Announcements

- Please ensure that your utoronto.ca e-mail address has been entered on ROSI.
- Lecture notes are now posted on Blackboard.
- Discussion group will be available next week.

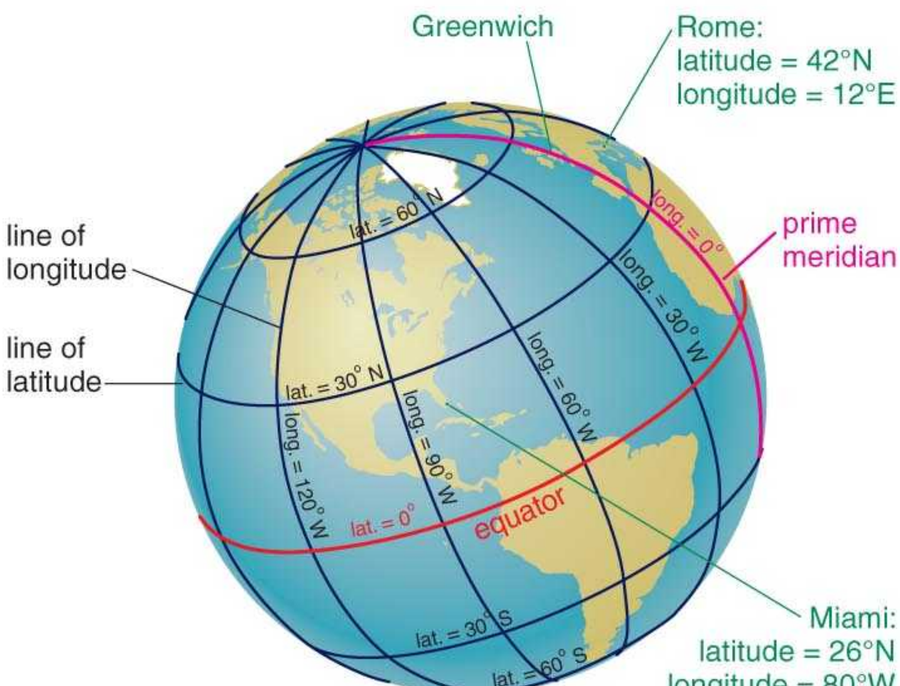
Lecture 2

- Celestial Coordinates
- The Sun's Motion Across the Sky
- The Ecliptic
- The Sun and Seasons
- Ch. 1, sec. 3 sidebar, the Calendar
- Ch. 1, sec. 4 The Moon's Phases
- Ch. 1, secs. 5 & 6: Eclipses

(These are all as in the 6th & 7th Editions of the Text)

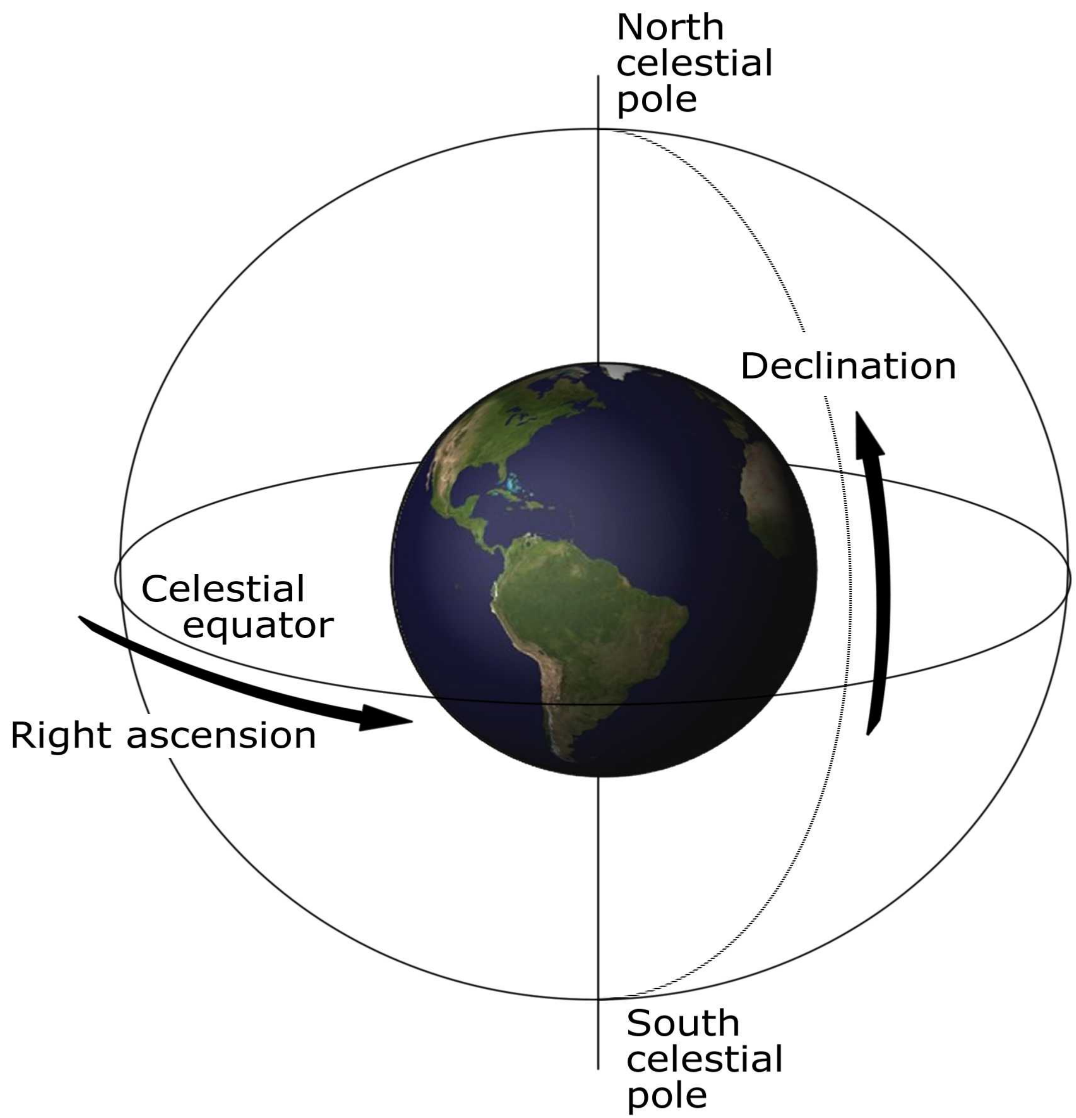
Review: Coordinates on the Earth

- **Latitude:** position north or south of equator
- **Longitude:** position east or west of prime meridian (runs through Greenwich, England)



Note: Lo 350 º = 10º deg W

Celestial coordinates



Celestial Coordinates

1. **Longitude and latitude uniquely define the position of an object on Earth. Similarly, right ascension and declination define the position of an object on the celestial sphere.**

2. **The *declination* of an object on the celestial sphere is its angle north or south of the *celestial equator* (a line on the celestial sphere directly above the Earth's equator); the scale ranges from –90° to +90°.**

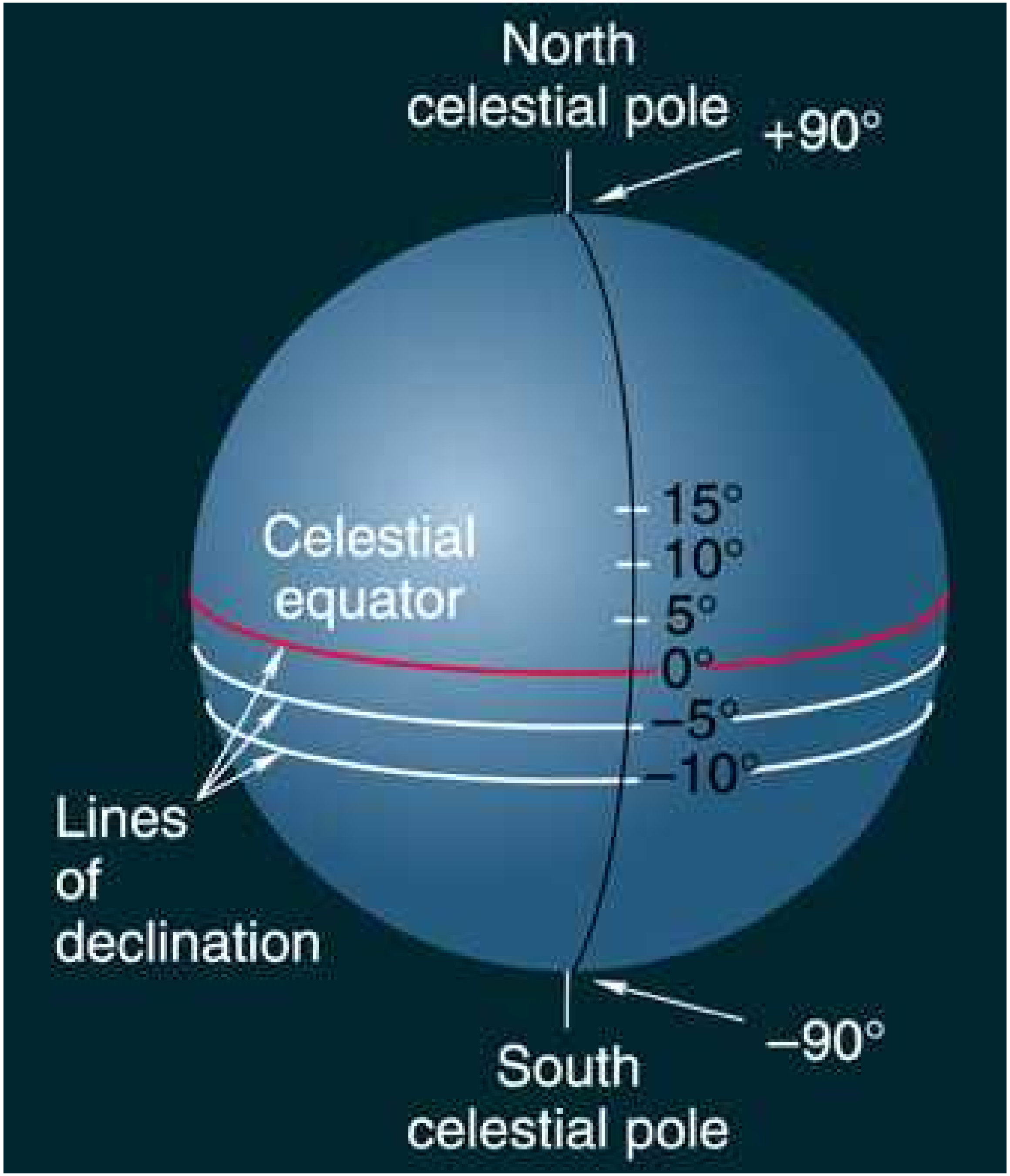
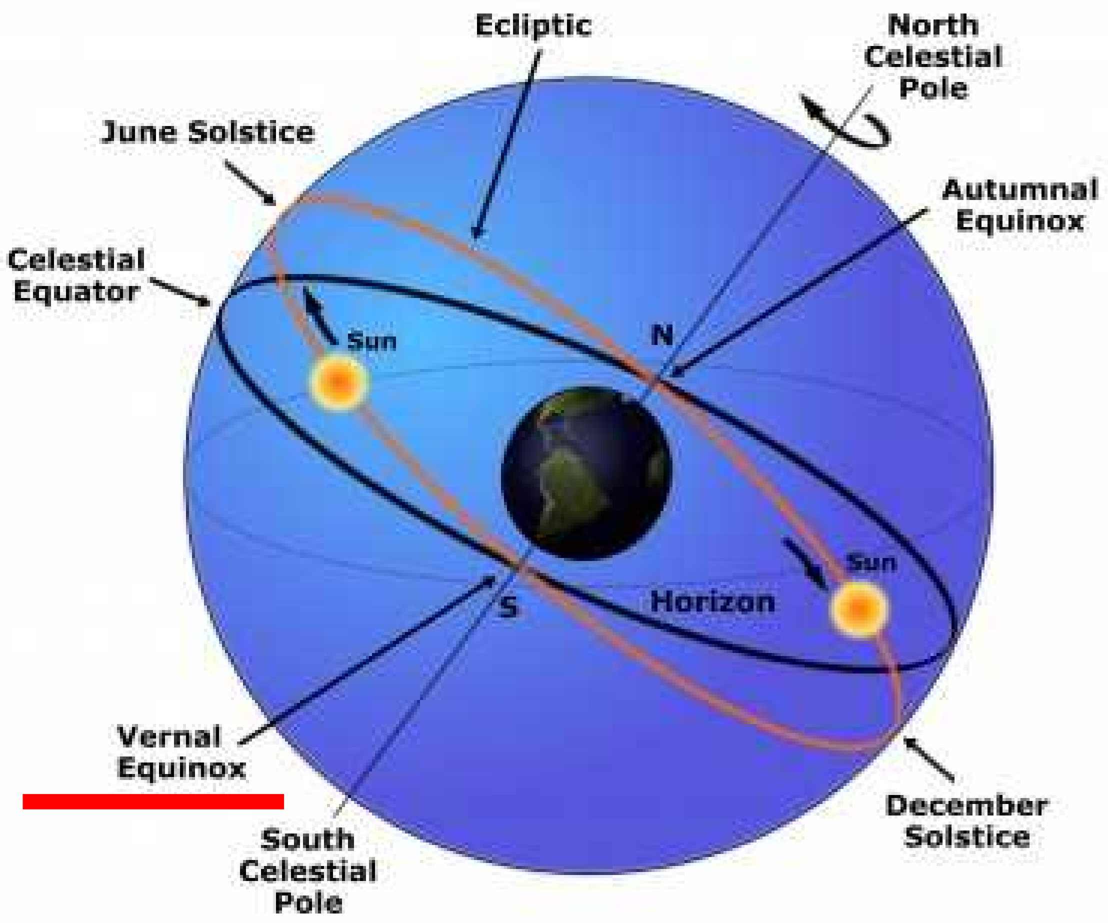

North
celestial pole
+90°
15°
10°
5°
0°
−5°
−10°
Celestial
equator
Lines
of
declination
−90°
South
celestial pole

