Discovering the Universe for Yourself (Chapter 2)

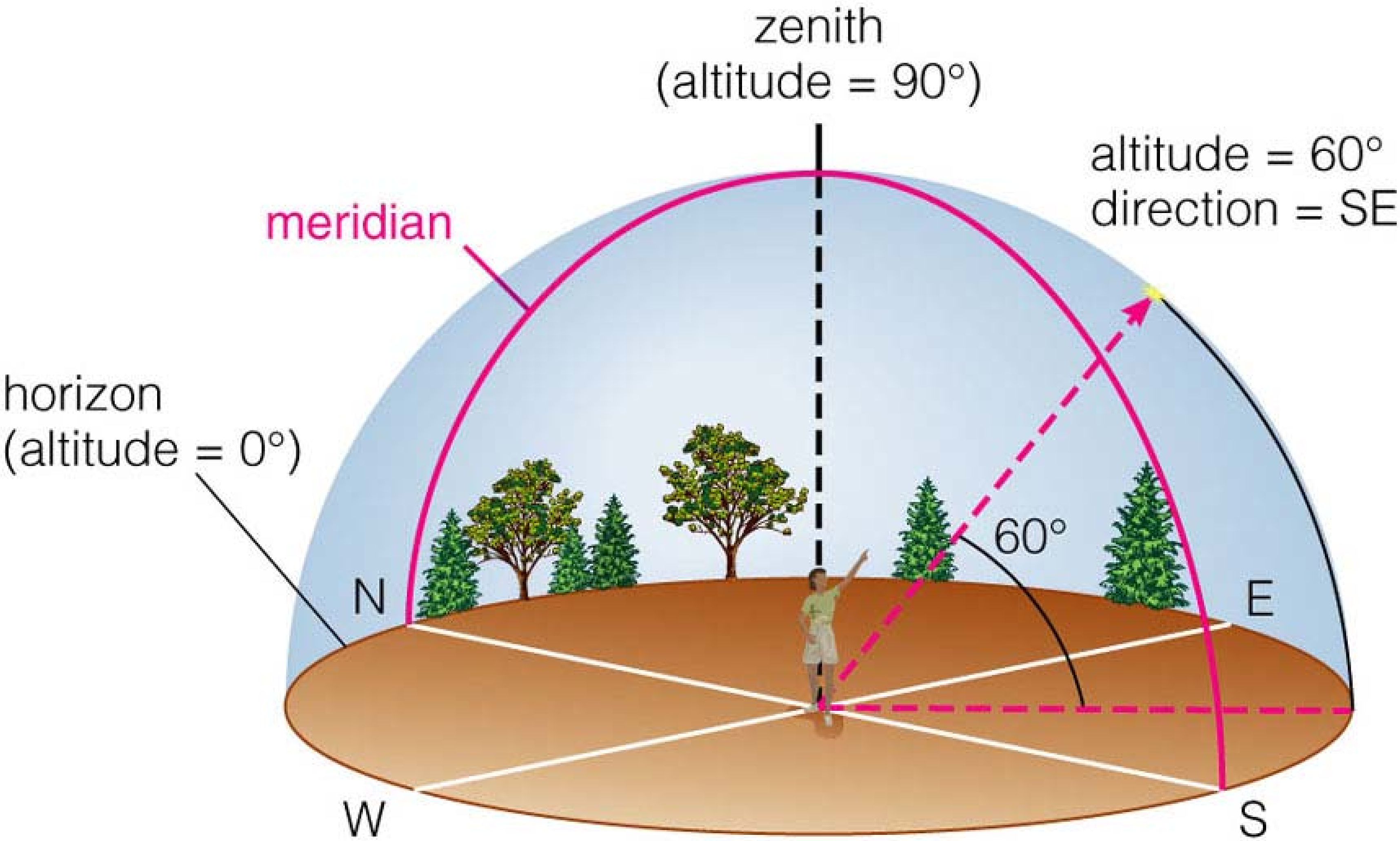
Years, Seasons, and Months: The Motions of Sun, Earth, and Moon

Based on Chapter 2

- This material will be useful for understanding Chapters 3 and 4 on “The Orbits of the Planets” and “Why Does Earth go Around the Sun?”
- Chapter 1 on “The Structure and Size of the Universe” will be useful for understanding this material

Goals for Learning

- How does the Sun move in the sky and what causes the seasons?
- What causes the phases of the Moon?
- What causes eclipses?
- What causes the night sky to change during the night and during the year?



Draw global-scale version of this figure

Apparent Motion of the Sun

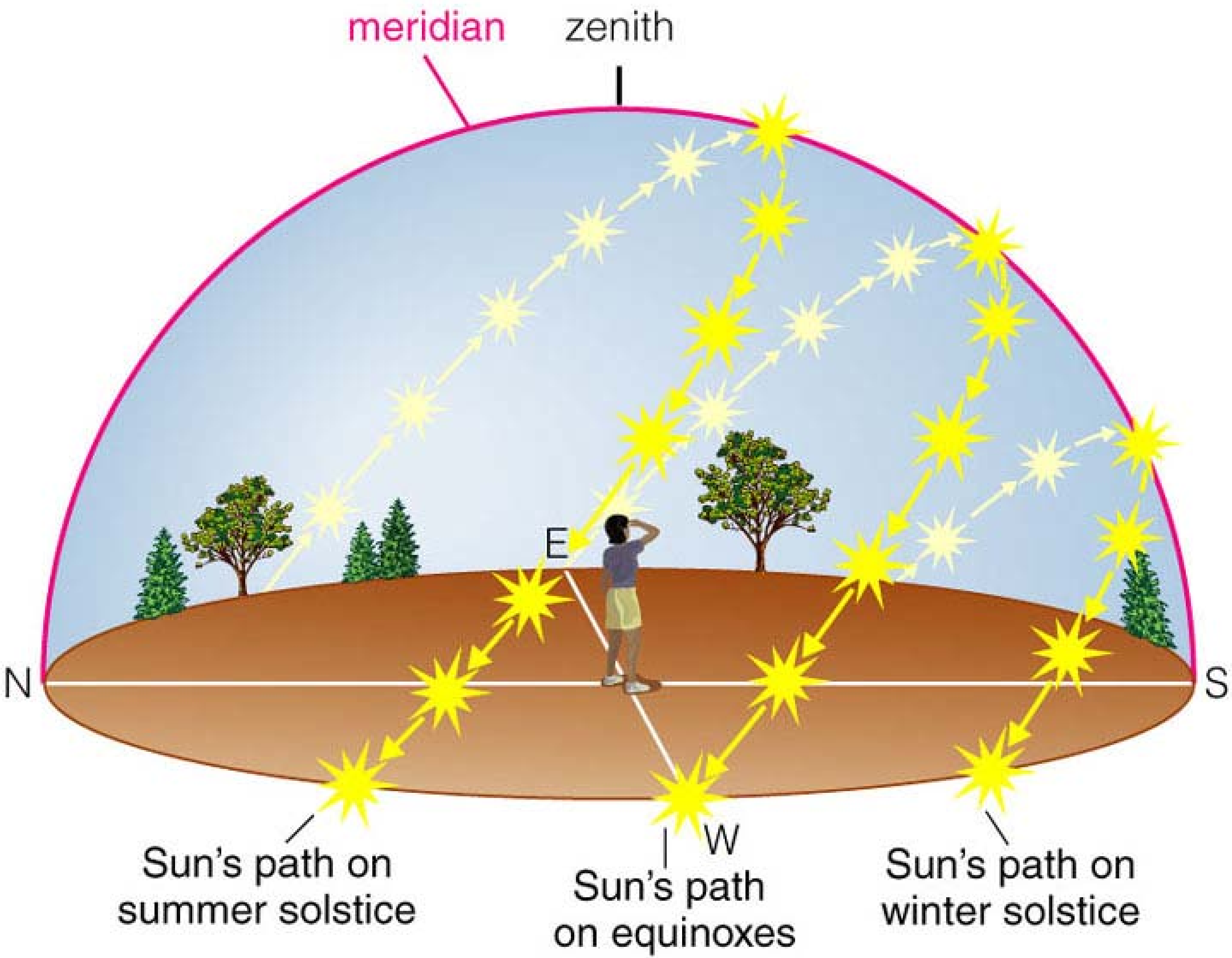
- Describe the motion of the Sun in the sky from dawn to dusk.
- Does the Sun rise at dawn in the north, south, east or west? Where does the Sun set at dusk?
- Does the Sun cross the meridian in the morning, around noon, or in the afternoon?
- Is the Sun's altitude greatest in the morning, around noon, or in the afternoon?
- Where does the Sun go at night?
- Are the answers to these questions the same everywhere on Earth?

