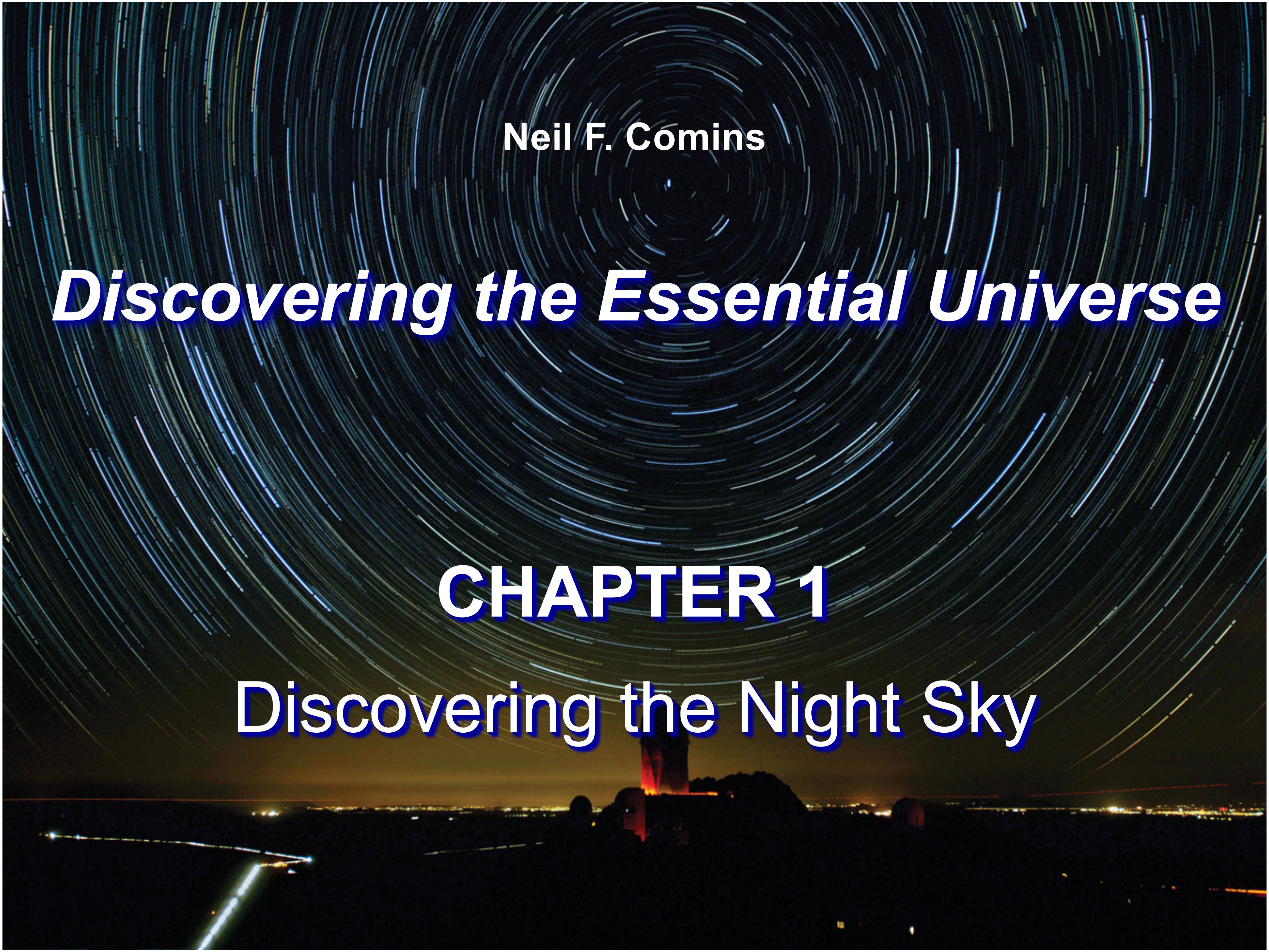
Neil F. Comins

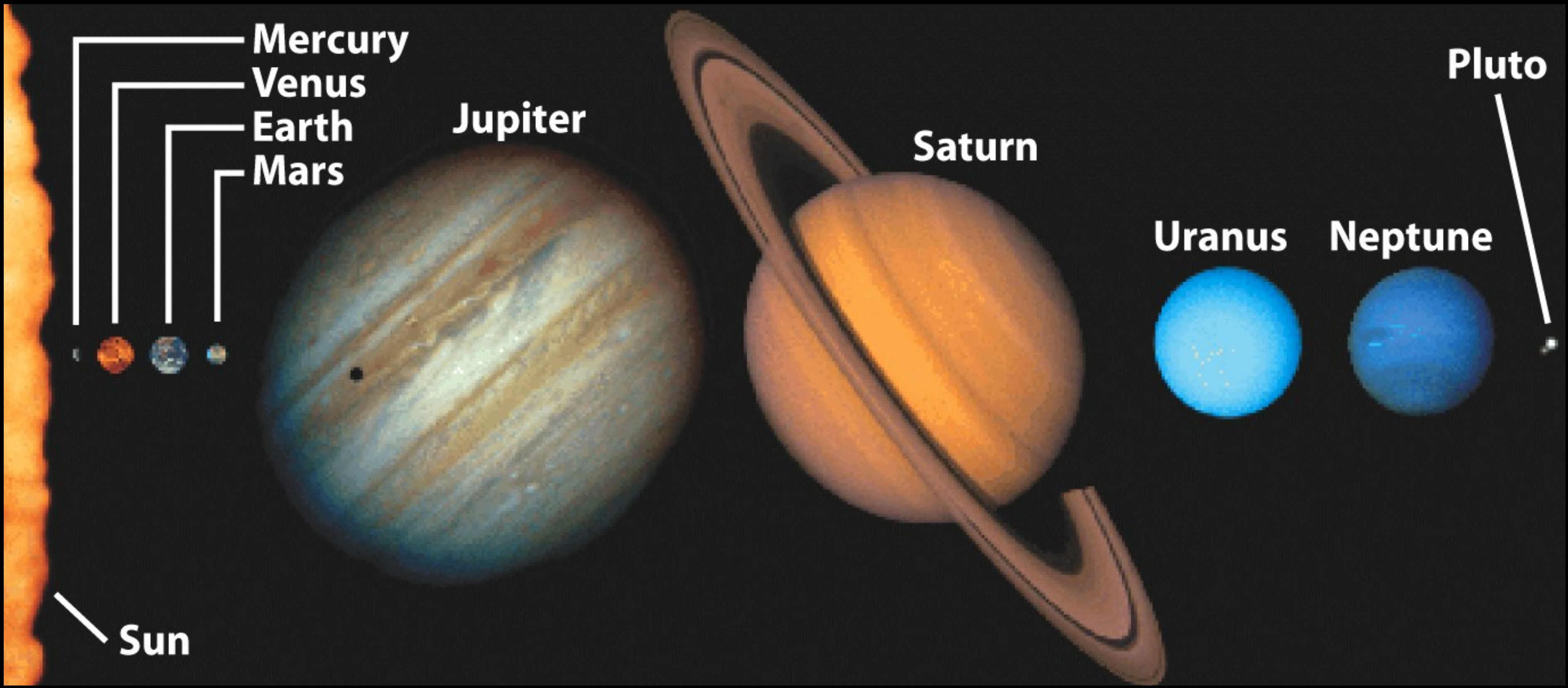
Discovering the Essential Universe

CHAPTER 1

Discovering the Night Sky



By exploring the planets, astronomers uncover clues about the formation of the solar system



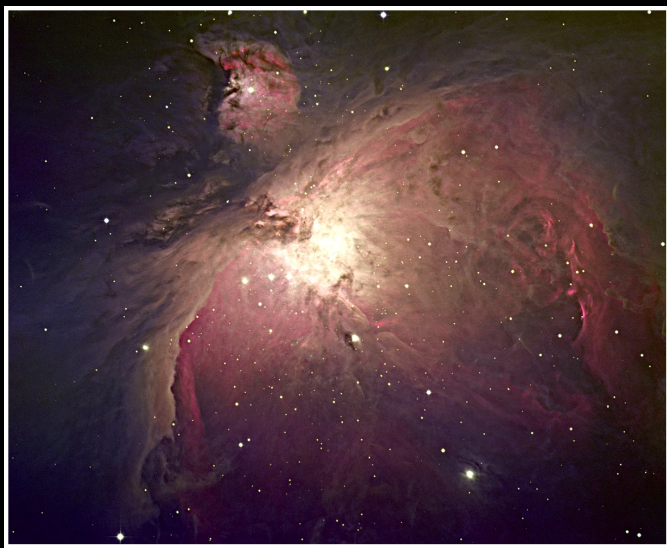
- The star we call the Sun and all the celestial bodies that orbit the Sun
  - including Earth
  - the other eight planets
  - all their various moons
  - smaller bodies such as asteroids and comets

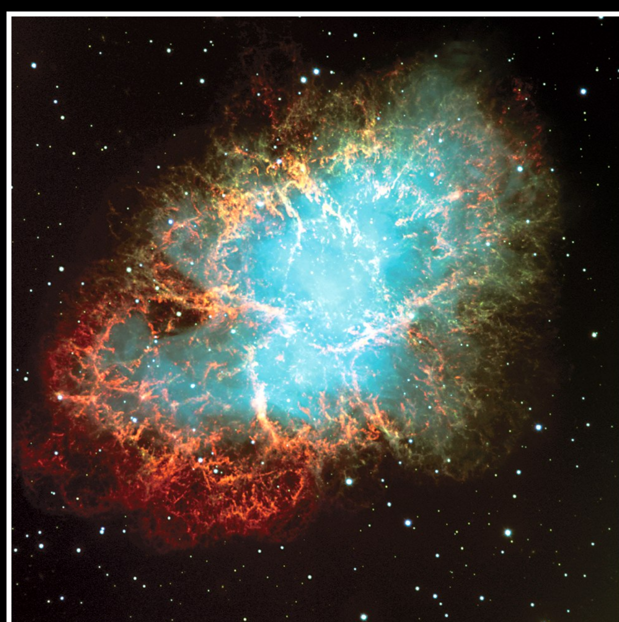
If we shrink the solar system and its environment such that the Sun has a diameter of 1 cm, then..

- Earth has a diameter of 0.1 mm and is at a distance of 1 m.
- Jupiter has a diameter of 1 mm and is at a distance of 5 m.
- Neptun has a diameter of 0.4 mm and is at a distance of 30 m.
- The spacecraft Voyager 1 is at a distance of 140 m.
- The nearest star, Proxima Centauri is then at a distance of 250 km (Kingston, ON).

Approximate scale where 1 m $\approx$1 AU

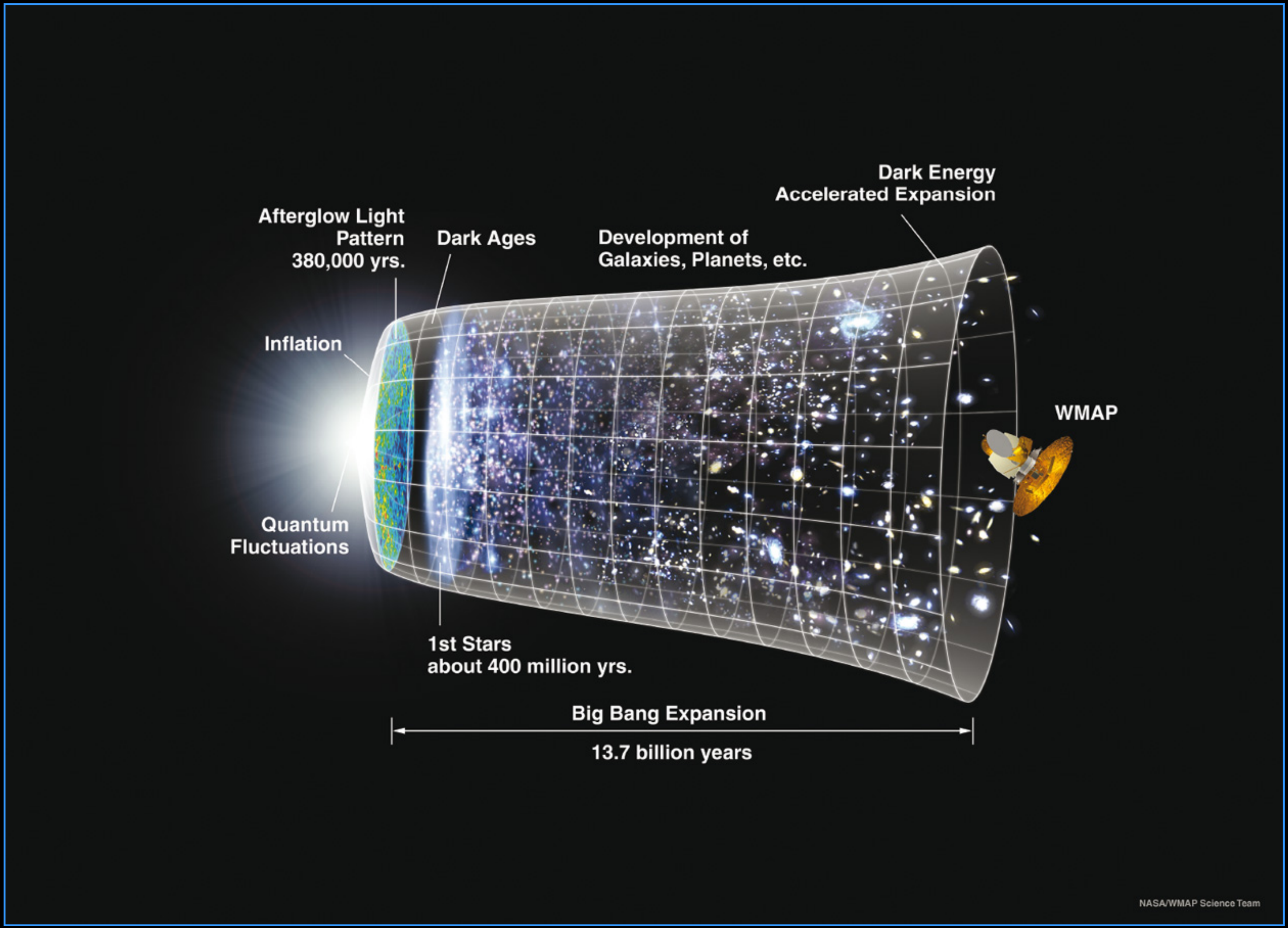
By studying stars and nebulae, astronomers discover how stars are born, grow old, and die





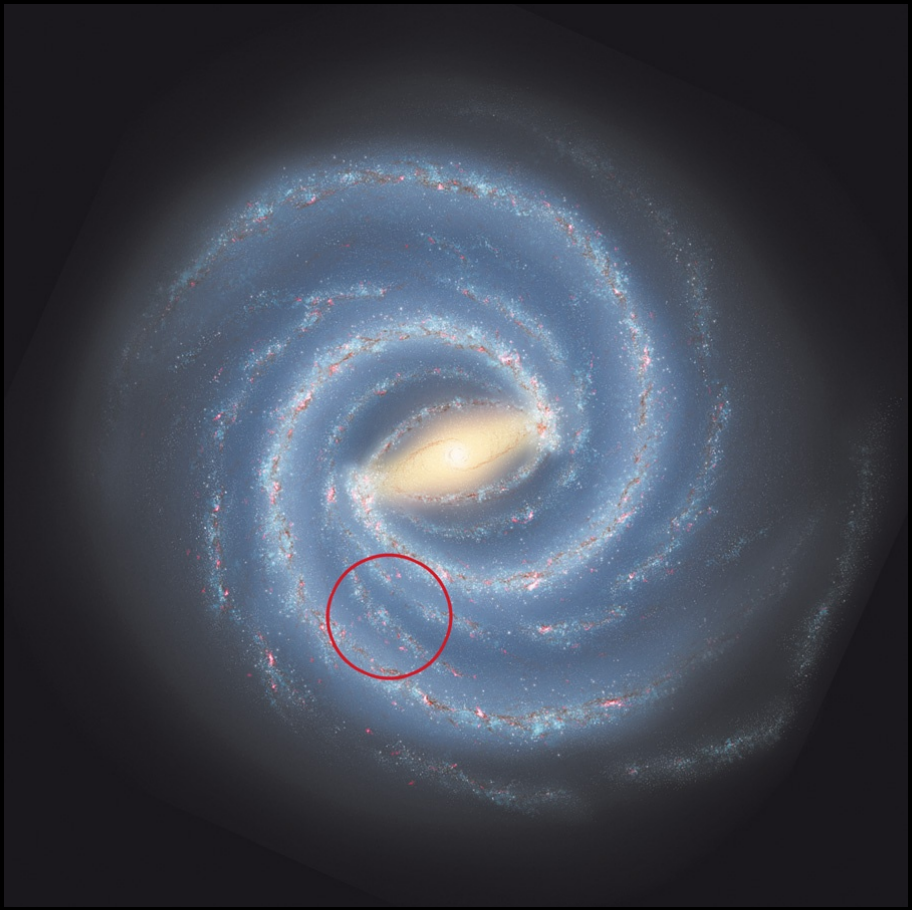
By observing galaxies, astronomers learn about the origin and fate of the universe

Big Picture of the Evolution of the Universe



This figure shows our current thinking about the evolution of star and galaxy formation in the early universe, as well as the present-day acceleration of the universe's expansion.

