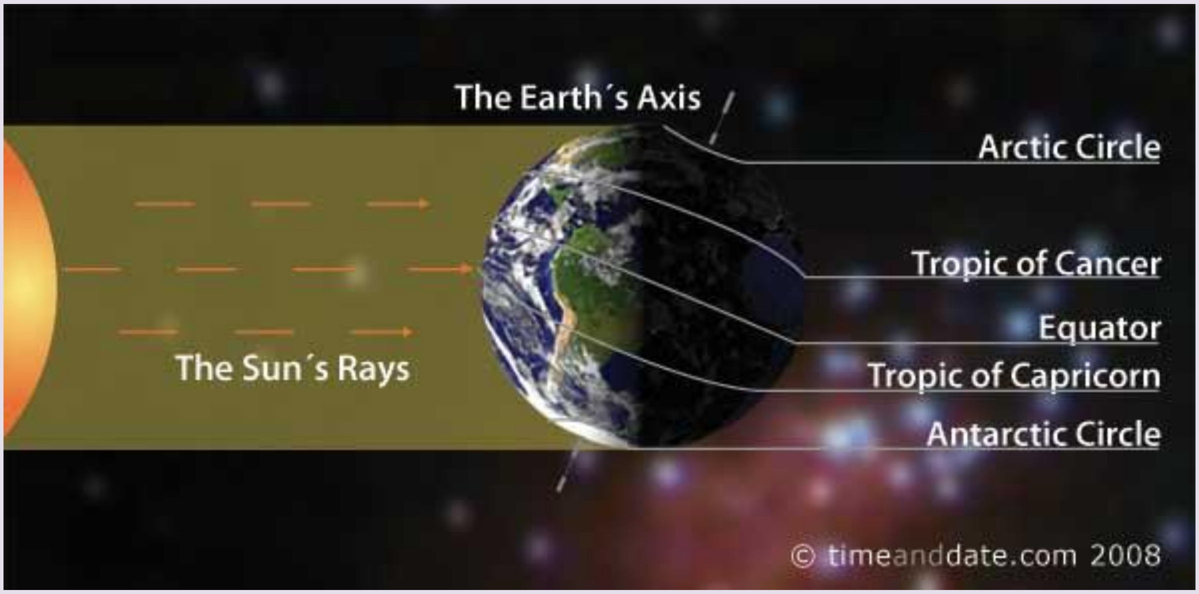
CELESTIAL CLOCK - THE SUN, THE MOON, AND THE STARS

INTRODUCTION

This is a scientific presentation to provide you with knowledge you can use to understand the sky above in relation to the earth. Before there were clocks ancient people kept time using the sun, moon, and stars. They counted hours, days, months, seasons and epochs this way. We will explain how they did it.

THE SUN – MEASURING THE YEAR

The earth is tilted on its axis at 23.44°. Winter Solstice is the one day a year the position of the Sun as it is seen directly above a spot in earth reaches its lowest latitude. This spot will be somewhere on the Tropic of Capricorn. On this day[1] locations on the Earth above the equator receive their lowest sunlight of the year, and locations below the equator receive the most sunlight of the year.



The orbit of the earth around the Sun is not a perfect circle. At the farthest point from the Sun, the earth is 152 million kilometers away. At the nearest point to the Sun, the earth is 147 million kilometers away. Coincidentally, Solstice occurs 12 days before the earth reaches its nearest point to the Sun, usually on January 3rd.

<u>The lines on the Earth tracing where the Sun is directly overhead swirl around the earth like the tight peelings of an orange</u>. Starting at noon on the Winter Solstice the Sun touches a spot on the Tropic of Capricorn. In the following 24 hours the Sun traces its journey around the earth moving close to the line of the Tropic of Capricorn but ever so slightly North as it goes so that at noon the next day it is at a

[1] December 21 or 22

different spot 0.26° North[2] and 1.0° West[3] of its starting point the previous day. When it reaches the Tropic of Cancer it reverses its motion and moves 0.26° South but continues advancing 1.0° West.

The Sun is only directly overhead at most once a year any place on earth. Outside the band of the Tropic of Capricorn to the Tropic of Cancer the Sun is never directly overhead at any time of the year.

Equinox is the point where the Sun is directly overhead at the Equator. This happens twice a year, at March Equinox and at September Equinox, but at different places on the Equator. This is a significant day in the calendar because there are exactly 12 hours of daylight and 12 hours of night. On this day every place on Earth has almost exactly equal hours of night and day.[4]

The amount of time it takes for the earth to start at a spot where the Sun is directly above the Tropic of Capricorn and return back to another spot directly above the Tropic of Capricorn is called the "Tropical Year", which is 365.2422 days.

