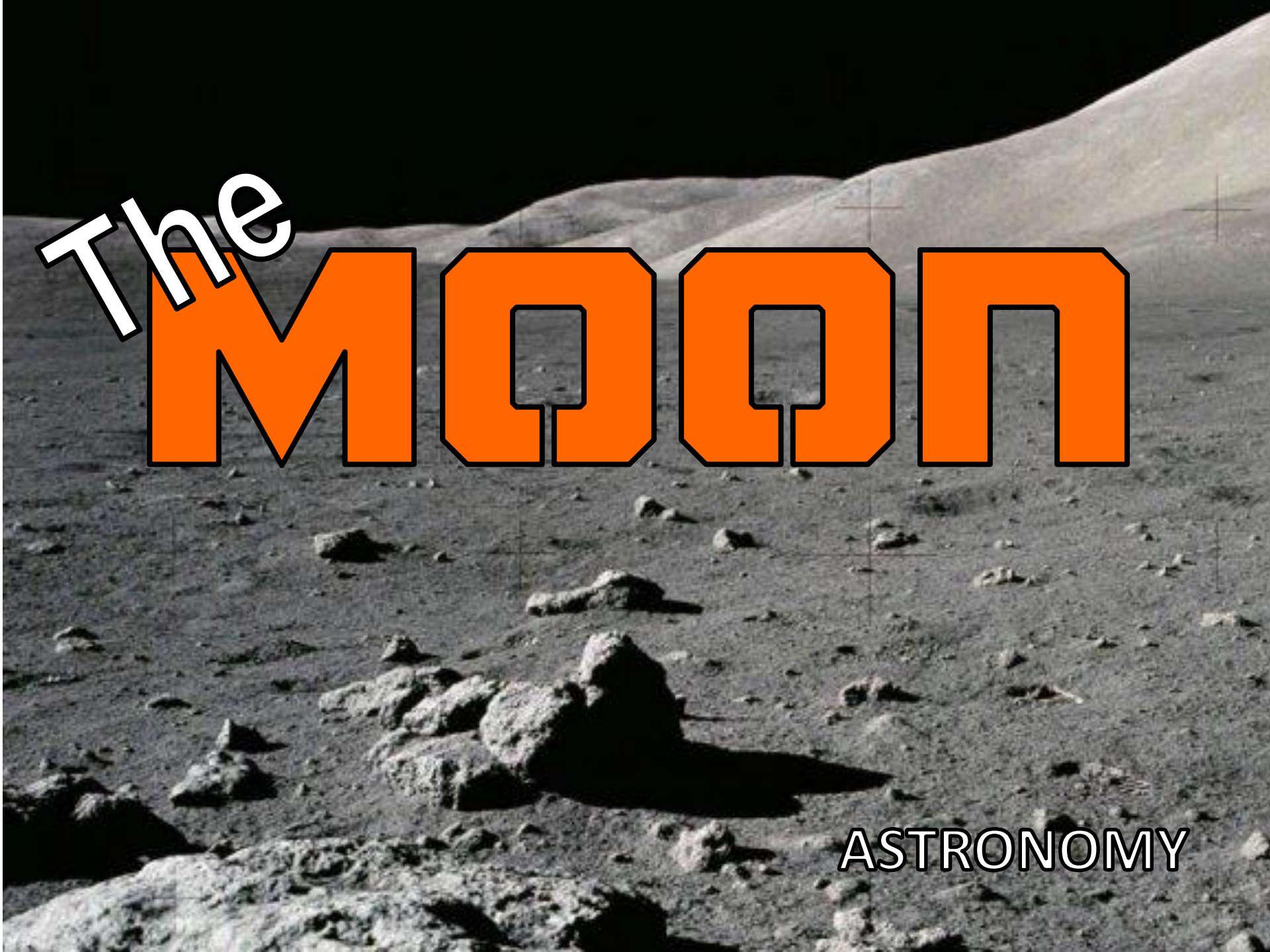

The
MOON
ASTRONOMY

# The Moon!

**Sections:**

1. Introduction
2. Surface and Atmosphere
3. Orbit and Lunar Phases
4. Lunar and Solar Eclipses
5. Tides

# MOON'S SURFACE & ATMOSPHERE

# Introduction

**Fast Facts…**

- Nearest neighbor
- Our largest natural satellite
- 1/4$^{th}$ the diameter of Earth
- Barren ball of rock
- No air, water, or life
- Hasn't always been inactive
- Heavily hit in its early days by massive rock fragments – creating most of its current landscape

# Surface of the Moon

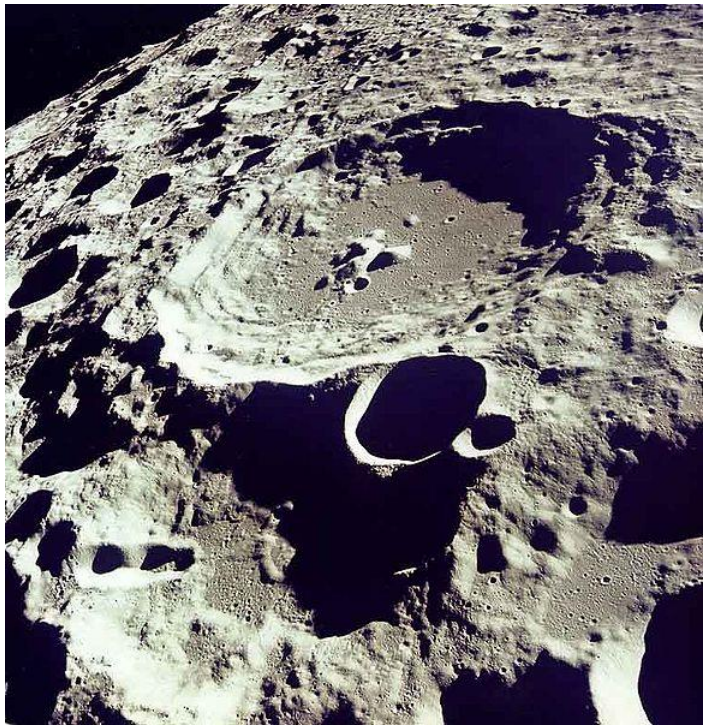
## Surface Features

- Lots of gray colors
- Some areas are darker than others
  - Some see a face known as the “Man on the Moon”
- The darker areas are much different in composition than the lighter ones
  - Darker = smoother
  - Lighter = cratered

# Surface of the Moon

## Surface Features

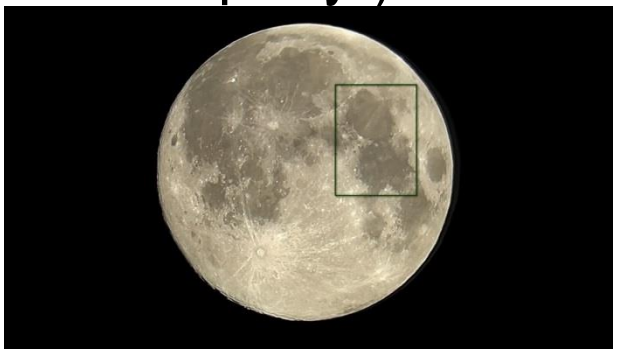
- Craters – large circular pits
  - These were formed billions of years ago
  - Preserved due to the lack of atmosphere, weather, and erosion



# Surface of the Moon

## Surface Features

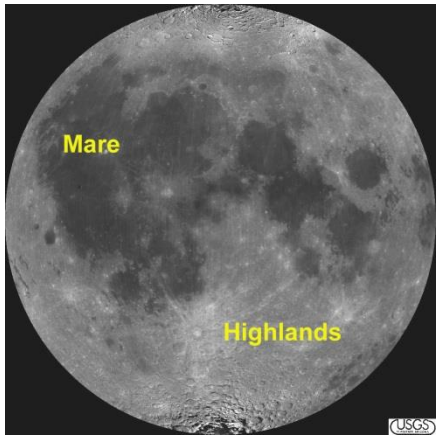
- Maria (MAR-ee-ah) – large, smooth, dark areas on the Moon's surface
  - From the Latin word "seas"
    - Contain no water though
    - Ancient astronomers thought they looked like dark oceans
  - The *Mare Tranquillitatis* ("Sea of Tranquility") is where the first Moon landing occurred



# Surface of the Moon

## Surface Features

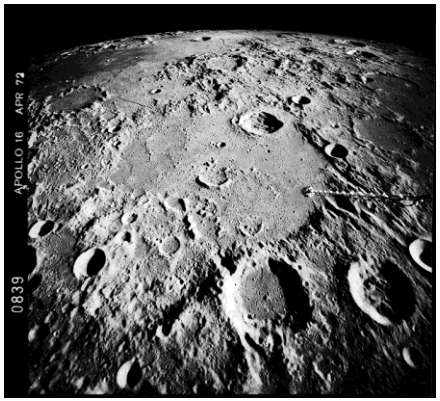
- Highlands – bright areas that surround the maria
  - Brighter because it contains different rock material than the maria
  - Less dense and much older
    - Maria = basalt
      - dark, congealed lava rich in Fe, Mg, Ti, silicates
      - similar to the ocean floor here on Earth
    - Highlands = anorthosite
      - Rock rich in Ca, Al silicates