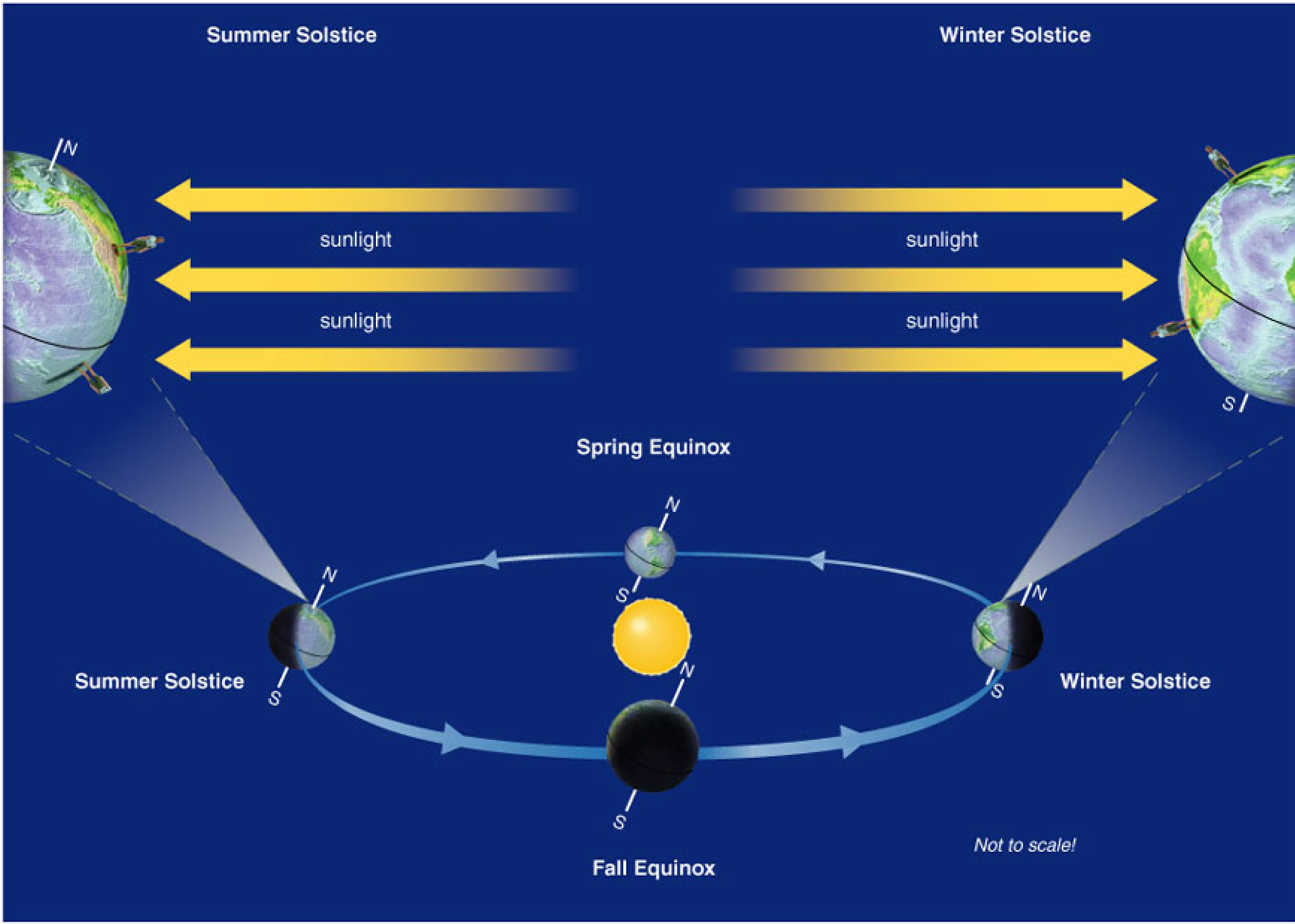
Conclusions from Sun's daily motions

- Earth rotates about its axis once per day
- Russian Midnight Sun on VoyagerSkyGazer, vary latitude and so on

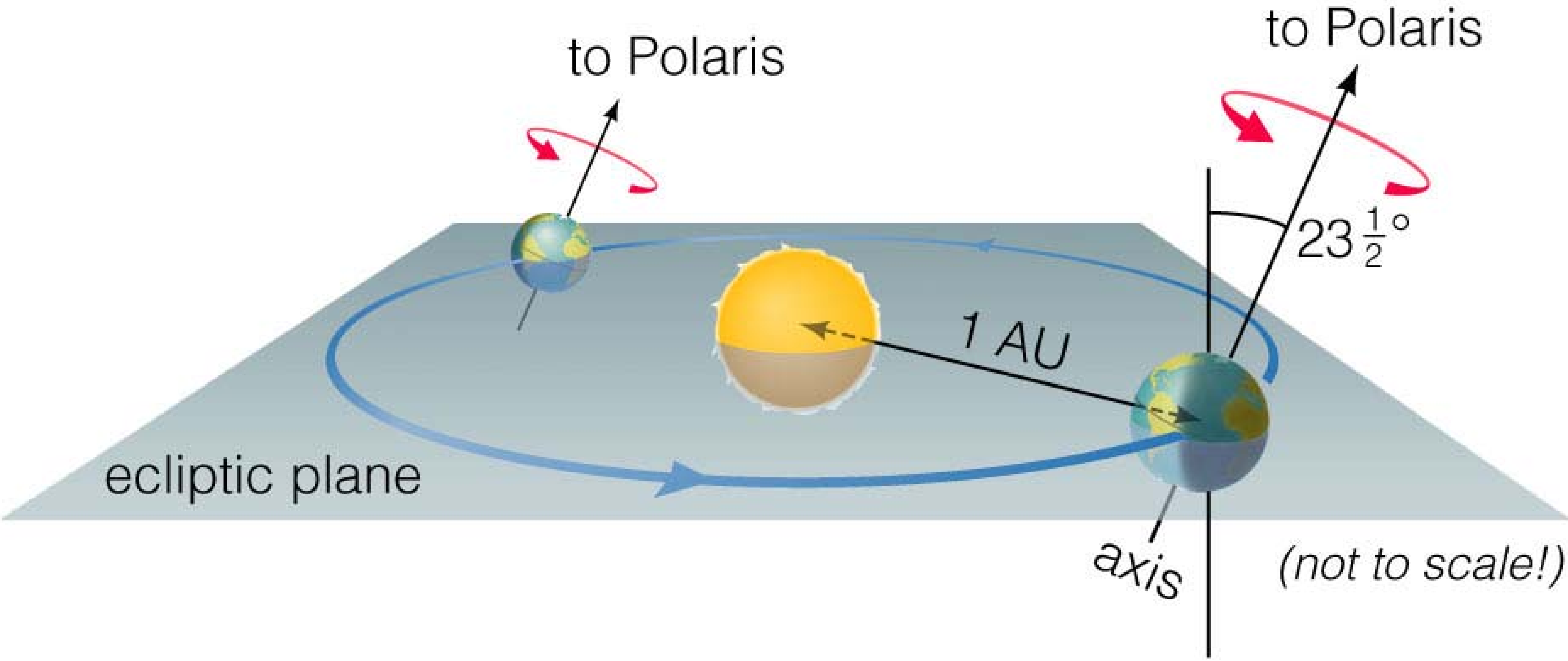
Seasonal Variations in the Sun's Daily Motion

- How many hours of daylight are there in December, March, June, and September in Boston?
- What about at the North Pole, the Equator, Australia, and the South Pole?


meridian
zenith
E
N
S
W
Sun's path on summer solstice
Sun's path on equinoxes
Sun's path on winter solstice



Show Interactive Fig 2.15


to Polaris
to Polaris
23 1/2°
1 AU
ecliptic plane
axis
(not to scale!)

STOP!

- Mechanical orrery
- Earth’s orbit and rotation again

Hot and Cold

- Change in the length of day is the true seasonal cycle, not changes in temperature
- North Pole is tilted towards Sun in June, tilted away from Sun in December
- Northern hemisphere gets more direct sunlight than southern hemisphere in June, whereas the opposite is true in December

- Why are July/August warmer than June and why are January/February colder than December?
- Answer: It takes time for Earth to respond to the changing heating

Changes in Earth-Sun Distance?

- Winter in Boston occurs during summer in Australia
- Summer in Boston occurs during winter in Australia
- Changes in the Earth-Sun distance can't cause patterns like these

- Plus: Sun is always same size in sky, so Earth-Sun distance is not changing much

STOP!

- Show how angle of sunlight on Earth’s surface relates to axis tilt
- Use flashlight and lightmeter

Observations of the Moon

- The Moon rises in the east and sets in the west once per day
  - Due to the Earth's rotation about its axis
- The size of the Moon is always about the same
  - The distance of the Moon from the Earth is always about the same

