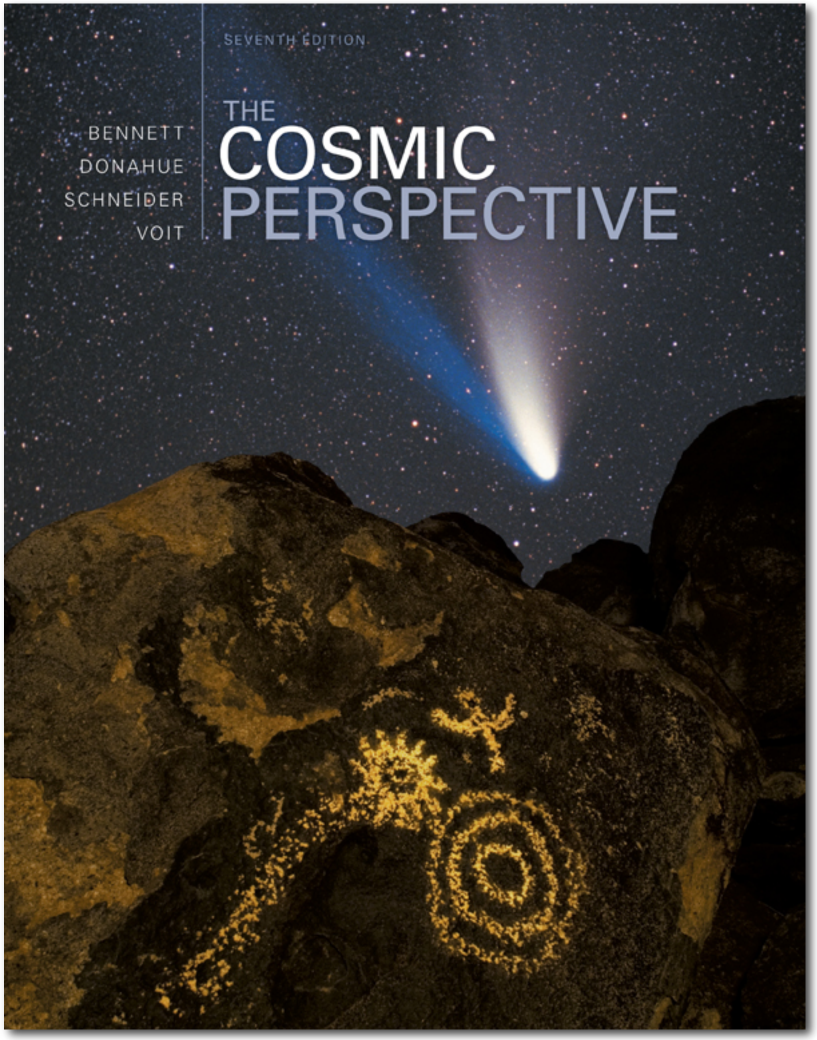
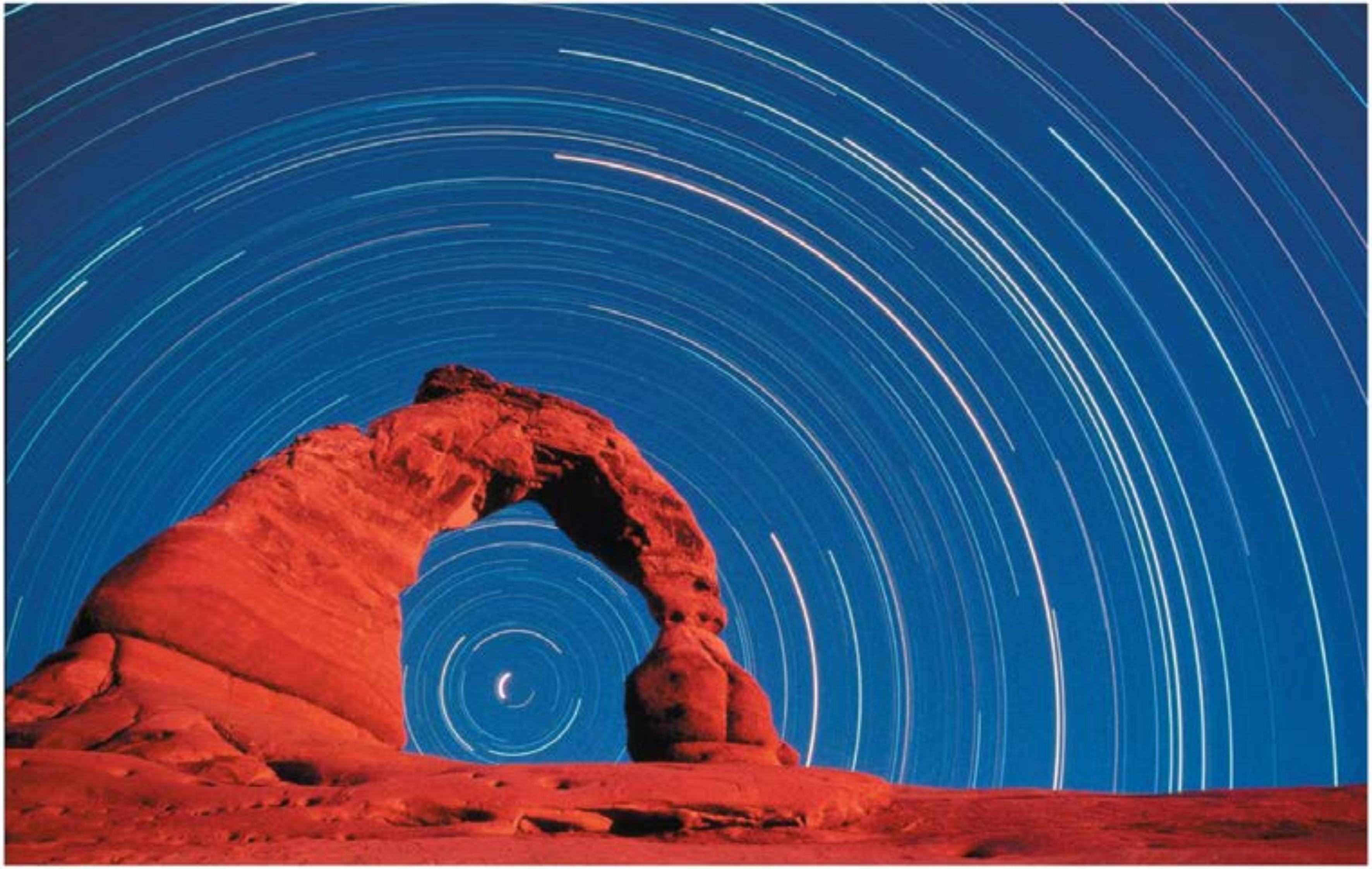
The Cosmic Perspective

Seventh Edition



Discovering the Universe for Yourself

Discovering the Universe for Yourself



2.1 Patterns in the Night Sky

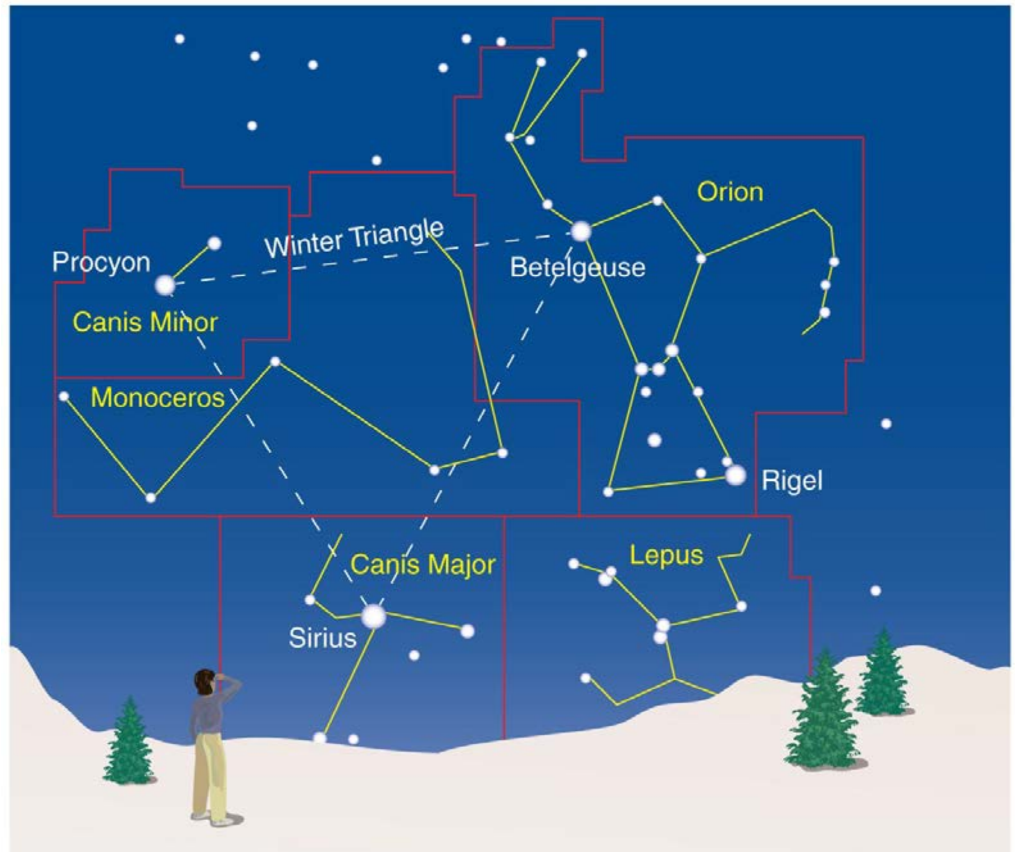
- Our goals for learning:
  - **What does the universe look like from Earth?**
  - **Why do stars rise and set?**
  - **Why do the constellations we see depend on latitude and time of year?**

What does the universe look like from Earth?

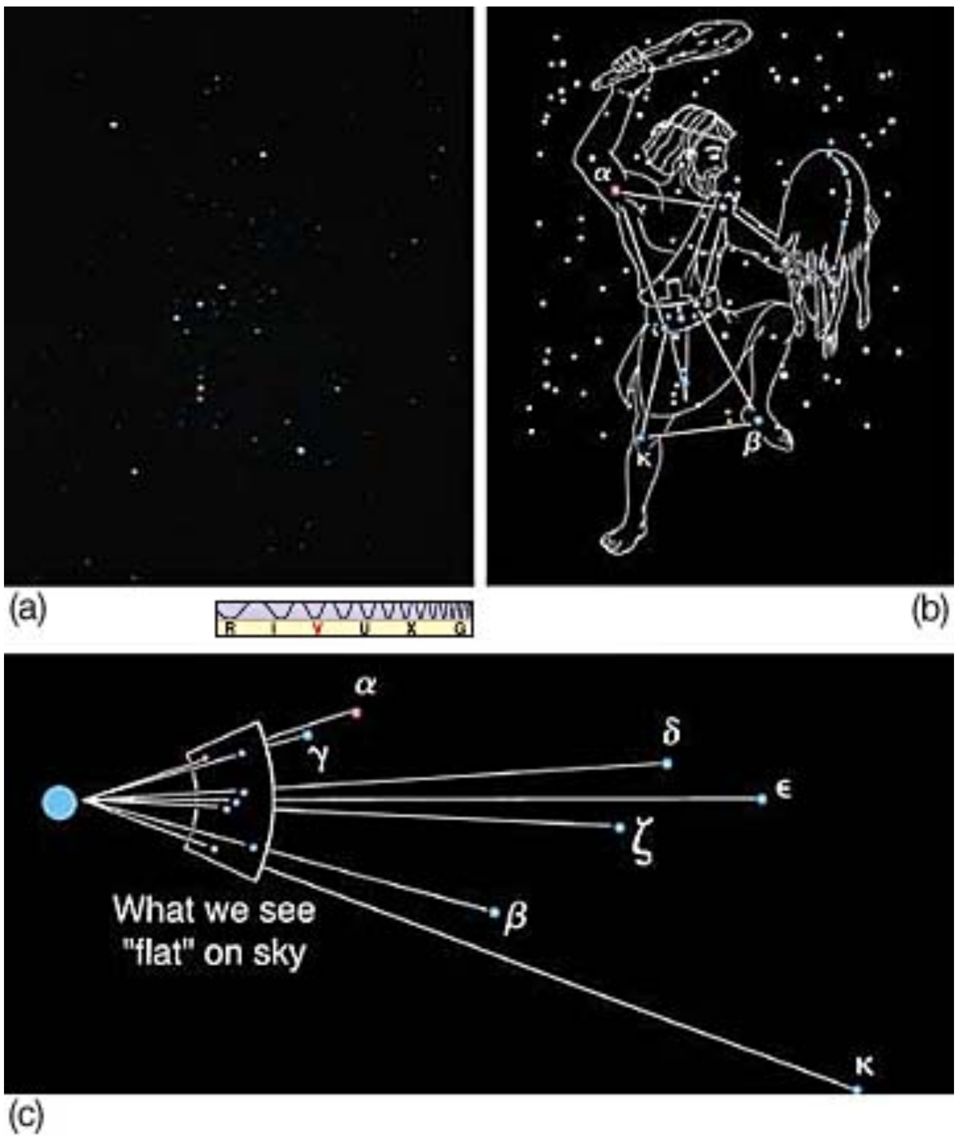
- With the naked eye, we can see more than 2000 stars as well as the Milky Way.

Constellations

- A constellation is a *region* of the sky.
- Eighty-eight constellations fill the entire sky.

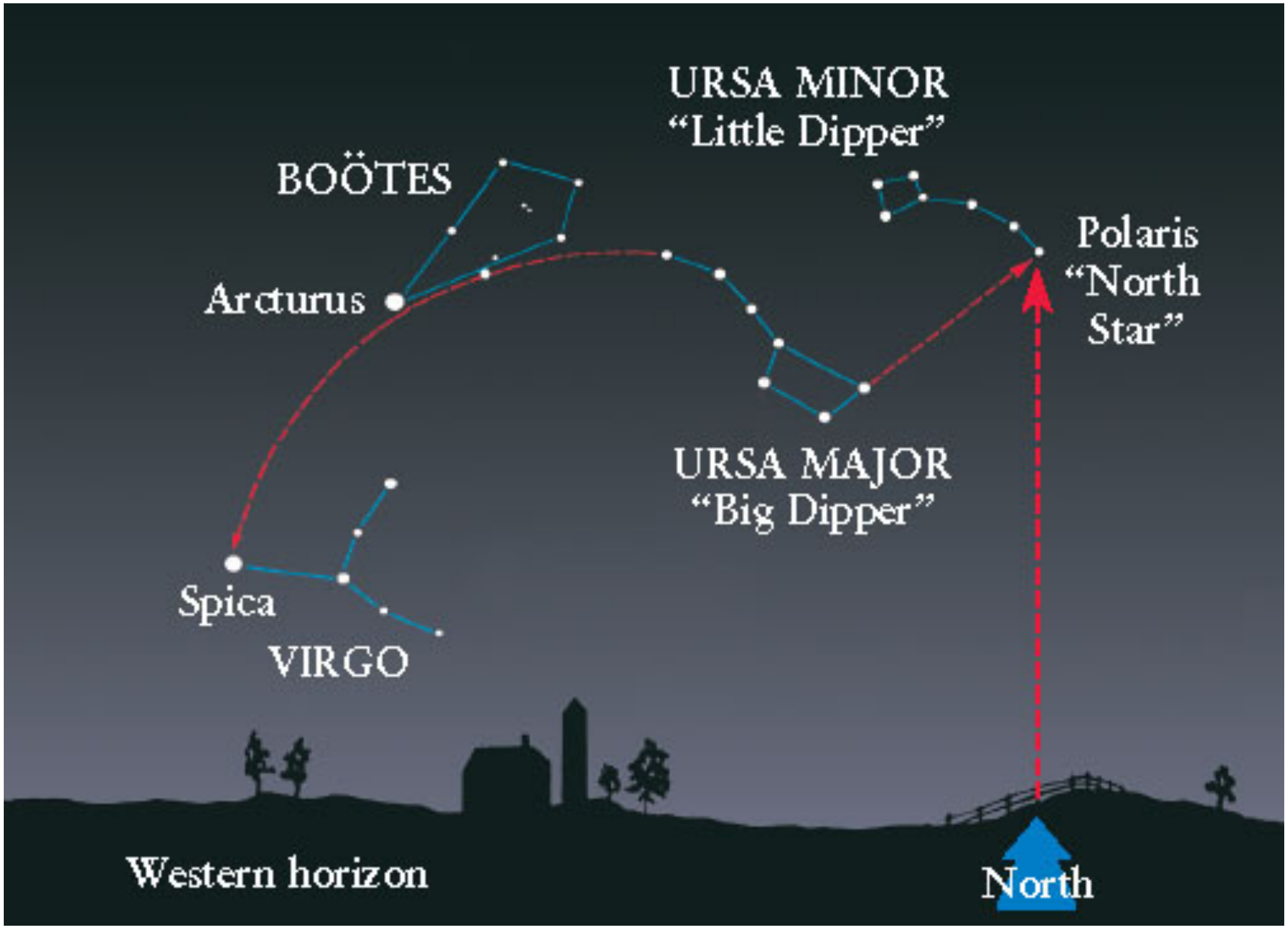


Constellations

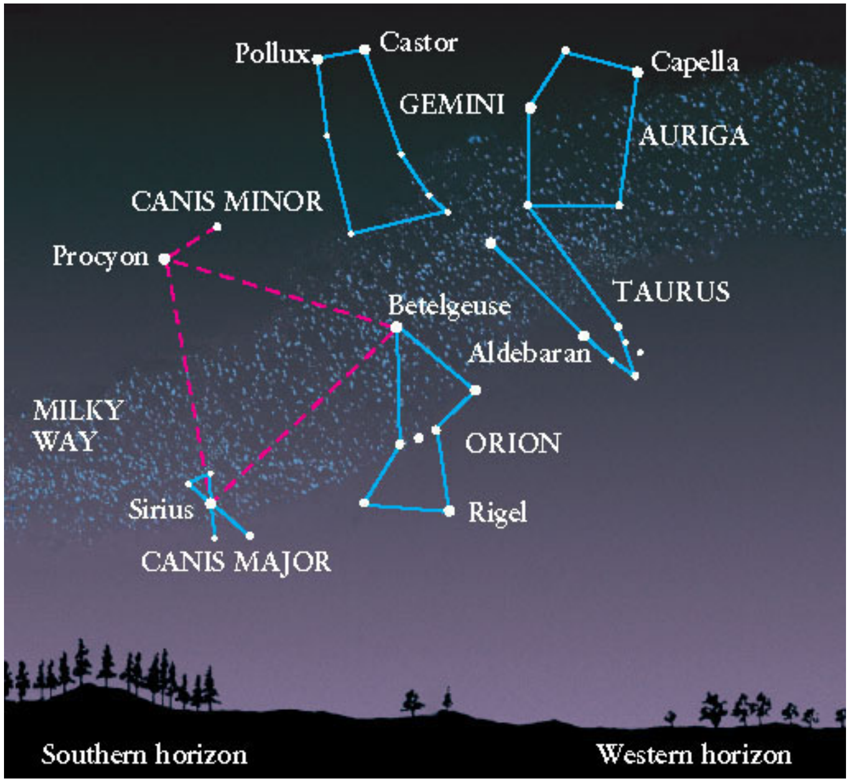


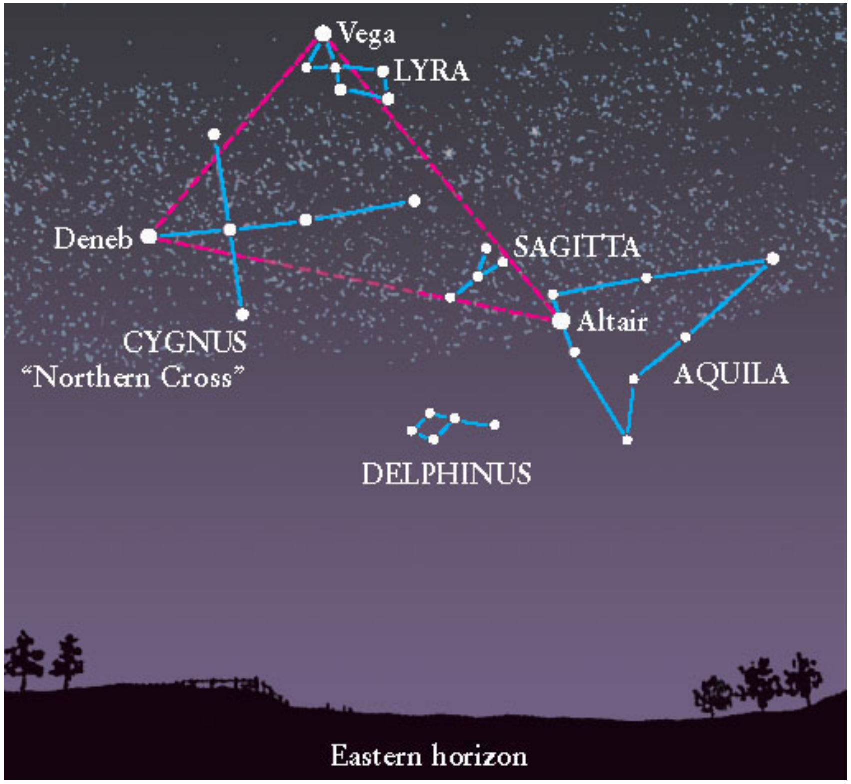
The stars in a constellation are usually not near each other; they just lie in the same direction.

Constellations



Winter and Summer Triangles





Thought Question

The brightest stars in a constellation

A. all belong to the same star cluster.
B. all lie at about the same distance from Earth.
C. may actually be quite far away from each other.

Thought Question

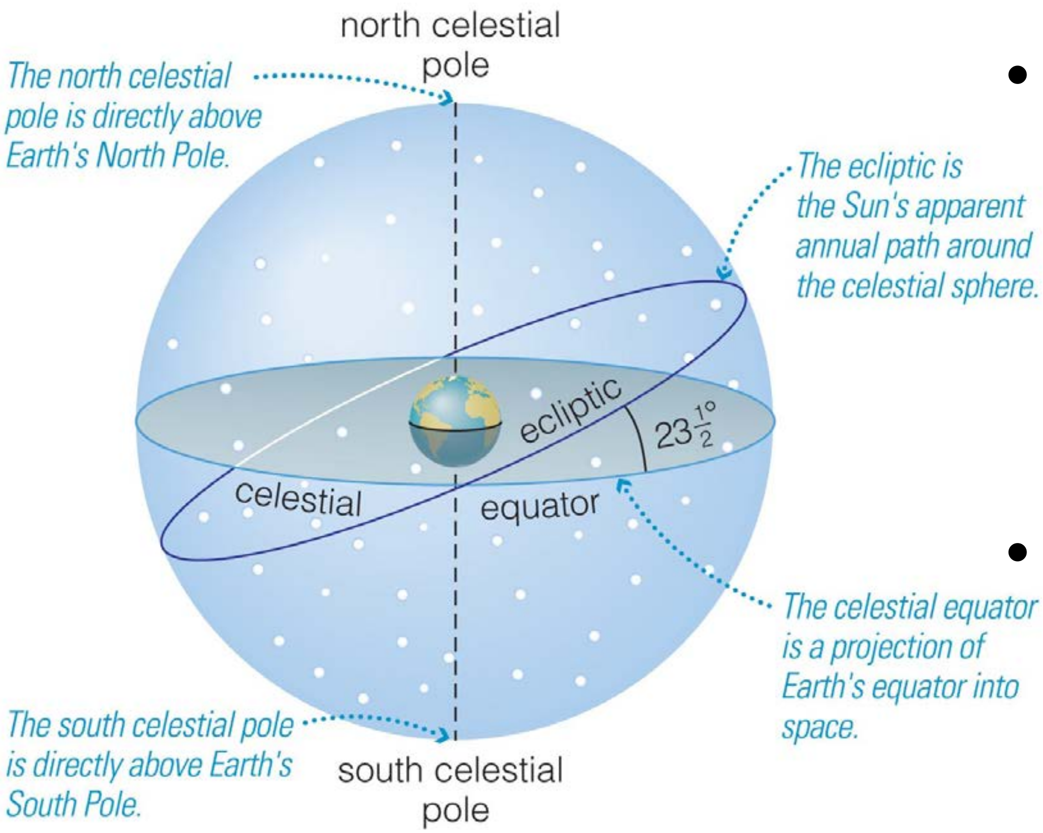
The brightest stars in a constellation

A. all belong to the same star cluster.

B. all lie at about the same distance from Earth.

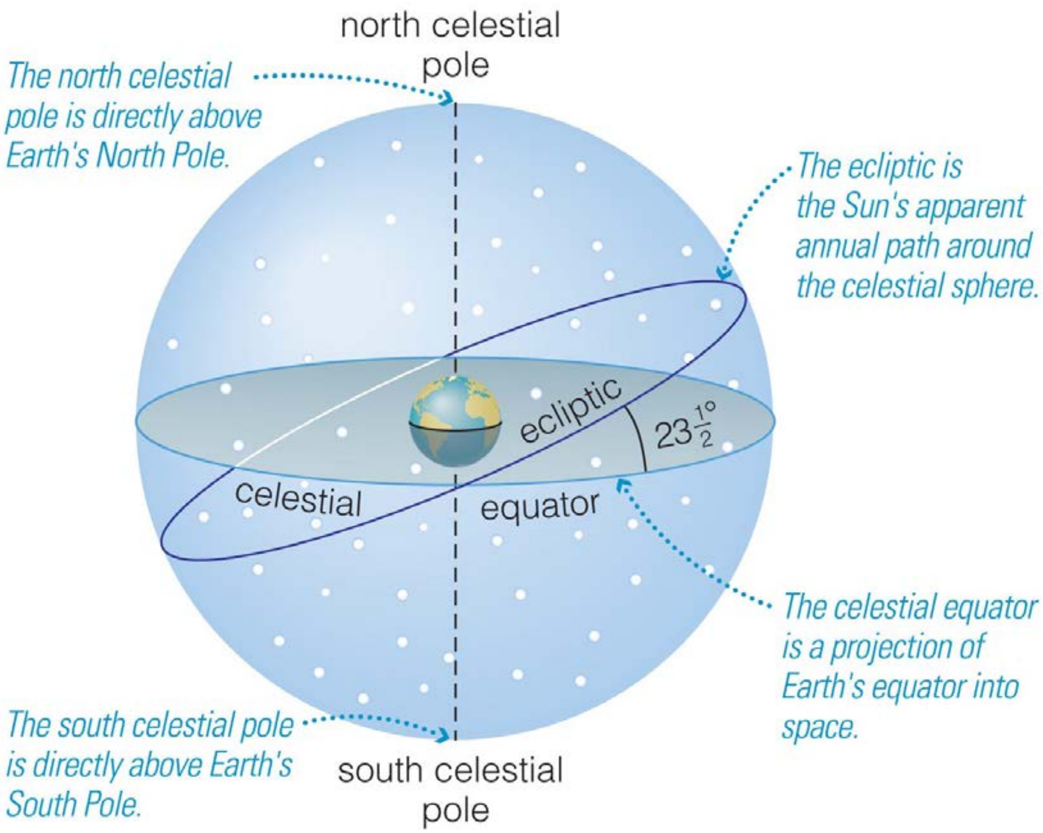
C. may actually be quite far away from each other.

