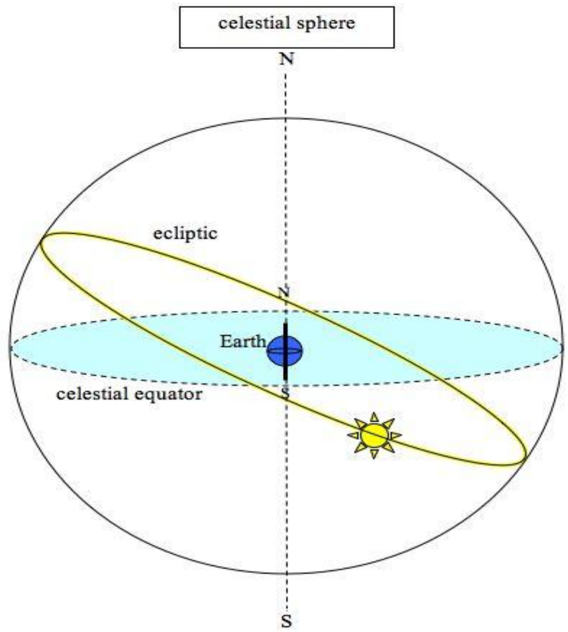
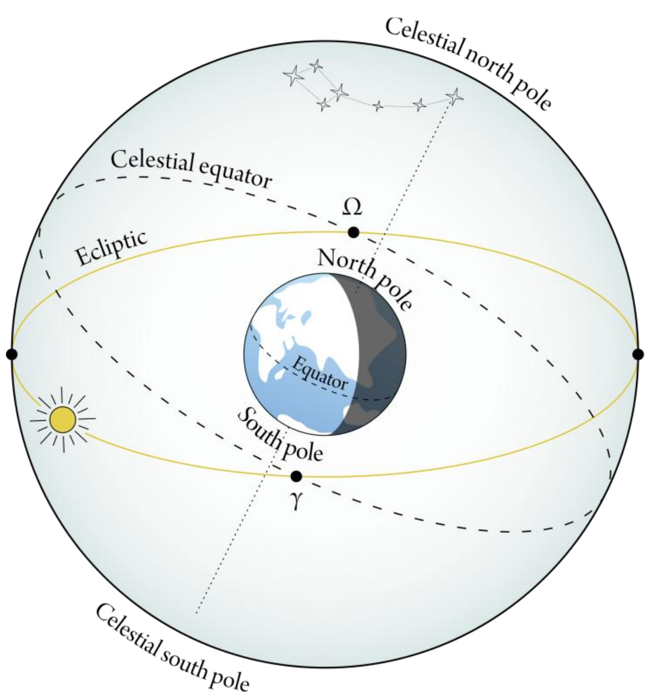
Topic 10: Earth in Space **Workbook Chapters 10 and 11**

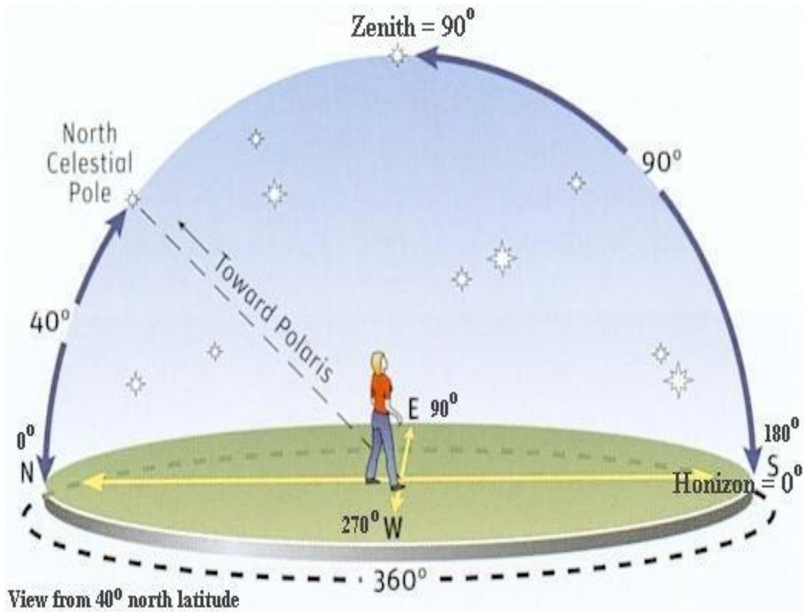
We can imagine all the celestial objects seen from Earth—the sun, stars, the Milky way, and planets—as being positioned on a celestial sphere. Earth would lie at the center of this celestial sphere, where the celestial equator and north and south poles are extensions of Earth's equator and north and south poles. In this manner, all the objects we see at night can be plotted on the celestial sphere:



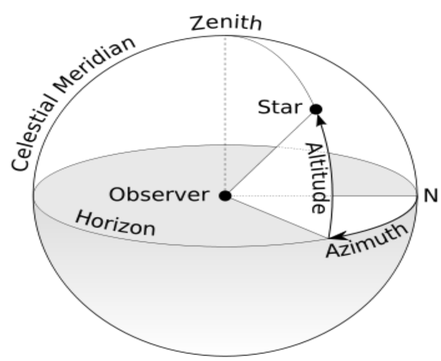
While we cannot tell how far away a celestial object is using this method, we can give it a position in the sky:



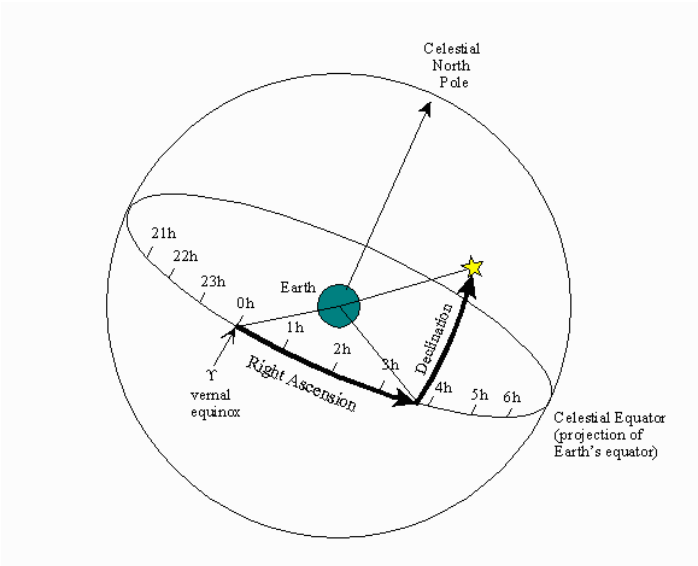
We only see half the celestial sphere at any time. Because we live in the Northern Hemisphere, we see the northern celestial hemisphere.   It forms a dome around us, with the edge of the dome on the horizon and the highest point, the zenith, directly overhead:

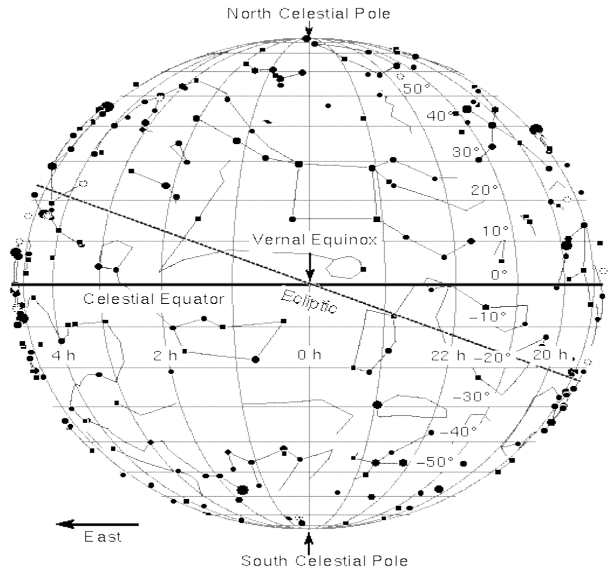


We chart celestial positions using altitude and azimuth readings.
Altitude: the vertical angle from the horizon of the observer up to the celestial object.
Azimuth: the angle of the celestial object from a specific point around the circle formed by the horizon.



