The Sky

What do we see?
- Stars
- Sun
- Moon
- Planets

How do we organize what we see?

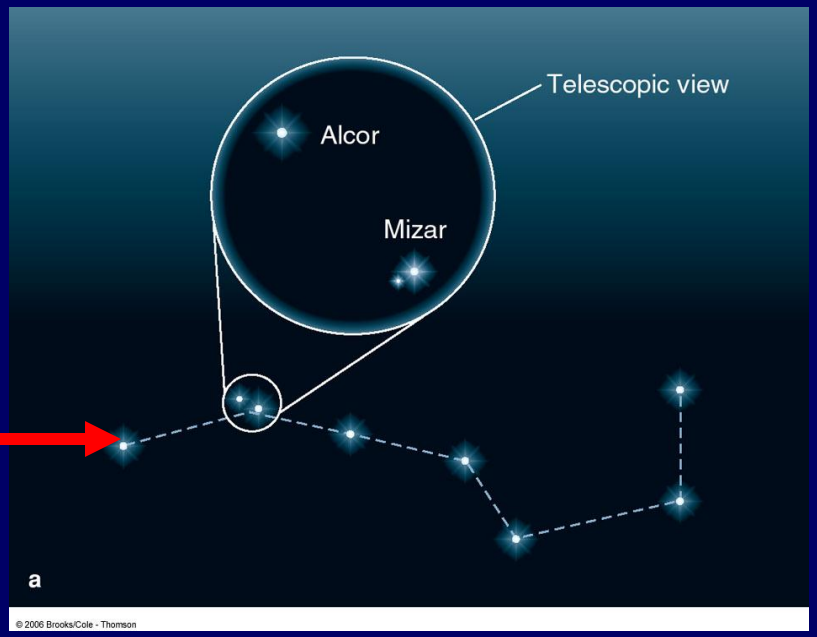
How do they move?

Eclipses

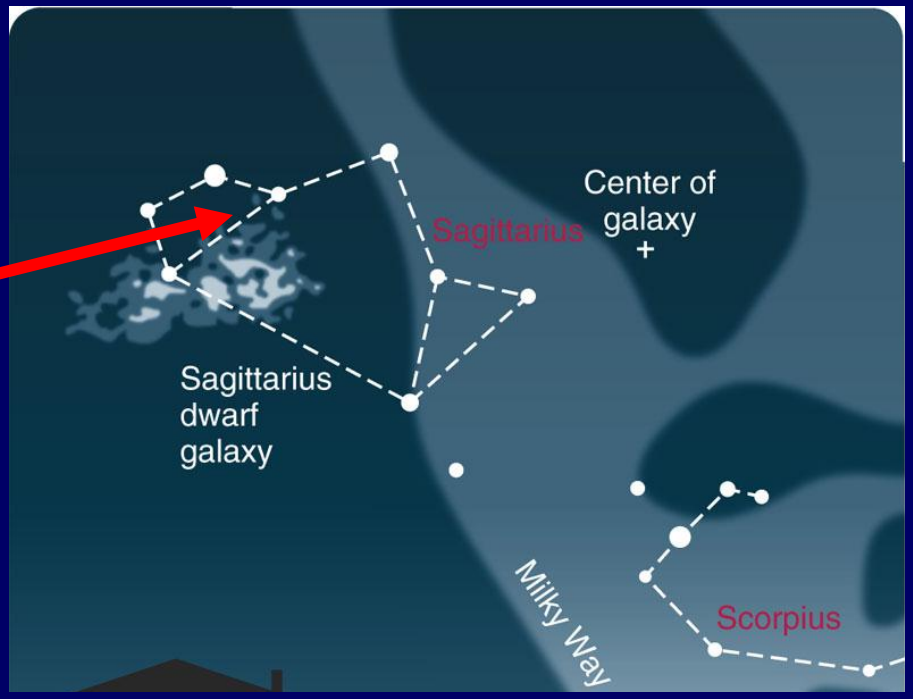
Time and Calendars

Asterisms

The Big Dipper

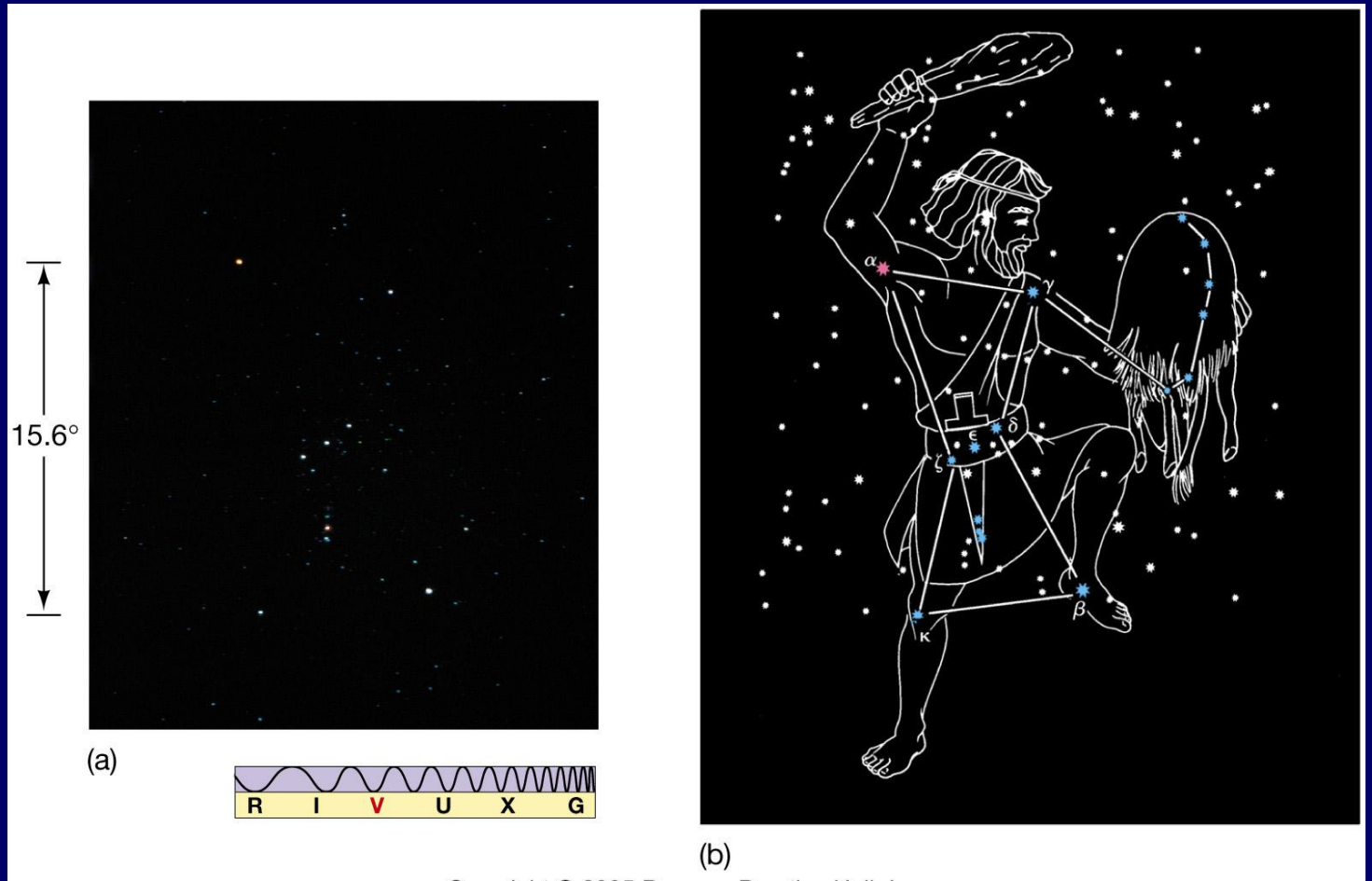


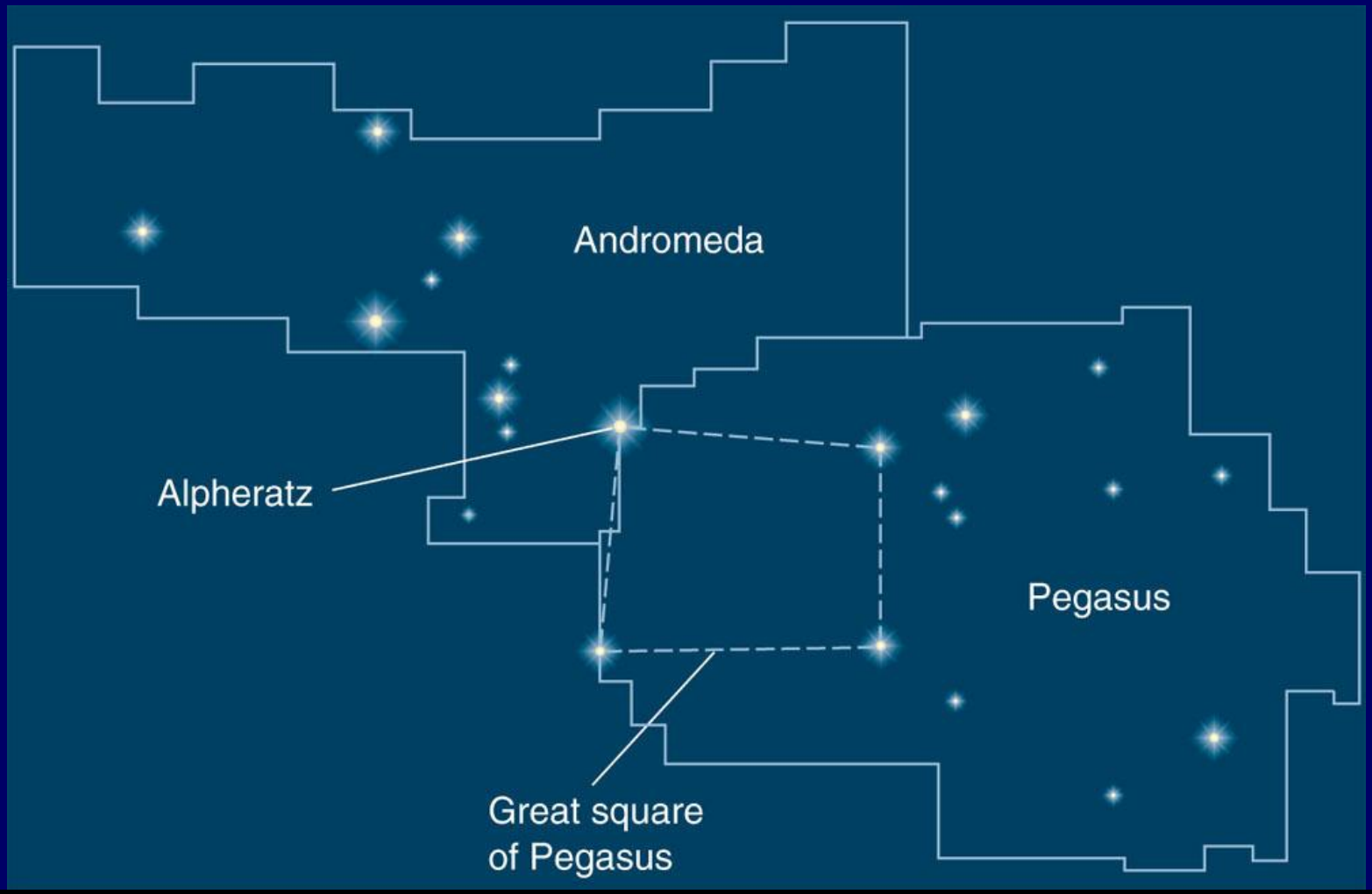
The Teapot



Constellations

In ancient times, constellations only referred to the brightest stars that appeared to form groups, representing mythological figures, such as Orion.

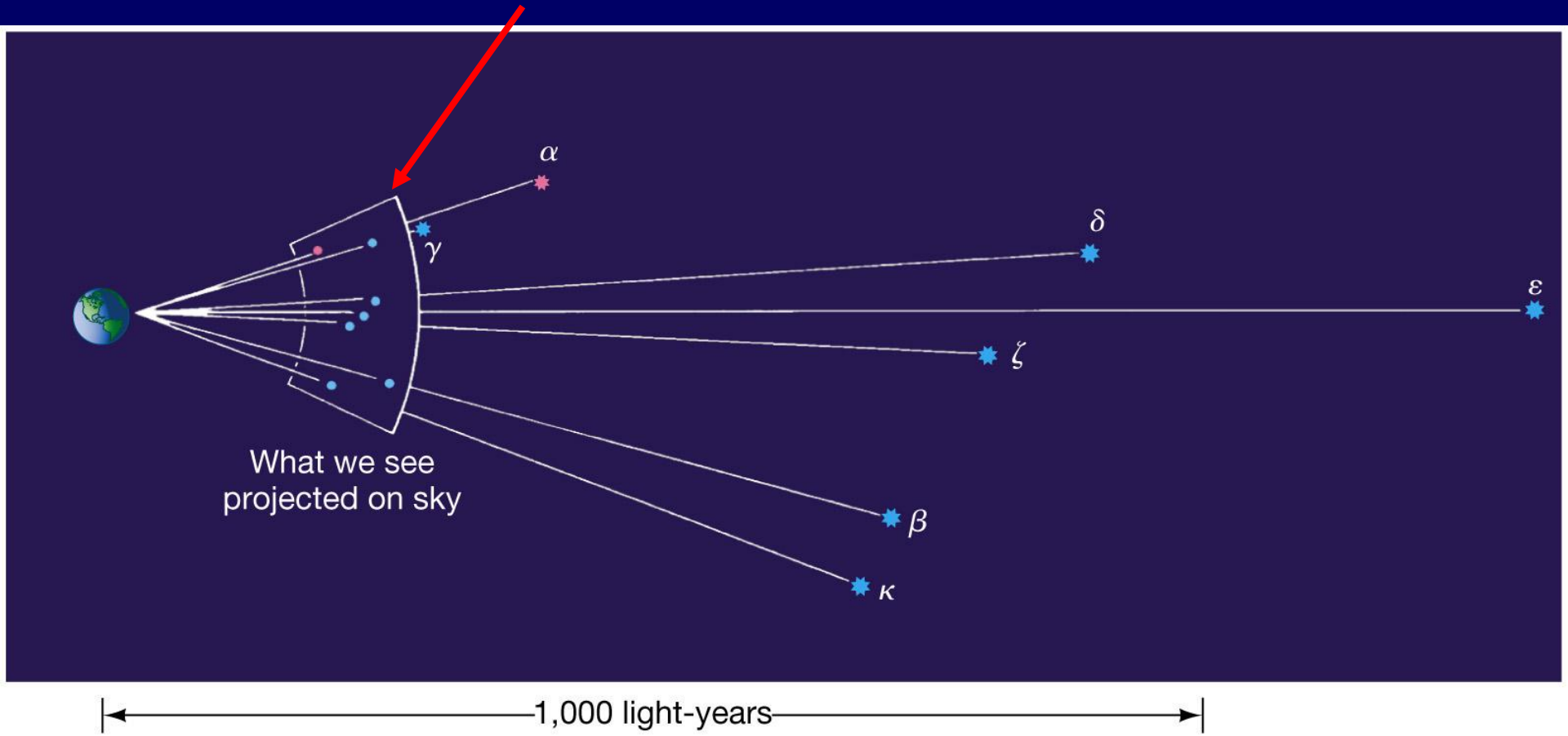




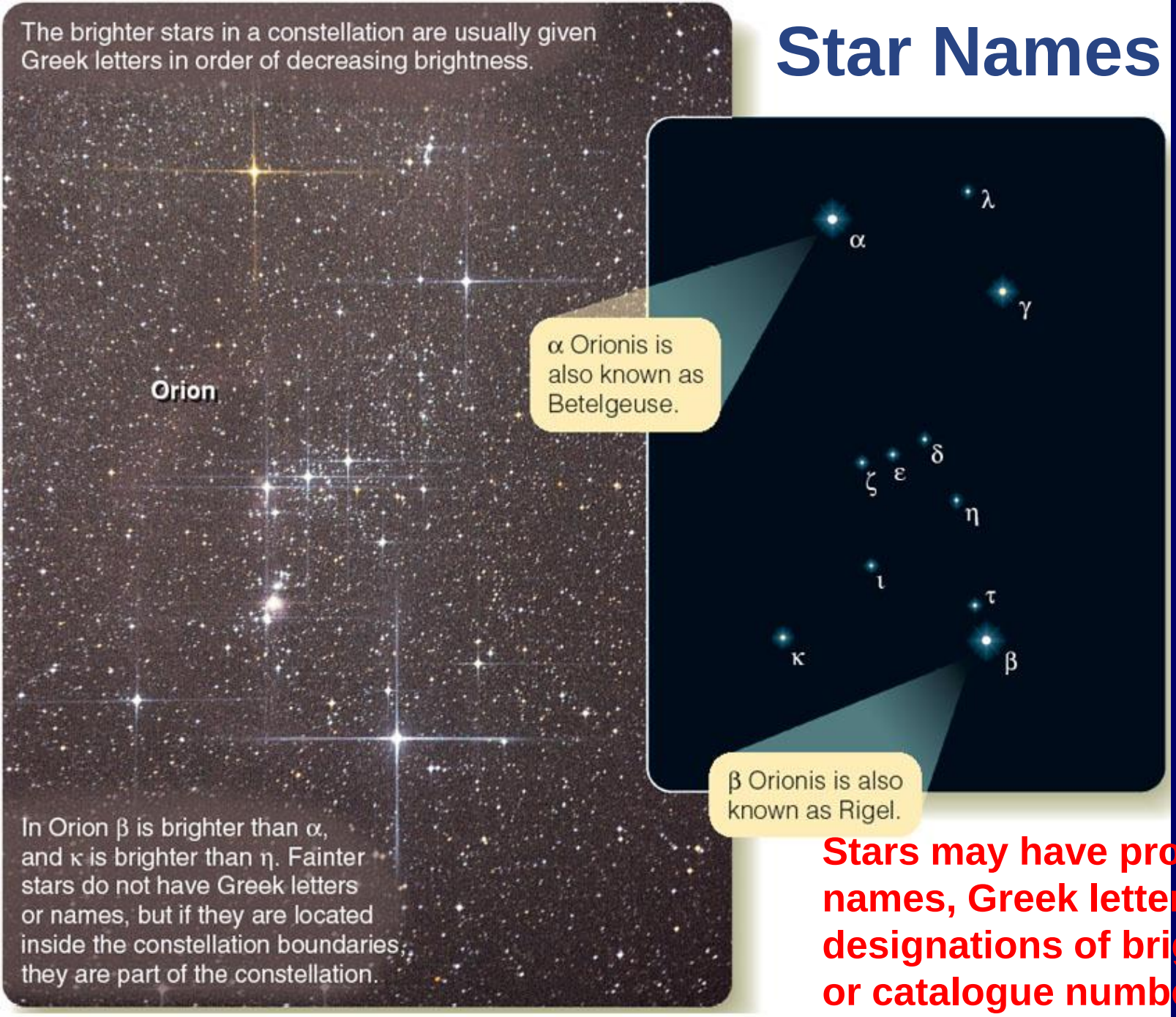
Today, constellations are well-defined regions of the sky, irrespective of the presence or absence of bright stars in those regions. There are 88 constellations. Latin nominative and genitive cases are used.

Stars in a constellation are actually at differing distances away from us, but they appear to project onto a sphere. We call it the celestial sphere. We use angular displacements to refer to relative positions of stars on the celestial sphere.

A small segment of the celestial sphere



Star Names



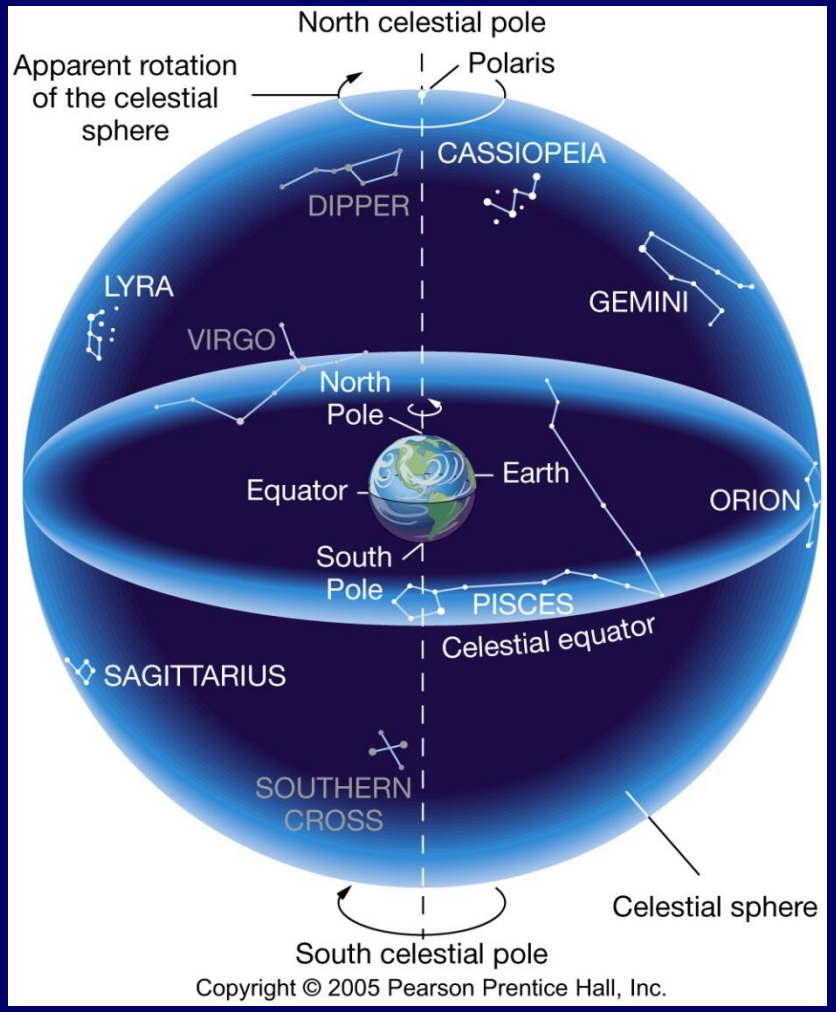
Stars may have proper names, Greek letter designations of brightness or catalogue numbers.

The Celestial Sphere

Stars *seem* to be on the inner surface of a sphere surrounding the Earth

Stars appear to rotate from east to west as if the celestial sphere is rotating. We know that it is the Earth that rotates.

