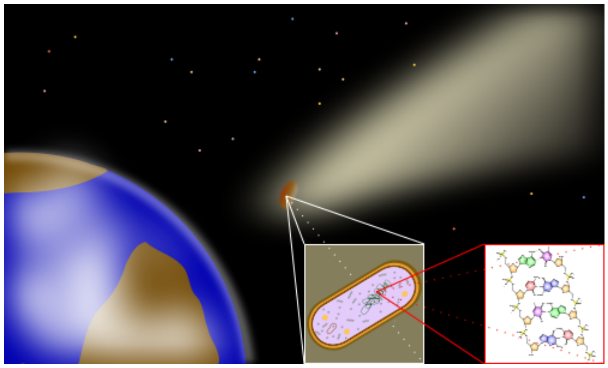
Lots of things may meet some of these criteria. Fire, for example, takes in energy and can grow and reproduce, but it is not organized and does not evolve. A car is organized and processes energy to power its energy, but it cannot reproduce or evolve. Crystals are organized and can growth, but they cannot evolve or process energy. Organisms, from the single-celled bacterium to human beings meet all the above characteristics. On the other hand, viruses meet most of these criteria, but cannot reproduce on their own. They require a host cell whose machinery they can hijack to make new viruses. For that reason, many biologists do not consider viruses to be living organisms.

Image credit: https:/commons.wikimedia.org/wiki/File:The_History_of_the_Universe.jpg;

15.1: Abiogenesis

Where did life come from?

The study of **abiogenesis**, the process by which life originates from nonliving matter, is a lively field of science. However, there is no one single accepted model to explain how the first true living organisms appeared on Earth. One proposed idea is **panspermia**, in which Earth was "seeded" with microorganism delivered by meteorites or comets. The difficulty with panspermia is that does not explain how life originated. It just moves the origin of life from the Earth to somewhere else in space.



Panspermia: The idea that life originated somewhere in space and was "seeded" on Earth by asteroids or comets.

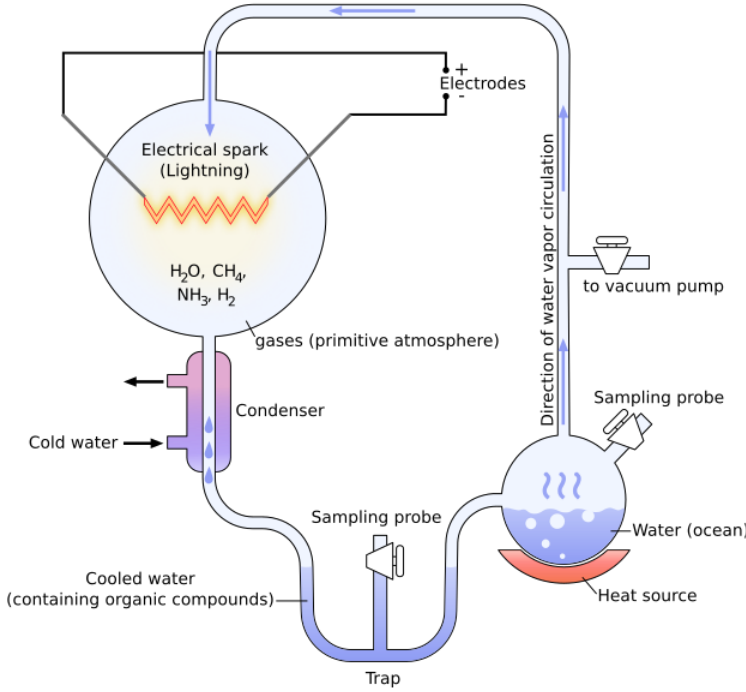
https://commons.wikimedia.org/wiki/F...Panspermie.svg

As we noted in Chapter 8, finding the first evidence of life on Earth is difficult as rocks dating back to the first billion years of Earth's history are rare and difficult to find. Because plate tectonics constantly remodels the Earth's surface, most of the crust dating back to between three and four billion years ago has long been destroyed. However, the evidence we have been able to gather indicates that simple one-celled organisms, such as algae, appeared on Earth about 3.5 billion years ago. More complex one-celled creatures, such as the amoeba, appeared about 2 billion years ago while multicellular organisms began to appear about 1 billion years ago. In contrast, the fossil evidence indicates that anatomically modern homo sapiens evolved between 200,000 and 300,000 years ago while the entirety of human civilization, from the discovery of agriculture to walking on the Moon occurred in the last 10,000 years.

Miller-Urey Experiment

Charles Darwin suggested that life may have begun in a "warm little pond" somewhere. The first attempt to see if organic molecules was conducted in the 1950s by Stanley Miller and supervised by his thesis adviser, Stanley Urey. The Miller-Urey experiment attempted to recreate conditions like those of early Earth. Miller created an apparatus condition water, ammonia, methane, and hydrogen and heated it provide a source of energy. He included an electric spark to simulate lightning. Within a few days, Miller had produced a soup of organic molecules. These included amino acids, the building blocks of proteins. Later evidence from geochemistry indicates that Miller may not have precisely replicated the Earth's early atmosphere, so he may not have discovered the exact process through which these early organic compounds formed. However, his experiment was a proof of the idea that complex organic molecules can be formed from inorganic molecules through simple chemical reactions.

Since the Miller-Urey experiment, we have detected organic compounds such as amino acids in meteoroids and comets. We have even found them in interstellar clouds. This has led many scientists to suggest that at least some of these organic compounds may have been delivered to Earth from space. One meteorite that fell in Australia contained 12 different amino acids found in Earthly life, although some of them are slightly different in form.



The Miller-Urey experimental setup.

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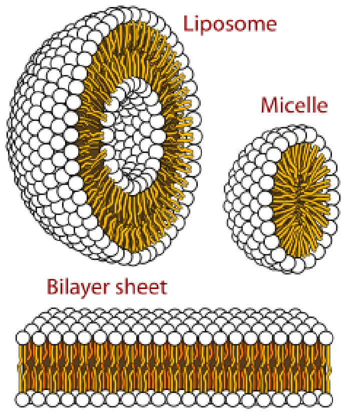
The First Cells

Wherever the first organic compounds came from, eventually, the first **protocells** formed as phospholipids came together as membranes. We have found that these phospholipids, when placed in water, natural form membrane-like structures. Lipids found in meteorites have been found to spontaneously form membranes in water. Other protein-like molecules can form clusters of billions of amino acid molecules. These droplets can grow and split into smaller droplets.

The
Murchison
Meteorite:

Several amino acids were detected in this meteorite.

https:/commons.wikimedia.org/wiki/File:Carbonaceous_chondrite_(Murchison_Meteorite)_(14601493358).jpg;



Phospholipids like these naturally form bilayers and membrane-like droplets in water.

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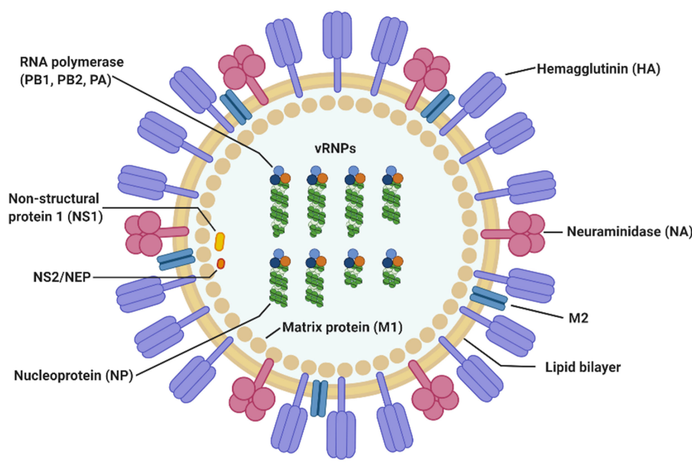
But these organic compounds are merely the building blocks of life. They are not life itself.

At some point between 3.7 and 4.4 billion years ago, these organic molecules came together to form the first living cells. There is no single, accepted model for abiogenesis, however, likely the most popular one is the **RNA World hypothesis**. This hypothesis assumes the first self-replicating molecule was RNA. RNA is similar to DNA, but usually forms as single strand instead of the double helix structure of DNA. Today, most organisms use DNA to store genetic information and then use RNA to carry the "blueprint" for building cells out of the nucleus and then use RNA to assemble the amino acids into protein molecules.



Some viruses use RNA instead of DNA to store their genetic information.

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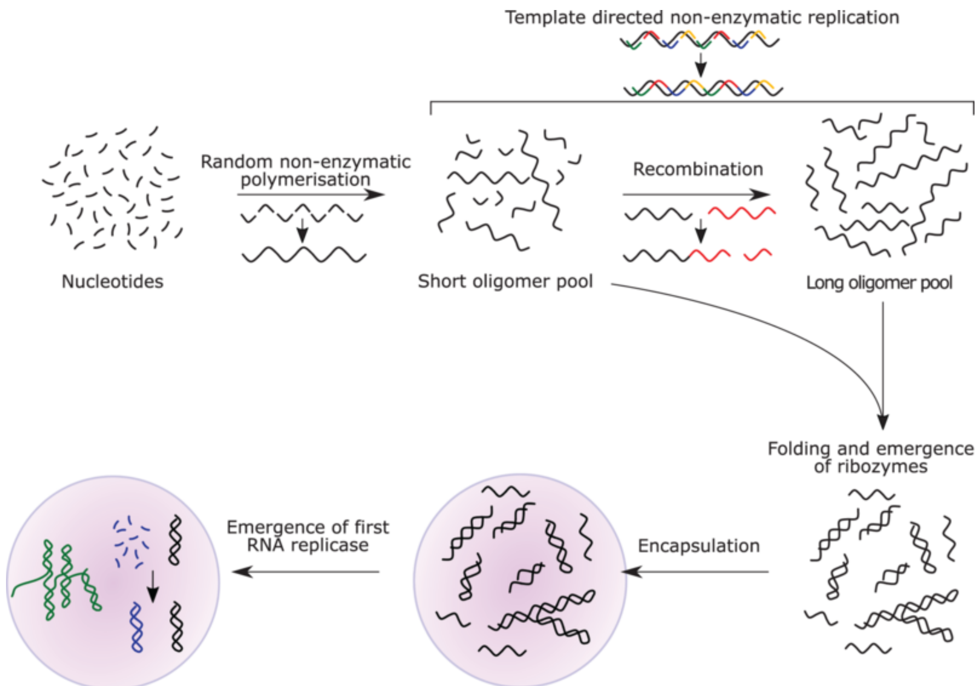
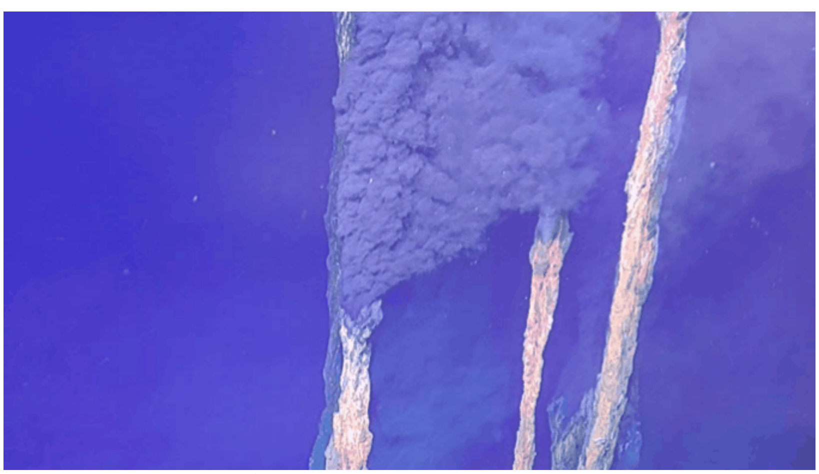


RNA may have become the first self-replicating molecule.

https://commons.wikimedia.org/wiki/F...19-0024c.01.pn

The RNA world hypothesis suggests that as RNA began to self-replicate, it eventually started to assemble amino acids into the first proteins. Many viruses use RNA instead of DNA to carry genetic information, so this hypothesis suggests that the first organisms were viruses. But how did the first RNA molecules get assembled. One idea is the clay hypothesis is which clay served as a catalyst to build polymers of RNA and the first lipids.

