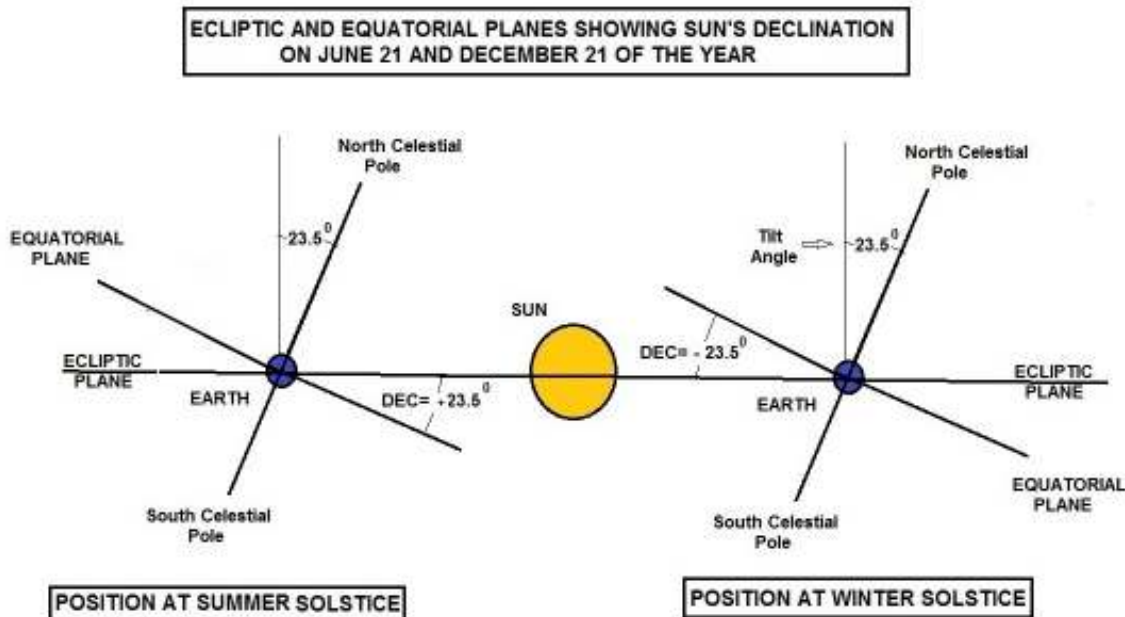


EXPLAINING THE SEASONS AND LOCATING THE NORTH AND SOUTH CELESTIAL POLES

Although people are very aware of the seasons, most cannot give a good explanation of why they occur and how they are produced because the earth's rotation axis is not perpendicular to the ecliptic plane formed by the earth's trajectory about the sun. Likewise many have learned in elementary school how to locate the north-star (Polaris) using the Big Dipper as a guide, but are clueless when one mentions the Celestial Sphere of infinite radius which is intersected at its north and south celestial poles by an extension of the earth's spin axis. We give here a brief explanation of both why the seasons occur and how one locates the north and south celestial poles on the Celestial Sphere.

Our starting point is the fact that the earth's spin axis is tilted at 23.5° from the normal to the ecliptic plane. The ecliptic plane is defined as the area swept out by the planets in their elliptic trajectories about the sun. It is at present not clear why this tilt angle differs from zero according to the present theory that planets were formed by gravitational condensation of a nebular disc rotating about the sun. Be that as it may, there would be no seasons and likely no magnet north pole, if this tilt did not exist. One can think of the earth as a giant gyroscope whose spin axis is fixed throughout the year as shown on the accompanying picture-



We see from the picture that, when sitting on the earth, the sun will range from its maximum local noon declination of $+23.5^{\circ}$ on June 21 and thus putting it directly above the Tropic of Cancer to a minimum of -23.5° on December 21 and thus putting it directly above the Tropic of Capricorn. Here in Gainesville, Florida

where our latitude LAT is about 29.5° , the sun will be $29.5^{\circ}-23.5^{\circ}=6^{\circ}$ from the zenith at the summer solstice. That is, the altitude above the horizon will be $ALT=\pi/2-LAT+DEC=84^{\circ}$. It will reach a much lower maximum height during the winter solstice on December 21. There the maximum altitude reached will be just $ALT=\pi/2-29.5^{\circ}-23.5^{\circ}=37^{\circ}$ from the horizon at local noon. The sun's declination varies in an approximately sinusoidal manner throughout the year as-

$$DEC = 23.5^{\circ} \sin\left(\frac{2\pi x}{365.25}\right)$$

where x represents the number of days after the Vernal (Spring) Equinox. Thus on June 21 where $x=365.25/4$ we find $DEC=23.5^{\circ}$ and on Sept. 21 at the Autumnal Equinox we are back to $DEC=0^{\circ}$. At the equinoxes the sun's declination is always zero and day and night will be equal. The four seasons of Spring, Summer, Fall, and Winter (and I am not referring to Vivaldi) are just manifestations of the sinusoidal variation of the sun's declination throughout the year. Instead of relying on declinations given by the above formula, extensive tables for the precise declination of the sun on any day in the year have been published and have been used extensively in the past. You can also find such tables on the Internet like the one at –