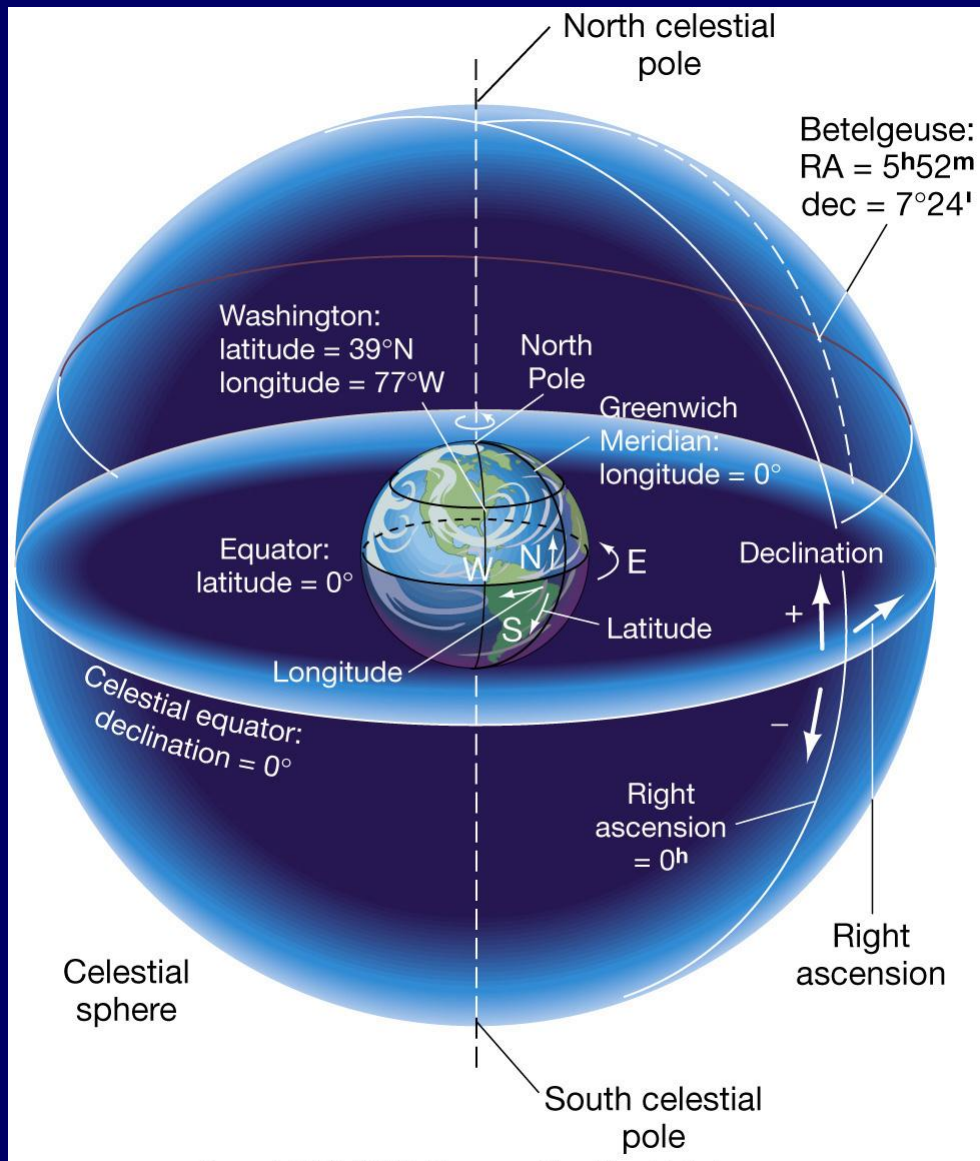
Two-dimensional spherical coordinates (similar to latitude and longitude) are used to locate sky objects



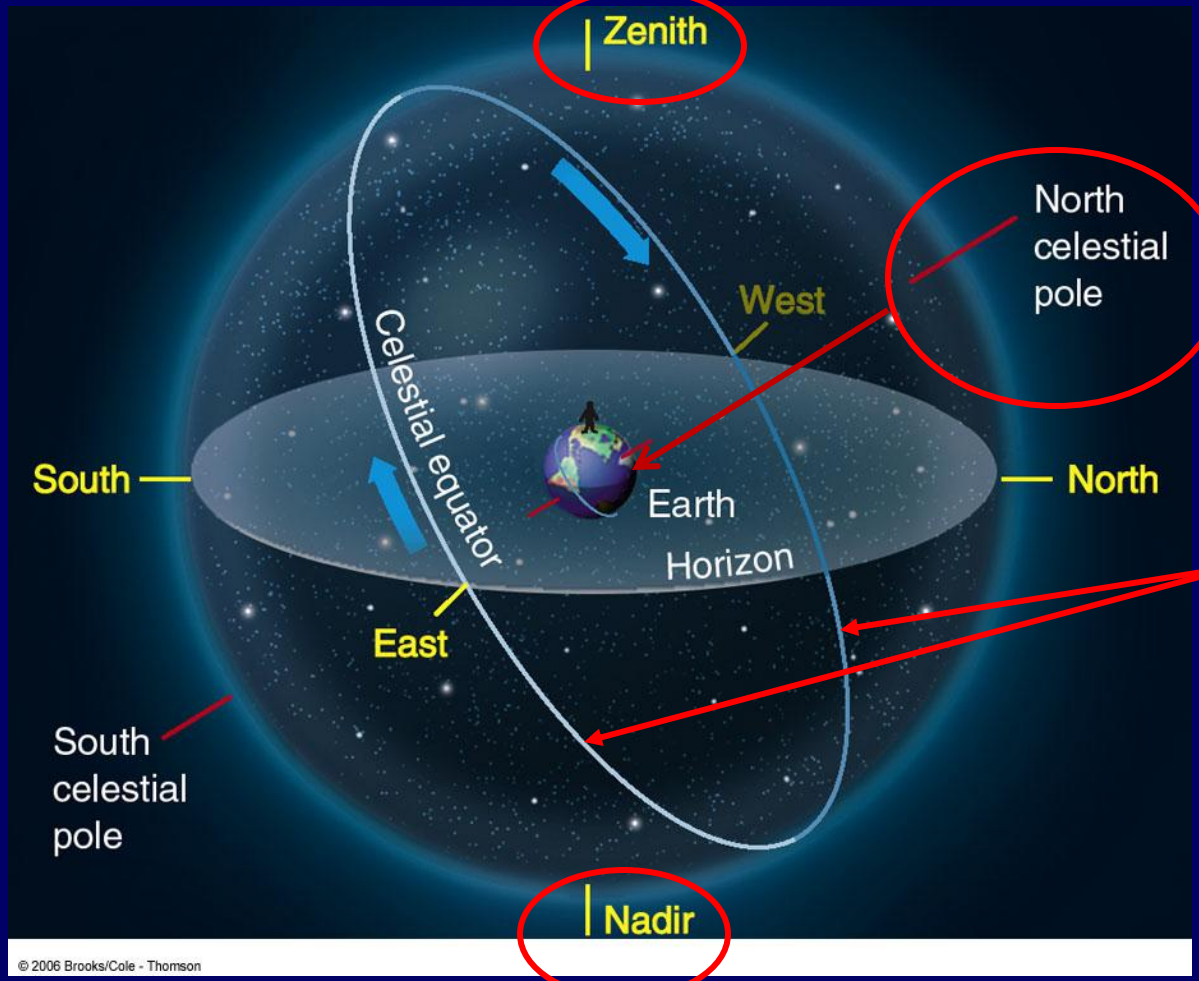
Celestial Coordinates

Declination (dec, δ): degrees north (+) or south (-) of celestial equator

Right ascension (RA, α): measured in hours, minutes, and seconds eastward from position of Sun at vernal equinox (defined later)

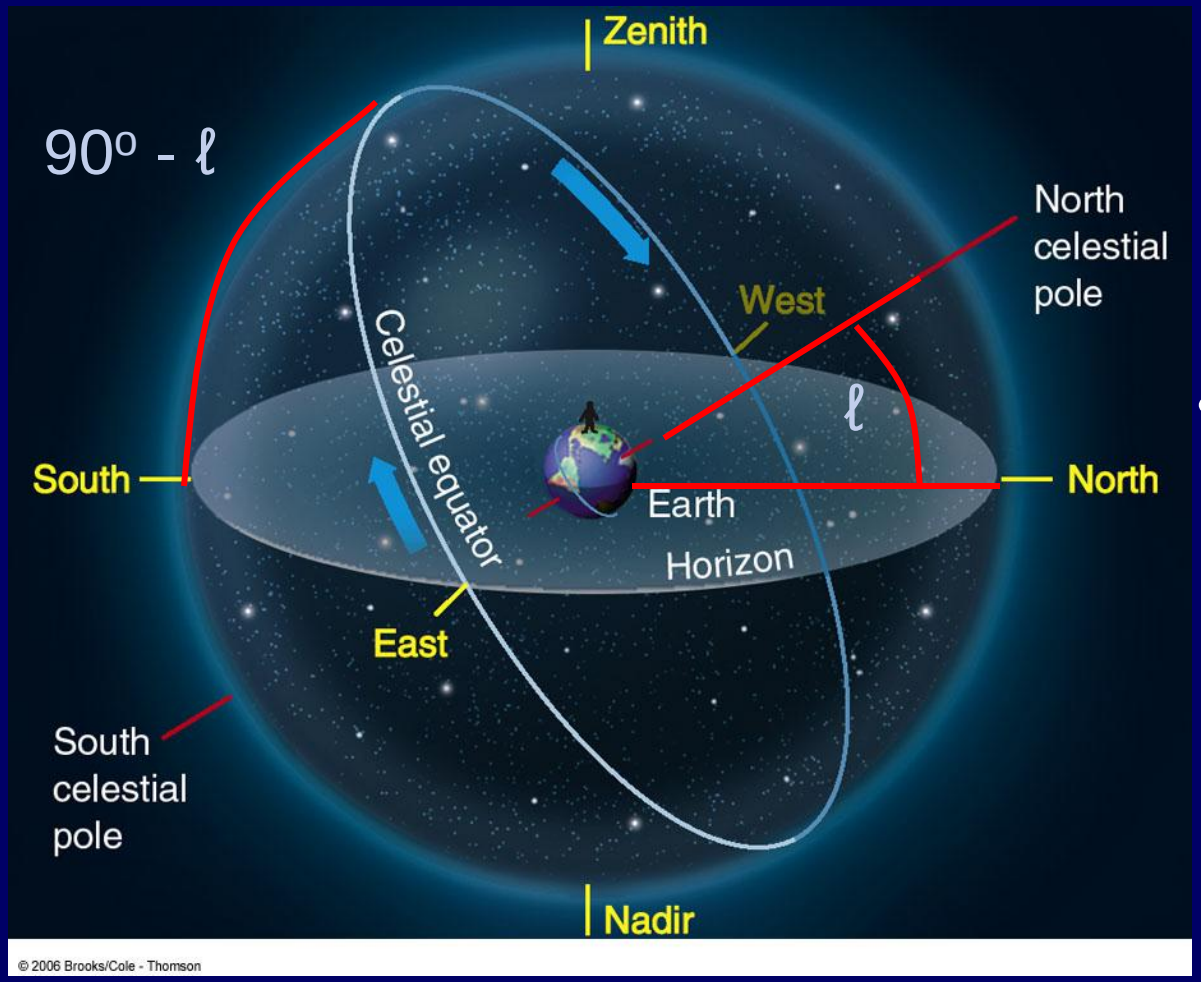


The Celestial Sphere



- **Zenith** = Point on the celestial sphere directly overhead
- **Nadir** = Point on the c.s. directly underneath (not visible!)
- **Celestial equator** = projection of Earth's equator onto the c.s.
- **North and south celestial poles** = projection of Earth's north and south poles onto the c.s.

The Celestial Sphere

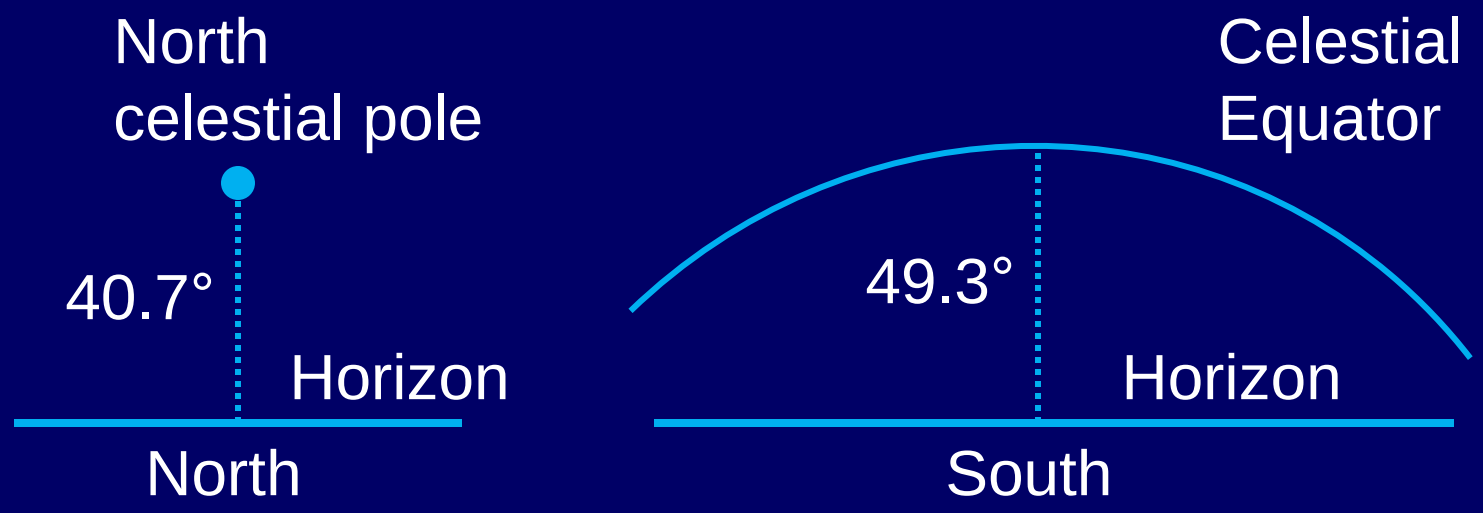


- From geographic latitude ℓ (northern hemisphere), you see the celestial north pole ℓ degrees above the horizon;
- From geographic latitude -ℓ (southern hemisphere), you see the celestial south pole ℓ degrees above the horizon.

- Celestial equator culminates 90° – ℓ above the horizon.

Example:

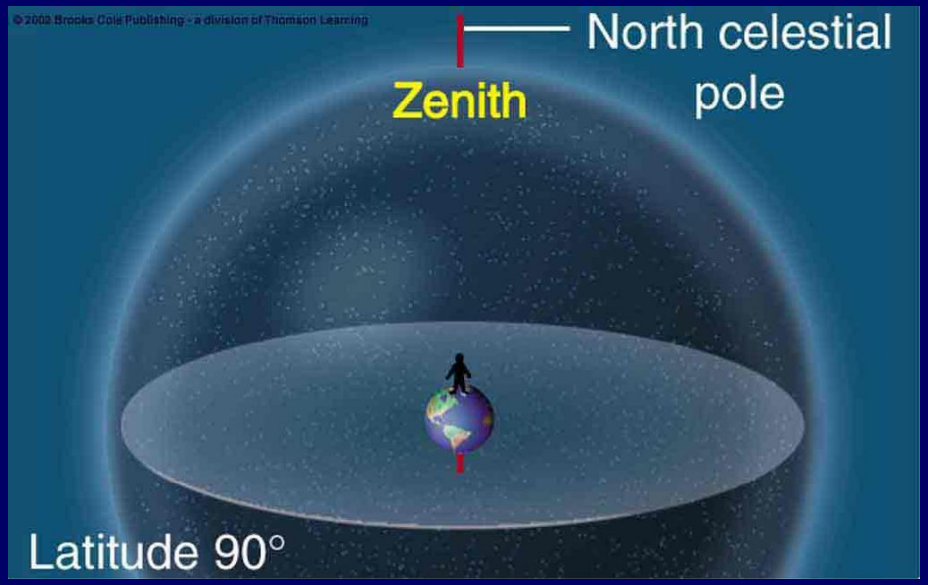
New York City: $\ell \approx 40.7°$ North

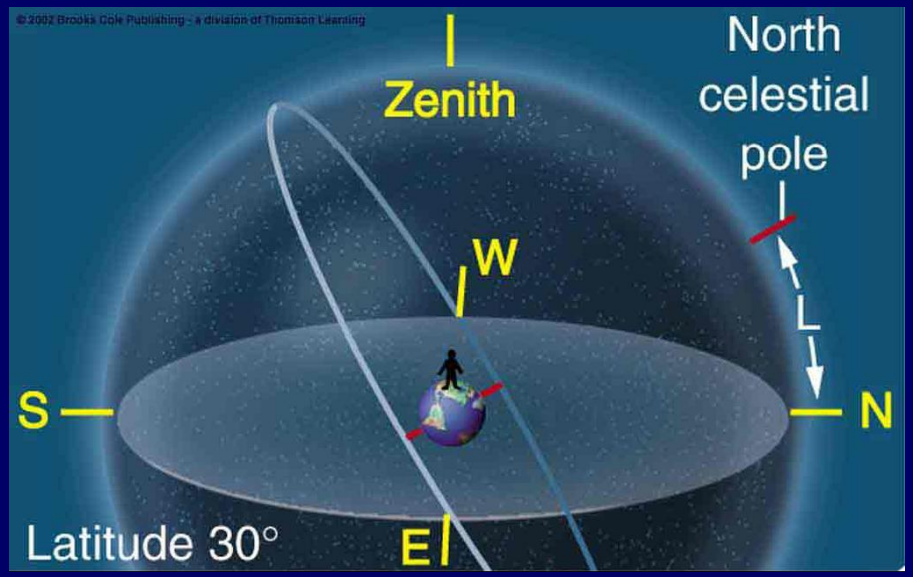


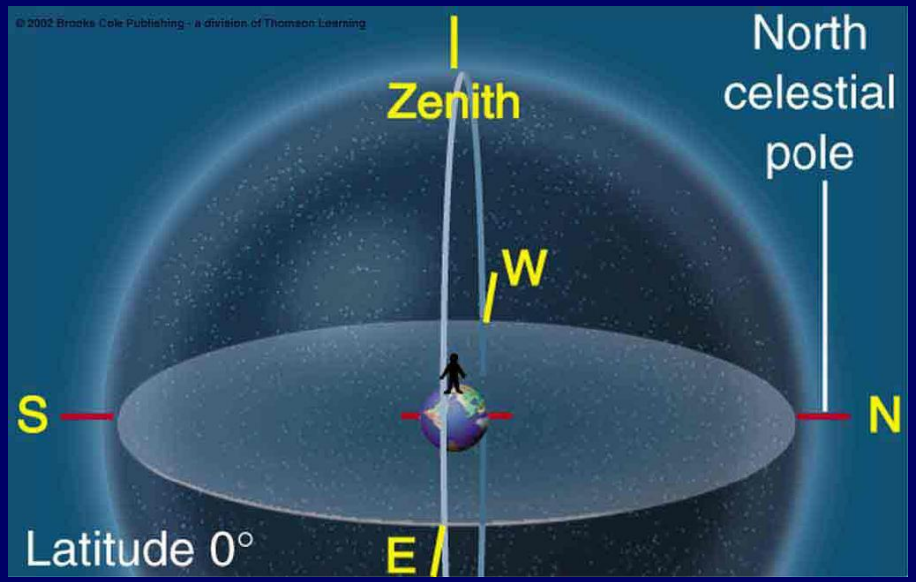
$$40.7° + 49.3° = 90°$$

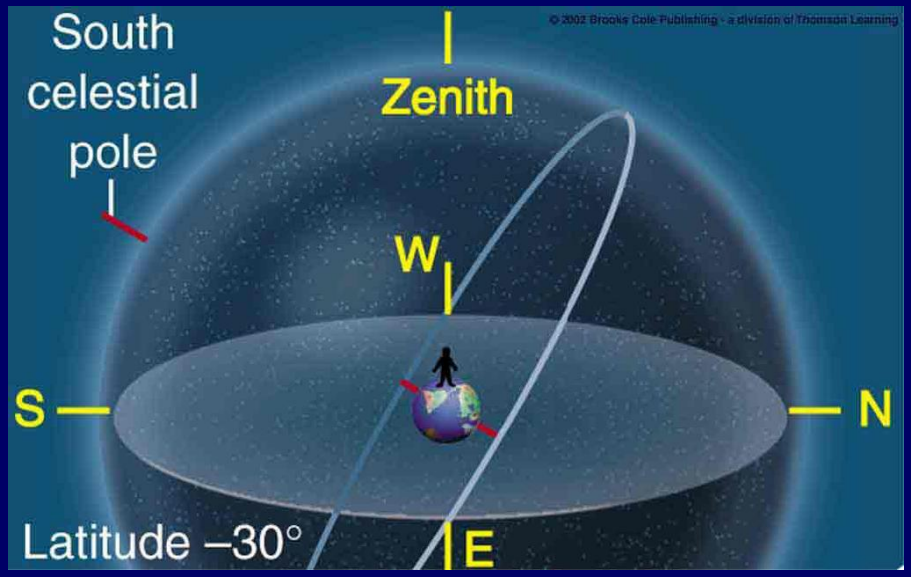
The south celestial pole is not visible from the northern hemisphere.

