Lecture 4

Motion of the Moon

- phases of the Moon
- Solar and Lunar eclipses
- tides

Time & Calendar

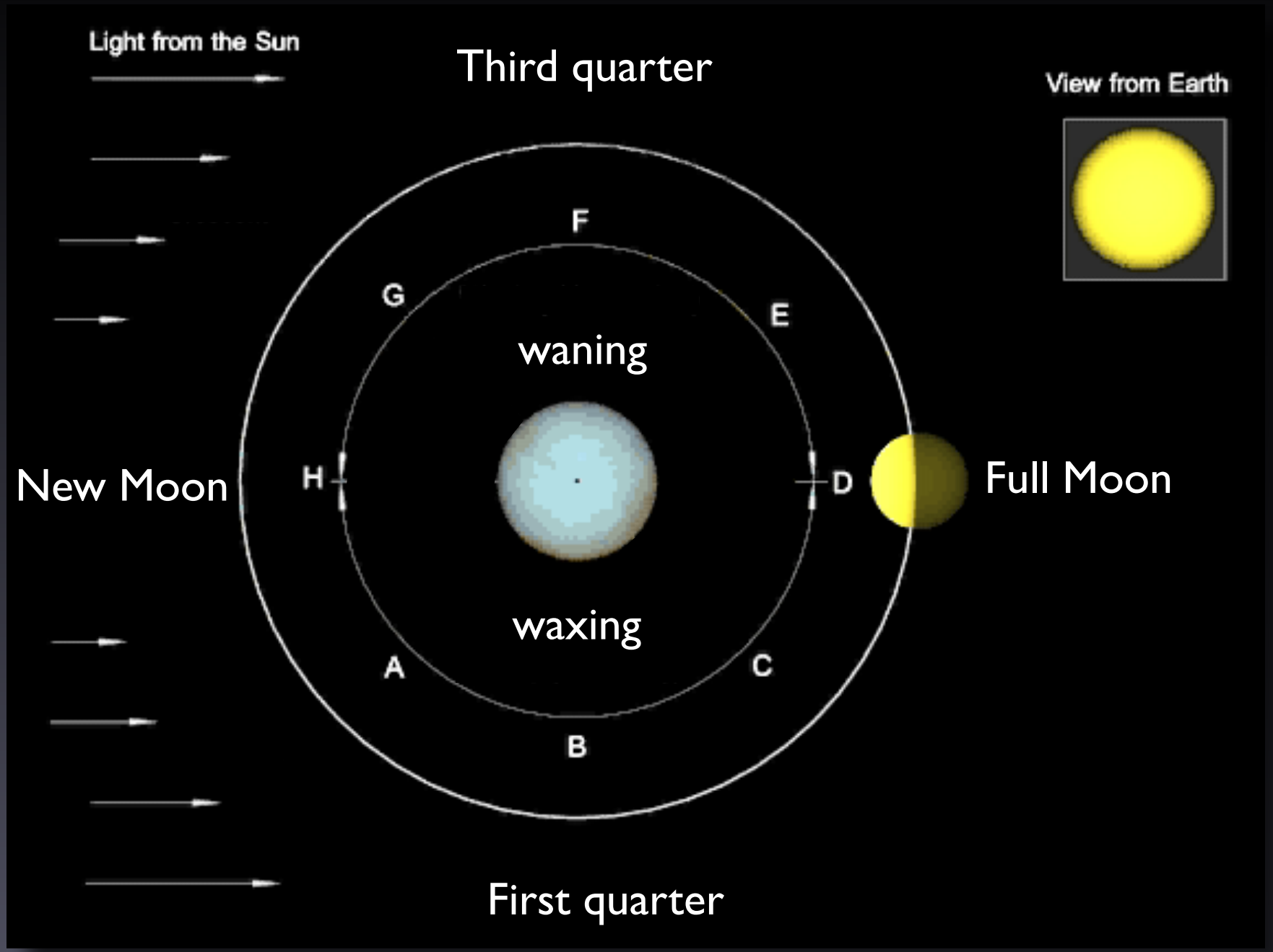
Properties of the Earth and Moon

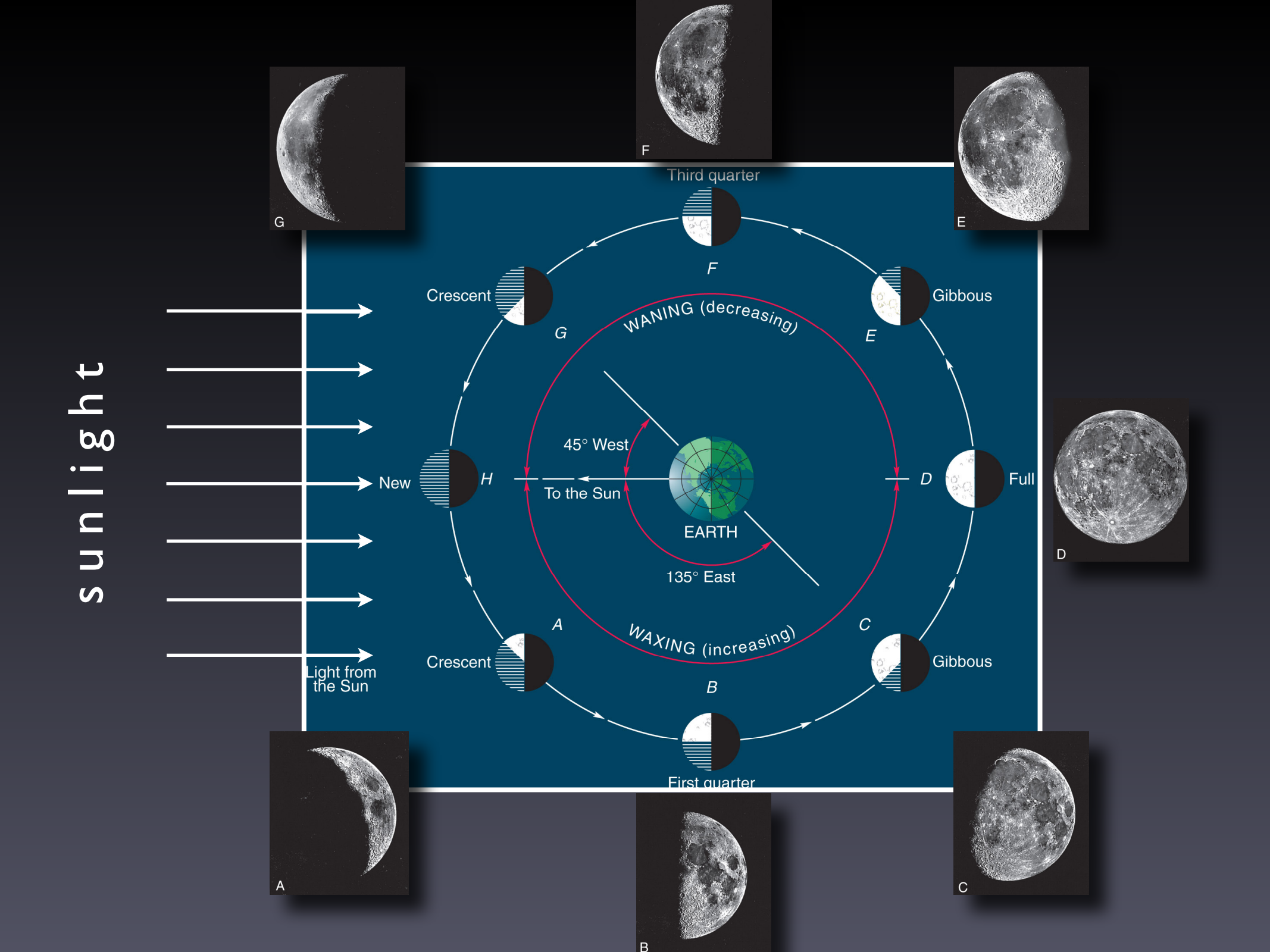
Koupelis : chapters 1 and 6
OpenStax : sections 4.3→4.7
8.1 and 8.5
9.1→9.4

Simple observations of the Moon

- The Moon reflects sunlight
- Displays phases with a period of 29.5 days
- Full Moon: opposite to the Sun
- Half Moon: 90 degrees from the Sun
- New Moon: same side as the Sun

Phases are caused by the illumination by the Sun

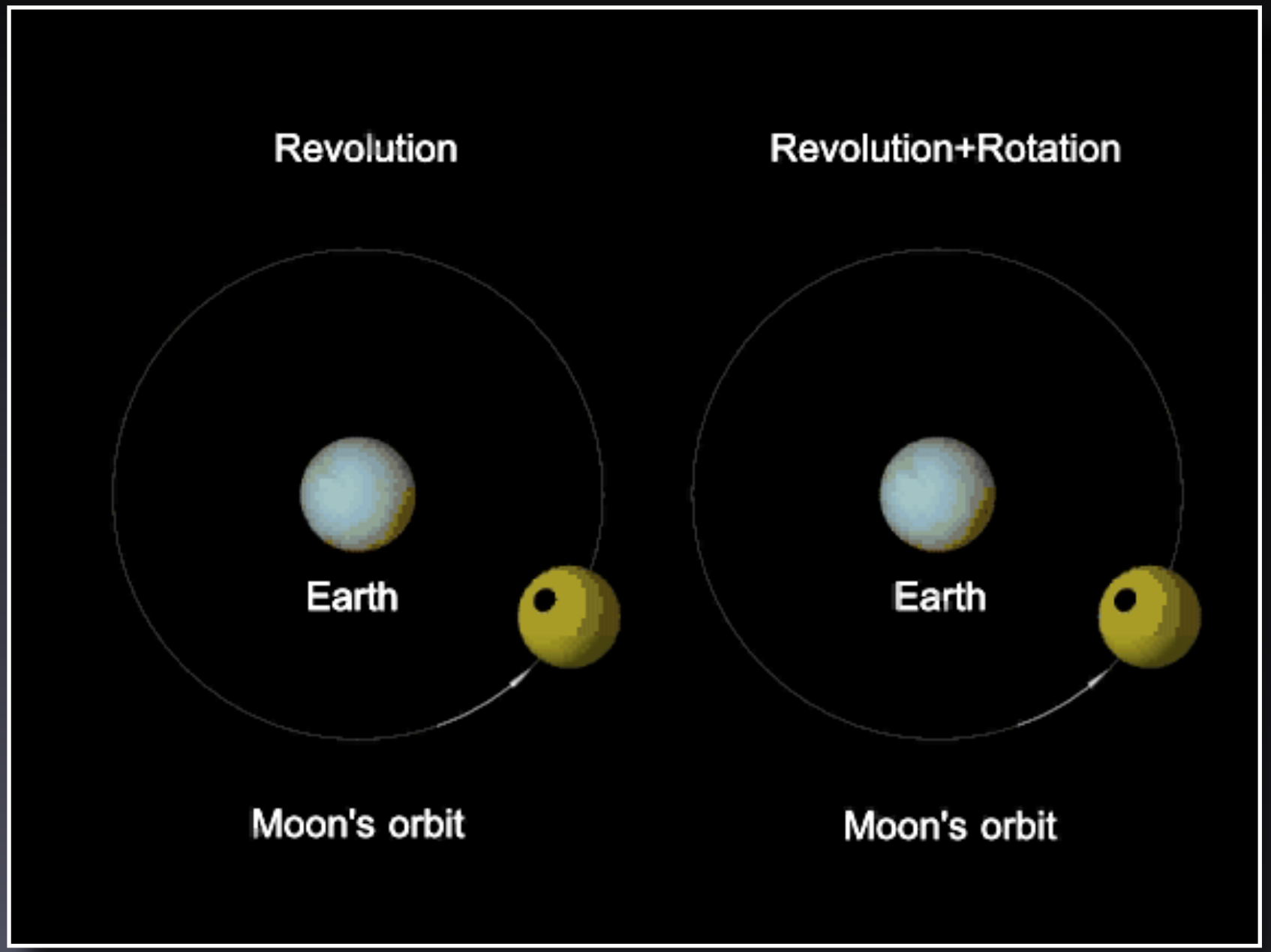



sunlight
Third quarter
F
Crescent
G
WANING (decreasing)
E
Gibbous
45° West
New
H
To the Sun
D
Full
EARTH
135° East
A
C
Crescent
WAXING (increasing)
Gibbous
B
First quarter
Light from the Sun
F
G
E
D
A
B
C

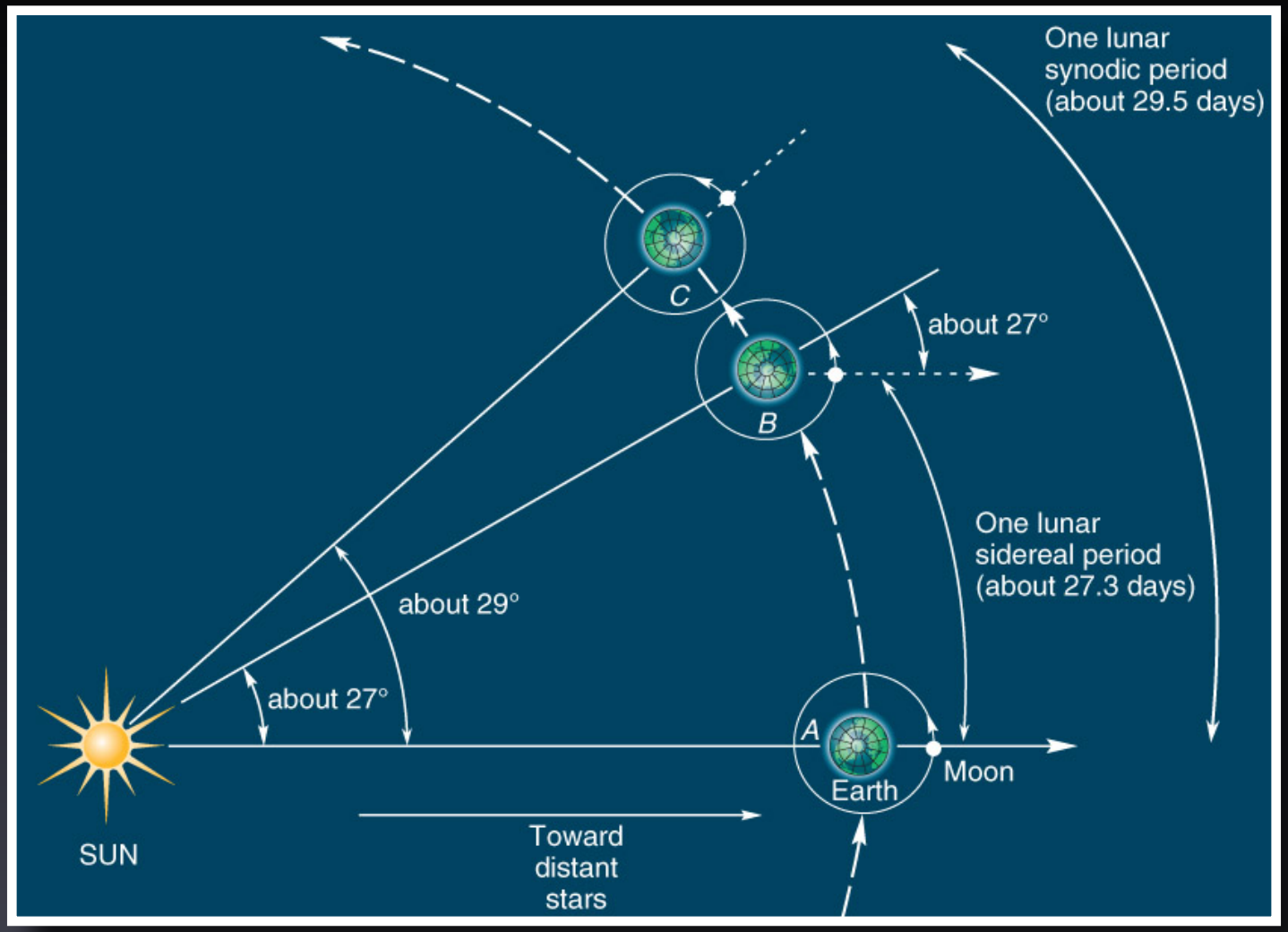
Simple observations of the Moon

- The Moon reflects sunlight
- Displays phases with a period of 29.5 days
- Full Moon: opposite to the Sun
- Half Moon: 90 degrees from the Sun
- New Moon: same side as the Sun
- Always displays the same hemisphere to the Earth

orbital period and rotation period are synchronised



Sidereal and Synodic months



Sidereal month: Moon reaches the same position wrt the stars (27.3 days)

Synodic month: Moon reaches the same position wrt the Sun (29.5 days)

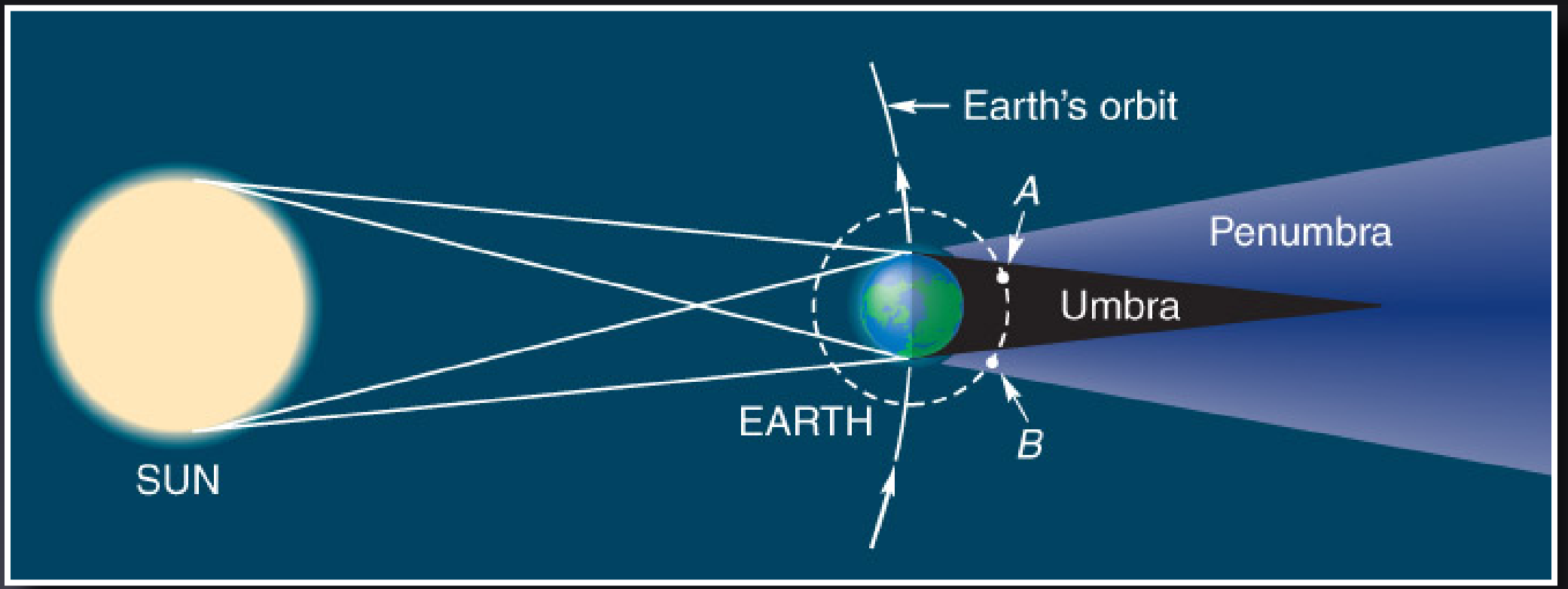
A second Full Moon in the same month: '*Blue Moon*'

Simple observations of the Moon

- The Moon reflects sunlight
- Displays phases with a period of 29.5 days
- Full Moon: opposite to the Sun
- Half Moon: 90 degrees from the Sun
- New Moon: same side as the Sun
- Always displays the same hemisphere to the Earth
- Sometimes the Moon undergoes an eclipse
- Lunar eclipses always at full Moon, but not every month!

