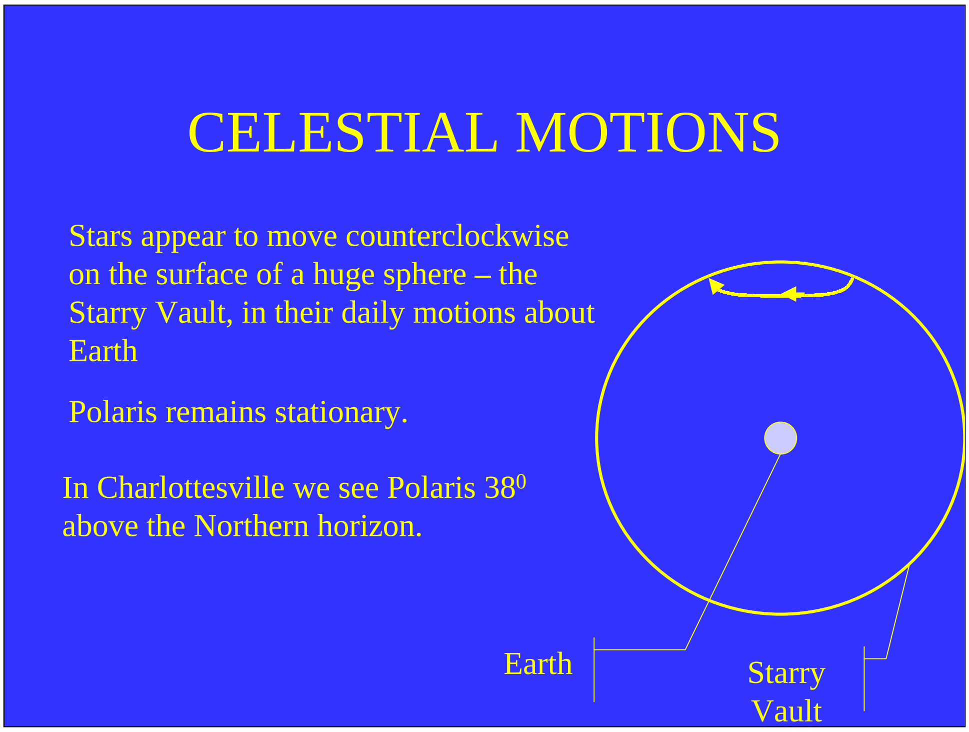
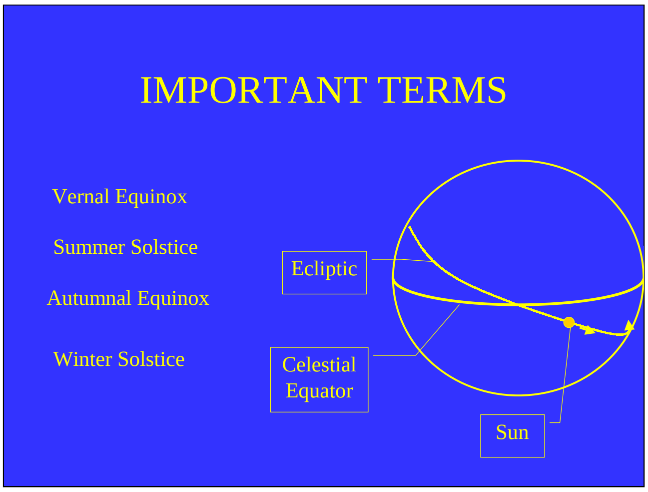



We know, of course, that the Earth and other planets orbit around the Sun which is one of about 100 billion stars in the Milky Way galaxy. When we look at the night sky we see the celestial objects from a moving, rotating Earth. Since we humans have no way of sensing this motion or rotation, ancient astronomers were unaware of them, and assumed, quite reasonably, that the Earth was stationary. It certainly *feels* stationary. In that case, everything else up there must be rotating and moving in peculiar ways to account for what we observe. Here we will describe how the various celestial objects appear to move as seen from Earth.

The stars rise in the east and set in the west, each appearing to move on a circle whose plane is parallel to that of the Earth's equator. Directly above the north pole of the earth is Polaris, a star that is nearly stationary. Moving southward from Polaris, the stars move on larger and larger circles. The stars move as they would if they were fixed on a huge sphere, called the starry vault, rotating approximately once every 24 hours and centered on Earth. Charlottesville is located at 38 degrees North Latitude, so we see Polaris 38 degrees above the northern horizon. Stars near Polaris move in circles about it. Other than Polaris, stars move in circles whose planes make an angle of 52 degrees (90 – 38) with our horizon plane.