The Celestial Sphere



- The **Ecliptic** is the Sun's apparent path through the celestial sphere.
- The Celestial Sphere rotates following the Earth's rotation.

The Celestial Sphere



- **North celestial pole** is directly above Earth's North Pole.
- **South celestial pole** is directly above Earth's South Pole.
- **Celestial equator** is a projection of Earth's equator onto sky.

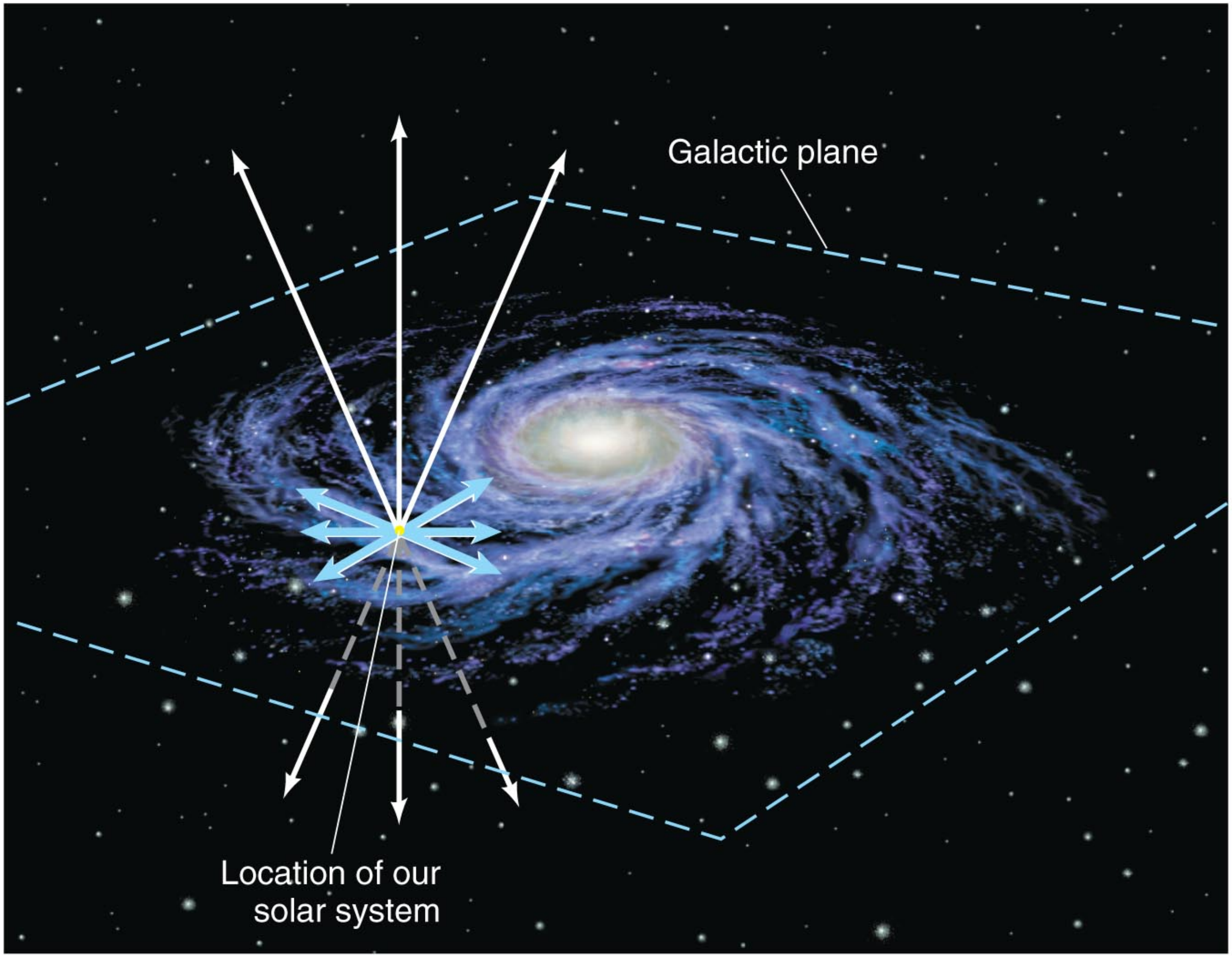
The Milky Way

- A band of light making a circle around the celestial sphere.

What is it?

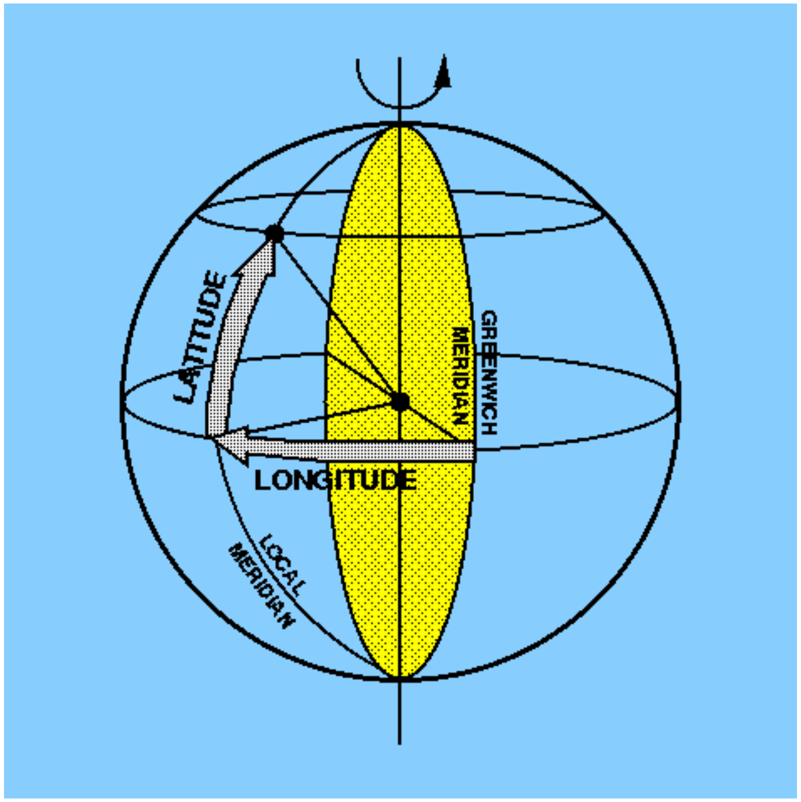
- Our view into the plane of our galaxy.

The Milky Way



Latitude-Longitude

- Latitude is the angle in degrees, North or South of the equator.
- Longitude is an angle East or West of the Greenwich Meridian in England, which is arbitrarily defined to be 0º longitude.



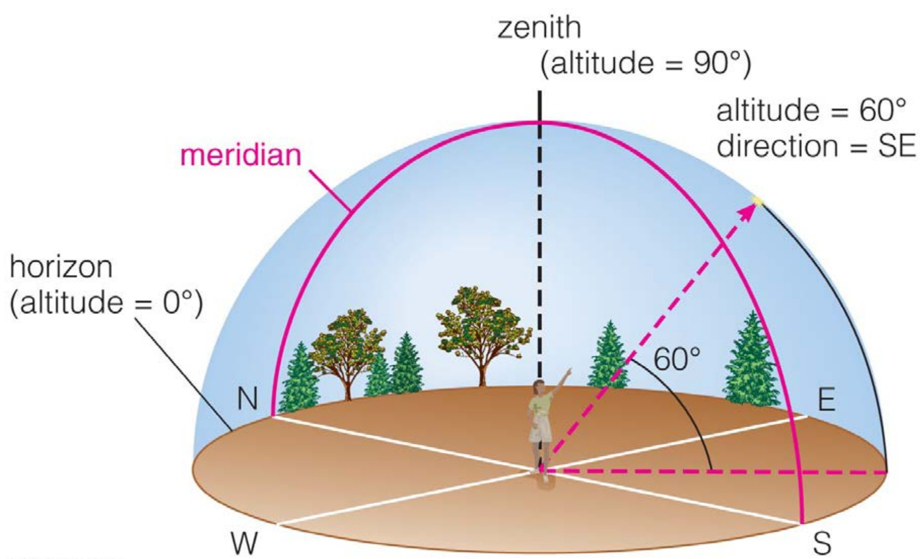
- For Charleston, SC:

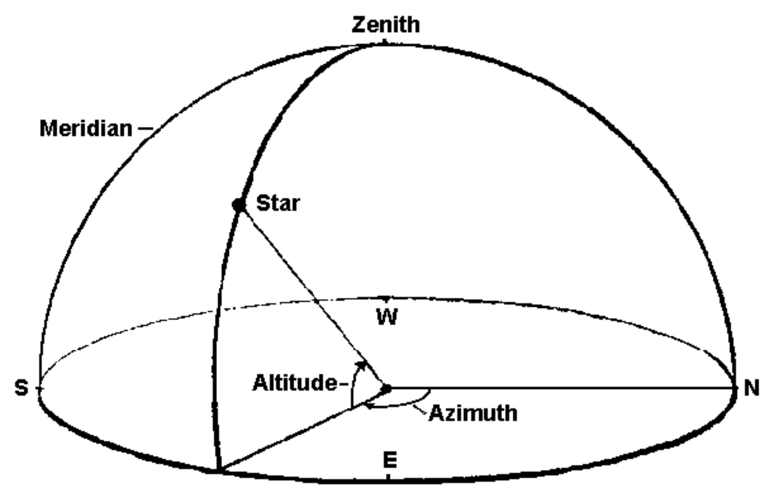
$$\text{Latitude} = 32^\circ\ 47'\ (North)$$

$$\text{Longitude} = 79^\circ\ 56'\ (West)$$

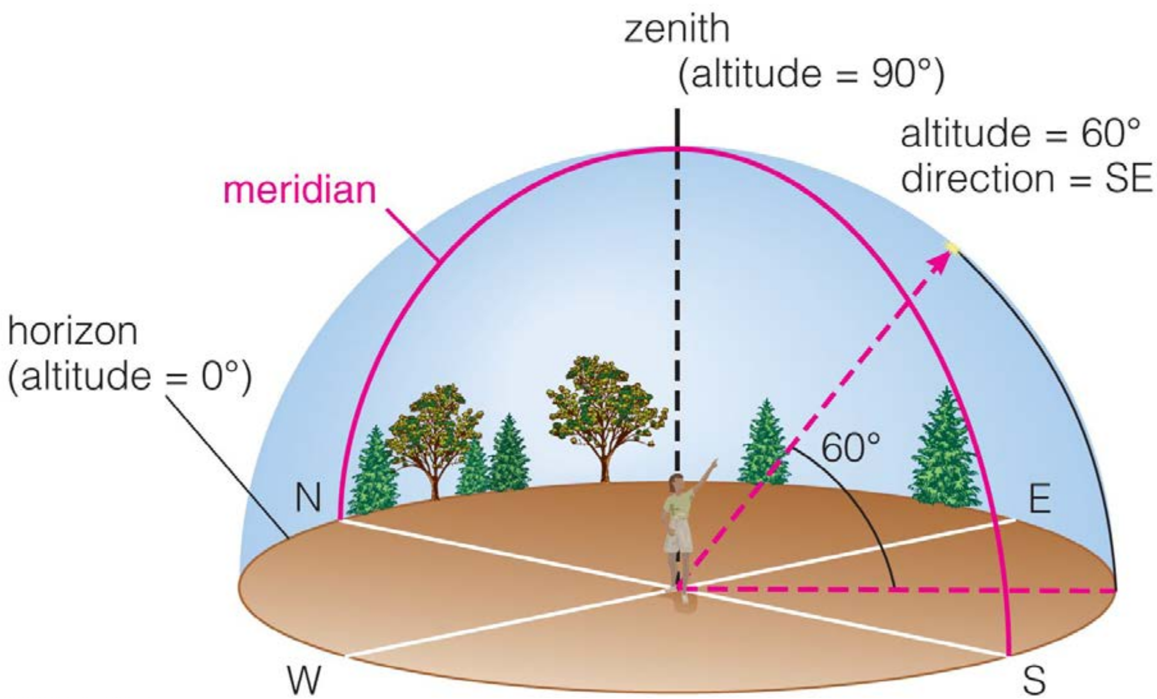
The Local Sky (Altitude-Azimuth)

- An object's **altitude** (above horizon) and azimuth (along horizon) specify its location in your local sky. **Altitude** is measured in degrees above the horizon. **Azimuth** is measured along the horizon, in degrees East from North.





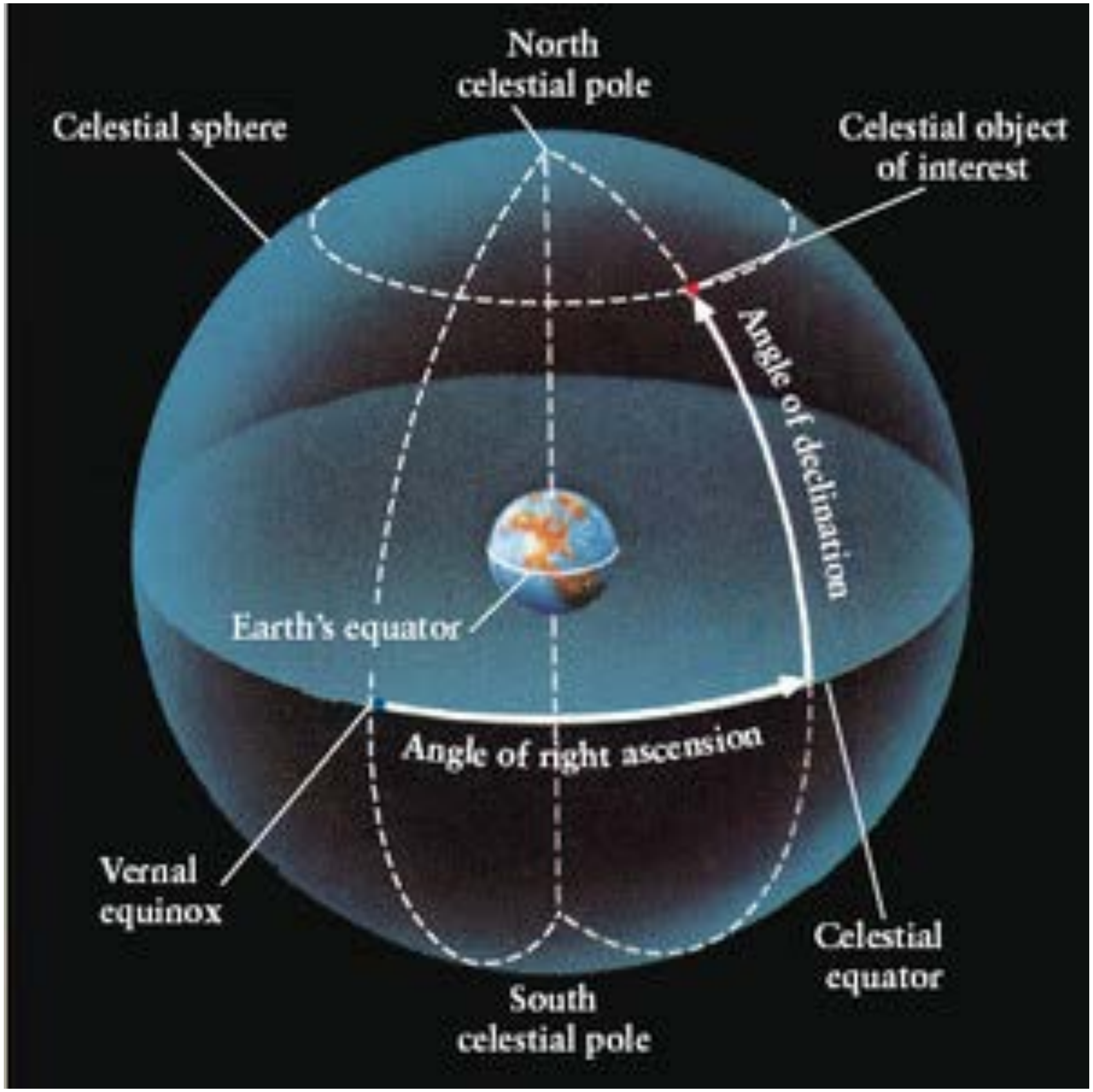
The Local Sky (Altitude-Azimuth)



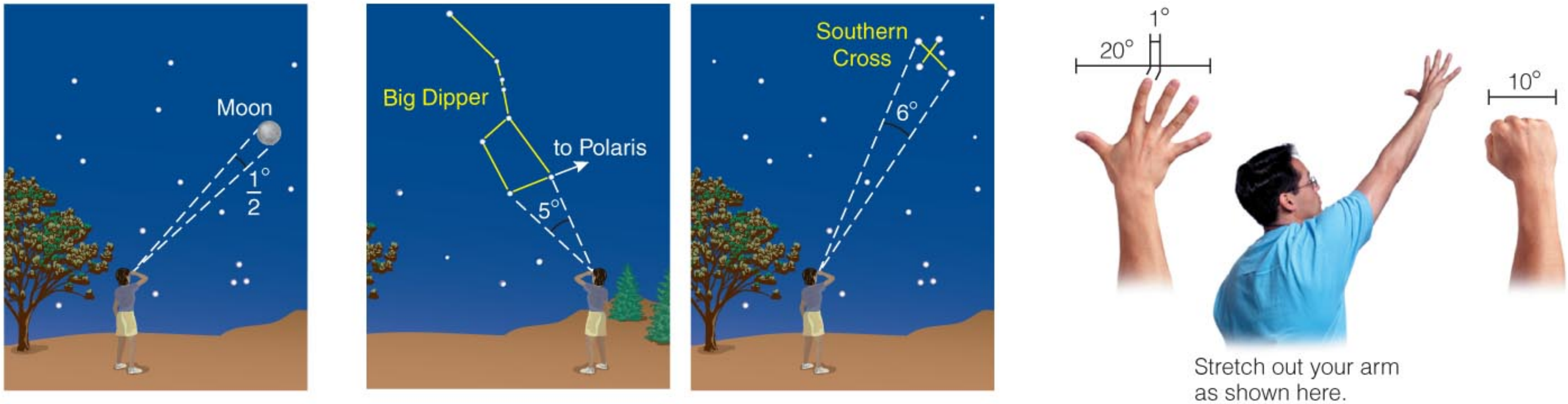
- **Meridian:** line passing through zenith and connecting N and S points on horizon

- **Zenith:** the point directly overhead
- **Horizon:** all points 90° away from zenith

Celestial Coordinates



We measure the sky using *angles*.



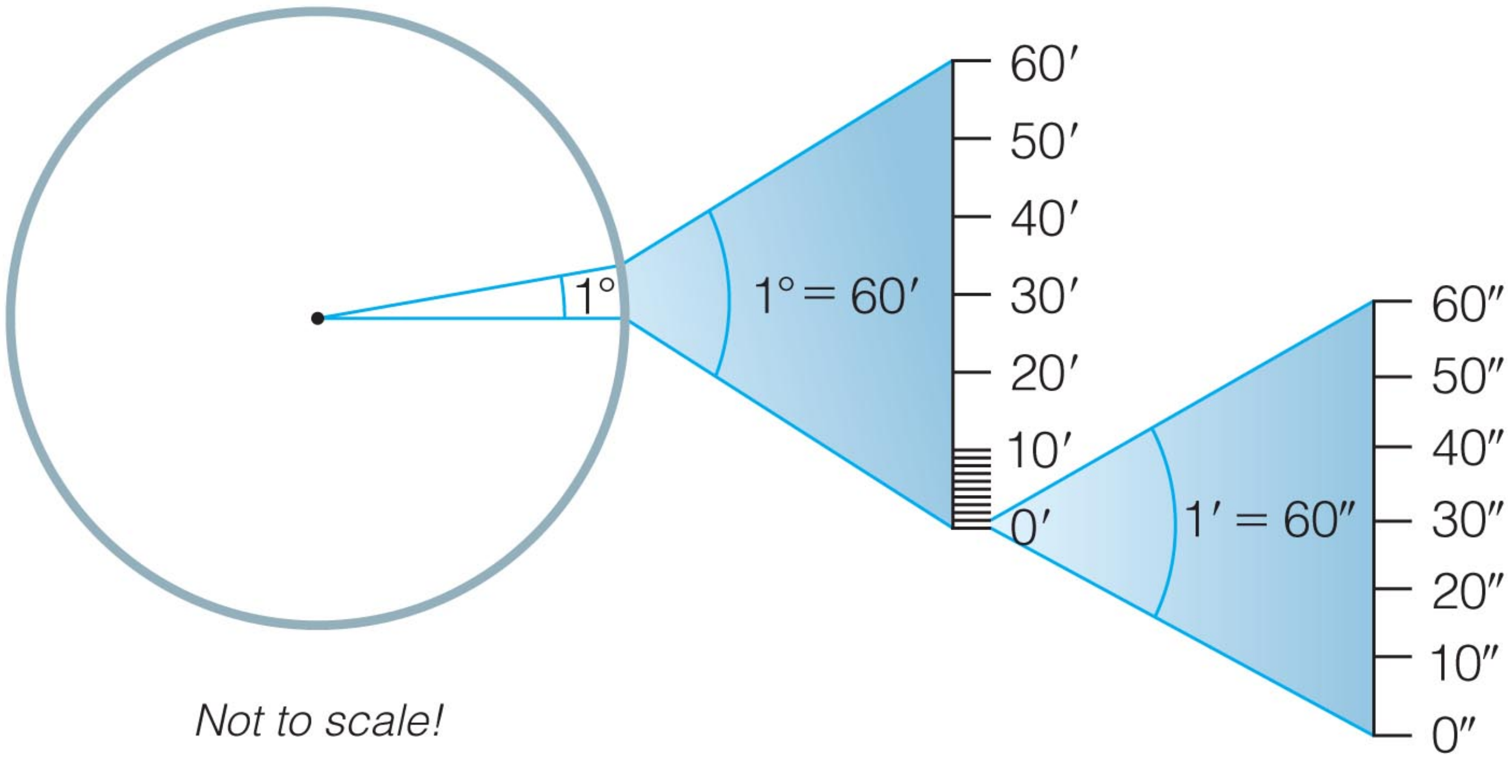
a The angular sizes of the Sun and the Moon are about 1/2°.

b The angular distance between the "pointer stars" of the Big Dipper is about 5°, and the angular length of the Southern Cross is about 6°.

c You can estimate angular sizes or distances with your outstretched hand.

Angular Measurements

- Full circle = 360º
- 1º = 60′ (arcminutes)
- 1′ = 60″ (arcseconds)



Thought Question

The angular size of your finger at arm's length is about 1°. How many arcseconds is this?

A. 60 arcseconds

B. 600 arcseconds

C. $60 \times 60 = 3600$ arcseconds

Thought Question

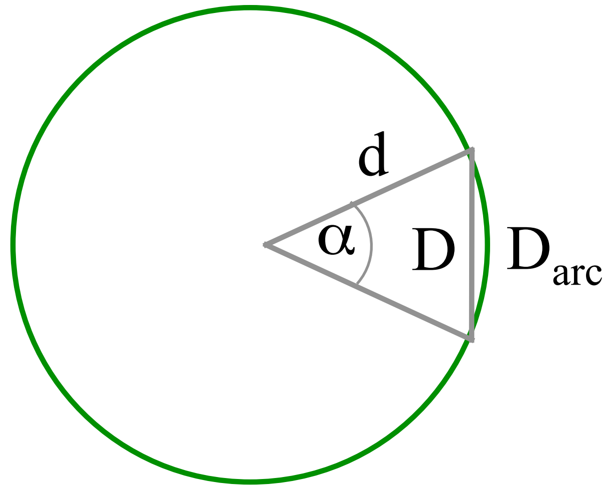
The angular size of your finger at arm's length is about 1°. How many arcseconds is this?

