Thought Question

We see a bright supernova explode in the Andromeda galaxy (the other big galaxy in the local group). The remnants from such explosions disperse in about 10,000 years.

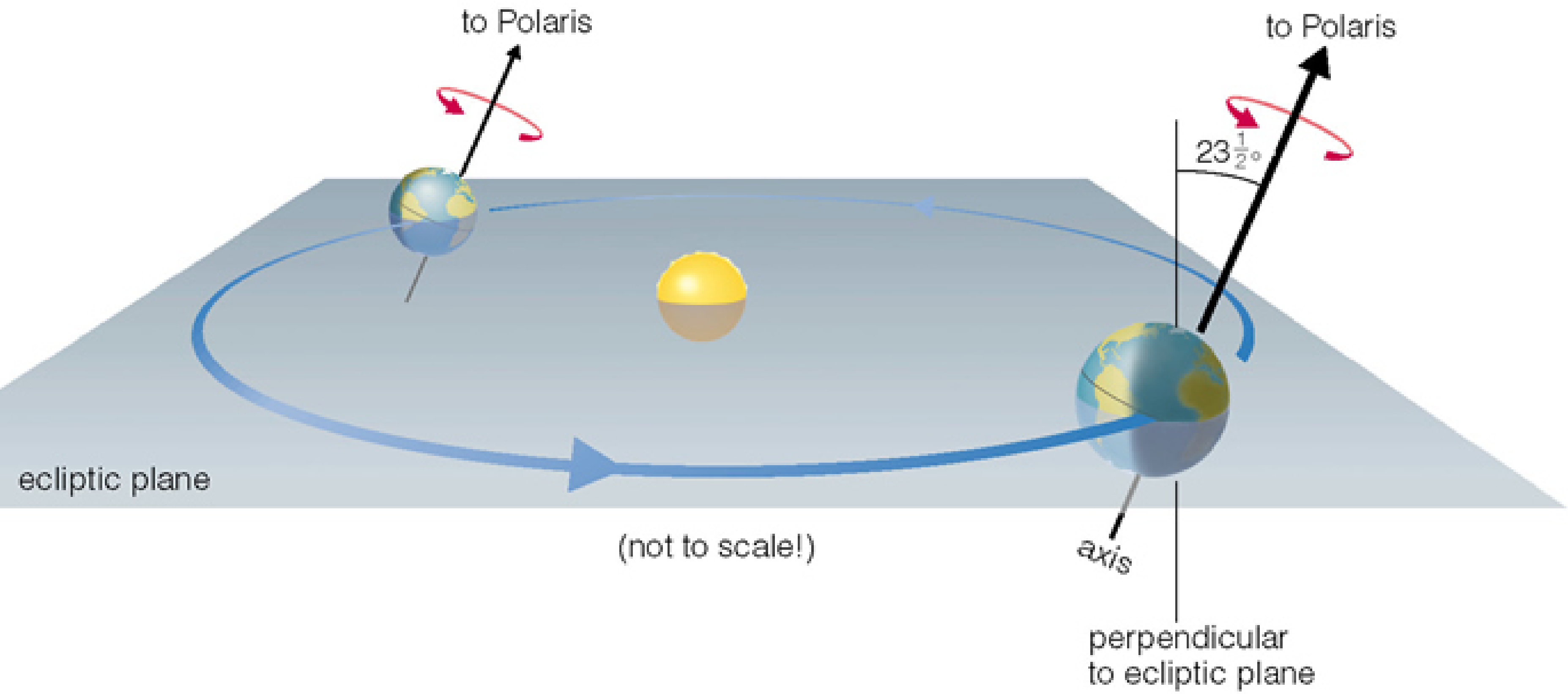
A. The supernova remnant still exists now, and we will watch it disperse over the next 10,000 Earth years.
B. In reality, the supernova remnant has already dispersed, but we will watch it disperse over the next 10,000 Earth years.
C. The image of the supernova dispersing will not reach us for another 2 million years.
D. We will never see the supernova remnant because it has already dispersed.

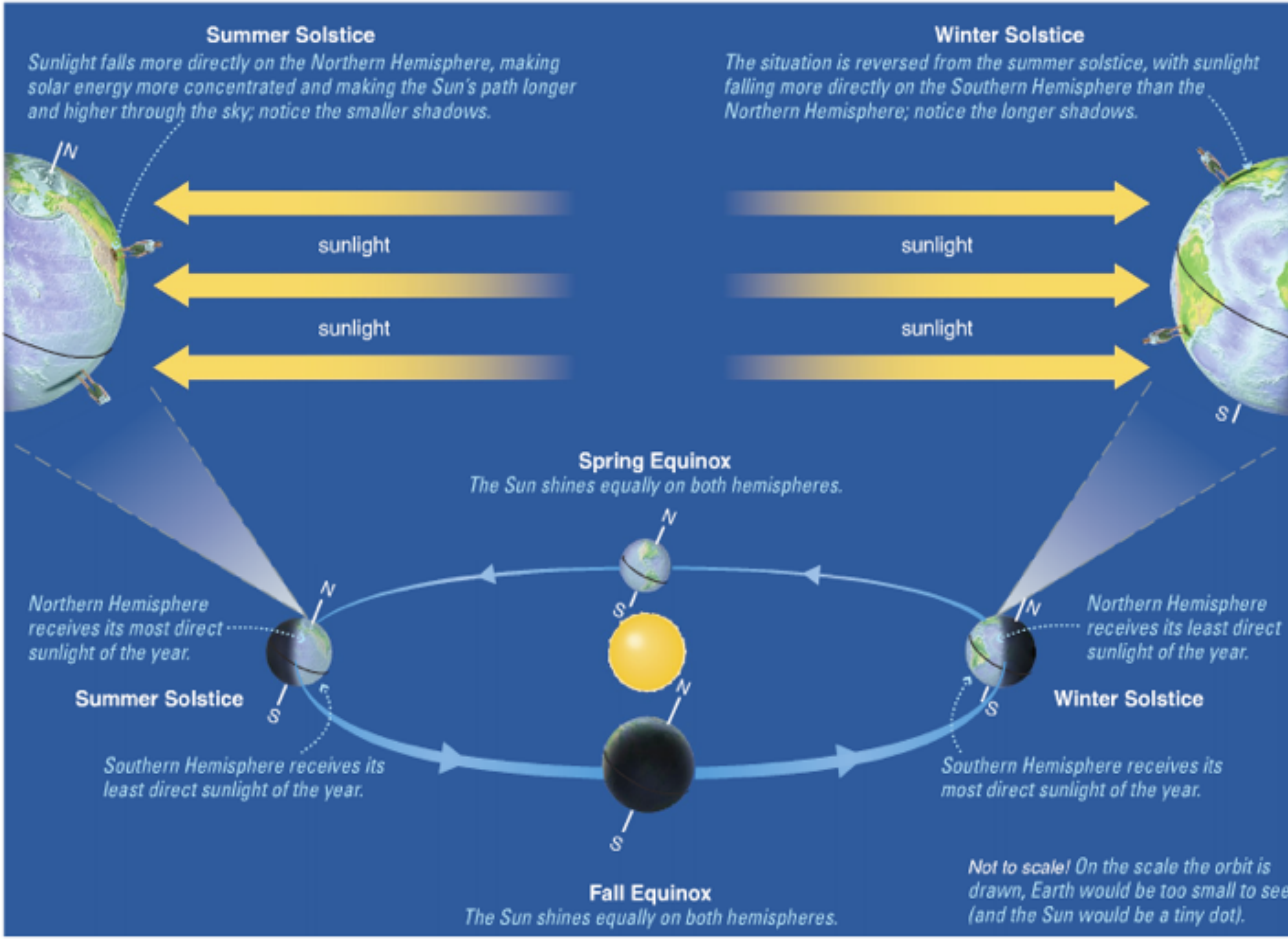
Chapters 2 and S1

Our goals for learning:

- How does the Earth move around the sun?
- What does the universe look like from Earth?
- Why do stars rise and set?
- How does the sky change with latitude and over the year?
- What are the reasons for the seasons, what are the seasons?
- Why does the moon change phases?
- Why do we get eclipses and what are they?
- What exactly is the zodiac?

Earth's Annual and Daily Motion



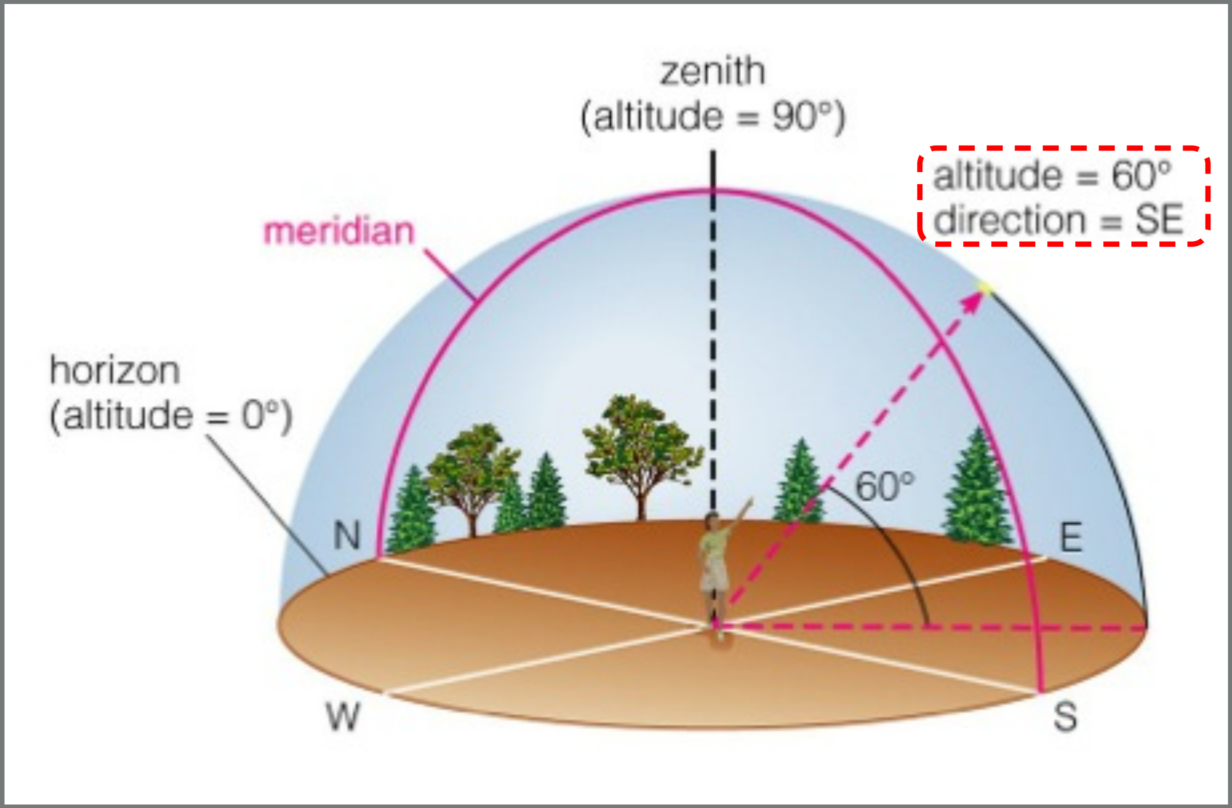

Summer Solstice
Sunlight falls more directly on the Northern Hemisphere, making solar energy more concentrated and making the Sun's path longer and higher through the sky; notice the smaller shadows.
Winter Solstice
The situation is reversed from the summer solstice, with sunlight falling more directly on the Southern Hemisphere than the Northern Hemisphere; notice the longer shadows.
N
sunlight
sunlight
sunlight
sunlight
S
Spring Equinox
The Sun shines equally on both hemispheres.
N
S
N
Northern Hemisphere receives its most direct sunlight of the year.
Summer Solstice
S
N
Northern Hemisphere receives its least direct sunlight of the year.
Winter Solstice
S
N
S
Southern Hemisphere receives its least direct sunlight of the year.
Southern Hemisphere receives its most direct sunlight of the year.
Fall Equinox
The Sun shines equally on both hemispheres.
Not to scale! On the scale the orbit is drawn, Earth would be too small to see (and the Sun would be a tiny dot).

BUT FROM OUR PERSPECTIVE THE SUN MOVES

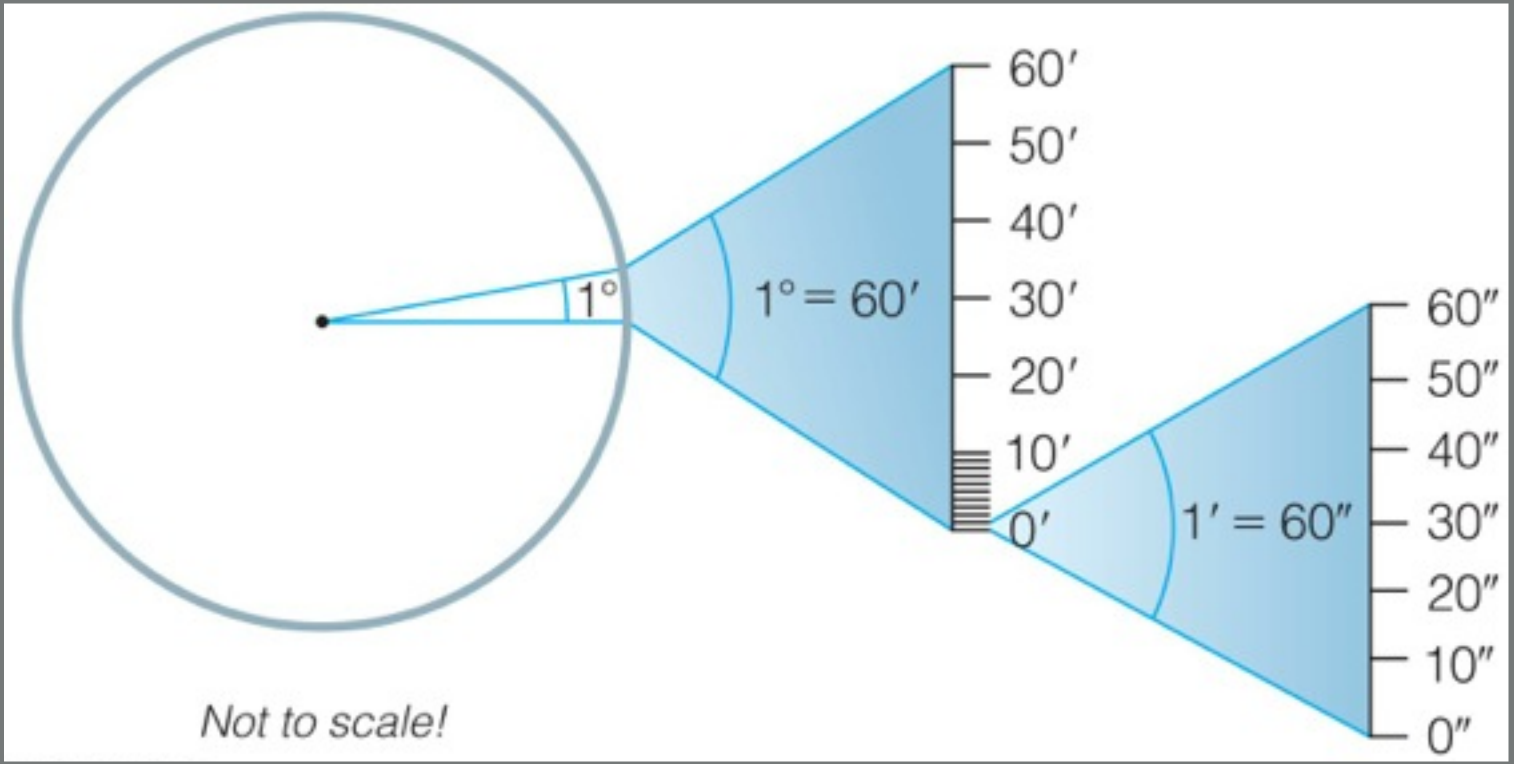
- Celestial Equator - Projection of the equator on the sky
- Ecliptic - Apparent path of sun in sky
- But we are tilted 23.5 degrees with respect to our orbital place so these two don't line up
- The sun looks like it is getting higher and lower in the daily sky

The Local Sky

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



Angles

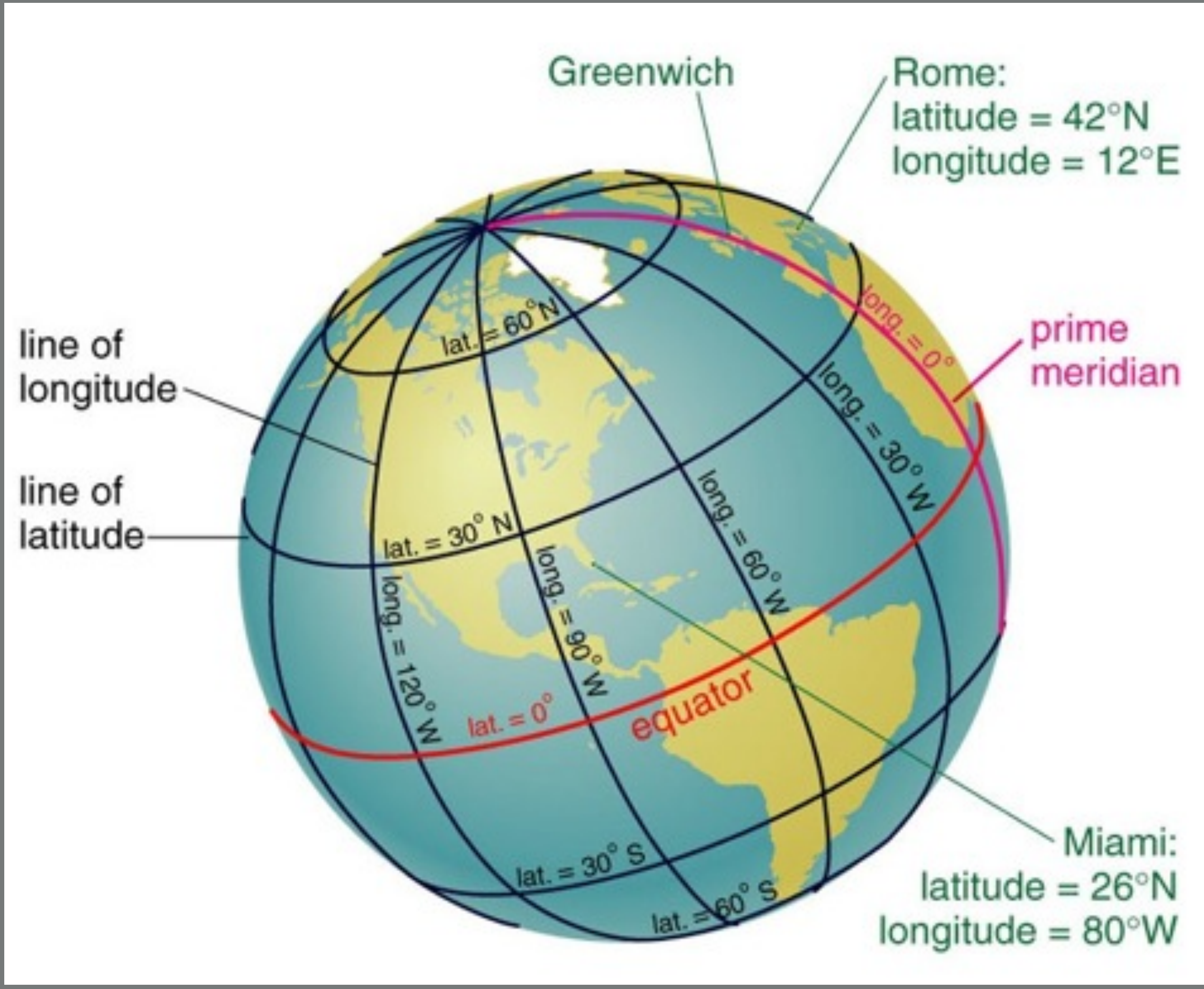


- There are 360° (degrees) in a circle or 2π radians in a circle.
- There are 60’ in a degree, ‘ means arcminute.
- There are 60” in an arcminute, “means arcsecond.
- There are 24 hours in a day, the earth rotates a full 360 degrees in a day.

Latitude & Longitude

Latitude:
position north or south of equator

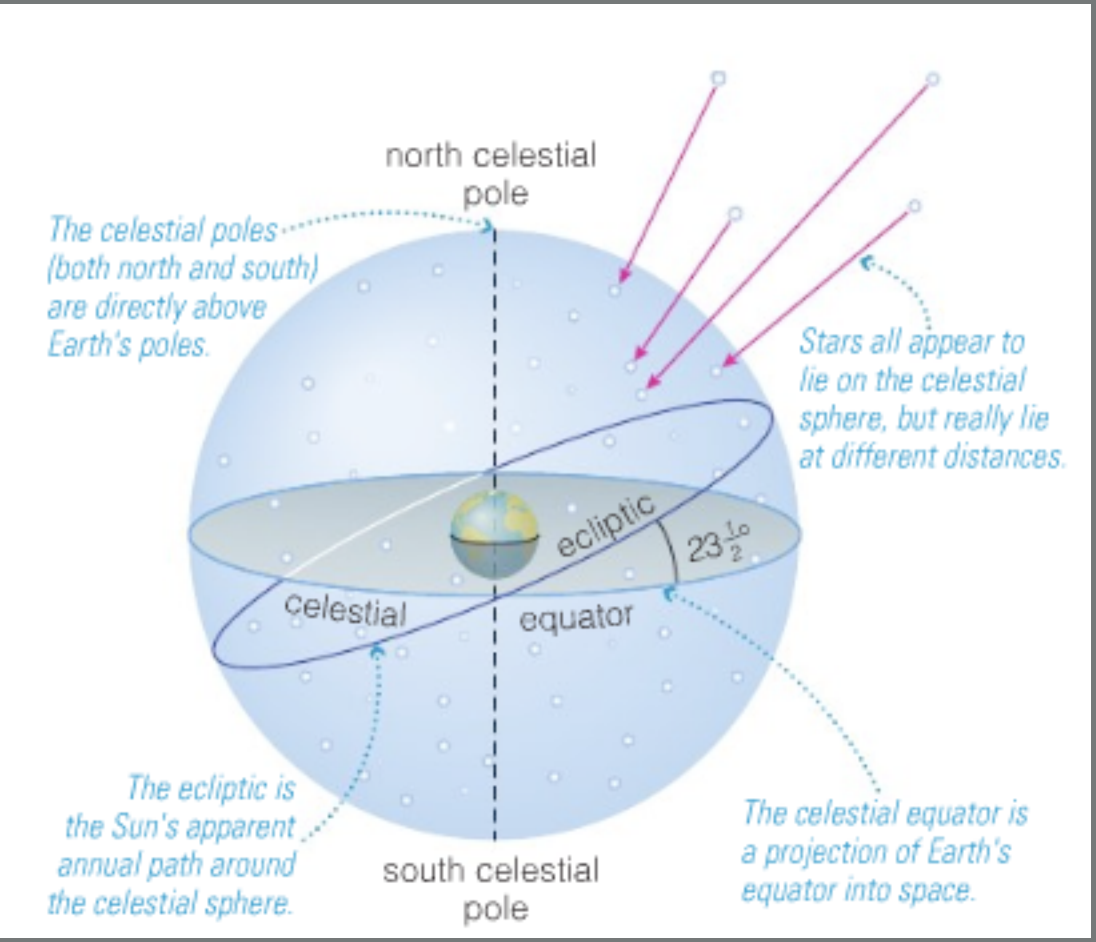
Longitude:
position east or west of prime meridian (runs through Greenwich, England)



Question

- How many degrees in longitude does the earth rotate through in one hour?
- Talk to a friend for a minute or two and write your answer down on a piece of paper

The Celestial Sphere



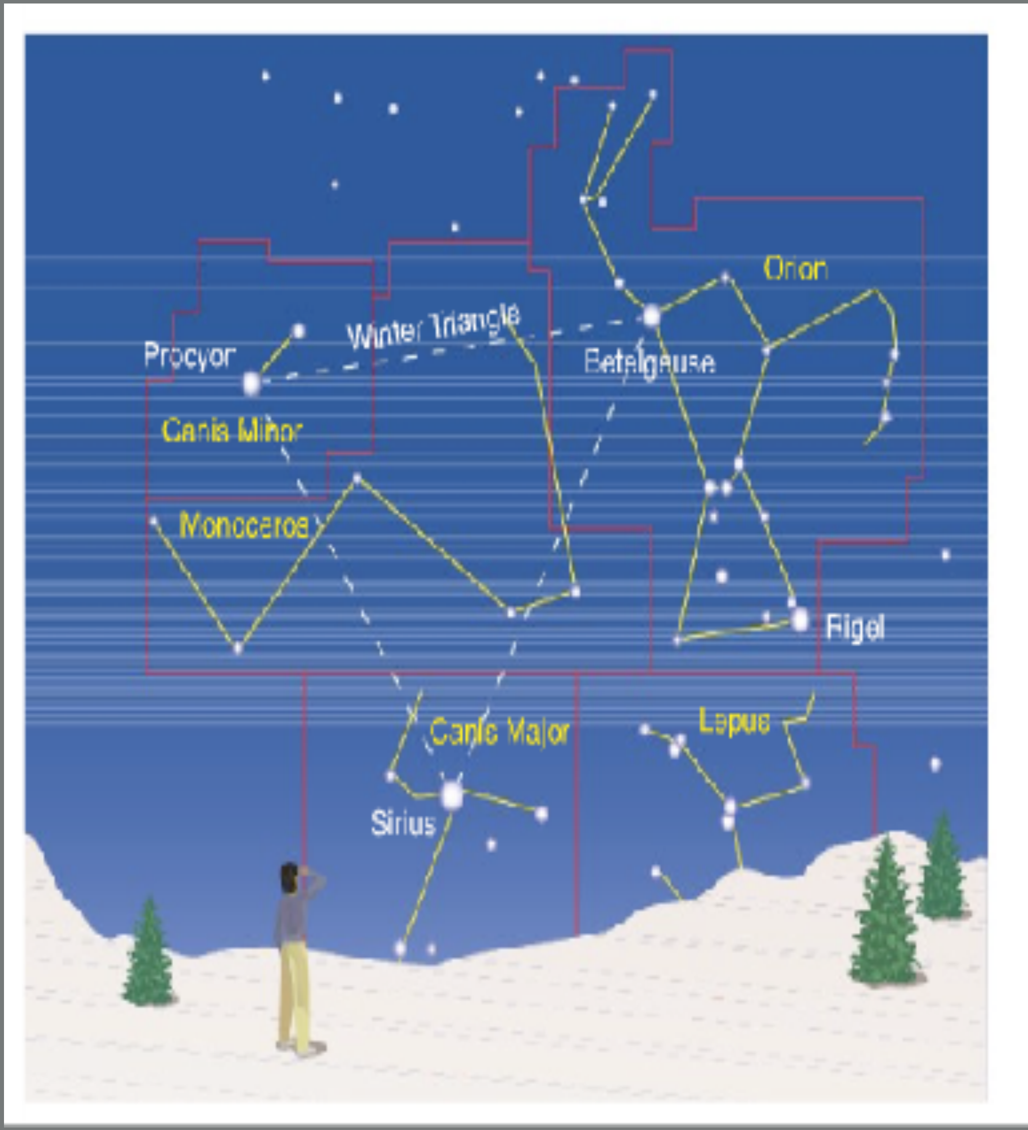
- Project the coordinates on the earth onto the sky
- The Earth is tilted towards the North Star, Polaris, at 23.5 degrees from the plane of our orbit
- The North Celestial Pole Points towards Polaris
- The ecliptic, the apparent motion of the sun in the sky, is tiled 23.5 degrees from the celestial equator

