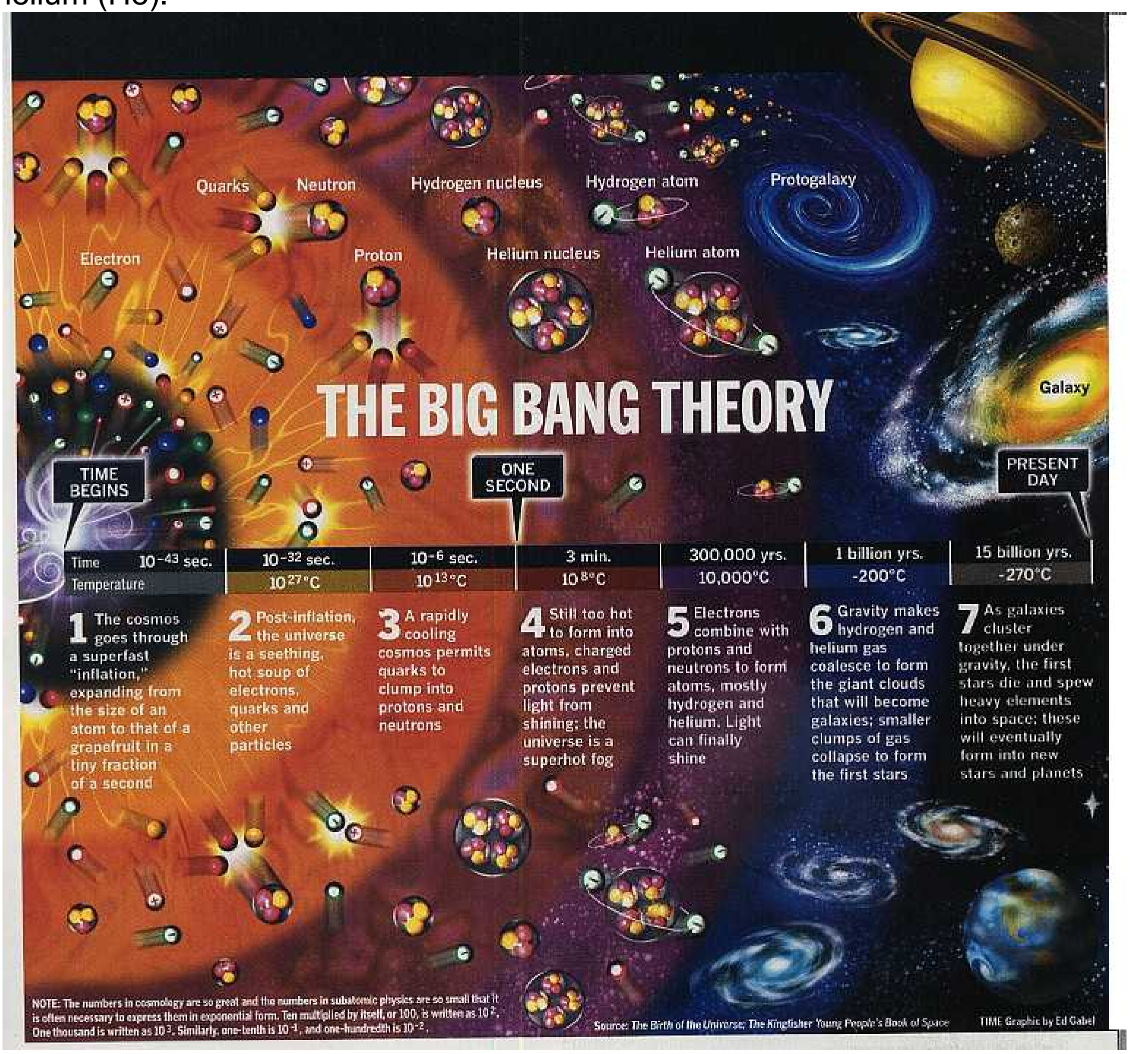
Key Content Summary - Astronomy

(These summaries are works in progress and are subject to change at anytime. They are intended to help provide core information and basic understanding allowing students to spend more time investigating areas of interest at greater depth.)

The Universe

Let's begin with, well the beginning --- [the **Big Bang**] – the theory of the formation of the universe some 13.7 billion years ago. Not an actual explosion but an immensely rapid expansion. Start with all the mater in the universe (before it was actually matter) shrunk down to about one billionth the size of a proton, we call this a **singularity**. Then in a fraction of a second it expands to something billions of light years across! Out of this rapid expansion the fundamental forces of nature appear: gravity, electromagnetism and strong and weak nuclear forces are formed along with subatomic particles. These subatomic particles began to combine forming the lightest elements: hydrogen (H) and helium (He).



About a billion years later, after the universe had cooled, the force of gravity, that force of attraction between all matter with mass, began to cause the clouds of hydrogen and helium to coalesce, to come closer together, eventually forming galactic clouds and the first stars. And thus the life cycle of star formation and death had begun. In this process lighter elements are fused into heavier elements in the cores of stars and during their explosive deaths, giving rise to the elements we see around us today.

Approximately 9 billion years after the big bang (about 4.6 billion years ago), in a process that had been repeated innumerable times, a nebular cloud of dust and gas, the remains of a previous star that had exploded in a supernova, began to contract under the force of gravity. As the process continued a section of the cloud flattens and begins to spin. Approximately 99% of the material, mostly hydrogen and helium coalesces to form a star. The remaining material, in what is called an accretion disk, begins to form planets. A typical process called the **nebular hypothesis** has repeated itself again, only this time on a rocky planet third from the star, the process takes a special twist. Through billions of years of gradual evolution and sometimes cataclysmic events, the atoms that were once a part of that nebular cloud have now formed into something uniquely you.