A. 60 arcseconds

B. 600 arcseconds

C. $60 \times 60 = 3600$ arcseconds

Relation Between Angular and Physical Sizes



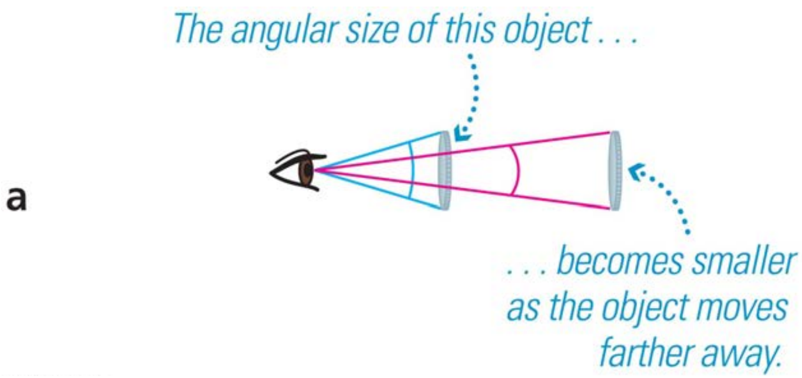
$2\pi d$ = circumference of circle = corresponds to 360 degrees
D_{arc} = segment of circle = corresponds to α degrees

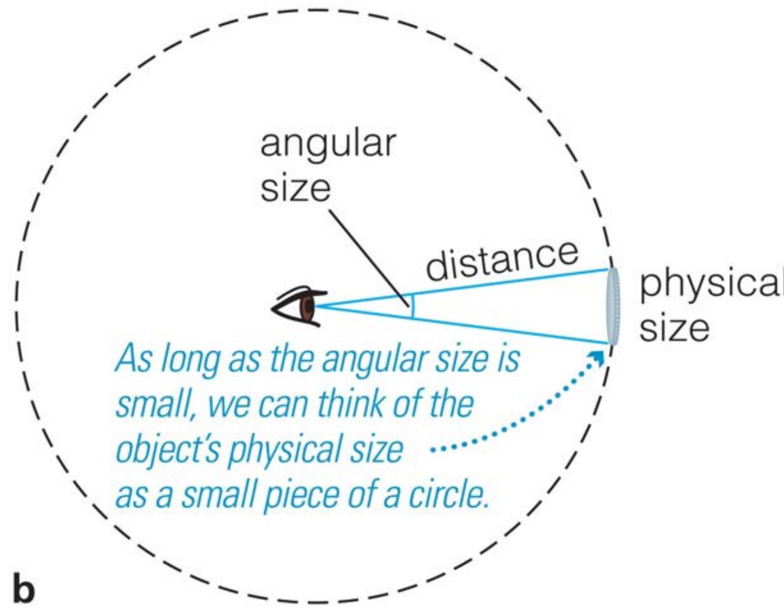
$$\frac{2\pi d}{D_{arc}} = \frac{360^\circ}{\alpha} \Rightarrow D_{arc} = \left(\frac{2\pi}{360^\circ}\right)\alpha d,$$ where α is in the angular size in degrees and d is the distance.

Small angle approximation: The physical size $D \approx D_{arc}$

Angular Size

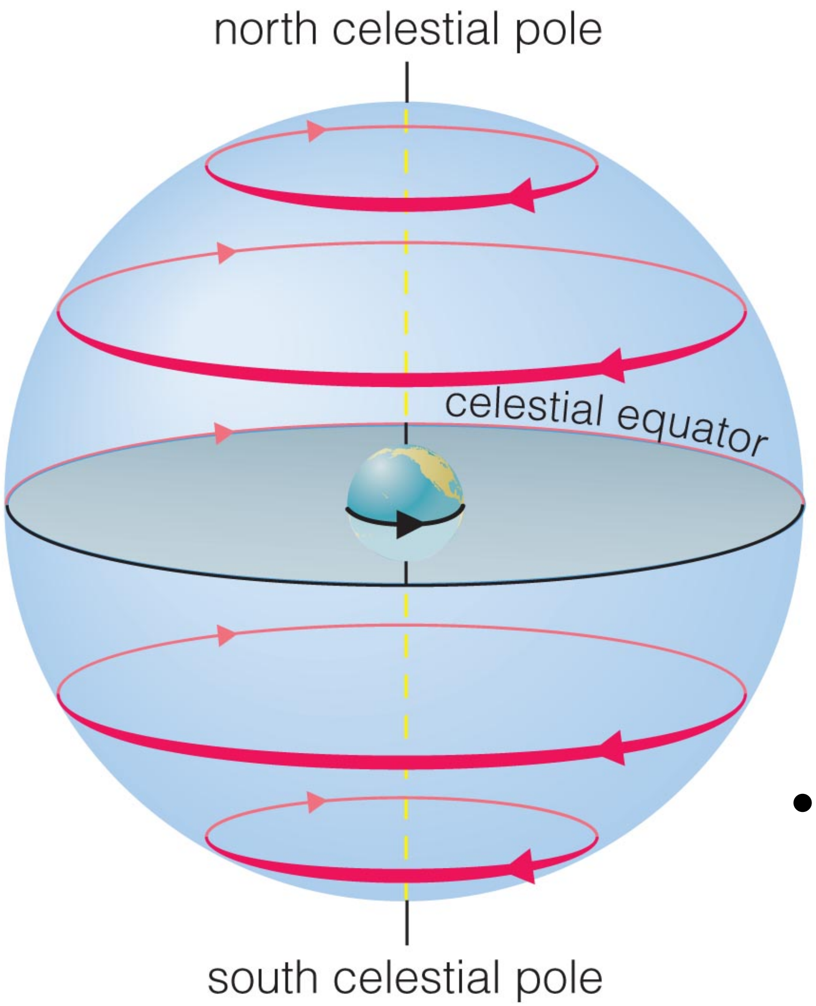
$$\text{angular size} = \text{physical size} \times \frac{360 \text{ degrees}}{2\pi \times \text{distance}}$$





- An object's angular size appears smaller if it is farther away.

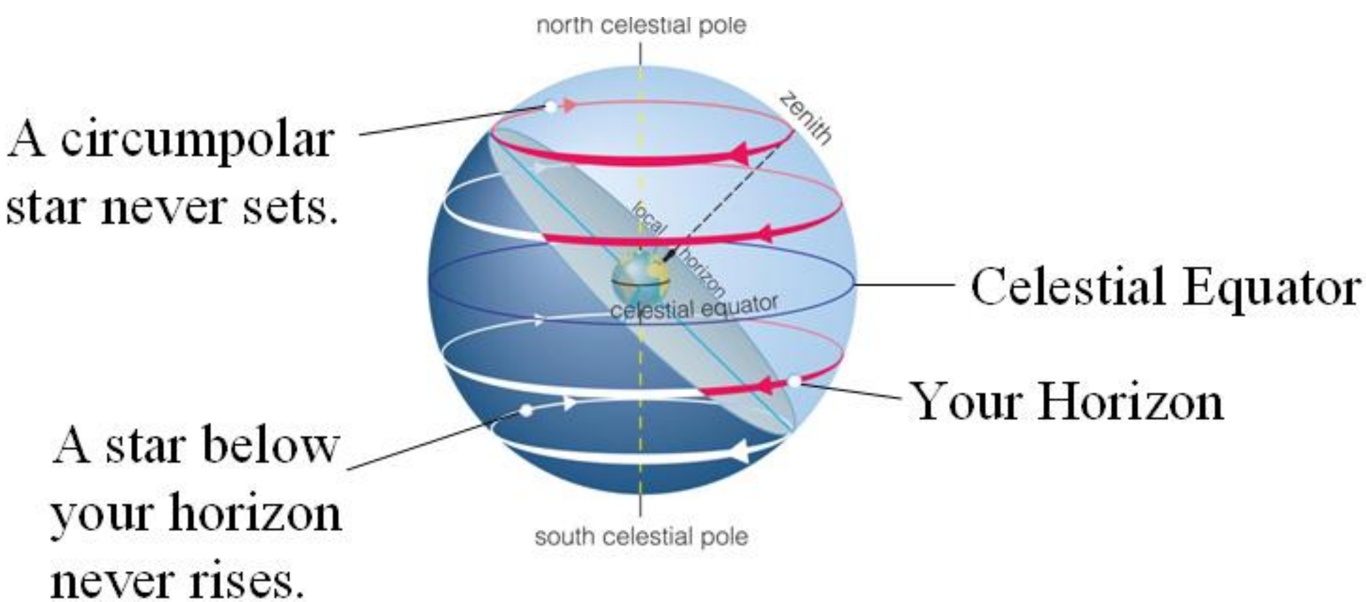
Why do stars rise and set?



- Earth rotates from west to east, so stars appear to circle from east to west.

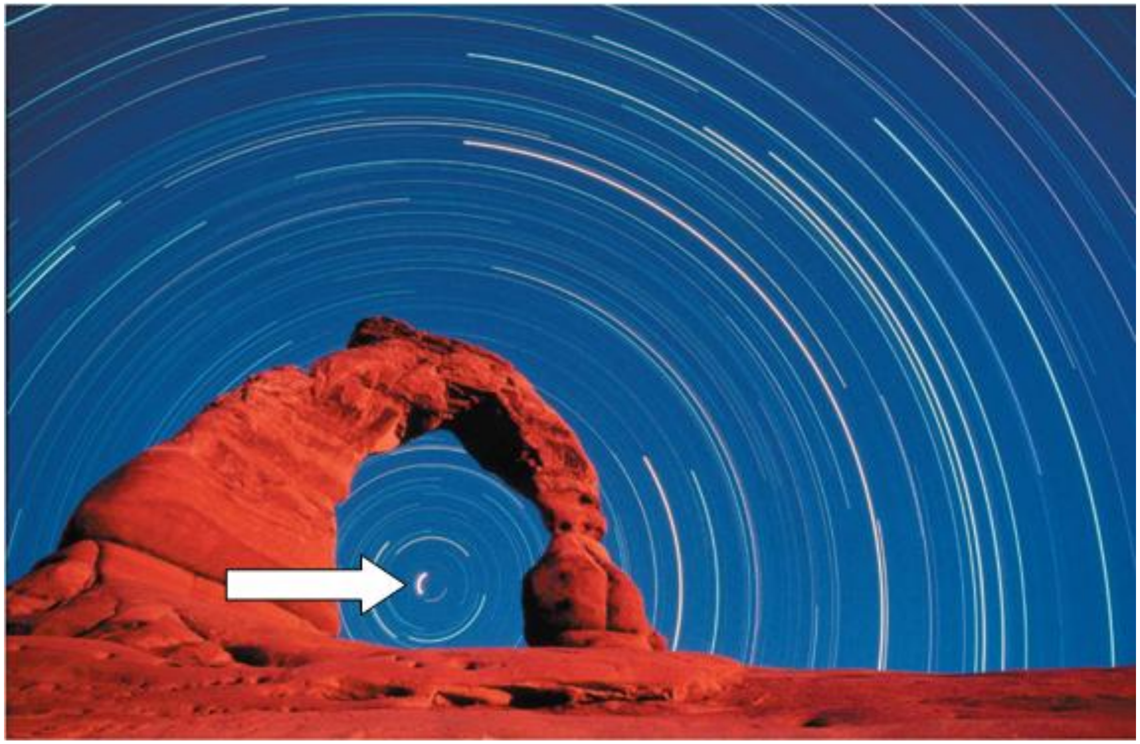
Our view from Earth:

- Stars near the north celestial pole are circumpolar and never set.
- We cannot see stars near the south celestial pole.
- All other stars (and Sun, Moon, planets) rise in east and set in west.



Thought Question

What is the arrow pointing to in the photo below?
A. the zenith
B. the north celestial pole
C. the celestial equator



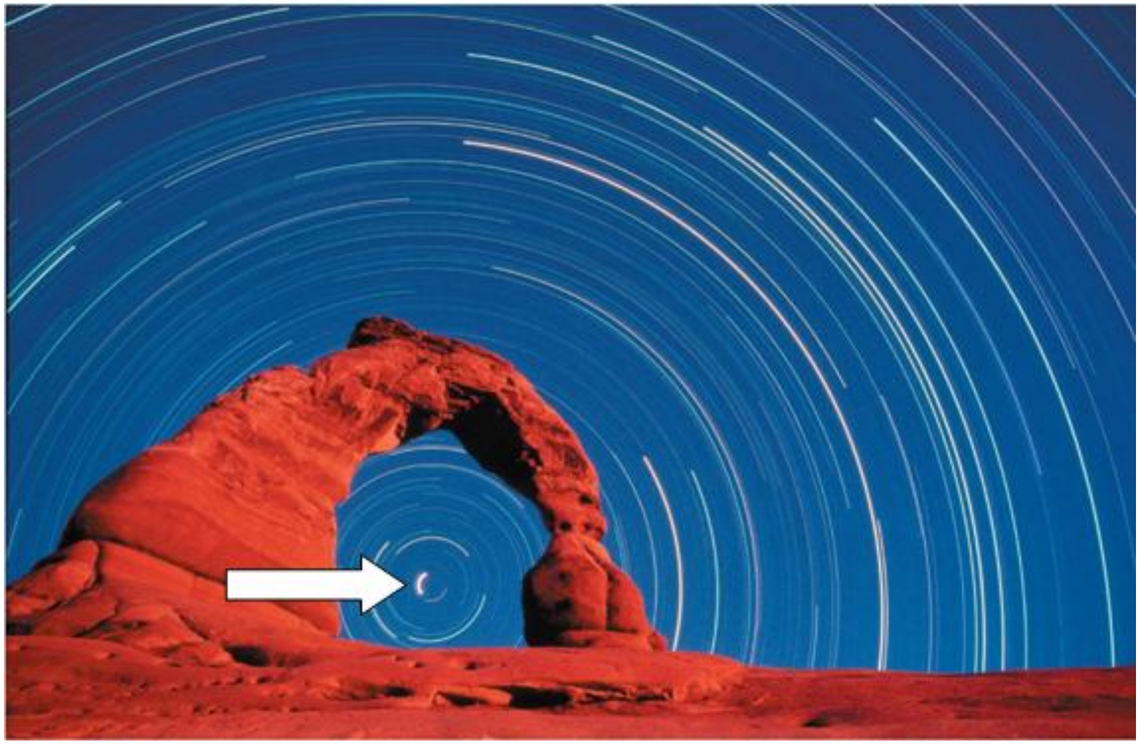
Thought Question

What is the arrow pointing to in the photo below?

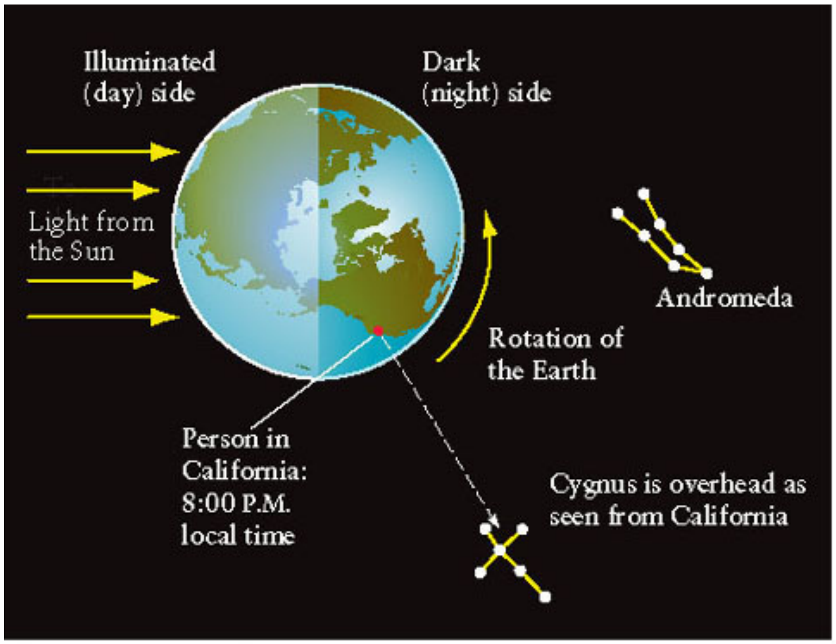
A. the zenith

B. the north celestial pole

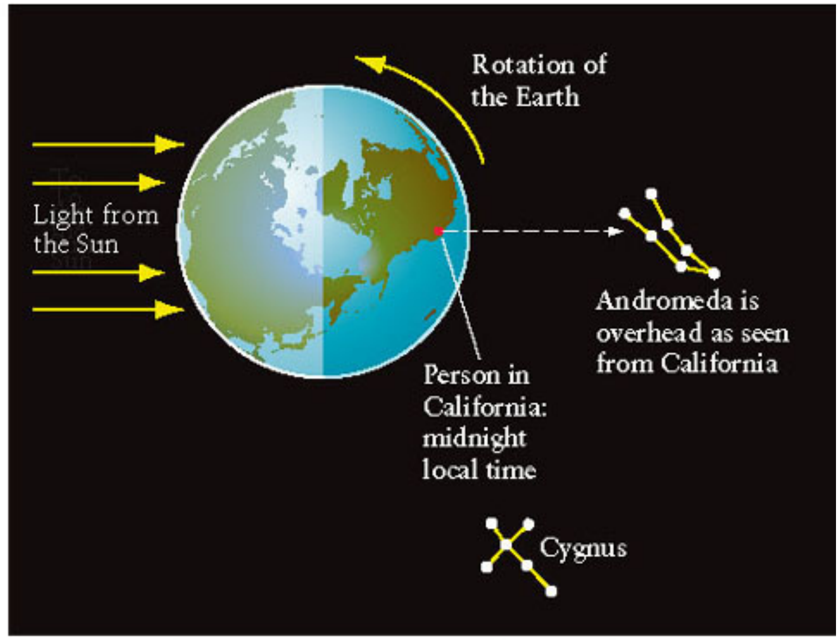
C. the celestial equator



Diurnal (Daily Motion)

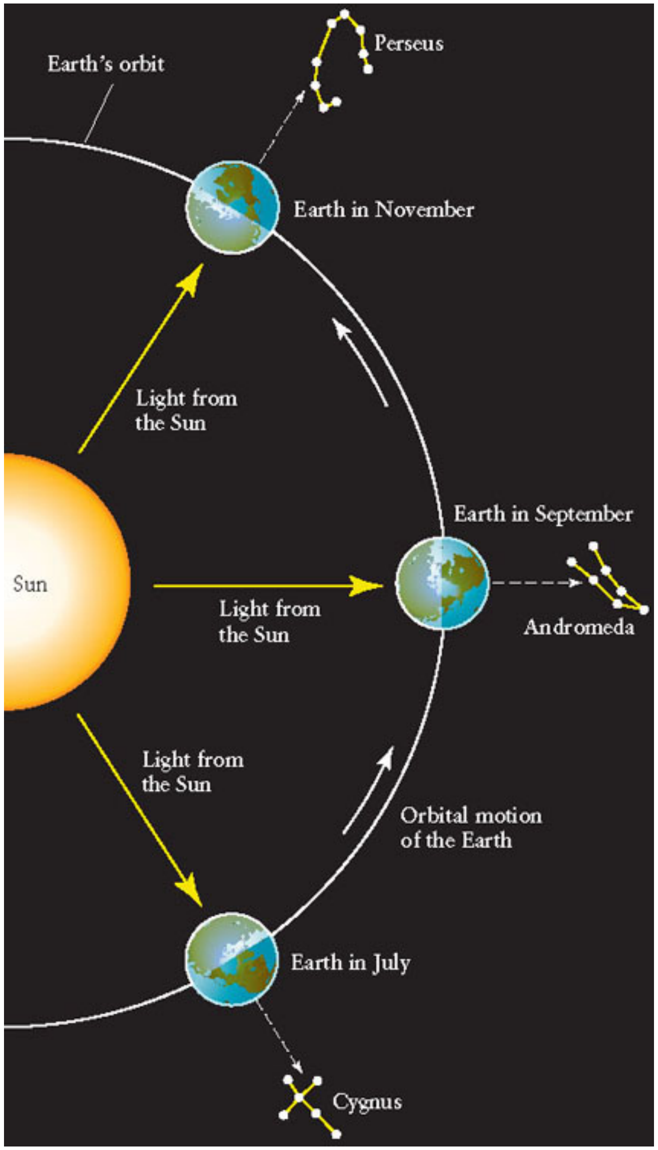


(a) Earth as seen from above the north pole



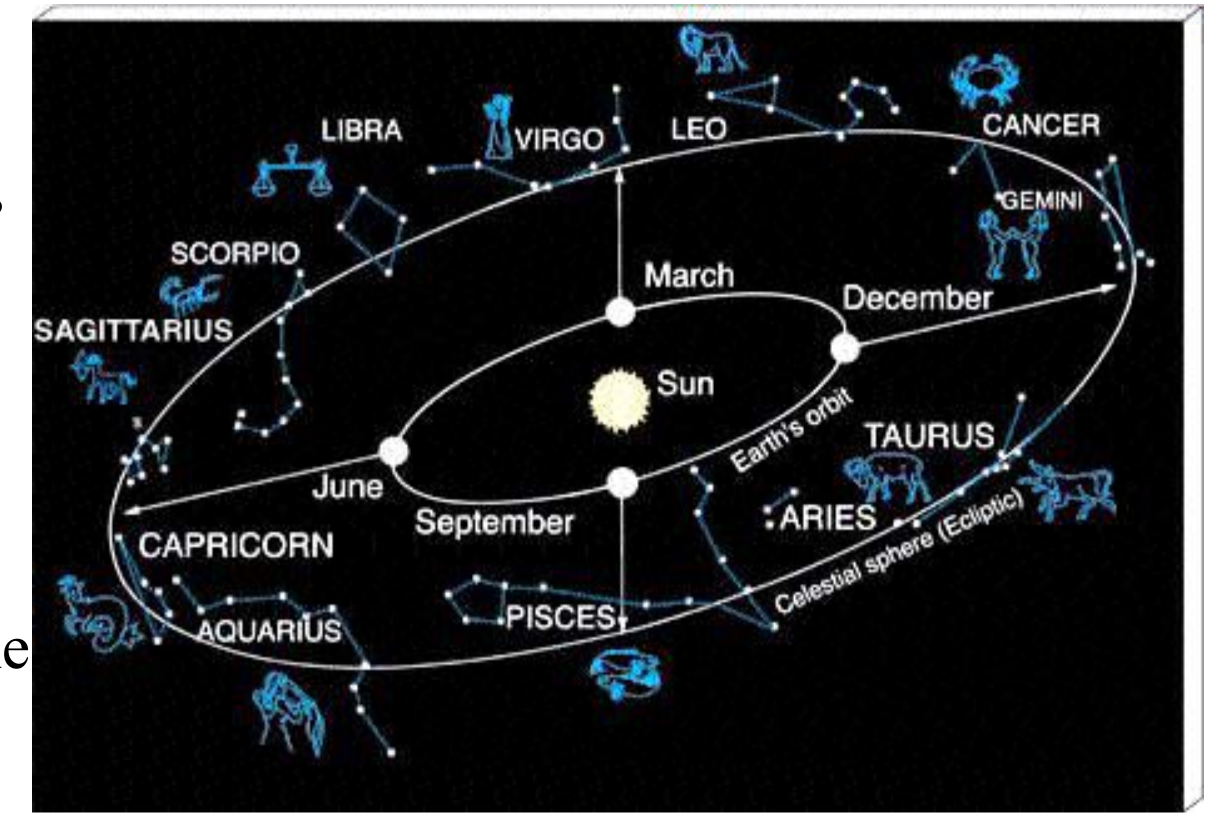
(b) 4 hours (one-sixth of a complete rotation) later

Yearly Motion



Yearly Motion

As the Earth revolves the Sun is projected in front of different constellations at different times of year. The path the Sun takes across the heavens is called the **ecliptic**. The constellations which the Sun passes through are the **zodiac constellations**.

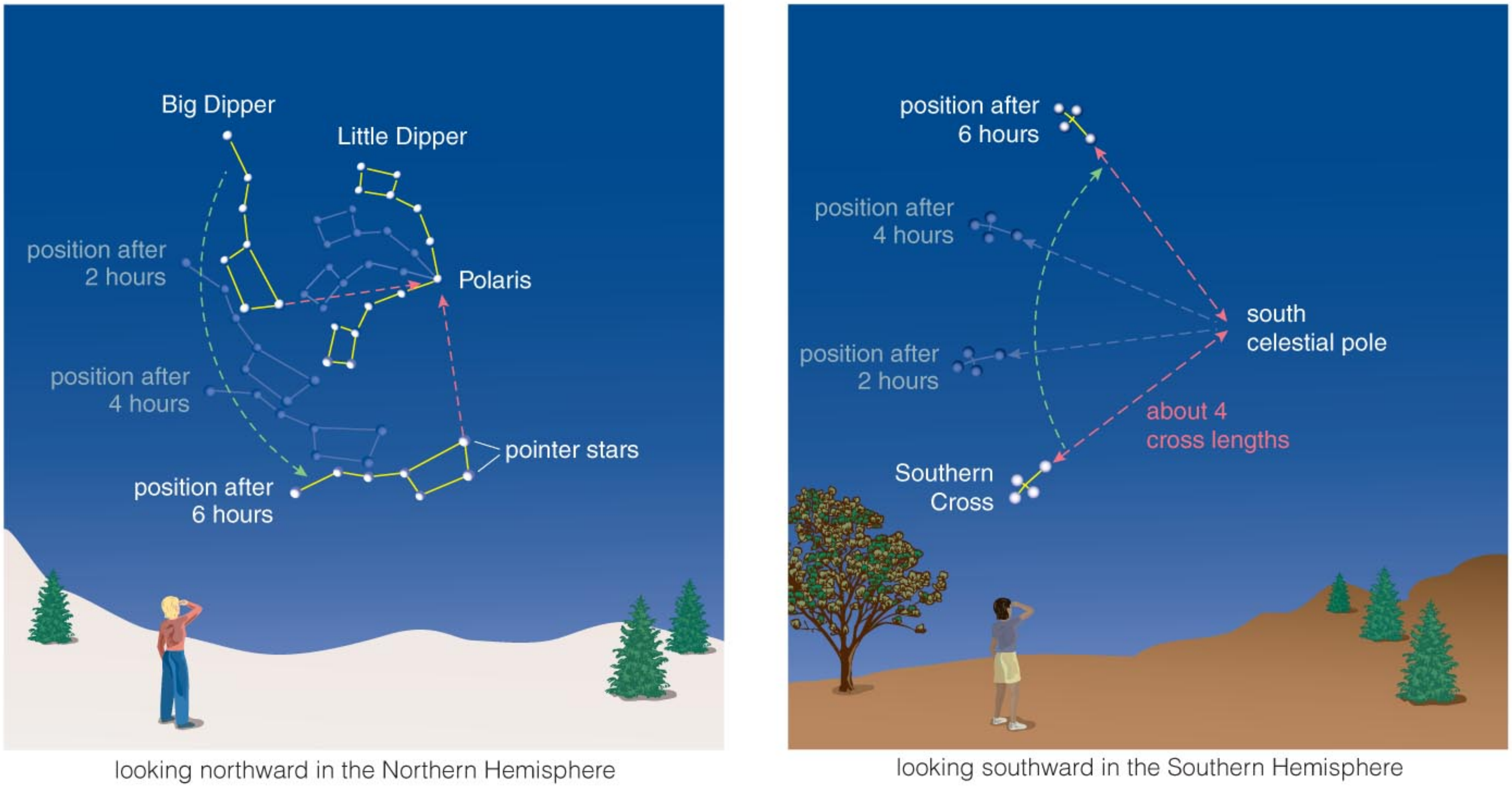


Interactive Figure

Why do the constellations we see depend on latitude and time of year?

