Chapter 2: Discovering the Universe for Yourself

Discovering the Universe for Yourself

2.1 Patterns in the Night Sky

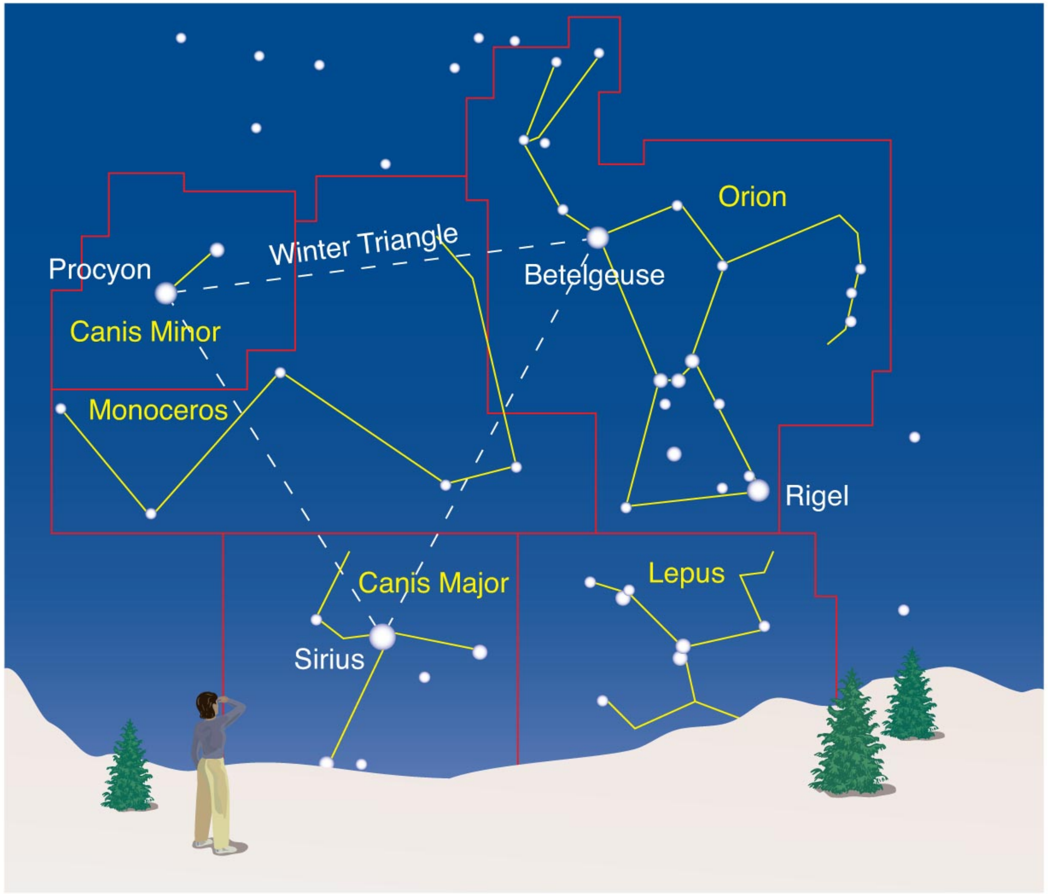
- Our goals for learning:
  - **What does the universe look like from Earth?**
  - **Why do stars rise and set?**
  - **Why do the constellations we see depend on latitude and time of year?**

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.



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

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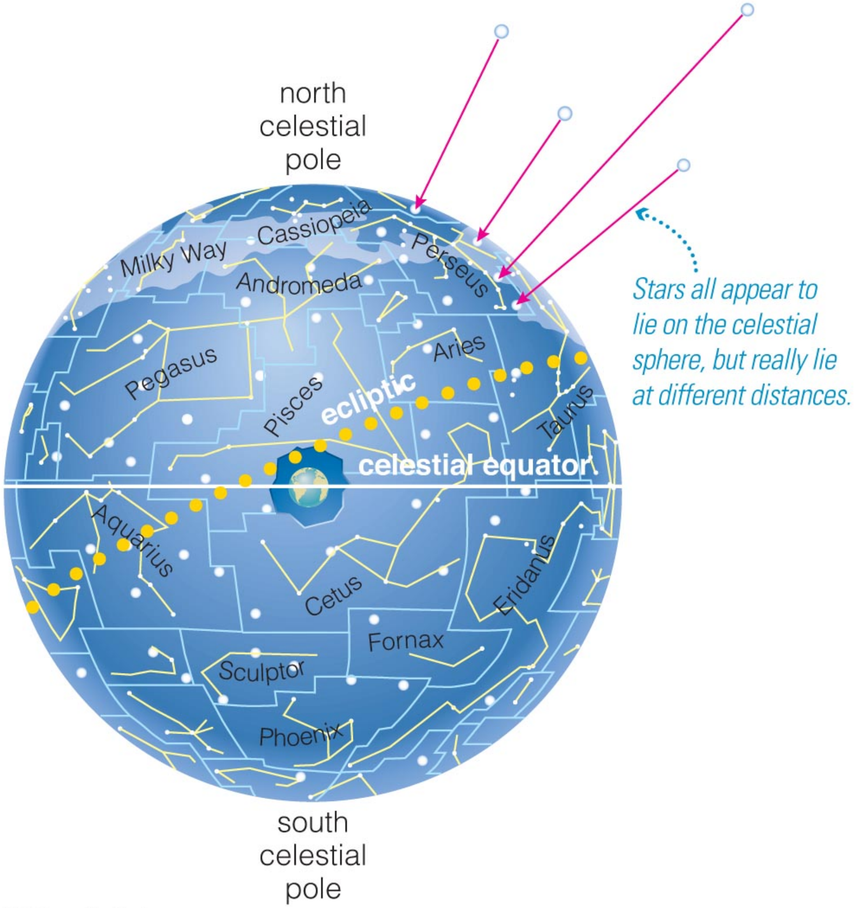
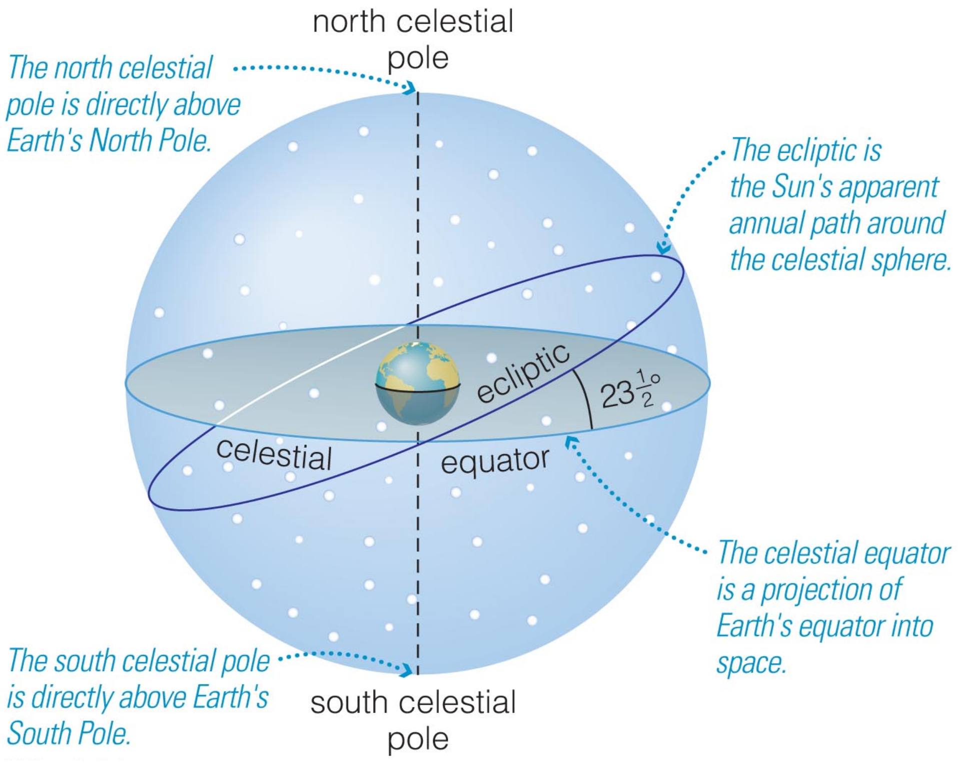
The Celestial Sphere



- Stars at different distances all appear to lie on the celestial sphere.
- The 88 official constellations cover the entire celestial sphere.

The Celestial Sphere



- The **ecliptic** is the Sun's apparent path through the celestial sphere.

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.

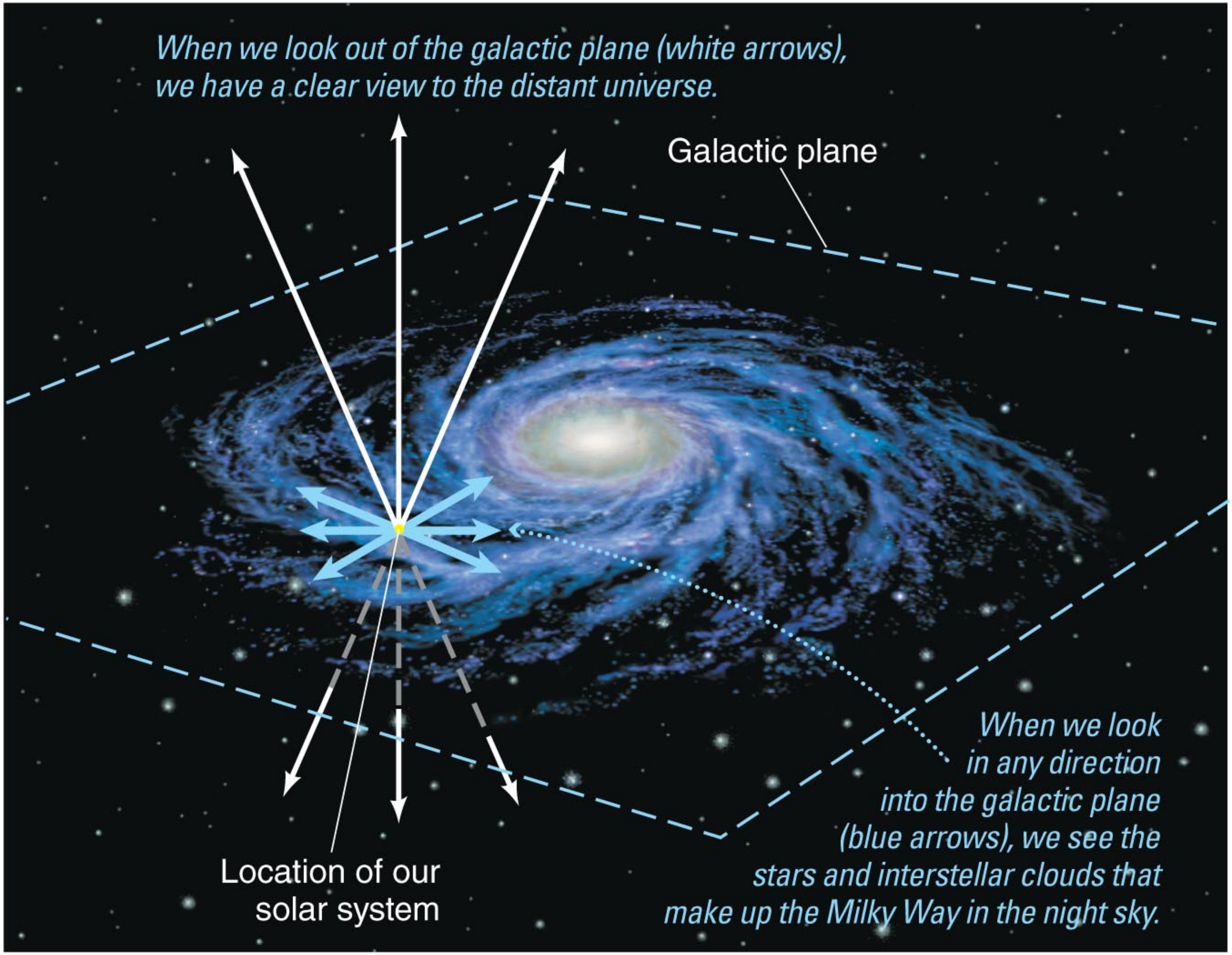
The Milky Way

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

What is it?