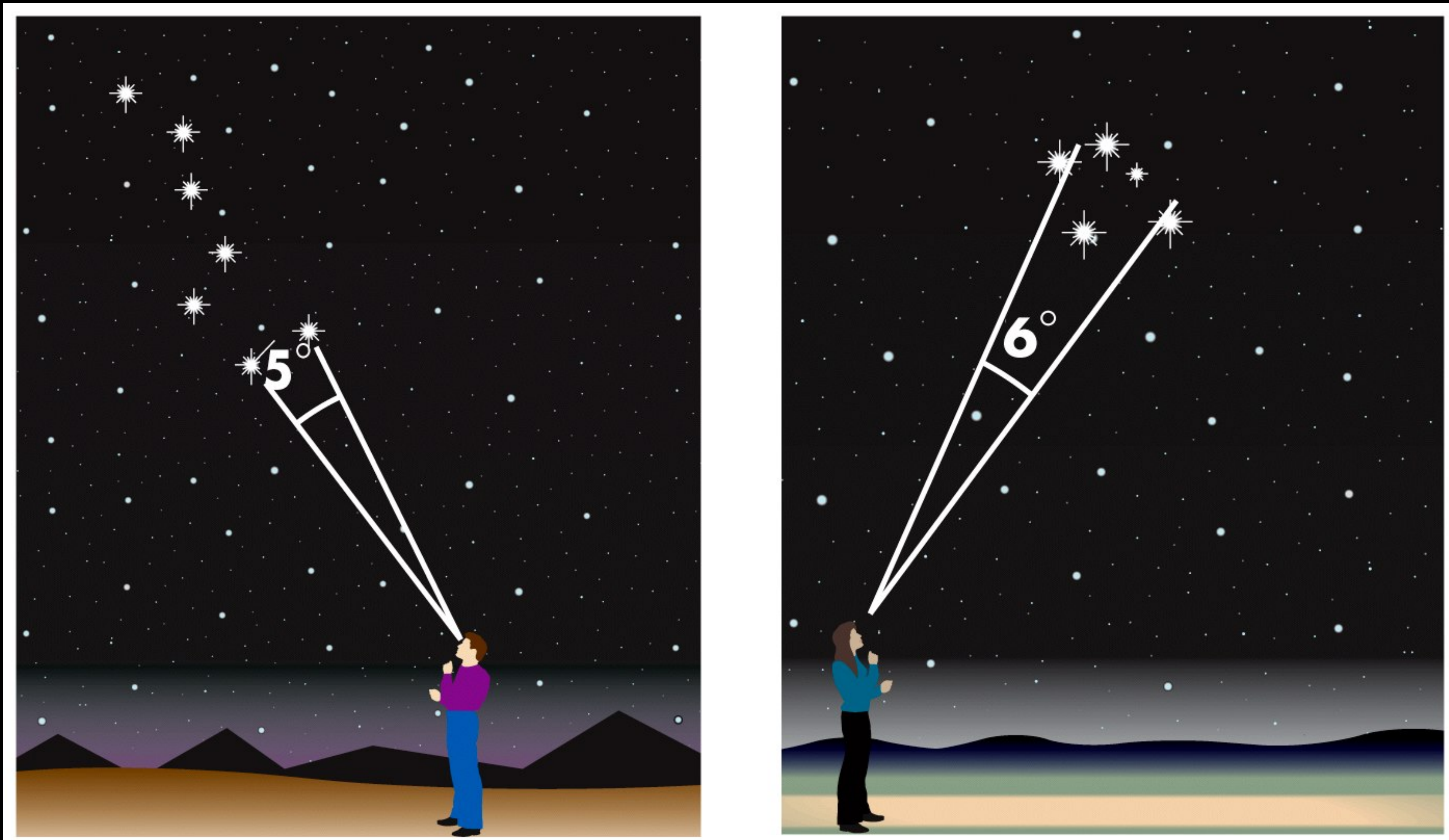
Region of the Search for Extraterrestrial Intelligence



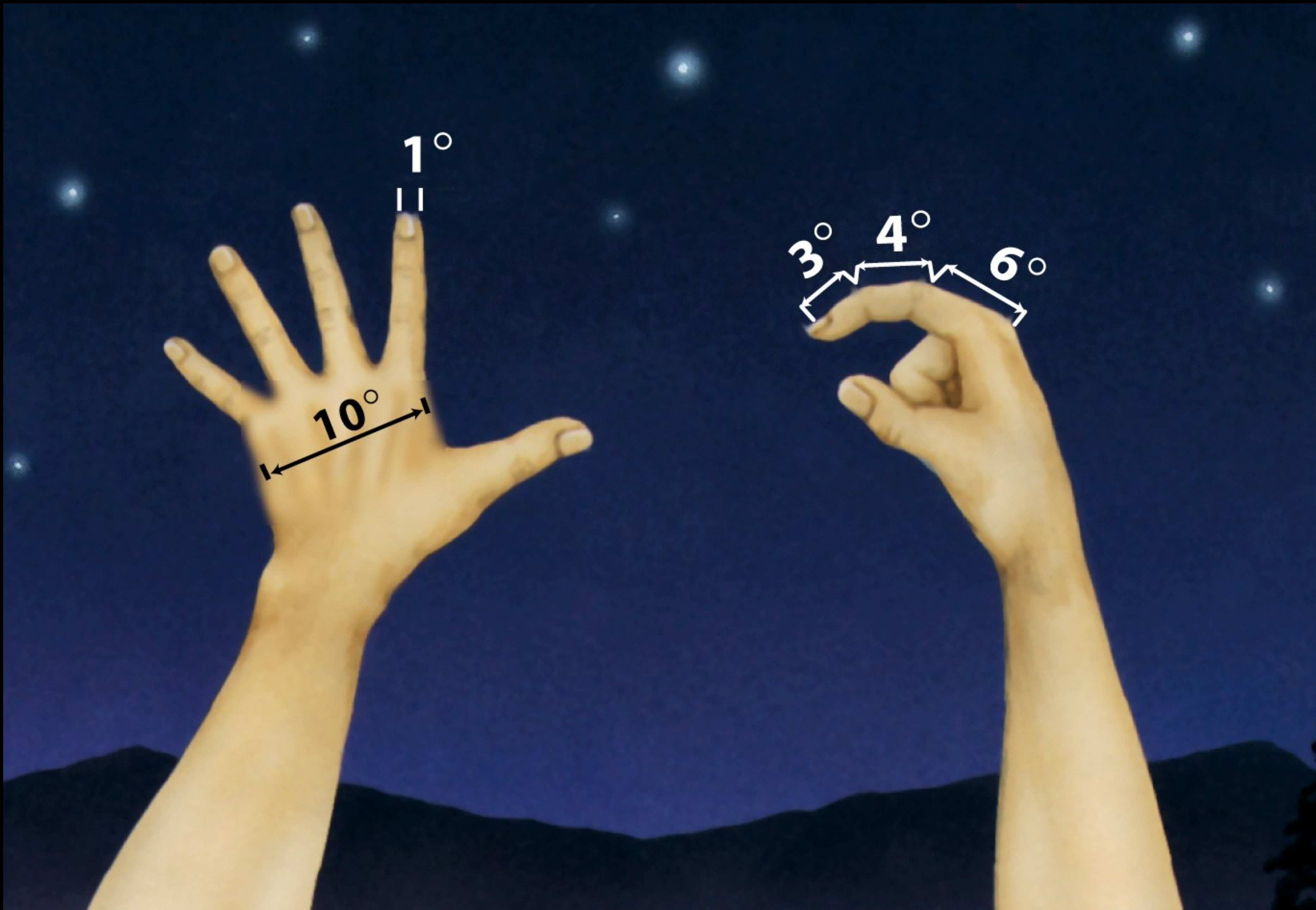
The red circle, centered on the solar system, shows the region of the Milky Way in which SETI searches can reasonably expect to detect radio emissions from alien civilizations. This reasoning assumes that the signals are similar in nature to the kinds of radio emissions we generate on Earth.

In this chapter you will discover…

- Essential angle, size and distance units
- how astronomers organize the night sky to help them locate objects in it.
- that Earth's spin on its axis causes day and night.
- how the tilt of Earth's axis of rotation and Earth's motion around the Sun combine to create the seasons.
- that the Moon's orbit around Earth creates the phases of the Moon.
- what causes both lunar and solar eclipses.
- the scales of the universe.



If you draw lines from your eye to each of two stars, the angle between these lines is the **angular distance** between these two stars



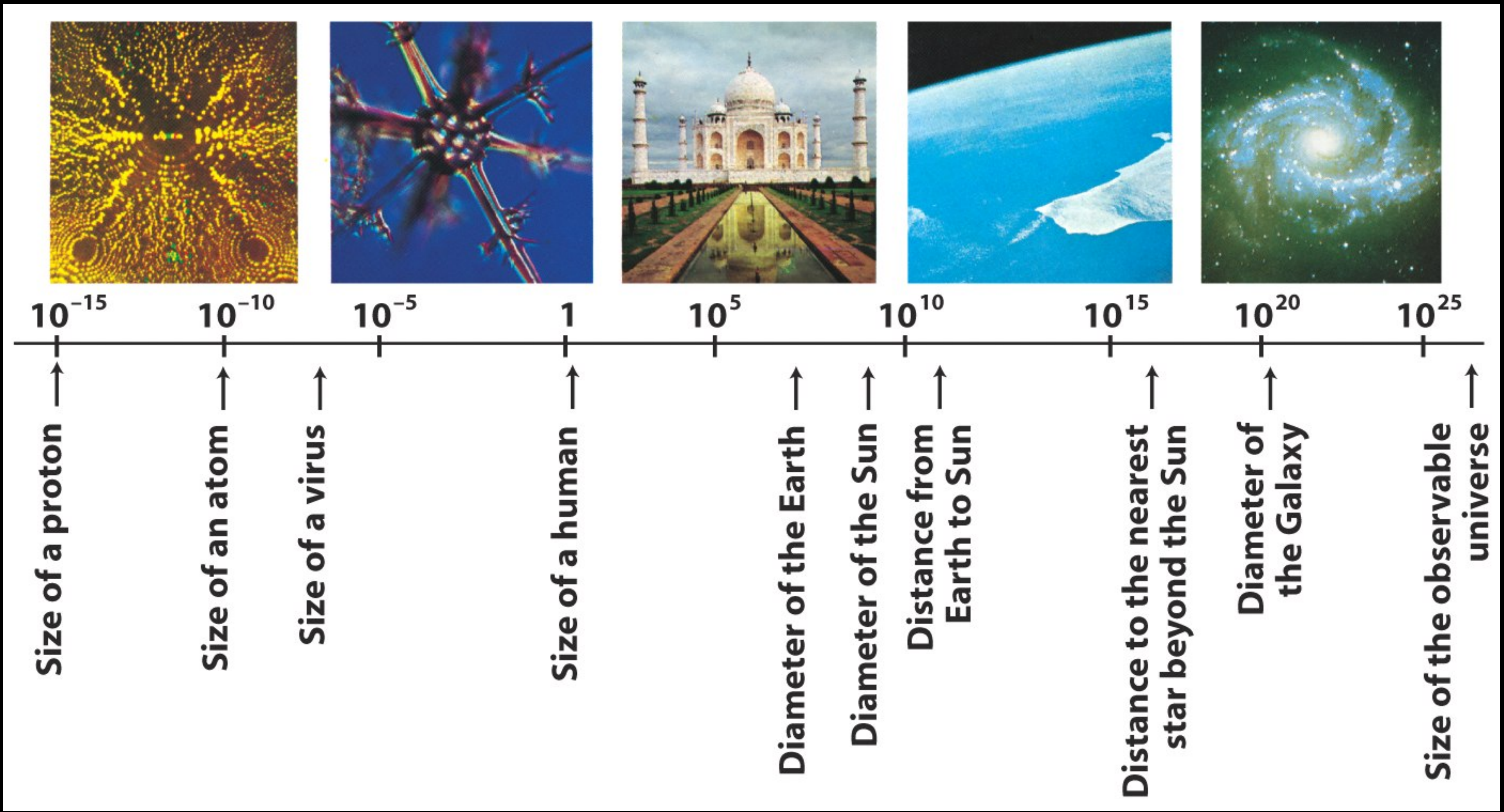
The adult human hand held at arm's length provides a means of estimating angles

Angular Measurements

$1^\circ = 60$ arcmin $= 60'$

$1' = 60$ arcsec $= 60''$

Powers-of-ten notation is a useful shorthand system for writing numbers

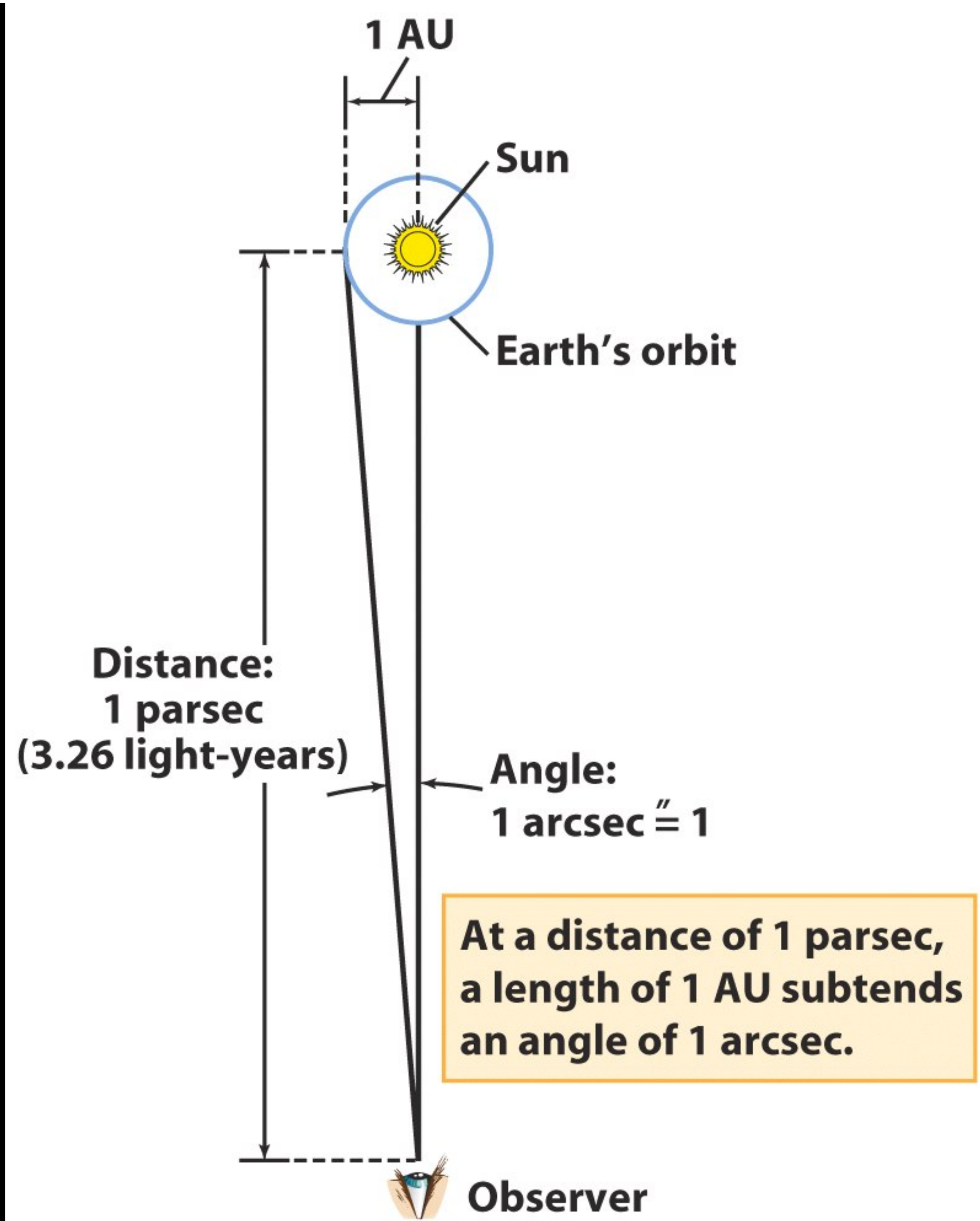


Common Prefixes

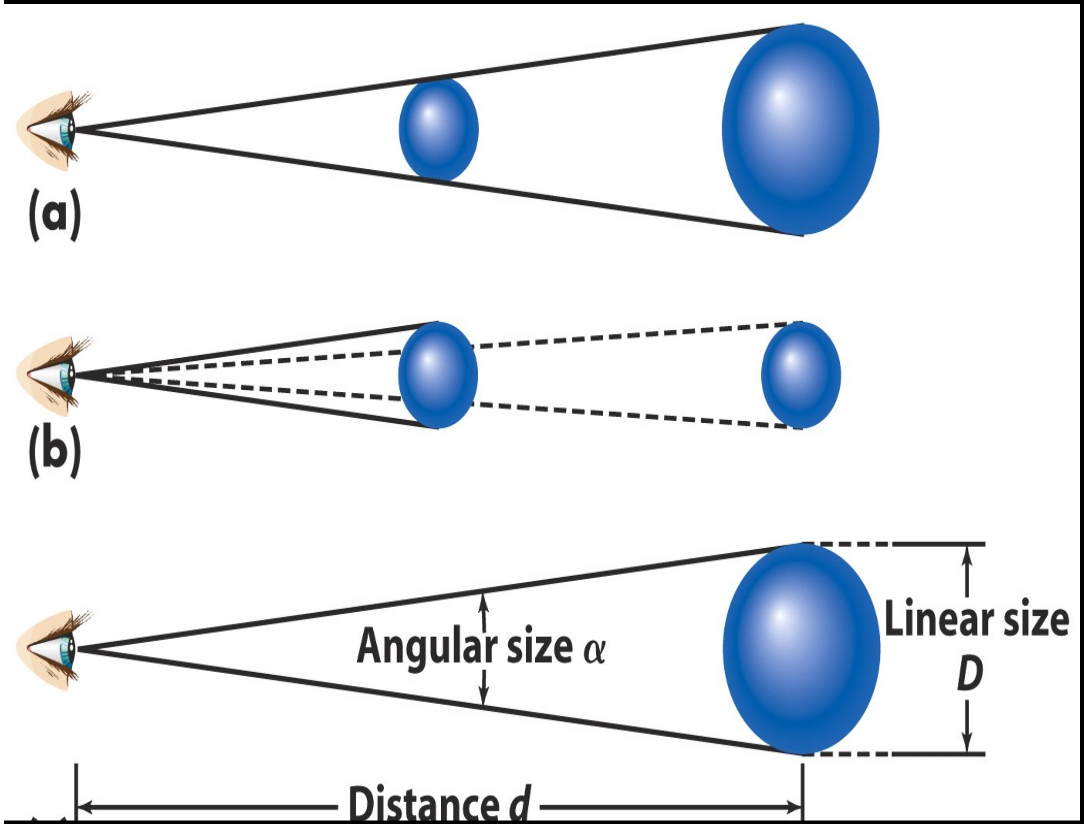
Factor	Name	Symbol
(billion) 10^9	Giga-	G
(million) 10^6	Mega-	M
(thousand) 10^3	kilo-	k
(hundredth) 10^{-2}	centi-	c
(thousandth) 10^{-3}	milli-	m
(millionth) 10^{-6}	micro-	μ
(billionth) 10^{-9}	nano-	n

Astronomical distances are often measured in astronomical units, parsecs, or light-years

- **Astronomical Unit (AU)**
  - One AU is the average distance between Earth and the Sun
  - 1.496 X 10^8 km or 92.96 million miles
- **Light Year (ly)**
  - One ly is the distance light can travel in one year at a speed of about 3 x 10^5 km/s or 186,000 miles/s
  - 9.46 X 10^{12} km or 63,240 AU
- **Parsec (pc)**
  - the distance at which 1 AU subtends an angle of 1 arcsec or the distance from which Earth would appear to be one arcsecond from the Sun
  - 1 pc = 3.09 × 10^{13} km = 3.26 ly


1 AU
Sun
Earth's orbit
Distance:
1 parsec
(3.26 light-years)
Angle:
1 arcsec = 1″
At a distance of 1 parsec, a length of 1 AU subtends an angle of 1 arcsec.
Observer