Today we know that the universe is filled with hundreds of billions of galaxies each with hundreds of billions of stars. Our own Milky Way galaxy might hold as many as 400 billion stars. However we are just beginning to explore and learn about our universe and the amount we don’t know is far greater than what we do know.

Changing Theories:

Through meticulous observations of those little specs of light in the sky our knowledge of the universe and our solar system developed. Advances in technology often brought new discoveries and challenged existing theories about its formation, organization and fate.

It is easy to understand how early views placed the **Earth at the center (geocentric**). This theory, often accredited to Ptolemy, persisted until the 16th and 17th centuries when the work of Copernicus, Kepler and Galileo changed the accepted theory from a geocentric view (Earth at the center) to **Heliocentric (sun at center)**.

In the 20th century our concept of the origin, size and composition of the universe was radically changed by the work of individuals like Einstein, Lemaitre, Hubble, Hoyle, Wilson, Penzias and many others. Their work and the advances in technology allowed us to “peer” into the vast distances of space and look back in time to almost the beginning of it all.

Now we are challenged with new theories of dark matter and dark energy, these unknown entities that seem to make up 95% of the universe.

Aristotle (~350 BC) determined the **Earth to be round** because it cast a curved shadow on lunar eclipses.

Eratosthenes (~250 BC) calculated the **circumference of the Earth** using a little math and a well in Syene.

Hipparchus (~150 BC) **catalogued 850 stars,** calculated the year to within minutes, measured the distance to the moon and predicted lunar eclipses to within a few hours.

Greek astronomer **Ptolemy** (AD 141) presented a model of the universe with a motionless earth at the center (**Geocentric**). This view lasted for many centuries.

Copernicus (~1500) after the Middle Ages, proposed the **Heliocentric** (sun at the center) model and stated that the Earth was just a planet like the others known at that time.

Tycho **Brahe** – (1546-1601) made **20 years of precise observations** of planetary motions.

Johannes **Kepler** – (1571-1630) used Brahe's measurements to develop 3 laws of planetary motion. He found that **planets move in ellipses** (oval-shaped) paths around the sun; they move faster when closer to the sun and there is a mathematical relationship between distance from the sun and period of revolution.

Galileo Galilei – (1564-1642) described the **behavior of moving objects**. Using a telescope discovered 4 satellites (moons) orbiting Jupiter showing that other objects could be a center of revolution, added evidence supporting the Heliocentric view. He also observed phases of Venus and craters/mountains on the surface of the moon.

Isaac **Newton** – (1642-1727) is noted for the **law of universal gravitation**: Every body in the universe attracts every other body with a force proportional to their masses and inversely proportional to the square of the distance between them.

Albert **Einstein** - (1879-1955) noted for his theory of general relativity which depicted gravitational forces as causing the curvature of spacetime. This theory helps to explain black holes, the bending of light and the expansion of the universe. Also and probably more famously known for his equation $E=MC^2$.

Edwin **Hubble** - (1889-1953) changed the understanding of the universe by confirming the existence of other galaxies and noting the red shift of galaxies indicating that they are moving away. Hubble's Law - the degree of red shift is proportional to the distance (galaxies farther away are moving faster).

Robert **Wilson** and Arno **Penzias** - (1936- ,1933-) using the Bell Laboratory's radio telescope identified static noise as the cosmic background radiation from the big bang.

<u>Distance in Space:</u>

While we understand that the universe contains billions of galaxies each containing billions of stars, it is often difficult to comprehend that space, like matter, is comprised of mainly empty space. Because of the enormous distances between objects it is impossible to create scale models which represent both size and distance. For example if our solar system were the size of a quarter, the Milky Way would be the size of the continental United States.

In the movies we often see spaceships streaking across the universe, visiting far away stars and distant galaxies, however our understanding of current space travel makes that unlikely. After 34 years of travel the Voyager space craft has only reached the edge of the heliosphere, about 120 AU from the Sun. At that speed it would take it another 12,500 years to reach the edge of our solar system (the Oort cloud) and you'd still be very far from anything else. Even if spacecraft could travel at the speed of light (186,000 miles per second) it would take 100,000 years to cross our galaxy and 2 million years to reach Andromeda, the next major galaxy.

Astronomical Unit (AU) the distance between the Earth and the Sun (~150,000,000 km; 93 million miles). Used to measure within a solar system.

Light Year (ly) the distance light travels in 1 year (9.46 trillion km; 5.9 trillion miles). A common measure used for distance to other stars.

Parsec (pc) is 3.26 light years. A more scientific measure used for galaxies and beyond.

Megaparsec (Mpc) is 1,000,000 parsecs.

Review the classroom presentation on distances in space

Galaxies:

At some point maybe 500 million to a billion years after the big bang, the universe cooled and clouds of hydrogen and helium gases formed. Gravity interacting with these clouds resulted in the formation of the first galaxies and stars. Today we estimate there to be as many as 400 billion galaxies.

Galaxies are generally classified by their shape: irregular, elliptical, and spiral.

- Irregular galaxies do not have a defined shape, contain clouds of dust and gas, and actively form new stars.
- Elliptical galaxies have an oval shape, are older, contain less dust and gas and therefore fewer stars are forming now.
- Spiral galaxies have spiral arms, contain clouds of dust and gas, and actively form new stars.