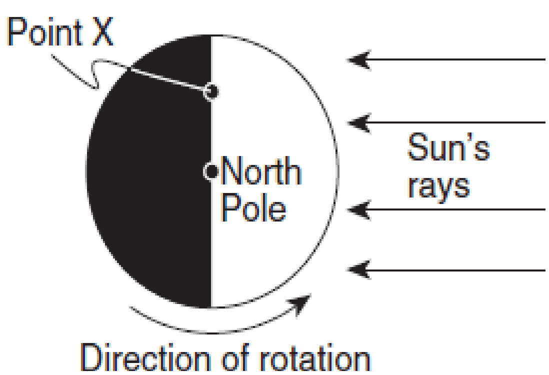
Objects are also positioned on the celestial sphere by extending Earth's latitude and longitude lines onto the celestial sphere. Declination (latitude) is expressed in degrees while Right Ascension (longitude) is measured in hours:

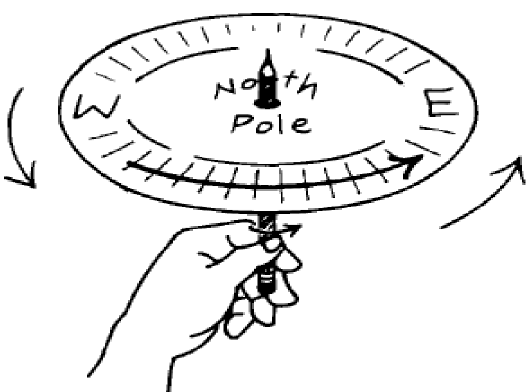


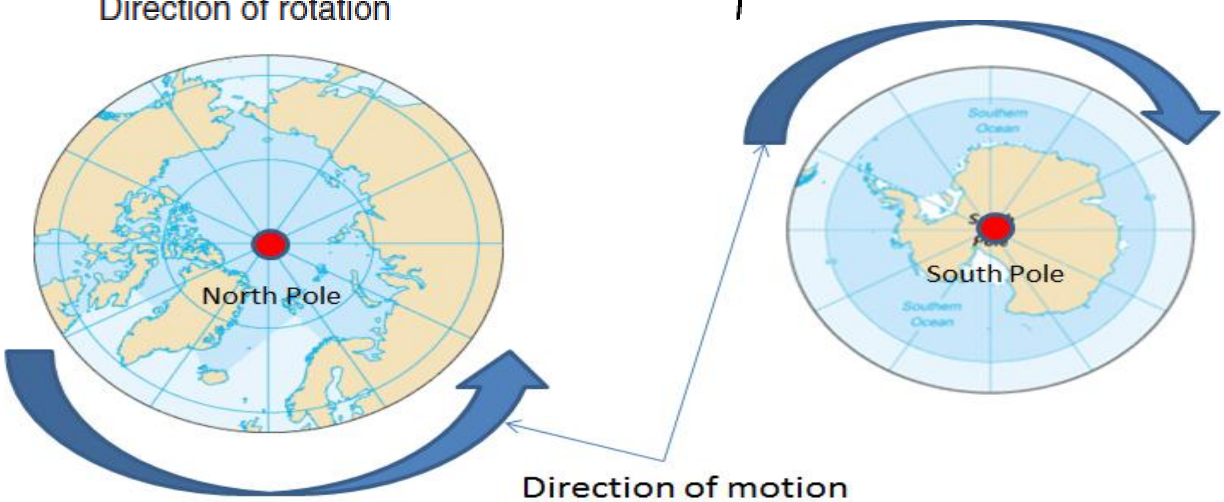


Celestial Motions:

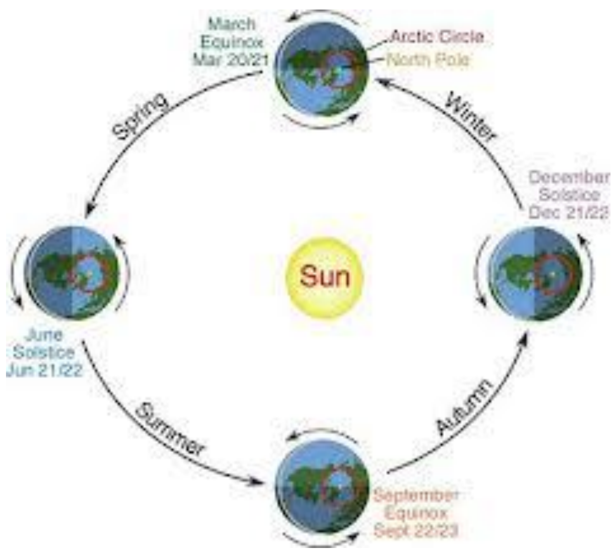
For the most part, celestial objects appear to move in a path from EAST TO WEST across the sky at a speed of 15° per hour. This is due to Earth's rotation from WEST TO EAST at 15° per hour--<u>counterclockwise</u> when viewed from the north pole:

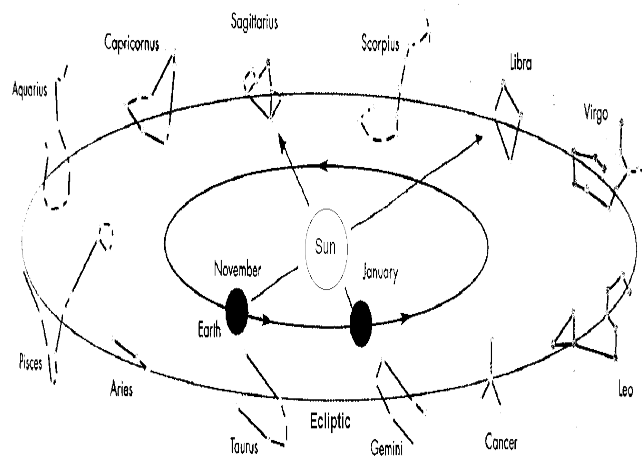






Celestial objects also appear to rise further west each day because the Earth is revolving counterclockwise around the sun:



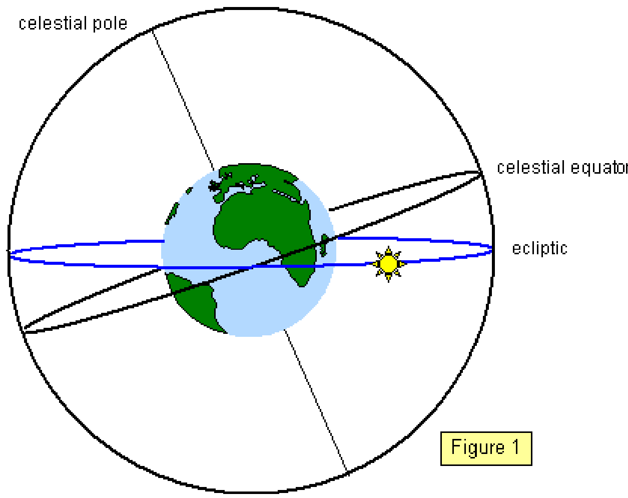


Motions of the Sun

We cannot see the position of the sun among the stars during the day, because its light blocks out the stars. As we revolve around the sun in a counterclockwise motion (from west to east), we see new groups of stars in the sky every few weeks.

Thus, every few weeks the sun rises and sets in a new group of stars. If we were to track the sun's path through these stars, the path would form a circle called the **ecliptic** (the apparent motion of the sun through the stars when viewed from Earth).

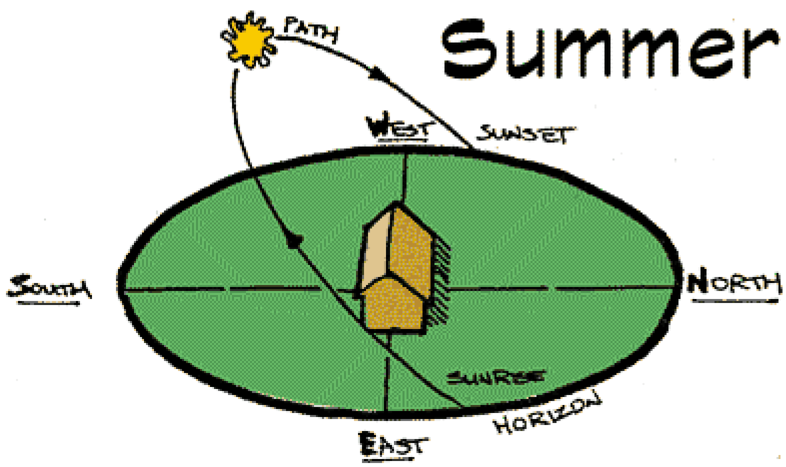
1 year = 1 complete circuit of the ecliptic; the plane of the ecliptic is tilted 23.5^o from Earth's equatorial plane (Earth's tilt in degrees):