The Small Angle Formula



tan α/2 = D/2d, α in radians

α = D/d, for α « 1

D = αd

1 rad has 360/2π deg

1 deg has 60•60 arcsec

----

1 rad has 206265 arcsec

1 arcsec = 1/206265 rad

D = linear size of object

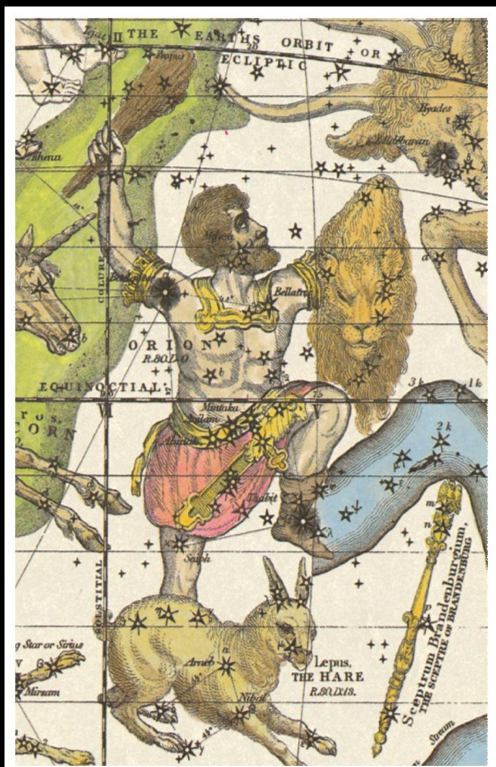
α = angular size of object (in arcsec)

d = distance to the object

$$D = \frac{\alpha d}{206265}$$

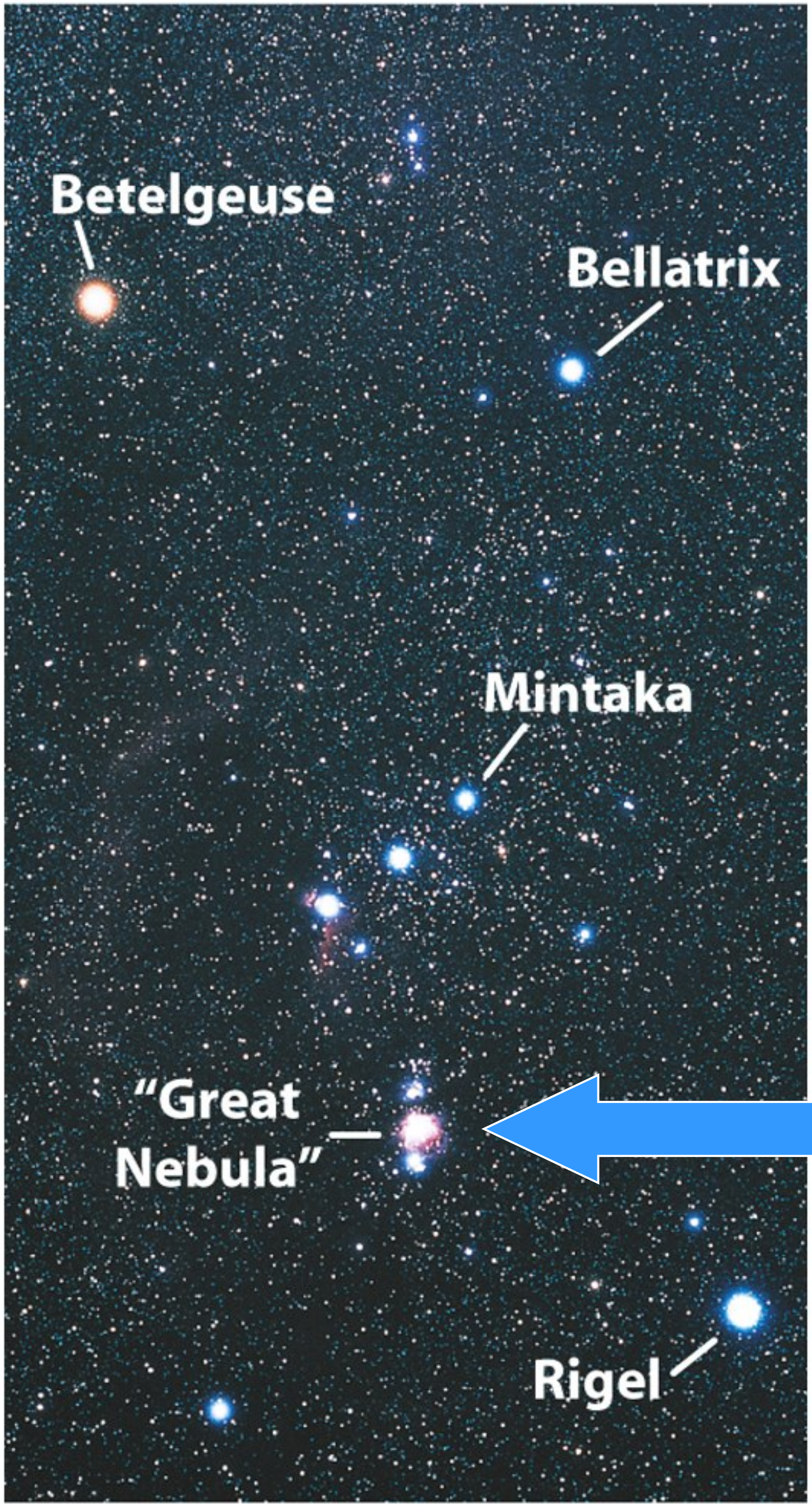
- Who volunteers to be the class rep?

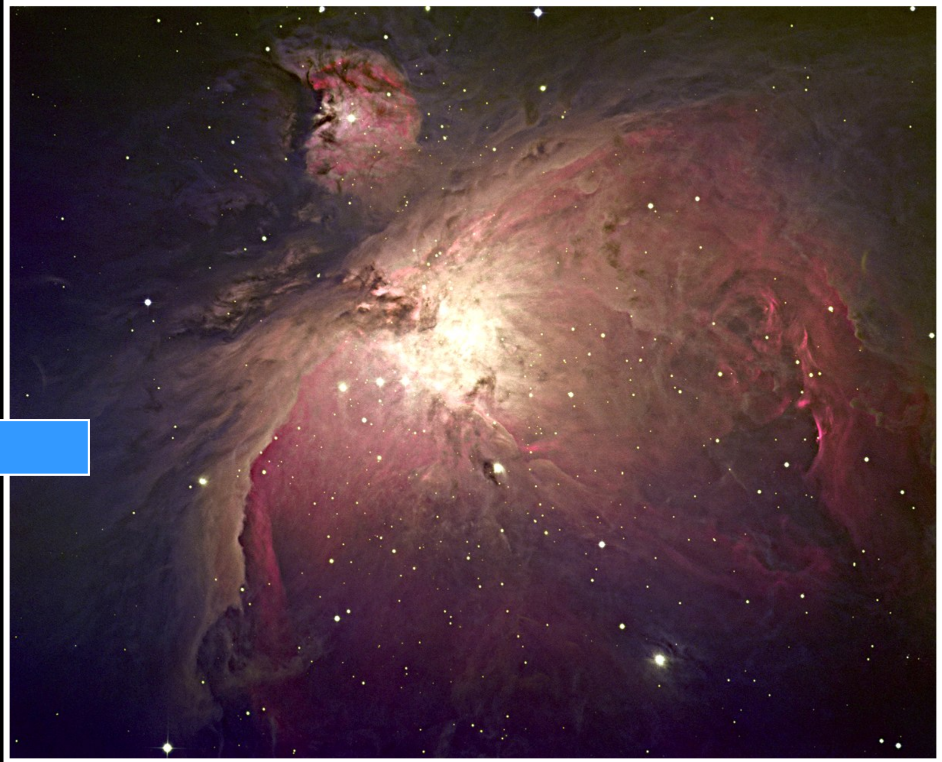
Constellations



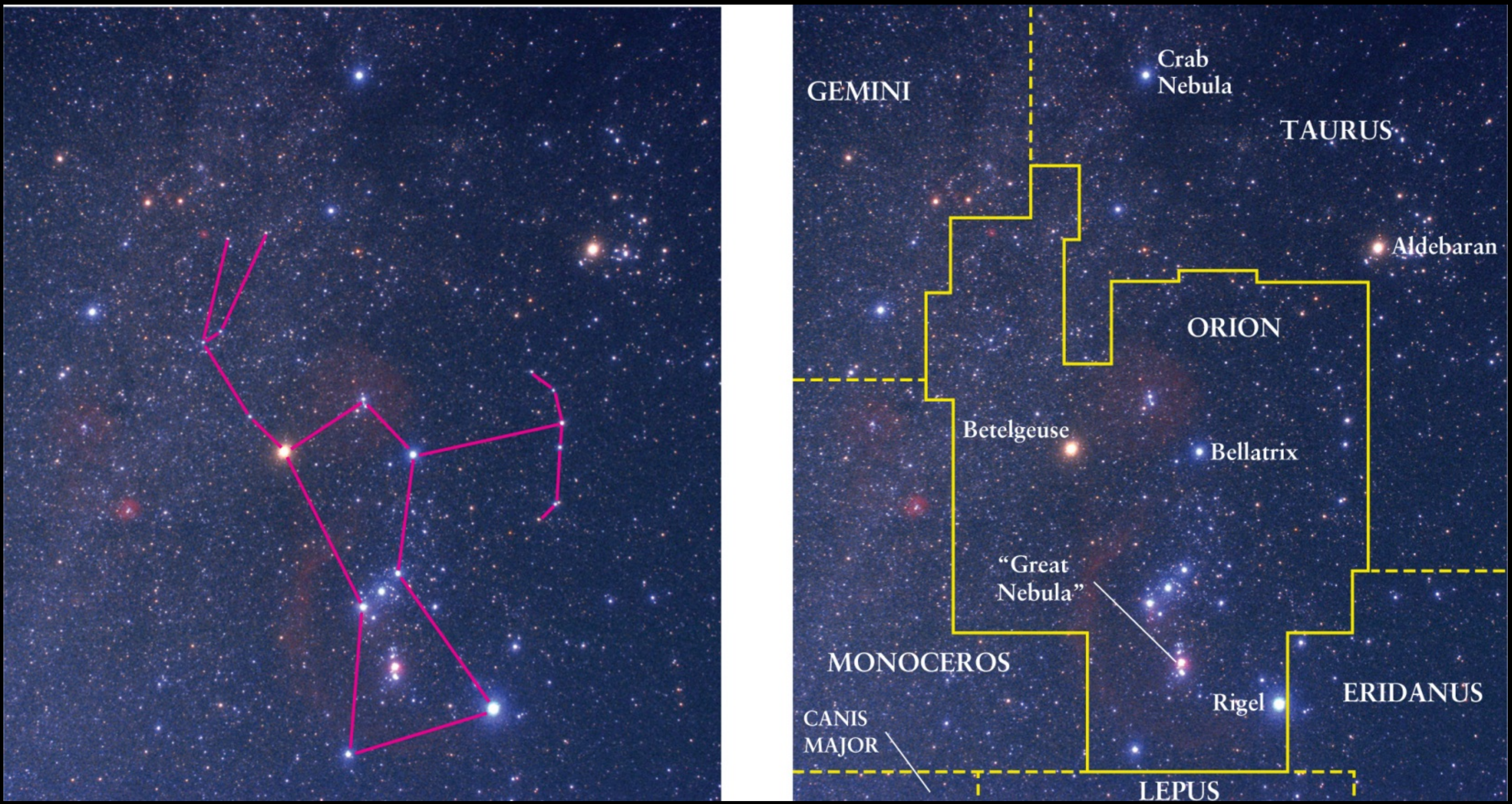
- Ancient peoples looked at the stars and imagined groupings made pictures in the sky
- We still refer to many of these groupings
- Astronomers call them **constellations** (from the Latin for “group of stars”)

Orion

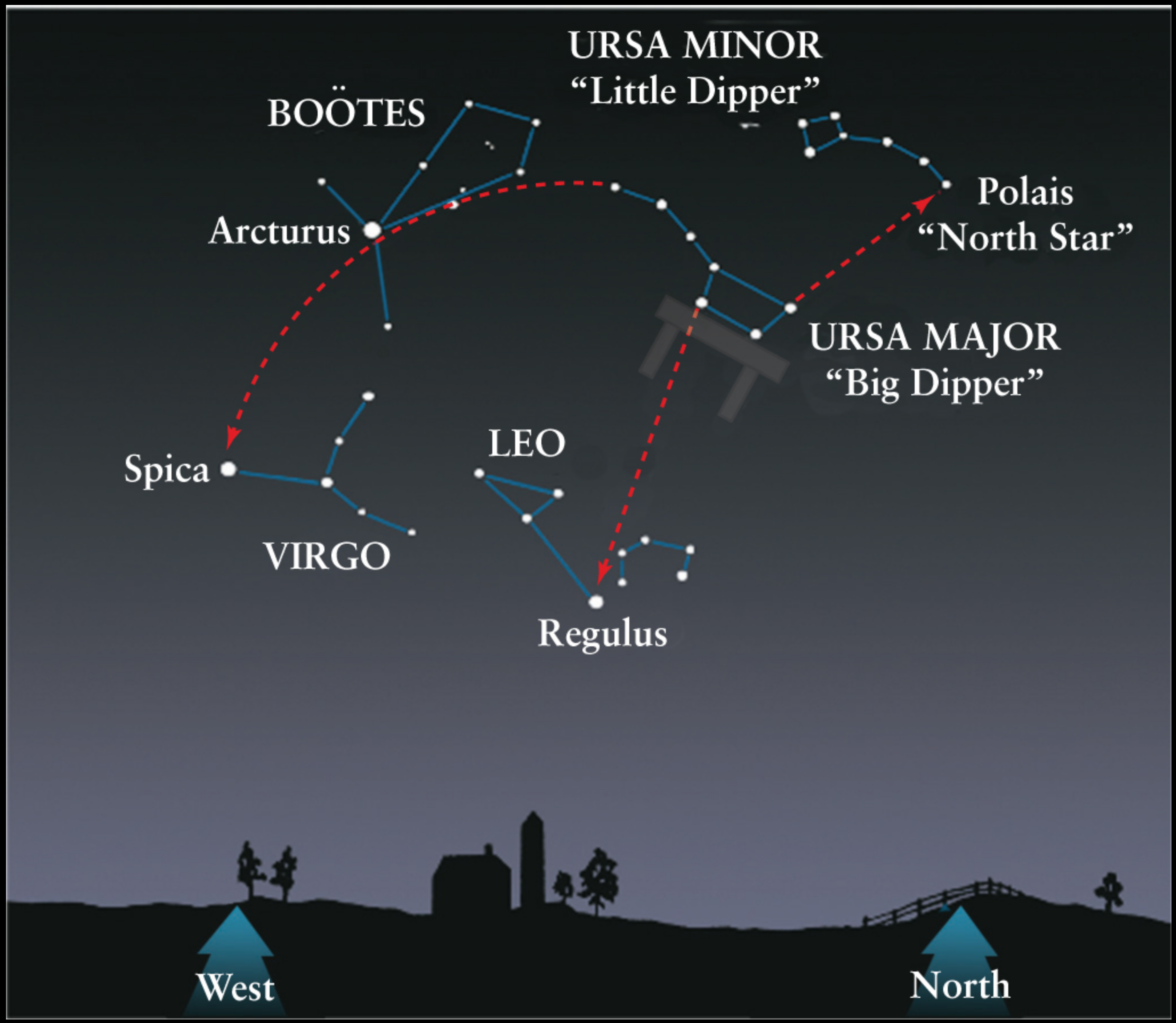




In order to more easily locate objects in the sky, we divide the sky into 88 regions named after *constellations*.

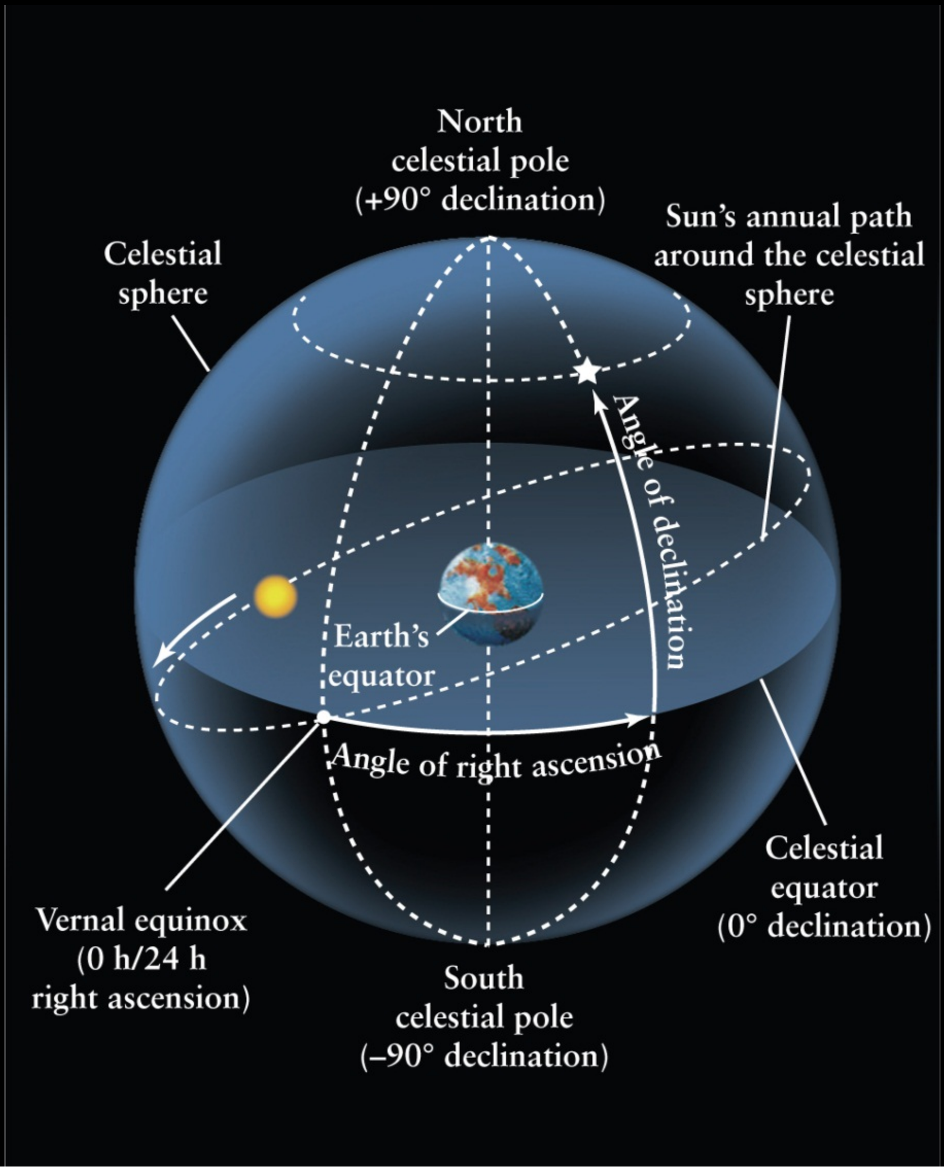


Common Guides to Finding Constellations and Stars



Using the "Big Dipper" as a guide

Astronomers describe the universe as an imaginary sphere surrounding the Earth on which all objects in the sky can be located, called the *CELESTIAL SPHERE*.