Another hypothesis is the **iron-sulfide world**. This hypothesis suggests the first self-replicating organic molecules formed using reactions from sulfides of iron or other metals. Life may have first begun in begun in deep hydrothermal vents instead of in shallow pools of “primordial soup.” Today, hydrothermal vents are home to bacteria and other organisms like tube worms that use the energy from these vents. Before the Earth had substantial amounts of oxygen in the atmosphere, it had no ozone layer to protect life from the Sun’s ultraviolet rays. So, it is unlikely that life originated near the surface. The iron-sulfide hypothesis provides a location for life to originate that is shielded from UV-rays and has a source of energy to produce the first self-replicating organisms.



Perhaps life began at deep sea hydrothermal vents.

https://commons.wikimedia.org/wiki/F...eebe_Vents.gif

Other hypotheses include hypotheses that the first organic molecules something other than RNA, such as lipids, polycyclic aromatic hydrocarbons (PAH), polyphosphates. In addition, Gold’s deep hot biosphere hypothesis suggests life began several kilometers below the Earth’s surface, using heat from the Interior.

Another hypothesis, called the radioactive beach hypothesis suggests that when the Moon was closer to the Earth, its gravity might have concentrated uranium or other radioactive elements near the high-water mark of early beaches. This energy could have “kicked started” life. Another idea proposed that life originated in fluctuating hydrothermal pools on volcanic islands or proto continents. Some scientists have concluded that cell membranes cannot be formed in salty seawater. During this time before continents, the only dry land on Earth would be volcanic islands. On these islands, rainwater could have formed freshwater ponds where lipids could have formed into protocells.

Finally, it is possible that there were multiple occasions where life began simultaneously from multiple sources, with one ultimately winning out.

15.2: Astrobiology

15.2.1 Extremophiles

The discipline of **astrobiology** involves the study of the origins, evolution, distribution, and future of life in the universe. It may seem strange to have a discipline devoted to studying something that has yet to be discovered. After all, we only have one place where life is confirmed. However, we can study life in locations on Earth that were more extreme than the norm. We have found life in places on Earth that we would not have expected them to be. These organisms are called **extremophiles**. These organisms live in environments considered too extreme for most living organisms. However, for the extremophiles, these environments perfectly suited for them and the "normal" environment most other organisms live are the extremes.

There are different categories of extremophiles, including:

- **Themophiles:** Bacteria and archaea that thrive in extreme temperatures. These are often found in the scalding waters of geyser such as Old Faithful in Yellowstone National Park.
- **Psychrophiles:** These extremophiles that thrive in temperatures lingering around the freezing point of water. Often, they are found in pools of water buried under sheets of ice in places like Antarctica.
- **Acidophiles:** Microorganisms that thrive in pH at lowers at or below 2. They can be found in deep-sea vents, volcanic areas, areas subjected to acids draining from metal mines, or even in the stomachs of animals.
- **Alkaliphiles:** The opposite of acidophiles, alkaliphiles thrive in environment of pH, often in ranges of 8.5 to 11. These environments include soda lakes found in Yellowstone or other locations where the alkaline compounds can accumulate in water.
- **Radioresistant:** These microbes are resistant to high levels of ionizing radiation or UV radiation. Their ability to resist and repair the damage radiation causes to DNA has enabled them to survive even in the coolant waters of nuclear power plants.
- **Barophiles:** These can resist the intense pressures found in the deep waters of places like the Mariana Trench
- **Halophiles:** These microbes can survive in environments with extreme levels of salinity, such as the Great Salt Lake or the Dead Sea.
- **Xerophiles**: These include fungi and yeast that have adapted unique features that allow them to survive extreme desiccation.

The Mammoth Hot Springs are home to thermophiles.

https:/commons.wikimedia.org/wiki/File:MAMMOTH_HOT_SPRINGS_-_EXTREMOPHILES.jpg;

The waters in the Rio Tinto have a pH of about 2.2 and are home to acidophiles.

https:/commons.wikimedia.org/wiki/File:Rio_Tinto_water,_pH_2,2.jpg;

Halophiles thrive in environments with high salt content like the Dead Sea.

https:/commons.wikimedia.org/wiki/File:Figure_22_01_05.jpg;

15.2.2 Tardigrades

Adult tardigrade.

https:/commons.wikimedia.org/wiki/File:Adult_tardigrade.jpg;

Most extremophiles are single-celled organisms like bacteria, archaea, or protozoa. However, there is one multicellular animal that may be the champion of extremophiles, the Tardigrade or water bear. Tardigrades can survive in extreme environments that would kill almost any other animal. These include:

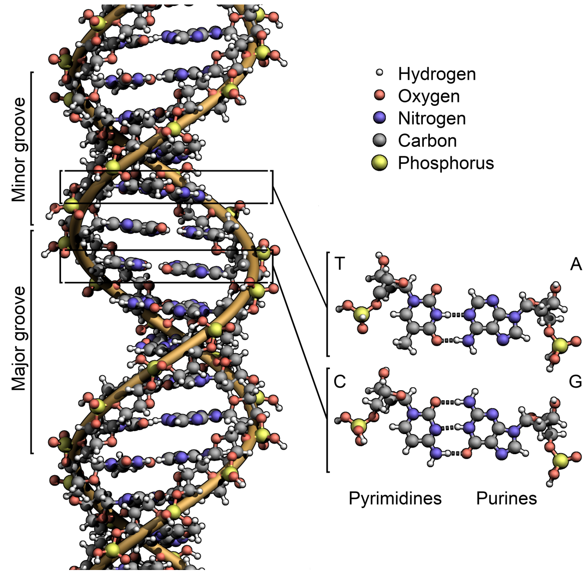
- Temperature: Tardigrades can survive have been known to survive:
  - A few minutes at 151 °C (304 °F)
  - 30 years at −20 °C (−4 °F)
  - A few days at −200 °C (−328 °F; 73 K)
  - A few minutes at −272 °C (−458 °F; 1 K)
- Pressure: They can withstand the extremely low pressure of a vacuum and also very high pressures, more than 1,200 times atmospheric pressure. Tardigrades can survive the vacuum of open space and solar radiation combined for at least 10 days.
- Dehydration: The longest that living tardigrades have been shown to survive in a dry state is nearly 10 years, where they go into a dormant state until rehydration.
- Radiation: Tardigrades can withstand 1,000 times more radiation than other animals.

Tardigrades are the first known animal to survive in the harsh environment of space. In September 2007, dehydrated tardigrades were taken into low Earth orbit on the FOTON-M3 craft. For 10 days, groups of tardigrades were exposed to either the hard vacuum of outer space or vacuum and solar UV radiation. After being rehydrated back on Earth, over 68% of the subjects protected from high-energy UV radiation revived within 30 minutes following rehydration.

15.2.3 Commonalities of Life

Because it is doubtful that any alien planet will exactly replicate the conditions on Earth, studying extremophiles can give us an idea of the range of environments in which life can survive.

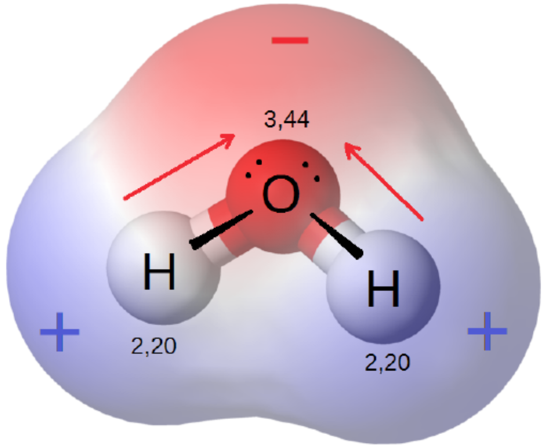
In studying life on Earth, we do have some commonalities even among the extremophiles. All organisms use organic molecules, that is, molecules based on carbon. Carbon's ability to form four distinct bonds and form long chains or other shapes of flexible molecules has made it the basis for all life. Organic molecules are used for all aspects of biochemistry, from structural material (proteins), energy storage (lipids, carbohydrates), catalysts (proteins), and encoding genetic information (DNA and RNA).



The DNA double helix.

https://commons.wikimedia.org/wiki/F...DNA_RNA-EN.svg

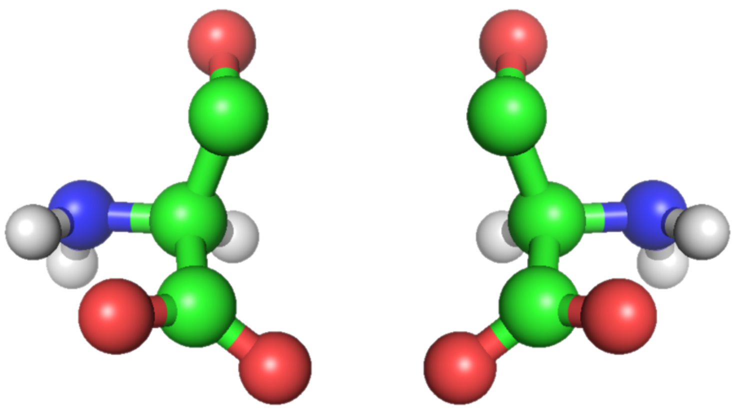
In addition, life as we know it requires water as the medium in which to conduct the chemical reactions necessary for life. Water is a **polar molecule**. Even though the molecule as a whole is neutral, the oxygen atom exerts a stronger pull on the electrons than the two hydrogen atoms. These means the shared electrons spend more time around the oxygen atom, giving it a slight negative charge while the hydrogen atoms have a slight negative charge. This **polarity** gives water is relatively high freezing temperature and makes it a powerful solvent. More substances dissolve in water than any other fluid. This makes water ideal as the medium for organisms to conduct their chemical reactions as well as for cells to use to take in nutrients and expel wastes.



