The Earth & Moon

Astronomy 101: Exploring the Night Sky

January, 2018

Question: Human output of CO_2 is less than the CO_2 output of volcanoes.

a. True

b. False

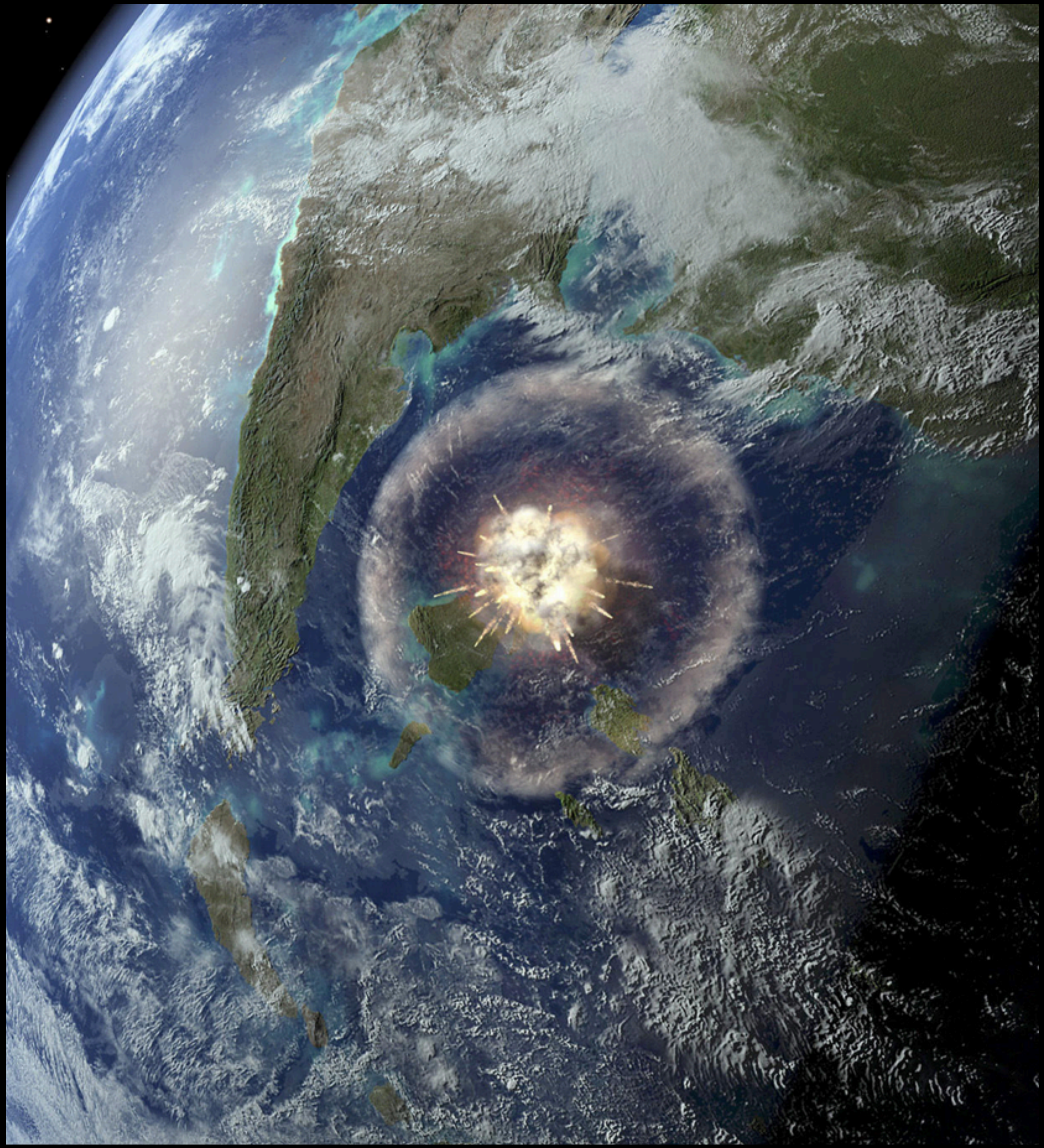
Fossil History

Earth is the only planet we know of that supports any type of life.