Lunar eclipses

The Moon traverses the shadow cone of the Earth



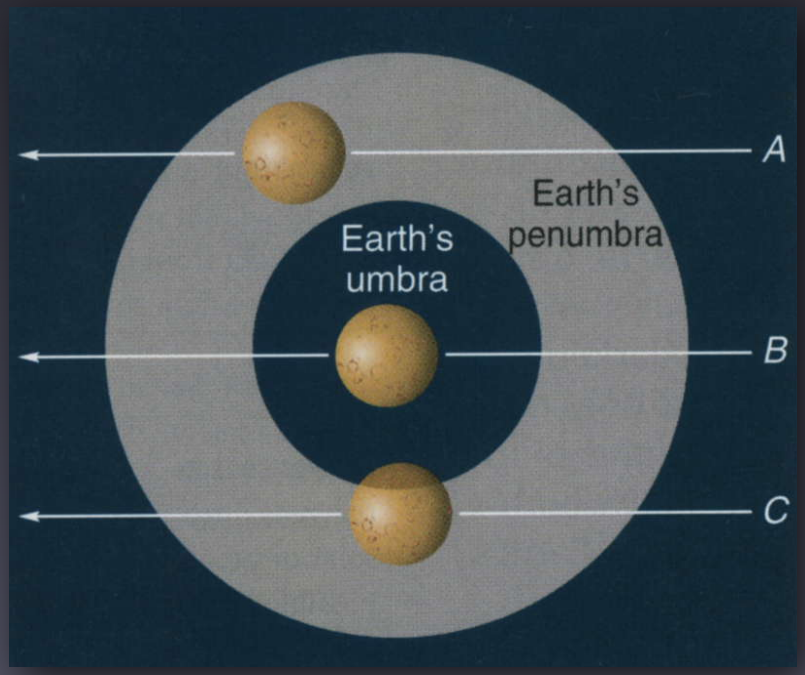
Umbra : area of the shadow cone from which the Sun is totally *in*visible.

Penumbra : area of the shadow cone from which the Sun is partially visible.

The eclipsed Moon (composite)

Visible from anywhere on Earth where the Sun is below the horizon.

3 kinds of Lunar eclipses

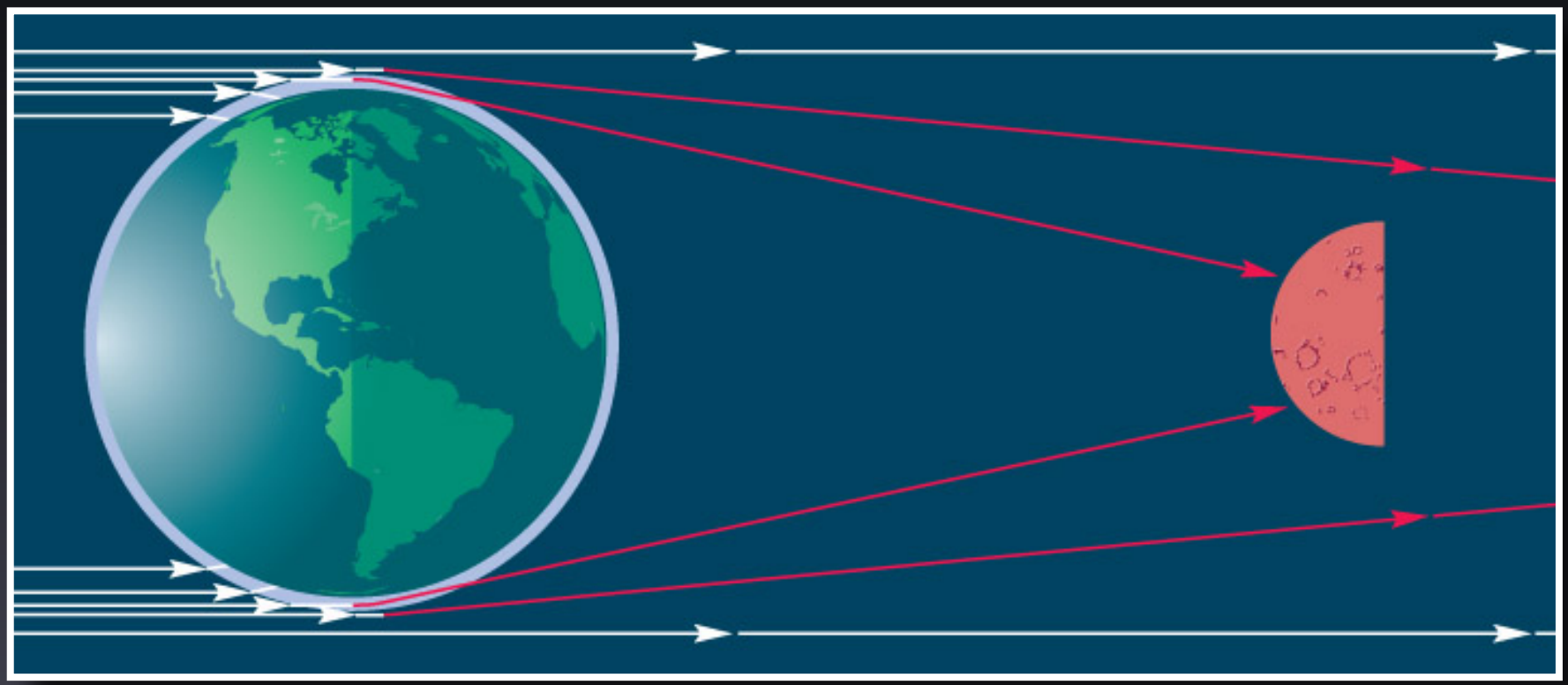


A : eclipse in the Penumbra

B : total eclipse of the Moon

C : partial eclipse of the Moon

The Earth atmosphere bends (refracts) the sunlight like a lens, and filters out the blue light.

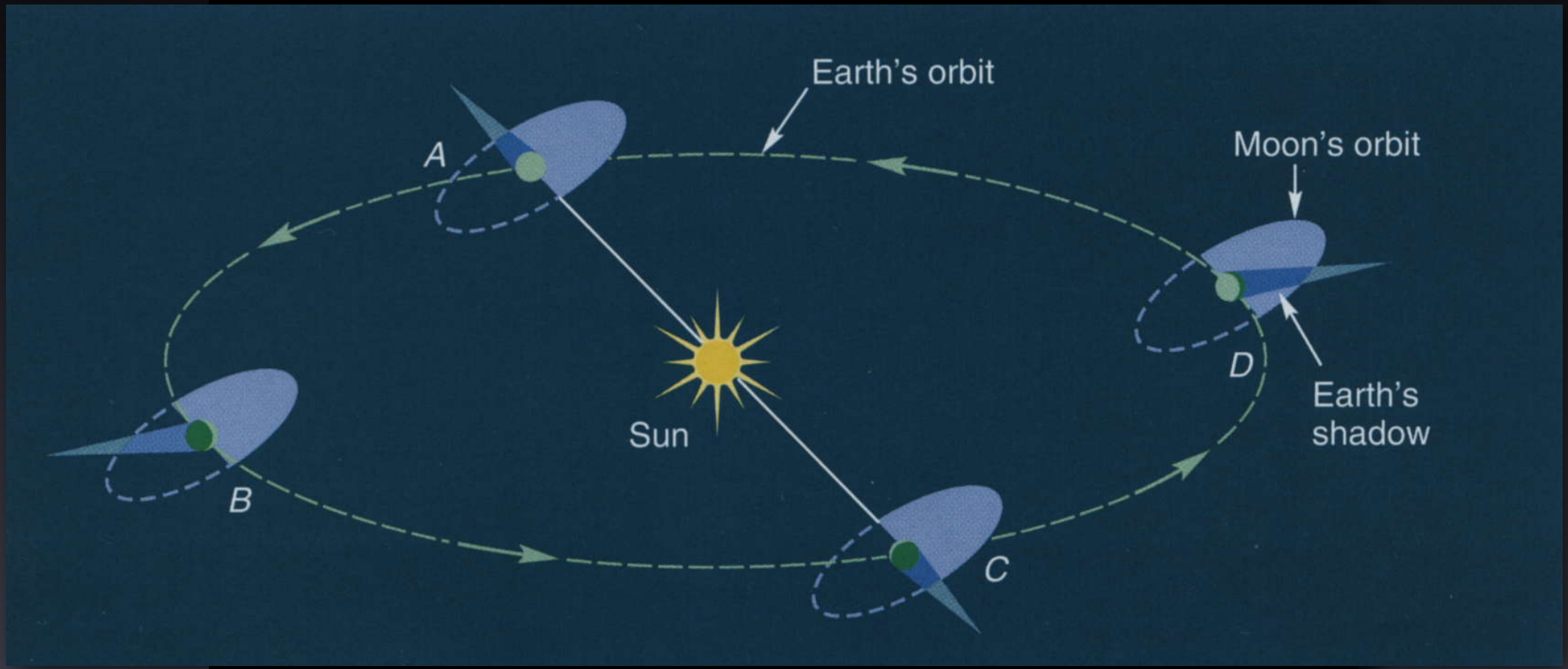


The Moon displays a dark red/copper glow during a total Lunar eclipse: *'Blood Moon'*

Simple observations of the Moon

- The Moon reflects sunlight
- Displays phases with a period of 29.5 days
- Full Moon: opposite to the Sun
- Half Moon: 90 degrees from the Sun
- New Moon: same side as the Sun
- Always displays the same hemisphere to the Earth
- Lunar eclipses always at full Moon, but not every month!
- Path along the sky deviates from the ecliptic

A Lunar eclipse does not occur every month!



The orbit of the Moon around the Earth is inclined by 5 degrees with respect to the orbit of the Earth around the Sun (ecliptic).

The Moon orbit only crosses the Earth-Sun line during two periods

By the way, the orbit of the Moon is also elliptical.

Libration

'Super Moon'

analemma of the Moon

31 January 2018:

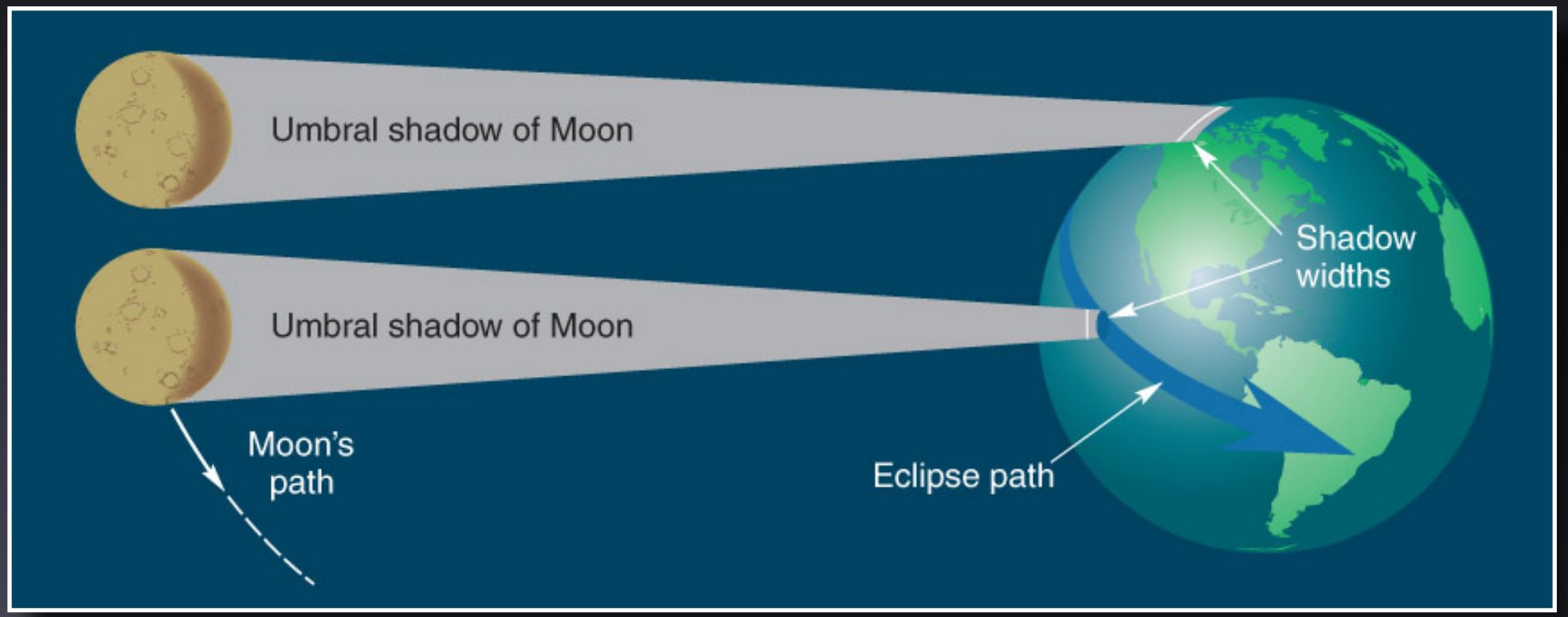
a *Super Blue Blood Moon*

Simple observations of the Moon

- The Moon reflects sunlight
- Displays phases with a period of 29.5 days
- Full Moon: opposite to the Sun
- Half Moon: 90 degrees from the Sun
- New Moon: same side as the Sun
- Always displays the same hemisphere to the Earth
- Path along the sky deviates from the ecliptic
- Lunar eclipses always at full Moon, but not every month!
- Solar eclipses at new Moon are less frequent

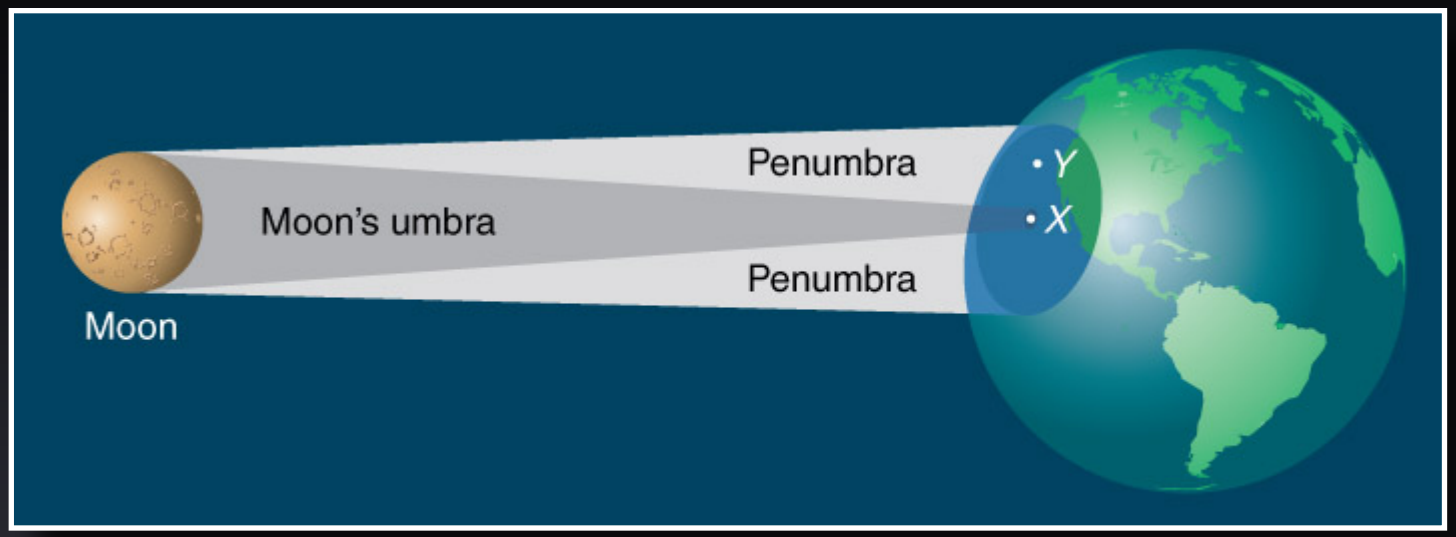
Solar eclipses

The shadow of the Moon moves across the Earth

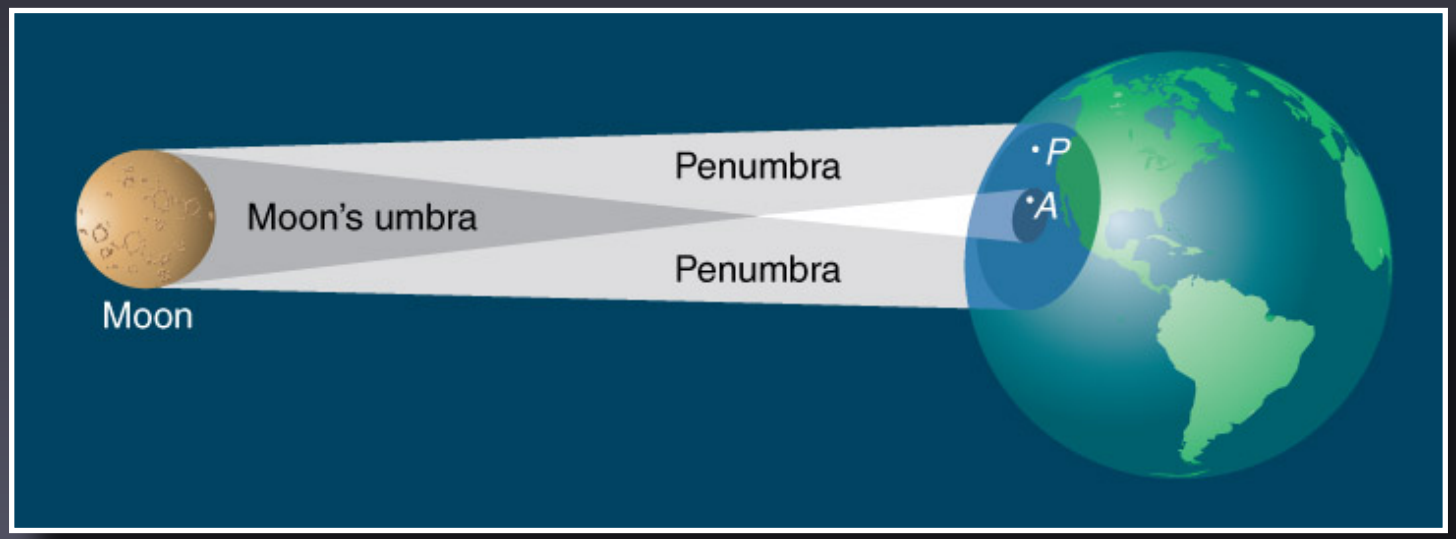


A total solar eclipse is only visible from a narrow strip on Earth.

