Introduction to the sky

A rough estimate of your latitude can be obtained by noting the elevation angle of:

a. the Sun at noontime
b. Sirius as it transits the celestial meridian
c. Polaris
d. the ecliptic

On a clear, moonless night, far from city lights, the night sky is magnificent. Roughly 2000 stars are visible to the unaided eye. If you know where to look, you can see Mercury, Venus, Mars, Jupiter, Saturn, and even Uranus. Occasionally, a bright comet is visible. On certain nights of the year there are many meteors (shooting stars) to be seen. Sometimes man-made debris falls back to Earth and burns up in the atmosphere.

Space Shuttle fuel tank reentry, April, 1984. Lava from Kilauea volcano illuminates clouds on the horizon.

We all know that the Sun rises in the east and sets in the west. The ancient Greeks attributed this to Apollo driving his chariot across the sky.

The Sun *appears* to complete a whole circle (360 degrees) around the Earth every 24 hours. Thus, its apparent motion is 15 degrees per hour from east to west. This apparent motion is due to the rotation of the Earth.

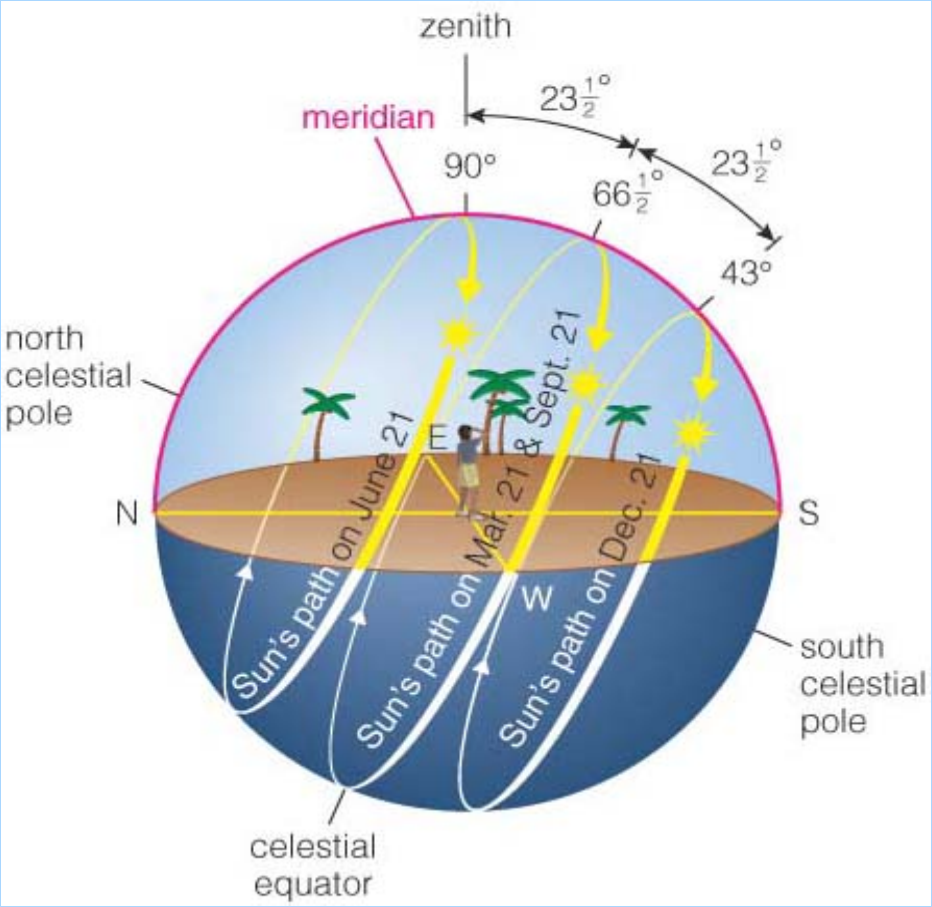
It turns out that the Sun can rise in the east-northeast, due east, or east-southeast depending on the day of the year.

Your *latitude* is equal to the number of degrees that the North Celestial Pole (near the star Polaris) is above the northern horizon.

If you're close the Earth's equator, but still in the northern hemisphere, Polaris will be low in the sky, near the horizon.

If you're above the Arctic Circle, Polaris will be high in the sky at all times.

Daily path of the Sun in the sky at latitude 23.5 deg N.



The Sun rises due east and sets due west only on the first day of spring and the first day of autumn.

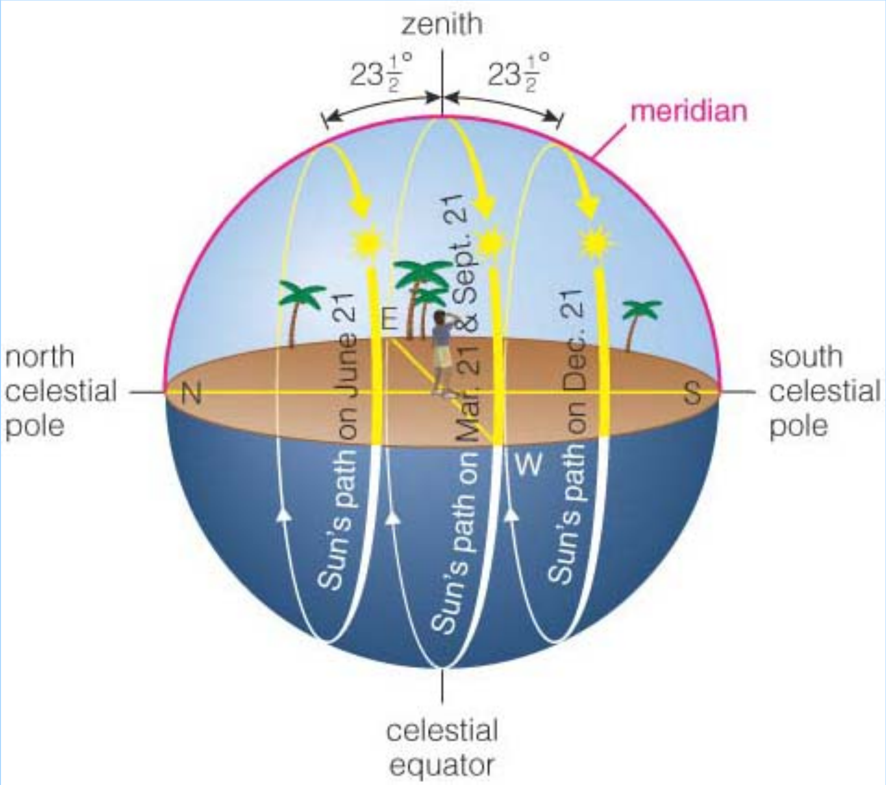
Note that the Sun at noontime on June 21st is 47 degrees higher in the sky than on December 21st.

The first day of spring occurs about March 20th or March 21st. (That's in the northern hemisphere.)

The first day of autumn occurs about September 22nd. (This would be the first day of spring in the southern hemisphere.)

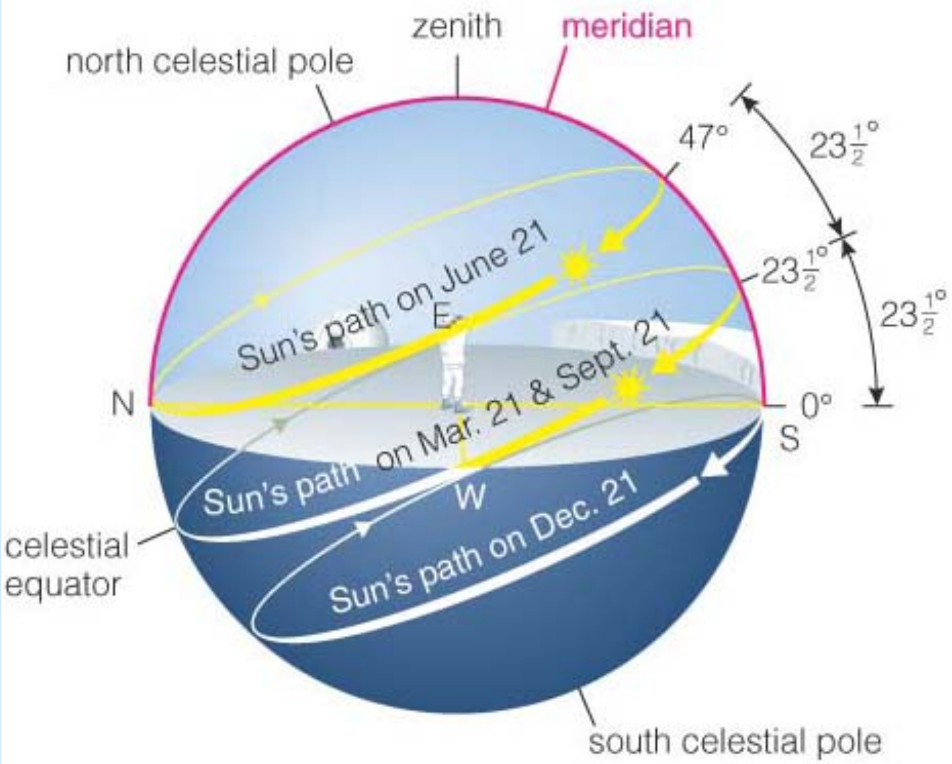
The key thing is that the equinoxes occur when the declination of the Sun is zero degrees (i.e. located on the celestial equator).

Daily path of the Sun in the sky at the Earth's equator.

