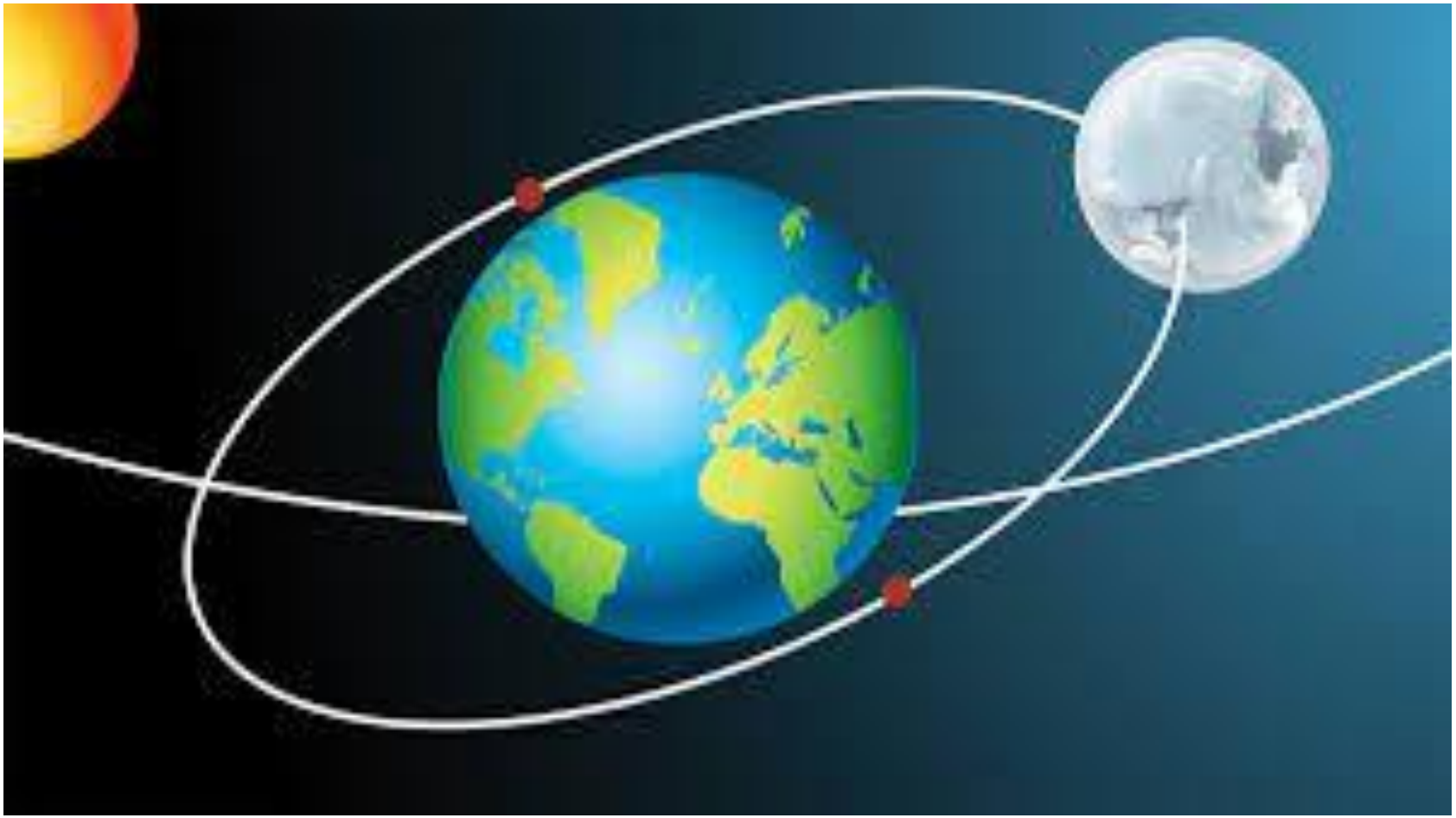
Lesson 03

# Earth's Moon
# Part 3
# Eclipses and Tides

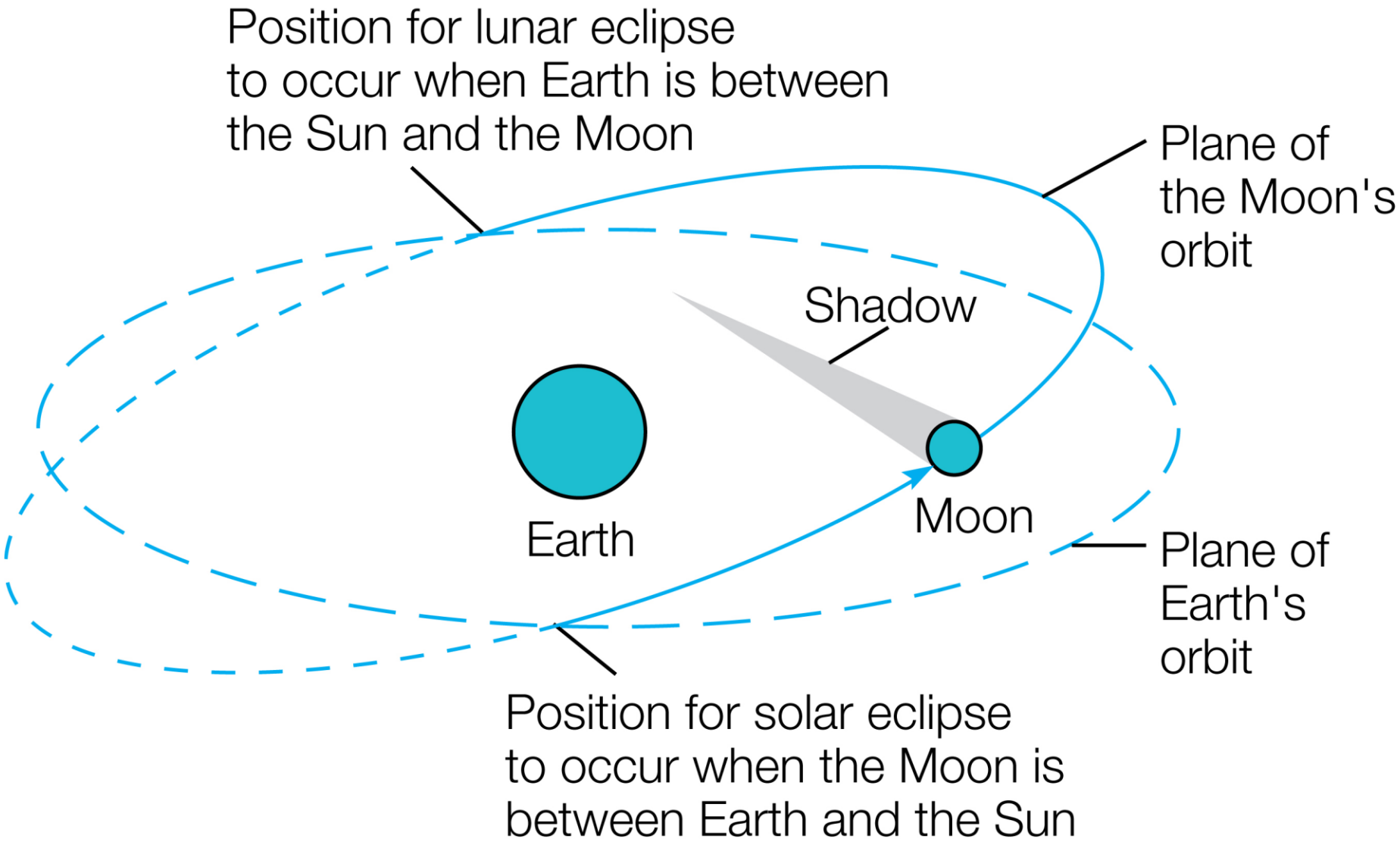
The moon's orbit has an **inclination** of **(tilted by) 5°** relative to the **plane of the ecliptic**. The moon's orbit and Earth's equator do not exactly align. They are offset by **~19º.**



An **eclipse** happens when one celestial body is temporarily obscured from view because it passes into the shadow of another body or is blocked from view by another body.

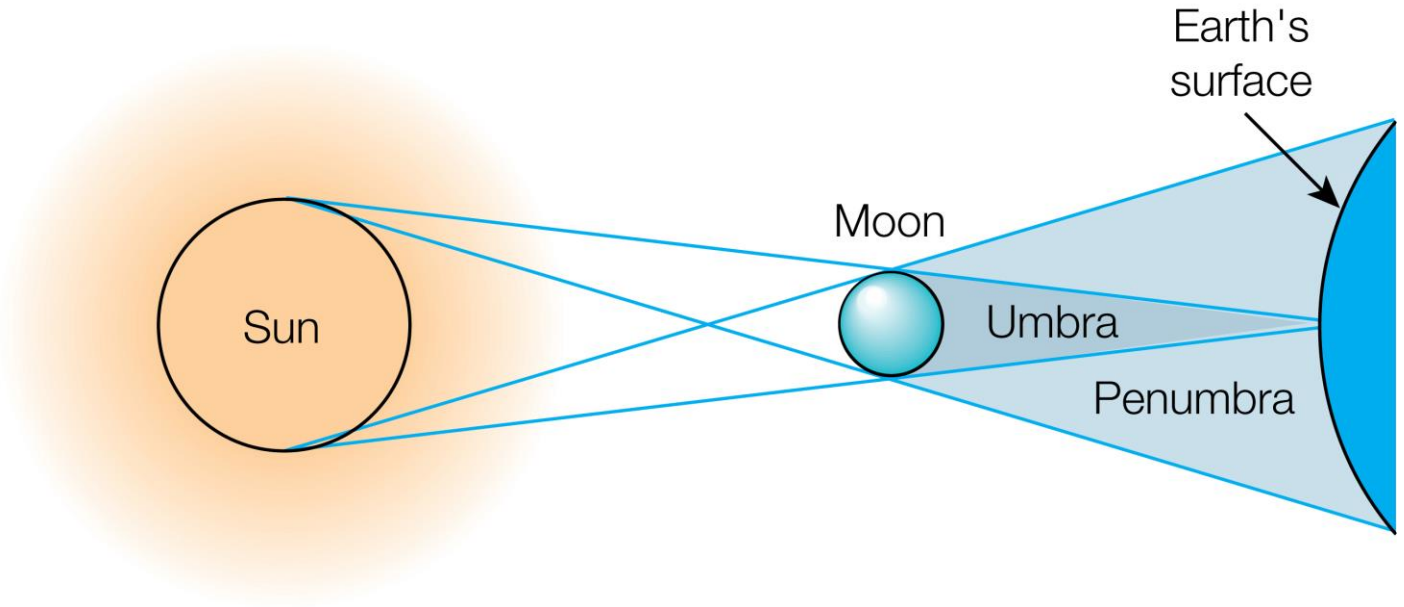
Eclipses are rare events because…

- The moon's orbit is offset by ~5º relative to the Plane of the Ecliptic
- The moon's orbit is offset by ~19º relative to the Earth's equator.
- The moon orbital period is ~29.5 days
- The moon must pass through the **nodes** where the moon's orbit intersects the plane of the ecliptic.
- The moon must be at the **new moon** or the **full moon** phase.