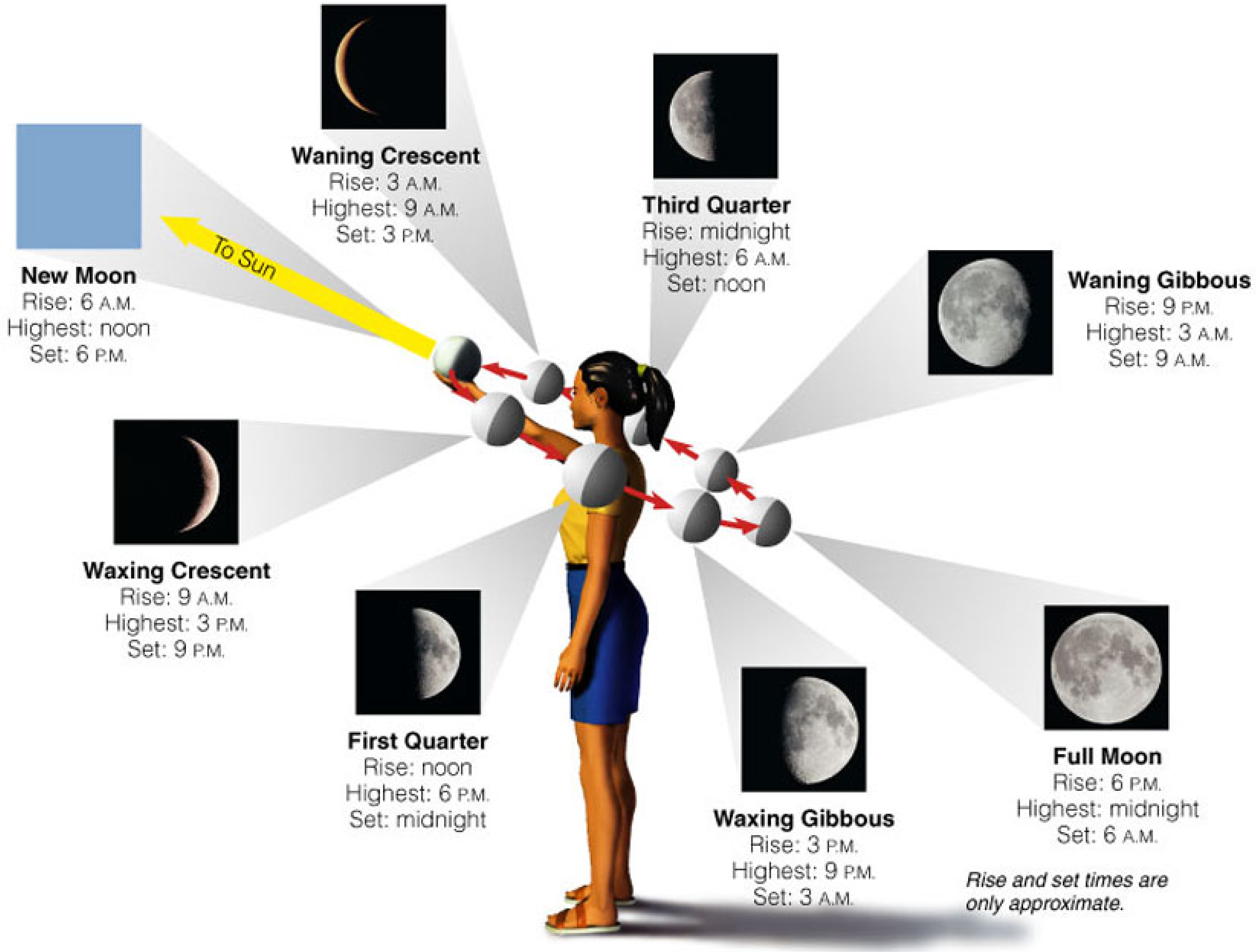
Phases of the Moon

- The Moon’s appearance (new, crescent, half, full) changes in a 29.5 day cycle
  - This is the origin of the time interval called a month, or “moon”th
  - Half the Moon is illuminated by the Sun at any time, and half is not. From Earth, we see different proportions of illuminated/shaded regions during each “moon”th
- The time of Moon-rise and Moon-set also changes during this 29.5 day cycle

\Documents and Settings\Paul Withers\Desktop\teaching\imagesfromweb\anim_lunation.ht

Open anim_lunation.gif in Windows Media Player

- Interactive “Phases of the Moon”

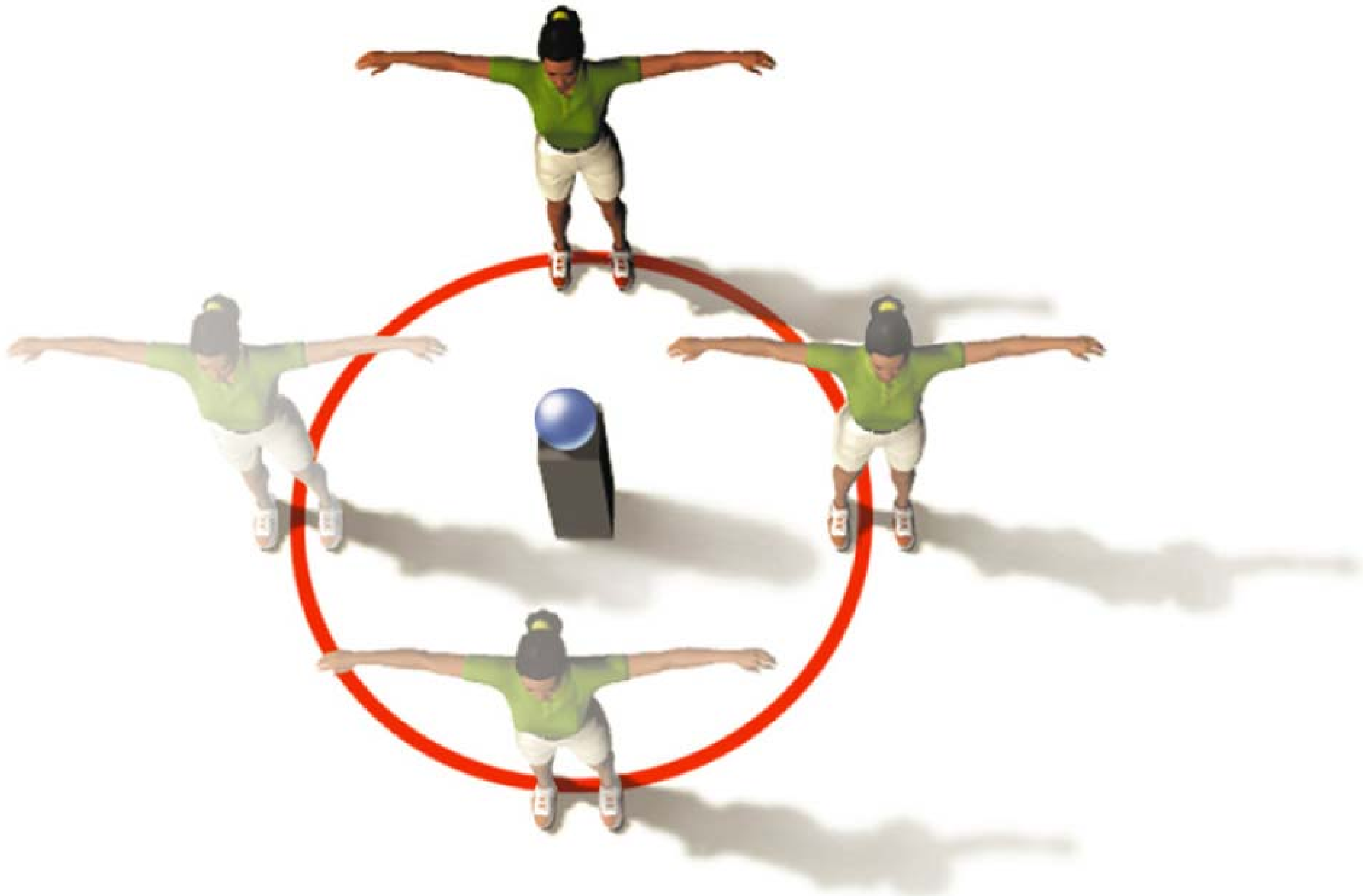


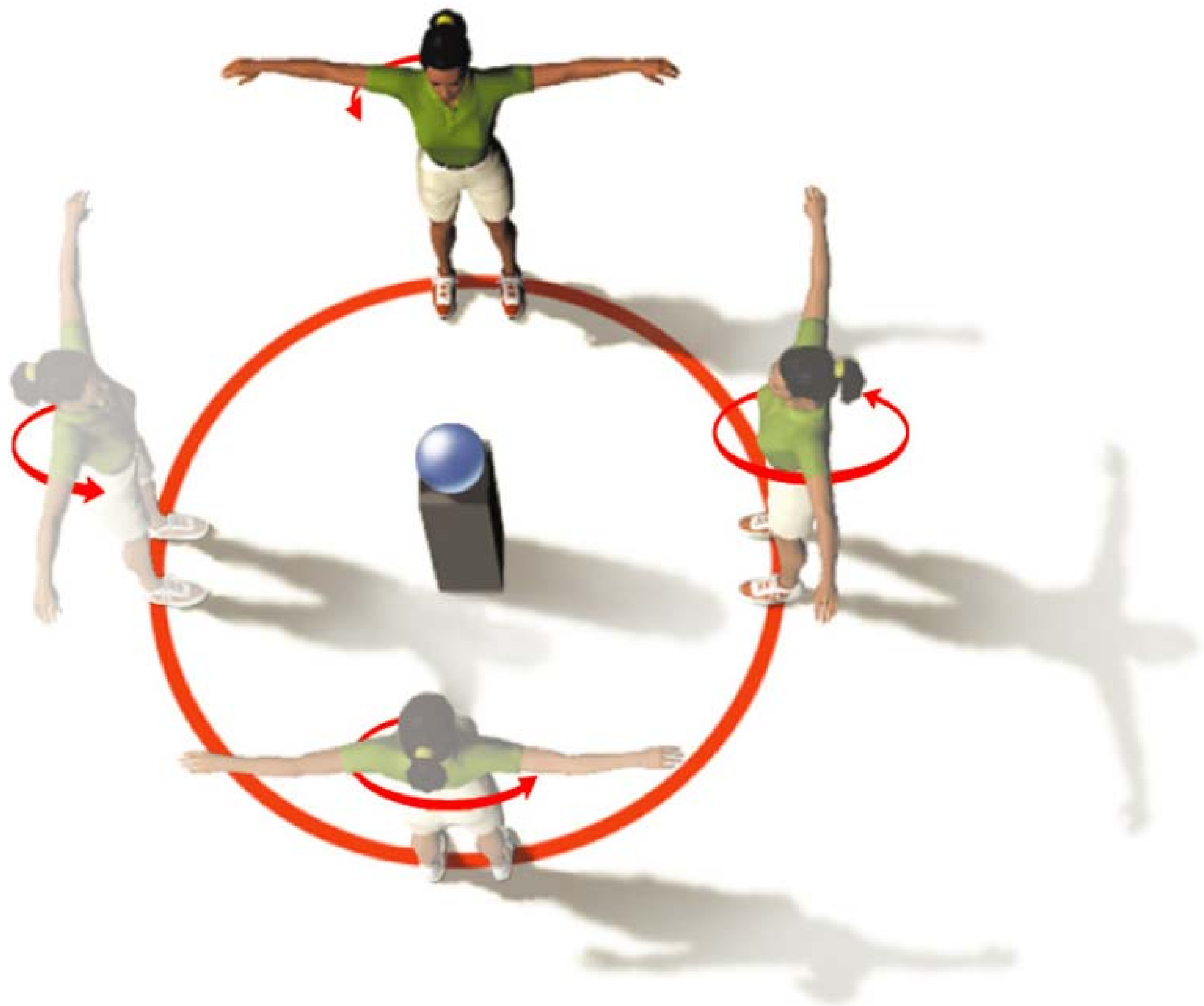
Waning Crescent
Rise: 3 A.M.
Highest: 9 A.M.
Set: 3 P.M.
Third Quarter
Rise: midnight
Highest: 6 A.M.
Set: noon
New Moon
Rise: 6 A.M.
Highest: noon
Set: 6 P.M.
To Sun
Waning Gibbous
Rise: 9 P.M.
Highest: 3 A.M.
Set: 9 A.M.
Waxing Crescent
Rise: 9 A.M.
Highest: 3 P.M.
Set: 9 P.M.
First Quarter
Rise: noon
Highest: 6 P.M.
Set: midnight
Waxing Gibbous
Rise: 3 P.M.
Highest: 9 P.M.
Set: 3 A.M.
Full Moon
Rise: 6 P.M.
Highest: midnight
Set: 6 A.M.
Rise and set times are only approximate.