Total Solar eclipse:
the umbra of the Moon's shadow 'touches' the Earth

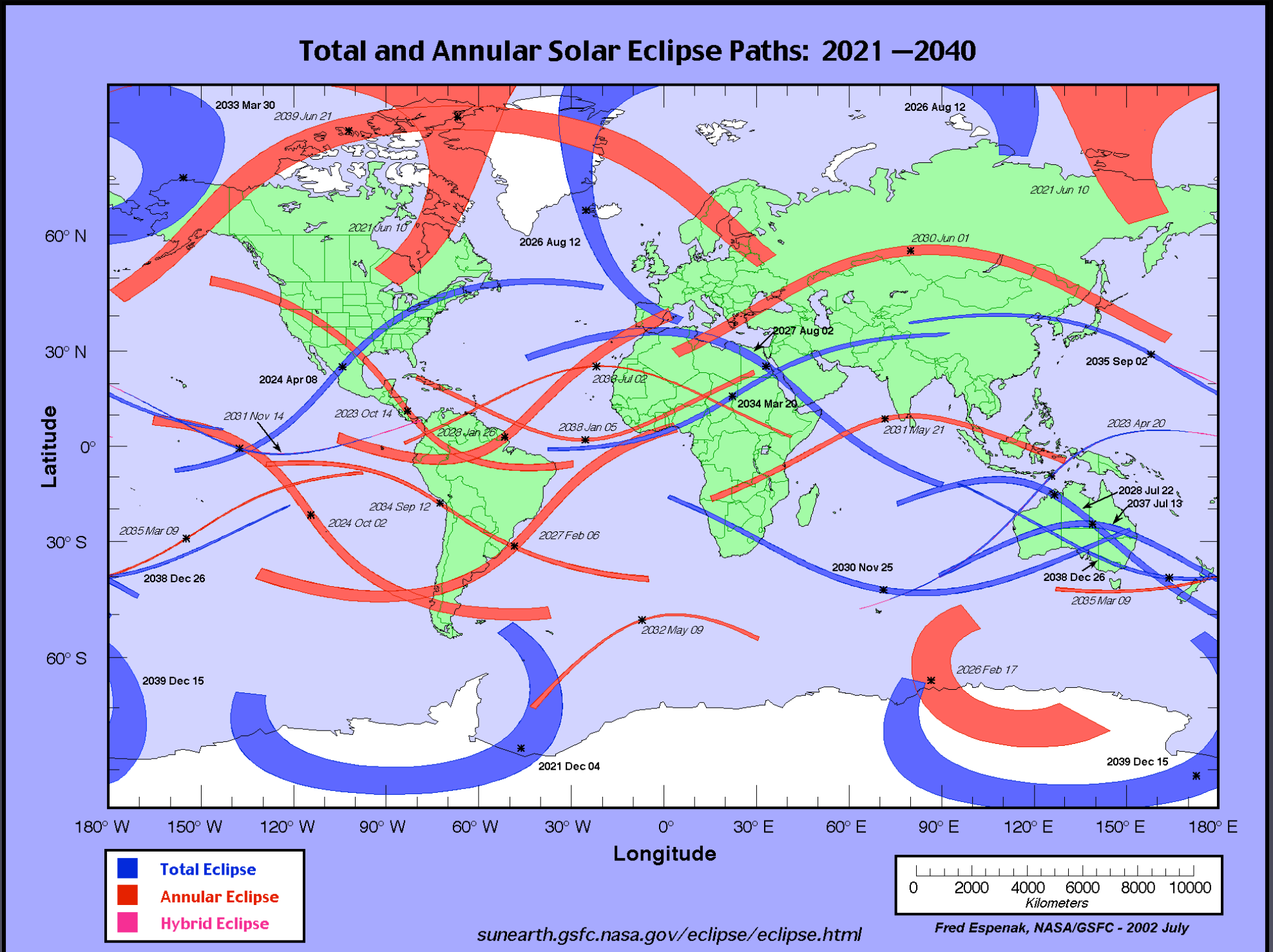


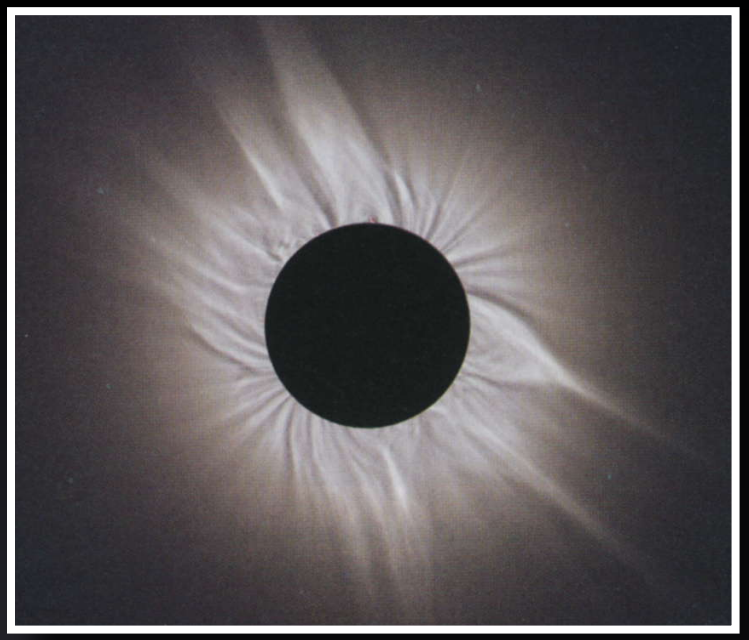
Annular Solar eclipse:
the umbra of the Moon's shadow does not 'touch' the Earth



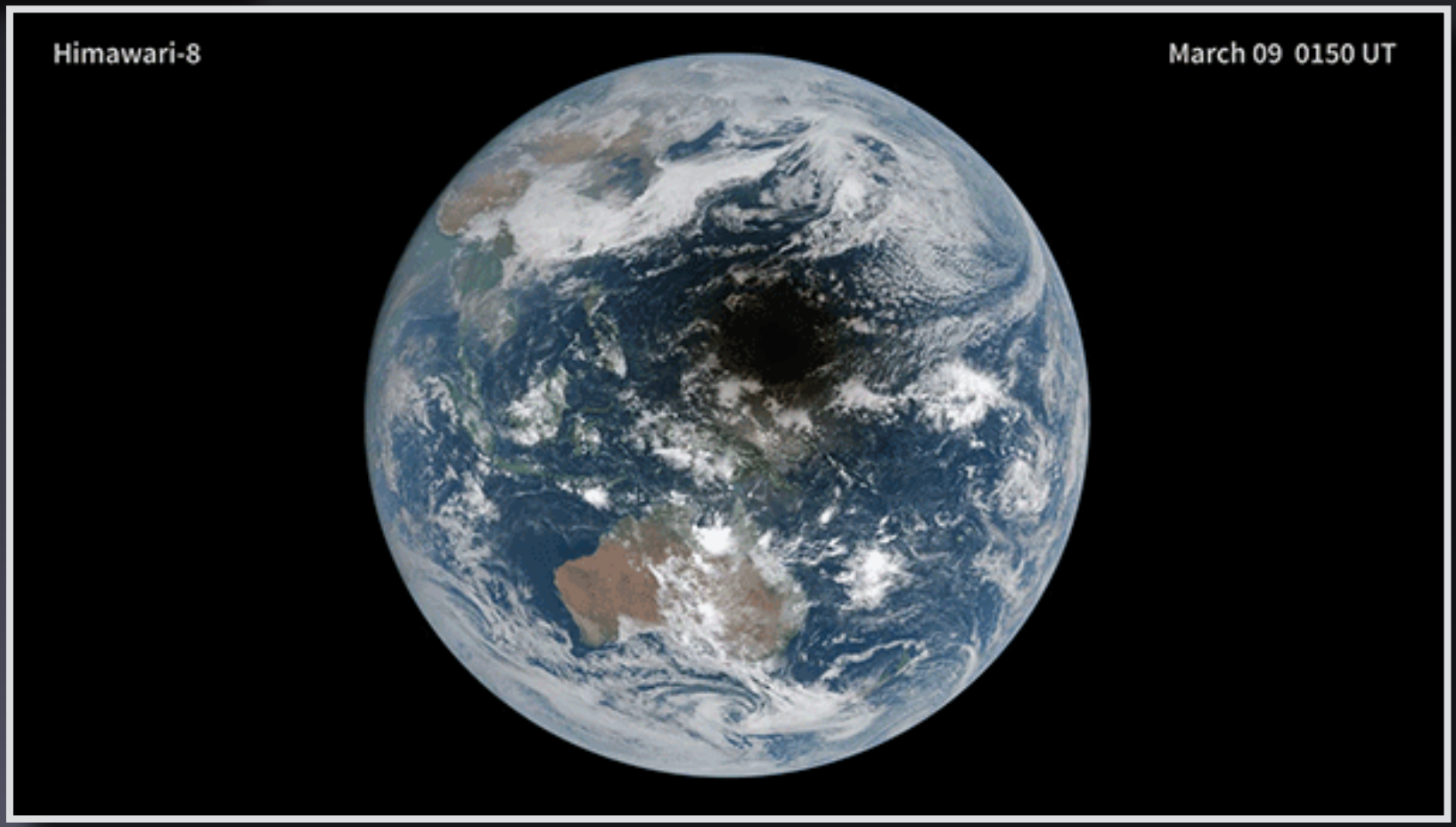

UMBRA
PENUMBRA
75°N
60°N
45°N
60°W
45°W
30°W
15°W

Predicted paths of total and annular Solar eclipses.



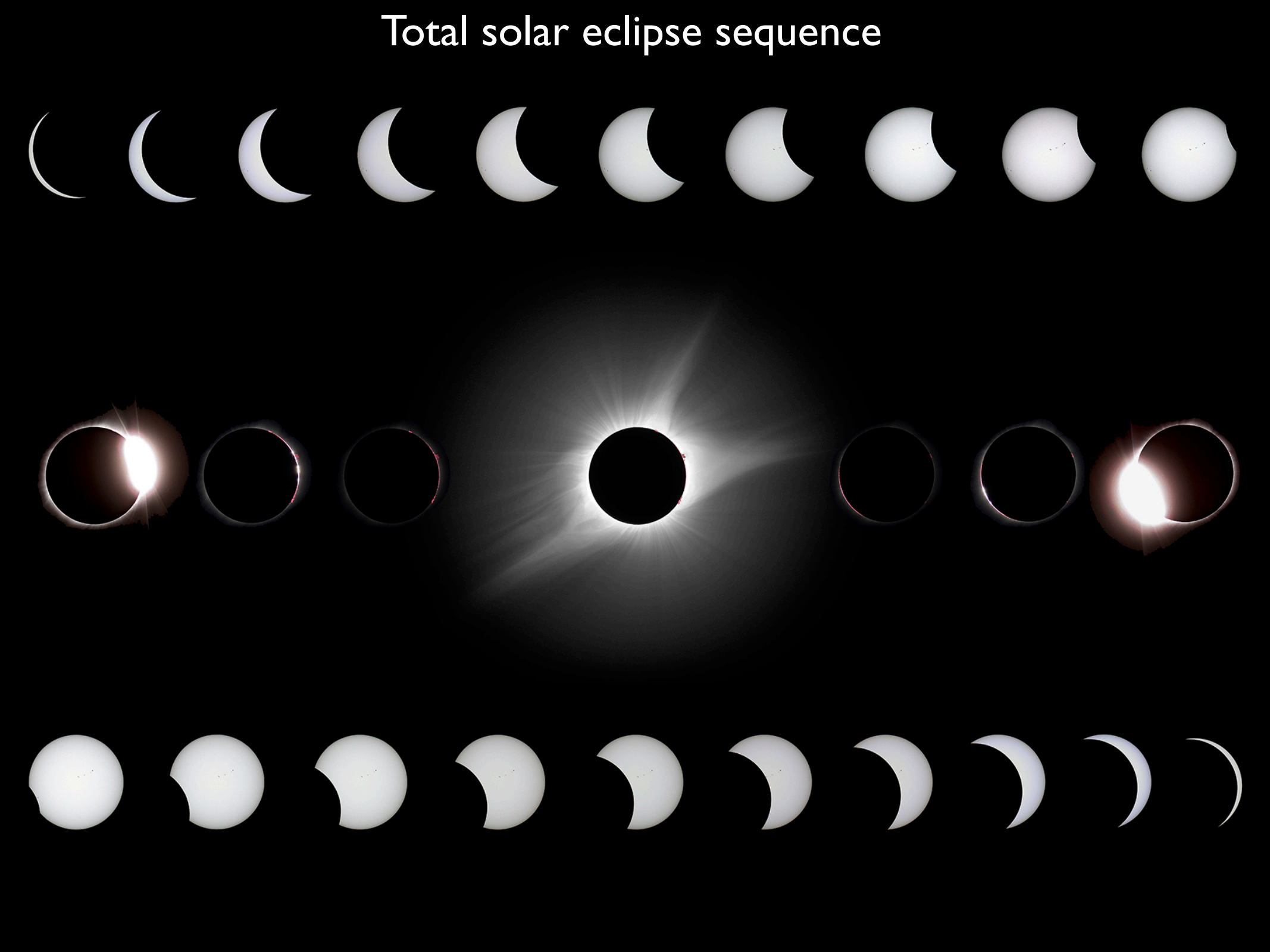


The Corona of the Sun
becomes visible
for a few minutes.



The shadow of
the Moon seen
from space.

Total solar eclipse sequence



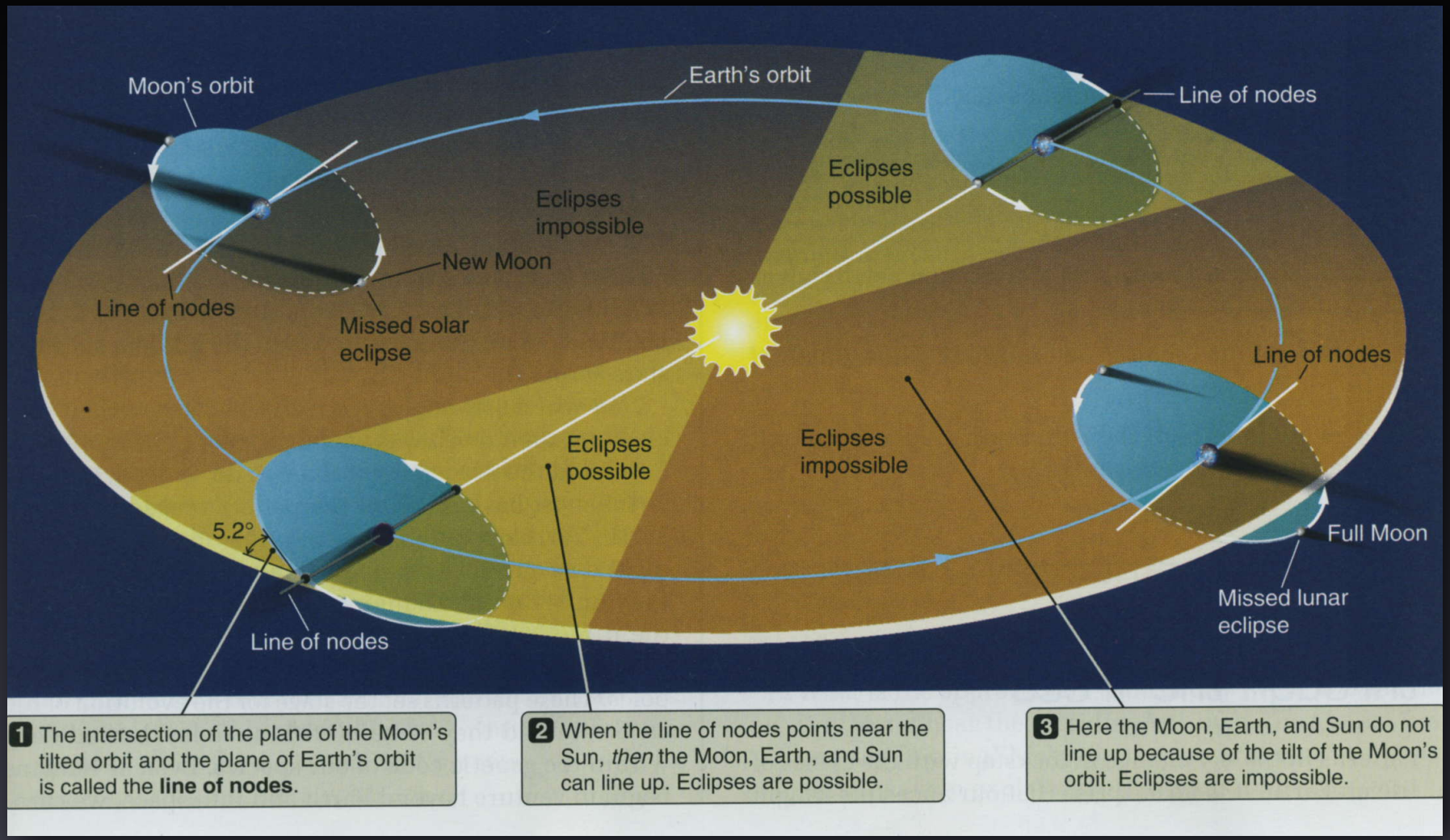
Total solar eclipse sequence

'Diamond ring'

Baily's Beads

Totality

Eclipse seasons

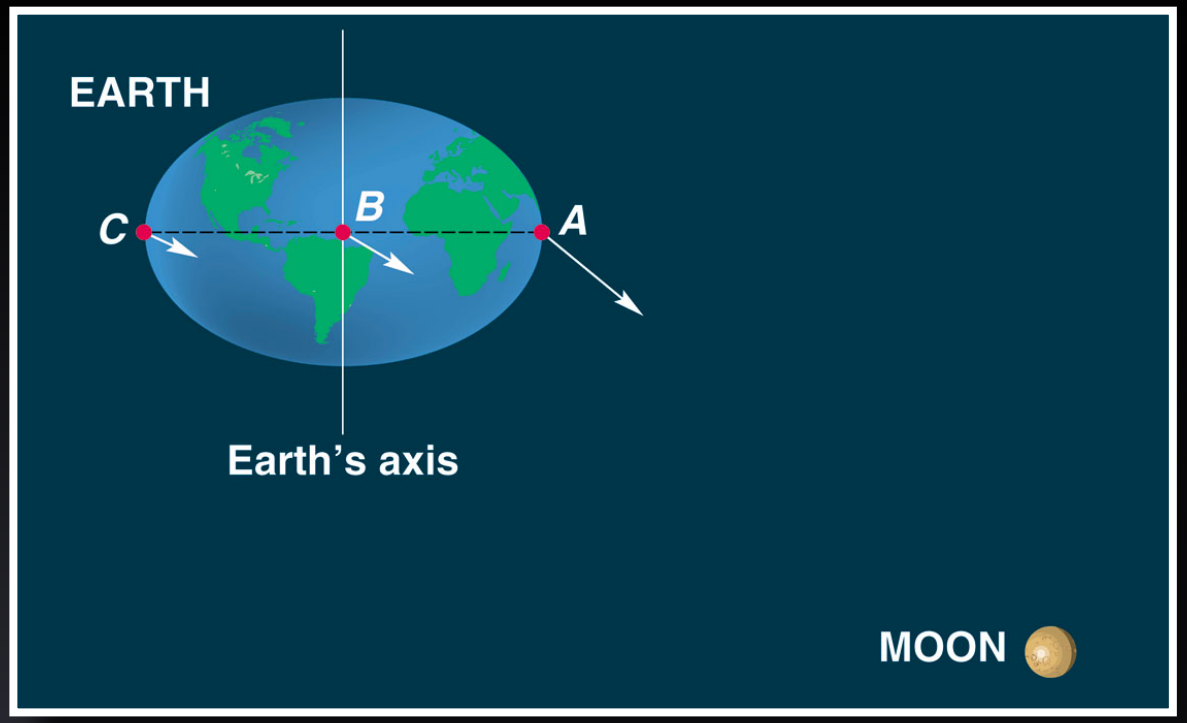


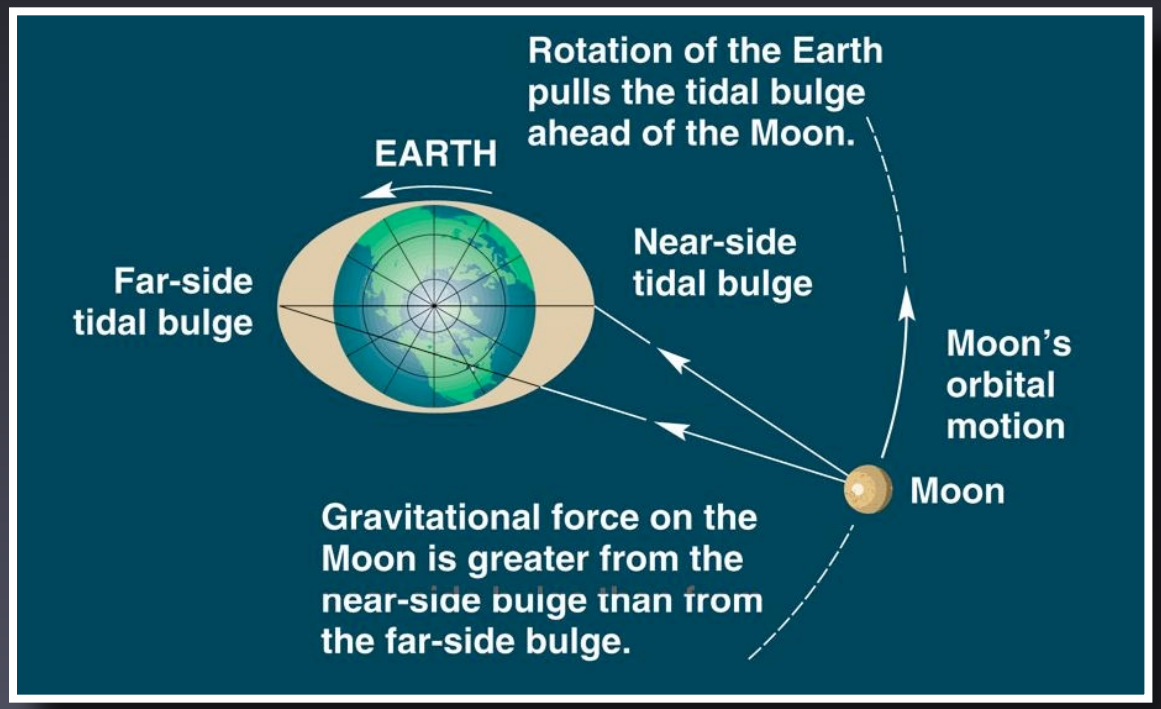
Eclipses only happen when line-of-nodes points toward the Sun.