Notice how everything looks like it is equally far away

Describing our way around the celestial sphere

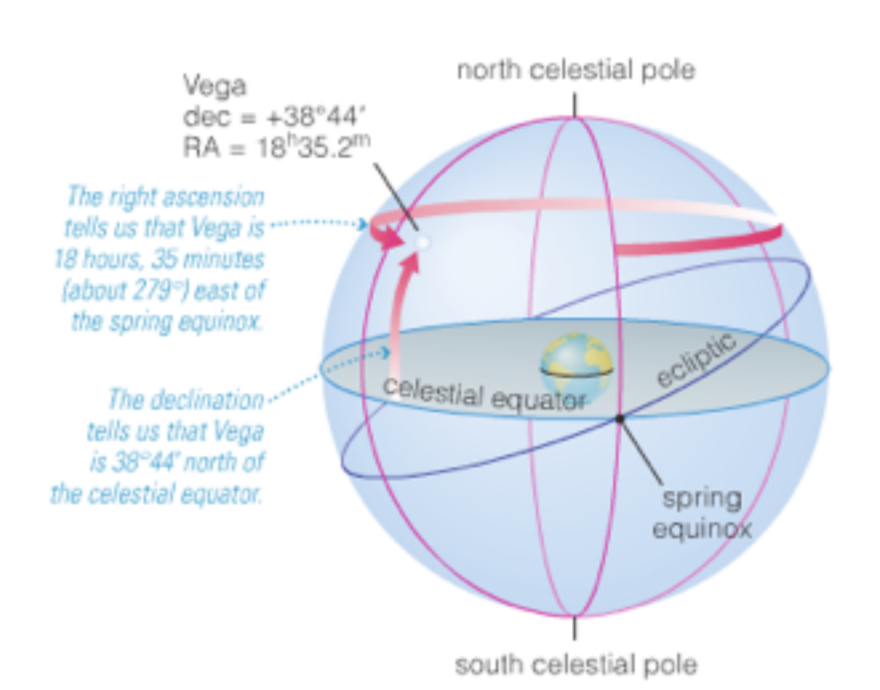
Constellations

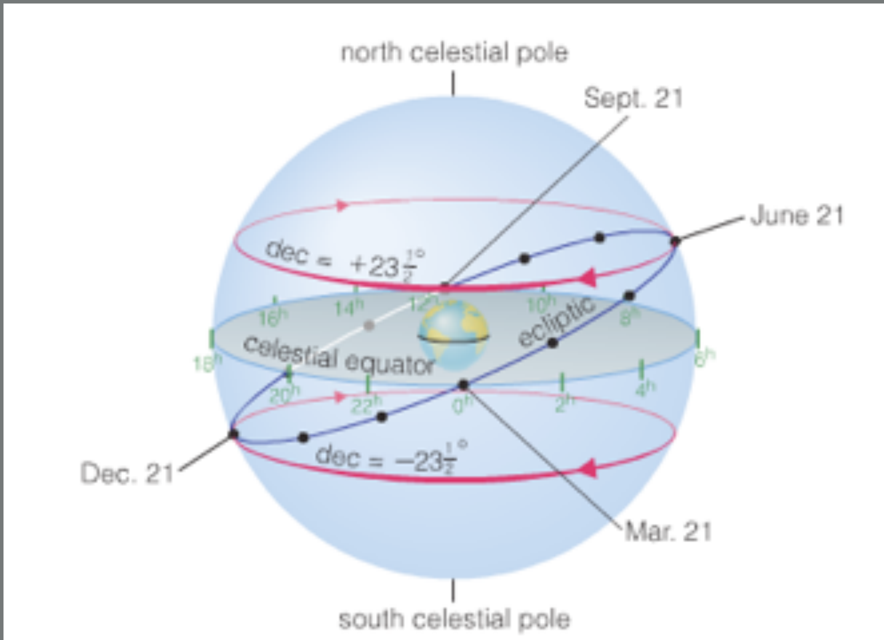
- 88 of them defined by the IAU
- 13 in the Zodiac (Ever heard of Ophiuchus, a guy holding a snake)
- Interestingly it has Barnard's star ~6 light years away, only Alpha and Proxima Centauri, a binary pair ~ 4.3 lys away is closer



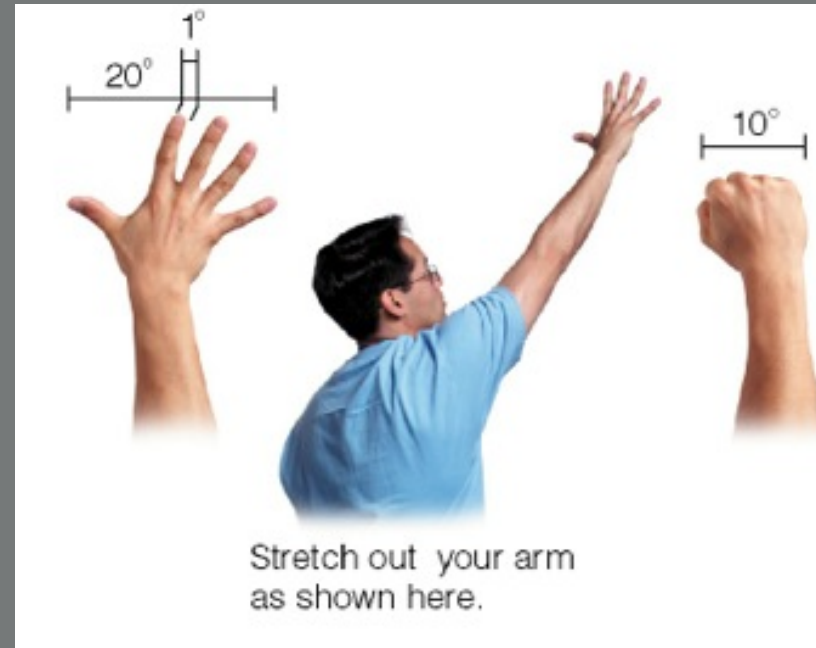
Coordinates on The celestial sphere

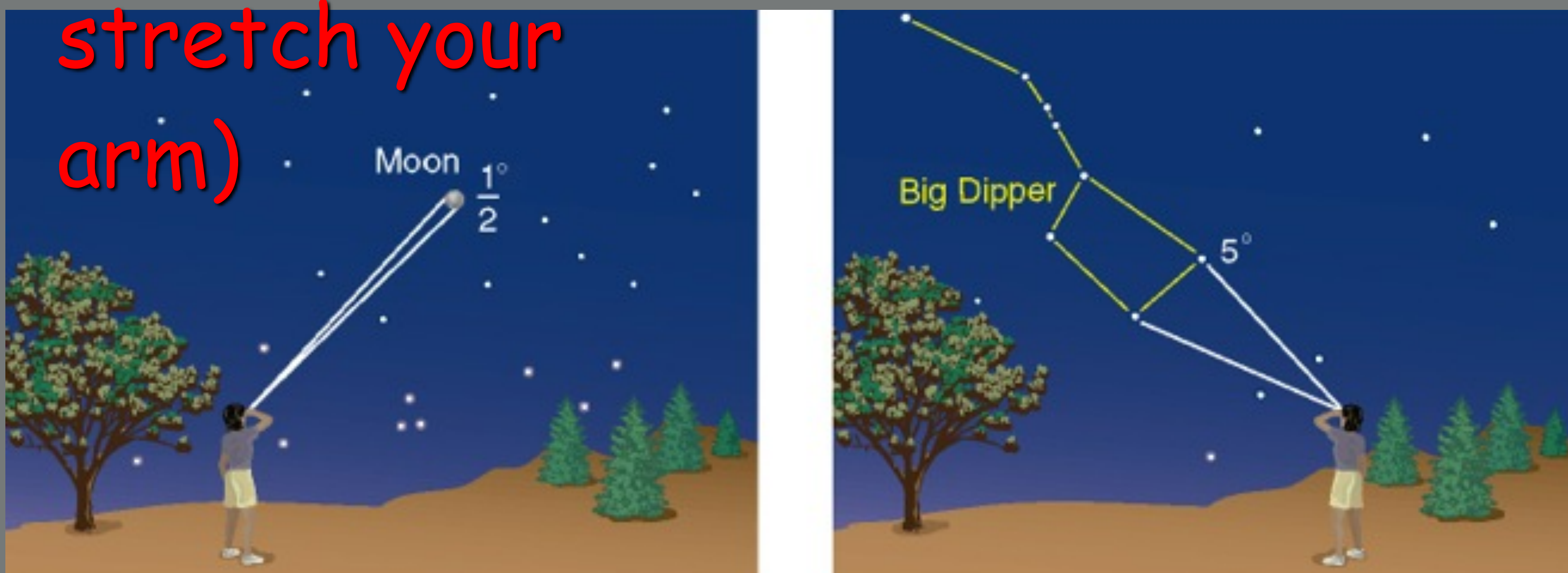
- Right Ascension (RA) describes east to west and runs from 0,1,2,…24=0 hours
- Declination is just the projection of latitude on the night sky
- The zero hour for RA is where the Ecliptic intersects the celestial sphere on the Spring Equinox





We measure the sky using angles (make sure to stretch your arm)

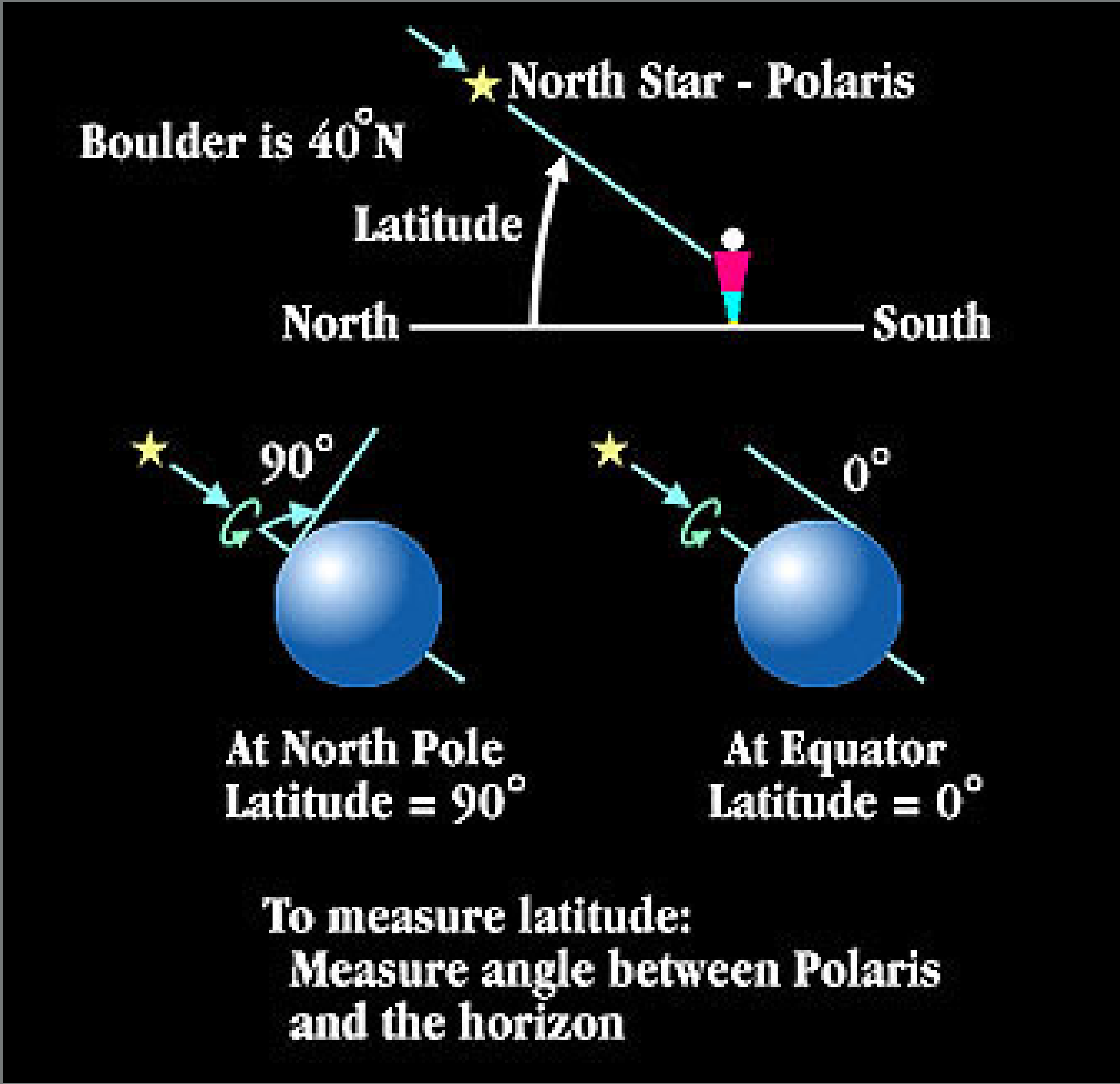




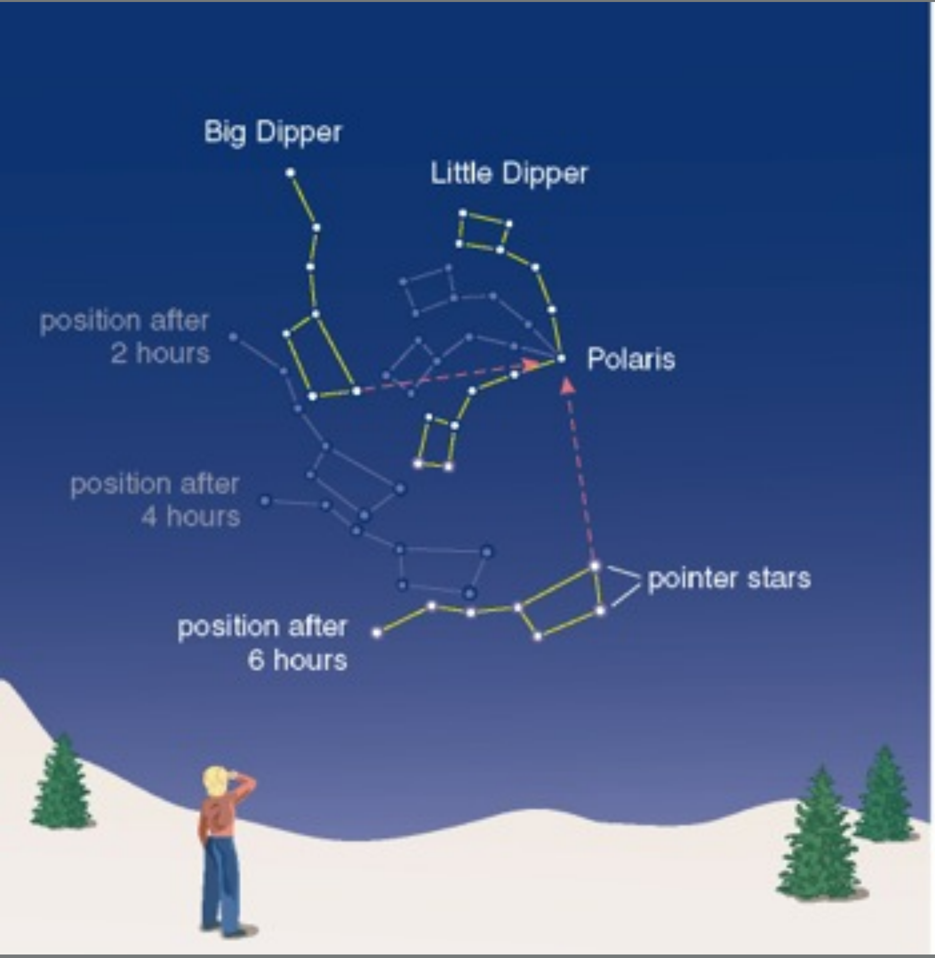
North Celestial Pole - Polaris

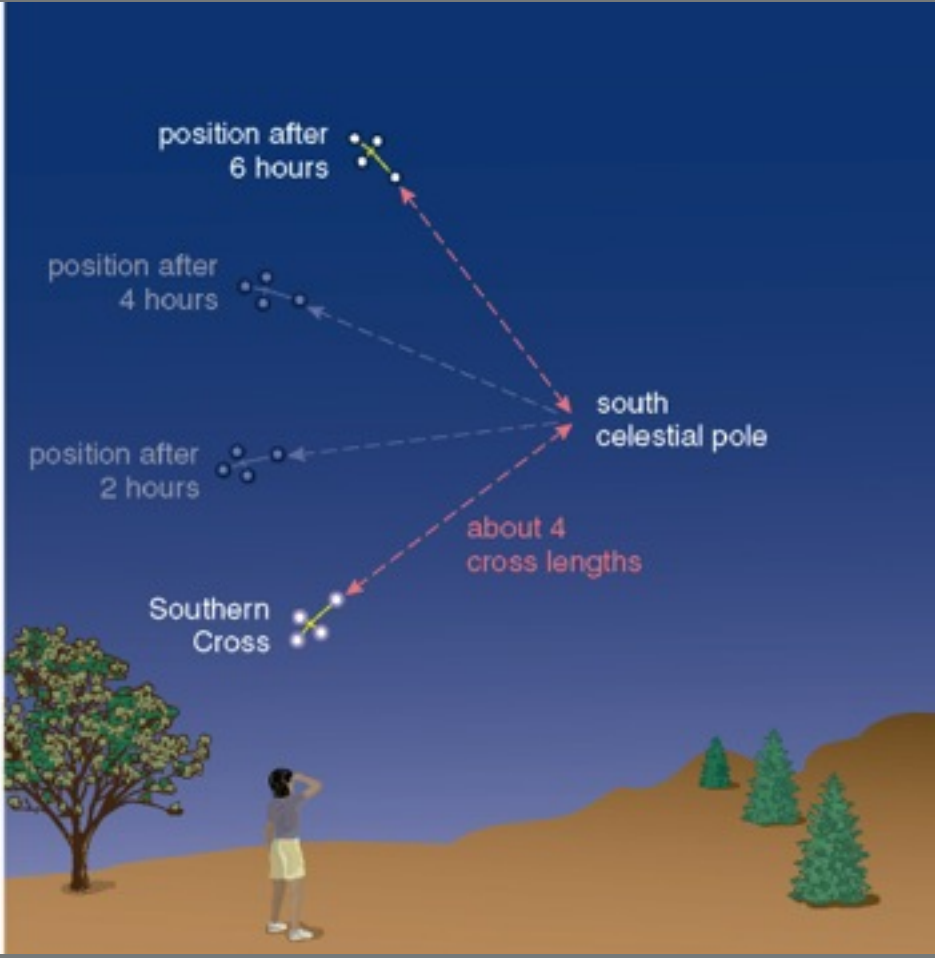
- Everything appears to circle this point in the night sky because out north pole, which is in the direction of our rotation axis, points to it.
- If Polaris is at the zenith at the North Pole where is it in Boulder?
- How about at the equator?
- How about in Southern Latitudes?

Latitude


North Star - Polaris
Boulder is 40°N
Latitude
North
South
90°
0°
At North Pole
Latitude = 90°
At Equator
Latitude = 0°
To measure latitude:
Measure angle between Polaris
and the horizon

Finding The Celestial Pole





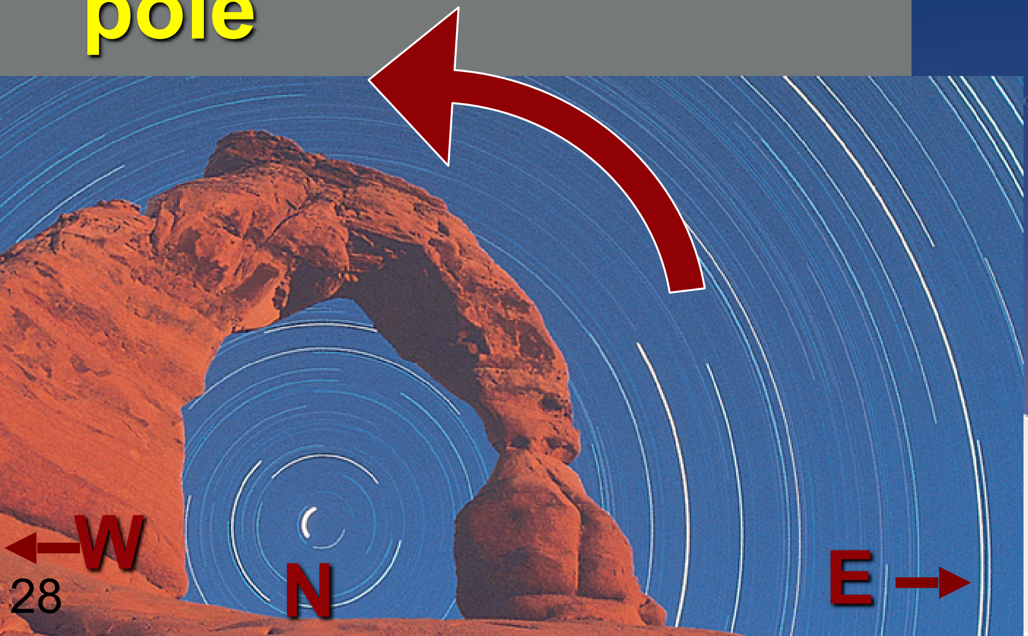
Northern Hemisphere

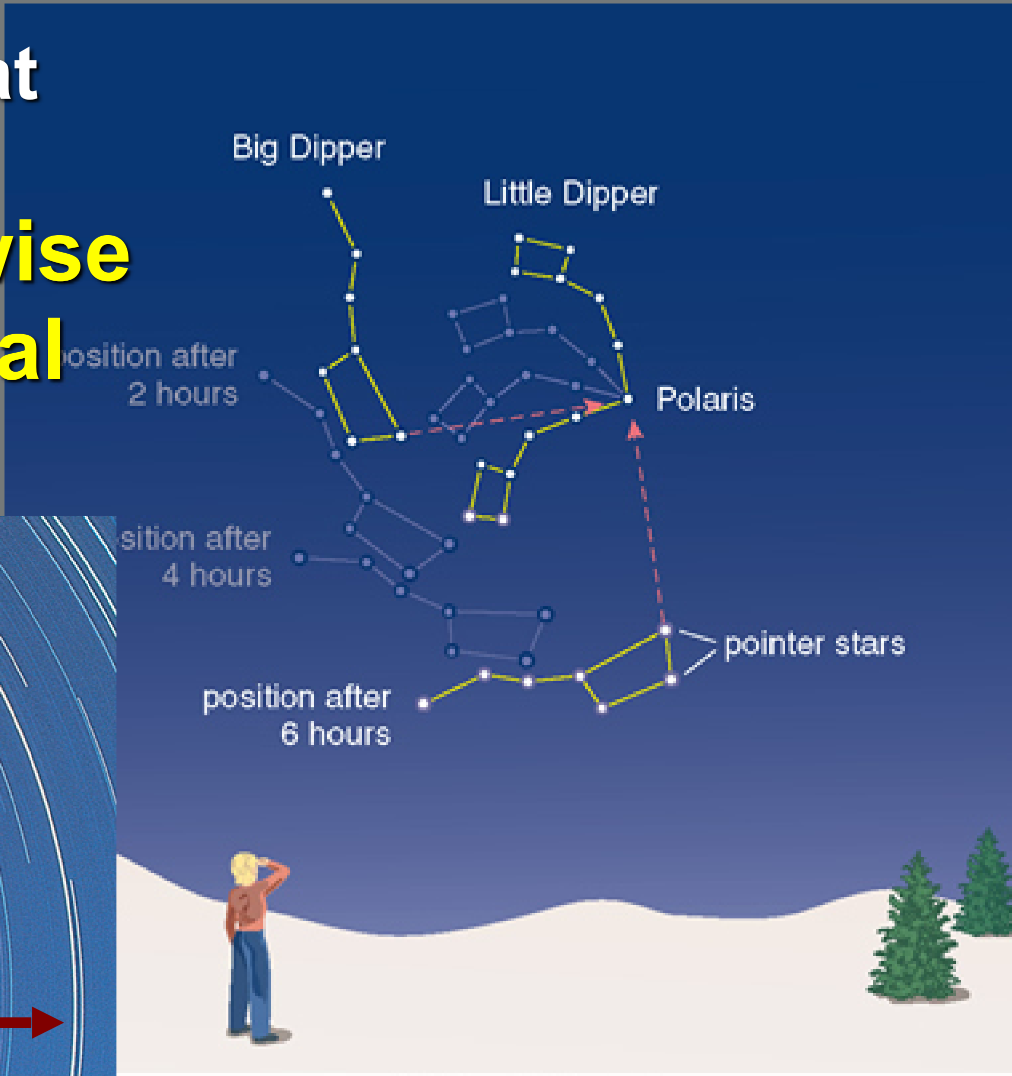
Southern Hemisphere

Circumpolar Motions

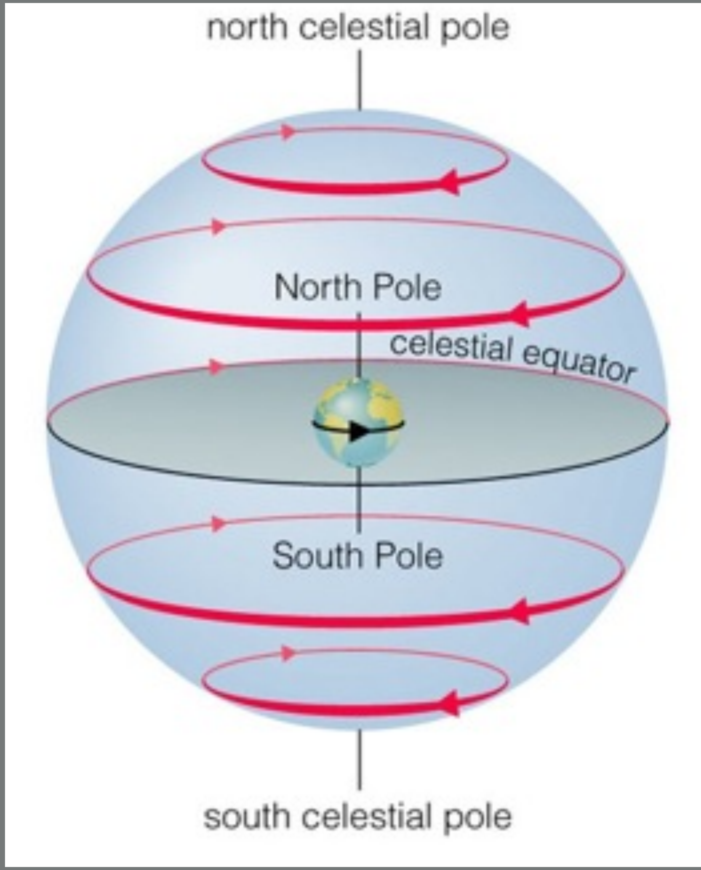
Circumpolar **stars**

- – **Stars that never set at your location**
- **Move counterclockwise around north celestial pole**