Why do we always see the same side of the Moon?

- The Moon orbits around the Earth once per month.
- How does the Moon’s rotation affect which side of the Moon we see?

- Interactive “Causes of Lunar Phases” (which is all about rotation, not phases)





- Phases of the Planets, Phases of the Moon, on VoyagerSkyGazer

How to work with Units

- The mass of the Moon is 30
- The mass of the Moon is 30 hours
- The mass of the Moon is 30 miles

- The units must make sense. If they don’t make sense, then the answer is wrong

Test whether an equation is wrong

- t = time (seconds, minutes, hours…)
- d = distance (metres, kilometres, …)
- s = speed (metres per second, miles per hour)
  - "per" suggests division, m / s

- $E = d\ t^2$, $F = d\ t$, $G = t / d$, $H = 3\ d$, $J = d / t$,
  $K = 3\ d / t$
- What are the units of E, F, G, H, and J?
- Can any of these be an expression for speed?

Changing Units

- Multiply by 1!

$$1\,\text{min} = 60\,\text{sec}$$

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$$\frac{1\,\text{min}}{60\,\text{sec}} = \frac{60\,\text{sec}}{60\,\text{sec}} = 1$$

Changing Units

- Multiply by 1!

$$1\,\text{min} = 60\,\text{sec}$$

$$\frac{1\,\text{min}}{60\,\text{sec}} = \frac{60\,\text{sec}}{60\,\text{sec}} = 1$$

$$120\,\text{sec} = 120\,\text{sec} \times 1 = 120\,\text{sec} \times \frac{1\,\text{min}}{60\,\text{sec}}$$

Changing Units

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$$\frac{1\,\text{min}}{60\,\text{sec}} = \frac{60\,\text{sec}}{60\,\text{sec}} = 1$$

$$120\,\text{sec} = 120\,\text{sec}\times 1 = 120\,\text{sec}\times \frac{1\,\text{min}}{60\,\text{sec}}$$

$$= \frac{120\times 1}{60}\times \frac{1\,\text{sec}\times 1\,\text{min}}{1\,\text{sec}} = 2\times 1\,\text{min} = 2\,\text{min}$$

More Units

$$3\,\text{km}^2 = 1\,\text{km} \times 3\,\text{km}$$

More Units

$$3\ \text{km}^2 = 1\ \text{km} \times 3\ \text{km} = 1\ \text{km} \times \frac{1000\ \text{m}}{1\ \text{km}} \times 3\ \text{km} \times \frac{1000\ \text{m}}{1\ \text{km}}$$

More Units

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$$= \frac{1\ \text{km}}{1\ \text{km}} \times 1000\ \text{m} \times \frac{3\ \text{km}}{1\ \text{km}} \times 1000\ \text{m}$$

More Units

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$$= \frac{1\ \text{km}}{1\ \text{km}} \times 1000\ \text{m} \times \frac{3\ \text{km}}{1\ \text{km}} \times 1000\ \text{m}$$

$$= 1 \times 1000\ \text{m} \times 3 \times 1000\ \text{m}$$

More Units

$$3\ \text{km}^2 = 1\ \text{km} \times 3\ \text{km} = 1\ \text{km} \times \frac{1000\ \text{m}}{1\ \text{km}} \times 3\ \text{km} \times \frac{1000\ \text{m}}{1\ \text{km}}$$

$$= \frac{1\ \text{km}}{1\ \text{km}} \times 1000\ \text{m} \times \frac{3\ \text{km}}{1\ \text{km}} \times 1000\ \text{m}$$

$$= 1 \times 1000\ \text{m} \times 3 \times 1000\ \text{m} = 3000000\ \text{m}^2 = 3 \times 10^6\ \text{m}^2$$

Even More Units

$$1\ \text{minute} = 60\text{seconds}$$

$$1 = \frac{1\text{minute}}{60\text{seconds}} = \frac{60\text{seconds}}{1\text{minute}}$$

$$120\text{metres per minute} = \frac{120\text{metres}}{\text{minute}} = 120 \times 1\text{metre} \times \frac{1}{1\text{minute}}$$

Even More Units

$$120\text{metres per minute} = \frac{120\text{metres}}{\text{minute}} = 120 \times 1\text{metre} \times \frac{1}{1\text{minute}}$$

$$= 120 \times 1\text{metre} \times \frac{1}{1\text{minute}} \times \frac{60\text{seconds}}{1\text{minute}}$$

- Is there a problem?

Even More Units

$$120\text{metres per minute} = \frac{120\text{metres}}{\text{minute}} = 120 \times 1\text{metre} \times \frac{1}{1\text{minute}}$$

$$= 120 \times 1\text{metre} \times \frac{1}{1\text{minute}} \times \frac{1\text{minute}}{60\text{seconds}}$$

$$= 120 \times 1\text{metre} \times \frac{1}{60\text{seconds}} = \frac{120\text{metres}}{60\text{seconds}}$$

$$= 2\frac{\text{metres}}{\text{seconds}} = 2\text{m/s}$$

Units Exercises

- Convert 1 km into cm (convert into metres first)
- Convert 1 km^2 into m^2
- Convert 2000 kg / metre into g / km

Goals for Learning

- How does the Sun move in the sky and what causes the seasons?
- What causes the phases of the Moon?
- What causes eclipses?
- What causes the night sky to change during the night and during the year?

Goals for Learning

- How does the Sun move in the sky and what causes the seasons?
  - The position of the Sun in the sky is affected by Earth’s rotation about its axis
  - The position of the Sun in the sky is also affected by the direction in which Earth’s axis is pointing

Goals for Learning

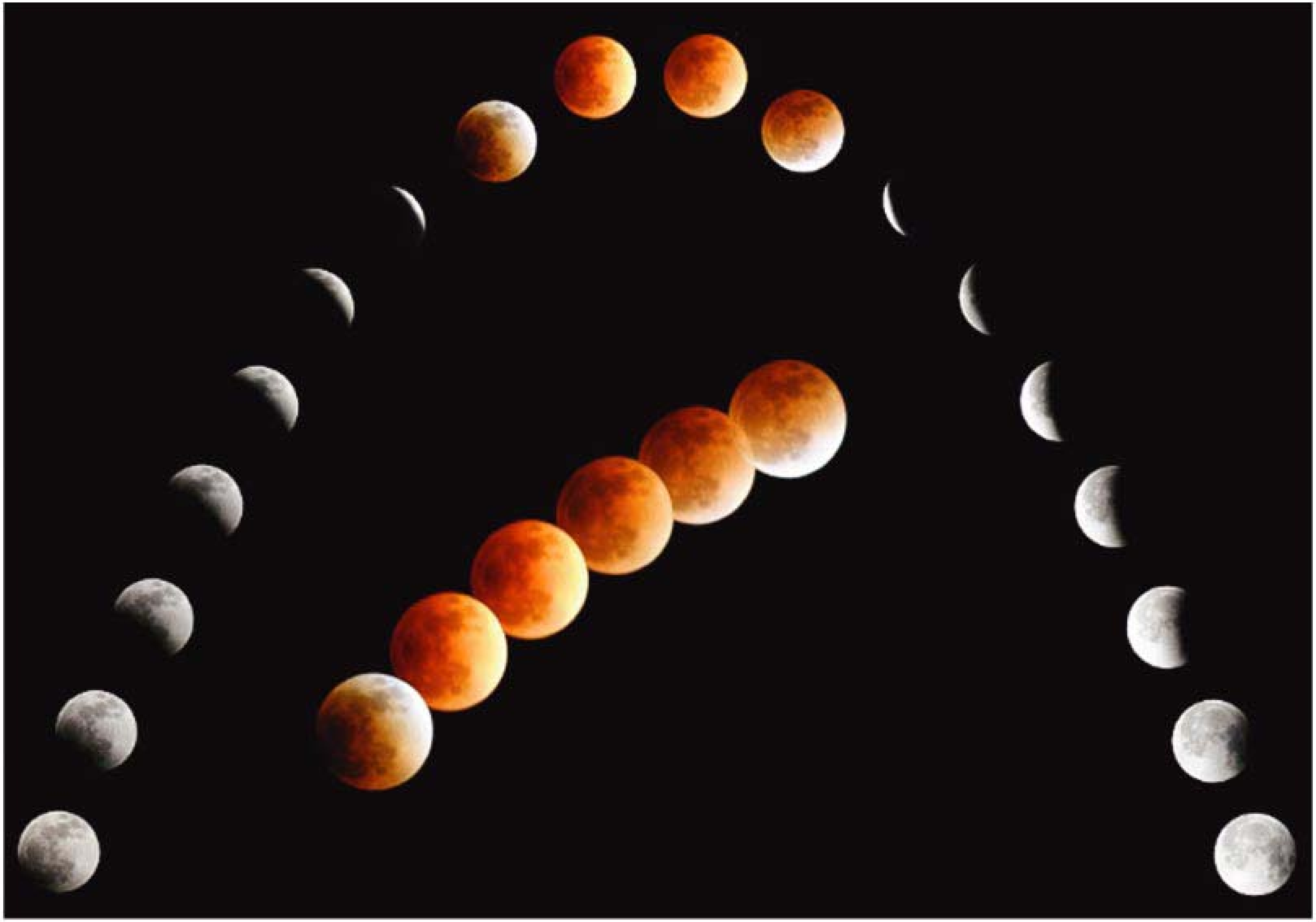
- What causes the phases of the Moon?
  - At any time, half of the Moon is illuminated by the Sun and half is not. The Moon's phases are caused by how much of the illuminated half and how much of the shadowed half that we see from Earth