Here we see two stars on the starry vault in their daily motions. Their circular orbits are shown much closer to Earth than they really are. If you were standing on the North Pole, you would see them move in circles parallel to your horizon plane. Here in Charlottesville at $38^0$ N latitude, the planes of the stars' orbits make an angle of $38^0$ with a line from the center of the Earth through Charlottesville. So they make an angle of $52^0$ with our horizon plane which is perpendicular to the line from the center of the Earth through Charlottesville.

This means we see the stars rise in the east, then move in an arc tilting south across the sky, then setting in the west.




The **Celestial Equator** is a line on the starry vault that lies directly above the earth's equator. The **Ecliptic** is a line on the starry vault along which the sun moves. Its name comes from the fact that the moon must be on this line for an eclipse to occur (either solar or lunar). The plane of the ecliptic makes an angle of $23.5^0$ with the plane of the celestial equator. The sun moves once around the ecliptic every 365.2422 days, so it moves about one degree in its annual orbit, moving from west to east (opposite the motion of the stars) each day. This motion is in addition to its apparent motion about the earth each day. The plane of the ecliptic makes an angle of 23 1/2 degrees with the plane of the celestial equator. The sun travels on its daily path about the earth in circles whose planes are parallel to that of the celestial equator, and in its annual motion, moves along the ecliptic.

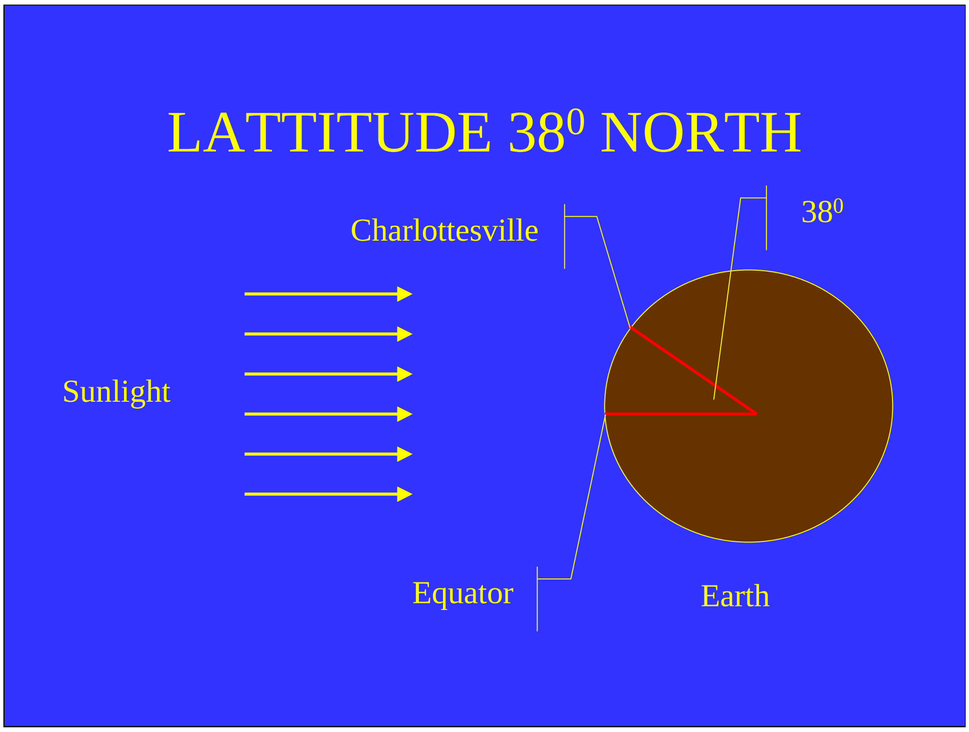
**Vernal equinox:** The point where the ecliptic crosses the celestial equator with the sun moving toward the northern half of the heavens. This happens around March 21.

**Summer Solstice:** The most northerly point on the ecliptic. This happens around June 22. In the northern hemisphere, this Is the day when the sun at noon is at its highest point in the sky.

**Autumnal Equinox:** The point where the ecliptic crosses the celestial equator with the sun moving toward the southern half of the heavens. This happens around September 23. When the sun is at an equinoctial point, days and nights are of equal length all over the earth (except for the two poles where there is no distinction between day and night).