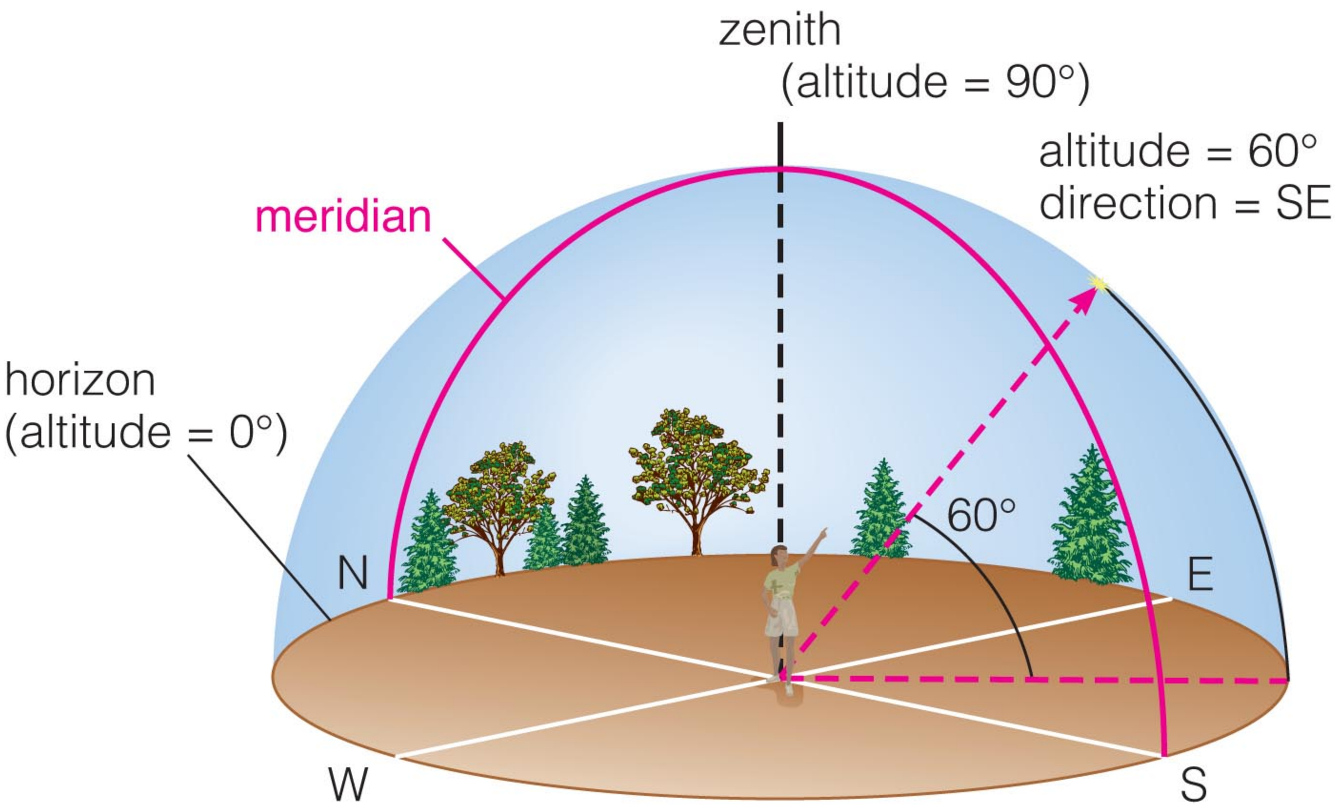
- Our view into the plane of our galaxy.

The Milky Way



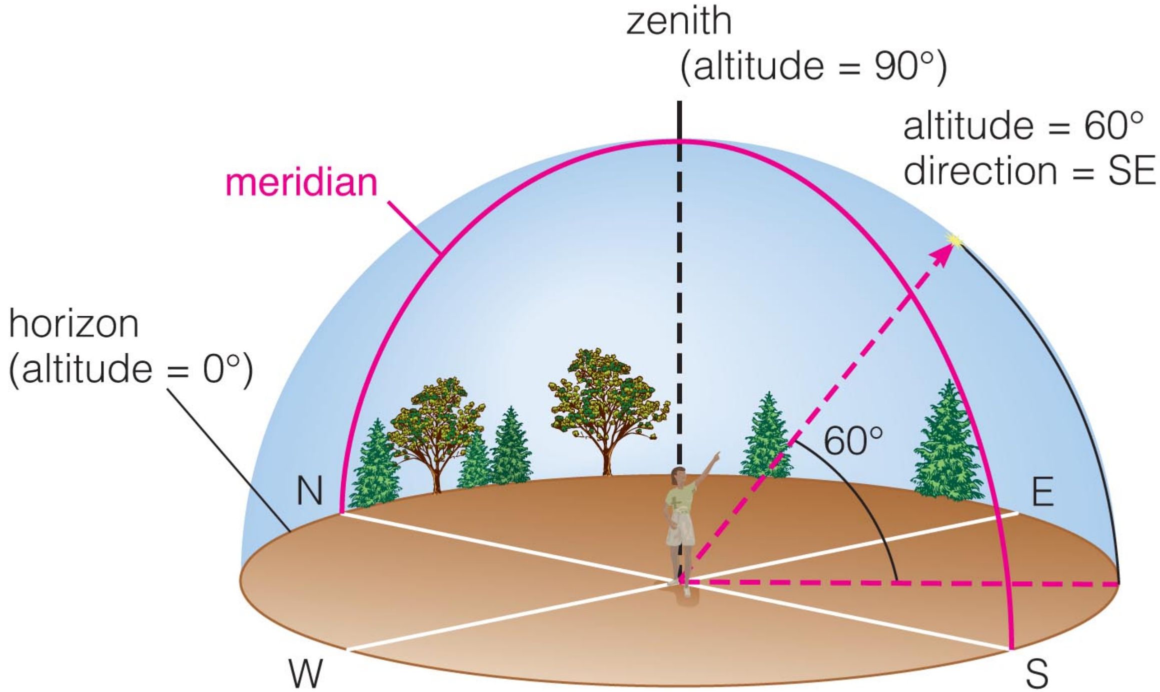
The Local Sky

- An object's **altitude** (above horizon) and **direction** (along horizon) specify its location in your local sky.

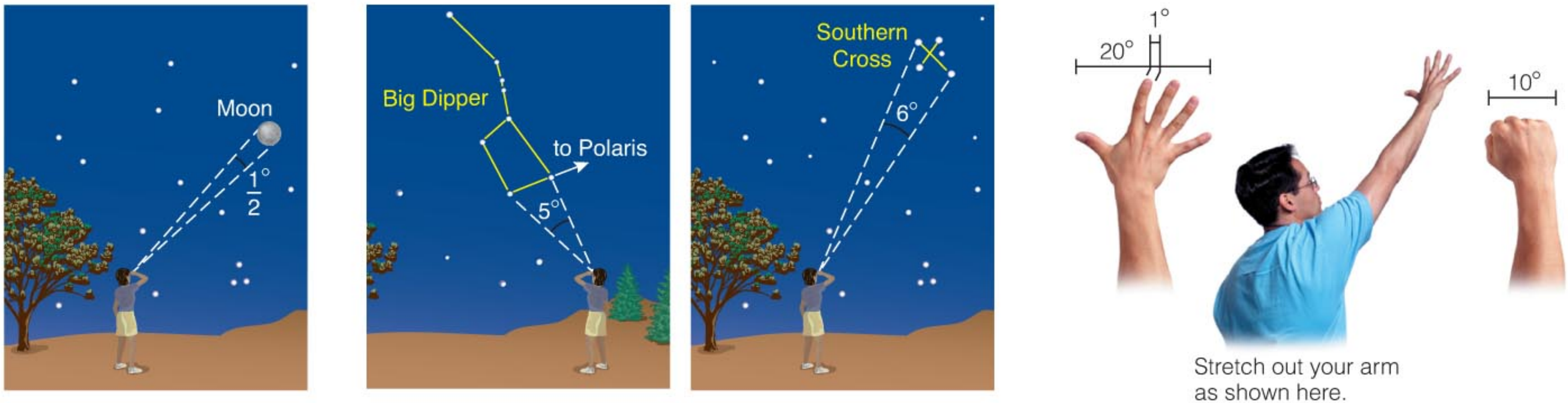


The Local Sky

- **Meridian:** line passing through zenith and connecting N and S points on horizon
- **Zenith:** the point directly overhead
- **Horizon:** all points 90º away from zenith



We measure the sky using *angles*.



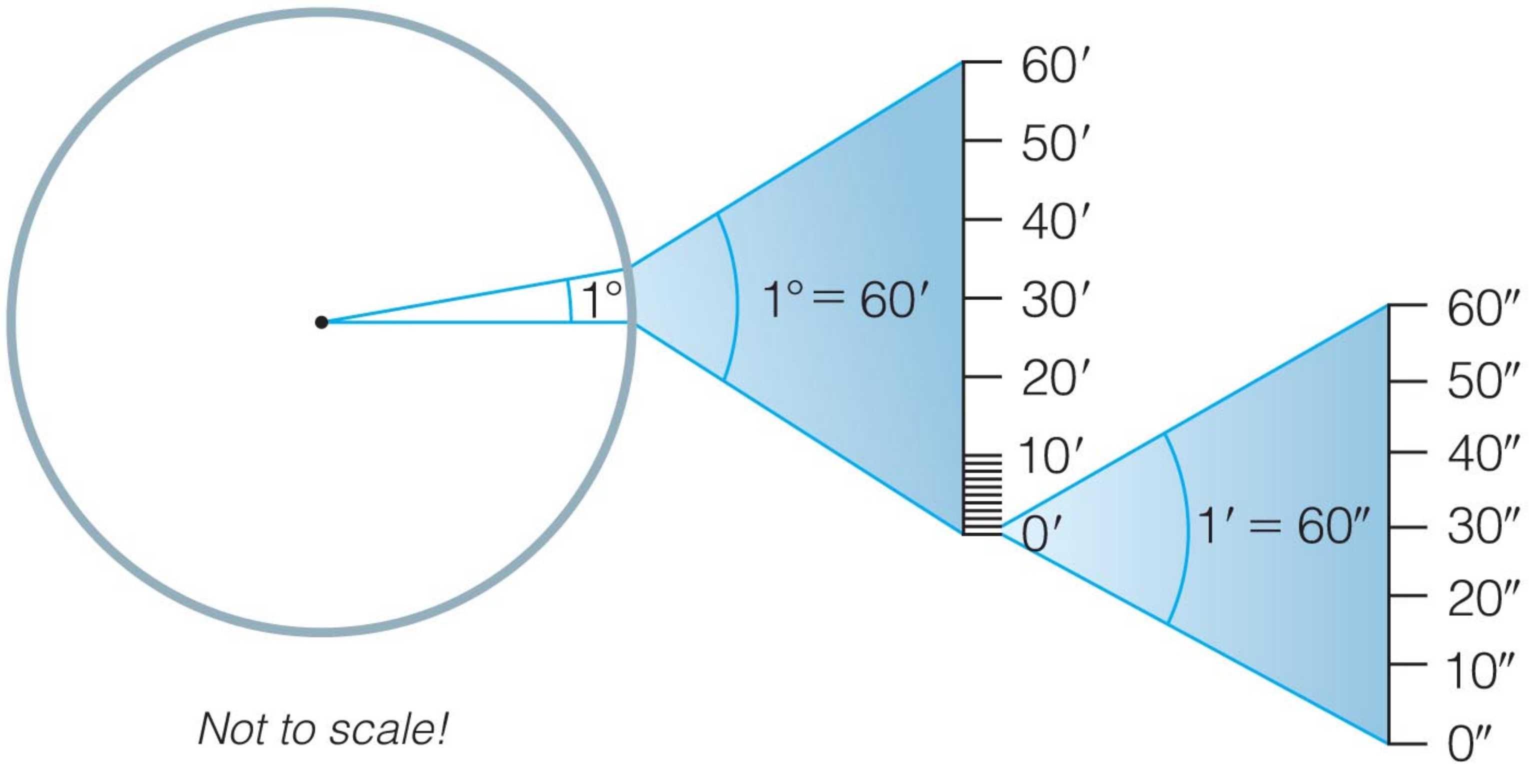
a The angular sizes of the Sun and the Moon are about 1/2°.

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 1º. How many arcseconds is this?