# Surface of the Moon

## Surface Features

- Scientists have been able to clarify these rock findings thanks to the samples collected during the Apollo missions
- The highlands are heavily cratered to the point where some overlap
- Many range from less than a cm in diameter to over 200 km across



# Surface of the Moon

## Surface Features

- Very few craters are volcanic originally
- Some have rounded rims (older) while others have sharper ones (more recent)
- “cratering” has gone on here for a very long time
  - Getting hit by rock debris

# Surface of the Moon

## Surface Features

- Rays – long, light streaks of pulverized rock that reach out from a crater
- Best example: *Tycho*
  - Rays can be seen during a full moon

# Surface of the Moon

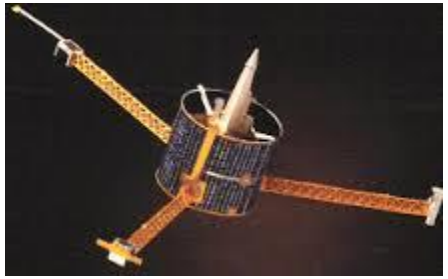
## Origin of the Lunar Surface

- Impaction
- The size of the craters depend on the mass and velocity of the impacting object
  - As the vaporized rock expands from the point of impact, it forces surrounding rock outward, piling it into a raised circular rim
  - Sometimes they can hit so hard that they create a peak of debris in the center of the crater
    - Ex: Tycho

# Surface of the Moon

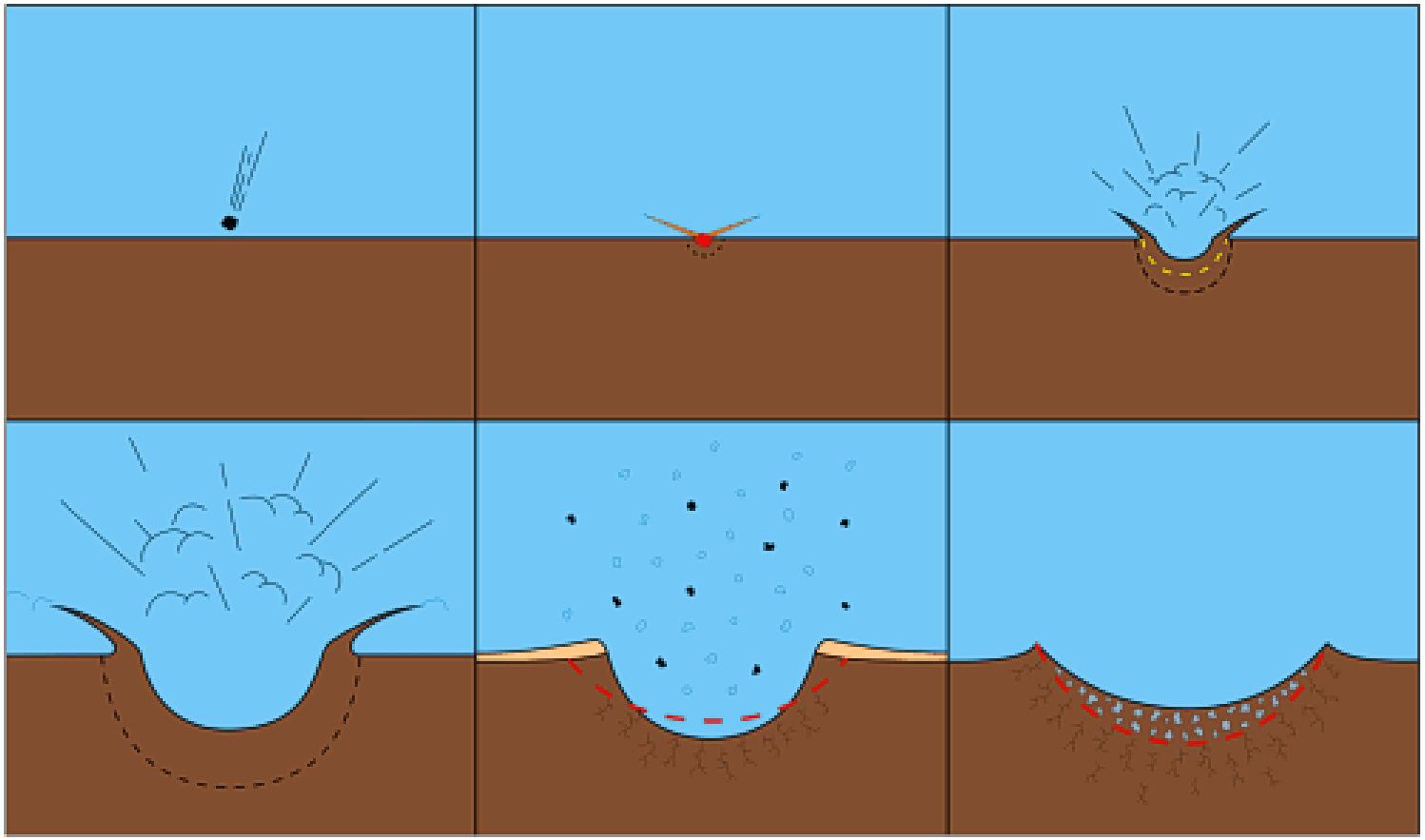
## Origin of the Lunar Surface

- The Moon was molten when it was first forming
  - Full of heat and melted rock (lava)
- It quickly cooled with all of the impaction and became barren early in its lifetime
- Able to detect this history thanks to gamma rays from the *Lunar Prospector* satellite
  - Determined that radioactive heat was present after a large body strike, melting the rock and allowing magma to rise to the surface
  - This created the maria



# Surface of the Moon

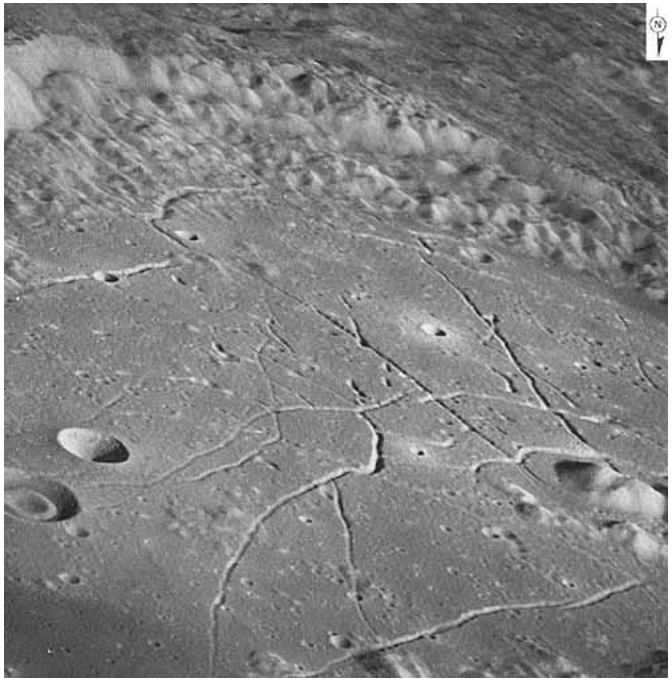
## Origin of the Lunar Surface



# Surface of the Moon

## Origin of the Lunar Surface

- Rilles – lunar canyons
  - Some look like river valleys
  - Carved by ancient lava flows and just simple cracking of the surface



# Surface of the Moon

## Origin of the Lunar Surface

- Regolith – rock chunks and fine powder that covers the moon
  - Means “blanket of rock”
  - Comes from the rock settling and lack of plate tectonics to recycle it
  - Several meters deep
  - Common on both maria and highlands, just specific to the rock type in those areas

# Absence of Moon Atmosphere

## Lunar Atmosphere

- Only tiny amounts of gas have been detected on the Moon's surface
  - Mostly helium as a by-product of radioactive decay
  - Some hydrogen near the Moon's poles
- Density is one-quadrillionth (1/1e-15) of Earth's atmosphere

# Absence of Moon Atmosphere

## Lunar Atmosphere

- Gone for 2 reasons:
  1. no internal activity means no heat being produced
  2. low mass = low gravity and can't hold heat
- Temperatures will soar during the day and crash at night

# Moon's Orbit & Lunar Phases

# Moon's Orbit

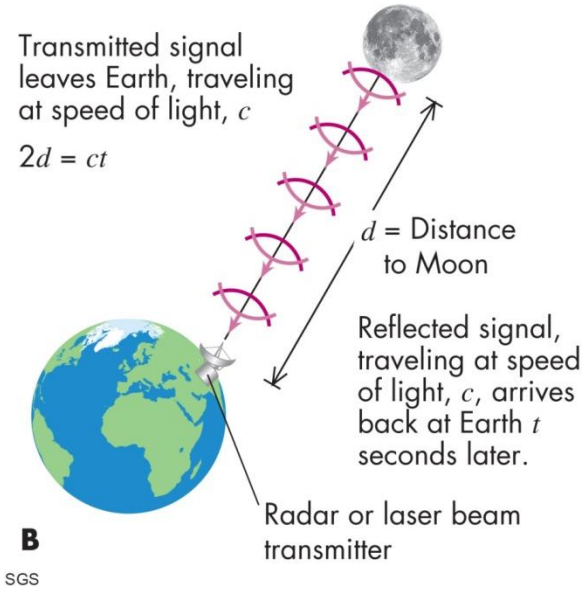
## Introduction

- The Moon can be measured using *angular size*
  - the size of an object in the sky by angle measurement
- The Moon can vary about 14% in angular size because of its elliptical orbit (oval)
- Averages about 380,000 km in distance from Earth
  - About 250,000 mi
  - Actually varies from 360,000 to 405,000 km during its orbital period