Water is a polar molecule.

https://commons.wikimedia.org/wiki/F...poli_acqua.png

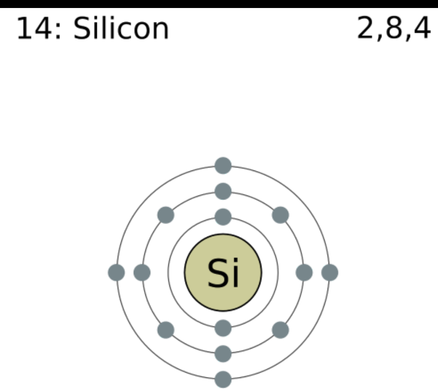
Finally, all life on Earth has the same **chirality** or "handedness." The amino acids used to build proteins all share the same left-handed orientation. Amino acids with right-handed orientation are mirror images of their left-handed counterparts. Molecules that are mirror images of each other are called **isomer**s. Scientists are not sure why left-handed amino acids came to be the basis for life on Earth. It is possible that on other planets, right-handed amino acids may be utilized.



Left and right-handed molecules are mirror images of each other.

https://commons.wikimedia.org/wiki/F...mino_acids.png)

So far, we have discussed the chemistry of life as we know it on Earth. What about alternative biochemistries? One staple of science fiction is life based on silicon instead of carbon. Silicon does have similar chemical properties as carbon, including the ability for up to four bonds with other atoms. However, silicon tends to form more rigid, crystalline molecules instead of the flexible organic molecules that carbon does. In addition, silicon is less likely to form complex chains like carbon does without large amounts of energy. In addition, some astrobiologists point to the fact that silicon is more abundant than carbon in Earth's crust. So, if silicon-based life were possible, it would have made use of the abundant silicon instead of the rarer carbon.



Silicon has some similar chemical properties to carbon.
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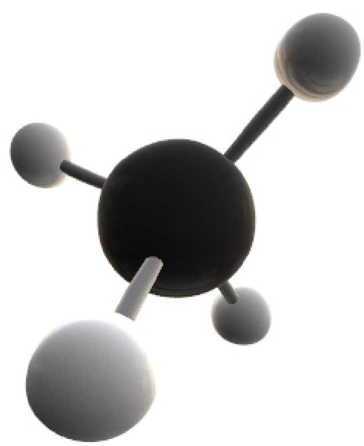
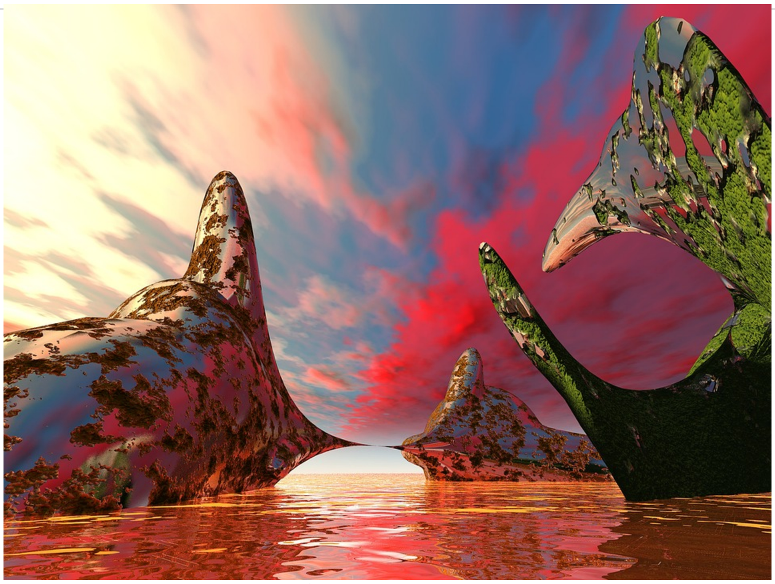


Methane and other hydrocarbons are abundant on Titan.

Methane_Molecule_3D_X.jpg https://commons.wikimedia.org/wiki/F...ecule_3D_X.jpg

Another possibility could be using fluids like ammonia or methane as the solvent instead of water. However, these fluids have much lower boiling temperatures than water, so any chemical reactions occurring in liquid methane or ammonia would happen very slowly, making active organisms like animals unlikely. In addition, methane lacks the polarity of water, making it a far less effective solvent.

15.3: Life Beyond Earth



What would life on an alien planet look like?

https:/pixabay.com/illustrations/alien-life-form-alien-planet-cosmos-3287912;

15.3.1 Life in Our Solar System

Are there any possible locations in our solar system outside of Earth where life may be found? Many scientists think that a few other worlds may be possible candidates to search for life. The four leading candidates are:

Mars: Today, Mars is a frozen desert with an atmosphere too thin to allow for liquid water to exist on the surface. Any liquid water released on the surface of Mars would quickly freeze or evaporate. However, our studies of Mars have found abundant evidence that Mars had a thicker atmosphere and warmer conditions and that liquid water flowed on the surface. Even though we have not found definitive evidence of life on Mars, it is possible that fossilized remains of microbes could be found on Mars. In addition, recent radar surveys have found evidence for liquid water beneath the surface. This water is likely heavily laden with salts that lower its freezing point, making it inhospitable to most life on Earth, but perhaps some extremophiles could still survive in these waters.

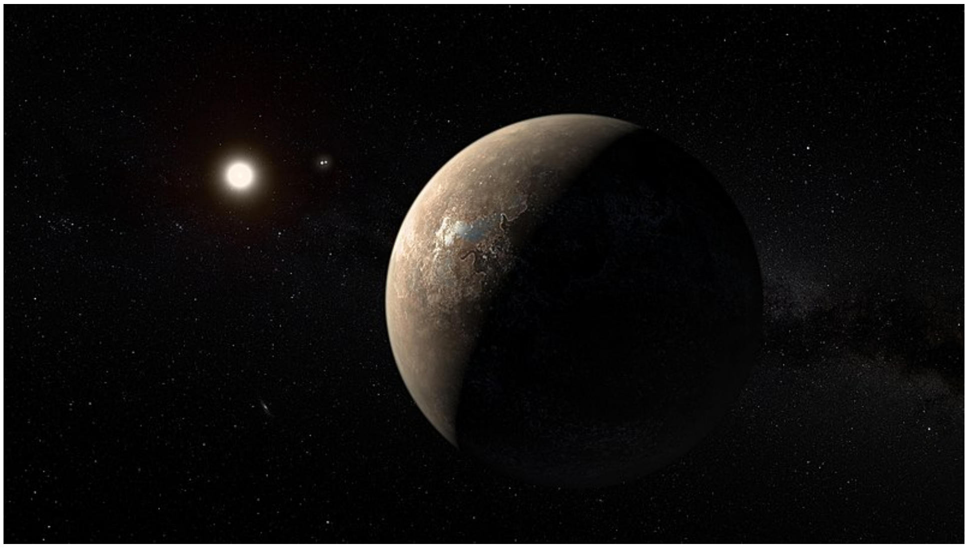
Europa: As noted in Chapter 12, tidal forces acting on Europa produce frictional heating and there is evidence of a liquid water beneath its icy crust. The tidal heating may not only melt some of its internal water, but it may also provide a source of energy to power life. These conditions might be conducive to extremophiles using a similar biochemistry as those found in volcanic sea vents in the deep oceans of Earth.

Enceladus: Like Europa, there is evidence of a liquid water ocean beneath the icy crust of Enceladus due to tidal heating. In addition, the Voyager probe found geysers of water erupting from the south pole of this moon of Saturn. So, while confirming the existence of life on Europa would require us to drilling through kilometers of ice, we could fly a probe close enough to take evidence of life in those geysers.

Titan: Saturn's largest moon is very cold, covered with "rocks" made of ice and cryovolcanoes of cold "lava" flows on the surface. However, it also has a thick atmosphere and pools of liquid hydrocarbons on the surface. It may be that some cold-loving extremophile microbes could find a way to surface in that environment.

When people think of aliens, they usually think of something like little green men. However, if life exists on any of the other planets or moons in the Solar System, it is most likely to be single-celled organisms. Multicellular organisms are very unlikely, and we can now confidently rule out the possibility of any intelligent life in the Solar System.

To find an intelligent alien species with which we may one day communicate, we will have to look outside our Solar System to the exoplanets. The biggest difficulty to communicating with alien life though, is the distances. The closest star to the Sun is Proxima Centauri, which is about 4 light years away. Recently, a potentially Earth-sized planet has been discovered around Proxima Centauri. However, any message we might send to aliens on this world is limited by the speed of light. That means, if we sent a message today, it would not reach Proxima Centauri until four years later. Then, it would take another four years for their reply to reach us. An eight-year gap in sending messages make meaningful communication difficult and that is our best case scenario.



Proxima Centauri B: A "super earth" has recently been detected around our closest neighboring star.

https://commons.wikimedia.org/wiki/F...uper-earth.jpg

As of 1 August 2018, there are 3,815 confirmed exoplanets in 2,853 systems, with 633 systems having more than one planet. The first exoplanets were found around exotic bodies like pulsars and most of the early exoplanets were “hot Jupiters,” gas giants orbiting close to their stars. That was a limitation of our early detection methods and limited data. These planets were easy to detect because their gravity caused a large “wobble” in the star’s movement.

Using Kepler and other telescopes, scientists now look for exoplanets based on the slight dimming of a star’s brightness as the planet transits in front of it. This enables us to infer the planet’s size, orbital period, and density. Today, the most common exoplanet discovered is a “Super Earth,” a planet between Earth and Neptune in size. As we gather and analyze more data, we expect to find more Earth-sized planets throughout the galaxy.

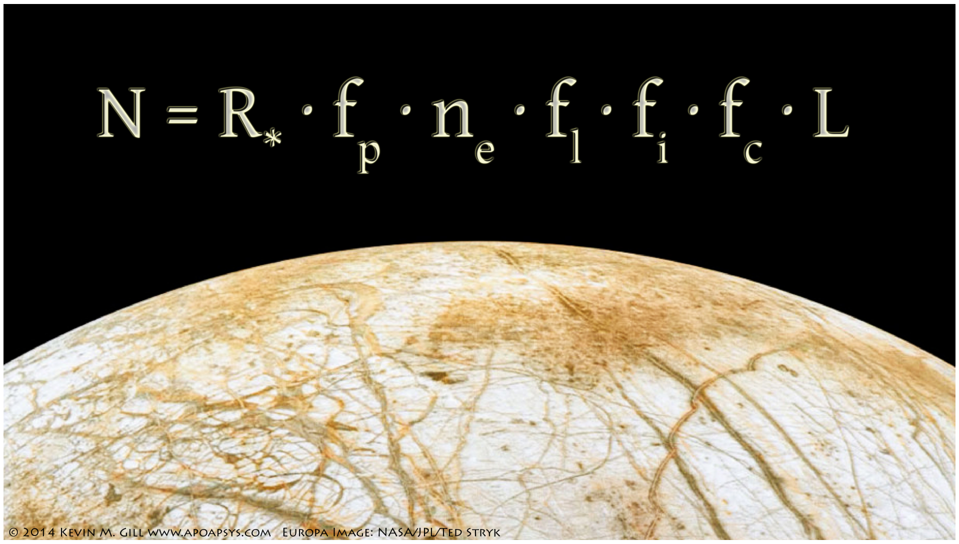
There are billions of stars in the galaxy and it now appears that most stars have planetary systems. Odds are good that there should be many planets in the “goldilocks zones” capable of supporting life. Therefore, the galaxy should be teeming with life.