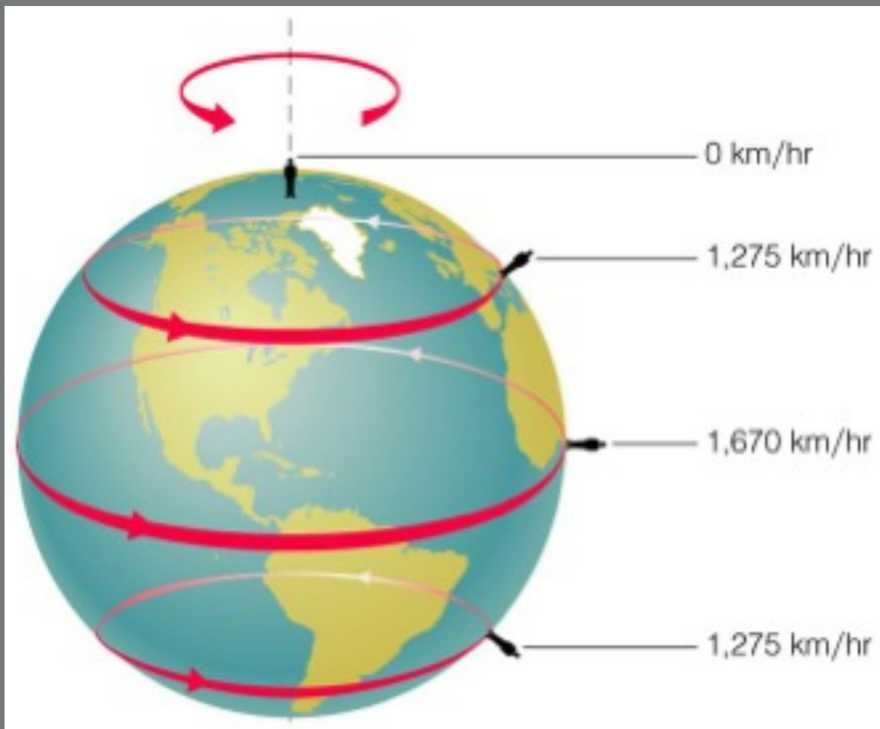
Daily Motions - Apparent



Rise in the east -
Set in the west

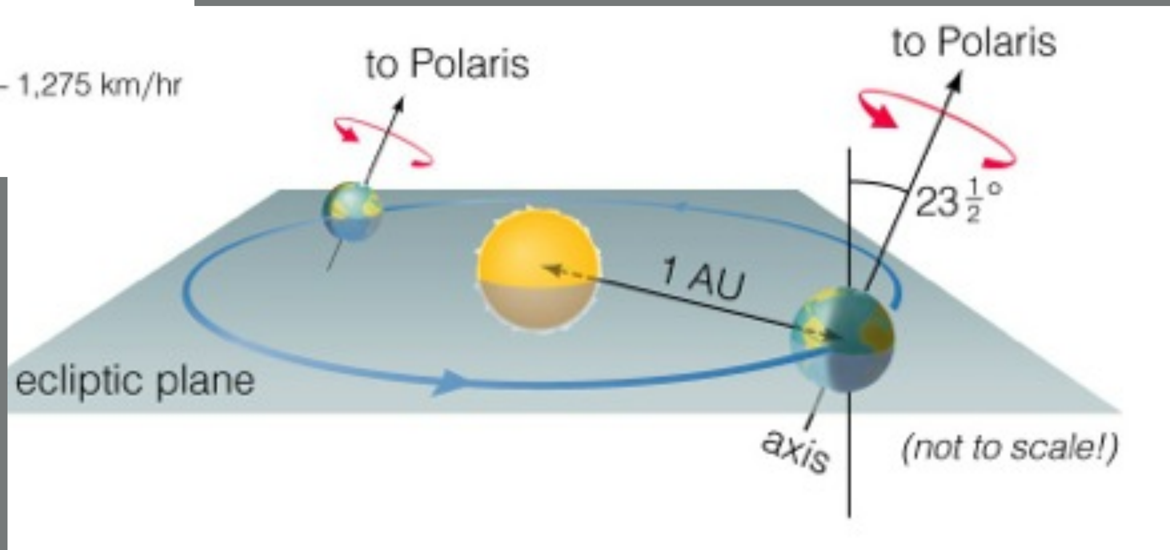
Apparent motion **= Stars appear to move counter-clockwise (when looking north)**

Daily Motions - Actual



Actual motion = Earth spins with axis pointed in fixed direction - towards Polaris

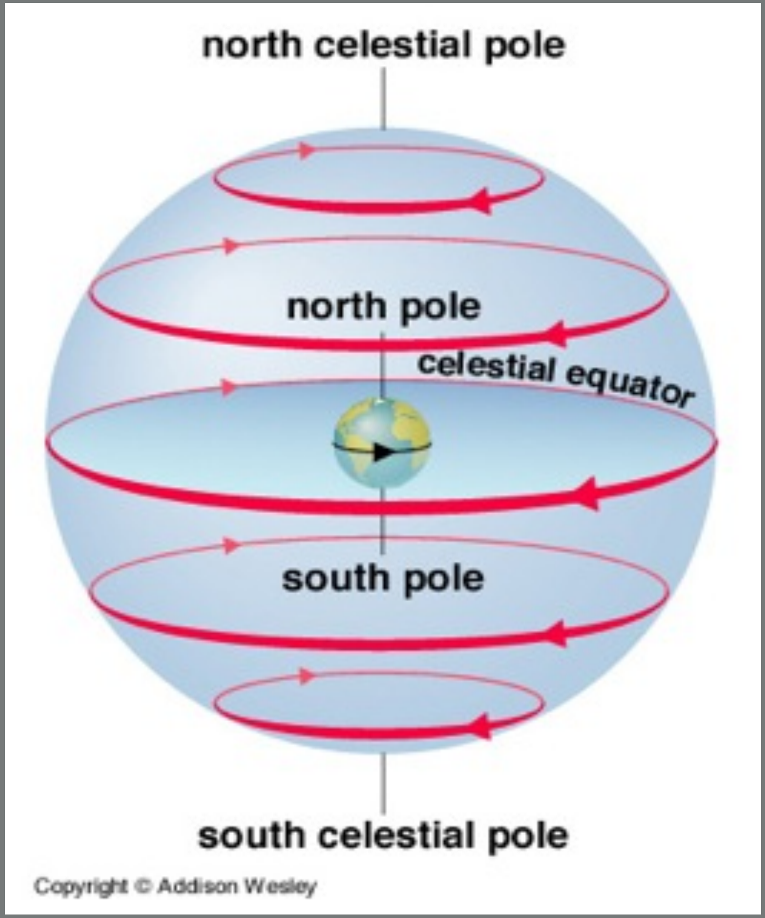
West to East: NY leads LA



Remember The Right Hand Rule

- Put your right hand out.
- Make a thumbs up.
- Now you know the direction of the earth's rotation, the planets orbit around the sun, the moon's orbit around the Earth.
- Everything goes from West to East so everything appears to rise in the east and set in the west, think of the merry-go-round

Why do stars rise and set?



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

Which way do stars appear to move in the northern hemisphere? How about the Southern?

Hint, Rise in the East, Set in the West, always.

Stand up

- The sun and stars appear to go counter clockwise or counterclockwise in the hemispheres?
- Rise in the east set in the west
- Visualize a clock
- Try it

Thought Question

What about the Sun? What causes the Sun to rise and set?

A. The Earth's orbit around the Sun
B. Earth spinning on its axis
C. Our solar system moving in the Milky Way Galaxy
D. The Sun's movement around the Earth
E. The Earth changing its axial tilt

Proof of Earth Spinning

Foucault's Pendulum

Paris, 1851

- Newton's 1st Law: Objects in motion tend to stay in motion
  - More on this later.
- Pendulum swinging wants to stay swinging in the same direction
  - Even if the Earth moves underneath it!

More Proof of Spinning Earth

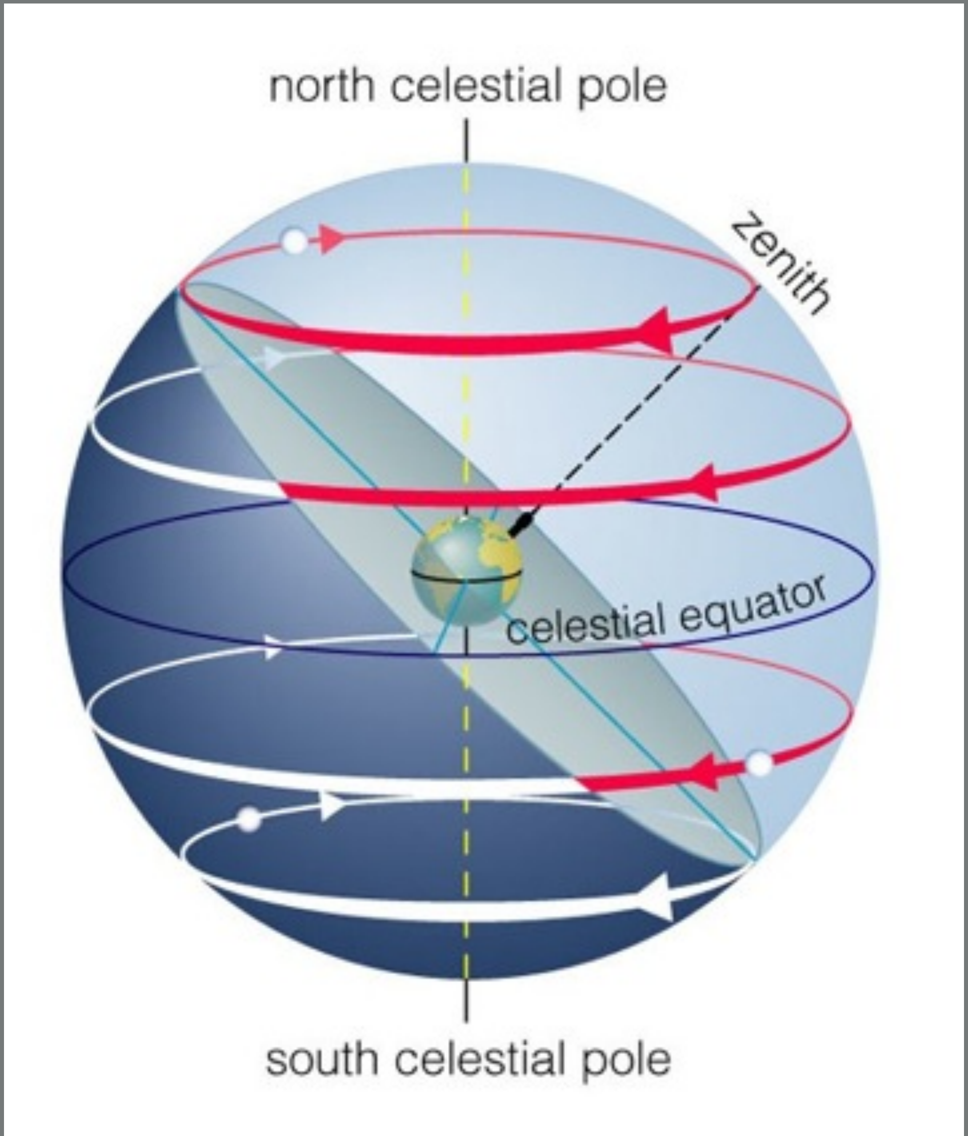
MESSENGER spacecraft looks back at Earth on its way to Mercury

Can we see all the stars each night?

No

- Only stars always above our Horizon, remember what the Horizon is?

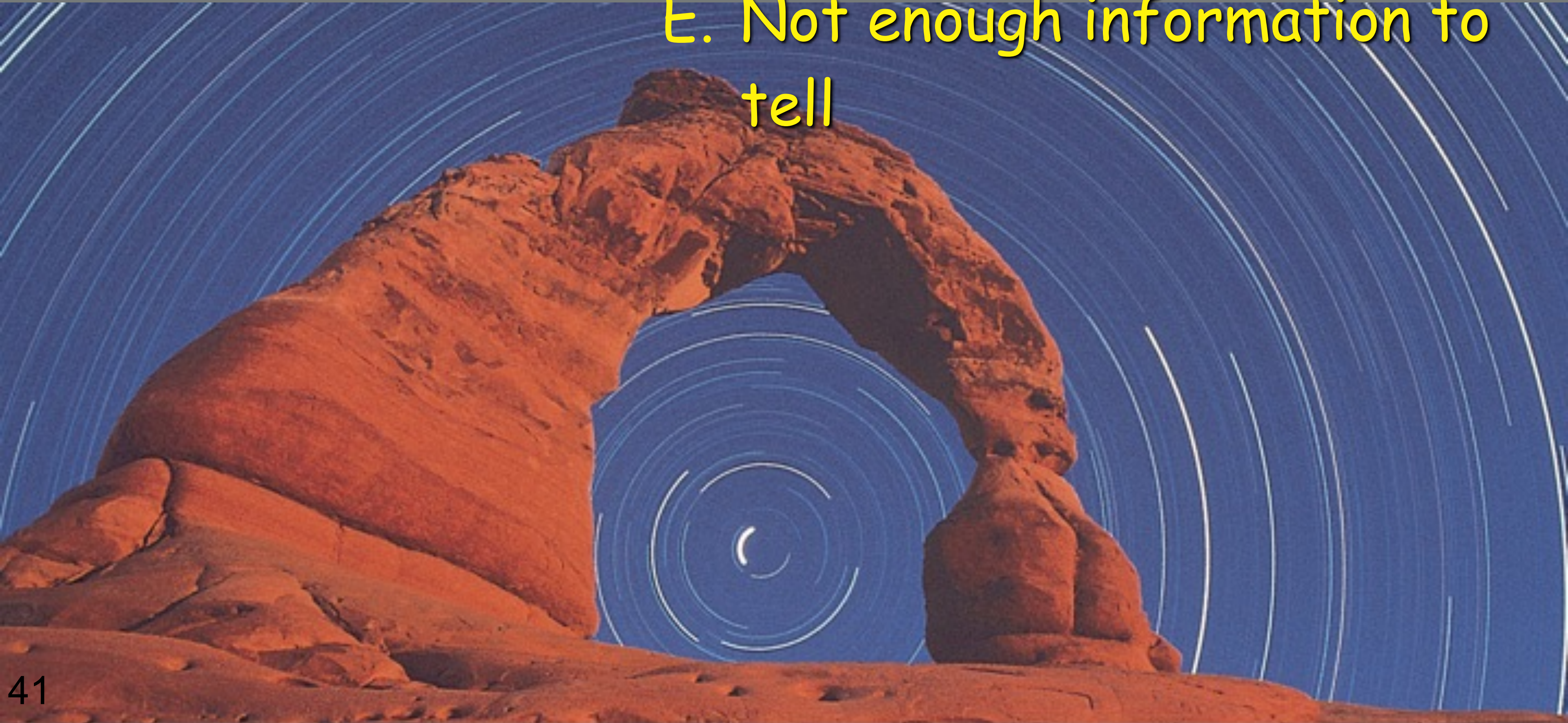
Visibility of Stars



Thought Question

Which direction was the photographer facing?

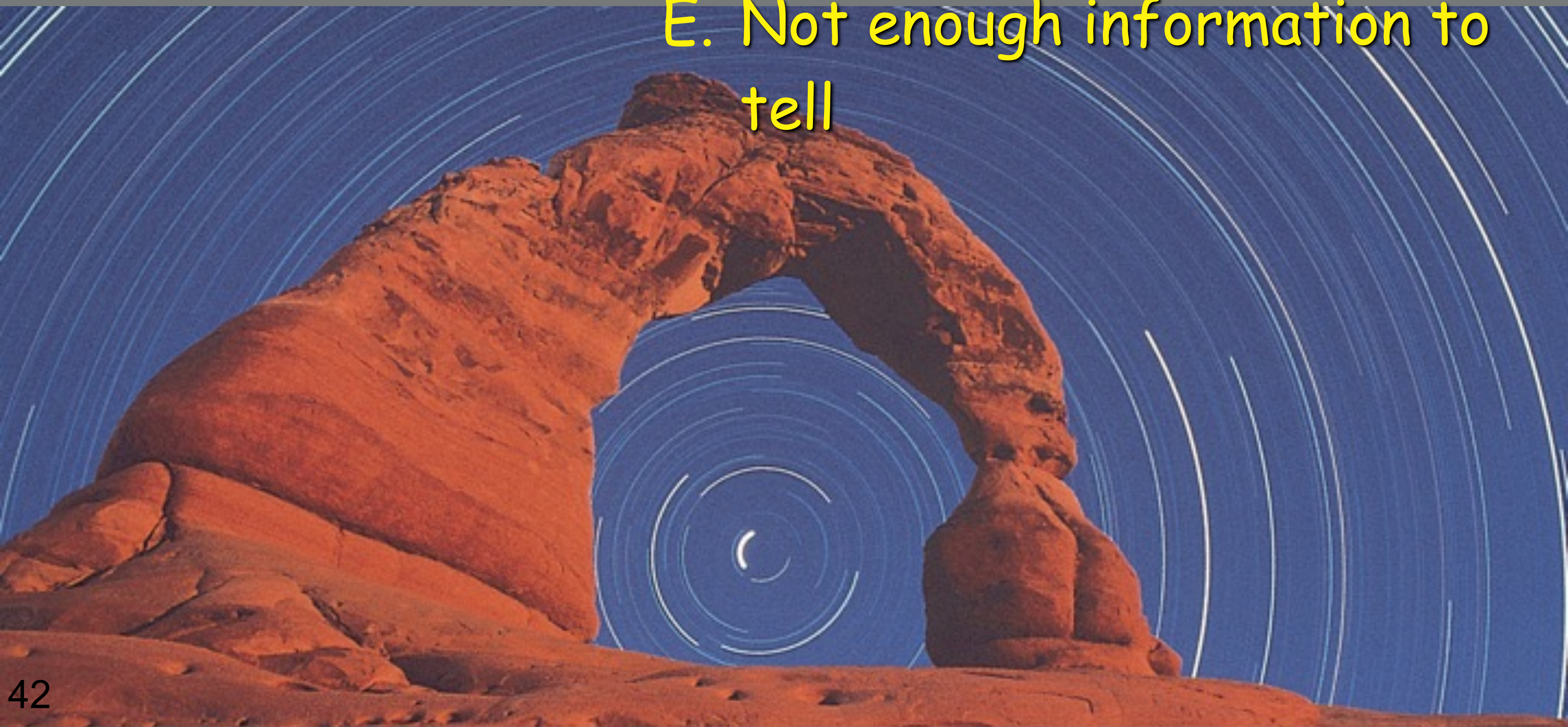
A. North
B. East
C. South
D. West
E. Not enough information to tell



Thought Question

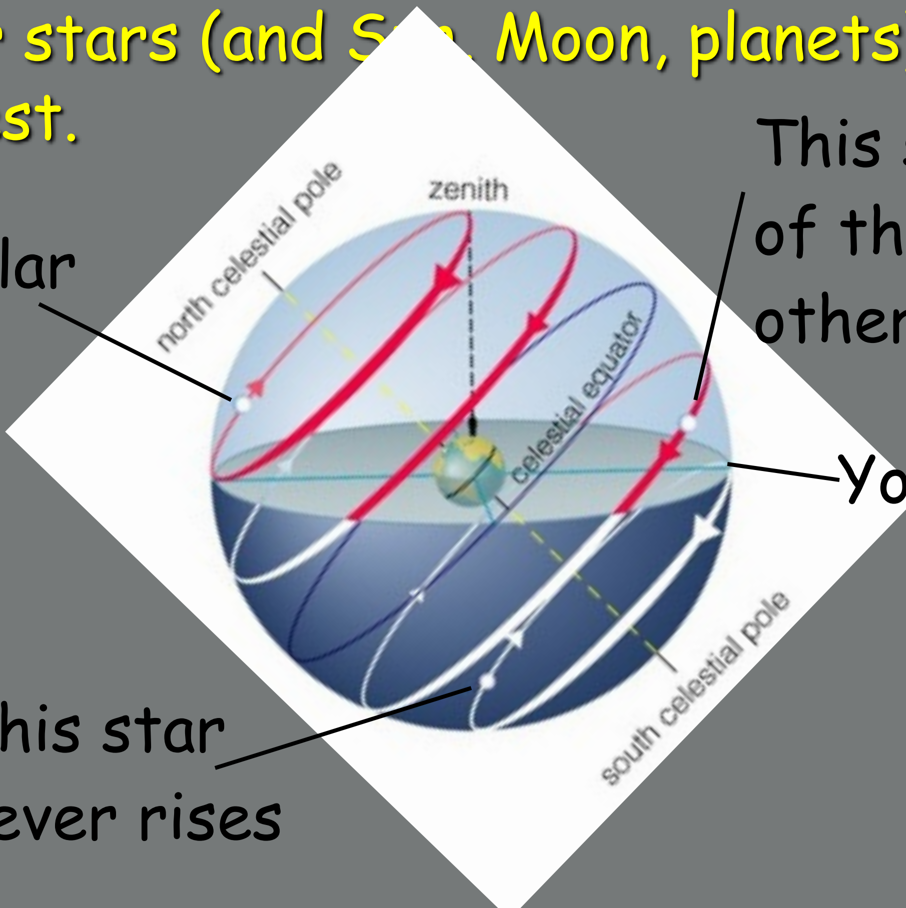
How long was this photograph?

A. About 10 minutes
B. About 1 hour
C. About 8 hours
D. About 24 hours
E. Not enough information to tell



Our view from Grand Junction

- 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.



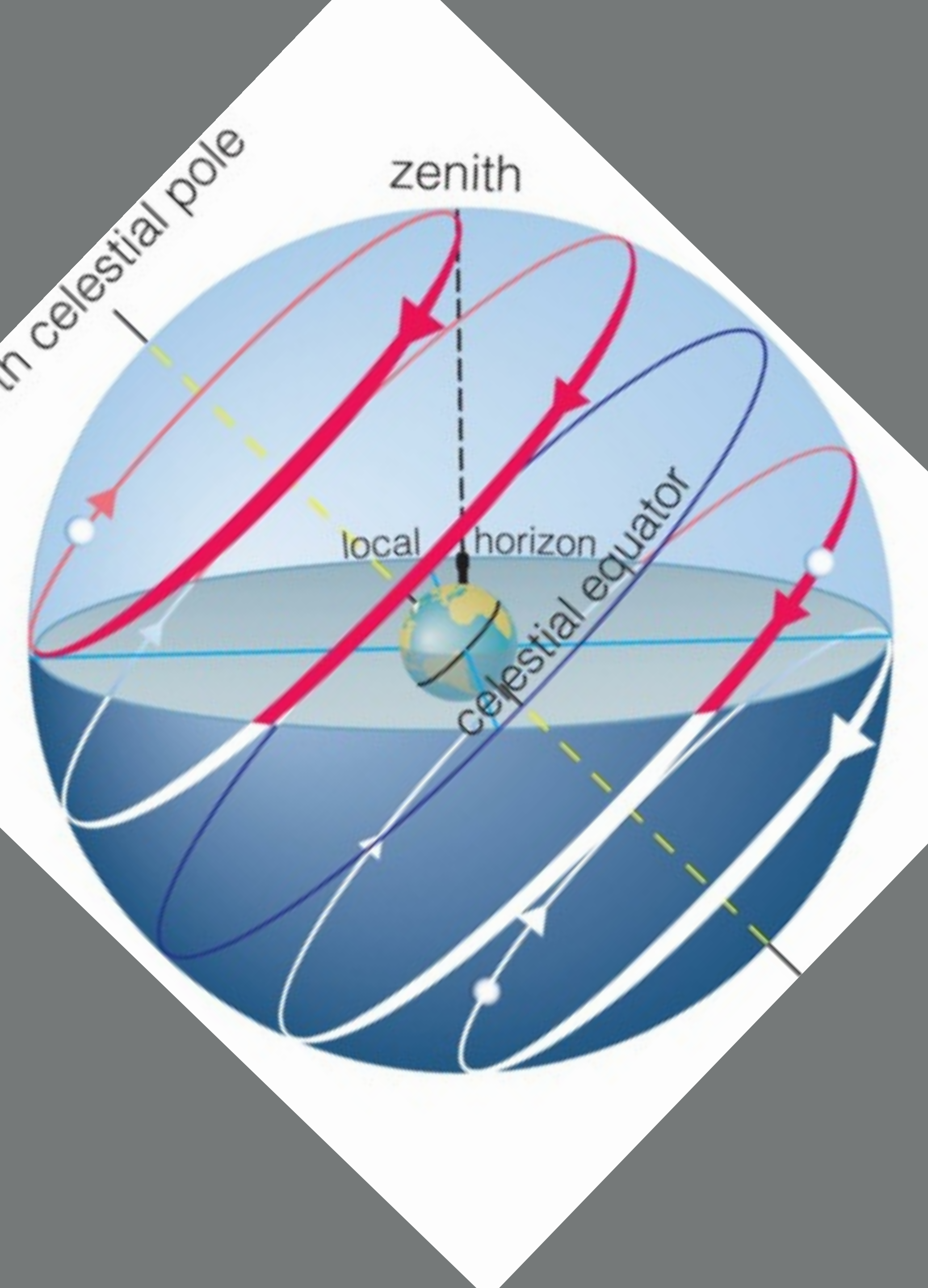
A circumpolar star never sets

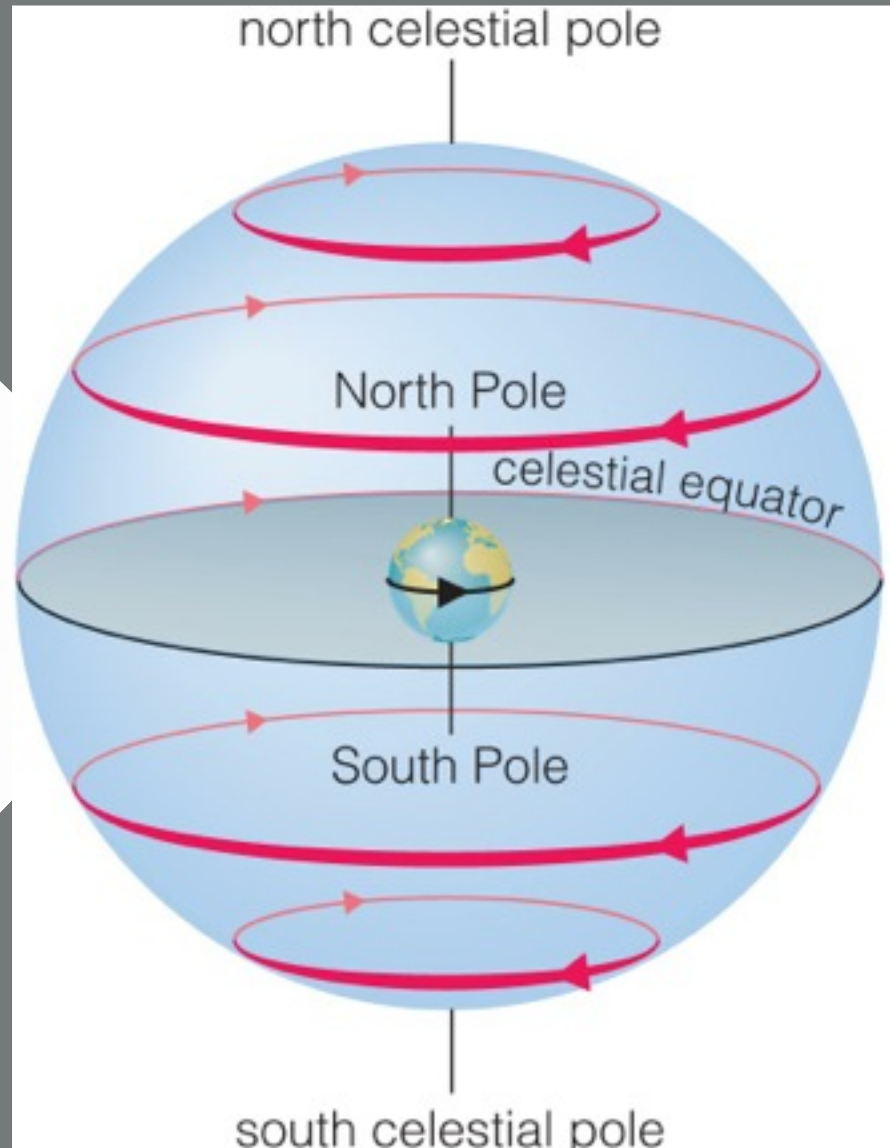
This star is up some of the time and down others

Your Horizon

This star never rises

Why does the sky look different from different latitudes?


celestial pole
zenith
local
horizon
celestial equator


north celestial pole
North Pole
celestial equator
South Pole
south celestial pole

Thought Question

What would the sky look like from the North Pole (at night)?