A. 60 arcseconds
B. 600 arcseconds
C. $60 \times 60 = 3600$ arcseconds

Thought Question

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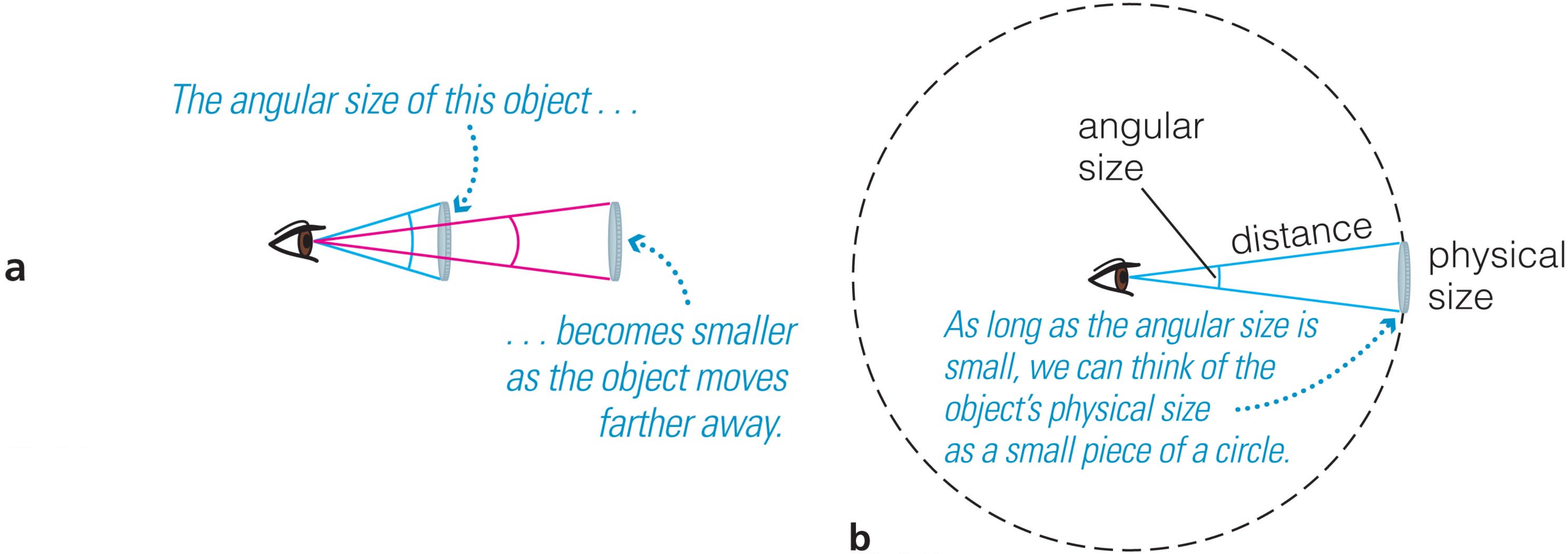
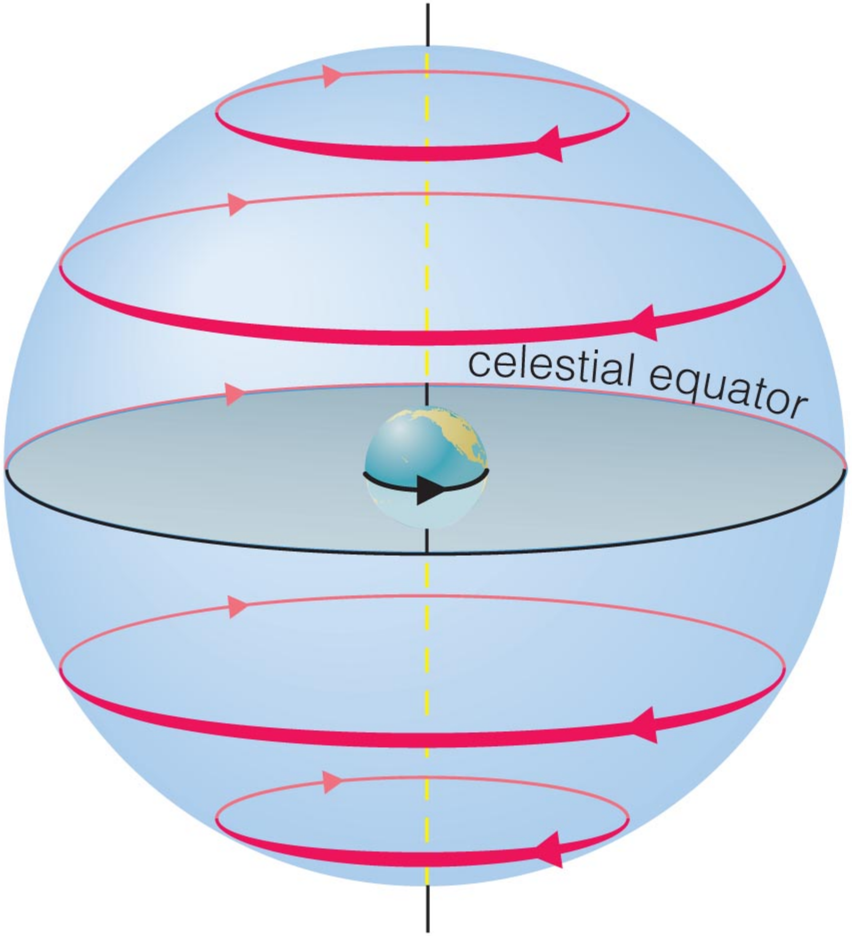
Angular Size

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



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

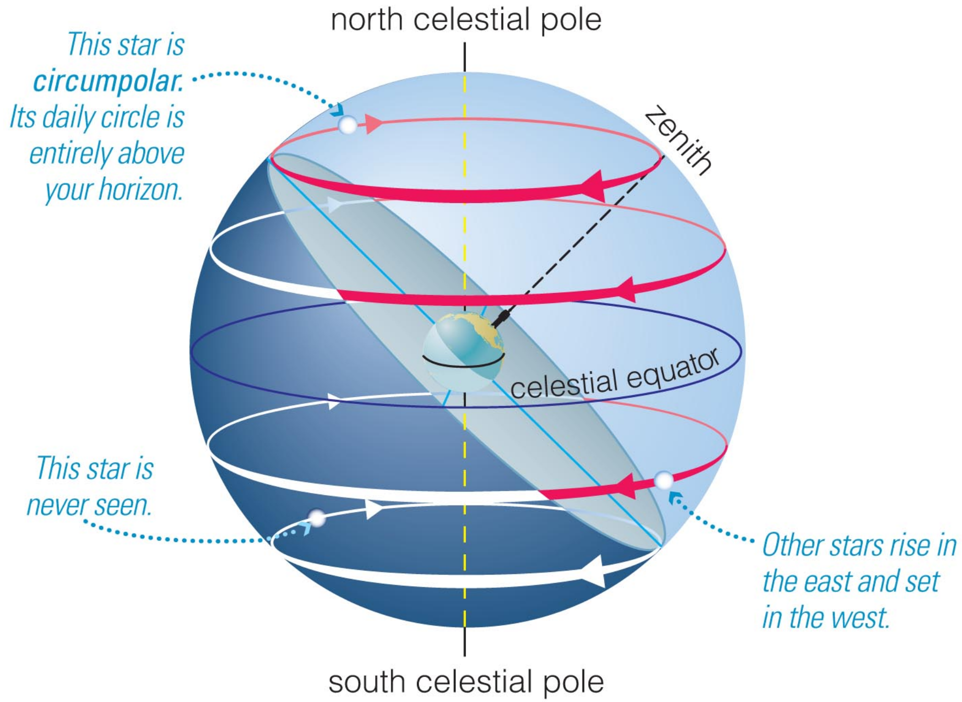
Why do stars rise and set?



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

Our view from Earth:

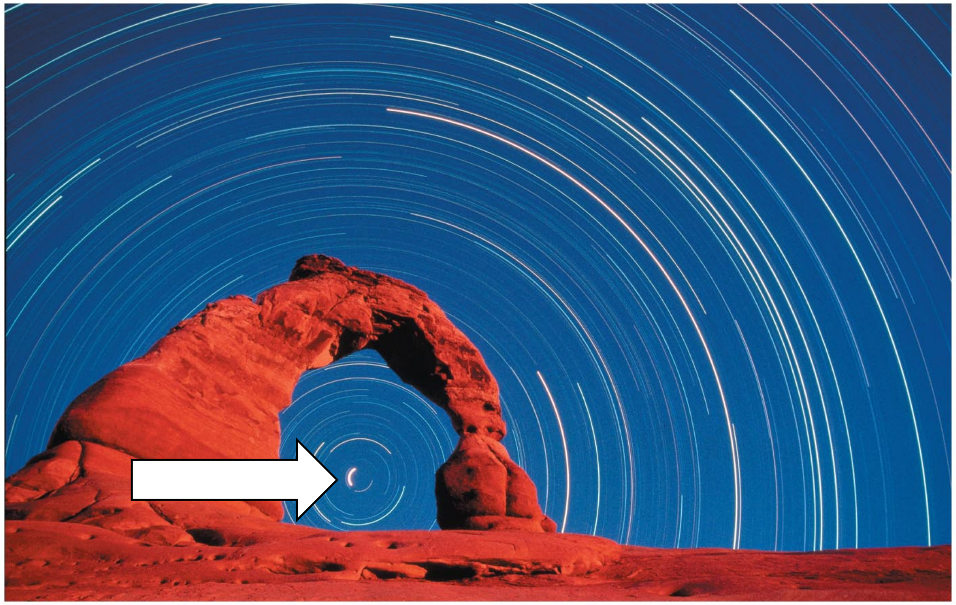
- Stars near the north celestial pole are circumpolar and never set.
- We cannot see stars near the south celestial pole.
- All other stars (and Sun, Moon, planets) rise in east and set in west.



Thought Question

What is the arrow pointing to in the photo below?

A. the zenith
B. the north celestial pole
C. the celestial equator



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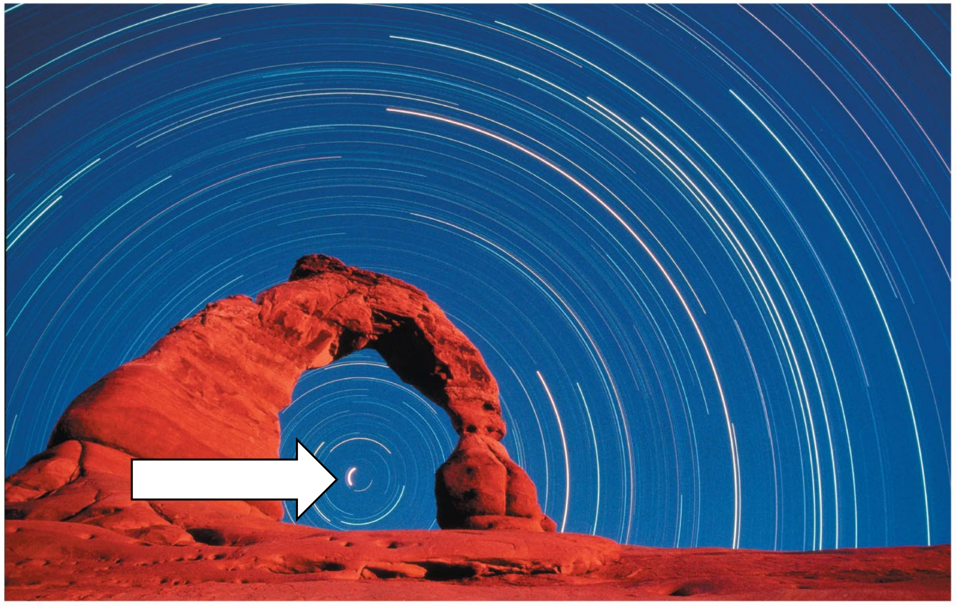
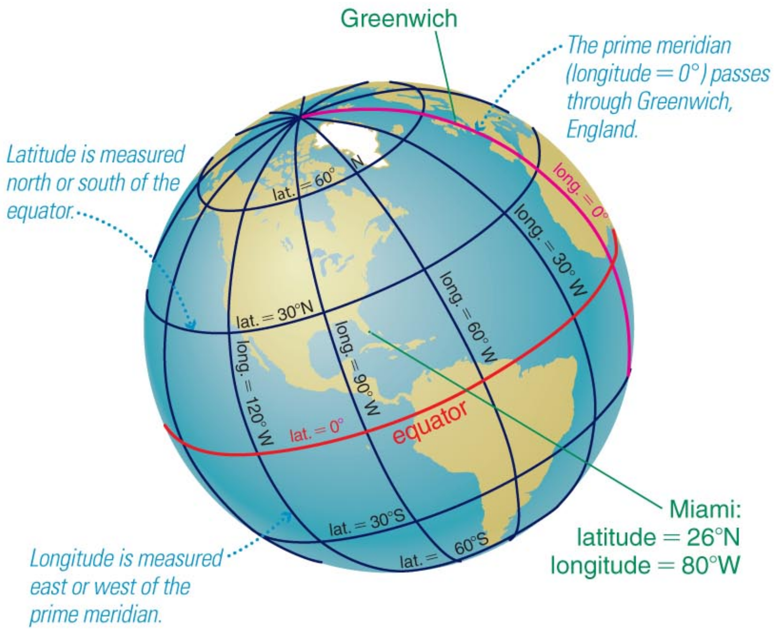


Why do the constellations we see depend on latitude and time of year?

- 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.