# Moon's Orbit

## Moon's Orbit

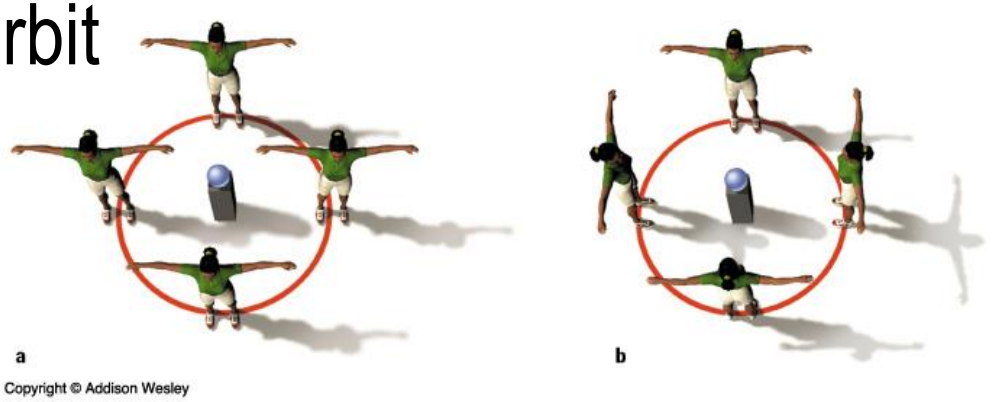
- The distance to the Moon is measured very precisely using a radar pulse or a laser beam and special reflectors
  - They use the time it takes to travel and the speed of light to figure this out (2d = ct)
- Accurate down to the cm



# Moon's Orbit

## Moon's Rotation

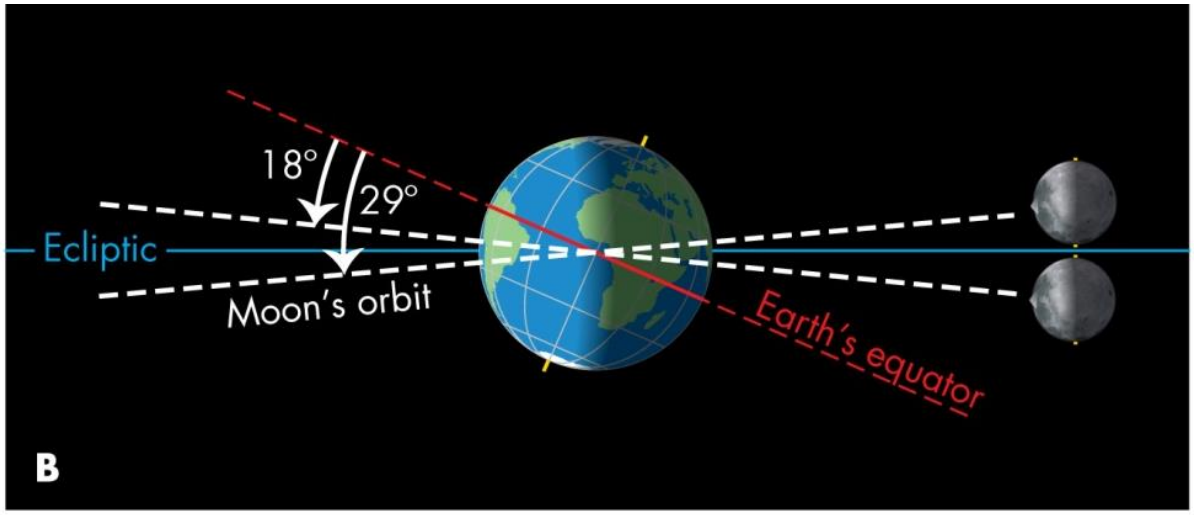
- As it orbits, the Moon keeps the same side facing Earth
- It has to slowly rotate in order for the entire planet to see the same face
- Synchronous Rotation – when an object does turn on its axis once for every orbital period
  - 1 rotation = 1 full orbit



# Moon's Orbit

## Odd Features

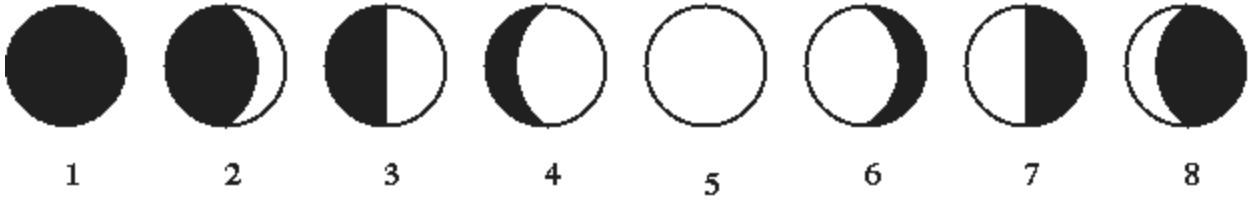
- Unlike other Moons, ours is tilted in respect to the Earth's equator
  - 5 degree tilt
- It gradually wobbles over an 18 year time frame
  - This results in a tilt anywhere from 18 to 29 degrees



# Moon's Phases

## Phase Period

- Moon rises in the east and sets in the west
- The Moon's shape will change throughout a month's time due to its orbit around Earth
- Synodic Period – the cycle of lunar phases from new Moon to full Moon and back to new Moon
  - takes 29.5 days
  - Fun Fact! This was the basis for the month time frame!