Eclipse pattern repeats every 11 months, not every 12 months.
This is a consequence of the precession of the Moon's orbit with a period of 18.6 years: The line-of-nodes rotates over 19.4 degrees every year.

Tides

caused by *differential* gravity





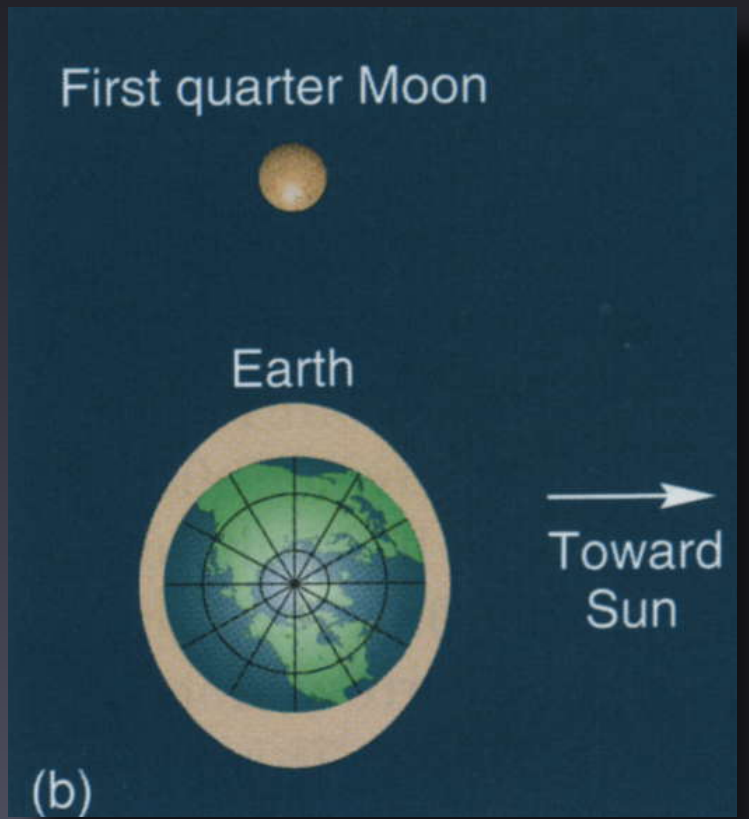
Because the Earth rotates faster than a Lunar period, the ocean's waters are dragged forward by the Earth.

Compared to the Moon, the Sun's gravity 'pulls' 180x harder on the Earth, but the Sun is also 390x more distant.

The differential gravity from the Moon is 2.2x stronger than that from the Sun.

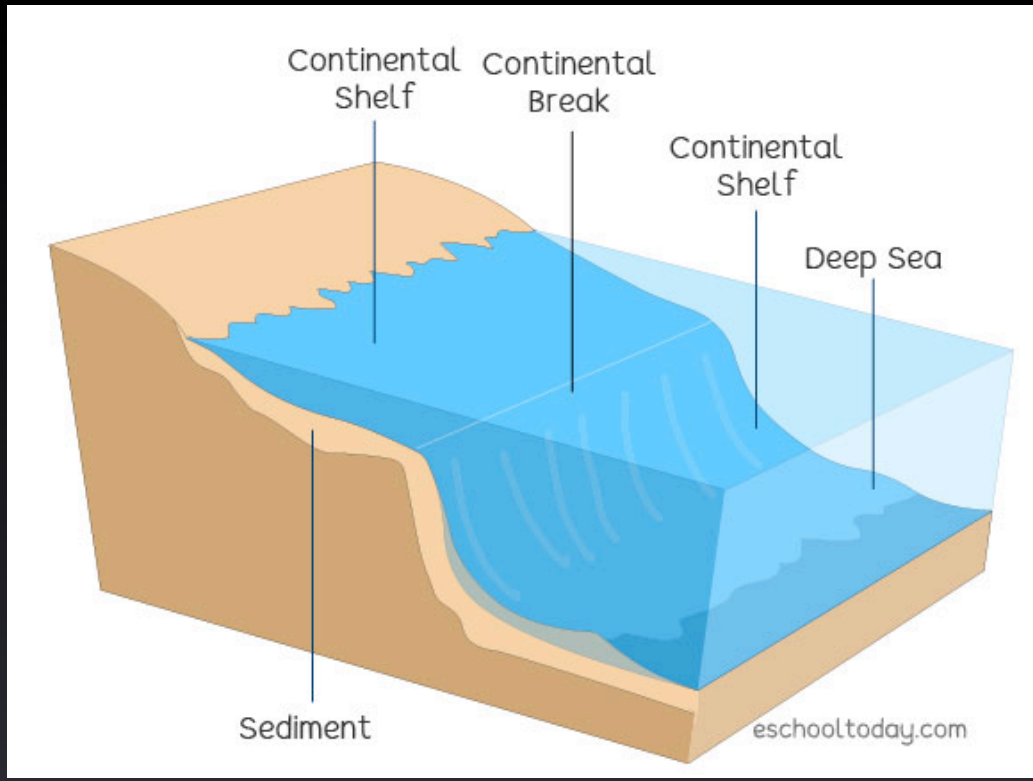
spring tide

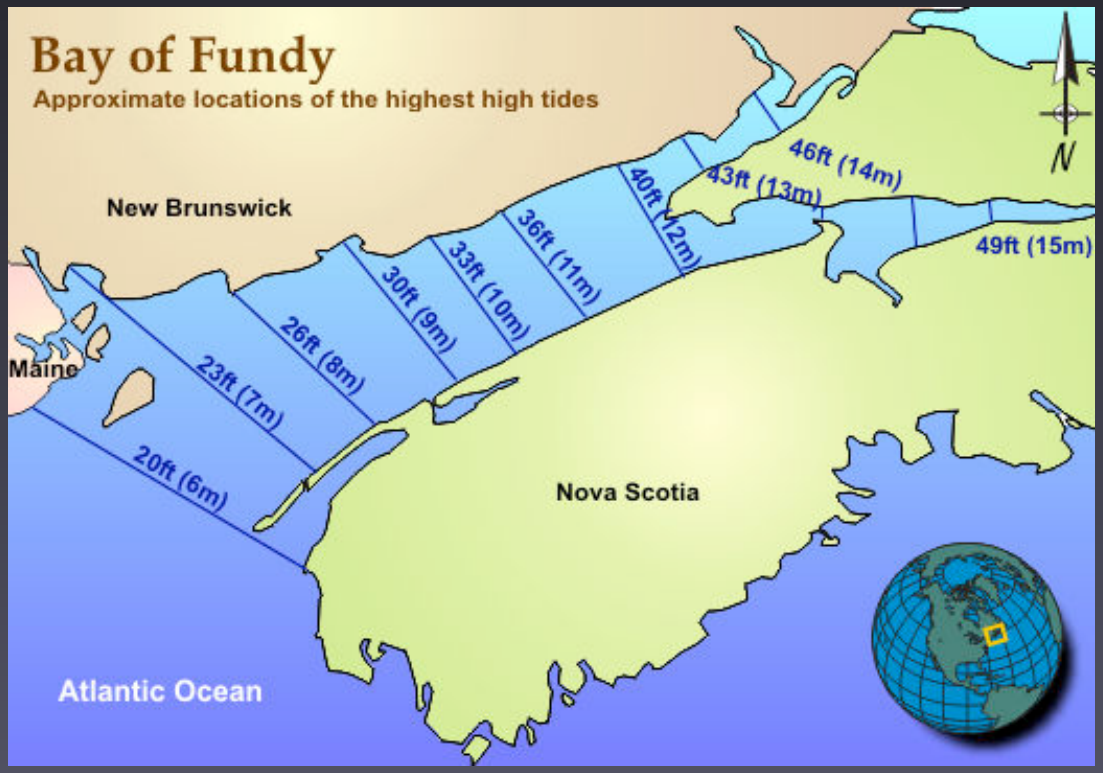
neap tide



Tides may be larger than just ~1m

Water moving into shallow areas => pushed up to greater height

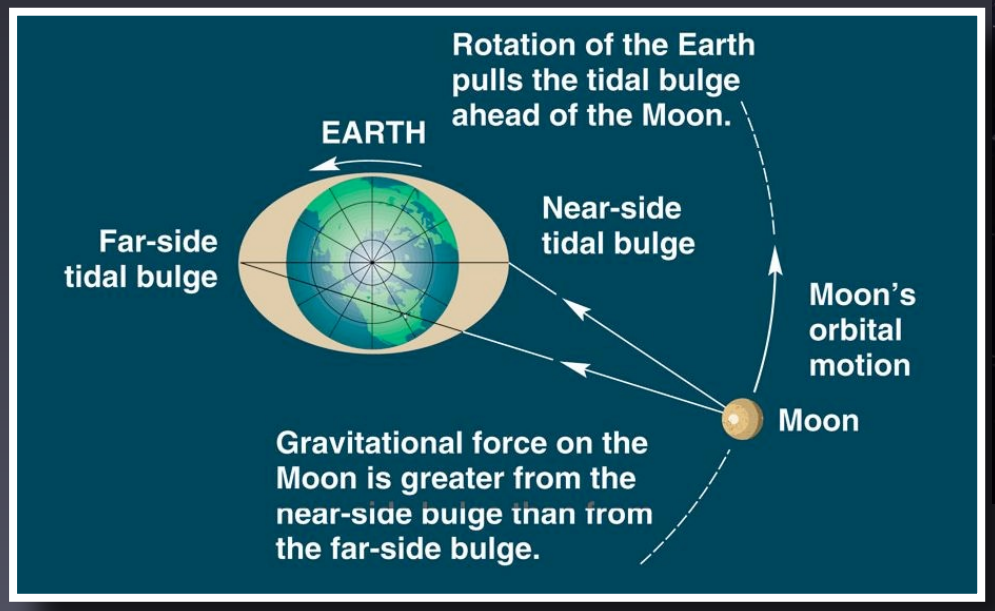




Narrow bay: Resonance

Due to friction, the Earth rotation slows down

And the Moon moves further away from the Earth.



Time

&

Calendar

Seasons & constellations

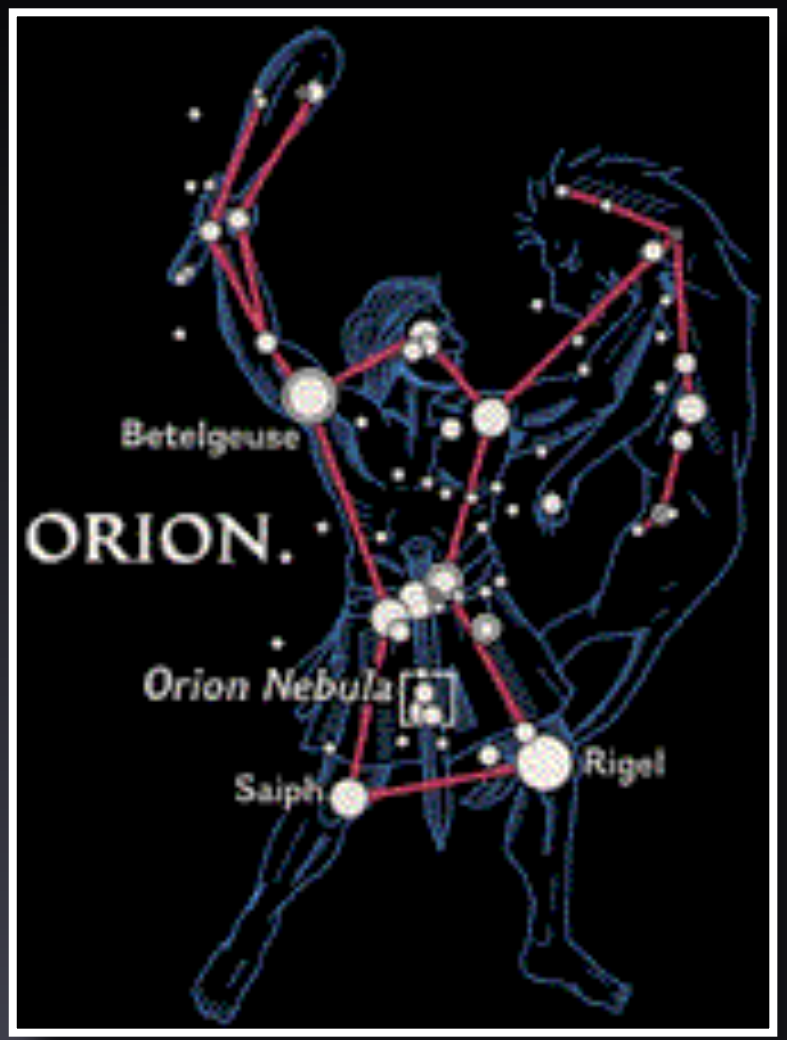
⇒ concept of a year

Planets

⇒ concept of a week

Sun

⇒ concept of a day

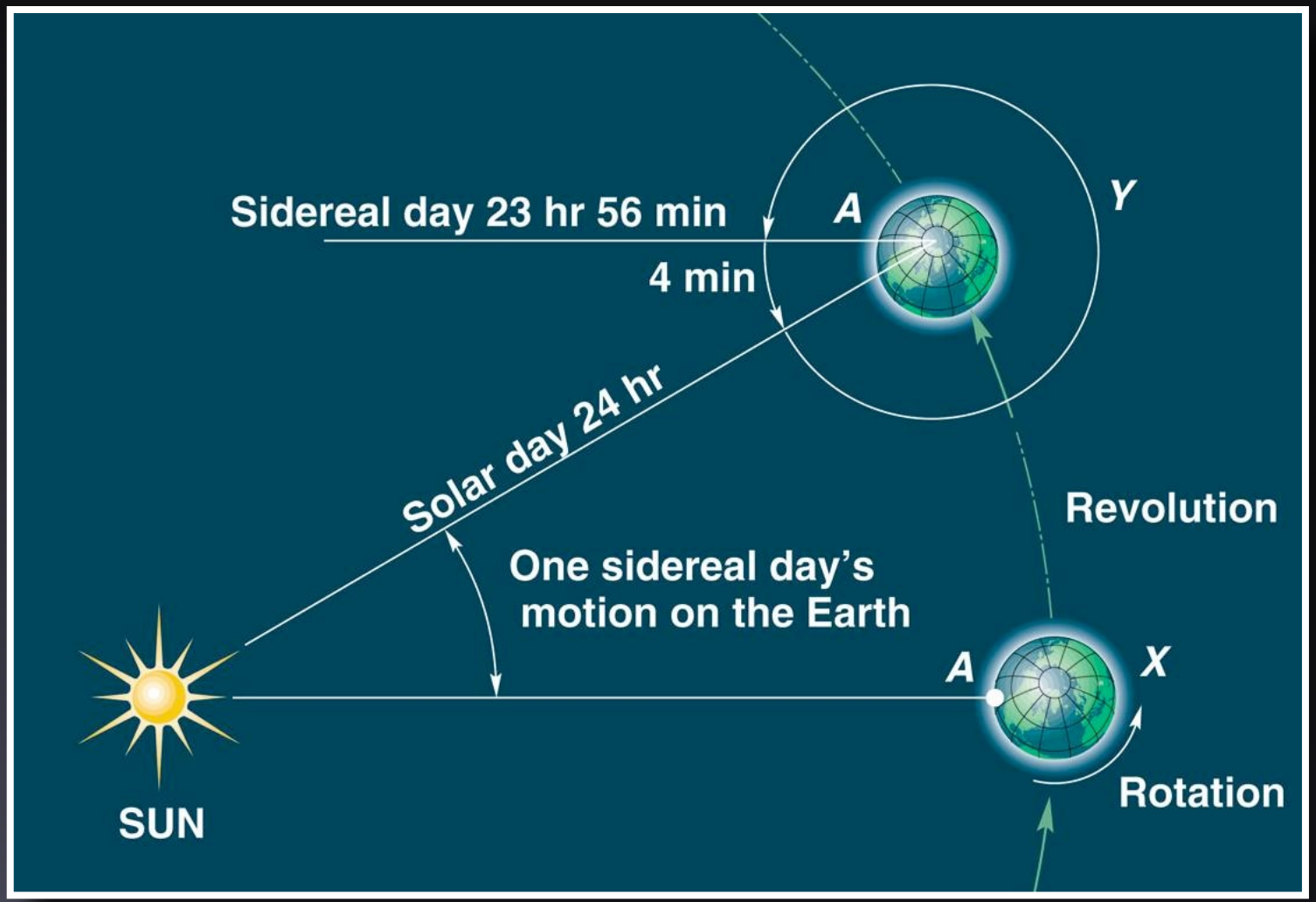


B.t.w.