Review: Coordinates on the Earth

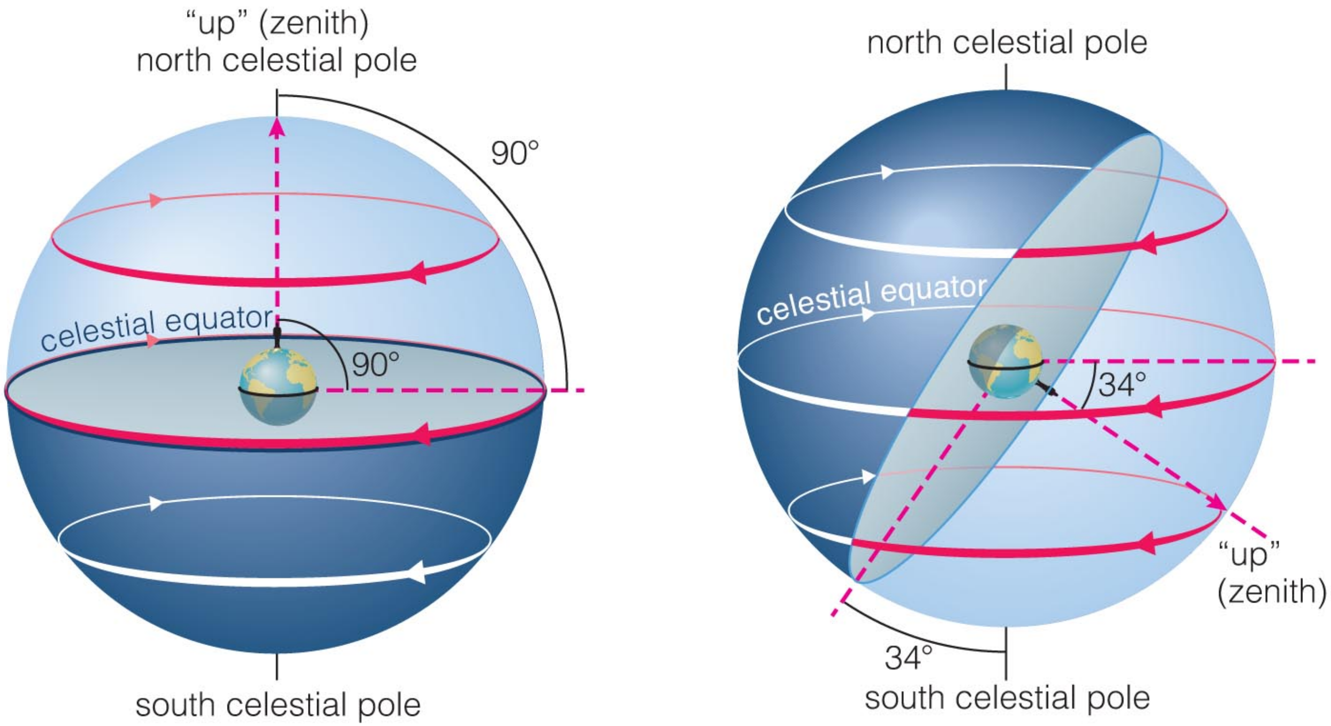
- **Latitude:** position north or south of equator
- **Longitude:** position east or west of prime meridian (runs through Greenwich, England)



a We can locate any place on Earth's surface by its latitude and longitude.

b The entrance to the Old Royal Greenwich Observatory, near London. The line emerging from the door marks the prime meridian.

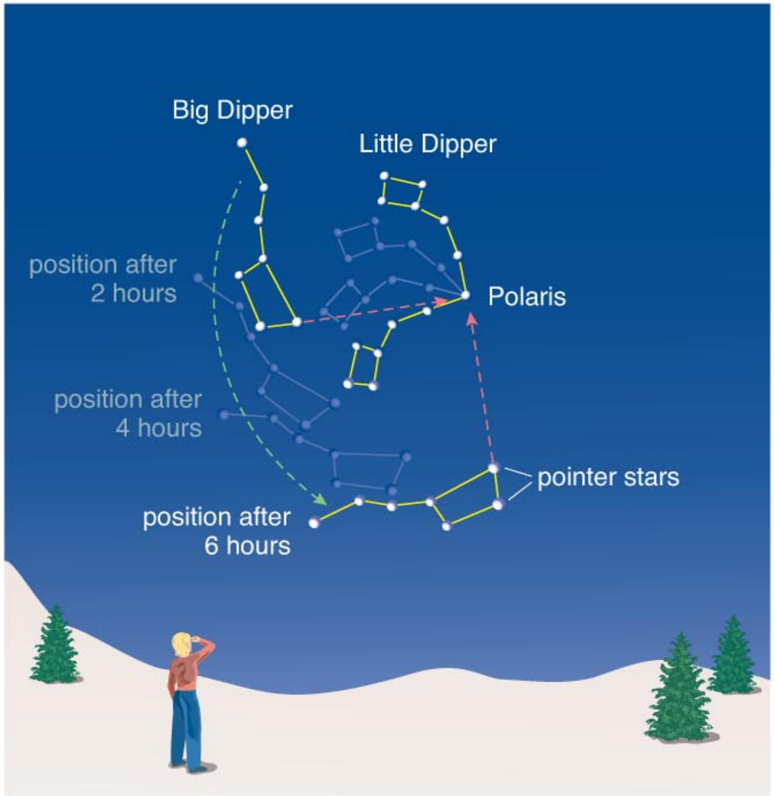
The sky varies with latitude but not with longitude.



a The local sky at the North Pole (latitude 90°N).

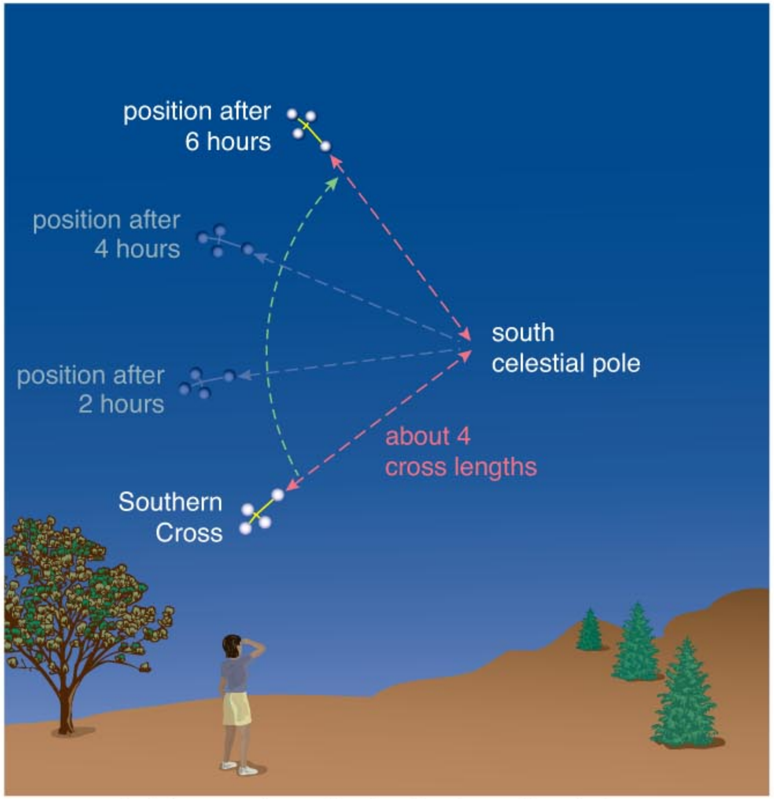
b The local sky at latitude 34°S.

Altitude of the celestial pole = your latitude



looking northward in the Northern Hemisphere

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.



looking southward in the Southern Hemisphere

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.

Thought Question

The North Star (Polaris) is 50º above your horizon, due north. Where are you?

A. You are on the equator.
B. You are at the North Pole.
C. You are at latitude 50ºN.
D. You are at longitude 50ºE.
E. You are at latitude 50ºN and longitude 50ºE.

Thought Question

The North Star (Polaris) is 50º above your horizon, due north. Where are you?

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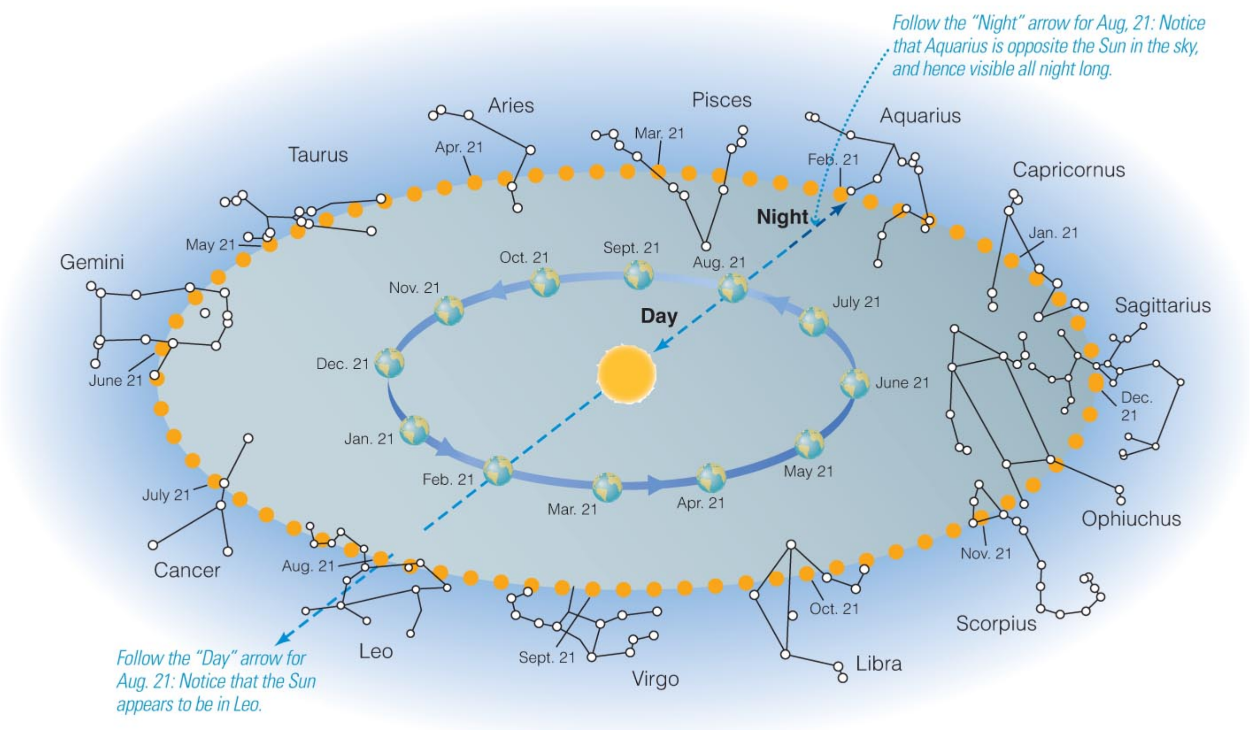
The sky varies as Earth orbits the Sun

- As the Earth orbits the Sun, the Sun appears to move eastward along the ecliptic.
- At midnight, the stars on our meridian are opposite the Sun in the sky.



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 **direction** 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.

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.

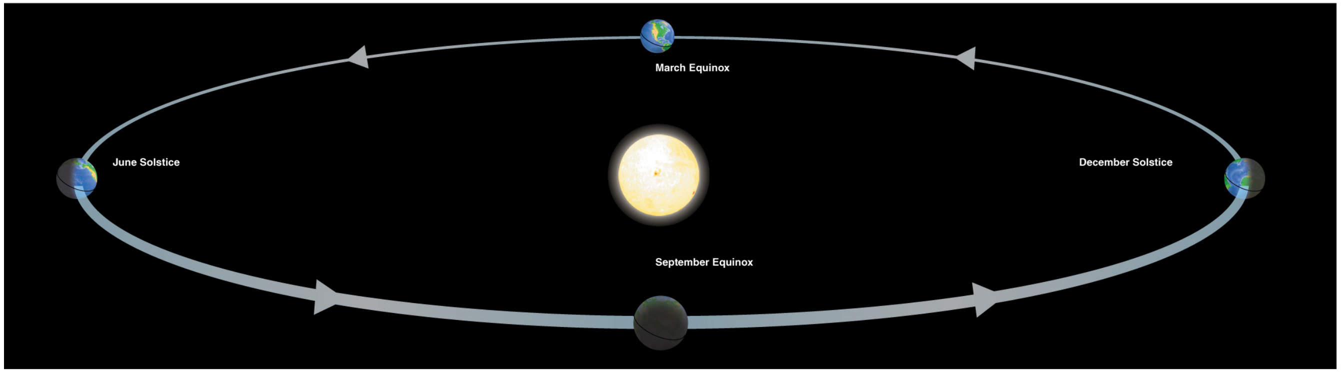
Hint: When it is summer in America, it is winter in Australia.