A. All stars would be circumpolar
B. No stars would be circumpolar (everything would rise and set)
C. Exactly the same as Boulder.
D. Some circumpolar stars, some normal; but would be different stars than Boulder.
E. There would be a big guy in a red suit flying all over the place.

Question

If the North Star (Polaris) is 50° above your horizon, due north, where are you?

A. You are on the equator.
B. You are at latitude 40°S.
C. You are at latitude 50°N.
D. You are at longitude 50°E.
E. You are at latitude 40°N

You wake up in the middle of nowhere

- It better be the northern hemisphere to make it easy
- Your altitude is Polaris's Latitude
- Do you have a watch?
- Add 6 hours to that and you have Greenwich mean time.
- For every hour your watch is earlier for sunrise or sunset or noon (sun at meridian) you are 15 degrees longitude to the west, for every hour later you are 15 degrees to the east;

So far, everything we've been talking about is Daily Motion

- Rising, setting, changing positions over a few hours…

Annual Motion – Apparent

- The Sun appears to move (along the ecliptic) a little bit each day
  - This is the origin of zodiac symbols
- Astronomers usually talk about what constellation the Sun is "in"
  - We are referring to the constellation that the Sun is in front of (if we could see the stars during the day)

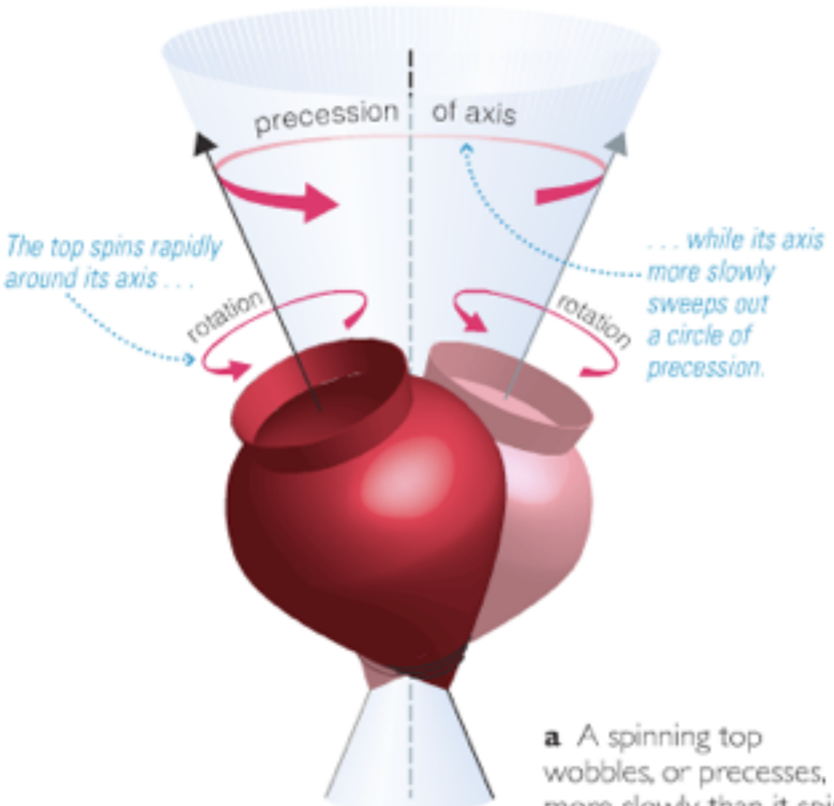
Reading Question

What is precession?

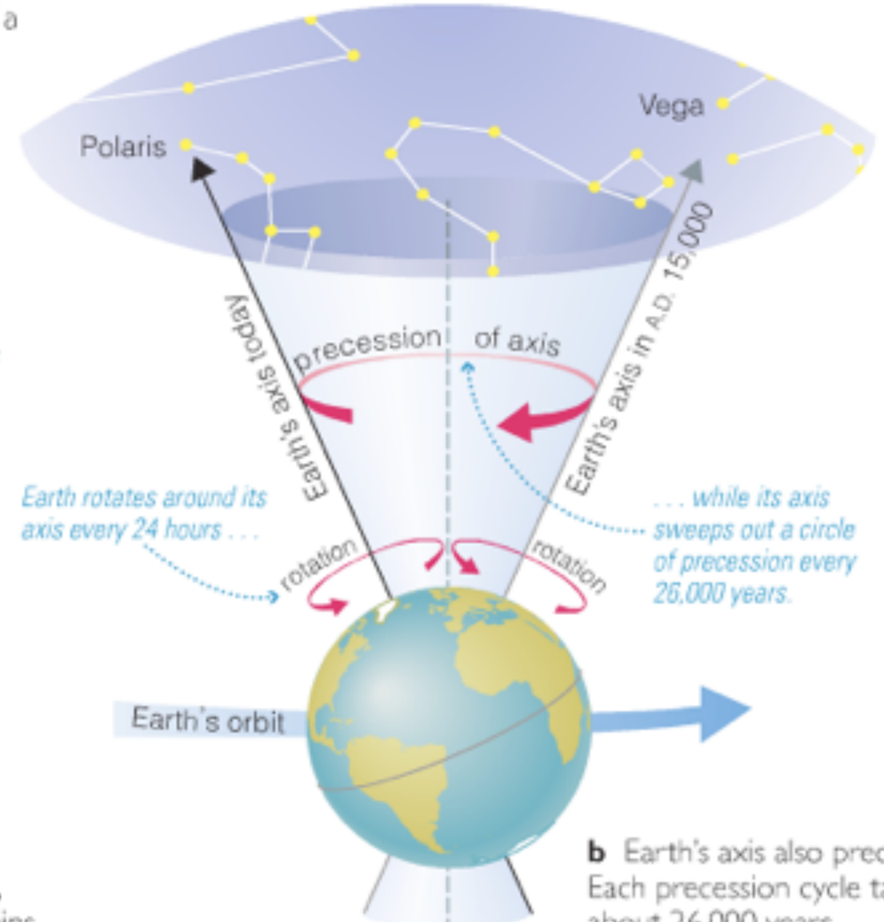
A. The path that the Earth orbits around the Sun.
B. The gradual change of the Earth's axis in space.
C. The apparent movement of the stars due to the Earth's rotation.
D. The reverse movement of the planets due to the Earth's orbit around the Sun.
E. The actual path of the planets in their orbit around the Sun.

- Precession, 26,000 year cycle
- Equinoxes and solstices change so obviously must RA and seasons
- The Earth is not a perfect sphere, it bulges due to spinning, actually, it bulges about 43 km at equator
- Gravity from the sun and moon tugs on the Earth and causes it to precess much like a spinning top
- Earth's tilt with respect to its orbital plane does not change
- The North Star does
- So does the zodiac

Figure 2.20 Interactive Figure Precession affects the orientation of a spinning object's axis but not the amount of its tilt.



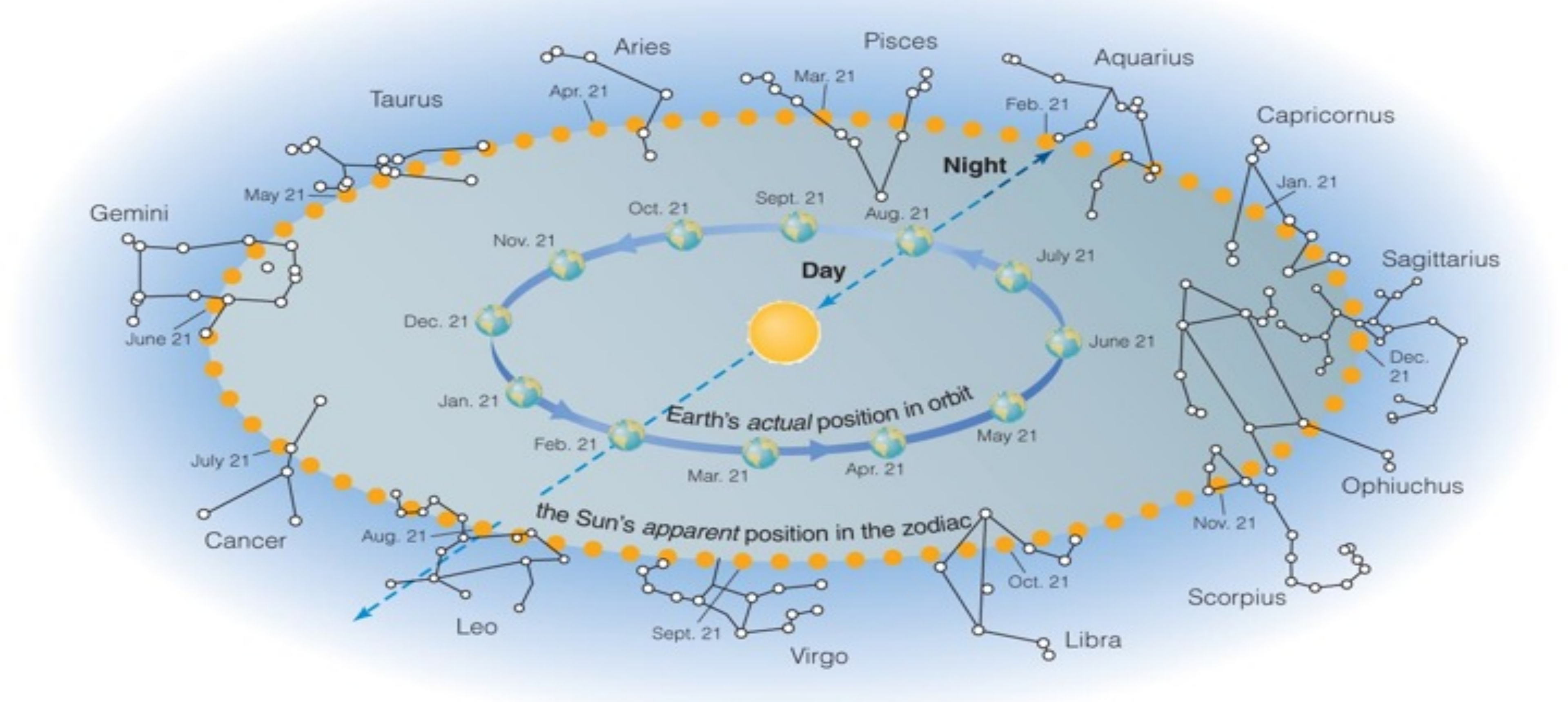
a A spinning top wobbles, or precesses, more slowly than it spins.



b Earth's axis also precesses. Each precession cycle takes about 26,000 years.

Annual Motions - Actual

Actual motion = Earth orbits the Sun.
Plane of orbit = ***ecliptic***



What about 13000 years from now?
What sign will you be?
What sign are you really right now?

Ever heard of The Age of Aquarius?

Reading Question

What happens during the apparent retrograde motion of a planet?

A. The planet rises in the west and sets in the east.
B. The planet fades in in brightness over the period of several hours.
C. The planet moves backwards through the sky over a period of many nights.
D. The planet moves backwards in its orbit around the Sun.
E. The planet moves through constellations that are not part of the zodiac.

The Reason for the Seasons

CLOSER means MORE right?

- Heat
  - The closer you are the hotter it is
- Sound
  - The closer you get, the louder it is
- Light
  - The closer you get, the brighter it is

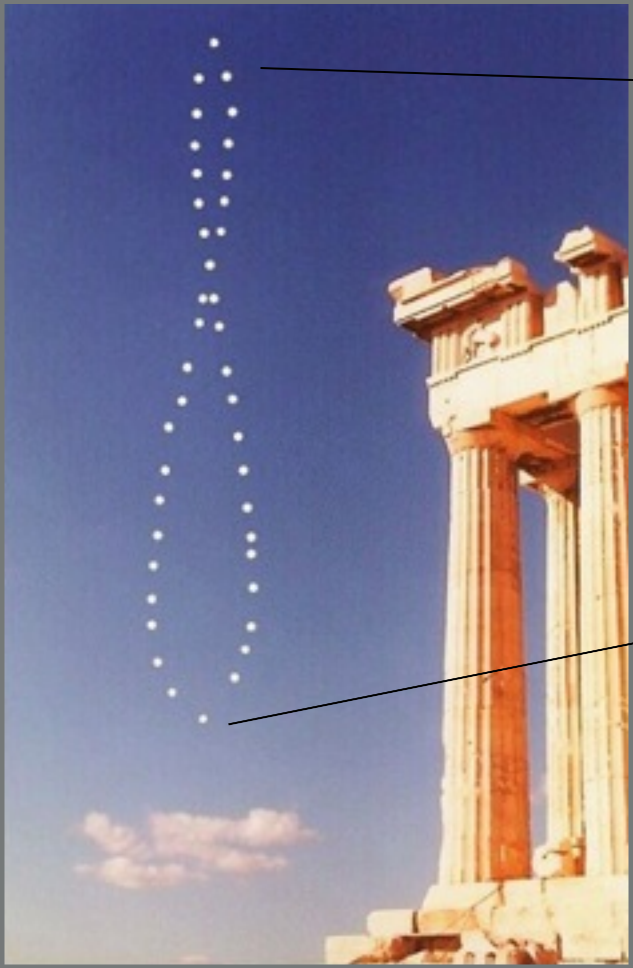
Complete this statement

When the Sun is _______, it is summer; and when the Sun is _________, it is winter.

Complete this statement

When the Sun is CLOSER, it is summer; and when the Sun is FARTHER, it is winter.

Sun's altitude changes throughout the year… due to tilt



Sun's position at noon in summer: higher altitude

Sun's position at noon in winter: lower altitude

This picture is an analemma it arises due to the variation of the solar day due to a change in the Earth's orbital velocity and the tilt of our axis with respect to the ecliptic, don't worry about it.

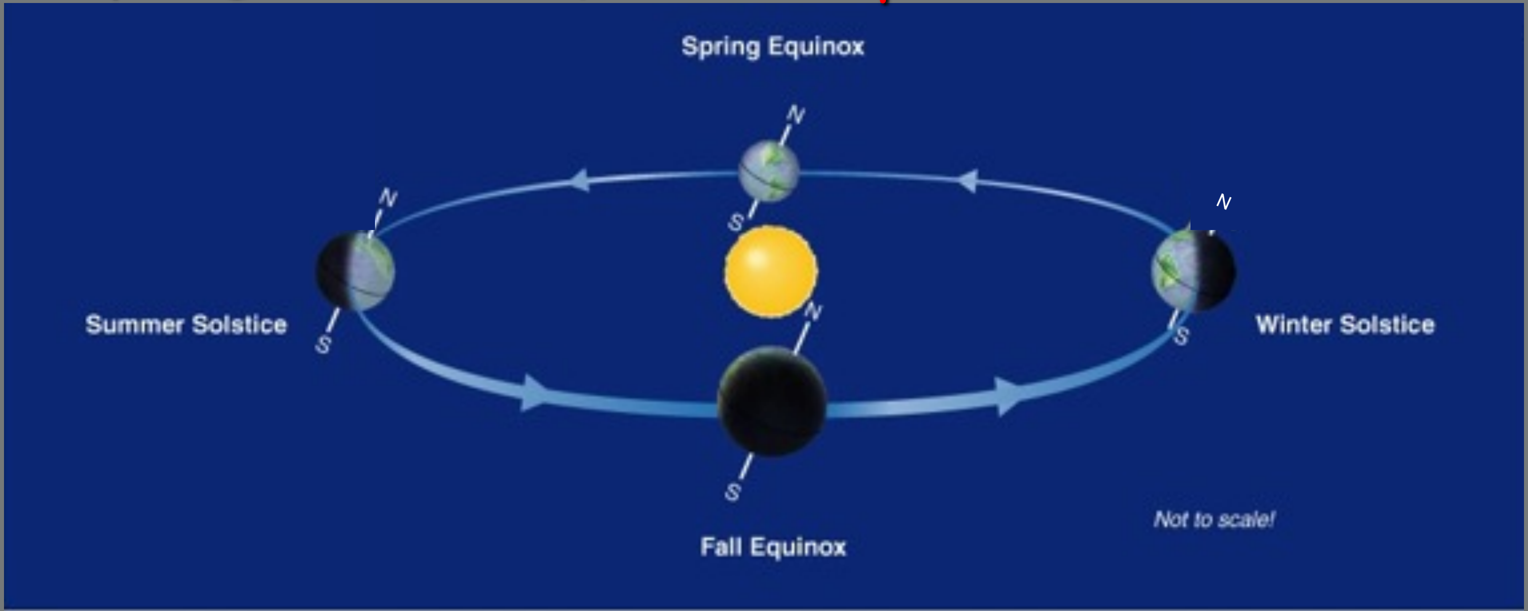
When the Sun is high in the sky, the amount of direct sunlight received is greater. This results in SUMMER

When the Sun is low in the sky, the amount of direct sunlight received is less. This results in WINTER

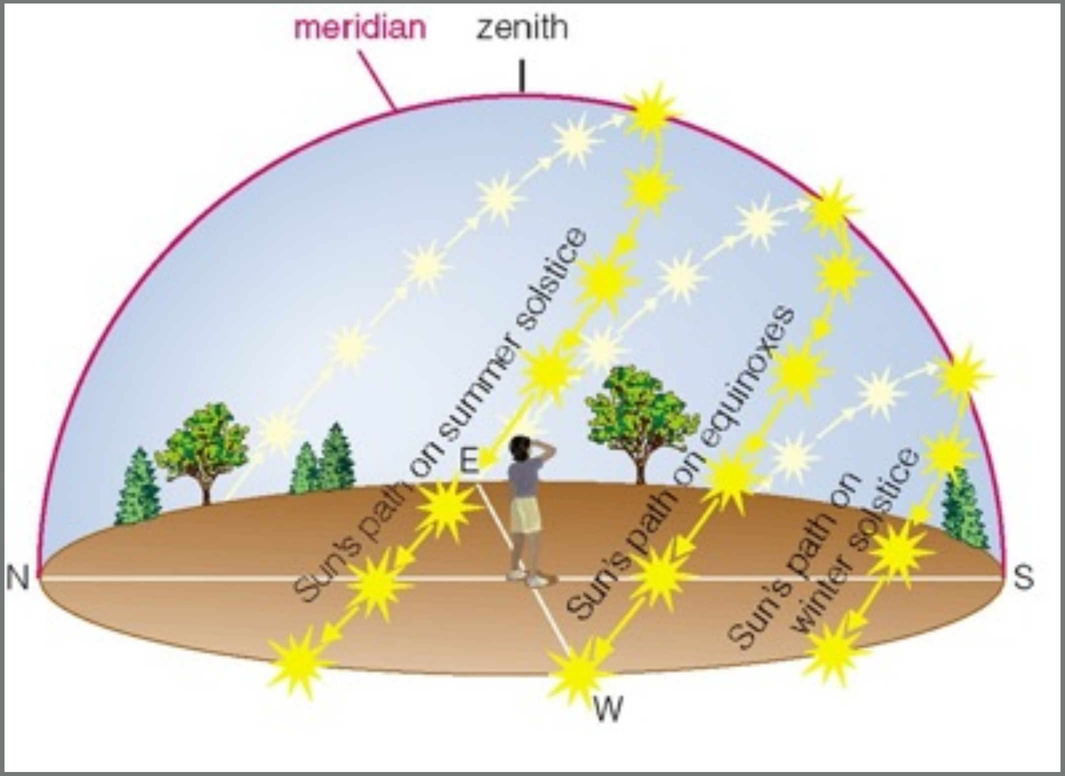
How do we mark the progression of the seasons?

- We define four special points in our orbit (dates):
  - Summer solstice
    - Northern hemisphere tilted towards the Sun
  - Winter solstice
    - Northern hemisphere tilted away from the Sun
  - Spring (vernal) equinox
  - Fall (autumnal) equinox

equal distance from the Sun



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



Summer solstice: Highest path, rise and set at most extreme north of due east.

Winter solstice: Lowest path, rise and set at most extreme south of due east.

Equinoxes: Sun rises precisely due east and sets precisely due west.

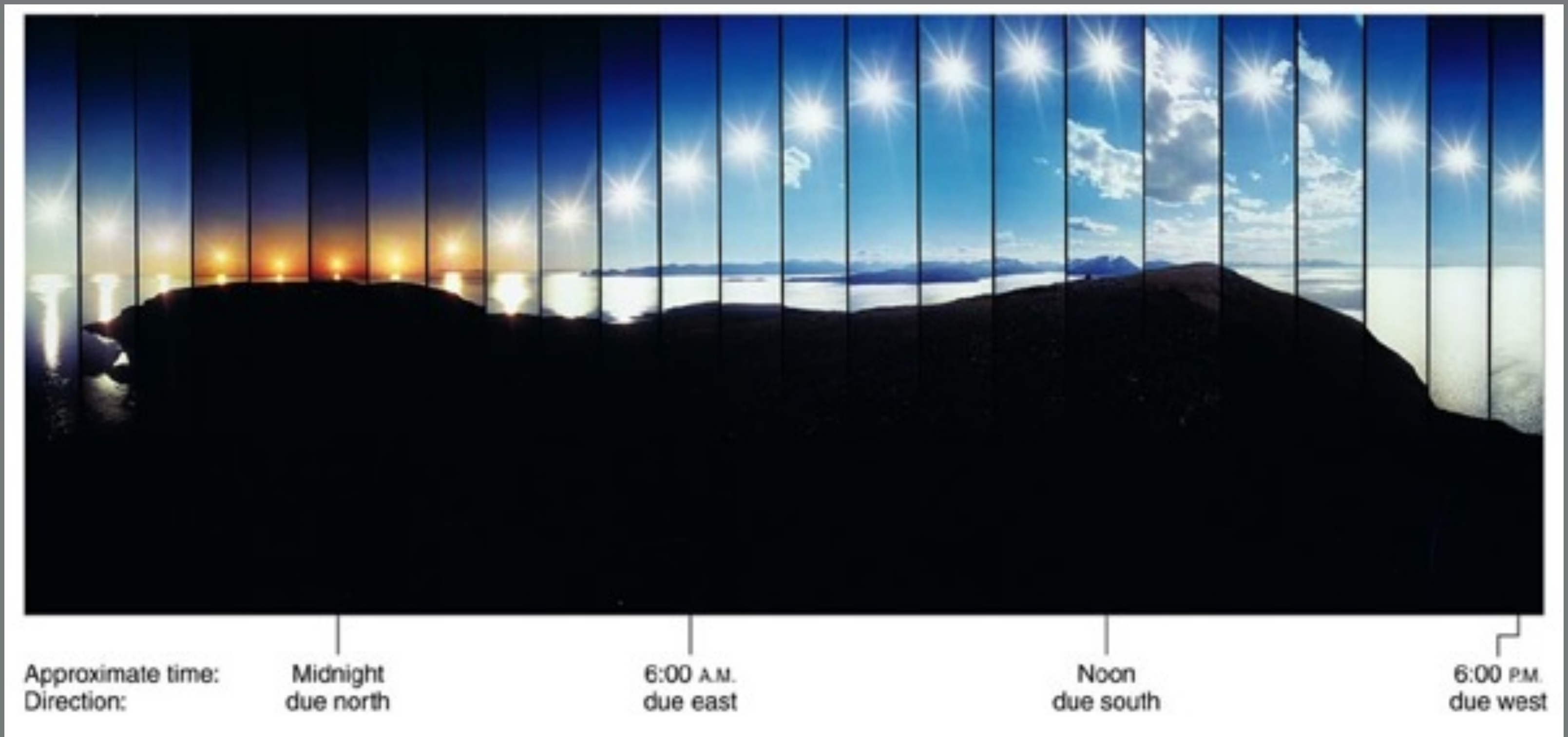
Thought Question

If the Sun rises precisely due east,

A. you must be located at Earth's equator, any time of year.
B. it must be the day of either the spring or fall equinox.
C. you must be at the equator AND it's the spring or fall equinox
D. it must be the day of the summer solstice
E. it must be the day of the winter solstice

Why *doesn't* distance or hours of daylight really matter?

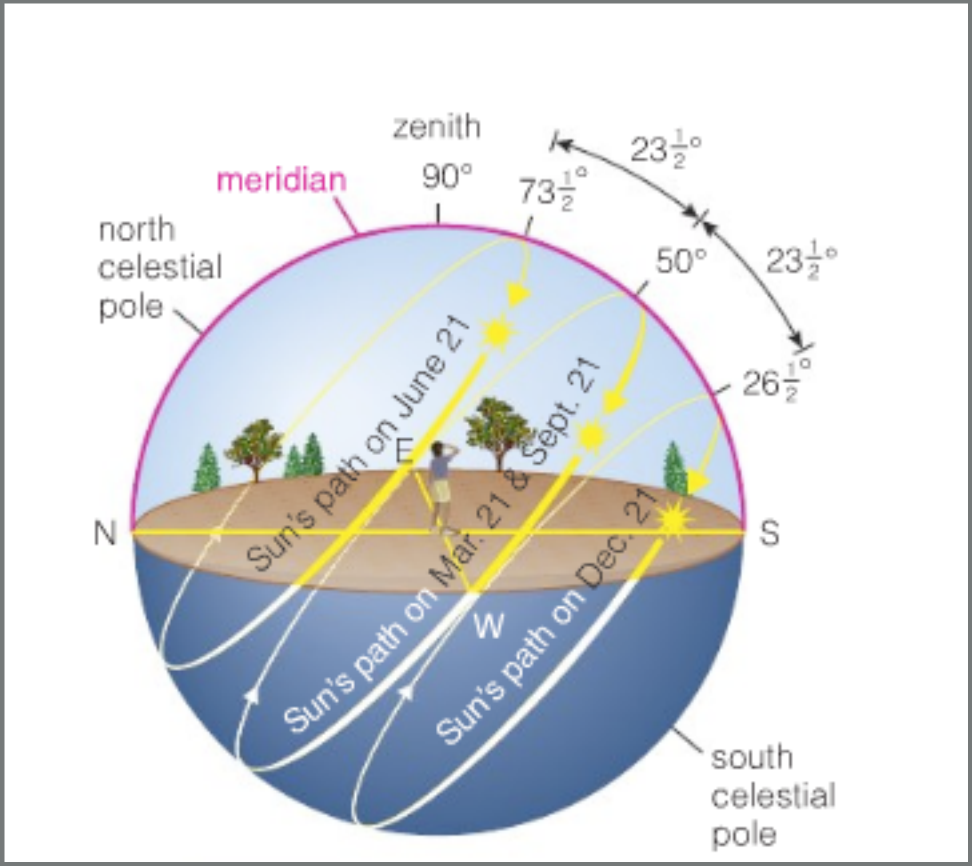
- Variation of Earth-Sun distance is small!
  - about 3%
  - this small variation is overwhelmed by the effects of axis tilt, water distribution, and orbital speed.



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.