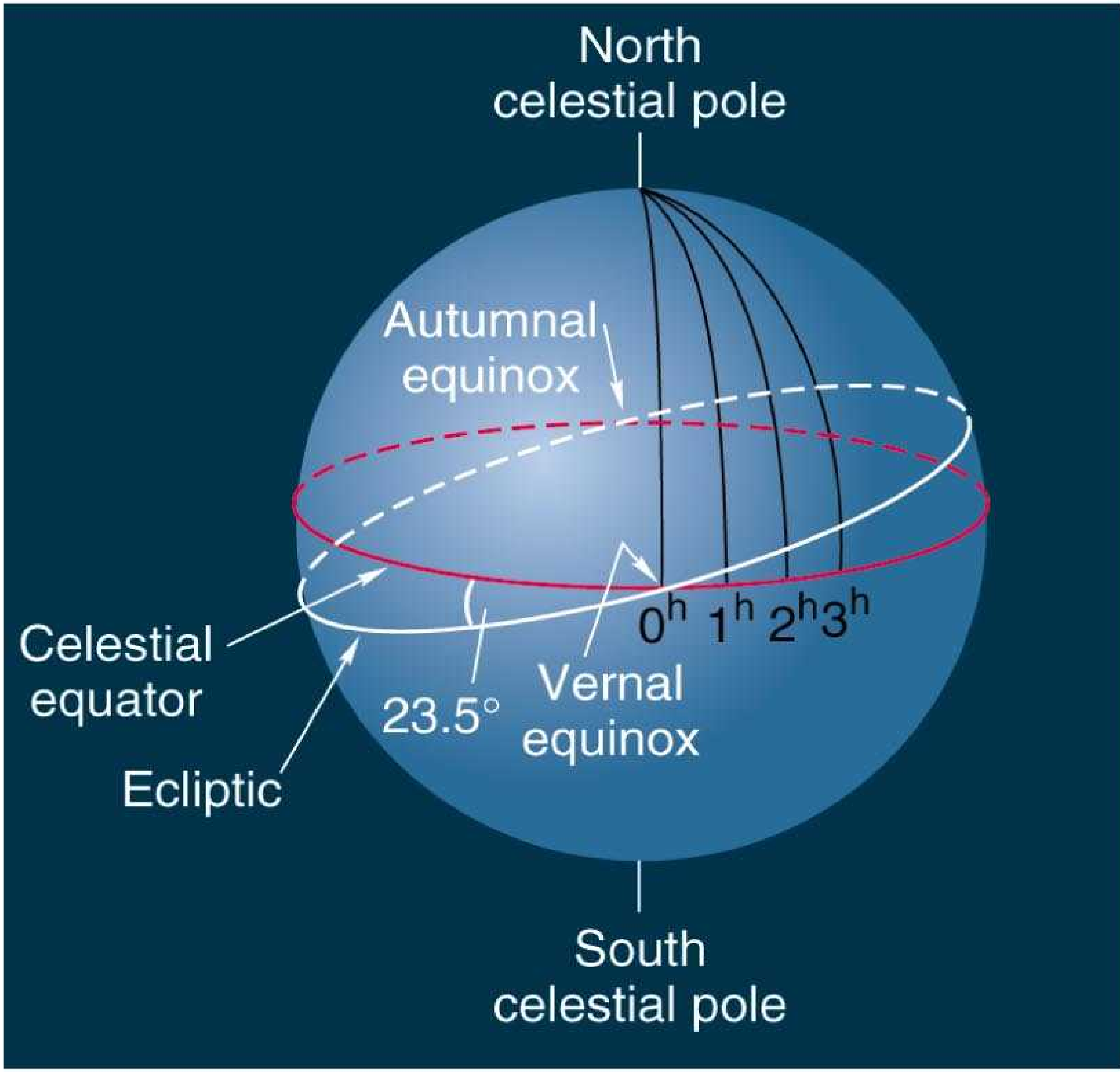
Fig. 1-9a

Just as Greenwich serves to define the Prime Meridian on the Earth's surface, so the Vernal Equinox serves to define the zero right ascension line.



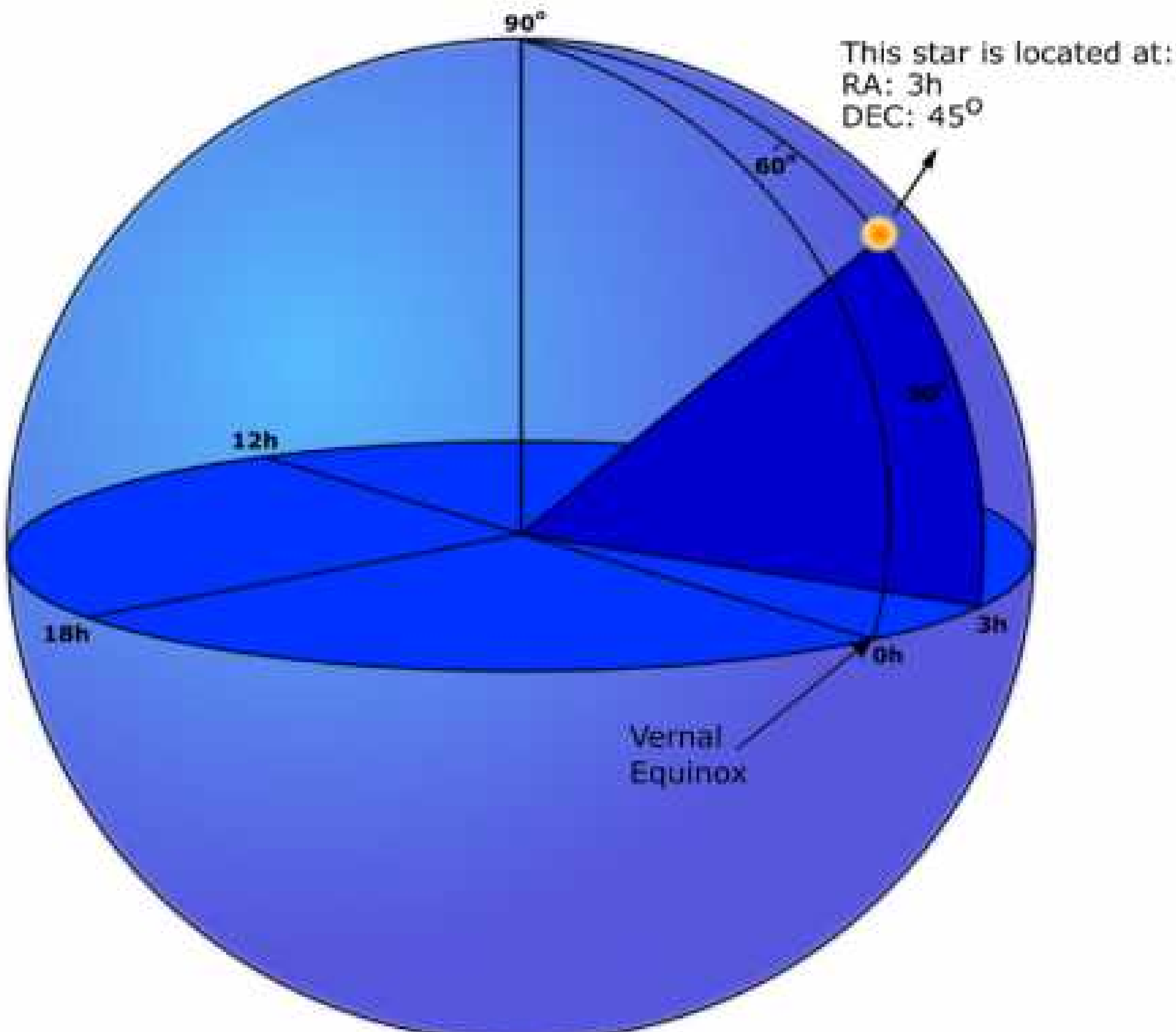
(b) Right ascension measures the angle around the celestial equator eastward from the vernal equinox, where the Sun crosses the equator moving northward.

Figure 1.9b



(b)

Right Ascension and Declination: Celestial Coordinates



Celestial Coordinates (cont.)

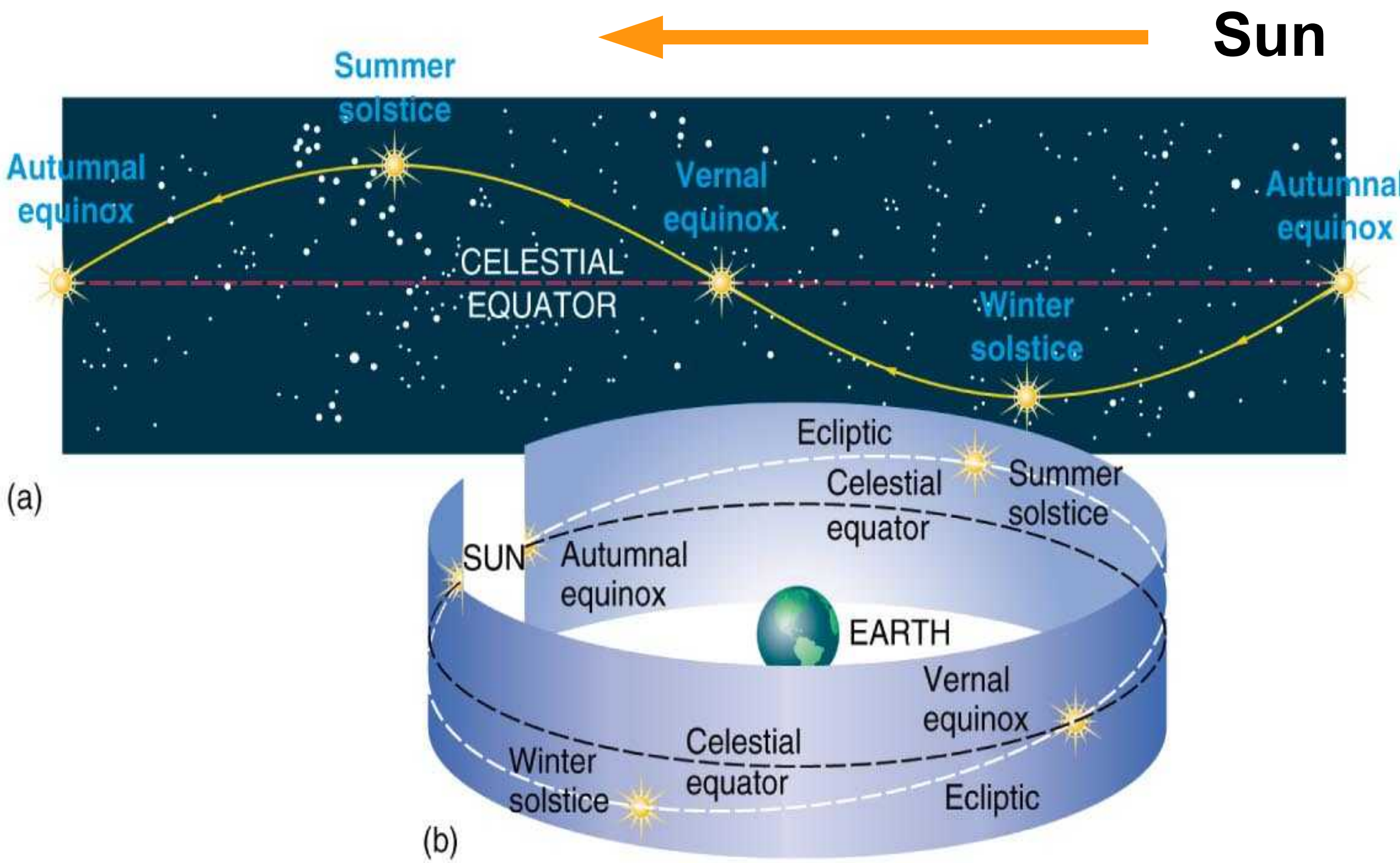
3. The ***right ascension*** **of an object states its angle around the celestial sphere, measuring eastward from the vernal equinox (the location on the celestial equator where the Sun crosses it moving north). It is stated in hours, minutes, and seconds (with 24 hours encompassing the entire celestial equator).**

The Sun's Motion Across the Sky

1. The Sun seems to rise in the east and set in the west just like the rest of the stars. However, as time goes on, the Sun appears to move constantly eastward among the stars.

2. The time the Sun takes to return to the same place among the stars is about 365.25 days.

The Ecliptic



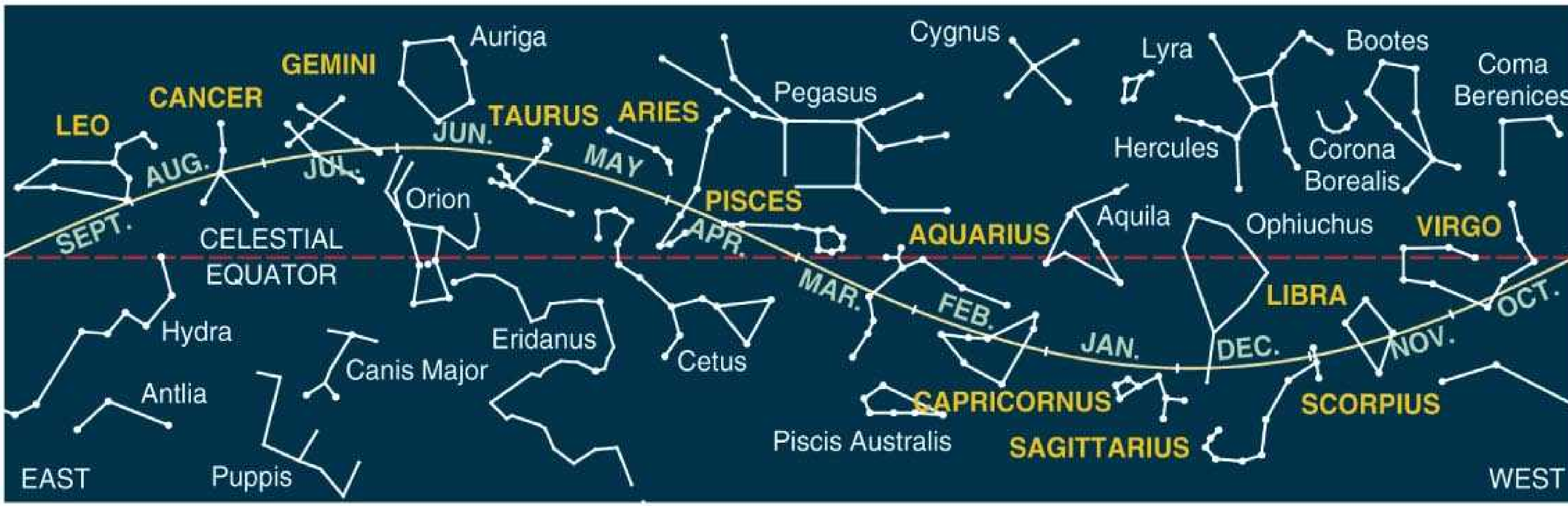
Part (a) is a map of the stars within 30 degrees of the equator. Picture this map wrapped around the Earth as shown in part (b).

Figure 1.10

Sun's path across the sky over the year

Constellations of the Zodiac

The ecliptic is the apparent path of the Sun on the celestial sphere.



The zodiac is the band that lies 9° on either side of the ecliptic on the celestial sphere and contains the constellations through which the Sun passes.

The Sun and the Seasons

1. For an observer in the Northern Hemisphere, the Sun rises and sets farther north in the summer than in the winter.

2. The Sun is in the sky longer each day in summer than in winter. This is one of the reasons for seasonal differences.

3. In summer, the Sun reaches a point higher in the sky, than in winter. Each portion of the Earth’s surface receiving more energy in a given amount of time in the summer than in winter. Sunlight passes through more atmosphere in winter than in summer, resulting in more scattering and absorption in the atmosphere.

Apparent path of Sun across sky of Northern Hemisphere in winter, spring/autumn & summer.