- They depend on latitude because your position on Earth determines which constellations remain below the horizon.
- They depend on time of year because Earth's orbit changes the apparent location of the Sun among the stars.

Altitude of the celestial pole = your latitude

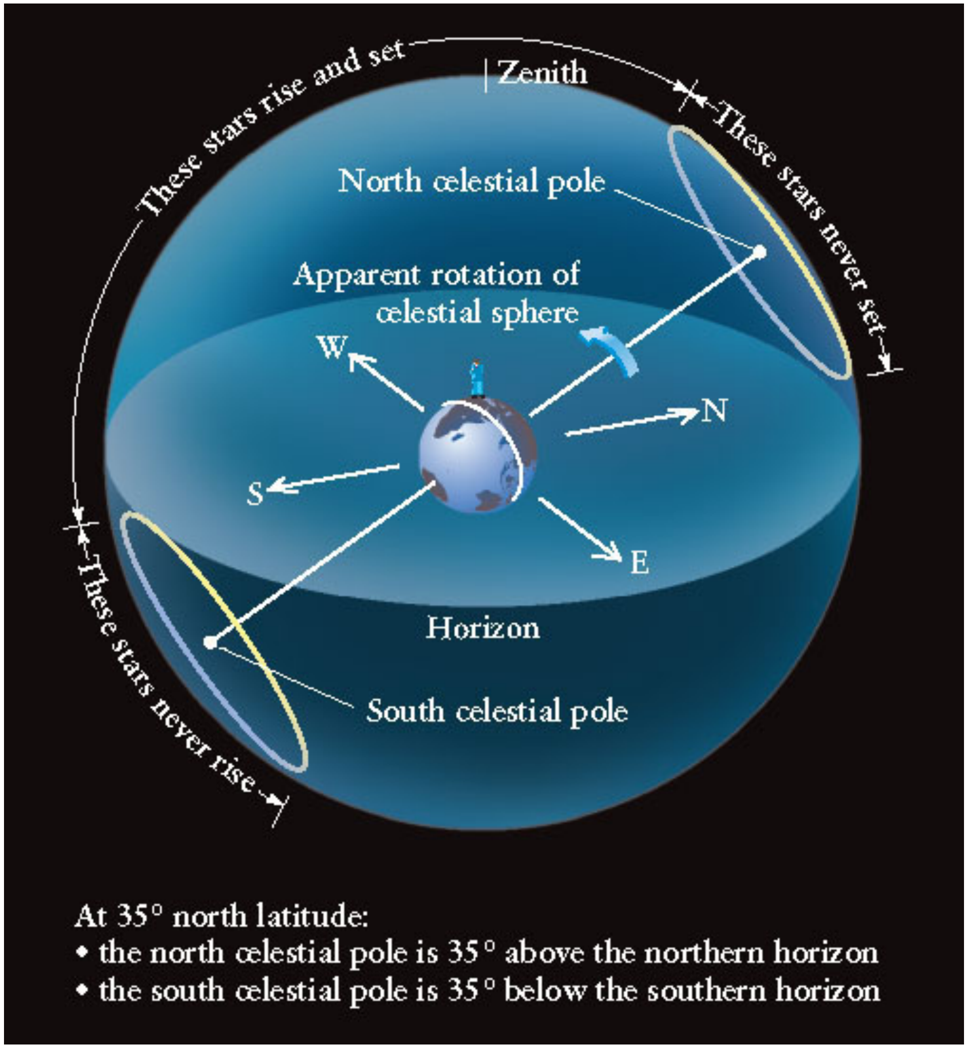


a The pointer stars of the Big Dipper point to the North Star, Polaris, which lies within 1° of the north celestial pole. The sky appears to turn *counterclockwise* around the north celestial pole.

b 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.

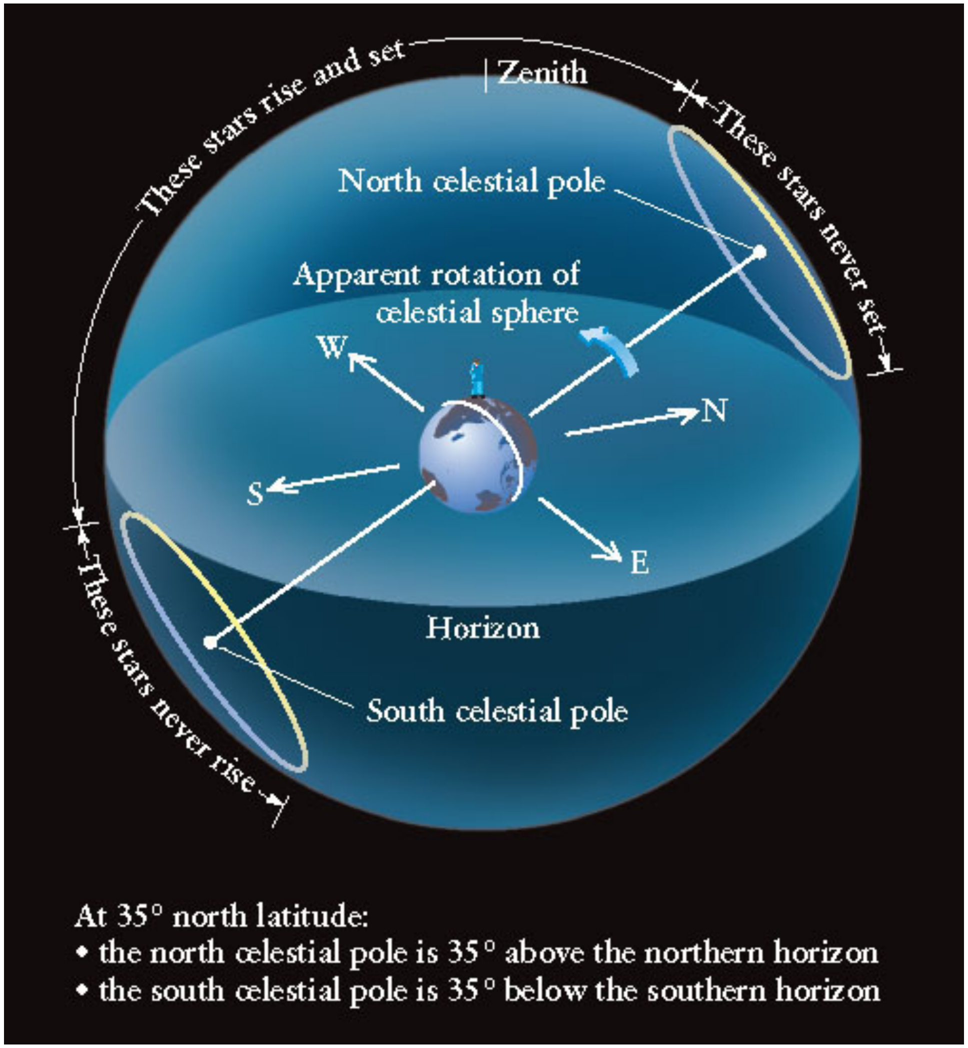
Interactive Figure

Zenith



These stars rise and set
Zenith
These stars never set
North celestial pole
Apparent rotation of celestial sphere
W
N
S
E
Horizon
South celestial pole
These stars never rise
At 35° north latitude:
• the north celestial pole is 35° above the northern horizon
• the south celestial pole is 35° below the southern horizon

Zenith



What is the angle between the North celestial pole and the horizon for an observer :

(a) In Charleston?

(b) At the North Pole?

(c) At the Equator?

What have we learned?

- **What does the universe look like from Earth?**
  - We can see over 2000 stars and the Milky Way with our naked eyes, and each position on the sky belongs to one of 88 constellations.
  - We can specify the position of an object in the local sky by its **altitude** above the horizon and its **azimuth** along the horizon.
- **Why do stars rise and set?**
  - Because of Earth's rotation.

What have we learned?

- **Why do the constellations we see depend on latitude and time of year?**
  - Your location determines which constellations are hidden by Earth.
  - The time of year determines the location of the Sun on the celestial sphere.

The Apparent Motion of Stars

(a) At middle northern latitudes (b) At the north pole (c) At the equator

Animation of motion of stars

2.2 The Reason for Seasons

- Our goals for learning:
  - **What causes the seasons?**
  - **How does the orientation of Earth's axis change with time?**

Thought Question

TRUE OR FALSE? Earth is closer to the Sun in summer and farther from the Sun in winter.

Thought Question

TRUE OR FALSE? Earth is closer to the Sun in summer and farther from the Sun in winter.

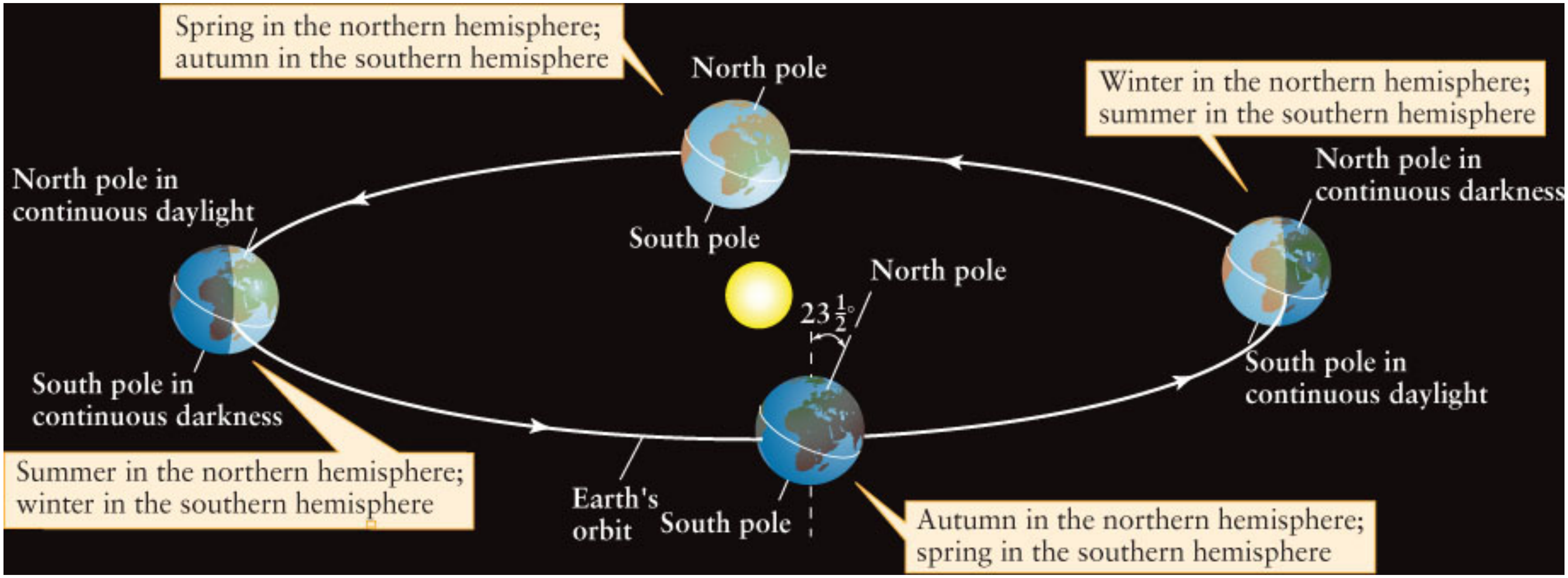
Hint: When it is summer in America, it is winter in Australia.

Thought Question

TRUE OR **FALSE!** Earth is closer to the Sun in summer and farther from the Sun in winter.

- Seasons are opposite in the N and S hemispheres, so distance cannot be the reason.
- The real reason for seasons involves Earth's axis tilt.

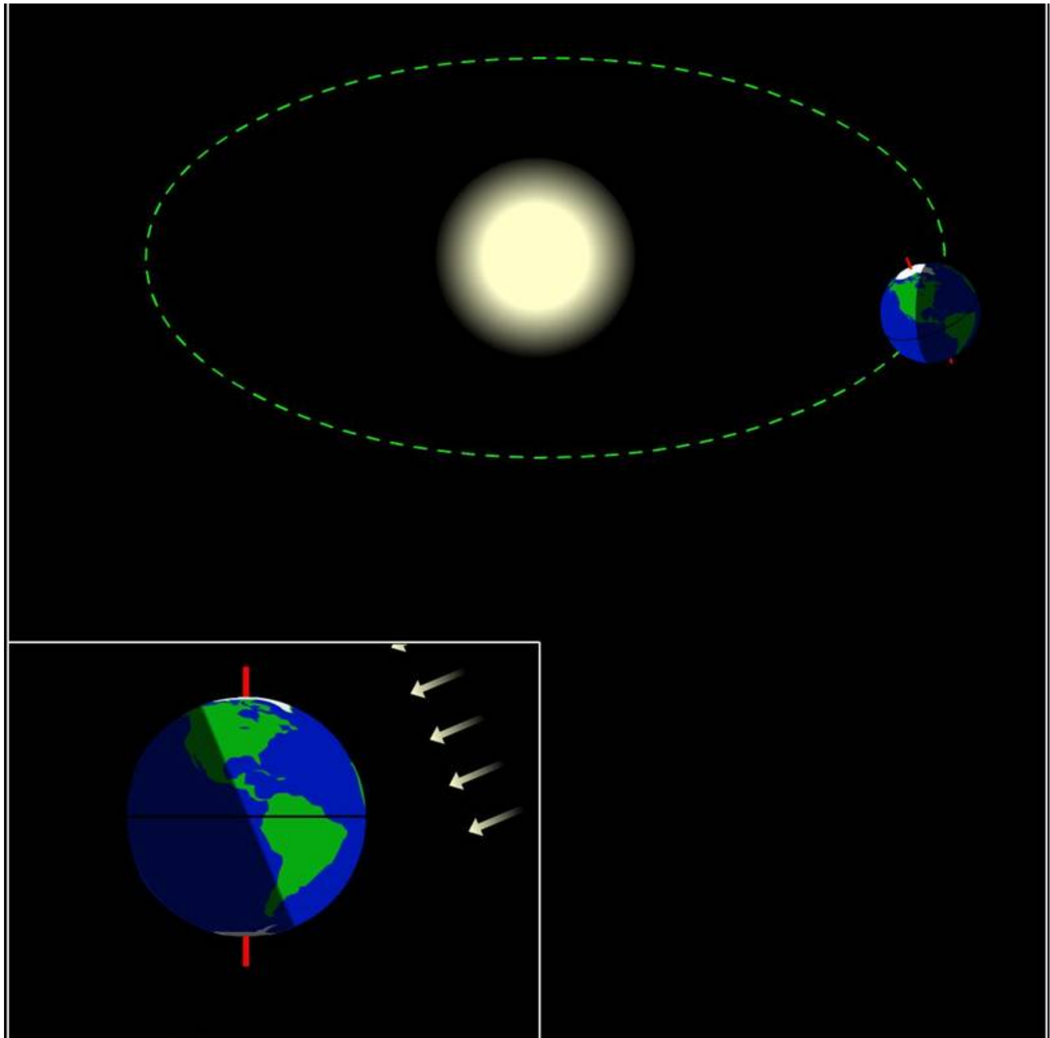
What causes the seasons?



Interactive Figure

- Seasons depend on how Earth's axis affects the directness of sunlight.

Axis tilt changes directness of sunlight during the year.



Interactive Figure

Sun's altitude also changes with seasons.

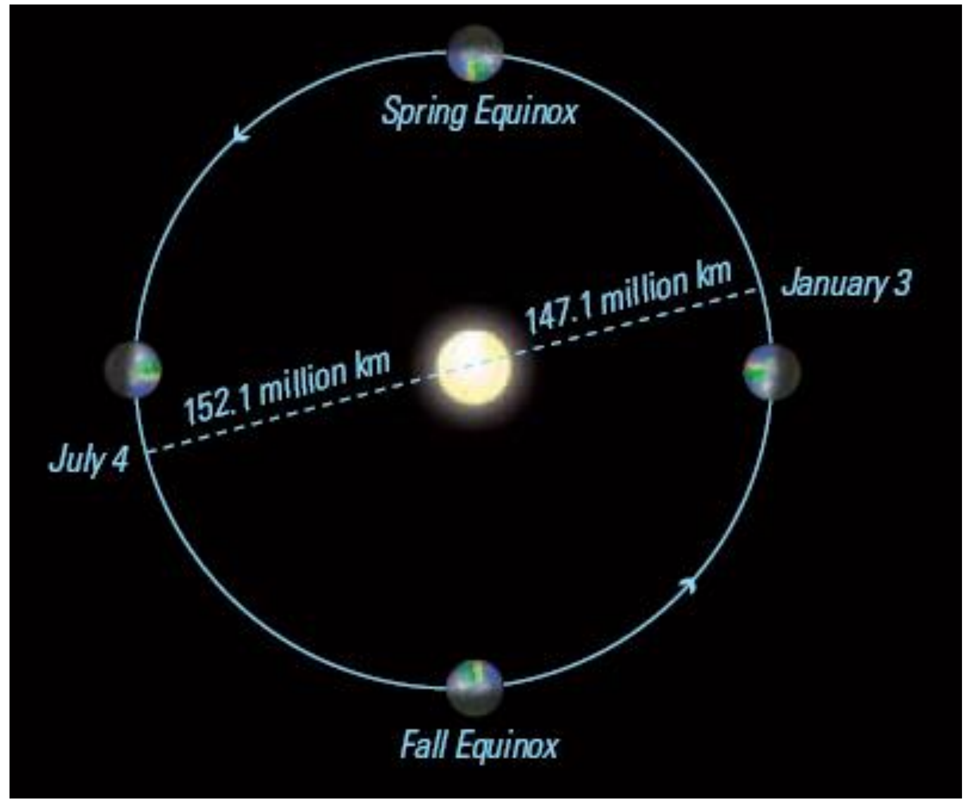
- Sun's position at noon in summer: Higher altitude means more direct sunlight.
- Sun's position at noon in winter: Lower altitude means less direct sunlight.

Summary: The Real Reason for Seasons

- Earth's axis points in the same direction (to Polaris) all year round, so its orientation *relative to the Sun* changes as Earth orbits the Sun.
- Summer occurs in your hemisphere when sunlight hits it more directly; winter occurs when the sunlight is less direct.
- **AXIS TILT** is the key to the seasons; without it, we would not have seasons on Earth.

Why *doesn't* distance matter?

- Variation of Earth–Sun distance is small—about 3%; this small variation is overwhelmed by the effects of axis tilt.
- Variation in any season of each hemisphere-Sun distance is even smaller!



How do we mark the progression of the seasons?

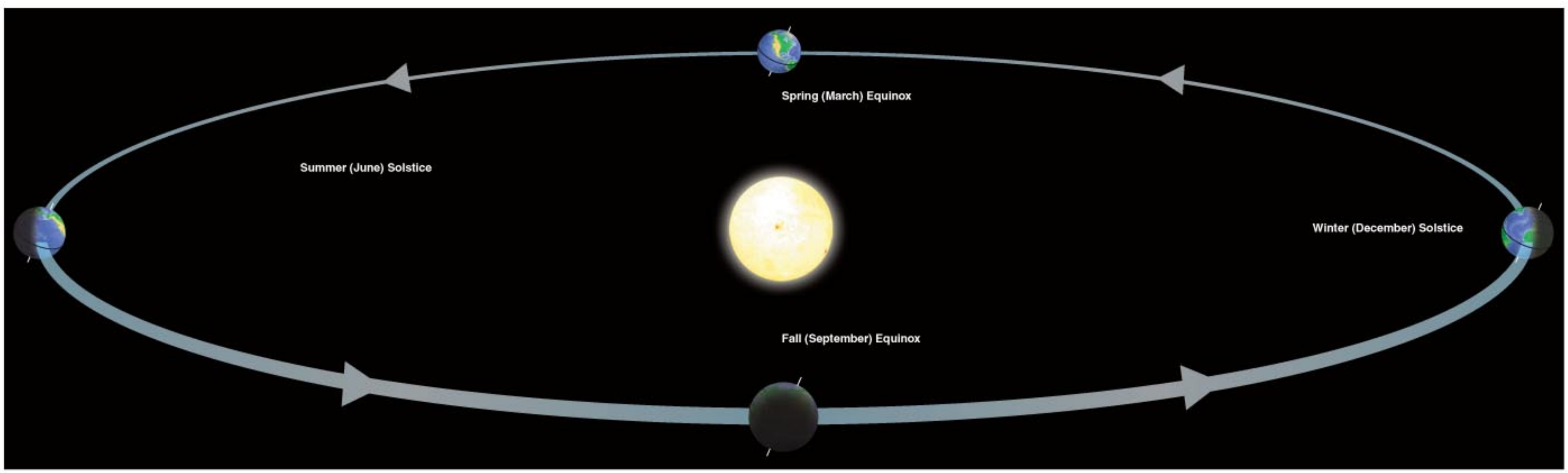
- We define four special points:

  summer (June) solstice

  winter (December) solstice

  spring (March) equinox

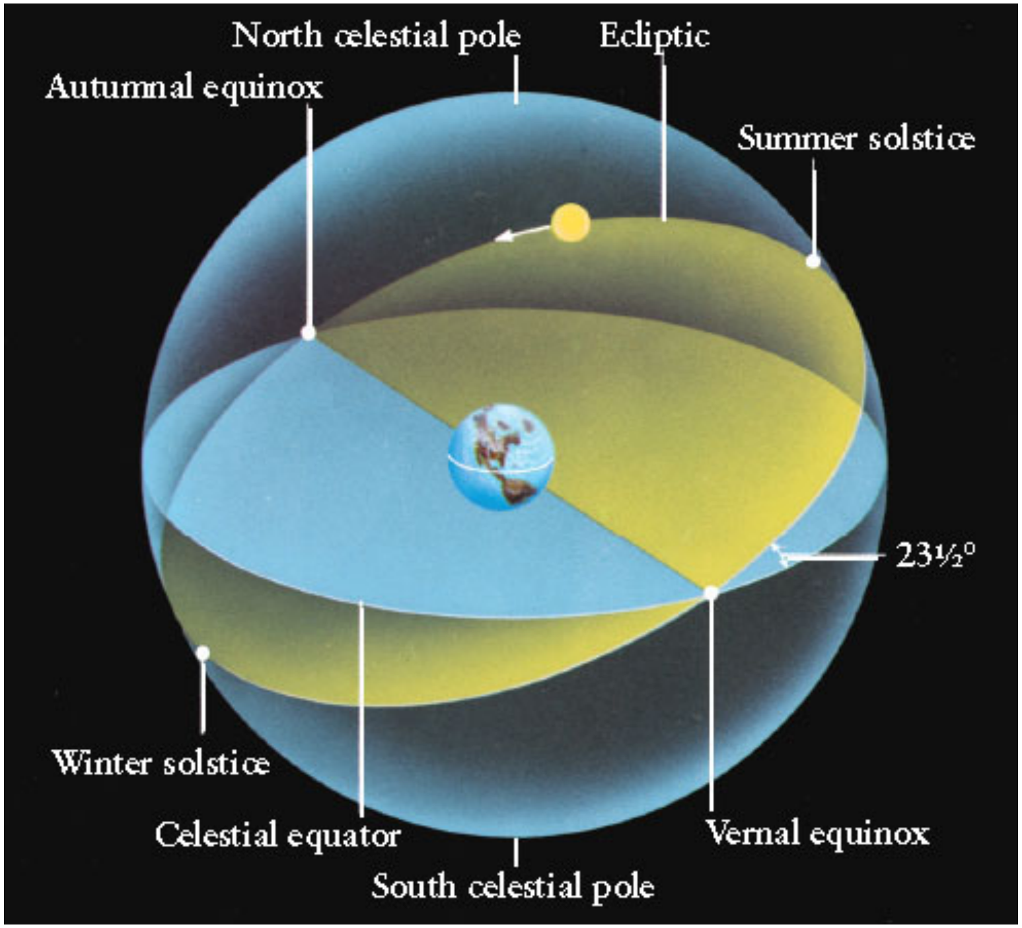
  fall (September) equinox



The Ecliptic, Equinoxes and Solstices

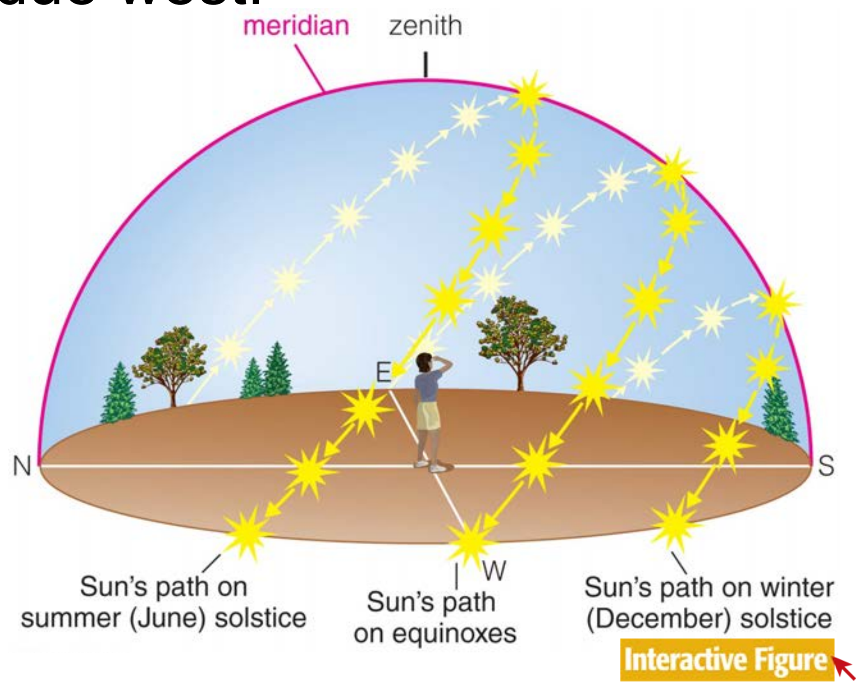
The ecliptic intercepts the celestial equator at the vernal equinox (March 21) and the autumnal equinox (Sept 22).