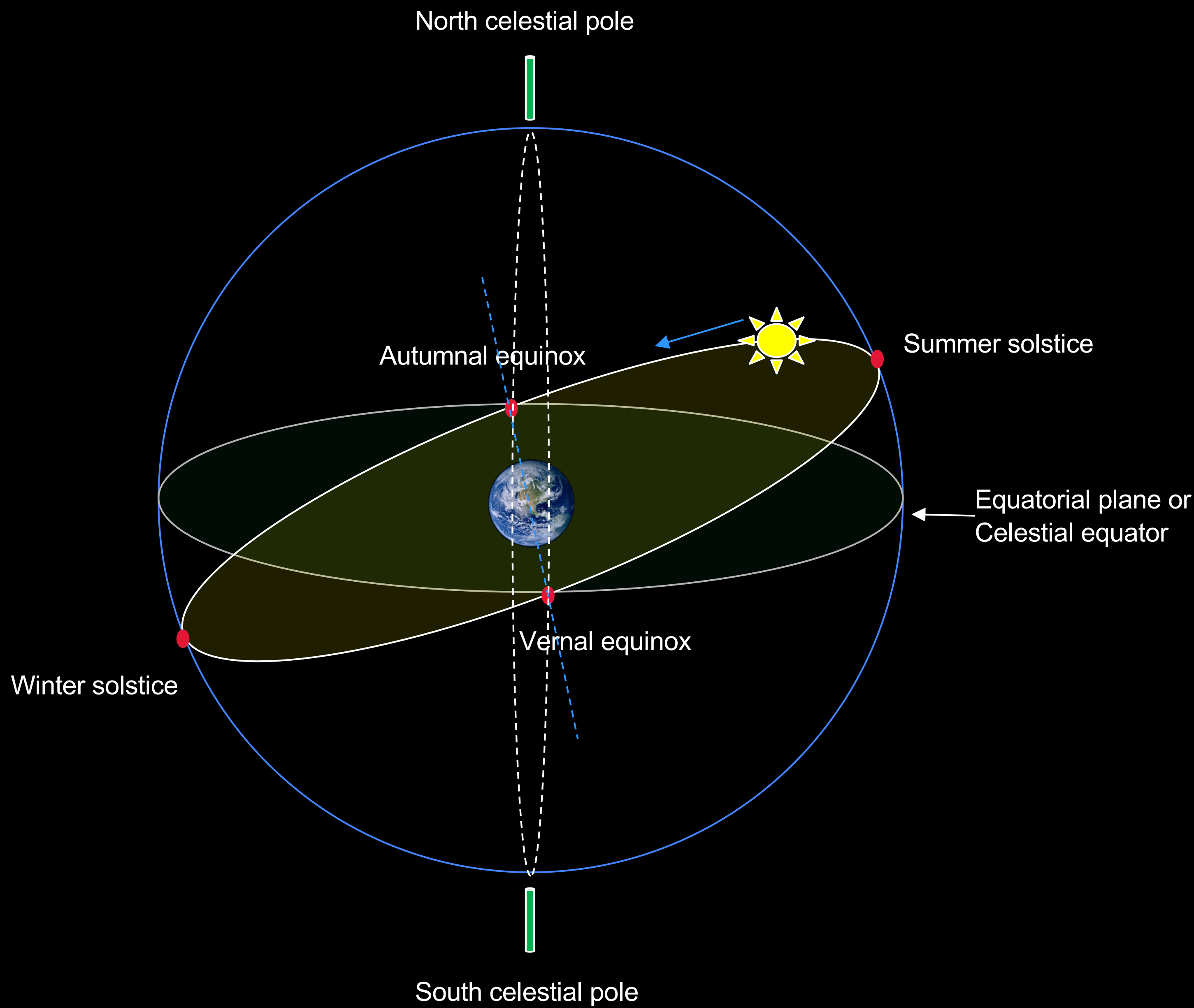


- **Celestial equator** divides the sky into northern and southern hemispheres
- **Celestial poles** are where the Earth's axis of rotation would intersect the celestial sphere
- Polaris is less than 1° away from the north celestial pole, which is why it is called the **North Star** or the Pole Star.
- Point in the sky directly overhead an observer anywhere on Earth is called observer's **zenith**.

Cyclic motions of the Sun and stars in our sky are due to motions of Earth.

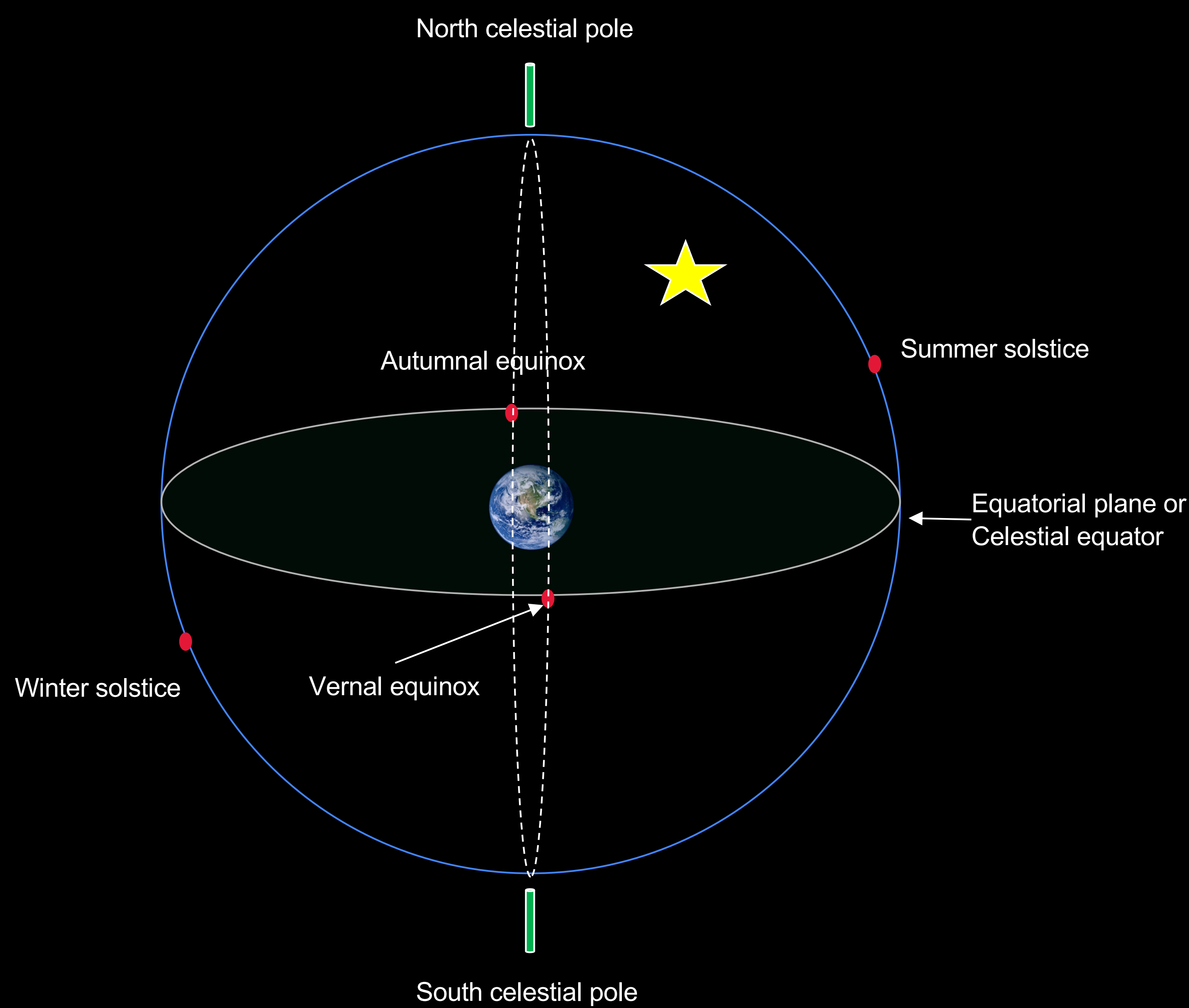
1. ROTATION = the spin of Earth on its axis. It takes one day for Earth to complete one rotation.
2. REVOLUTION = the movement of Earth in orbit around the sun. It takes one year for Earth to complete one revolution.
3. PRECESSION = the slow conical (top-like) motion of Earth's axis of rotation. It takes 26,000 years for Earth to complete one cycle of precession.

Celestial sphere



Geocentric equatorial coordinate system

what are the coordinates of the star?

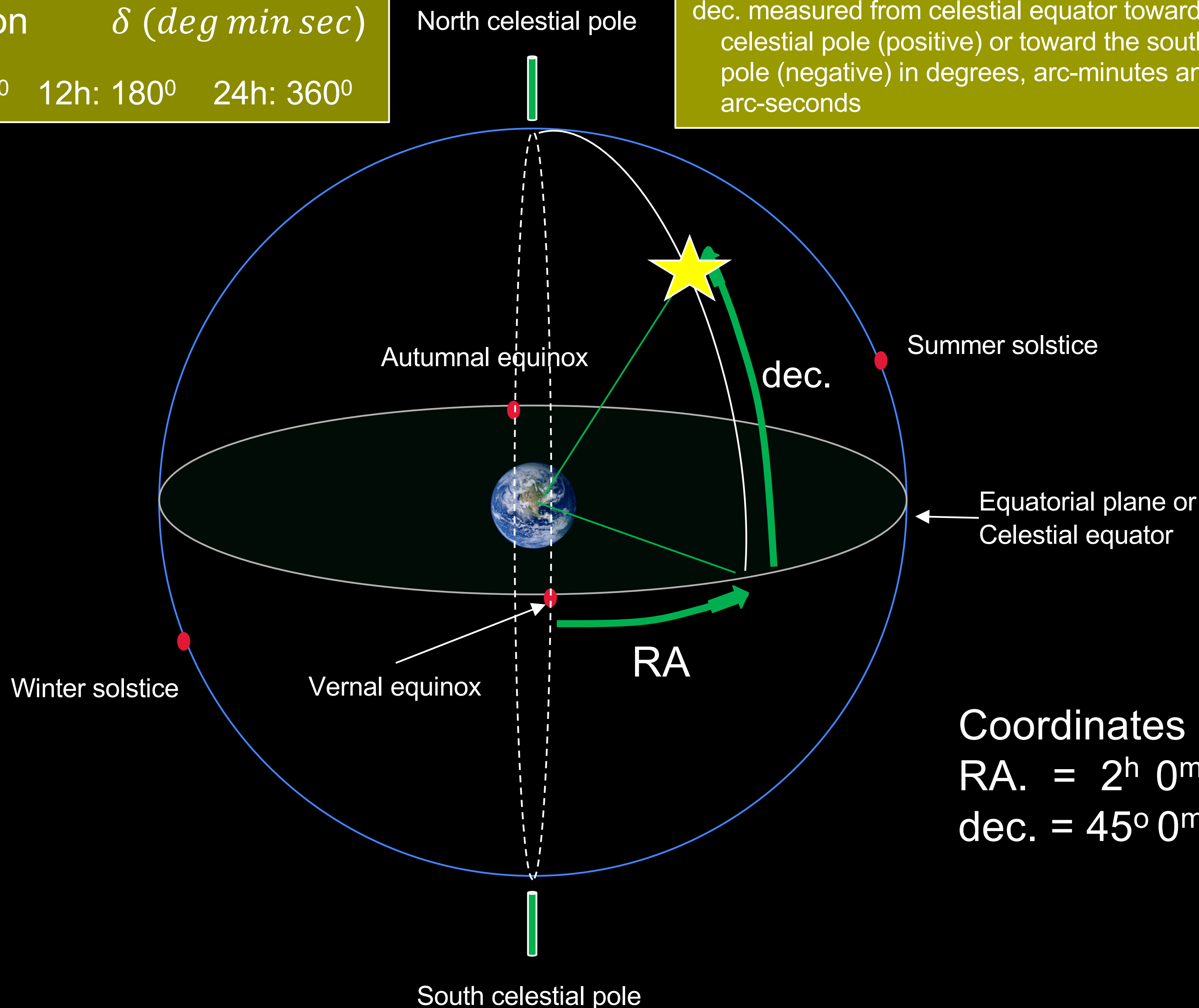


Geocentric equatorial coordinate system

RA: right ascension $\alpha\ (hh\ mm\ ss.s)$
dec.: declination $\delta\ (deg\ min\ sec)$

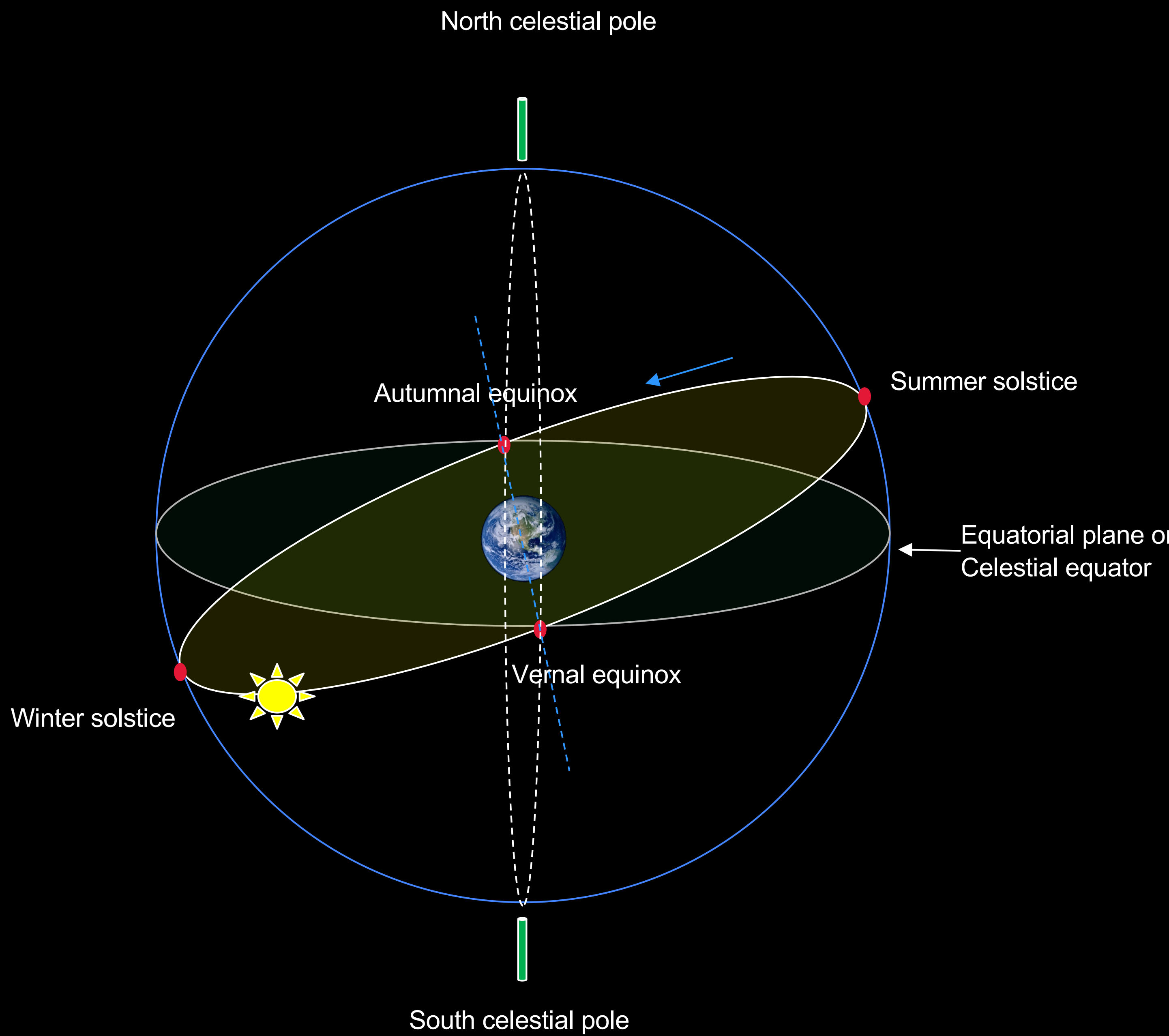
1h : 15^0 6h: 90^0 12h: 180^0 24h: 360^0

RA: measured eastward along the celestial equator in hours , minute, seconds
dec. measured from celestial equator toward the north celestial pole (positive) or toward the south celestial pole (negative) in degrees, arc-minutes and arc-seconds

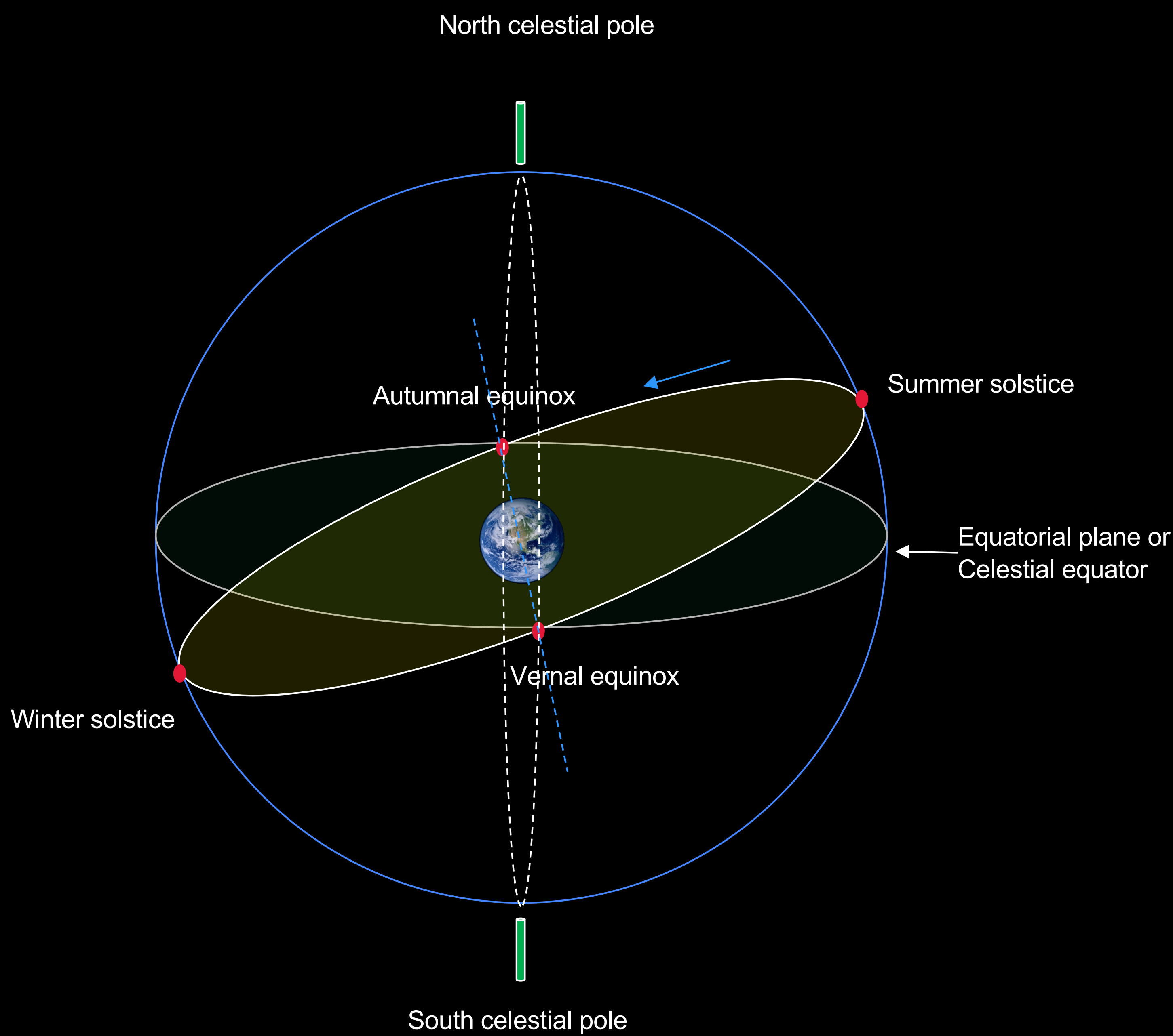


Coordinates of star:
RA. = $2^h\ 0^m\ 0^s.000$
dec. = $45^o\ 0^m\ 0^s.000$

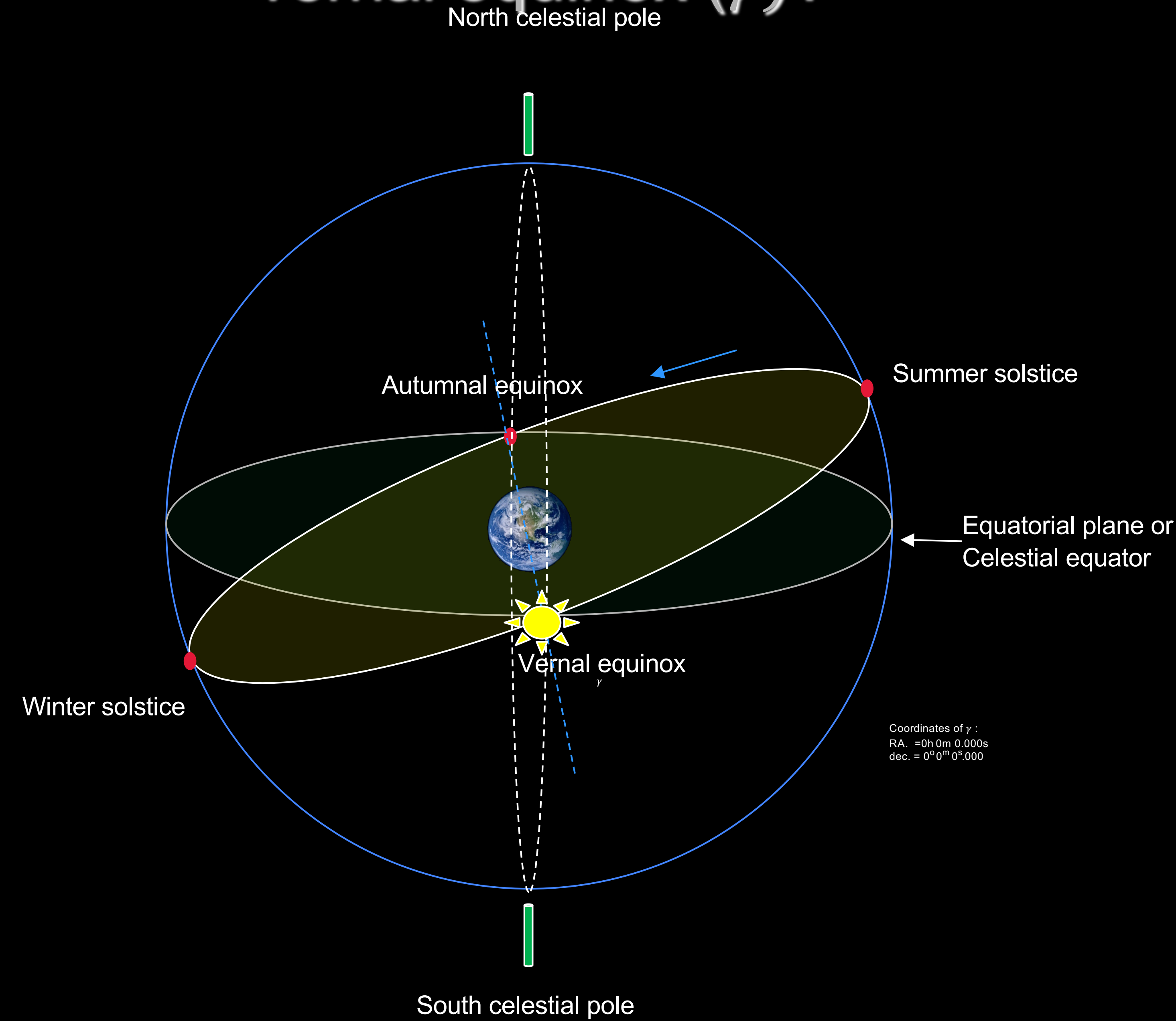
What are RA and dec. of Sun in sketch?