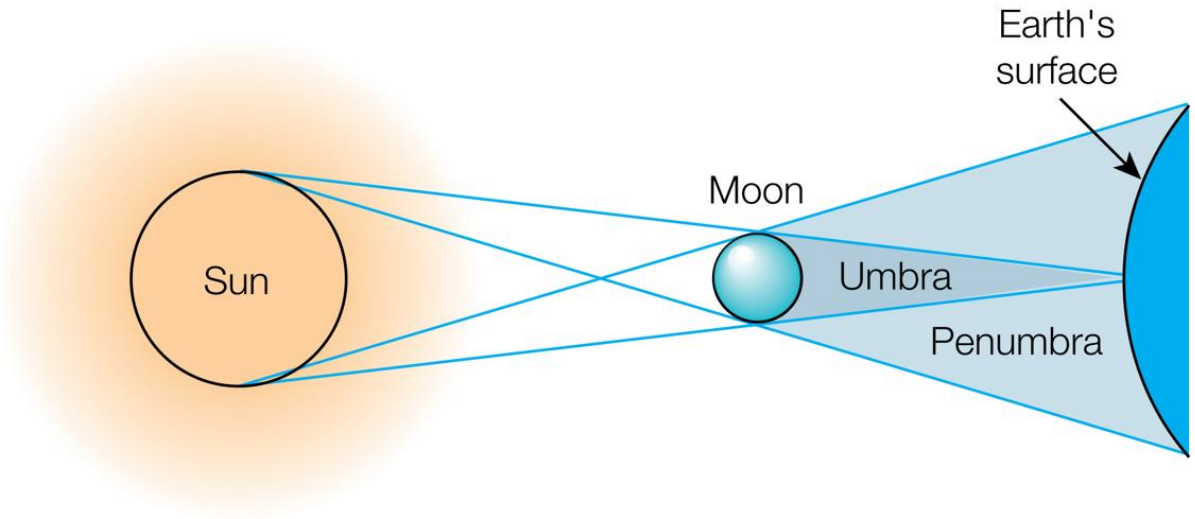

Position for lunar eclipse
to occur when Earth is between
the Sun and the Moon
Plane of
the Moon's
orbit
Shadow
Earth
Moon
Plane of
Earth's
orbit
Position for solar eclipse
to occur when the Moon is
between Earth and the Sun

# Solar Eclipse

- Moon must be at the ***new moon phase***
- Moon passes through the Plane of the Ecliptic between the sun and Earth. (Conjunction)

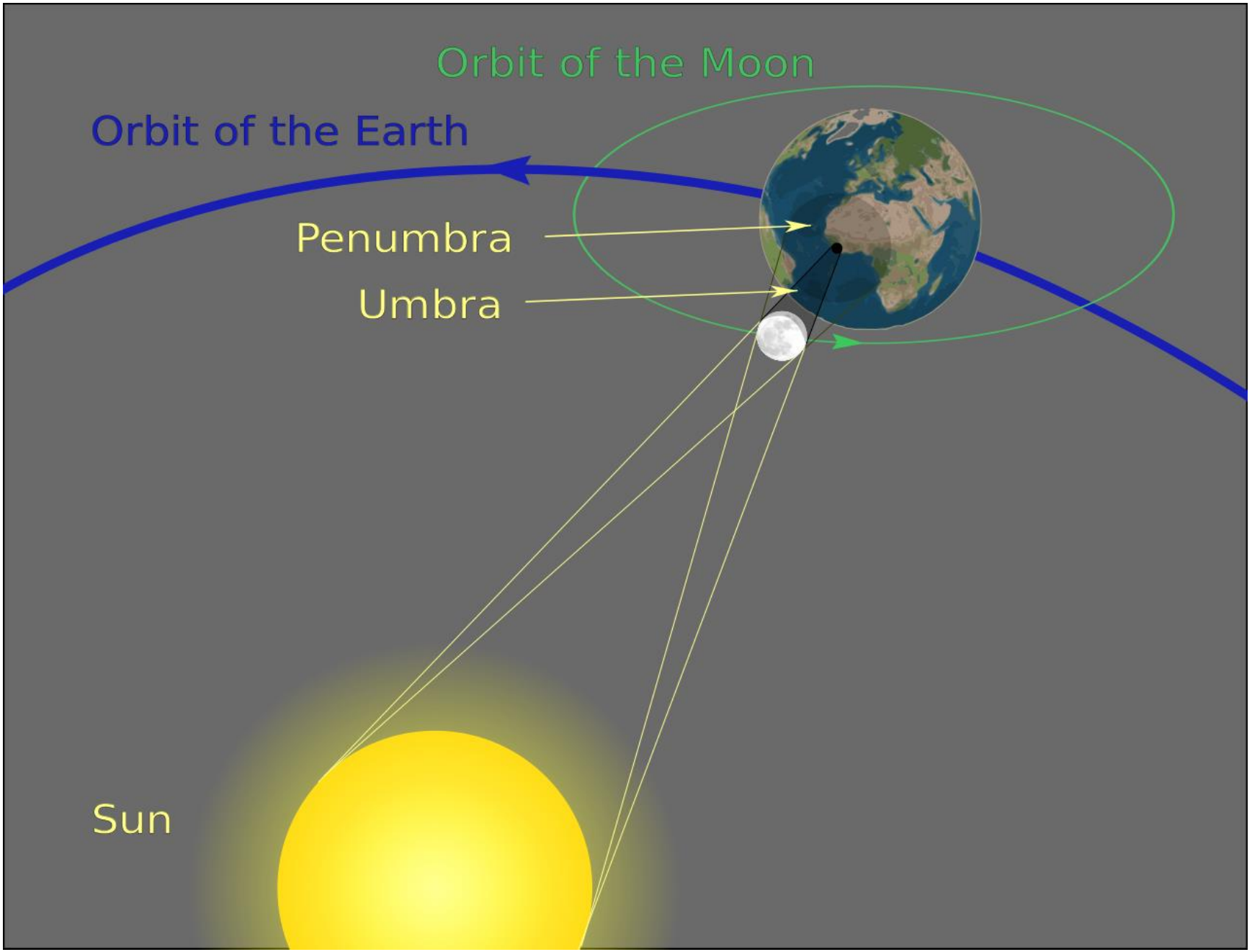



The moon blocks sunlight from shining on a discrete surface of the Earth.



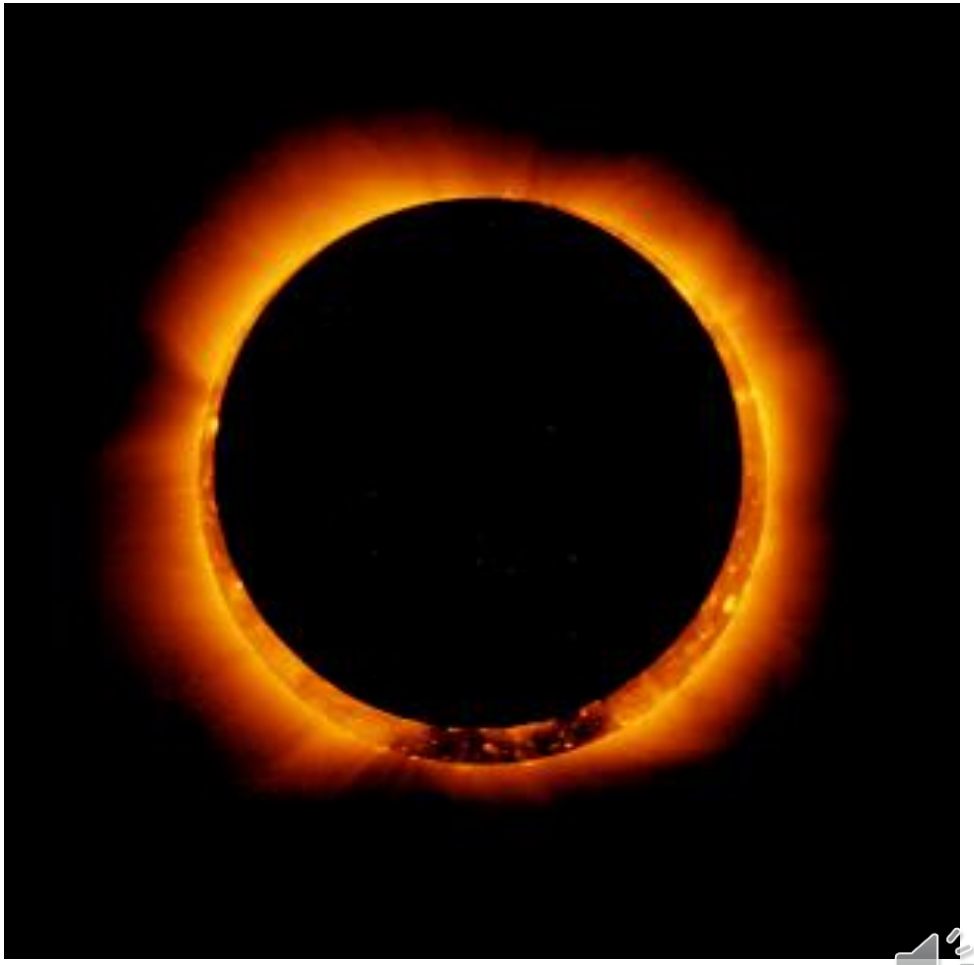

**Umbra**: The "cone" of the darkest shadow cast on the Earth's surface. From the surface, the sun's disk is totally covered by the moon's disk during the solar eclipse.

**Penumbra**: The "cone" of diffuse shadowy region cast onto the Earth's surface. From the surface, the sun's disk is partially blackened during the solar eclipse—a partial solar eclipse appears in the sky.