Sunday	- Sun
Monday	- Moon
Mardi	- Mars
Mercredi	- Mercury
Jeudi	- Jupiter
Vendredi	- Venus
Saturday	- Saturn

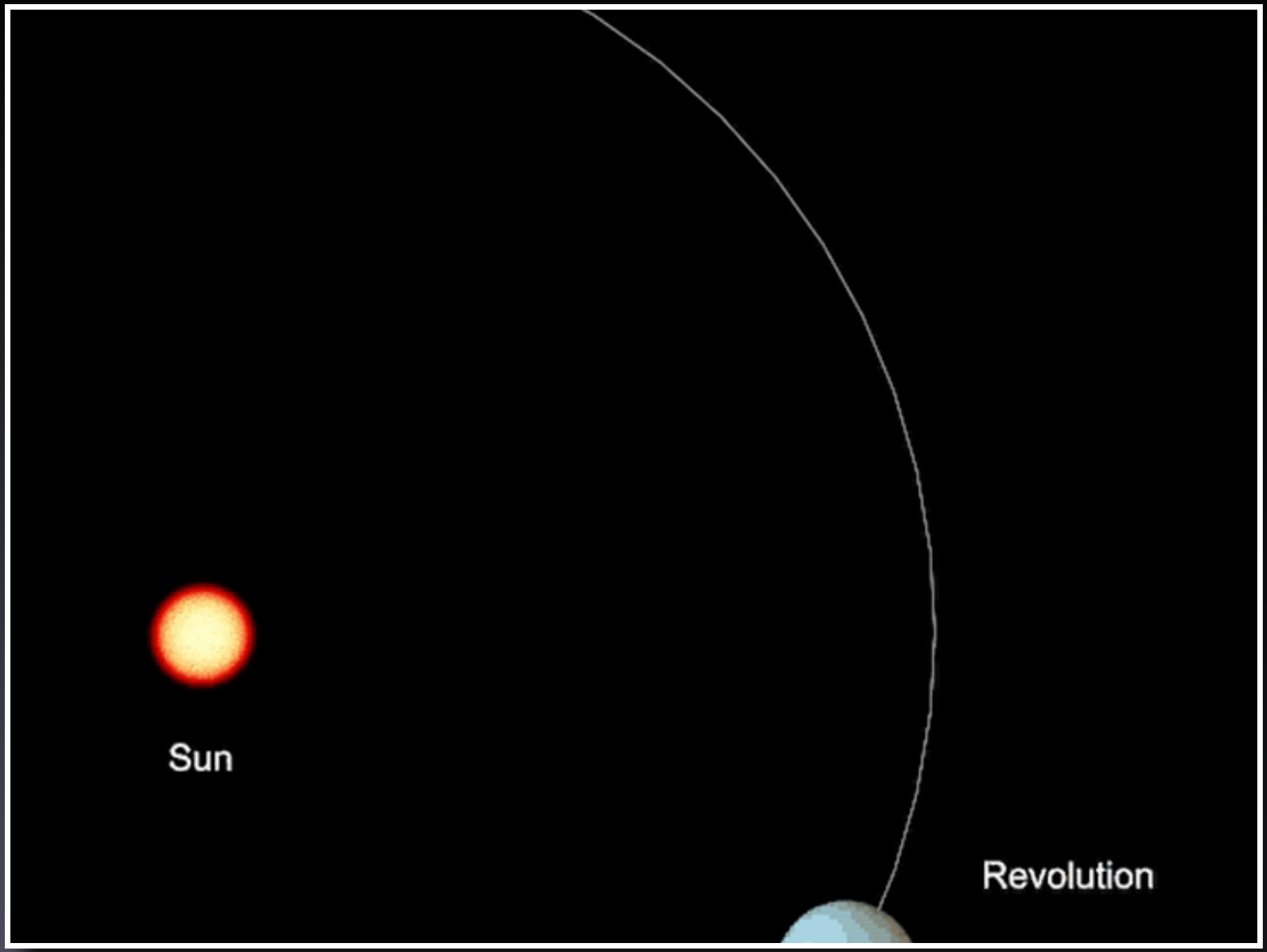
Sidereal time vs Solar time

Distinguish sidereal time from (mean) Solar time.



A sidereal day is shorter than a Solar day!

Stars rise at the same time on a sidereal day, but shift in time on a Solar day


Sun
Revolution

Note that the Earth is further from the Sun in July than in January.
Therefore, a Solar day in January lasts longer than a Solar day in July.
→ *equation of time*!

Analemma

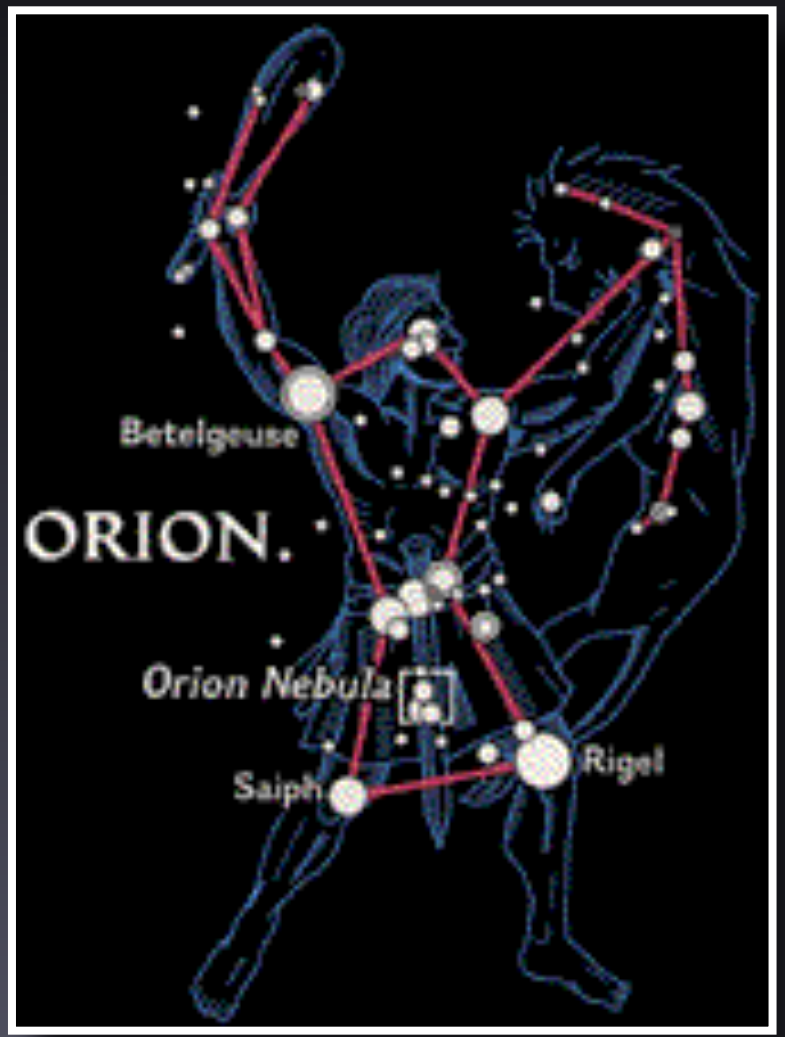
The result of:
- obliquity of the Earth axis of rotation
- elliptical orbit of the Earth

Calendars

Calendars are based on observations in the sky:
Day => Sun
Month => Moon
Year => Stars

... But these are not easily
collected into one whole

Day: 1.000 days
Lunar month: 29.5306 days
Stellar year: 365.2422 days



Months

The Moon revolves around the Earth in 29,5 days (synodic month).
Consequently, 12 MONths almost make up a year, but not quite:
12 x 29.5 = 354 days

Some 11 extra days are required to fit 12 months in 1 year.
→ distribute these extra days over the months.

Calendars

Early calendars:
Stonehenge?

Mayan calendar: days, and movement of planets

Chinese calendars: Include 12 year cycle of Jupiter. Lunar years.

Julian calendar: no Lunar month; leap year

Leap year

The Julian kalender was replaced in 1582 by the Gregorian calender.
This fixed the error due to the definition of a Julian year as 365.25 days.

Let's engage in some geosciences

What is the Earth?
What is the Moon?
(Geologically)
And how do we know?

The Earth

Mass and volume yield an average density $\langle\rho\rangle$

$\langle\rho\rangle = 5.52\ gr/cm^3$

This is significantly more dense than the surface material,
water ($\langle\rho\rangle = 1.0\ gr/cm^3$)
rocks ($\langle\rho\rangle = 3.2\ gr/cm^3$)

the Earth contains a core of iron and nickel
($\langle\rho\rangle = 12.5\ gr/cm^3$)

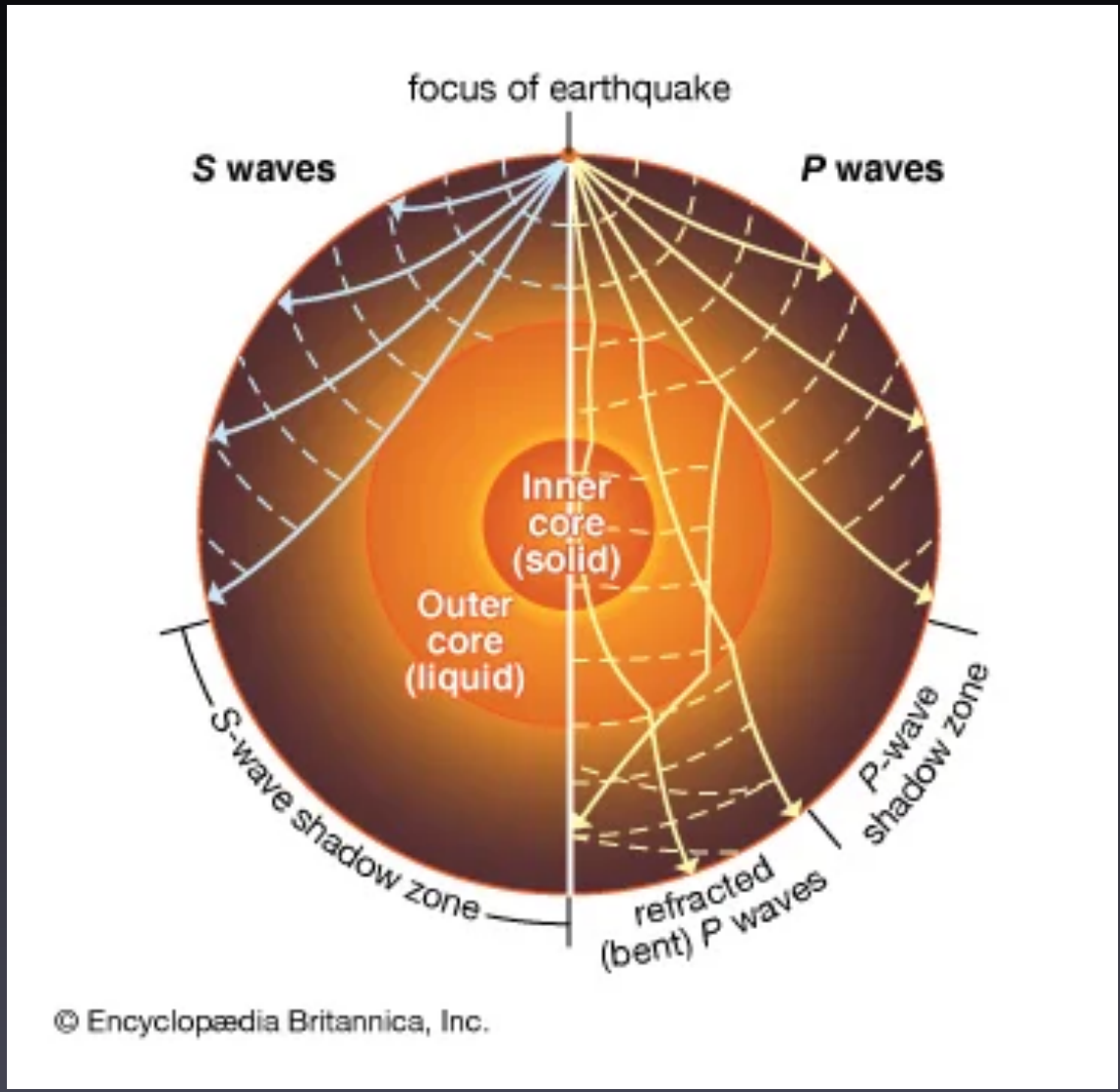
Seismological research has revealed:

Waves go faster when density is high

Dense core

Seismic S-waves cannot go through liquids =>
The outer core is liquid

We have a solid inner core

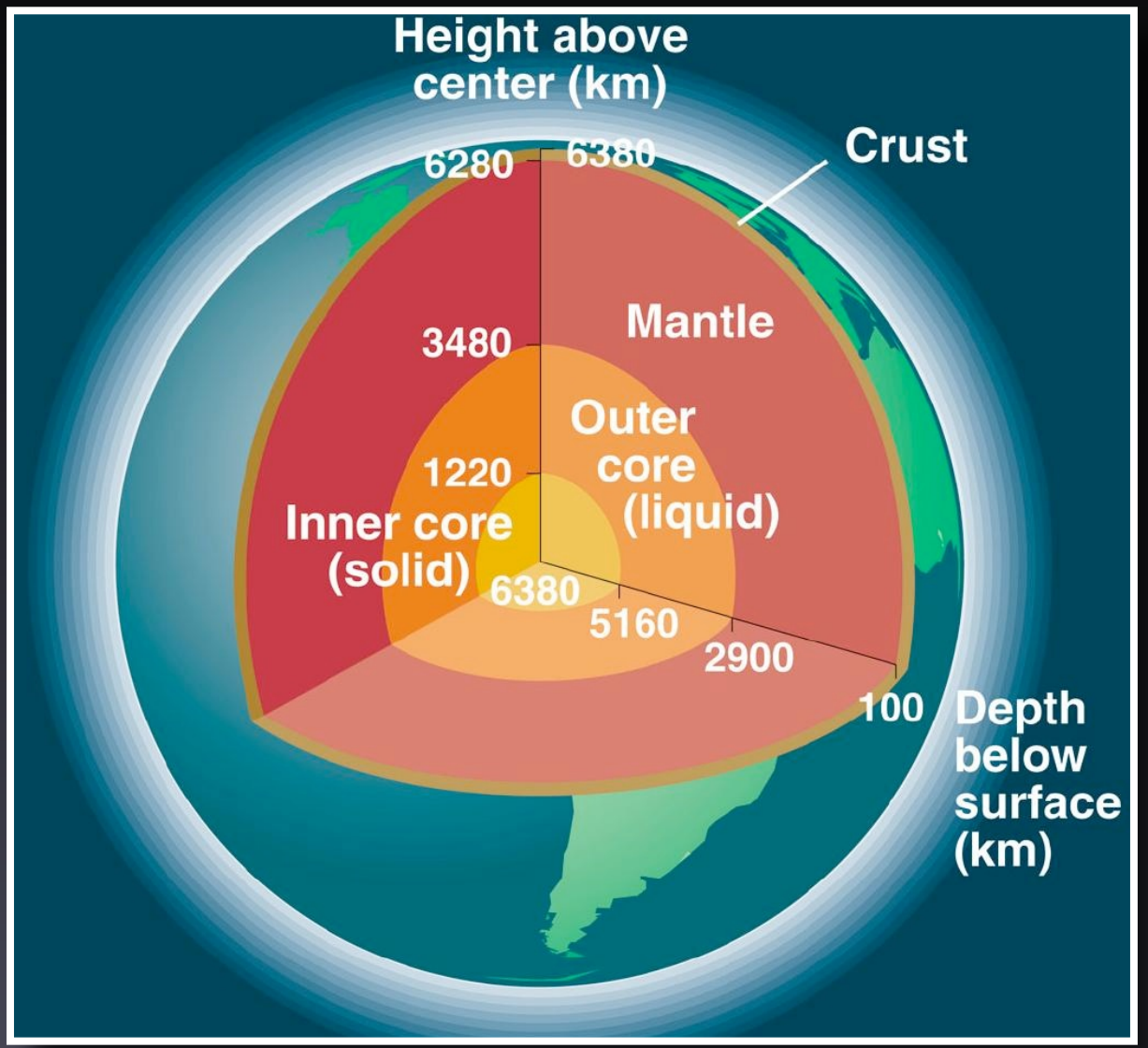


Seismological research has revealed:

There is a liquid outer core below the mantle; the inner core is solid.

The crust is relatively thin (7 - 70 km)

Most of the Earth is a solid rocky mantle

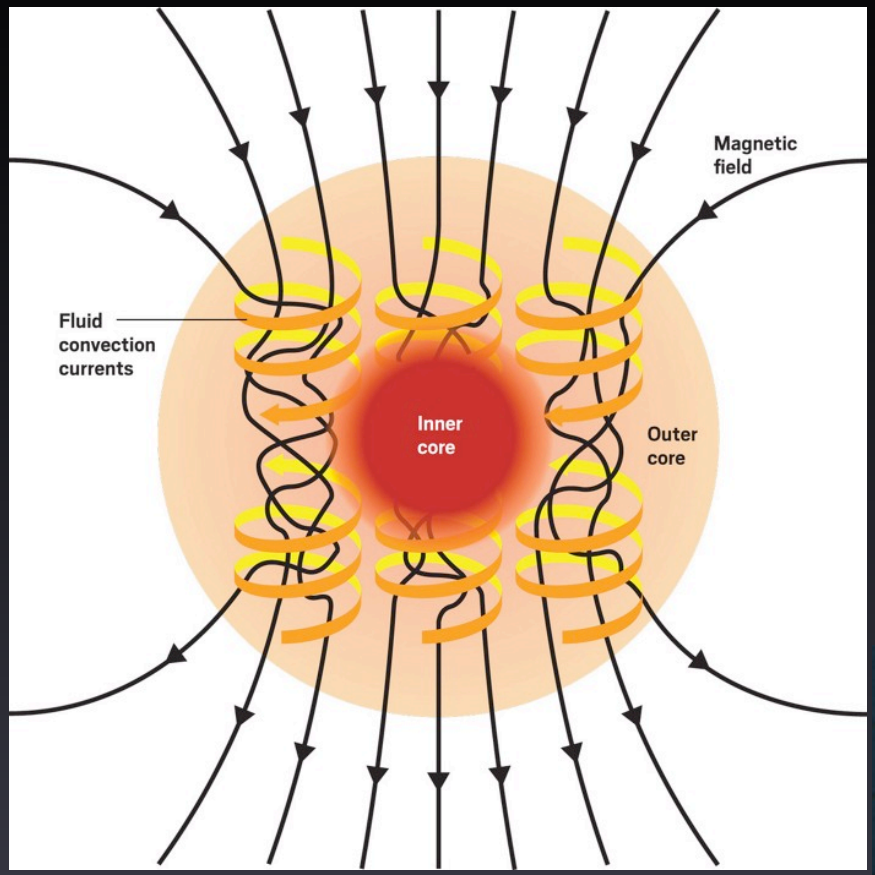


Furthermore, the Earth retains an atmosphere!