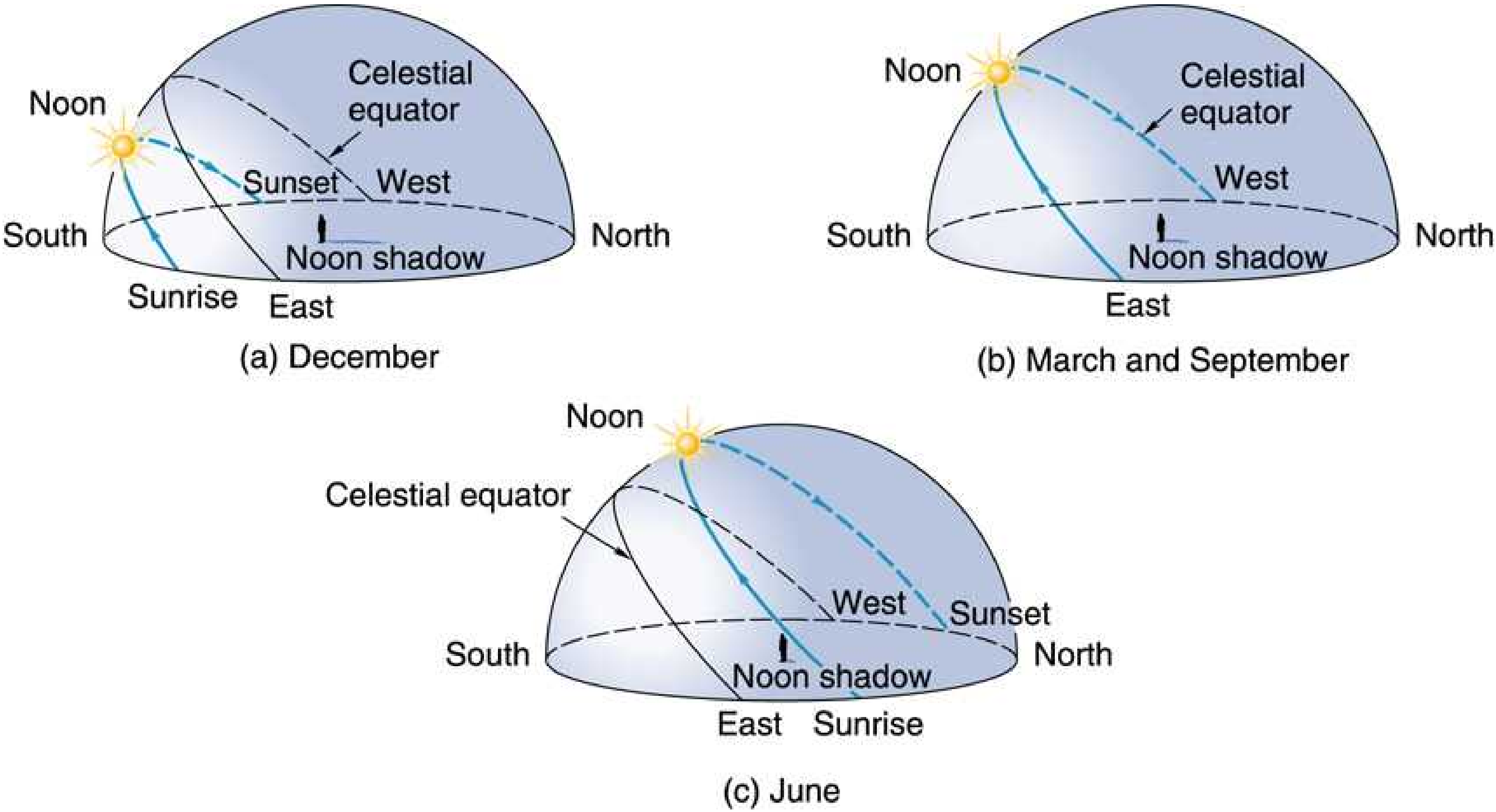
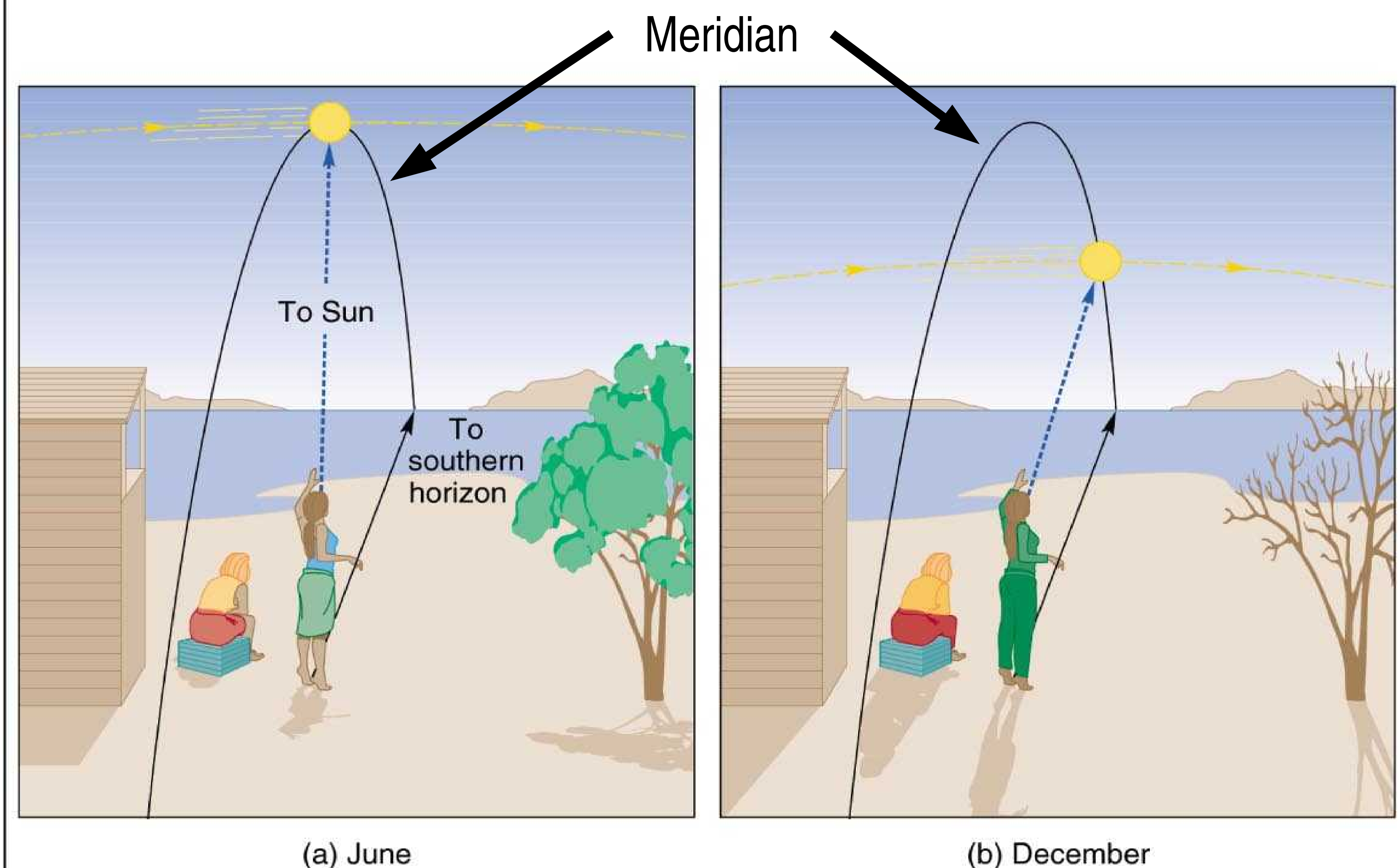
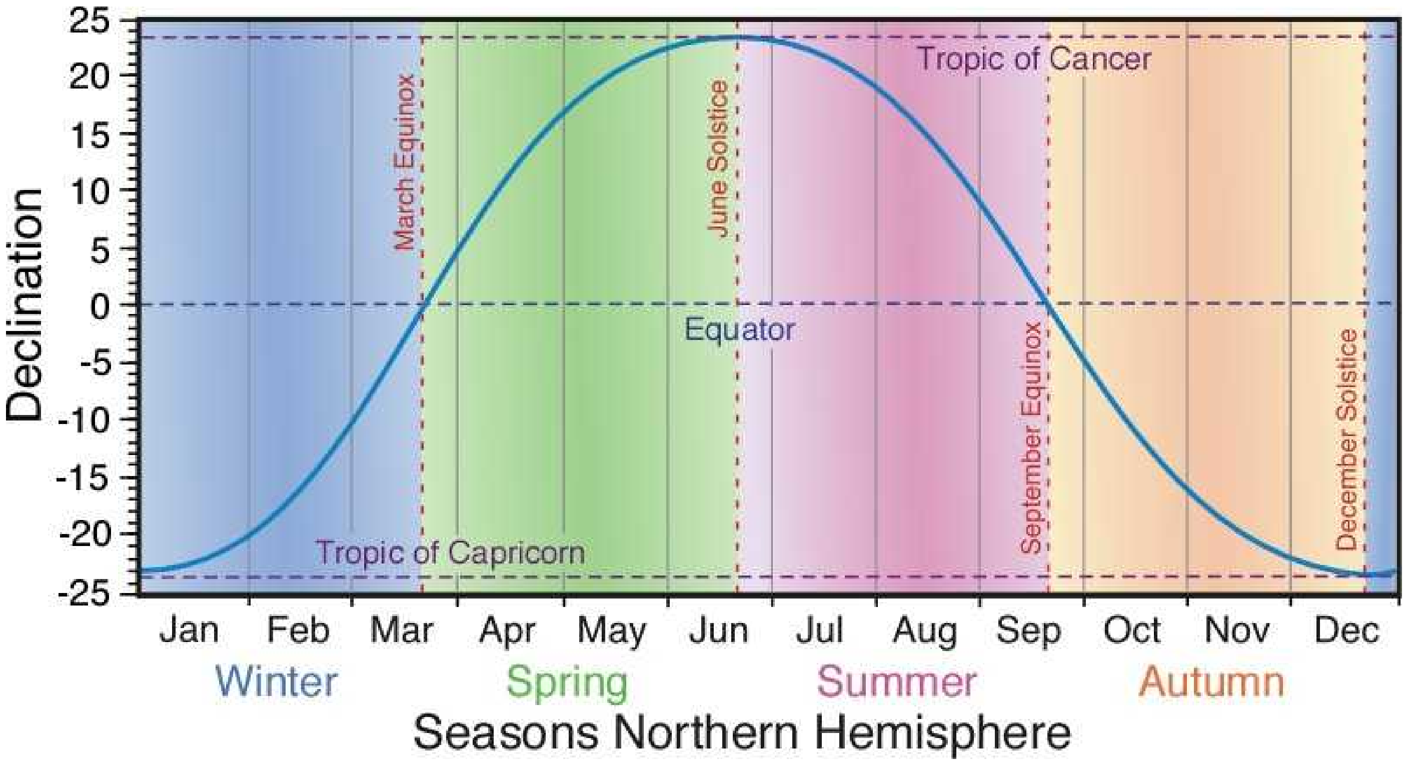


Fig. 1-12



Looking South



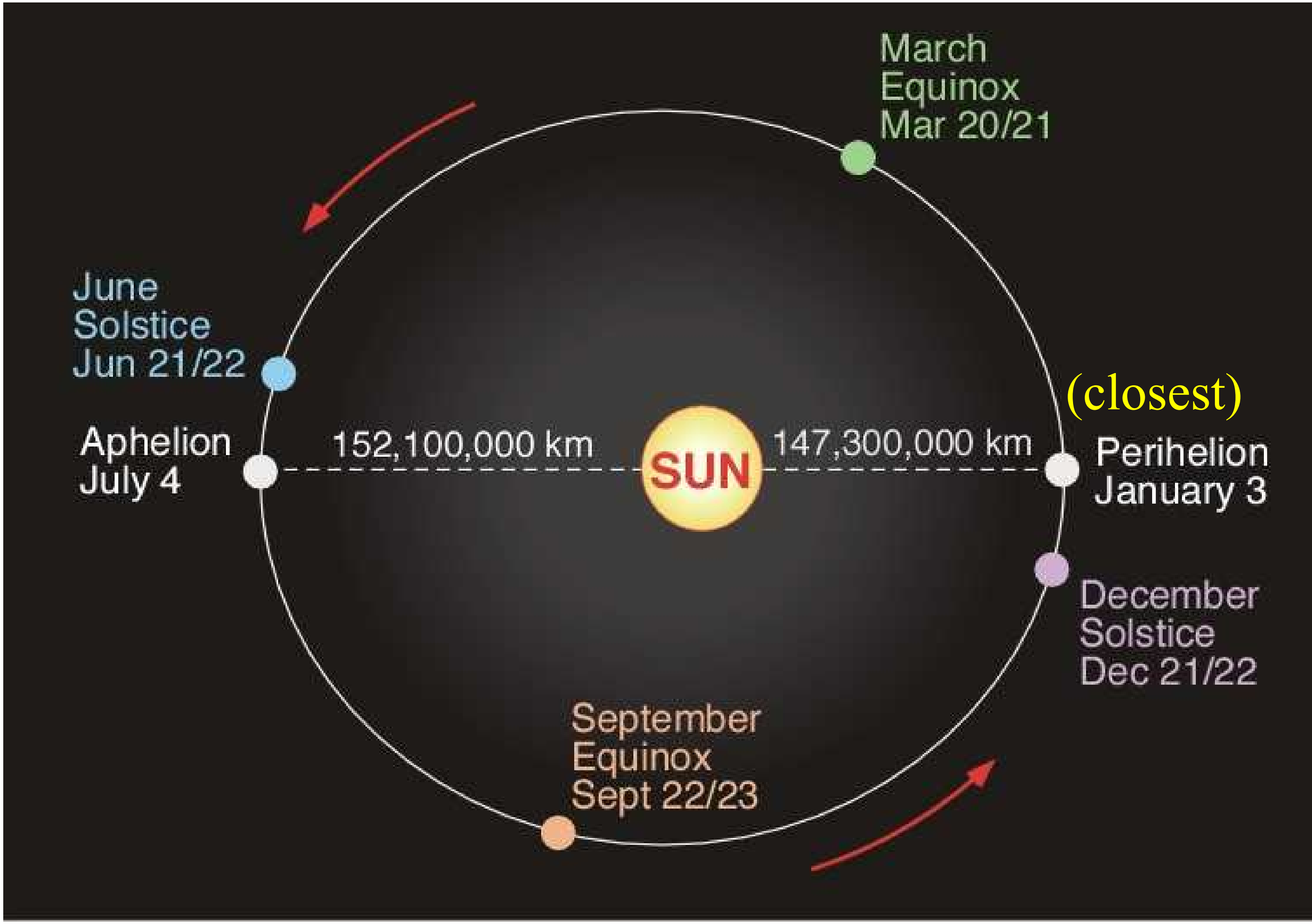
Angle of the Sun’s declination and latitude of the subsolar point throughout the year. Seasons are for the *Northern* Hemisphere.

The Sun and the Seasons (cont.)

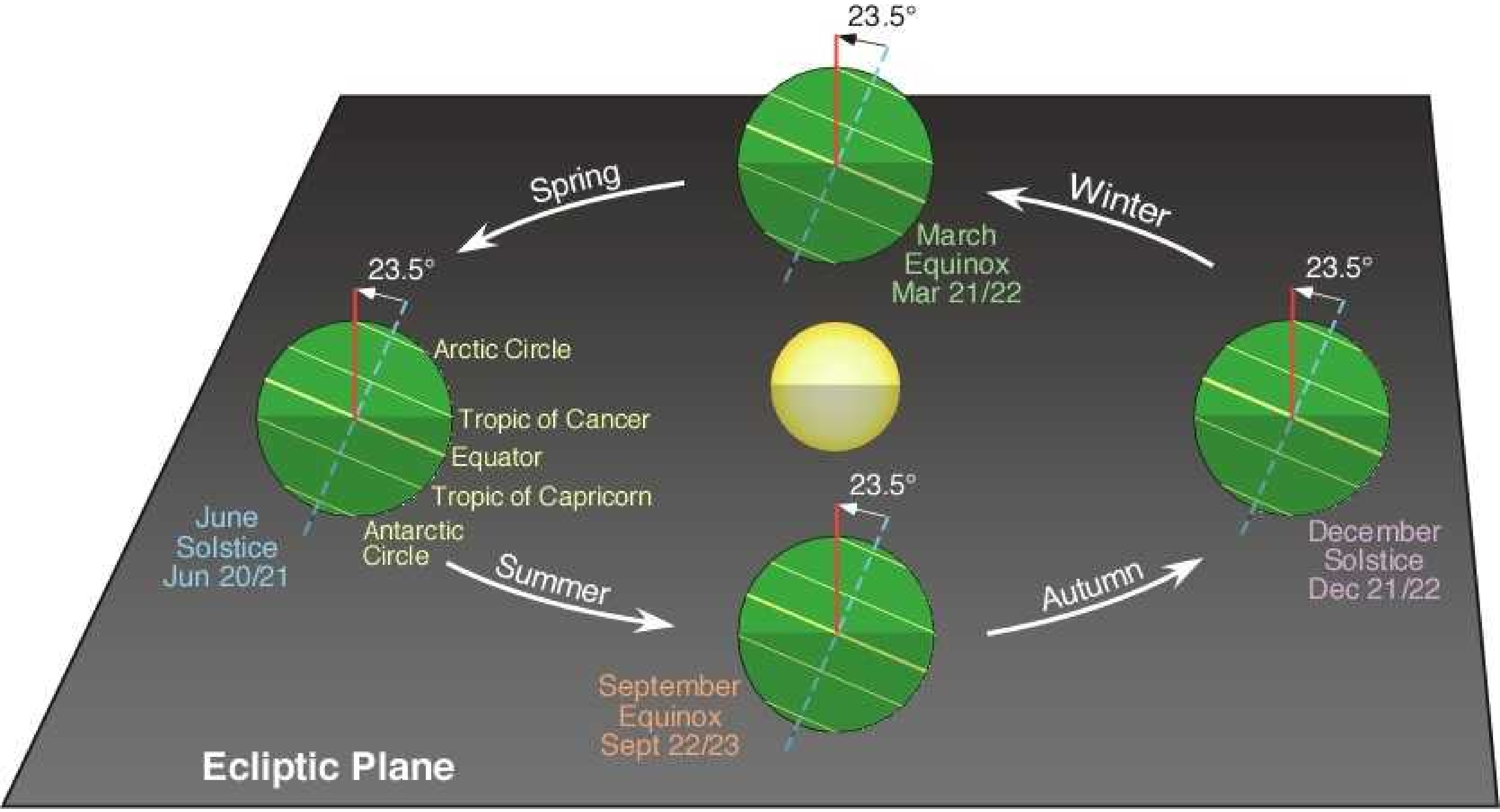
4. For an observer in the Southern Hemisphere the above explanation is backward: the Sun is lower when it's further North (Southern winter).