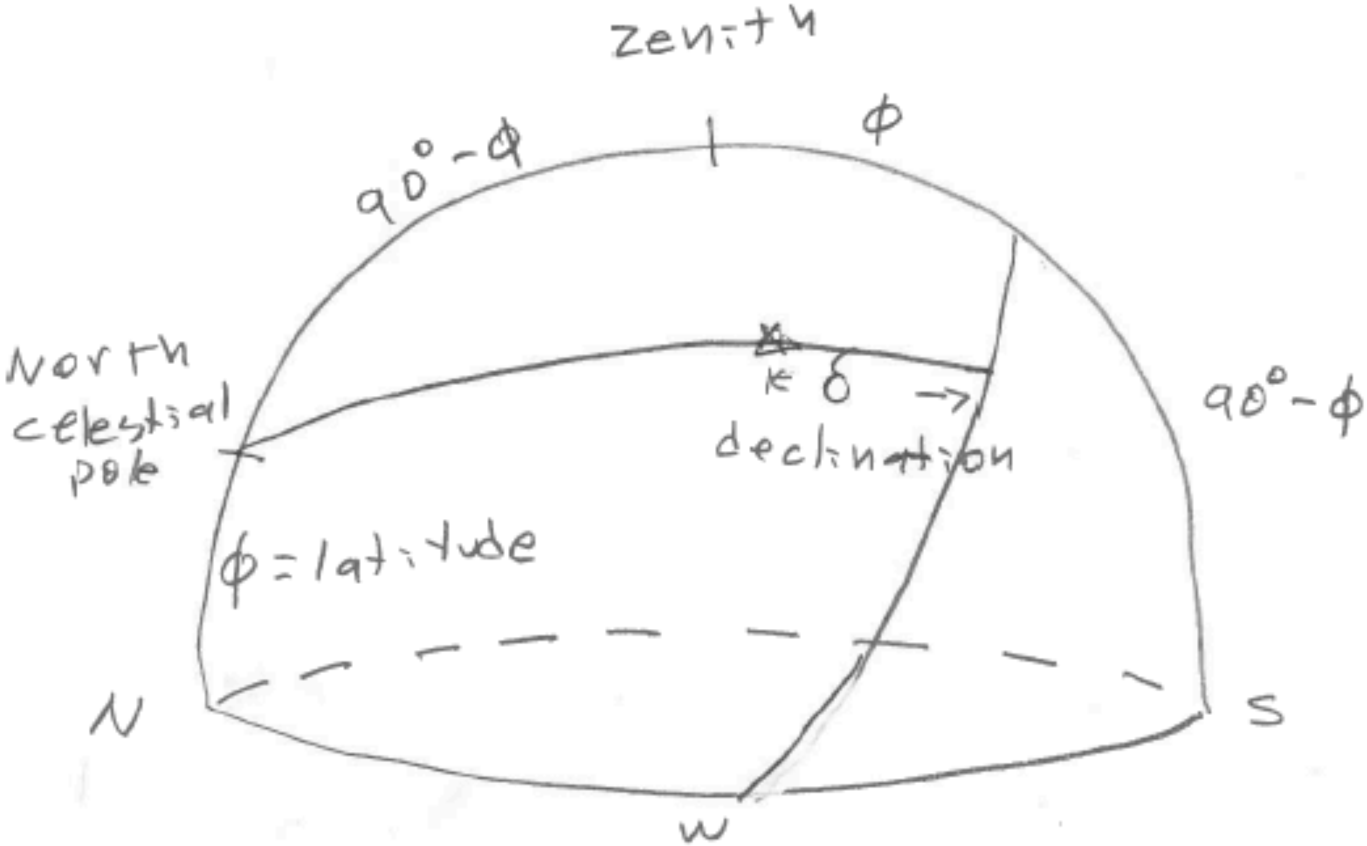


Note that the Sun rises due east and sets due west only on the first day of spring and the first day of autumn (about March 21st and September 22nd).

Daily path of the Sun in the sky at latitude 66.5 deg N. On June 21st the Sun is 47 degrees higher in the sky at noontime than on December 21st.



Note that the Sun rises due east and sets due west only on the first day of spring and the first day of autumn (about March 21st and September 22nd).

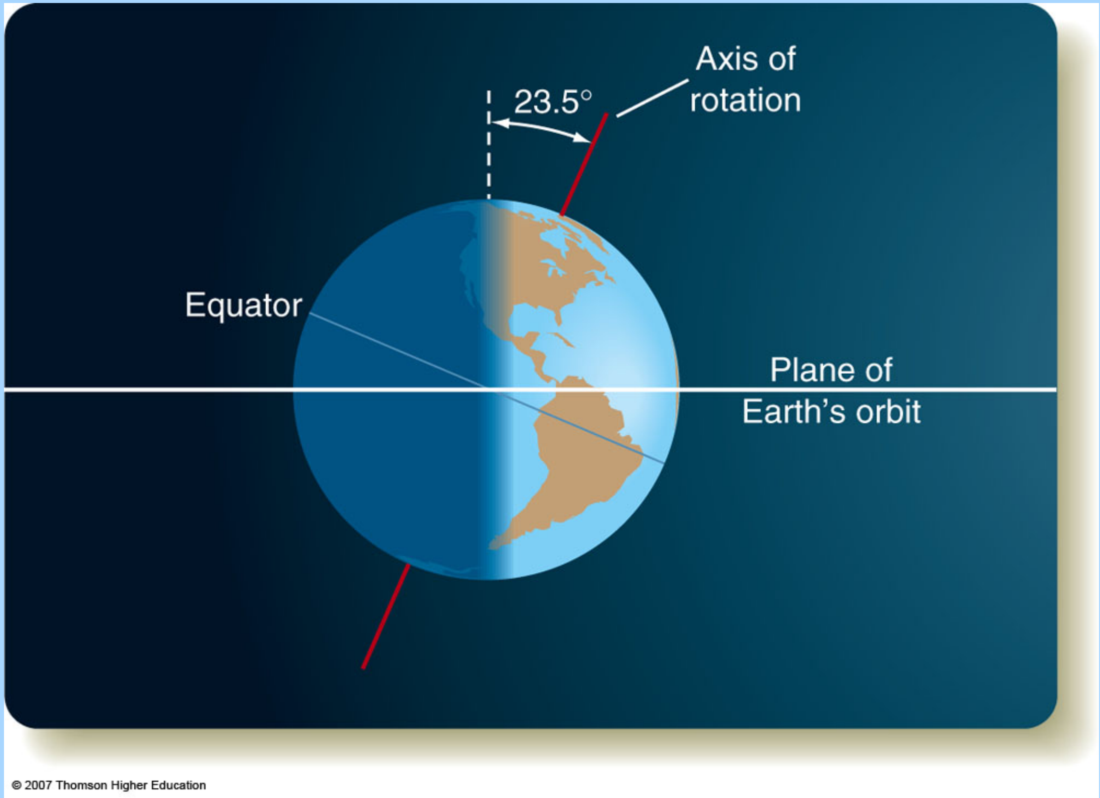


Maximum elevation above S point on horizon =

$$h_{max} = [90° - \phi] + \delta$$

Say that where you lived the Sun is 70 degrees above the horizon at noontime on the first day of summer. How high above the horizon would the Sun be at this location at noon on the first day of winter?

A. 70 deg
B. 47 deg
C. 43 deg
D. 23 deg

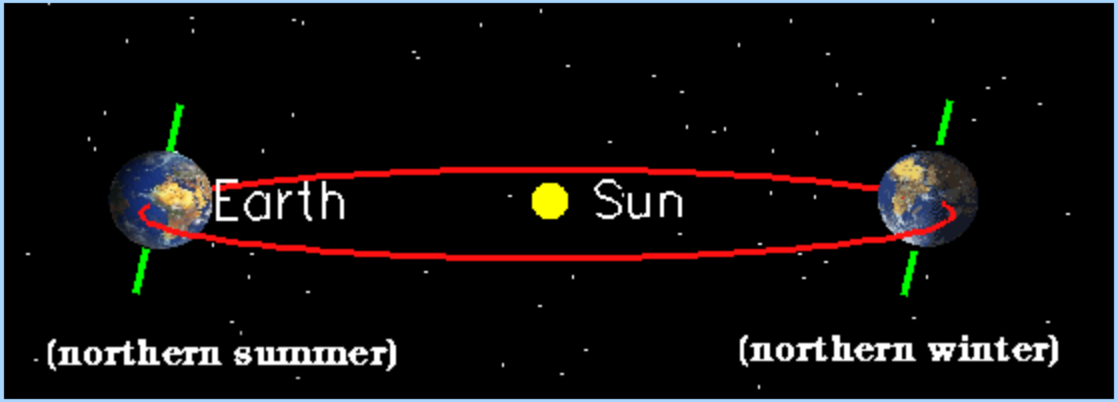


The Earth's axis of rotation is tilted 23.5 degrees to the plane of its orbit about the Sun.

When the northern hemisphere is tilted towards the Sun we have summer in the northern hemisphere and winter in the southern hemisphere.

When the northern hemisphere is tilted away from the Sun we have winter in in the northern hemisphere and summer in the southern hemisphere.

This is the cause of the seasons.



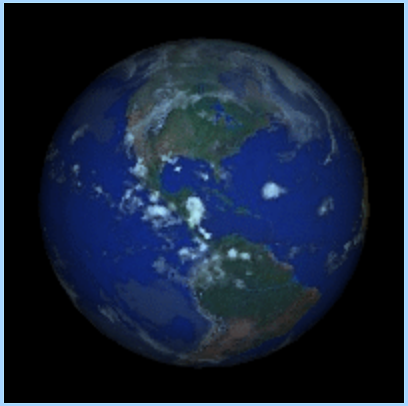


Image of the Earth as it would appear from the Sun over the course of one year.   Locations between +23 and -23 deg latitude see the Sun at the zenith twice a year at noontime.

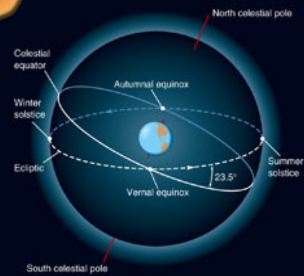
The analemma.

What you get if you take a photo of the Sun in the sky at the same time of day at the same location over the course of a year.

The Cycle of the Seasons

1 You can use the celestial sphere to help you think about the seasons. The celestial equator is the projection of Earth's equator on the sky, and the ecliptic is the projection of Earth's orbit on the sky. Because Earth is tipped in its orbit, the ecliptic and equator are inclined to each other by 23.5° as shown at right. As the sun moves eastward around the sky, it spends half the year in the southern half of the sky and half of the year in the northern half. That causes the seasons.

The sun crosses the celestial equator going northward at the point called the **vernal equinox.** The sun is at its farthest north at the point called the **summer solstice.** It crosses the celestial equator going southward at the **autumnal equinox** and reaches its most southern point at the **winter solstice.**



1a The seasons are defined by the dates when the sun crosses these four points, as shown in the table at the right. *Equinox* comes from the word for "equal"; the day of an equinox has equal amounts of daylight and darkness. *Solstice* comes from the words meaning "sun" and "stationary." *Vernal* comes from the word for "green." The "green" equinox marks the beginning of spring.

Event	Date*	Season
Vernal equinox	March 20	Spring begins
Summer solstice	June 22	Summer begins
Autumnal equinox	September 22	Autumn begins
Winter solstice	December 22	Winter begins

* Give or take a day due to leap year and other factors.

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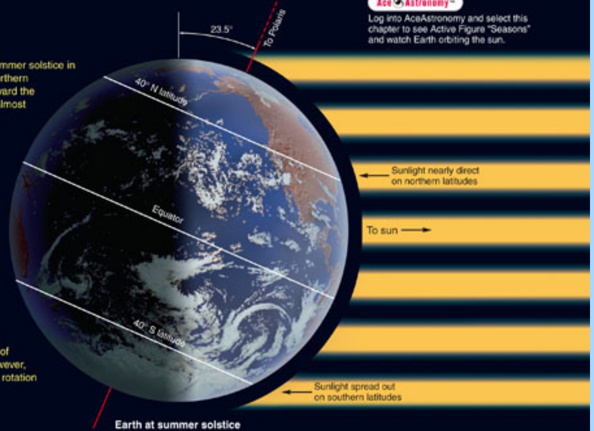
Log into AceAstronomy and select this chapter to see Active Figure "Seasons" and watch Earth orbiting the sun.