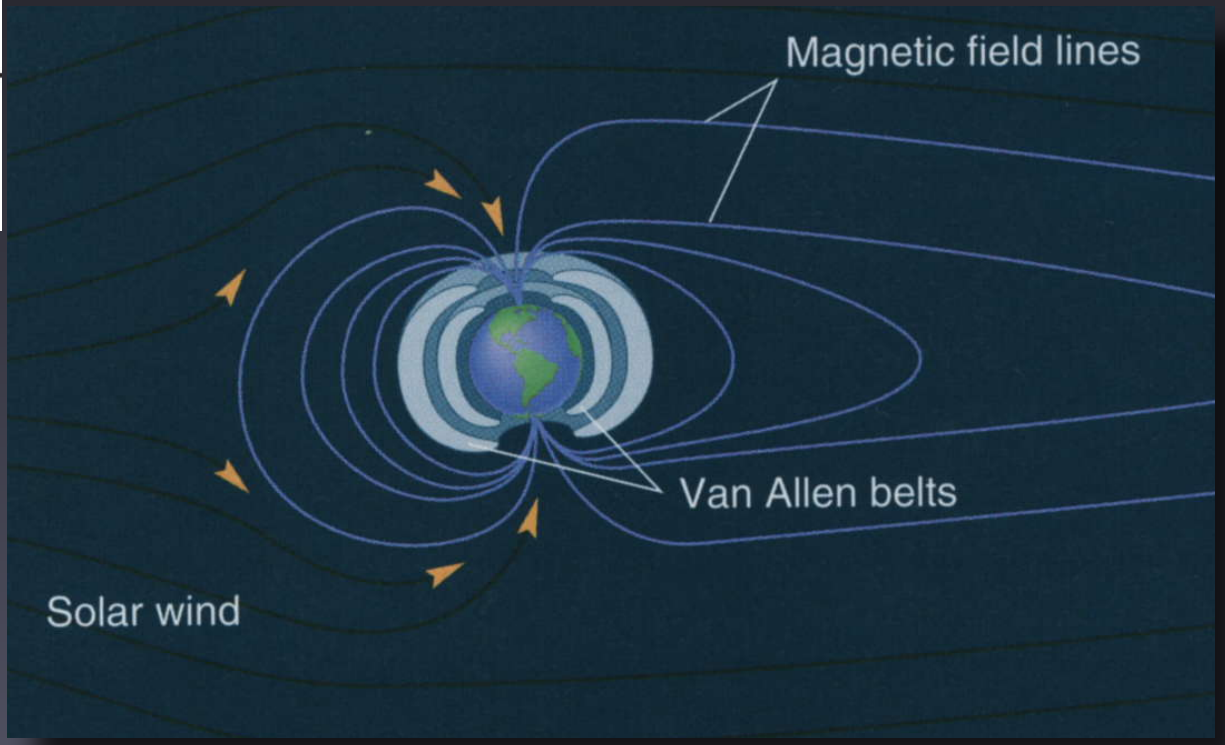
Crust: oceanic and continental parts
Oceanic crust: Basalt
Continental crust: Granite
Unique to Earth: Division into plates

Unique to the Earth: plate tectonics

Almost unique to the Earth : a magnetic field

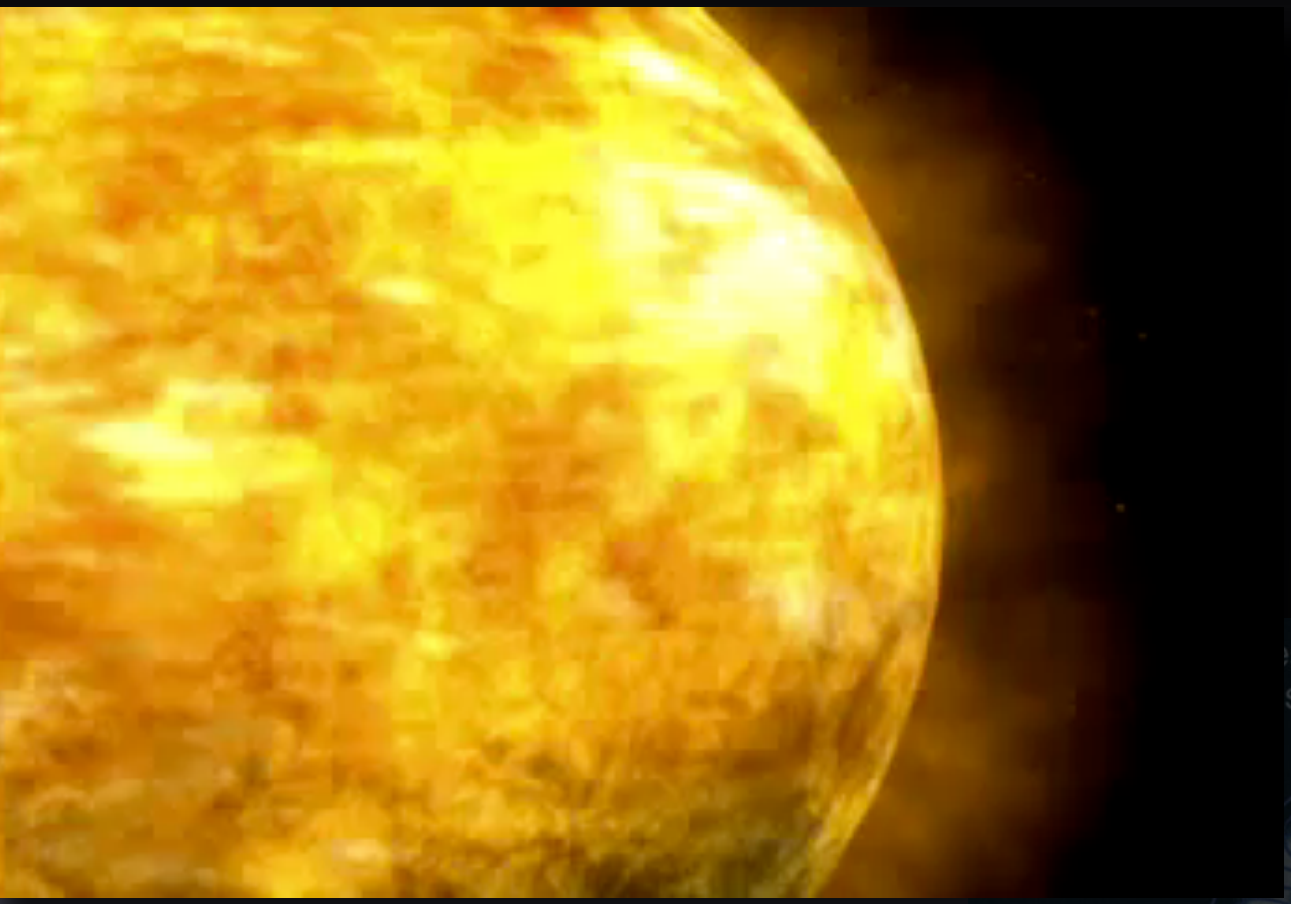


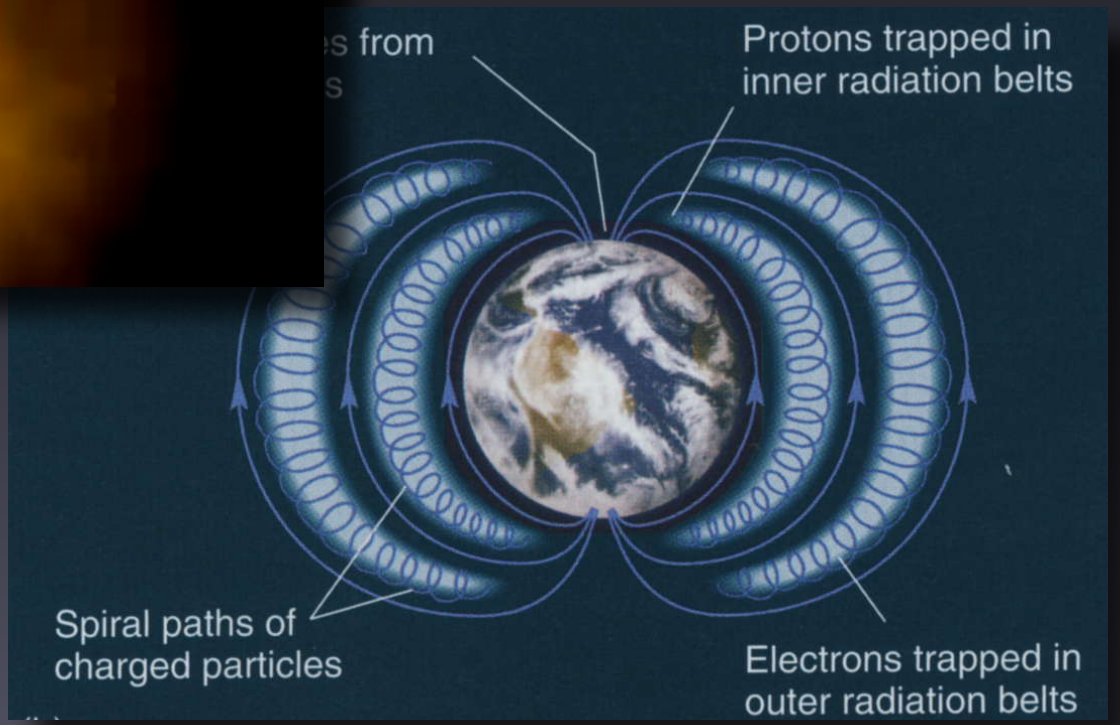
Convection in the liquid outer core drives "geodynamo"



The Earth magnetic field directs charged particles from the Solar wind to the magnetic poles.

Almost unique to the Earth : a magnetic field





The Earth magnetic field
directs charged particles
from the Solar wind
to the magnetic poles.

Aurora Borealis - Northern Lights

Aurora Australis over the Indian Ocean

The Moon

- diameter is 27% of Earth
- low gravity (17% of Earth's)
- $\langle\rho\rangle$ = 3.34 gr/cm^3:
  the core is small or absent
- many impact craters
- no atmosphere
- no magnetic field
- but it does have water ice??

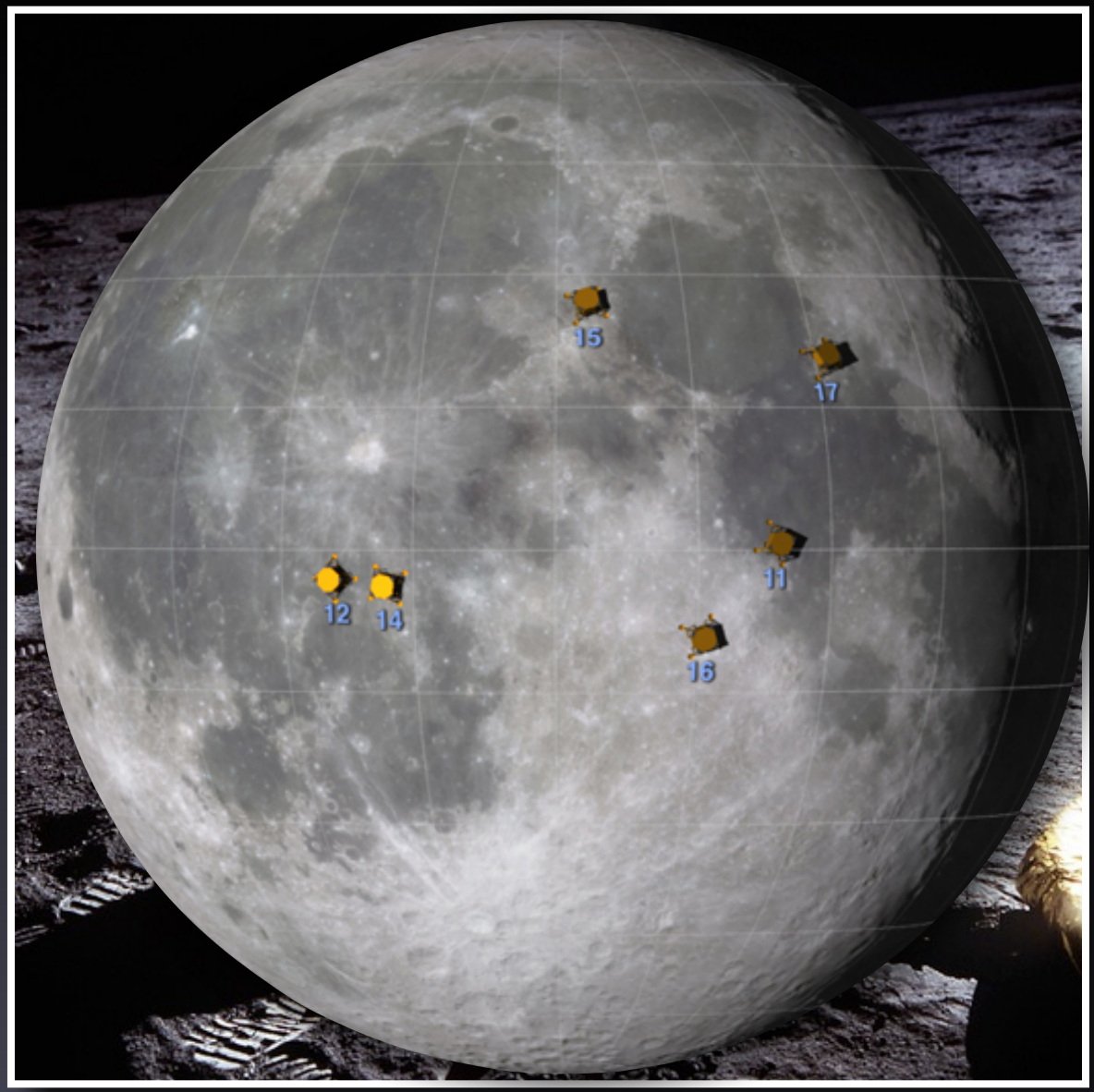
The dual face of the Moon

The Lunar surface

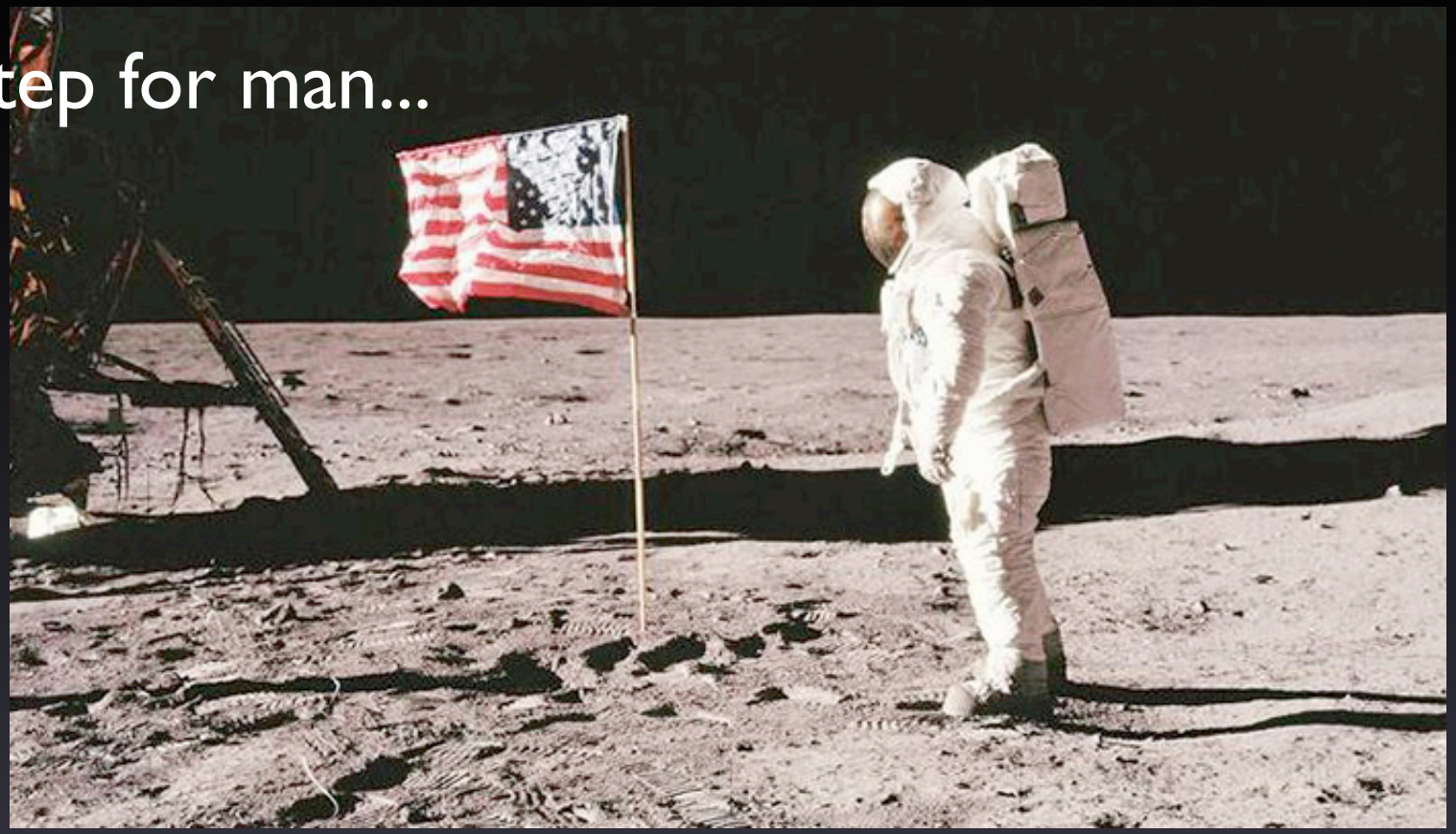
Light crust: feldspar
Formed early (4.1-4.4 Gyr)

Dark maria: basalt
Formed later (4.1-3.3 Gyr)

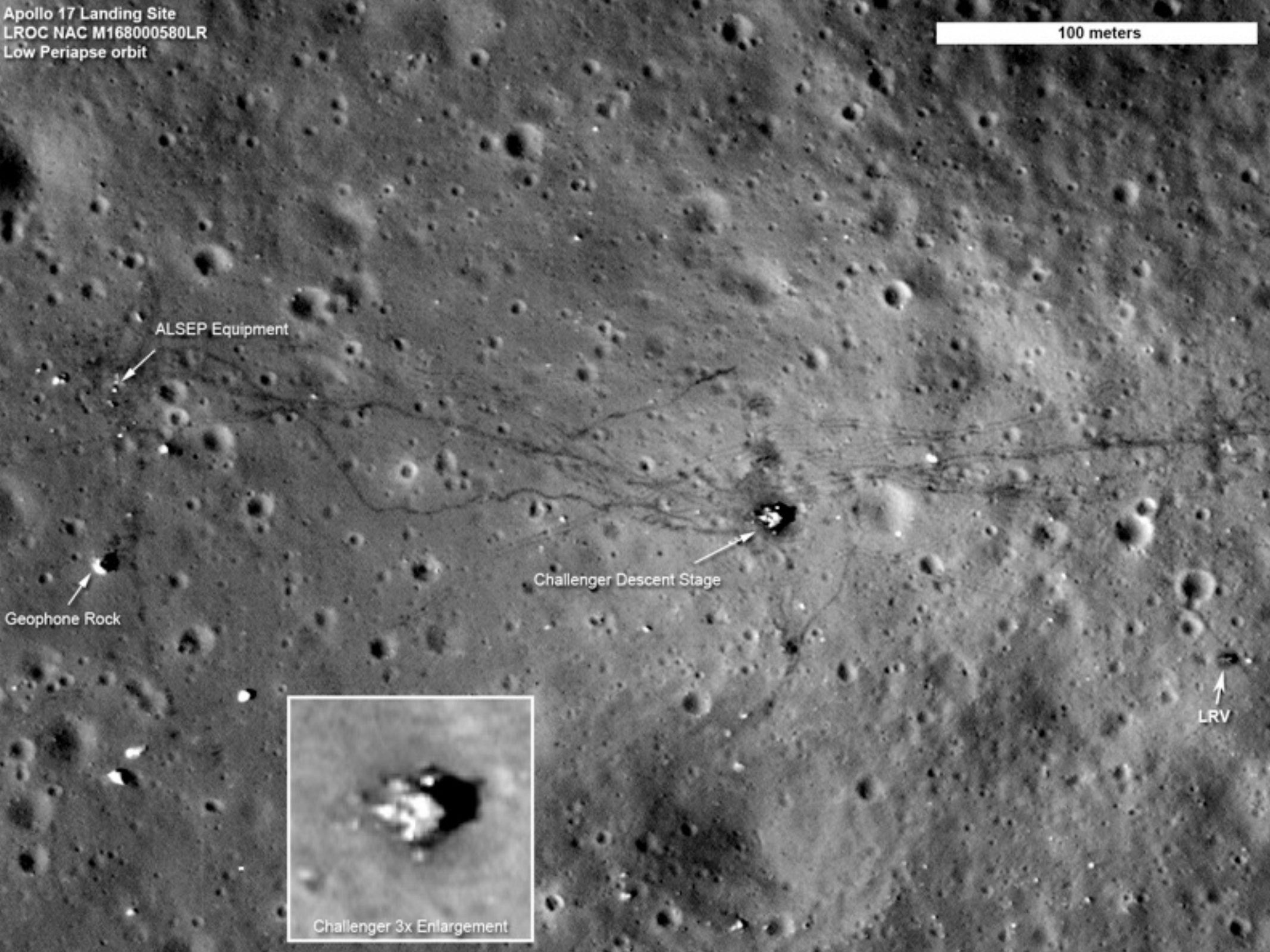
More on this distinction later....