The northernmost point on the ecliptic is the summer solstice (June 21), and the southernmost point is the winter solstice (December 21).

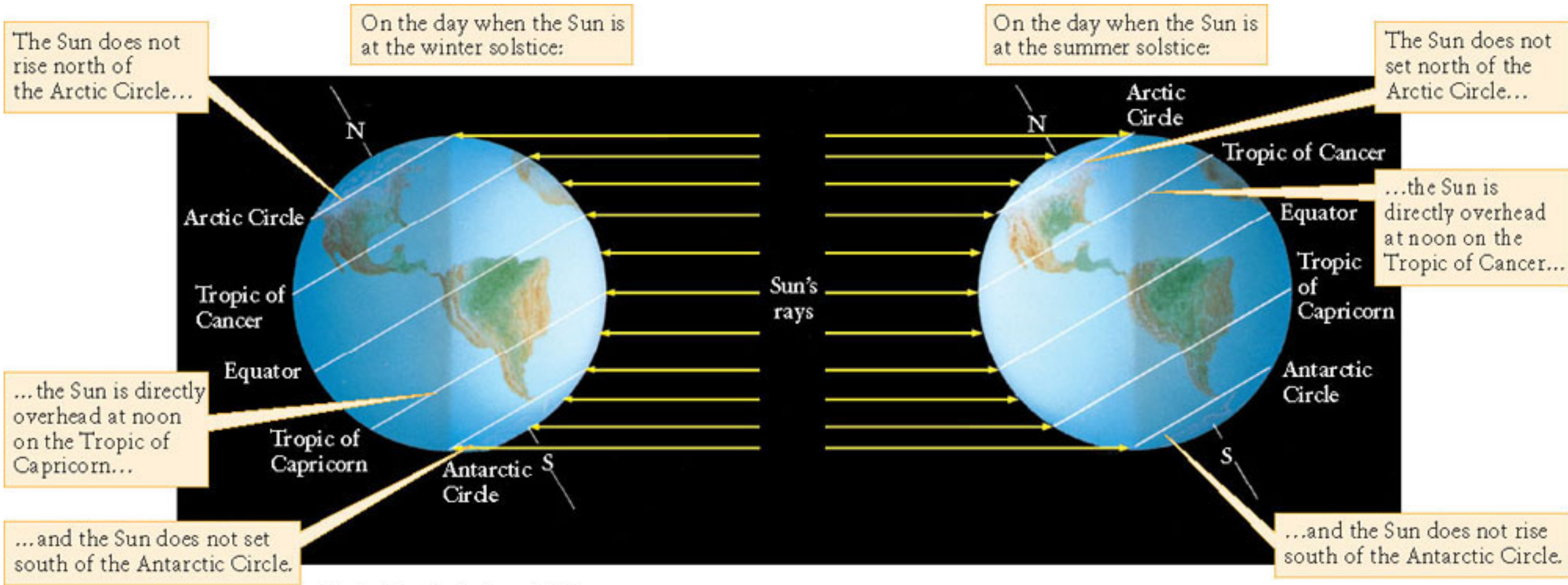


We can recognize solstices and equinoxes by Sun's path across sky:

- Summer (June) solstice: highest path; rise and set at most extreme north of due east
- Winter (December) solstice: lowest path; rise and set at most extreme south of due east
- Equinoxes: Sun rises precisely due east and sets precisely due west.



Tropics and Circles



(a) Earth at winter solstice

(b) Earth at summer solstice

Artic Circle: 66 1/2° North Latidute

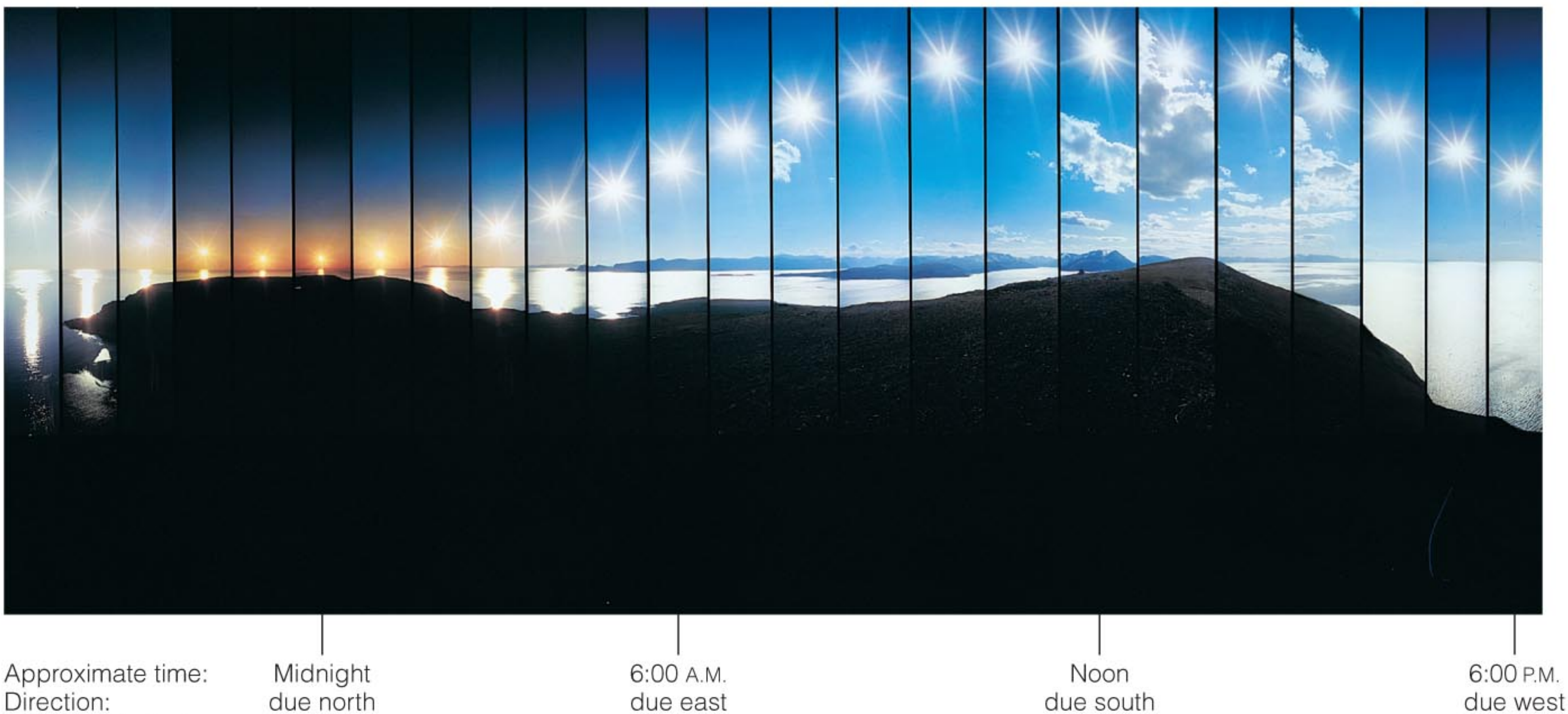
Antartic Circle: 66 1/2° South Latitude

Tropic of Cancer: 23 1/2° North latitude

Tropic of Capricorn : 23 1/2° South Latitude

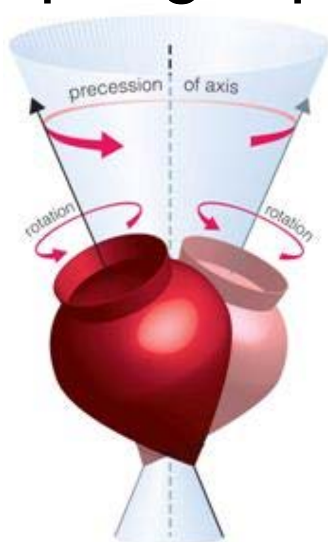
Seasonal changes are more extreme at high latitudes.

- Path of the Sun on the summer solstice at the Arctic Circle

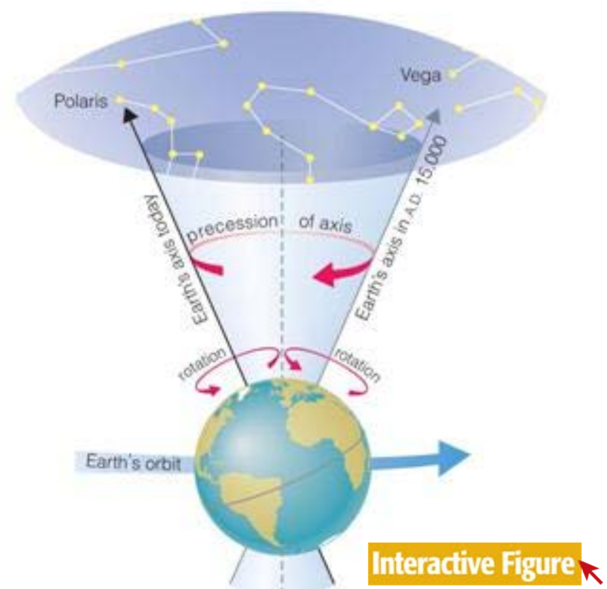


How does the orientation of Earth's axis change with time?

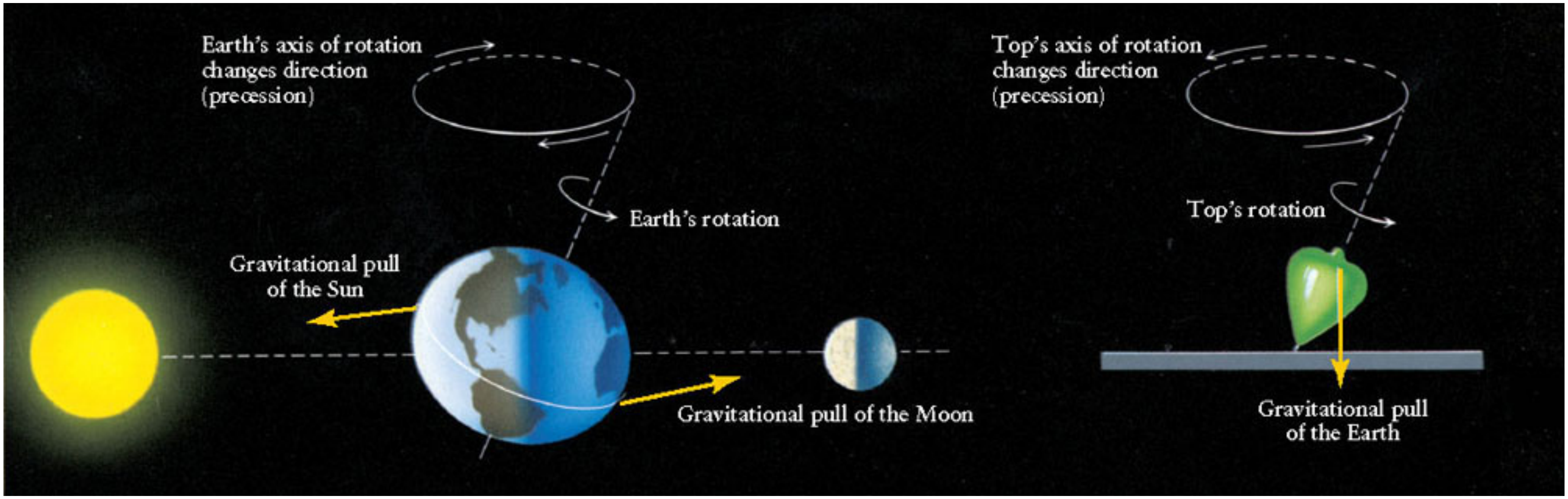
- Although the axis seems fixed on human time scales, it actually precesses over about 26,000 years.
  - ⇒ Polaris won't always be the North Star.
  - ⇒ Positions of equinoxes shift around orbit; e.g., spring equinox, once in *Aries*, is now in *Pisces*!



Earth's axis precesses like the axis of a spinning top



Earth’s Precession



In addition to its rotation and revolution, the Earth’s axis also precesses (wobbles) like a top. The angle between the ecliptic and the equator remains at 23.5°, but the direction changes. The period of this precession of the equinoxes is about 26,000 years. [Animation of Earth's Precession.]

What have we learned?

- **What causes the seasons?**
  - The tilt of the Earth's axis causes sunlight to hit different parts of the Earth more directly during the summer and less directly during the winter.
  - We can specify the position of an object in the local sky by its **altitude** above the horizon and its **azimuth** along the horizon.
  - The **summer and winter solstices** are when the Northern Hemisphere gets its most and least direct sunlight, respectively. The **spring and fall equinoxes** are when both hemispheres get equally direct sunlight.

What have we learned?

- **How does the orientation of Earth's axis change with time?**
  – The tilt remains about 23.5° (so the season pattern is not affected), but Earth has a 26,000 year precession cycle that slowly and subtly changes the orientation of Earth's axis.

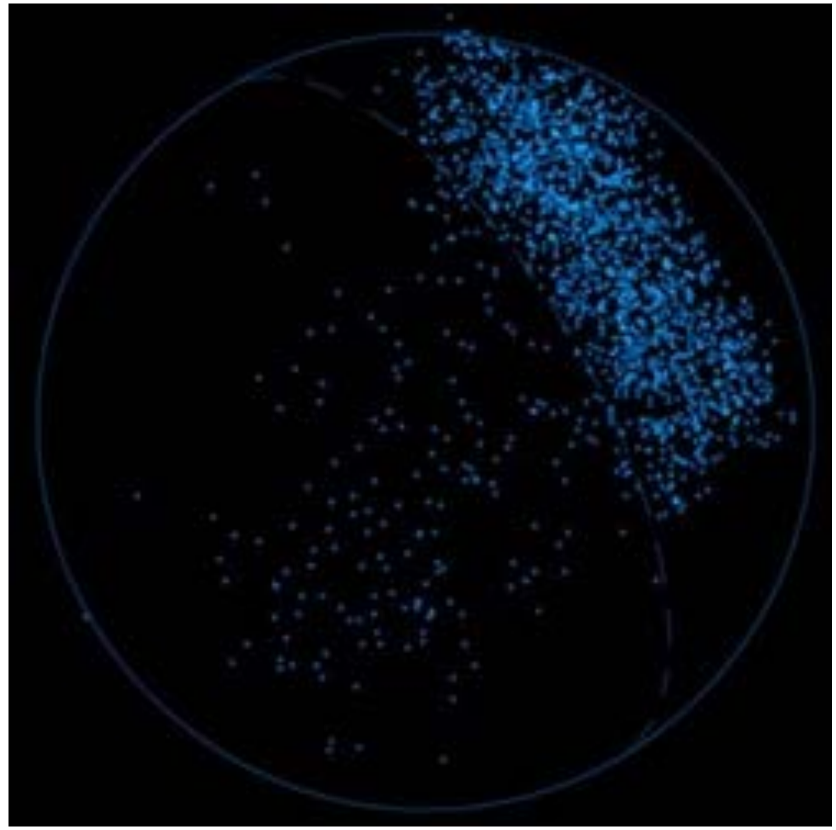
2.3 The Moon, Our Constant Companion

- Our goals for learning:
  - **Why do we see phases of the Moon?**
  - **What causes eclipses?**

The Orbital Motion of the Moon

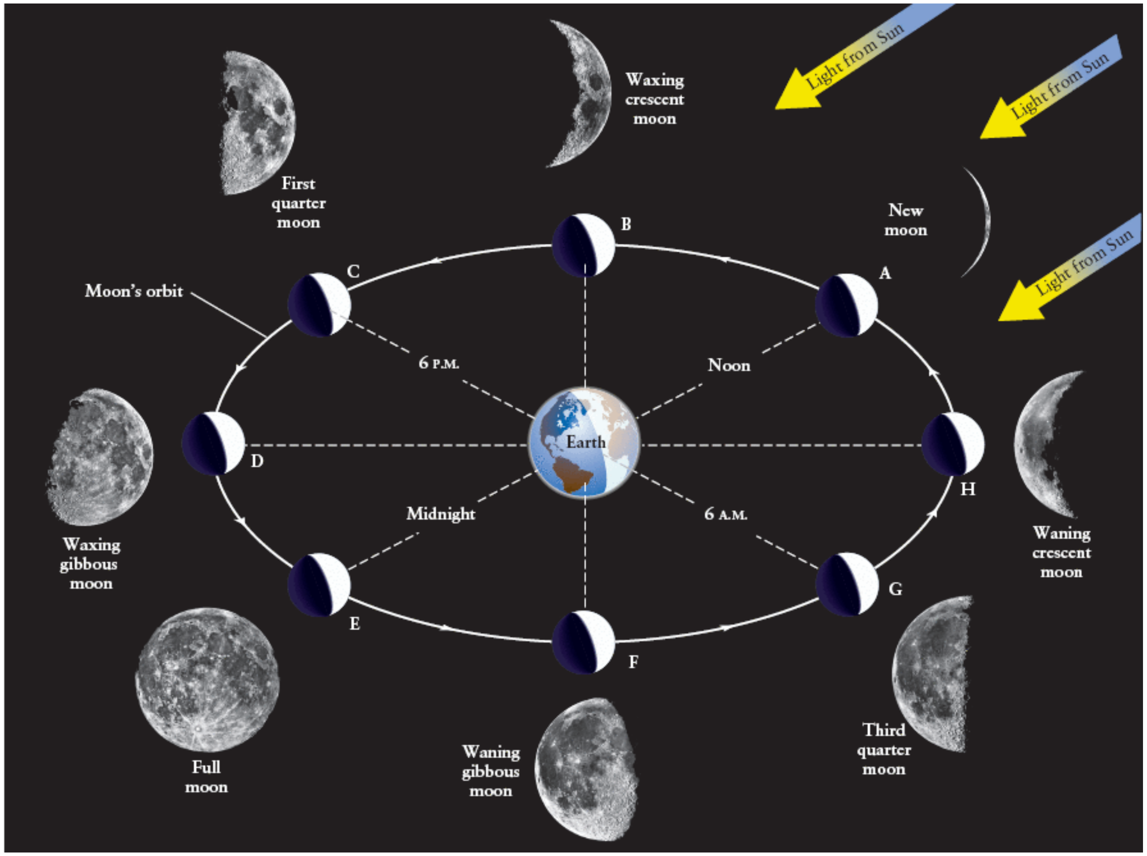
Optical and X-ray light from the Moon

Image taken from Apollo 11 during its trip back to Earth



X-rays from the Moon

Optical and X-ray light from the Moon



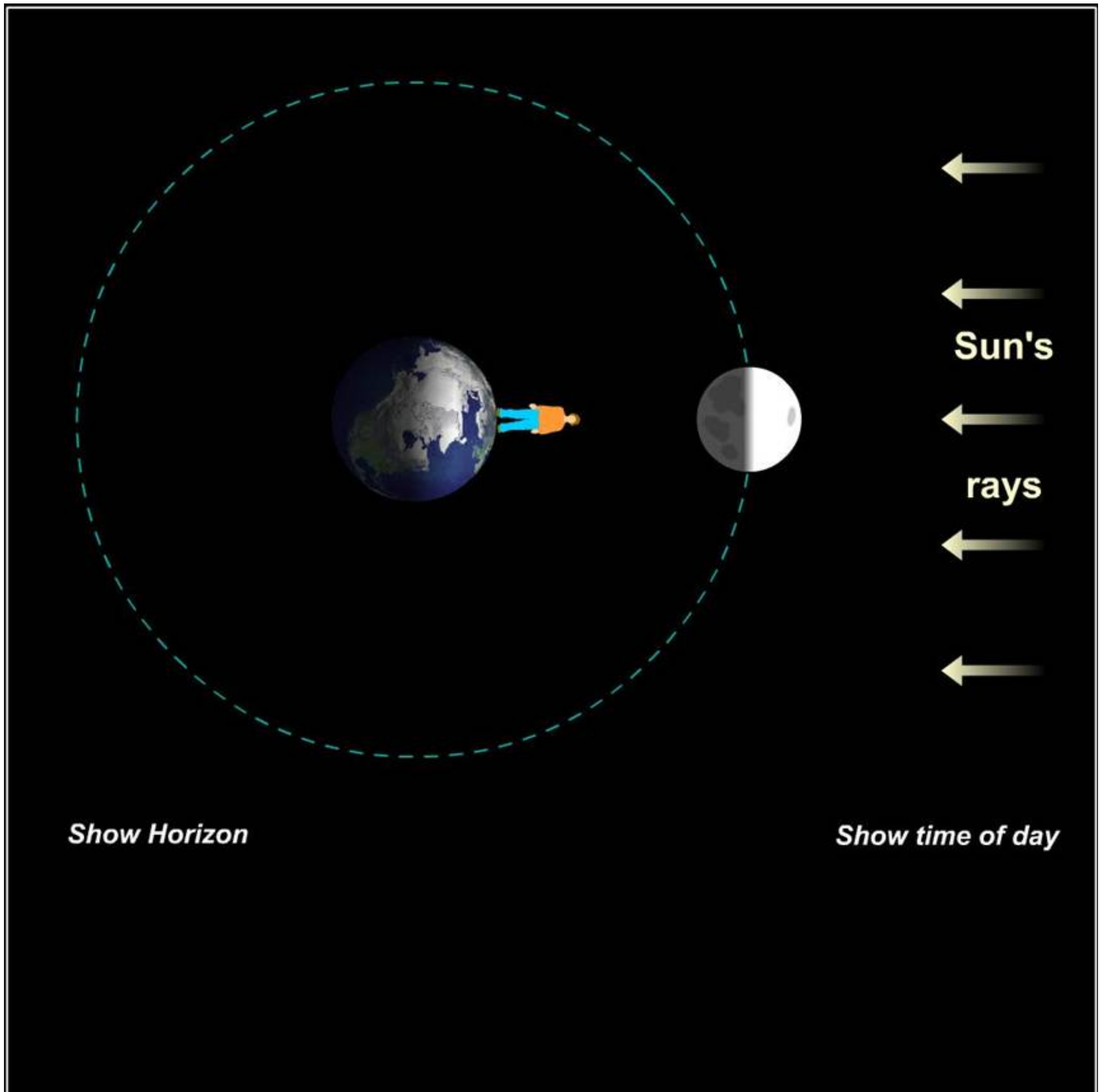
Full Moon occurs when the Moon is opposite *in the sky* from the Sun. This is called opposition.

New Moon occurs when the Moon is in the same direction as the Sun, *i.e.*, in conjunction.

Half the moon is always illuminated by the sun.