But where should we look for it?

What are the best candidate stellar systems?

And what are the odds that there exists an alien civilization with which we can communicate?

15.3.2 Drake Equation



The Drake Equation

https:/commons.wikimedia.org/wiki/File:Europa_Rising_-_Drake_Equation_(14486519161).jpg;

The first attempt to estimate the probability of intelligent life in our galaxy was formulated by Frank Drake. The **Drake equation** is a series of estimates of factors that must be present for a long-lasting technological civilization to arise. Multiplying them together would give us an estimate of on the number of intelligent civilizations in the galaxy. These seven factors are:

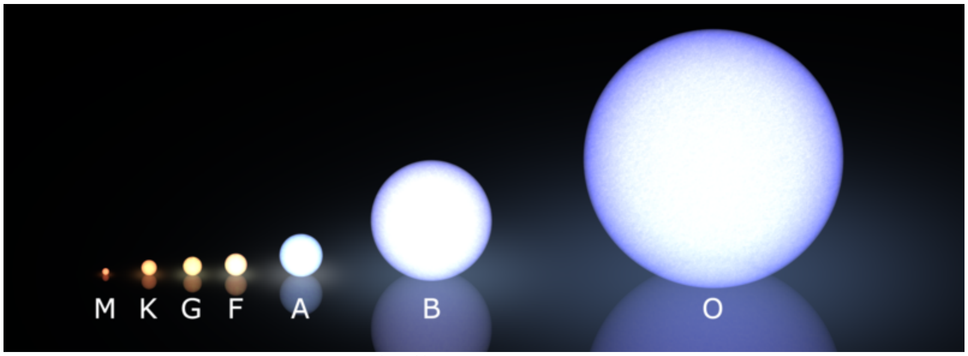
- R_* = The rate of star formation.
- f_p = Fraction of stars having planetary systems.
- n_e = Number of habitable planets per planetary system.
- f_l = Fraction of habitable planets where life emerges.
- f_i = Fraction of inhabited planets where intelligence emerges.
- f_c = Fraction of intelligent civilizations that develops and uses technology.
- L = The average lifespan of a technological civilization.

Since Drake originally proposed this equation in the 1960s, we have gained considerable information for the first couple of factors, but we still have almost no information about the remaining factors.

For example, we can estimate the rate of star formation by dividing population of Milky Way by its present age, giving us an average rate of star formation of about 10 new stars per year.

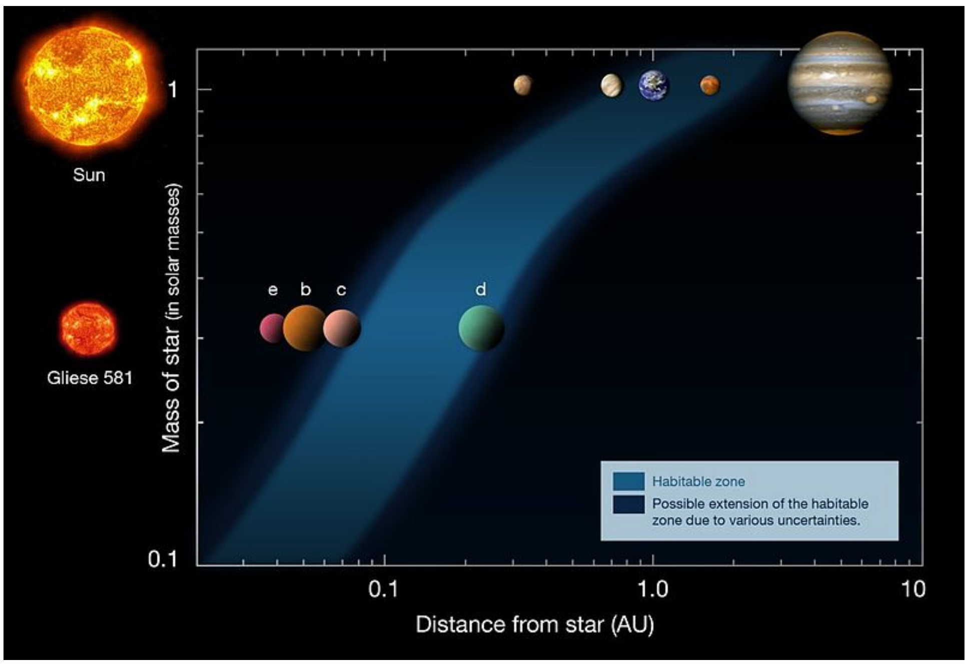
For the fraction of stars having planetary systems, we have detected thousands of planets around other stars. We have not surveyed the entire galaxy, but with the data collected so far and our current model for star formation lead us to expect that planets are a necessary by product of star formation. As a result, we expect most star systems to have formed planets as well. Therefore, we will assume that all stars have planets around them and assign this factor a value near 1.

The number of habitable planets per planetary system is a bit more difficult. Stars come in numerous sizes. The smallest detected star, SCR 1845–6357 A, has a mass of 0.084 times that of the Sun. The most massive star, R136a1, has a mass of 315 times that of the Sun. Smaller stars dimmer and emit less light, and as a result, have a too-small **habitable zone,** the orbital region around a star where temperatures can exist to allow for life as we know it. They also tend to poor in "metals," what astronomers call elements heavier than helium, which would be necessary for life. In addition, larger stars a too-short lifetime. While our Sun has an overall expected lifetime of about 10-15 billion years, the massive blue-white stars have lifespans of only a few hundred million years. Since the evidence indicates that life took around a billion years to first appear on Earth, these stars would be too short-lived for life to emerge on any of their planets. This would limit us to stars close to the Sun in mass, which are those classified as A-, F-, G-, and K-type stars (Our Sun is a G2 type star).



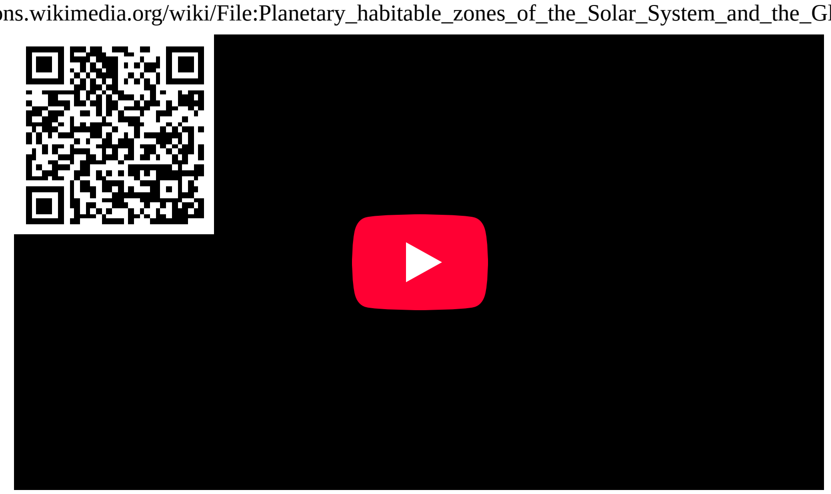
Stars of different sizes and masses.

https://commons.wikimedia.org/wiki/F...sification.png

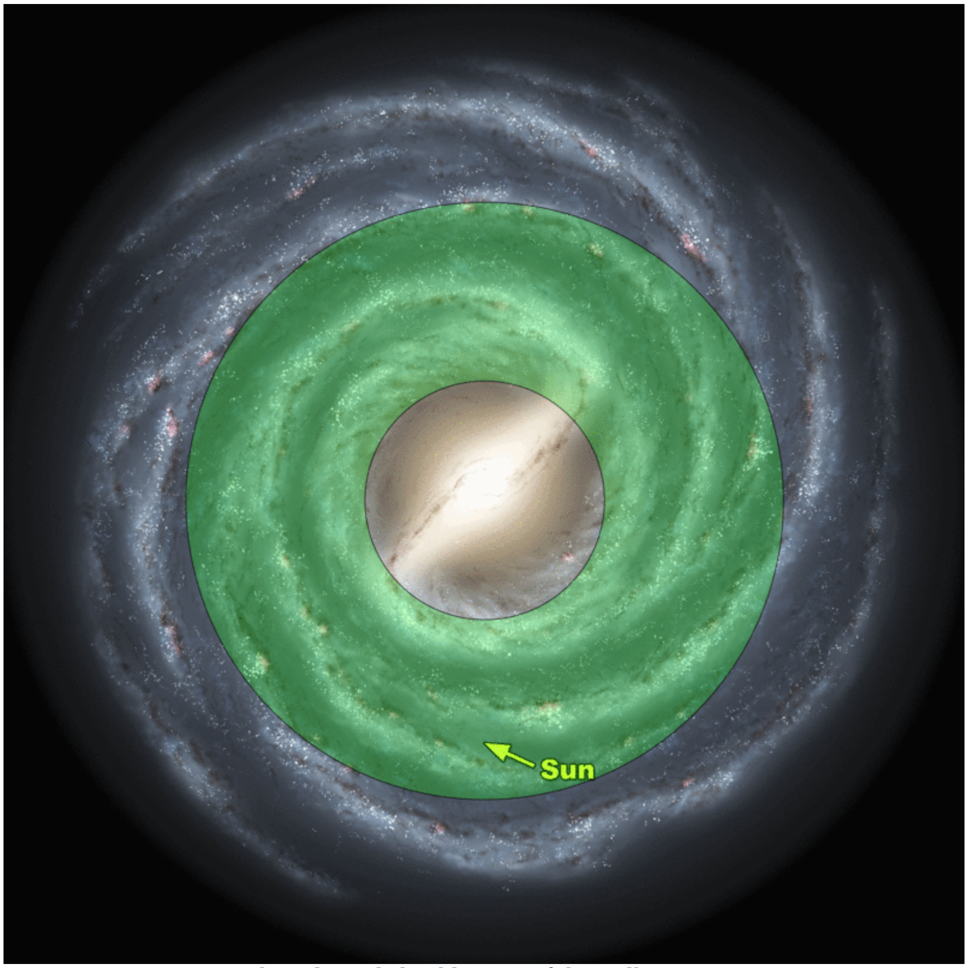


Planets around Gliese 581 and its possible habitable zone.

https:/commons.wikimedia.org/wiki/File:Planetary_habitable_zones_of_the_Solar_System_and_the_Gliese_581.jpg;



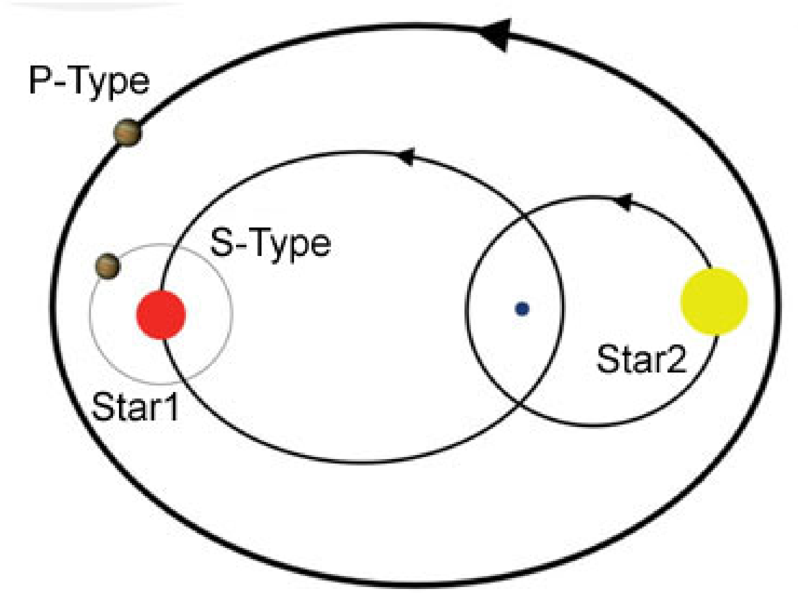
In addition, there are galactic habitable zones. Too close the galactic core and there is too much radiation. Too far away from the center and there will be too few of the heavier elements necessary for life.