In Colorado

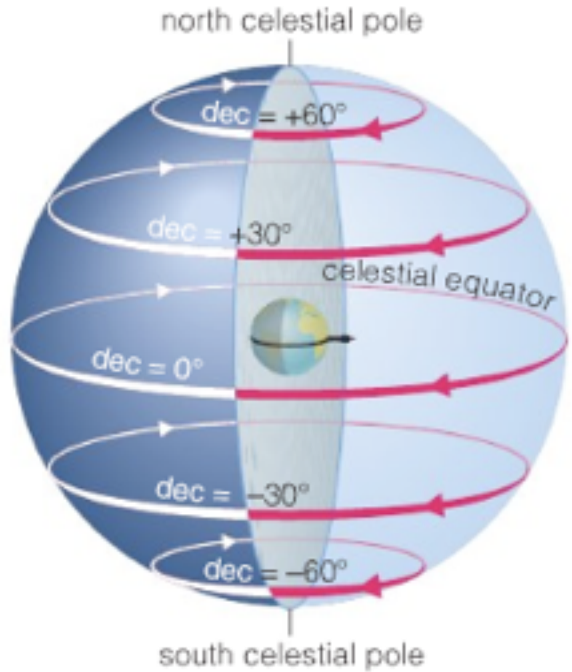

zenith
meridian
90°
$73\frac{1}{2}°$
$23\frac{1}{2}°$
$23\frac{1}{2}°$
50°
$26\frac{1}{2}°$
north celestial pole
Sun's path on June 21
Sun's path on Mar. 21 & Sept. 21
Sun's path on Dec. 21
E
W
N
S
south celestial pole

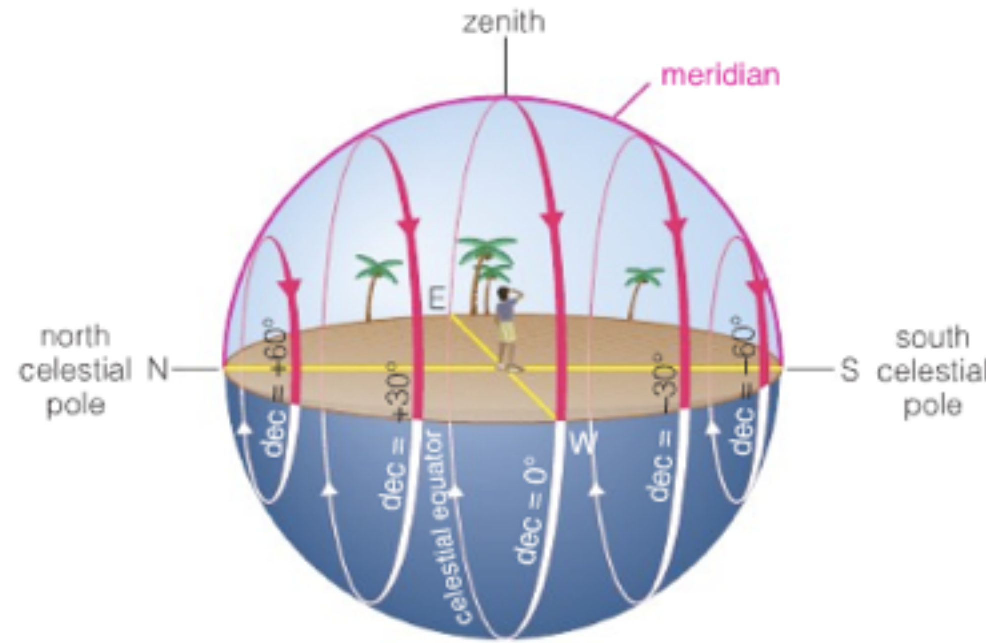
Have you been reading/paying attention?

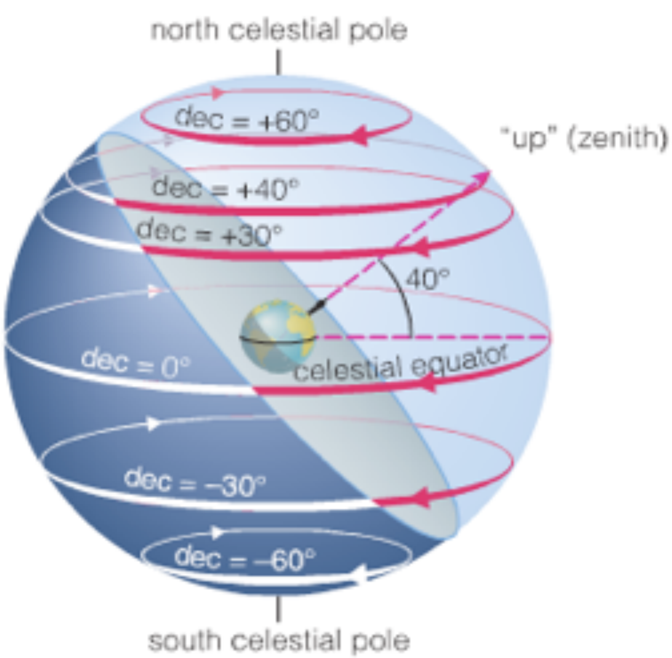
Thought Question

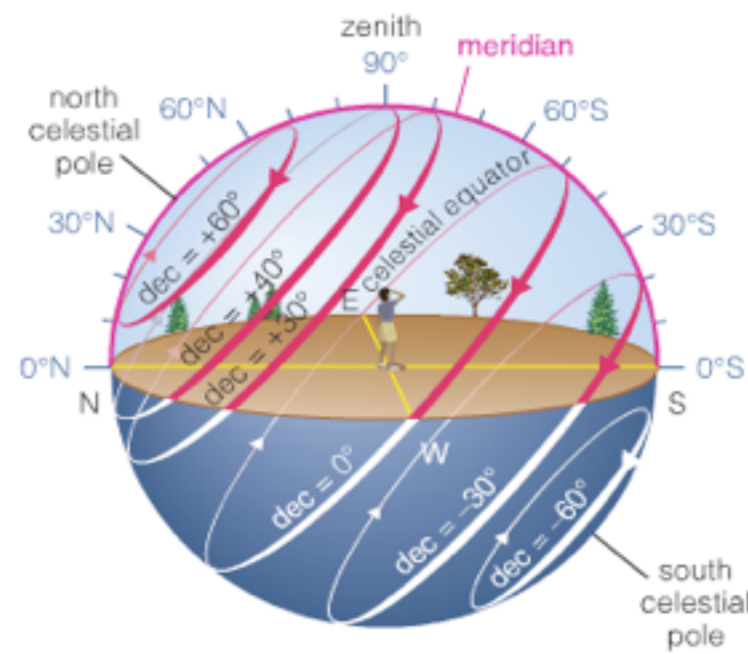
What would the sky look like from the Equator?

A. All stars would be circumpolar (except possibly Polaris)
B. No stars would be circumpolar (except possibly Polaris)
C. Exactly the same as Boulder.
D. Some circumpolar stars, some normal; but would be different stars than Boulder.
E. There would be a big guy in a red suit drinking piña coladas.


north celestial pole
dec = +60°
dec = +30°
celestial equator
dec = 0°
dec = −30°
dec = −60°
south celestial pole


zenith
meridian
north celestial pole
N
E
W
S
south celestial pole
dec = +60°
dec = +30°
celestial equator
dec = 0°
dec = −30°
dec = −60°


north celestial pole
dec = +60°
"up" (zenith)
dec = +40°
dec = +30°
40°
dec = 0°
celestial equator
dec = −30°
dec = −60°
south celestial pole


zenith
90°
meridian
north celestial pole
60°N
60°S
30°N
30°S
0°N
0°S
N
S
E
W
dec = +60°
dec = +40°
dec = +30°
celestial equator
dec = 0°
dec = −30°
dec = −60°
south celestial pole

Thought Question

Which way will stars appear to circle the South Celestial Pole from Tasmania (40º S)?

A. Clockwise
B. Counter-clockwise
C. It depends on the season
D. There is no south celestial pole so there will be no circumpolar stars.

Reading Question

What are the nodes of the Moon's orbit?

A. The points in the Moon's orbit where it is directly in front or behind the Earth (compared to the Sun).
B. The point in the Moon's orbit where it crosses the ecliptic plane.
C. The points in the Moon's orbit where it can be seen as full.
D. The points where you can see First and Third Quarter moons.
E. The points on the horizon where the Moon should rise or set.

The Moon, Our Constant Companion

- Why do we see phases of the Moon?
- How can we tell time by the phase and position of the moon

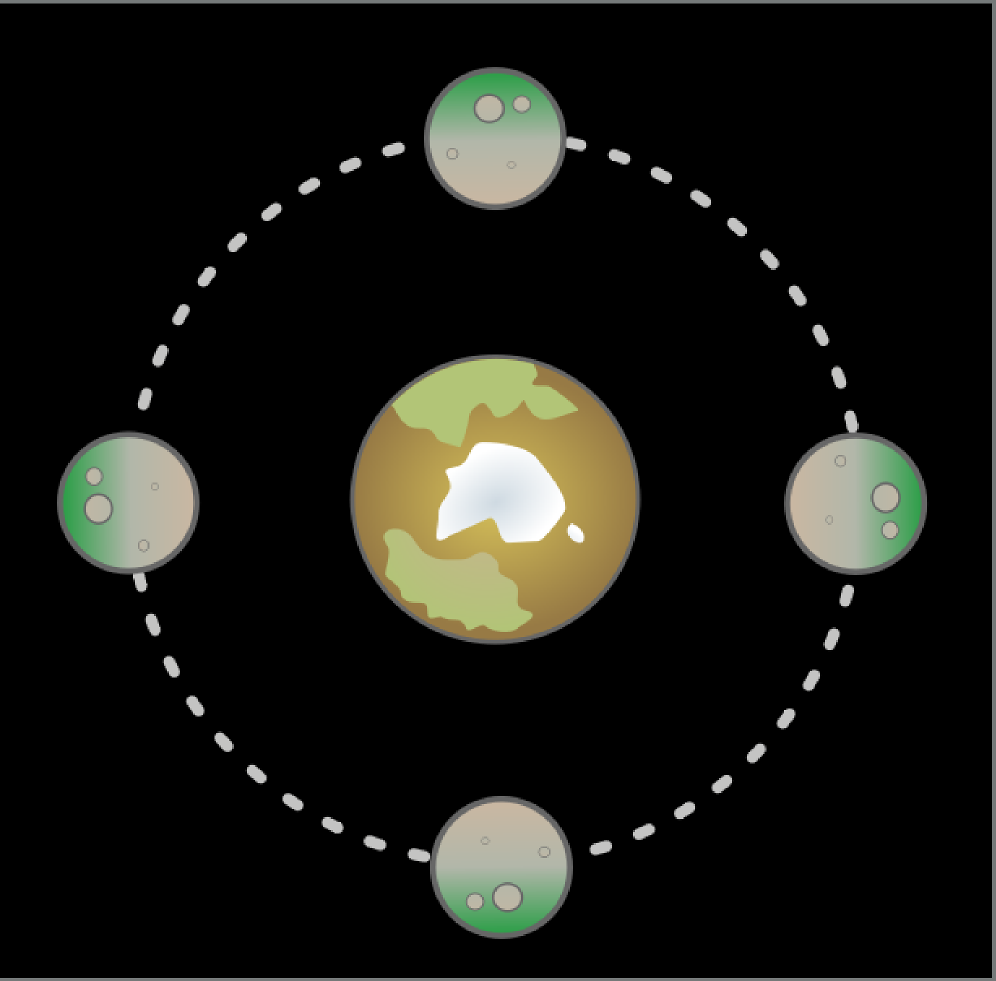
The moon is thought to have been formed by a huge impact with the Earth early in our planets history

The moon is ~ 1.25-1.5 light seconds away, how far is that?

The moon is slowly moving away from us but right now is the same angular size on the sky as the sun, this is important, why?

The moon is also responsible for the tides on the earth.

Why do we see only one side of the Moon?



<u>Synchronous rotation:</u> the Moon rotates <u>exactly</u> one complete time with each complete orbit

The changing phases of the Moon originally inspired the concept of the ***month***

September 2009

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
		1	2	3	4 FM	5
6	7	8	9	10	11	12 LQ
13	14	15	16	17	18 NM	19
20	21	22	23	24	25	26 FQ
27	28	29	30			

Phases of the Moon

New


waxing crescent


first quarter


waxing gibbous


full


waning gibbous


last quarter


waning 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.

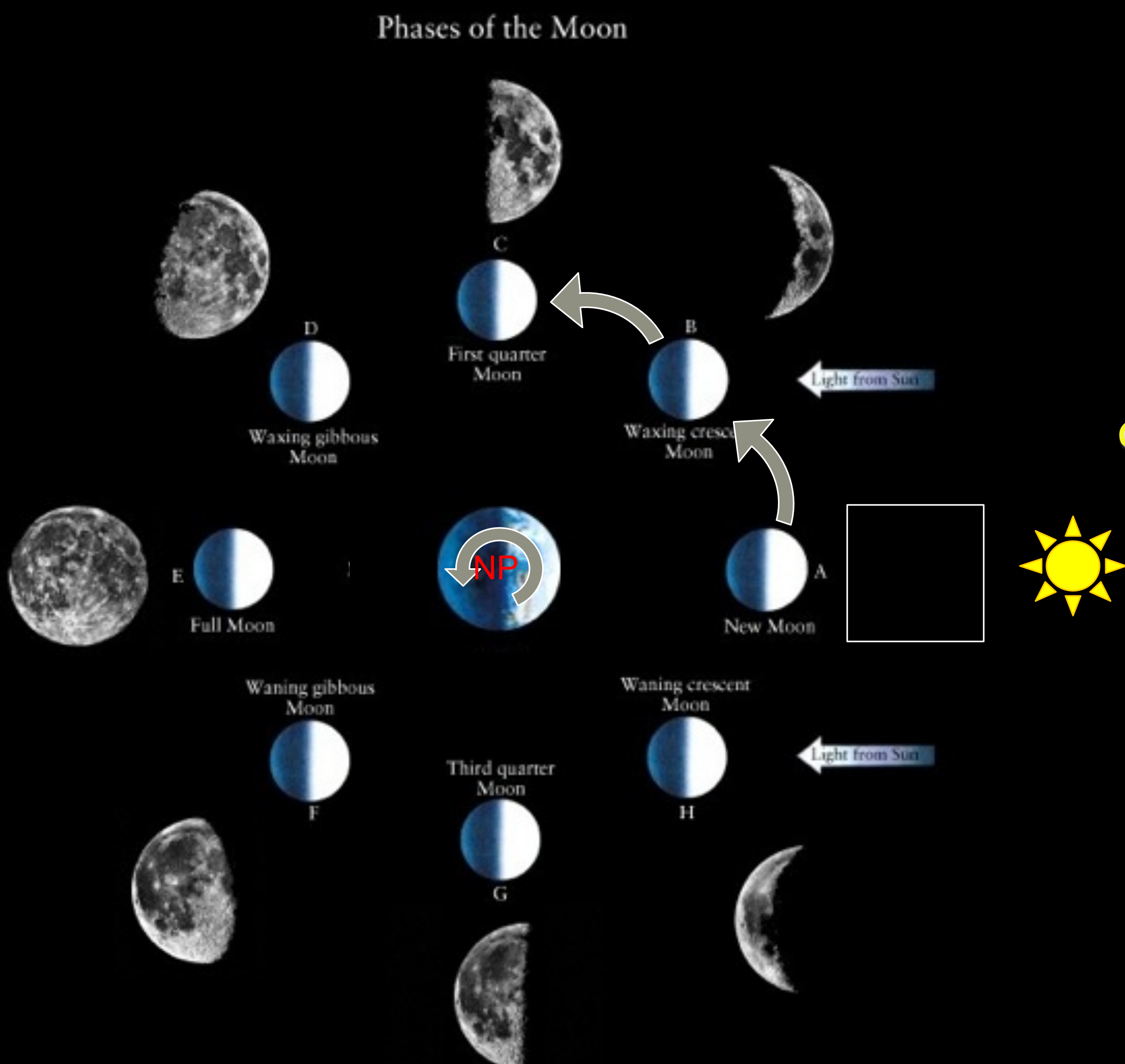
Watch Movie at:

http://antwrp.gsfc.nasa.gov/apod/image/9911/lunation_ajc.gif

Thought Question

If the Moon was in the full phase today, how many of the Moon phases shown above would the Moon go through during the next 11 days?

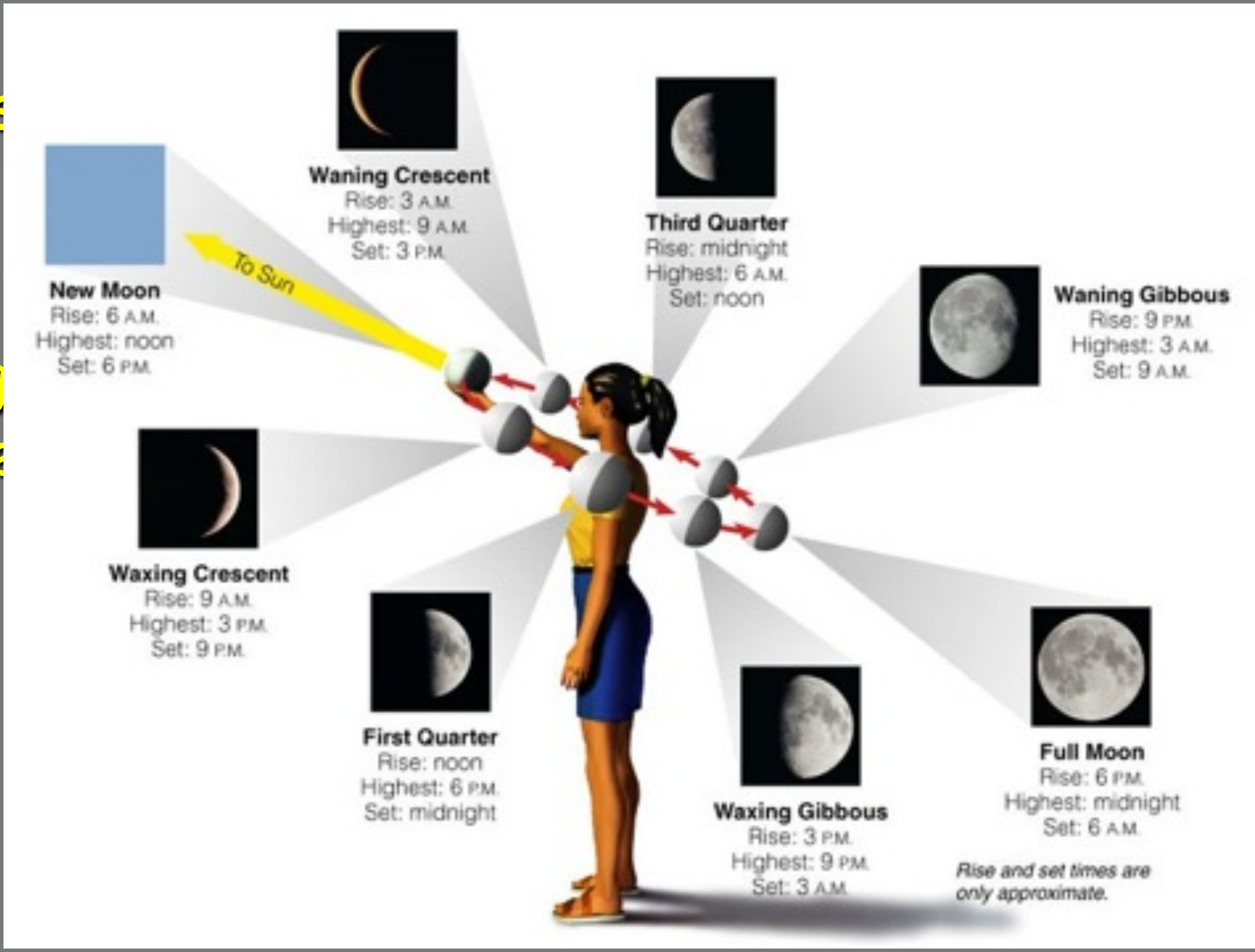
A. Only one
B. Two
C. Three
D. More than three
E. None



Although the Moon is always ½ lit by the Sun, we see different amounts of the lit portion from Earth depending on where the Moon is located in its orbit.

Phases of Moon

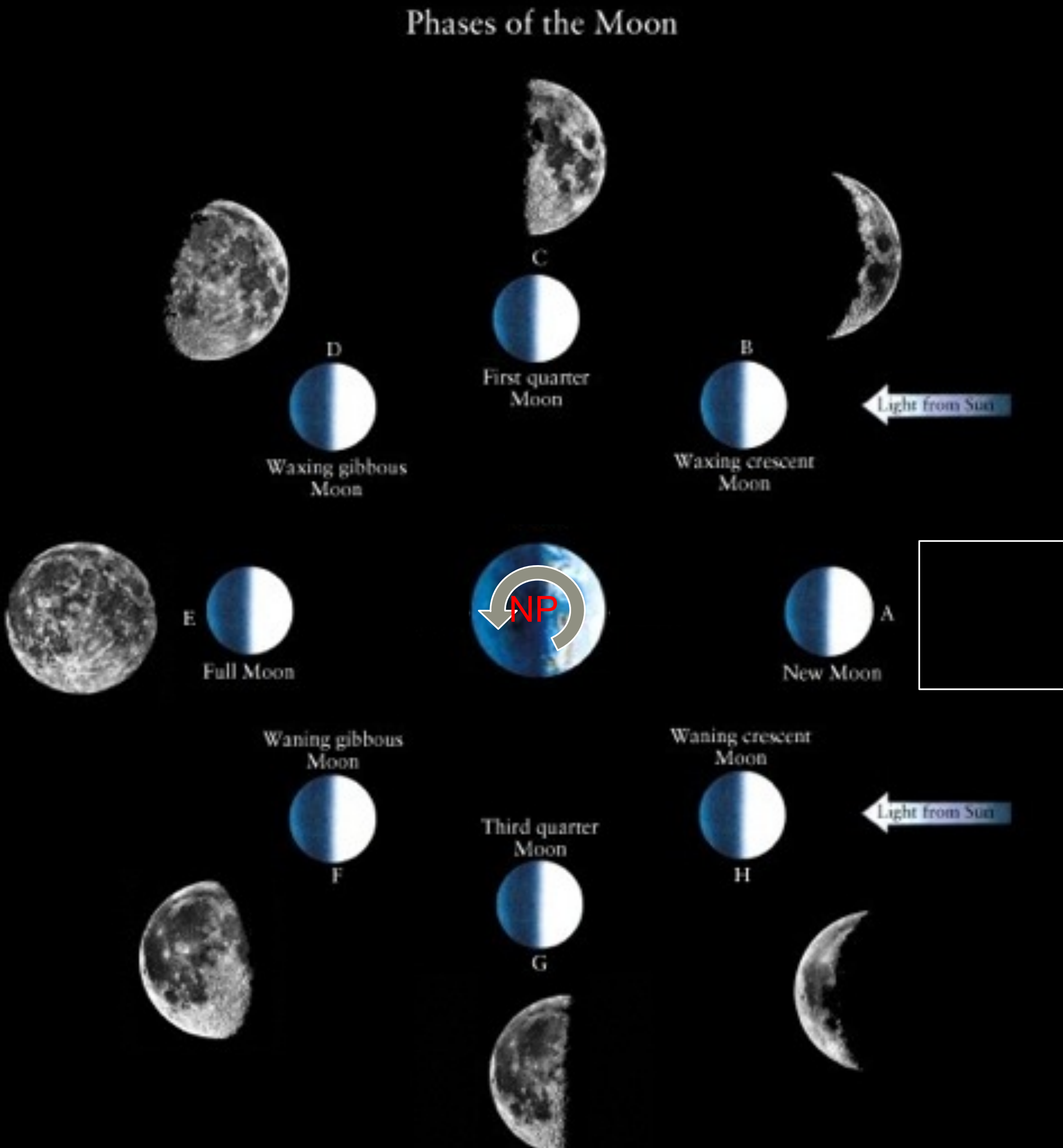
- Moon is illuminated (always ½) by Sun
- We see a changing combination of the bright and dark faces as Moon orbits the Earth



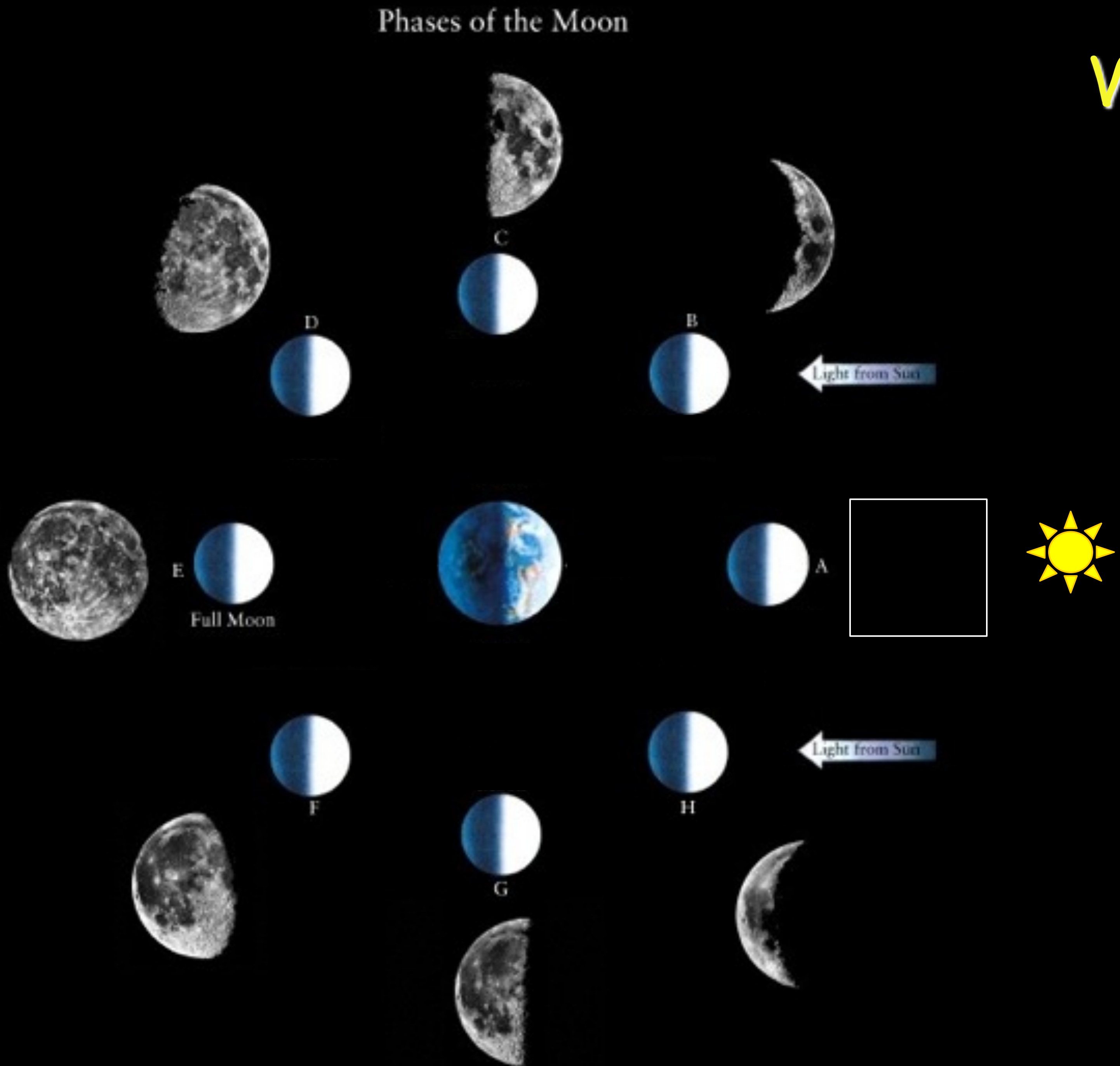
The Power of Moon Phases

- Time
- Moon Phase
- Moon Position in the sky

If you know any two, you can figure out the third!