**Winter Solstice:** The most southerly point on the ecliptic. The sun is at the winter solstice around December 22.

Why is it hot in the summer and cold in the winter? Many people when asked this question will guess that the sun must be closer during the summer and farther away in winter. This guess fails to explain why the seasons are reversed in the southern hemisphere. The chief cause of temperature variations throughout the year is the change in angle of incidence of the sun's rays.




A line from Charlottesville to the center of the earth, which defines what we mean by straight up and straight down, makes an angle of 38$^0$ with a line from the center of the earth to the equator. The above diagram is drawn for the Earth at an equinoctial point so the sun is directly above the equator hence its rays are parallel to a line from the center of the earth to the equator drawn towards the sun. So at noon on the vernal or autumnal equinox, the sun's rays are incident on Charlottesville at an angle of 38$^0$ from the vertical.

At the summer solstice, the sun is 23.5$^0$ to the north of the equator. This means that the sun's rays at noon on that day are incident on Charlottesville at an angle of 38 – 23.5 = 14.5$^0$ from the vertical. At noon on the winter solstice, the sun's rays arrive at an angle of 38 + 23.5 = 61.5$^0$ from the vertical. Because of this angle change, more heat energy from the sun is absorbed by the land during the summer than during the winter. About twice as much solar energy is incident on Charlottesville around noon on the summer solstice than on the winter solstice. This is a significant change, and is what causes the seasonal temperature variations that we observe.

# MOON

Siderial Period: Time for the Moon to orbit Earth and realign with a star. Equal to 27.32 days.
Synodic Period: Time for the Moon to orbit Earth and realign with the Sun. Equal to 29.53 days.

Zodiac: A band extending $8^0$ on either side of the ecliptic. The Sun, Moon, and planets move through the zodiac.

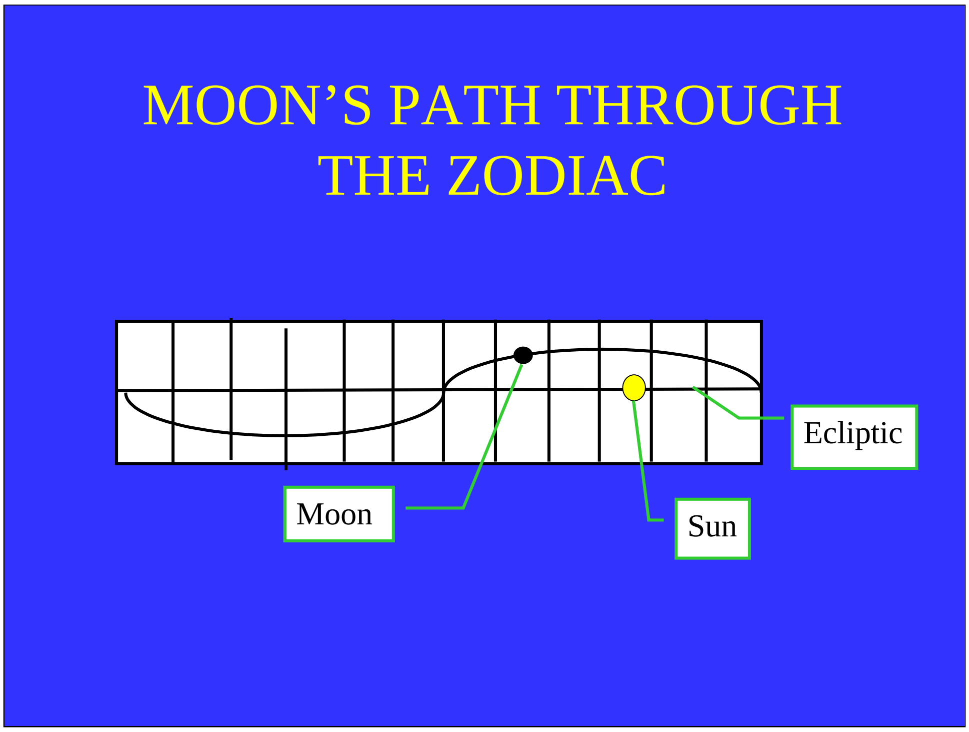
The Moon was more interesting than any of the planets to the ancient astronomers. It was visible more of the time, was closer and larger, and could be observed with greater precision than the planets. Many of the older calendars were based on a lunar rather than solar cycle. And, the Moon played a special role in eclipses, both lunar and solar, which were regarded as spectacular and significant.