5. The distance of the Earth from the Sun does not vary much during the year and thus is not a determining factor for the seasons.

6. The orientation of the Earth with respect to the Sun is the main reason for the seasons.

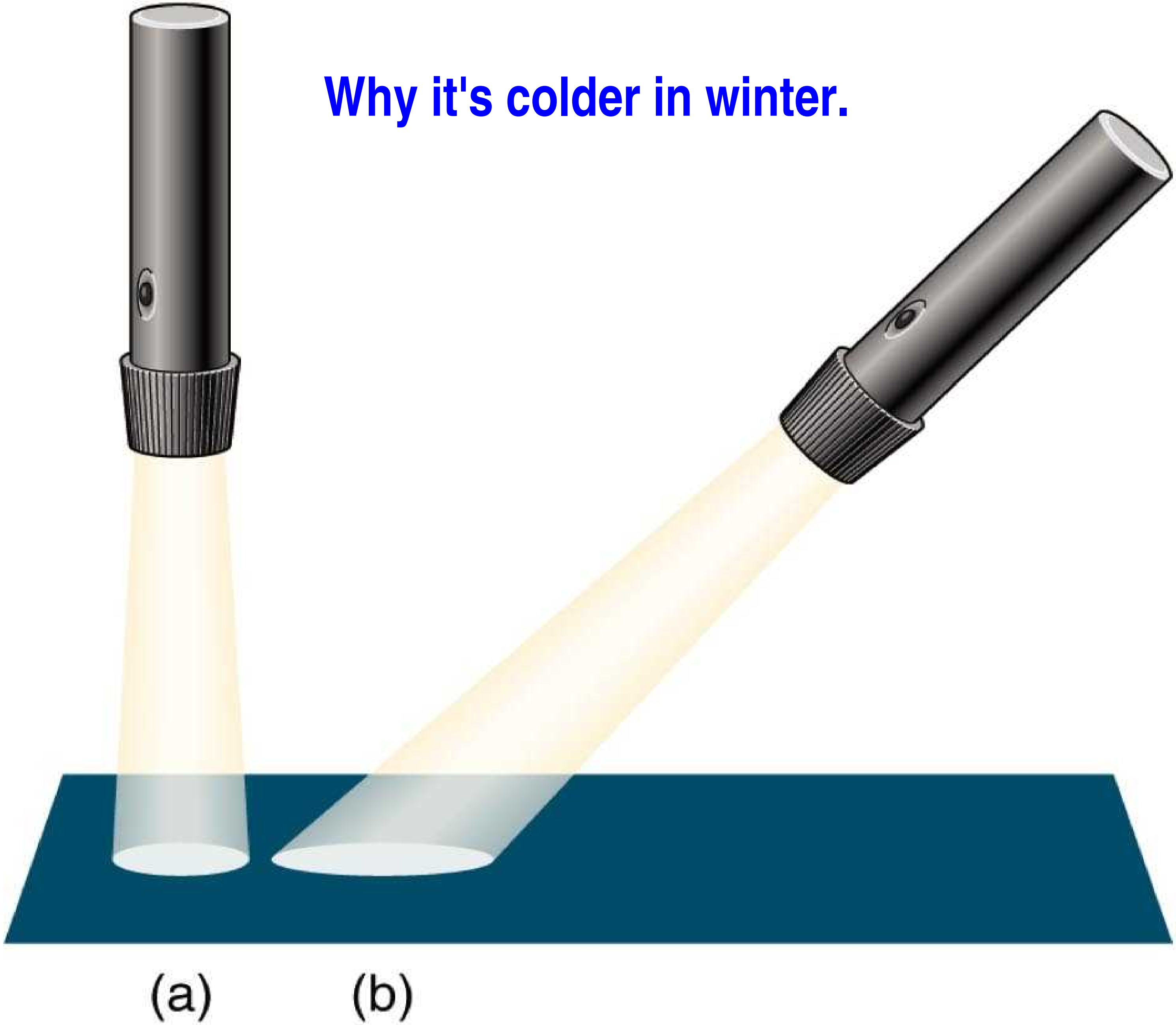


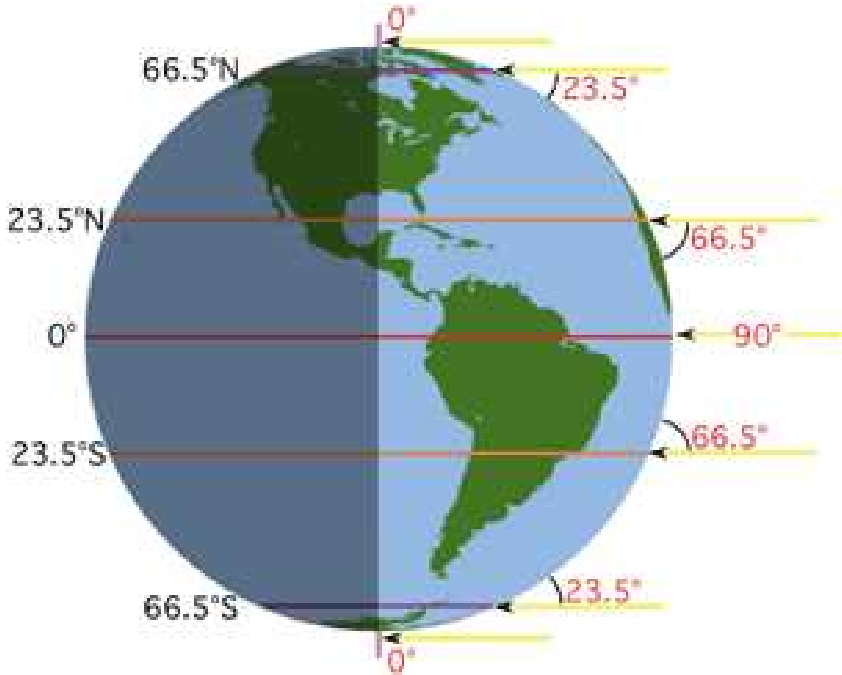
Position of the equinoxes, solstices, aphelion, and perihelion relative to the Earth's orbit around the Sun.



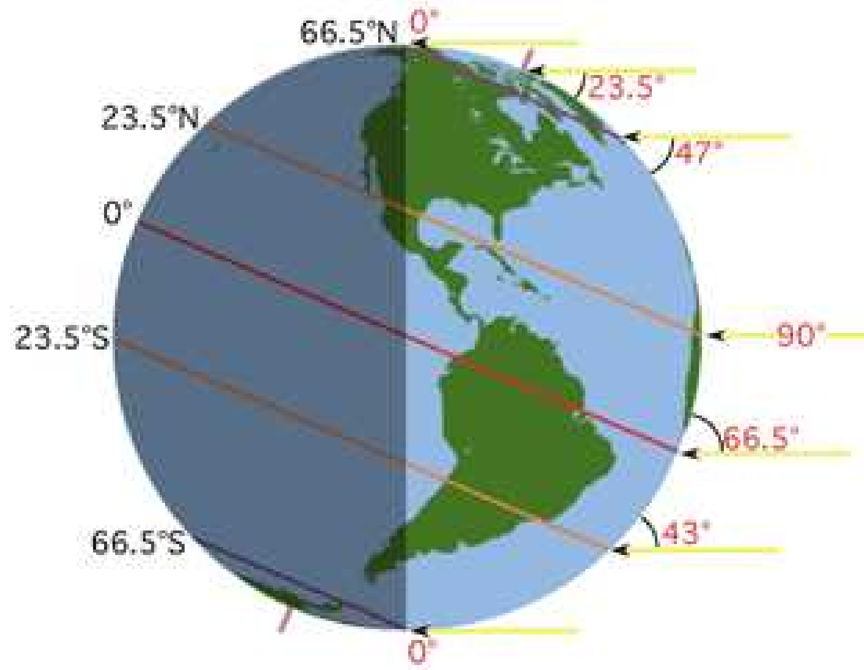
The Earth's rotational axis is tilted 23.5° from the red line drawn perpendicular to the ecliptic plane. This tilt remains the same anywhere along the Earth's orbit around the Sun. Seasons indicated are appropriate only for the Northern Hemisphere.

Why it's colder in winter.





At Equinox



At June Solstice

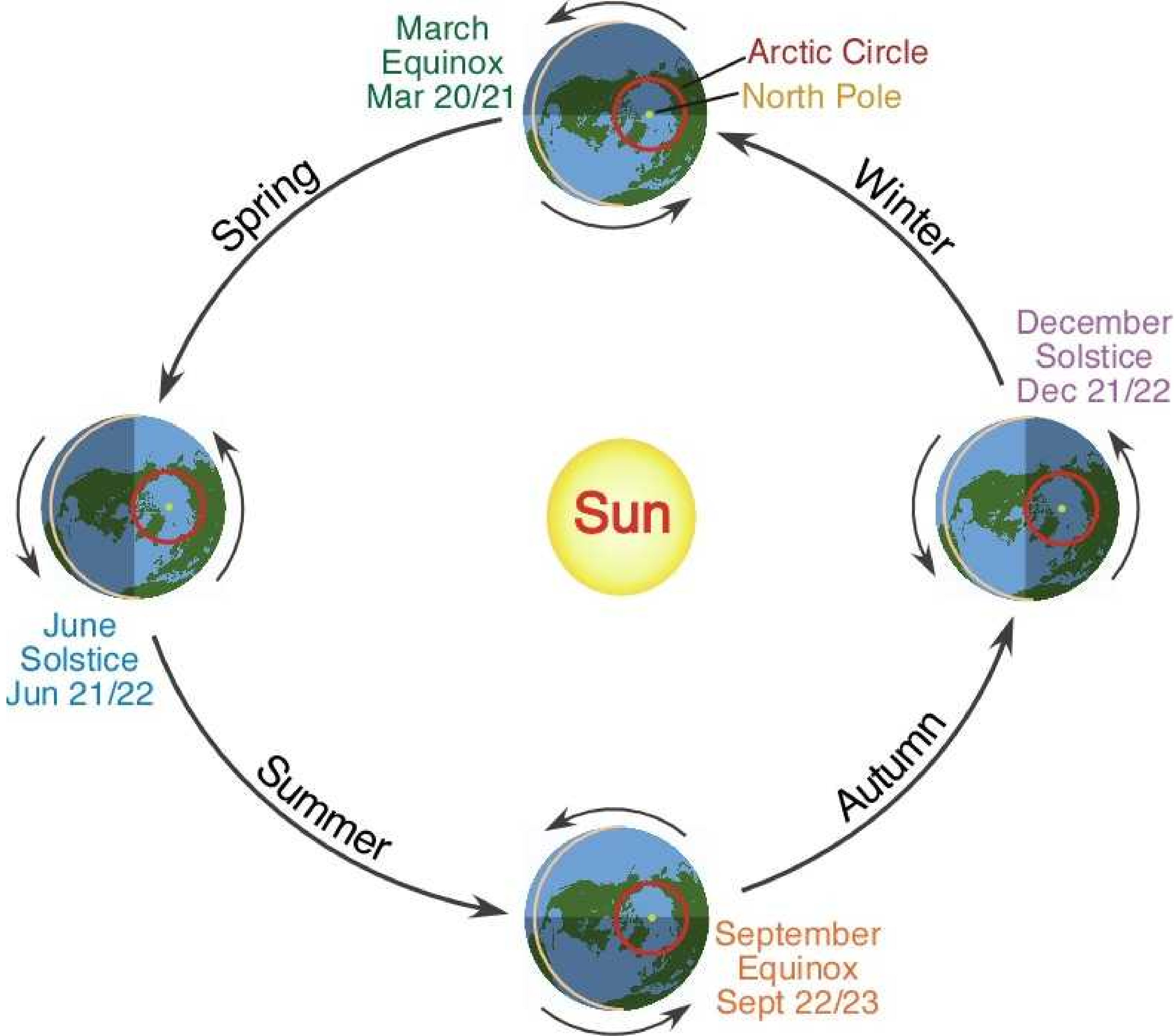
Angles of incidence of sunlight over the Earth

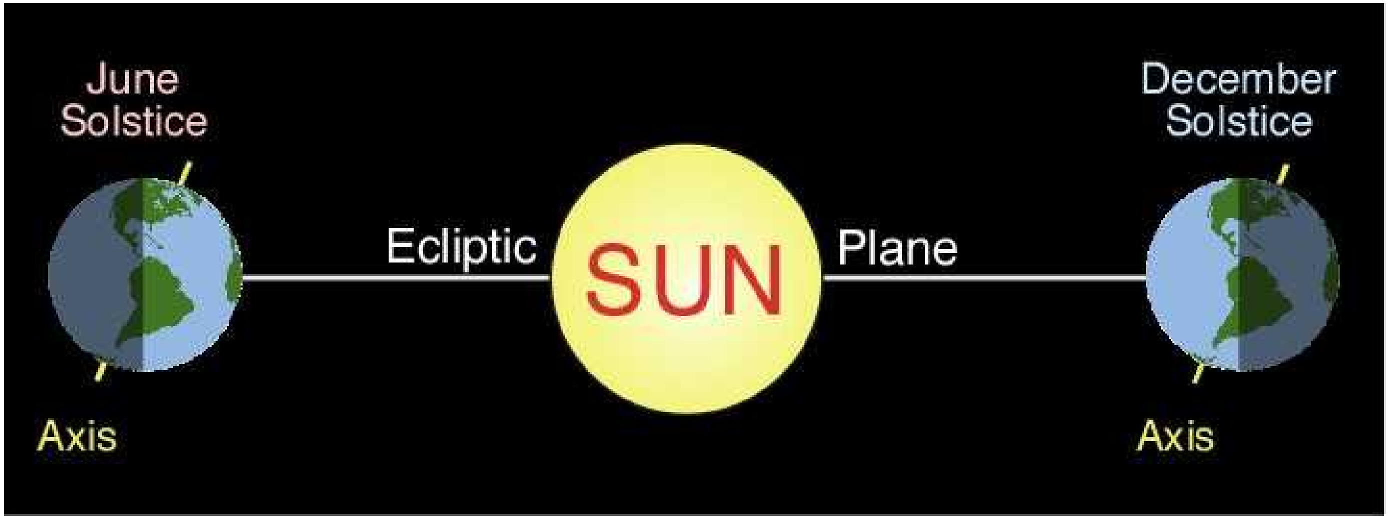
The Sun and the Seasons (cont.)