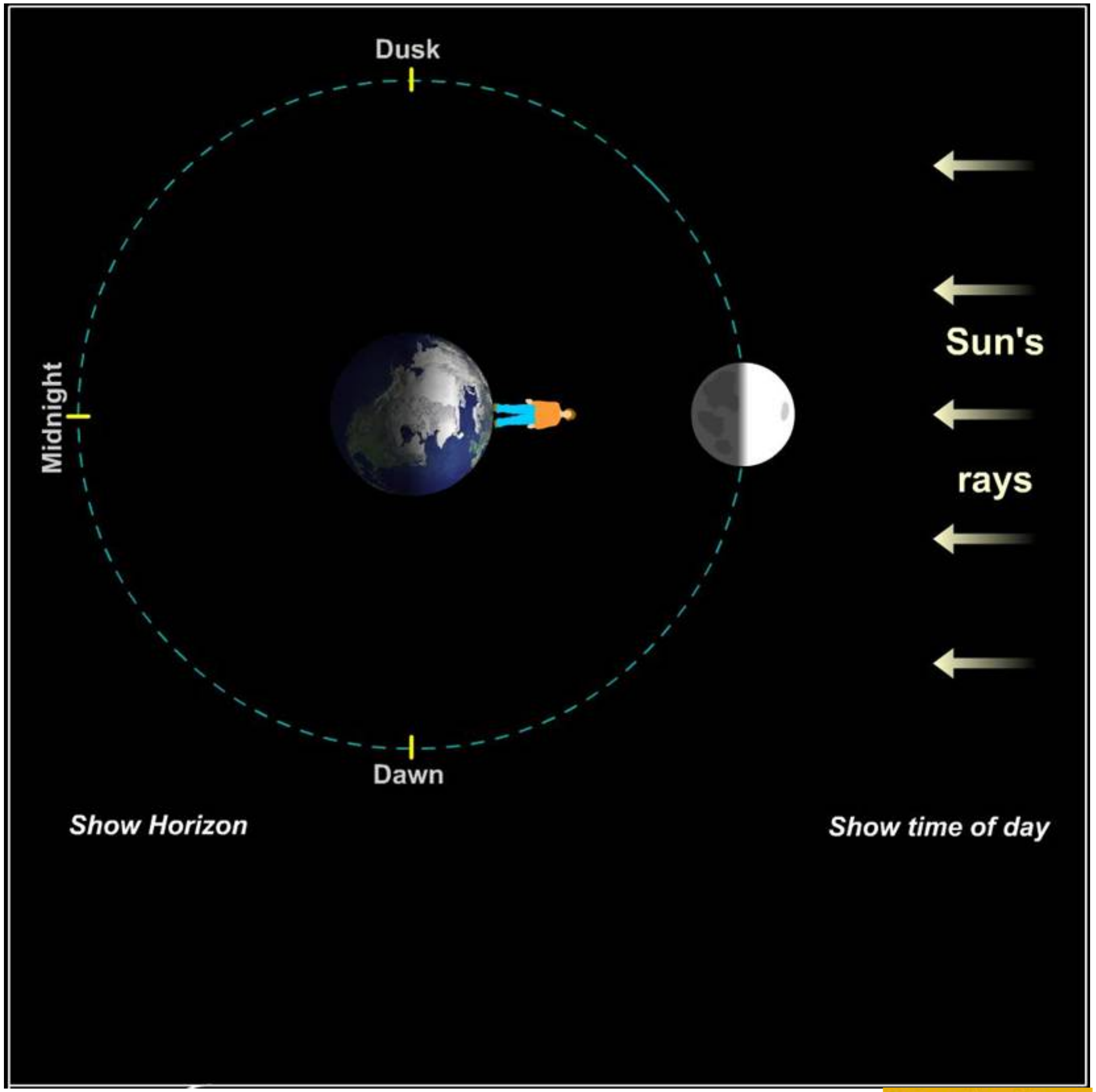
[Animation of Phases](#)

Phases of the Moon



Interactive Figure

Moon Rise/Set by Phase

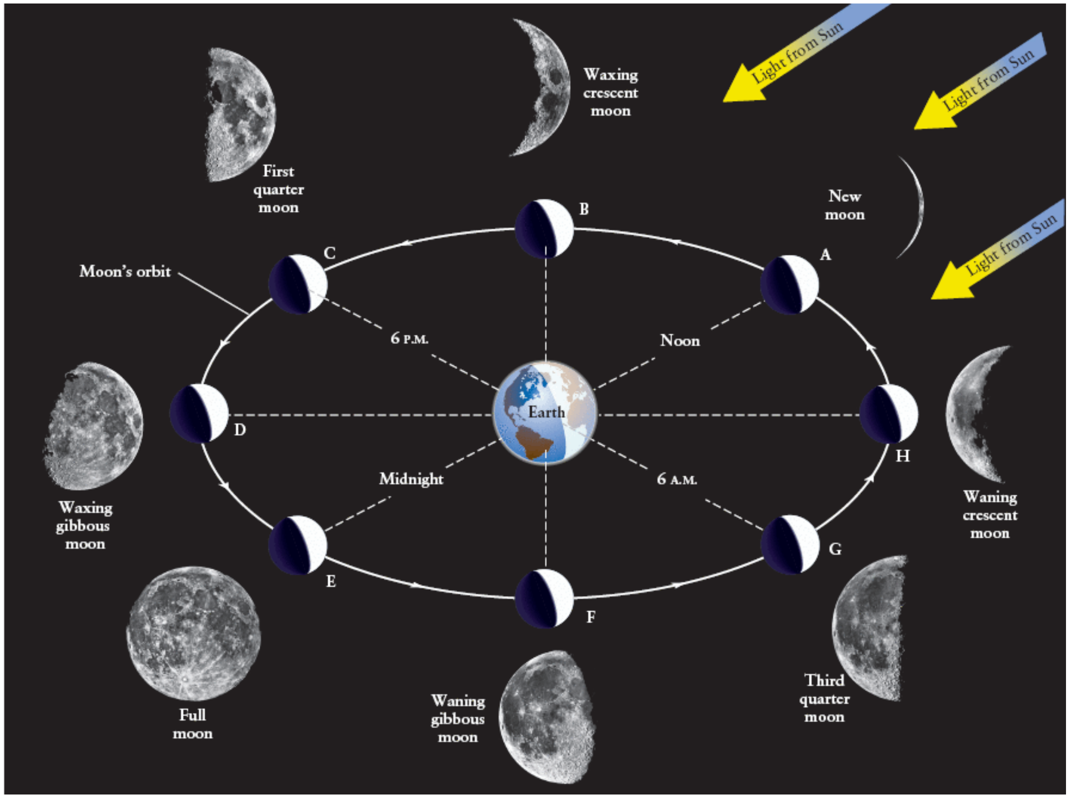


Interactive Figure

Thought Question

It's 9 a.m. You look up in the sky and see a moon with half its face bright and half dark. What phase is it?

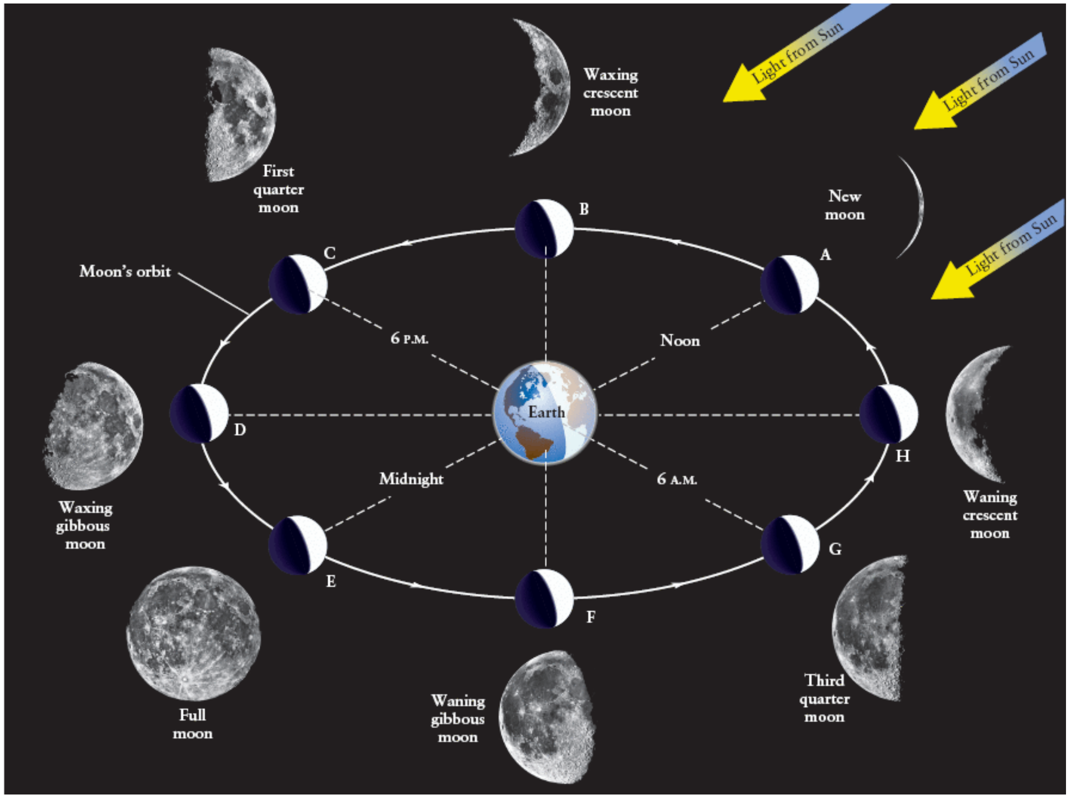
A. first quarter
B. waxing gibbous
C. third quarter
D. half moon



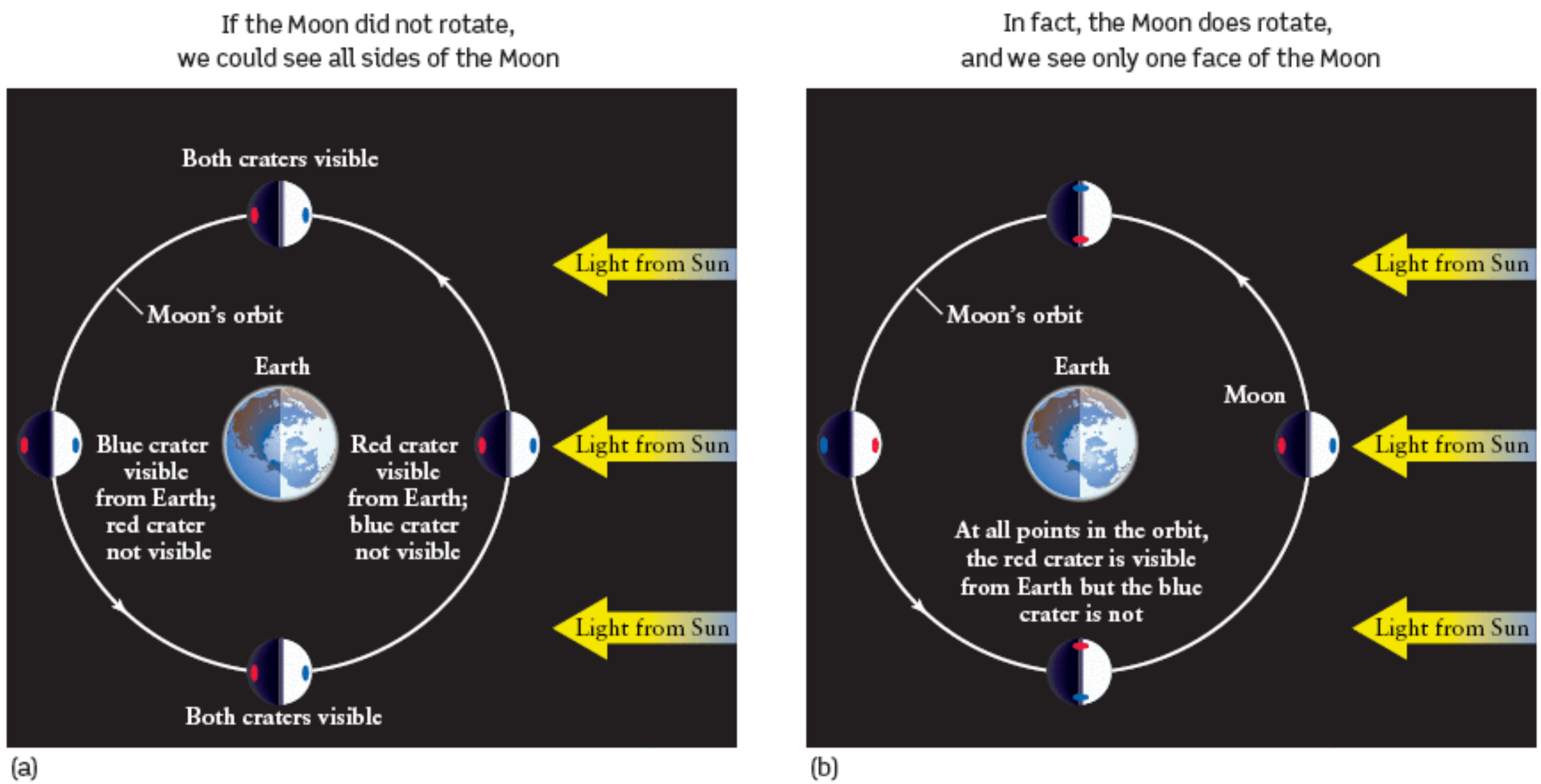
Thought Question

It's 9 a.m. You look up in the sky and see a moon with half its face bright and half dark. What phase is it?

A. first quarter
B. waxing gibbous
C. third quarter
D. half moon



Keeping the Same Face



We always see the same face of the Moon. This occurs because the moon is locked in a synchronous orbit with the Earth.

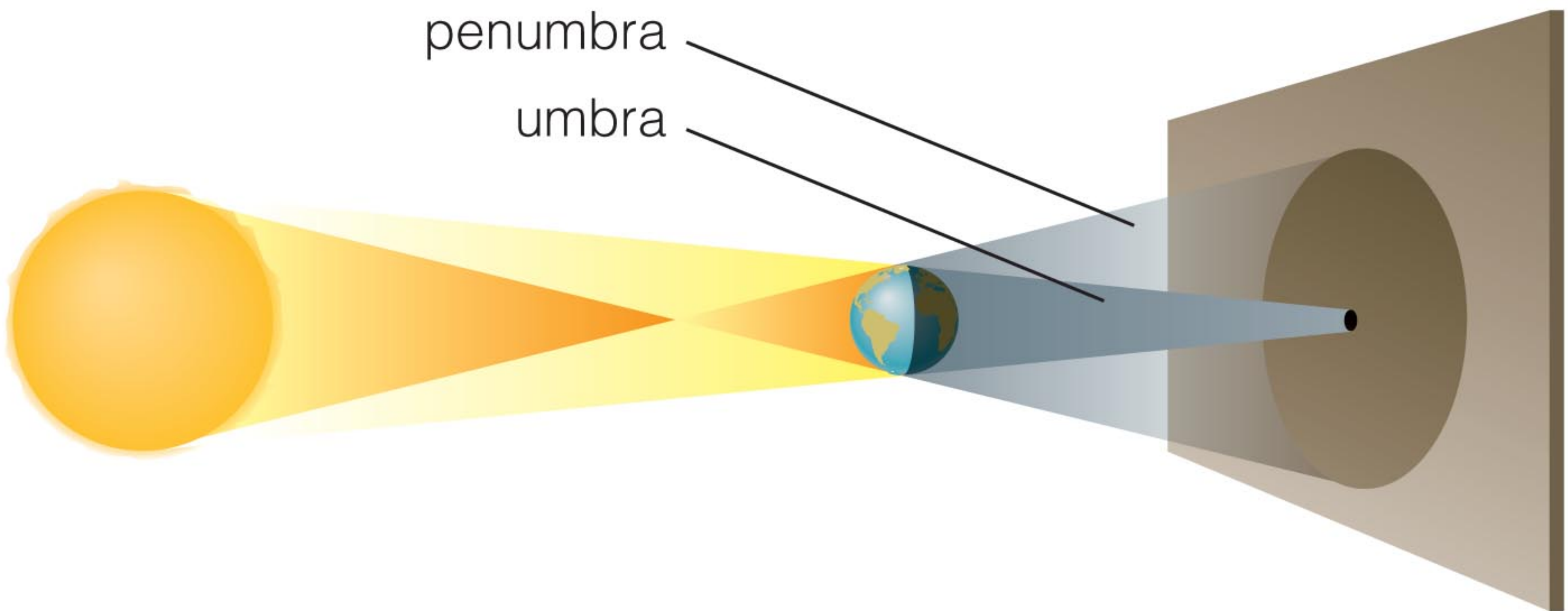
The moon performs one revolution about its spin axis for one revolution around the Earth. [Animation of Moon's rotation]

But what about Pink Floyd's… The Dark Side of the Moon

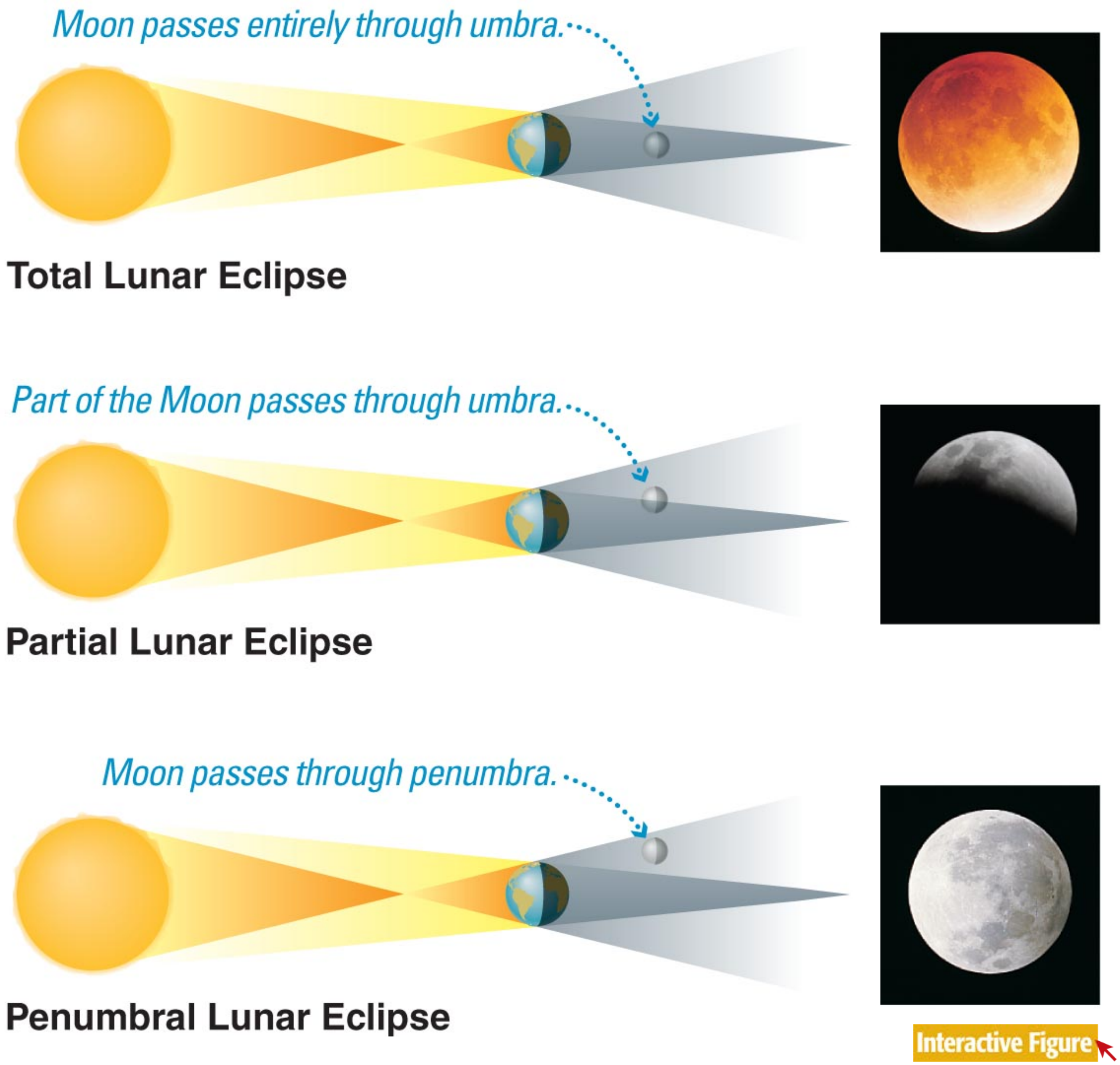
What if Pink Floyd had taken Astro 129… there would be no *dark side of the moon* album.

What causes eclipses?

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

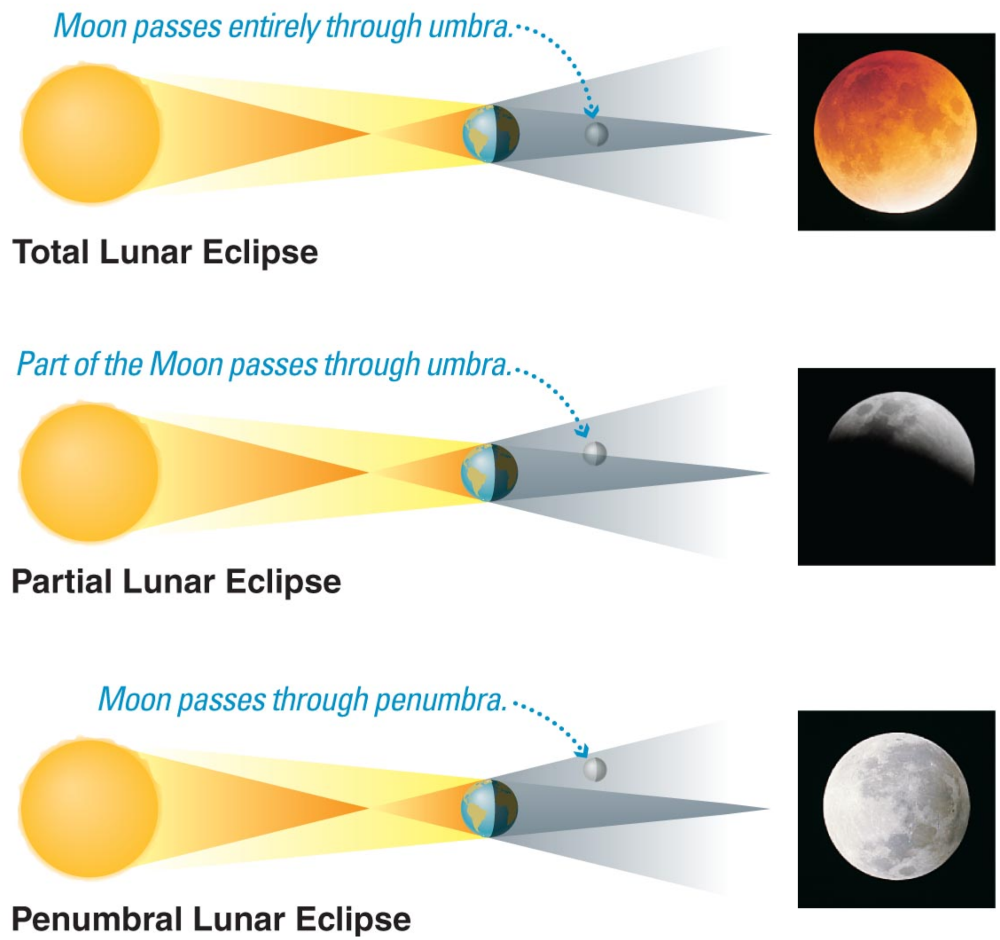


Lunar Eclipse

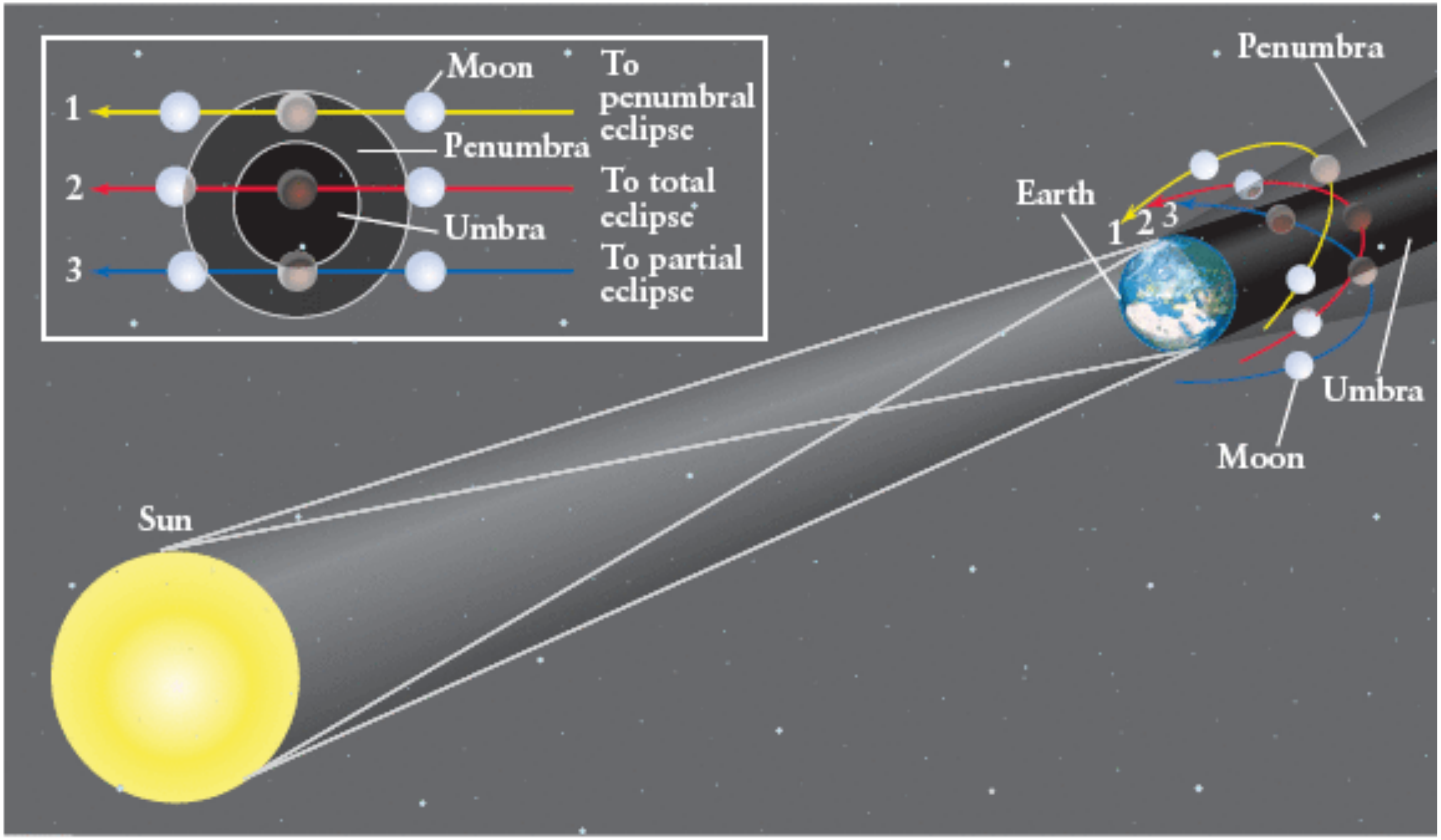


When can lunar eclipses occur?