One small step for man...



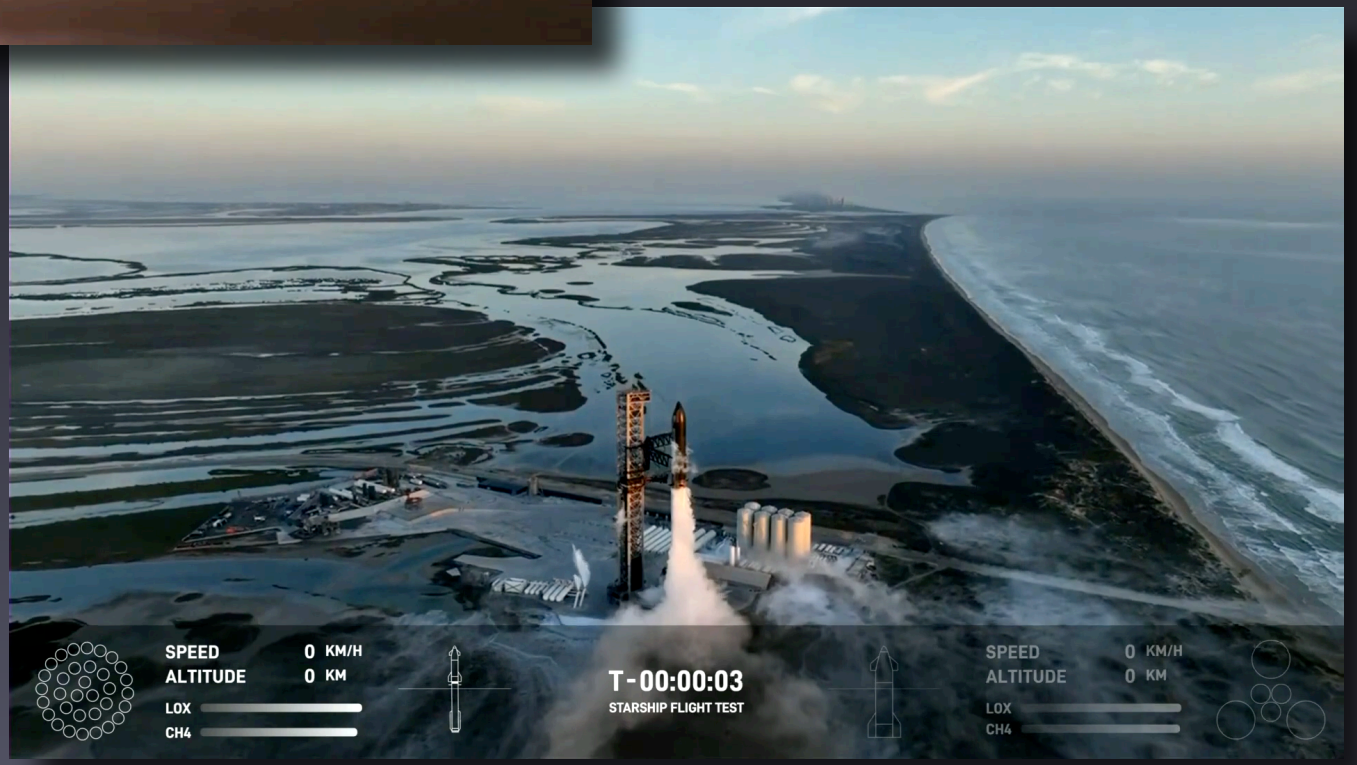
... decades of work for scientists


Apollo 17 Landing Site
LROC NAC M168000580LR
Low Periapse orbit
100 meters
ALSEP Equipment
Challenger Descent Stage
Geophone Rock
LRV
Challenger 3x Enlargement

Back to the Moon…

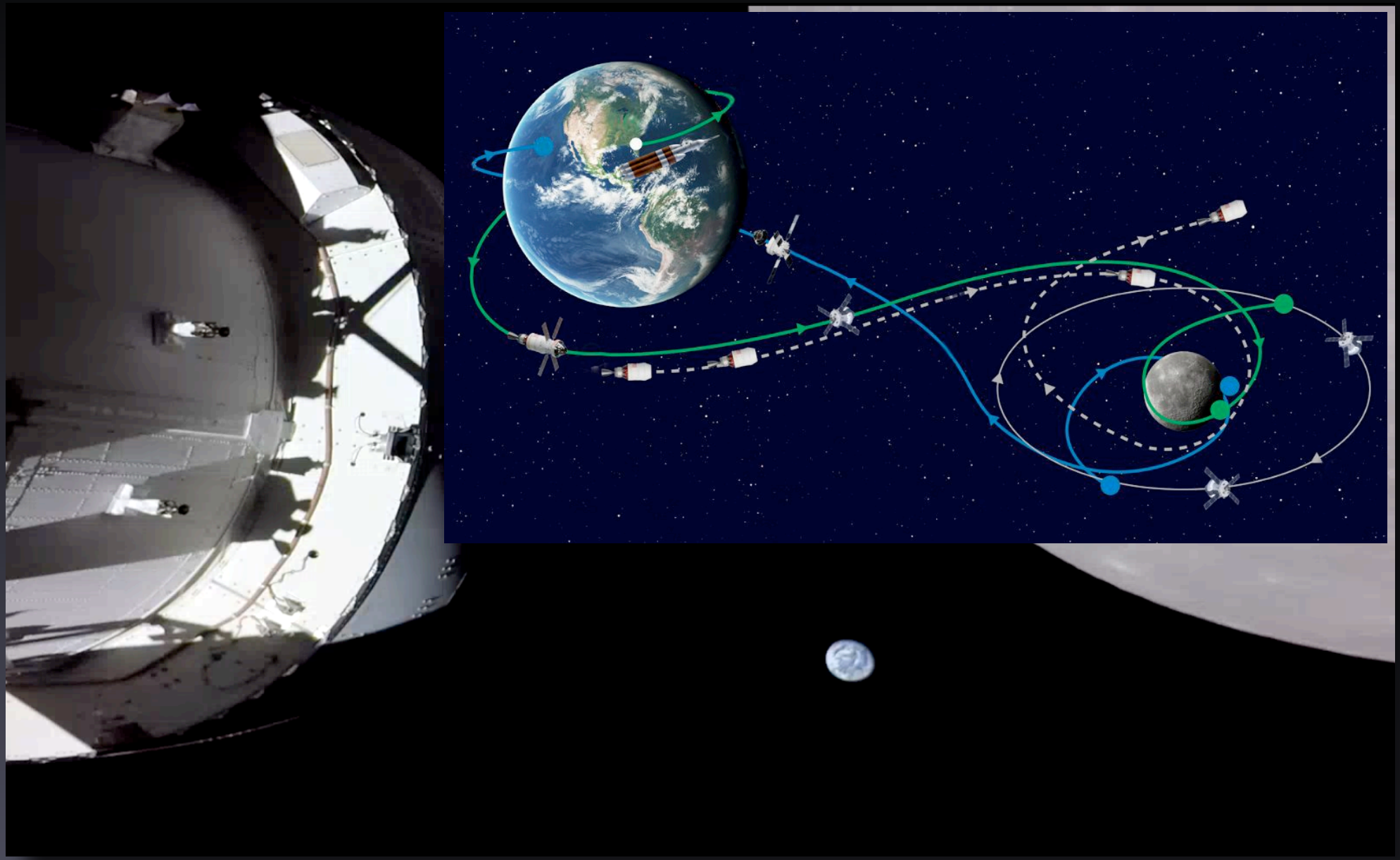
NASA
Artemis - I
Cape Canaveral
16 Nov 2022

SpaceX
Starship
Boca Chica
18 Nov 2023

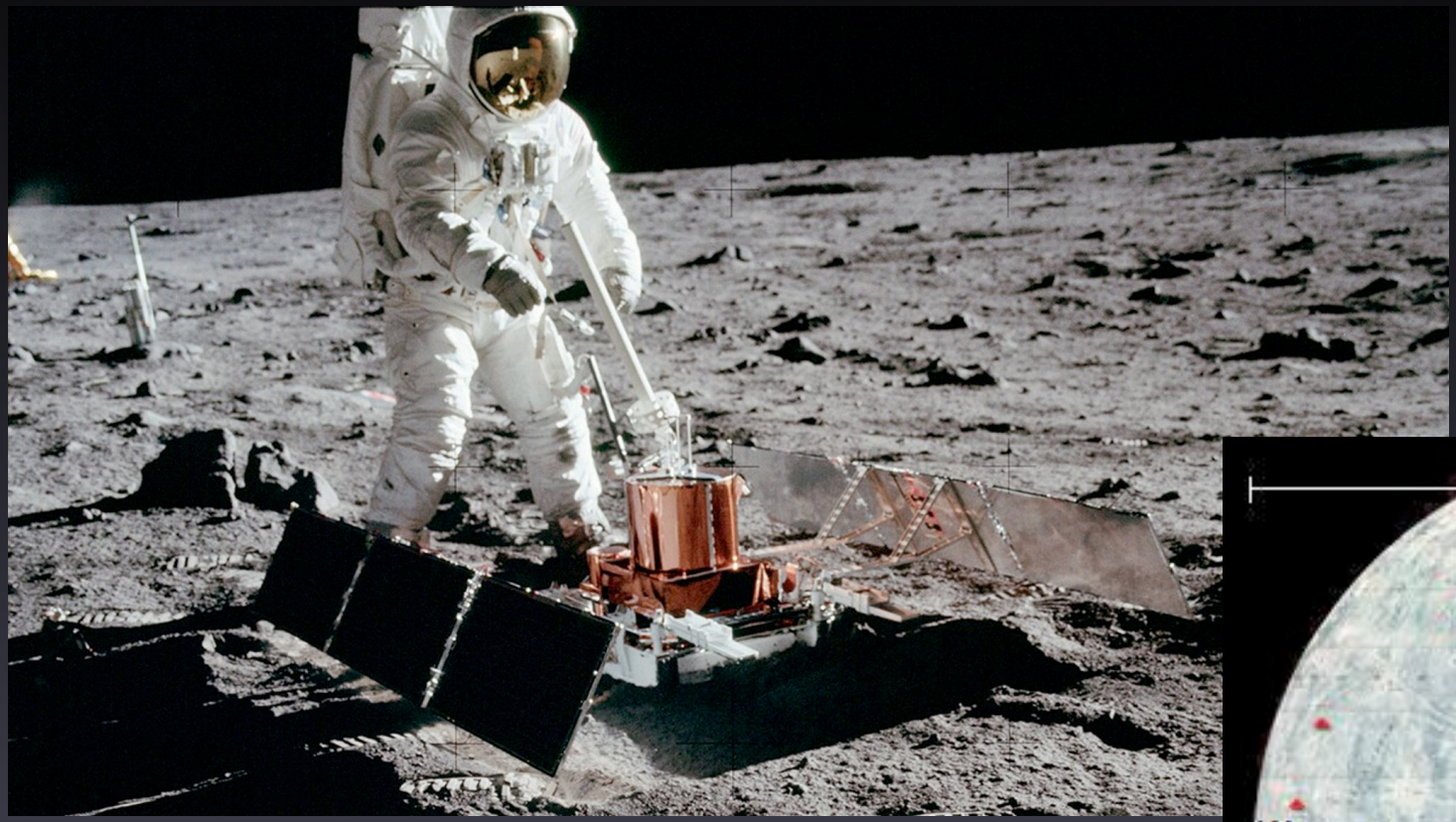


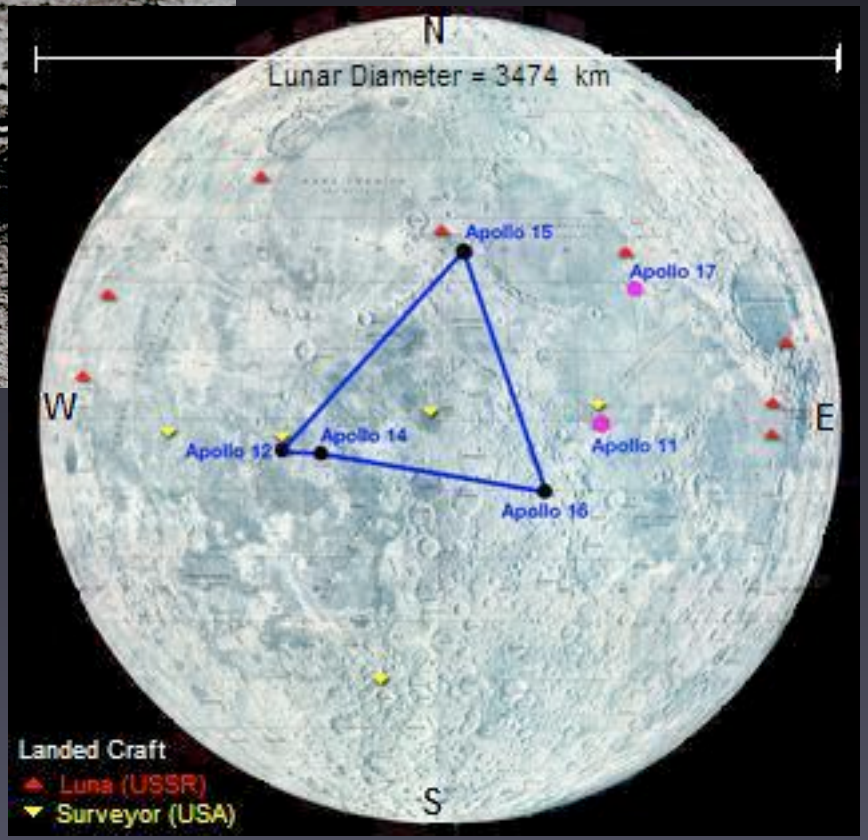
Back to the Moon…

Artemis - I fly-by to lunar orbit injection (21 Nov 2022)

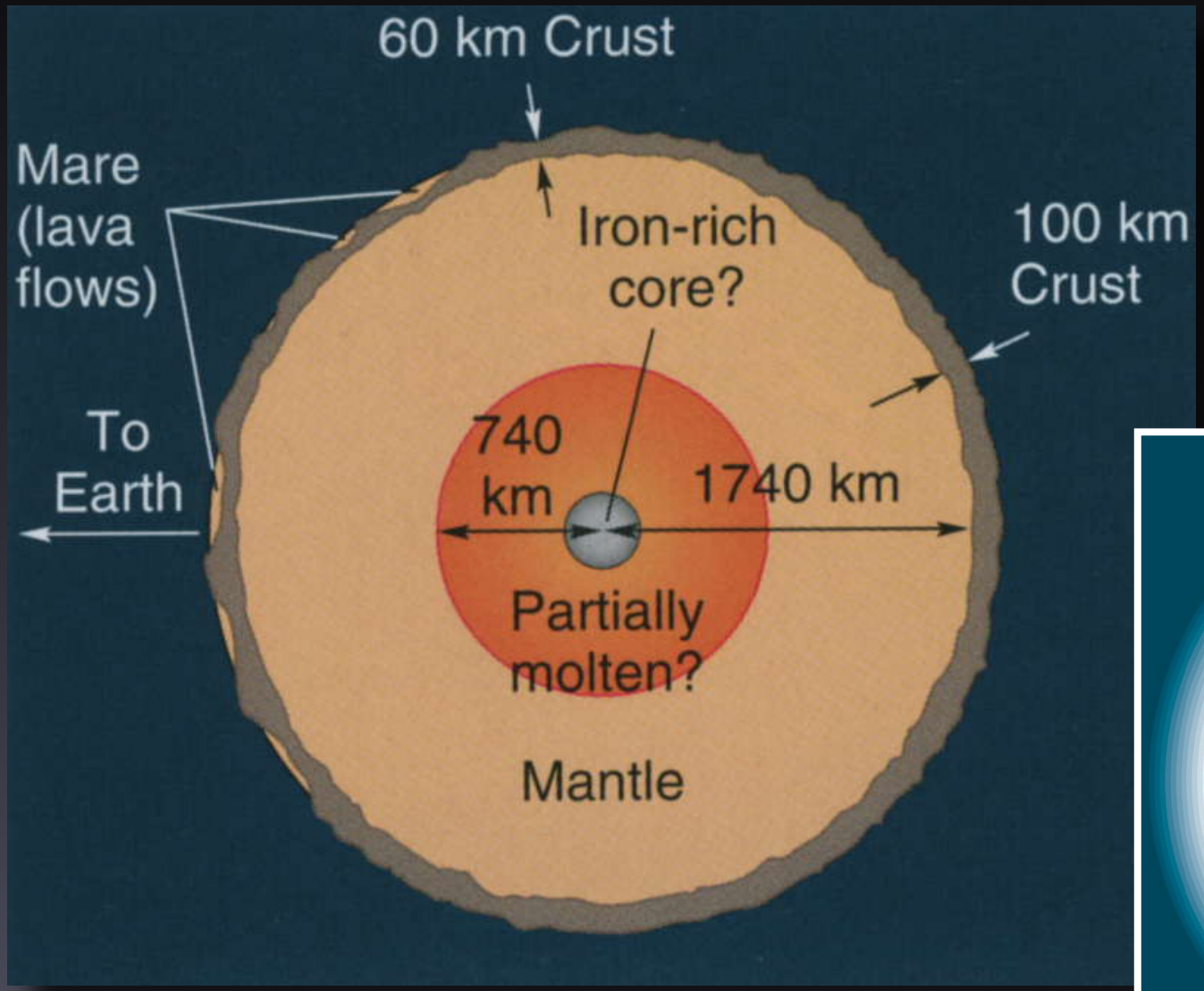


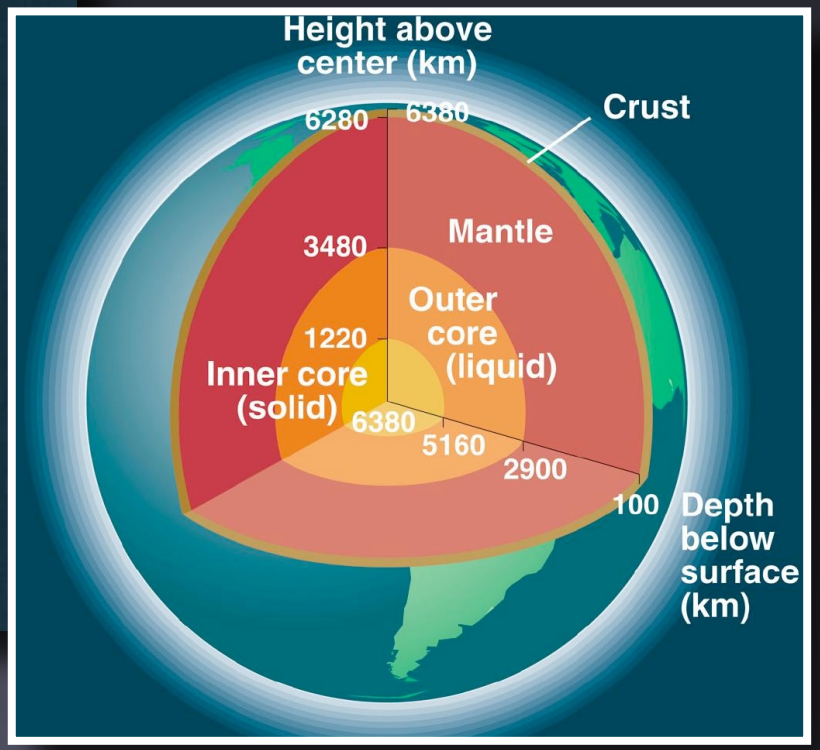
Observations: rock samples and seismometers