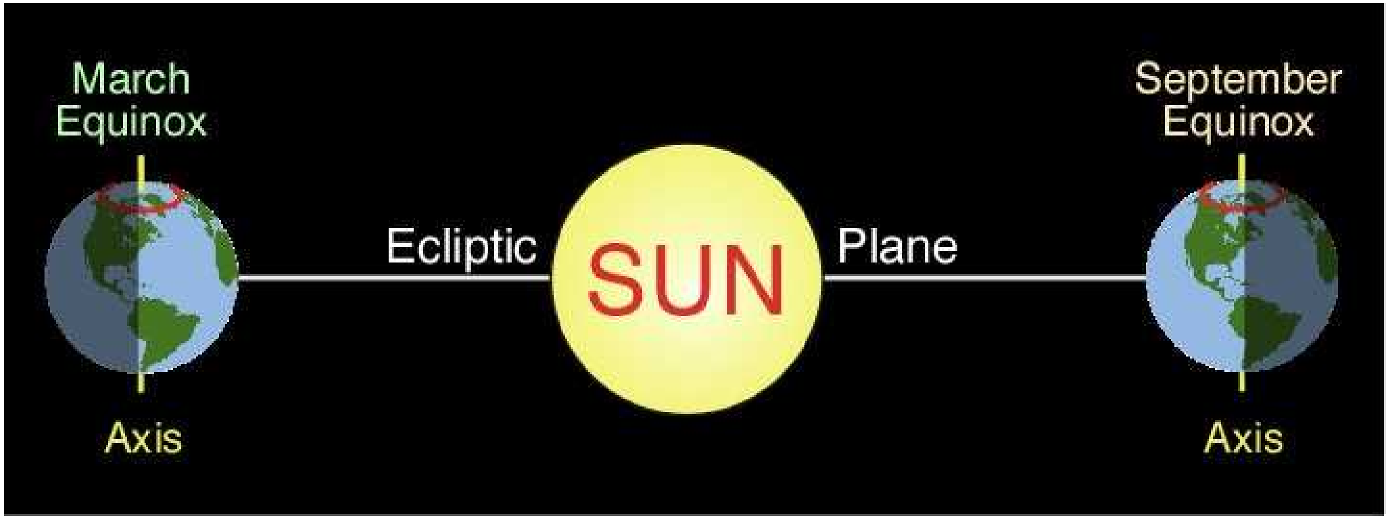
7. ***Altitude*** **is the height of a celestial object (such as the Sun) measured as an angle above the horizon.**

8. **The *summer* and *winter* solstices are points on the celestial sphere where the Sun reaches its northernmost and southernmost positions, respectively.**

9. **The *vernal* and *autumnal equinoxes* are the points on the celestial sphere where the Sun crosses the celestial equator while moving north and south, respectively.**


March
Equinox
Mar 20/21
Arctic Circle
North Pole
Spring
Winter
December
Solstice
Dec 21/22
Sun
June
Solstice
Jun 21/22
Summer
Autumn
September
Equinox
Sept 22/23


June
Solstice
December
Solstice
Ecliptic
SUN
Plane
Axis
Axis


March
Equinox
September
Equinox
Ecliptic
SUN
Plane
Axis
Axis

Leap Year and the Calendar

1. **The *tropical* year (365.242190 days) determines the seasons and is the time the Sun takes to return to the vernal equinox.**

2. **The Julian calendar was 365 days long and added one day at the end of February every four years. Thus it had an average of 365.25 days.**

Leap Year and the Calendar (cont.)

3. The difference between the tropical and Julian year caused the calendar to get out of synchronization with the seasons. The Gregorian calendar has an average of 365.2425 days.

4. The leap year rule: every year whose number is divisible by four is a leap year, except century years, unless they are divisible by 400.

Of course, we are jumping ahead!

It took a long time for a Sun-centered "universe" to be accepted. How we arrived at our current understanding, with the development of the scientific method, is the theme of this course.

The Moon's Phases

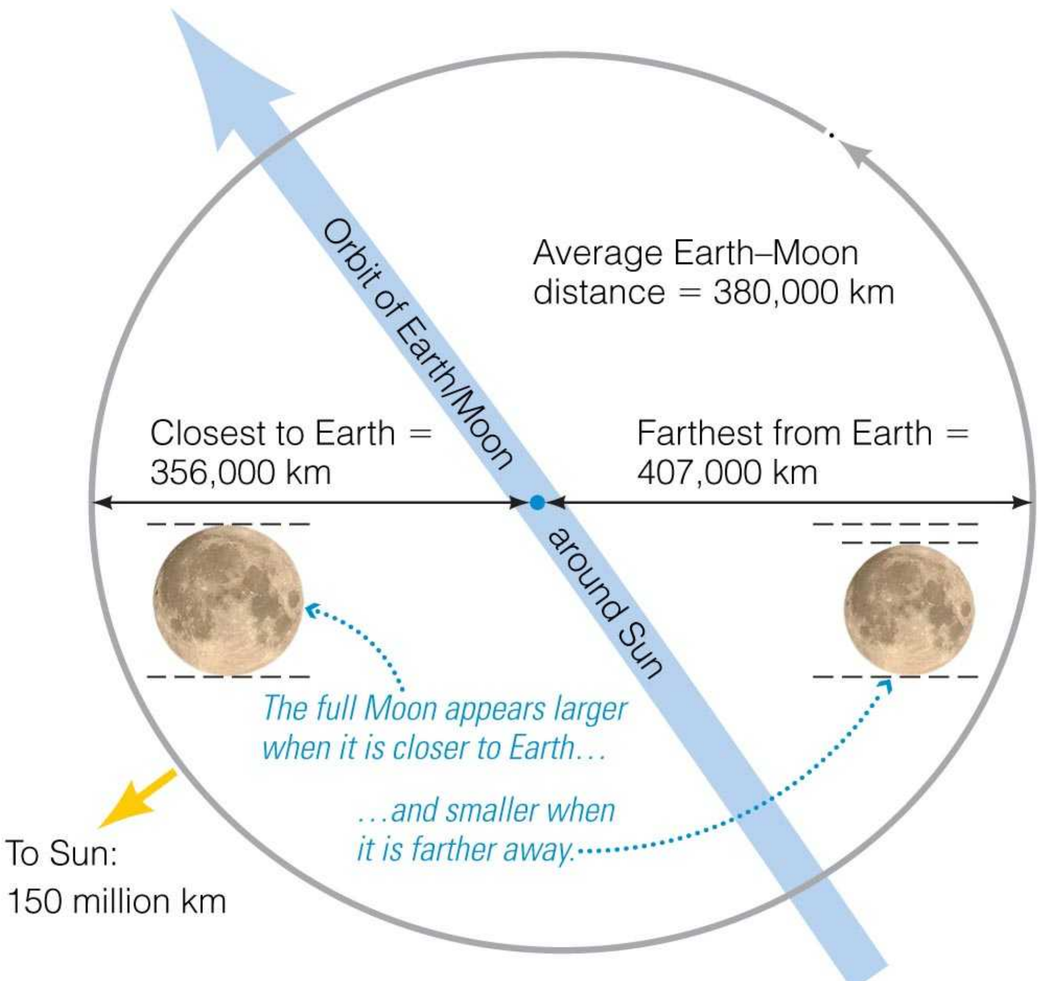
1. **The rotation and revolution period of the Moon are equal and can be explained by the law of universal gravitation.**

2. **Rotation is the spinning of an object about an axis that passes through it.**

3. **Revolution is the orbiting of one object around another.**

4. **Phases of the Moon—the changing appearance of the Moon during its cycle—are caused by the relative positions of the Earth, Moon, and Sun.**

Why do we see phases of the Moon?

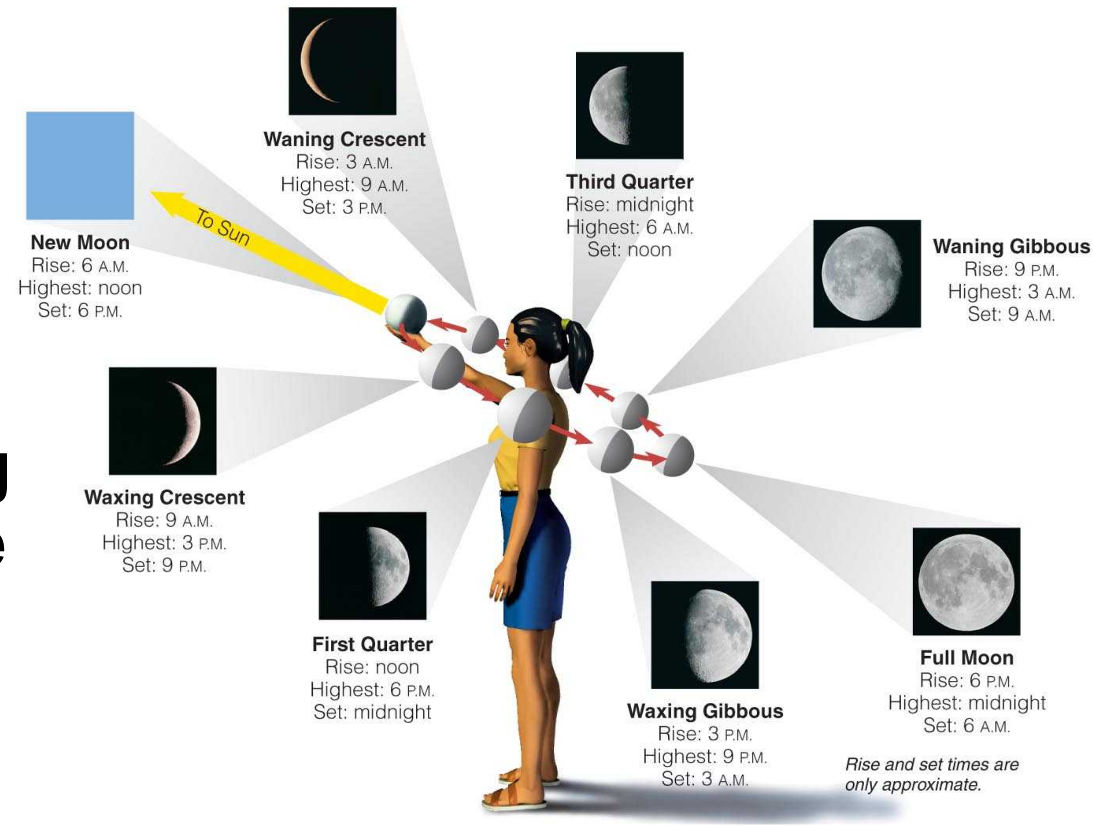


- **Lunar phases are a consequence of the Moon's 27.3-day orbit around Earth. That orbit is, of course, *elliptical*.**
- **Thus the angular size of the Moon as seen from Earth varies somewhat.**

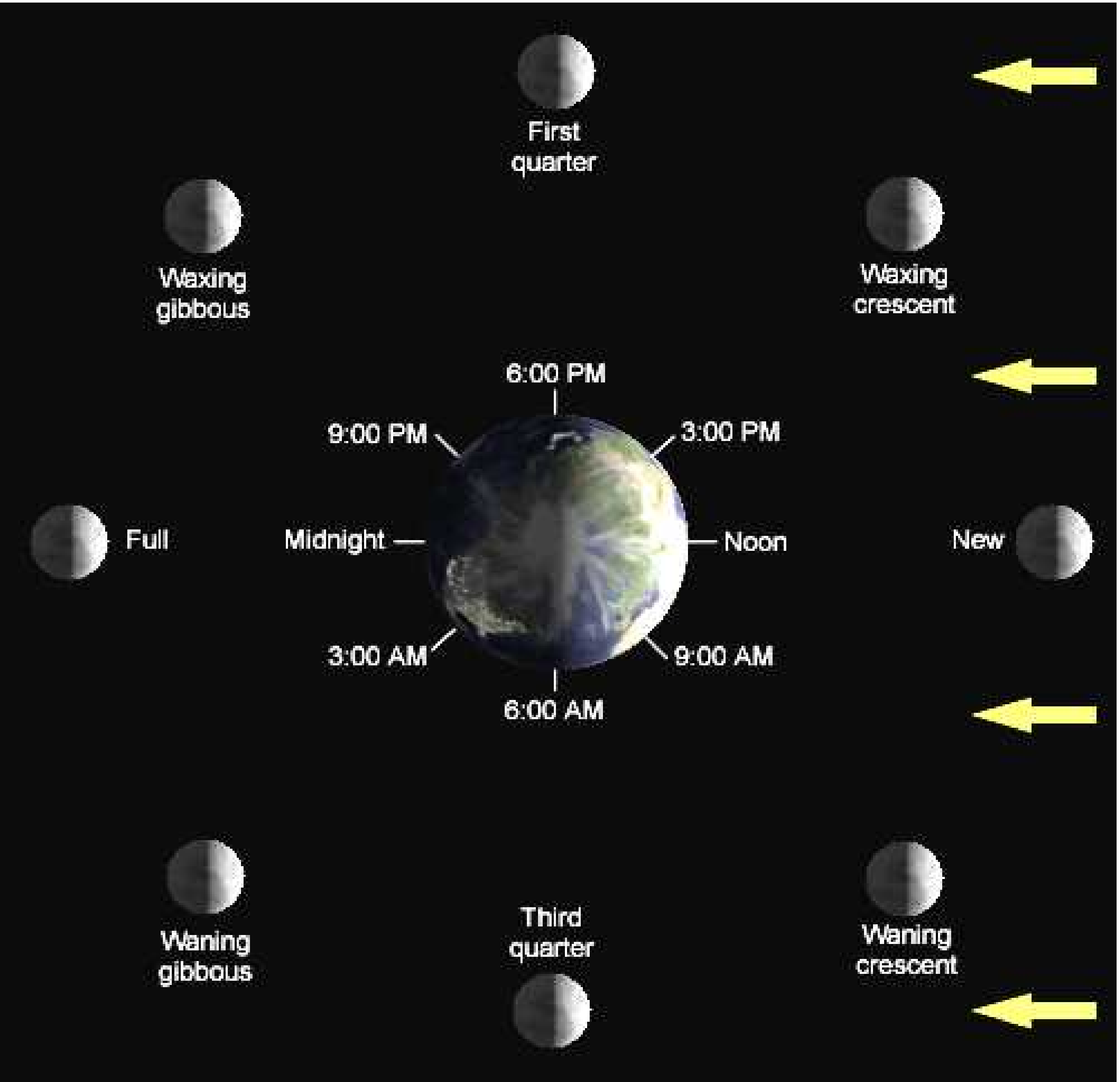
Phases of Moon

- **Half of Moon is illuminated by Sun and half is dark**

- **We see a changing combination of the bright and dark faces as Moon orbits**



Phases of the Moon



Light from the Sun

Not to Scale!!

Phases of the Moon: 29.5-day cycle

new

crescent

first quarter

gibbous

full

gibbous

last quarter

crescent

waxing
- Moon visible in afternoon/evening.
- Gets “fuller” and rises later each day.