Orbit of the Moon
Orbit of the Earth
Penumbra
Umbra
Sun

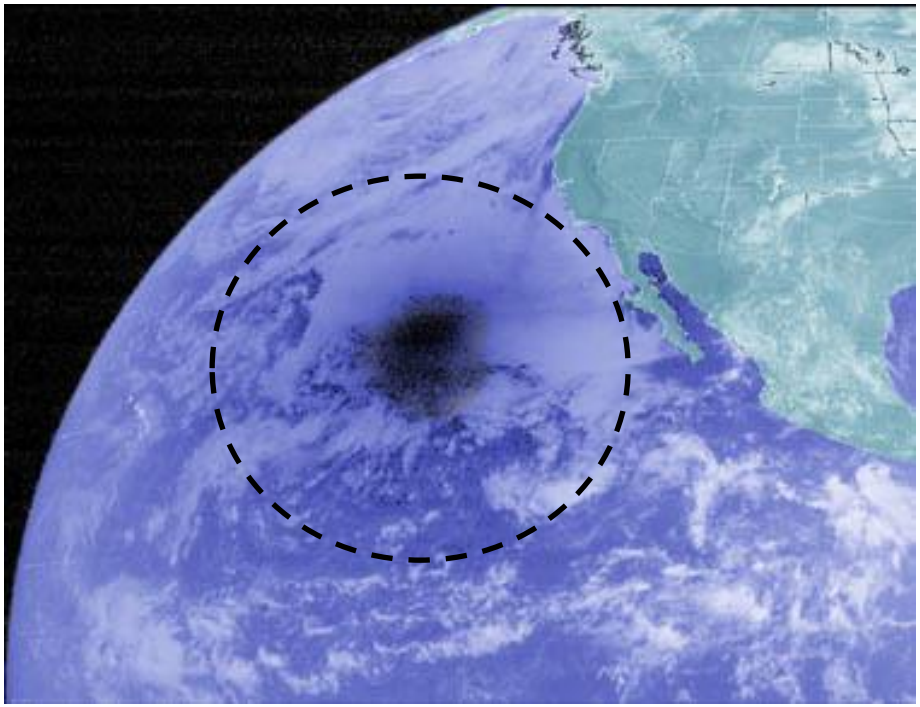
**Annular solar eclipse**: the moon's disk does not cover the sun's disk. Moon is near apogee. The apparent diameter of the moon is smaller than the apparent diameter of the sun.

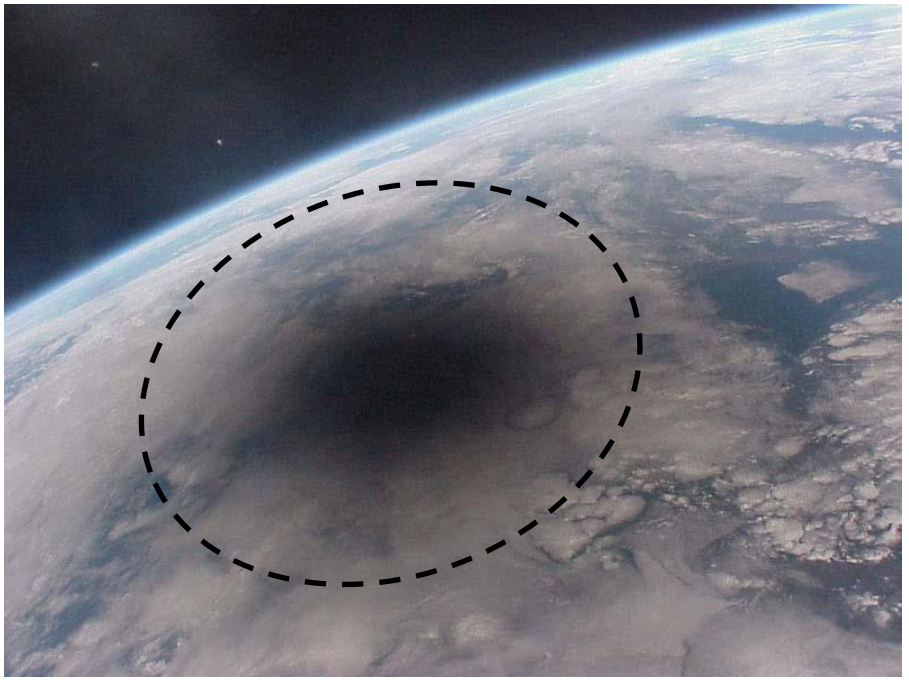
Red wavelengths refract and bend to a greater degree than blue wavelengths. The reddish light in the sunlight is bending around the moon towards the Earth.



**Total solar eclipse**: the moon's disk totally covers the sun's disk. Moon is near **perigee**. Coincidentally, the apparent diameter of the moon and the diameter of the sun as viewed from Earth almost are equal in size.

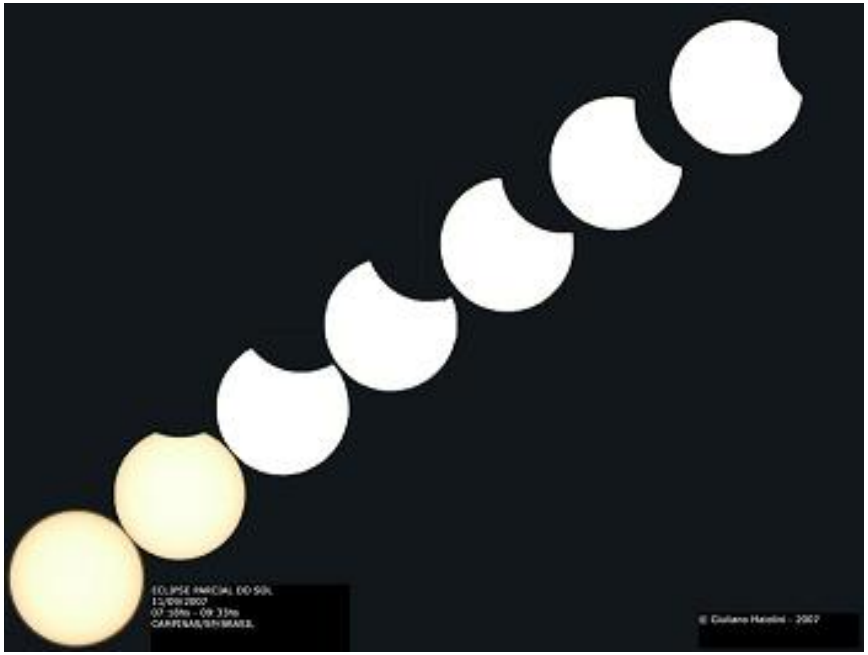
The corona, the diffuse outer atmosphere of the Sun is visible briefly by the total solar eclips.



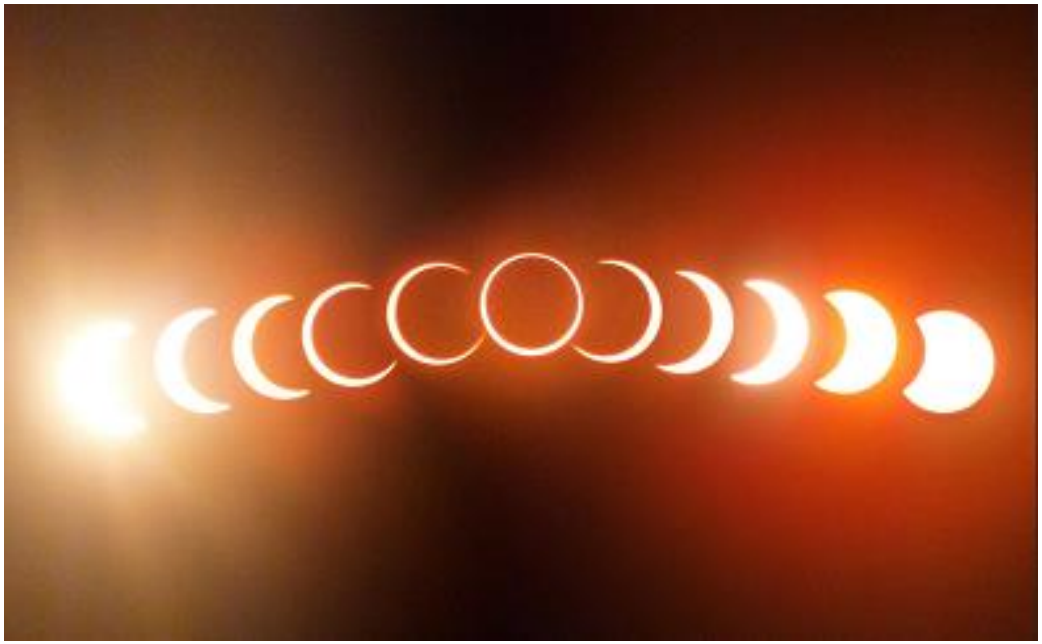


An observer in the **umbra** (dark shaded region) would see a total or annular eclipse of the sun.

An observer within the **penumbra** (dashed circle) would see a partial eclipse of the sun.



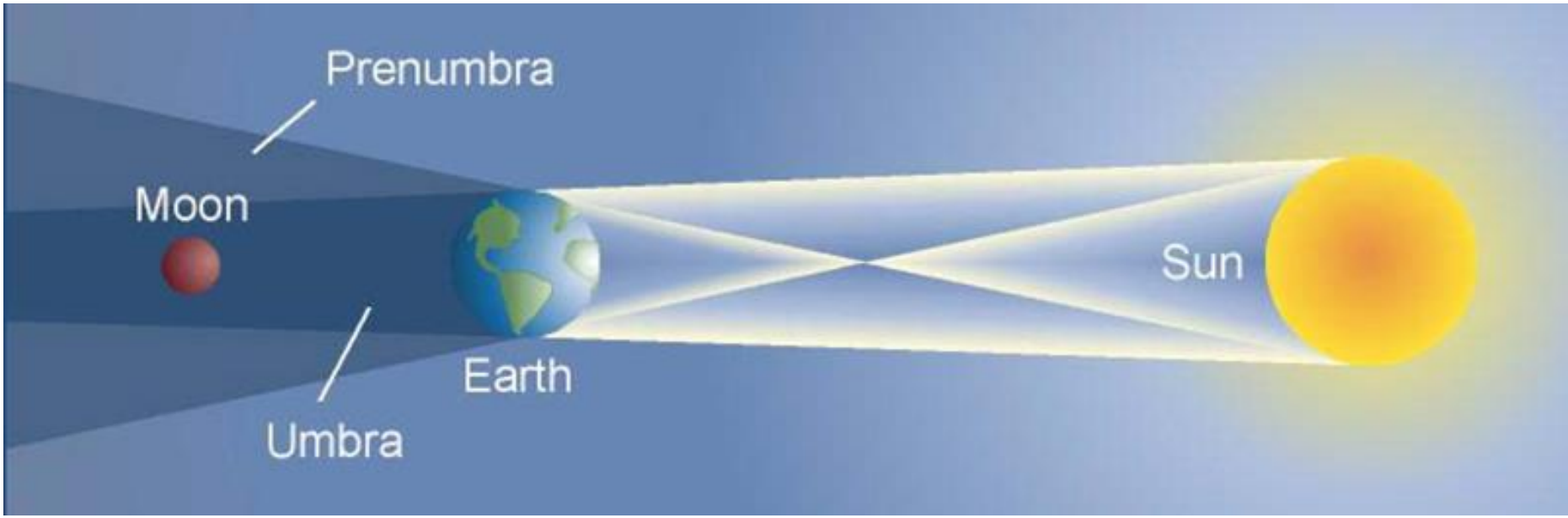
Time lapse images of a ***partial solar eclipse*** if the observer is in the ***penumbra region*** of the Earth.