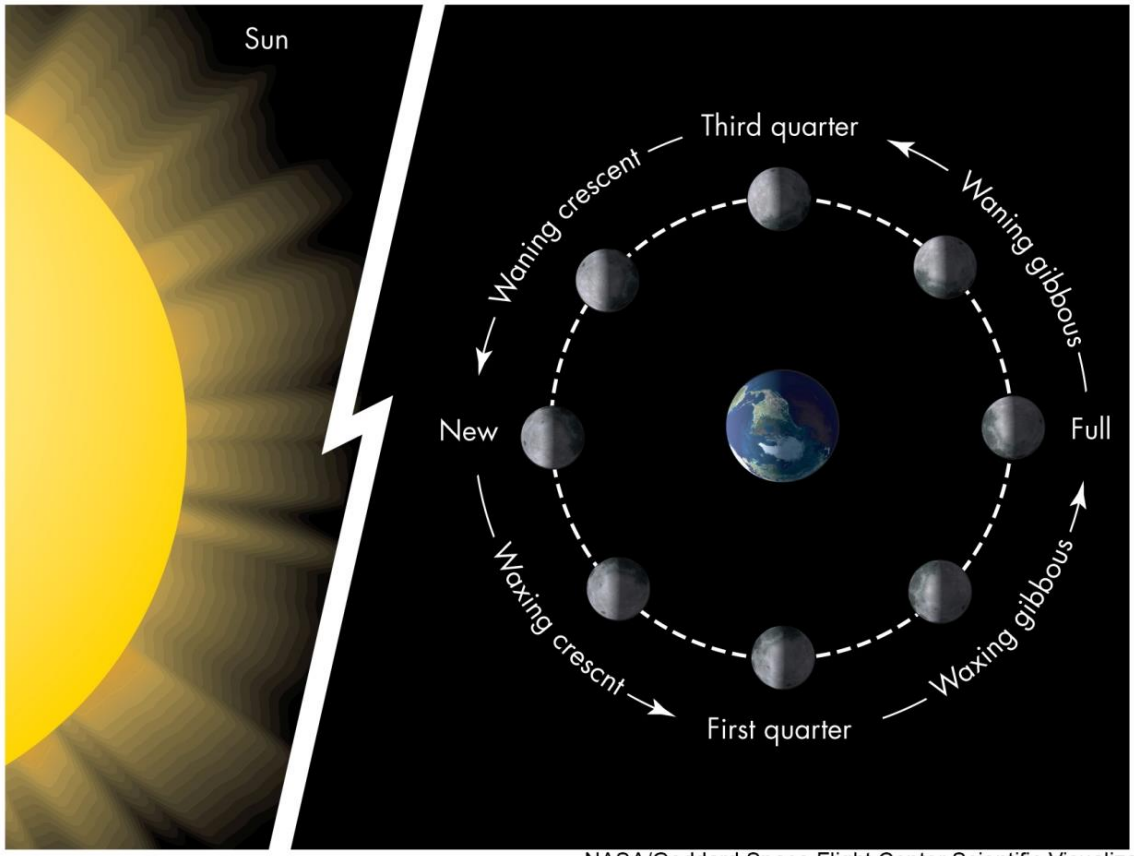
# Moon's Phases

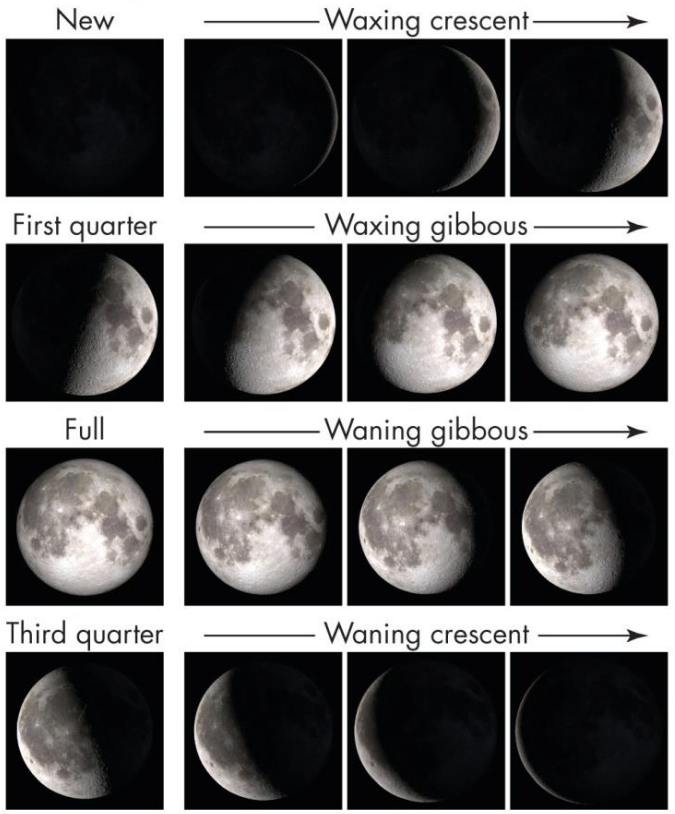
## Phase Period

- The visual moon changes due to changes in the way sunlight angles off of it
  - Waxing – progressing towards a full moon
    - What we see gets larger
  - Waning – progressing towards a new moon
    - What we see gets smaller
  - Gibbous – more than ½ of the moon is illuminated
  - Crescent – less than ½ of the moon is illuminated

# Moon's Phases

## Phase Period




Appearance of the Moon from Earth

NASA/Goddard Space Flight Center Scientific Visualization Studio

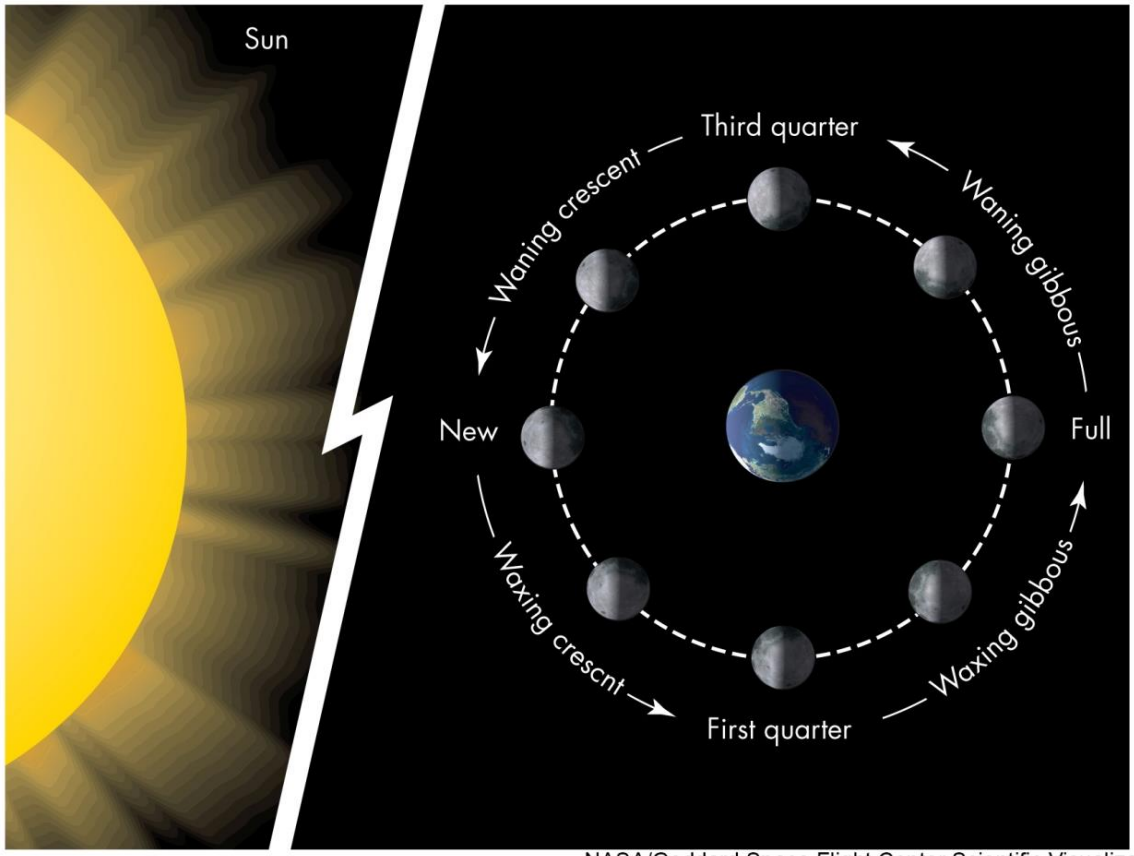
# Moon's Phases

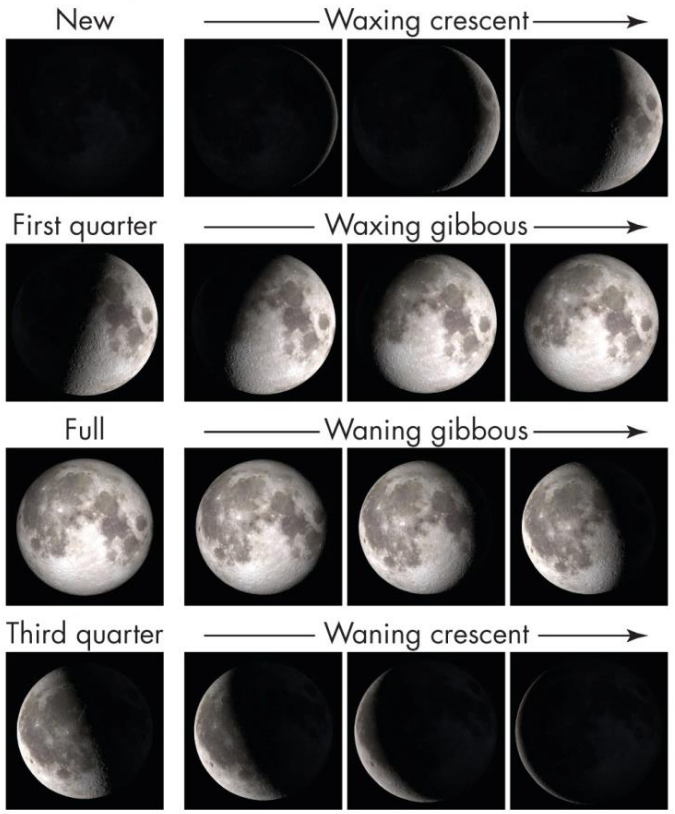
## Phase Period

- Fact: half of the Moon is always lit by the Sun
- What we see depends on the Moon's positioning throughout its orbit around Earth
- Key points in orbit:
  1. Full Moon: Moon is directly behind Earth
  2. New Moon: Moon is directly in front of Earth
  3. $1^{st}/3^{rd}$ Quarter Moon: the angle from the Sun to Earth to the Moon is 90 degrees

# Moon's Phases

## Phase Period




Appearance of the Moon from Earth

NASA/Goddard Space Flight Center Scientific Visualization Studio

# Moon's Phases

## Phase Period

- The Moon's motion around Earth causes it to shift eastward against the stars
- This means the Moon will rise about 50 minutes later each day/night
  - Ex: day 1 = 8:00 PM rise, day 2 = 8:50 PM rise, etc.
- It is NOT always directly opposite of the Sun!
- The Moon and Sun will gradually shift from rising and setting at the same time to rising and setting at opposite times