The siderial period of the Moon is the time it takes to make one orbit of the Earth relative to the stars. This is what an observer outside our solar system would call its period about earth.

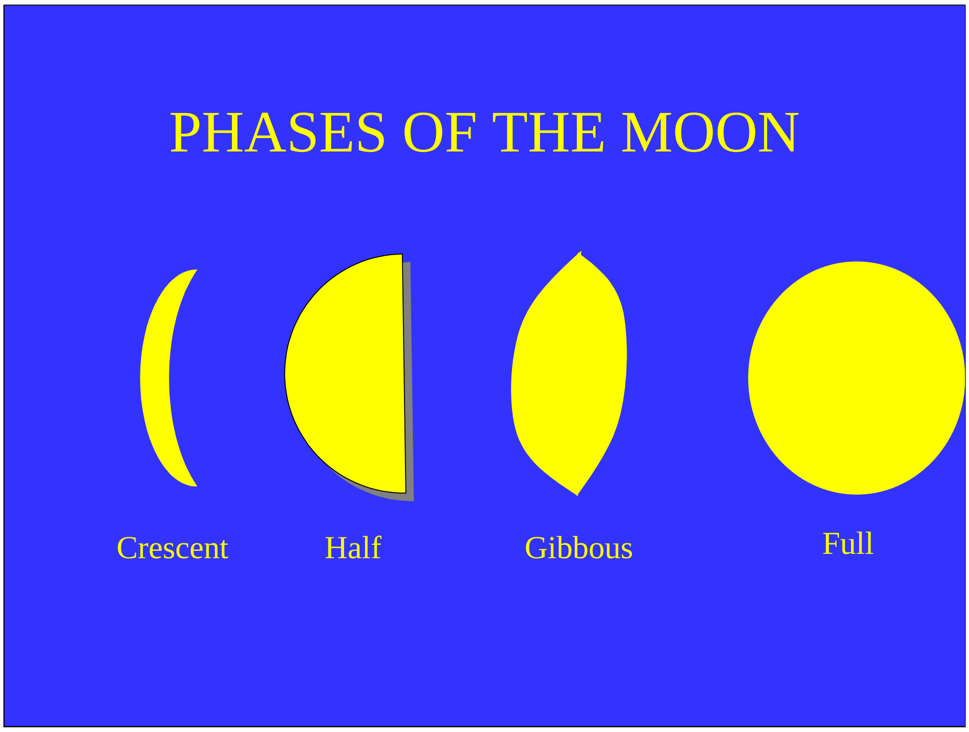
There is another different way way to state the Moon’s period: The time it takes to go once around Earth and realign with the Sun. This is the time between full Moons, or new Moons. Calendars based on a lunar cycle use this period as a starting point.

The reason the synodic period is larger is that the Earth has moved in its orbit around the Sun as the Moon was orbiting Earth, so the angle to the Sun has changed. The Moon has farther to go to realign with the Sun. It must go about 1/12 of a rotation farther since this is how far Earth has moved during that month.

The ecliptic is a circular line on the starry vault along which the sun moves in its annual motion. The Moon and planets move in orbits close to the ecliptic. The Zodiac is a band $16^0$ wide and centered on the ecliptic. The Moon and planets all move within that band in their orbits. Since ancient times the Zodiac has been divided into 12 constellations corresponding roughly to the 12 months of the year. Astrologers use these constellations in fortune telling.




The ecliptic is so named because the Moon must be on it for an eclipse to occur. Above we see the Zodiac divided into its 12 constellations with the Sun and Moon moving to the left on their annual journey. The Moon’s orbit is inclined at an angle of $5^0$ to that of the Sun about Earth (or in modern terms, of the Earth about the Sun) so in this diagram the Moon follows a sinuous line going above and below the straight line of the ecliptic. Only when the Moon crosses the ecliptic can there be an eclipse of either the Sun or Moon.