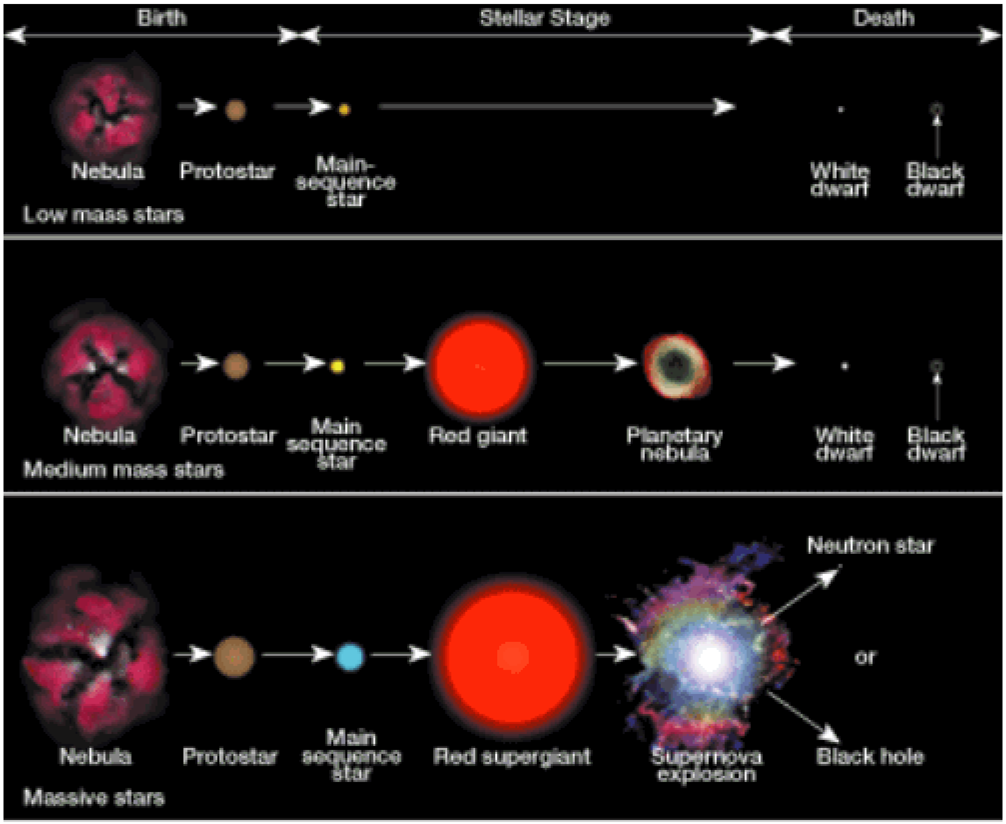
Our Milky Way galaxy is a spiral galaxy and our solar system is located on a spiral arm about ⅔ the way out from the center (approximately 30,000 light years).

The center of galaxies contain the galactic nuclei; a glowing center comprised of many stars closer together, although still quite far apart, and often a super massive black hole. Black holes are regions of space where the force of gravity, caused by extremely compact mass, is so strong that even light can not escape it. Although its interior is “invisible” we can detect their interactions with other matter. There is no fear of runaway black holes swallowing up the galaxy because the force of gravity weakens quickly with increased distance from the black hole.

All galaxies rotate about their centers, this rotation is similar to the revolution of planets around the sun. This angular force balances the force of gravity and prevents the galaxy from collapsing into the center. Galaxies also move in other ways. In general all galaxies are moving away from all other galaxies and the further away they are the faster they are moving (Hubble’s Law). A few galaxies are actually moving towards and will or are colliding with the Milky Way.

Stars:

Born from the contraction of nebular clouds (the remains of previous stars), a star becomes a star when it is hot enough to begin nuclear fusion of hydrogen into helium. The life cycle of stars is a constant battle of forces; gravity pulling towards the center and the pressure from the heat of fusion wanting to expand.The more massive a star is the greater the force of gravity, the greater the force of gravity the higher the temperature (gasses heat when compressed) and the more rapidly the fuel is used up. More massive stars burn faster, hotter and brighter. Their ends are more spectacular --- Supernova explosions.