The Celestial Sphere

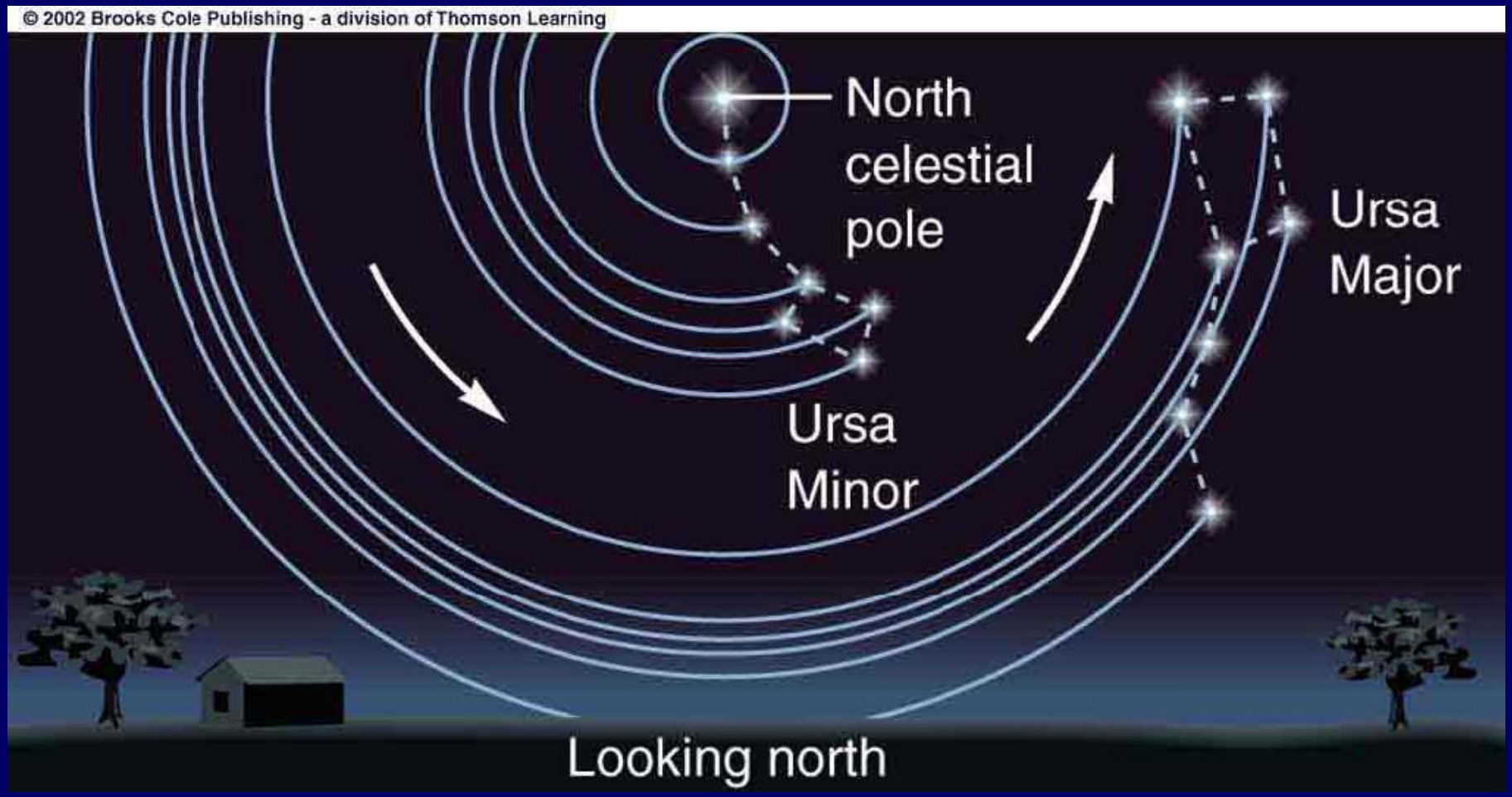






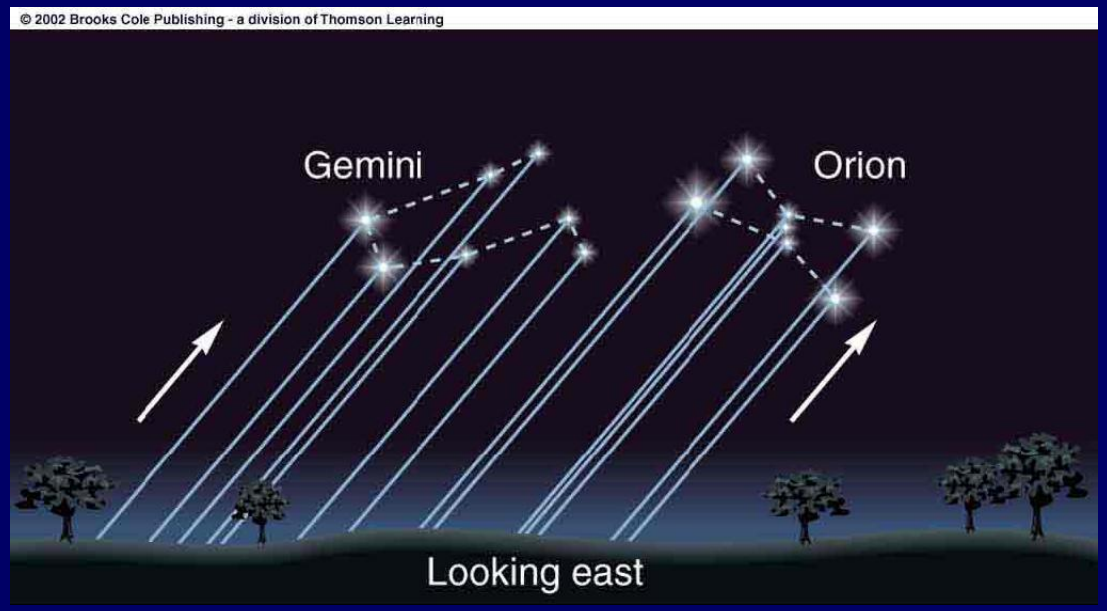


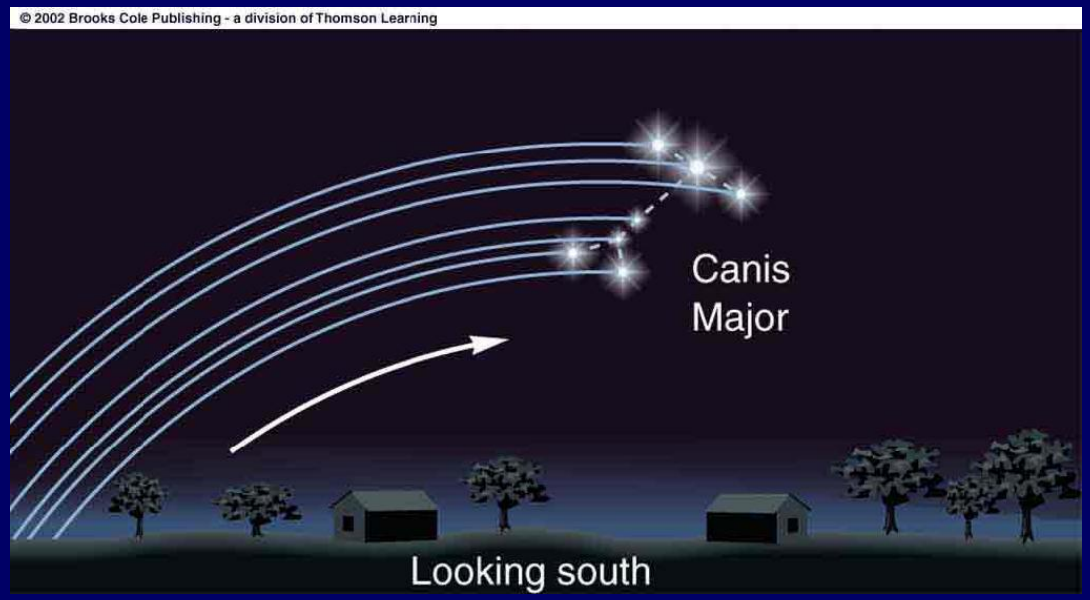
Apparent Motion of the Celestial Sphere



Apparent Motion of the Celestial Sphere

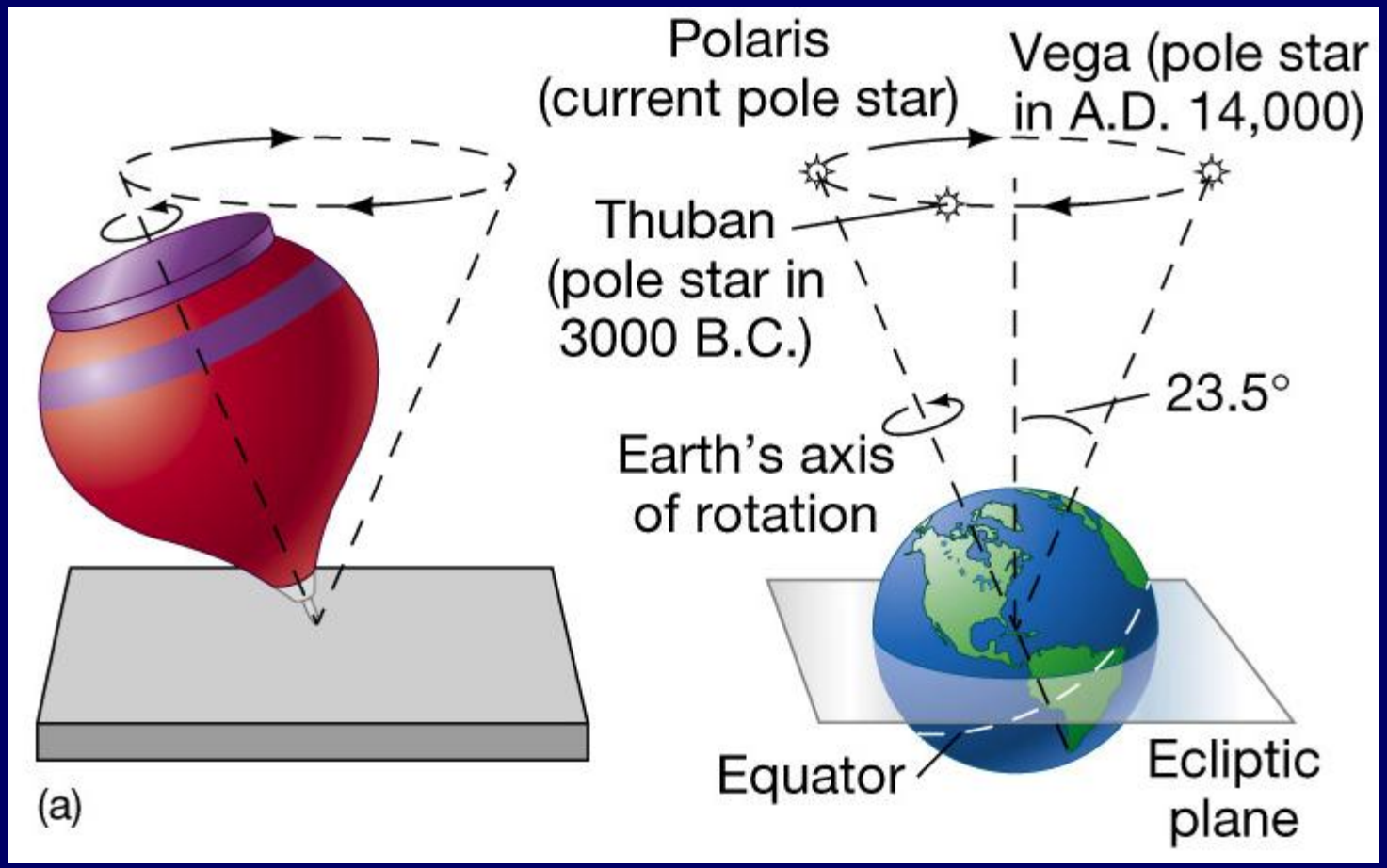
Motion is from East to West



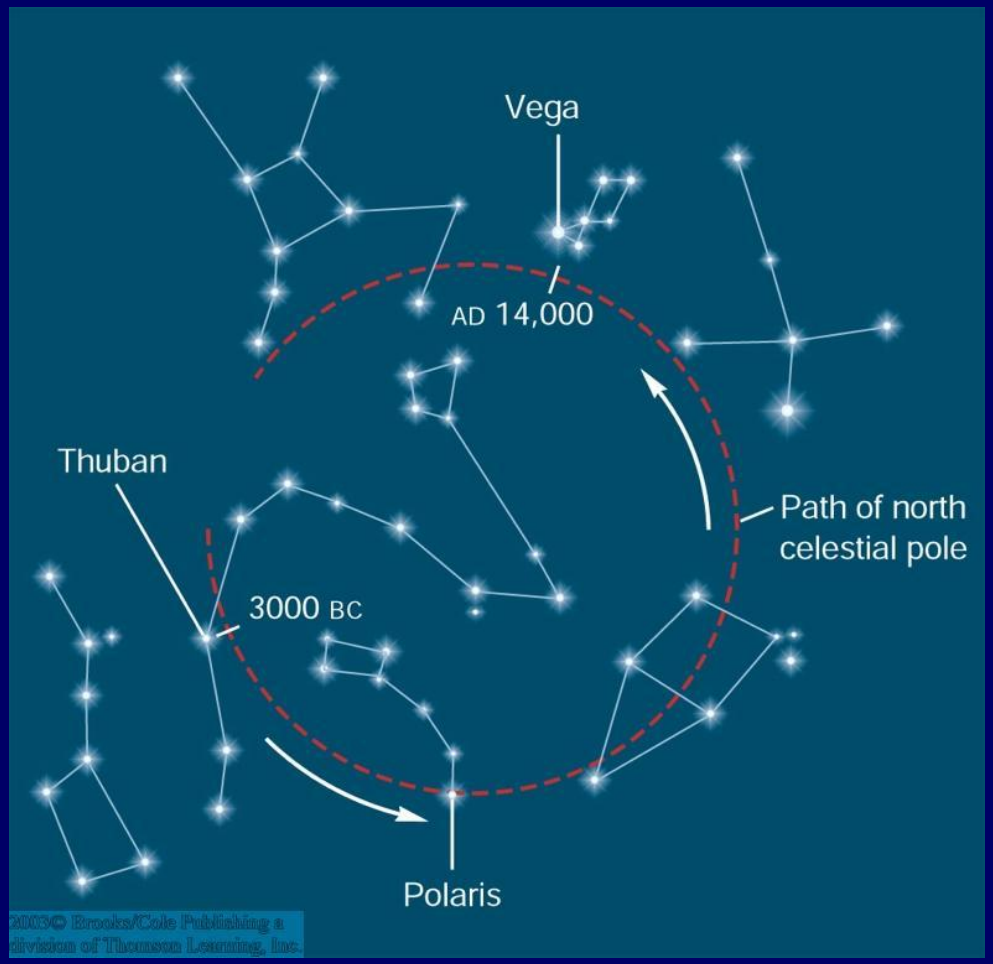


Precession

Rotation of Earth's axis itself; makes one complete circle in about 26,000 years. Celestial coordinates change with time



Precession



As a result of precession, the north celestial pole follows a circular pattern on the sky, once every 26,000 years.

It will be closest to Polaris ~ A.D. 2100.

~ 12,000 years from now, it will be close to Vega in the constellation Lyra.

There is nothing special about Polaris (It is neither particularly bright nor nearby *etc.*)

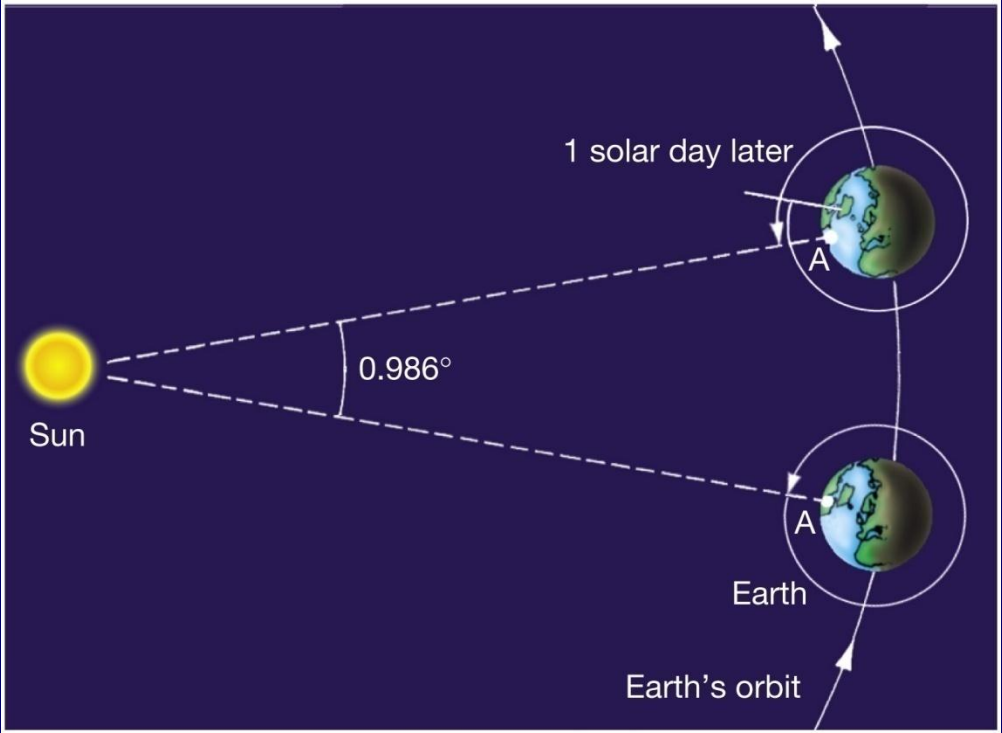
Apparent Motion of the Sun
Diurnal Motion of the Sun

- The Sun appears to move across the sky daily rising in the east and setting in the west which is caused by the Earth's rotation on its axis
- The time to go from noon to noon is a solar day
- Astronomical noon occurs when the Sun crosses the meridian
- The meridian is a line on the celestial sphere that passes through the zenith and the celestial poles

True Rotation of the Earth

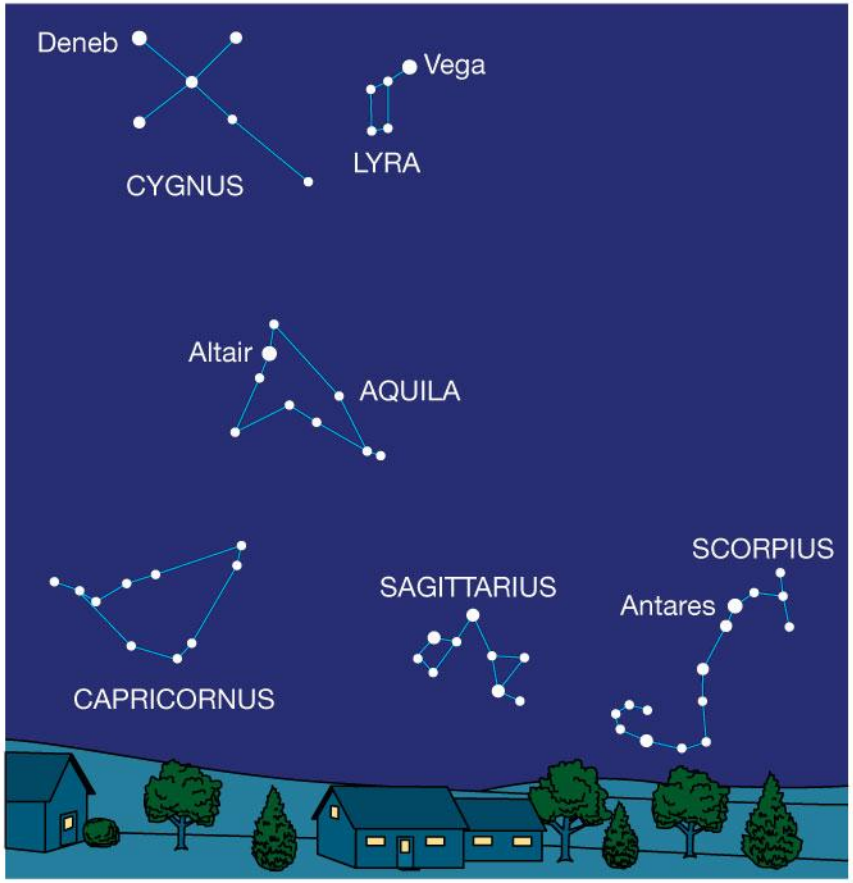
- A solar day is the time interval for the Sun to cross the meridian successively. The Earth will advance in its orbit and it must turn a little bit more than one full turn from noon to noon.

- A sidereal day is the time interval for the same fixed star to cross the meridian successively. It is the true rotation period of the Earth. A sidereal day is ~4 minutes shorter than a solar day.

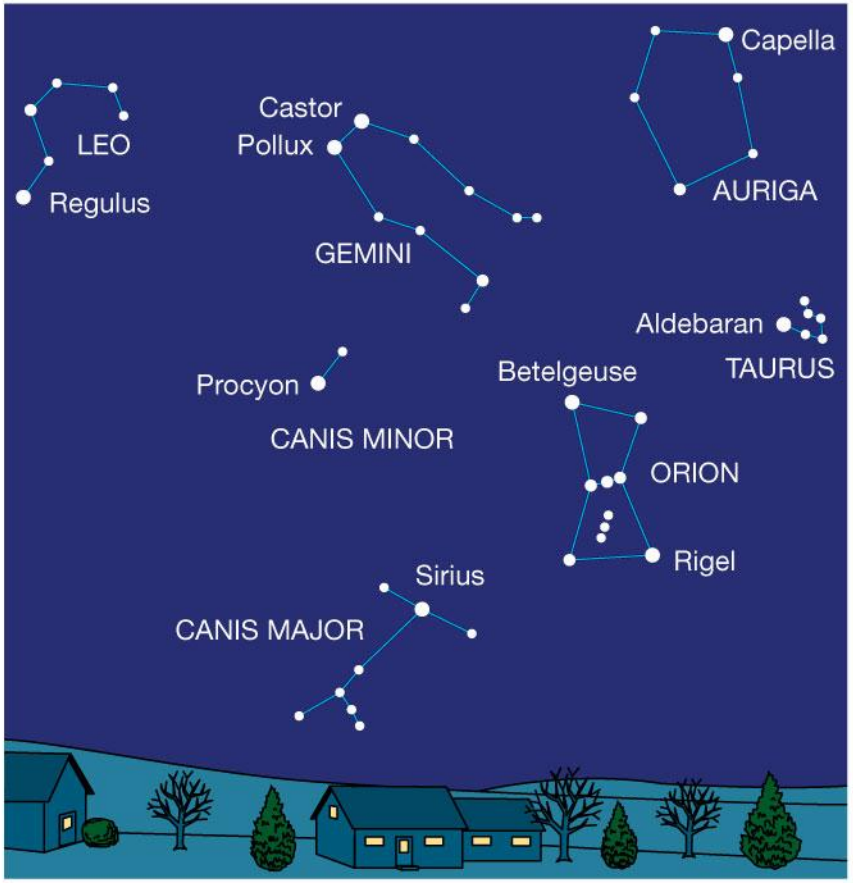


Apparent Annual Motion of the Sun

Seasonal changes to night sky are due to Earth's motion around Sun

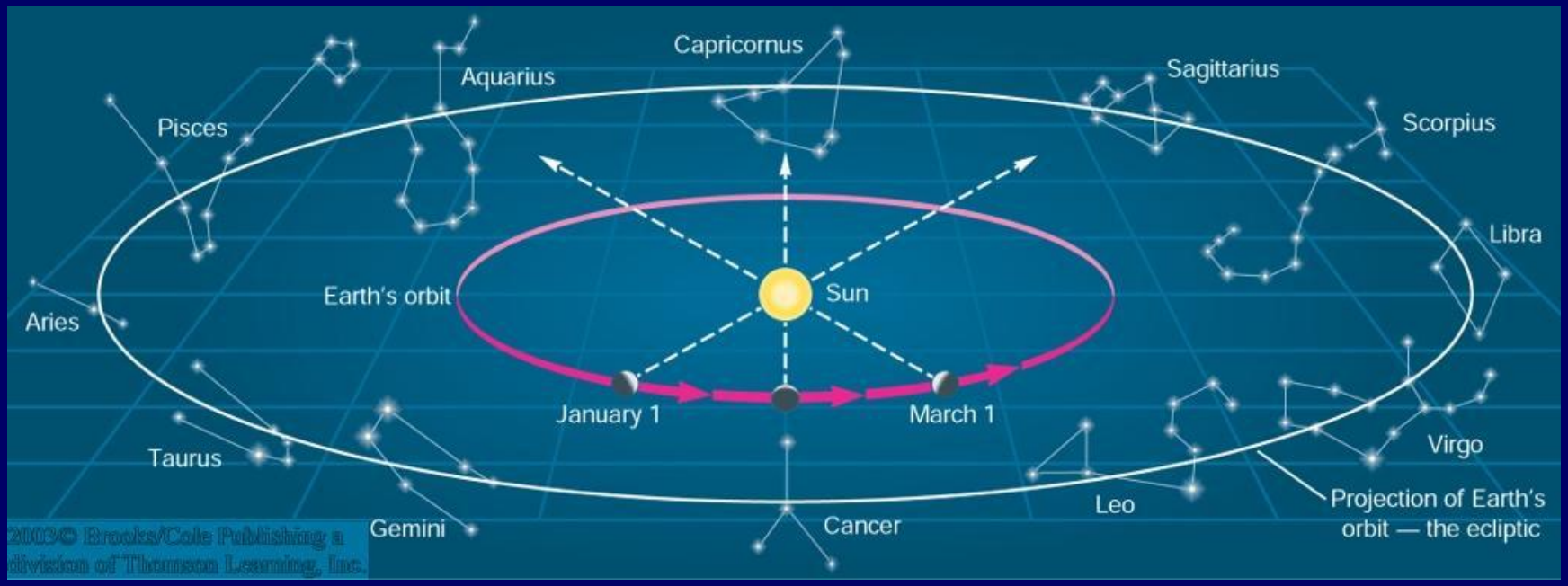


(a) Southern horizon, summer



(b) Southern horizon, winter

Apparent Annual Motion of the Sun

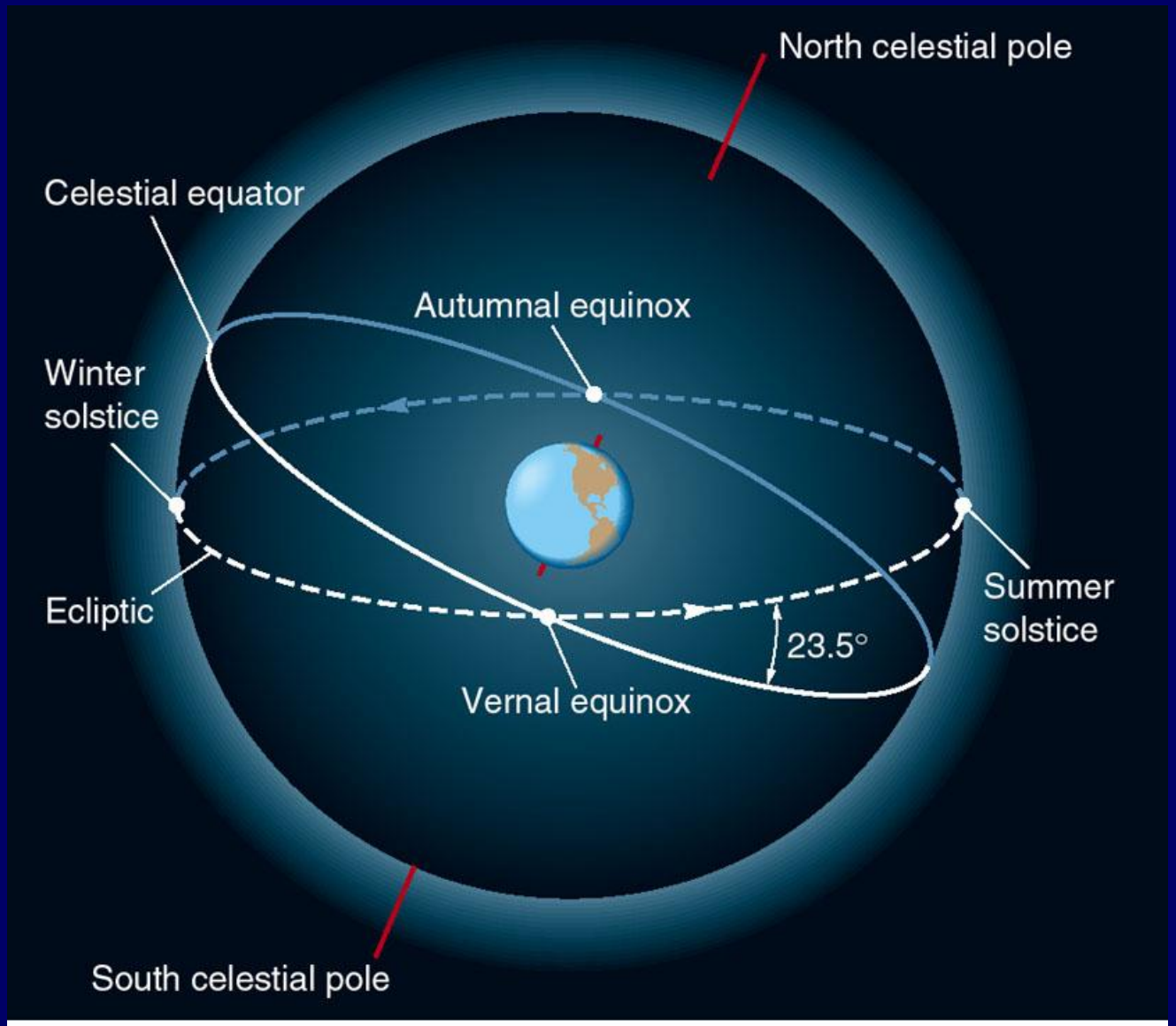


Because of Earth's revolution around the Sun, the Sun appears to move through the zodiacal constellations (the **zodiac**).

The Sun's apparent path on the sky is called the **ecliptic**.

Equivalent: The **ecliptic** is the projection of Earth's orbit onto the celestial sphere.