Where is the Sun today?

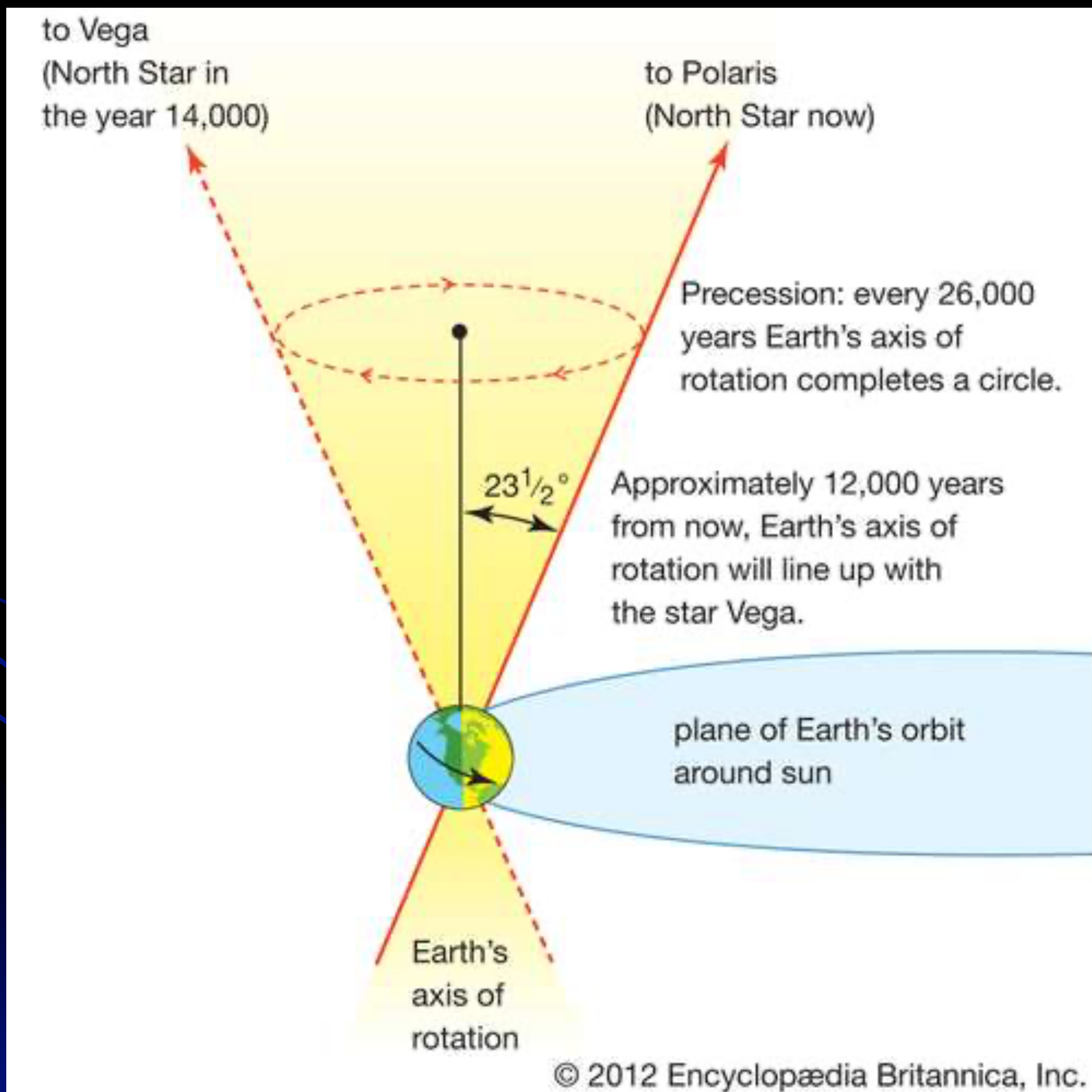


What are the RA and dec. coordinates of the vernal equinox (γ)?



Precession of the equinoxes

motion of the equinoxes along the ecliptic (plane of the orbit of Earth)



Circumpolar Star Trails

The stars near the poles of the celestial sphere (shown here) move in trails that circle the pole and never set. They are called *circumpolar*.

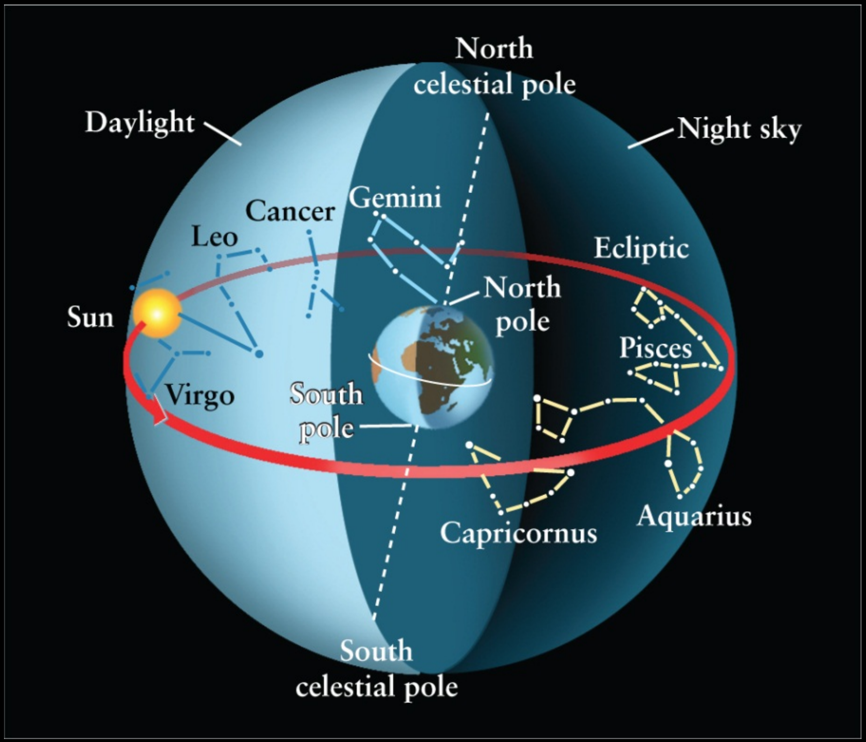
Motion of Stars at the Poles

Rising and Setting of Stars at the Equator

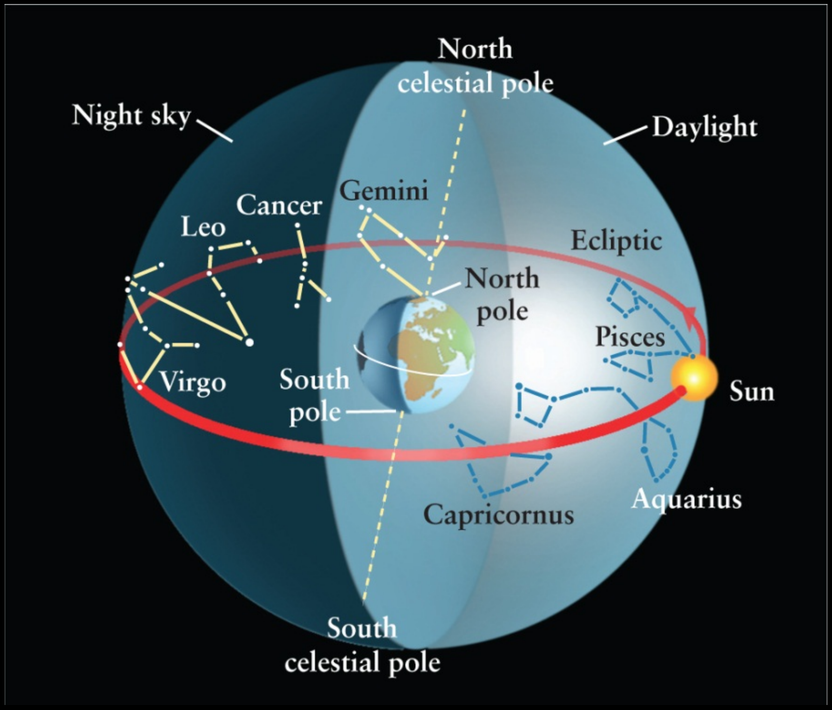
Rising and Setting of Stars at Middle Northern Latitudes

What is the latitude of the observatory?

Different constellations are visible at different times of the year

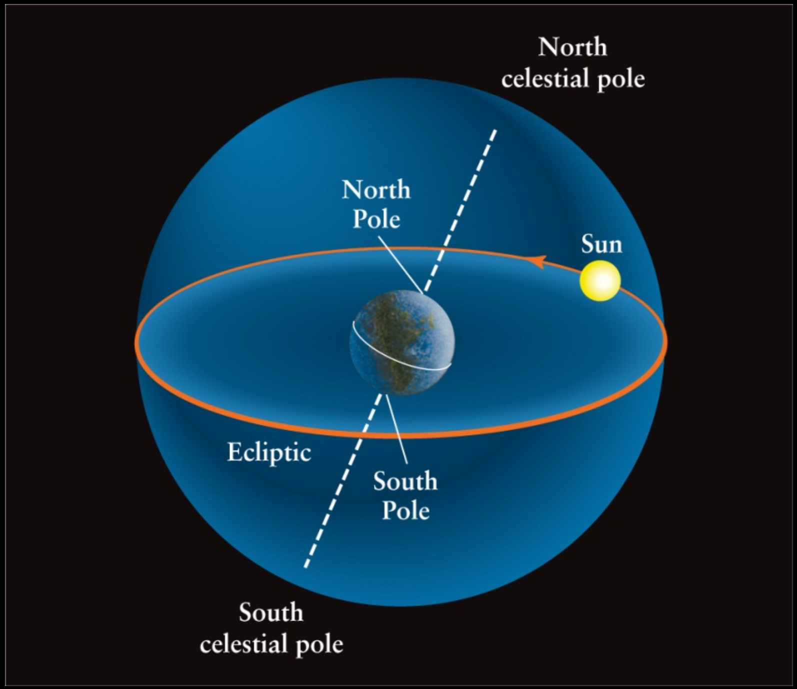


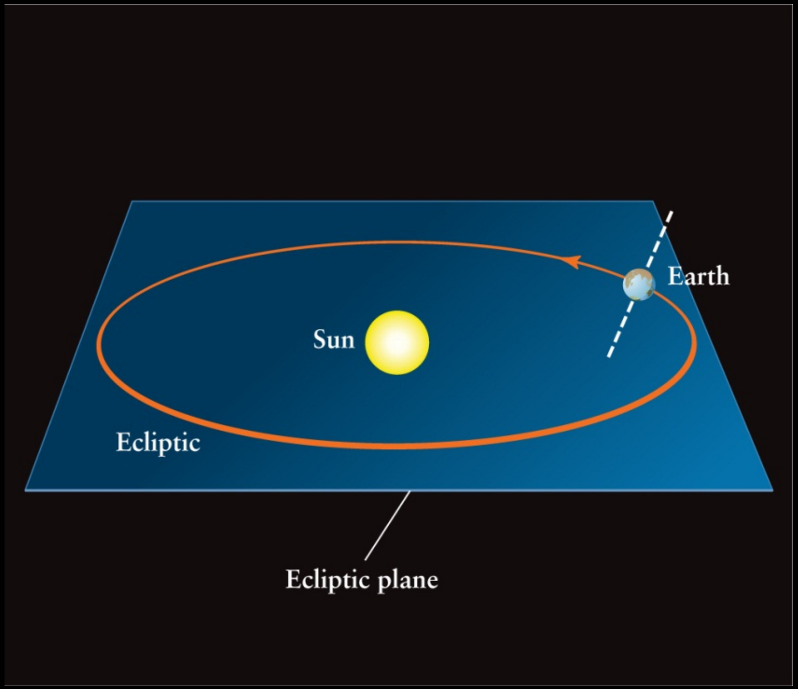
SEPTEMBER



MARCH

The sun follows a path at the celestial sphere

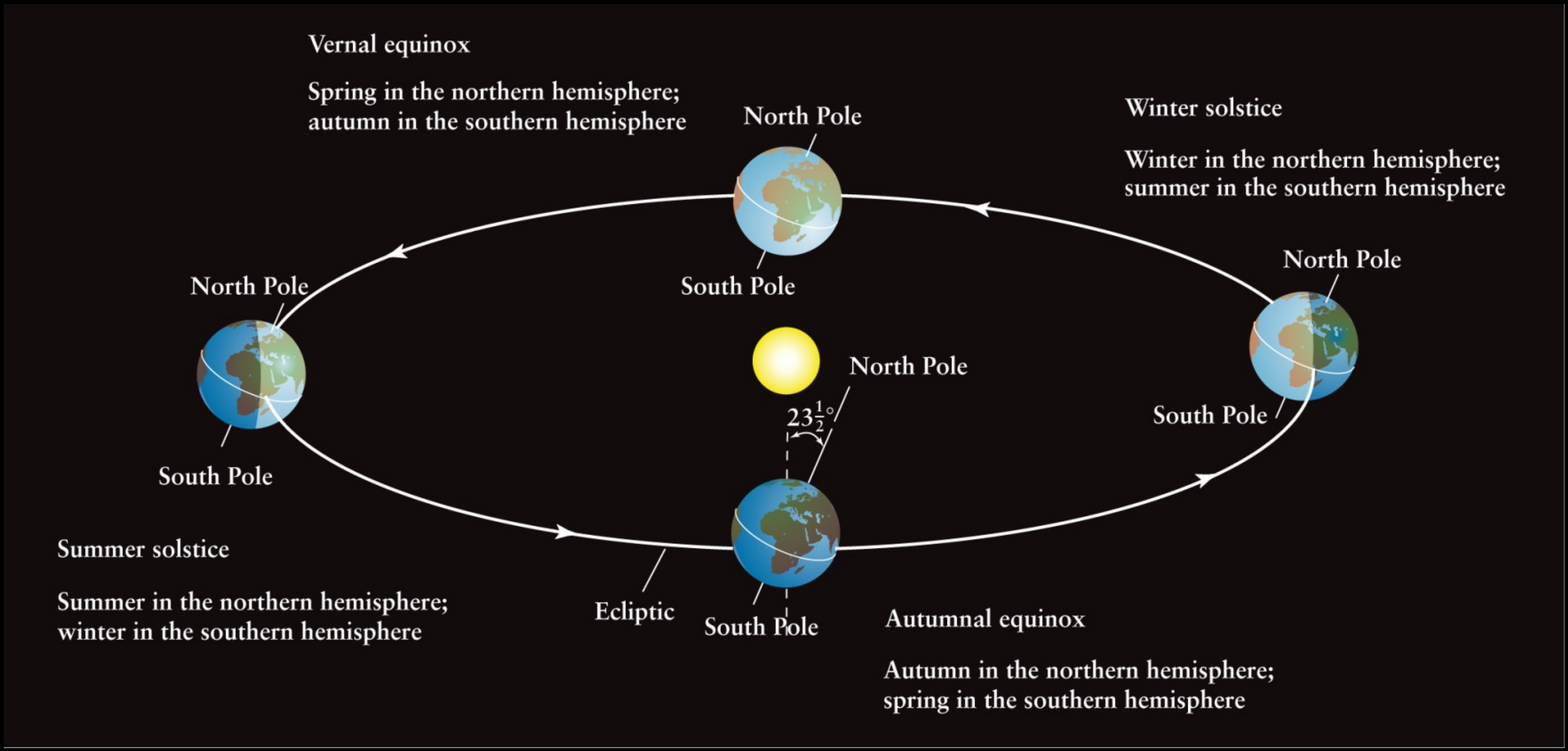




From our perspective, the Sun appears to move through the stars along a special path called the *ecliptic*.

From an outside view, we see Earth revolve around the Sun. We define the plane of Earth's orbit as the ecliptic plane.