Eclipses

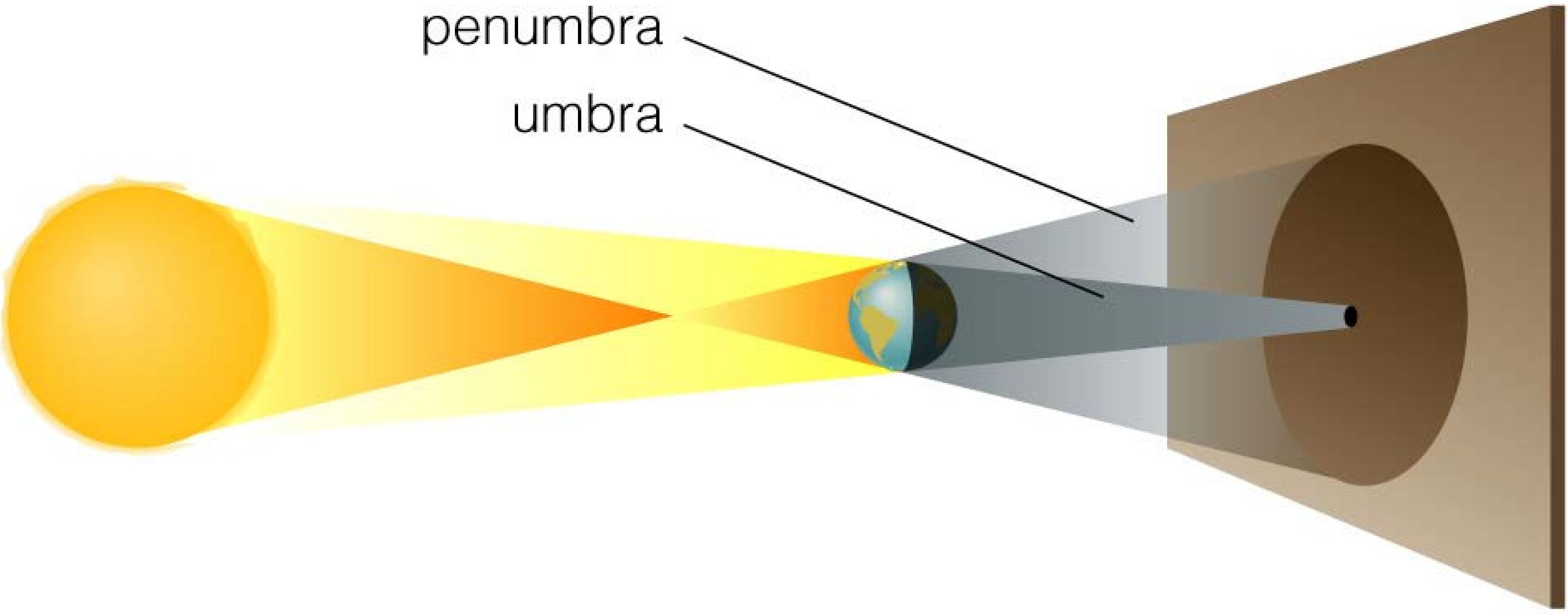
- Lunar Eclipse
  - The Moon goes dark
  - Only occur at Full Moon
  - Seen from half of Earth's surface
- Solar Eclipse
  - The Sun goes dark
  - Only occur at New Moon
  - Seen from small fraction of Earth's surface

STOP!

- Mechanical orrery and eclipses



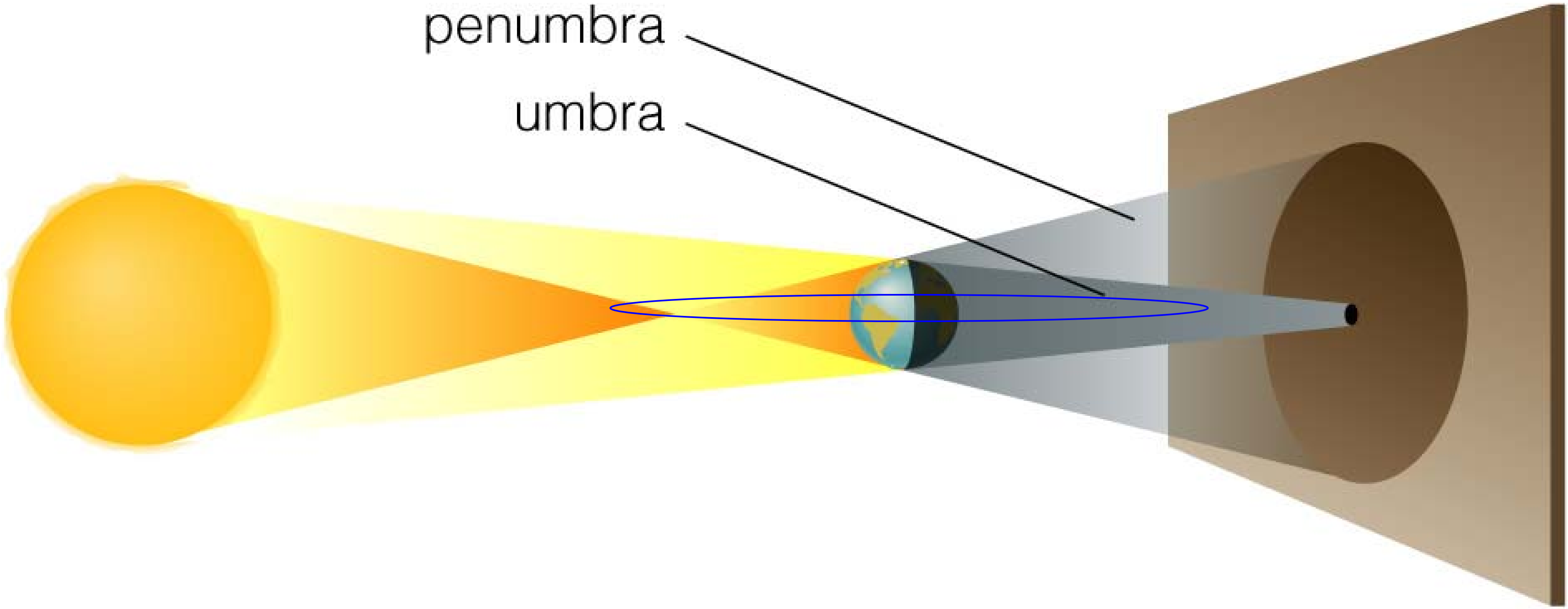
Up-and-down motion of Moon was introduced by artist, not real



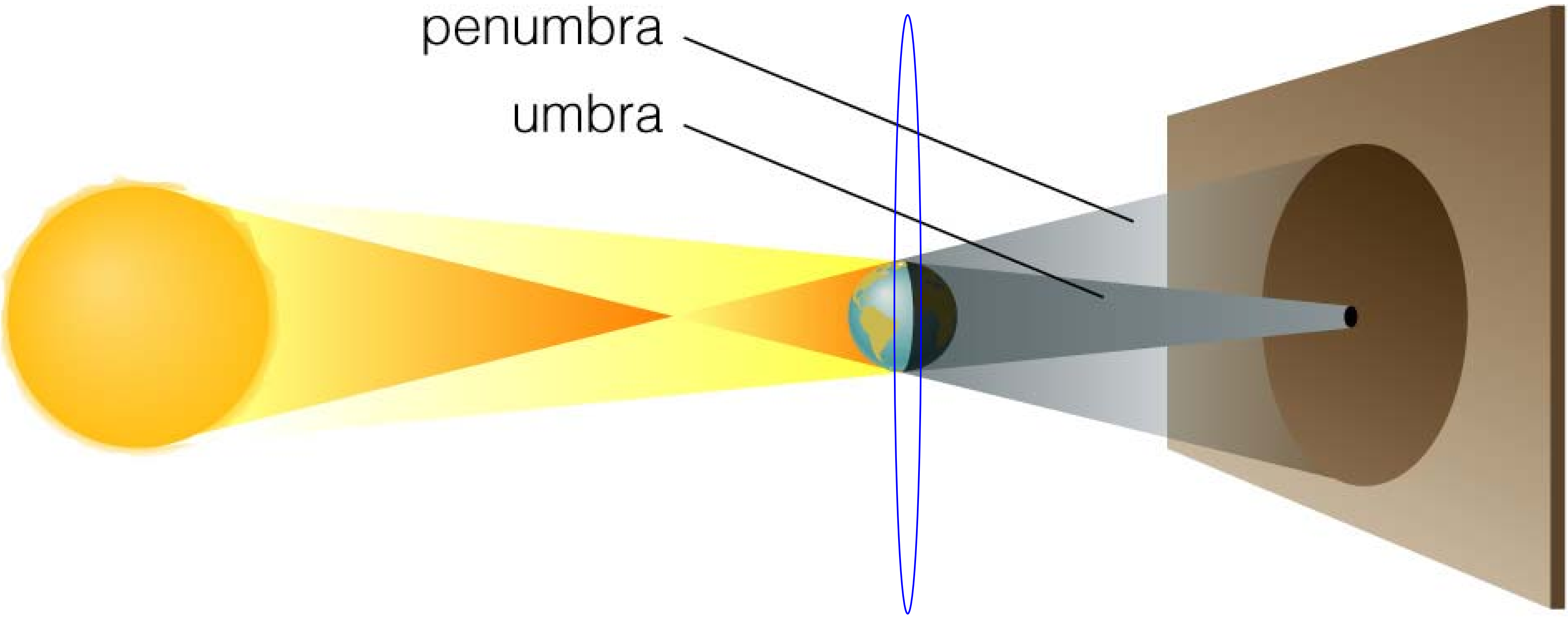
Where is the Moon's orbit?