Time lapse images of an ***annular solar eclipse*** if the observer is in the ***umbra region*** of the Earth.

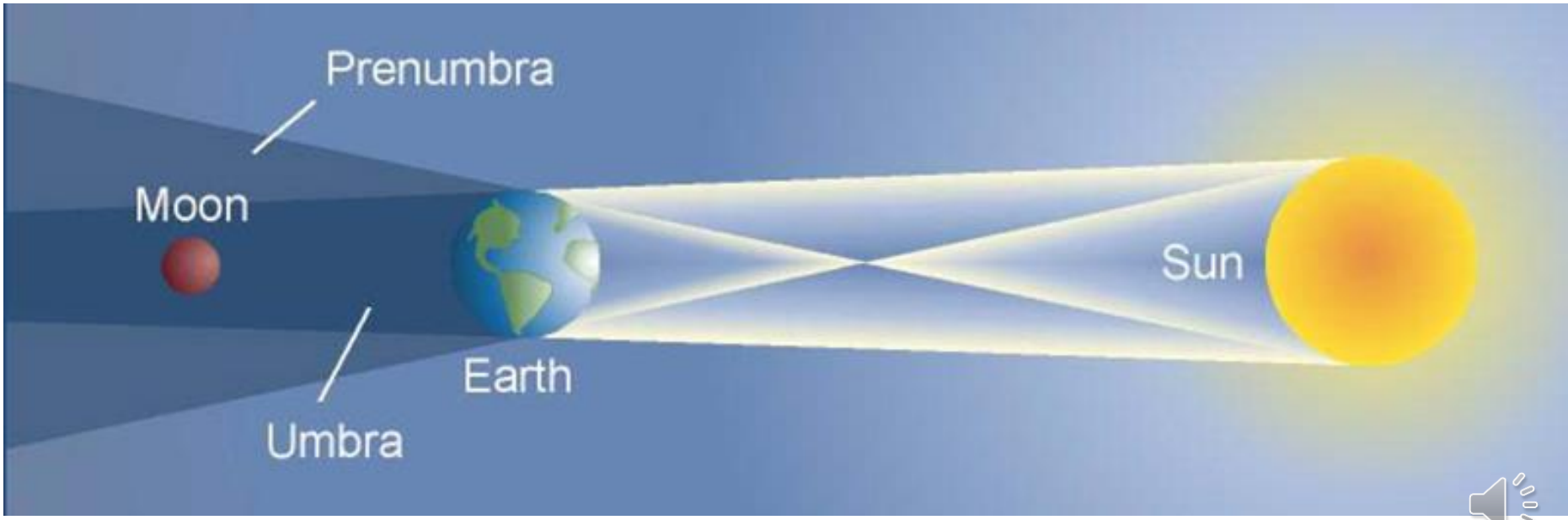
# Lunar Eclipse

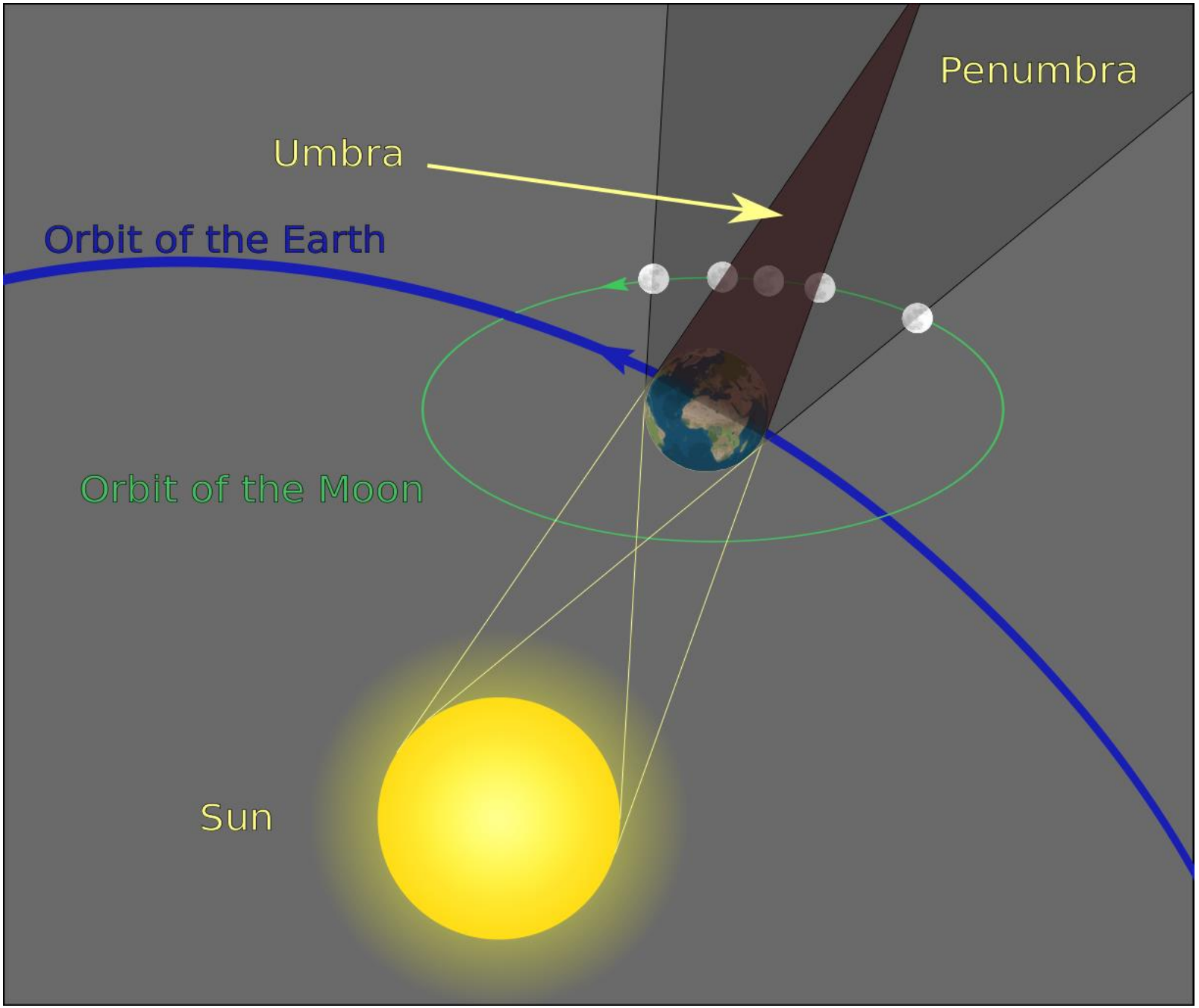
- Moon must be at the **full moon** phase
- Moon passes through the Plane of the Ecliptic in opposition to the sun.
- The Earth's shadow is cast on the moon.



If the moon passes through the ***penumbra***, the moon's disk becomes ***slightly darkened***—inside the diffuse shadowed cone.

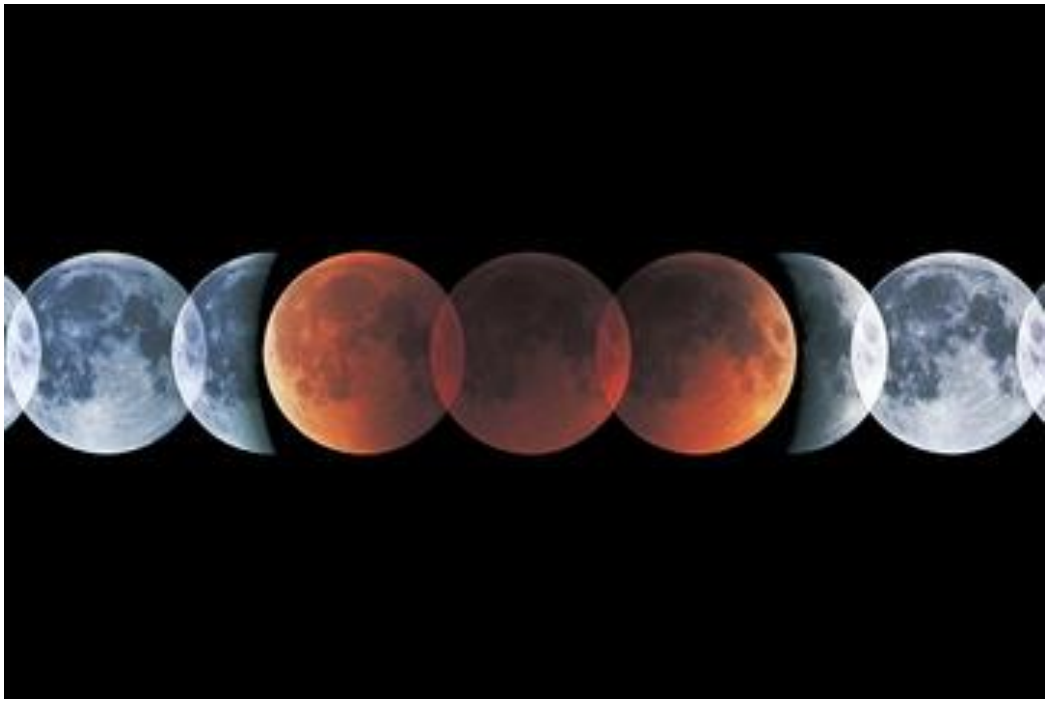
If the moon passes through the ***umbra***, the moon's disk becomes ***reddened and darkened***—inside the concentrated shadow and refraction zone.