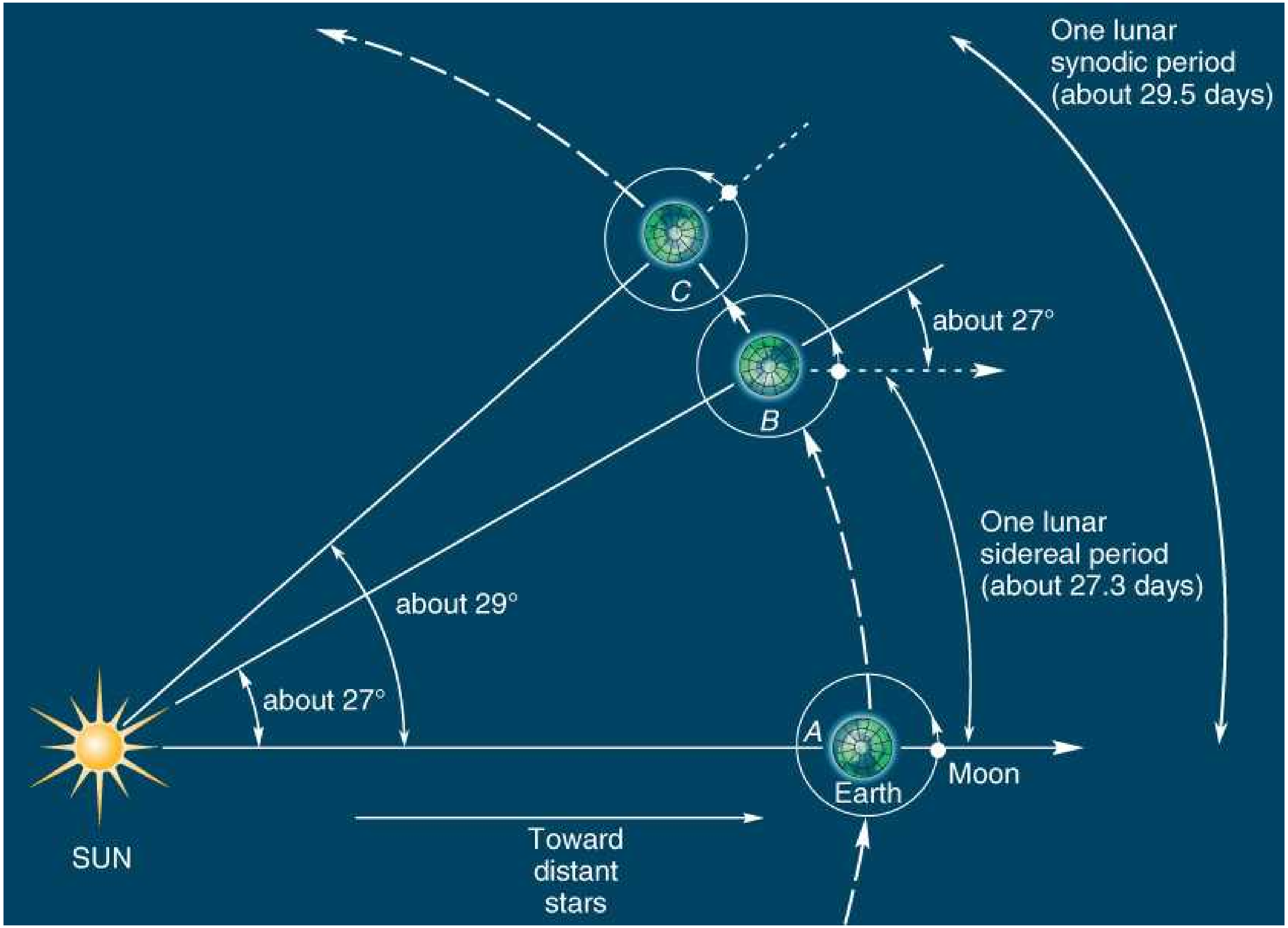
waning
- Moon visible in late night/morning.
- Gets “less” and sets later each day.

5. The phases follow the sequence of waxing crescent, first quarter, waxing gibbous, full Moon, waning gibbous, third (or last) quarter, waning crescent, new Moon.

6. Elongation is the angle of the Moon (or planet) from the Sun in the sky.

7. A sidereal revolution of the Moon takes about 27 1/3 days.

8. A sidereal period is the amount of time required for one revolution (or rotation) of a celestial object with respect to the distant stars.



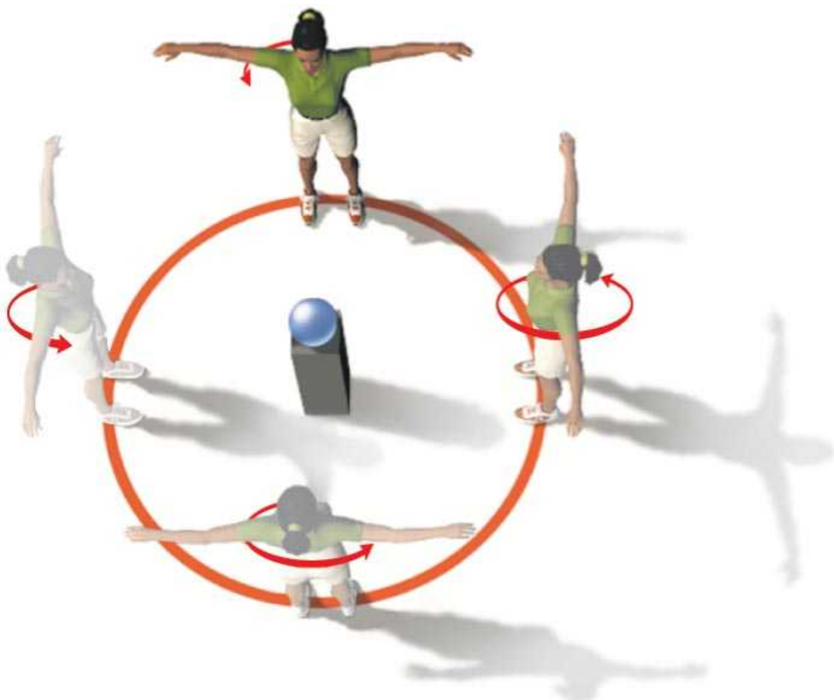
Sidereal versus synodic period

9. A **synodic period** is the time interval between successive similar alignments of a celestial object with respect to the Sun.

10. A synodic revolution of the Moon takes about 29 1/2 days.

11. Lunar month is the Moon's synodic period, or the time between successive phases: $29^{d}12^{h}44^{m}2^{s}.9$.

We see only one side of the Moon



b You will face the model at all times only if you rotate exactly once during each orbit.

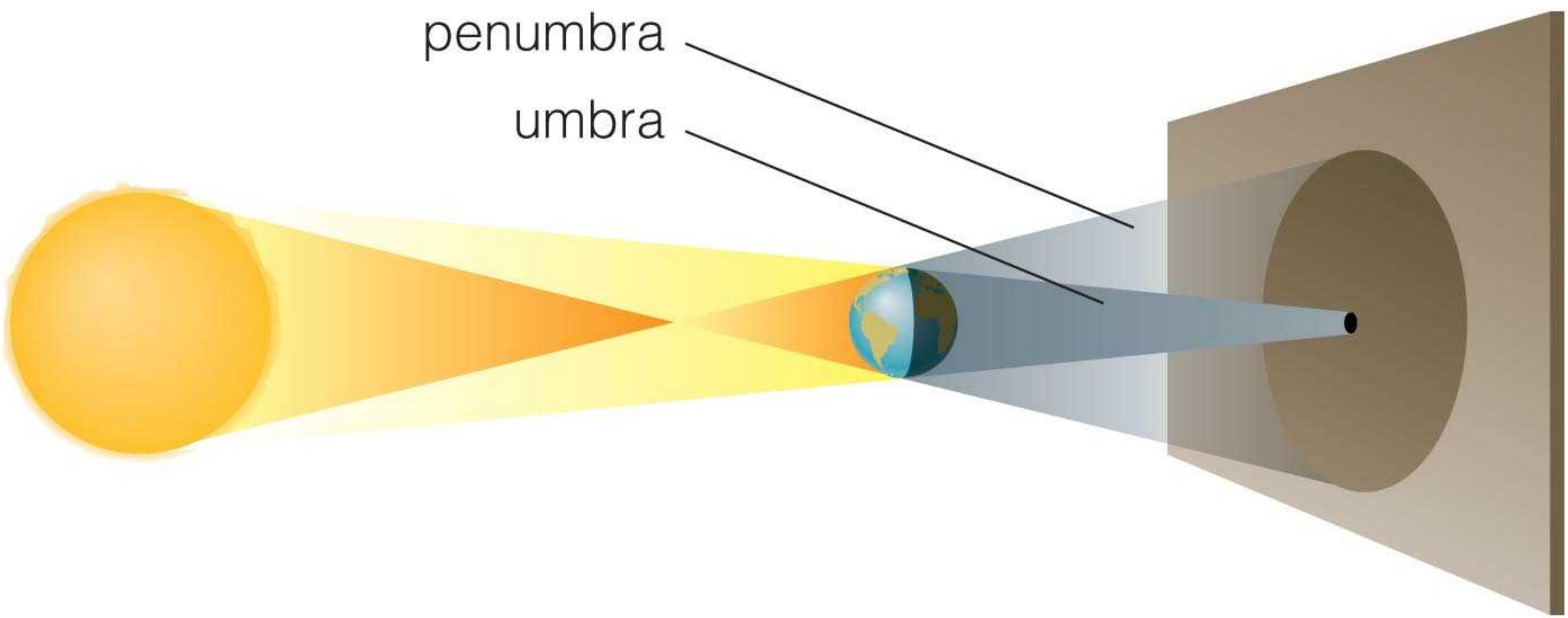
<u>Synchronous rotation</u>: the Moon rotates exactly once with each orbit

That is why only one side is visible from Earth

We will learn why when we discuss *tides*.

What causes eclipses?

- The Earth and Moon cast shadows.
- When either passes through the other's shadow, we have an eclipse.

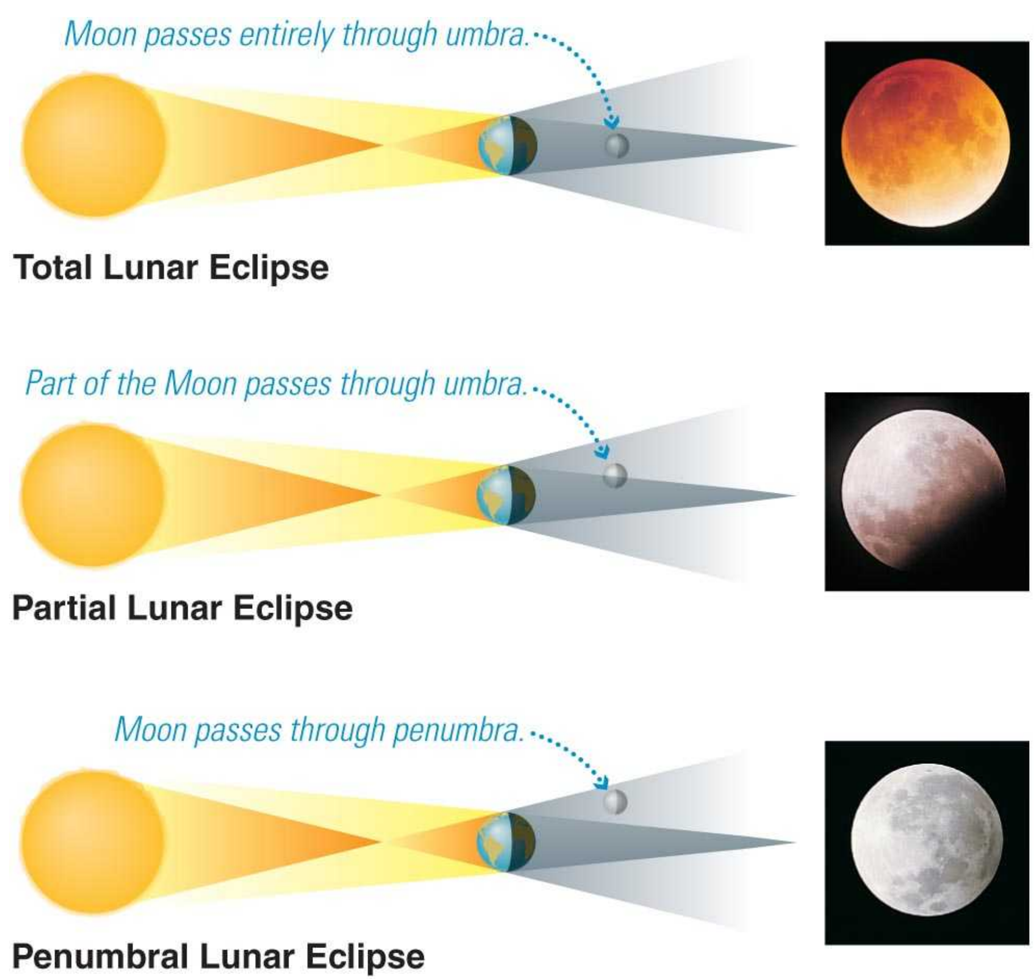


Lunar Eclipses

1. **Lunar eclipse** is an eclipse in which the Moon passes into the shadow of the Earth.
2. **Umbra** is the portion of a shadow that receives no direct light from the light source.
3. **Penumbra** is the portion of a shadow that receives direct light from only part of the light source.

When can lunar eclipses occur?

- **Lunar eclipses** can occur only at *full moon*.
- Lunar eclipses can be **penumbral**, **partial**, or **total**.

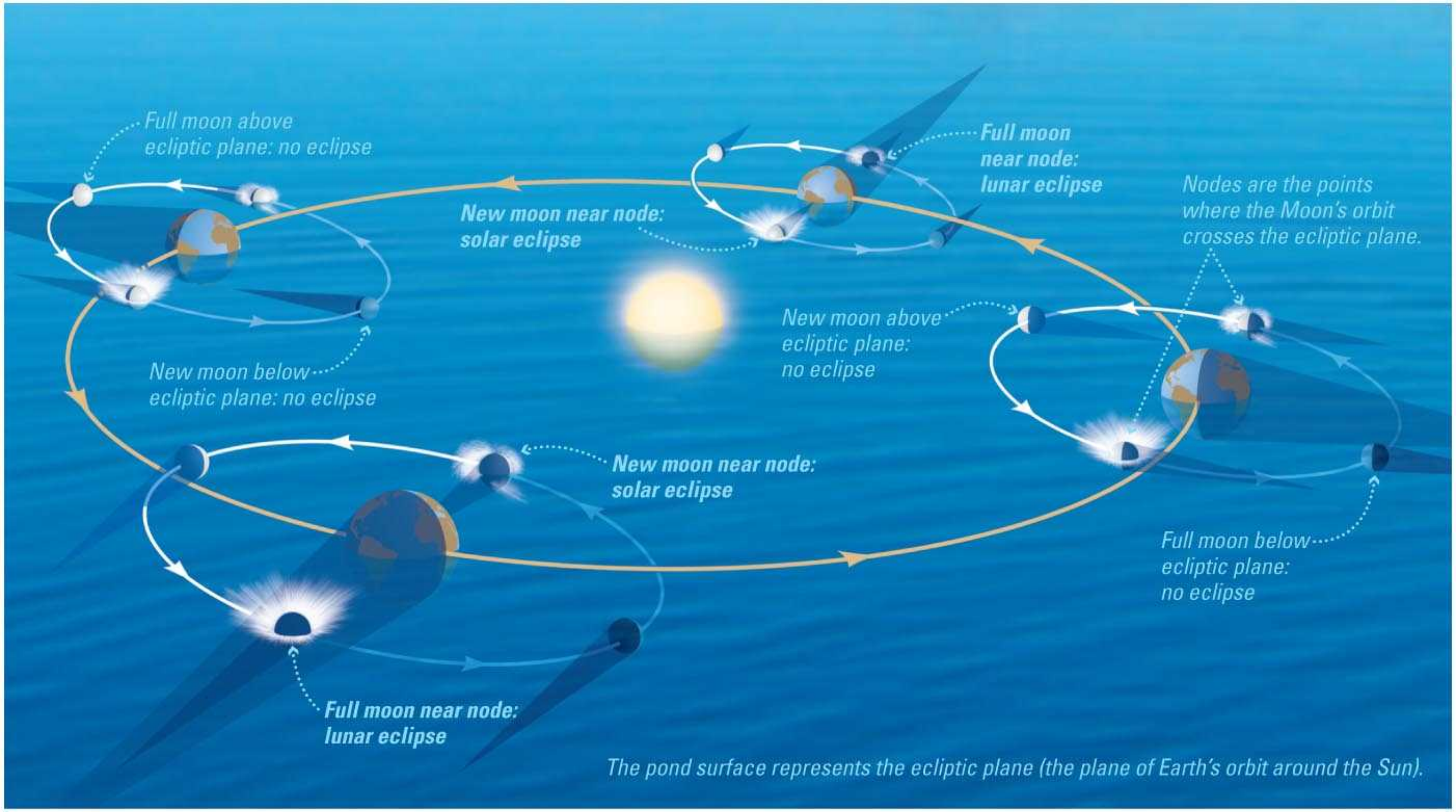


4. **Eclipse season** is a time of the year during which a solar or lunar eclipse is possible.