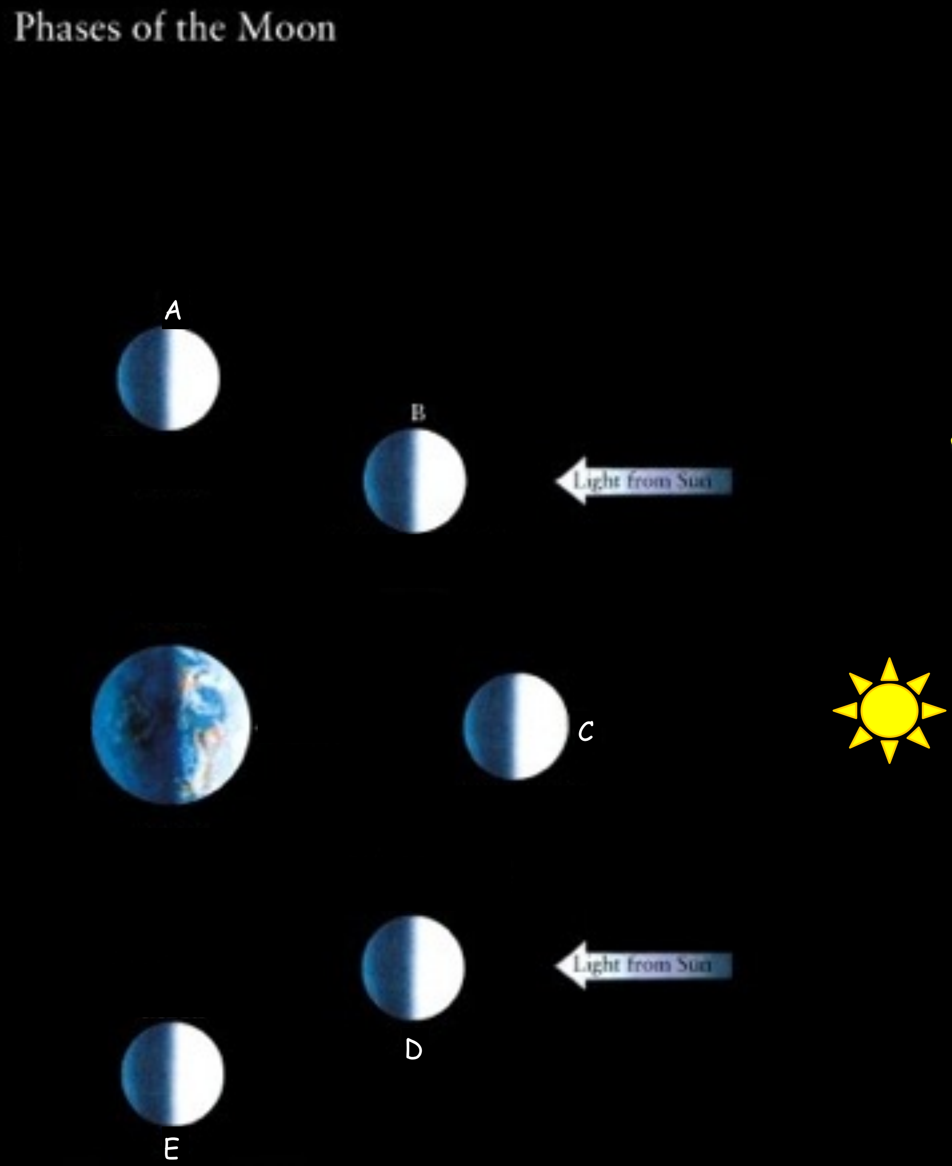


Understanding this picture is key to being able to tell time by moon phases

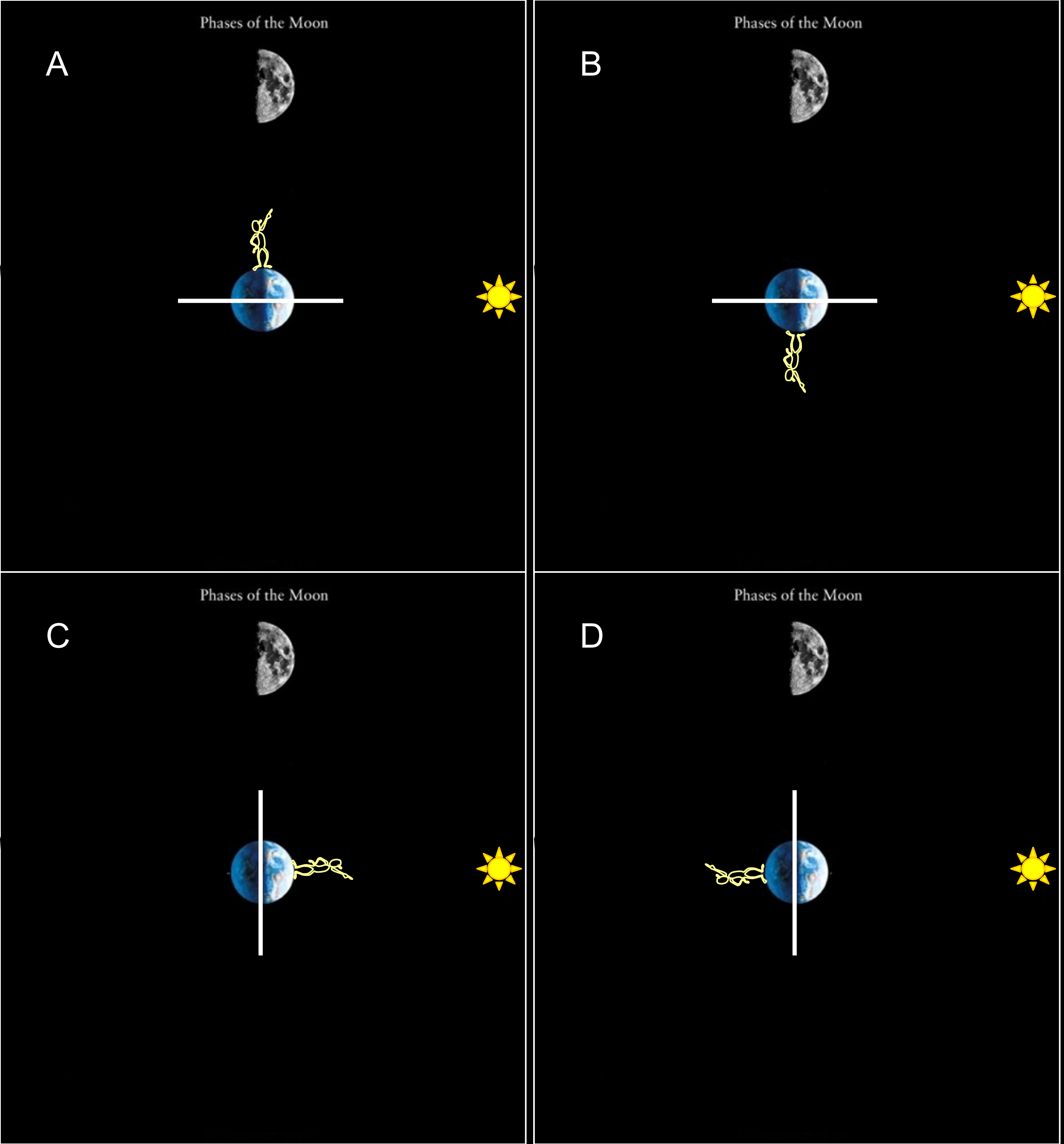


What time does a first quarter Moon rise?

Thought Question



Which one is the first quarter Moon?



Which situation shows the Moon on the eastern horizon?

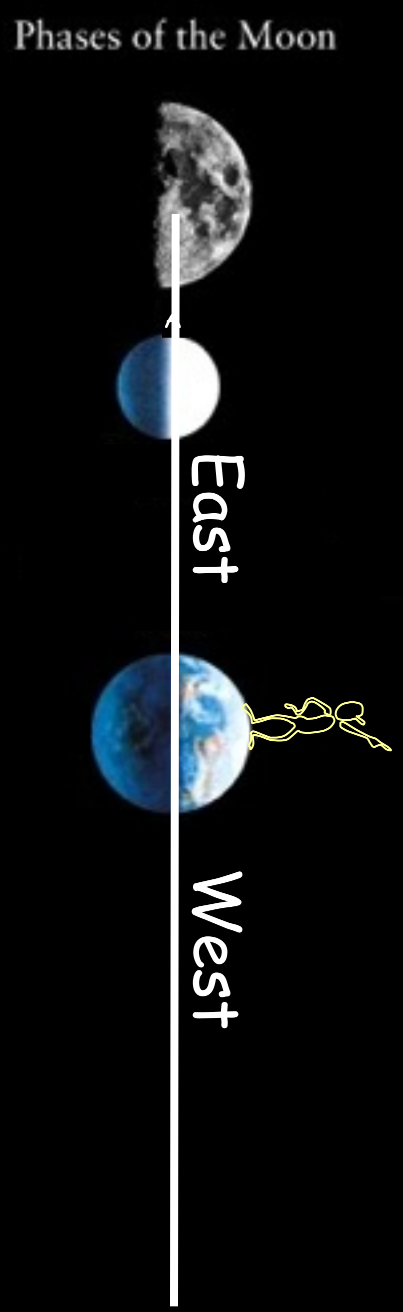
A.
B.
C.
D.

Thought Question

Phases of the Moon

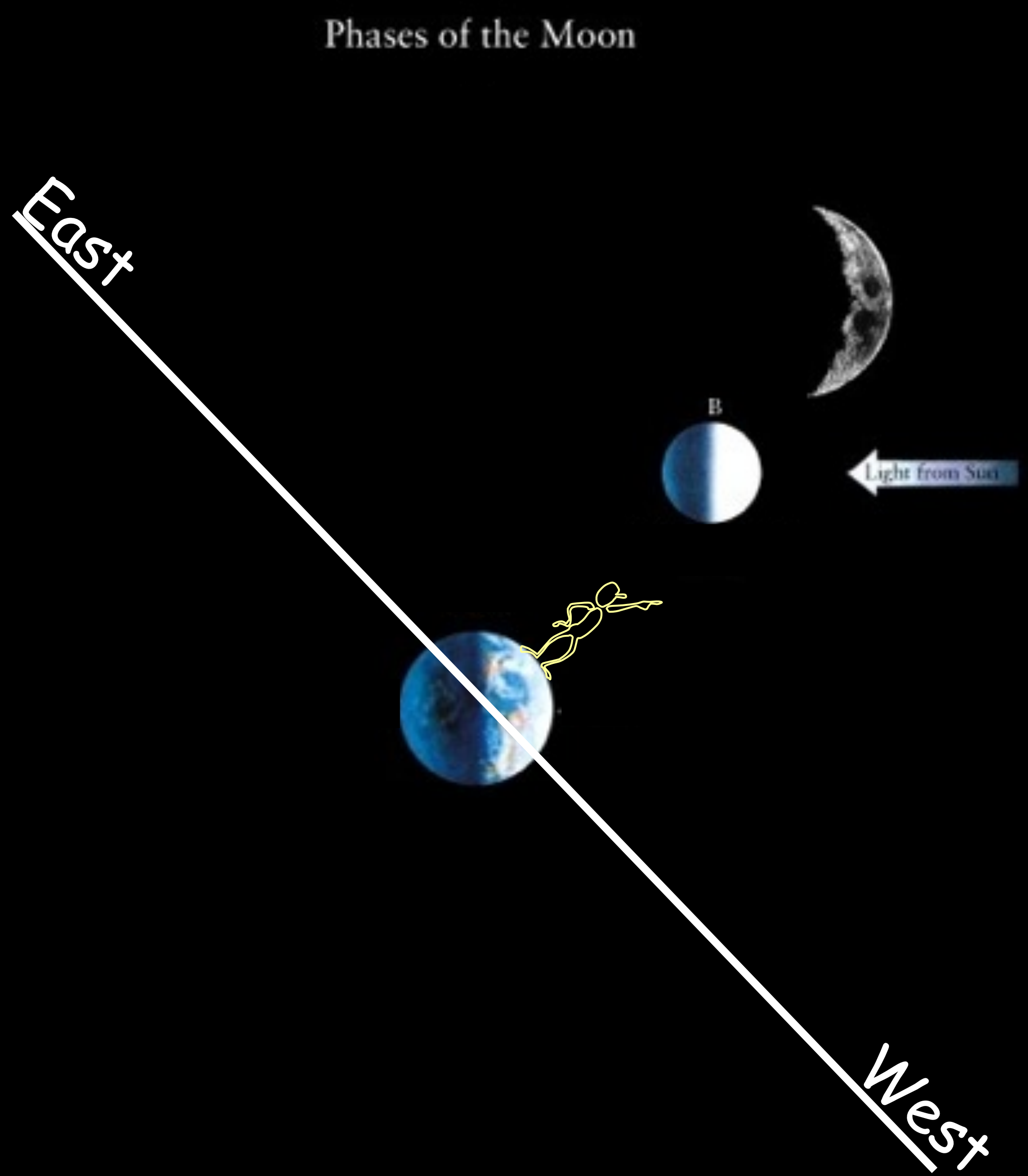
What time is it for the guy standing on the Earth?

A. ~6AM
B. Noon
C. ~6PM
D. Midnight



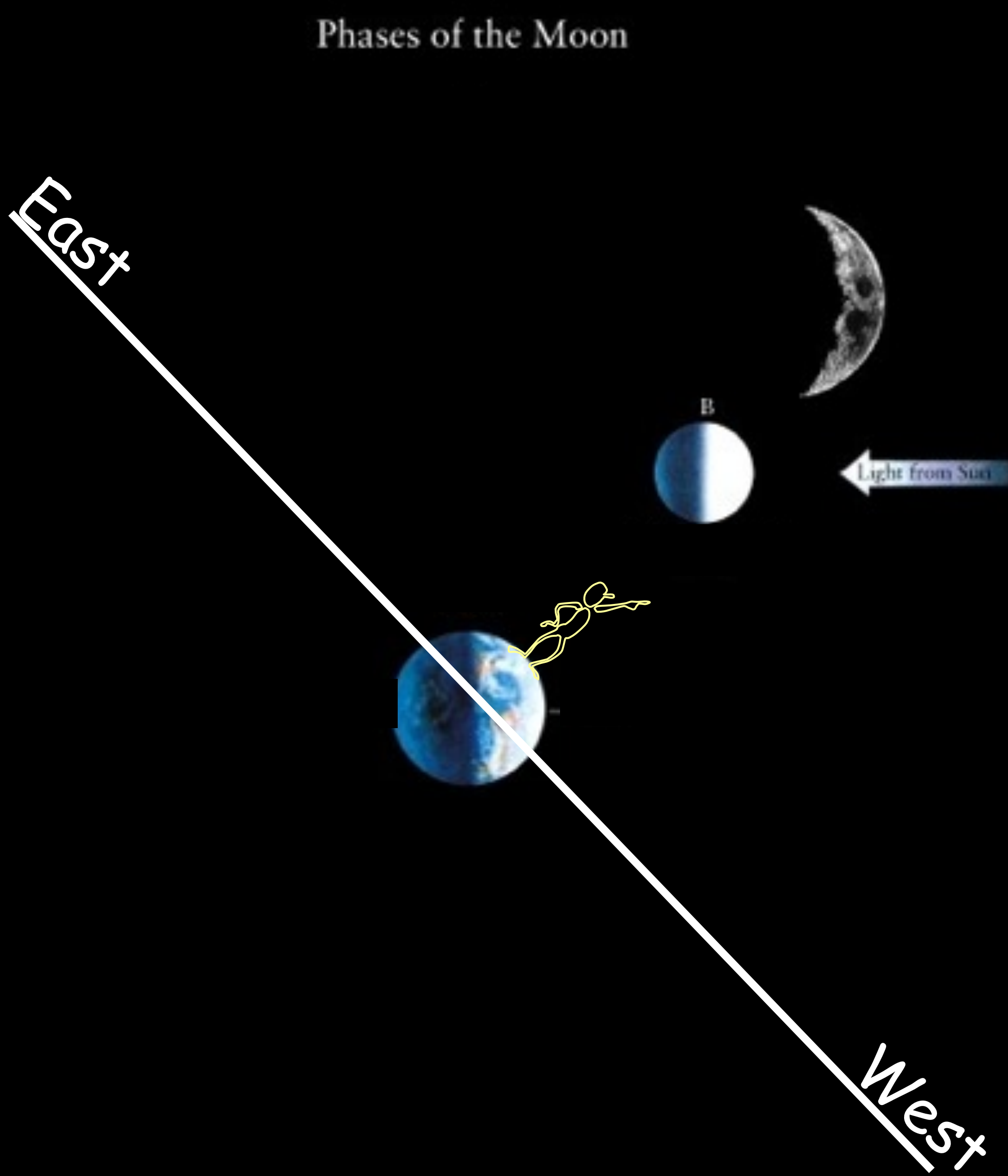
What time does a first quarter Moon rise?

A. 3am
B. 6am
C. Noon
D. 3pm
E. 6pm



What time is it when the waxing crescent moon is on the meridian?

A. 3am
B. 6am
C. Noon
D. 3pm
E. 6pm



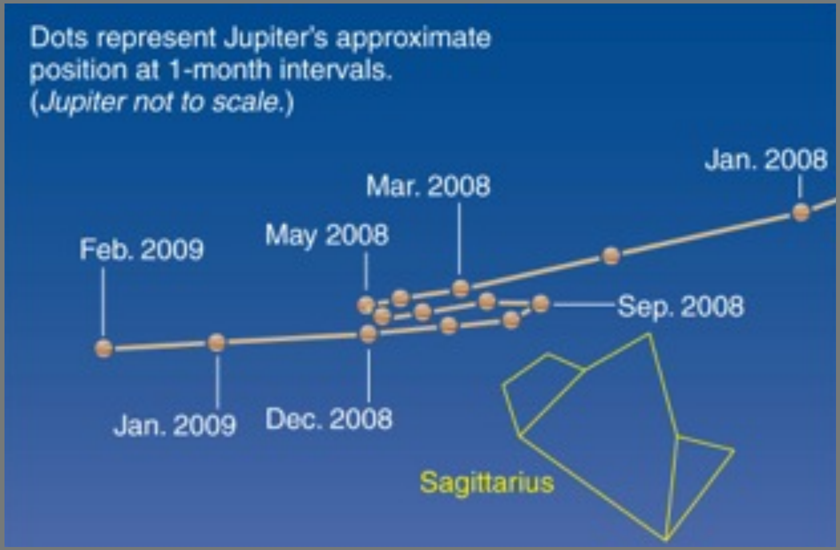
What time is it when the waxing crescent moon is on the meridian?

9 PM

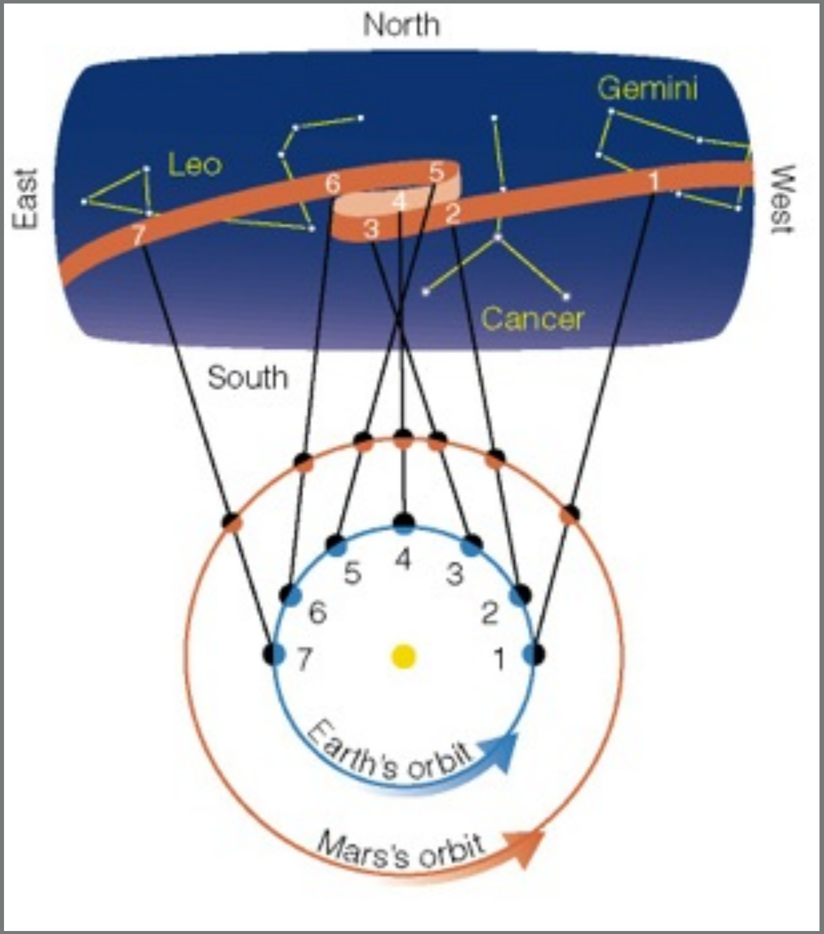
Planetary motion

Do the planets reverse course?

- Planets usually move slightly eastward from night to night (not in the course of one 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.

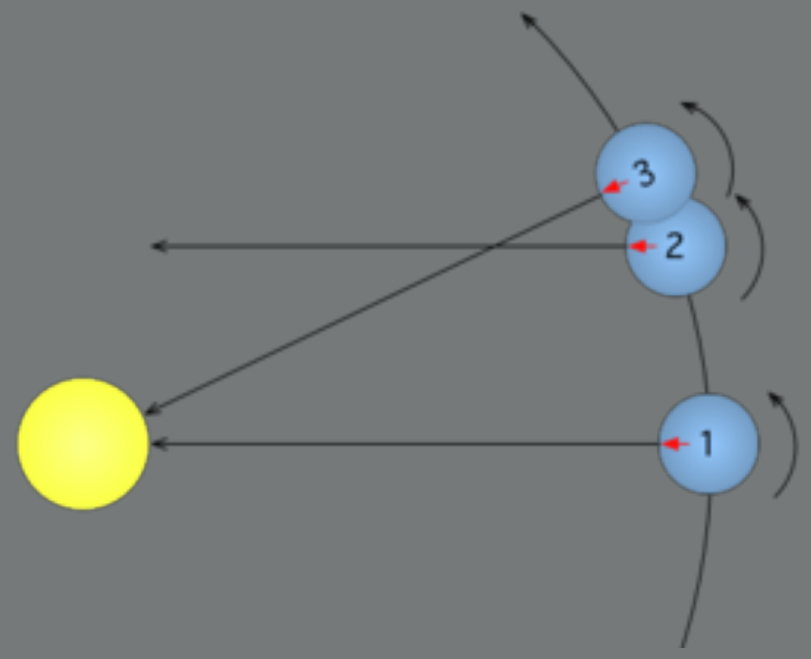


Explaining Apparent Retrograde Motion

- 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

Synodic vs Sidereal

- Sidereal (1-2) is motion with respect to background stars
- Synodic (1-3) is derived from the greek word for assembly, it refers to the body being orbited

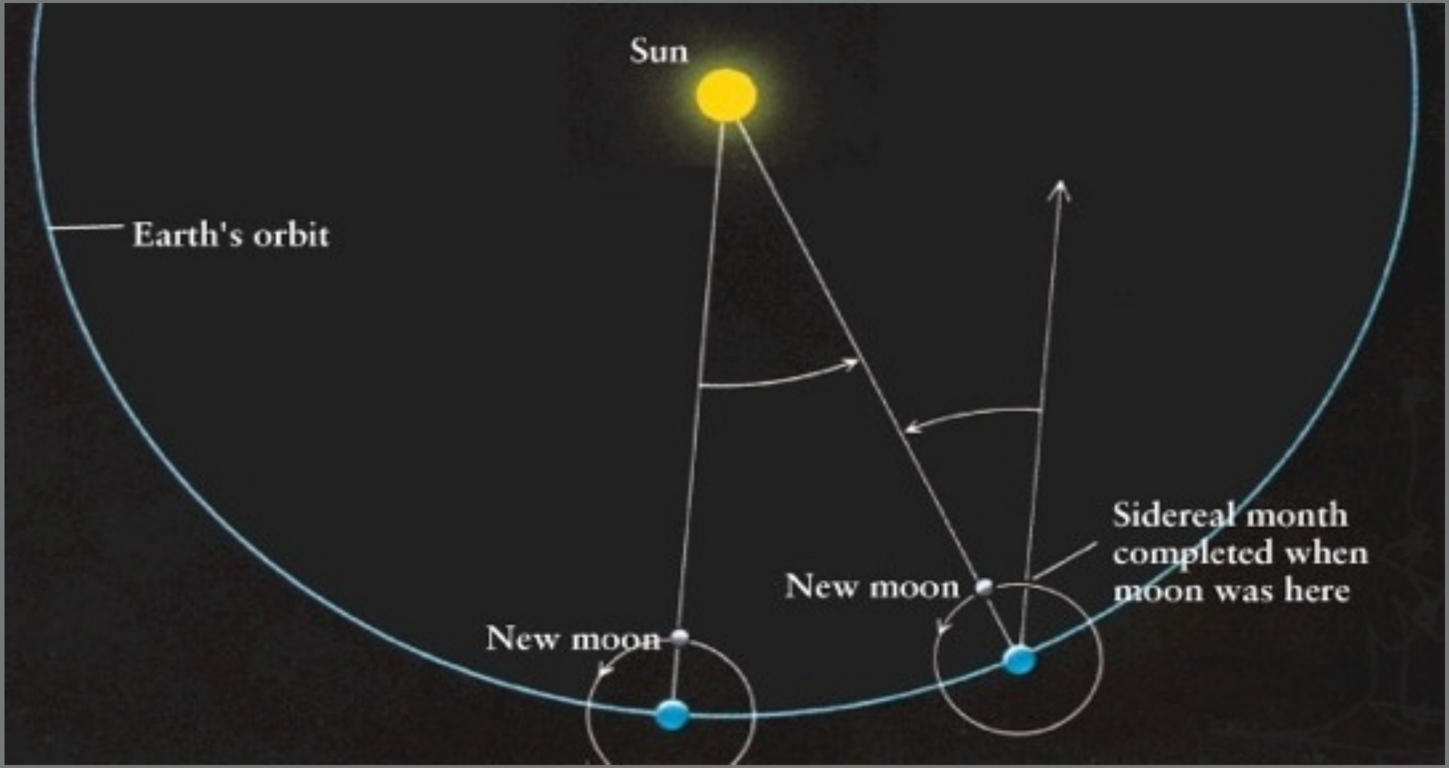


Synodic vs Sidereal

- A sidereal day is 23 hours, 56 minutes, and 4 seconds
- A mean solar day is 24 hours
- Due to the precession of the earth the sidereal and solar year vary by about 20 minutes (try to convert 1/26000 years to minutes)
- Leap years were invented to keep the Vernal Equinox on March 21st, basically to prevent the precession of the earth from changing our calendar

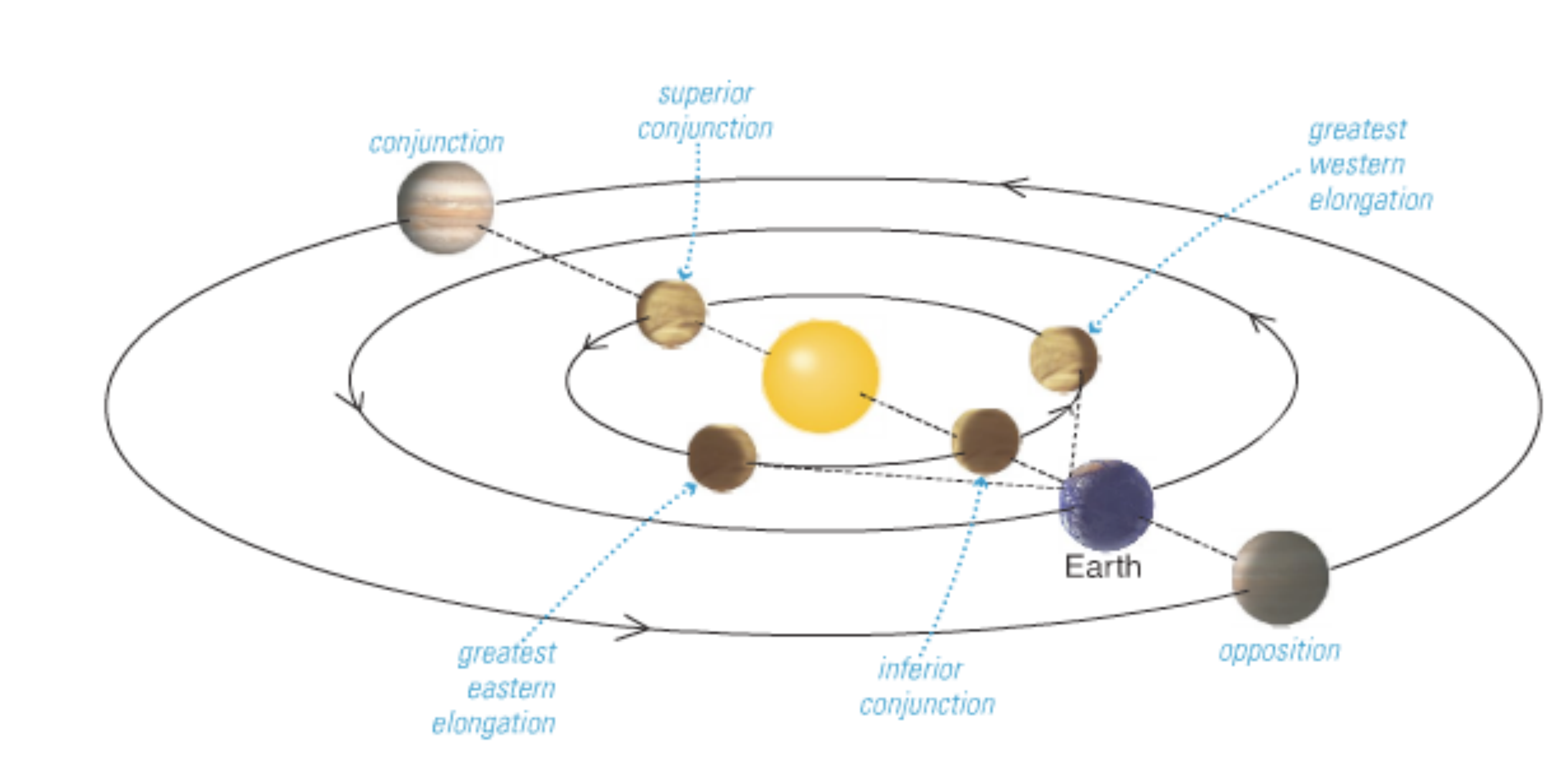
How about the Month?