Penumbra
Umbra
Orbit of the Earth
Orbit of the Moon
Sun


The moon’s disk is slightly dimmed during a penumbra lunar eclipse.

The moon’s disk is reddened and shaded as it passes through the umbra (blood moon)



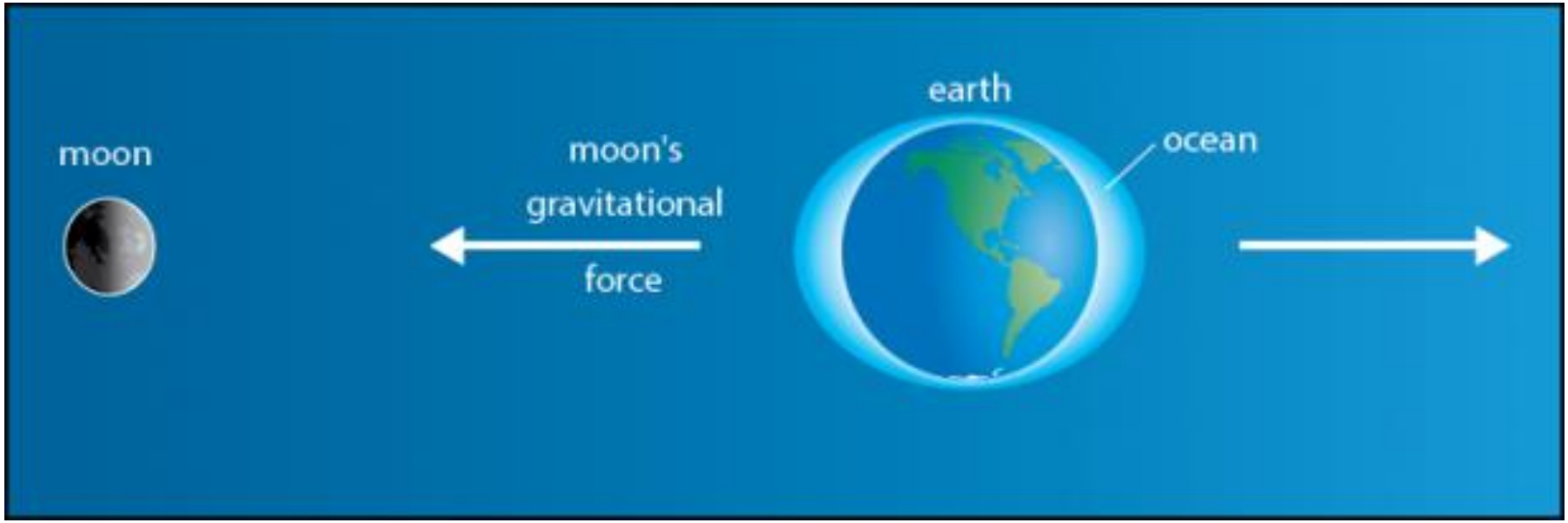
**Lunar Eclipse frequency**

- Total lunar eclipses 5-8 months
- Usually 2 times per calendar year
- ~ 3-3.5 hours from penumbra edge to penumbra edge
- “total eclipse” in the umbra lasting ~1.5 hours.

**Solar Eclipse frequency**

- Total lunar eclipses 3-5 months
- Usually 3 times per calendar year
- ~ 20 minutes from penumbra edge to penumbra edge
- “total eclipse” in the umbra lasting ~7 min.

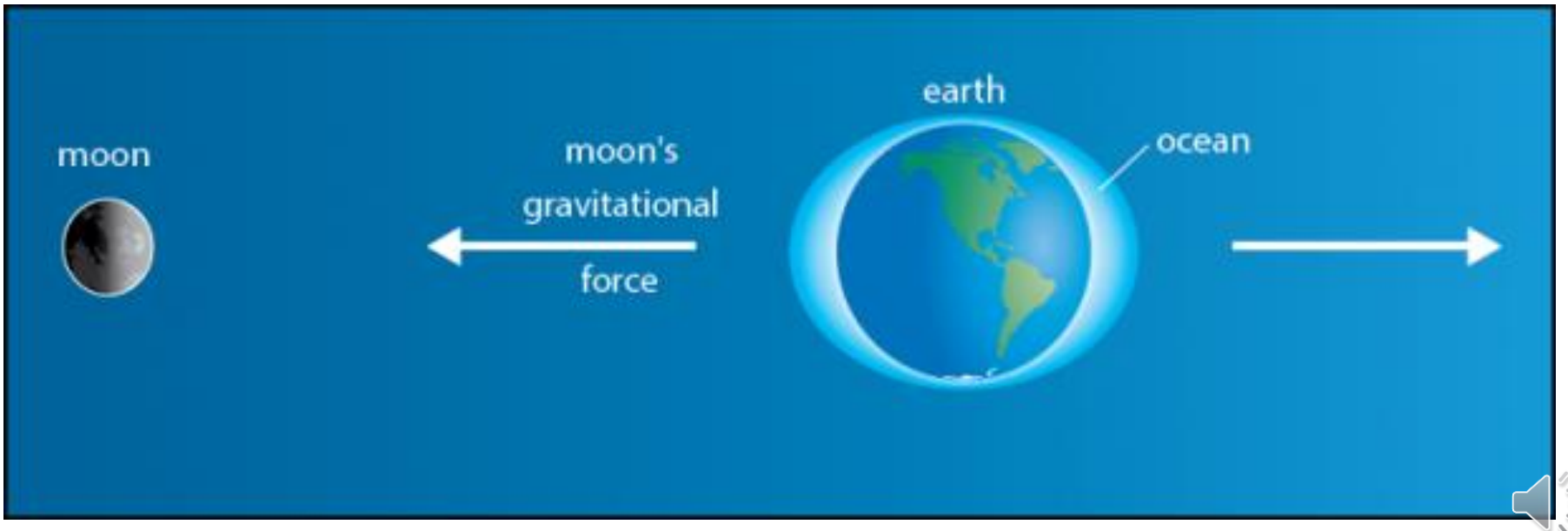
**Ocean tides**: The localized increase and decrease of surface ocean water relative to mean sea level induced by the moon's and Sun's gravitational attraction.

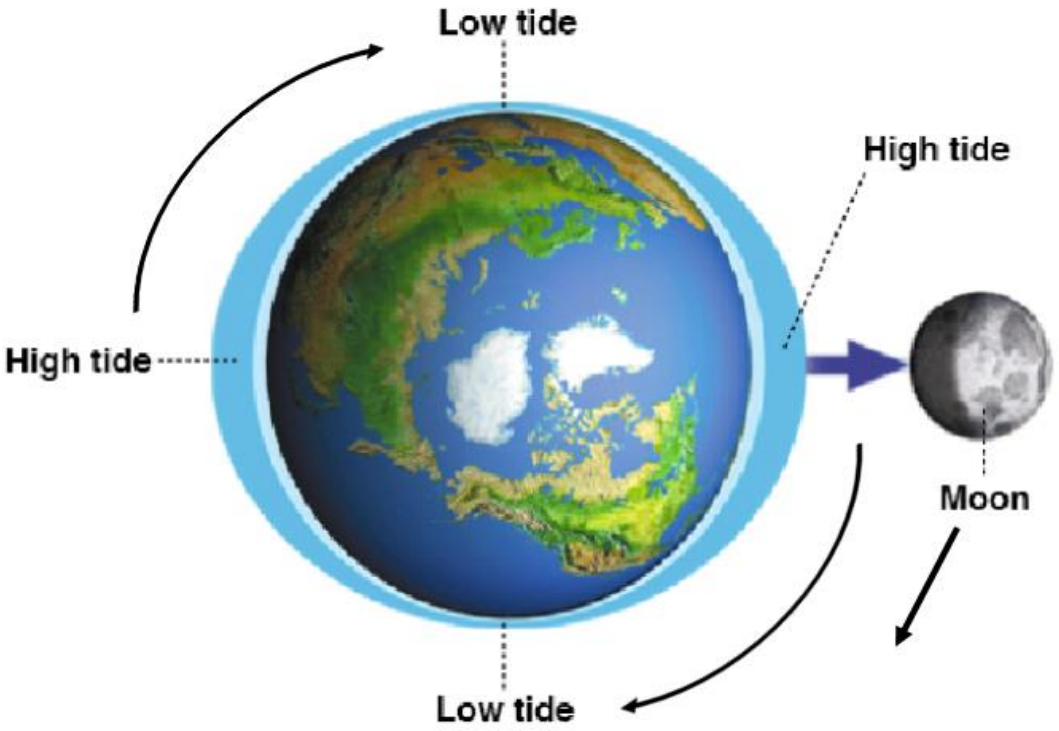


Moon’s gravity effect >> Sun’s gravity effect

Both moon and Sun affect ocean tides.  Even though the moon is much lesser in mass than the Sun, the moon is very close to the Earth.

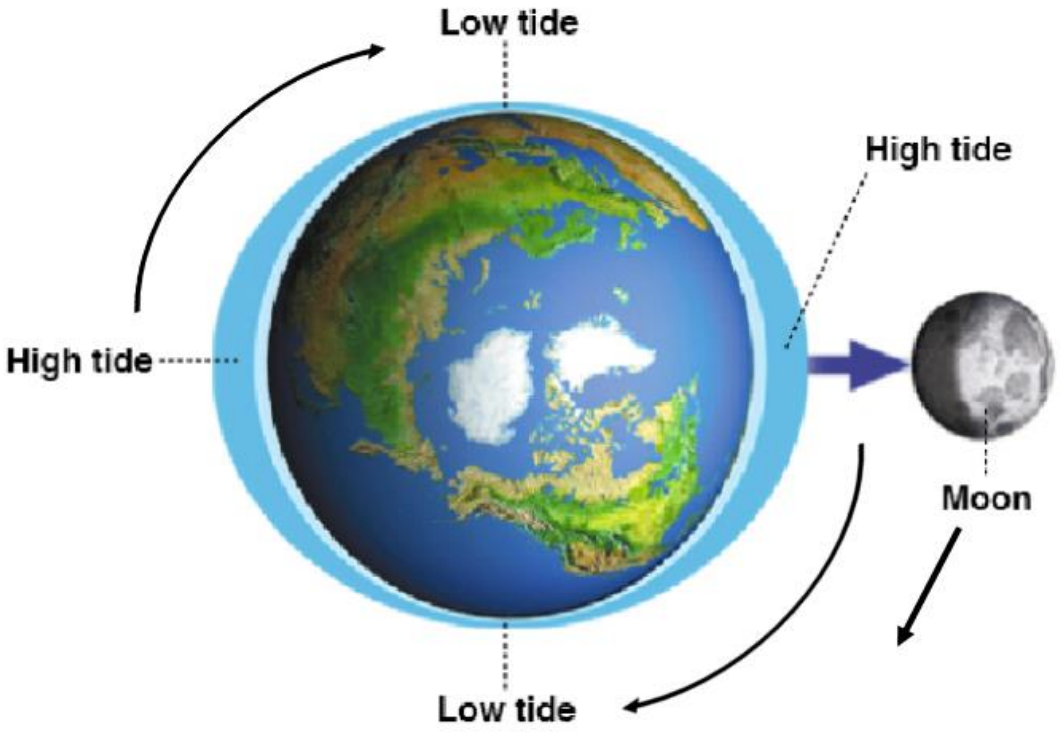
The high tide of the ocean follows the moon, and another high tide will be exactly on the opposite side of the Earth..