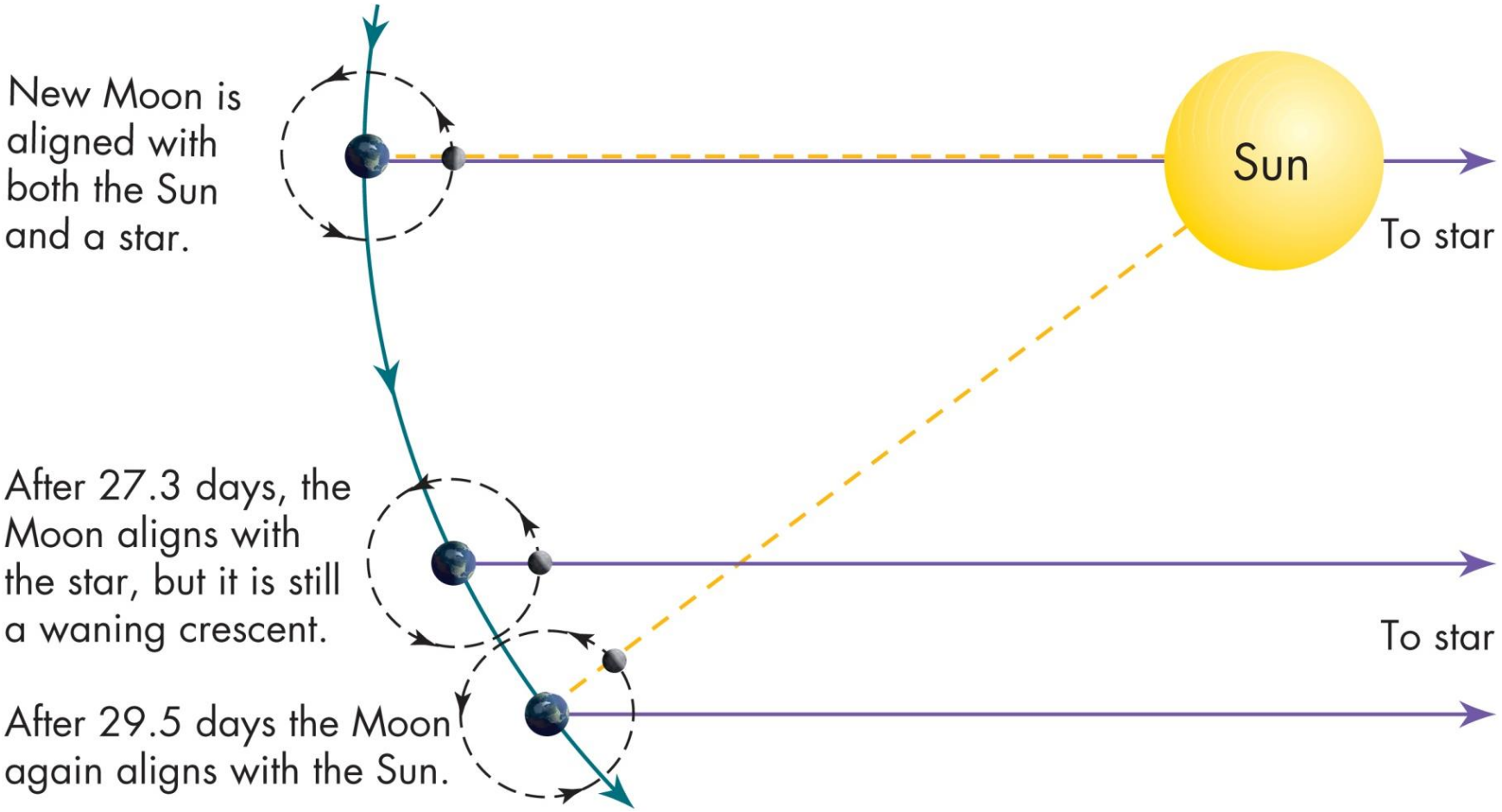
# Moon's Phases

## Phase Period

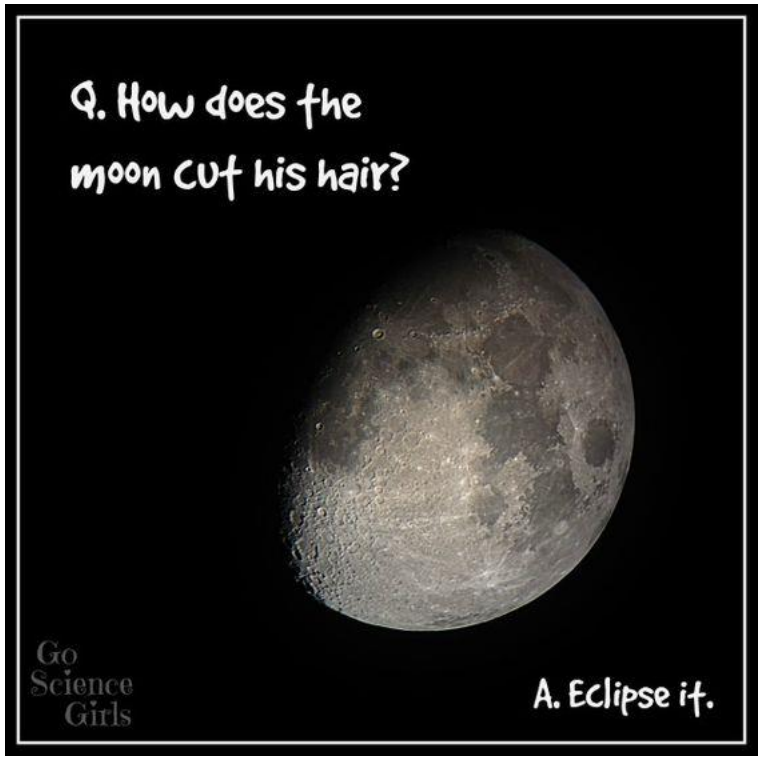
- The time it takes for the Moon to orbit Earth is different than the time it takes to get through all of the lunar phases
  - Synodic period = 29.5 days
  - Sidreal period = 27.3 days
    - The period of time for the Moon to revolve around Earth

# Moon's Phases

## Phase Period



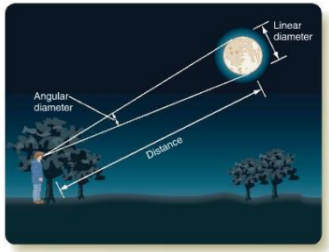
# Solar & Lunar Eclipses



# Eclipses

## Angular Diameter and Distance

- The Moon has about the same angular diameter as the Sun
  - Even though they are different sizes and distances away
- Linear Diameter – the distance between an object's opposite sides
  - The further away an object is, the smaller the angular diameter
- The Moon's linear diameter=3470 km (2160 mi)



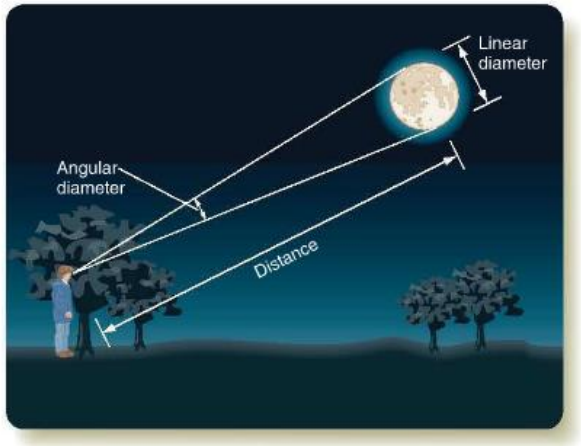
# Eclipses

## Angular Diameter and Distance

- Small-Angle Formula – how to find the angular diameter of an object

$$\frac{\text{angular diameter (arc seconds)}}{2.06 \times 10^5} = \frac{\text{linear diameter}}{\text{distance}}$$

*The units for distance and linear diameter must be the same!



# Eclipses

## Angular Diameter and Distance

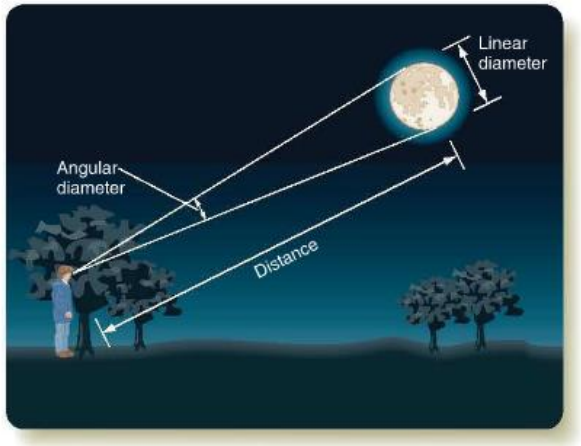
- Ex: Moon:

$$\frac{\text{angular diameter}}{2.06 \times 10^5} = \frac{3470 \text{ km}}{384{,}000 \text{ km}}$$

= 1862 arc seconds

= 31 arc minutes

= 0.5˚



# Eclipses

## Angular Diameter and Distance

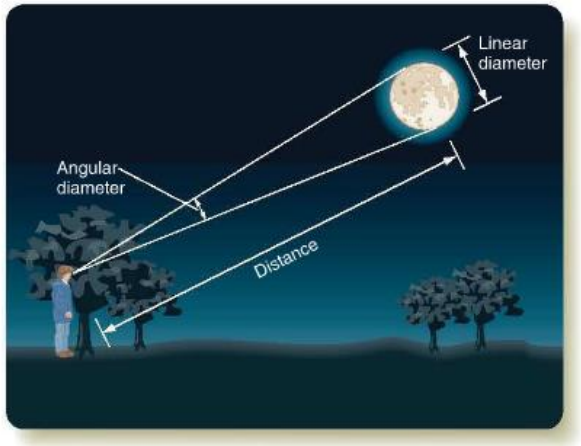
- Ex: Sun:

$$\frac{\text{angular diameter}}{2.06 \times 10^{5}} = \frac{1.39 \times 10^{6}\ \text{km}}{1.5 \times 10^{8}\ \text{km}}$$