Seasons

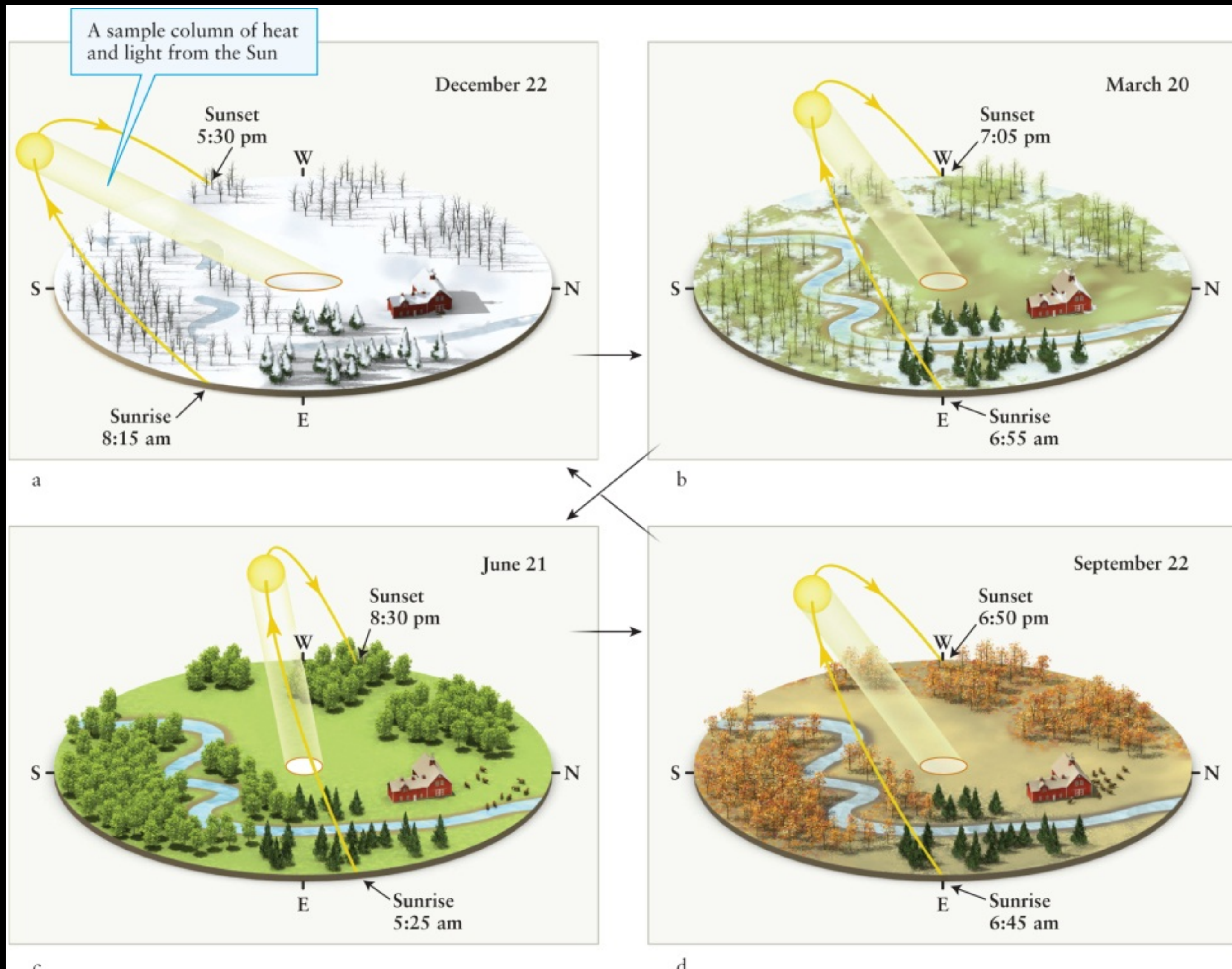


Vernal equinox
Spring in the northern hemisphere;
autumn in the southern hemisphere
North Pole
South Pole
Winter solstice
Winter in the northern hemisphere;
summer in the southern hemisphere
North Pole
South Pole
North Pole
South Pole
North Pole
$23\frac{1}{2}°$
Summer solstice
Summer in the northern hemisphere;
winter in the southern hemisphere
Ecliptic
South Pole
Autumnal equinox
Autumn in the northern hemisphere;
spring in the southern hemisphere

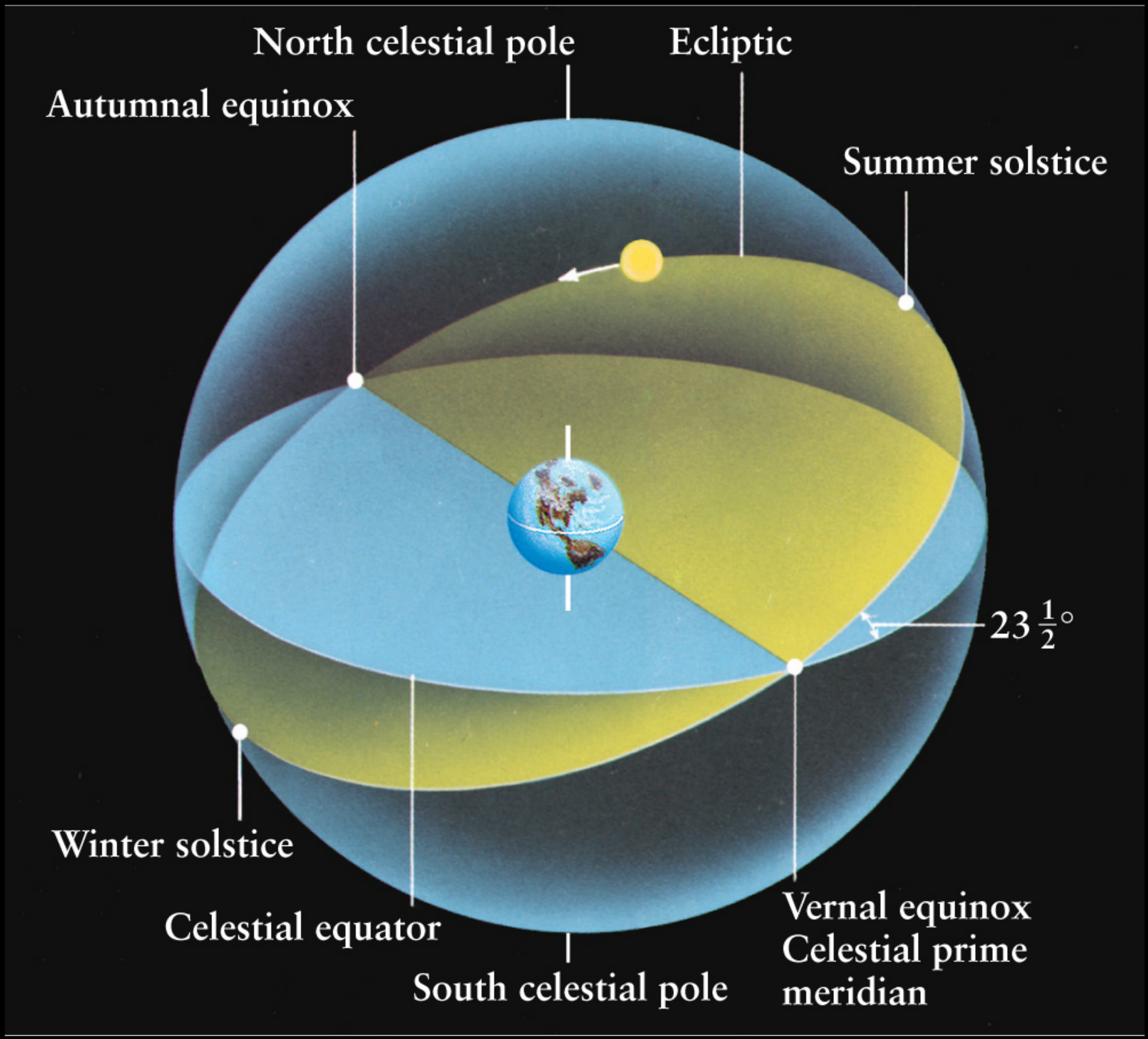
The Midnight Sun

This time-lapse photograph was taken on July 19, 1985, at 69°
north latitude in northeastern Alaska. At that latitude,
the Sun is above the horizon continuously from mid-May
until the end of July.

The Sun's Daily Path and the Energy It Deposits Here depending on the seasons

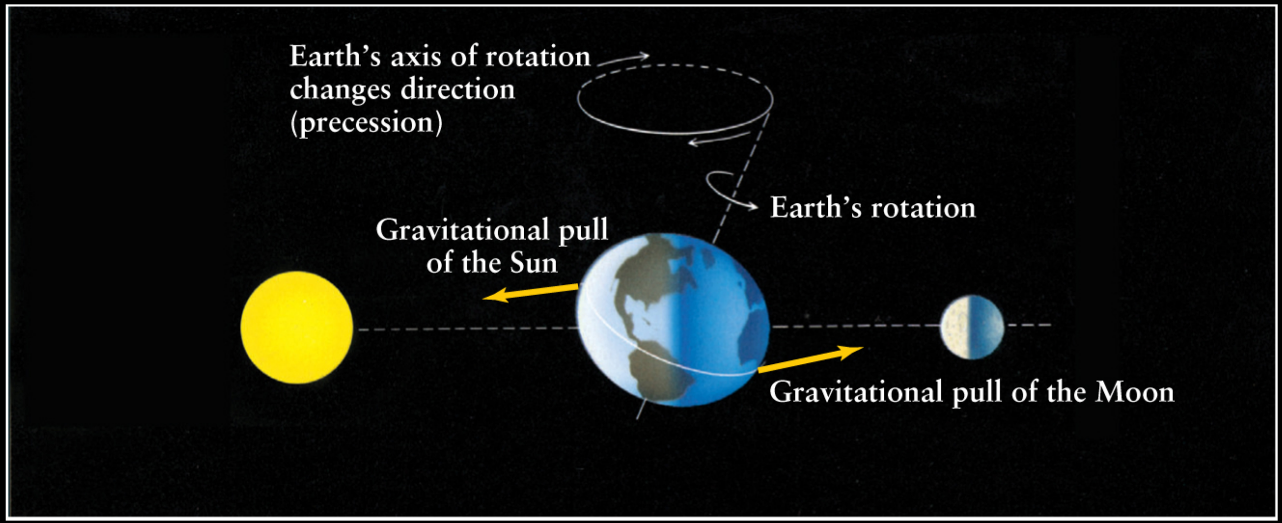


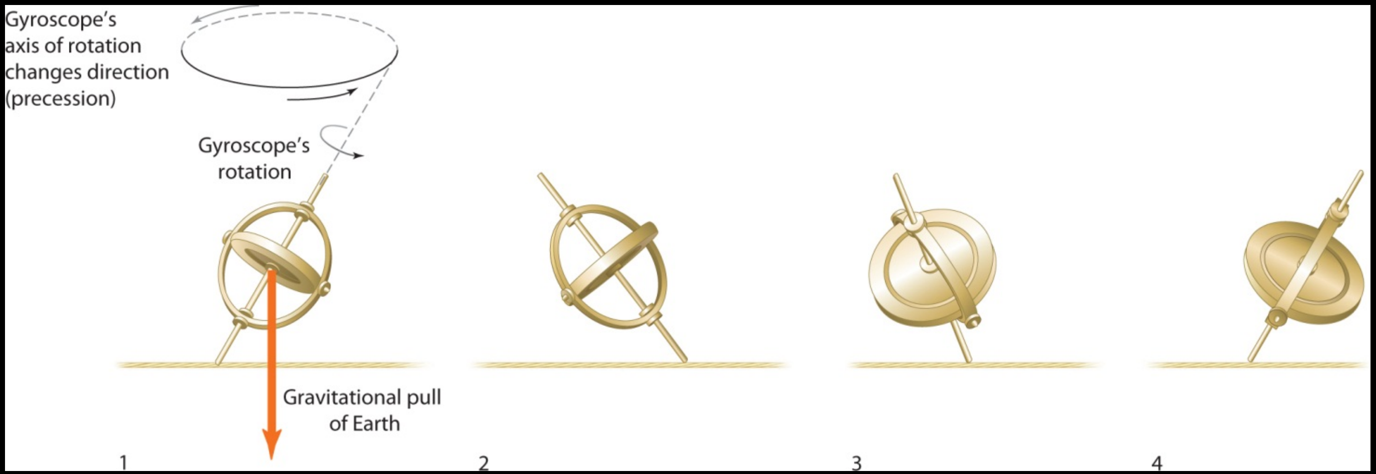
The seasons we experience are due to the Sun's motion across the celestial sphere.



The point of the Sun's path farthest north on the celestial sphere is called the summer solstice (JUN 21), whereas the point of the ecliptic farthest south is called the winter solstice (DEC 21).

The two points on the ecliptic where the Sun crosses the celestial equator are called equinoxes. During the vernal equinox (MAR 21), the Sun is moving north, while during the autumnal equinox (SEPT 21), the Sun is moving south.





Gravitational forces of the Sun and the Moon pulling on Earth as it rotates cause Earth to undergo a top-like motion called precession. Over a period of 26,000 years, Earth's rotation axis slowly moves in a circular motion.

This precession causes the position of the North Celestial Pole to slowly change over time. Today, the North Celestial Pole is near the star Polaris, which we call the “North Star.” However, in 3000 BC, Thuban was close to the North Celestial Pole and in 14,000 AD, Vega will be in this location.

Precession also causes the vernal equinox to move along the celestial equator by 360^0 in 26,000 years. That means that the RA and dec changes slowly due to precession. In astronomy we therefore need to refer to a date for RA and dec. That date is the start of the year 2000. The coordinates are then in J2000.

Astronomical observations led to the development of the modern calendar

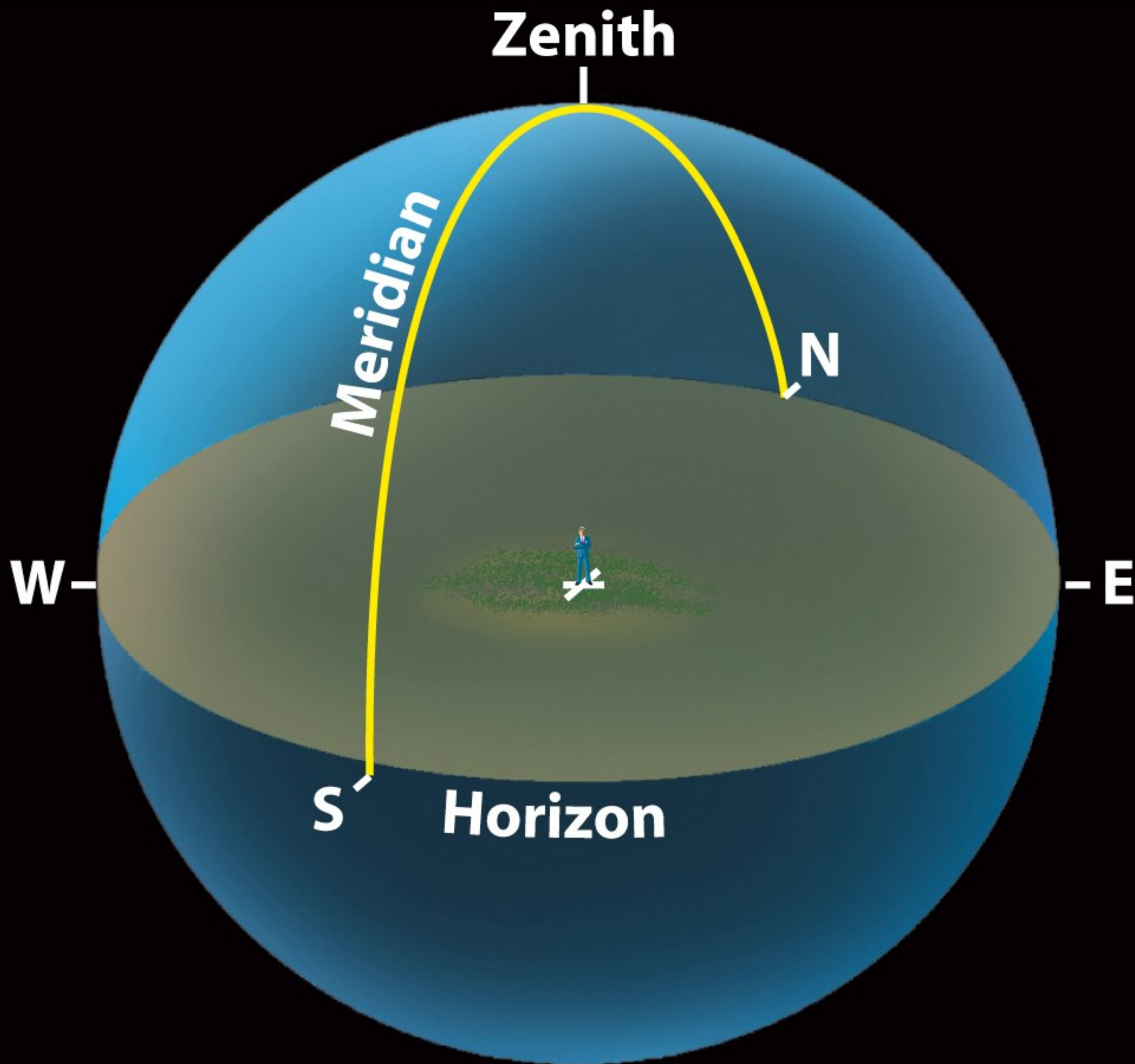
- Day is based on Earth's rotation
- Month is based on the lunar cycle
- Year is based on Earth's orbit

Different types of "day"

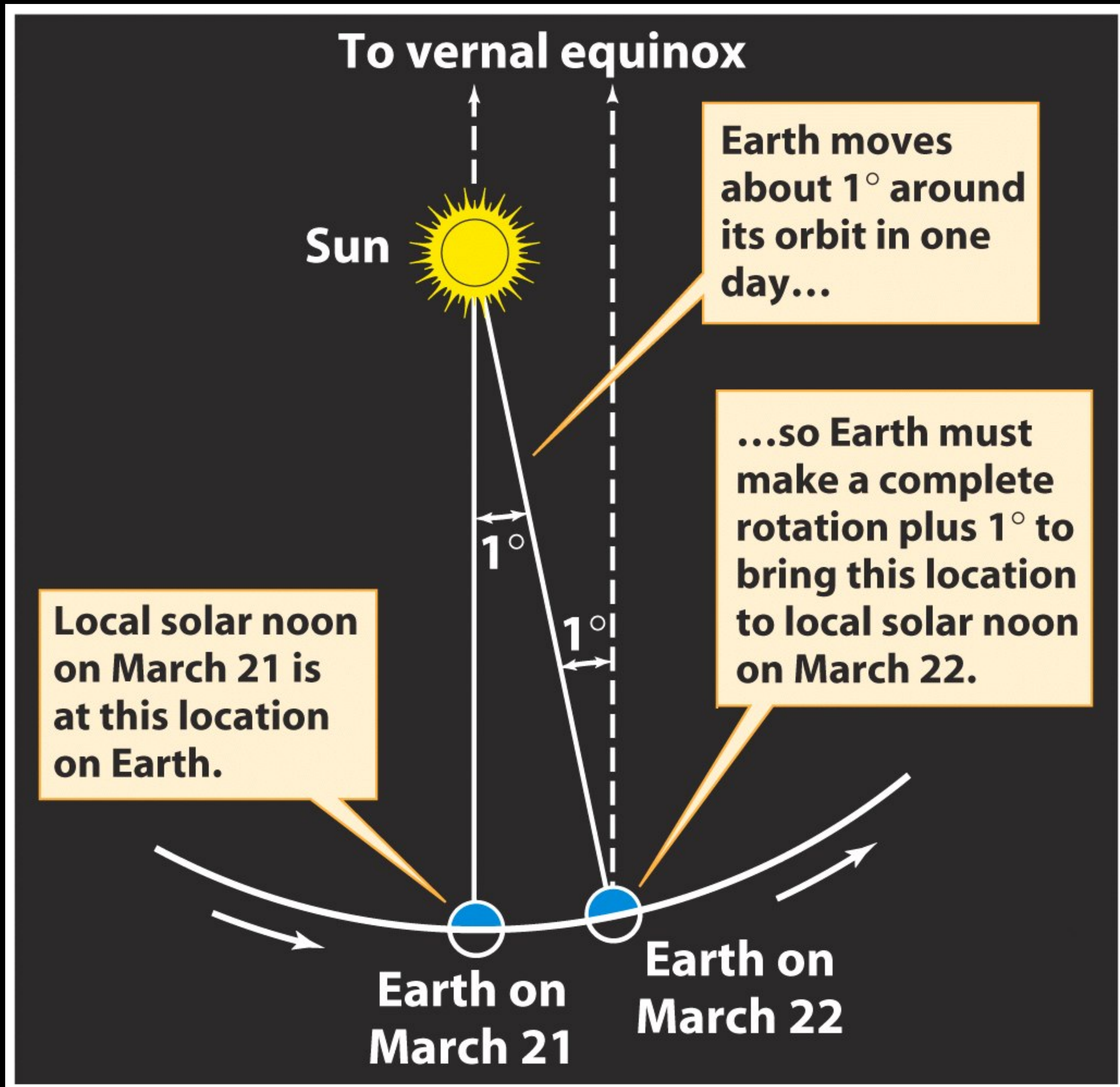
- Apparent solar day: time between two upper meridian transits of the sun.
- Mean solar day: time between two upper meridian transits of the mean sun. (~361deg rotation)
- Sidereal day: time between two upper meridian transits of the vernal equinox. (360 deg rotation)

1 mean solar day : 24 h

1 sidereal day : 23 h 56 m 4.091s



- *Local noon* is defined to be when the Sun crosses the **upper meridian,** which is the half of the meridian above the horizon



To vernal equinox
Sun
Earth moves about 1° around its orbit in one day…
…so Earth must make a complete rotation plus 1° to bring this location to local solar noon on March 22.
1°
1°
Local solar noon on March 21 is at this location on Earth.
Earth on March 21
Earth on March 22

Two more types of angle and time

- Hour angle (HA) of a celestial object is the angle measured from the meridian on which the object is situated to the (observer's) local meridian. HA is negative if object is east of observer, positive if it is west of observer.
- Local Sidereal Time (LST) is the right ascension of an observer's local meridian.