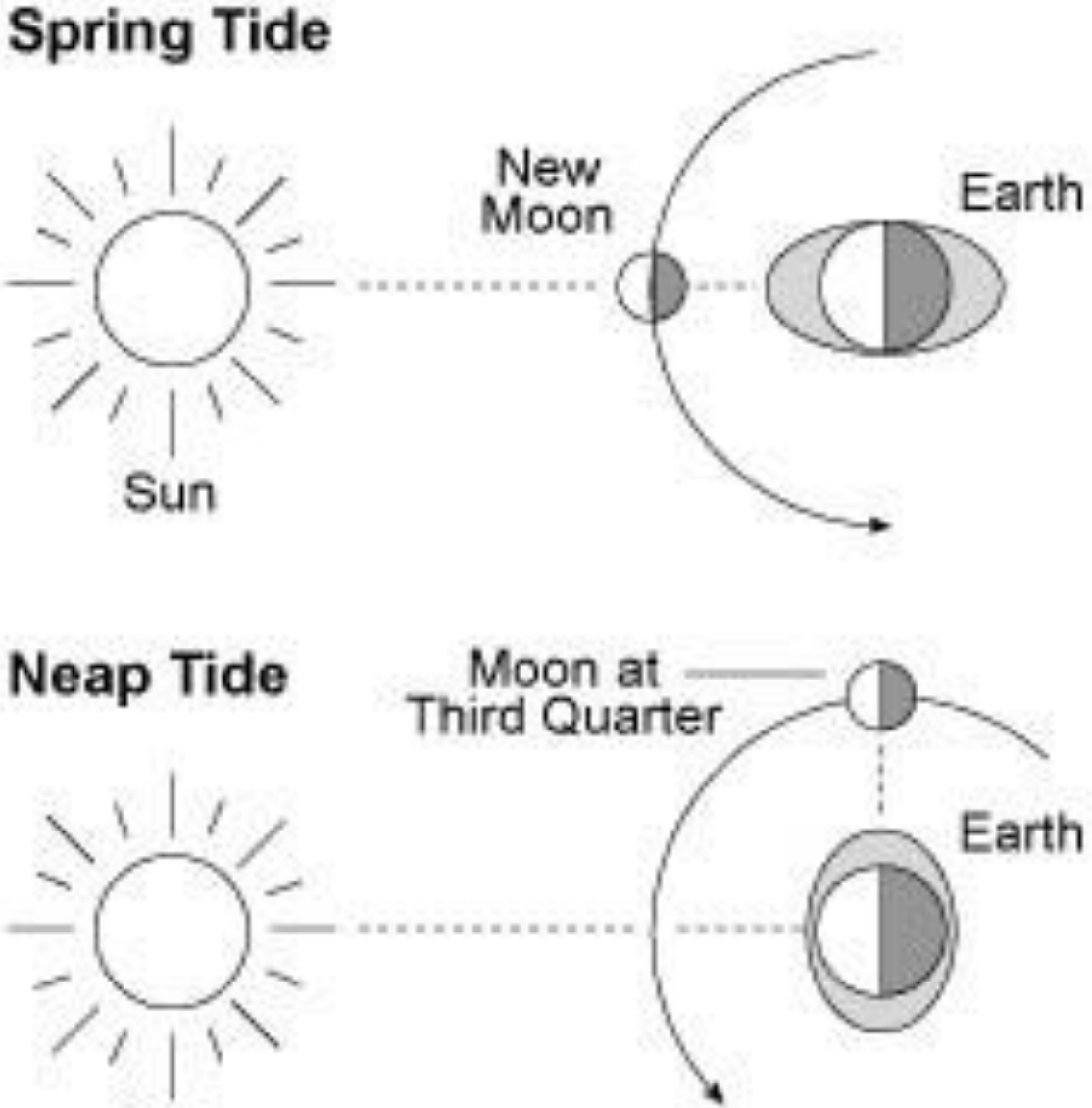



The Earth's rotation is every 24 hours (1 day). The moon's orbit period is 1 revolution every 28 days. The Earth is spinning under the moon

There are two **high tides** and **two low** tides on Earth at the same time. High tides follow the moon and exactly opposite (180°) of the moon. Low tides are at 90° to the moon. Tides are the result of gravitational attraction between the moon and Earth's oceans.

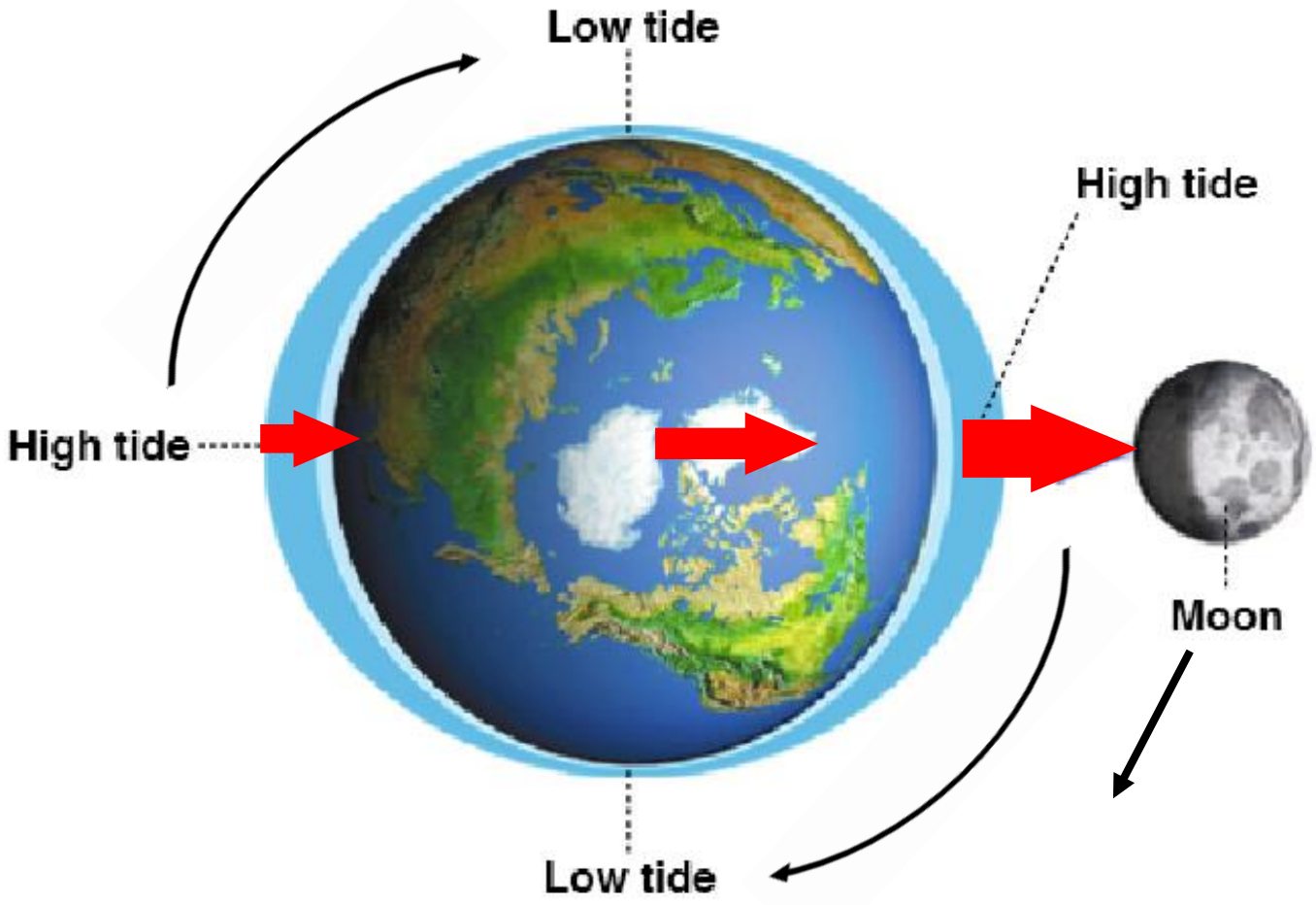


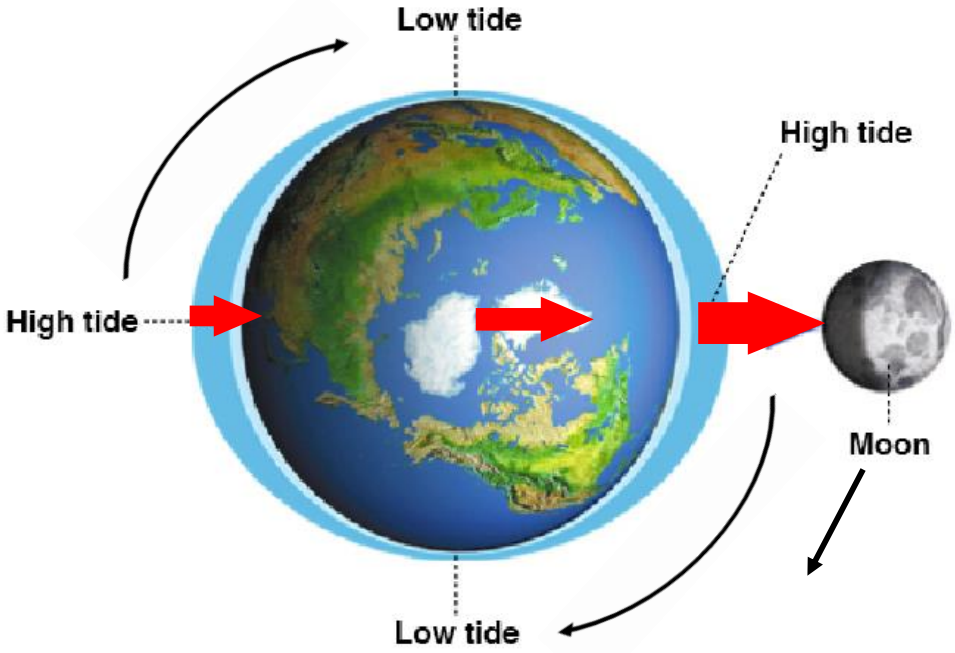

Because of the difference in the motion of the Earth (fast spin) and the moon (slow orbit), the high tide "bulges" stay in a fixed position under the orbiting moon. The Earth spins under the tides pushing the water upward onto the shorelines.