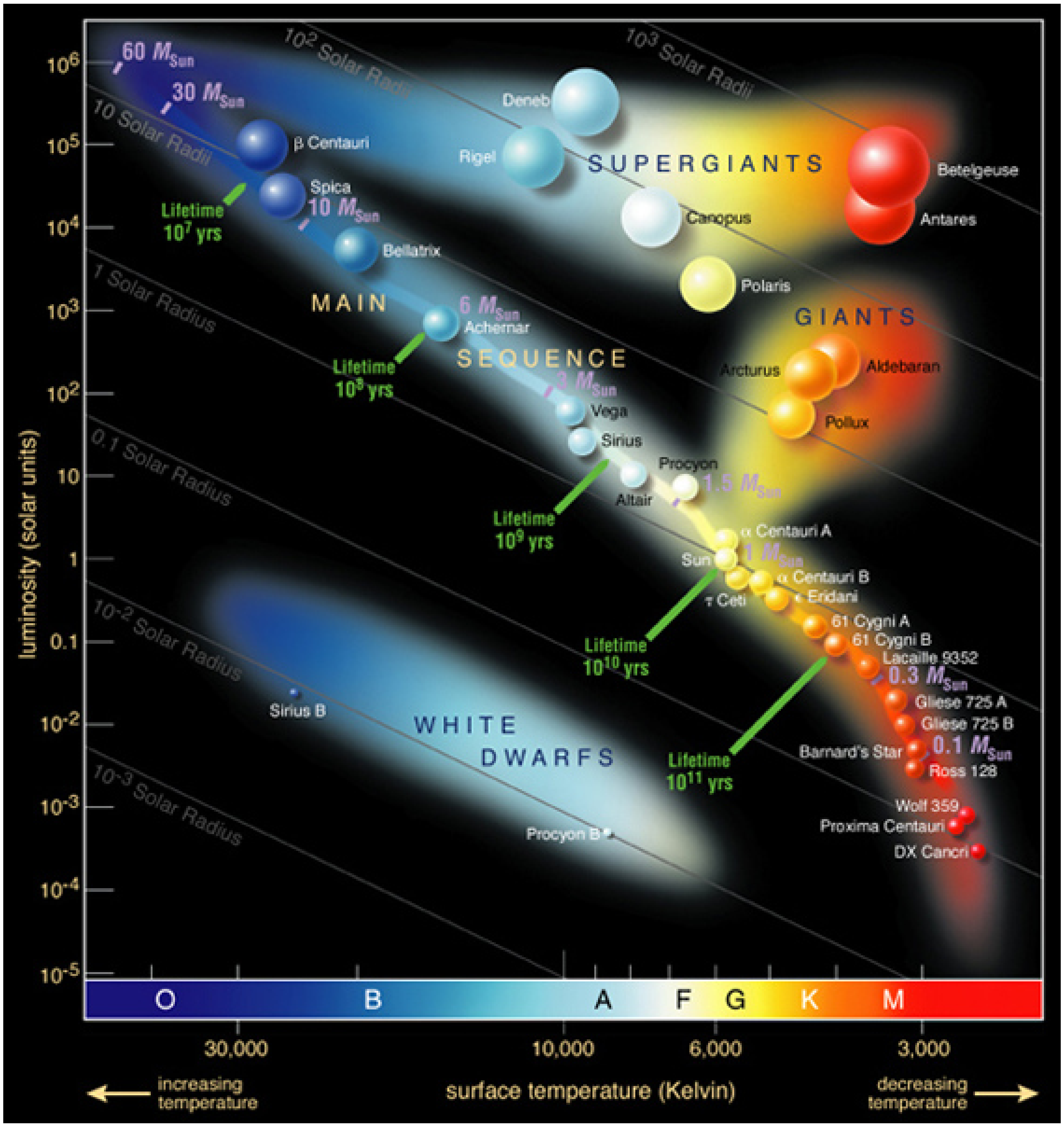


Dennis Tasa

Small mass stars last a long time perhaps trillions of years (no small mass star has reached the end if its “life” yet). High mass stars may last only a million years. Many of these have already burned out.

Stars spend most of their lives as main sequence stars. During this period of time stars are “stable” as they burn their hydrogen fuel. The forces of gravity and expansion pressure are balanced. When their hydrogen fuel is used up the forces are no longer balanced and the star goes through a period of expansion/contraction. No longer a main sequence star it may become a red giant or super giant.

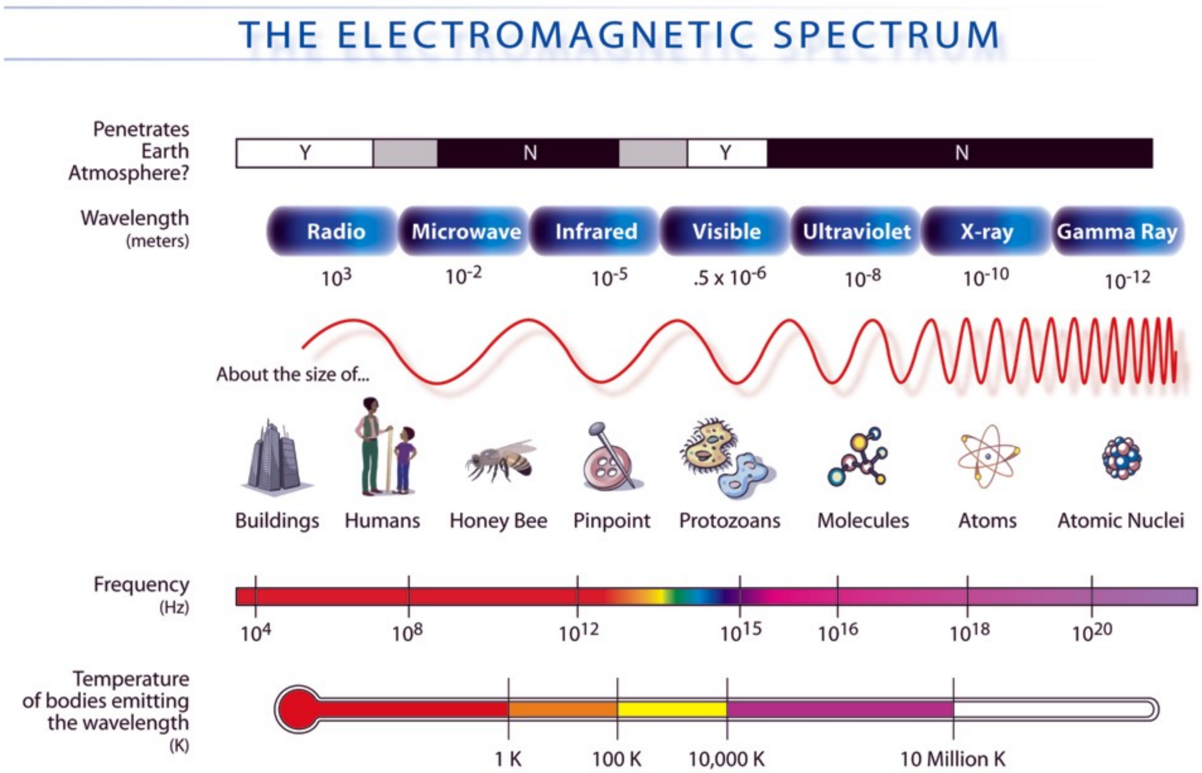
The sun is an medium mass main sequence star with an absolute magnitude (how bright the star really is) of about +5 and is located near the middle of the HR Diagram. As our star ages it will use up its hydrogen fuel, this will take about another 5 billion years, then it will become a red giant (it will not become a supernova, only very massive stars do that). Remember as you look at the HR Diagram that it shows the relationship between temperature and brightness (expressed as luminosity or absolute magnitude). Color also tells us about the temperature of stars, blue being more energetic and hotter.