The galactic habitable zone of the Milky Way.

https://upload.wikimedia.org/wikiped...table_zone.gif

Finally, we could probably eliminate binary star systems. It is very unlikely that a planet in a binary system would have a stable orbit unless it is extremely close to one star (an **S-Type orbit**), or very far away from both (a **P-Type orbit**). Either orbit would take it outside of the Goldilocks zone.



Planets orbiting a binary star system can orbit both stars at once (P-Type) or tightly around just one star (S-Type)

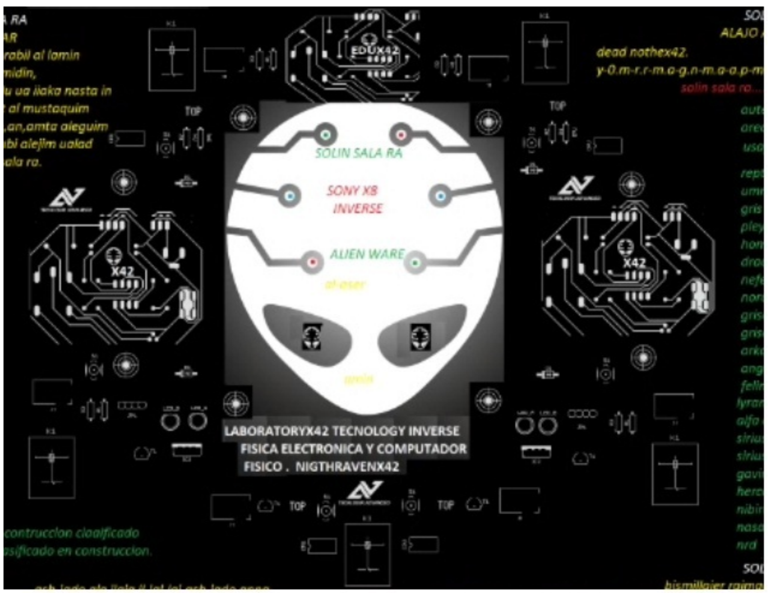
https://www.univie.ac.at/adg/schwarz...N/coorbin.html

As a result, we will give this factor a value of 1/10: one habitable planet in every 10 planetary systems.

We know nothing about the fraction of habitable planets on which life arises. Experiments like the Miller-Urey experiment suggest that this may be quite likely. However, we only have a sample size of one. We do not know if life is likely to emerge any where conditions are right for it to emerge. The fact that life appears able to get a toehold wherever it can on Earth and has endured through five mass extinction events, indicates that life may be common in the galaxy. As a result, we will continue to be optimistic and give this factor a value of 1.

For the fraction of life-bearing planets where intelligence arises, we have no facts, just speculation and opinion. There is no indication that intelligence is a necessary result of evolution and life on Earth existed for billions of years before our species appeared a mere 200,000 to 300,000 years ago. However, we will continue being optimistic, assume that life inevitably evolves wherever life appears, and assign this factor a value of 1.

Again, we have no facts about the next factor: the fraction of planets where intelligent life develops and uses technology. Also, we must consider that even though our species has been around for thousands of years, we only developed the technology to communicate over long distances around a century ago. Image an alien species sending us a message using radio waves that arrived here five hundred years ago, during the time of Galileo, no one would have heard it. However, it does seem reasonable to assume that intelligent life will develop technology sooner or later. So, we will give this factor a value of 1 also.



We don't know how many intelligent, technological civilizations exist in our galaxy.

https:/commons.wikimedia.org/wiki/File:Tecnologia_inversa.jpg;

Multiplying the values we have assigned to the first six factors gives us a result of:

10 X 1 X 1/10 X 1 X 1 X1 = 1

Therefore, using these optimistic assumptions, we can estimate that the number of intelligent, technological civilizations in the galaxy = the average lifespan of such a civilization. For this final factor, we cannot even use ourselves as an example: Our civilization has been technological for about 100 years, but who knows how long it will last? We could run out of energy or cause or civilization to collapse through war, global warming, or a plague within this century. Or we could discover solutions to these problems and have a technological civilization that lasts for thousands of years.

If the average lifetime of a technological civilization is 1 million years, there should be a million such civilizations in our galaxy. This would give us a galaxy teeming with civilizations! However, given the size of the galaxy, these civilizations would be spaced about 30 pc, or 100 light years, apart on average. This means that any two-way communication will take about 200 years (if there is in fact a technological civilization 100 light-years or less away from us). So, even with the most optimistic assumptions, the possibility of finding an alien civilization with which we may be able to communicate is very low.

Also, we assigned optimistic values to several very uncertain factors; even if only one of them is low, the number of expected civilizations drops quickly.

15.4: The Fermi Paradox and the Search for Extraterrestrial Life

15.4.1 Traveling to other worlds

The previous section discussed the possibility of communicating with extraterrestrial civilizations using conventional radio signals, but could we travel to other star systems and perhaps colonize other worlds. Science fiction stories often assume that some kind of faster than light (FTL) means of traveling will be discovered, enabling us to travel to other star systems in a matter of days. However, for the time being the speed of light remains the ultimate speed limit. We do not know of any means of traveling FTL. Using any of the means of propulsion known today, traveling to even the closest stars would take hundreds, if not thousands of years. This would require us to use multi-generation ships or find a way to cryogenically freeze humans and safely revive them once they arrive at their destination.

Where are the aliens?

https:/www.pickpik.com/alien-walking-on-pathway-ufo-guy-pozaziemianin-53615;

Consider the following thought experiment: An advanced civilization develops space travel technology that is just feasible enough to reach a nearby star. Traveling at less than 1/10th the speed of life, they could reach a star 5 light years away in about 500 years. Once at their new home, the people establish a colony, and within 500 years, they build two new ships and send them off to two different stars, each about 5 light years away from the colony. Each of those ships establish a colony, build two next ships, and send them off. Every thousand years, the number of new ships launched doubles, extending the reach of this interstellar civilization further away from their home world. How long would it take them to colonize every habitable planet in the galaxy?

This thought experiment assumes that there are habitable worlds separated by a mere five light years, but even taking into account only a 1 in 4 chance of there being a habitable world found after each 5 light year "hop," mathematical models indicate that such a civilization will have extended its travels to a distance of 130,000 light years from its home world in about 50 million years.

The Milky Way Galaxy is about 100,000-120,000 light years across. This means, in 50 million years, our space faring civilization will have colonized the entire galaxy.

This may seem like a long time, but the Milky Way Galaxy is over 13 billion of years old, older than our own Solar System. Fifty million years is a small fraction of 13 billion. In all that time, there should have been at least one galaxy-colonizing civilization that has venture out and taken over the galaxy.

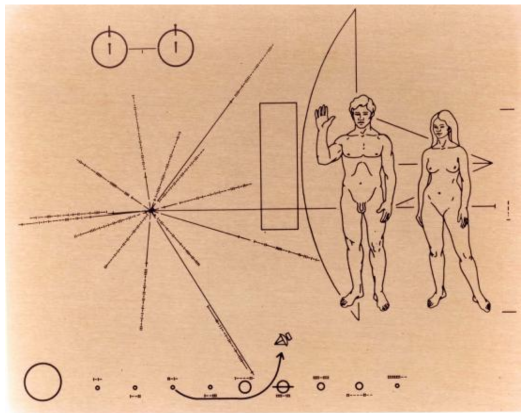
http://www.sentientdevelopments.com/2012/01/new-mathematical-study-reveals-that-our.html?m=1

So, where are they?

This lack of evidence of alien civilizations when mathematically, they should have already visited us, has been called the **Fermi Paradox**, after physicist Enrico Fermi. Even traveling at speeds slower than that speed of light and hopping from one star system to another every 1000 years, we would have expect an advanced alien civilization to reached our Solar System by now. On the other hand, even if the aliens did not travel to us, we should have detected their radio signals from any advanced alien civilization by now. After all, we have been sending our radio and television signals out into space for decades now. Why have we not picked out their signal? It could just be that the signals are too weak by the time they reach us that we cannot pick them up.

15.4.2 SETI

We have made a few attempts to reach out to alien civilizations. Both the Pioneer and Voyager probes carried a greeting with them. But it will be tens of thousands of years before any of them reach another star system, so we cannot expect a reply any time soon.



The Pioneer probes both carried this plaque as a greeting to alien civlizations.

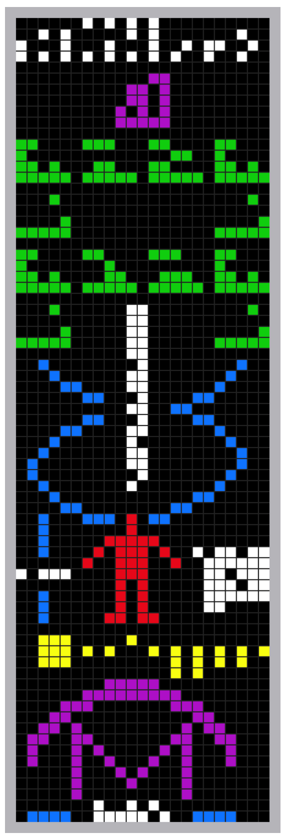
https:/pixabay.com/photos/pioneer-badge-pioneer-10-space-probe-11055;

We are also communicating—although not deliberately—through radio waves emitted by broadcast stations. These have a 24-hour pattern, as the Earth rotates, bringing different broadcast areas rotate into view. Any alien civilization within a few tens of light years away may have the technology to pick them up.

However, we have not made many attempts to deliberately send a signal to any aliens who might be listening. In 1973, the Arecibo Radio Telescope in Puerto Rico was used to transmit an image in binary code that some scientists hope could be decoded by aliens. This message was beamed into the direction of the globular cluster M13 and included pixels encoding the following:

- The numbers one (1) to ten (10) (white)
- The atomic numbers of the elements hydrogen, carbon, nitrogen, oxygen, and phosphorus, which make up deoxyribonucleic acid (DNA) (purple)
- The formulas for the chemical compounds that make up the nucleotides of DNA (green)
- The estimated number of DNA nucleotides in the human genome, and a graphic of the double helix structure of DNA (white and blue, respectively)
- The dimension (physical height) of an average man (blue/white), a graphic figure of a human being (red), and the human population of Earth (white)
- A graphic of the Solar System, indicating which of the planets the message is coming from (yellow)
- A graphic of the Arecibo radio telescope and the dimension (the physical diameter) of the transmitting antenna dish (purple, white, and blue)

Since then, however, no other significant attempts have been made.