Fossil records show it is very vulnerable: 5 previous mass extinctions

Permian-Triassic extinction caused by large asteroid collision, triggering supervolcano eruption, causing runaway greenhouse effect

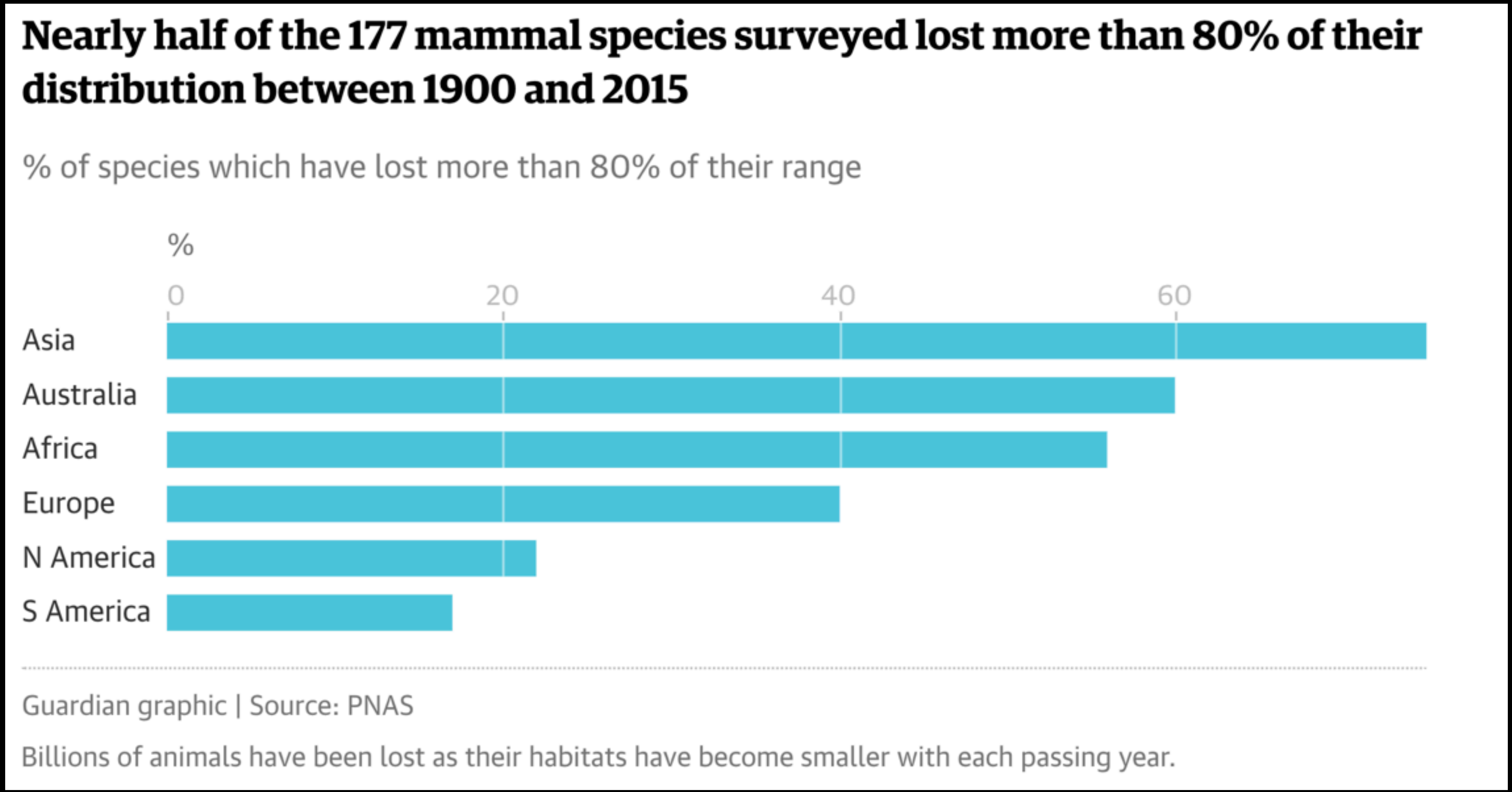
Artist impression of size of extinction impact.



Current Extinction

Currently experiencing 6th mass extinction.