Remember the top left of the HR diagram is the hottest and brightest.

<u>The Electromagnetic Spectrum</u>

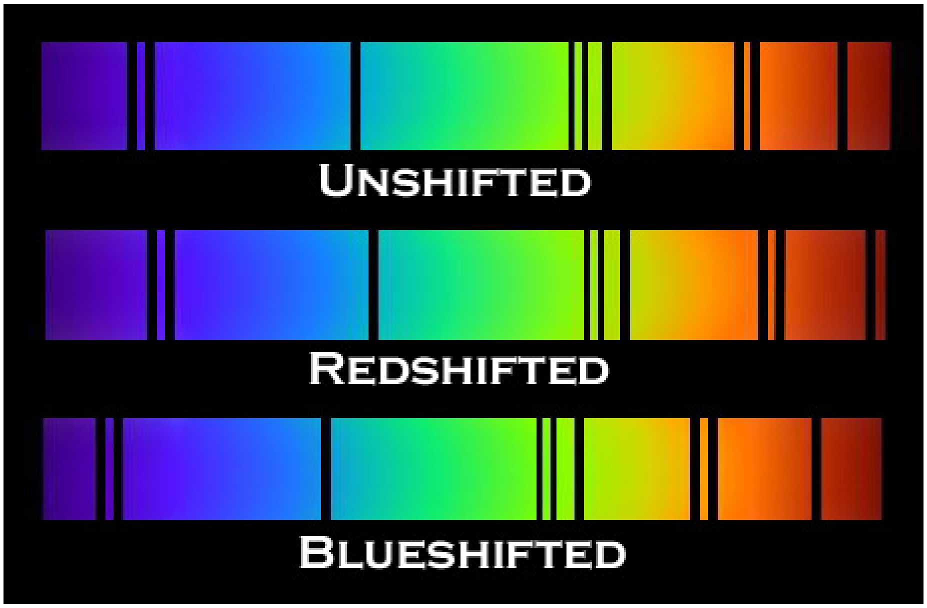
Stars give off electromagnetic radiation and knowledge of the electromagnetic spectrum is essential to our understanding of the universe. Humans, using our normal senses, can only detect a very small portion of electromagnetic waves -- visible light. We must use a variety of technologies to measure the presence of wavelengths longer or shorter than visible light.



As you increase wavelength you decrease the energy and frequency of the waves. High energy, high frequency waves have short wave lengths and are the most dangerous, fortunately our magnetosphere and atmosphere protect us from most of these rays. Recognize that electromagnetic waves are around us all the time but we can't observe them because their wave lengths are either too short or too long (we can only see visible light).

Looking at spectrum can tell us about the source. Continuous spectrum indicates an incandescent source that emits light when heated, while emission and absorption spectra can be used to identify chemical composition. Imaging space in different wavelengths tells us much more than we would learn using just visible light.

The Doppler Effect is the shortening of wavelengths from an object moving towards us (blueshift) and the lengthening of wavelengths from objects moving away from us (redshift), as shown in the absorption spectra below.



Want to learn more? Follow this link.