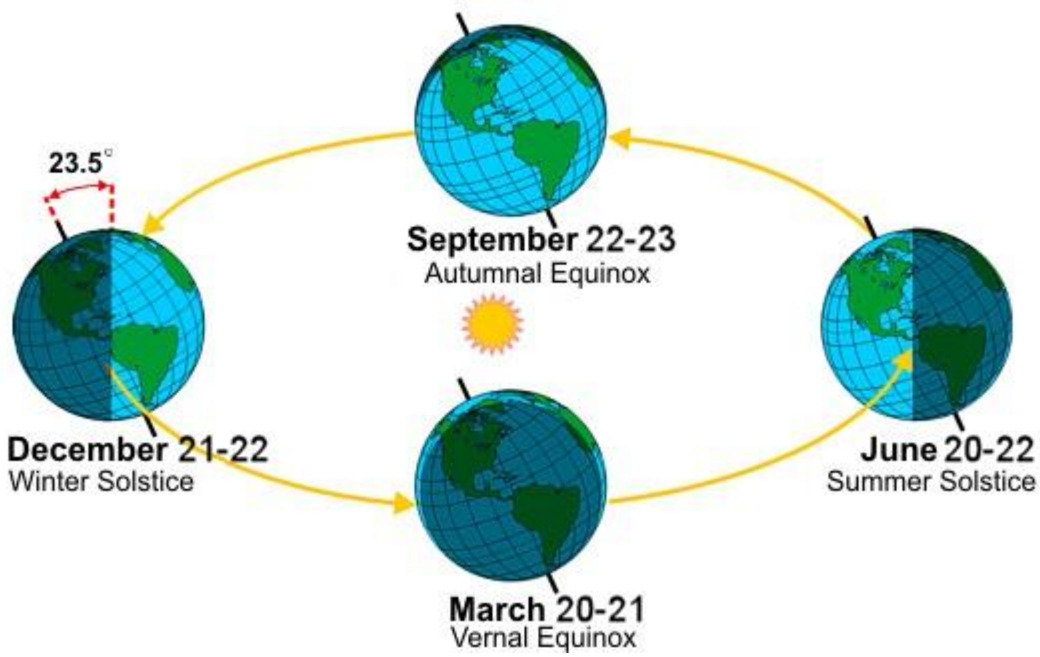
Where the plane of the ecliptic crosses the celestial equator = the equinoxes (March 21 and Sept. 21).

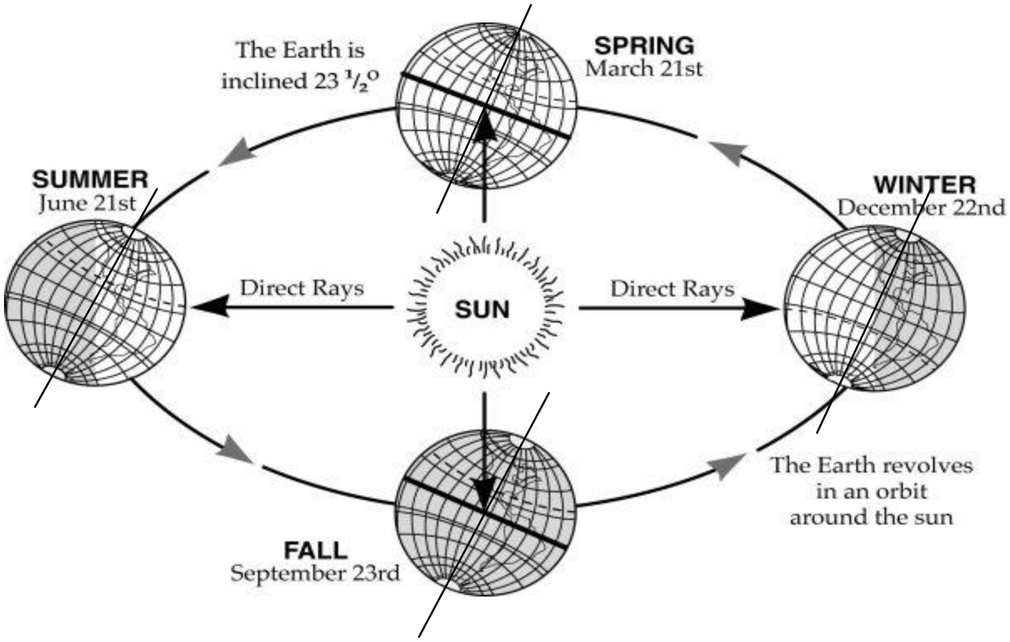
Diurnal (daily) Motions of the Sun

The sun appears to rise in the east and set in the west each day, forming an arc across the sky. It moves at a rate of 15° per hour (Earth's rotational speed) and its highest altitude is at noon:

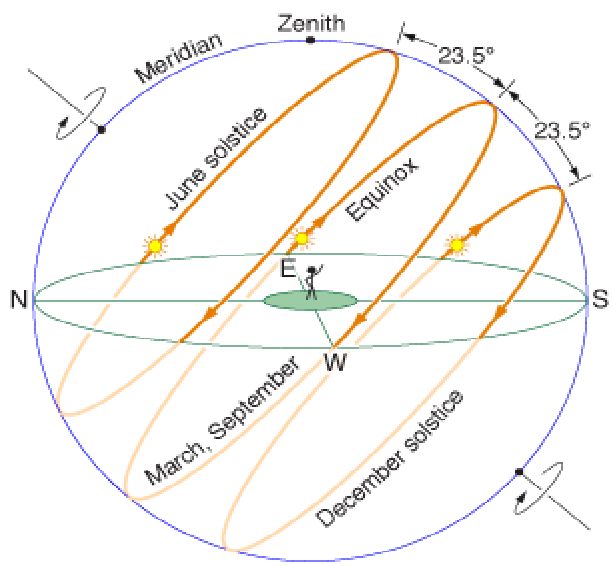


The altitude of the noon day sun in the sky changes with the seasons. This is due to the tilt of Earth's rotational axis as the Earth revolves around the sun. In summer, the axis tilts toward the sun in the northern hemisphere, causing the noon sun to be at a higher altitude. In winter, it tilts away from the sun, causing the altitude of the noon sun to be lower than in summer or during the equinoxes:



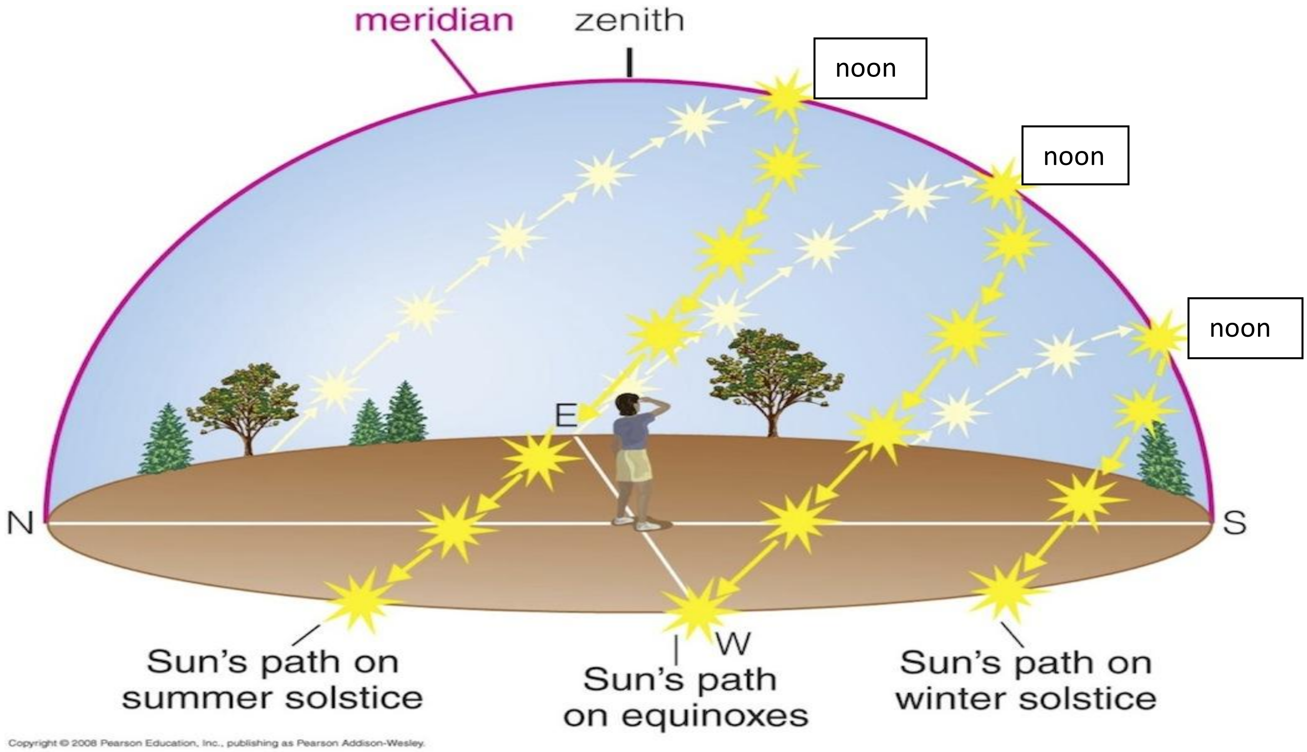


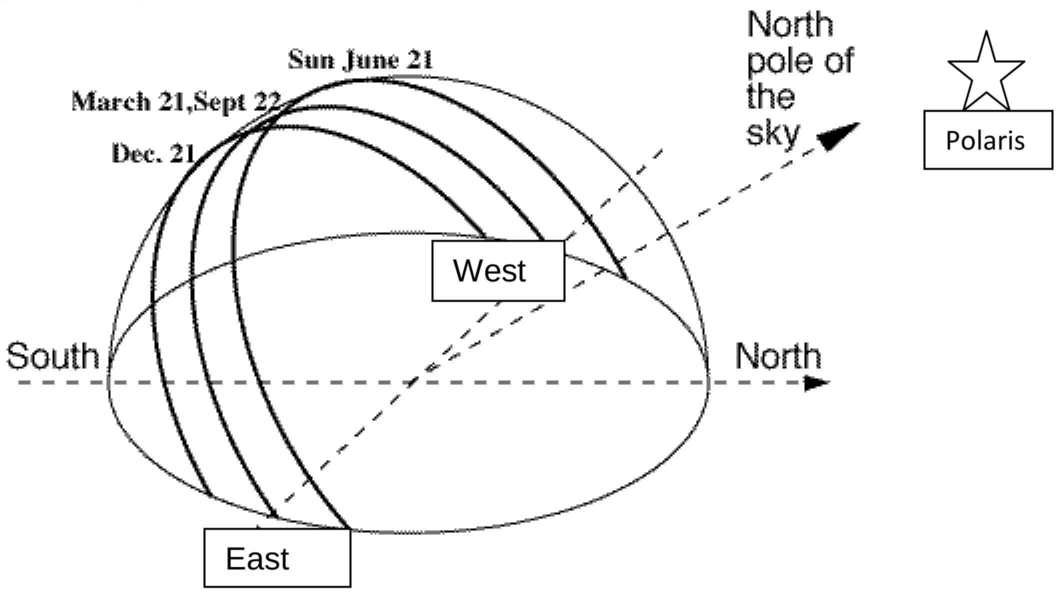
Thus, the sun's arc across the sky changes with the seasons. The sun's path at 41°N latitude during the year is shown below:



***The only places on Earth where the sun can be seen directly overhead (at zenith) at noon is between 23.5°N and 23.5°S latitudes. At different times throughout the year, these locations receive the vertical rays of the sun. At all other latitudes, the sun will NEVER be directly overhead at noon.**

It is for this reason that latitudes higher than 23.5°N must look south to see the sun at noon.





While the sun's daily path makes an arc across the southern sky in the northern hemisphere, where the sun rises and sets each day changes with the seasons:

** The sun rises north of east in the summer, south of east in the winter, and due east on the equinoxes.

**The sun sets north of west in the summer, south of west in the winter, and due west on the equinoxes.

The sun is directly south and highest in the sky at noon each day!

To calculate the altitude of the **noon** sun throughout the year:

90^o – latitude of the observer ($\pm$ tilt of 23.5^o or zero) = altitude of noon sun

Ex: altitude of noon sun for an observer at 50°N latitude on June 21—

$90^\circ - 50^\circ + 23.5^\circ = 63.5^\circ$ (in summer, Earth's axis tilts toward the sun, so the noon sun is higher in the sky)

The angular length of the arc formed by the sun's path equals the number of daylight hours x 15° per hour. Example: 9 hours of daylight x 15° per hour = 135° arc

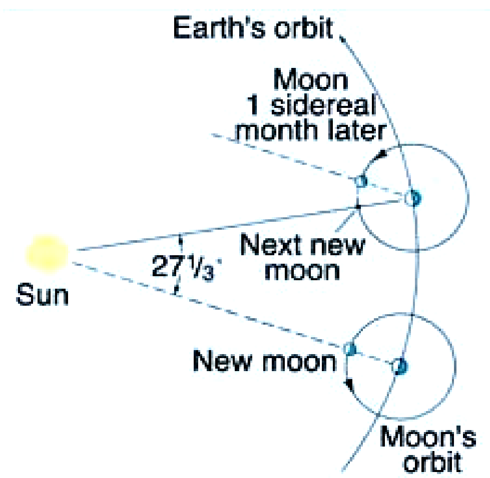
Clocks measure mean solar time, because there are only four times during the year when the sun's highest altitude actually occurs at noon.

Motions of the Moon

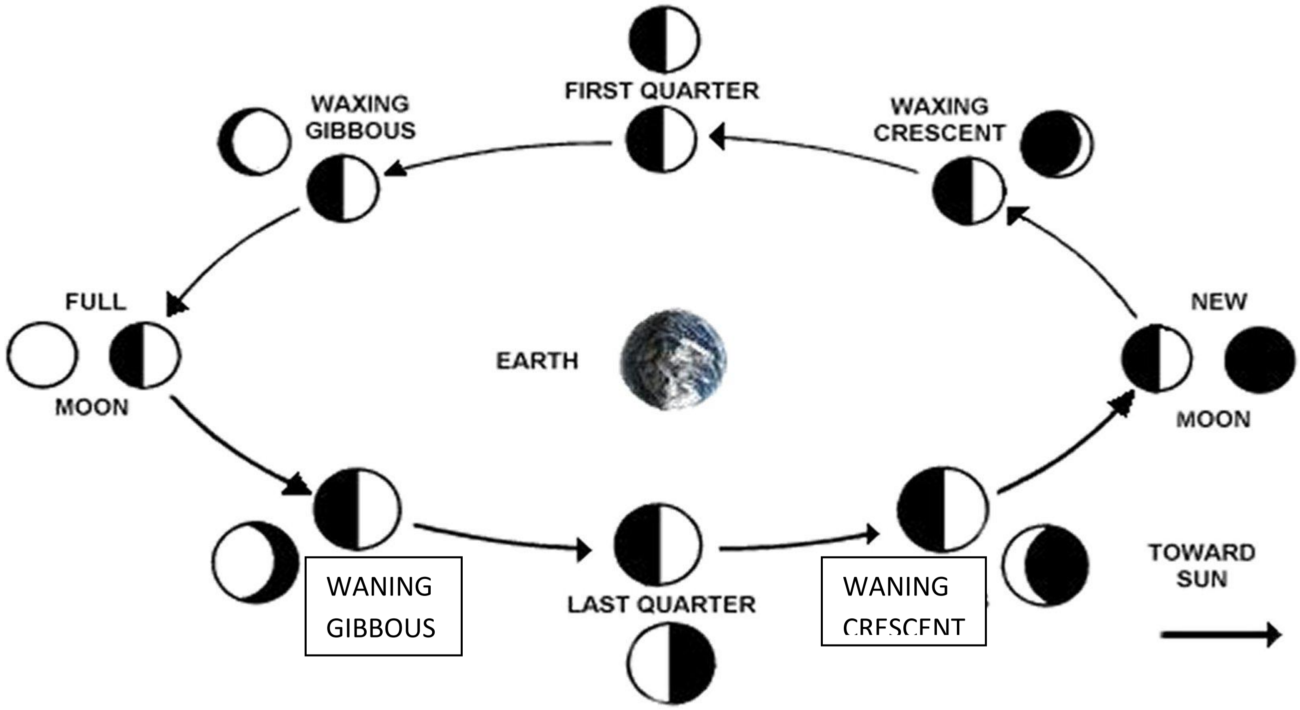
One complete revolution of the moon around the Earth takes 27-1/3 days. This 360° of motion is a lunar **sidereal month.**

One complete cycle of lunar phases—from full moon back to full moon again, for instance—is called a **synodic month** and takes 29.5 days.

The reason for the difference in time between these two lunar months is due to the fact that as the moon revolves around the Earth, the Earth continues to revolve around the sun, thus changing the orientation of the Earth, sun and moon to each other.



We see the moon because its surface is illuminated by the sun. The sun always illuminates half the moon's surface, as it always illuminates half the Earth's surface (day and night). As the moon revolves around Earth, we see portions of the lit half of the moon that we call "phases." If the entire lit portion faces the Earth, we call it a full moon; if the entire unlit portion faces the Earth, we don't see a moon at all; this is the "new moon" phase.