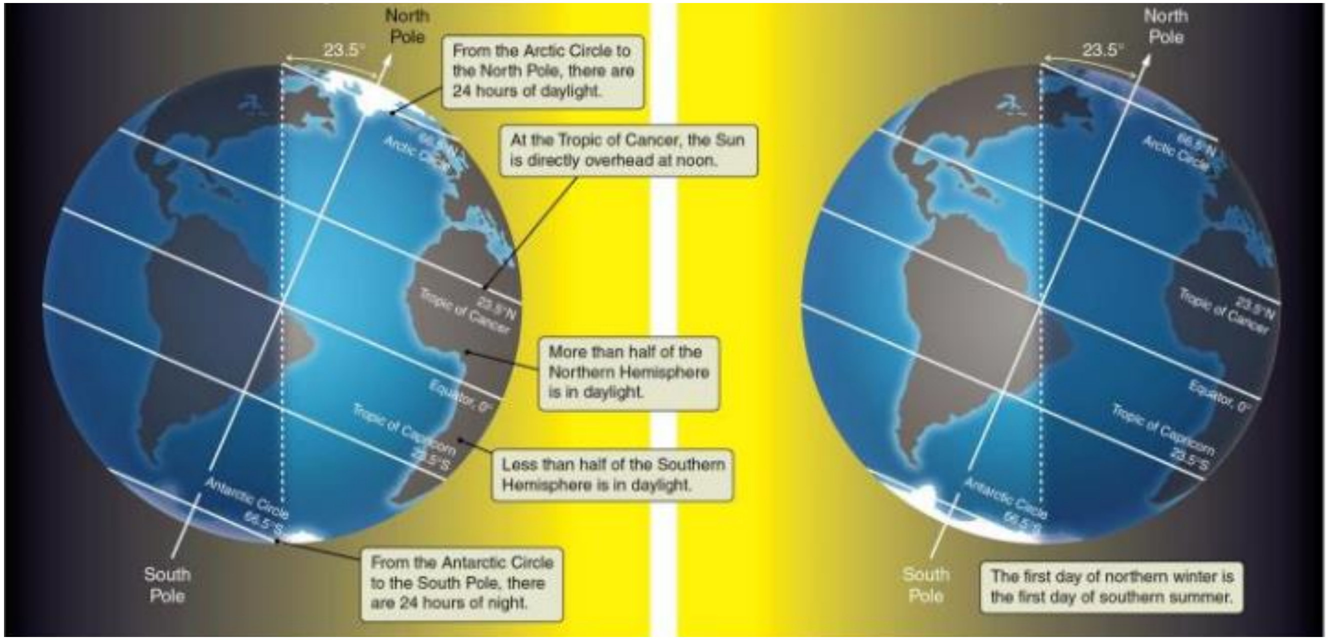
Thought Question

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?





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

Sun's altitude also changes with seasons.

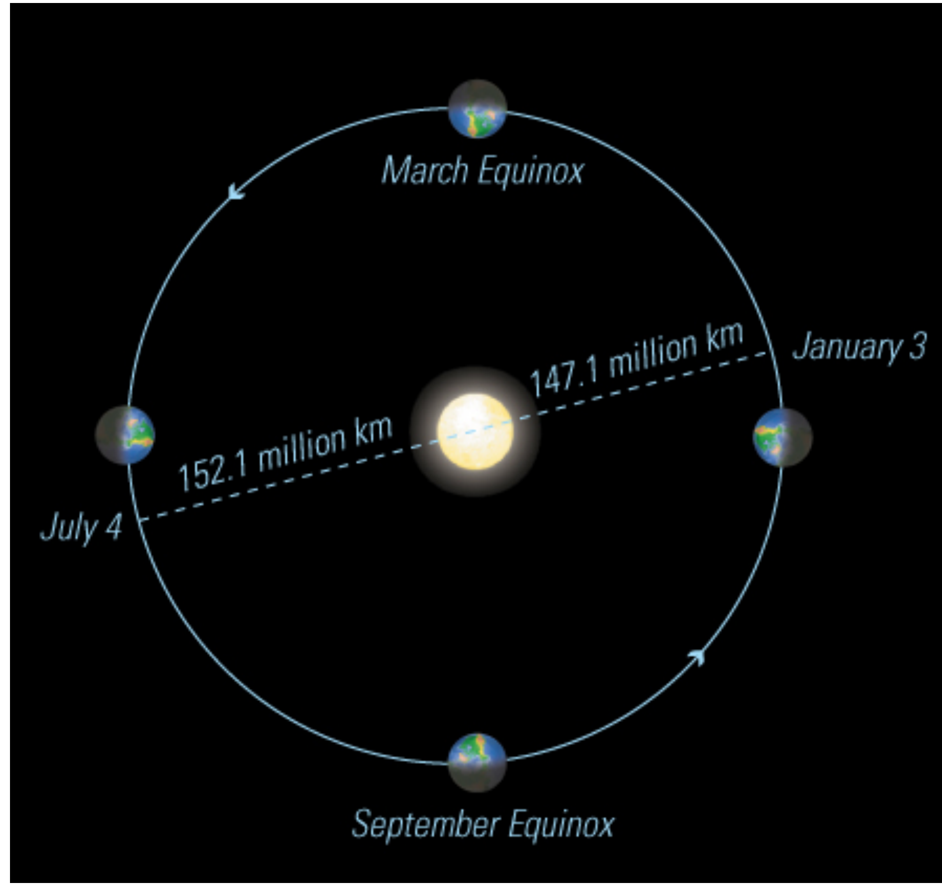
- Sun's position at noon in summer: Higher altitude means more direct sunlight.
- Sun's position at noon in winter: Lower altitude means less direct sunlight.

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.

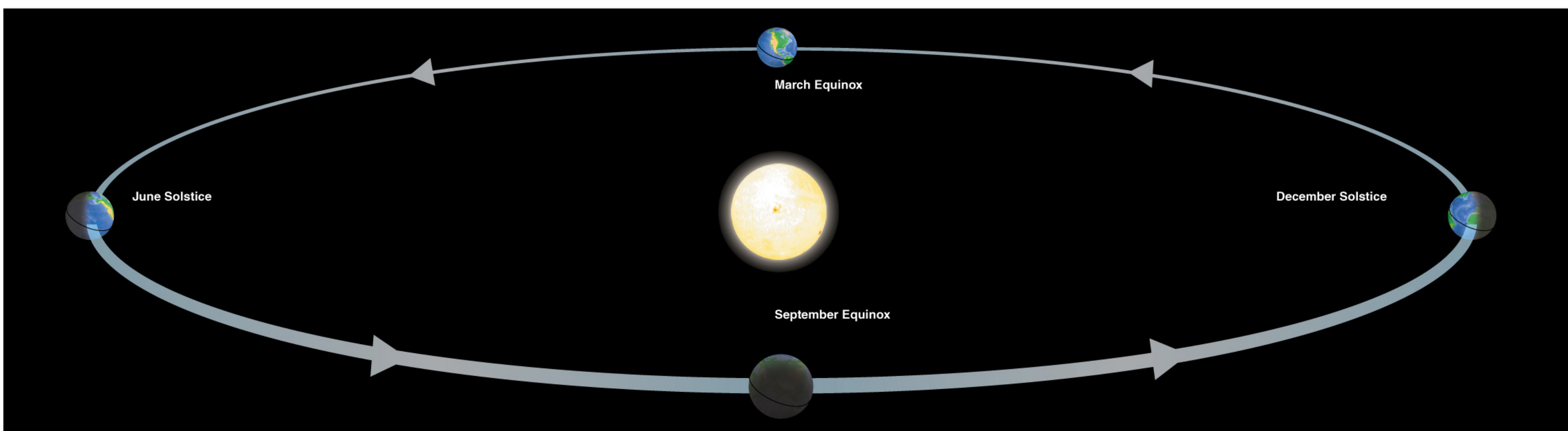
Why *doesn't* distance matter?

- 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!



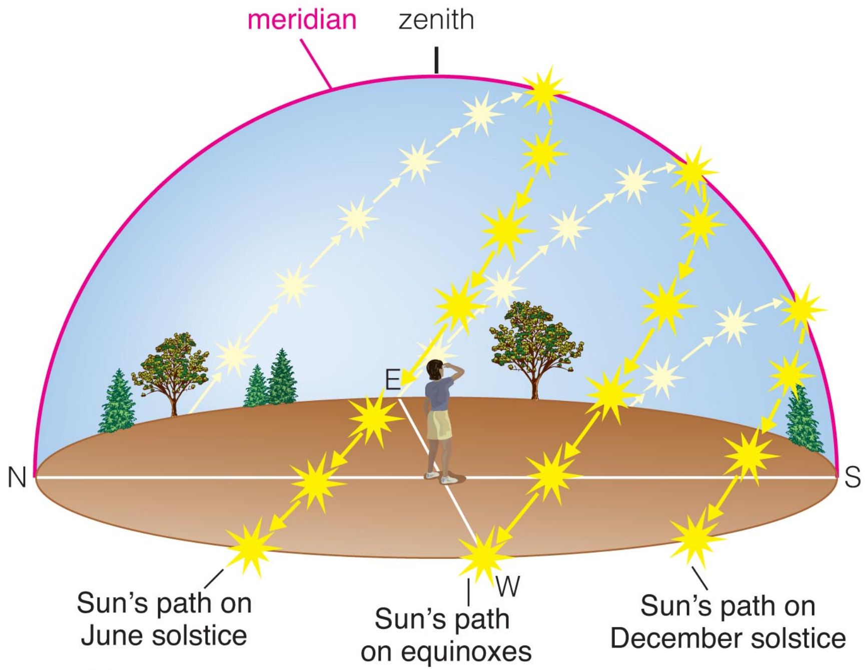
How do we mark the progression of the seasons?

- We define four special points:
  - summer (June) solstice
  - winter (December) solstice
  - spring (March) equinox
  - fall (September) equinox



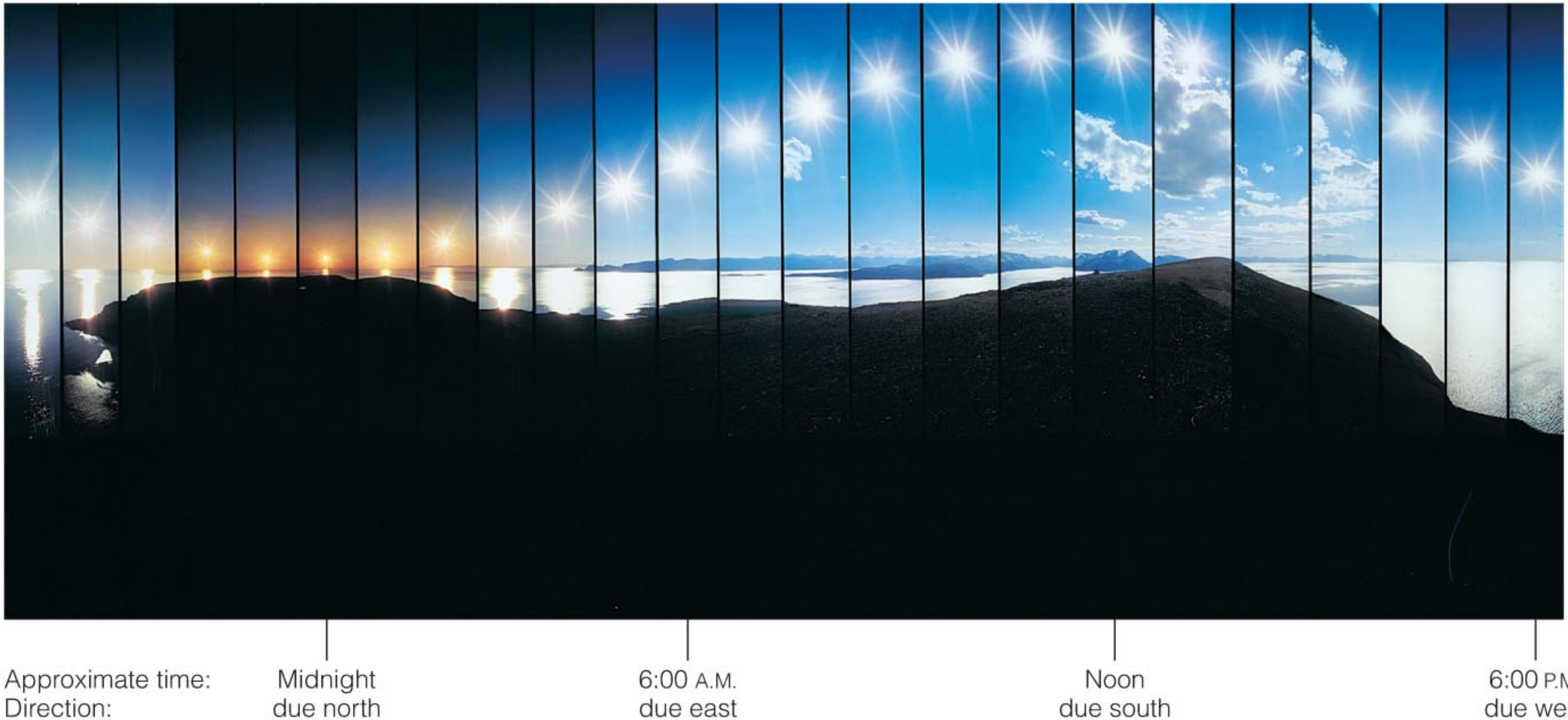
We can recognize solstices and equinoxes by Sun's path across sky:

- 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.



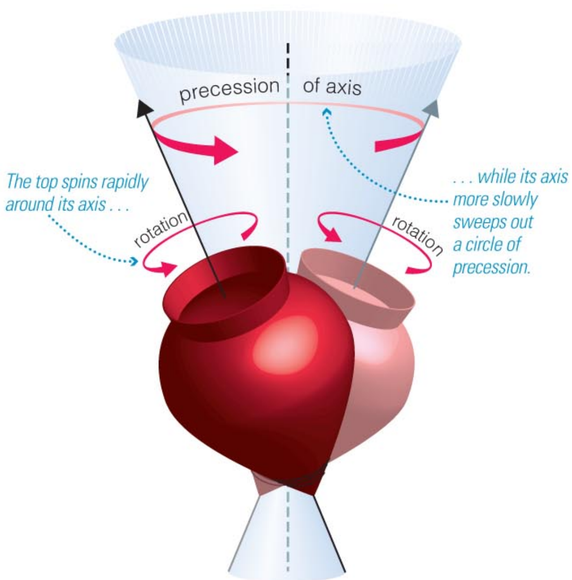
Seasonal changes are more extreme at high latitudes.