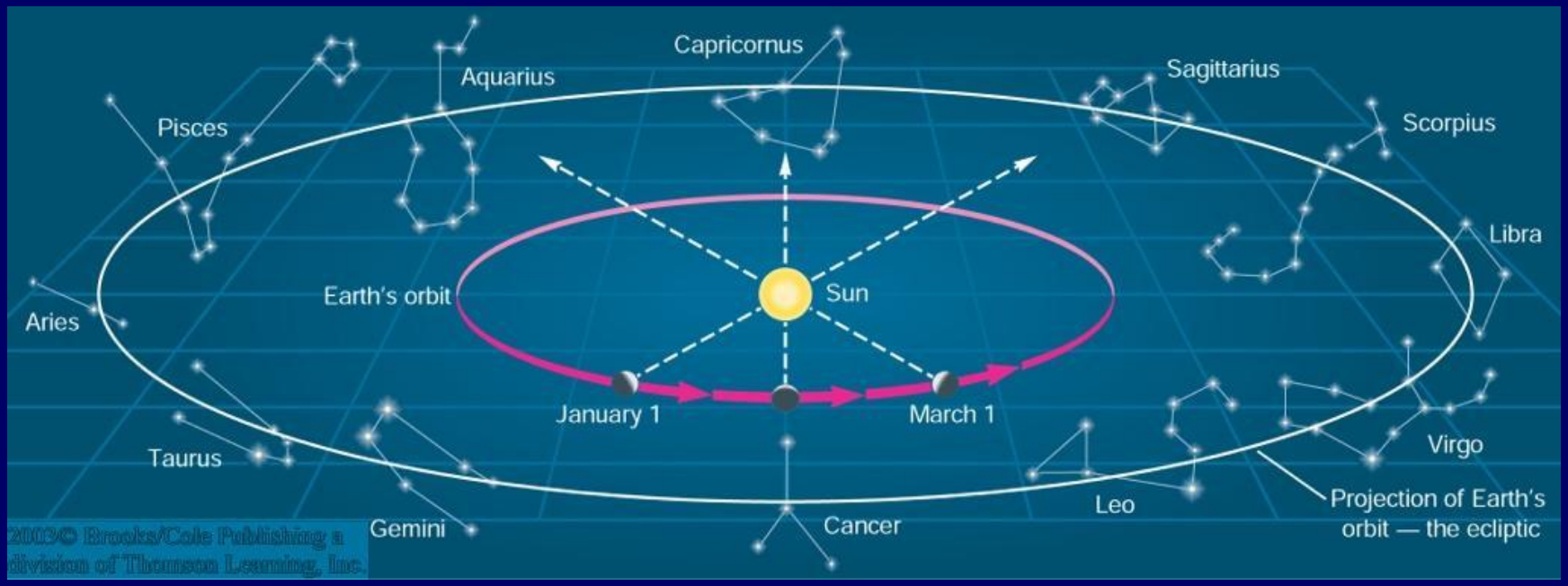
Equinoxes and Solstices



Equinoxes occur when the Sun crosses the celestial equator

The solstices mark the extremities of the Sun's displacement from the celestial equator

Precession of the Equinoxes



As a result of the precession of the Earth's axis of rotation, the equinoxes rotate through the zodiac over 26,000 years

The vernal equinox is now in the constellation Pisces. Around 100 CE it was in the constellation Aries. During the first Babylonian empire it was in the constellation Taurus

We are in "the dawn of the age of Aquarius"

Astronomy vs. Astrology

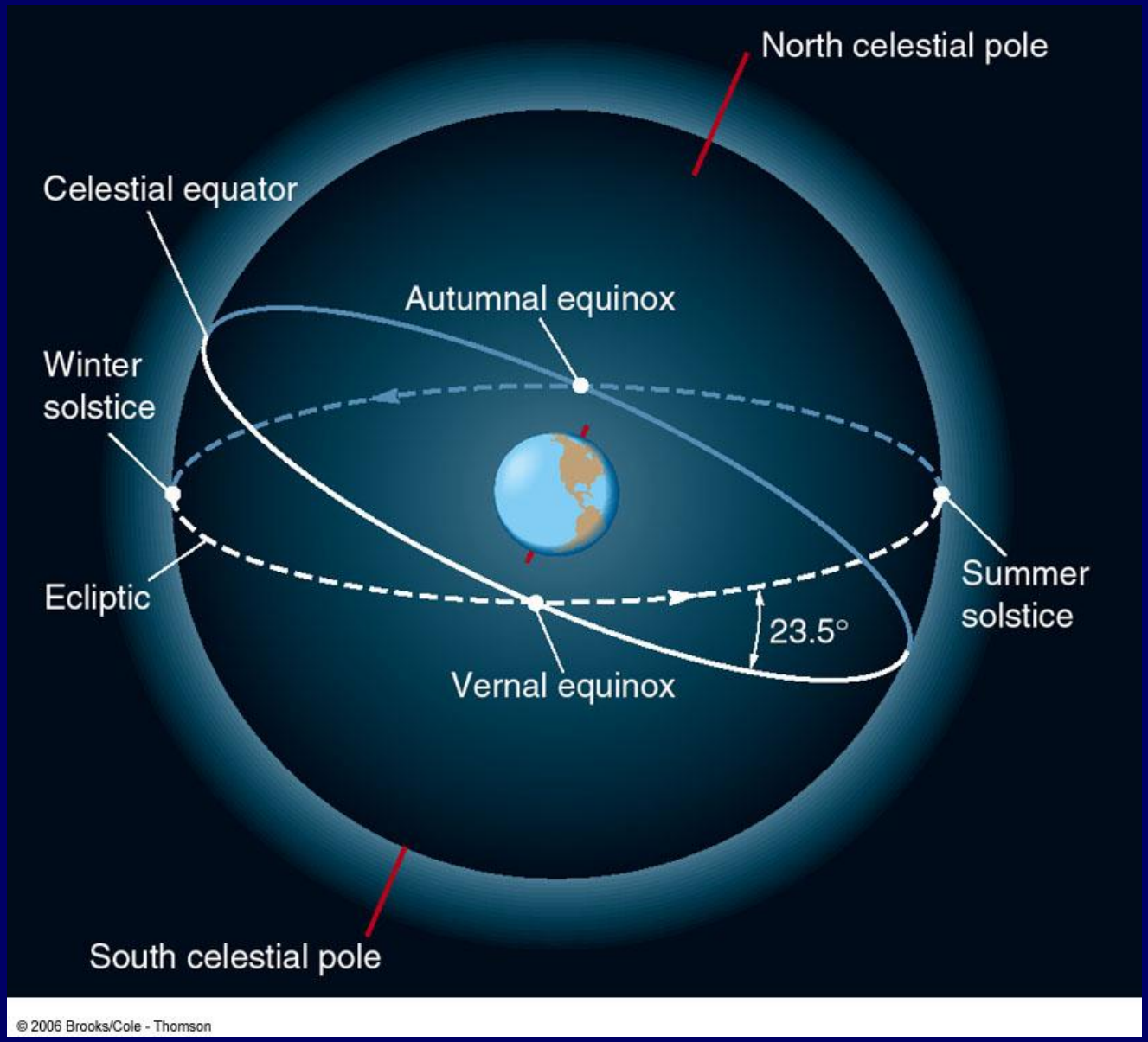
- Astronomy (the name of stars)—the observation of position and measurement of radiation from celestial bodies with the use of the laws of the physical sciences to understand them
- It began to be distinguished from astrology with the development of modern science in the 17th century

- Astrology (the study of stars)—from the assumption that celestial bodies have effects on happenings on Earth
- Based on the strong effect of the Sun (energy and gravity) and the Moon (gravity—tides), but gravitational effects from planets are small and nonexistent from stars.
- Traditional interpretations come from Claudius Ptolemy (c. 100 CE), but with no justification acceptable to modern science

The Sun's Position through the Year

Constellation	*Ptolemy (~100 CE)*	*Actual (2000 CE)*	*Days*
Pisces	Feb. 22-Mar. 21	Mar. 11 – April 18	38
Aries	Mar. 22 – April 21	April 18 – May 13	25
Taurus	April 22 – May 21	May 13 – June 22	40
Gemini	May 22 – June 21	June 22 – July 21	29
Cancer	June 22 – July 21	July 21 – Aug. 10	20
Leo	July 22 – Aug. 21	Aug. 10 – Sept. 16	37
Virgo	Aug. 22 – Sept. 21	Sept. 16 – Oct. 31	45
Libra	Sept. 22 – Oct. 21	Oct. 21 – Nov. 23	23
Scorpio	Oct. 22 – Nov. 21	Nov. 23 – Nov. 29	6
Ophiuchus		Nov. 29- Dec. 18	19
Sagittarius	Nov. 22 – Dec. 21	Dec. 18 – Jan. 21	34
Capricorn	Dec. 22 – Jan. 21	Jan. 21 – Feb. 16	26
Aquarius	Jan. 22 – Feb. 21	Feb. 16 – Mar. 11	24

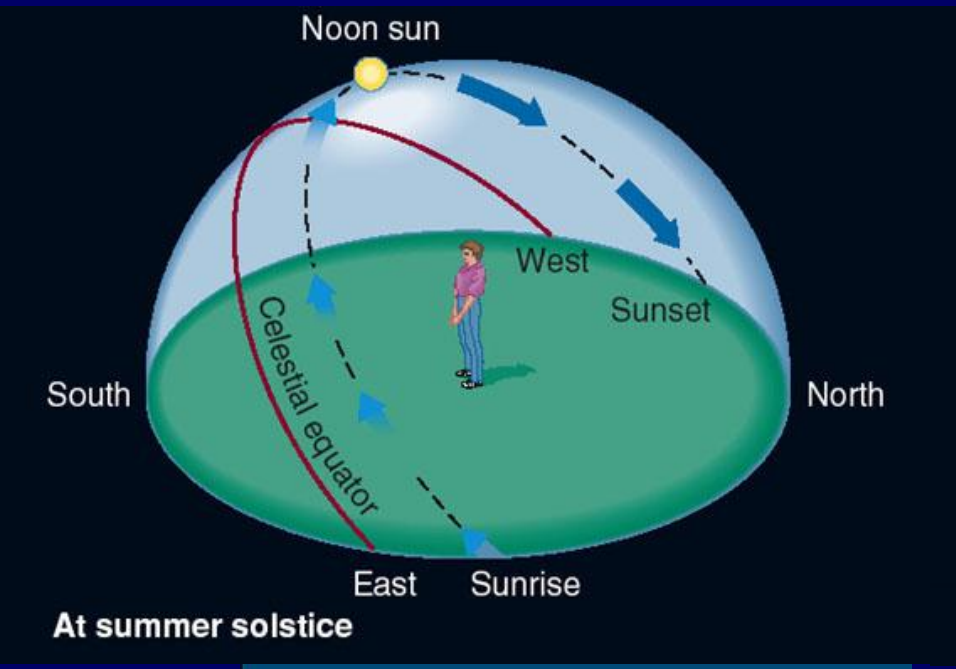
The Seasons

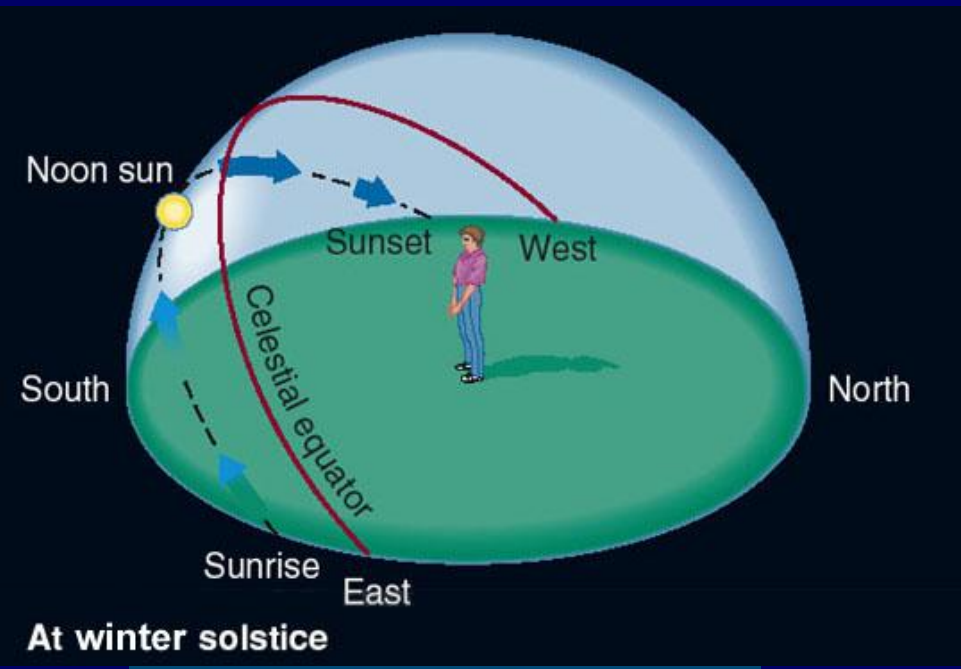


Earth's rotational axis is inclined to the ecliptic by 23.5°.

The different incidence angle of the Sun's rays as the Earth orbits the Sun causes the seasons on Earth

The Seasons


Noon sun
West
Sunset
South
North
Celestial equator
East
Sunrise
At summer solstice


Noon sun
Sunset
West
South
North
Celestial equator
Sunrise
East
At winter solstice

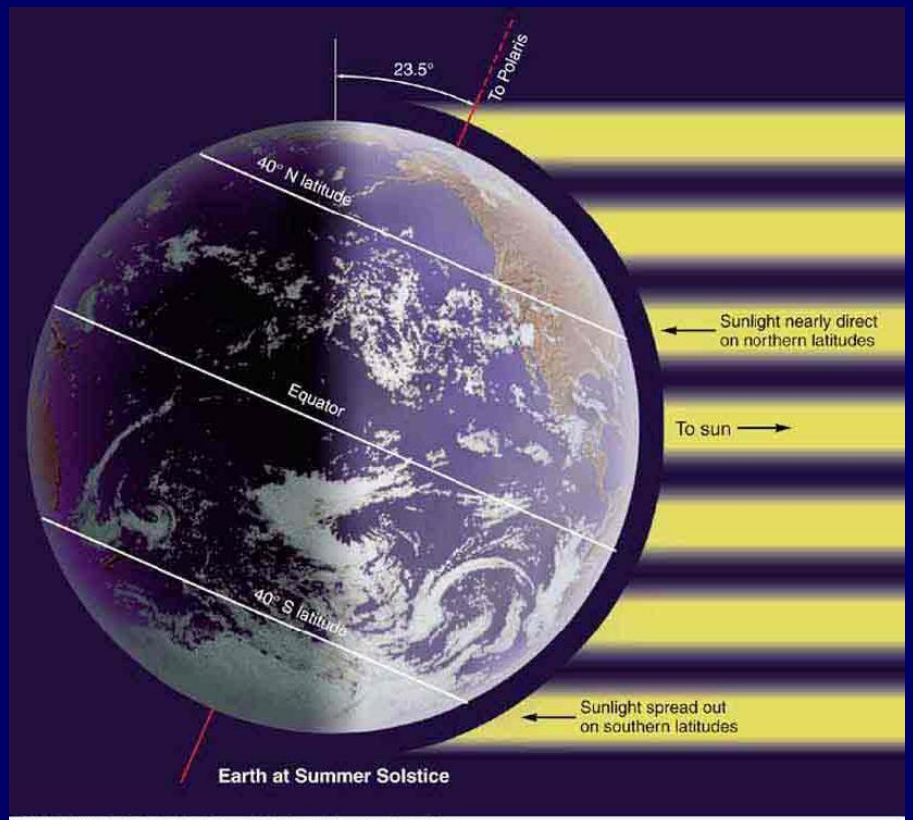

Summer solstice light

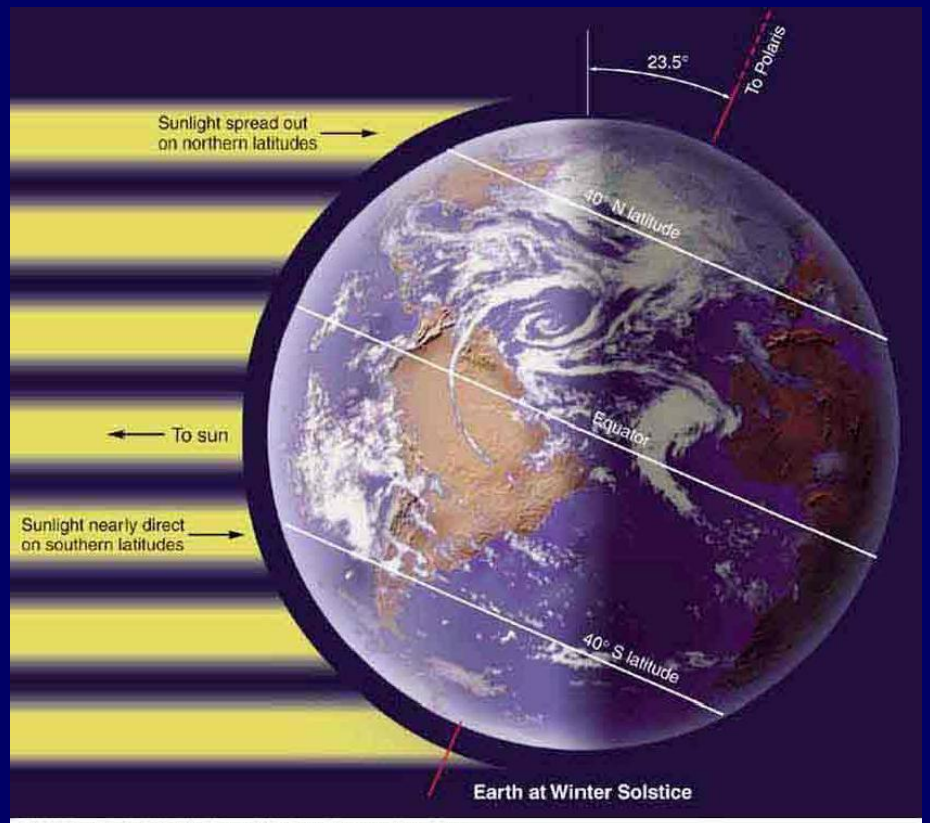

Winter solstice light

The Seasons

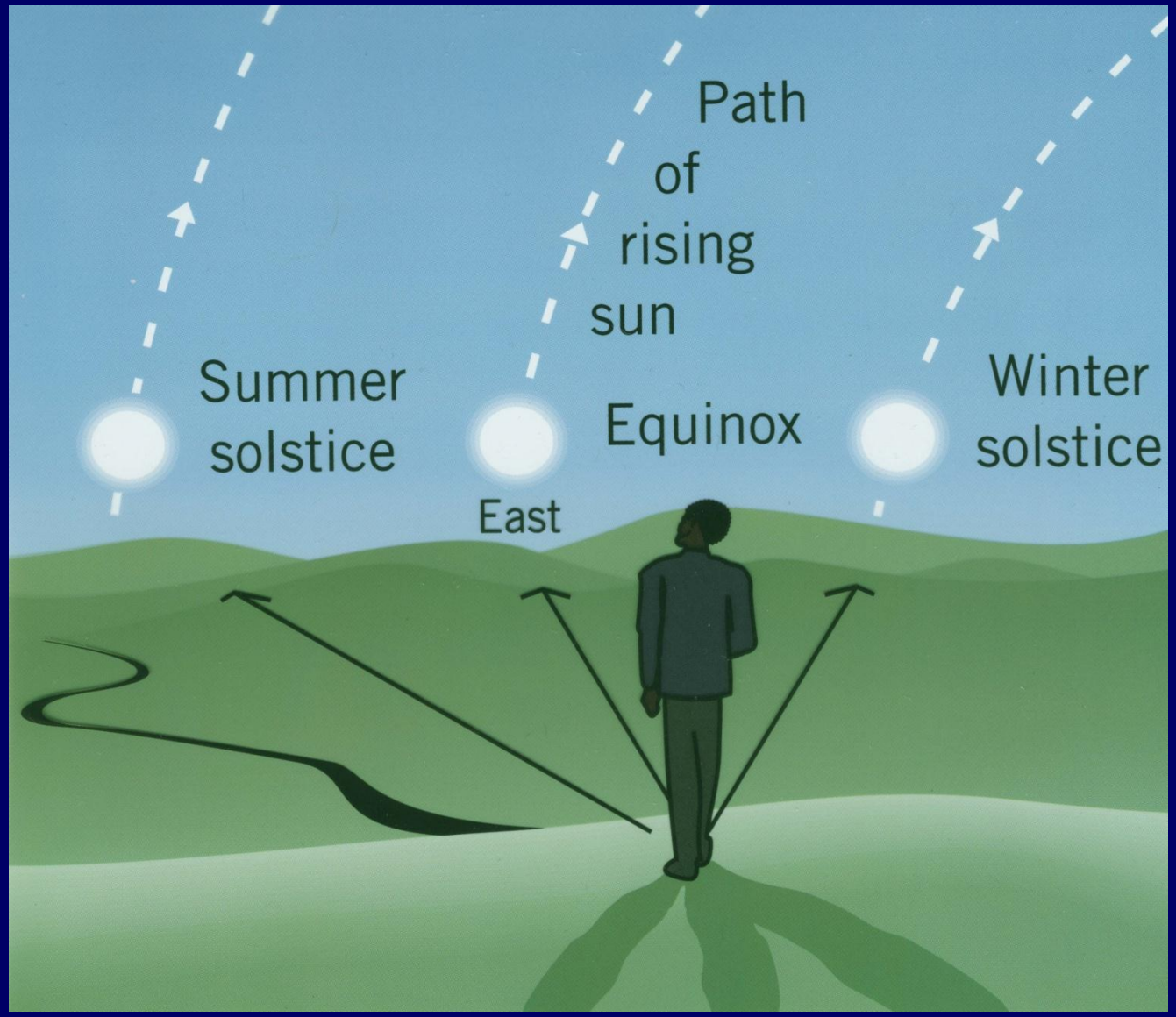
Northern summer = southern winter

Northern winter = southern summer





Seasonal Rising of the Sun



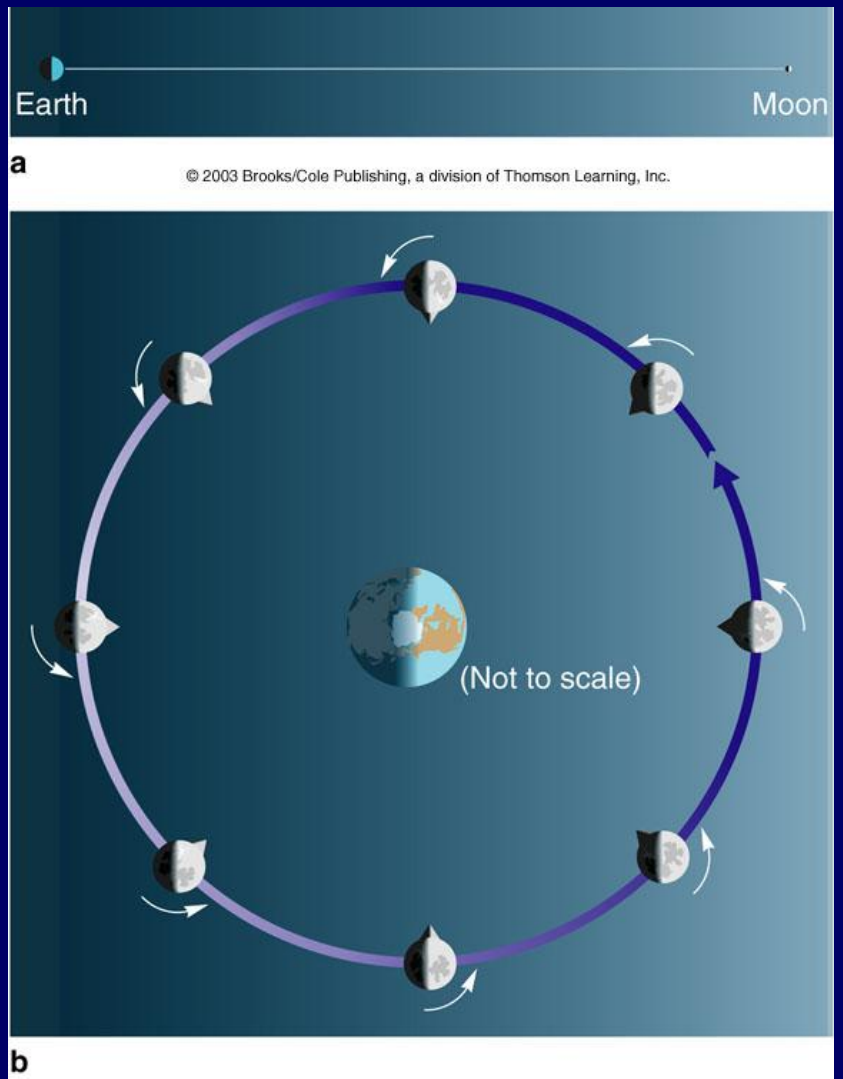
Summary of the Sun's Apparent Motion

- Diurnal—rises in the east and sets in the west (reason: Earth rotates on its axis)
- Annual—moves through the zodiac from west to east (reason: Earth revolves in its orbit)
- Seasonal—rises higher in the sky at noon in summer and lower in winter. It rises above the horizon north of east in summer and south of east in winter (reason: Earth's axis is tilted 23.5° with respect to the ecliptic plane)