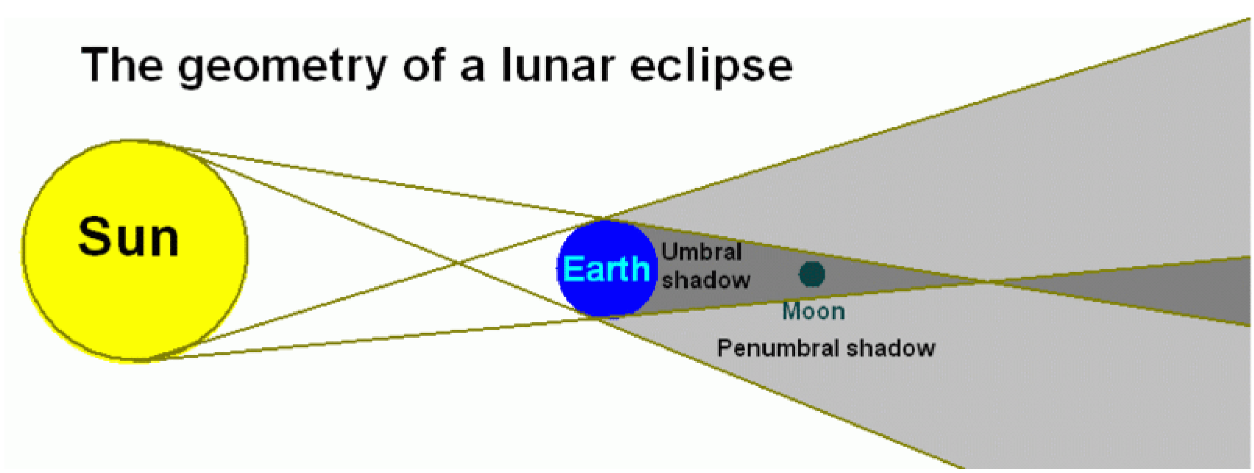


Because the distance between the Earth and the moon changes, the moon's angular diameter changes. The moon's apparent diameter **increases** as its distance from the Earth **decreases**.

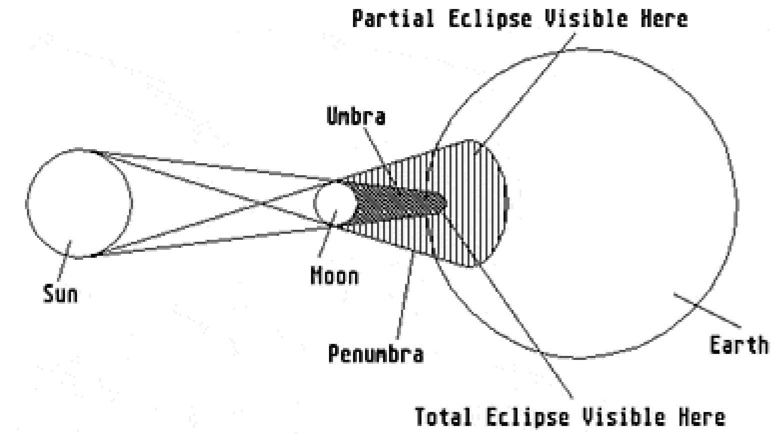
The moon appears to move eastward through the stars; it moves further east in its orbit around the Earth.

<u>Eclipses</u>

Eclipse means "to shadow." During a **<u>lunar eclipse</u>**, a shadow created by the earth falls across the surface of a full moon, blocking its light:



During a **solar eclipse**, the moon moves in between the Earth and the sun, blocking out the sun during the day and leaving only a "corona" of light:



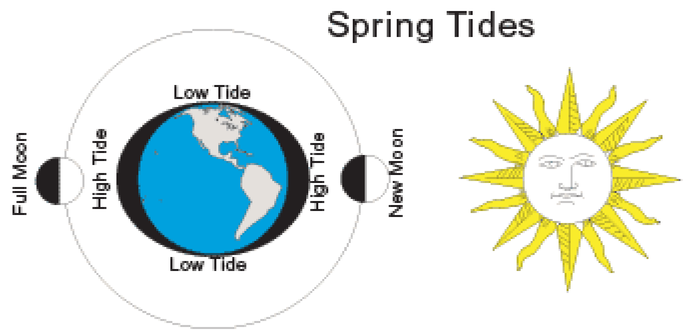
Note: the name of the eclipse tells you what gets hidden from observers on Earth. For example, during a lunar eclipse, the moon "disappears" at night.

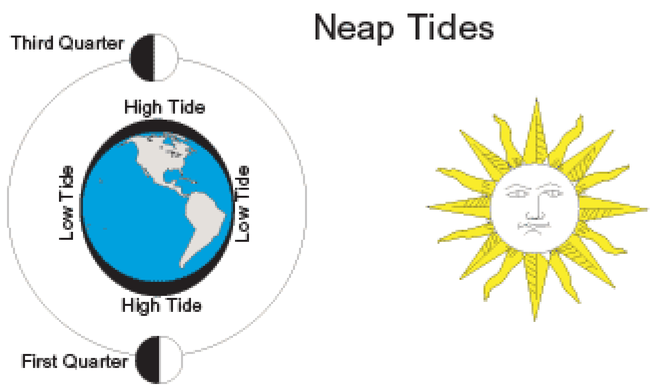
Tides

Because water is a liquid, the gravitational pull of both the moon and the sun can draw out the water from the surface of the Earth, creating tidal bulges. The moon's gravity has a greater influence on tides than the sun, because it's closer to us.

Spring tides occur during **full and new moon phases**. High tides are much higher than normal and low tides are lower than normal.

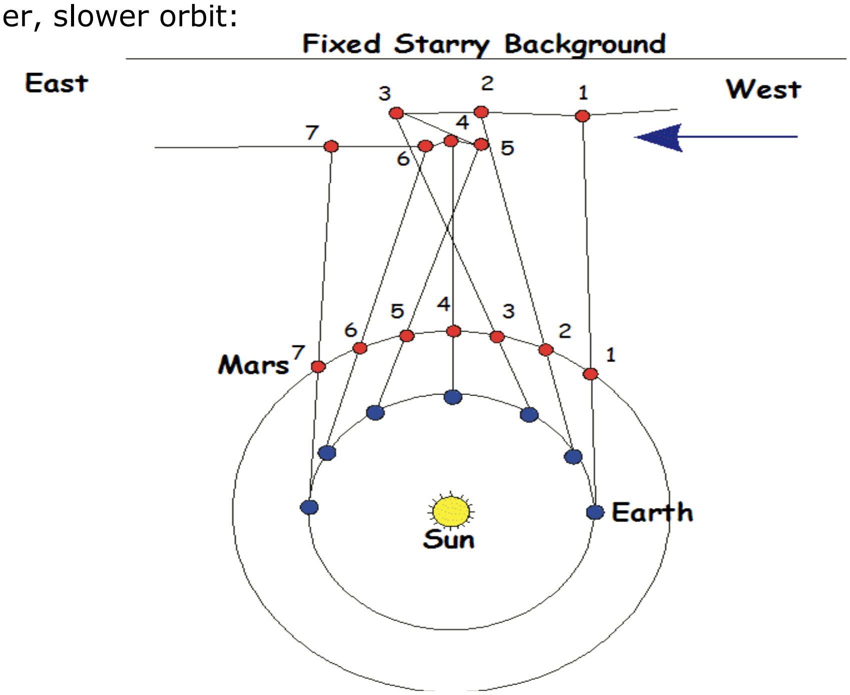
Neap tides occur during **first and third quarter moons**. During neap tides, there is very little difference between high and low tide water levels--the gravitational pull of the moon and sun work at right angles to each other, creating more uniform tidal bulges:





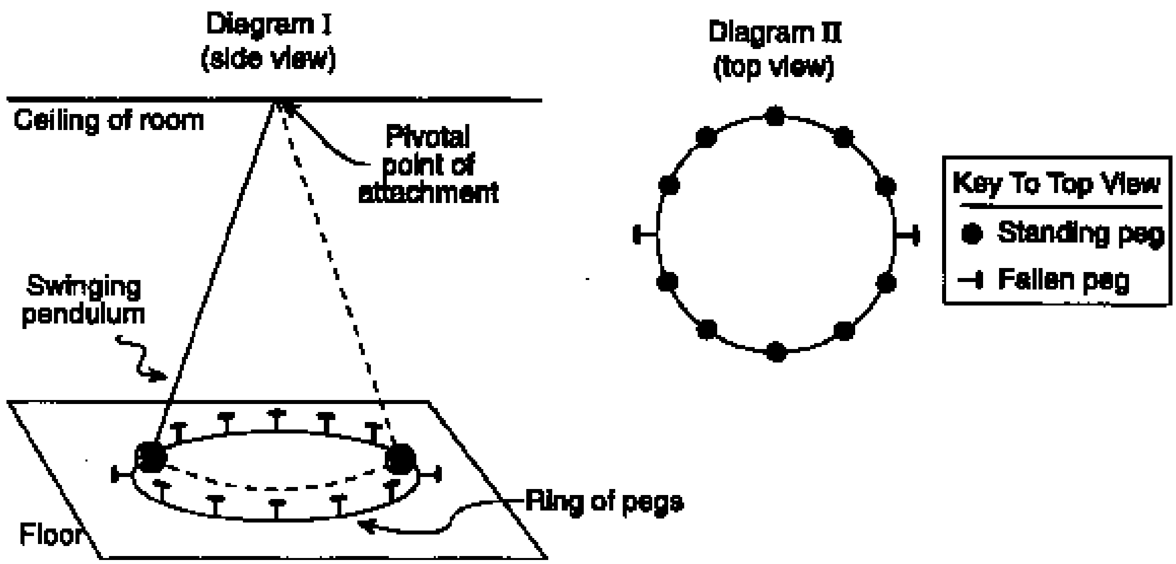
Planets

Planets appear to vary in brightness and size in a cyclical manner when viewed from Earth because in their orbit around the sun they move closer to and farther from Earth. For most of their revolution, planets seem to move eastward through the sky when viewed from Earth. The exception**: retrograde motion**. This is when planets appear to move backwards in their orbit. It occurs when one planet moving in a smaller, faster orbit overtakes and passes another planet moving in a larger, slower orbit:



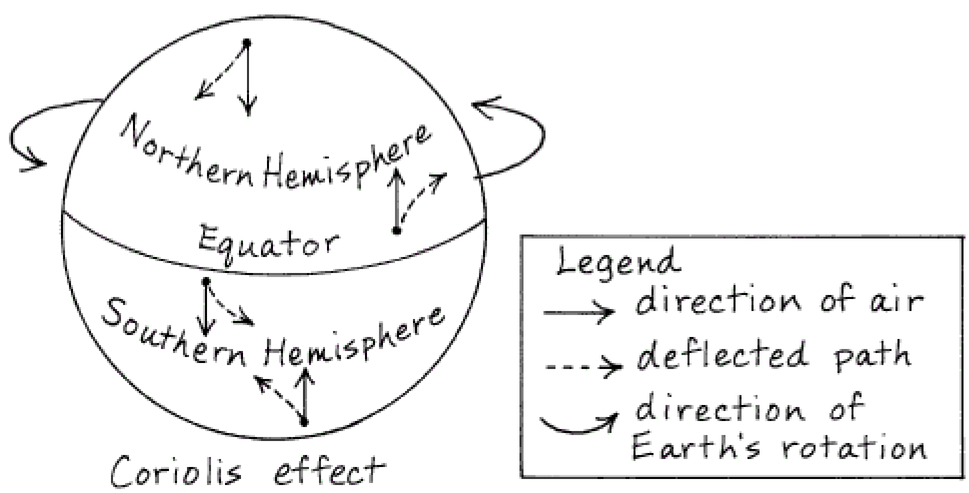
Earth Motions

Foucault's Pendulum: once set in motion, a pendulum will swing in a fixed direction due to inertia. Foucault showed that a pendulum appears to change direction over time because Earth has rotated underneath it:



pendulum explanation

Coriolis Effect: particles of matter moving at the Earth's surface (winds, ocean currents) have a tendency to deflect to the right in the northern hemisphere and to the left in the southern hemisphere due to Earth's rotation.

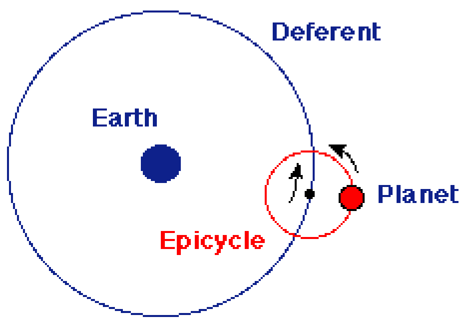


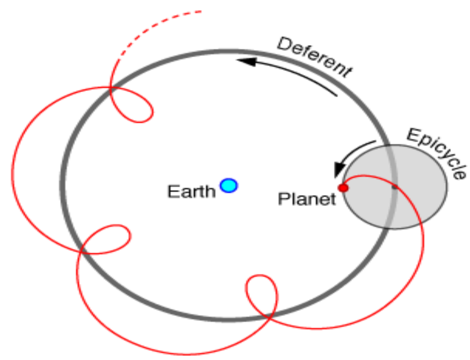
CELESTIAL MODELS

Scientists and mathematicians throughout the ages proposed theories to explain the movement of celestial objects. As technological advances were made (the improvement of telescopes, for example), scientists were able to observe movements more accurately, and explanations of celestial motions changed.

Geocentric Model of the Universe (Ptolemy): Earth is stationary and at the center of the universe, with celestial bodies moving around it.

- Stars on transparent sphere that rotates once a day from east to west
- Sun, moon and planets all carried on different spheres with different radii
- The **deferent** is the circular orbital path of the planets around the Earth. As each planet moved along its deferent, it also revolved in circles to form **epicycles.** Epicycles explained planetary and retrograde motions:





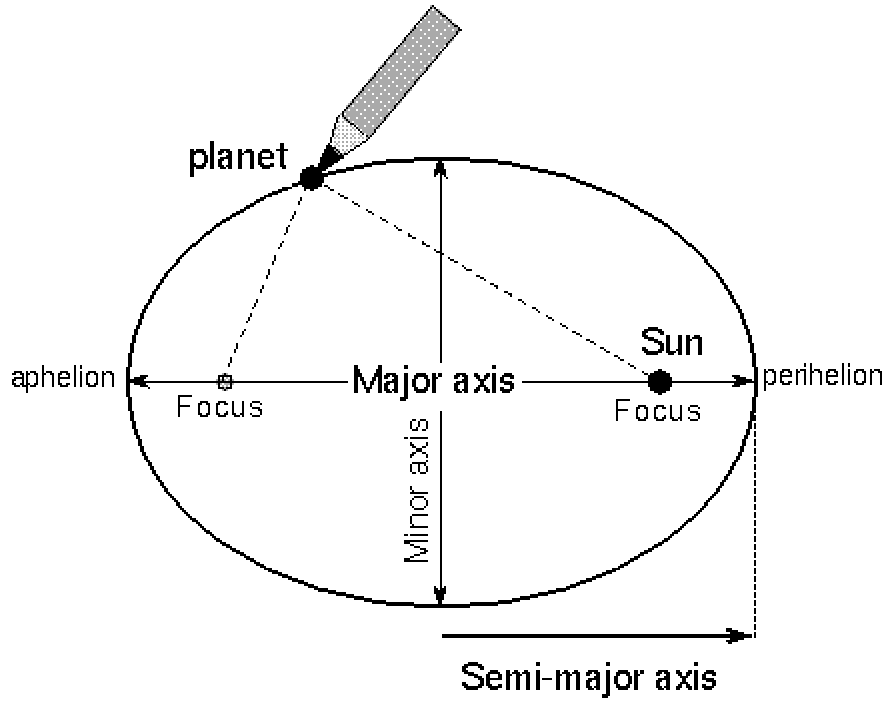
Ptolemy's model explained the motion of the stars, the motion of the moon and planets, and retrograde motion, and changes in brightness and planet proximity (using epicycles), but it was not able to predict the future positions of planets and terrestrial motions such as Foucault's pendulum and Coriolis.

Heliocentric Model of the Universe (Copernicus): the sun, not the Earth, is at the center and it does not move. Stars are on an unmoving sphere, a great distance from Earth.

- Earth and other planets move around the sun in an eastward motion when viewed from Earth
- The moon revolves around Earth
- Earth rotates from west to east
- Sun's apparent motion through the stars is eastward
- Venus and Mercury's orbits are inside Earth's orbit, and their apparent size and brightness increase and decrease with their distance from Earth
- Retrograde motion of outer planets occurs because their orbits are larger than Earth's; as Earth passes these planets, they appear to move backwards
- Foucault's pendulum and Coriolis is explained by Earth's rotation

The Copernican model does not explain the change in the angular diameter of the sun and the moon or the change in the sun's speed along the ecliptic, because he described orbits as being circular.

Improving the Heliocentric Model (Kepler): Johannes Kepler, assistant to the Danish astronomer Tycho Brahe, used Brahe's meticulous measurements to show that the orbits of Earth and other planets **were elliptical, not circular** (Kepler's First Law):



Drawing an **ellipse**: loop string around thumb tacks at each **focus** and stretch string tight with a pencil while moving the pencil around the tacks. The Sun is at one focus.

Changing the distance between the foci changes the shape of the ellipse; the closer the foci come together, the more circular the ellipse becomes.