- Synodic month 29.5 days
- Sidereal month 27.33 days
- How much does the earth move in a mooonth?



Planetary Jargon and a picture

- **Inferior planets** are closer to the sun than we are (Mercury and Venus)
- **Superior planets** are farther (Mars, Jupiter, Saturn, Uranus, and Neptune)



Question

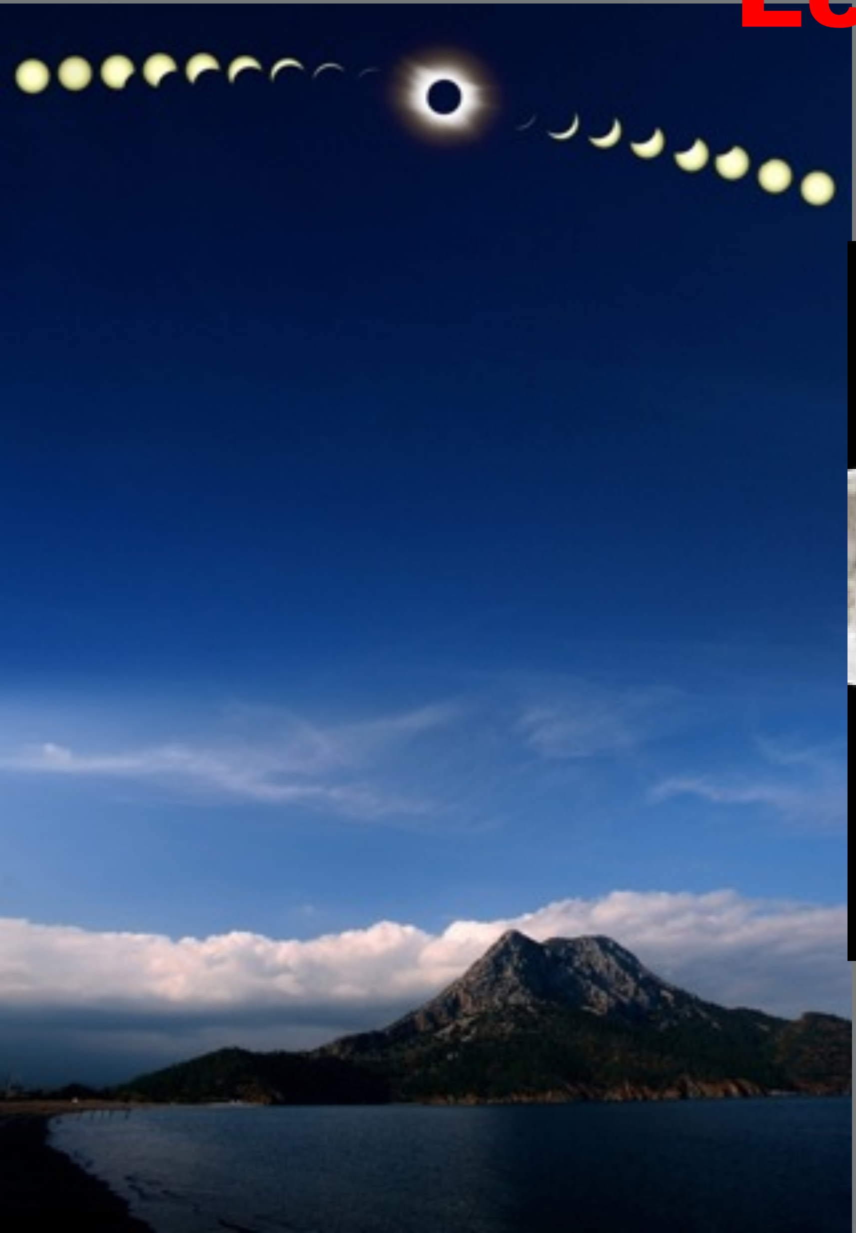
- Can inferior planets be in opposition?
- Which planets exhibit phases?

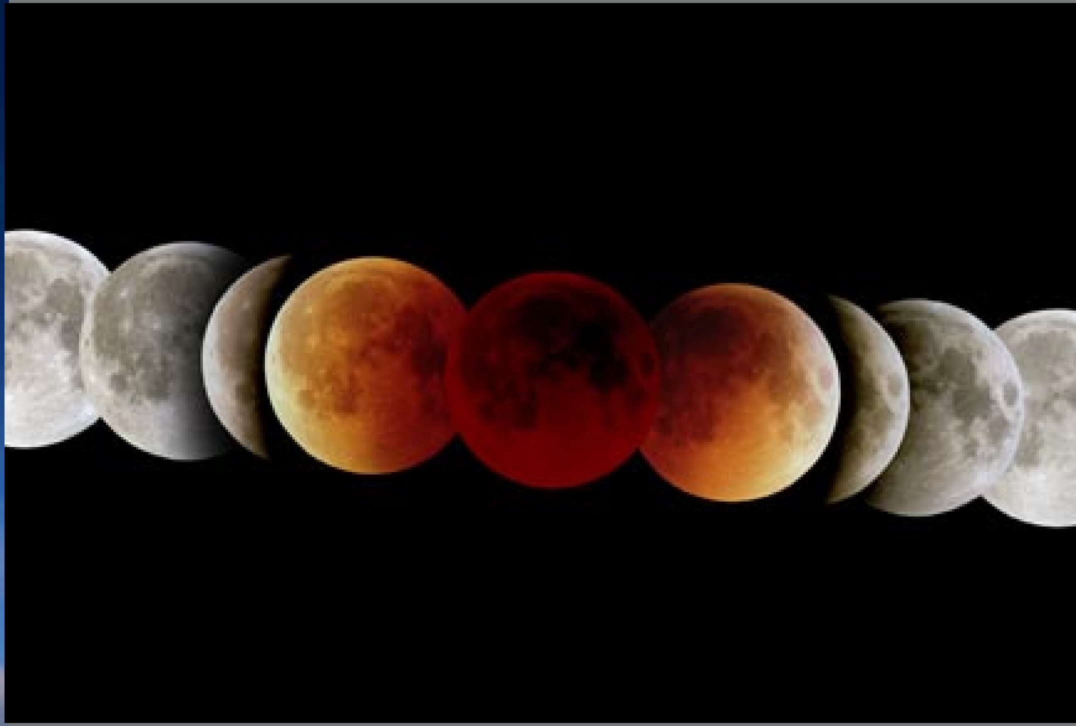
Reading Question

What is an epicycle?

A. The smaller circle around which the planets moved in Ptolemy's model of the solar system
B. A model in which the Sun is at the center of the Solar System.
C. When the Moon blocks only part of the Sun's shadow.
D. The point in a planet's orbit when it is closest to the Sun.
E. The believed orbit of the Sun around the Earth in early Greek models.

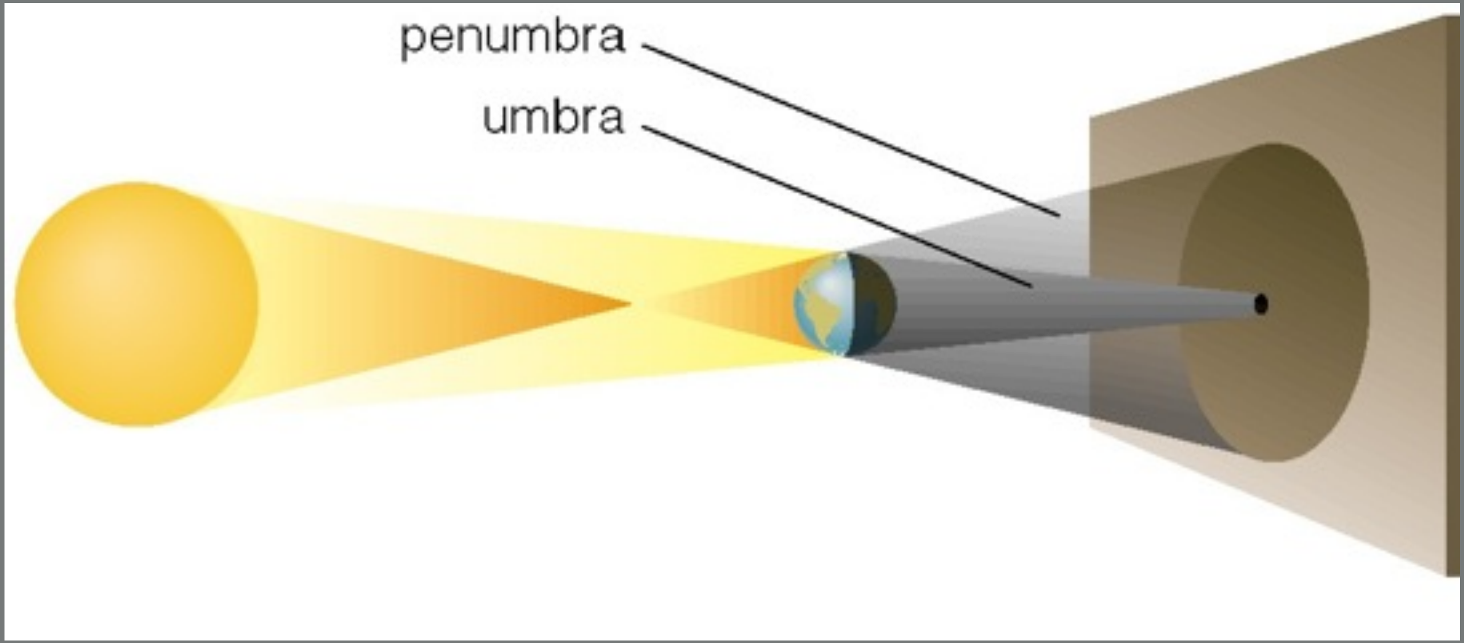
Eclipses





What causes eclipses?

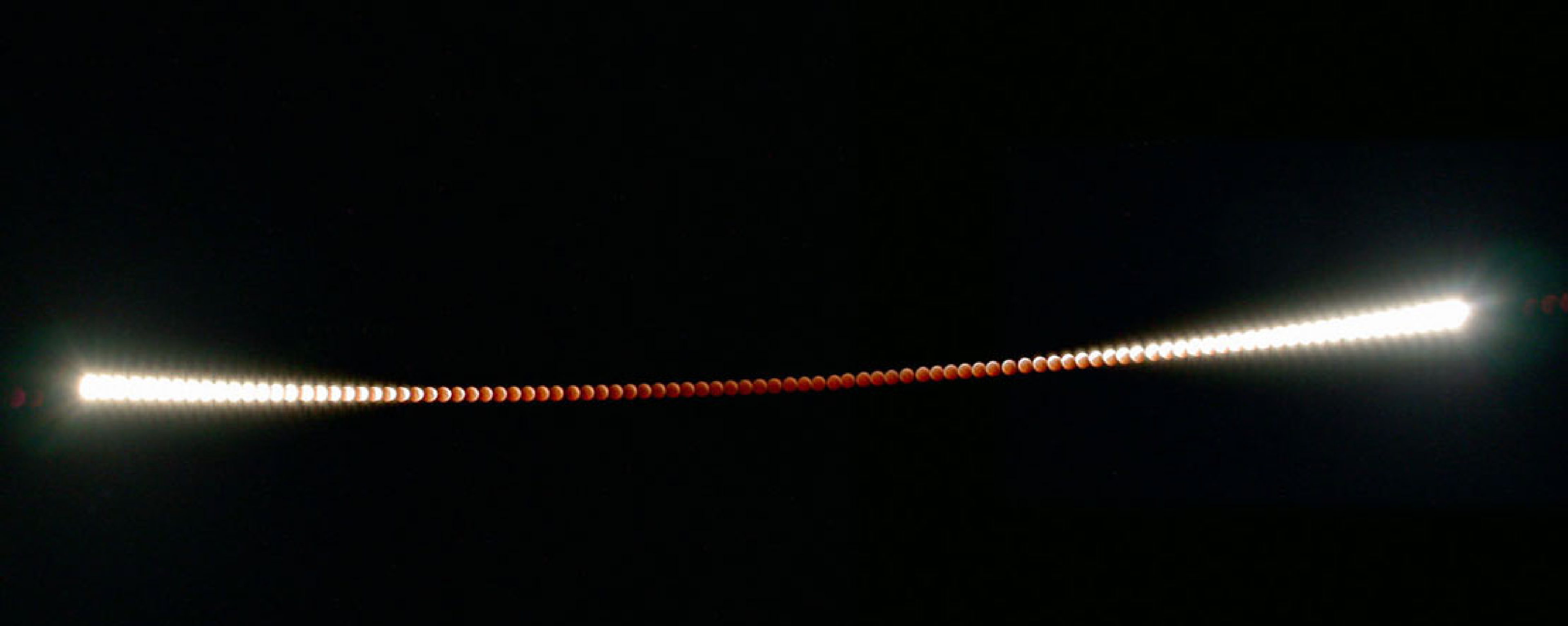
- When either the Earth or the Moon passes through the other's shadow, we have an **eclipse**.



Thought Question

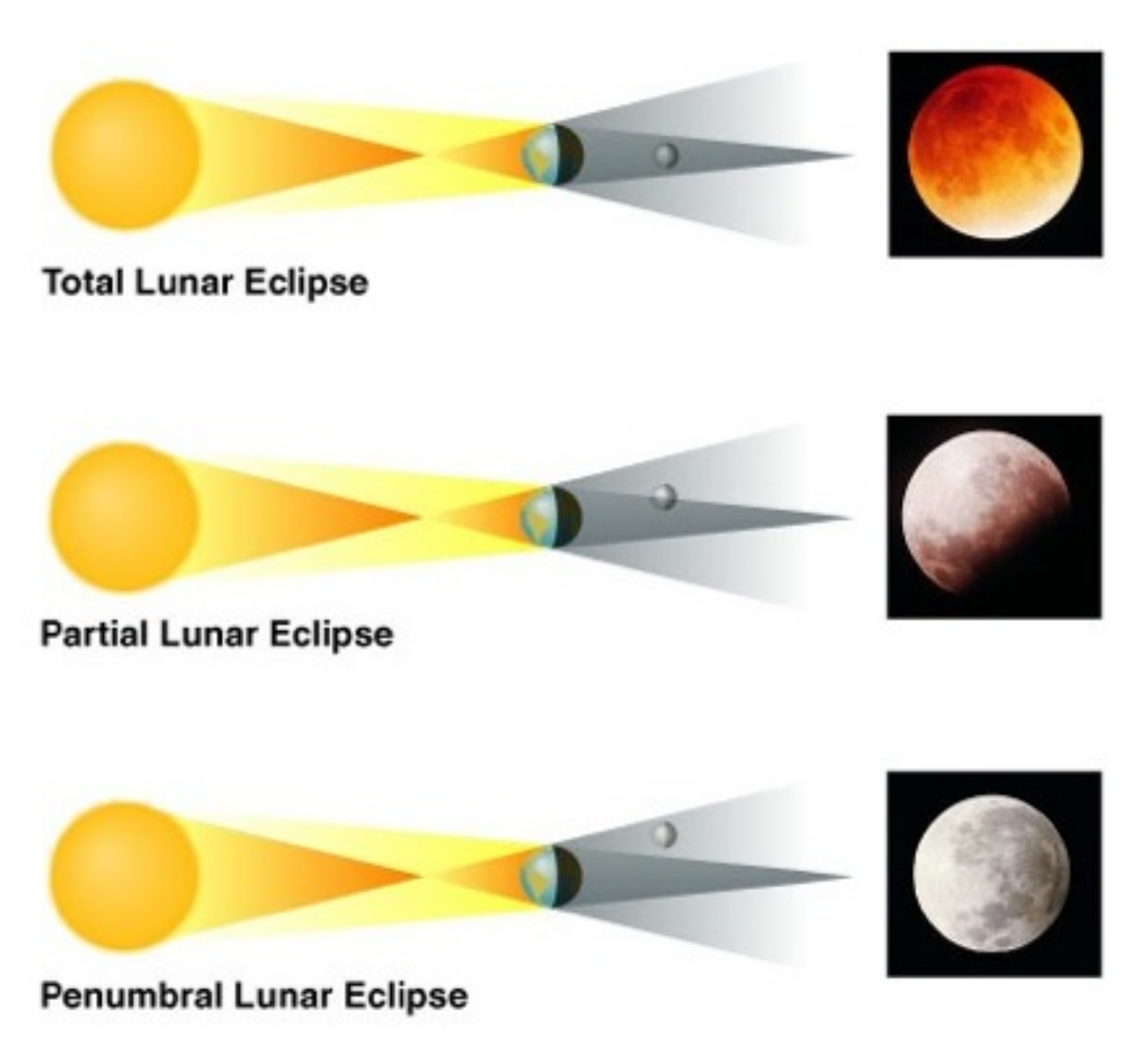
Lunar eclipses (Moon in Earth's shadow) can only happen when there is a ______ moon.

A. New
B. Full
C. Crescent
D. Gibbous
E. Bad

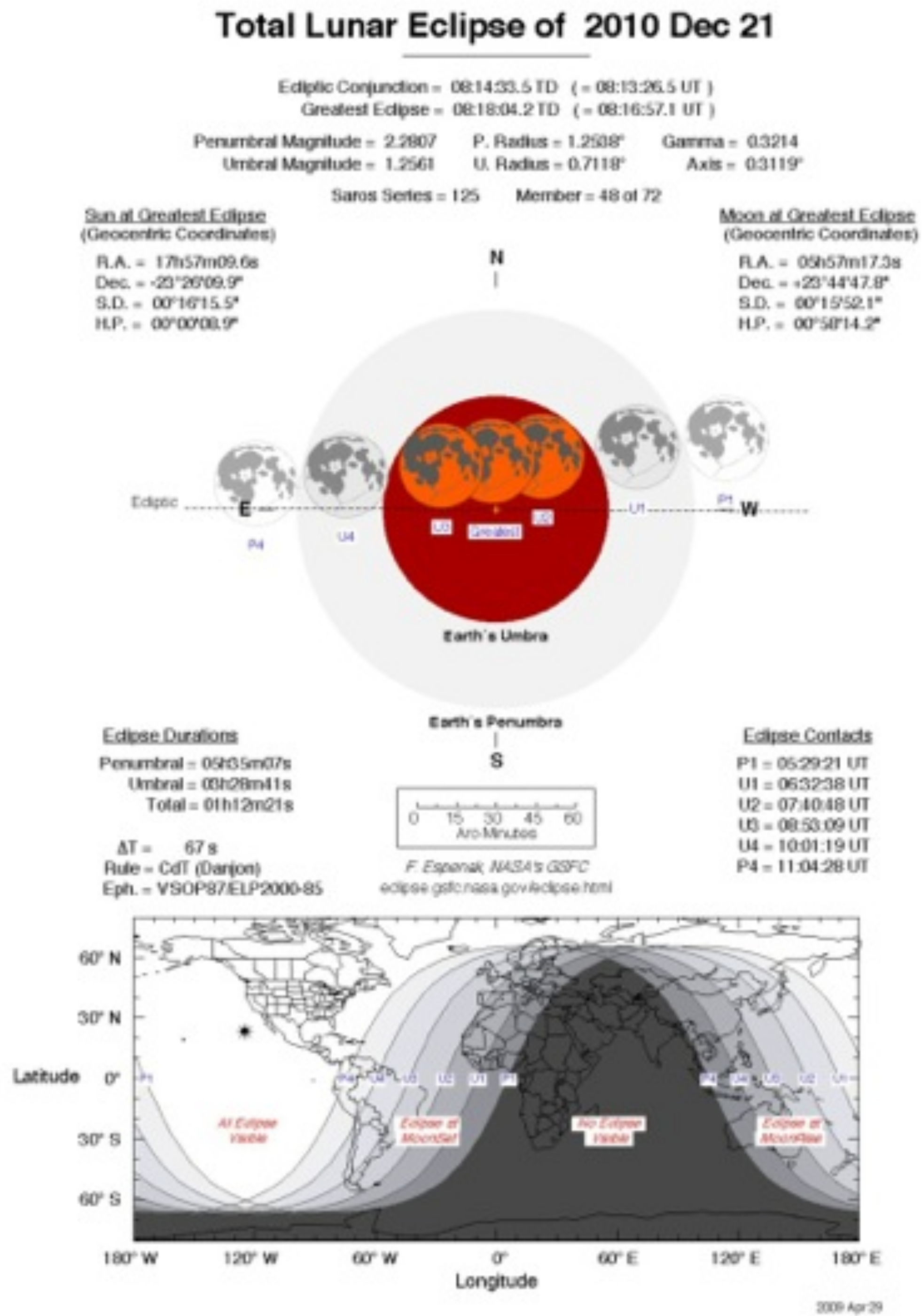


When can lunar eclipses occur?

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

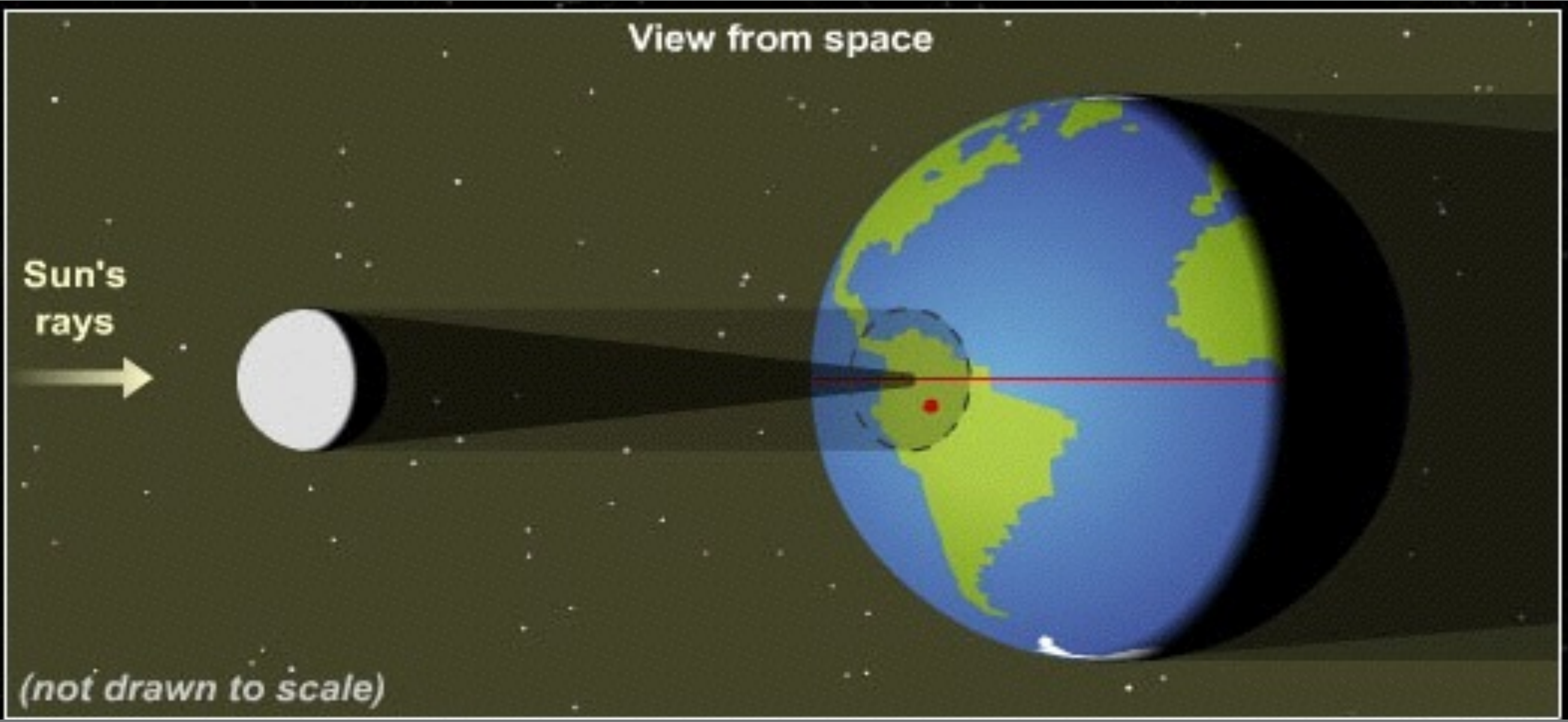


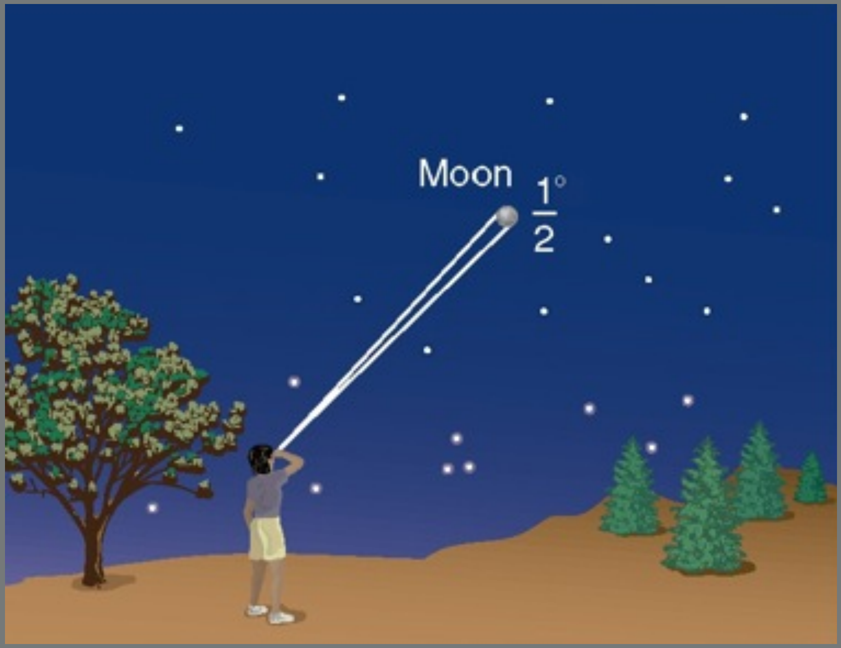
- Earth is ~4 time the size of the Moon
- Makes a **big** shadow
- Visible by the entire night side of the Earth