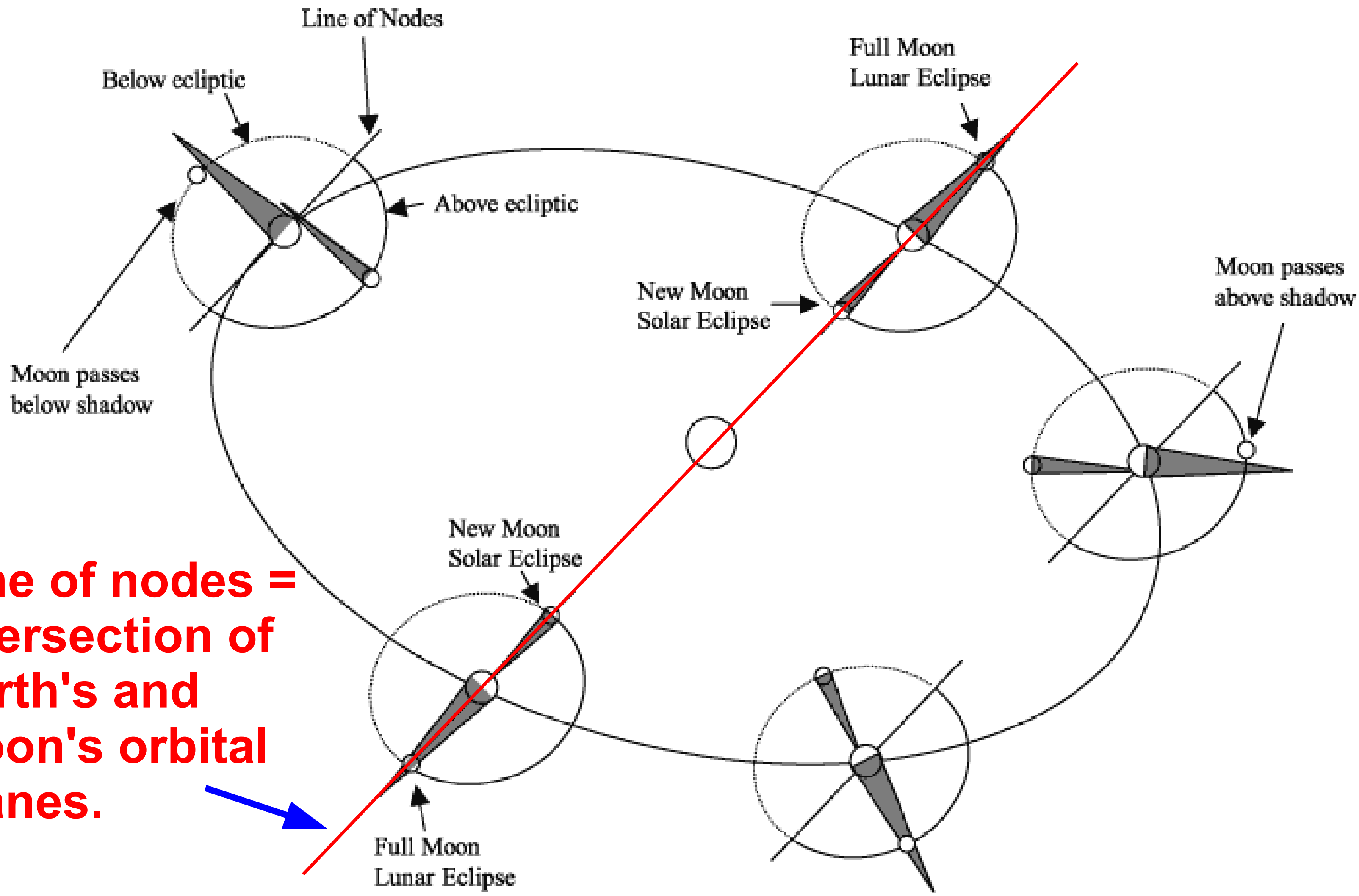
5. A lunar eclipse does not occur at each full Moon because the Moon's plane of revolution is tilted 5° compared to the Earth's plane of revolution around the Sun. Only during the two eclipse seasons that occur each year are the Earth and Moon positioned so that the Moon will enter the Earth's shadow during a full Moon.

Why don't we have an eclipse at every new and full moon?

- The Moon's orbit is tilted 5° to ecliptic plane…
- So we have about two **eclipse seasons** each year, with a lunar eclipse at full moon and solar eclipse at new moon.



Eclipse Seasons



Line of nodes = intersection of Earth's and Moon's orbital planes.

Summary: Two conditions must be met to have an eclipse:

1. It must be full moon (for a lunar eclipse) or new moon (for a solar eclipse).

AND

2. The Moon must be at or near one of the two points in its orbit where it crosses the ecliptic plane (its nodes).

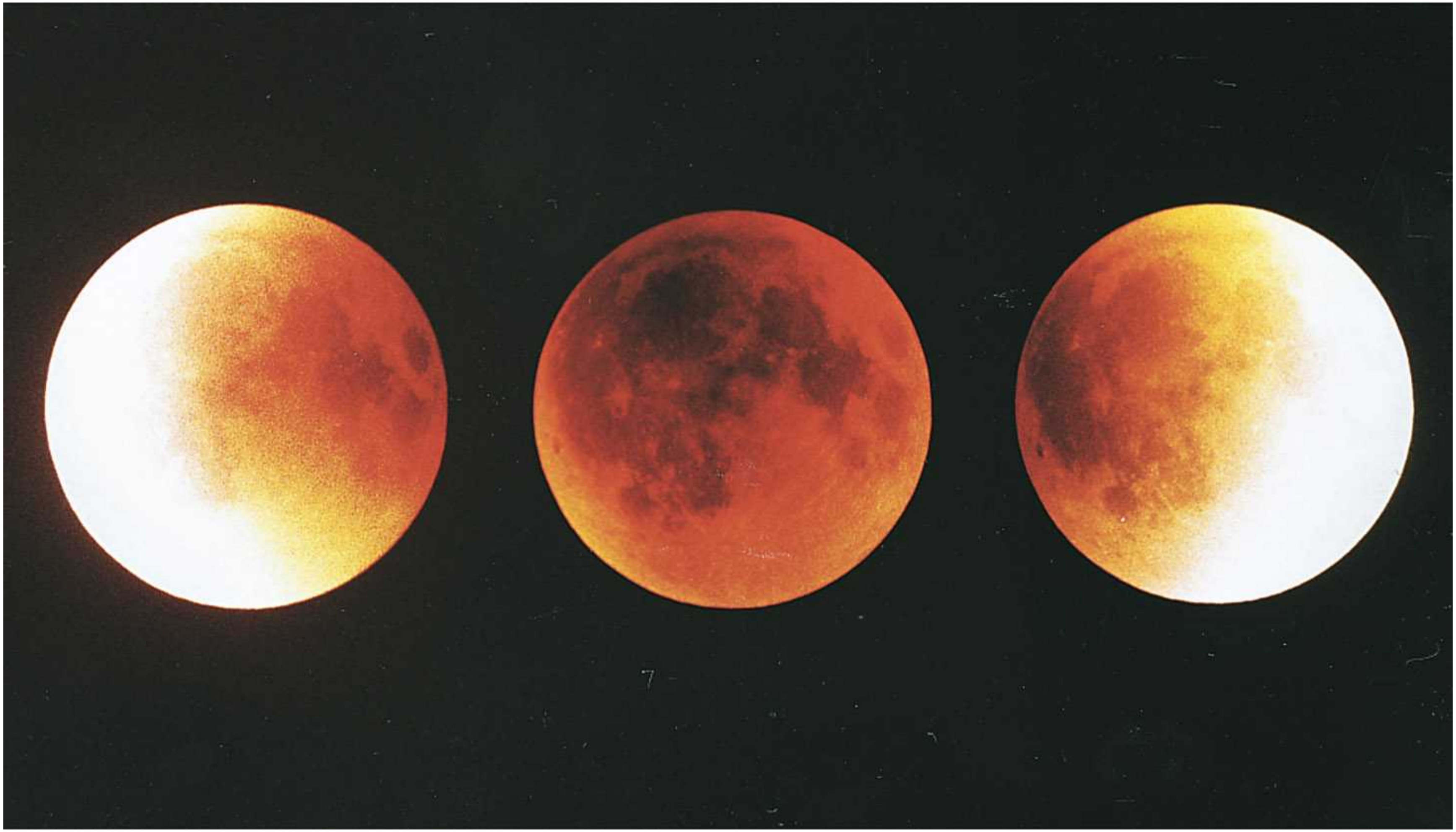
Types of Lunar Eclipses

1. **Penumbral lunar eclipse** is an eclipse of the Moon in which the Moon passes through the Earth's penumbra but not through its umbra.

2. **Total lunar eclipse** is an eclipse of the Moon in which the Moon is completely in the umbra of the Earth's shadow.

3. **Partial lunar eclipse** is an eclipse of the Moon in which only part of the Moon passes through the umbra of the Earth's shadow.

4. A total eclipse of the Moon is never totally dark because some light is refracted toward the Moon by the Earth's atmosphere. Most of this refracted light reaching the Moon is red; the blue portion has been scattered out.



Moon during lunar eclipse

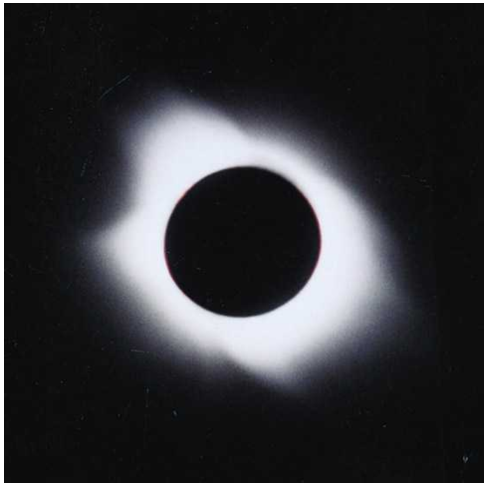
Photo by Jim Rouse

Solar Eclipses

1. **Solar eclipse** is an eclipse of the Sun in which light from the Sun is blocked by the Moon.

2. **Total solar eclipse** is an eclipse in which light from the normally visible portion of the Sun (the photosphere) is completely blocked by the Moon.

3. The **corona**—the outer atmosphere of the Sun—is visible during a total solar eclipse.

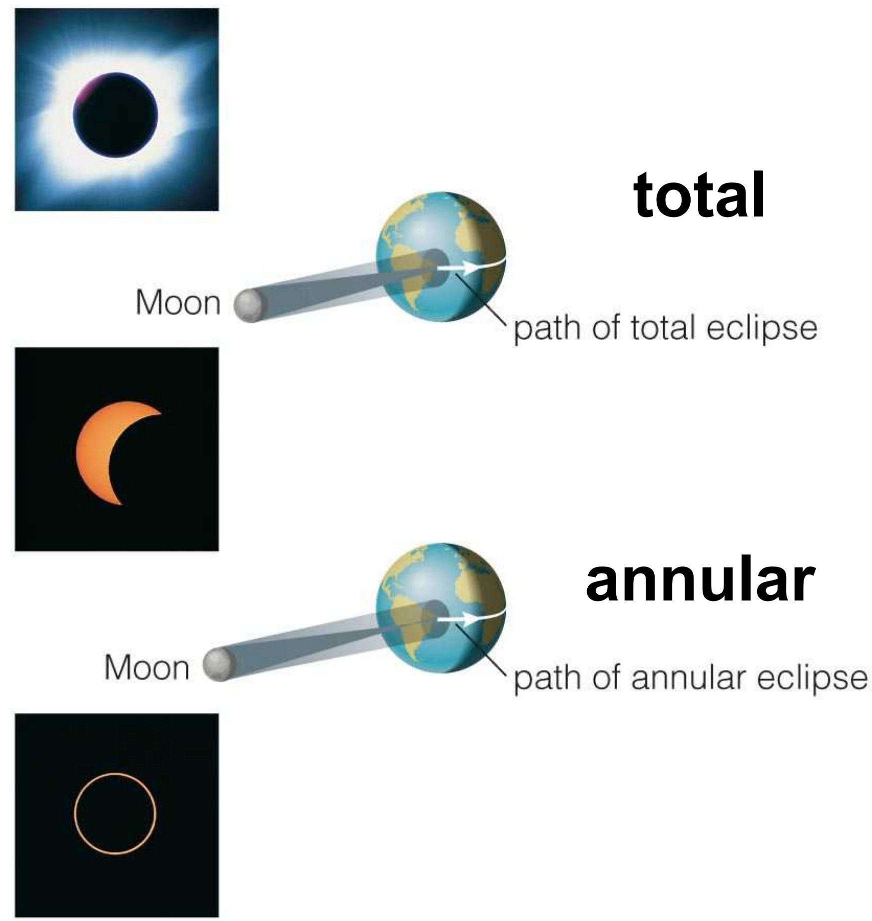


Courtesy of Alex York

Figure 1.32: Sun at total eclipse

When can solar eclipses occur?

- **Solar eclipses** can occur only at ***new moon*.**
- Solar eclipses can be **partial**, **total,** or **annular**.