This pixel message was sent out by the Arecibo Telescope as an attempt to greet alien civilizations in 1973.

https://commons.wikimedia.org/wiki/F...bo_message.svg

If we were to deliberately broadcast signals that we wished to be found, what would be a good frequency? One suggestion has to be transmit in the "water hole" around the radio frequencies of hydrogen and the hydroxyl molecule. This corresponds to frequencies between 1.42 and 1.67 gigahertz. The background is minimal there, and it has been where we have been focusing many of our searches for alien signals.

SETI, the Search for Extraterrestrial Intelligence, is a privately funded effort to search for alien signals. These include the radio the telescopes of Project Phoenix, designed to search for extraterrestrial signals. Still, besides a few false alarms, we have not found anything that could be described as an artificial signal from an alien civilization.

So, why have we not heard anything? There are a few explanations for the Fermi Paradox. There is no definitive answer, so we will discuss a few them below.

Everybody is listening, but nobody is sending.

https:/www.flickr.com/photos/
cwkarl
/9958455855;

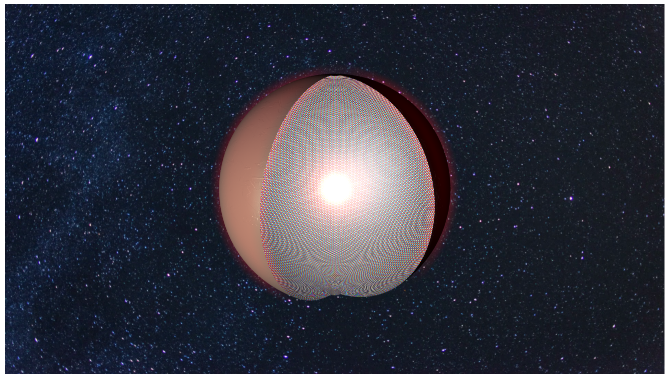
SETI is dedicated to listening for alien signals but is not actively sending out messages for extraterrestrials. Maybe the aliens are all doing the same. That might explain the absence of deliberate message but not any "leaked" messages from their own communications. Perhaps as we improve the sensitivity of our telescopes, such signals might be found.

The aliens have a non-interference rule.

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

This is a staple of science fiction, where advanced civilizations do contact less developed ones. In this scenario, aliens are observing us but are following a rule of non-interference so that they do not "damage" our culture. A related hypothesis is that they are treating us like zoo specimens. Could such a rule be enforced, especially if there are multiple, competing civilizations? What if a rogue actor decided to defy it?

We are looking in the wrong place.



Could aliens be living inside a Dyson sphere?

https://commons.wikimedia.org/wiki/F...in_cutaway.png

SETI has been focusing on frequencies in the "**Water Hole**" ~1.5 GHz where there is little background noise. What if the aliens are transmitting on a different set of frequencies? Or not sending out radio signals at all. Physicist Freeman Dyson suggested that a highly advanced civilization would need to capture virtually all of their sun's output. To do this, they would need to surround their star with a construct or swarm of solar plants. If such a Dyson sphere, as they have come to be called, existed instead of looking for radio signals, perhaps we should be looking for waste heat in the form of infrared radiation instead.

Space is big.

large-group-of-galaxies.jpg

In the previous section, we estimated that under a very optimistic set of assumptions, alien civilizations would be spaced an average of 100 light years away. We have only had radio technology for about a century, so if the aliens are more than 100 light years away, maybe their initial signals have not reached us yet. Such distances would also make it virtually impossible to ever visit them.

Advanced civilizations have a short lifespan.

How long can a technological civilization last before it destroys itself?

science-fiction-fantasy-weapons-ufo-warfare-female-warrior-future-mystery.jpg https:/www.pikist.com/free-photo-iptqh;

The truth is, we do not know how long technologically sophisticated civilizations last. If they have very short lives of few hundred years, they may be few and far between and never overlap.

Robots have replaced organic life.

What if robots have replaced organic life?

fantasy-alien-robot-futuristic-surreal-extraterrestrial.jpg https:/www.pxfuel.com/en/search?q=alien&page=5;

One reason technological civilizations might have short lives is because they were “replaced” by artificial intelligence. And now the robots see no reason to communicate with organic life.

They have retreated inwards.

https:/pixabay.com/illustrations/matrix-full-program-data-code-3145364;

This idea is that instead of looking outward to the stars, the aliens uploaded their consciousness into a computer simulation. In such a simulation, they could explore any kind of reality imaginable and have lost interest in the “real” universe. So, they are not interested in talking to us.

Intelligence is rare.

How common is intelligence in the galaxy?

the-thinker-rodin-paris-sculpture-preview.jpg https:/www.pickpik.com/search?q=thinking;

Life may be common, but intelligent life is rare. We tend to overvalue intelligence as it is our primary survival advantage, but the majority of species that have existed have gotten along fine without it.

Perhaps there are several filters, such as mass extinctions, that prevent intelligence from emerging. Considering the history of Earth and the numerous species that have gone extinct before homo sapiens evolved, perhaps we were just lucky to reach the level of intelligence we have. If we ever venture beyond our Solar System, perhaps will we find that on most worlds, life never evolved beyond the single cell stage.

We are like ants to them

We may be as far below the aliens as ants are to us.

https:/www.pickpik.com/wood-ants-hand-risk-disgust-ants-spooky-87431;

They are so advanced that we are beneath their notice. Communicating with us might be to them what trying to have a meaningful conversation with insects would be for us. They just operate on a level that is beyond our understanding and we have nothing to offer them.

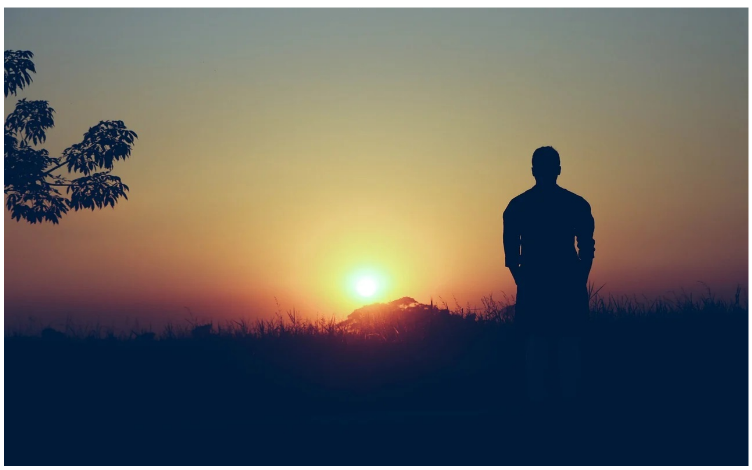
There is a conspiracy to hide them.

Are aliens already here and the government is hiding them?

600px-Conspiracy_Theories_Fallacy_Icon.png

This another staple of science fiction: Aliens have already been detected but the government is covering it up for some reason. This is probably unlikely, however. Despite the beliefs of numerous conspiracy theorists, governments are actually pretty bad at keeping secrets. The more people involved in a conspiracy to cover up something big like alien contact, the more likely someone will speak out or accidentally let the information slip out.

We are alone.



Are we alone in the galaxy?

https://pixabay.com/photos/alone-sad...onely-4672965/

Finally, we may have to face the possibility that life is rare. So rare, that it has only happened once in our entire galaxy.

Index

Glossary

Abiogenesis | The study of how life could emerge from nonliving matter.

Absorption Lines | Discrete wavelengths of Electromagnetic radiation that are removed from a continuous spectrum as photons are absorbed by an atom's elections.

Acceleration | The rate change of a velocity in magnitude and/or direction.

Adaptive Optics | A system that corrects for atmospheric distortion by deforming the mirror in a reflecting telescope.

Altitude | The measure in degrees of an object's position above the horizon.

Amplitude | The maximum height of a wave's crest.

Angular Momentum | The measure of an object's rotational motion.

Angular Size | The apparent size in degrees of an object in the sky.

Annular Eclipse | A solar eclipse in which the Moon's shadow is smaller than the Sun's angular size, resulting in a ring surrounding the Moon's shadow.

Antikythera Mechanism | A brass artifact that was used by the ancient Greeks for navigation and to calculate the position of the Moon, the planets, and stars for any given date.

Aphelion | The point in a planet's orbit that is furthest from the Sun.

Apollo Asteroid | An asteroid whose orbit crosses the Earth's orbital path.

Archeoastronomy | The study of astronomical practices of ancient peoples.

Asteroid | A small, rocky body in the solar system.

Asthenosphere | The uppermost region of Earth's mantle, consider of very soft or melted rock.

Astrobiology | The study of the origin, evolution, and future of life in the universe.

Atmospheric Probe | A probe that enters in the atmosphere of a planet or moon to gather data about the atmosphere.

Atom | The smallest particle that still possesses the chemical properties of an element.

Atomic Mass | The number of protons and neutrons in the nucleus of an atom

Atomic Number | The number of protons in the nucleus of an atom.

Aurorae (Northern and Southern Lights) | Currents of lights produced when charged particles interact with the atmosphere near the poles.

Autumnal Equinox | 1. One of two days in which the Sun's path across the sky intersects the celestial equator. 2. The first official day of autumn.

Azimuth | The measure in degrees of an object's position east or west of the celestial meridian.

Black Body | A hypothetical object whose thermal radiation is dependent only on its temperature.

Blueshift | The shortening of the wavelength of electromagnetic radiation caused by a source moving towards the observer.

Bright Zone | A light colored band on a gas giant where warm, light gases rise.

Celestial Equator | An imaginary circle produced by project the Earth's equator onto the celestial sphere.

Celestial Meridian | An imaginary arc running across the sky, connecting north and south points and passing through the zenith.

Celestial Sphere | An imaginary sphere surrounding the Earth in which the stars are embedded on its inner surface. Astronomers use the celestial sphere model to locate objects in the sky.

Center of Mass | A point in a system in which can be treated as if all of the mass were concentrated at that point. According to Newton's law of gravity, the Sun and a planet orbit around their common center of mass.

Charged Couple Device | An electronic device that converts the light from an image into an digital electronic signal.

Chirality | The "handedness" of certain molecules which are mirror images of each other.

Chlorofluorocarbons (CFCs) | A class of chemicals whose production has been phased out due to the effect they have on the ozone layer.

Chromatic Aberration | A rainbow-colored halo that forms around images due to different wavelengths of light being bent at slightly different angles by the lens of a refracting telescope.

Chromosphere | The slightly cooler region of the solar atmosphere above the photosphere.

Circum-Pacific Belt (Ring of Fire) | An arc of subduction boundaries and transform boundaries around the edge of the Pacific Ocean where 90% if Earth's volcanic eruptions and earthquakes occur.

Comet | A body of ice and rock originating in the Oort cloud.

Compound | A molecule consisting of atoms from two or more different elements.

Conduction | The transmission of heat through physical contact.