Note that regardless of the moon's phase, one of the high ocean tides is always under the moon.

Why are there two high tides if the high tide supposedly always follows the moon due to the gravitational attraction between the ocean surface and the moon?



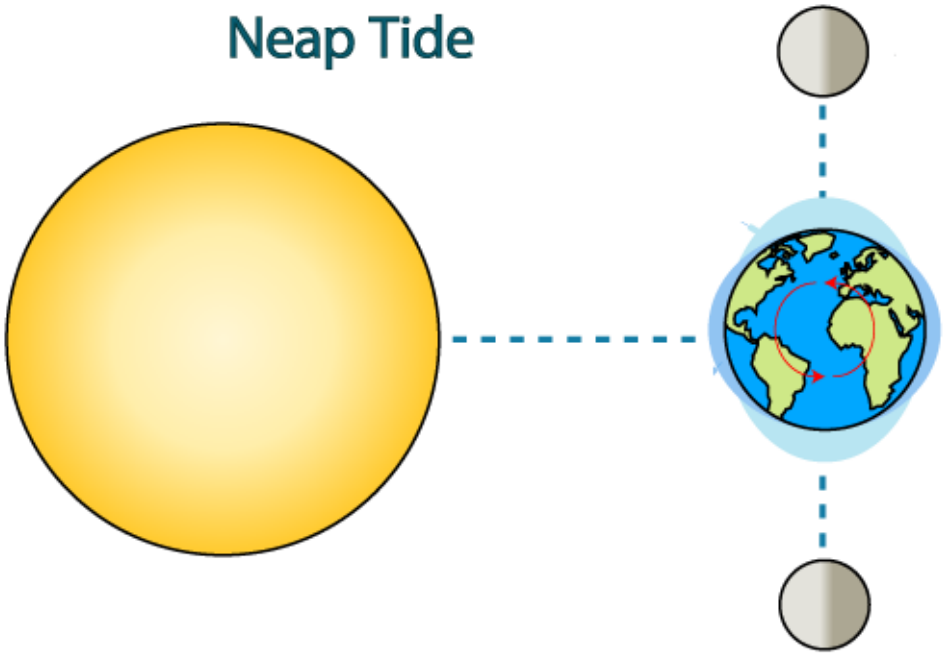



The moon's gravity pulls on the surface ocean closest to the moon, creating the high tide—the ocean bulges outward to the moon.

At the same time, the moon's gravity pulls the Earth slightly toward the moon. This slight pull on the Earth towards the moon pulls the Earth away from the ocean on the opposite side, leaving the ocean to bulge slightly.

**Neap tide**: a lower-than-average high tide.

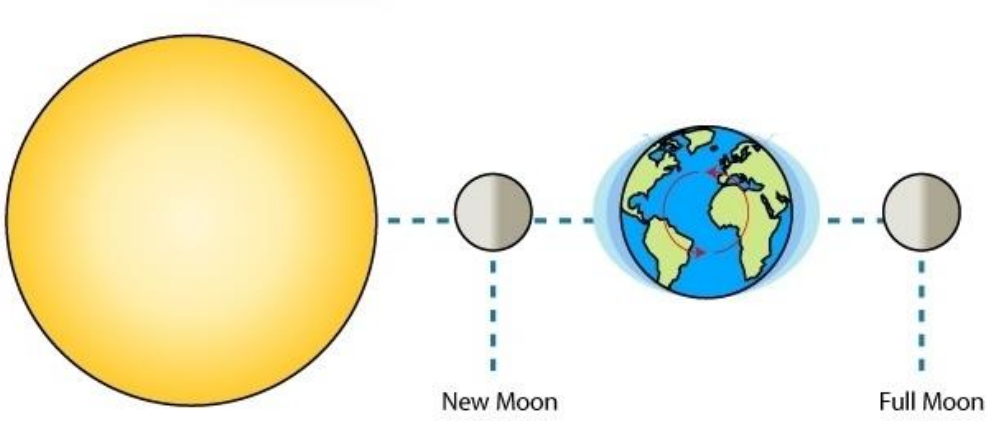
- Occurs at the first quarter and third quarter moon (moon and sun are perpendicular relative to the Earth)
- The low tide that follows is slightly higher than an average low tide.



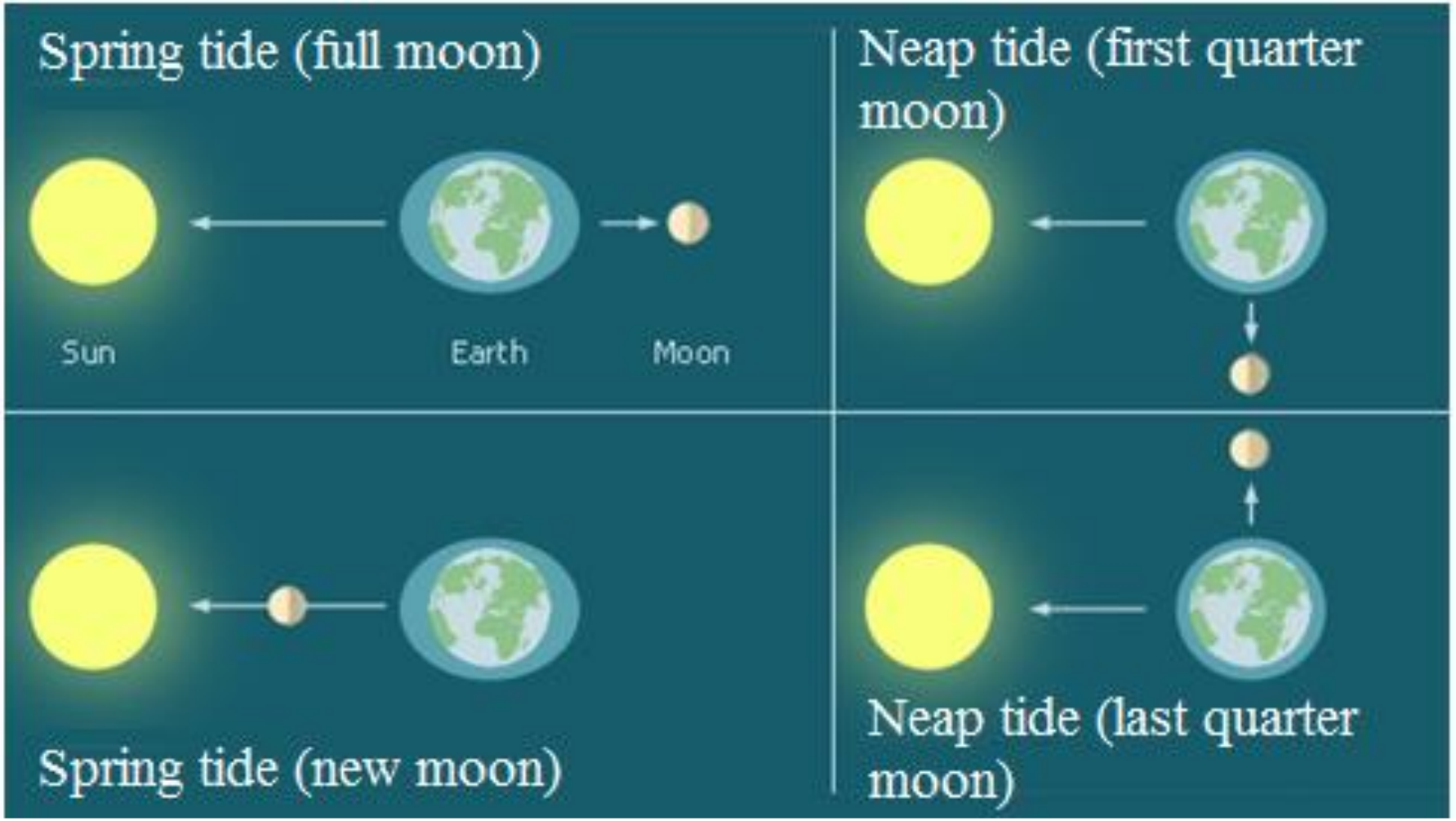

The gravitational pull of the moon and Sun are not aligned. They pull perpendicular on the surface oceans.

**Spring tide**: a higher-than-average high tide

- Occurs at the new moon and full moon phases (moon and sun are in conjunction or opposition. Spring tide at new moon is higher than at the full moon phase.
- The low tide that follows is slightly lower than an average low tide.