LST = RA (object) + HA (object)

HA(object) indicates how much sidereal time has passed since the object was on the local meridian

Different types of "year"

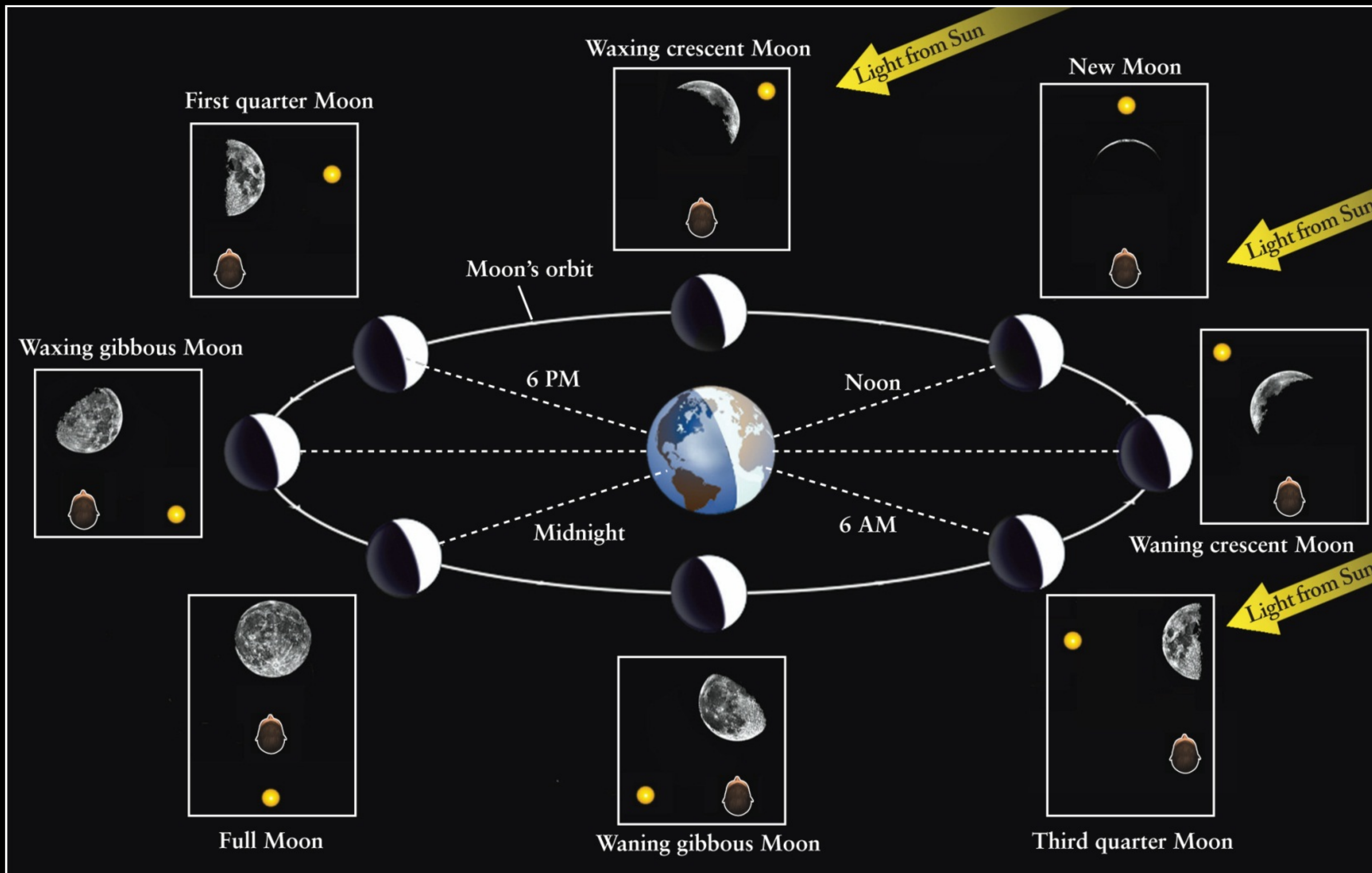
- Calendar year: integer number of mean solar days, (365 or 366)
- Sidereal year: time for the sun to return to the same position with respect to the stars (time of one 360 deg orbit of the earth around the sun).
- Tropical year: time for the sun to return to the vernal equinox.

1 sidereal year = 365.2564 mean solar days

1 tropical year = 365.2422 mean solar days

Calendars

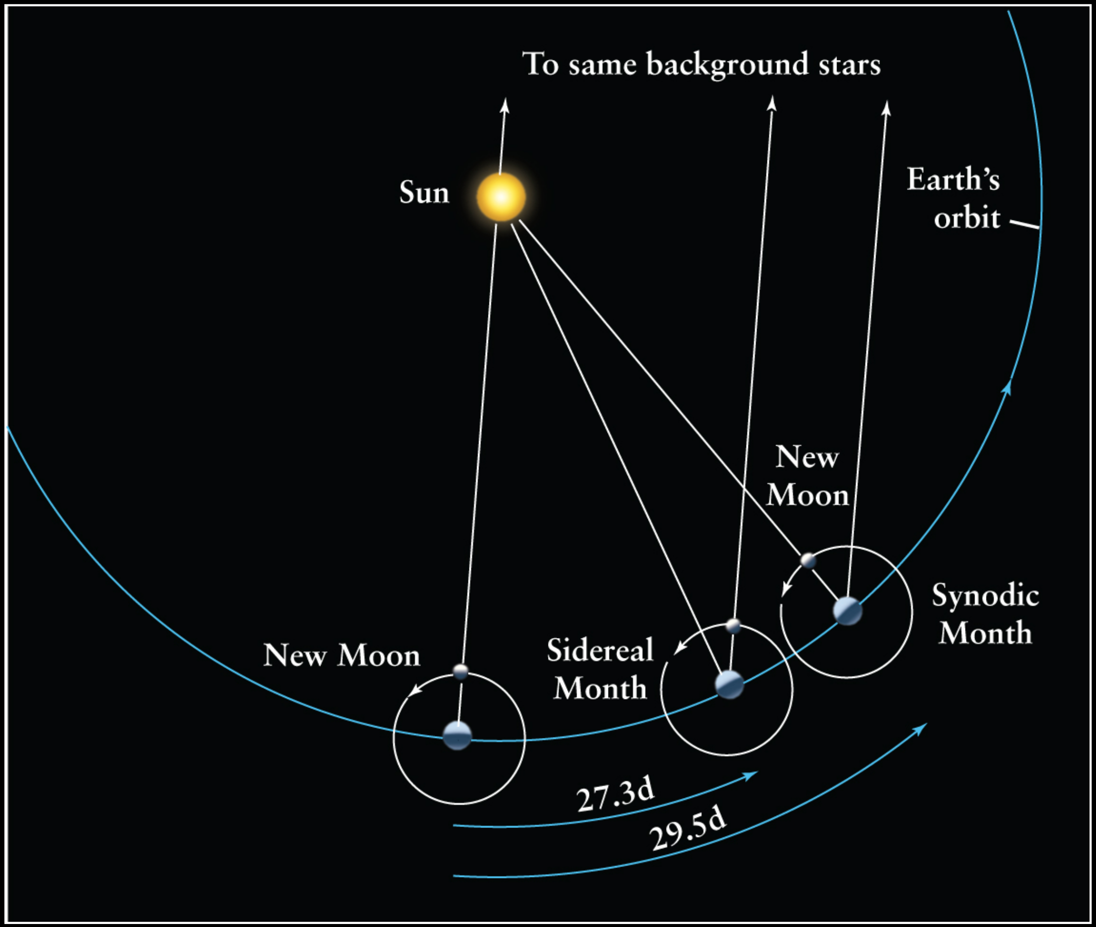
- Caesar introduced the 365.25 days calendar and thus the Leap Year (an extra day, February 29, every year divisible by 4) .
- However, this is 11^m 14^s longer than a (tropical) year.   This accumulates to 3 days in 4 centuries error.
- To correct, October 4 was followed by October 15, in 1562 and the century rule was invoked (Gregorian calendar).
  - Leap year: if year is divisible by 4, except it is a centennial year. However if the centennial year is divisible by 400, then it is also a leap year. ➔$P_{earth,\ orbit}$~365.2422 mean solar days.



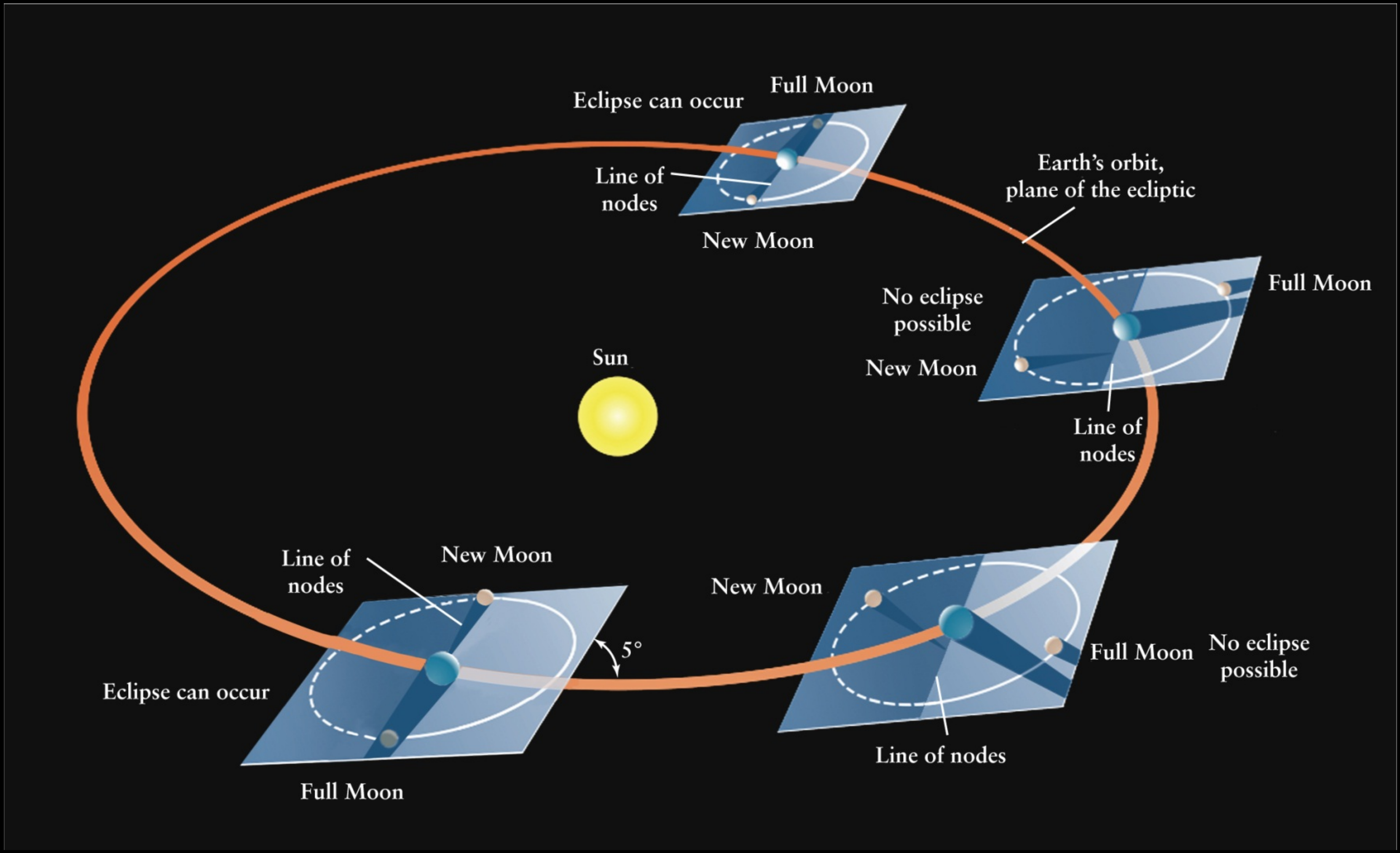
Another familiar cycle is the lunar cycle. When the Moon orbits Earth, the amount of the side facing Earth that is lit changes, creating the Moon's phases. This phase cycle is called the synodic period and is 29½ days long.

A *synodic month* is the time it takes for the Moon to orbit Earth with respect to the Sun and is 29½ days long.

A *sidereal month* is the time it takes for the Moon to orbit Earth with respect to the stars and is 27.3 days long.



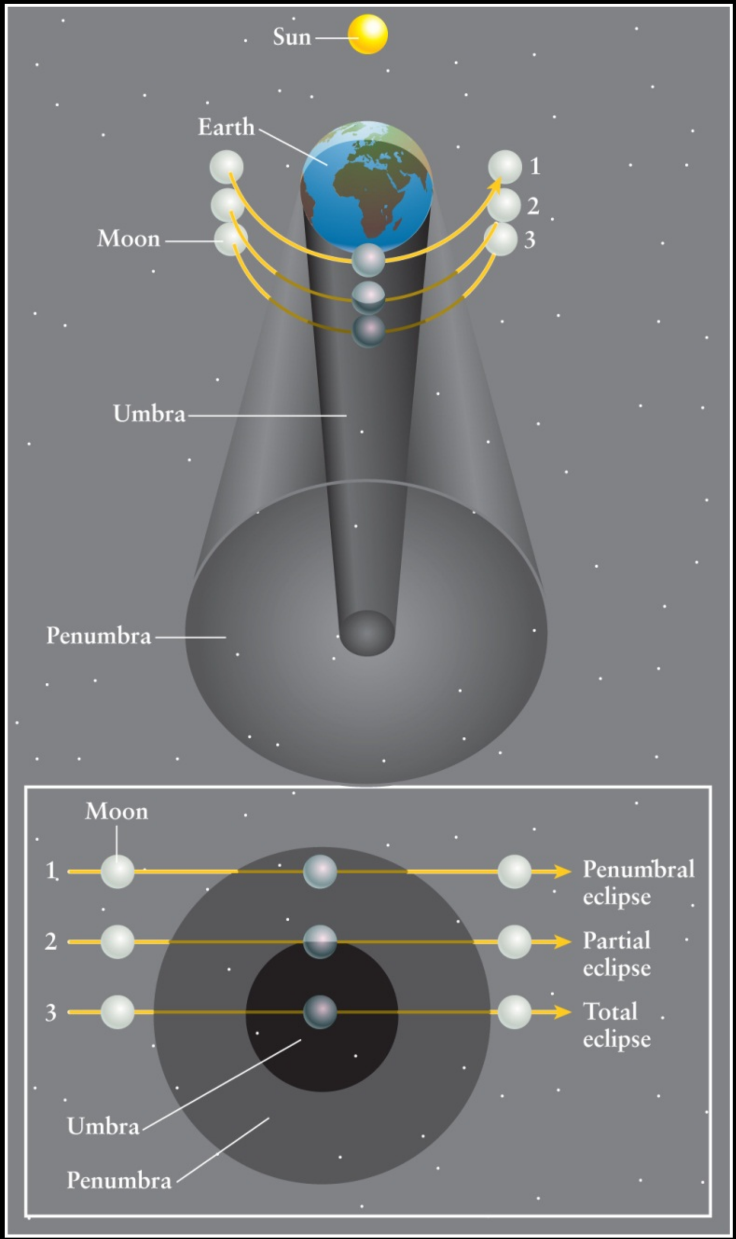
During a new or full moon phase, when the Moon, Sun, and Earth are aligned, the Moon may enter the shadow of Earth, or the shadow of the Moon may reach Earth, creating eclipses. However, these eclipses do not occur during every full or new moon because the Moon's orbit is tilted by 5° with respect to the Earth-Sun (ecliptic) plane.

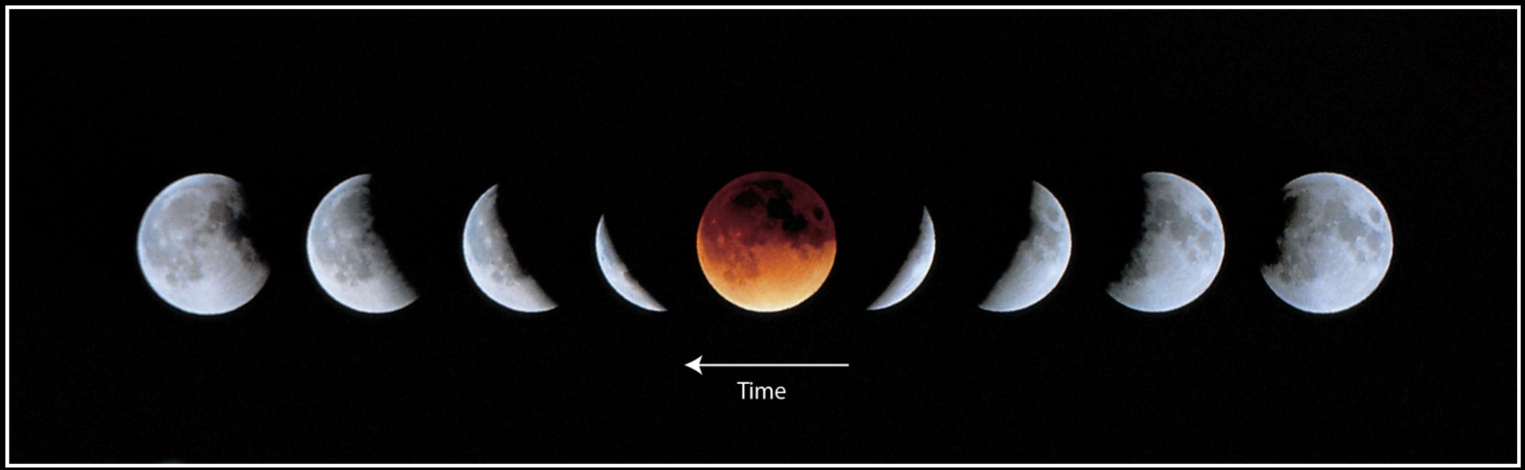


PENUMBRAL = the Moon appears dimmed.