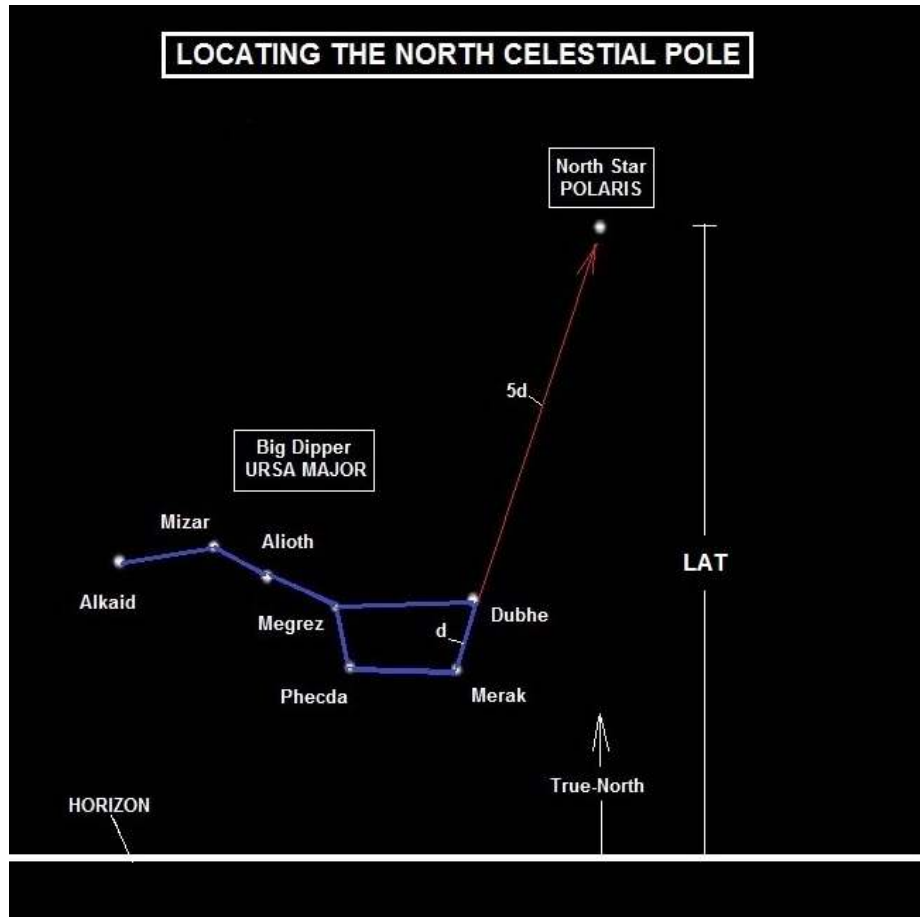
http://www.wsanford.com/~wsanford/exo/sundials/DEC_Sun.html

According to these tables, the sun's declination today (April 8th, 2013) is $DEC=+6.98^{\circ}$. The above formula gives the close approximation of $DEC=23.8\sin(35\pi/365.5)=6.97^{\circ}$ for $x=17.5$ days after the spring equinox. Notice that if the earth's tilt angle were zero, then the sun's declination would remain unchanged throughout the year and there would be no seasons.

Next let us look at the Celestial Sphere. This is an imaginary sphere of infinite radius to which the ancients thought all stars were attached. The sphere has its north and south poles defined as the intersection points of the extended earth's spin axis with the sphere. The celestial equatorial plane is formed by extending the earth's equatorial plane out to infinity and makes a right angle with the earth's spin axis. To find the precise locations of the celestial poles one can use the constellations (zodiacs) sitting on the Celestial Sphere. Remember the ancients had no idea that stars are located at different distances from us and thus thought of them as attached to the inner surface of the Celestial Sphere. They also had the mistaken belief that a person's future could be predicted by what sign of the zodiac he or she was born under (astrology). It is said that the famous astronomer Johannes Kepler, who was imperial court mathematician to king Rudolph II in southern Germany, had as his main function the casting of horoscopes for local dignitaries and that his astronomical observations were just a sideline.