Apparent Motion of the Moon

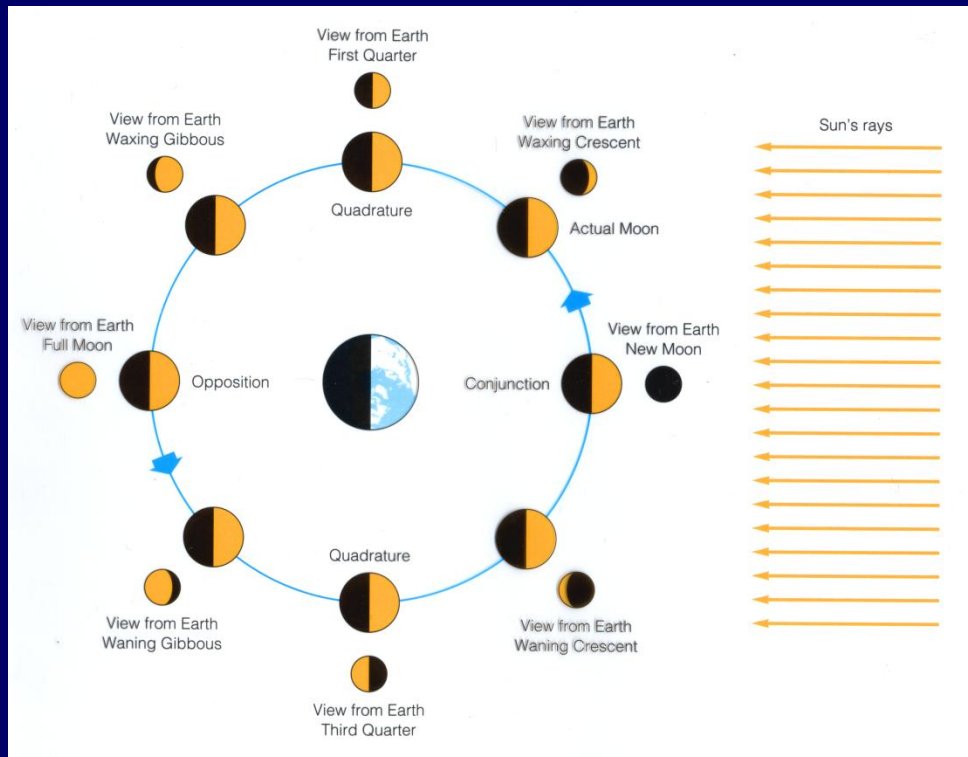
The Tidally Locked Rotation of the Moon

- The Moon is rotating with the same period around its axis as it is orbiting Earth (tidally locked).
- We always see the same side of the Moon facing Earth.
- This is an example of 1:1 spin-orbit resonance



The Phases of the Moon

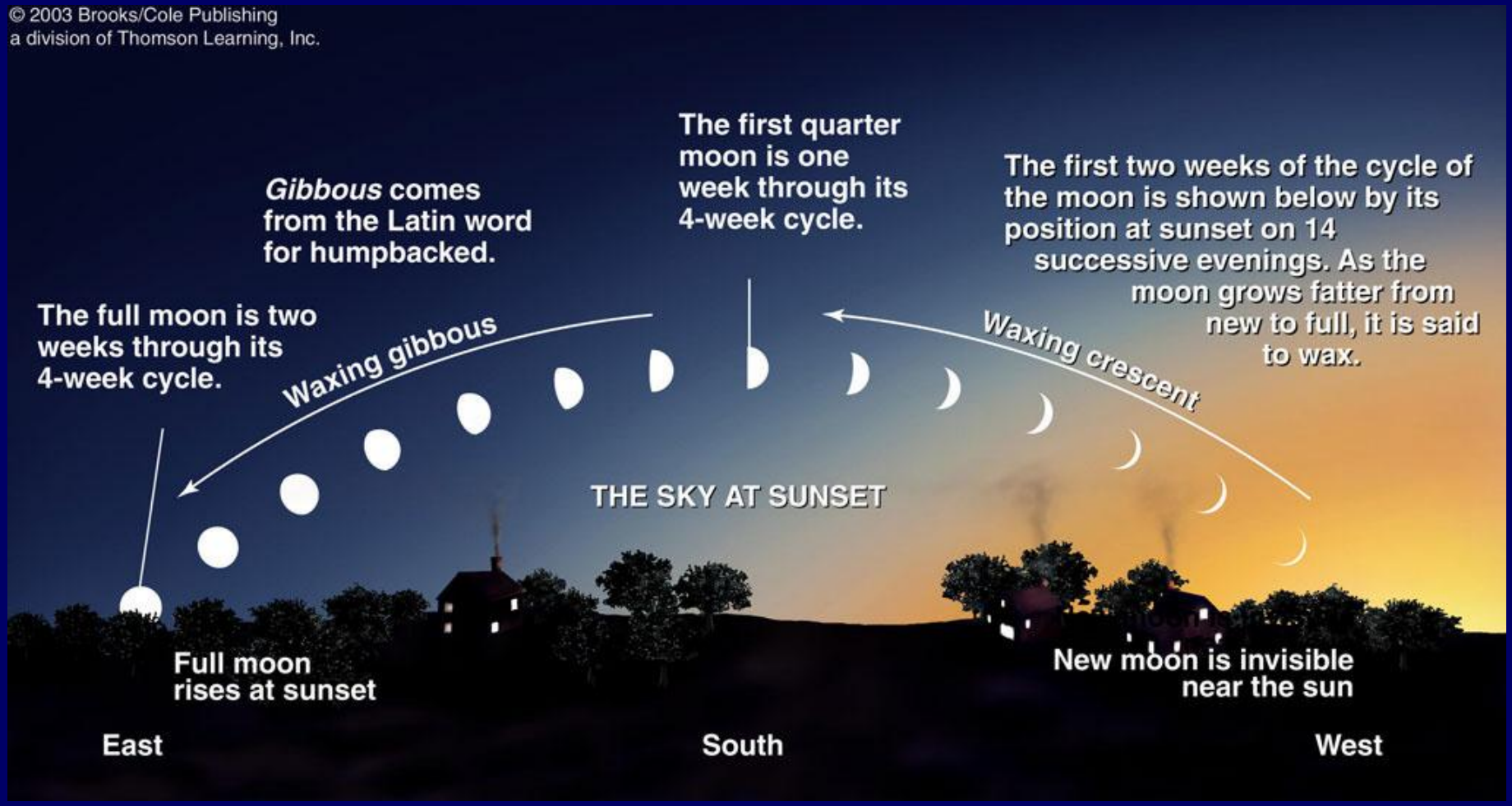
As the Moon orbits the Earth, we see different portions of the Moon's surface lit by the Sun, causing the phases of the Moon.



The Phases of the Moon

New Moon → First Quarter → Full Moon

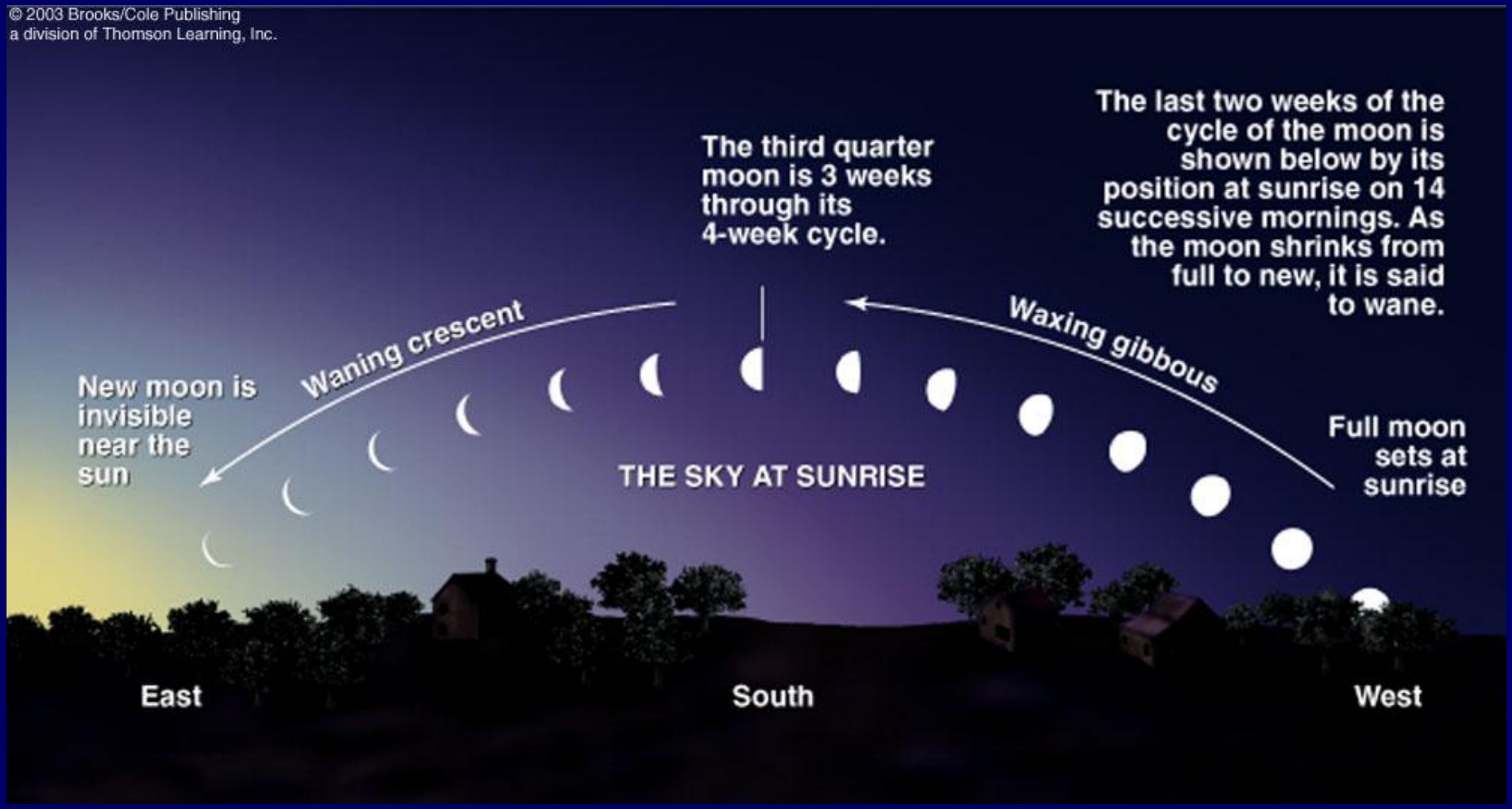
Evening Sky



The Phases of the Moon

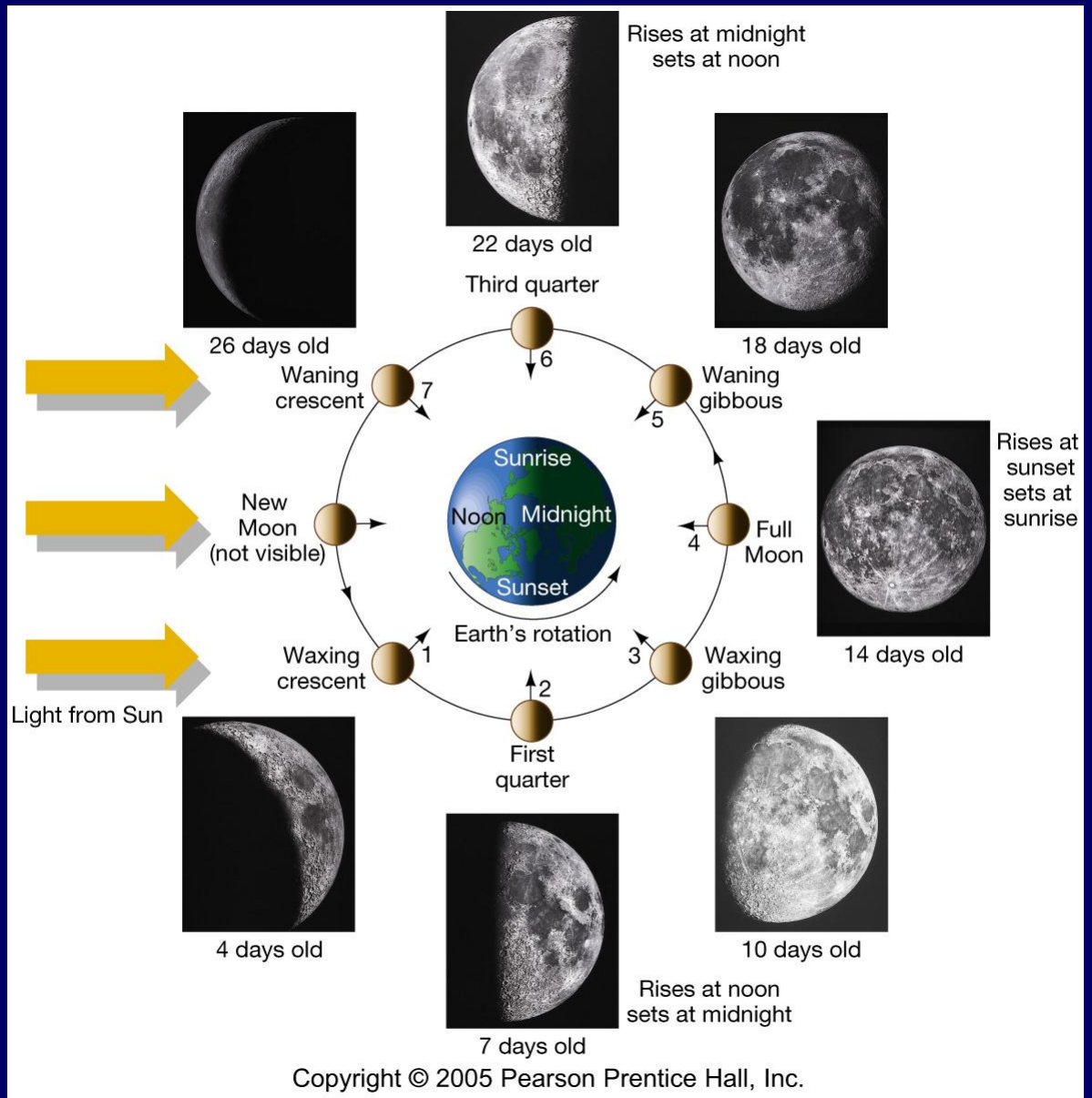
Full Moon → Third Quarter → New Moon

Morning Sky



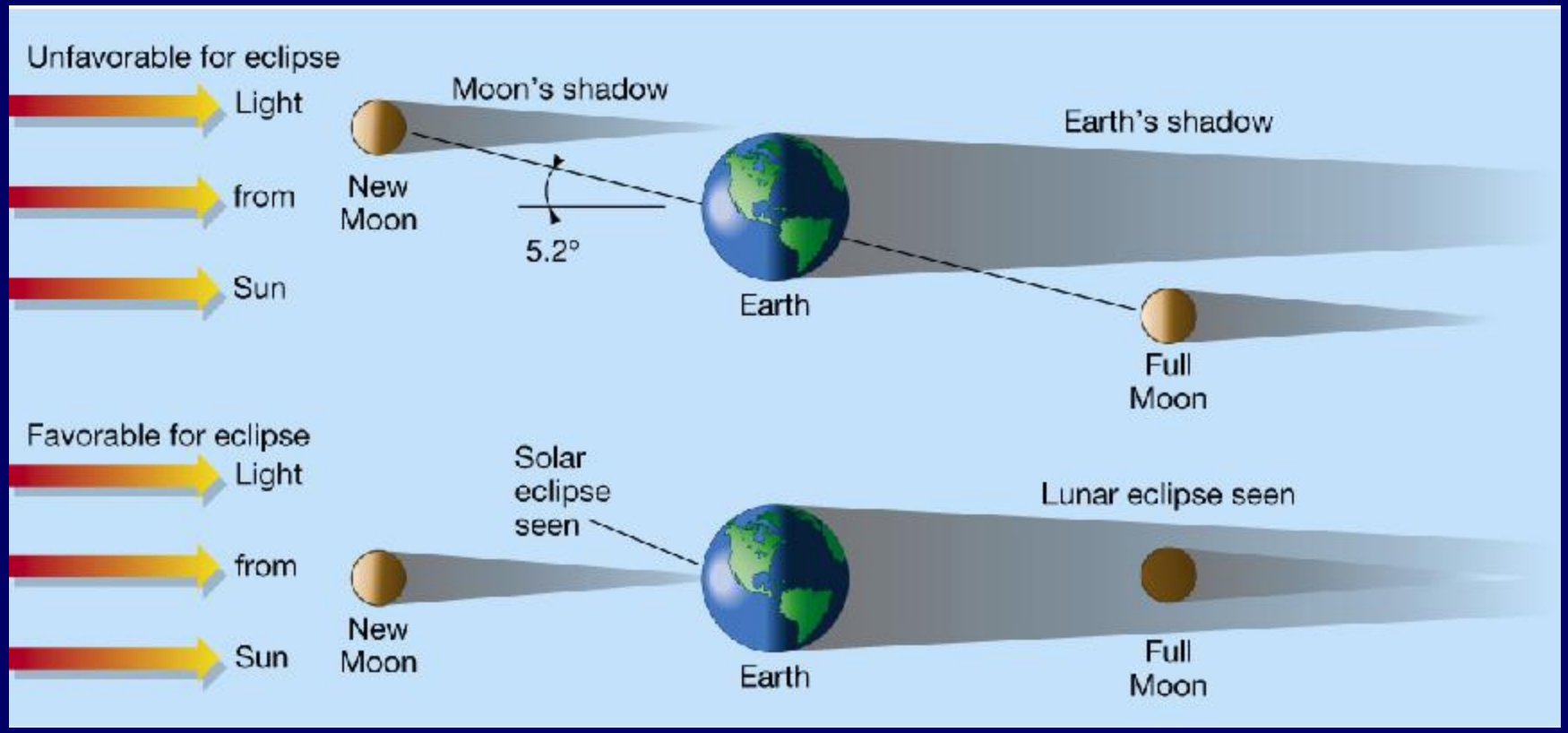
Apparent Motion of the Moon

- Moon takes about 29.5 days to go through the whole cycle of phases – synodic month
- Time to revolve 360° around Earth, sidereal month, is about 2 days shorter
- Reason: Earth revolves in its orbit about 29° in a synodic month.

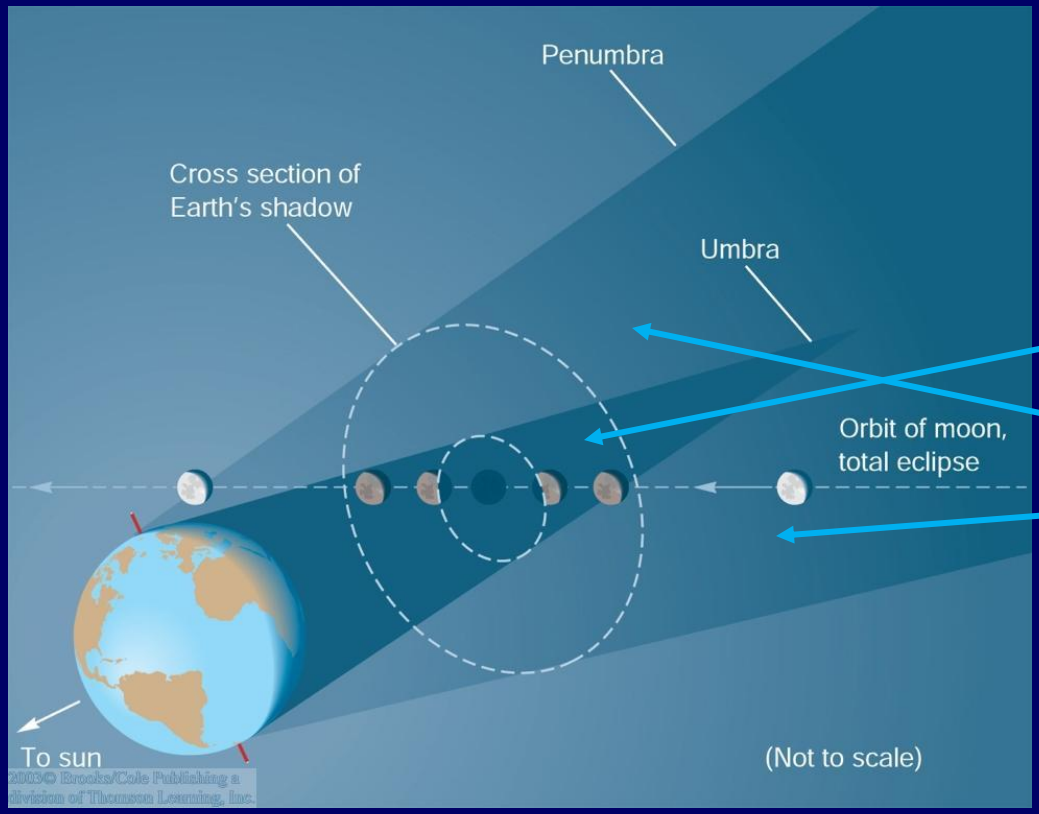


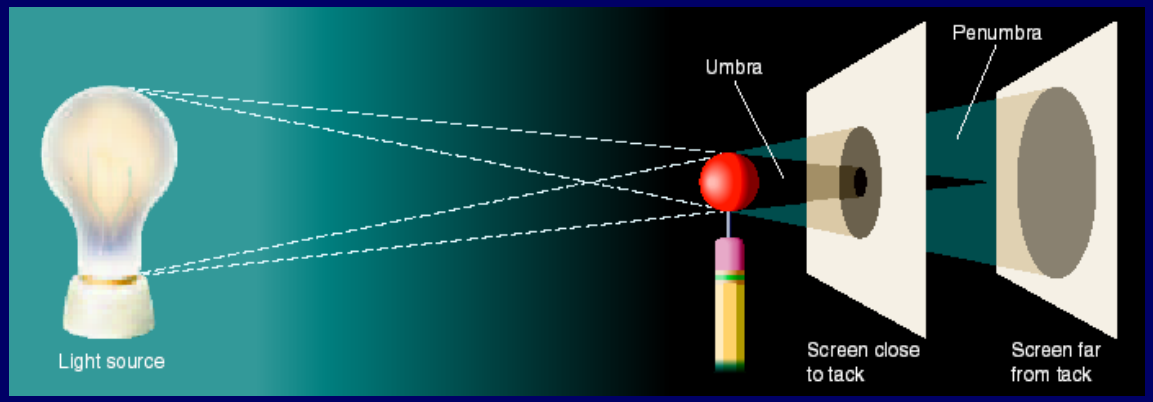
Apparent Motion of the Moon

Eclipses occur when Earth, Moon, and Sun form a straight line



Lunar Eclipses



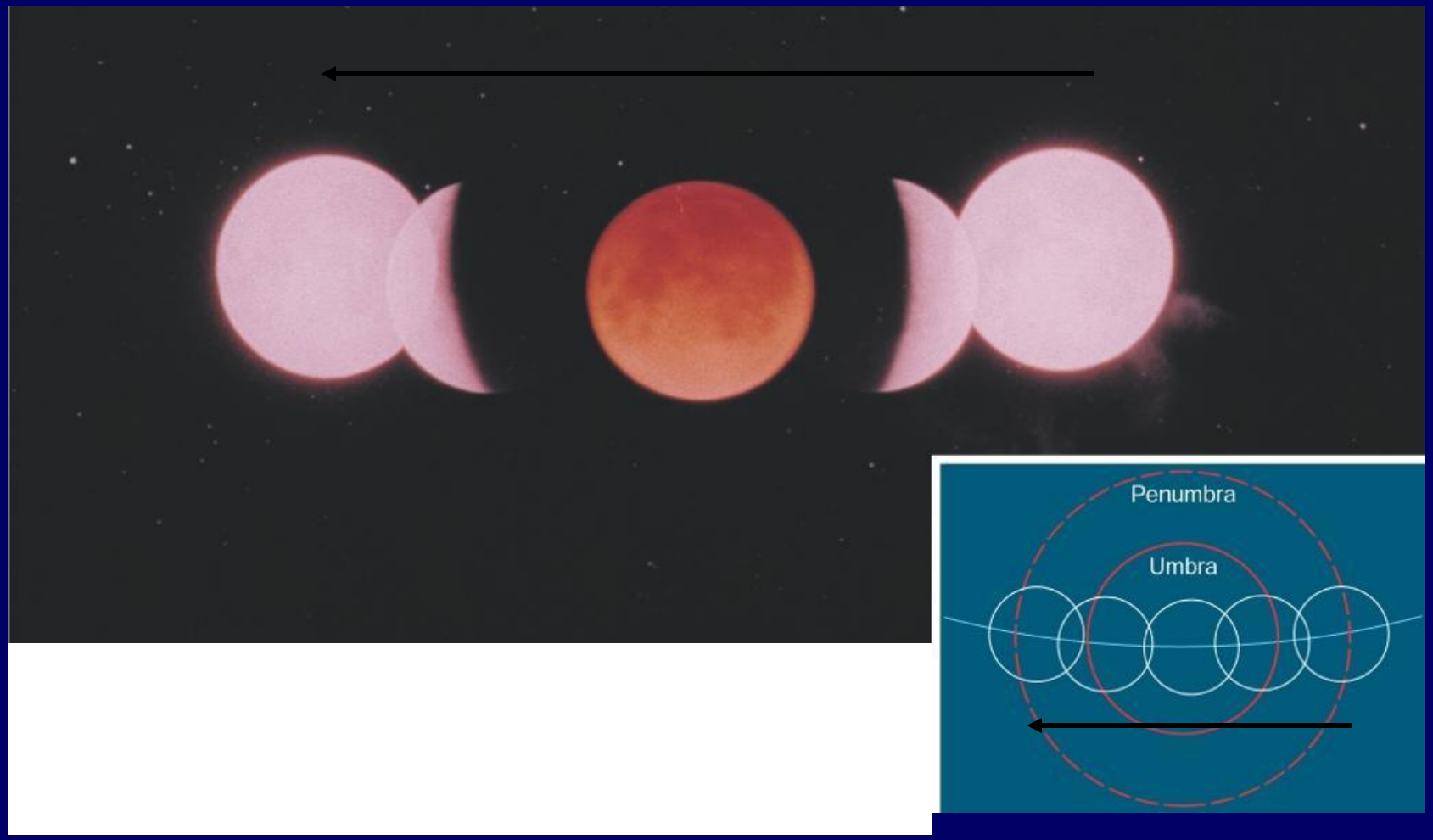


Earth's shadow consists of a zone of full shadow, the **umbra**, and a zone of partial shadow, the **penumbra**.