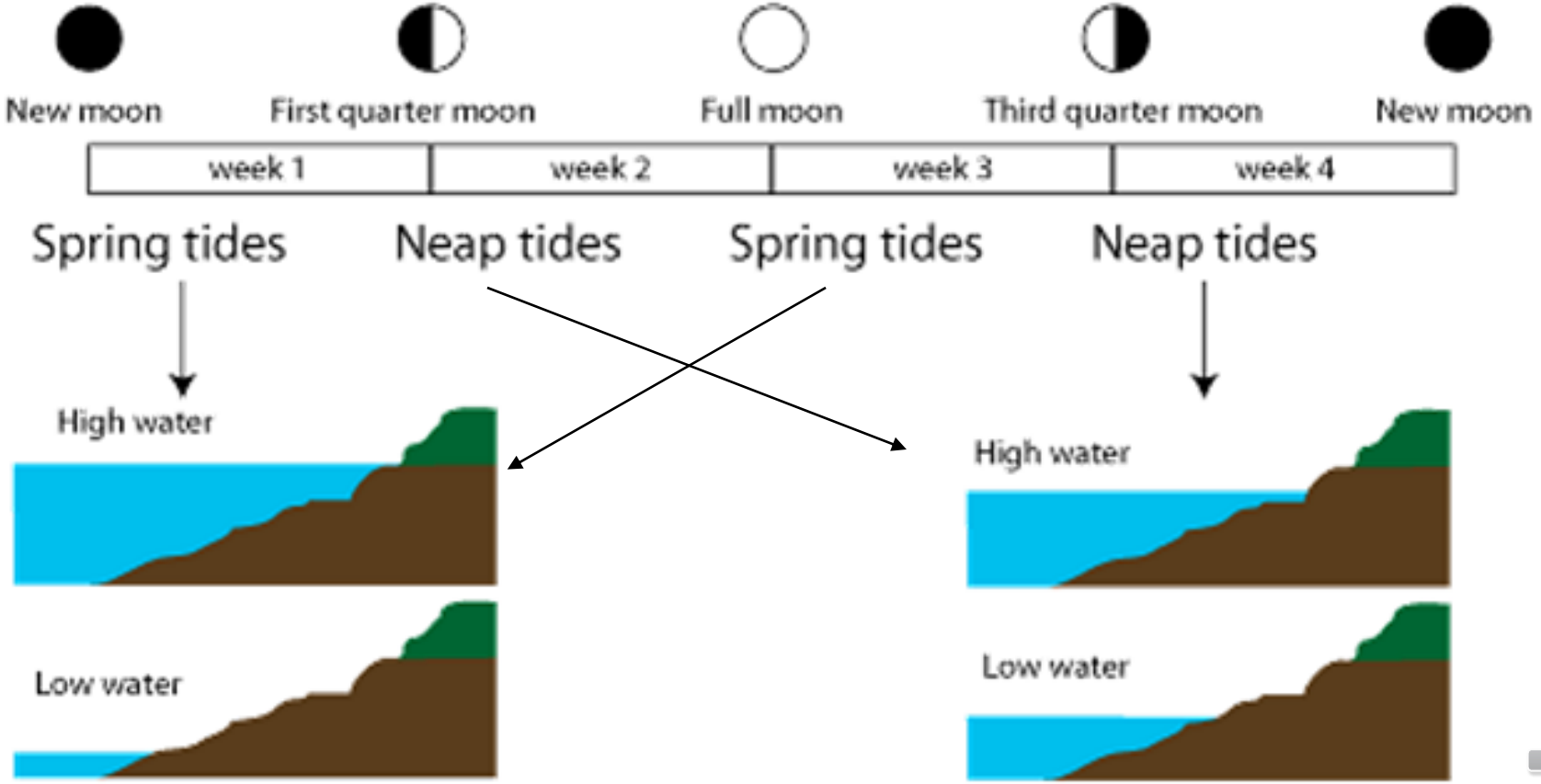



The gravitational pull of the moon and Sun are aligned and strengthen each other.


Spring tide (full moon)
Sun
Earth
Moon
Neap tide (first quarter moon)
Spring tide (new moon)
Neap tide (last quarter moon)

Over the course of a lunar cycle,

- Spring tides correspond to when the moon is near its new and full moon phases
- Neap tides occur when the moon is near its quarter moon phases



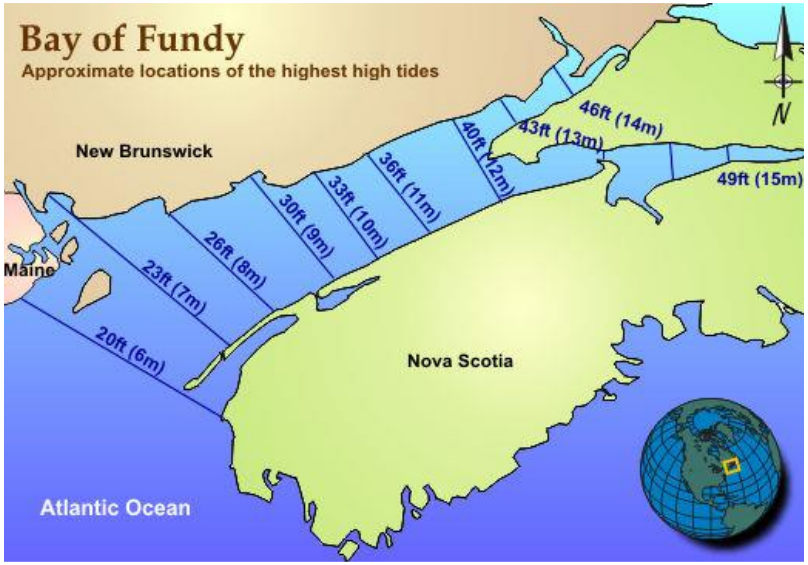
**Ebb tide**: The outgoing tide, water's elevation at the shoreline is decreasing. Ebb tides occur from peak high tide to low tide.

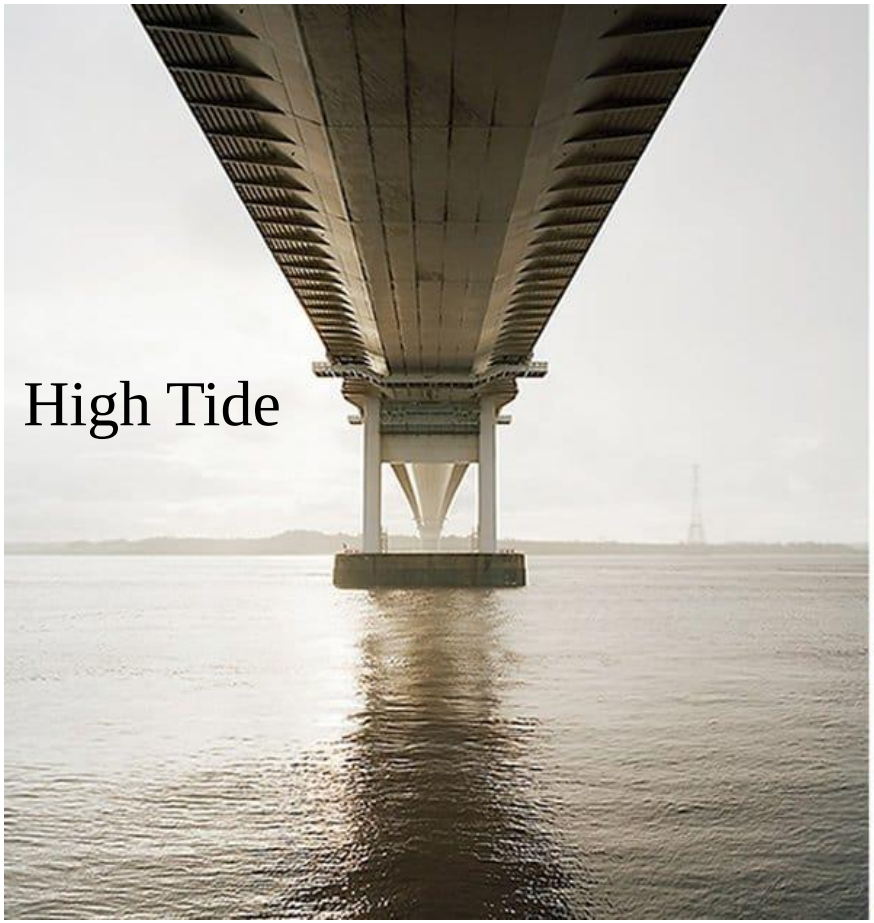
**Flood tide**: The incoming tide, water's elevation at the shoreline is increasing Flood tides occur from peak low tide to high tide.

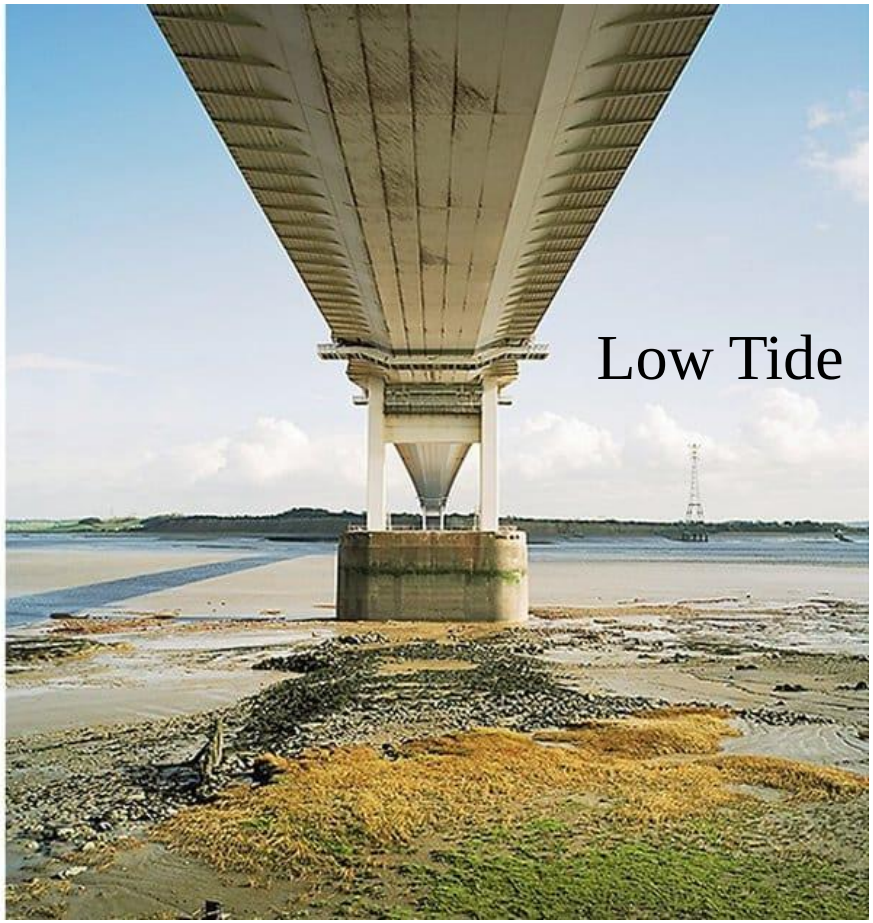

Low Tide
High Tide

Bay of Fundy (Nova Scotia) at high tide and low tide

Greatest change in tides on Earth




High Tide


Low Tide

At the same time…

The Earth's tides and the spin of the Earth causes the moon to move faster in its orbit and move farther away from the Earth over geologic time.

- Tidal acceleration
- The gravitational attraction of the tidal bulge and the Earth pulls the moon forward, making it accelerate in its orbit.

The moon's effect on the tides is gradually ***slowing the Earth's rotation*** over geologic time. This is called **tidal braking**.

- The friction of the rotating Earth's surface against the ocean water slows the Earth.
- The gravitational attraction of the moon onto the tidal bulge  and onto the spinning Earth itself "pulls" the Earth backward—pulls against the Earth's direction of rotation.

# Tidal braking and Tidal acceleration