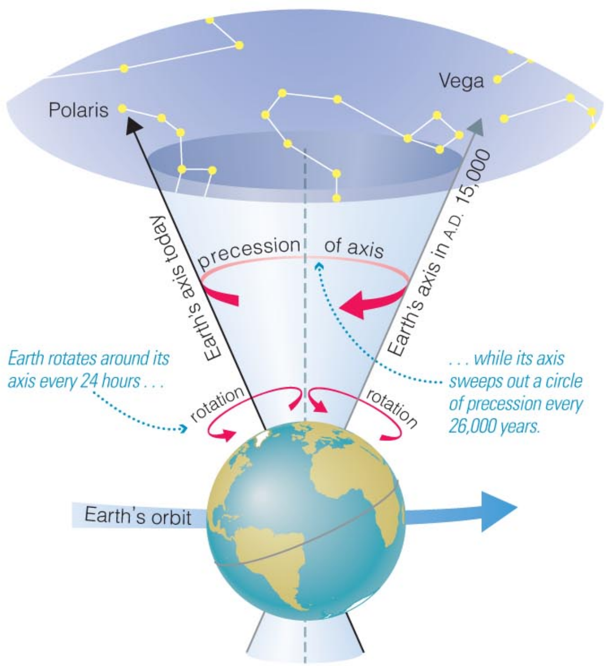
- Path of the Sun on the summer solstice at the Arctic Circle



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

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 **direction** 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.

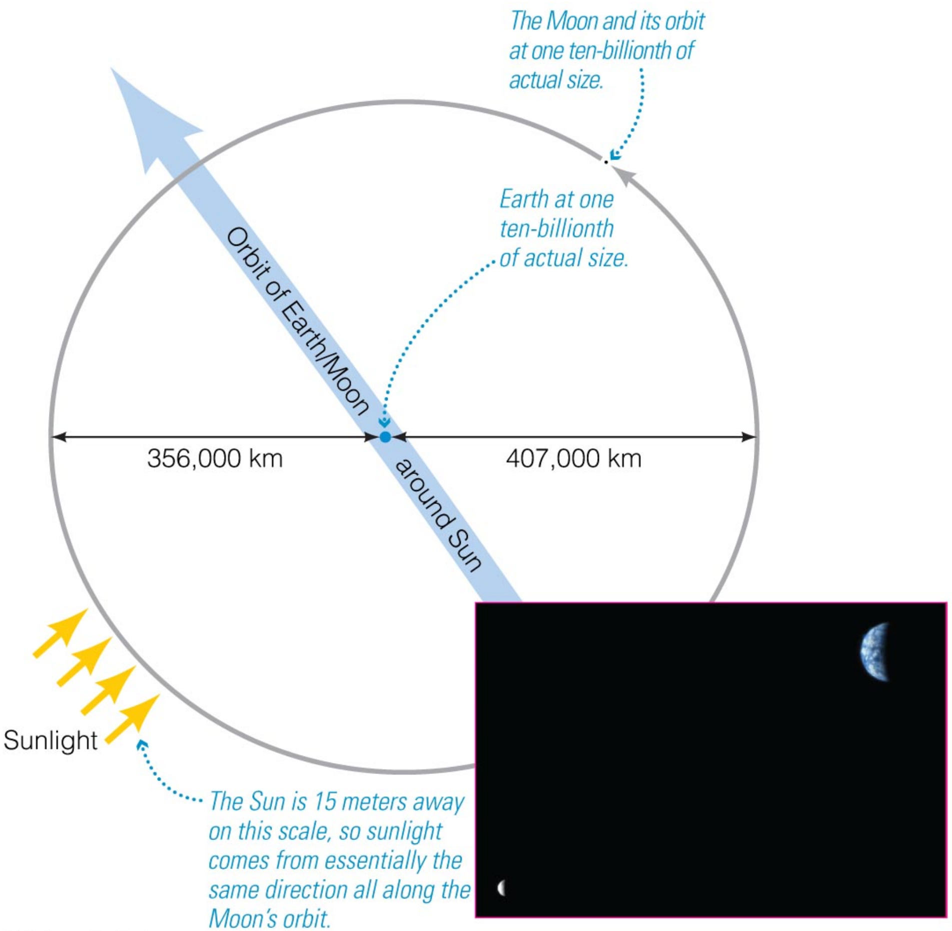
What have we learned?

- **How does the orientation of Earth's axis change with time?**
  - The tilt remains about 23.5º (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?**

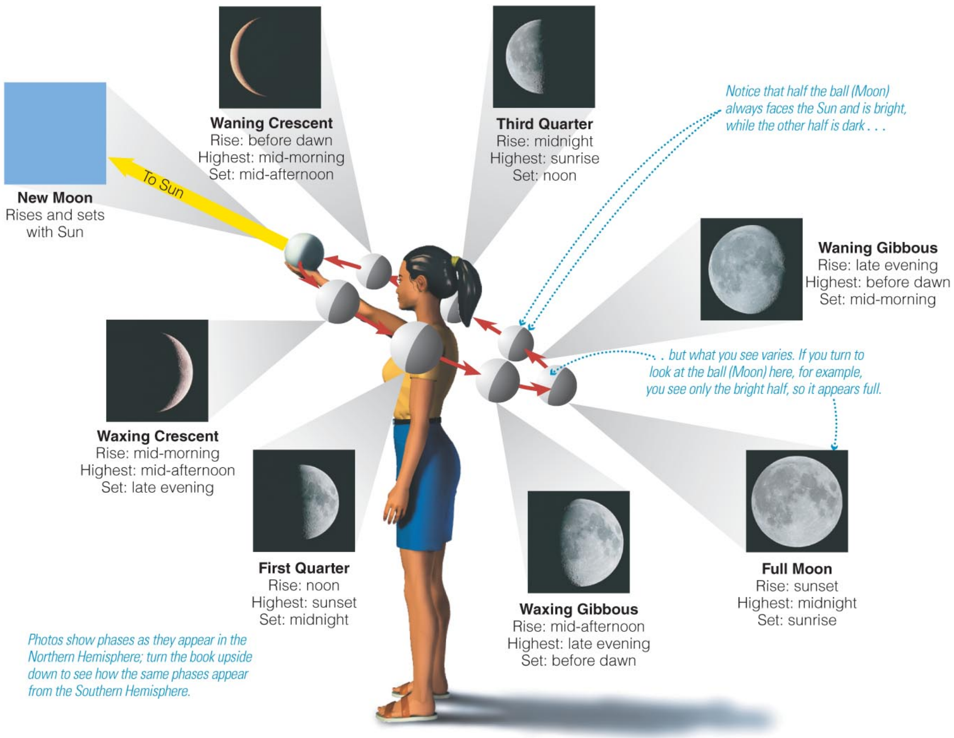
Why do we see phases of the Moon?



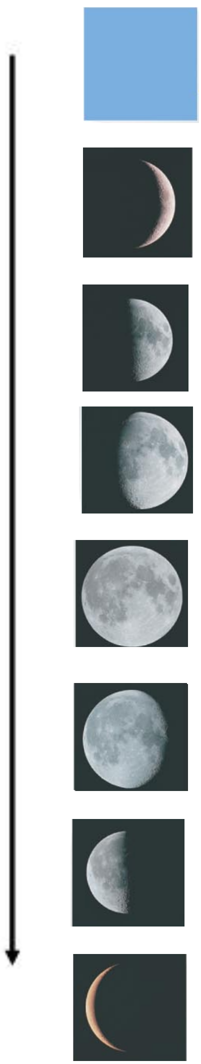
- Lunar phases are a consequence of the Moon's 27.3-day orbit around Earth.

Phases of the 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: 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 full" and sets later each day

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?

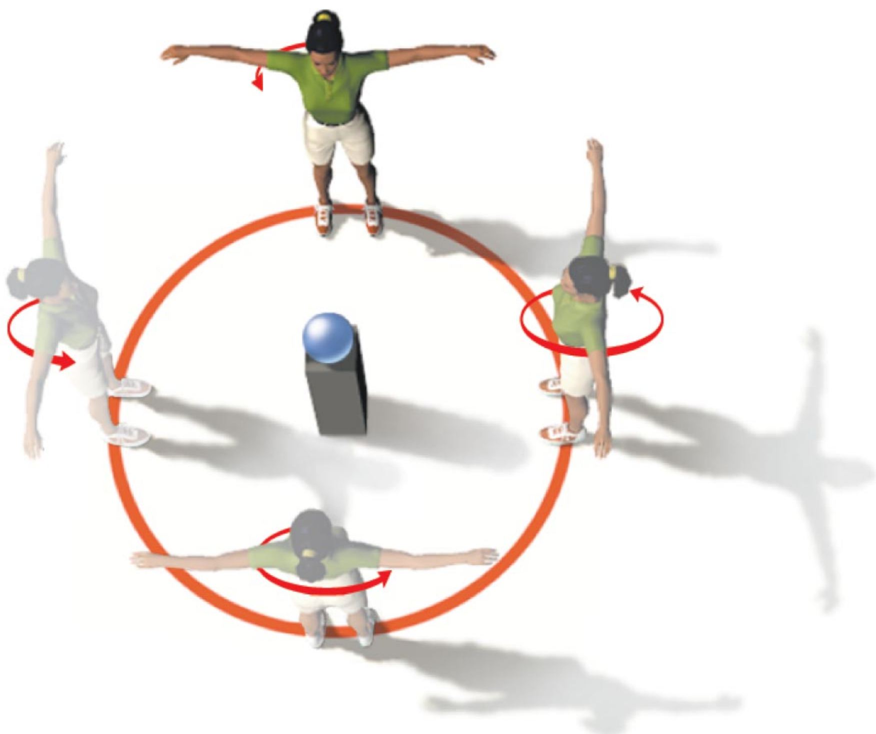
A. first quarter
B. waxing gibbous
C. third quarter
D. half moon

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

We see only one side of Moon

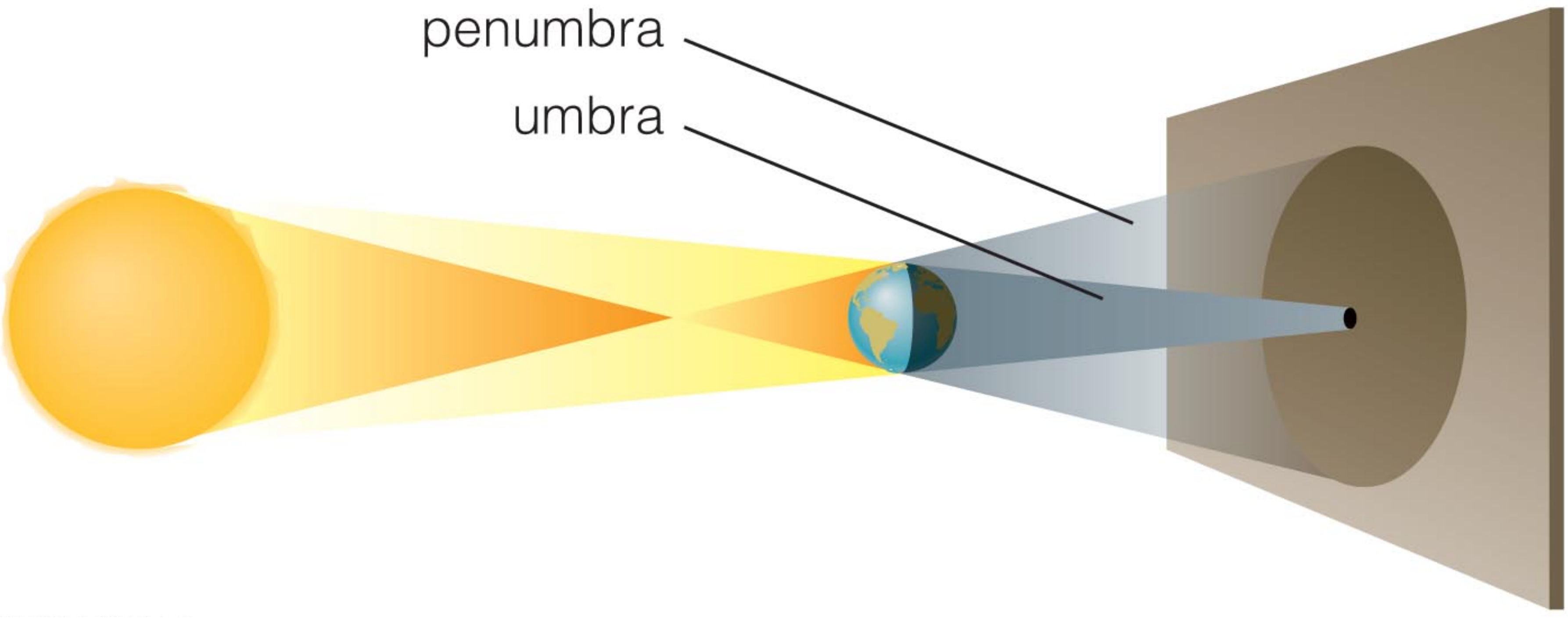


b You will face the model at all times only if you rotate exactly once during each orbit.