If the Moon passes through Earth's full shadow (**umbra**), we see a lunar eclipse.

If the entire surface of the Moon enters the umbra, the lunar eclipse is total.

A Total Lunar Eclipse



A Total Lunar Eclipse

A total lunar eclipse can last up to 1 hour 40 min.

During a total eclipse, the Moon has a faint, red glow, reflecting sunlight scattered by Earth's atmosphere.

Lunar Eclipses

Eclipses do not occur every month because Earth's and Moon's orbits are not in the same plane

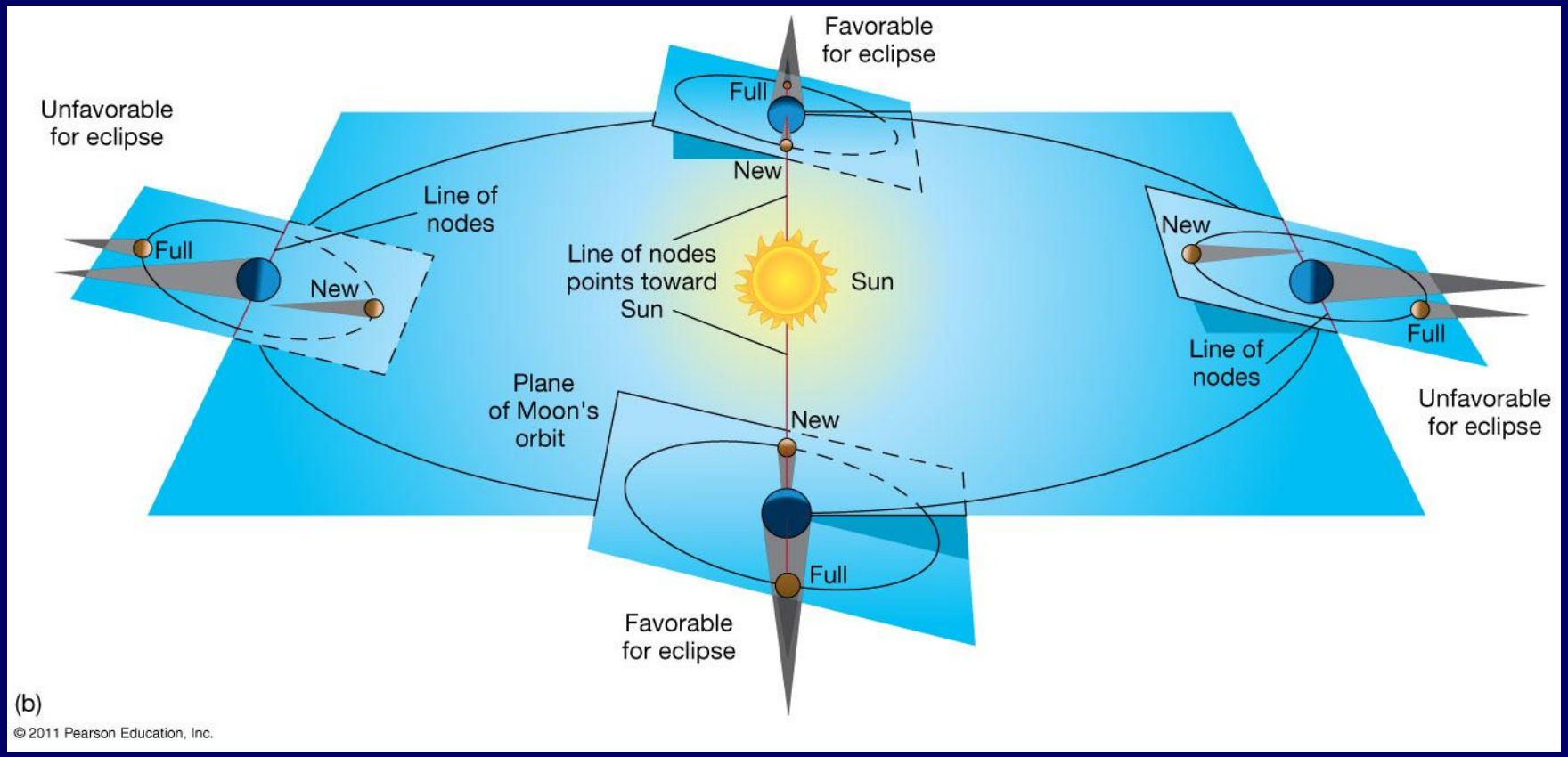


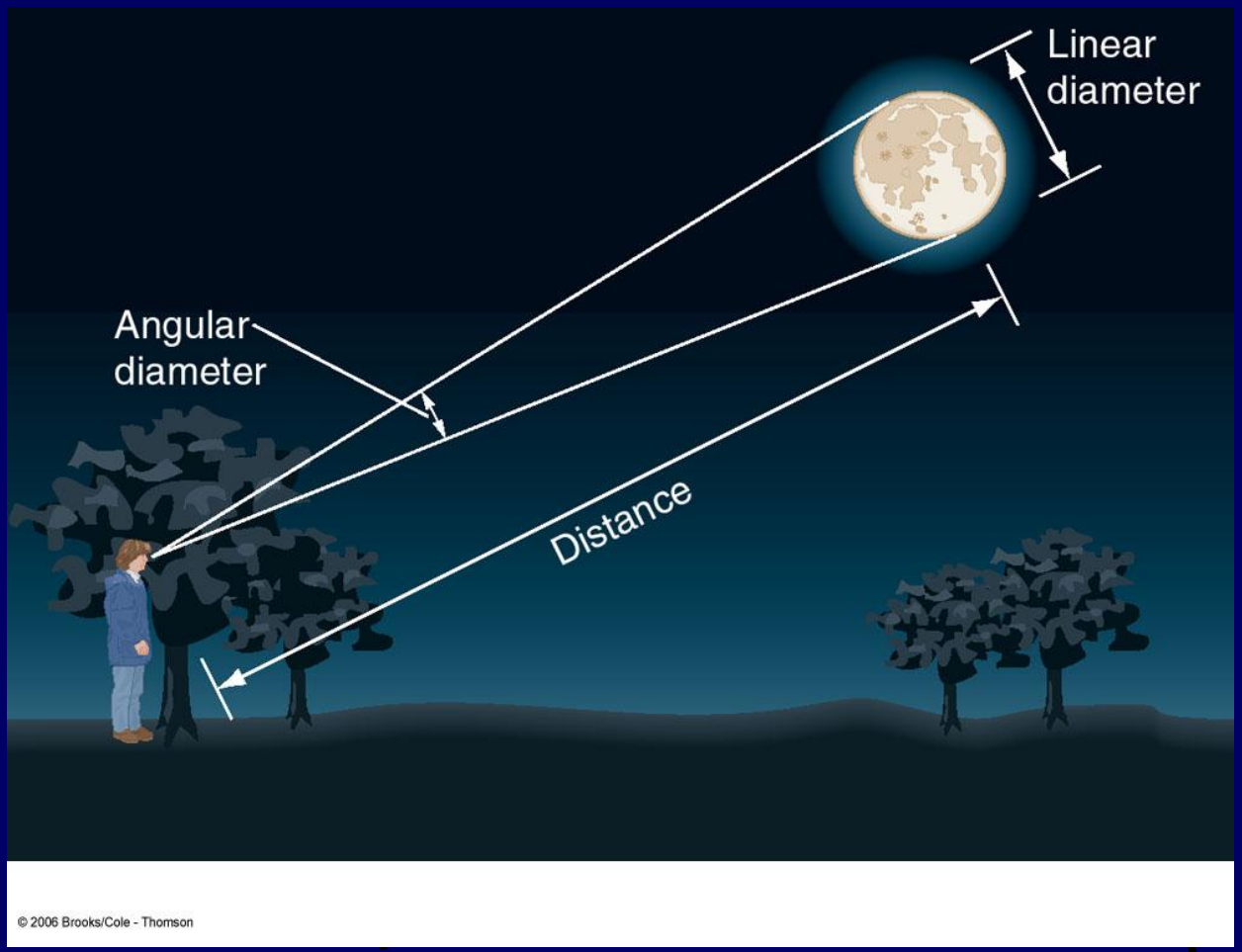
Table 3-1 | Total and Partial Eclipses of the Moon, 2005–2012

Date	Time* of Mideclipse (GMT)	Length of Totality (Min)	Length of Eclipse (Hr:Min)
2005 Oct. 17	12:04	Partial	0:56
2006 Sept. 7	18:52	Partial	1:30
2007 Mar. 3	23:22	74	3:40
2007 Aug. 28	10:38	90	3:32
2008 Feb. 21	3:27	50	3:24
2008 Aug. 16	21:11	Partial	3:08
2009 Dec. 31	19:24	Partial	1:00
2010 June 26	11:40	Partial	2:42
2010 Dec. 21	8:18	72	3:28
2011 June 15	20:13	100	3:38
2011 Dec. 10	14:33	50	3:32
2012 June 4	11:04	Partial	2:06

*Times are Greenwich Mean Time. Subtract 5 hours for Eastern Standard Time, 6 hours for Central Standard Time, 7 hours for Mountain Standard Time, and 8 hours for Pacific Standard Time. From your time zone, lunar eclipses that occur between sunset and sunrise will be visible, and those at midnight will be best placed.

Typically, 1 or 2 lunar eclipses per year.

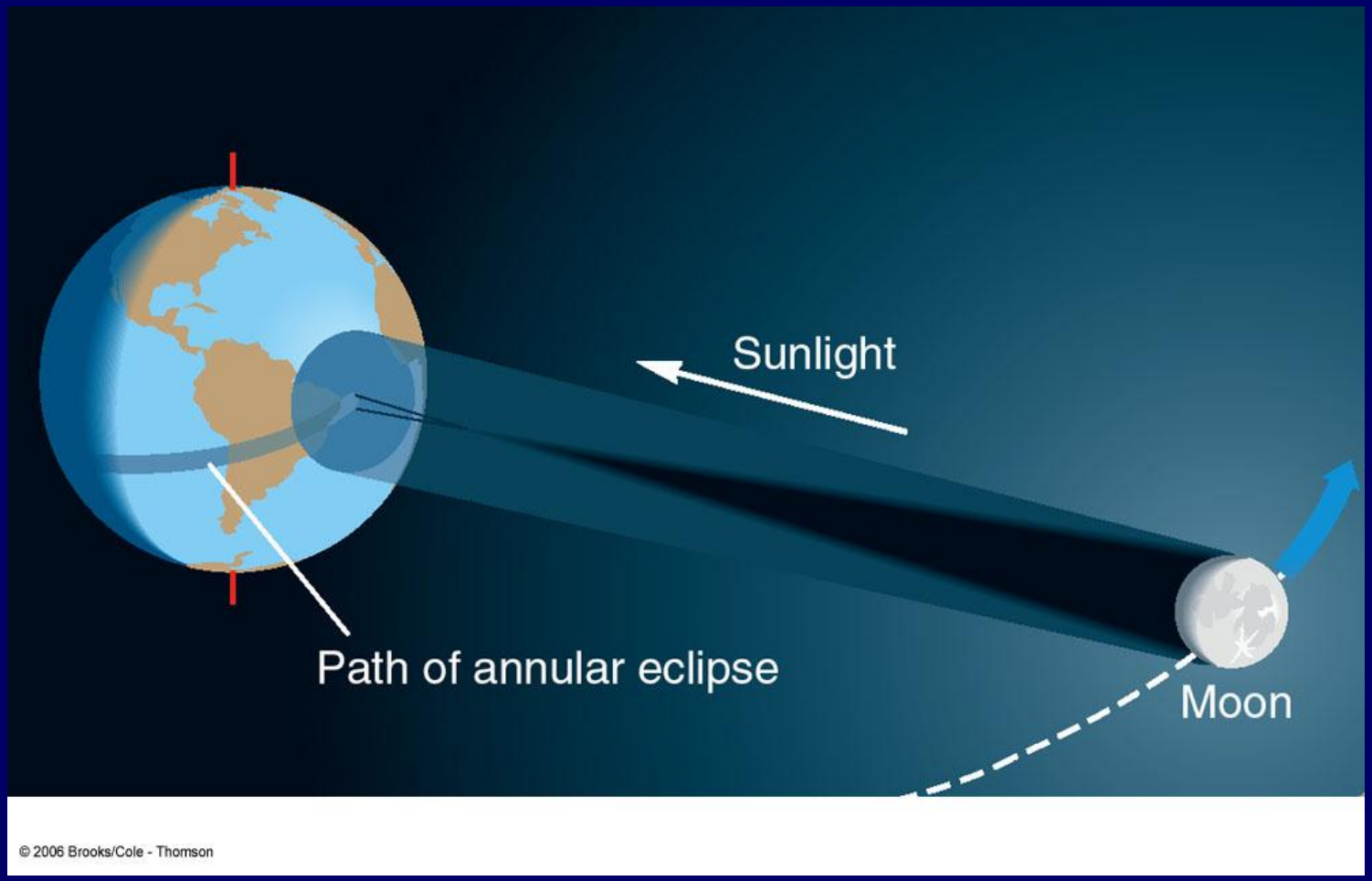
Solar Eclipses



The angular diameter of the Moon (~ 0.5º) is almost exactly the same as that of the Sun.

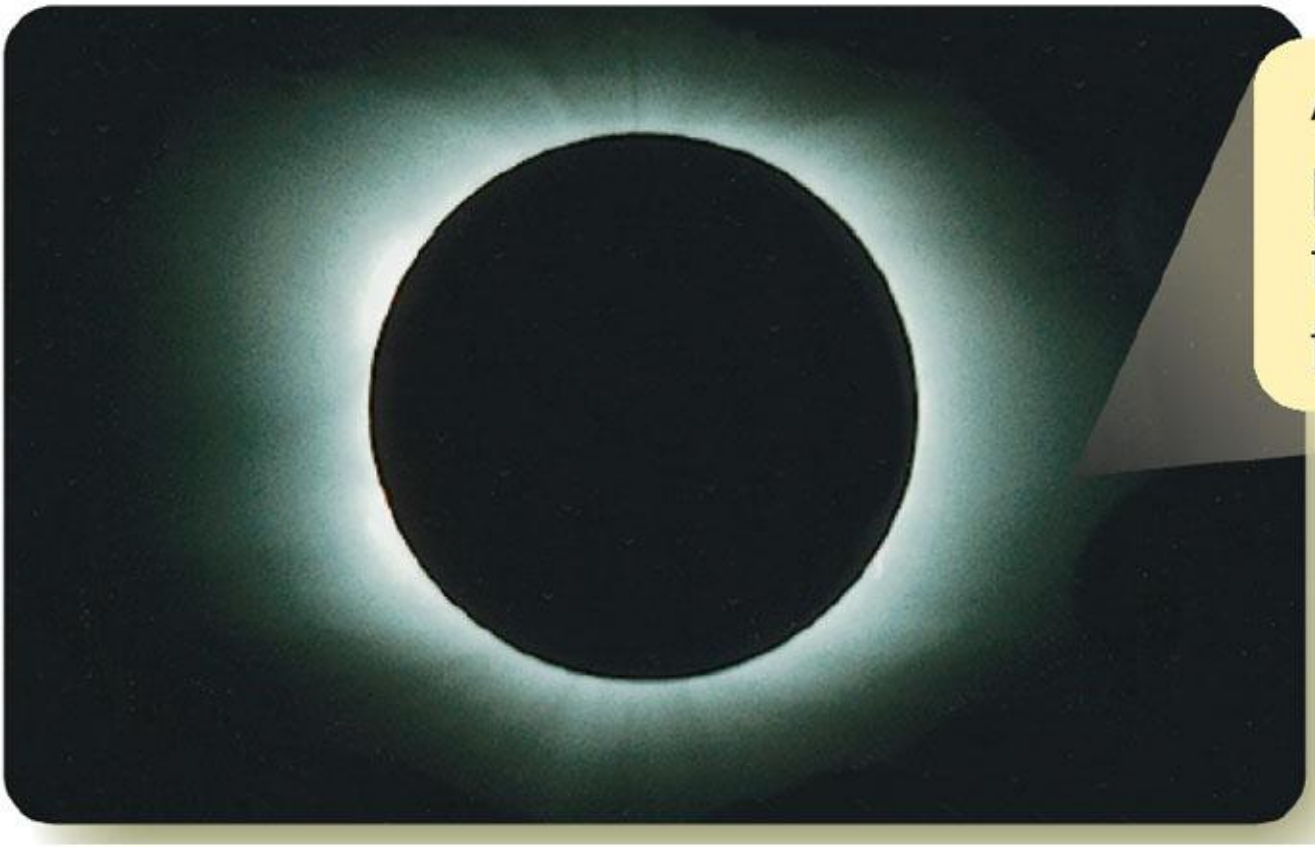
This is a chance coincidence. The Moon's linear diameter is much smaller than that of the Sun.

Solar Eclipses



Because of the equal angular diameters, the Moon can cover the Sun completely when it passes in front of the Sun, causing a total solar eclipse.

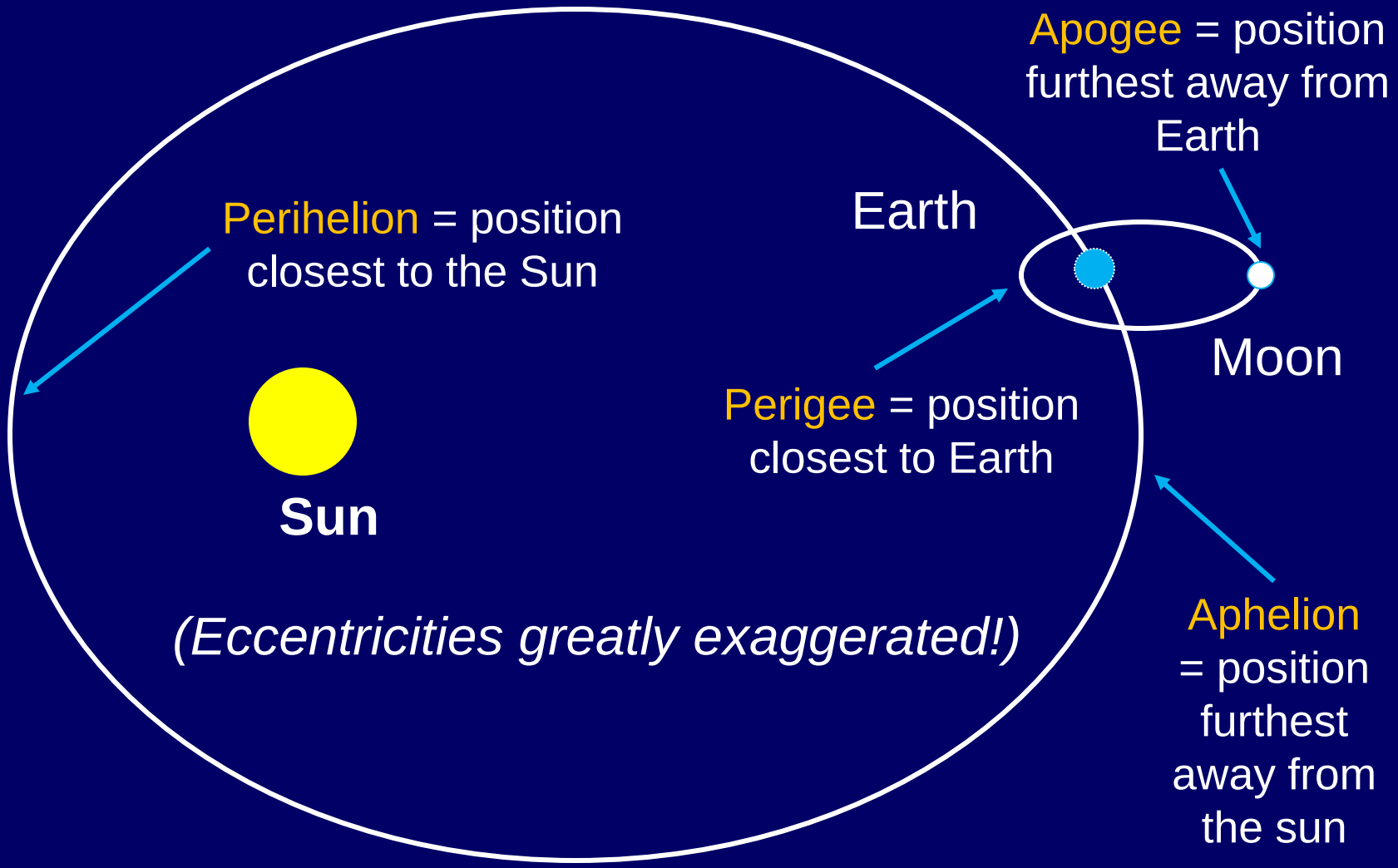
A Solar Eclipse



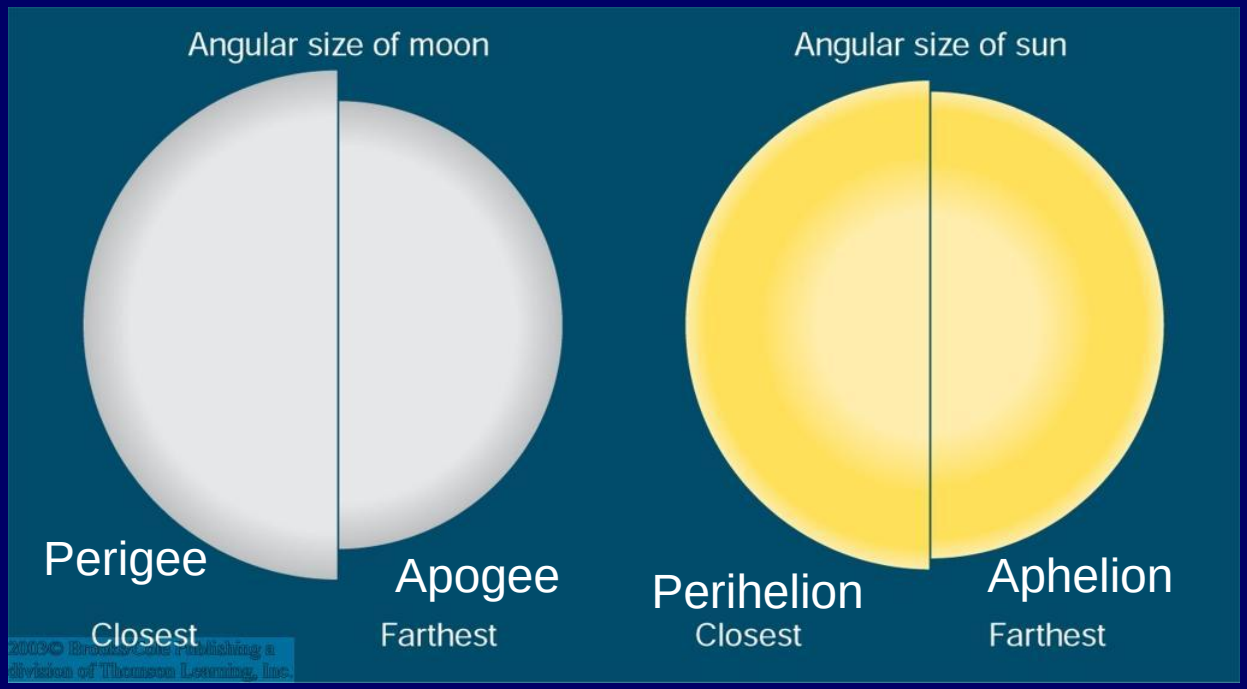
A longer-exposure photograph during totality shows the fainter corona.

Elliptical Orbits

Earth's and Moon's orbits are slightly elliptical



Annular Solar Eclipses



The angular sizes of the Moon and the Sun vary depending on their distance from Earth.

When Earth is near perihelion and the Moon is near apogee, we see an annular solar eclipse.