PARTIAL = part of the Moon enters the umbra of Earth's shadow and is darkened.

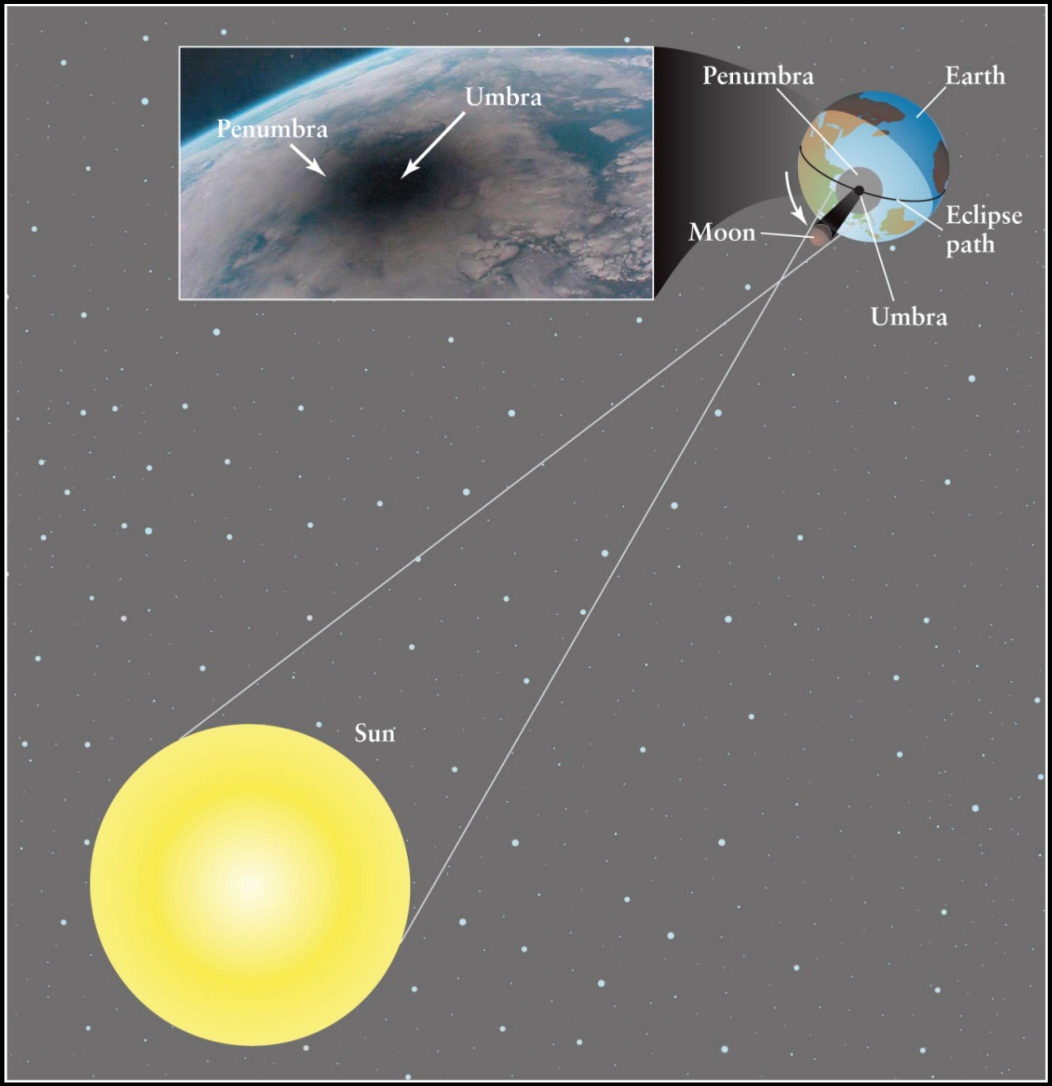
TOTAL = all of the Moon enters Earth's shadow and becomes a reddish color, only lit from light bending around Earth's atmosphere.



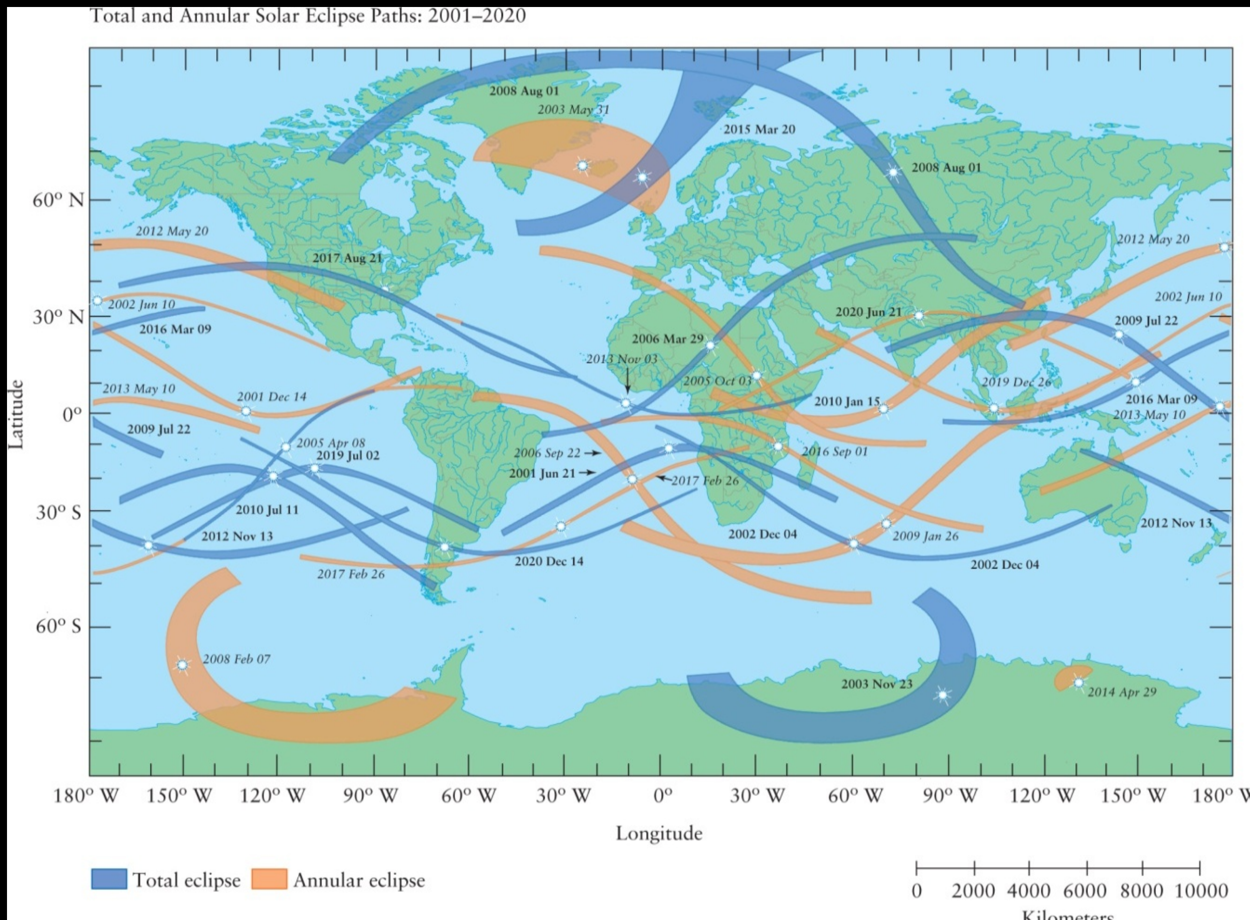


During a total lunar eclipse, the Moon moves in and out of the umbra of Earth's shadow.

Unlike lunar eclipses, solar eclipses occur at specific places on Earth, indicated by the arrow.

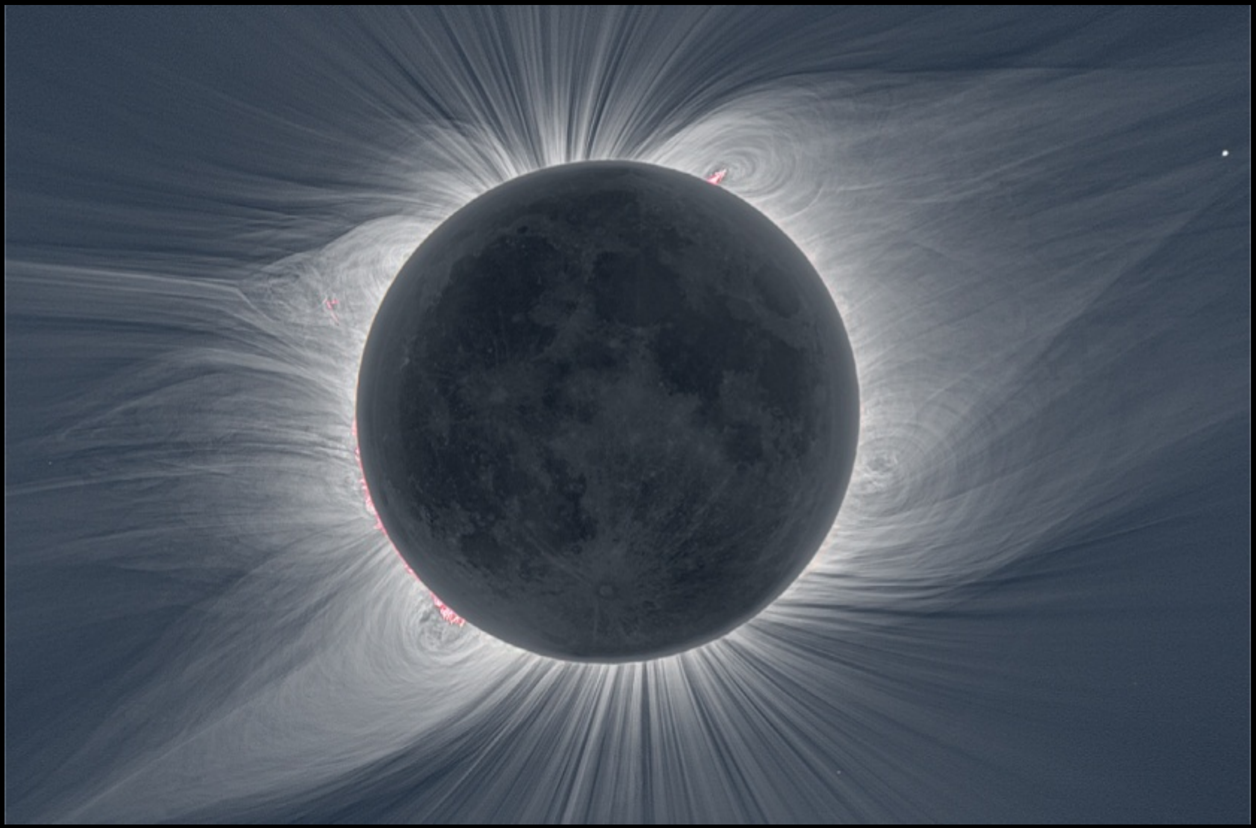


Eclipse Paths for Total and Annular Eclipses 2001–2020



This map shows the eclipse paths for the 14 total solar and 13 annular eclipses that occur between 2001 and 2020. In each eclipse, the Moon's shadow travels along the eclipse path in a generally eastward direction across Earth's surface.

A Total Eclipse of the Sun

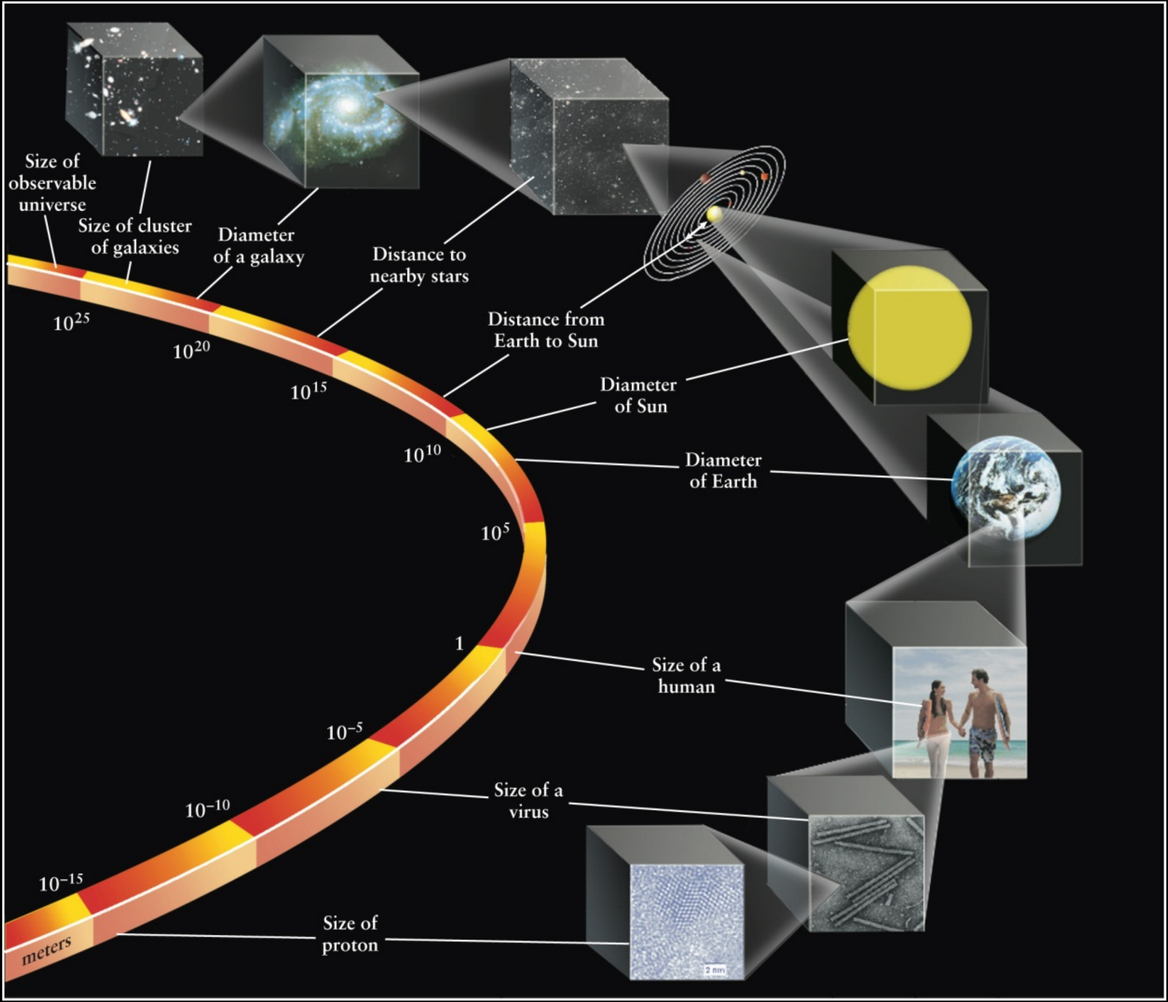


Sometimes eclipses occur when the Moon is too far away from Earth to completely cover the Sun in our sky. When this occurs, the Moon appears in the center and a thin ring, or “annulus,” of light surrounds it. These are called annular eclipses.

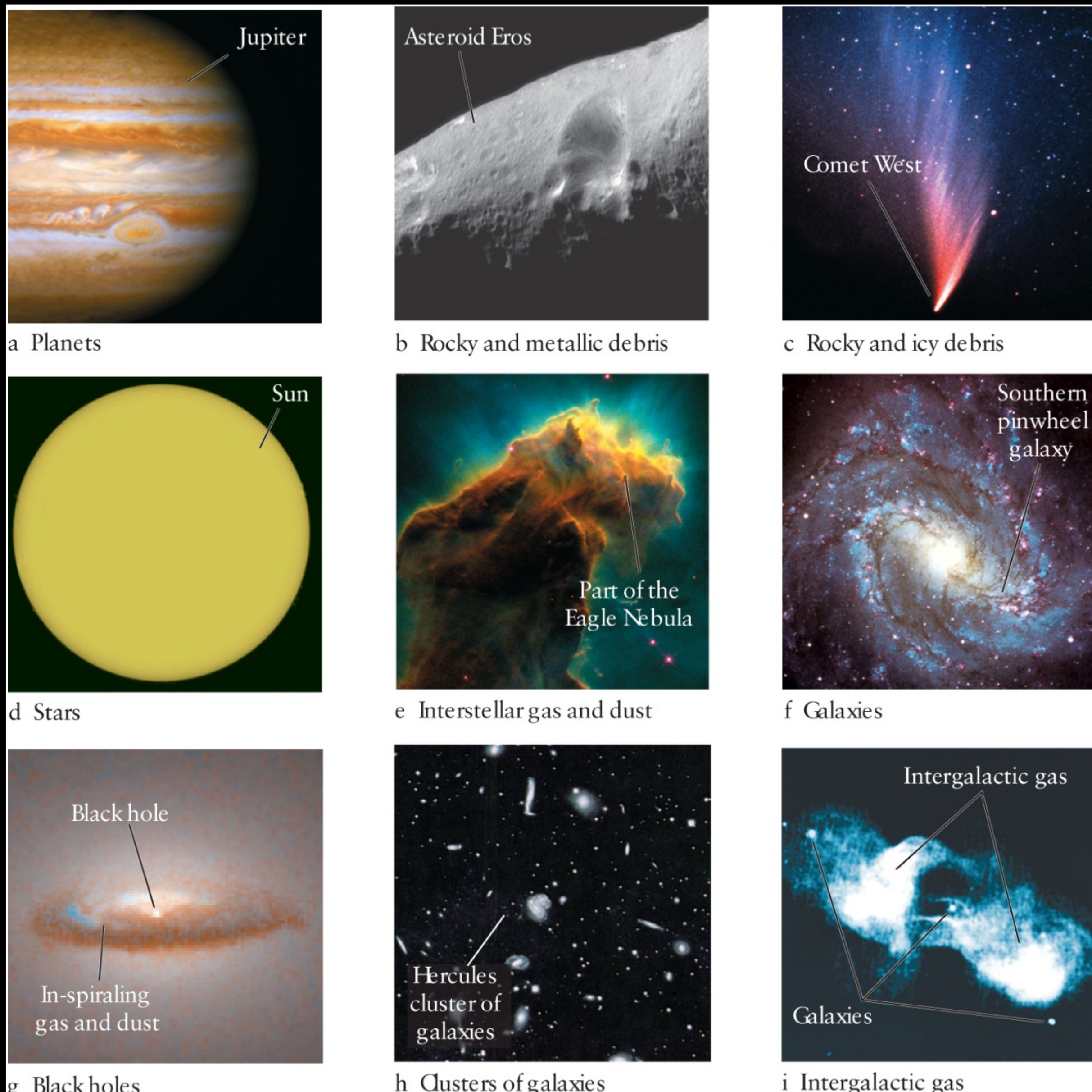
THE SCALES OF THE UNIVERSE

The range of objects we study are from the extremely small subatomic particles, to objects that are gigantic, such as a galaxy or the size of the known universe itself.

Each division up the line indicates an increase in size by 100,000.



What Have Astronomers Discovered in Our Universe?



a Planets
b Rocky and metallic debris
c Rocky and icy debris
d Stars
e Interstellar gas and dust
f Galaxies
g Black holes
h Clusters of galaxies
i Intergalactic gas