The Solar System

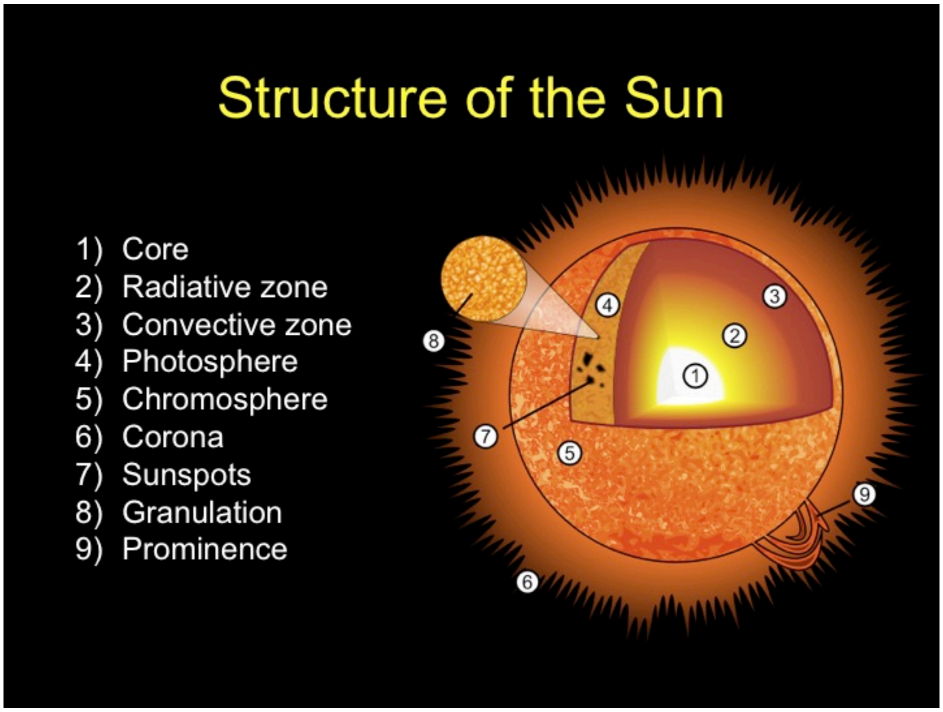
Nebular Theory: Our solar system began to form about 5 billion years ago from a rotating cloud of dust and gas, a nebula, the remains of a previous star. Under the force of gravity about 99% of all the matter formed into the sun. The remaining material formed the planets and other objects which orbit the sun.

The Sun comprised mainly of hydrogen and helium has a layered structure which gets denser and hotter as you move from the surface towards the core. The core is the energy producing area, here thermonuclear fusion takes place. As hydrogen nuclei collide in this dense hot soup they fuse together to form helium and release energy (matter is converted to energy). $E=MC^2$

Photons of energy generated in the core slowly make their way through the radiative zone taking up to hundreds of thousands of years. Once they reach the convective zone the photons ride the convection currents to the surface (photosphere) where they rocket into space at the speed of light, reaching Earth in just 8 minutes.

The photosphere is the visible surface of the Sun which has a granular appearance caused by the tops of the convecting cells. Scattered across the surface are sunspots, slightly cooler areas that appear dark. The motions of these spots was the first indication that the Sun rotates, however the Sun has what is called differential rotation meaning that its surface does not all rotate at the same speed. This rotation causes twisting of the magnetic fields and the formation of prominences and solar flares. Solar activity increases and decreases over an 11 year cycle. We will be approaching a solar maximum in 2012. Solar activity can cause beautiful auroras, or damage satellites, power lines and pose hazards to people in airplanes.

Directly above the photosphere is a thin layer called the chromosphere and above that the corona from which ionized gasses, electrons and protons stream into space forming the solar winds.



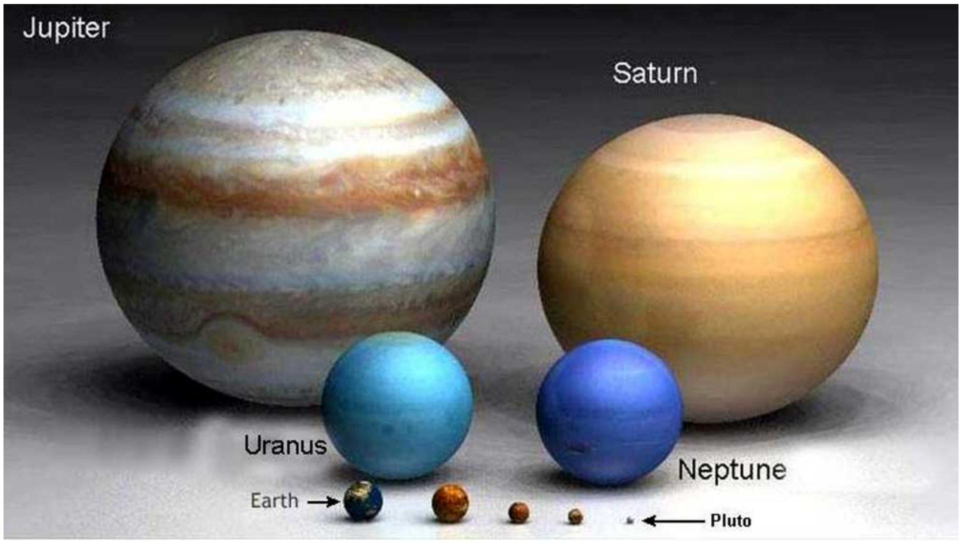
The planets can be divided into 2 groups: Terrestrial or inner planets and Jovian or outer planets (sometimes called gas giants).

Terrestrial planets are "earth like" rocky silicate minerals and iron, more dense, smaller, have little to no atmosphere, have fewer satellites and orbit closer to the sun and therefore have shorter periods of revolution.

- Mercury - smallest, no atmosphere, highest temperature extremes, 3 month days
- Venus - 2nd brightest, Earth's twin, volcanoes, 97% CO_2 atmosphere, rotates in the opposite direction (retrograde)
- Earth - water planet, life
- Mars - red planet, water erosion, thin atmosphere, dust storms, 2 moons

Jovian planets (gas giants) are comprised mainly of gases, hydrogen (H) and helium (He), and ices of water, ammonia and methane. They may have rocky and metallic cores. They are less dense, but much larger and massive, have thick atmospheres and many satellites.

- Jupiter - largest mass, 1 rotation in 10 hrs, great red spot, rings
- Saturn - most prominent rings, less dense than water
- Uranus - rotates sideways, rings
- Neptune - winds exceed 1000 km/h, great dark spot (might be gone now), rings



Asteroids: small rocky irregular shaped bodies that mainly lie in the asteroid belt between Mars and Jupiter. A few have eccentric orbits that bring them closer to the Sun and Earth.