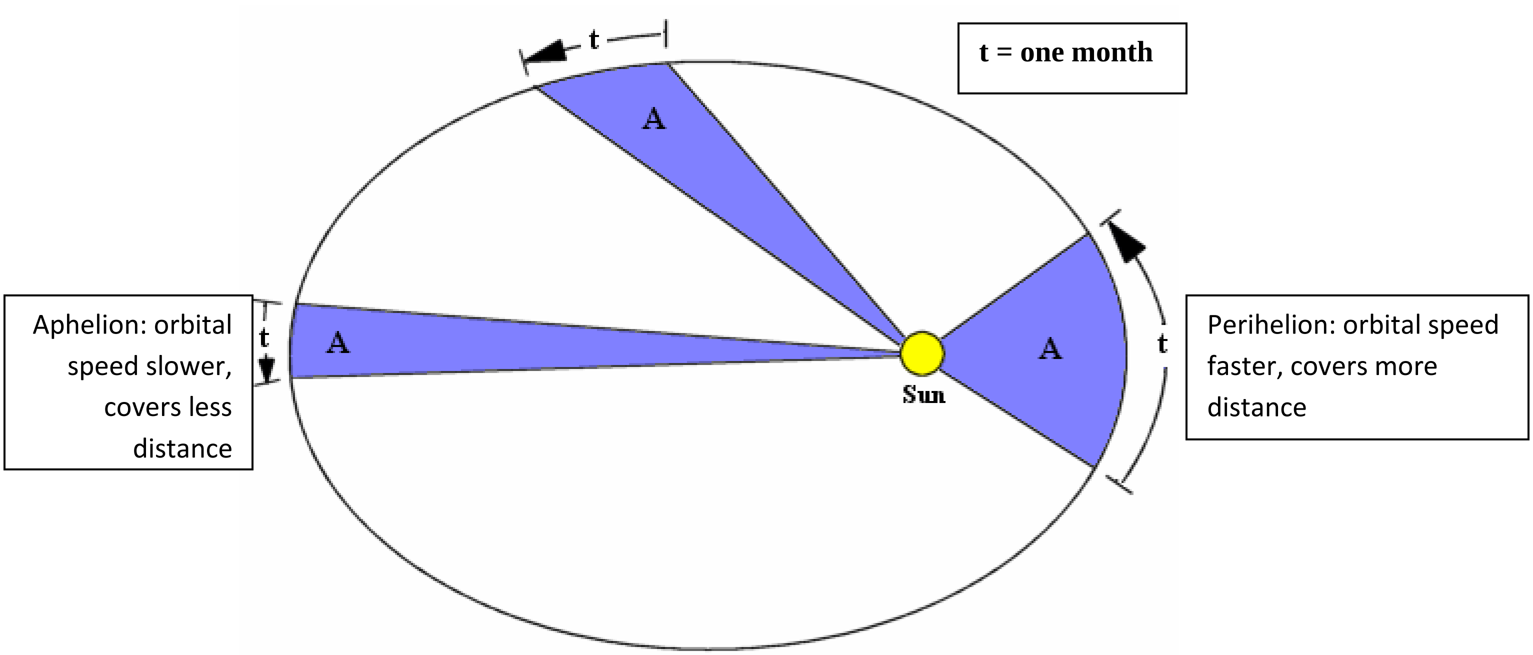
Eccentricity explains how "flat" or "oval" an ellipse is. Eccentricity is calculated using the formula: $E = \dfrac{\text{distance between the foci}}{\text{length of the major axis}}$

A circle has an eccentricity of 0; a line has an eccentricity of 1.
Thus eccentricity of an ellipse is greater than 0 and less than 1.

Kepler's First Law shows the orbit of each planet is an ellipse with the sun at one of the foci.

Orbital Speed

Kepler's elliptical model states that the speed of each planet changes during its orbit. A planet moves faster when it's closer to the sun (perihelion) and slower when it's farther from the sun (aphelion). This is explained by Kepler's Second Law--Law of Equal Areas:



An invisible line between a planet and its primary focus sweeps over equal areas in equal periods of time. The shaded "A" areas in the diagram are all equal.

Kepler's Third Law (Planetary Periods):

Kepler's Third Law states that the square of a planet's orbital period (in years) is equal to the cube of the planet's distance from the Sun, measured in Astronomical Units (AU):

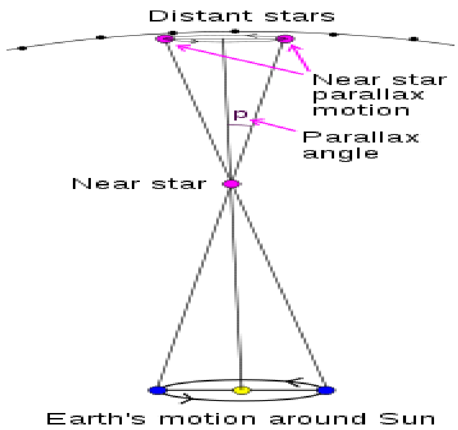
$$p^2 = a^3$$

p = orbital period measured in Earth years (365 days)
a = average distance from the sun in AU.

1 AU = average distance between the Earth and the sun—149,600,000 km or 92,956,000 miles.

Distance to Stars

Astronomers use the principle of parallax to measure distances and plot positions of celestial objects:



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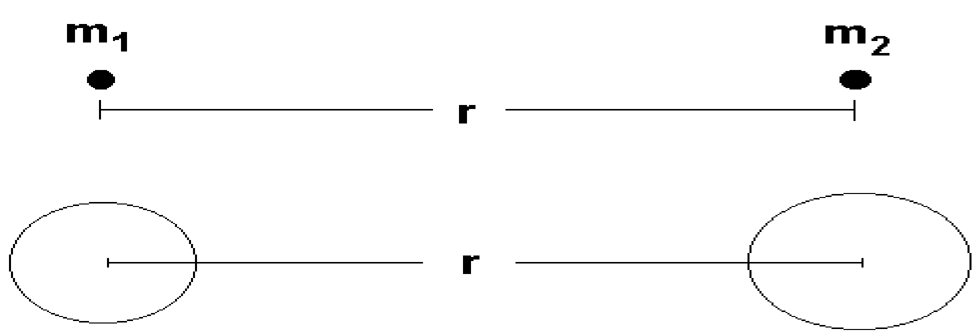
Newton's Universal Law of Gravitation

Gravity is a vector force, showing magnitude and direction (toward the center of the Earth, for example).

The magnitude of the gravitational force depends upon the mass of the objects and the distance between them. The greater the mass of an object, the greater its gravitational pull. The greater the distance between two objects, the less the gravitational pull.

This is explained by the equation below, where **r** is the distance between the centers of the two masses:

$$F_G = \frac{Gm_1m_2}{r^2}$$ G = gravitational constant



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Using the formula, if the distance between two objects doubles, the force of gravity between them is one-fourth as strong.

Energy Transformations and Orbital Motion

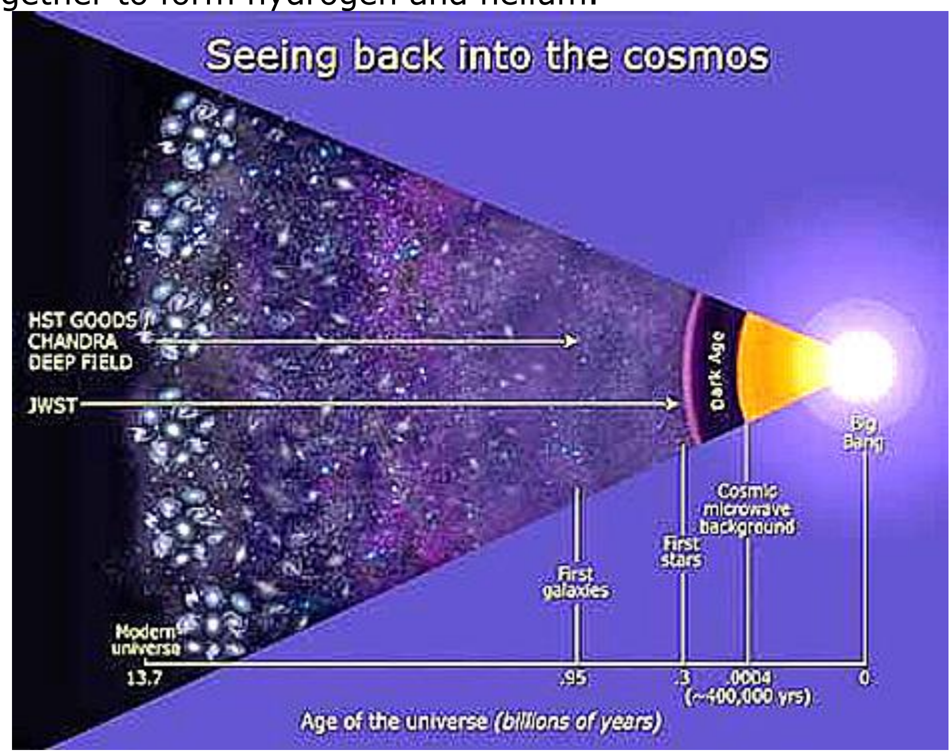
The kinetic and potential energy between a planet and its primary focus change throughout an orbit. As orbital speed increases, kinetic energy increases and potential energy decreases. As orbital speed decreases, kinetic energy decreases and potential energy increases.

At perihelion, where gravitational pull is strongest, a planet has the greatest orbital speed, highest kinetic energy, lowest potential energy. At aphelion, where gravitational pull is weakest, a planet has the lowest orbital speed, the lowest kinetic energy and the highest potential energy.