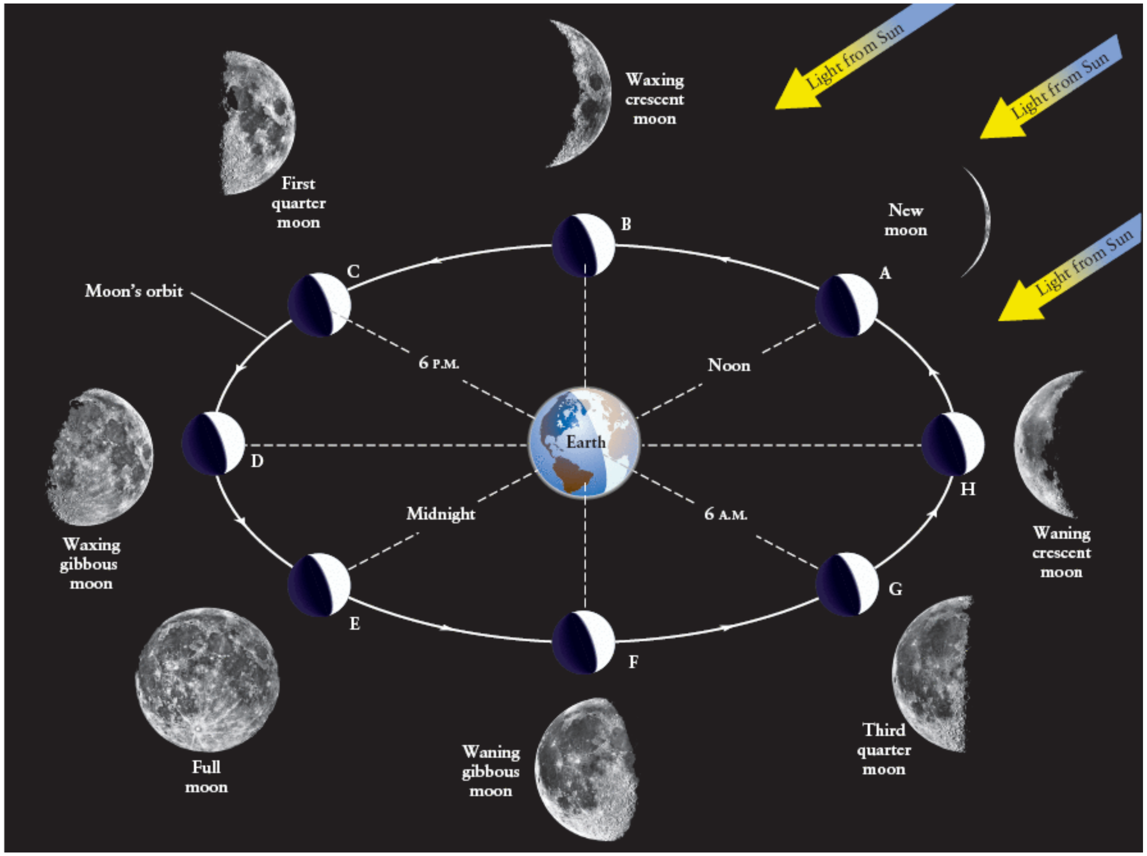
- **Lunar eclipses** can occur only at *full moon*.
- Lunar eclipses can be **penumbral**, **partial**, or **total**.



Three Types of Lunar Eclipses

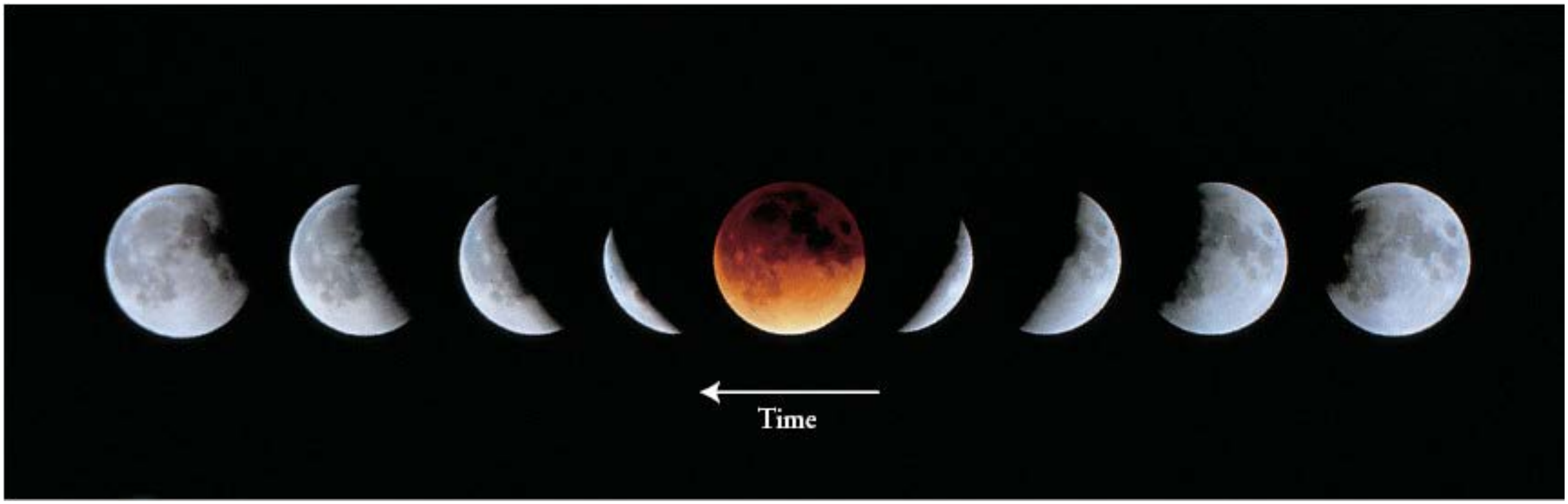


When can lunar eclipses occur?



For a lunar eclipse to occur the moon has to be in position E and the Earth, Moon and Sun must be on the same line.

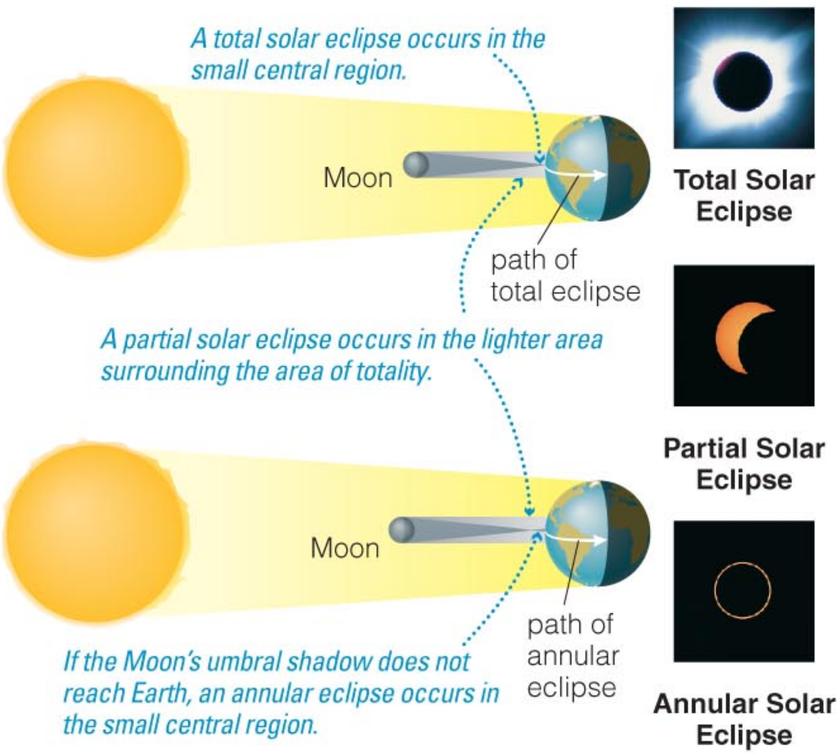
A Total Lunar Eclipse



How long does the lunar eclipse approximately last? (hint: v_{moon} = 1km/s, D_{Earth} = 12,800 km

Explain the right to left time arrow.

Solar Eclipse



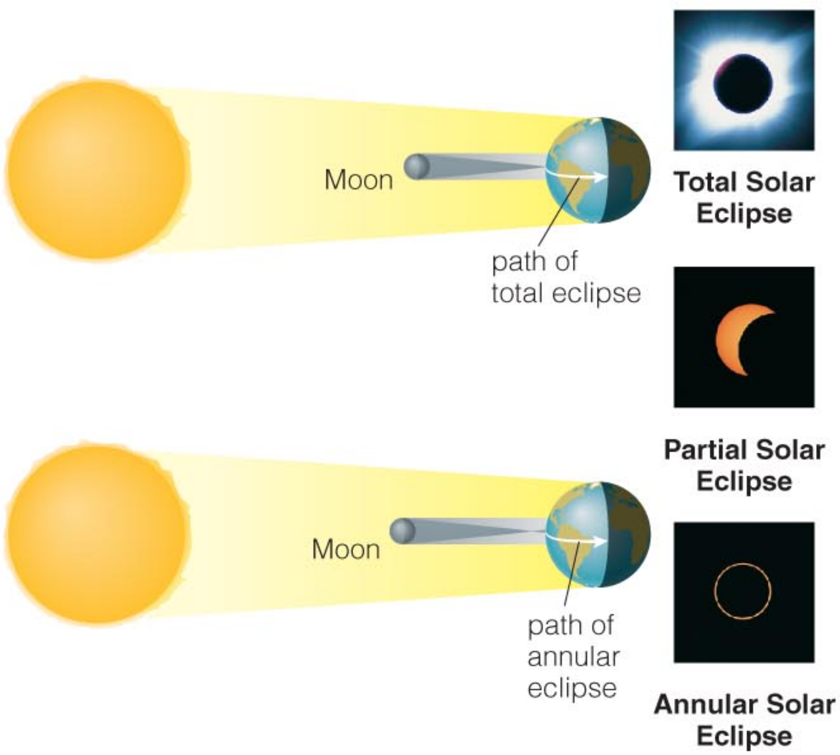
a The three types of solar eclipse. The diagrams show the Moon's shadow falling on Earth; note the dark central umbra surrounded by the much lighter penumbra.

b This photo from Earth orbit shows the Moon's shadow (umbra) on Earth during a total solar elipse. Notice that only a small region of Earth experiences totality at any one time.

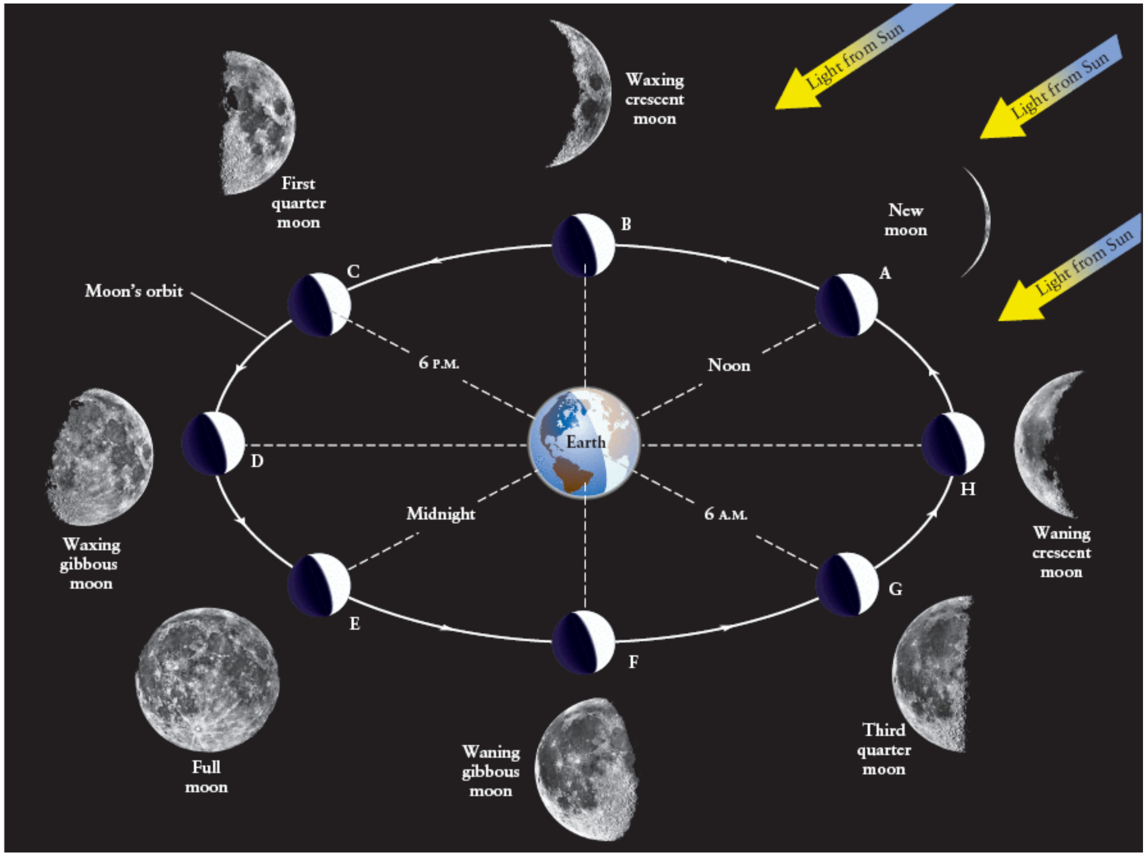
Interactive Figure

When can eclipses occur?

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

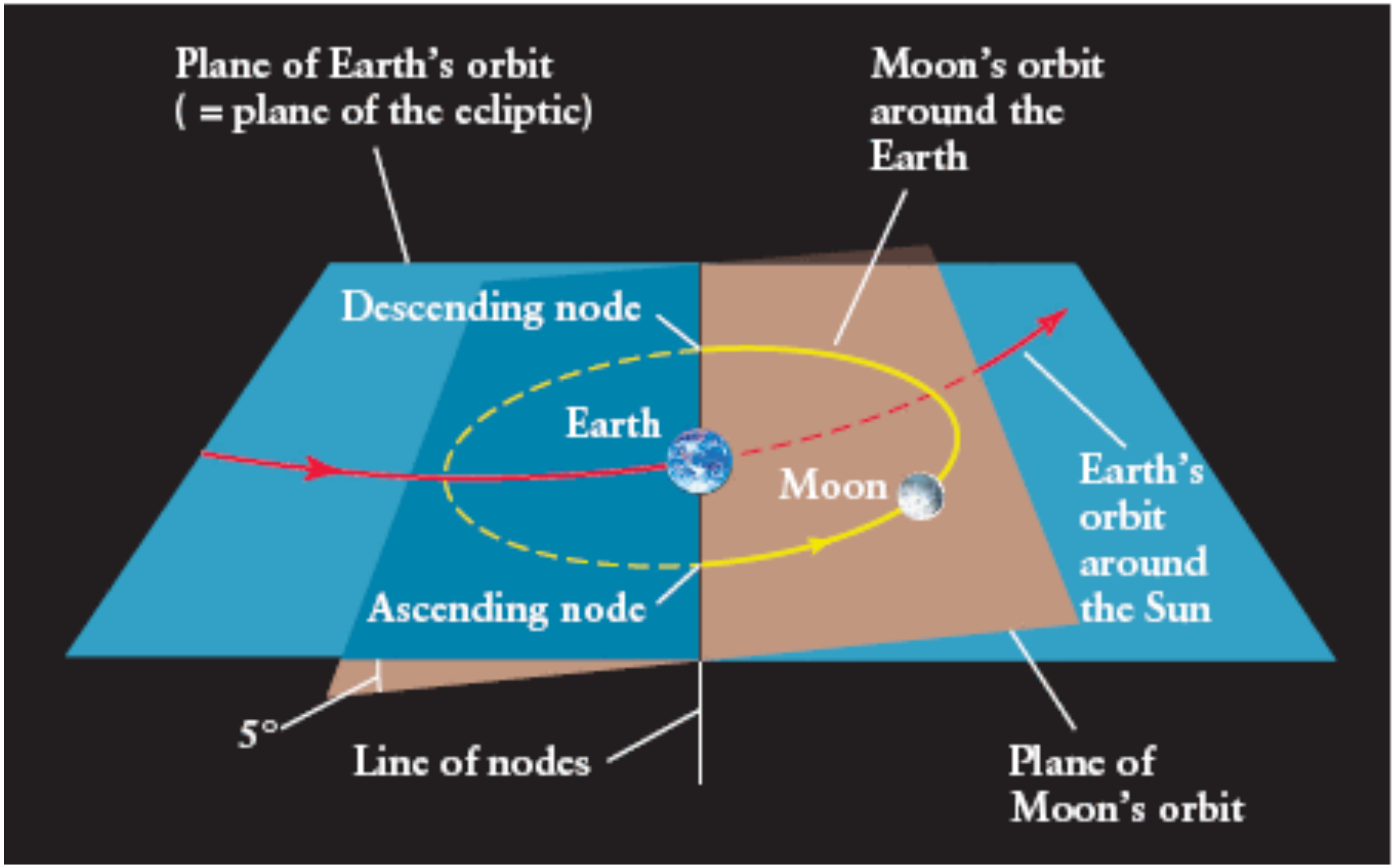


When can solar eclipses occur?



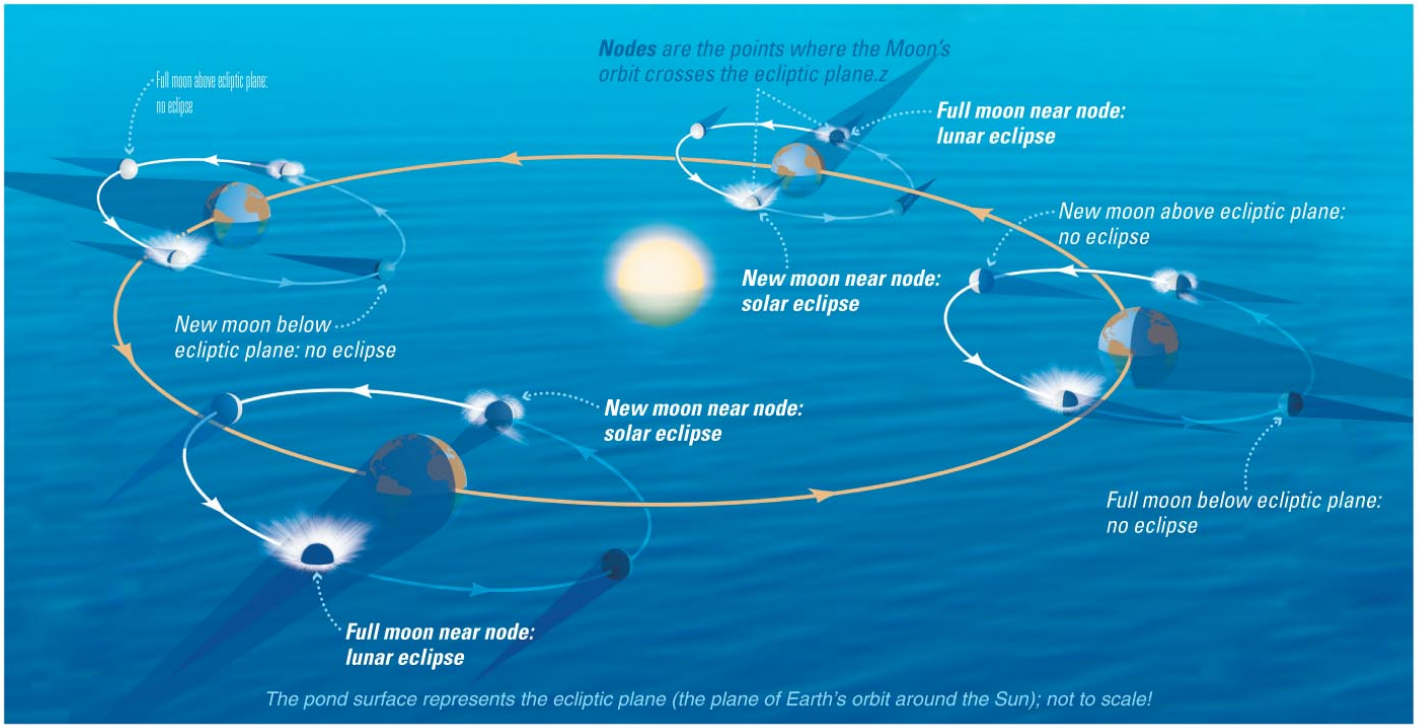
For a solar eclipse to occur the moon has to be in position A and the Earth, Moon and Sun must be on the same line.

Inclination of Moons Orbit

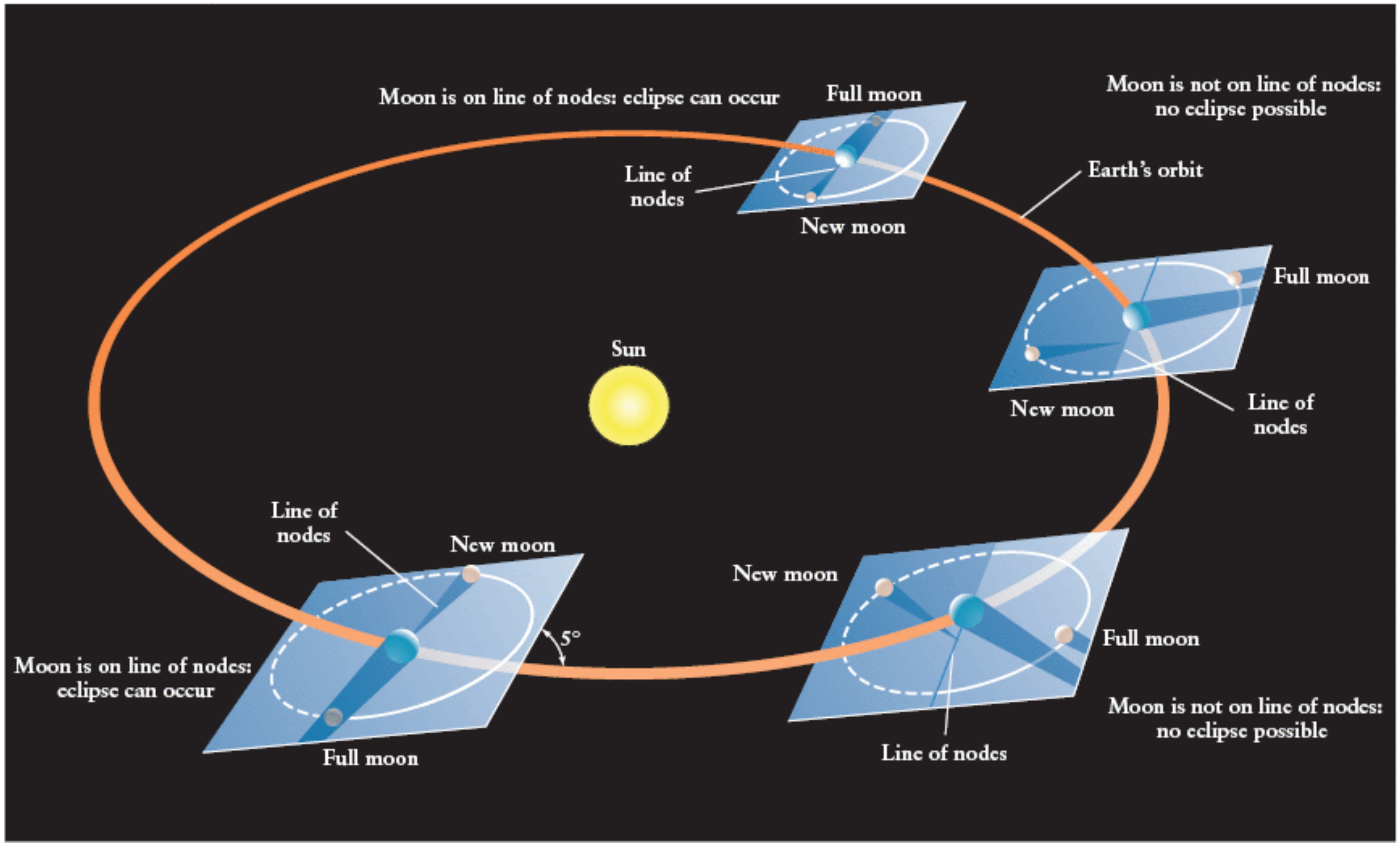


Why don't we have an eclipse at every new and full moon?

- 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.

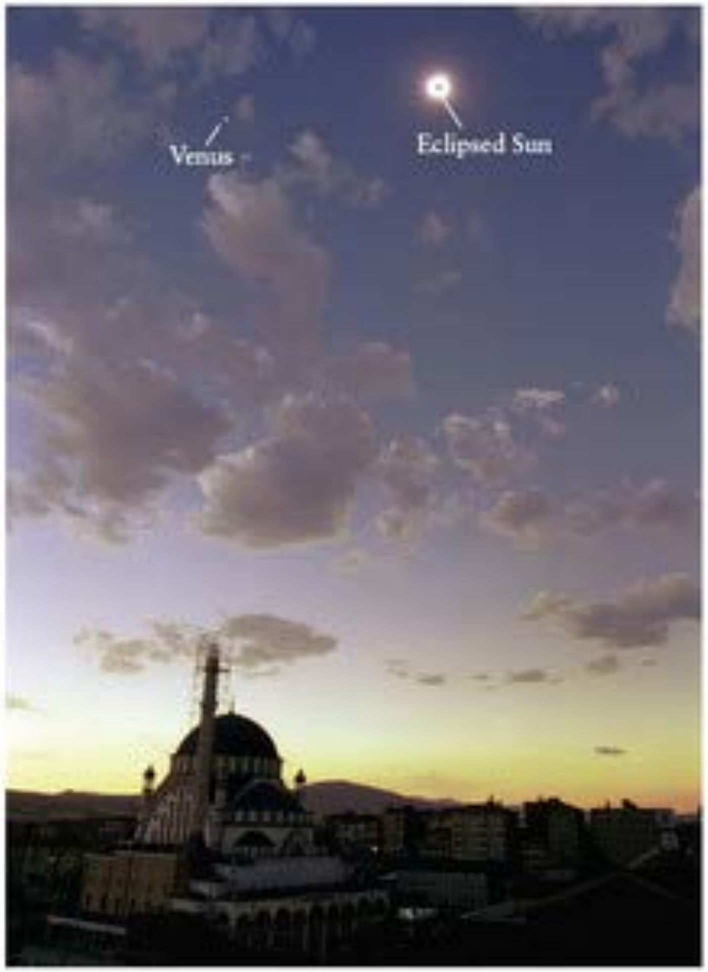


Conditions for Eclipses

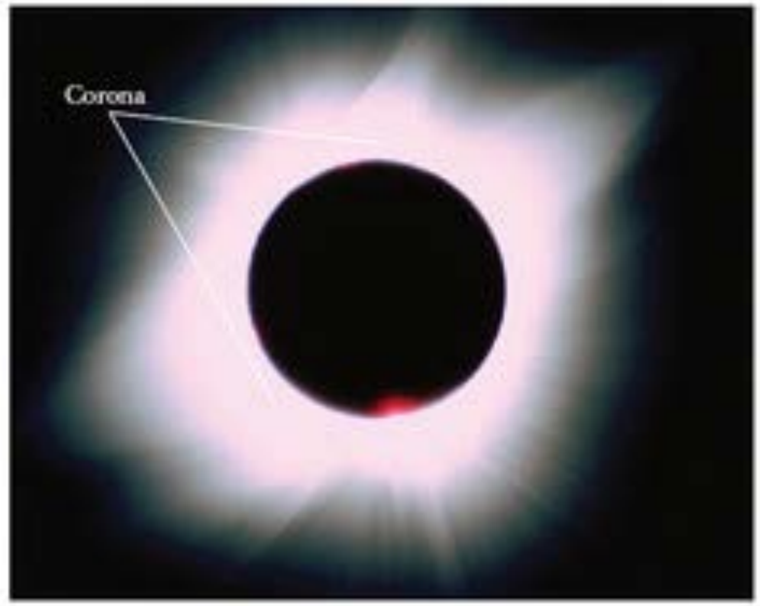


The Moon's orbital plane is tilted by 5.2° from the ecliptic plane. Hence, half the time, the Moon is slightly north of the ecliptic (and half the time, it is south of the ecliptic). The shadow of one body very rarely falls on the other.