Almost total, annular eclipse of May 30, 1984

Table 3-2 | Total and Annular Eclipses of the Sun, 2005–2016

Date	Total/Annular (T/A)	Time of Mideclipse* (GMT)	Maximum Length of Total or Annular Phase (Min:Sec)	Area of Visibility
2005 Apr. 8	AT	21^h	0:42	Pacific, N. of S. America
2005 Oct. 3	A	11^h	4:32	Atlantic, Spain, Africa
2006 Mar. 29	T	10^h	4:07	Atlantic, Africa, Turkey
2006 Sept. 22	A	12^h	7:09	N.E. of S. America, Atlantic
2008 Feb. 7	A	4^h	2:14	S. Pacific, Antarctica
2008 Aug. 1	T	10^h	2:28	Canada, Arctic, Siberia
2009 Jan. 26	A	8^h	7:56	S. Atlantic, Indian Ocean
2009 July 22	T	3^h	6:40	Asia, Pacific
2010 Jan. 15	A	7^h	11:10	Africa, Indian Ocean
2010 July 11	T	20^h	5:20	Pacific, S. America
2012 May 20	A	23^h	5:46	Japan, N. Pacific, W. US
2012 Nov. 13	T	22^h	4:02	Australia, S. Pacific
2013 May 10	A	0^h	6:04	Australia, Pacific
2013 Nov. 3	AT	13^h	1:40	Atlantic, Africa
2015 March 20	T	10^h	2:47	N. Atlantic, Arctic
2016 March 9	T	2^h	4:10	Borneo, Pacific
2016 Sept. 1	A	9^h	3:06	Atlantic, Africa, Indian Oc.

The next major total solar eclipse visible from the United States will occur on August 21, 2017.

*Times are Greenwich Mean Time. Subtract 5 hours for Eastern Standard Time, 6 hours for Central Standard Time, 7 hours for Mountain Standard Time, and 8 hours for Pacific Standard Time.

^{h}hours.

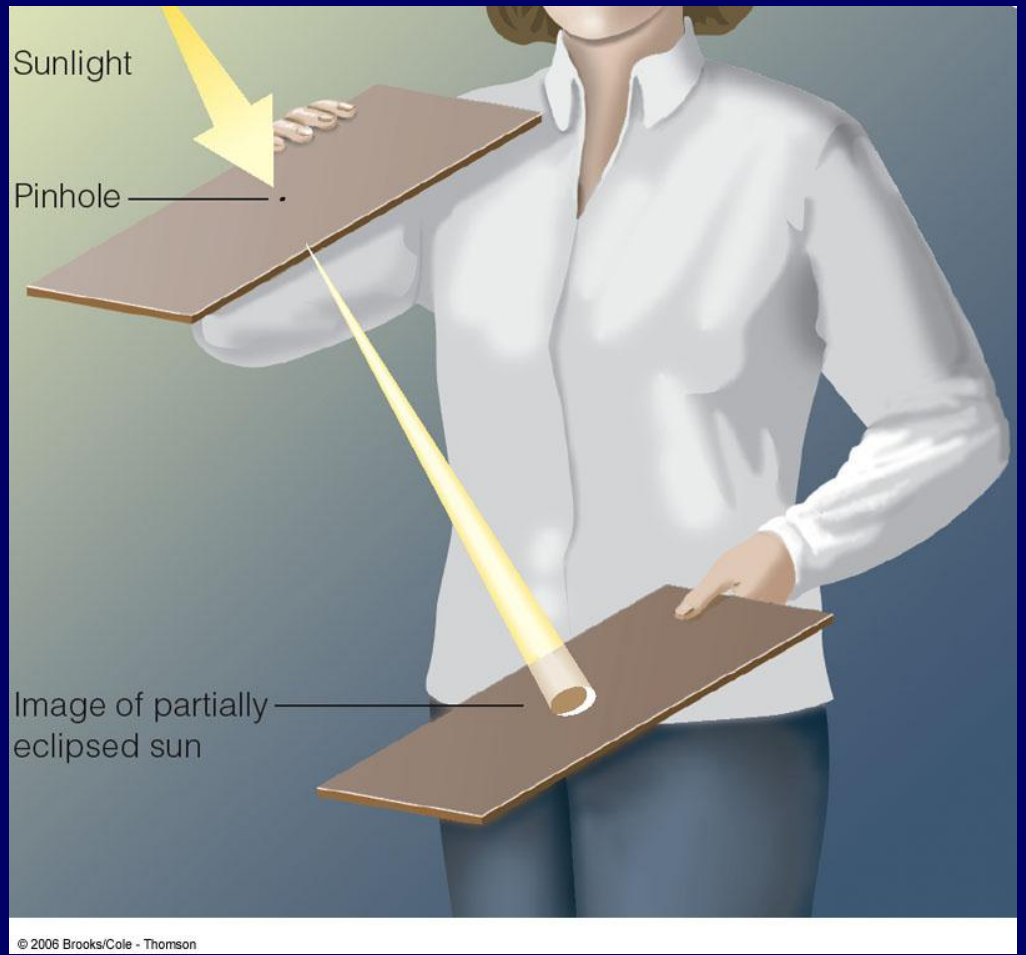
Approximately 1 total solar eclipse per year

Very Important Warning

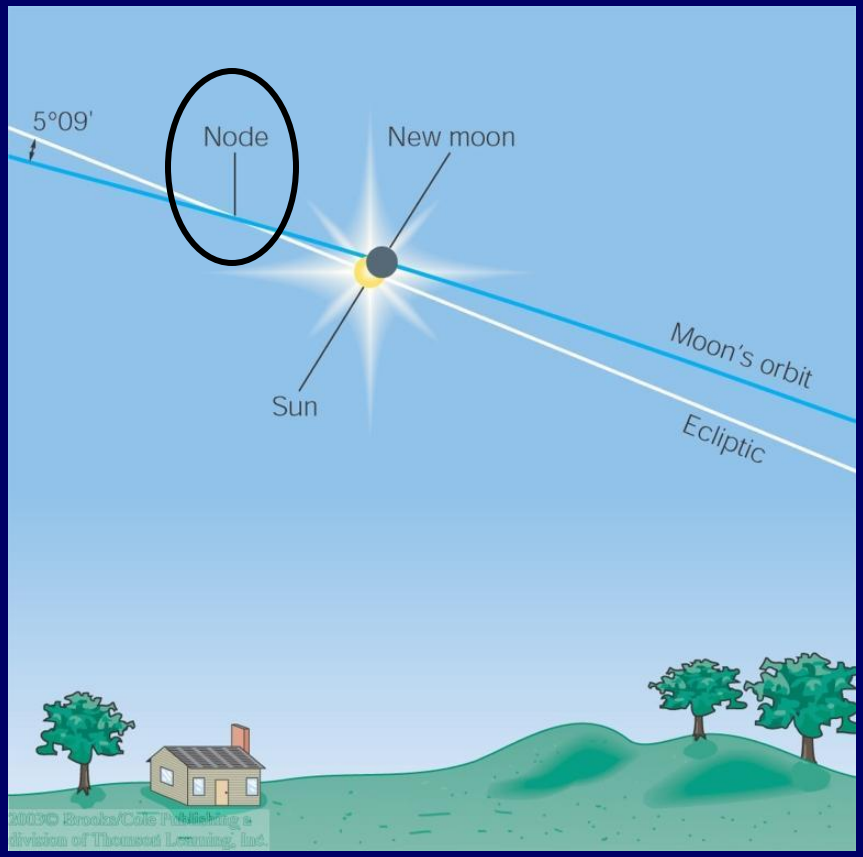
Never observe the Sun directly with your bare eyes, not even during a partial solar eclipse!

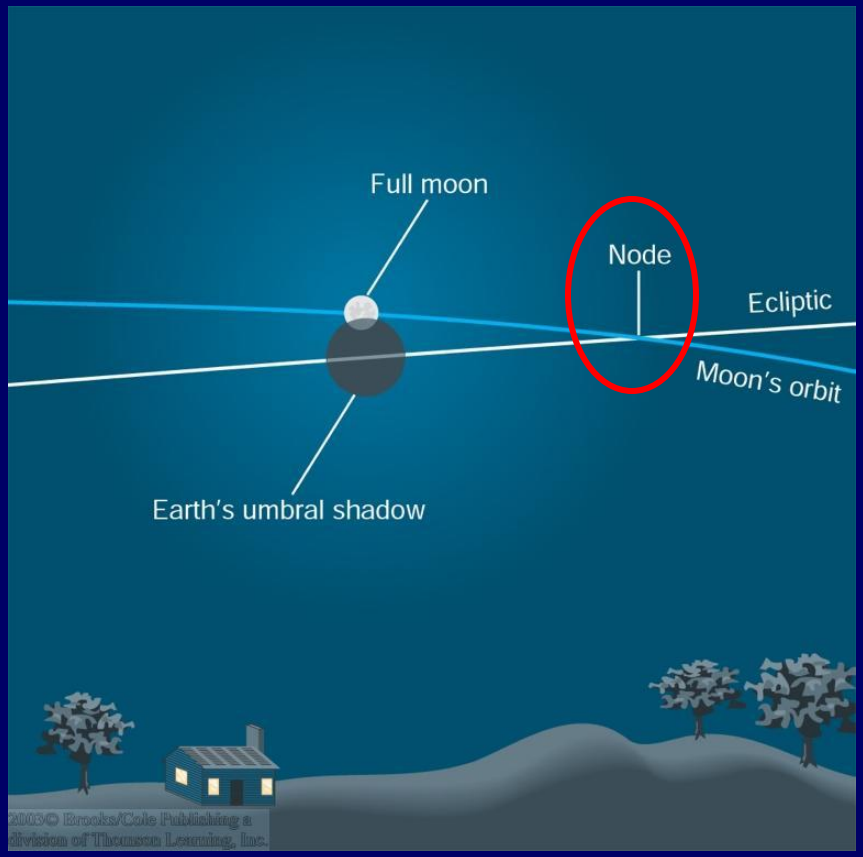
Invisible ultraviolet radiation is sufficiently intense to burn the eye's retina

Use specially designed solar viewing shades, solar filters, or a projection technique



Conditions for Eclipses



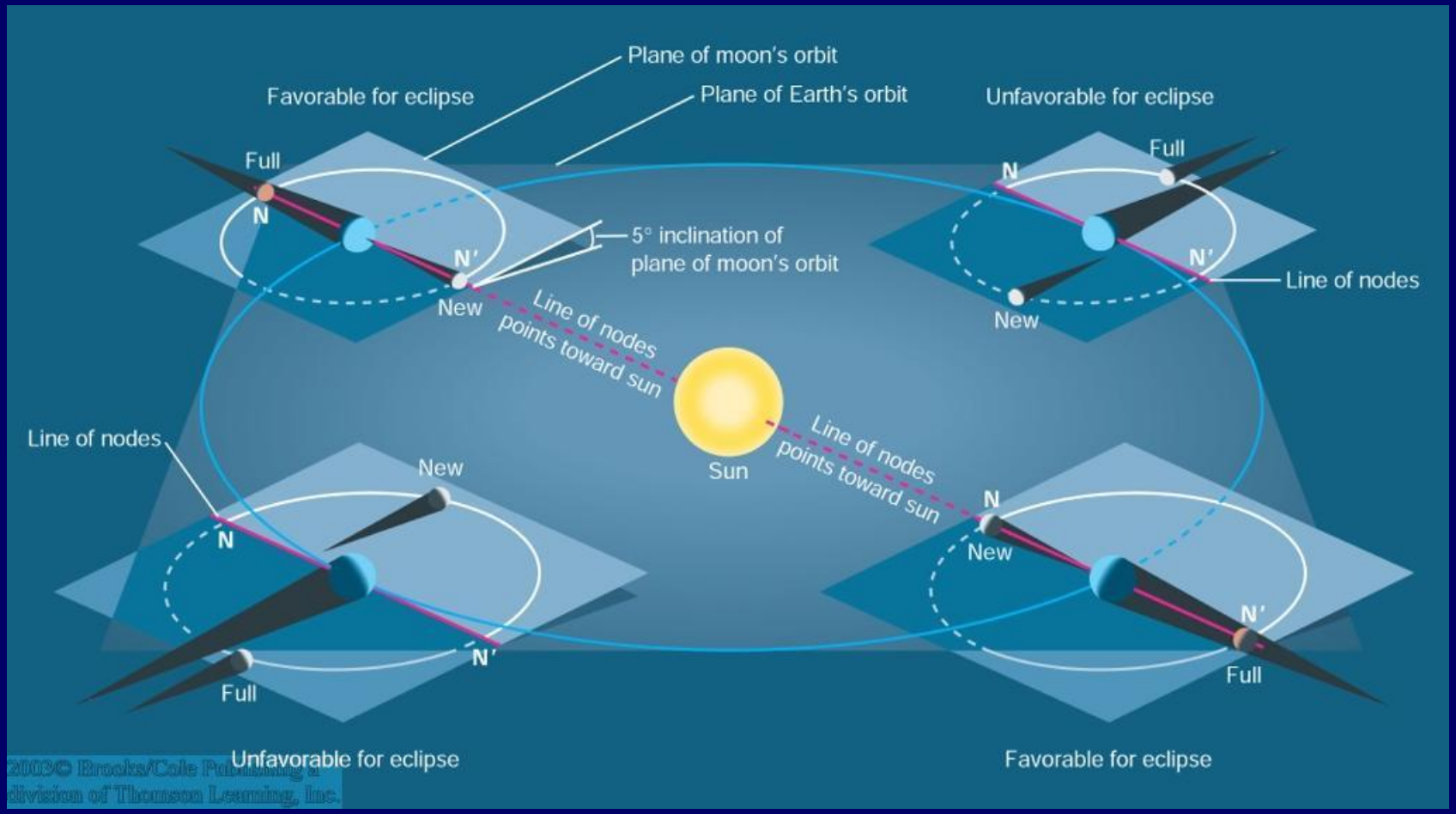


The Moon's orbit is inclined against the ecliptic by ~ 5°.

A solar eclipse can only occur if the Moon passes a node near new moon.

A lunar eclipse can only occur if the Moon passes a node near full moon.

Conditions for Eclipses

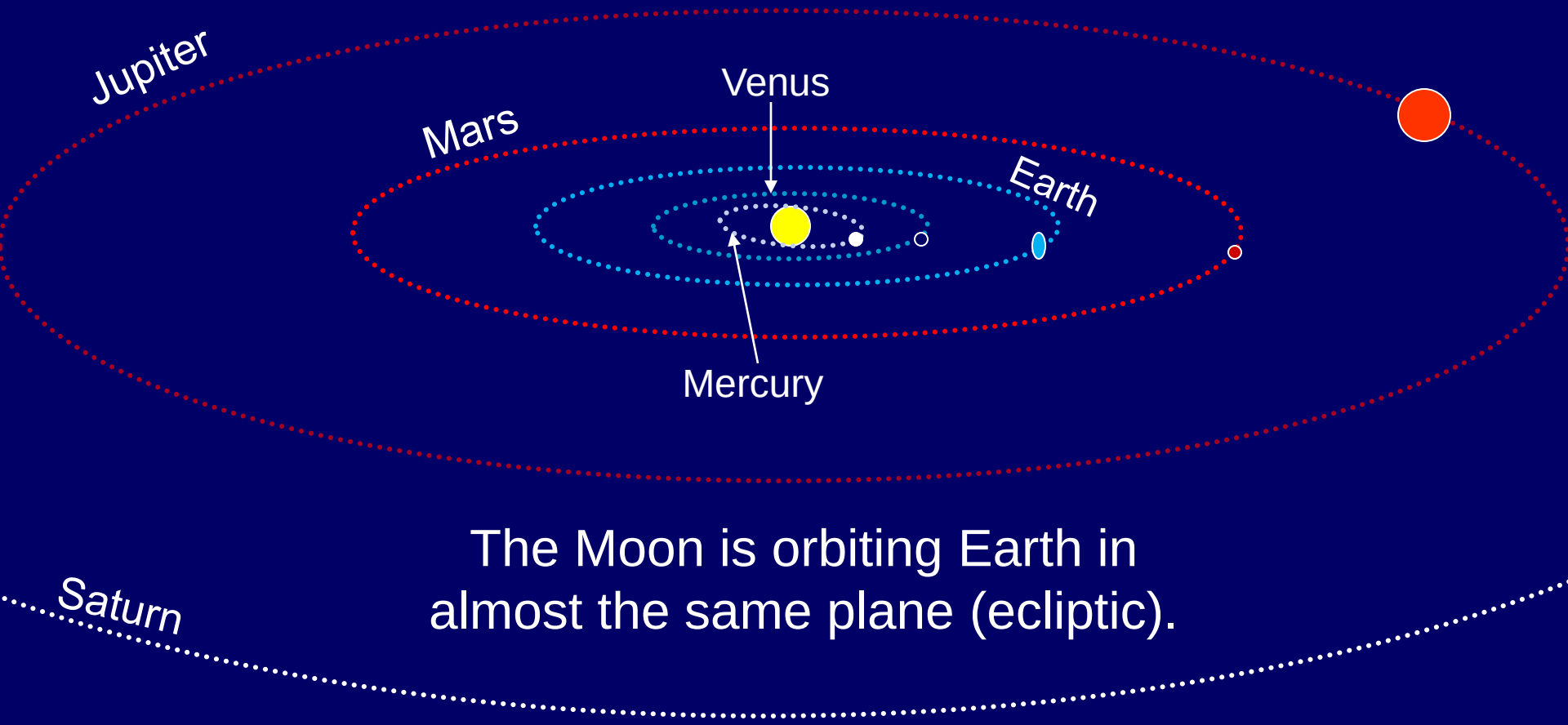


Eclipses occur in a cyclic pattern.

$\Rightarrow$ Saros cycle: 18 years, 11 days, 8 hours

The Motion of the Planets

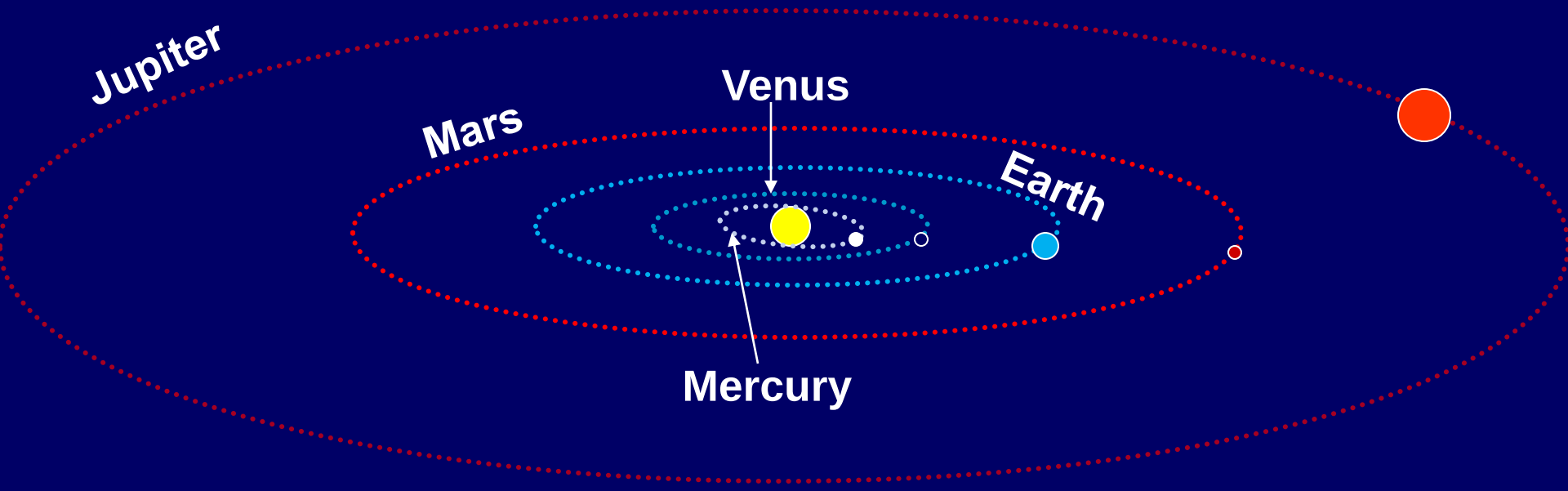
The planets are orbiting the Sun almost exactly in the ecliptic plane. This means that they will always be viewed in one of the constellations of the zodiac.



The Moon is orbiting Earth in almost the same plane (ecliptic).

The Motion of the Planets

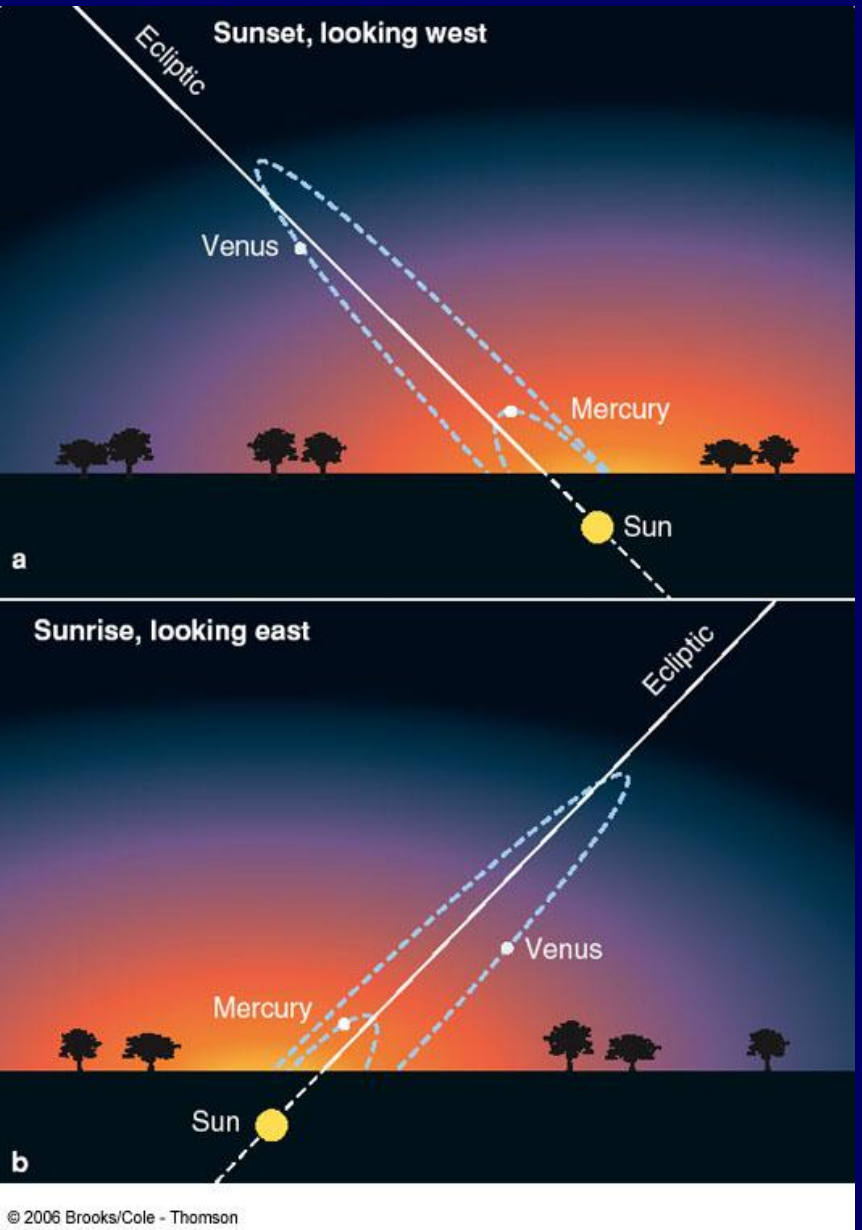
The planets are orbiting the Sun almost exactly in the ecliptic plane. This means that they will always be viewed in one of the constellations of the zodiac.



The Moon is orbiting Earth in almost the same plane (ecliptic).