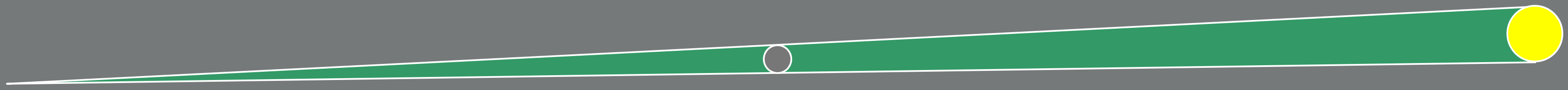


Partial Lunar Eclipse of 2006 September 7, Sighet, Romania
Dobson 150 mm f/5 and Canon PowerShot A510
(c) Sorin Hotea

Solar Eclipse





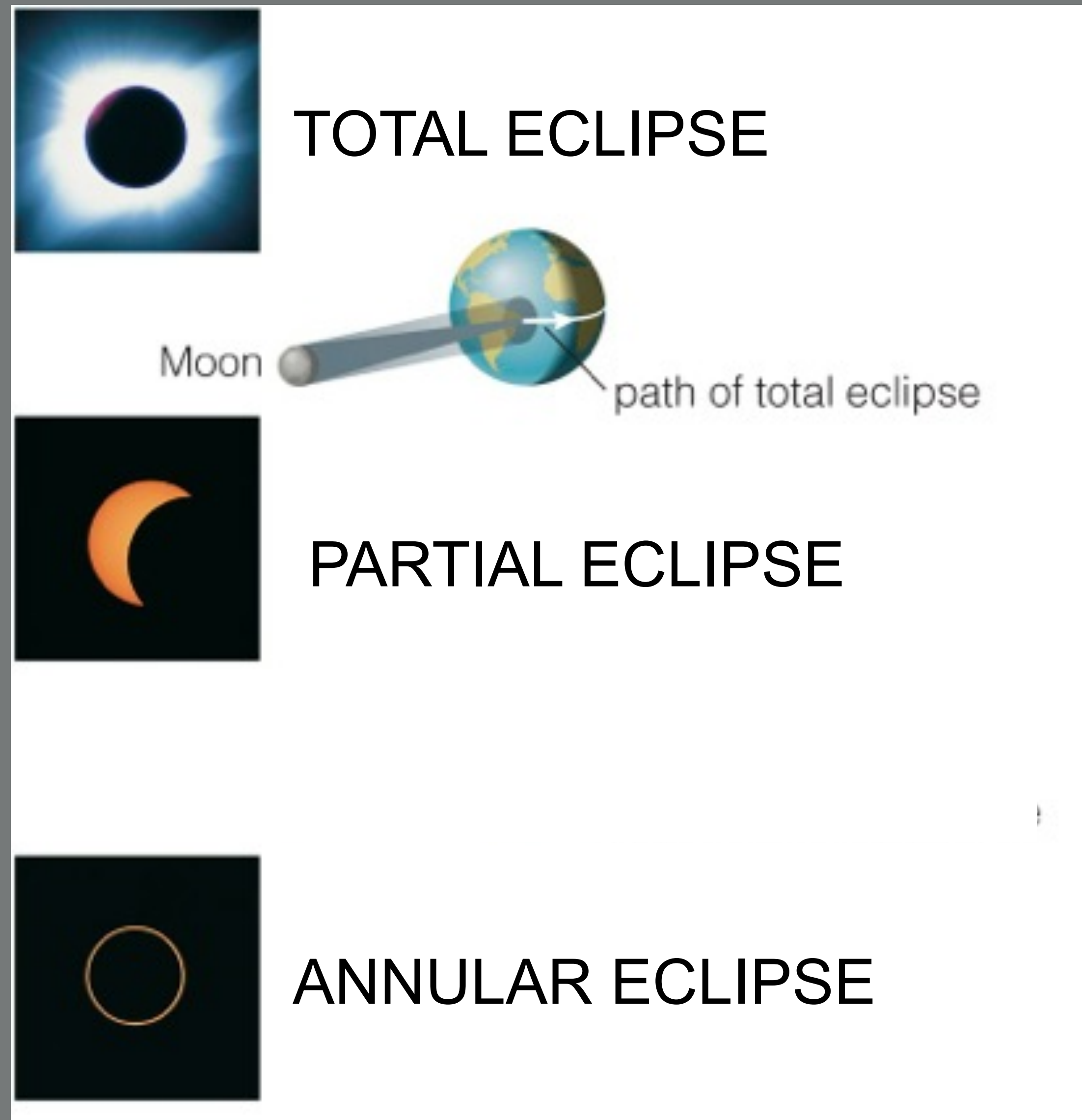


Remarkable fact: Sun and Moon are same angular size viewed from Earth!!

Realistic scale is HUGE - The Sun is 400 times bigger than the Moon but almost exactly 400 times farther away

When can solar eclipses occur?

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



Thought Question

Annular Eclipses …

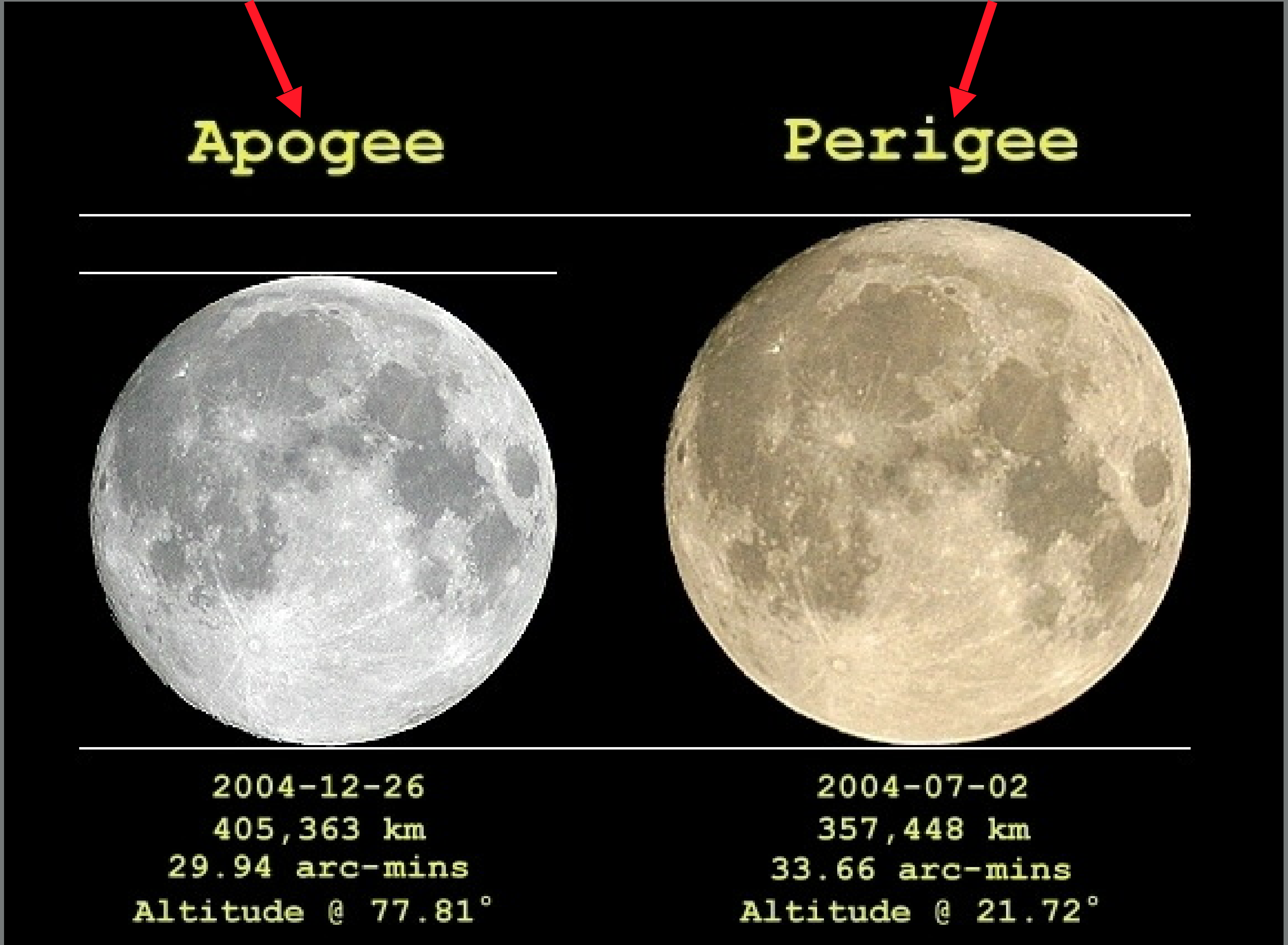
A. occur when the Moon is closer to the Earth
B. occur when the Moon is farther from the Earth
C. can occur at either time
D. only occur when the Moon is at just the right distance

Moon's apparent size changes throughout the Moon's orbit

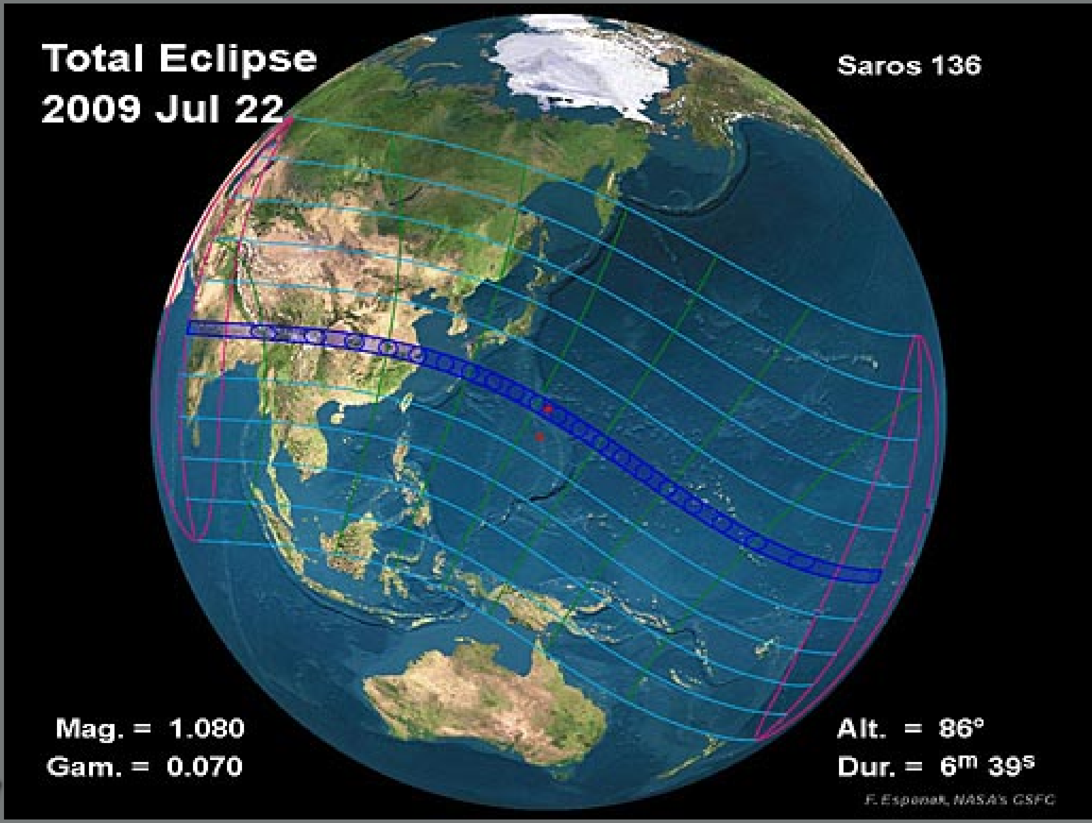
Moon's distance from Earth varies

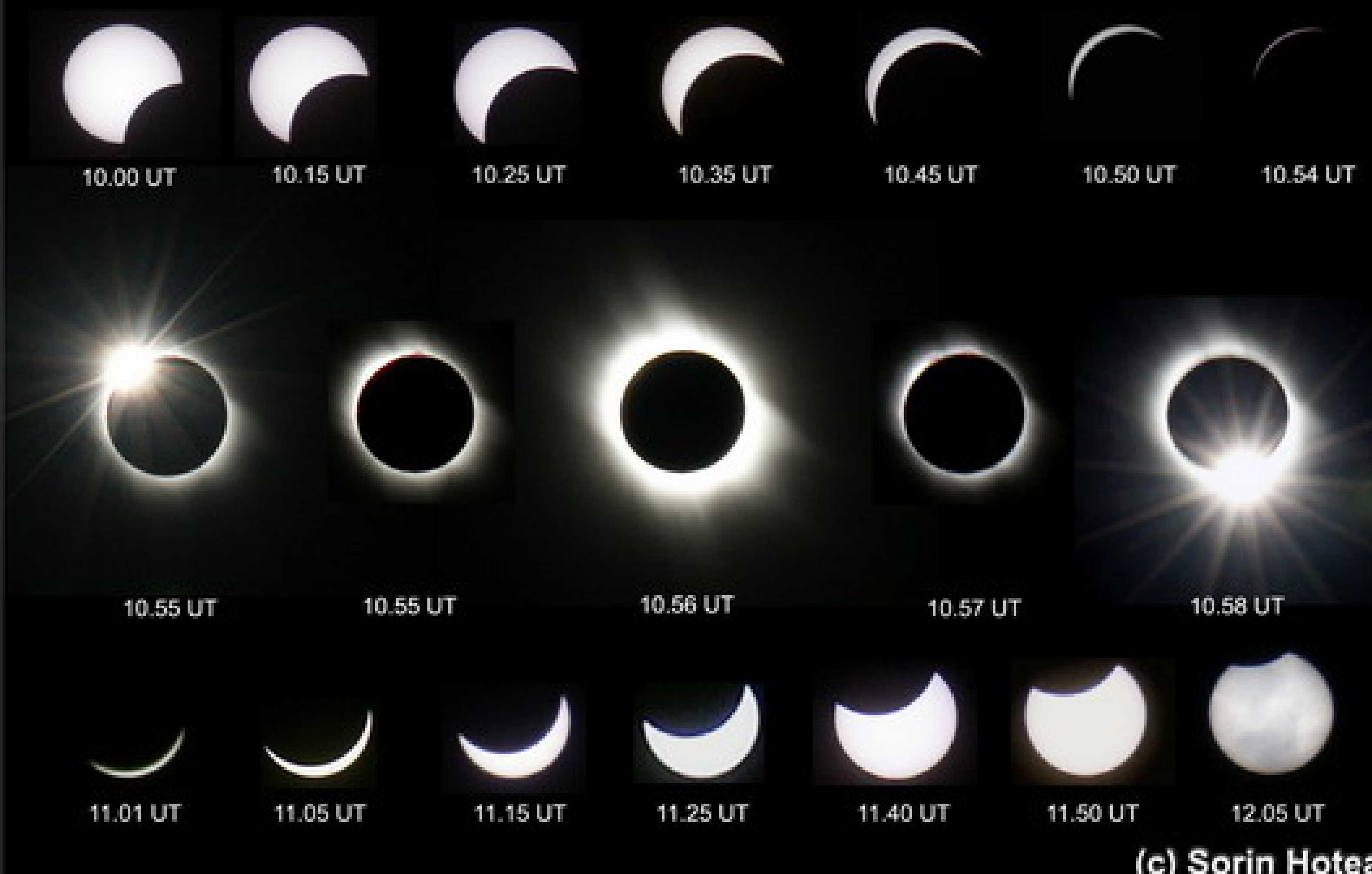
Moon farthest from Earth

Moon closest to Earth

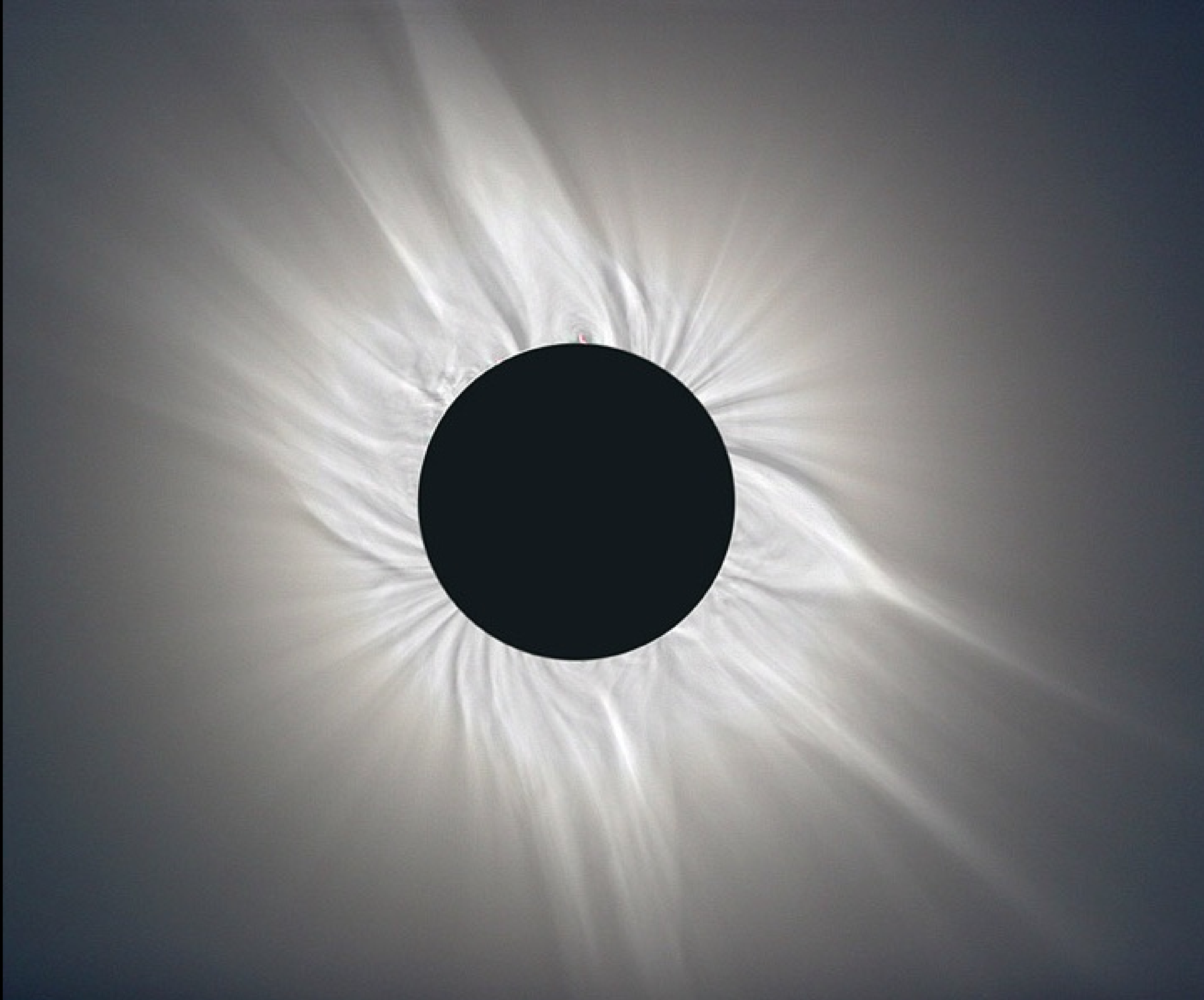


- Moon is ~1/4 times the size of the Earth
- Makes a small shadow
- Only visible by people in the "path of totality"

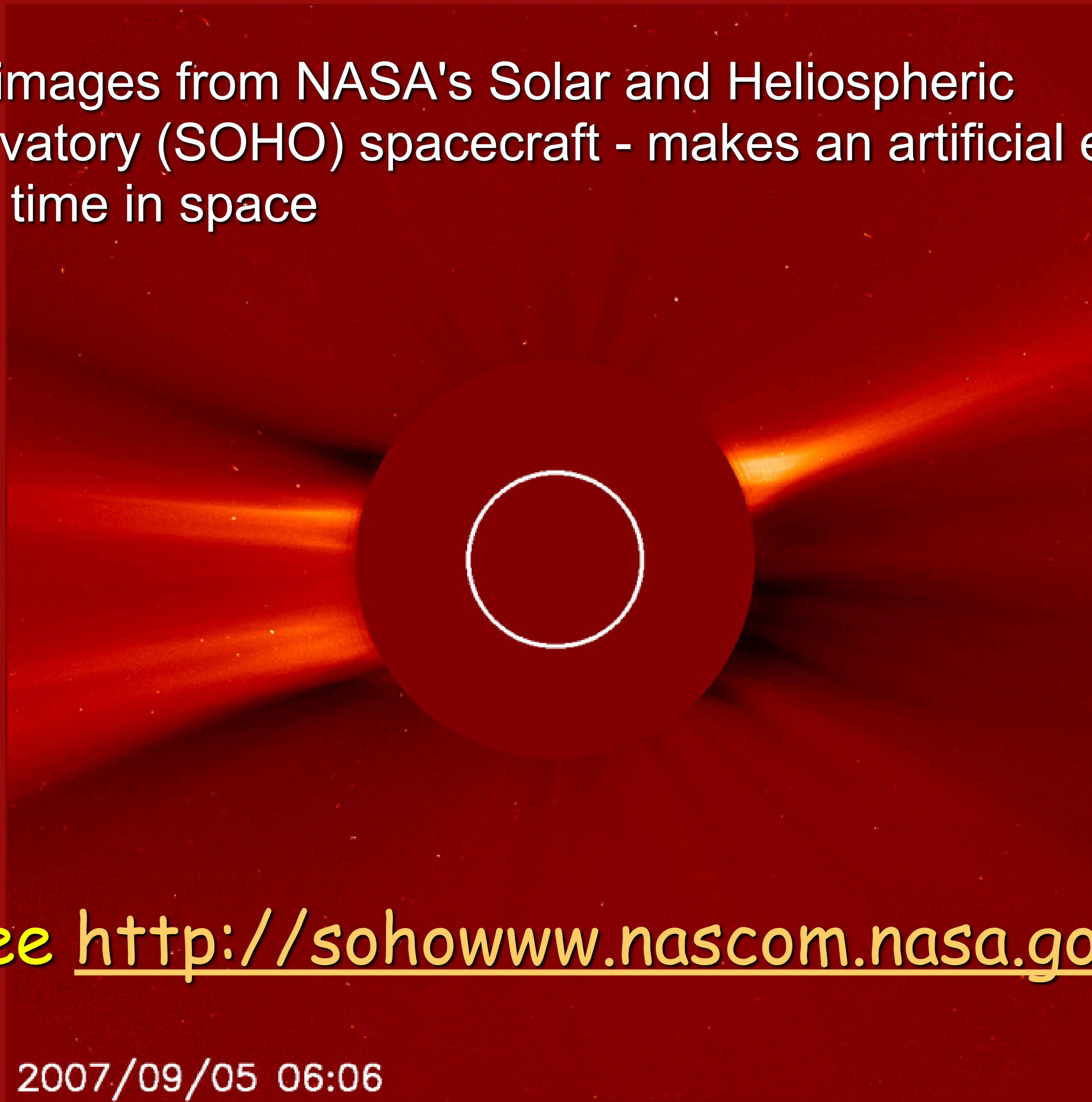




Total Solar Eclipse of 2006 March 29, Manavgat, Turkey
Minolta DiMAGE 7Hi and Baader AstroSolar filter



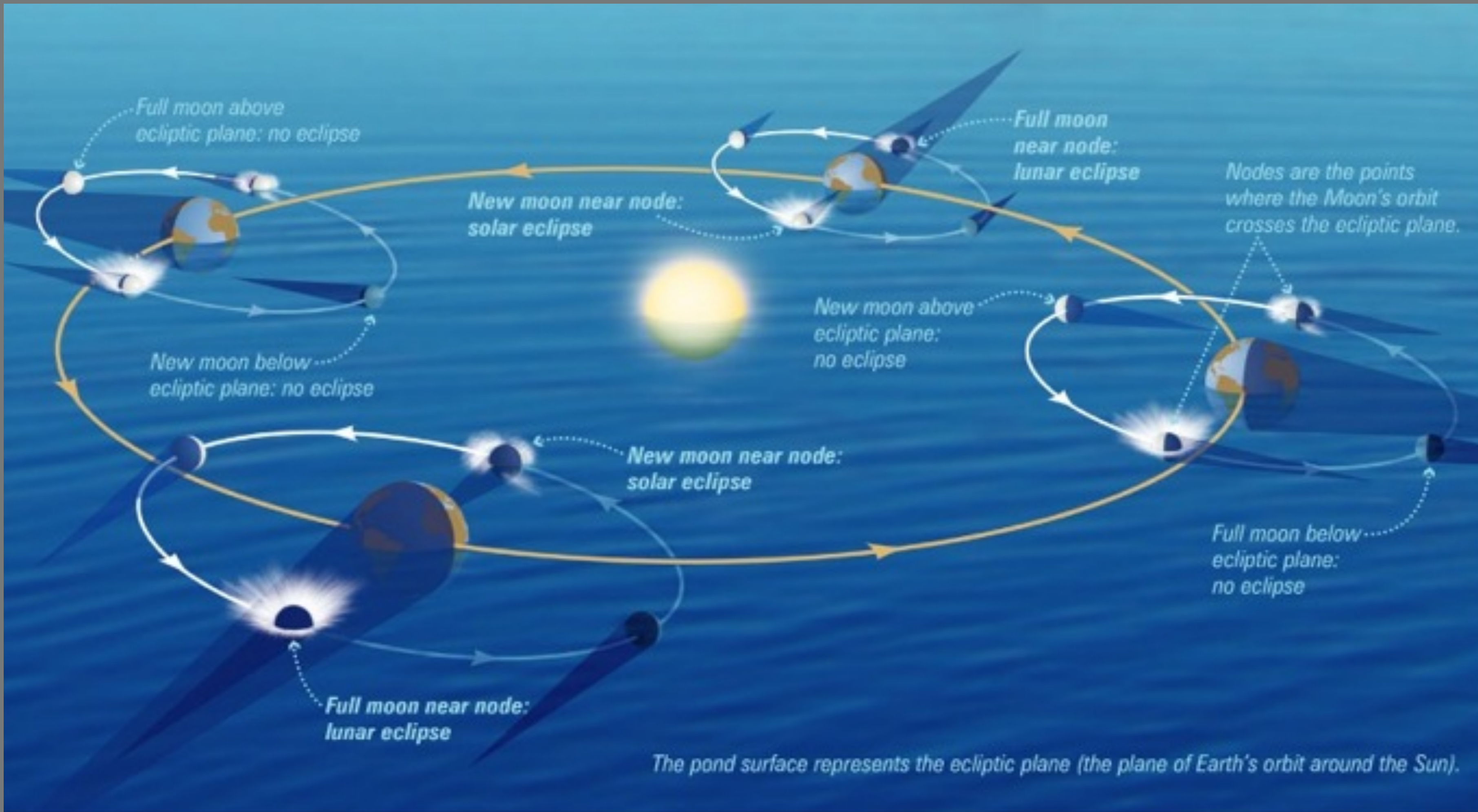
Solar images from NASA's Solar and Heliospheric Observatory (SOHO) spacecraft - makes an artificial eclipse all the time in space



- See http://sohowww.nascom.nasa.gov/

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 when a new or full moon occurs at the nodes of the Moon's orbit.



Thought Question

You are lucky enough to see a solar eclipse. Now what?

A. A lunar eclipse may occur in two weeks
B. A lunar eclipse may occur in about a month
C. Another solar eclipse will happen next month
D. You'll have to wait another year to get another chance.
E. You cannot easily predict when the next lunar or solar eclipse will occur

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 (the nodes).