Constellation | Apparent groupings of stars in the night sky that astronomers use as convenient markers for location objects in the sky.

Constructive Interference | Interference between two waves that results in a magnification of their amplitudes, producing higher crests and deeper troughs.

Control Group | A group of experimental subjects in which the independent is not change. The control group is used as a point of comparison to the treatment group.

Convection | The transportation of heat through the movement of fluids.

Convection Cells | Regions in the troposphere where convection currents where warm, moist air rises and cooler, dry air sinks.

Convection Zone | Region in the solar interior where energy is primarily transported by convection.

Convergent Plate Boundary | A boundar where two tectonic plates are coming together.

Core | The central region of a planet or star.

Corona | The hot, outermost region of the solar atmosphere.

Coronal Mass Ejection | A large blob of hot plasma with a strong magnetic field ejected from the Sun.

Cosmic Rays | Charged particles from deep space.

Cosmology | The view and understanding of the universe.

Crater | A depression in the surface of a planet, moon, or asteroid resulting from an impact with another object.

Crest | The point of highest displacement in a wave's motion.

Crust | The outmost layer of Earth, consisting of low-density, brittle rock.

CubeSats | Small, light weight satellites used for low cost missions.

Dark Belt | A darker band on a gas giant where cooler gas is sinking.

Data | Numerical information collected during an experiment.

Daughter Product | The atom produces by certain nuclear reactions such as radioactive decay or nuclear fusion.

Declination | The measure in degrees of an object's position north or south of the celestial equator.

Deferent | A circular path around the Earth in a geocentric model.

Dependent Variable | A condition that changed in response to changing an independent variable and is measured during an experiment.

Destructive Interference | Interference between two waves that results in the dampening of the waves' amplitudes, producing smaller crests and troughs.

Deuteron | A particle consisting of one proton and one neutron.

Diffraction | The bending of a wave front around a barrier.

Diffraction Limit | The limit of a telescope's resolving power.

Dissociation | The separating of the atoms in a molecule.

Divergent Plate Boundary | A boundary where to tectonic plates are pushed apart by magma rising from the asthenosphere.

Doppler Effect | The change in frequency of a wave caused by the relative motion of the source and the observer.

Drake Equation | A series of estimates of factors that must be present for a technological civilization to survive. Used to estimate the number of civilizations in the galaxy.

Dwarf Planet | An object orbiting a star in an elliptical orbit with sufficient mass for gravity to force it into a spherical shape but not even mass to have cleared its orbital path of similar-sized objects.

Dynamo Effect | A effect produced by a rotating, molten conductor that produces a magnetic field.

Ecliptic | 1. An imaginary arc tracing the Sun's apparent motion across the sky. 2. The plane of the Earth's orbit around the Sun.

Electromagnetic Radiation | The transmission of energy through space by varying electric and magnetic field.

Electromagnetism | The force of attraction/repulsion between charged particles. Electromagnetism governs chemical bonds between atoms, electromagnetic radiation, electric fields, and magnetic fields.

Electron | An atomic particle that orbits around the nucleus of an atom and possesses a negative electric charge.

Element | A substance that cannot be chemically broken down into other substances and consists of atoms that all have the same atomic number.

Ellipse | A curve consisting of all points the sum of whose distances from two foci equal a constant.

Emission lines | Discret wavelengths of electromagnetic radiation produced when an atom's electrons drop from a higher energy state to a lower one by the emission of a photon.

Energy | The intangible phenomenon which can changes in an object's motion, temperature, or chemical phase; the capacity to do work.

Entropy | The measure of disorder in a system.

Epicycle | A circle the moves around the edge of a deferent in a geocentric model.

Equant | The central point in Ptolemy's cosmology in which all the objects in the universe revolve around it and the Earth is located slightly off-center from the equant.

Equinox | A day when the number of night time hours equals the day light hours.

Erosion | The weathering away and transport of particulate matter.

Escape Velocity | The velocity an object must achieve in order to escape a planet's gravity and travel out into the Solar System.

Exoplanet | A planet orbiting a star other than the Sun.

Extremophiles | Organisms that can survive in environmental conditions (temperature, salinity, radiation) that are too "extreme" for what most other organisms on Earth can tolerate.

Extrusive (Volcanic) Rock | A rock that formed when lava cooled on the surface.

Fermi Paradox | The Lack of Evidence of extraterrrestrial life despite the fact that mathematically, there should be numerous alien civilizations.

Flyby | A spacecraft mission in which a probe passes close to a planet to gather data and while it continues on its path.

Force | Any phenomenon that produces an acceleration in an object's motion.

Fossil | An imprint of or the lithified remains of a deceased organism left in sedimentary rocks.

Free Fall | Falling in response to no forces other than gravity.

Frequency | The number of wave crests that pass a specific point per second.

Frost Line | An imaginary line in the Solar System, inside of which it was too hot for water to condense into ice crystals during the Solar System's early formation.

Galilean Moons | The four larges of Jupiter's moons: Io, Europa, Callisto, and Gannymede, that were discovered by Galileo.

Gas Giant | A large Jovian planet consisting mostly of hydrogen and helium.

Geocentrism | A cosmological view that places the Earth at the center of the universe and all other objects, including the stars, the planets, the Sun, and the Moon revolve around it.

Geostationary Equatorial Orbit | An orbit in which the satellite remains over a fixed point above the equator.

Gravitational Lensing | The bending of the path of electromagnetic wave in response to the warping of spacetime due to a strong gravitational force.

Gravity | A force produce by the mass of an object. Every object with mass exerts a gravitation attraction on every other object.

Gravity Assist | A maneuver that uses the gravity of a planet to increase or decrease the velocity of a spacecraft.

Greenhouse Effect | The ability of certain gases in the atmosphere to trap heat energy in the troposphere, making the surface warmer than it otherwise would be.

Habital Zone | Regional zone around a star in which a planet could have temperatures that support life as we know it.

Half-life | The amount of time it takes half of a given quantity of a radioactive isotope to undergo radioactive decay.

Heat Death of the Universe | The point in the future where the entire universe reaches maximum entropy and there will no longer be any energy available to do work.

Heliocentrism | A cosmological view in which all of the planets revolve around the Sun.

Heliopause | The boundary between the influence of the Sun's magnetosphere and the magnetic field of the galaxy.

Hohlman Transfer Orbit | An elliptical orbit that carries a probe from one planet to another in the most fuel efficient manner.

Horizon | The line where the Earth's surface appears to meet the sky. All points located 90 degrees from the zenith.

Hot Jupiter | A gas giant exoplanet orbiting very close to its companion star.

Hydroponics | The growing of plants in water without soil.

Hypothesis | A possible explanation for a phenomenon that can be subjected to testing through the scientific method.

Ice | Compounds which have relatively low freezing temperatures, such as water, methane, and ammonia.

Ice Giant | Jovian planets that contain large quantities of ices.

Igneous Rock | A rock that forms when magma cools and solifidies.

Impactor | A probe that gathers data as it is deliberately crashed onto the surface of a planet or moon.

Interference | The interaction between two waves.

Interferometry | The practice of using multiple telescopes to improve resolving power.

Intrusive (Plutonic Rock) | An igneous rock that formed when magma cooled slowly beneath the surface.

Ion Engine | A propulsion system that produces thrust by heating up a gas into a plasma state and ejecting charge particles.

Ionosphere | The uppermost region of Earth's atmosphere where gases are ionized by solar radiation

Iron-Sulfide World Hypothesis | The hypothesis of the origin of life in which life originated in hydrothermal vents on the ocean floor.

Isomers | Molecules that have the same chemical formula but are mirror images of each other, i.e., they have opposite handedness or chirality.

Isotope | An atom of the same element but has a different atomic mass, i.e., a different number of neutrons.

Jovian Planet | A large planet consisting mostly of gas or icy materials that lacks a solid surface.

Kepler's Laws | Three laws that describe the orbit motion of planets around the Sun as ellipses.

Kinetic Energy | Energy of motion.

Kirchoff's Laws | Laws that describe the emission and absorption of electromagnetic radiation by matter.

Kuiper Belt | A region beyond the orbit of Neptune where numerous dwarf planets and other icy/rocky bodies orbit the Sun.

Kuiper Belt Object | Any body of ice or rock orbiting in the Kuper Belt, also known as Trans-Neptunian Objects.

Lagrange Point | A point in which the gravity of two bodies where their mutual gravitational attraction produces a zone of stability where objects can maintain the same relative position relative to both bodies.

Lander | A probe that lands on the surface of a planet or moon to gather data for an extended period of time.

Late Heavy Bombardment | A period between 4.1 and 3. 8 billion years ago in whicn there were numerous planetismals which collided with planets and moons. The period during which most of the Moon's craters formed.

Latitude | The measure of degrees north or south of the equator.

Launch Window | The period of time when planets make their closest approach, affording the shortest transfer orbit for sending a spacecraft from one planet to another.

Lava | Magma that has been released to the surface by a volcano.

Lava Dome | Pancake-like formations caused by magma flows that caused the surface to distend and then collapsed when the magma withdrew.

Laws of Thermodynamics | The laws that describe the interaction between heat and motion in a system.

Light-Gathering Power | The amount of light a telescope's primary mirror or lens can collect.

Lithosphere | The upper most portion of Earth's mantle combined with the crust.

Long Period Comet | A comet with an orbital period greatr than 200 years.

Longitude | The measure of degrees east or west of the prime meridian.

Longitudinal Wave | A wave in which the motion of the medium is parallel to the motion of the wave front.

Low Earth Orbit | An Earth-centered orbit near the planet, often specified as having a period of 128 minutes or less and an eccentricity less than 0.25.

Luminosity | The total energy radiated by an object.

Lunar Eclipse | An eclipse in which the Moon passes throught the Earth's shadow.

Magma | The hot, molten form of rock.

Magnetic Sail | A electrically charged propulsion system that uses the solar wind to generate thrust.

Magnetosphere | The region surrounding a planet or star dominated by its magnetic field.

Manipulative Experiment | An experiment in which the independent variable is changed in a laboratory.

Mantle | A thick layer of soft, low density rock between the Earth's core and its crust.

Maria | Large, dark and flat areas on the Moon.

Mass | The measure of the amount of material substance in an object.

Maunder Minimum | A period in the 1600s and 1700s when there was unusually low sunspot activity.

Megalith | A large stone structure built by ancient people.

Mesosphere | The region of Earth's atmosphere between the stratosphere and the ionosphere.

Metal | In astronomy, metals are any elements heavier than hydrogen and helium.

Metallic Hydrogen | Hydrogen gas that has been subjected to enough pressure to allow its electrons to move freely, giving it metallic properties, such as being a good conductor of heat and electricity.

Metamorphic Rock | A rock whose crystaline structure has been altered by heat and/or pressure.

Meteor | A streak of light in the sky caused by a meteoroid enters the atmosphere. Also known as a shooting star.

Meteor Shower | A event where numerous meteors fall through the sky at once.

Meteorite | A piece of a meteoroid that survives entry in the atmosphere and reaches the ground.

Meteoroid | A small rocky body in space, generally smaller than an asteroid.