Saturn

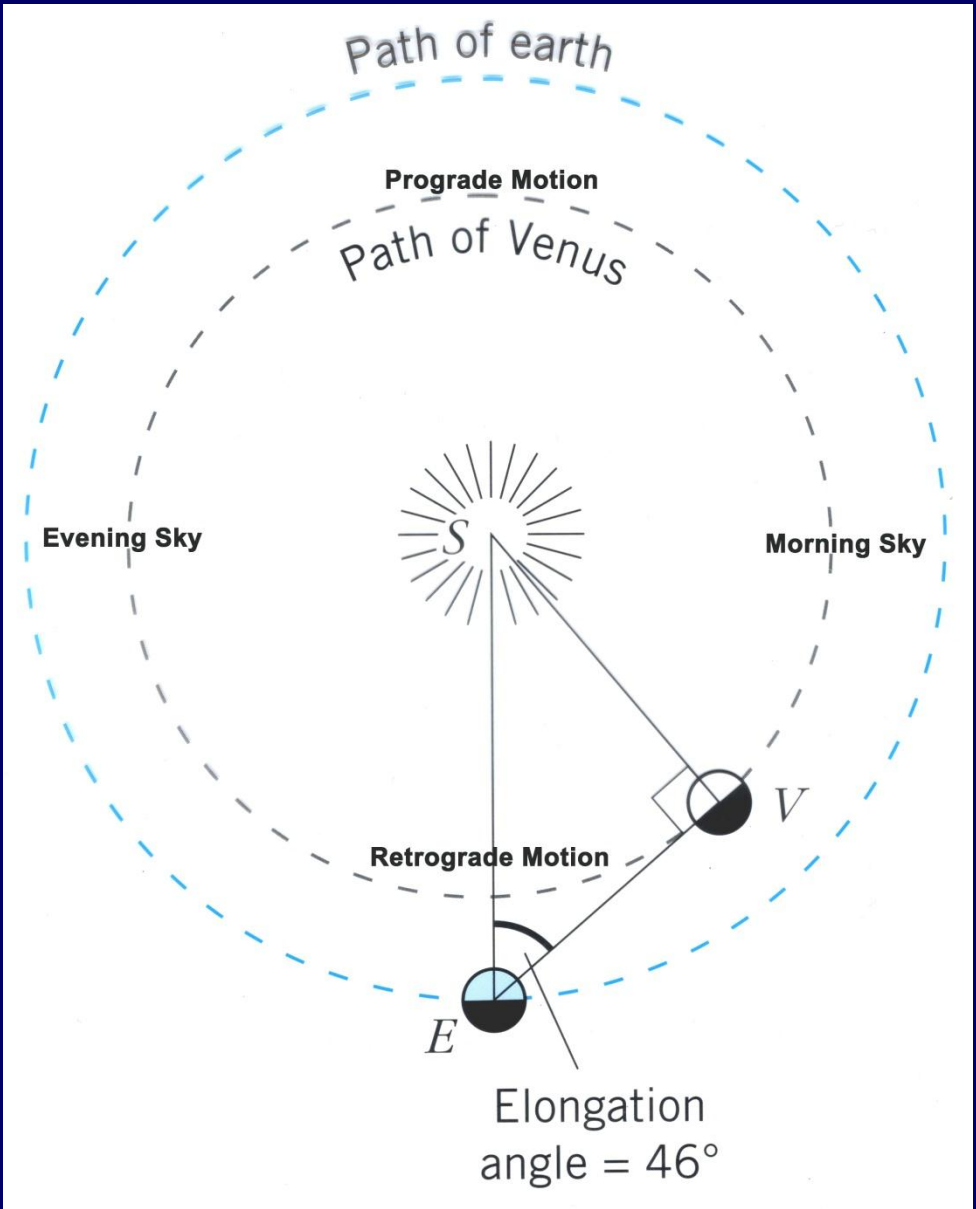
Apparent Motion of the Inner Planets



Mercury appears at most ~28° (maximum elongation) from the Sun. It can occasionally be seen shortly after sunset in the west or before sunrise in the east.

Venus appears at most ~46° (maximum elongation) from the Sun. It can occasionally be seen for at most a few hours after sunset in the west or before sunrise in the east.

Apparent Motion of the Inner Planets

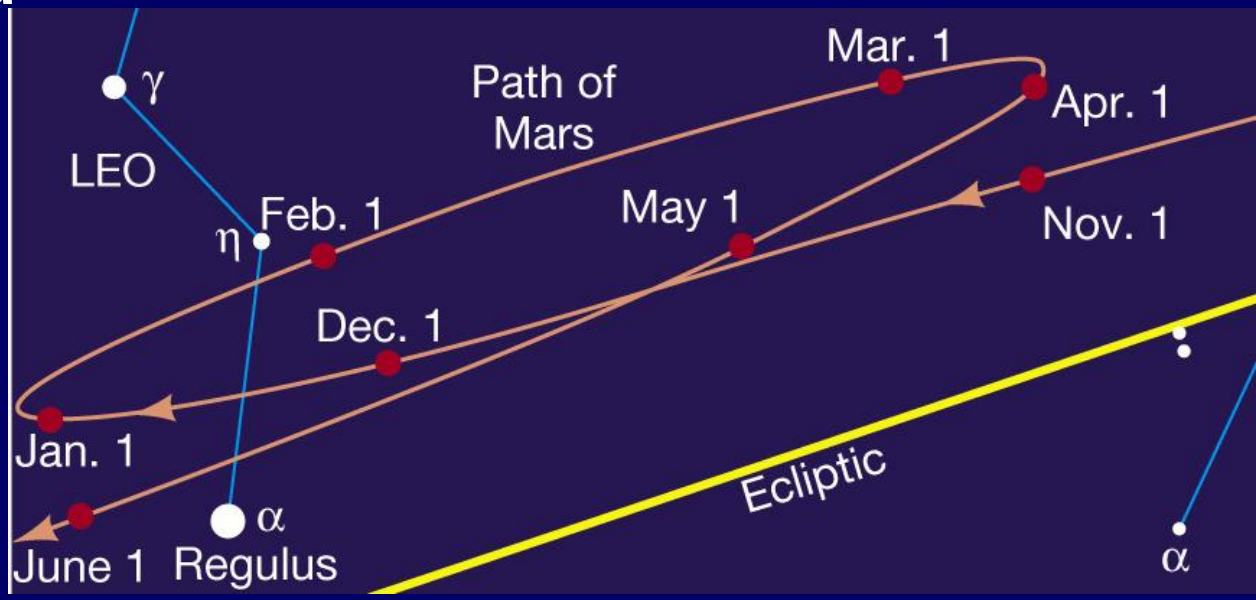


Apparent Motion of the Outer Planets

Sun, Moon, and stars all appear to rotate at a constant rate around the Earth

Planets appear to move:

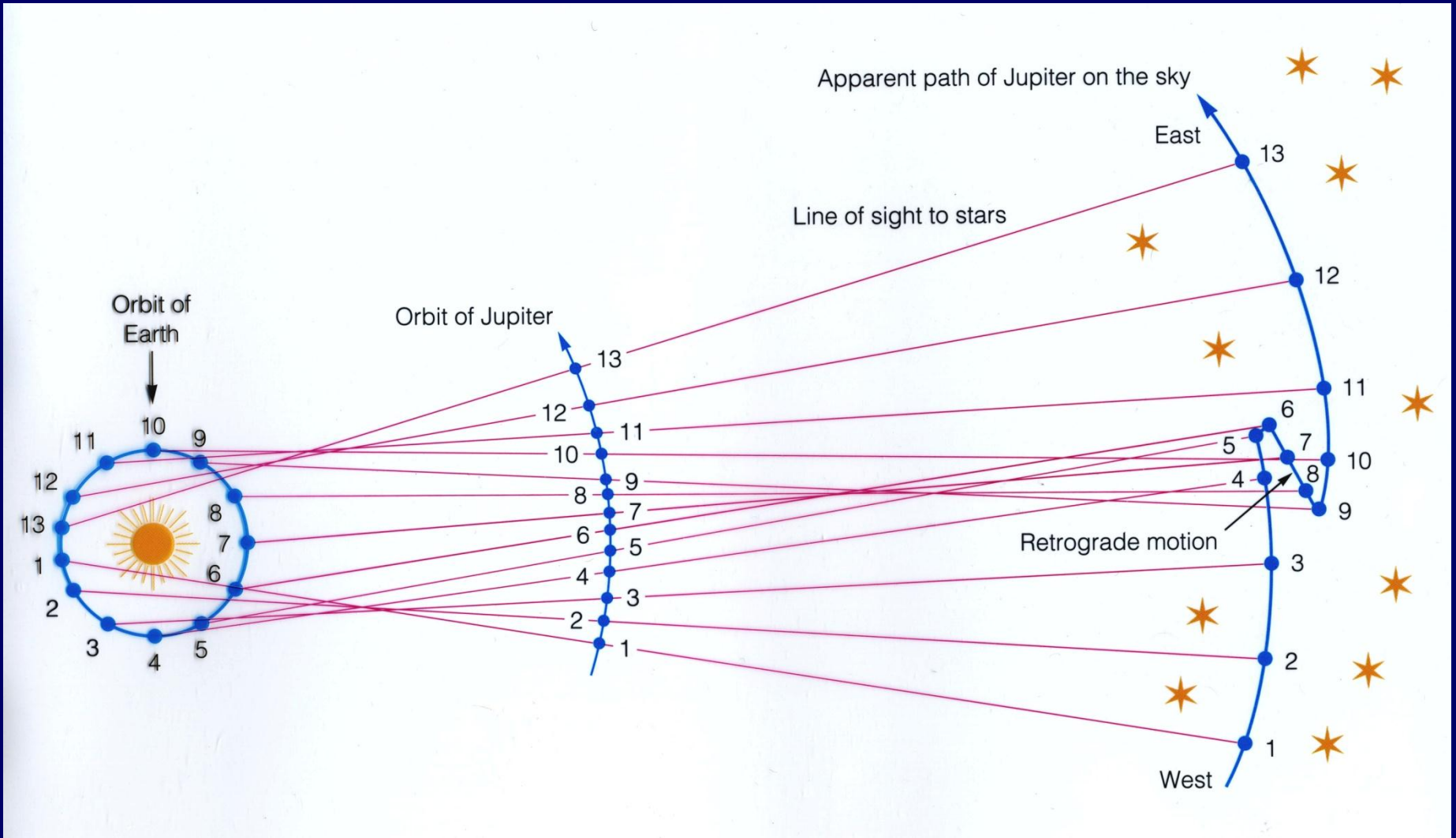
- like the Sun and Moon with respect to the fixed stars from West to East
- they change in brightness
- they change speed
- they exhibit retrograde motion



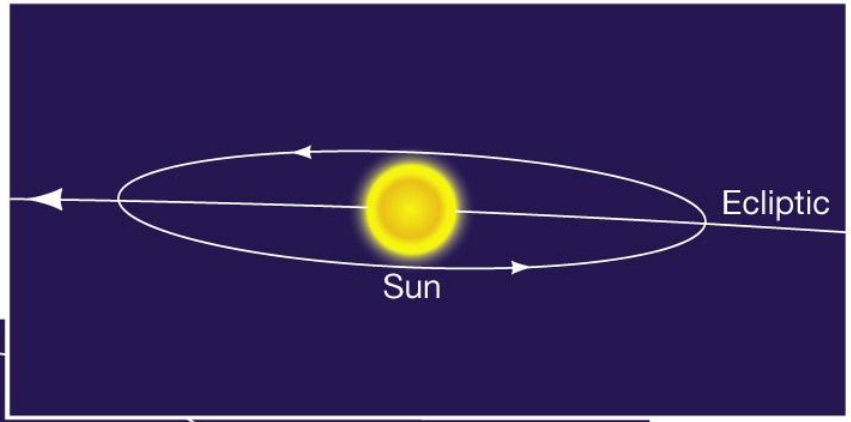
Retrograde Motion

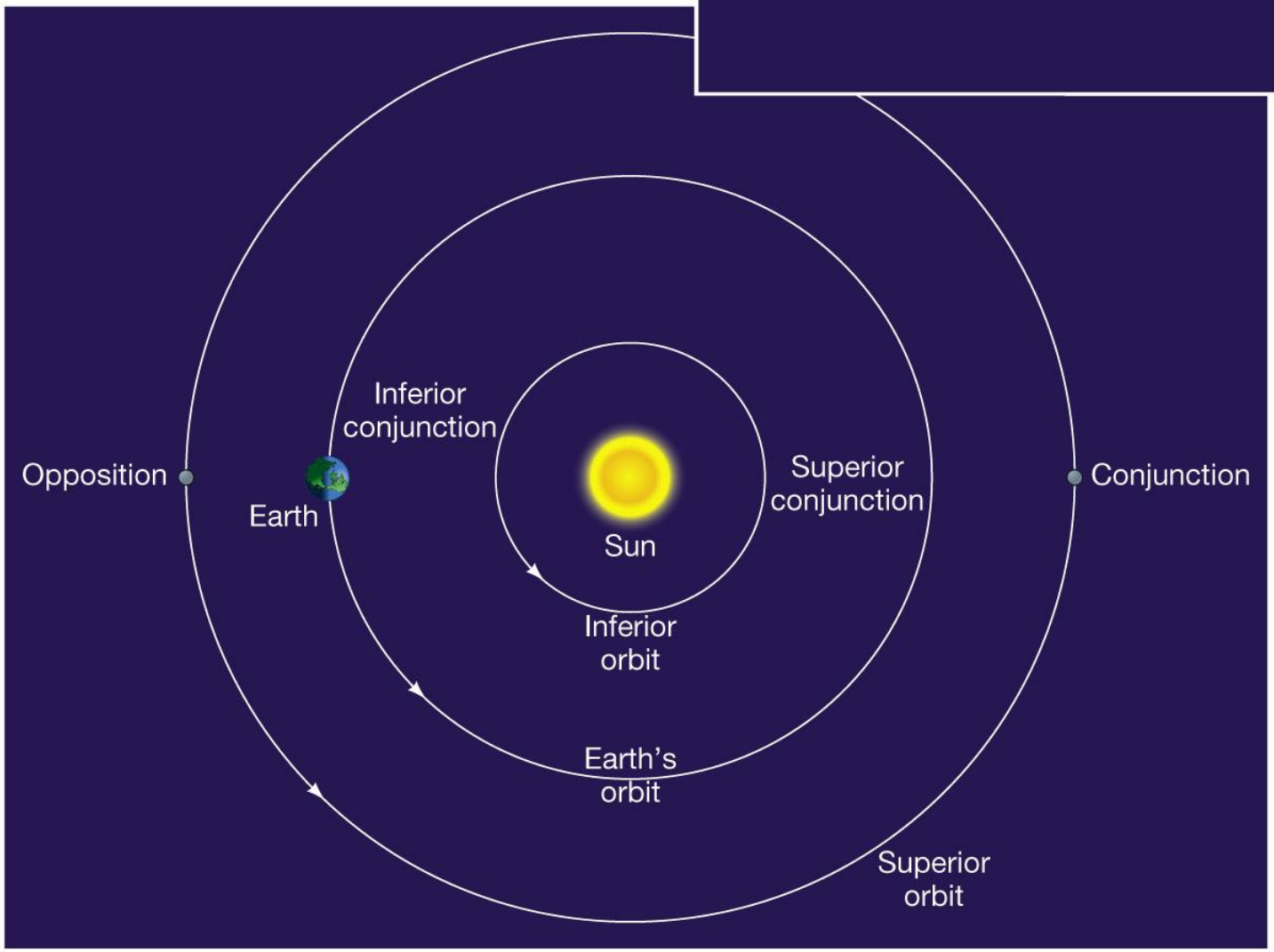
Explanation based on a heliocentric model of the solar system

Inner planets revolve around the Sun faster than outer planets. Retrograde (westward) motion of a planet occurs when Earth passes the planet.



Terminology of Planetary Alignments





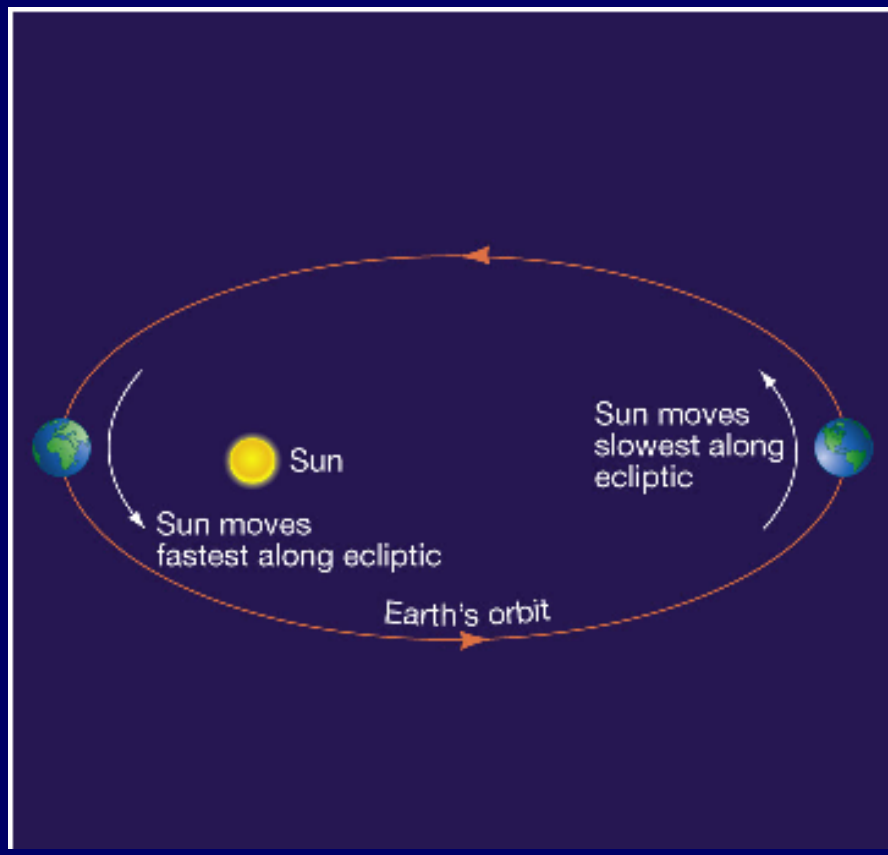
Astronomical Timekeeping

The solar day varies during the year; noon is different at different locations

We used to base time on the mean solar day.

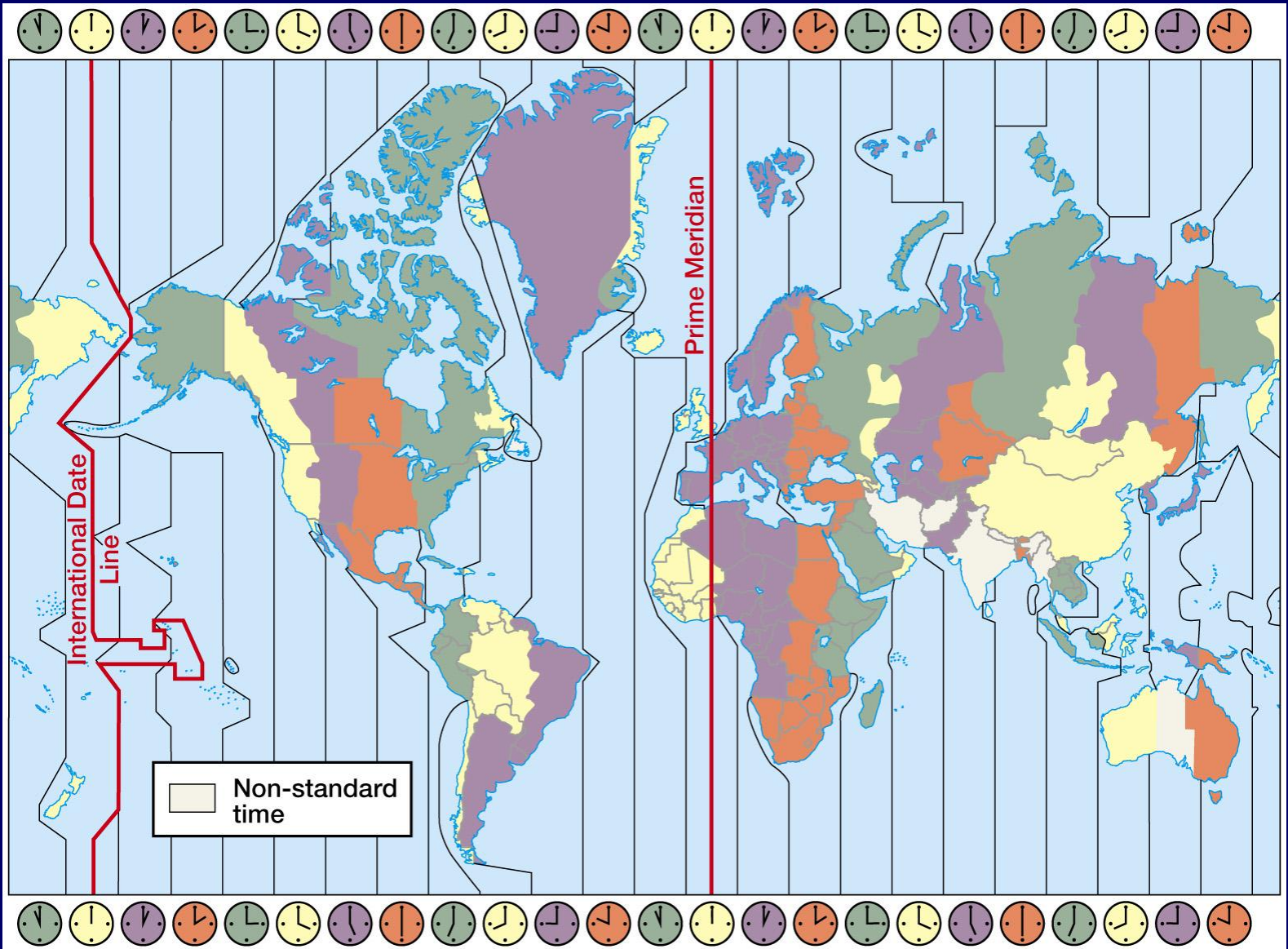
We now base time on atomic clocks.

We also define time zones around the Earth, with time the same within each one and then usually jumping an hour to the next. This takes care of noon variation.



Astronomical Timekeeping

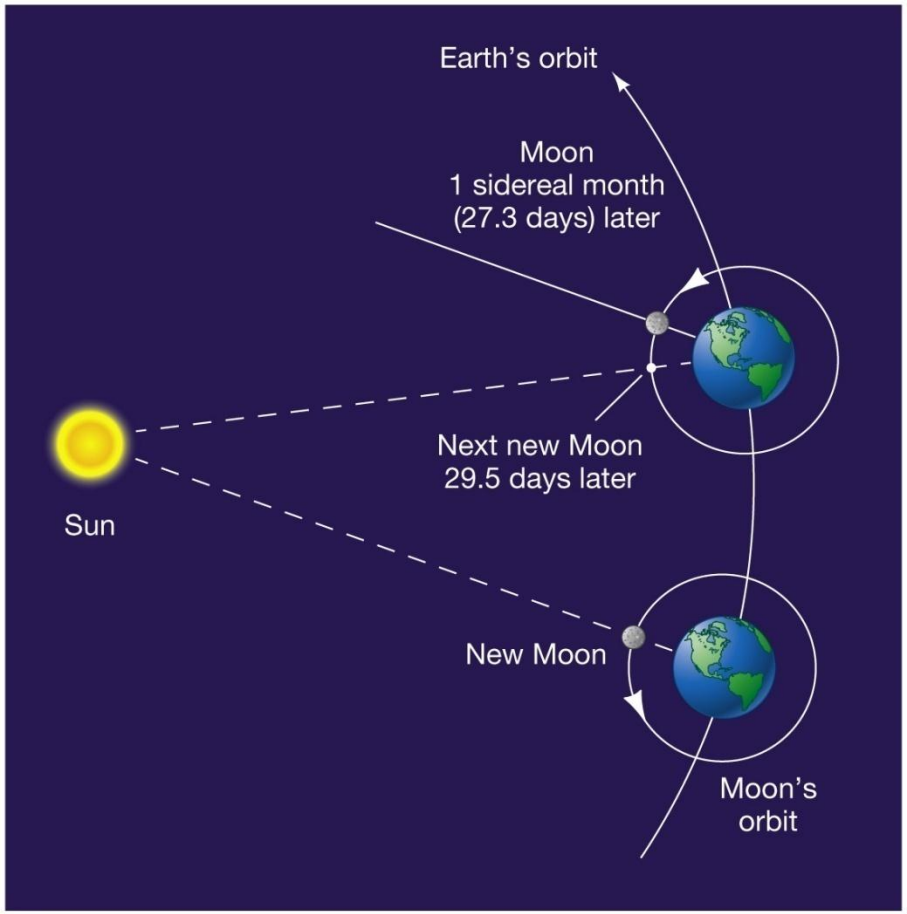
World time zones



Astronomical Timekeeping

The **lunar month** (complete lunar cycle) doesn't have a whole number of solar days in it, and the **tropical year** doesn't have a whole number of months or days

The solar calendar we use has months that are close to the lunar cycle, but adjusted so that there are 12 of them in a year



Calendars

- **Lunar Calendars**—based on the lunar month (new moon to new moon)
  - **Jewish**
    - Has a system of doubling months periodically over 18 years to keep the calendar approximately in sync with the tropical year
  - **Chinese**
    - Has leap years when there are 13 new moons in the year and a Chinese leap year has 13 months, not just one extra day
  - **Muslim**
    - Its year of 12 months is shorter than a tropical year by about 11 days
    - No provision is made to accommodate these 11 days so the Muslim new year comes earlier each year relative to a tropical year (the time for the Earth to revolve exactly one time around the Sun)
- **Solar Calendars**—based on the tropical year = 365.2422 days
  - **Julian**—promulgated by Julius Caesar in 46 BCE
    - adds a day every 4 years (a leap year)
    - This correction is too big
    - By 1582 CE, the vernal equinox had drifted 10 days from when it occurred in 46 BCE
  - **Gregorian**—promulgated by Pope Gregory XIII in 1582 CE

Gregorian Calendar

- Like the Julian calendar, it adds an extra day in years that are multiples of 4 (leap years)
- It omits years that are multiples of 100 but not of 400. The years 1700, 1800 and 1900 were not leap years. The year 2000 was a leap year.
- It omits years that are multiples of 1000 but not of 4000.
- It will take 20,000 years for this system to be off by a full day.