= 1909 arc seconds

= 32 arc minutes

= 0.5˚ ← same as the Moon



# Eclipses

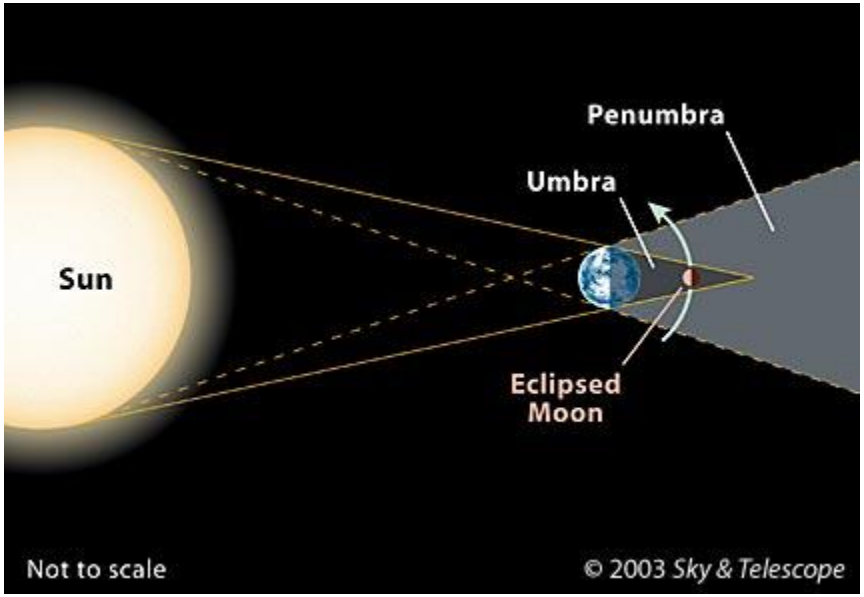
## Angular Diameter and Distance

- Apogee – Moon's farthest point from Earth
  - Angular diameter = 5.5% smaller
- Perigee – Moon's closest point from Earth
  - Angular diameter = 5.5% larger

# Eclipses

## Earth's Shadow

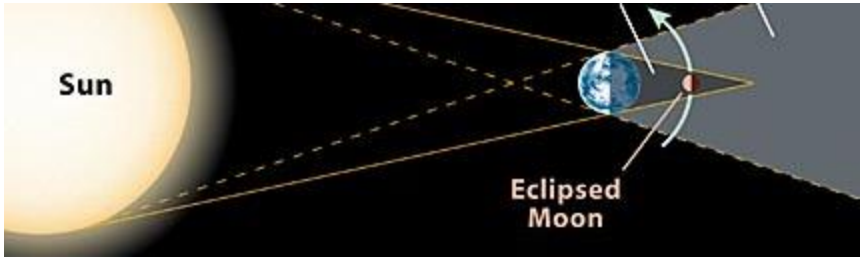
- The moon's orbit is only a few degrees off of Earth's orbit around the Sun
  - The Earth's shadow points directly away from the Sun at the same level of Earth's orbit



# Eclipses

## Earth's Shadow

- Lunar Eclipse – can occur at a full Moon if the Moon's path caries it through the shadow of Earth
  - sunlight is cut off, and the Moon becomes dim temporarily

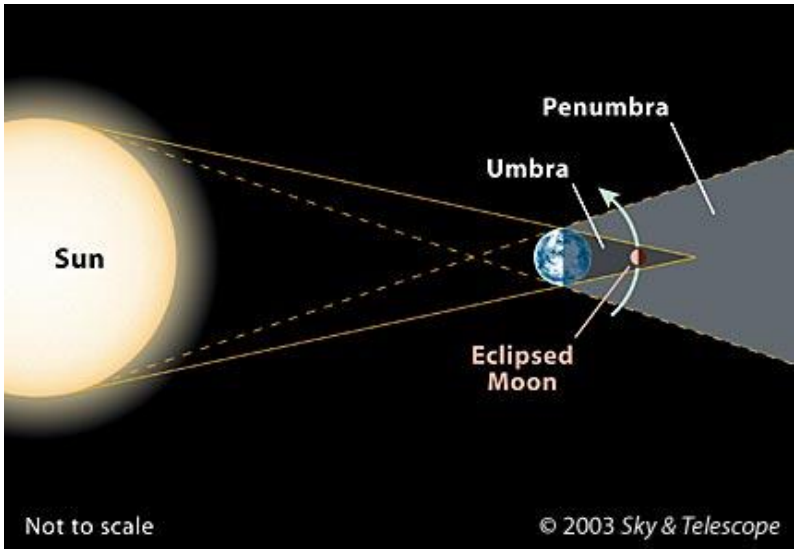



- These are unusual because the Moon usually is slightly north or south of Earth's shadow which is how we get a full Moon to be visible

# Eclipses

## Earth's Shadow

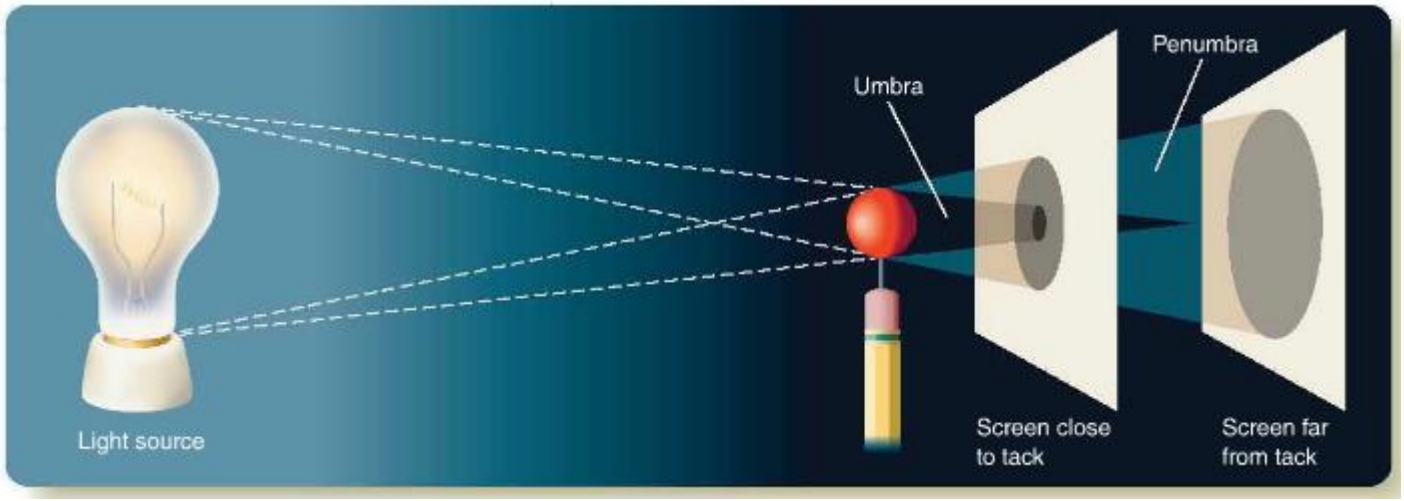
- Umbra – region of total shadow
  - The Sun is completely hidden from the Moon behind Earth
- Penumbra – partial shadow
  - Part of the Sun would peek around the edge of Earth
  - Sunlight is dimmed here, but not diminished



# Eclipses

## Earth's Shadow

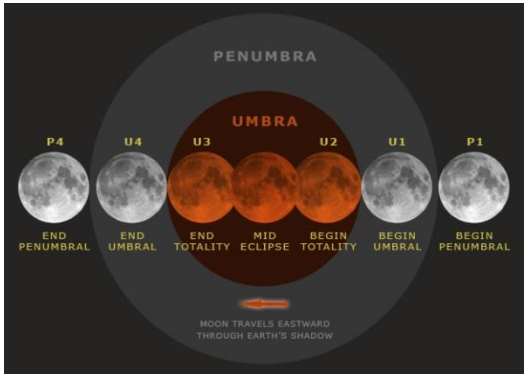
- Umbra & Penumbra
  - The umbra is more than 3x longer than the distance to the Moon
    - Points away from the Sun
  - The shadow is plenty big enough to hide the full Moon, but only when it lines up correctly



# Eclipses

## Total Lunar Eclipse

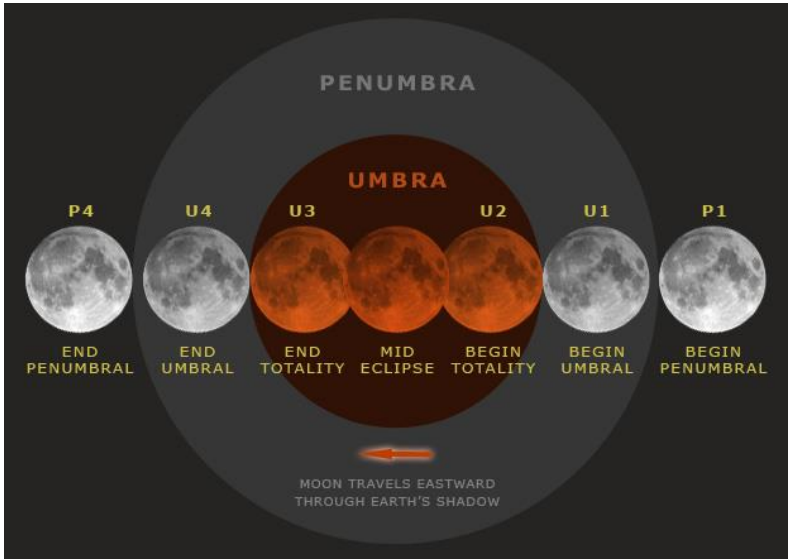
- Total Lunar Eclipse – Moon moves through the umbra and is completely covered by the umbra shadow
  - Moves into the penumbra and dims, then moves into the umbra and gets completely dark with an outer ring
  - The Moon will NOT disappear completely because it receives some refracted (bent) light through the atmosphere