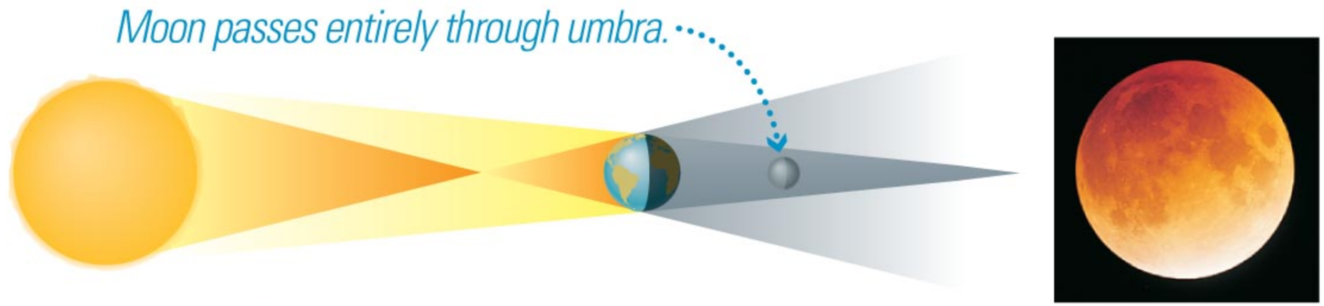
- Synchronous rotation: the Moon rotates exactly once with each orbit.
- That is why only one side is visible from Earth.

What causes eclipses?

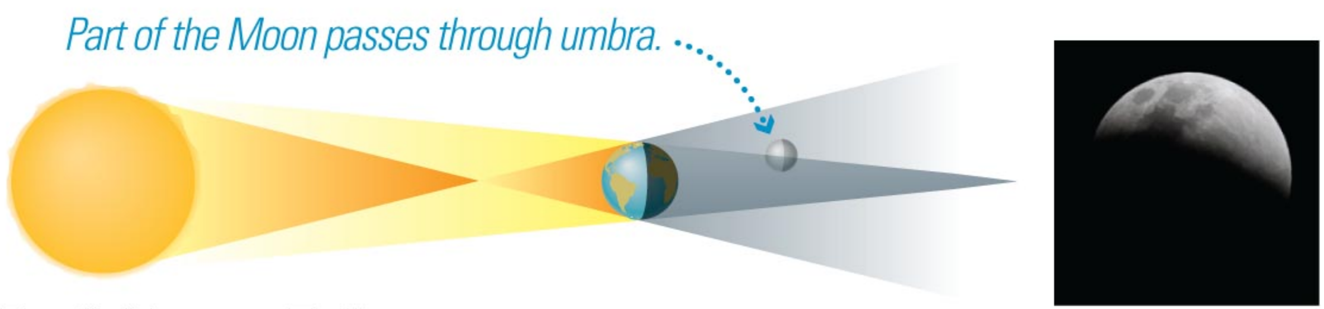
- The Earth and Moon cast shadows.
- When either passes through the other's shadow, we have an **eclipse**.



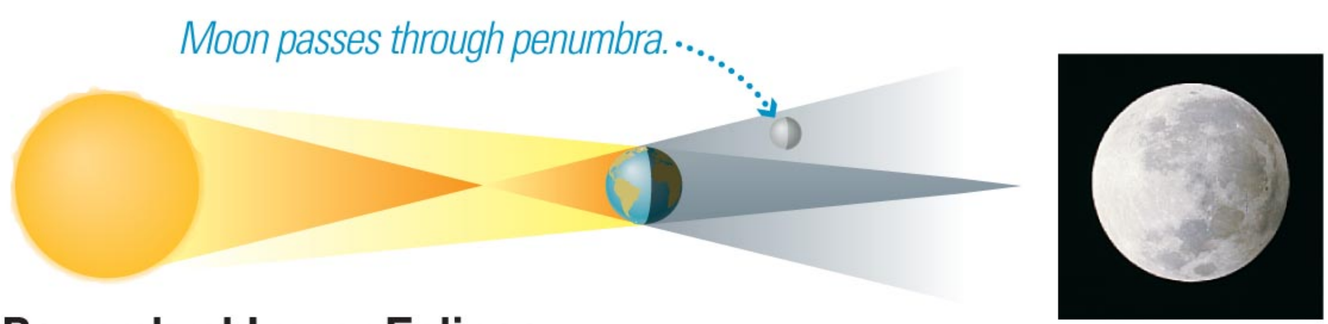
Lunar Eclipse



Total Lunar Eclipse



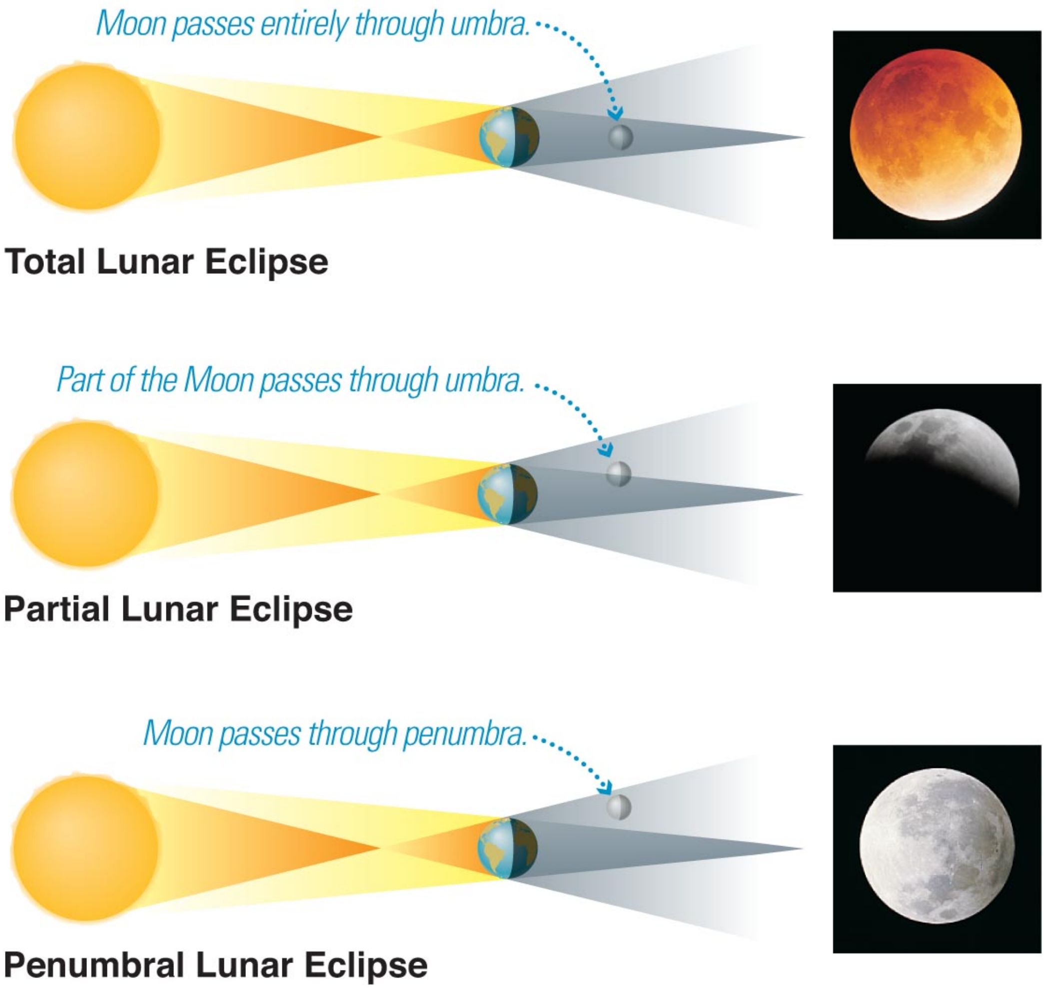
Partial Lunar Eclipse



Penumbral Lunar Eclipse

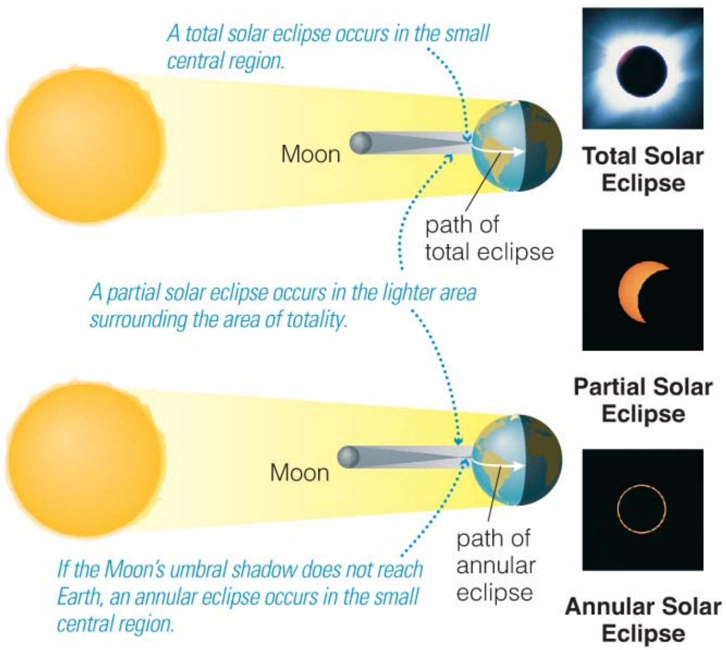
When can eclipses occur?

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



When can eclipses occur?

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

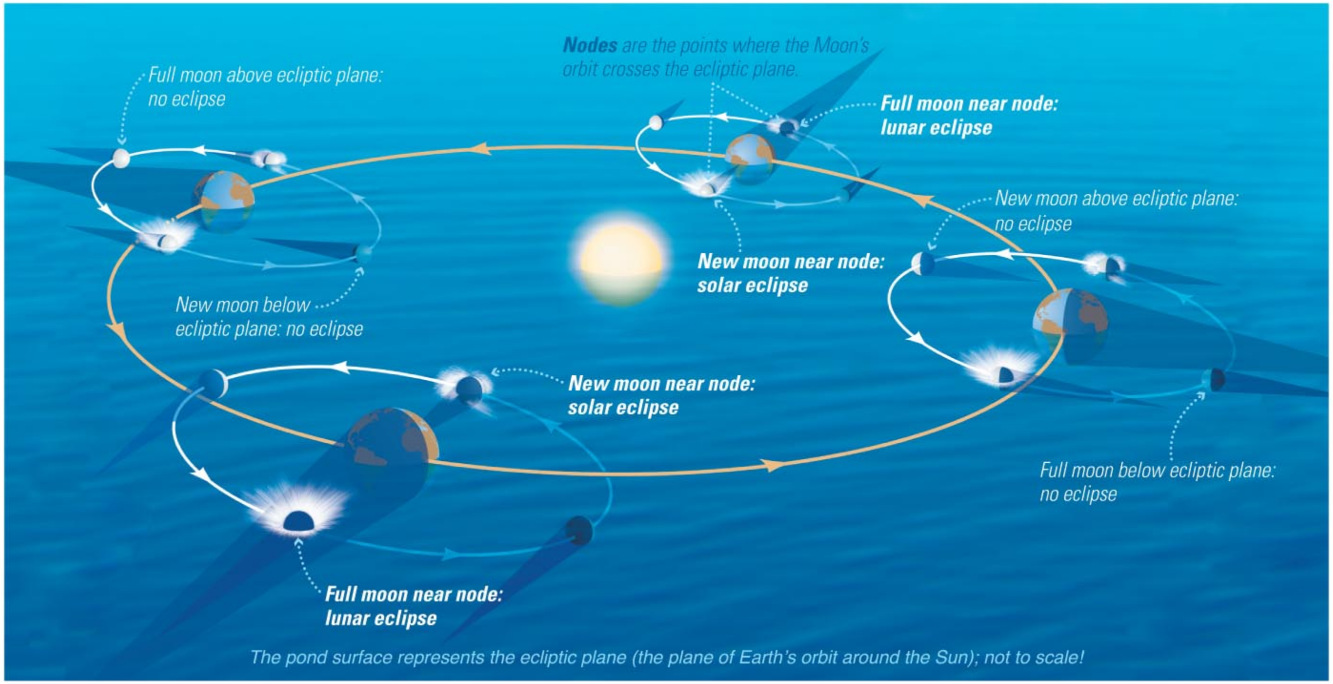


a The three types of solar eclipse. The diagrams show the Moon's shadow falling on Earth; note the dark central umbra surrounded by the much lighter penumbra.