Mineral | An element or compound with a crystalline structure, a specfiic chemical composition, and distinct set of properties.

Molecule | Two or more atoms bonded together.

Momentum | The measure of an object's motion.

Moon | A rocky or icy body that orbits another planet or dwarf planet.

Nebula | An interstellar cloud of gas and dust.

Nebular Theory | The model describing the origin of the Solar System as beginning with the collapse of a nebula.

Neutrino | Very low mass, weakly interacting subatomic particles produced in nuclear fusion reactions.

Neutron | A particle found in the nucleus of an atom that posseses no electric charge.

Newton's Law of Gravity | The law describing the gravitational attraction between two objects that posses mass.

Newton's Laws of Motion | Three laws describing the motion of object in an inertial frame of reference.

North Celestial Pole | An imaginary point in the sky around with all the constellations in the northern hemisphere rotate. For an observer standing on the north pole, the north celestial pole is located directly overhead.

North Star | A star known as Polaris that is located close to the celestial north pole and in the constellation Ursa Minor.

Nuclear Fusion | The combining of two or more light atomic nuclei into a heavier nucleus.

Nucleus | The central mass of an atom containing protons and neutrons.

Observation Science | A scientific method of studying large or complicated natural phenomena through making field observations.

Oort Cloud | A swarm of cometary bodies in interstellar space that surrounds the Solar System between 2,000 and 200,000 AU from the Sun.

Orbital Velocity | The necessary velocity an object must accelerate too in order to leave the surface of a planet and achieve orbit around it.

Orbiter | A probe that travels to another planet and places itself in orbit to engage in mapping and other extensive observations.

Ozone Hole | A portion of the ozone layer located above Antarctica where the concentration of ozone is lower than normal due the release of CFCs.

Ozone Layer | The region in the stratosphere with a high concentration of ozone.

P-Type Orbit | An orbit around a binary star system in which the planet orbits very far around both stars.

Pangaea | A supercontinent in which all of Earth's land masses were combined that existed between 335 million and 175 million years ago.

Panspermia | The hypothesis that life was "seeded" on Earth by asteroids and/or comets delivering microorganisms from space.

Parallax | The apparent change in position of objects against a more distant background.

Partial Eclipse | An eclipse in which either the Sun or the Moon is only partially covered by a shadow.

Penumbra | The lighter, outer region of the Moon's shadow that produces a partial solar eclipse.

Perihelion | The point on a planet's orbit that is closest to the Sun.

Period | The time between two successive wave crests.

Photon | A particle of electromagnetic energy.

Photosphere | The visible, granulated region above the Sun's convection zone.

Planet | An object that orbits a star in an elliptical orbit that has sufficient mass for gravity to force it into a spherical shape and has cleared its orbital path of any similar-sized objects.

Planetary Rings | Formations of millions of particles of ice and rock orbiting around a planet that, from a distance, appear like ringlike structures.

Plasma | Gas that as become ionized in which the electrons have been freed from their orbits around the nuclei.

Plate Tectonics | The theory that Earth's crust consists of several moving pieces called tectonic plates.

Polar Molecule | A molecule which has an uneven distribution of electric charge even though it still is neutral as a whole.

Positron | The anti-matter counterpart of the electron which possess a positive electric charge instead of the negative electric charge that an electron has.

Potential Energy | Energy of position or that is stored.

Pressure Waves (P-waves) | Longitindinal seismic waves.

Prime Meridian | An imaginary line running north to south and passing through Greenwich, England.

Protocells | Cell-like structures formed by phospholipid molecules coming together into membrane-like formations.

Proton | A particle found in the nucleus of an atom that has a positive electric charge.

Proton-Proton Chain | The process by which hydrogen nuclei are fused into helium nuclei in the core of the Sun.

Quantized | Existing in discrete states instead of a continuum.

Radiation | The transmission of heat or energy through space by electromagnetic radiation.

Radiation Zone | The region in the solar interior where energy is transported by radiation.

Radiative Energy | Energy produces from electromagnetic radiation.

Radioactive Decay | The spontaneous transformation of an unstable isotope by emitting particles and/or electromagnetic radiation.

Radioisotope | An isotope of an element that is unstable an undergoes radiactive decay.

Radiometric Dating | The use of radioactive decay to calculate the age of a rock by measuring the ratio of a radioisotope and its daughter product.

Redshift | The increase in the wavelength of electromagnetic radiation caused by source moving away from the observer.

Reflecting Telescope | A telescope that uses a curved mirror to gather light from distant objects and produce a magnified image.

Refracting Telescope | A telescope that uses a pair of lenses to gather light from distant objects and produce a magnified image.

Refraction | The bending of light waves as it passes from one medium to another.

Regolith | Dust and pulverized minerals on the surface of a planet or moon left behind by an impact.

Resolving Power | The ability to distinguish between two distinct objects.

Retrograde | The apparent backward motion of planets against the background stars.

Right Ascension | The measure of an object's postion in hours, minutes, and seconds from the ecliptic on the vernal equinox.

RNA World Hypothesis | The hypothesis of the origin of life in which the first self-replicating molecules were RNA instead of DNA.

Rock | A solid aggregation of minerals.

Rock Cycle | The heating, cooling, weathering, melting, and reassembling of minerals into different kinds of rocks.

Rocket | A projectile propelled by burning solid or liquid fuel.

Rover | A lander with wheels or trends, enabling it travel on the surface of a planet or moon.

S-Type Orbit | An orbit around a binaary star system in which the planet orbits close to one of the stars.

Satellite | A natural or artificial object orbiting another object in space.

Scalar | A quantity consisting of a magnitude without any direction.

Scarps | Long cliffs on the surface of Mercury that formed as the planet cooled and contracted.

Scientific Method | A formalized process of gaining knowledge about the natural world through observation, testing, and analysis.

Sedimentary Rock | A rock that formed when sediments are pressed or cemented together.

Sediments | Particles of minerals produced when rocks are weathered by wind, water, or other forces.

Seismic Waves | Waves that are produced by earthquakes or other seismic activity.

SETI (Search for Extraterrestrial Life) | An organized effort to search for signals from extraterrestrial civilizations.

Shear Waves (S-waves) | Transverse seismic waves.

Shepherd Moons | Moons whose gravity "shepherds" particles in orbit around a planet, keeping them in planetary rings.

Short Period Comet | A comet whose orbital period is less than 200 years.

Sidereal Day | A measure of the Earth's rotation based on the position of the stars in the sky from one night to the next.

Sidereal Month | The amount of time it takes the Moon to make one complete orbit around the Earth.

Sidereal Year | The measure of the Earth's orbit around the Sun relative to the constellations.

Solar Day | A measure of the Earth's rotation from noon one day to noon on the next.

Solar Eclipse | An eclipse in which the Moon passes between the Earth and Sun and blocks the Sun's light.

Solar Flare | An explosion on the surface of the Sun that emits X-rays and charged particles.

Solar Prominence | A large sheet of ejected gas from the sun that last for several days or weeks.

Solar Sail | A propulsion system that using a material with a high surface area to mass ratio and uses light pressure from the Sun's rays to produce thrust.

South Celestial Pole | An imaginary point in the sky around with all the constellations in the southern hemisphere rotate. For an observer standing on the south pole is located directly overhead.

Space Elevator | A hypetical means of bringing objects into orbit from the surface by means of a long tether.

Spectroscope | A device that can separate light into its component wavelengths.

Speed | The rate change of motion of an object.

Spontaneous Generation | A now-discredited hypothesis to explain how living cells are spontaneously produced from nonliving matter.

Stratosphere | The region of the atmosphere above the troposphere and contains the ozone layer.

Strong Nuclear Force | The short-range force that holds quarks together into the protons and neutrons in the nuclei of atoms.

Subduction | The sliding of a section of oceanic crust underneath a continental crust at a convergent plate boundary.

Summer Solstice | 1. The day on which the Sun's position in the sky at noon on each day stops moving higher in the sky and starts moving down again. 2. The first official day of summer.

Sunspot | A dark region on the surface of the sun that is slightly cooler than the surrounding photosphere.

Superearth | An exoplanet intermediate in size between that of Earth and Neptune.

Synodic Month | The amount of time it takes the Moon to go through a complete set of phases, for example, from full moon to the next full moon.

Tectonic Plate | A piece of Earth's crust that moves due to convective forces in the asthenosphere.

Temperature | The average kinetic energy in the particles of a system.

Terraforming | The altering of a planetary astmosphere and surface to create more Earthlike conditions where Earth like could survive without artificial life support.

Terrestrial Planet | A small planet consisting mostly of rocky or metallic material.

Thermal Energy | The collective kinetic energy of all the particles in a system.

Thermal Radiation | Electromagnetic radiation emitting by the thermal energy of a system.

Tides | The twice daily rising and falling of Earth's oceans due to the influence of gravity from the Moon and the Sun.

Torque | The produce of force distance the distance from the point of rotation.

Total Eclipse | An eclipse in which either the Sun or the Moon is complete covered by a shadow.

Transform Plate Boundary | A boundary where two tectonic plates are sliding against each other.

Transit | The period in which an exoplanet passes in front of the face of its companion star.

Transverse Waves | Waves in which the motion of the medium is perpendicular to the motion of the wave fronts.

Treatment Group | A group of experimental subjects in which the independent variable is changed in order measure the change in the dependent variable.

Trojan Asteroid | An asteroid in the L4 or L5 Lagrange point of a planet's orbit.

Tropical Year | A measure of the Earth's orbit using the seasons, such as from one vernal equinox to the next one.

Troposphere | The lowest region of the atmosphere. On Earth, the troposphere ranges from the surface to approximate 13 km above sea level.

Trough | The point of lowest displacement in a wave's motion.

Umbra | The darker, central region of the Moon's shadow that produces a total solar eclipse.

Uplift | The raising up of mountains as two continental plates collide at a convergent plate boundary.

Van Allen Belts | Two regions around Earth where charged particles from the solar wind are trapped.

Vector | A quantity that consists of both magnitude and direction.

Velocity | The rate change of motion of an object in a specific direction.

Vernal Equinox | 1. One of two days where the Sun's path across the sky intersects with the celestial equator. 2. The first official day of spring

Volcanism | The eruption of molten rock onto the surface.

Water Hole | A radiowave frequency ~1.5 GHz where there is little background noise that is a focus by SETI's efforts to look for alien signals.

Wave | The transmission of energy through a medium without the transportation of matter.

Wavelength | The distance between two successive wave crests.

Weak Nuclear Force | The short-range force that governs certain forms of radioactive decay, such as beta decay.

Weight | The measure of the graviational force an object experiences.

Winter Solstice | 1. The day on which the Sun's position at noon on each day stops moving lower in the sky and starts moving back up again. 2. The first official day of winter.

Work | Any change in an object's position due to an external force.

Zeeman Effect | The splitting of spectral lines due to a strong magnetic field.

Zenith | The point in the sky directly over head of the observer.

Zodiac Constellations | The group of twelve constellations located close to the ecliptic that the Sun appears to "pass through" throughout the course of a year.

Zonal Flow | The rising and falling of gases in different colored bands of a gas giant due to differences in temperature.

Glossary

Sample Word 1 | Sample Definition 1

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