Comets: Pieces of frozen rock and metallic minerals with very elongated orbits. May originate from the Oort cloud or Kuiper belt. As they approach the sun often a glowing head called a coma appears as well as a tail (sometimes 2 which always point away from the sun).

Meteoroids: “shooting stars” small solid particles, called a meteor as it travels travels through Earth’s atmosphere and a meteorite when it reaches Earth’s surface.

Rotation is the turning or spinning of a body on its axis. (night and day)

Revolution is the motion of a body along a path around another body in space. (year)

Apparent Retrograde Motion is the apparent westward motion of planets when viewed against the backdrop of stars

<u>Earth – Sun – Moon relationships.</u>

The moon was formed when a Mars sized object crashed into the early forming earth. The moon formed from the resulting debris (some theories indicate 2 moons were created but later collided forming one).

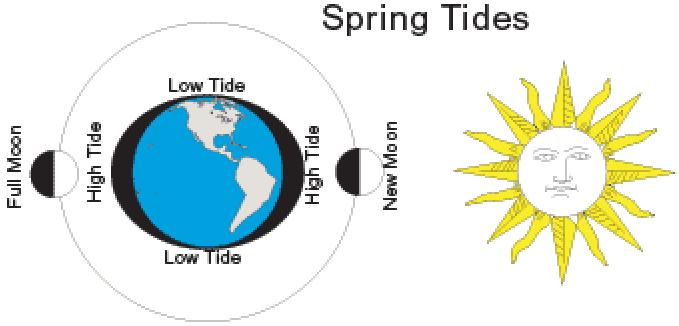
The surface of the moon is deeply cratered from the impacts of many objects of differing sizes. Many resulted in the flow of magma from within forming maria. The greatest factor affecting the energy of an impactor would be its velocity. The Earth does not show the evidence of impactors because many craters have been destroyed by tectonic forces, plant growth, erosion and oceans. Because these are not factors on the moon, craters remain for long periods of time. The only cause of erosion on the moon would be other impactors from space. This has resulted in fine dust on the moon's surface called regolith.

The moon's period of rotation and revolution are the same (approximately 1 month) this results in the same side of the moon always facing the Earth.

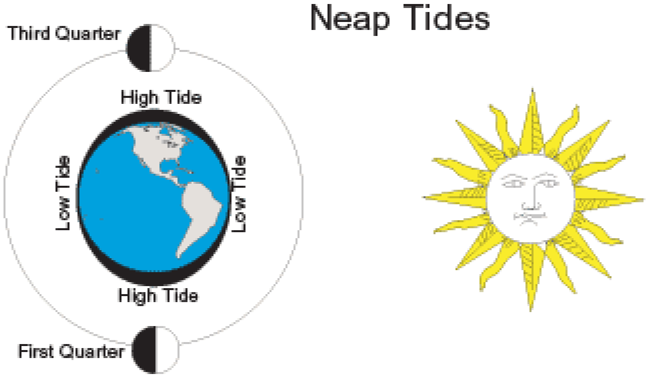
Tides are caused by the gravitational pull of the moon and sun. We usually experience 2 high and to low tides per day.

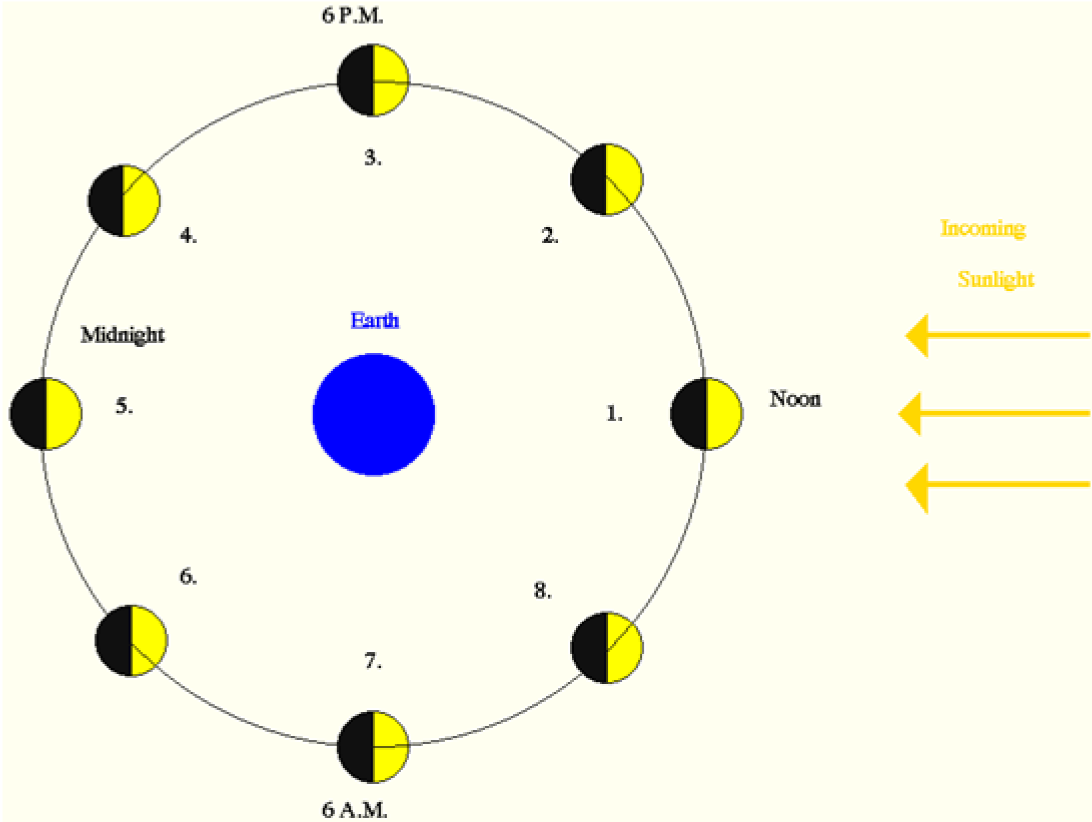
- When the sun, earth and moon are all in a line we experience the highest high tides and the lowest low tides (the greatest differences between tide heights). This is called spring tides.
- When the sun, earth and moon are at right angles we experience the least difference between high and low tides. This is called neap tides.