1b On the day of the summer solstice in late June, Earth's northern hemisphere is inclined toward the sun, and sunlight shines almost straight down at northern latitudes. At southern latitudes, sunlight strikes the ground at an angle and spreads out. North America has warm weather, and South America has cool weather.

Earth's axis of rotation points toward Polaris, and, like a top, the spinning Earth holds its axis fixed as it orbits the sun. On one side of the sun, Earth's northern hemisphere leans toward the sun; on the other side of its orbit, it leans away. However, the direction of the axis of rotation does not change.

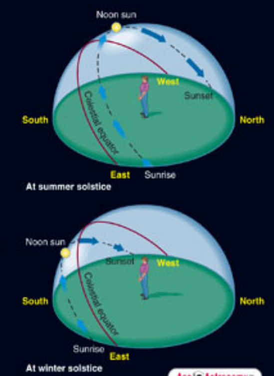


Earth at summer solstice

1c Light striking the ground at a steep angle spreads out less than light striking the ground at a shallow angle. Light from the summer-solstice sun strikes northern latitudes from nearly overhead and is concentrated.

Light from the winter-solstice sun strikes northern latitudes at a much steeper angle and spreads out. The same amount of energy is spread over a larger area, so the ground receives less energy from the winter sun.

2 The two causes of the seasons are shown at right for someone in the northern hemisphere. First, the noon summer sun is higher in the sky and the winter sun is lower, as shown by the longer winter shadows. Thus winter sunlight is more spread out. Second, the summer sun rises in the northeast and sets in the northwest, spending more than 12 hours in the sky. The winter sun rises in the southeast and sets in the southwest, spending less than 12 hours in the sky. Both of these effects mean that northern latitudes receive more energy from the summer sun, and summer days are warmer than winter days.



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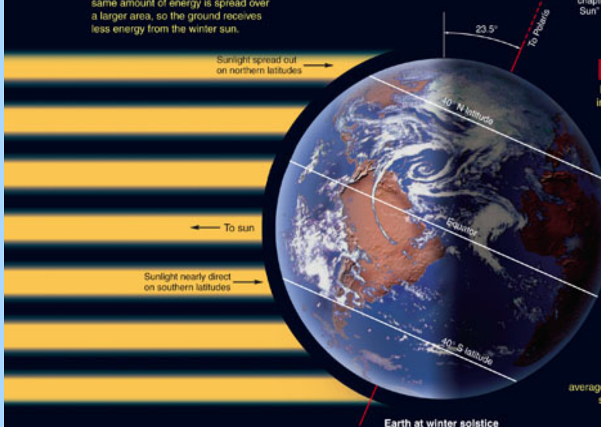
1d On the day of the winter solstice in late December, Earth's northern hemisphere is inclined away from the sun, and sunlight strikes the ground at an angle and spreads out. At southern latitudes, sunlight shines almost straight down and does not spread out. North America has cool weather and South America has warm weather.

Earth's orbit is only very slightly elliptical. About January 4, Earth is at **perihelion,** its closest point to the sun, when it is only 1.7 percent closer than average. About July 4, Earth is at **aphelion,** its most distant point from the sun, when it is only 1.7 percent farther than average. This small variation does not significantly affect the seasons.



Earth at winter solstice

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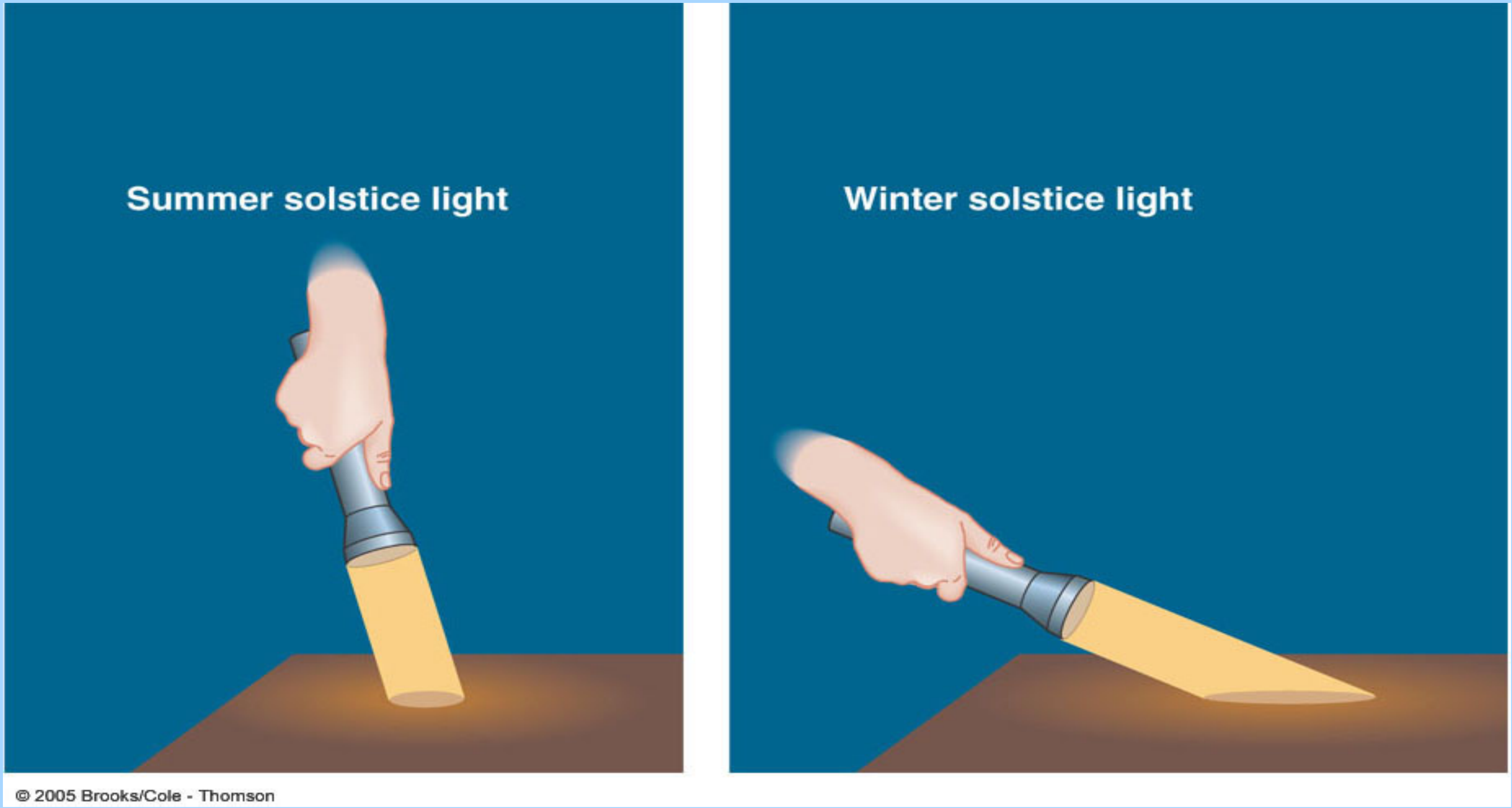
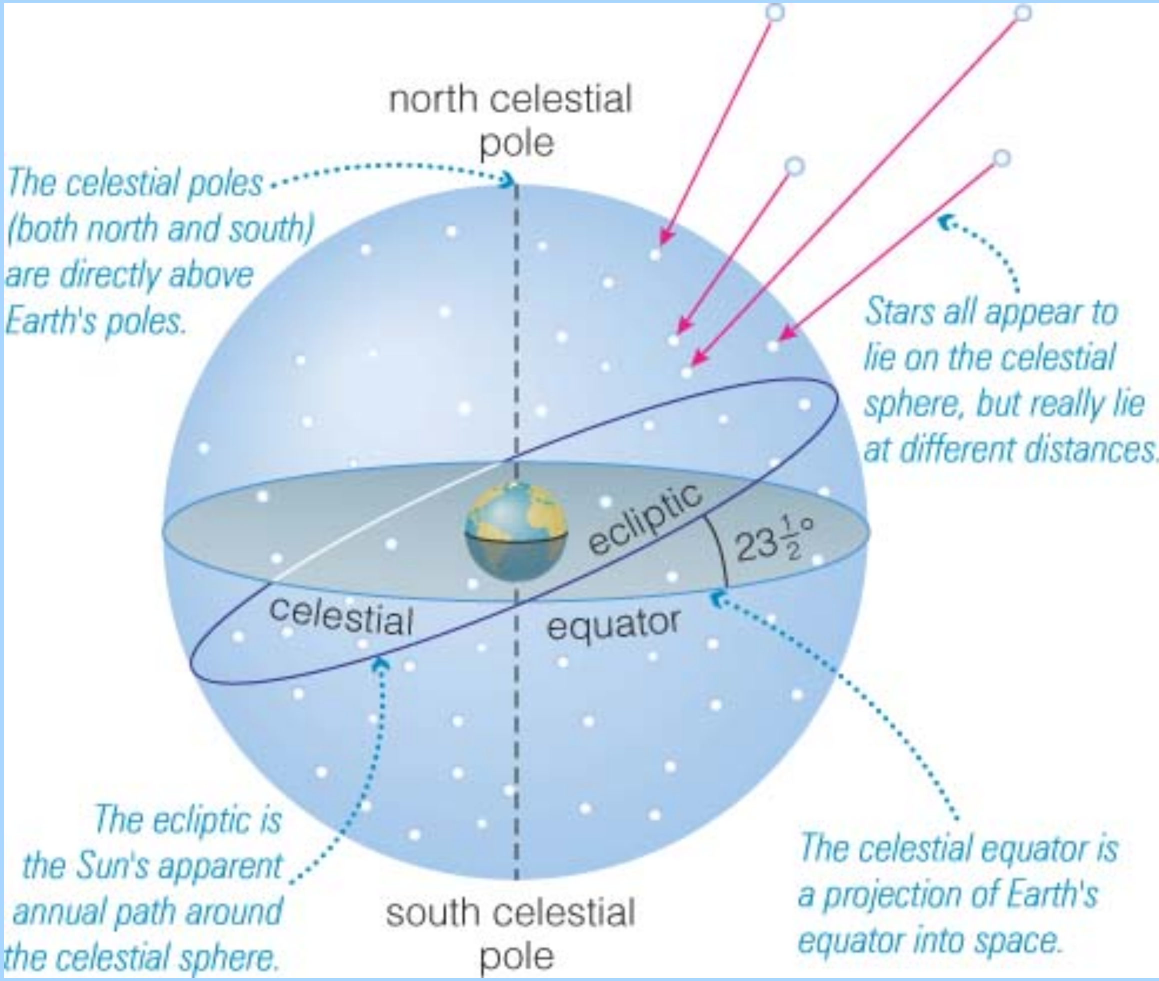
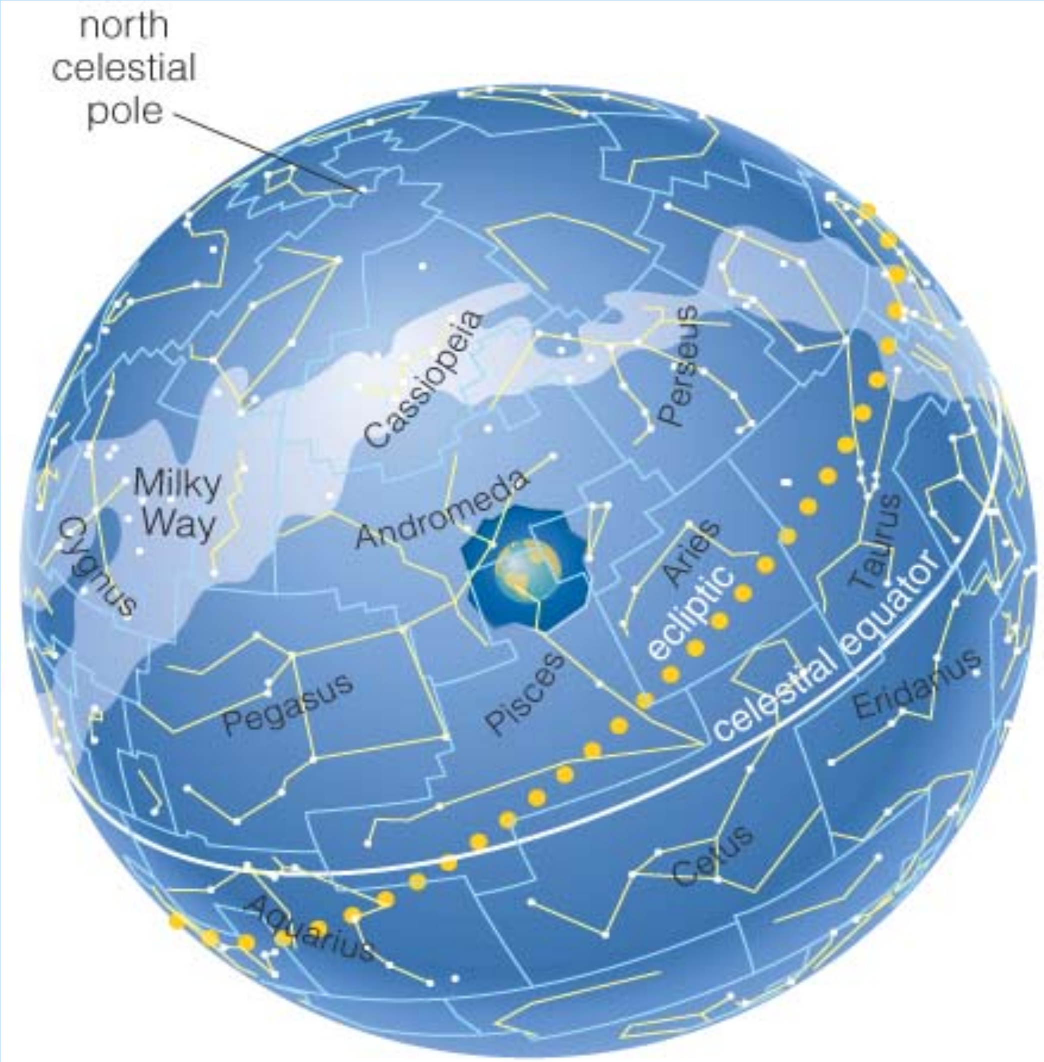
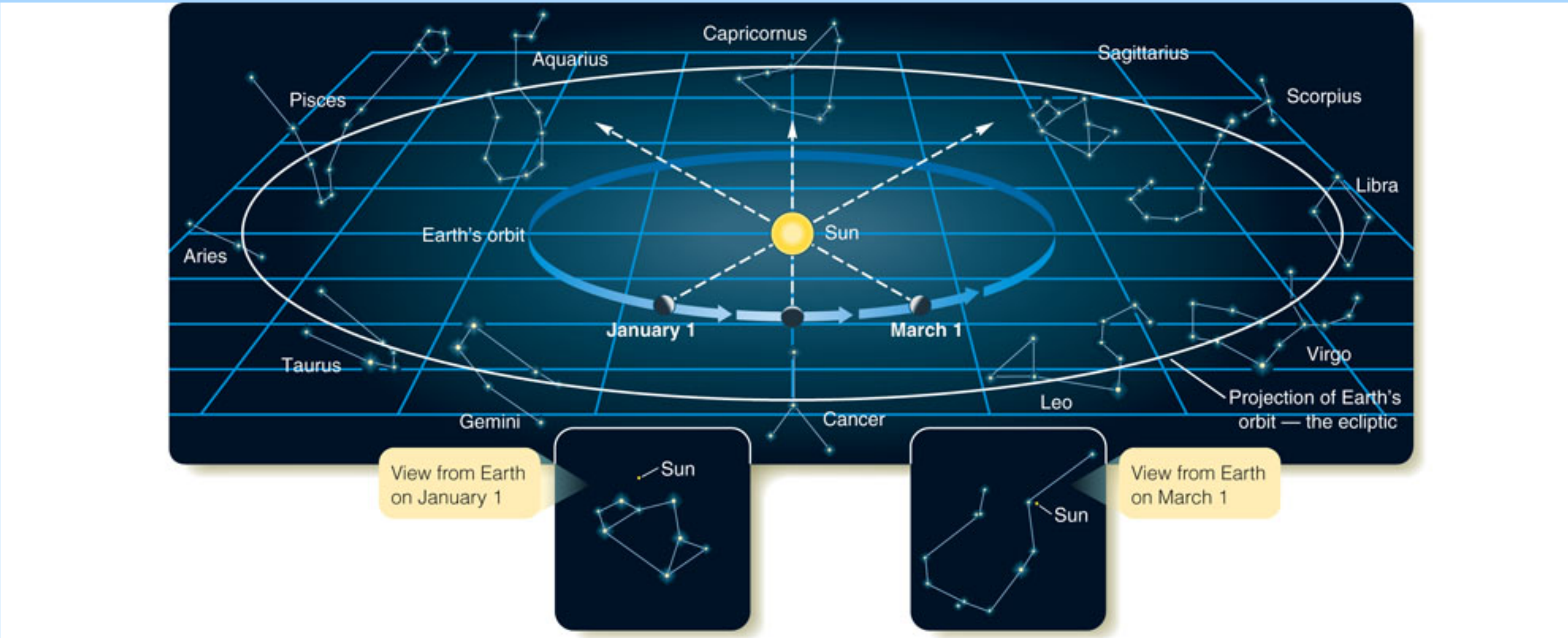