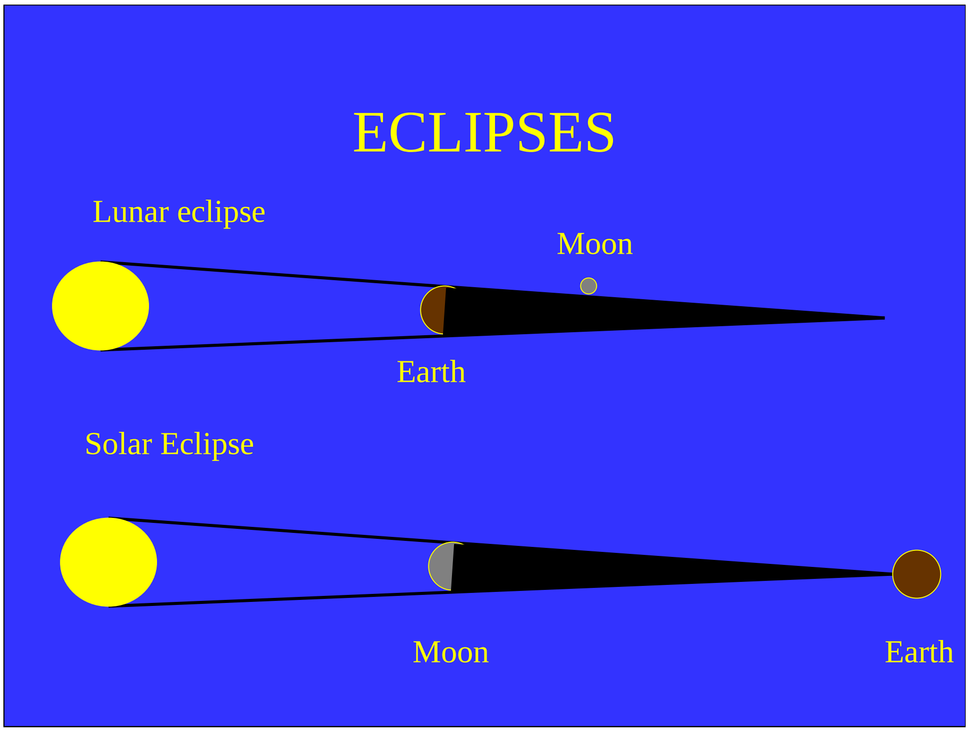



The phases of the Moon are changes in its apparent shape as seen from Earth caused by the fact that we see only the illuminated part of the Moon. The shaded part is nearly invisible to us. The Sun shines on the Moon illuminating the side toward the Sun. We look at it seeing the side facing Earth. As the Moon orbits around Earth, when it is in **opposition** to the Sun (on the opposite side of the Earth from the Sun) we see it fully illuminated – ie we see a full Moon.

When the Moon is lined up with the Sun on the same side of Earth as the Sun, we see it in **conjunction** with the Sun, and the side facing us is facing away from the Sun, so we see a new Moon.

In between we can see a crescent (convex on one side, concave on the other), a half moon (shadow border is a straight line), and a gibbous moon (convex on both sides).

The Moon moves all the way from between Earth and Sun to being on the opposite side of Earth from the Sun, and in doing so exhibits a full set of phases. The Greeks realized the origin of the phases of the Moon. No one was able to see the shapes of the planets in the night sky until Galileo made use of his telescope, at which time the phases of Venus became a very important observation.




When the Moon passes through the ecliptic, and at the same time is lined up either in conjunction with or in opposition to the Sun, an eclipse can occur. If the Moon's orbit were along the ecliptic, then there would be a lunar and a solar eclipse every month. But because of the $5^0$ tilt of the Moon's orbit, these alignments are rather rare.

Lunar eclipses are less rare, happening every other year or so. That is because the Earth's shadow is larger than the Moon so the chances of the Moon passing through it are larger. The Moon can be a little above or below the ecliptic and we will still see at least a partial eclipse. Also, a lunar eclipse is visible to roughly half the people on Earth since anyone on the side of Earth facing the Moon when the eclipse occurs can see it (if the weather is clear).

A solar eclipse is rarer because the Moon's shadow at the distance of Earth is very small – almost a point on the surface of the Earth. So when a solar eclipse does occur, only a small portion of the human population can see it.

# LUNAR ECLIPSE


This clip shows a lunar eclipse that will occur in 2007. It takes about two hours for the Moon to pass through the umbra, or dark part of the Earth’s shadow. The partial shadow region, or penumbra, is shown as well. The borders of the umbra and penumbra are shown sharper than they actually appear, in fact the penumbra is difficult to notice by eye at all.

# SOLAR ECLIPSE

This view of Earth during a solar eclipse shows how small the umbra of the Moon is on Earth. The penumbra is much larger. People living within the region covered by it will see a partial solar eclipse.

## MOTIONS OF THE PLANETS

The five planets visible by naked eye are:

Mercury
Venus
Mars
Jupiter
Saturn

# VENUS RETROGRADE MOTION

# VENUS AND MERCURY RETROGRADE MOTION


QuickTime Movie