Why don't we see lunar eclipses at every Full Moon?

- Show Interactive "Causes of Eclipses" (2^{nd})
- What lunar phase should we see a lunar eclipse at?
- What parts of Earth should see a lunar eclipse?



Moon orbits such that Moon always passes through the umbra at each Full Moon

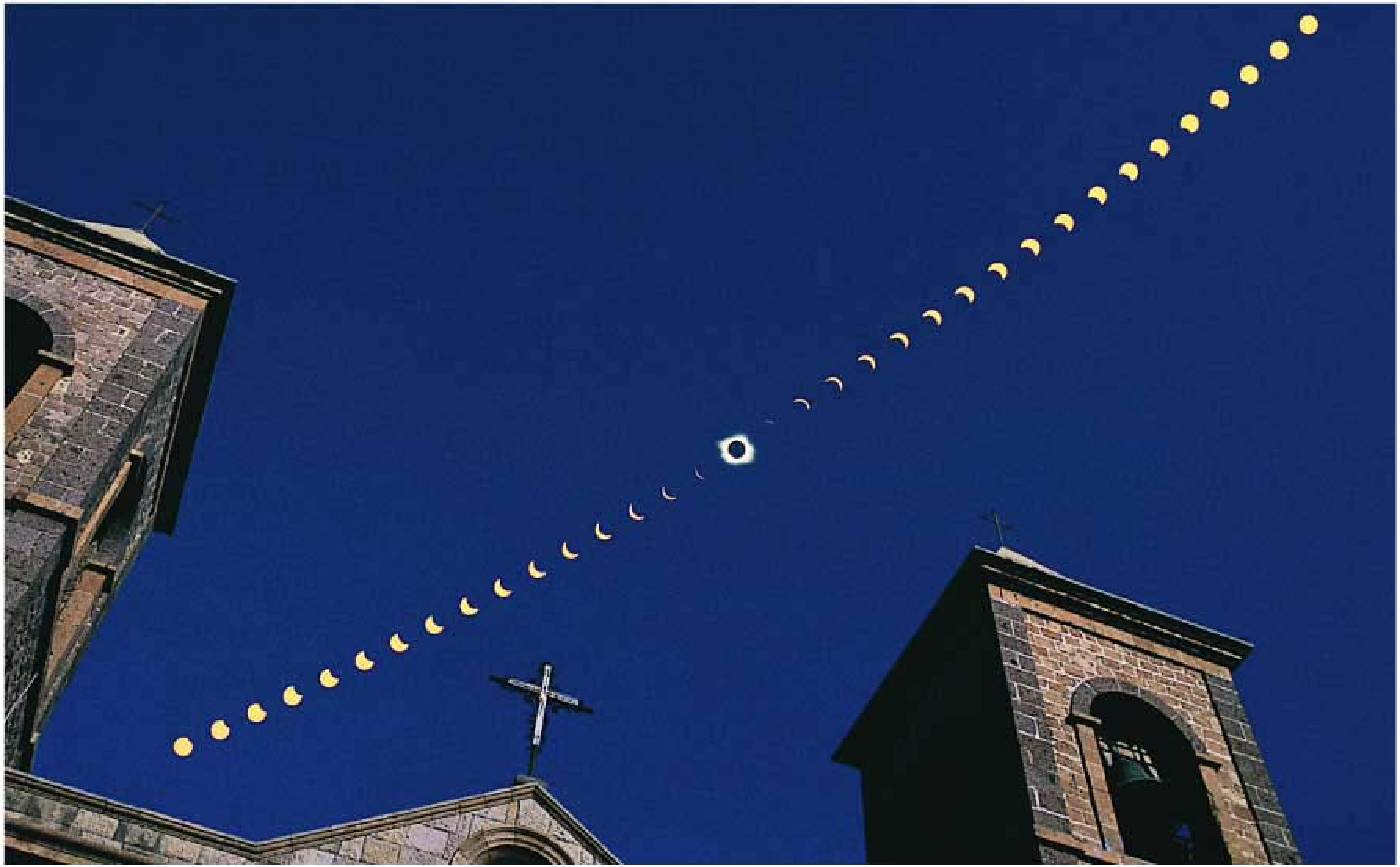


Moon orbits such that Moon never passes through the umbra

Why don’t we see a lunar eclipse at every Full Moon?

- Interactive Figure 2.24 showing how rare eclipses are

- Pages in textbooks are two-dimensional, so they often show the orbits of Earth and Moon as flat circles in the flat page
- The solar system is NOT two-dimensional



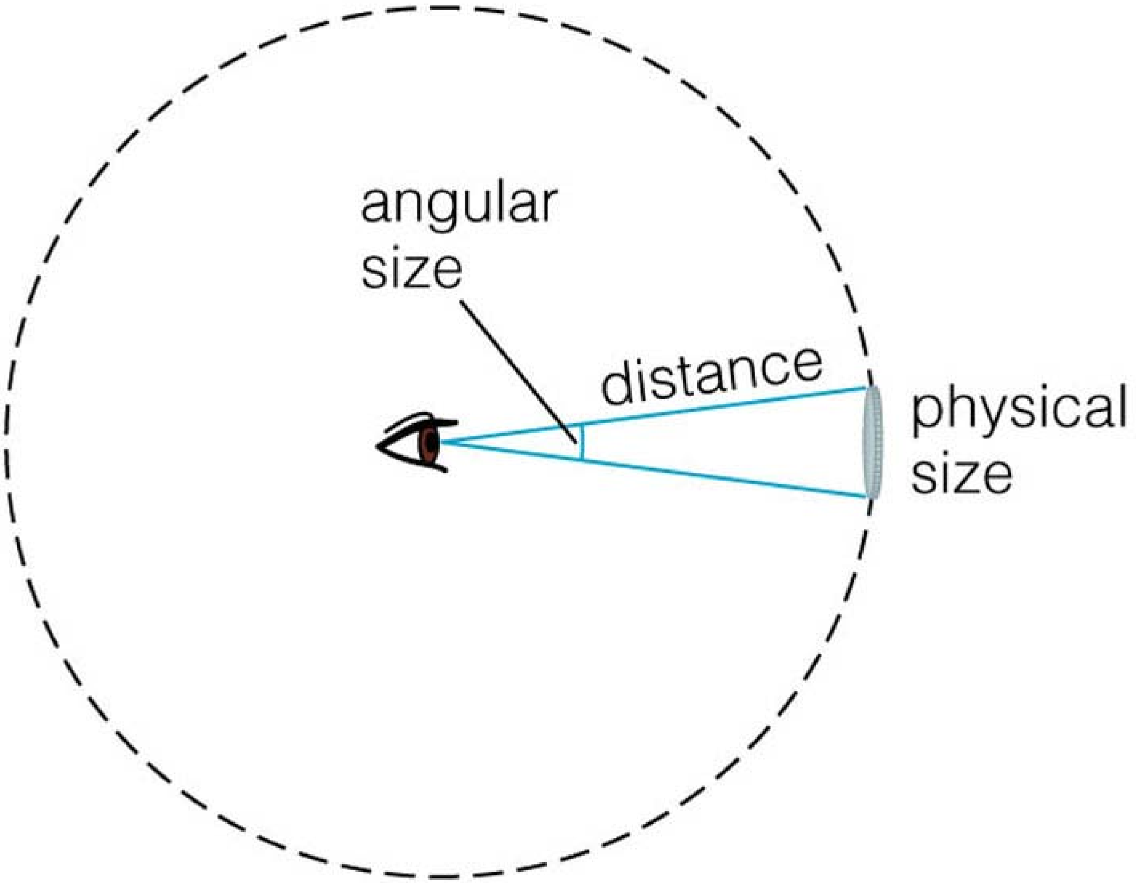
Interactive Figure 2.28

- Interactive Figure 2.24

Are the Sun and Moon the same size?

- The Moon is just big enough to completely cover the Sun during a total solar eclipse

- Are the Sun and Moon the same size?
- Are they the same distance from Earth?
- Which is bigger?
- Which is further away from Earth



Angular size / 360° = Physical size / (2π x distance)

Angular size of object is same fraction of 360° as its physical size is of the circle's circumference

Circumference = 2 x pi x radius

Measuring Angles

- 360 degrees in a circle
- 60 arcminutes in 1 degree
- 60 arcseconds in 1 arcminute

- The angular sizes of other planets seen from Earth are much less than one degree, so astronomers often use arcminutes and arcseconds instead

Cosmic Coincidence!

- The Sun's diameter is 1.4 million km (1.4×10^6 km)
- The Sun is 150 million km from Earth (1.5×10^8 km)
  - Angular size is 0.5 degrees

- The Moon's diameter is 3500 km (3.5×10^3 km)
- The Moon is 380 thousand km (3.8×10^5 km)
  - Angular size is also 0.5 degrees!

What if …

- What would a solar eclipse look like if the Sun was twice as big?
- Would lunar eclipses be more common or less common if the Moon was twice as far away from the Earth?

Constellations

- Are the shapes of the constellations the same today as they were 20 years ago?
- Does the night sky look the same at 9pm and at 3am?
- Does the midnight sky in Boston look the same in December as it does in June?
- Does the midnight sky look the same from all places on Earth?