The reason it is warmer in summer than in winter is that the sunlight is more concentrated on the ground when the Sun is higher in the sky. Also, in summer the Sun is above the horizon more hours per day.

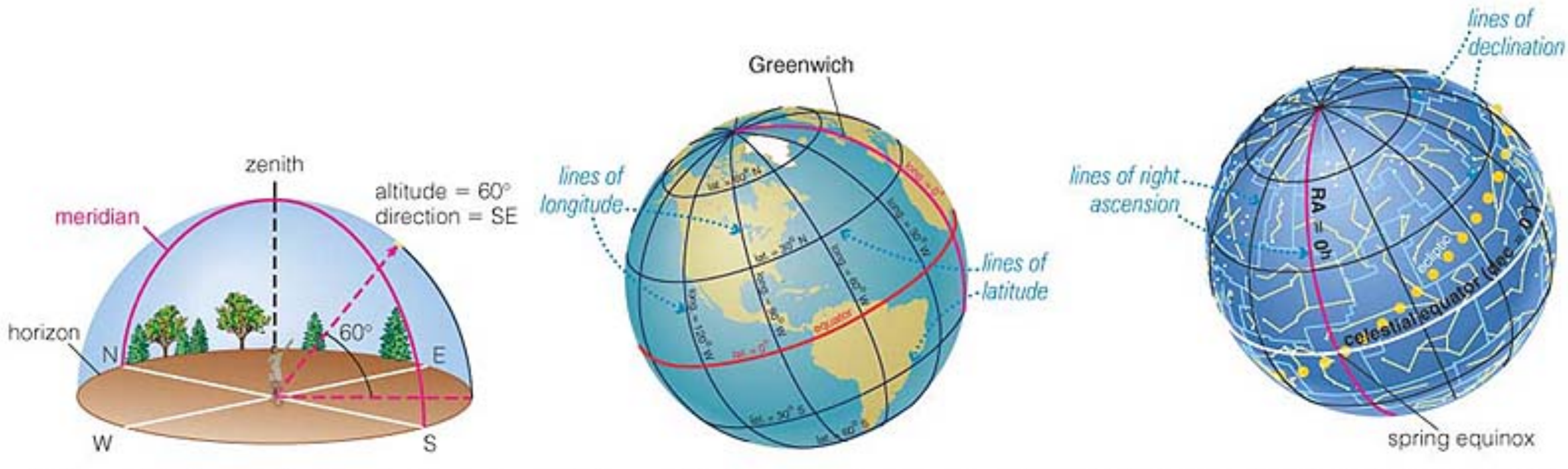

north celestial
pole
The celestial poles (both north and south) are directly above Earth's poles.
Stars all appear to lie on the celestial sphere, but really lie at different distances.
ecliptic
$23\frac{1}{2}°$
celestial
equator
The ecliptic is the Sun's apparent annual path around the celestial sphere.
south celestial
pole
The celestial equator is a projection of Earth's equator into space.



A model of the celestial sphere, showing the constellation borders, the celestial equator, and the apparent path of the Sun against the background of constellations.



The Sun is in the direction of the constellation Virgo in September, as viewed from the Earth. That is why people born in September are said to be born under the astrological sign of Virgo.



a We use altitude and direction to pinpoint locations in the local sky.

b We use latitude and longitude to pinpoint locations on Earth.

c We use declination and right ascension to pinpoint locations on the celestial sphere.