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

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

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



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

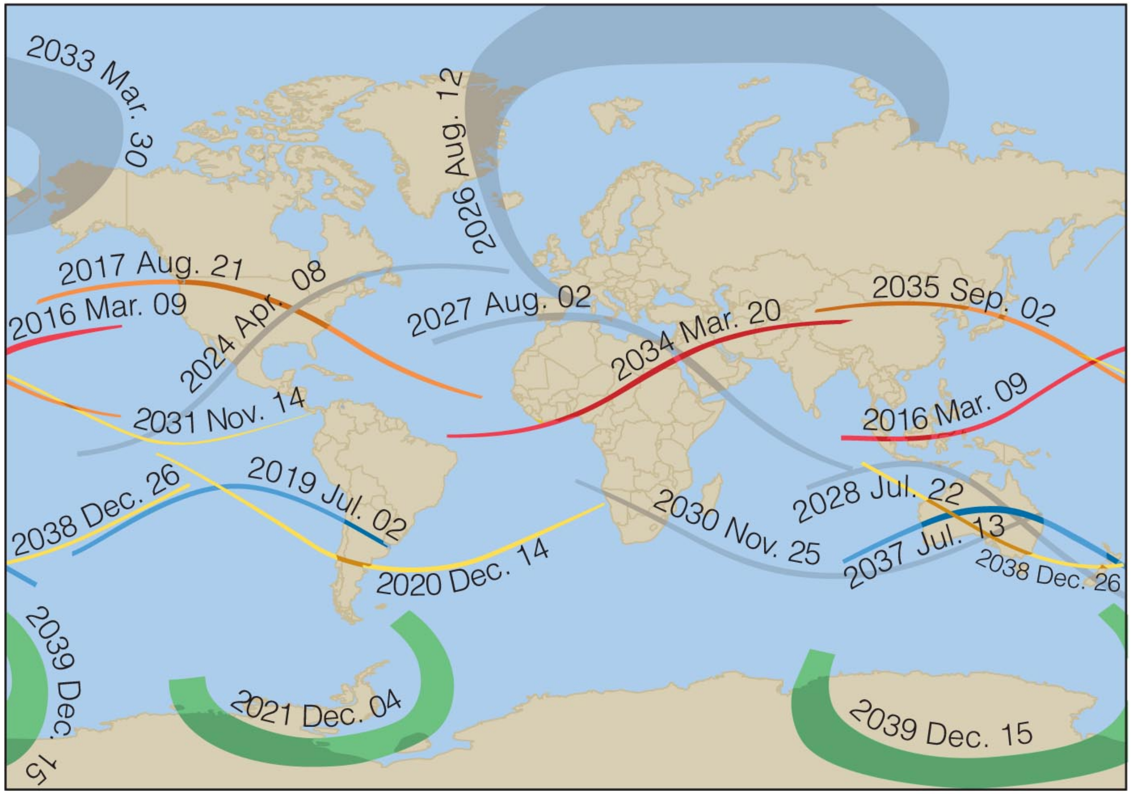
1. It must be full moon (for a lunar eclipse) or new moon (for a solar eclipse).

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

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



What have we learned?

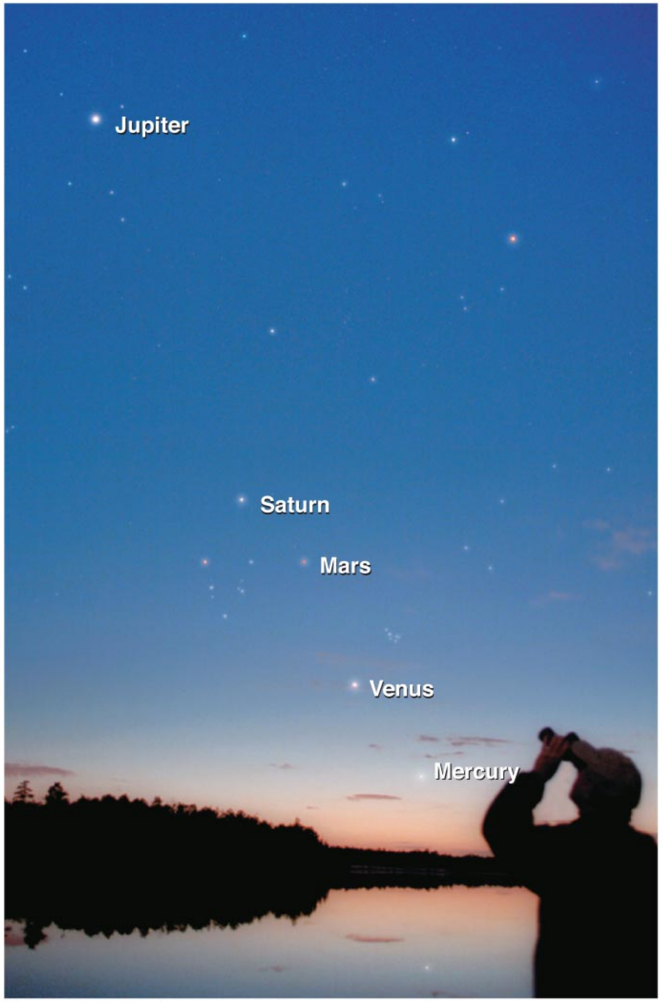
- **Why do we see phases of the Moon?**
  - Half the Moon is lit by the Sun; half is in shadow, and its appearance to us is determined by the relative positions of Sun, Moon, and Earth.
- **What causes eclipses?**
  - Lunar eclipse: Earth's shadow on the Moon
  - Solar eclipse: Moon's shadow on Earth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

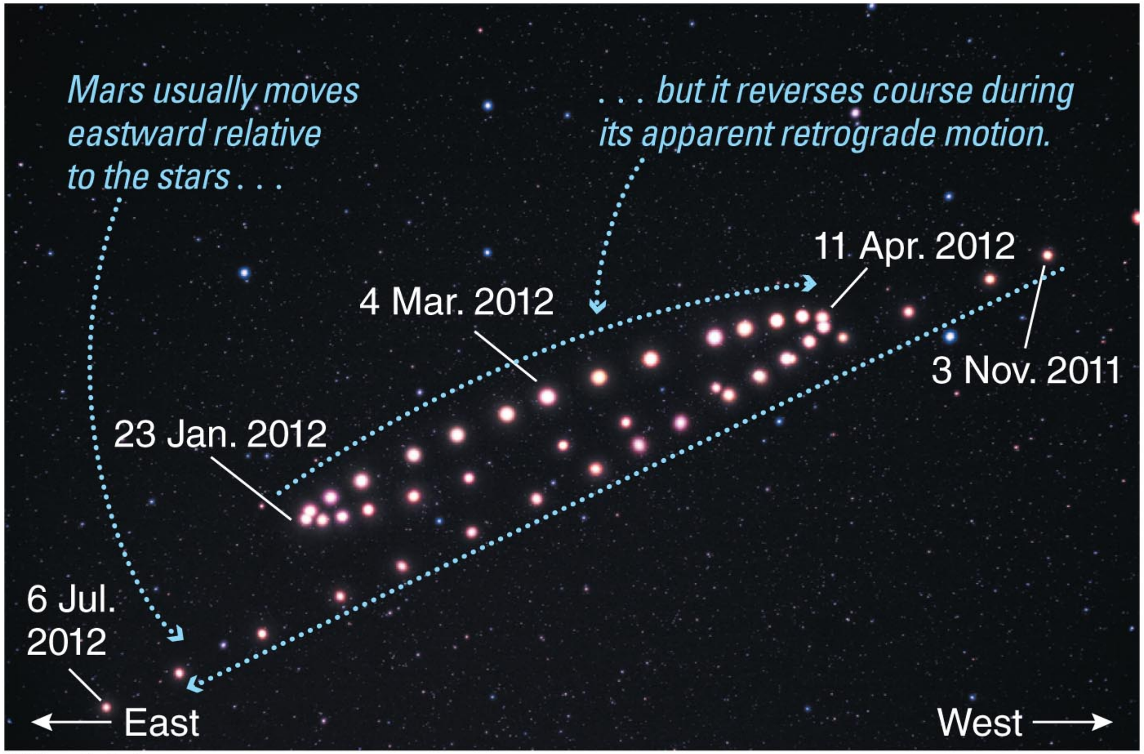
Planets Known in Ancient Times

- 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



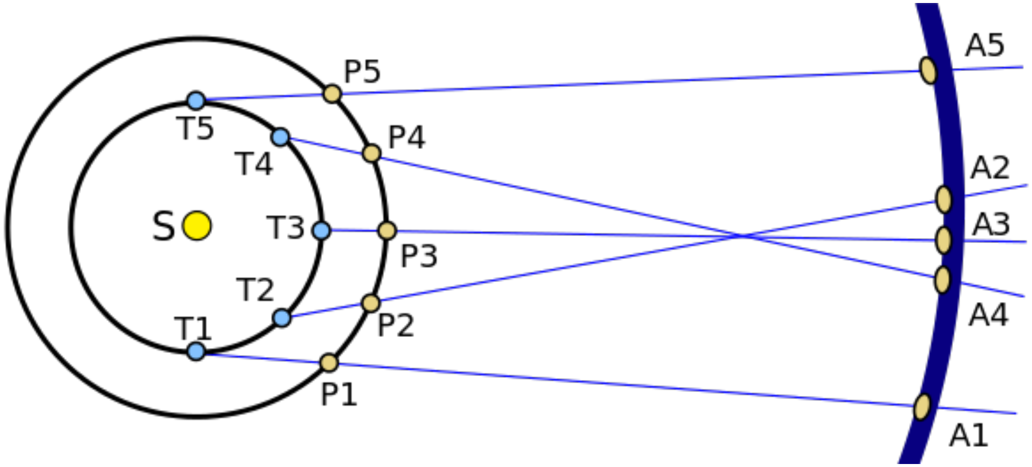
What was once so mysterious about planetary motion in our sky?

- 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**.



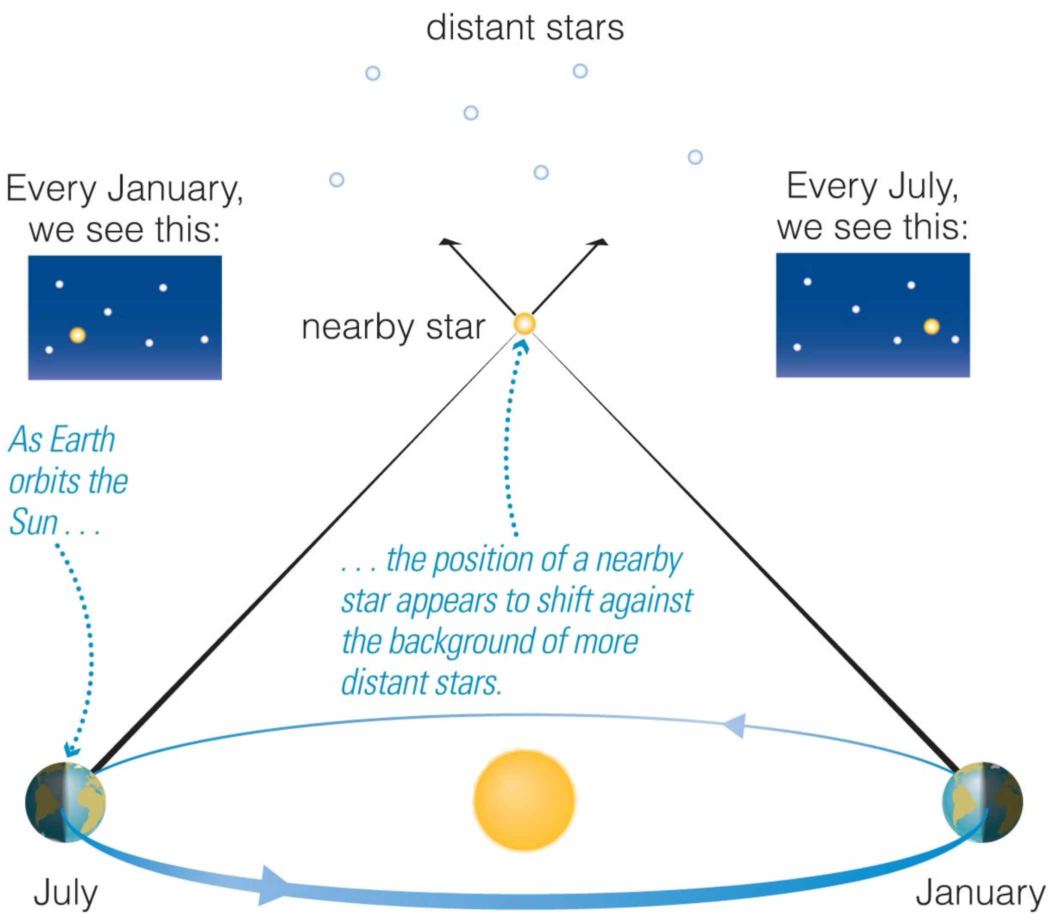
Explaining Apparent Retrograde Motion

- 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.