From one year to the next, the spot where the Sun is directly overhead shifts to the West by 86 degrees of longitude, or the spot moves roughly 24% of the globe to the West[5]at that latitude. The reason for the shift is the fraction at the end of the solar year: 365.242 days. If the earth rotated a whole number of times each year it orbited the Sun, one year later it would cross at the same spot it started the previous year. The fact the rotation is fractional means the spot where the Sun arrives one year later is further West each year: i.e. advancing in the same direction as the Sun moves. The amount of advance is 0.12° per day (86°/365 days).

In order for the Sun to be close to directly overhead every spot on earth within the band of the two Tropics would take 4.13 years (1/.242). By 'close' we mean within 0.06° East to West (0.12°/2) and 0.13° North to South (0.26°/2) of a point where the Sun is directly above. At the Equator 0.13° is 14.5 km.

Why did ancient people use Equinoxes to measure years? The answer is the length of a year is not an even number of days therefore it was necessary to mark the times between annual Equinoxes to determine when a year was completed. The numbers of hours of day and night at the Equinoxes are equal. The determination of an Equinox is somewhat simpler to prove than a Solstice.

Did the ancients track the Equinox for practical reasons or for spiritual reasons? The answer is both. We see monuments everywhere in the ancient world oriented to the Equinox. This is how they kept time.

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[2] There are 46.88° between the Tropic of Capricorn and the Tropic of Cancer. The Sun moves from Capricorn to Cancer in 181.7 days and from Cancer to Capricorn in 183.5 days. Therefore the average daily motion is 46.88° / 181.7 = 0.26° / day and 46.88° / 183.5 = 0.26°. The orbit of the earth is not a perfect circle, hence diff. in days.

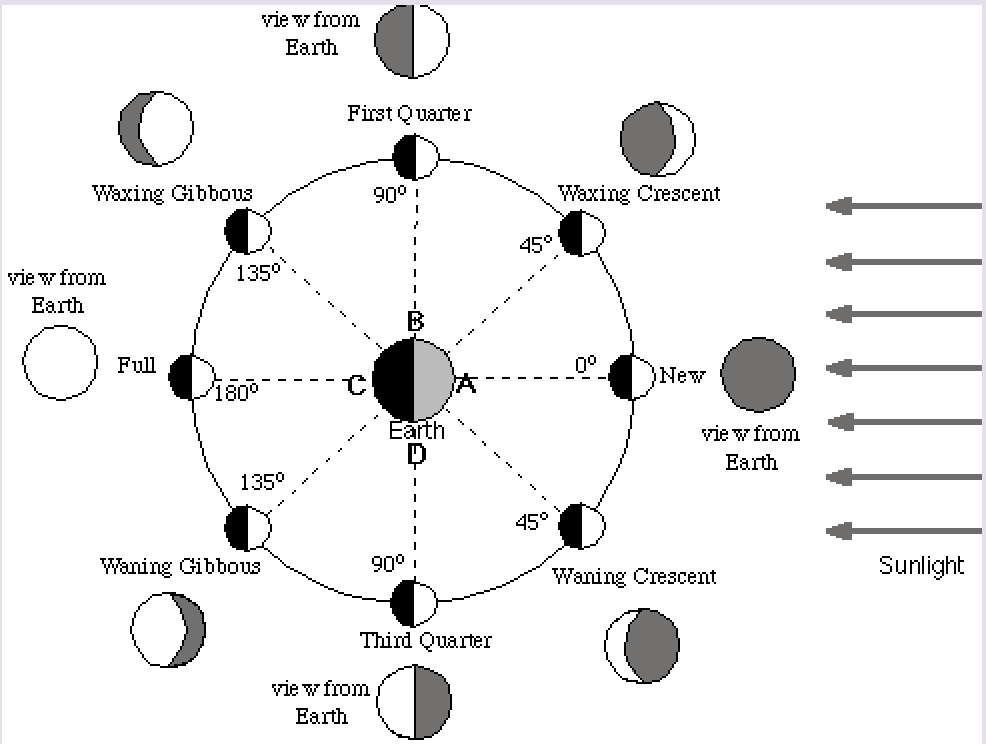
[3] As the Earth rotates around the Sun it returns to the same spot a year later. The location of the Sun on the earth at noon each day moves around the earth at the rate of 360° / 365 days ~ 1.0° per day.