# Eclipses

## Total Lunar Eclipse

- Totality– the loss of the direct sunlight on the Moon due to Earth being in the way
  - The sunlight beams around Earth and through it's atmosphere just like sunrises and sunsets causing a red glow to be casted on the Moon in the umbra
  - That red glow reflects off of the Moon and is what we see



# Eclipses

## Total Lunar Eclipse

- How dim the eclipse is depends on several factors:
  - The clouds in Earth's atmosphere
  - Dust in the atmosphere from eruptions (volcanoes)
  - Darkest eclipse if the Moon falls directly in the center of the umbra
- A total lunar eclipse can take up to 6 hours in progress from start to finish

# Eclipses

## Partial and Penumbral Lunar Eclipses

- Partial Lunar Eclipse – Moon passes through the penumbra and only *part* of the umbra
  - Don't usually have the red glow like a total eclipse would
- Penumbral Lunar Eclipse – Moon passes through the penumbra only
  - Tough to see because it's only partially dim
  - Looks very similar to a full Moon

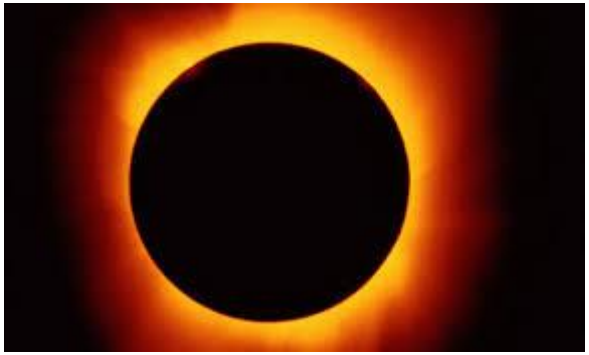
https://www.timeanddate.com/eclipse/north-america.html

# Eclipses

## Solar Eclipses

- Solar Eclipse – when the Moon moves between Earth and the Sun
  - Total Solar Eclipse – when the Moon covers the disk of the Sun completely
  - Partial Solar Eclipse – when the Moon covers only part of the Sun

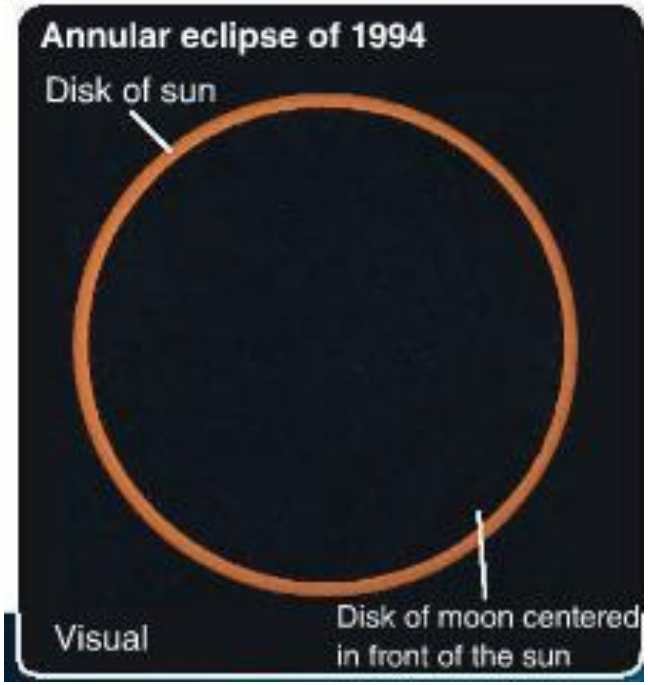
Both are location depending!



# Eclipses

## The Moon's Shadow

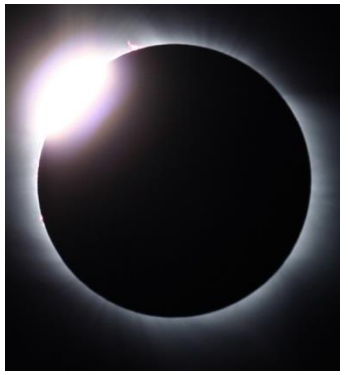
- Annular Eclipse – solar eclipse where an annulus (ring) of light is visible around the disk of the Moon
  - The Moon's angular diameter is less than that of the Sun, causing the ring



# Eclipses

## The Moon's Shadow

- Totality during a solar eclipse only lasts about 7.5 minutes at most
  - Usually about 2 to 3 minutes



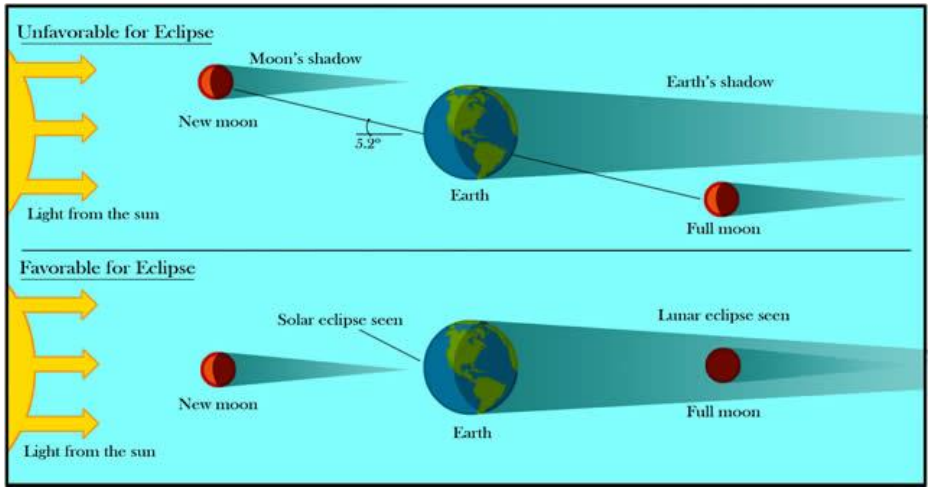
## Observing an Eclipse

- *Caution!*
  - Even during an eclipse, the surface of the Sun is still able to be seen (either progressing in or out) causing harmful radiation to burn your eyes!

# Eclipses

## Conditions for an Eclipse

- Eclipse Season – when the Sun is close to the same spot in the sky as the Moon's orbit
  - Eclipse season = about 32 days
  - Any new Moon during that time will produce a solar eclipse and any full Moon will encounter Earth's umbra and be eclipsed

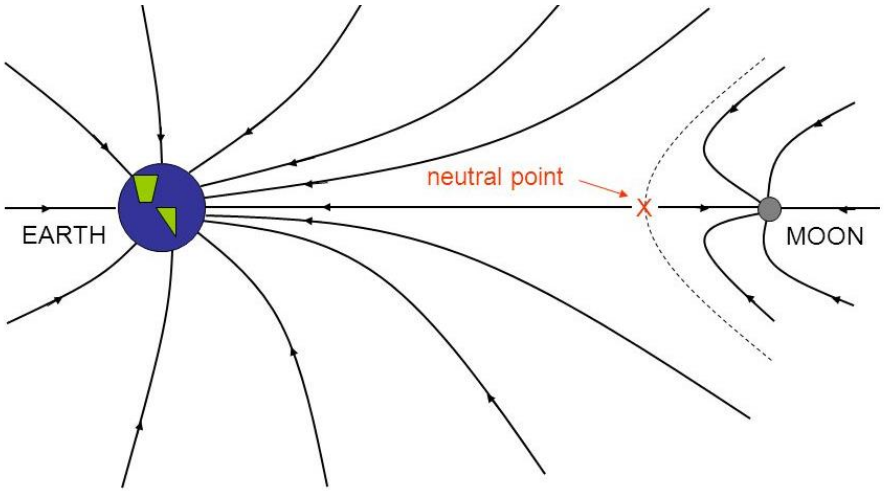


# Tides

# Tides

## Introduction

- Tides – the rise and fall of the Earth's oceans created by the gravitational pull of the Moon
- Just as the Earth pulls on the Moon, the Moon pulls back due to gravity being mutual