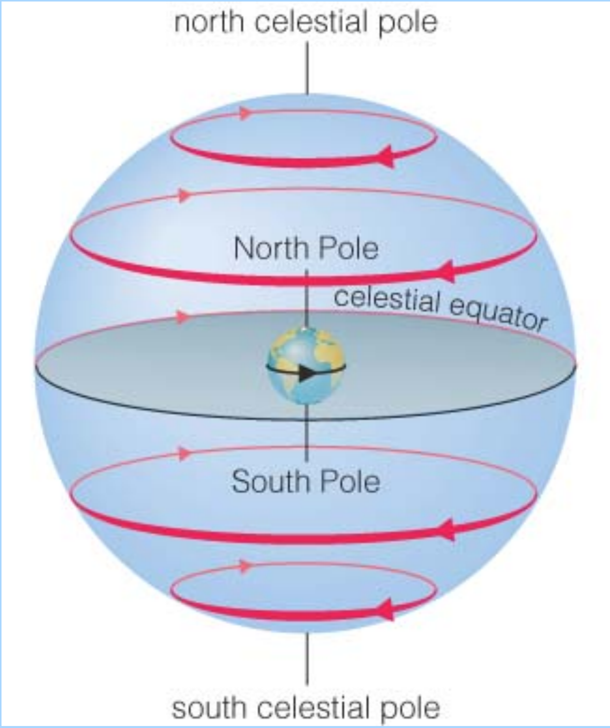
Just as we describe the location of a place on Earth by its latitude and longitude, we can specify the location of a star on the celestial sphere by its **right ascension** and **declination**.

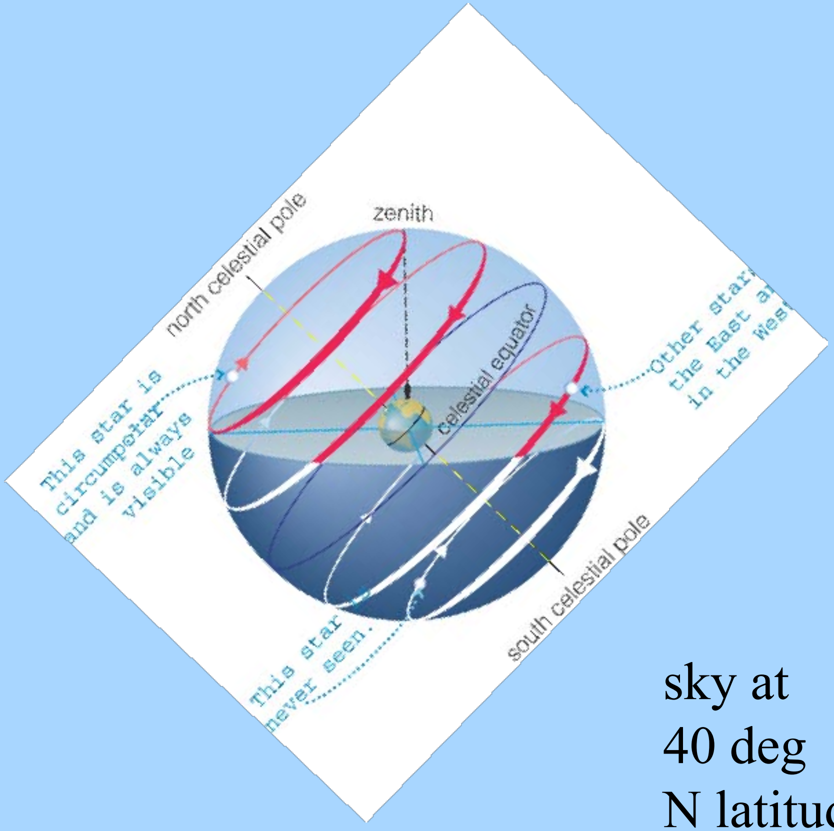
About June 21st the Sun has a declination of +23.5 degrees. It is 23.5 degrees north of the celestial equator.

About March 21st and September 22nd the Sun is on the celestial equator and has a declination of 0.

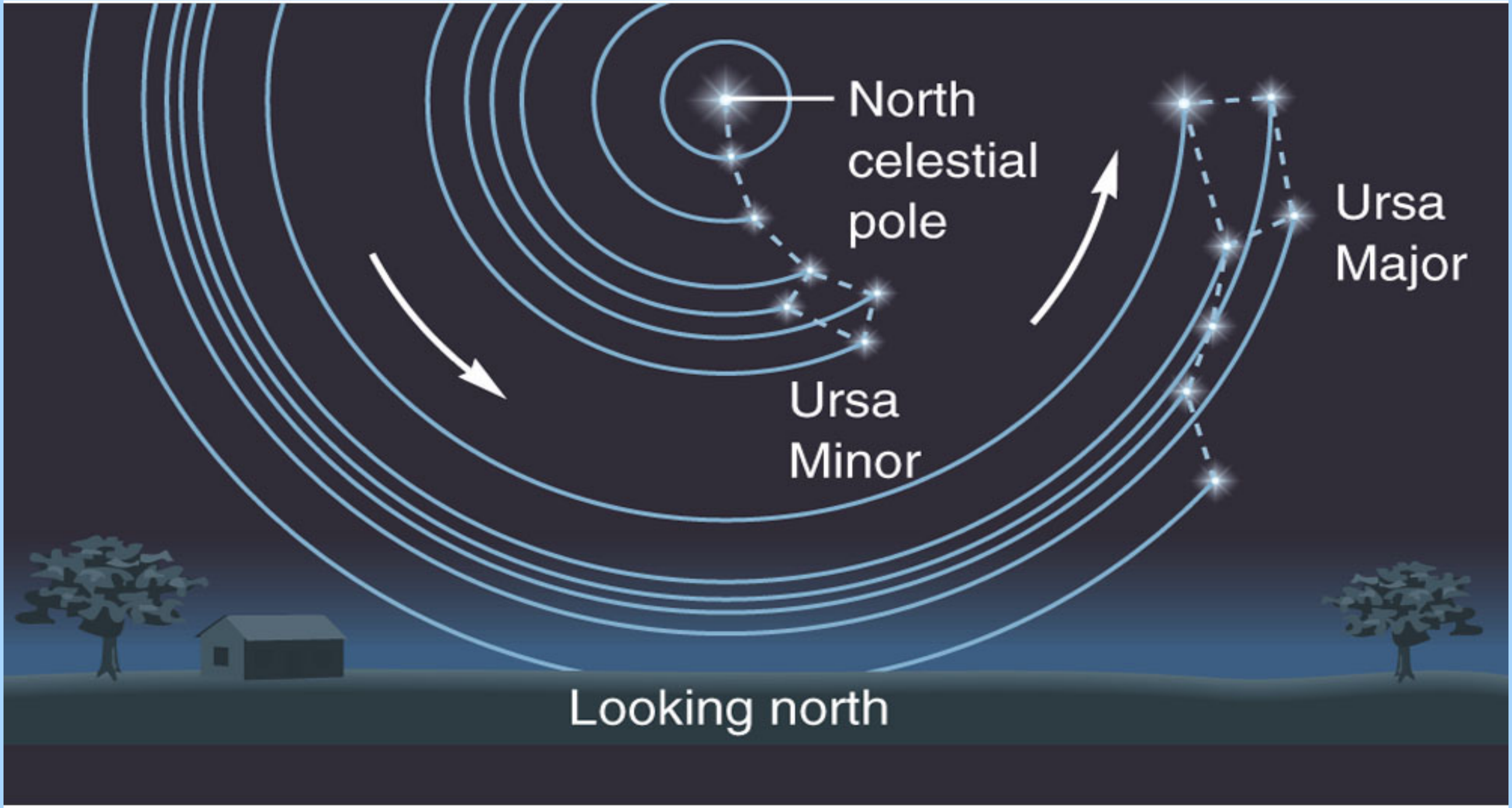
About December 21st the Sun is 23.5 degrees south of the celestial equator. Its declination is -23.5 deg.

Because the Earth turns on its axis once a day, it *appears* that the stars move around the north and south celestial poles.



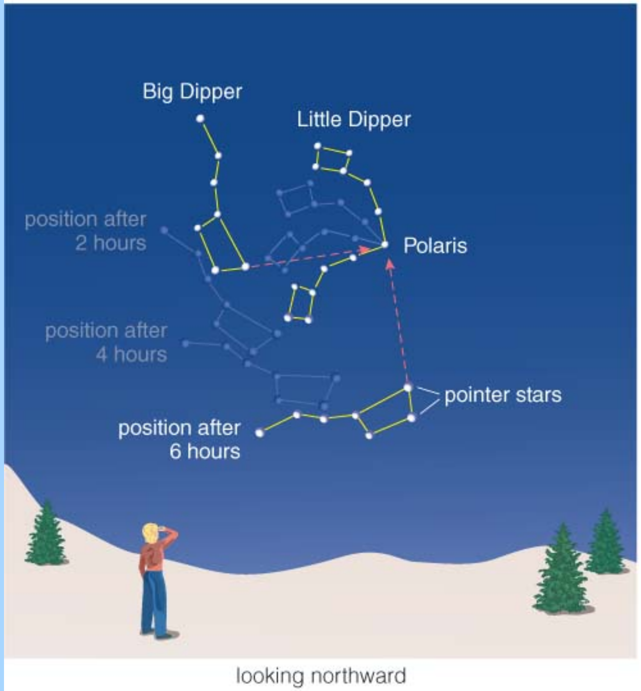


sky at
40 deg
N latitude

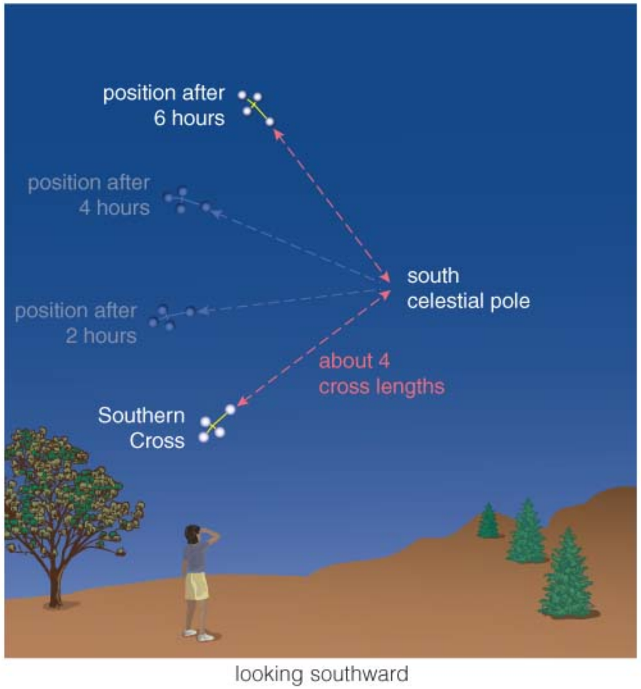


Stars close to the North Celestial Pole are always above the horizon. These are **circumpolar stars**.