[4] It is not exactly exact when the Sun passes off the equator because the moment the earth passes noon on the Equinox the tilt of the Earth begins to ever so slightly to manifest itself. The tilt manifests at a rate of 0.26° per day. In one hour the tilt will manifest at 0.0109°. In one second the tilt will manifest at 0.0002°. If noon occurs 12 hours later on the opposite side of the planet, the tilt by that time would be 0.13°. This would cause a 0.14% difference between day and night (0.13°/90°). The difference would amount to 1.04 minutes (0.14% x 12 hours x 60 minutes per hour). This is a small but measureable difference.

[5] Example: Longitudes: 2011 September Equinox = 41°51'E vs. 2012 Sept Equinox 44°8'W (www.timeanddate.com)

THE MOON – MEASURING THE MONTH

The orbit of the moon is inclined slightly relative to the equator of the earth by 5.15°. The band of earth where the Sun can be seen directly overhead is 46.88° wide: 23.44° north of the Equator and 23.44° south of the Equator. The band of earth where the moon can be seen directly overhead is 57.18° wide: 28.59° north of the equator, and 28.59° south of the Equator.



The Sun-Moon angle is the angle defined by Sun->Earth->Moon with Earth (where you are) as the angle vertex. As the Sun-Moon angle increases we see more of the sunlit part of the Moon. Note that if this drawing were to scale, then the Moon would be half this size and its orbit would be about 22 **times** larger in diameter and the Sun would be about 389 **times** farther away than the Moon! [6]

The moon orbits the earth every 27.32 days, but because of the fact the earth is turning in the same direction as the moon is orbiting the moon appears from the perspective of a viewer on the earth to return to the same phase every 29.53 days.

When viewed from the Northern hemisphere looking South, the moon orbits around the earth in a counter-clockwise direction. In other words, from that perspective the moon moves across the sky from West to East, in the opposite direction the Sun moves in the sky.

The mean radius of the moon is 1,737 km (27.3% of the earth's radius). The volume of the moon is 1/50th the volume of the earth. The surface of the moon is 1/13.5th of the surface of the earth. The mass of the moon is 1/81.3rd of the mass of the earth. The distance, center to center, from the earth to the moon is 384,405 km or 110,646 moons away. Light takes 1.26 seconds to get to the moon.

[6] http://www.moonphases.info/moon_phases.html

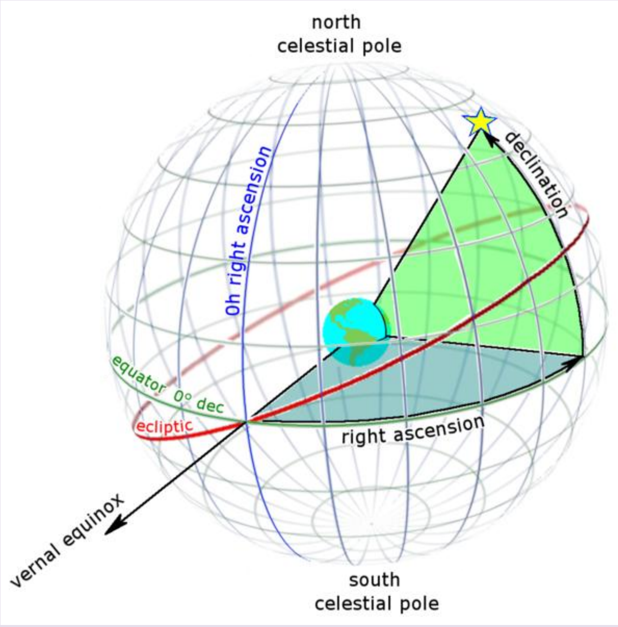
From the earth, the moon appears to be 29.3 to 34.1 arc minutes in width. An arc minute is equal to 1/60th of 1 degree (1/360) or 1/21,600 of the sky. So, the moon appears to be between 1/633 and 1/737 of the sky. The sky is all the way around the earth in a great circle.

Ancient people used the phases of the moon to count the 'moon-ths' or months. The year has 365.24 days, so it divides into 12 months of 29.5 days with 11.24 days left over. Calendars that count time based on equal months of 29.5 days need to add a month every three years to catch up. Even after adding the extra month, there are still 4.24 days lost. So, every twenty one years, another month is added. By this method the difference every twenty one years is only 0.08 day. **It would take 7,434 years before such a lunar calendar would be one whole day off true**. **That is a very accurate clock!**

THE STARS – MEASURING EPOCHS

Stars are points of light that are fixed in the heavens, but due to the rotation of earth they trace a circle across the night sky. Only at the extreme pole does a star not move. The stars trace circles around the **North and South celestial pole**. The closer the stars are to either pole, the tighter the circle.

Stars are assigned location co-ordinates in a similar way as locations on earth. Imagine the stars appear on the inside of a sphere looking outward from the vantage point of the earth. The co-ordinates of a star are based on the declination and right ascension (see diagram below).