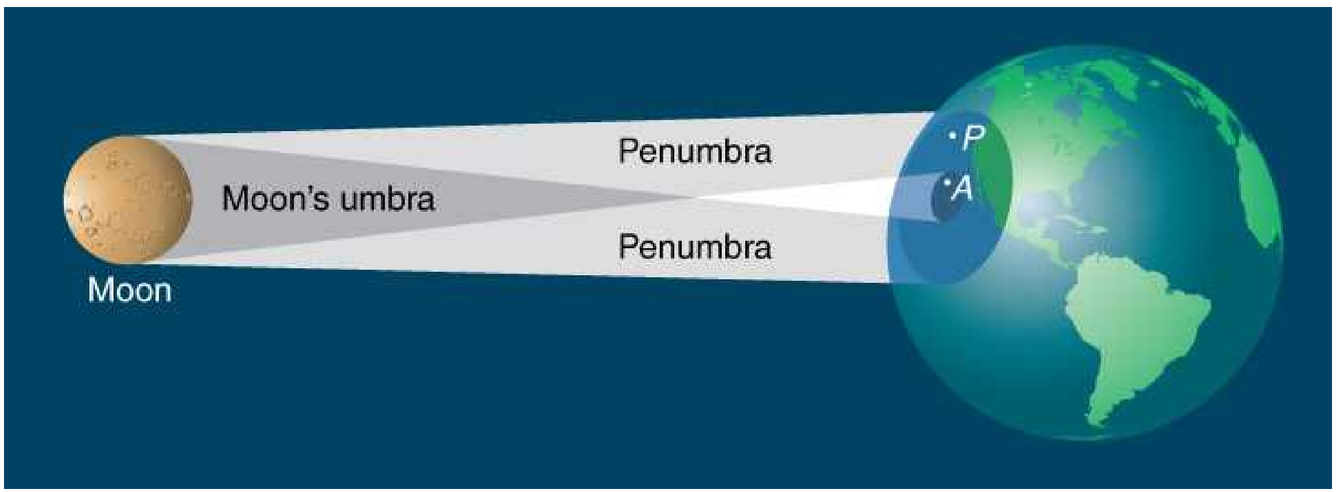


The Partial Solar Eclipse

1. In a **partial solar eclipse** only part of the Sun's disk is covered by the Moon (visible in region P)

The Annular Eclipse

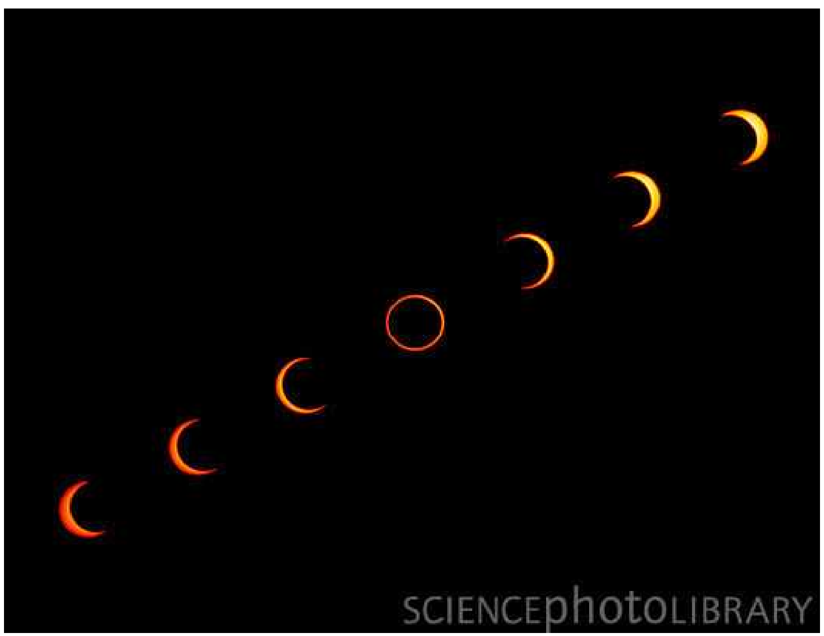
2. An **annular eclipse** is an eclipse in which the Moon is too far from the Earth for its disk to cover that of the Sun completely, so the outer edge of the Sun is seen as a ring or *annulus*.



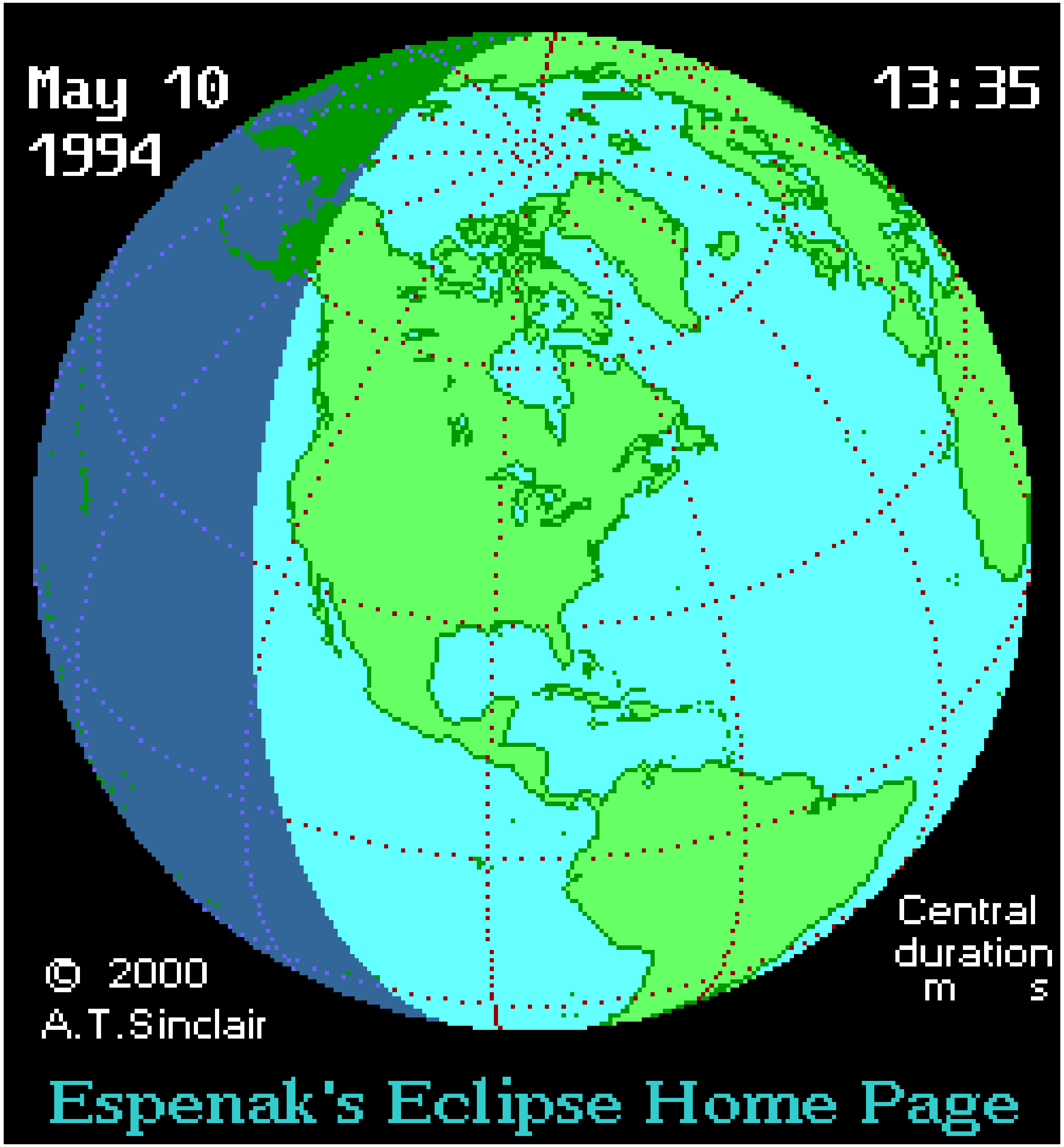
When the Moon is far away during a solar eclipse, the eclipse will be annular (seen in region A)

During an annular eclipse, we can see the entire ring—annulus—of the Sun around the Moon.

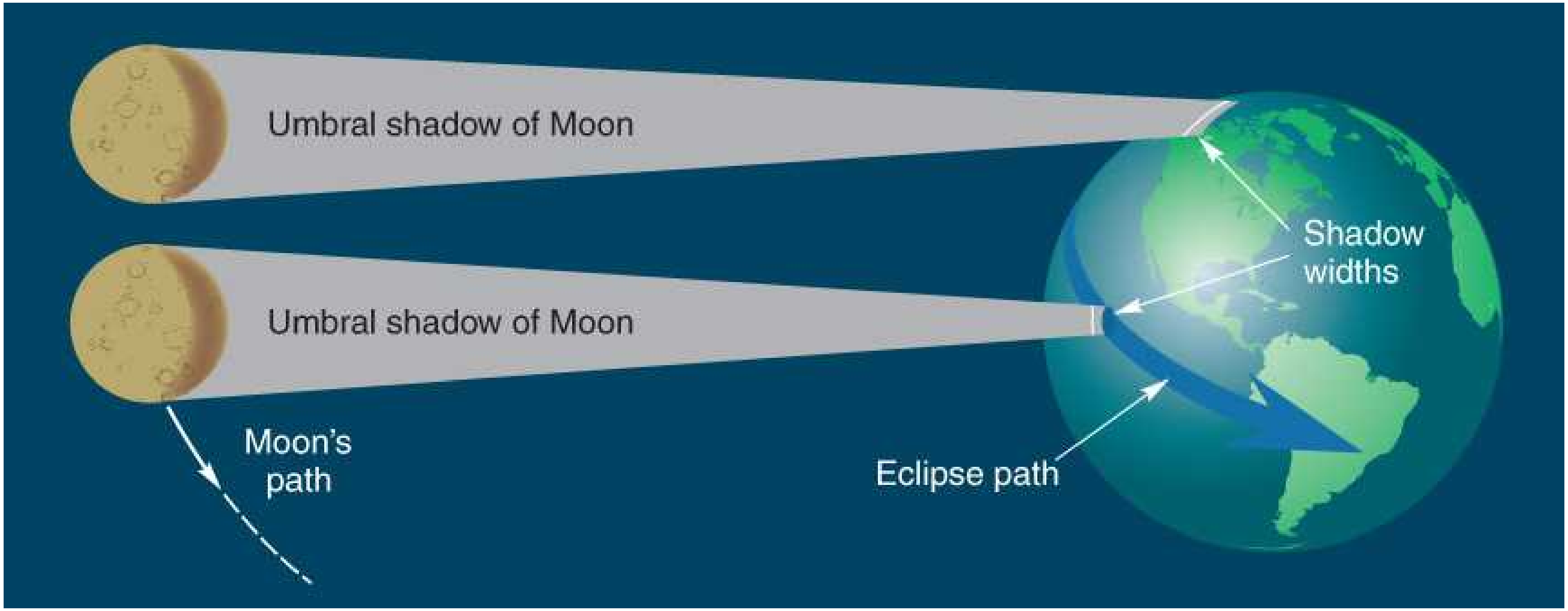
An annular eclipse was observed from downtown Toronto, 10 May 1994



Circumstances	Time (UT) h m	Longitude ° '	Latitude ° '
Eclipse begins; first contact with Earth	14 12.2	W 125 31.4	N 4 56.9
Beginning of southern limit of penumbra	15 03.7	W 130 56.0	S 17 50.7
Beginning of southern limit of umbra	15 21.9	W 145 22.5	N 12 20.9
Beginning of centre line; central eclipse begins	15 23.3	W 146 07.7	N 13 33.5
Beginning of northern limit of umbra	15 24.7	W 146 54.0	N 14 47.0
Beginning of northern limit of penumbra	16 48.1	E 160 15.9	N 61 58.8
Central eclipse at local apparent noon	17 19.8	W 80 51.9	N 42 21.8
End of northern limit of penumbra	17 34.5	E 87 47.2	N 72 09.5
End of northern limit of umbra	18 58.0	W 3 14.3	N 33 28.1
End of centre line; central eclipse ends	18 59.5	W 4 08.7	N 32 16.6
End of southern limit of umbra	19 00.8	W 5 01.2	N 31 05.8
End of southern limit of penumbra	19 19.3	W 20 23.0	N 1 04.0
Eclipse ends; last contact with Earth	20 10.6	W 25 27.5	N 23 47.5



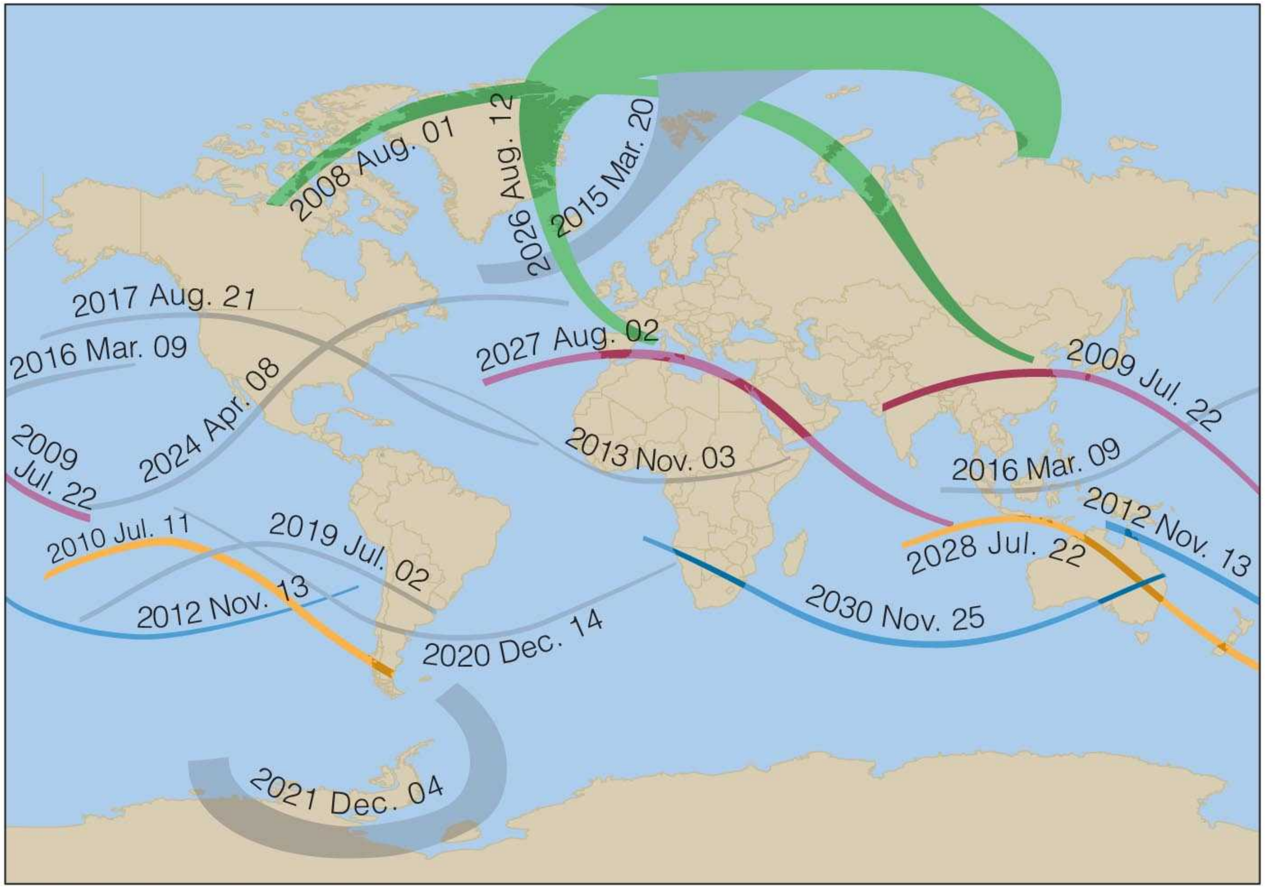
1994 Annular Eclipse



Shadows of the Moon on Earth

Predicting Eclipses

- Eclipses recur with the 18 yr, 11 1/3 day **Saros cycle**, but type (e.g., partial, total) and location may vary.



The Moon: Summary

- **Why do we see phases of the Moon?**
  - Half the Moon is lit by the Sun; half is in shadow, and its appearance to us is determined by the relative positions of Sun, Moon, and Earth
- **What causes eclipses?**
  - Lunar eclipse: Earth's shadow on the Moon
  - Solar eclipse: Moon's shadow on Earth
  - Tilt of Moon's orbit means eclipses occur during two periods each year

Reading for 3rd Lecture

- 1-7 to 1-10: Planetary Motions
- The Scientific Method
- Scientific Models
- The Greek Geocentric Model
- Aristarchus' Sun-Centred Model
- Measurements of Earth, Moon, Sun sizes & distances.