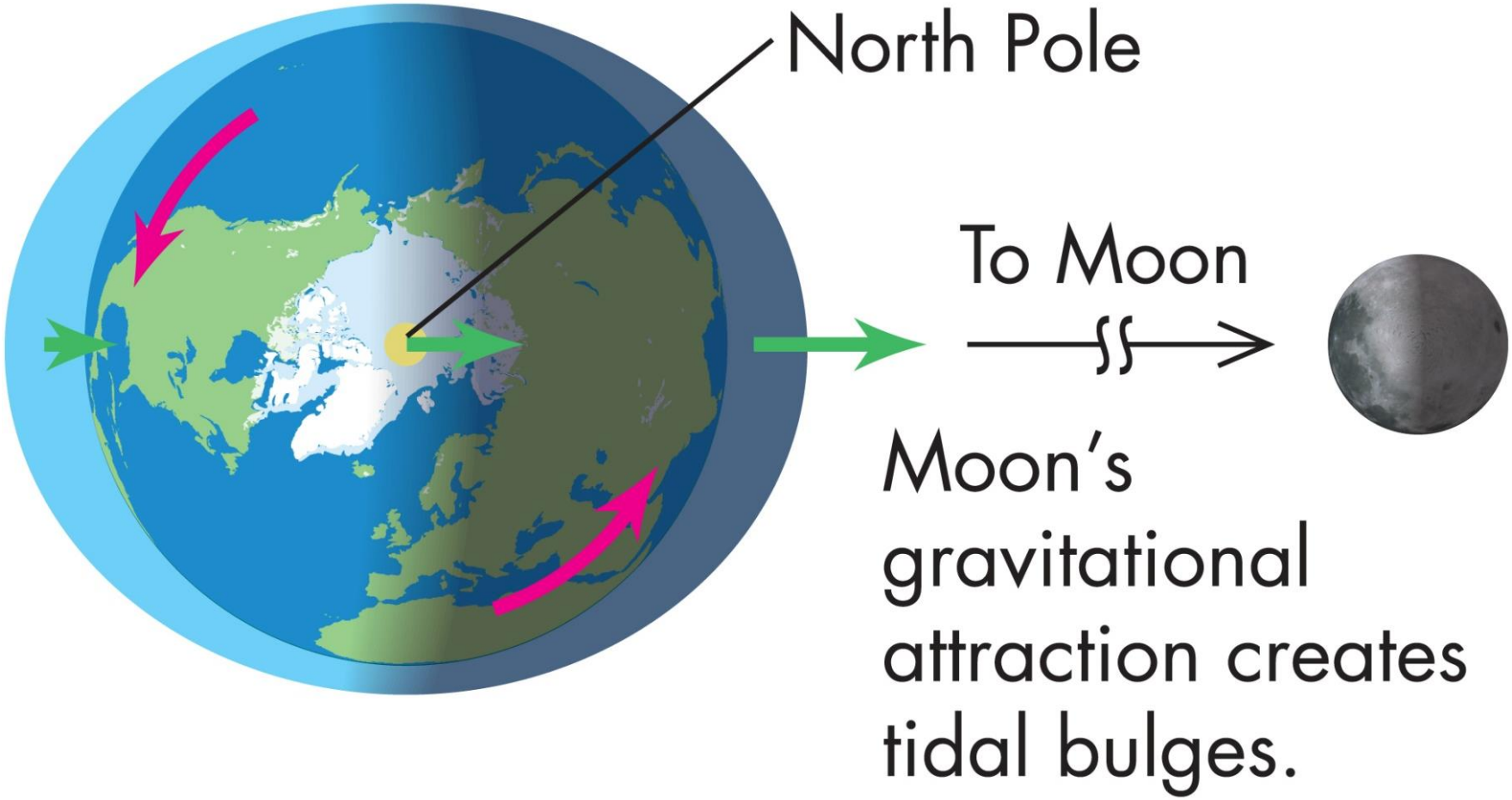
# Tides

## Causes of Tides

- The attraction of the Earth to the Moon is strongest on the side of Earth that faces the Moon and weaker on the side that doesn't (at the time)
- Gravity weakens with distance
  - The more distance put between the Earth's surface and the Moon at a certain location, the weaker the pull
- Differential Gravitational Force – the difference between the strong force on one side and the weaker force on the other side
  - Earth's side and the Moon

# Tides

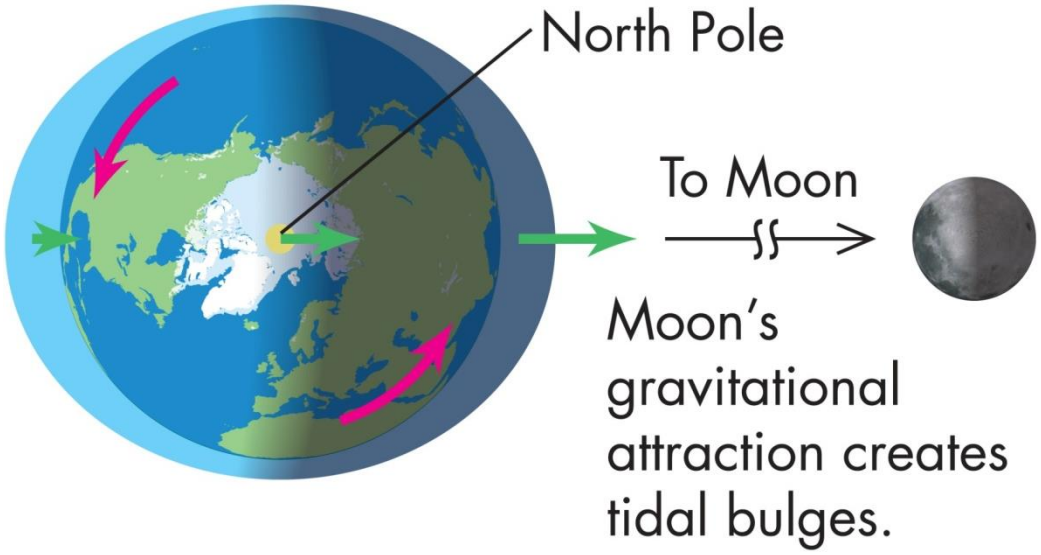
## Causes of Tides



# Tides

## Causes of Tides

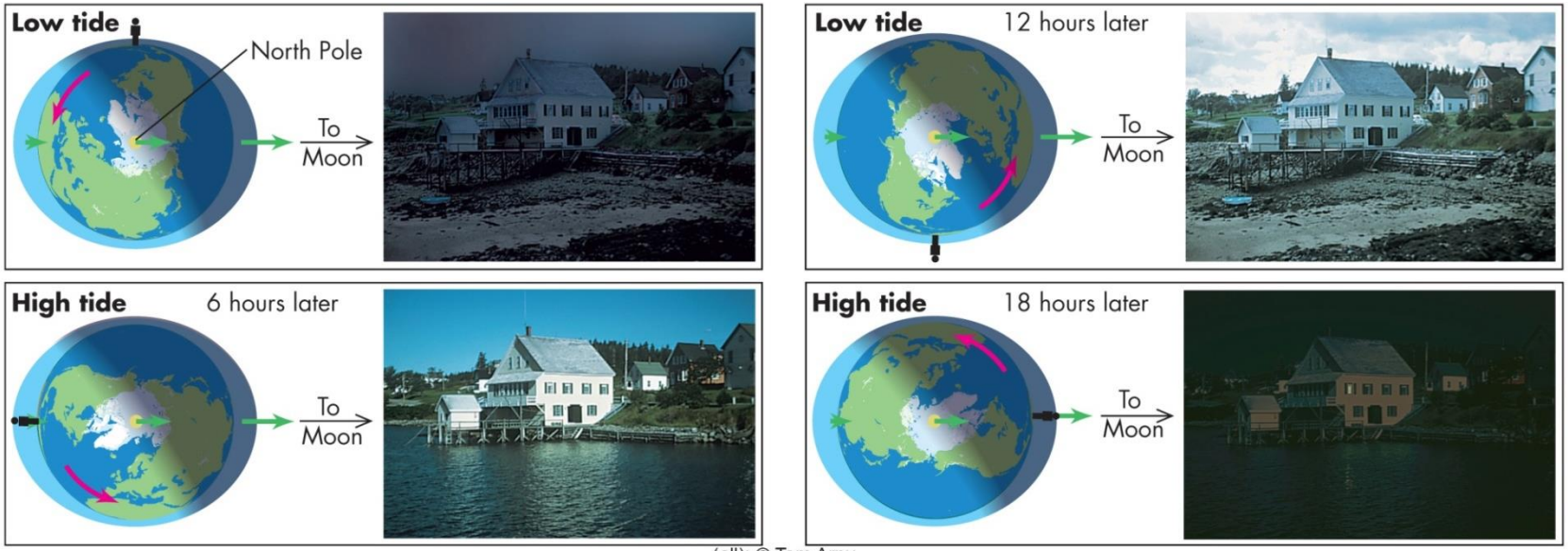
- Tidal Bulge – the bulge of a body (Earth's surface) created by another's gravitational attraction to it
  - Two form: one on the side nearest the pulling object (Moon) and one exactly opposite of it



# Tides

## Causes of Tides

- Because of the tidal bulge and Earth's rotation, we experience two time frames of "bulging" water and two of "low" water
- 24 hours: 2 high tides and 2 low tides




(all): © Tom Arny

# Tides

## Solar Tides

- The Sun can also create tides on Earth, but because it's so far away, they're half the strength of the Moon's
- These aren't really noticeable until they join up with the lunar tides
- Spring Tides – abnormally large tides that occur during full and new Moons
- Neap Tides – tides that occur during quarter Moons due to the right angle between Earth, Sun, and Moon

# Tides

## Solar Tides