Solar Corona

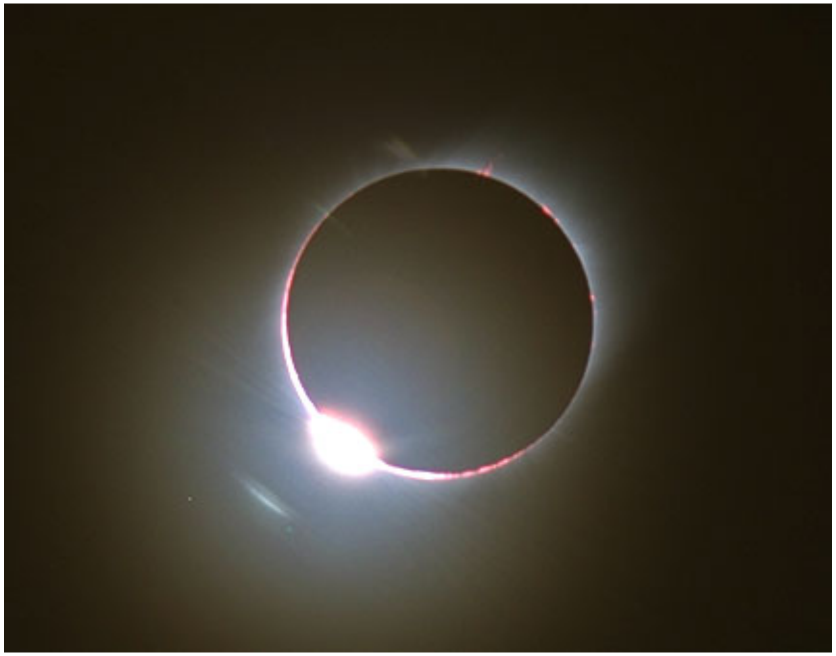


(a)

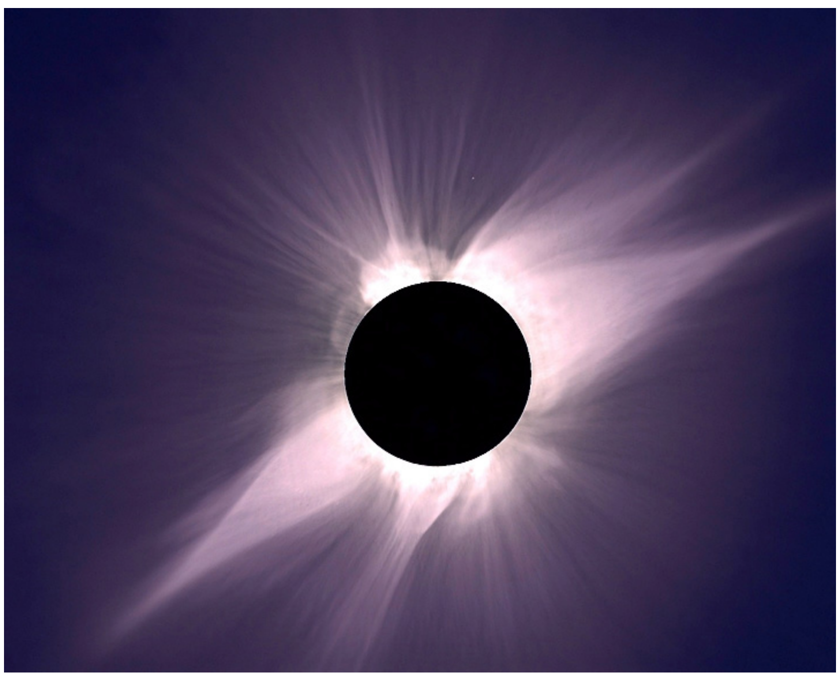


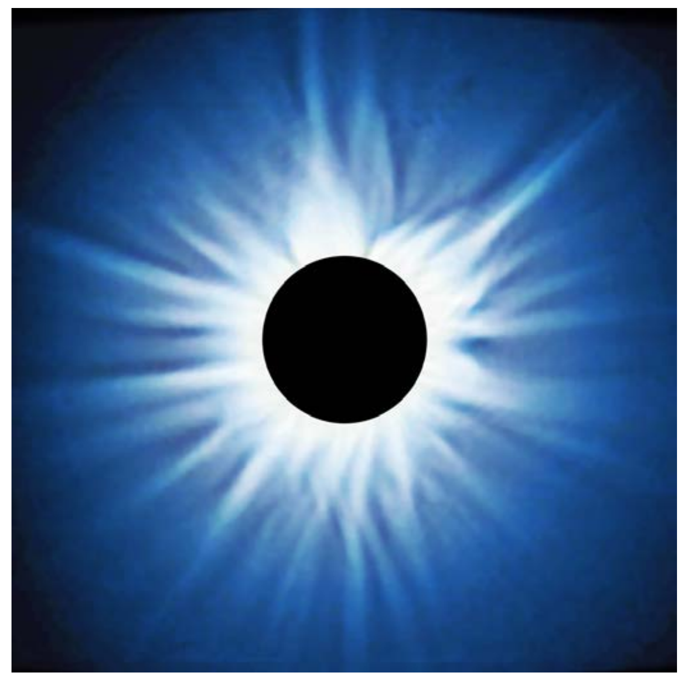
(b)

You only get to see this outer atmosphere (corona) of the Sun if the Sun's *entire* body is blocked out.




© 1999 Wendy Carlos & Jonathan Kern - All Rights Reserved





Total Solar Eclipse
of
1994 November 3

taped at
La Lava, Bolivia
by

Fred Espenak

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).

Predicting Eclipses

For a solar eclipse to occur the line of nodes needs to be pointed towards the sun and there must be a new moon.

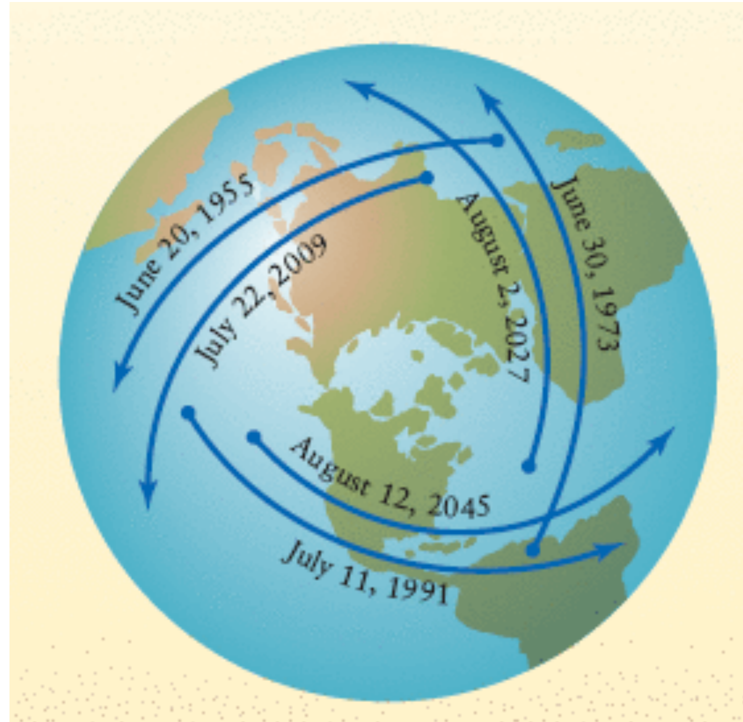
To predict when you will see another solar eclipse, you need to know how many whole lunar months (29.53days) equal some whole number of eclipse years.

lunar or synodic month: time between two successive new moons

eclipse year: time for the line of nodes to complete a rotation with respect to the sun

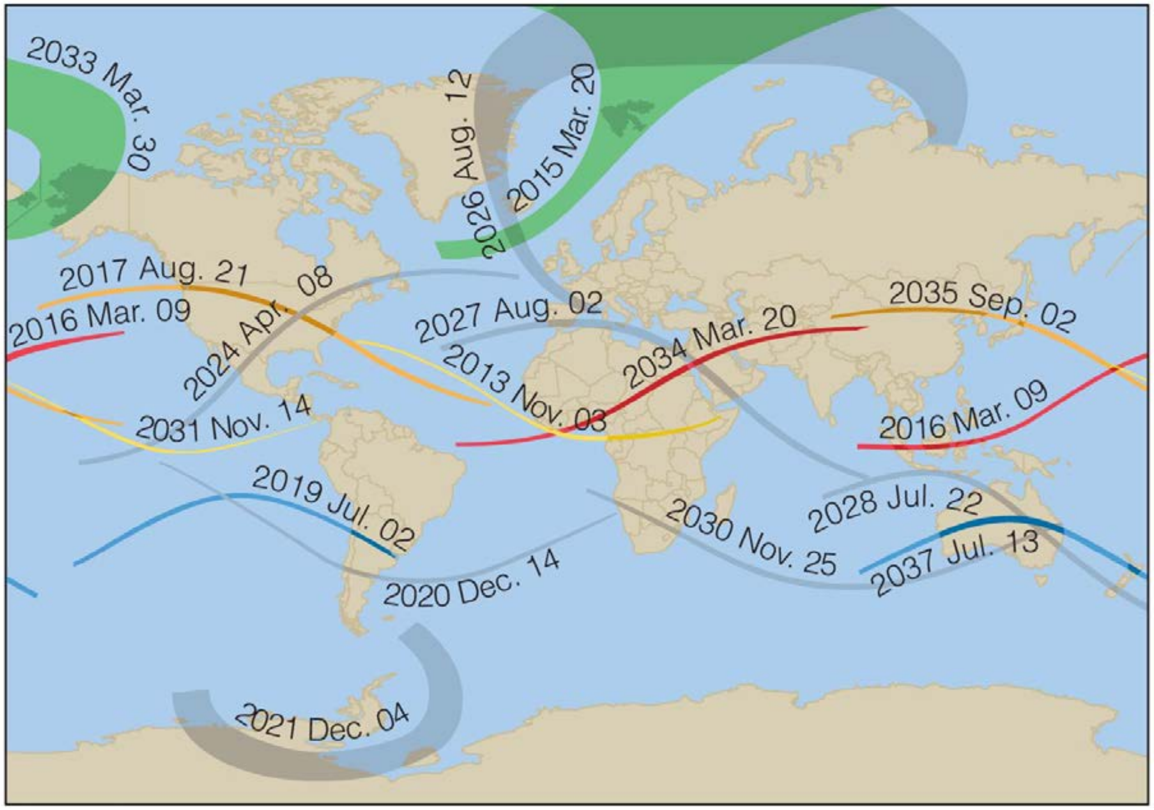
It turns out that 223 lunar months is the same length of time as 19 eclipse years.

1 Saros = 6585.3 days (~223 lunar months)



Because of 1Saros = 6585.3 days you must wait three full saros intervals (54 years, 34 days) before the eclipse path comes back around to your part of Earth.

Predicting Eclipses



Why are some eclipse paths wider than others?
What direction does the tip of the umbra go in along the eclipse path?
Why does the latitude of the path appear to vary?
How fast does the tip of the umbra travel along the eclipse path?

What have we learned?

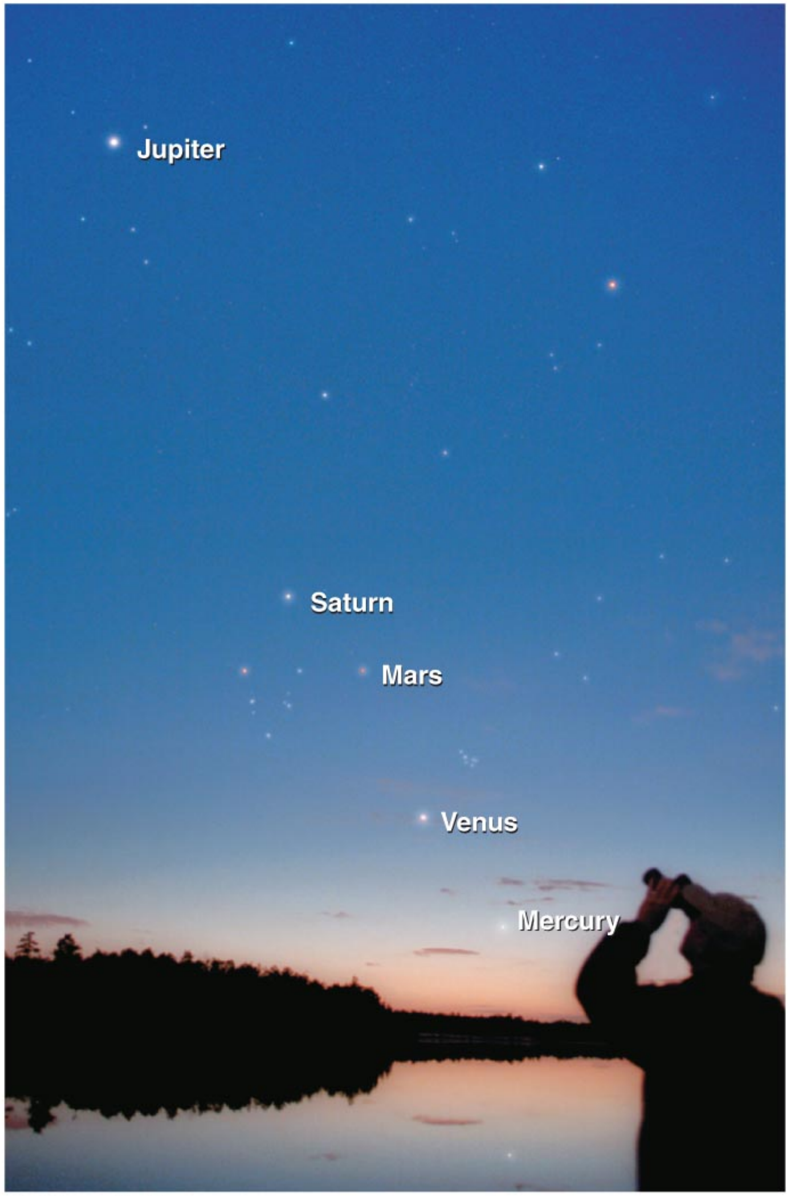
- **Why do we see phases of the Moon?**
  – Half the Moon is lit by the Sun; half is in shadow, and its appearance to us is determined by the relative positions of Sun, Moon, and Earth.
- **What causes eclipses?**
  – Lunar eclipse: Earth's shadow on the Moon
  – Solar eclipse: Moon's shadow on Earth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

2.4 The Ancient Mystery of the Planets

- Our goals for learning:
  - **What was once so mysterious about planetary motion in our sky?**
  - **Why did the ancient Greeks reject the real explanation for planetary motion?**

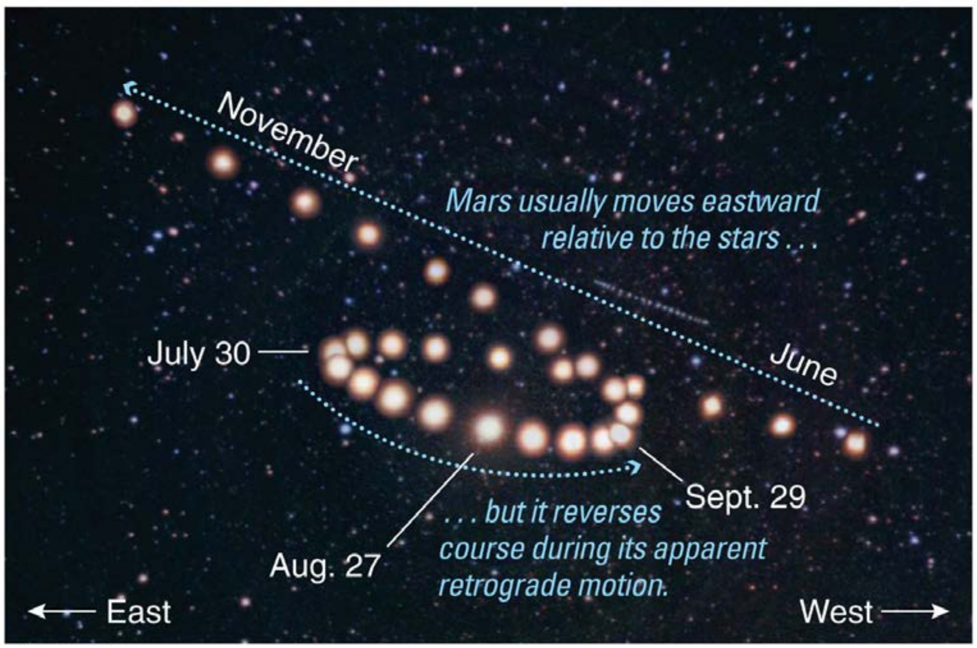
Planets Known in Ancient Times

- Mercury
  – difficult to see; always close to Sun in sky
- Venus
  – very bright when visible; morning or evening "star"
- Mars
  – noticeably red
- Jupiter
  – very bright
- Saturn
  – moderately bright

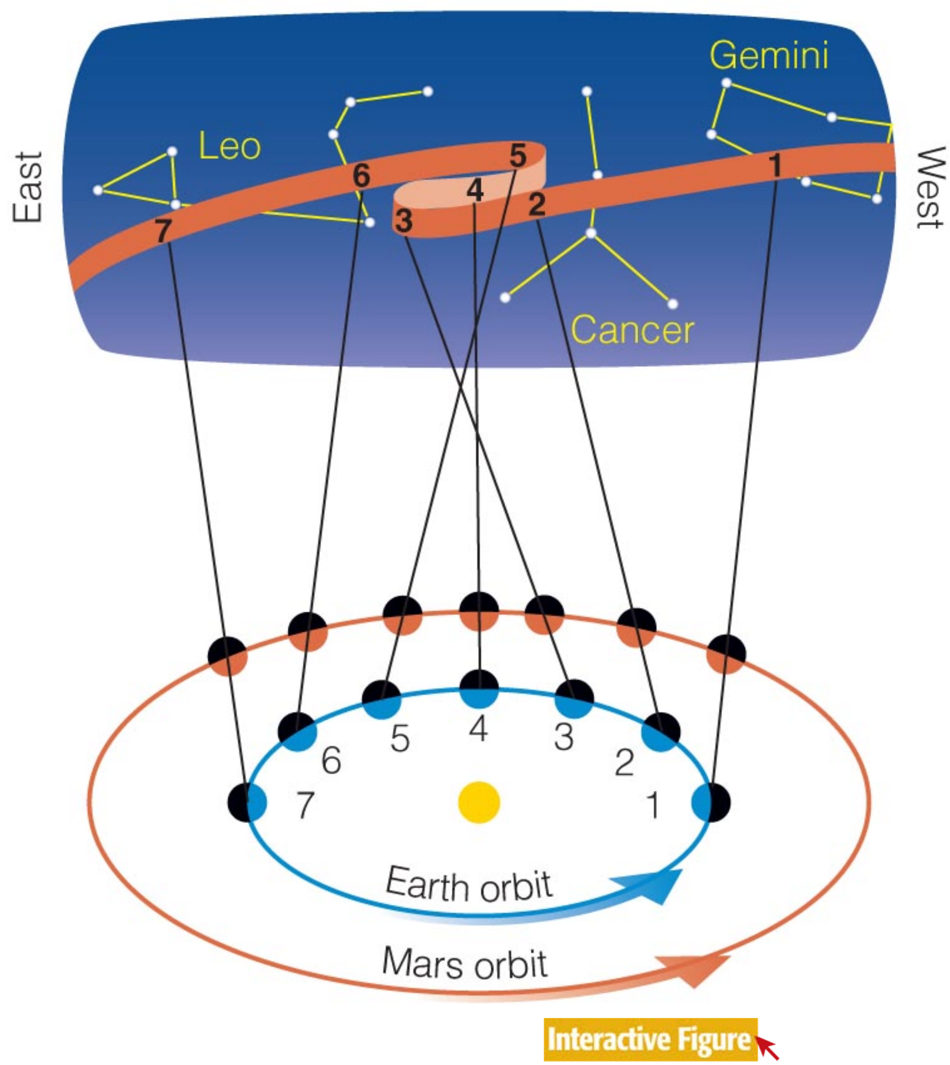


What was once so mysterious about planetary motion in our sky?

- Planets usually move slightly *eastward* from night to night relative to the stars.
- But sometimes they go *westward* relative to the stars for a few weeks: **apparent retrograde motion.**



We see apparent retrograde motion when we pass by a planet in its orbit.

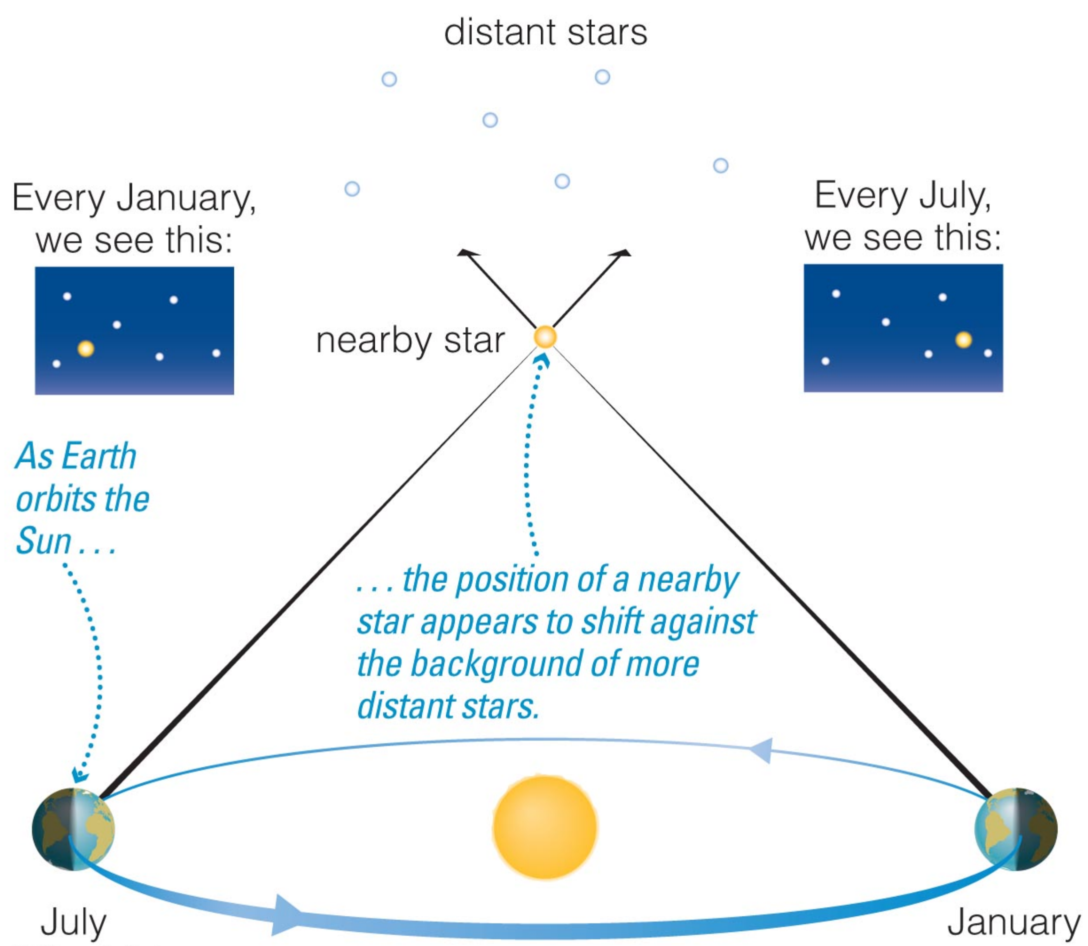


Explaining Apparent Retrograde Motion

- Easy *for us* to explain: occurs when we "lap" another planet (or when Mercury or Venus laps us).
- But very difficult to explain if you think that Earth is the center of the universe!
- *In fact, ancients considered but rejected the correct explanation*.

Why did the ancient Greeks reject the real explanation for planetary motion?

- Their inability to observe **stellar parallax** was a major factor.



The Greeks knew that the lack of observable parallax could mean one of two things:

1. Stars are so far away that stellar parallax is too small to notice with the naked eye.
2. Earth does not orbit the Sun; it is the center of the universe.

With rare exceptions such as Aristarchus, the Greeks rejected the correct explanation (1) because they did not think the stars could be *that* far away.

Thus, the stage was set for the long, historical showdown between Earth-centered and Sun- centered systems.

What have we learned?

- **What was so mysterious about planetary motion in our sky?**
  - Like the Sun and Moon, planets usually drift eastward relative to the stars from night to night, but sometimes, for a few weeks or few months, a planet turns westward in its **apparent retrograde motion**.
- **Why did the ancient Greeks reject the real explanation for planetary motion?**
  - Most Greeks concluded that Earth must be stationary, because they thought the stars could not be so far away as to make parallax undetectable.