Constellations

- Are the shapes of the constellations the same today as they were 20 years ago?
- Yes. The arrangement of stars in the sky takes thousands of years to change even slightly
- STOP! Show celestial sphere

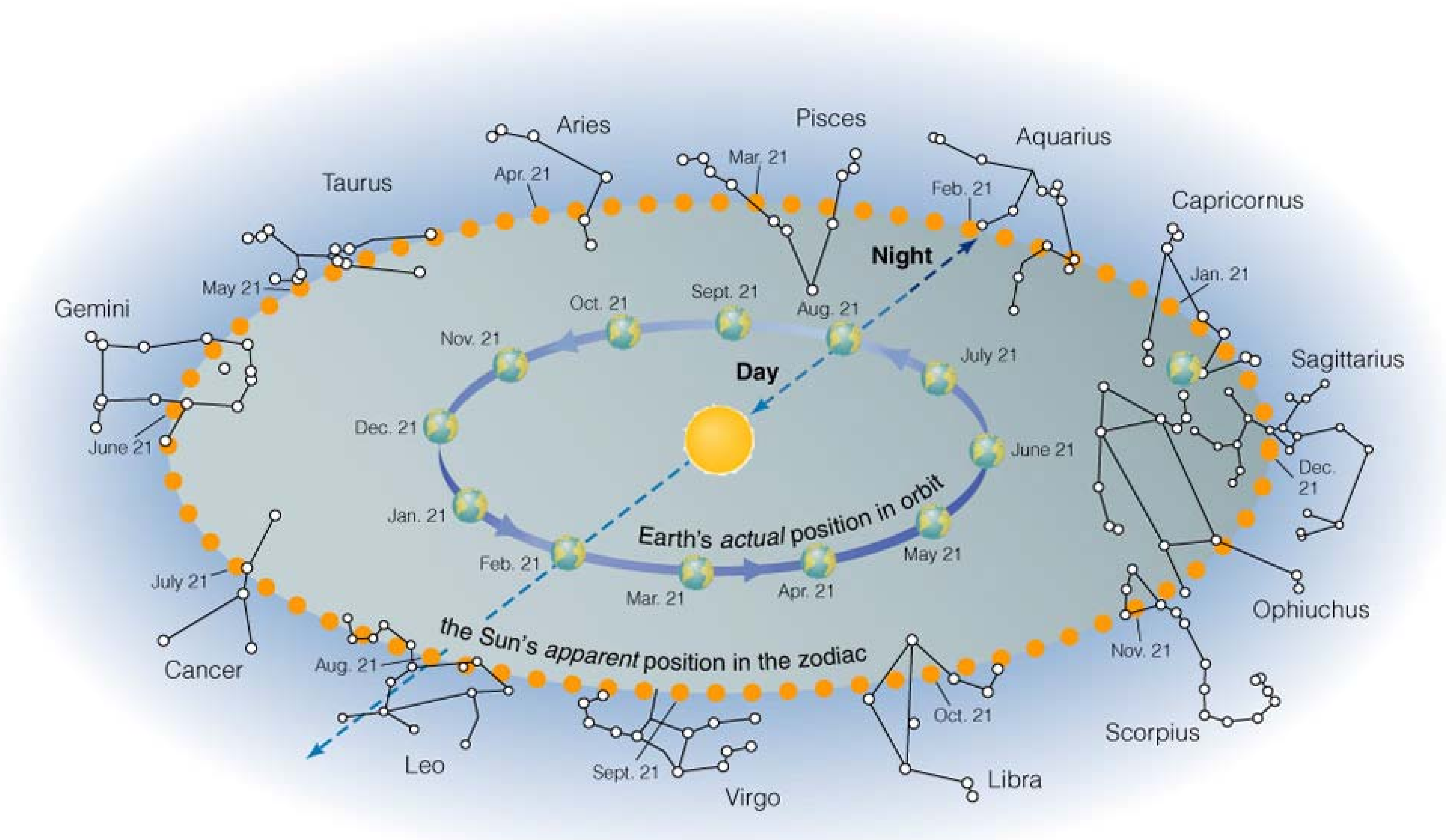
Constellations

- Does the night sky look the same at 9pm and at 3am?

- No. Constellations rise in the east, rotate across the sky, and set in the west. This is due to the Earth's rotation about its axis.

Constellations

- Does the midnight sky in Boston look the same in December as it does in June?
- No.