The Big Bang Theory

It has been theorized that the birth of the universe began with an intense explosion of matter and energy. Prior to this explosion, all matter and energy was concentrated in a very small area.

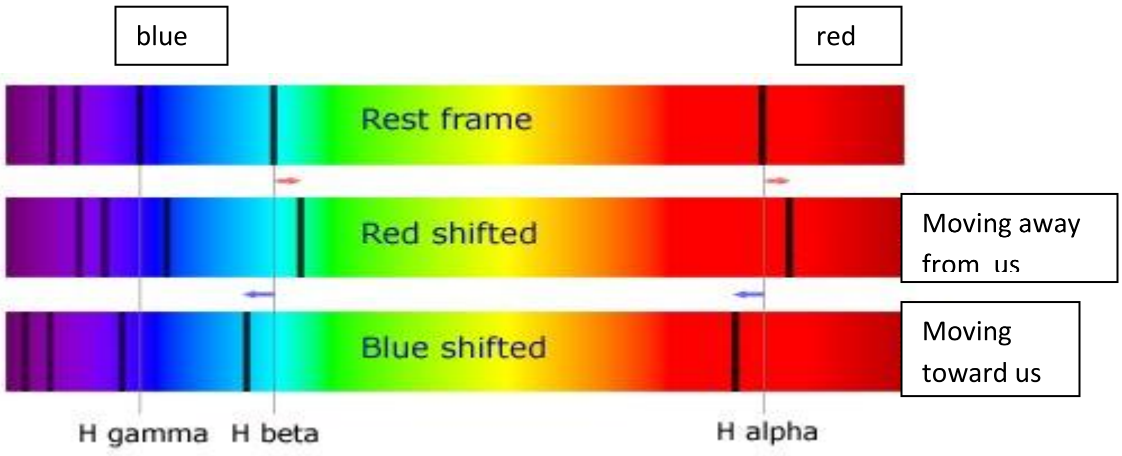
In the nanoseconds after the explosion, subatomic and atomic particles formed, and atoms came together to form hydrogen and helium.

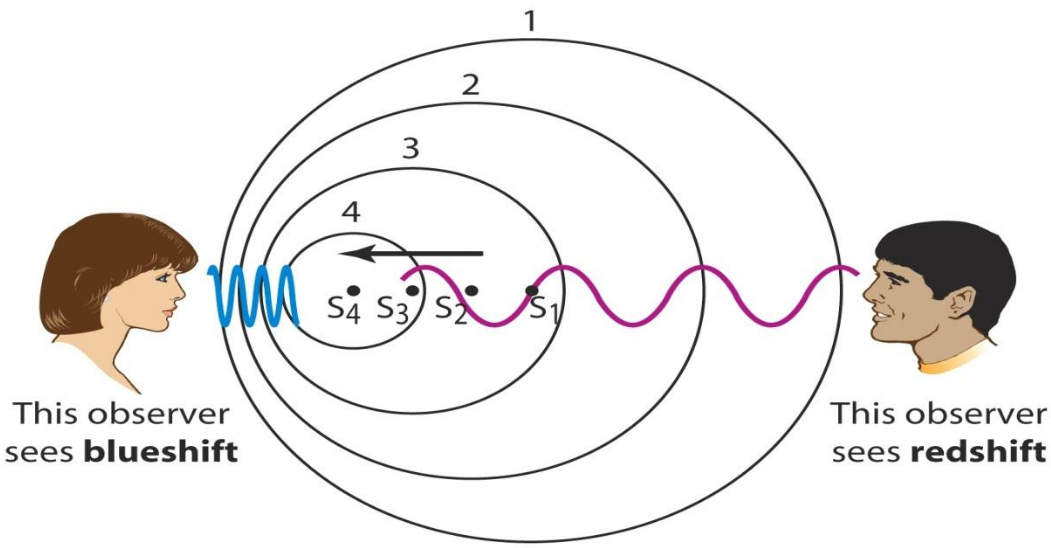


Evidence for the Big Bang:

- Background, long-wave radiation (microwave) is found in all parts of the observable universe—a leftover from the explosion

- **Doppler Effect:** the frequency and wavelength of electromagnetic energy (visible light) coming to us from celestial bodies changes over time, and seems to move toward the red end (long wavelength) of the visible light spectrum. As objects move away from an observer, the wavelengths of light they emit stretch out and lengthen, moving toward the longer wavelengths of visible light:





<u>Structure of the Universe</u>

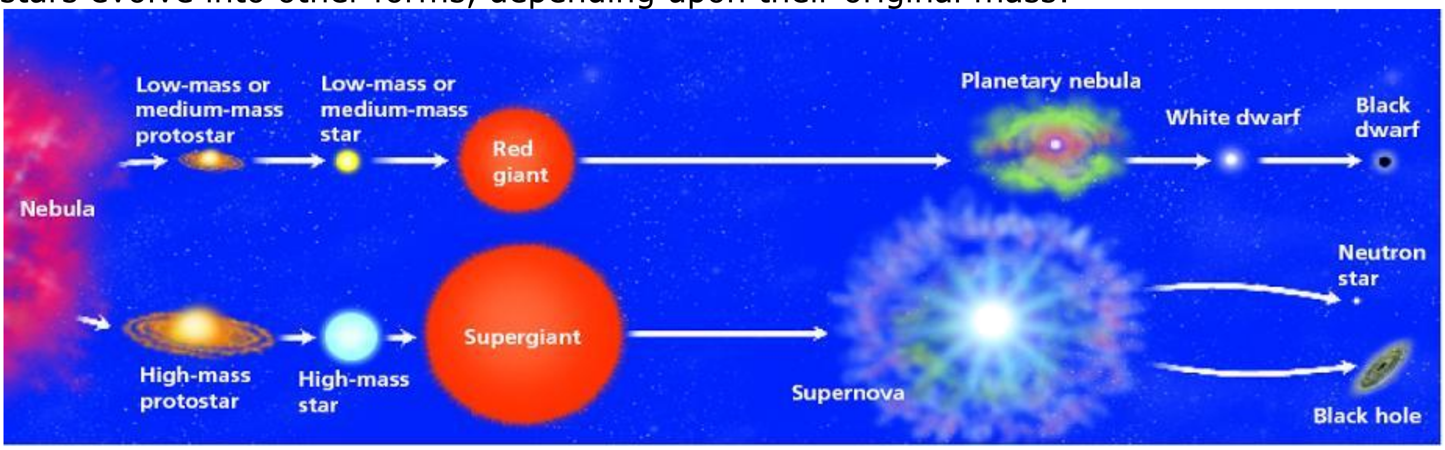
Galaxy: a collection of billions of stars, gas and dust held together by gravity. Our sun is located on one of the spiral arms of the Milky Way galaxy. Billions of galaxies exist.

Stars: originate from clouds of gas and dust that swirl, condense and form balls of gases held together by gravity. Stars are formed in huge celestial structures called nebulae.

As the mass of a protostar (early star) increases, its gravity increases and temperatures increase to a point where nuclear fusion begins. Star energy is nuclear fusion that radiates and travels through space as electromagnetic energy.

Stars are classified by their luminosity (brightness, magnitude) and their temperature. As temperature increases, star color changes from red (cooler) to blue (hotter). See Hertzsprung-Russell star chart in ESRT).

90% of all stars are categorized as main sequence stars. Stars spend most of their "life" as main sequence stars. Our sun is a main sequence star. Toward the end of their life, stars evolve into other forms, depending upon their original mass:



Asteroids: rocky, metallic celestial body that orbits the sun. Usually irregular in shape, asteroids can range from pebble-sized to 600 miles in diameter. The **asteroid belt** is located between Mars and Jupiter in our solar system. 65 million years ago, an asteroid struck Earth at the Yucatan Peninsula and created major environmental changes that led to dinosaur extinction. It measured 10 km in diameter.

Moon: a celestial body that orbits a planet

Comet: an icy, solid celestial body that orbits the sun. When it approaches the sun, some ice vaporizes into gas which form's a "tail" flowing from the comet. Comets have very eccentric orbits.

Meteoroids: small particles that orbit the sun. When they hit our atmosphere, they burn and streak across the sky as meteors. If a meteoroid is large enough and doesn't completely burn before hitting the Earth, it is called a meteorite.

Solar System: our solar system is about 5 billion years old. High pressure and temperatures from the sun drove less dense matter away from it; more dense matter remained closer to the sun.

Terrestrial planets: Mercury, Venus, Earth, Mars. Solid, small diameters, high density. Surfaces show impact craters. Few moons. Venus = hottest surface temperature due to its CO_2 cloud cover.

Jovian planets: Jupiter, Saturn, Uranus, Neptune. Gaseous planets with liquid or small solid cores. Planets have large diameters, low density. Have several moons or rings.