Spring Tides



Neap Tides





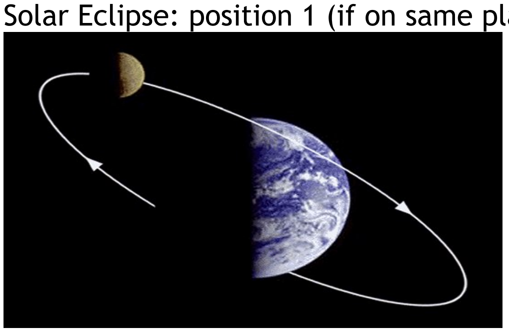
Note: Half of the moon is always illuminated. Phases are caused by how much of the illuminated side we can see from Earth.

1. New Moon
2. Waxing Crescent
3. First Quarter
4. Waxing Gibbous
5. Full Moon

Lunar Eclipse: position 5 (if on same plane)
Solar Eclipse: position 1 (if on same plane)

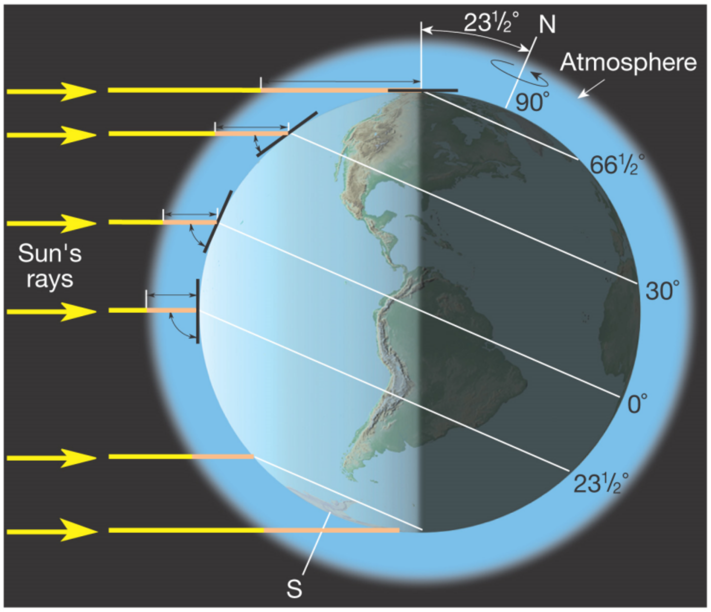
6. Waning Gibbous
7. Third or Last Quarter
8. Waning Crescent

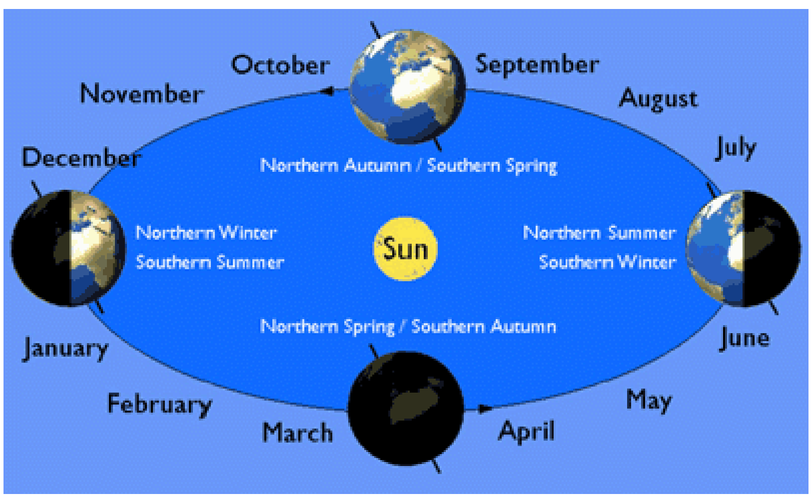
Spring Tides (higher): positions 1, 5
Neap Tides (lower): positions 3, 7



The moon does not orbit on the same plane otherwise we'd have solar and lunar eclipses every month.

The tilt of the Earth causes the seasons, not the distance from the sun. As the surface of the Earth tilts away from the sun's rays the rays travel through a greater amount of the atmosphere reducing the amount of energy that reaches the surface. In addition the sun's rays spread out over a greater surface area.


23½°
N
Atmosphere
90°
66½°
Sun's rays
30°
0°
23½°
S


October
September
November
August
December
July
Northern Autumn / Southern Spring
Northern Winter
Southern Summer
Sun
Northern Summer
Southern Winter
Northern Spring / Southern Autumn
January
June
February
May
March
April