[7]

Declination is measured relative to the **celestial equator**, which is the line which divides the sky between the North celestial pole and the South celestial pole. **Right ascension** is zero at the vernal Equinox and increases moving East in the sky when viewed looking South while in the Northern hemisphere. Coordinates can be expressed in hours and minutes of rotation or in degrees.

[7] http://en.wikipedia.org/wiki/File:Ra_and_dec_on_celestial_sphere.png

On the diagram above you will see a red line called the **ecliptic**. This is the path the Sun takes when it moves across the sky. The Sun moves from East to West across the sky when viewed looking South while in the Northern hemisphere. The stars also move from East to West across the sky. This is because when looking down from above the rotation of the earth is counter-clockwise and the orbit of the earth around the Sun is also counter-clockwise.

The speed of the Sun as it appears from earth is so similar to the speed of the stars the Sun looks like the Sun is stuck against the background of the starry heavens as they both move across the sky. However, the Sun is moving at the rate of about 1° per day opposite to the direction of the motion of the stars. In a year the Sun will move backwards through all the constellations of the ecliptic to return to the point where it started.

The plane of the Milky Way, or the **galactic plane,** is inclined about -65° to the celestial equator. This puts the galactic plane on the opposite side of the celestial equator to the ecliptic. Since the ecliptic is tilted 23° to the celestial equator, that means the galactic plane is almost perpendicular to the ecliptic (65° + 23° = 88°).

To picture this, imagine the solar system as a wheel spinning at a distance from the center of the galaxy. The orientation of the wheel is not as if it were attached by an axle to the galactic center. If that were true, the center of the Milky Way would appear at one of the two celestial poles. Rather, **relative to the Milky Way galaxy the solar system is oriented like a tennis racket, as if attached from the side to the pivot of the turning motion**. In this case, the Milky Way crosses the plane of the ecliptic with equal parts on either side of it. The center of the Milky Way is located very close to the spot where the two planes cross.

If we picture the **twelve constellations** occupying the band of star signs through which the Sun passes on its annual journey, the galactic plane crosses the ecliptic at Sagittarius on one side and at Gemini on the other side. Because of the effect of the Milky Way, the stars in the vicinity of these constellations are thick. In comparison, the star background of most of the other star signs through which the Sun passes are not as dense.

The **Vernal Equinox** is the place where the ecliptic plane crosses the celestial equator at the Spring Equinox. The word ‘vernal’ means: ‘like spring’ or ‘youthful’ (Latin).

In a phenomenon known as the **precession of the Equinoxes**, the Vernal Equinox moves on the line of the ecliptic very slowly. The earth has a slight bulge at the equator which is affected by the gravity of the moon. One effect of the gravitational pull of the moon is **the point in the sky which all stars appear to rotate around slowly moves in a little circle over time**. At the moment this point is the Pole Star, but only five thousand years ago this point was a different star. Another effect of the gravitational pull of the moon is **the Vernal Equinox moves advances along the line of the ecliptic at a tiny rate of 50.3 arc seconds per year**.

There are 1,296,000 arc seconds in a complete circle. **It therefore takes 25,765 years for the Vernal Equinox to make a complete circuit of the ecliptic**. That makes the transit through the stars signs on the ecliptic at a rate of 2,147 years per star sign on average.

To give an idea how small the progression of the Equinox is, consider this example. The moon appears in the sky to be roughly 30 arc minutes in diameter. If the moon were stationary in the sky on the ecliptic, it would take 36 years for the Vernal Equinox to transit the moon. Looking at it another way, it takes **72 years for the Vernal Equinox to move 1 degree**. If three score and ten are the years of man, it takes about one lifetime or generation of man for the Vernal Equinox to move 1 degree. The average epoch is equivalent to roughly 30.7 generations (2,147 years / 70 years per generation = 30.7 generations), which is remarkably close to the average number of days in a Julian month (30.4).

The ancients marked **epochs** of history as the time when the Vernal Equinox was within the part of the sky belonging to each of the star signs along the path of the Sun. For example, the Vernal Equinox is currently in Pisces so according to ancient understanding we are now in the Epoch of Pisces.

The Vernal Equinox is moving in the direction of Aquarius. Aquarius ends February 19th and Pisces ends March 20th, so **the months move in time in an opposite direction to the epochs**. The month of Pisces is after the month of Aquarius, but the epoch of Pisces is before the epoch of Aquarius.

Now we understand why the ancients took such great pains to measure the Equinox. They were not only interested in knowing when one year ended and another year began, they were also observing where the Vernal Equinox appeared on the ecliptic so they would know when one epoch ended and another epoch began.