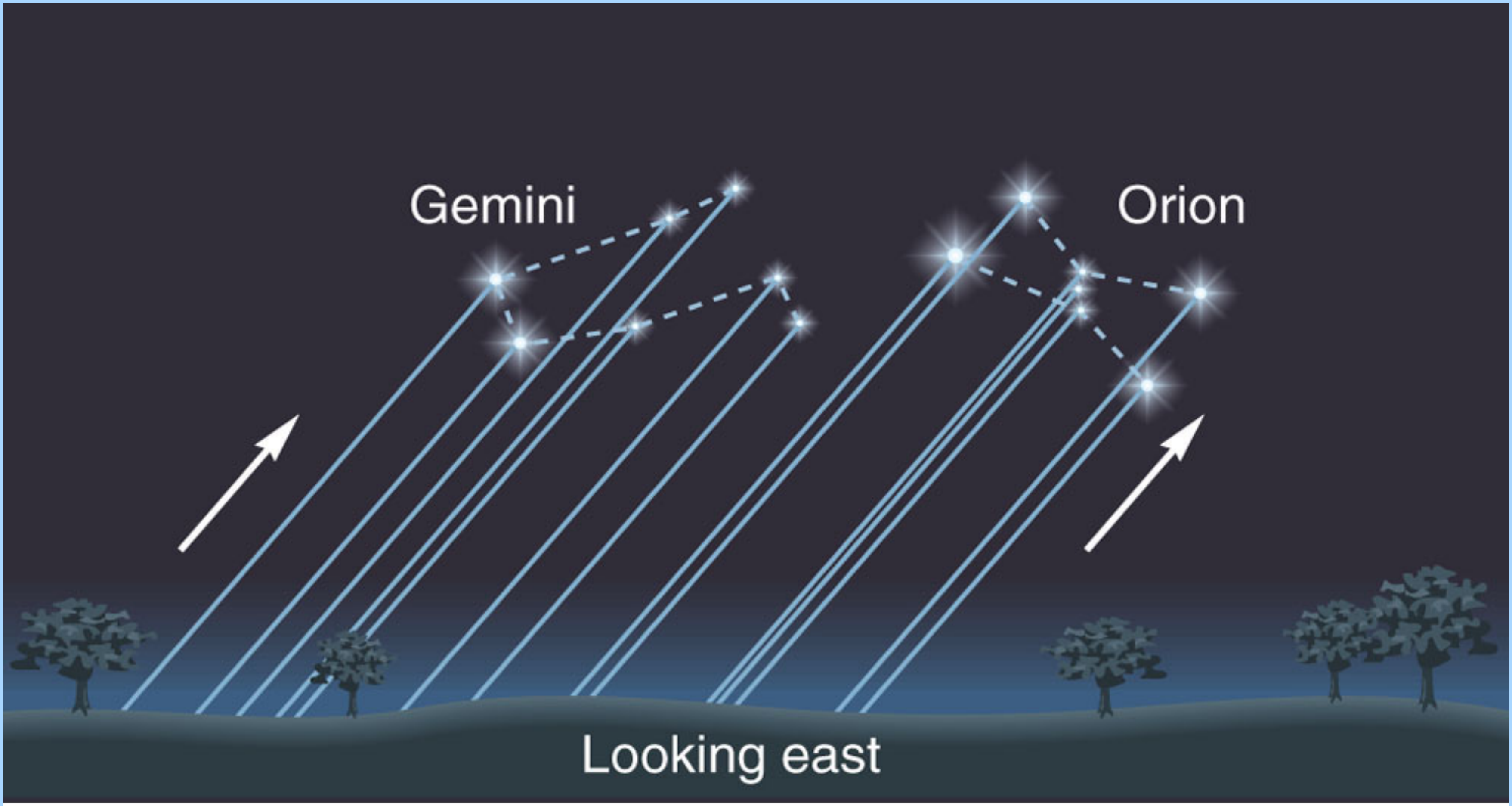
In the northern hemisphere the circumpolar constellations move counterclockwise around the North Celestial Pole. In the southern hemisphere the circumpolar constellations move clockwise around the SCP.

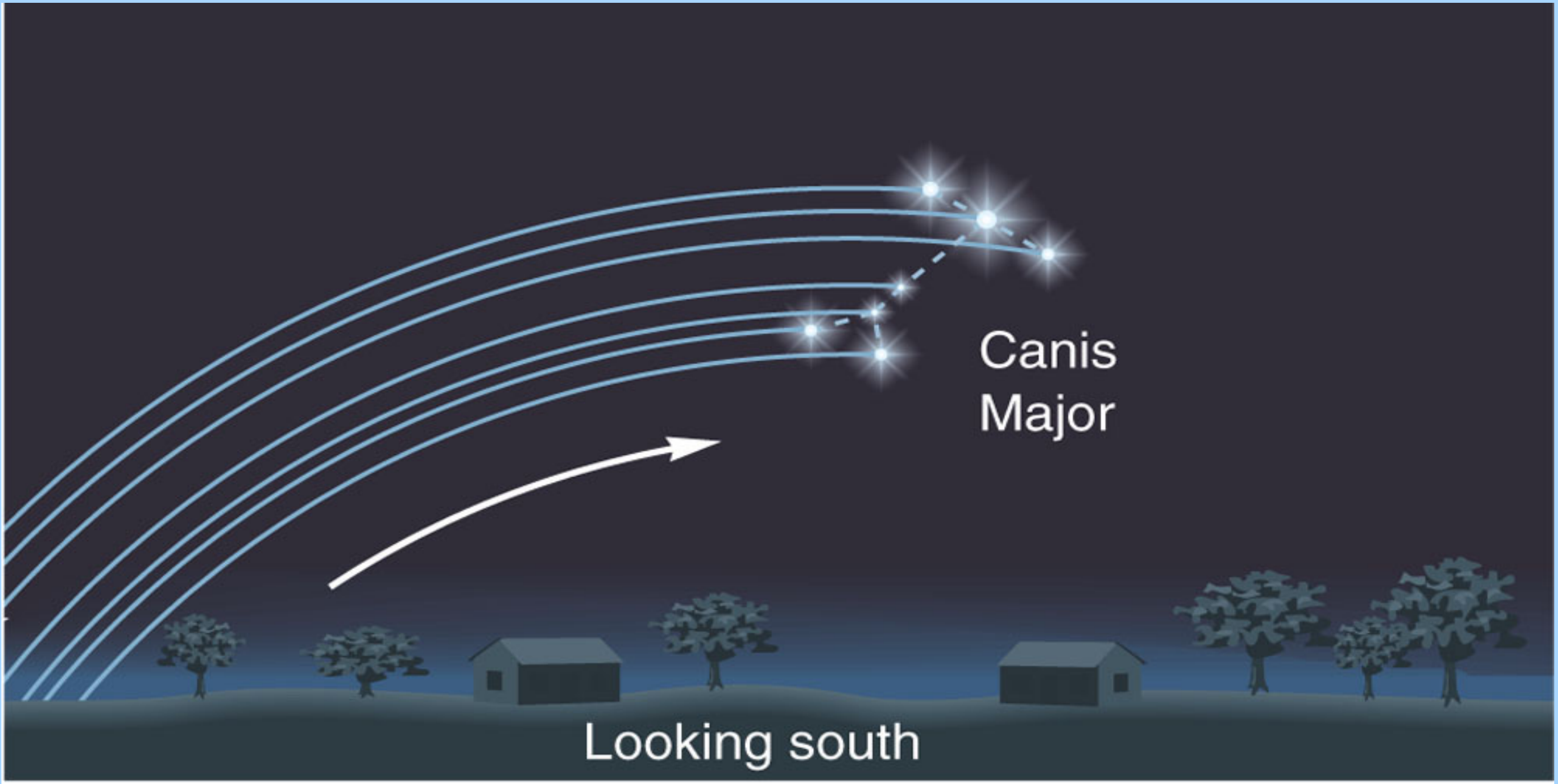


a In the Northern Hemisphere, the pointer stars of the Big Dipper point to the North Star, Polaris, which lies within 1° of the north celestial pole. Note that the sky appears to turn counter-clockwise around the north celestial pole.



b In the Southern Hemisphere, the Southern Cross points to the south celestial pole, which is not marked by any bright star. The sky appears to turn clockwise around the south celestial pole.


Gemini
Orion
Looking east


Canis
Major
Looking south

The apparent path of the Sun through the constellations of the zodiac traces out the

a) celestial equator
b) ecliptic
c) galactic plane
d) azimuth

The Sun rises in the east and sets in the west. Which direction does the Earth turn?

a. Towards the east
b. Towards the west
c. Towards the north
d. Towards the south

The first regular observers of the sky (shall we say "astronomers"?) were the Chinese and the Babylonians. They divided up the sky into *constellations* or *asterisms*.

By modern agreement, the sky is divided into 88 constellations, some ancient, some relatively recent (18^{th} century).

The twelve constellations of the zodiac (Capricornus, Aquarius, Pisces, Aries, Taurus, Gemini, Cancer, Leo, Virgo, Libra, Scorpius, and Sagittarius) are already familiar to you.

Hipparchus (ca. 140 BC) was perhaps the greatest astronomer of ancient times. He produced a catalogue of 1000 stars and classified them acording to their apparent brightness.

The brightest stars were called stars of the first **magnitude**. Fainter stars were classified as being of second, third, fourth, or fifth magnitude. Now stars can be measured to +/- 0.01 magnitude. We have also expanded the scale to include negative values, and much larger positive values. Sirius, for example, has an apparent magnitude of -1.42. The faintest stars detectable with the Hubble Space Telescope are almost 30th magnitude.

If you measure the brightness of the stars with a *photometer* (a light measuring device), you will find that a 1st magnitude star gives 100 times as many photons as a 6th magnitude star. A 2nd magnitude star is 100 times more luminous than a 7th magnitude star...

Thus, the *difference* of two magnitudes is related to the ratio of the intensity of the light as follows:

$$m_a - m_b = 2.5 \log (I_b/I_a)$$

If $I_b = 100 \times I_a$, $\log (I_b/I_a) = 2$ and $m_a - m_b = 5$.

The astronomical magnitude scale is somewhat confusing, since fainter stars have larger magnitudes. But astronomers use magnitudes so much, we will have to get used to them. The best way to get familiar with magnitudes is to compare the stars on a star chart with real stars in the sky.