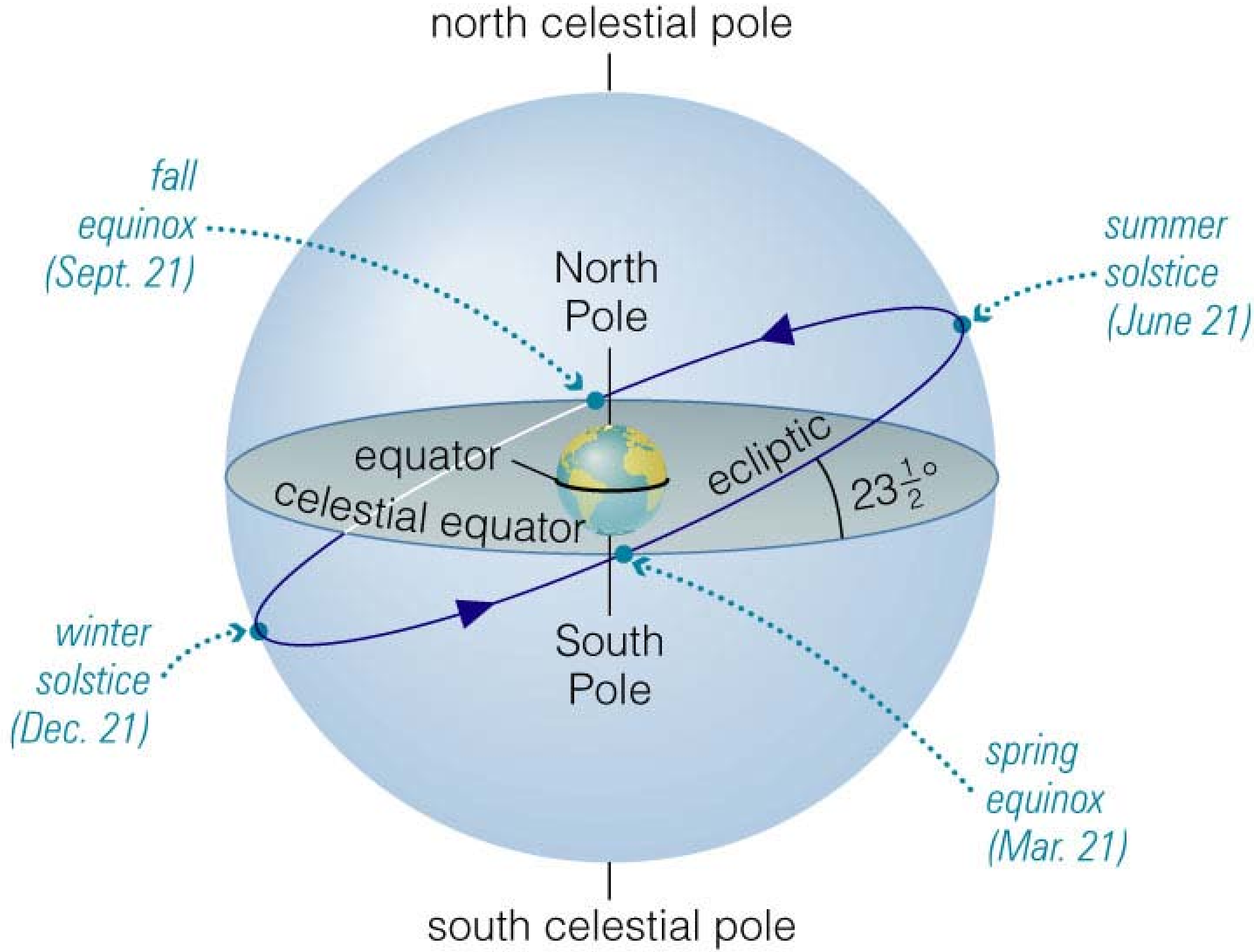


Paths of the planets, Sun along the ecliptic, on VoyagerSkyGazer

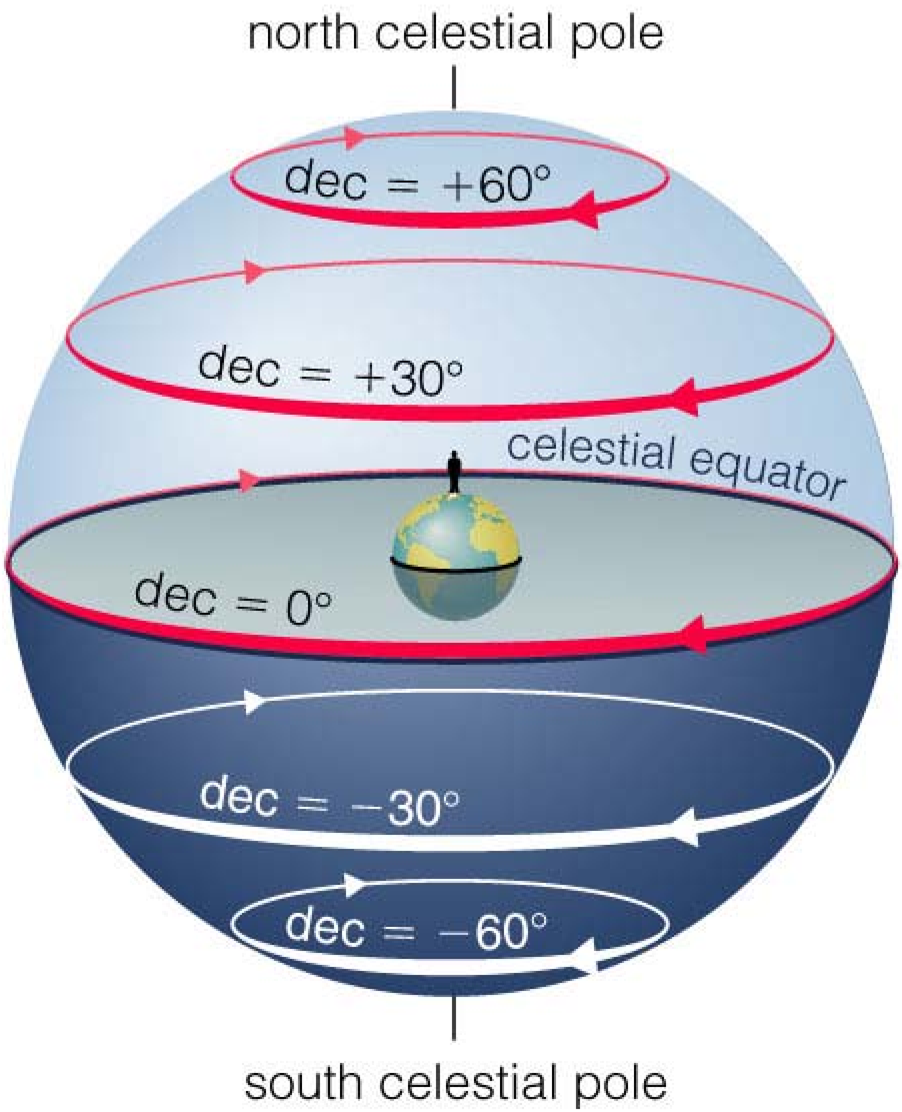
Constellations

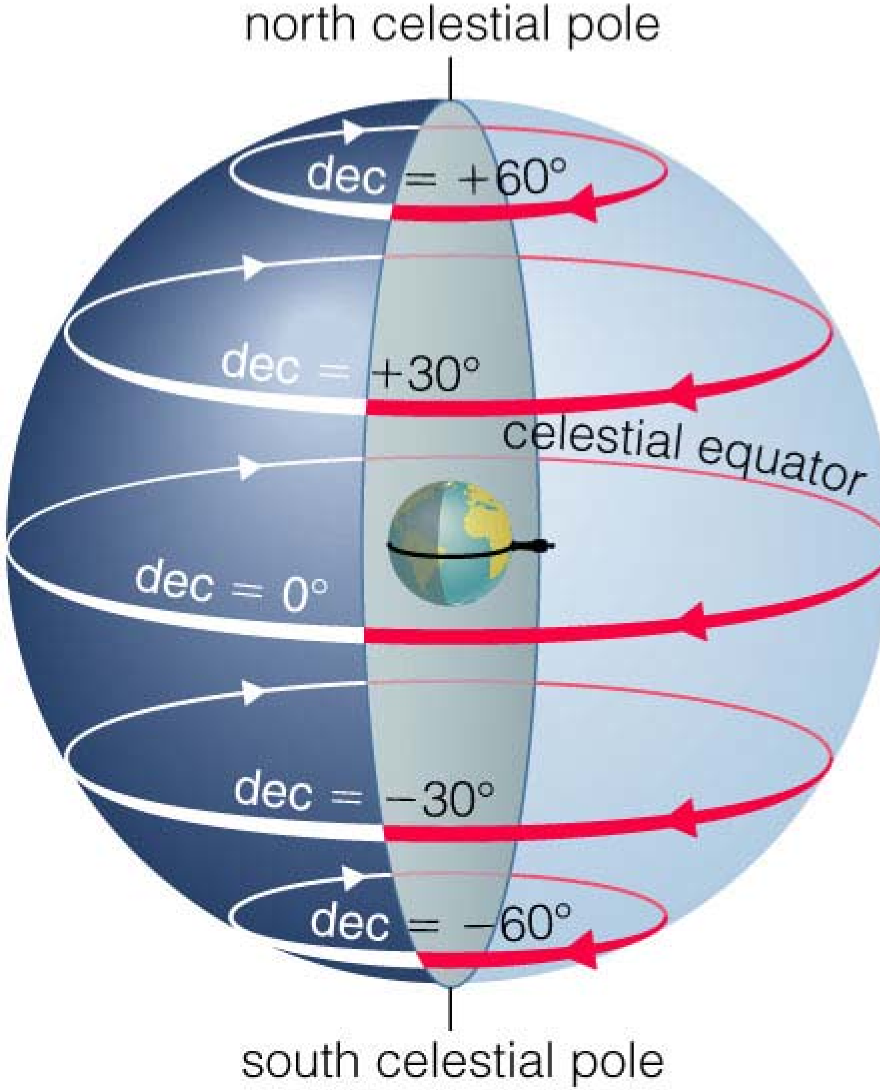
- Does the midnight sky look the same from all places on Earth?

- No. You can’t see the Big Dipper from Australia



Note – explain this geometry carefully, it's confusing


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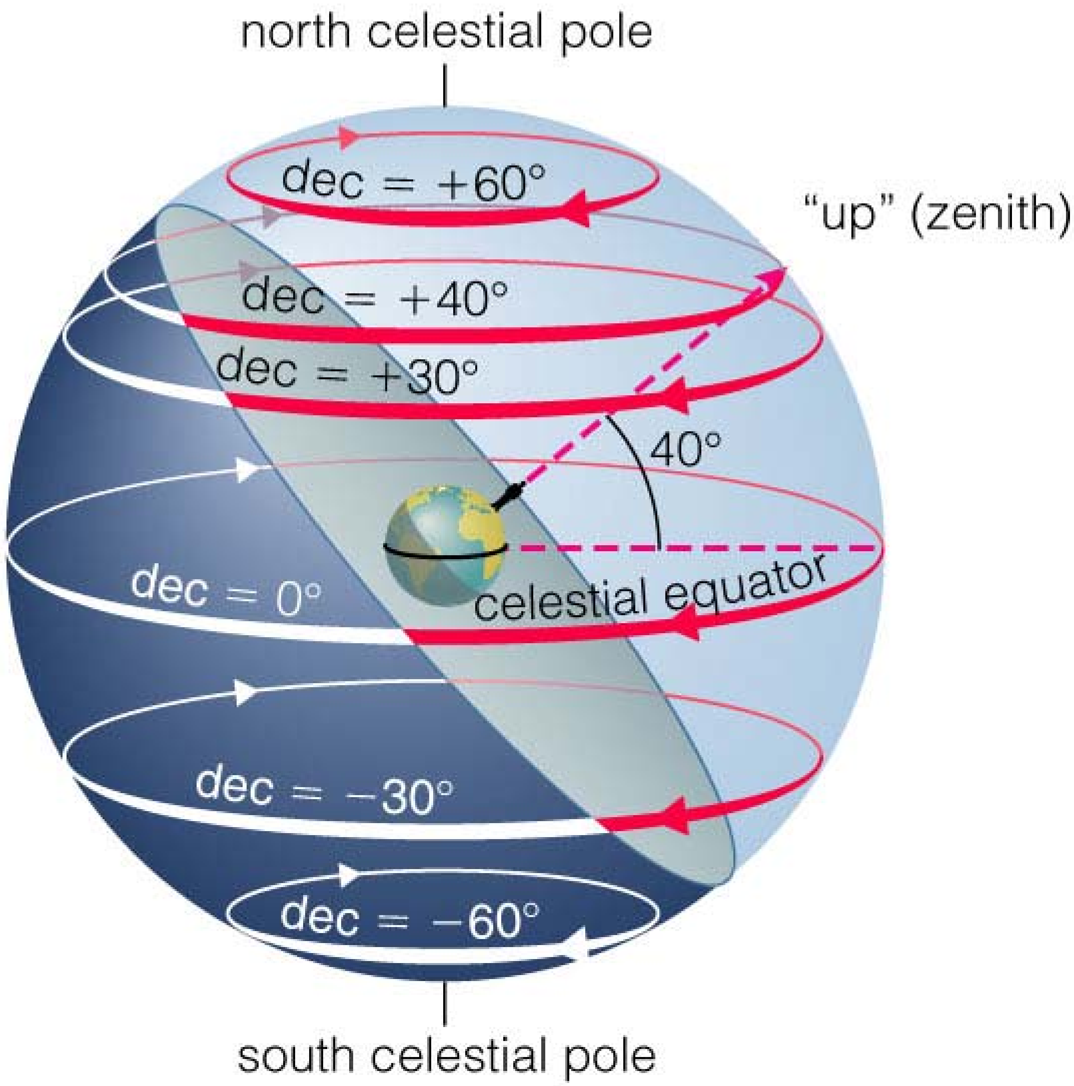
north celestial pole
dec = +60°
"up" (zenith)
dec = +40°
dec = +30°
40°
dec = 0°
celestial equator
dec = −30°
dec = −60°
south celestial pole

- Stars above the North Pole can never be seen from the Southern Hemisphere
- Stars above the South Pole can never be seen from the Northern Hemisphere

- Sunset in Winnipeg on VoyagerSkyGazer

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  - At any time, half of the Moon is illuminated by the Sun and half is not. The Moon’s phases are caused by how much of the illuminated half and how much of the shadowed half that we see from Earth

Goals for Learning

- What causes eclipses?
  - A solar eclipse occurs when the Moon is between Earth and the Sun (New Moon), blocking the Sun's light from reaching parts of Earth
  - A lunar eclipse occurs when Earth is between the Sun and the Moon (Full Moon), blocking the Sun's light from reaching the Moon and preventing the Moon from reflecting any sunlight back to Earth

Goals for Learning

- What causes the night sky to change during the night and during the year?
  - The night sky changes during each night due to the Earth's rotation
  - The night sky changes over the course of a year as Earth orbits around the Sun and Earth's nightside faces different regions of the celestial sphere