To locate the north celestial pole it was observed quite early that extending a line from the front part of the Big Dipper (part of Ursa Major) one reaches the north

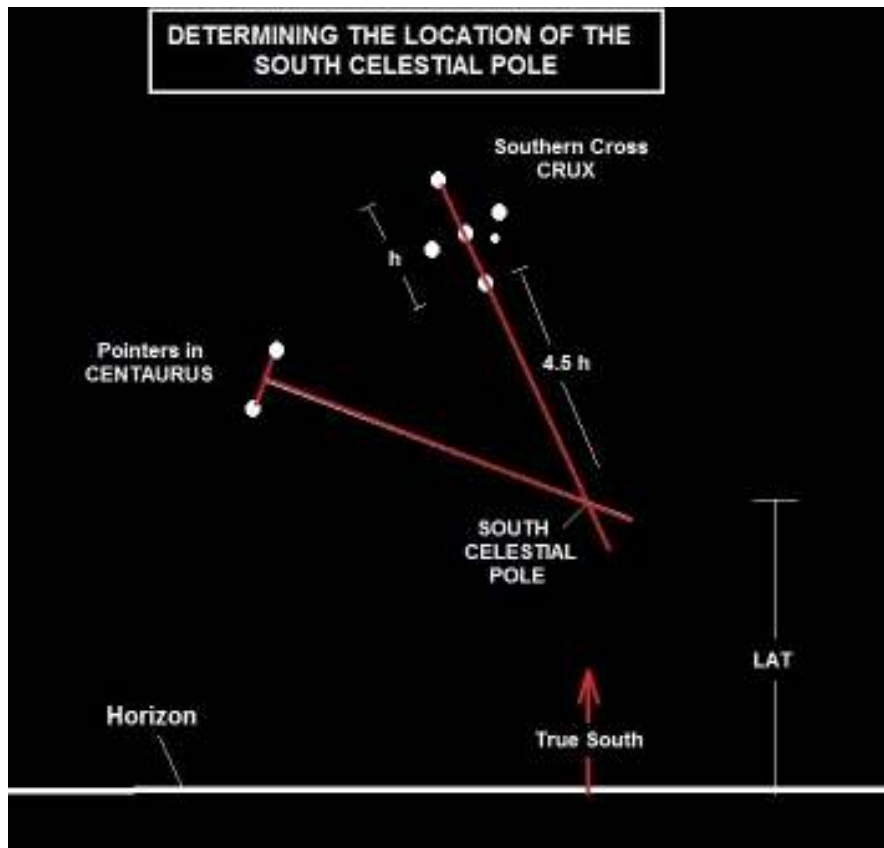
star Polaris . This star lies very close to the true north pole of the Celestial Sphere. Here is a diagram for finding the pole-



If one takes a time exposure of the northern sky, the stars will be noticed to move in circles about the north star Polaris. Once found, one has the direction of true north. Also measuring the altitude above the horizon yields the latitude LAT of the place in the northern hemisphere where one is observing from. Note this Latitude measure is independent of the season's . Much of world explorations from Diaz, Vasco da Gamma and Columbus to later explorers relied heavily on latitude measurements of the north star using astrolabes which also were able to furnish the same latitude information during day-time by measuring the altitude (ALT) of the sun at local noon. The sun elevation measurements however required an almanac giving the suns declination at a given date since $LAT = \text{Pi}/2 - \text{ALT} + \text{DEC}$. Measurements with the astrolabe and later sextant were the preferred instruments for latitude determination by sailors prior to the advent of radio and other later electromagnetic communication methods including Loran and GPS devices.

The south celestial pole has less historical significance since much of the early exploration by ships took place in the northern hemisphere. However with the opening up of South America and Australia, navigators needed to be able to locate the south celestial pole. Unfortunately there is no bright star in the immediate

vicinity of the south pole, however one can still determine where this point is located by using the Southern Cross (Crux) and the Pointer Stars in the Centaurus constellation. The procedure goes as shown in the following picture-



The south celestial pole is found at the intersection of a straight line through the southern cross and a line perpendicular to a line connecting the two bright pointer stars in the Centaurus constellation. There is no major star at the intersection point, however measuring the angle between a local horizon in the Southern Hemisphere and this pole yields the latitude of the place. In Sydney Australia the latitude is $LAT=33.8^{\circ}S$. The Australians have the Southern Cross depicted on their national flag.

Here is an interesting time exposure of the night sky taken in northern Australia by David Miller-



You can see the earth rotating beneath the Celestial Sphere. Time exposure shows a beautiful set of concentric circles centered on the south celestial pole. Note there is no bright star at the south pole unlike Polaris at the north celestial pole.

In my travels throughout the years I have been as far south as Ushuaia, Tierra del Fuego in Argentina at $LAT=54.8^{\circ}S$ and as far north as Sognefjord in Norway at $LAT=61.15^{\circ}N$. If one were to take a time exposure of the night sky at these locations the center of the resultant concentric circles would be much higher in the sky than that shown in the above photo.