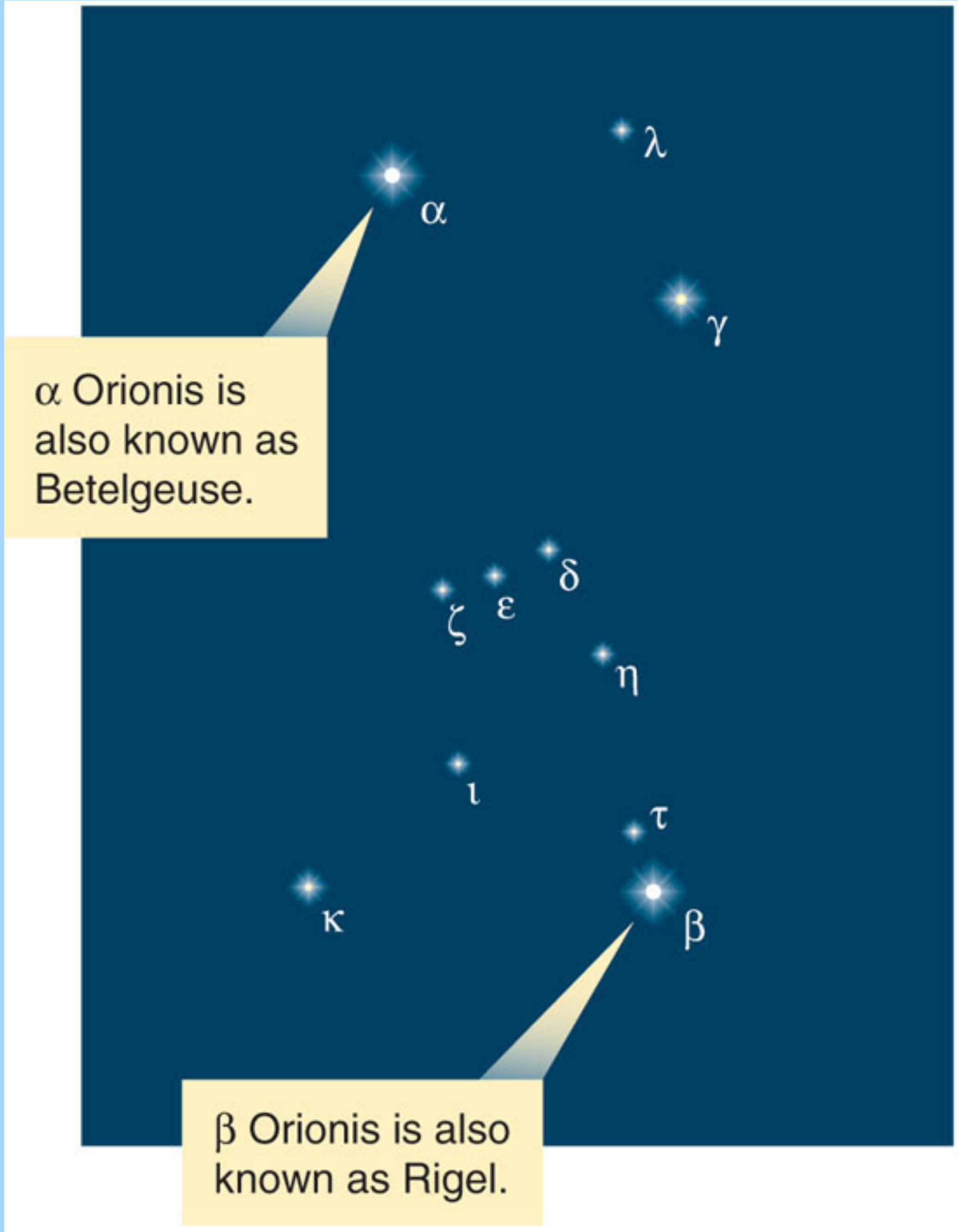
In order for a 5 magnitude difference to correspond to an intensity ratio of exactly 100, each magnitude actually corresponds to a factor of the fifth root of 100 (= 2.511886...) in light intensity.

Table 2-1 | Magnitude and Intensity

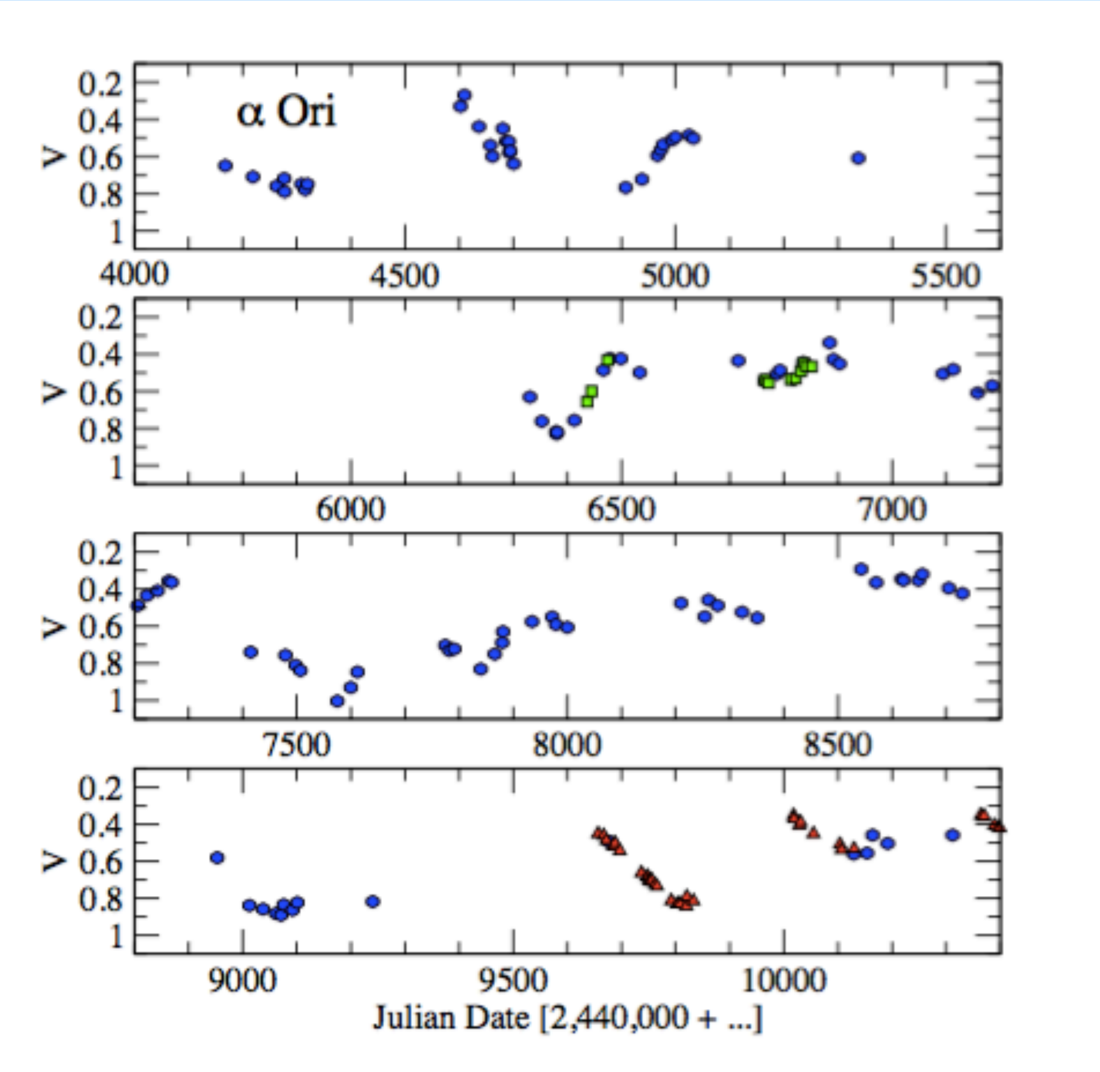
Magnitude Difference	Intensity Ratio
0	1
1	2.5
2	6.3
3	16
4	40
5	100
6	250
7	630
8	1600
9	4000
10	10,000
⋮	⋮
15	1,000,000
20	100,000,000
25	10,000,000,000
⋮	⋮

The number of degrees that a celestial object is north or south of the celestial equator is called the

A. latitude
B. declination
C. right ascension
D. elevation angle


λ
α
γ
α Orionis is also known as Betelgeuse.
δ
ε
ζ
η
ι
τ
κ
β
β Orionis is also known as Rigel.


The brighter stars in a constellation are usually given Greek letters in order of decreasing brightness.
Orion
In Orion β is brighter than α, and κ is brighter than η. Fainter stars do not have Greek letters or names, but if they are located inside the constellation boundaries, they are part of the constellation.



Light curve of Betelgeuse (α Ori) from Oct. 21, 1979, to Nov. 11, 1996.

It is a slowly pulsating star that will eventually explode as a Type II supernova.

In order to describe the position of the Sun, Moon, stars, and planets in the sky, we need a coordinate system. The system we are most familiar with is the **horizon system**.

"Straight up" is called the **zenith**. The opposite point on the sky, which would be below your feet, is the **nadir**. These are the two poles of the horizon system. The horizon traces out a circle 90 degrees from these poles. For convenience we designate four **cardinal points** along the horizon: the north, east, south, and west points.

The number of degrees an object is above the horizon is called the "altitude" or **elevation angle**.

If we draw a line from the zenith through a celestial object and extend that line to the horizon, we obtain the **azimuth** angle of the object. By convention, the north point on the horizon has azimuth 0 degrees, the east point has azimuth 90 degrees, the south point has azimuth 180 degrees, and the west point has azimuth 270 degrees.

The problem with the horizon system is that the azimuth and elevation angle of a star changes continuously owing to the rotation of the Earth. If I said, "I saw a bright star at 30 degrees above the horizon in the east," I would also have to specify the date and time of the observation, and my geographical coordinates, in order for someone to know for certain which star I was referring to.