Internal structure of the Moon



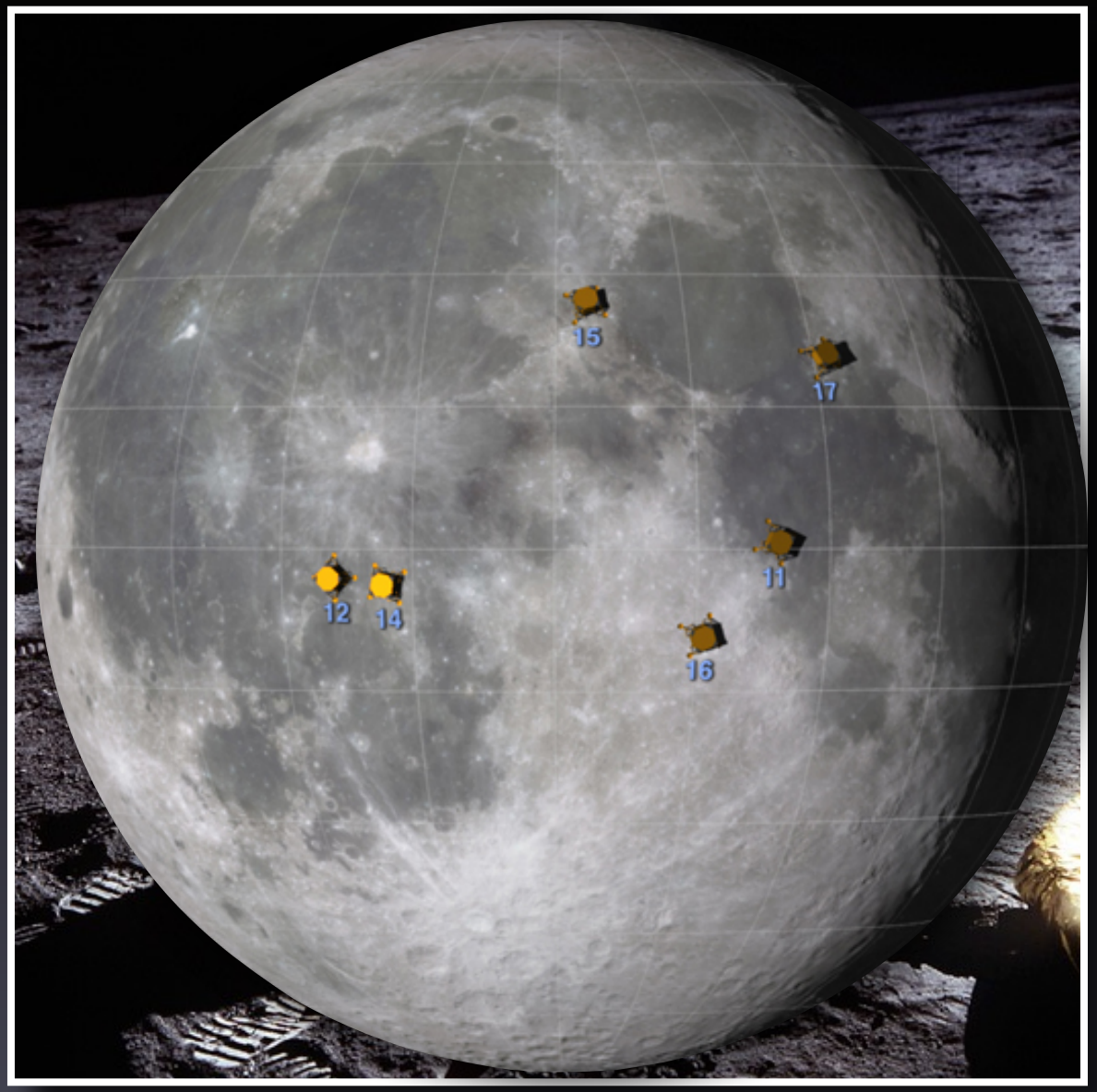


The Lunar surface

Light crust: feldspar
Formed early (4.1-4.4 Gyr)

Dark maria: basalt
Formed later (4.1-3.3 Gyr)

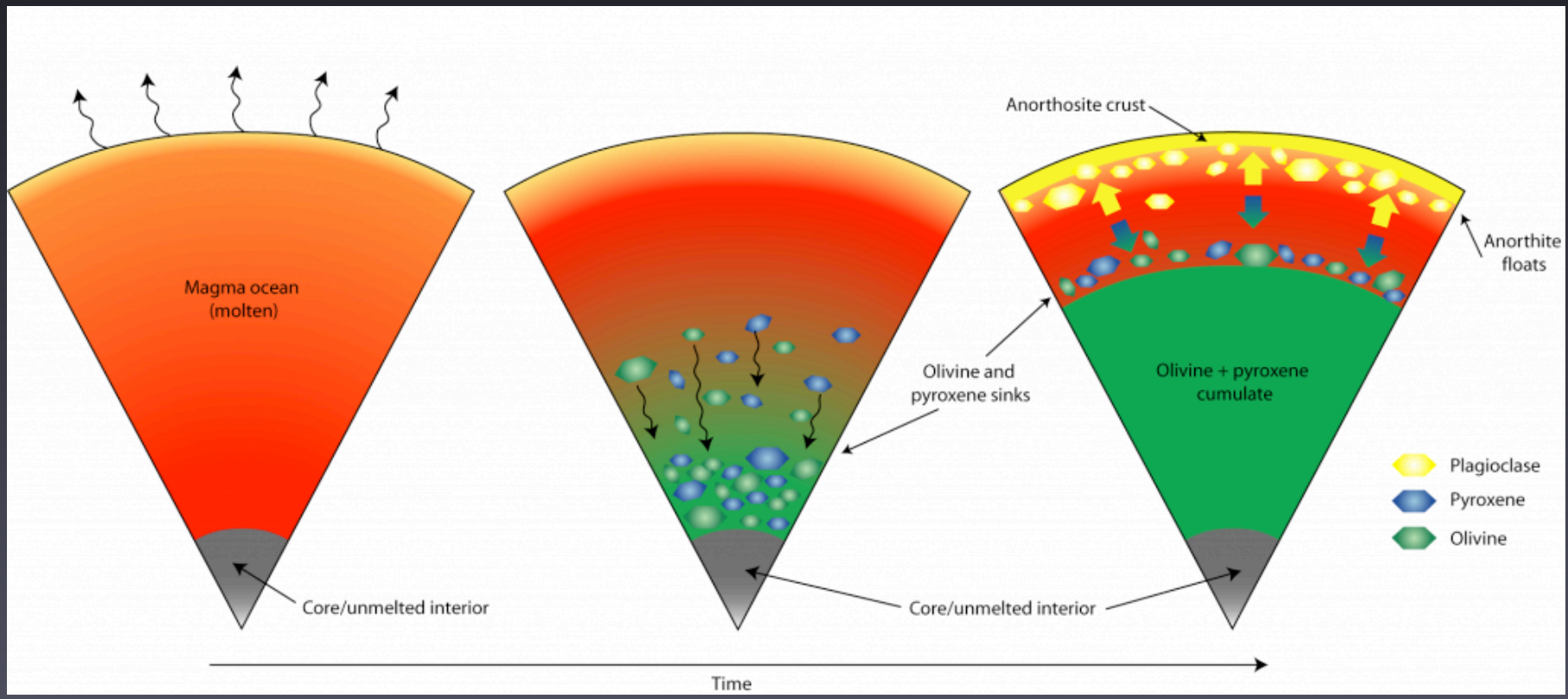
More on this distinction....
Now!



Moon formed fully molten

After some time, light feldspar (anorthite) crystallised in the magma

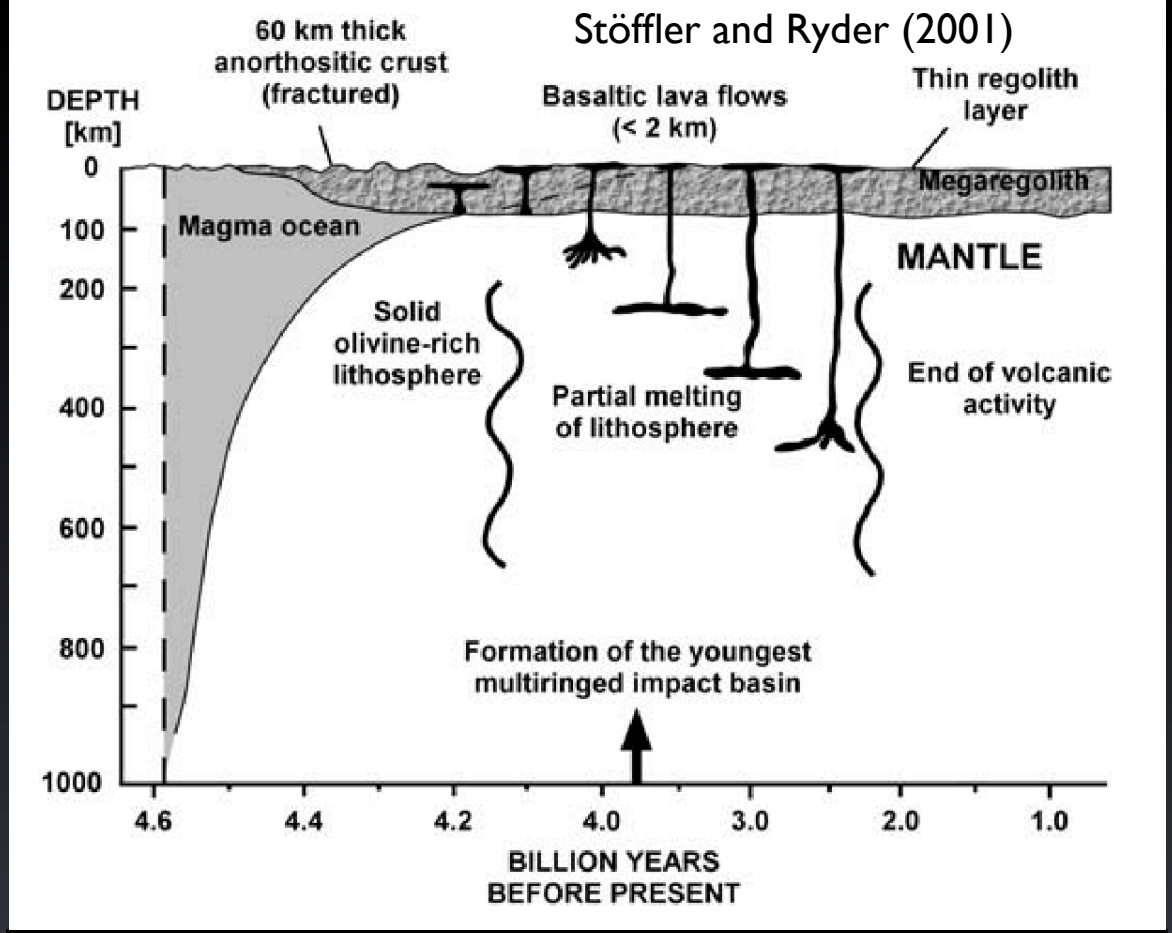
Crust floating on magma

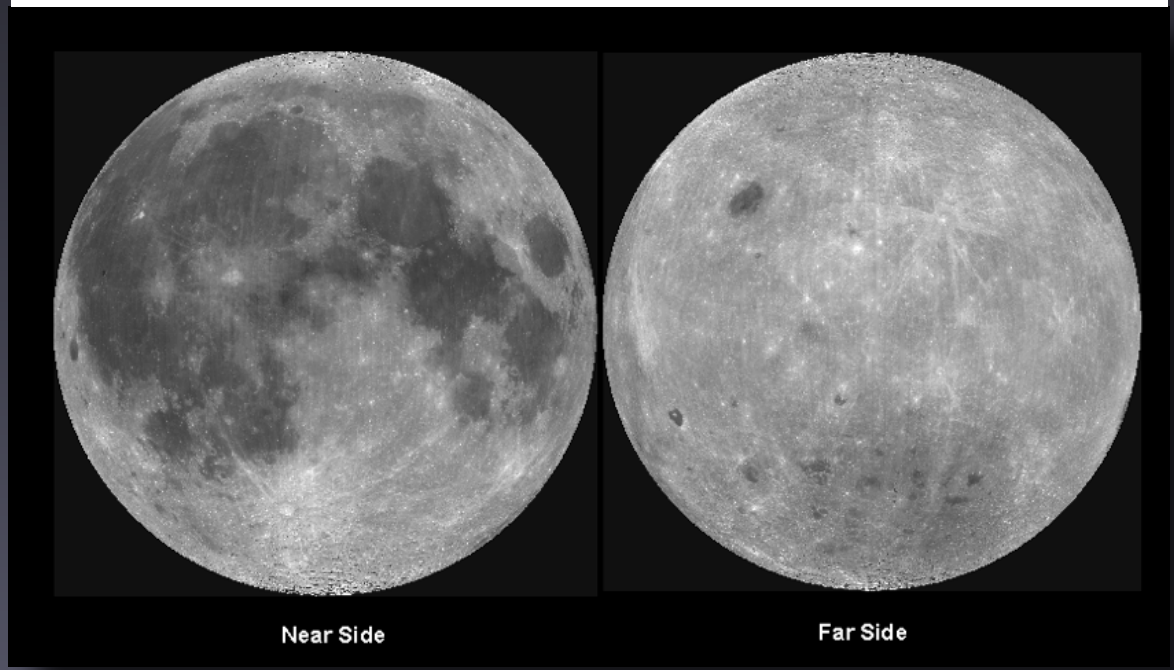


Maria: impact craters filled with lava

Magma forms in mantle, erupts

Flows to fill craters





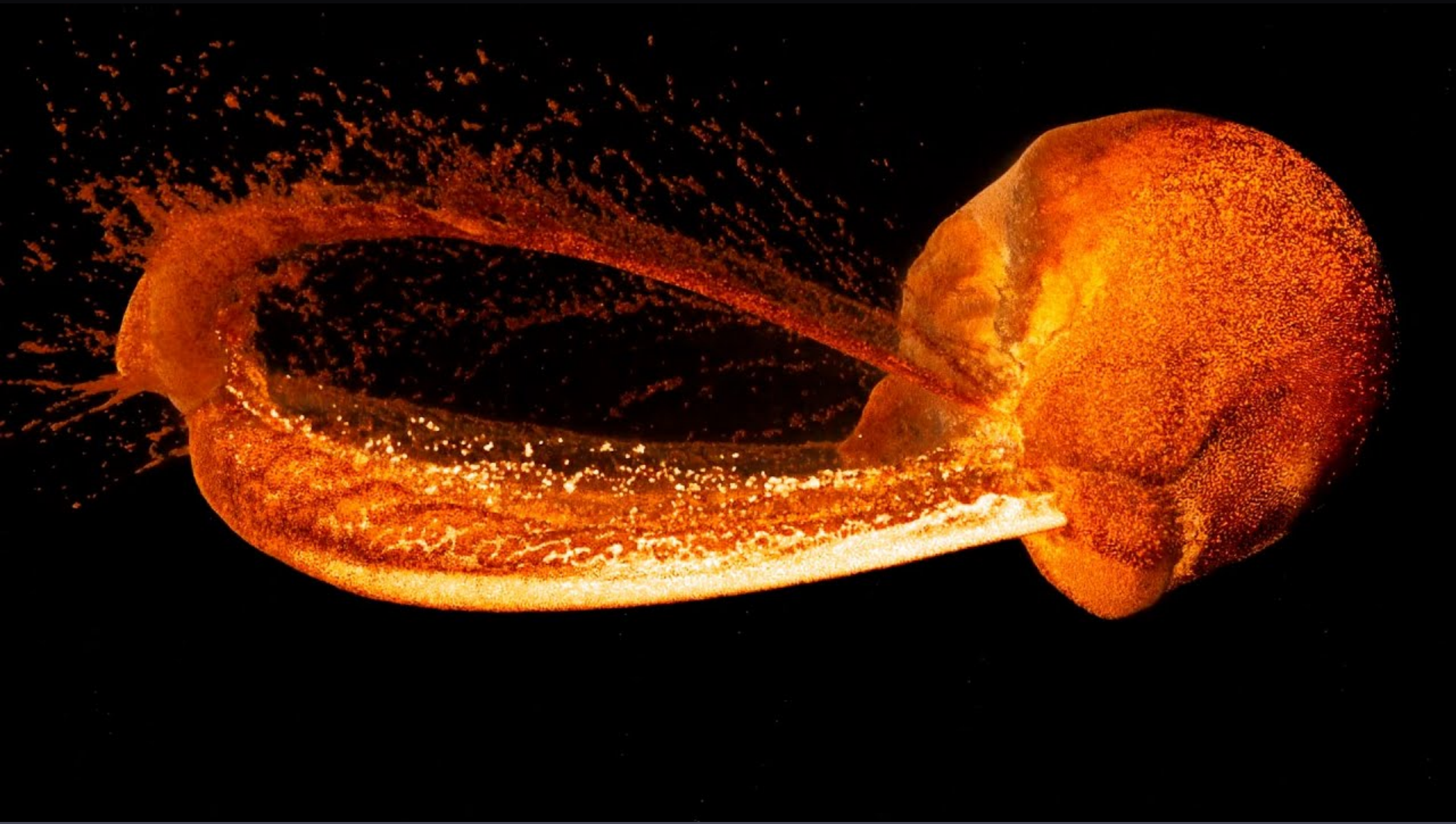
The Moons origin

The Moon orbits close to the Earth in a near-circular orbit => capture not likely

The Moon has very similar composition as Earth in terms of isotopes => material needs to come from Earth

Solution: Giant impact, bringing material from Earth and impactor into space, which can form the Moon

Impactor: Theia, same size as Mars



NASA

Summary

- Different phases of the Moon are caused by various lighting angles
- The Moon orbits at a tilt with the Earth-Sun plane, and Solar and Lunar eclipses only occur during two seasons per year
- Gravity of the Moon imposes tides in the oceans on Earth
- Tidal friction slows the rotation of the Earth, increases the Earth-Moon distance
- Calendars are based on the movements of the Moon, Sun, and stars
- Periods do not align well, posing challenges to calendars, which the Western calendar solves with leap years and decoupling months from the Lunar month
- We know the internal structure of the Earth from seismology
- Metallic core, rocky mantle and crust
- The Earth crust is subdivided into plates which can move wrt each other, which is unique to the Earth
- The Moon surface is mostly a light, old feldspar crust, with some younger dark basaltic planes (mare)
- From Lunar seismology we know it has a small metal core

next lecture:

Light
&
Electro-Magnetic radiation

Koupelis : chapter 4
OpenStax : chapter 5