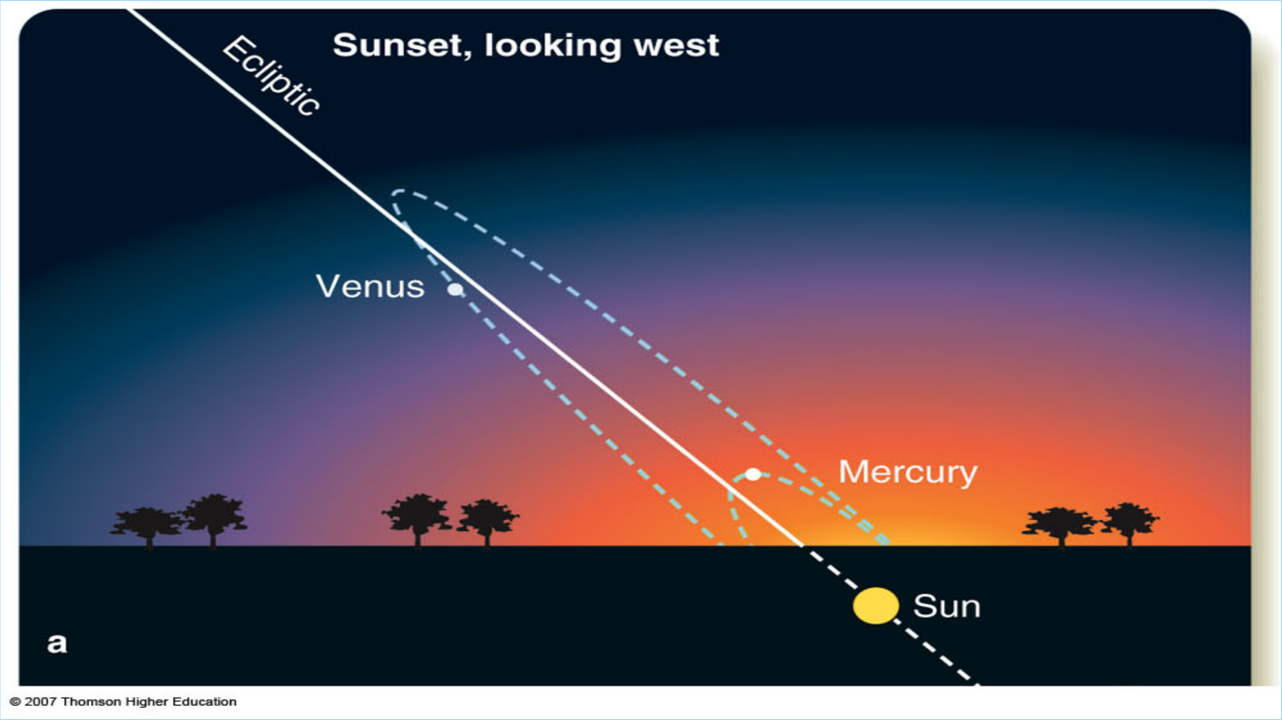
Halfway between the NCP and the SCP is the **celestial equator**. It is a projection of the Earth's equator out to the celestial sphere.

The number of degrees that a celestial object is north or south of the celestial equator is called the **declination** (DEC) It is the analogue of latitude on the sky. The analogue of longitude is called **right ascension** (RA). While the RA and DEC of a star change slowly with time, these changes are very small fractions of a degree each year. Thus, we can make a star catalogue or star chart that is useful for observers at any location on the Earth. For example, the coordinates of Betelgeuse in the year 2000 were RA = 5 hours 55 minutes 10.3 seconds, DEC = +7 deg 24' 25".

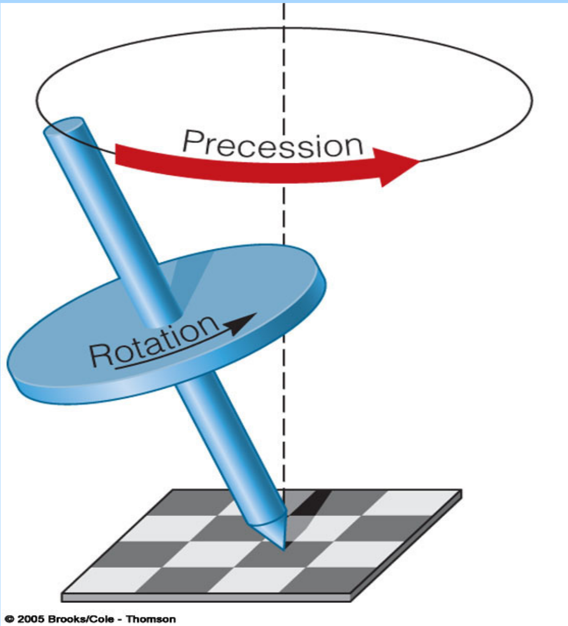
It is also common to designate the right ascension by the Greek letter alpha (α) and the declination by the Greek letter delta (δ).

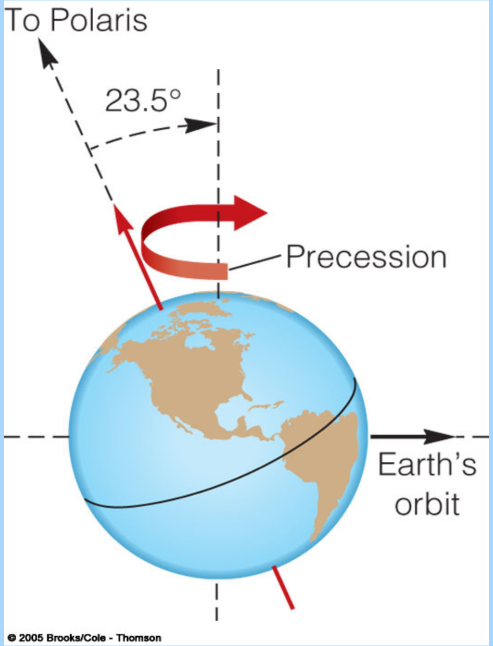
A third coordinate system uses the **ecliptic** as the fundamental great circle. This is the apparent path of the Sun in the sky against the background of stars. The Sun passes through all the constellations of the **zodiac** (plus Ophiuchus).

The word **planet** to the ancient Greeks meant "wandering star. We now know that they are other worlds.
The orbital planes of the other planets are oriented quite similarly to that of the Earth. Thus, the planets are usually found within a few degrees of the ecliptic.

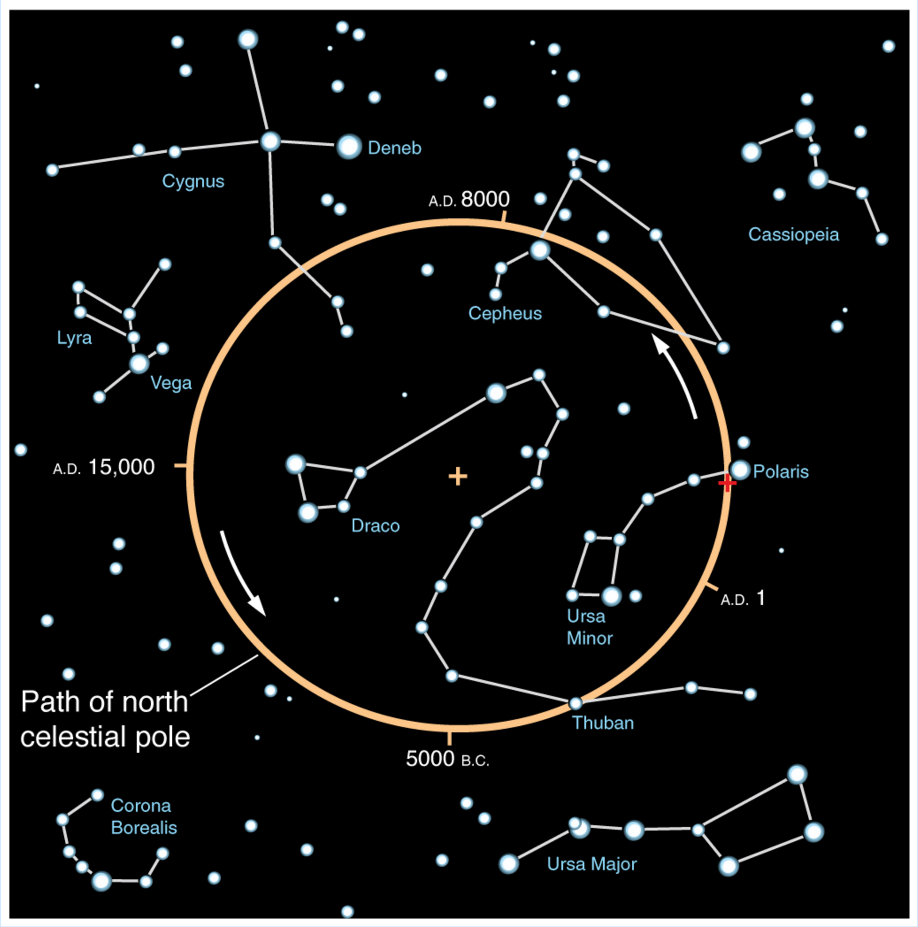


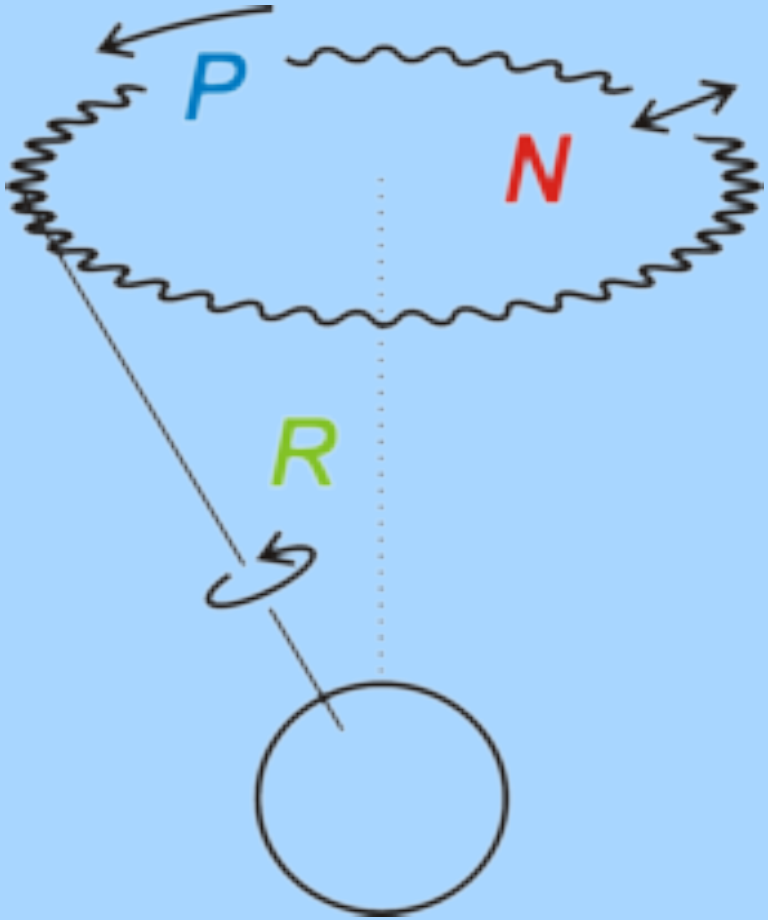
Hipparchus compared the coordinates of some stars with records made by the Babylonians and discovered that the ecliptic longitudes of the stars were increasing with time, about 1 degree per century. (The modern value is about 1 degree in 72 years.) This is called **precession** (not to be confused with the word "precision"). The Earth turning on its axis is like a spinning top.





While Polaris is close to the NCP now, it was not always the case. Due to the 26,000 year period of precession, many stars take their turns being the pole star.





Nutation ("nodding") of the axis of rotation is due to the tidal forces not being constant over time. R = rotation of Earth. P = precession. N = nutation.