Humans risk causing an ecological collapse that will result in an uninhabitable Earth.



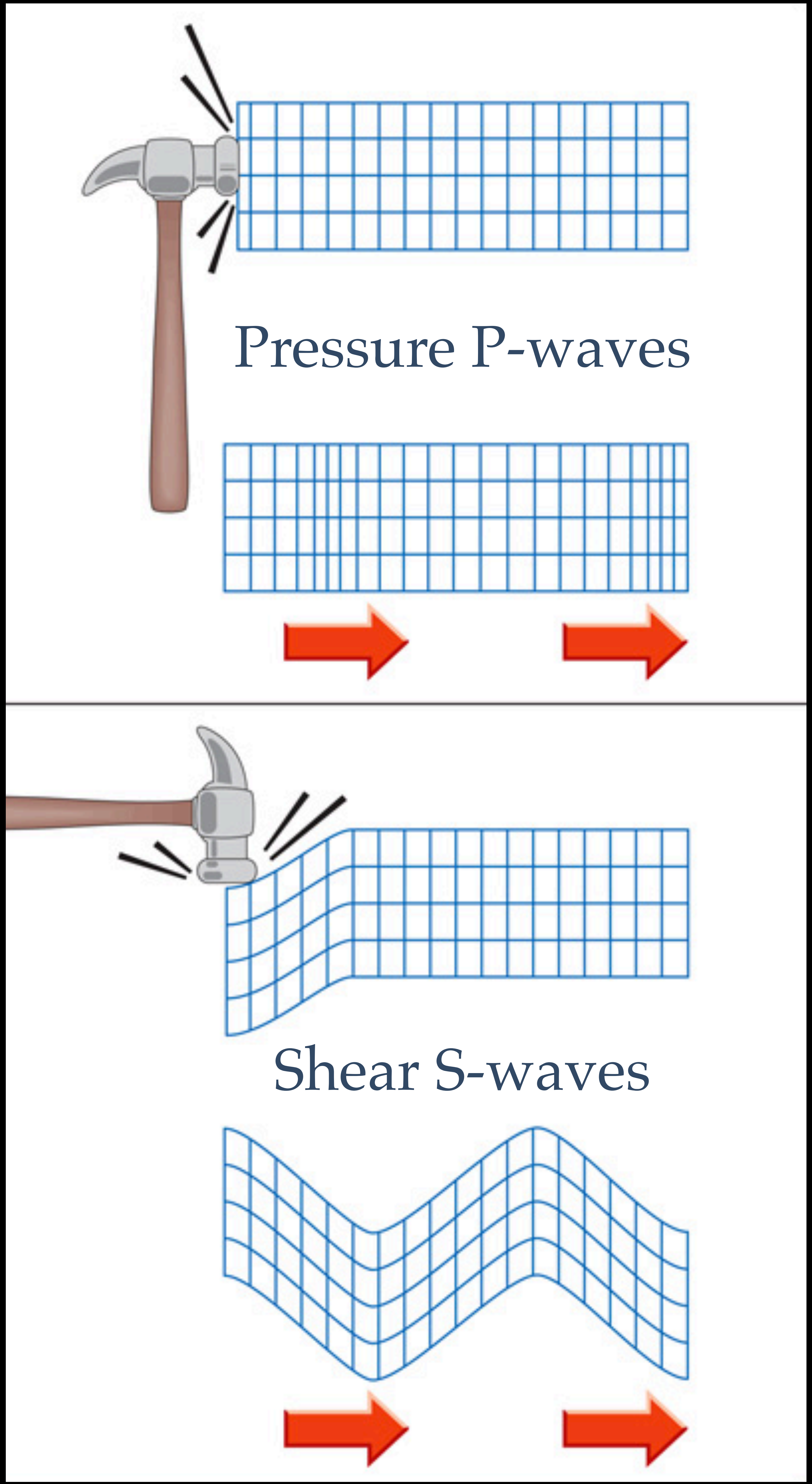
A common thread in science fiction: If humanity is to survive, we need to spread out amongst the stars

Inside the Earth

Seismology

When an earthquake happens, the vibrations are sent as waves around the world, and recorded on seismometers.

There are two types of waves: transverse S-waves and longitudinal P-waves.

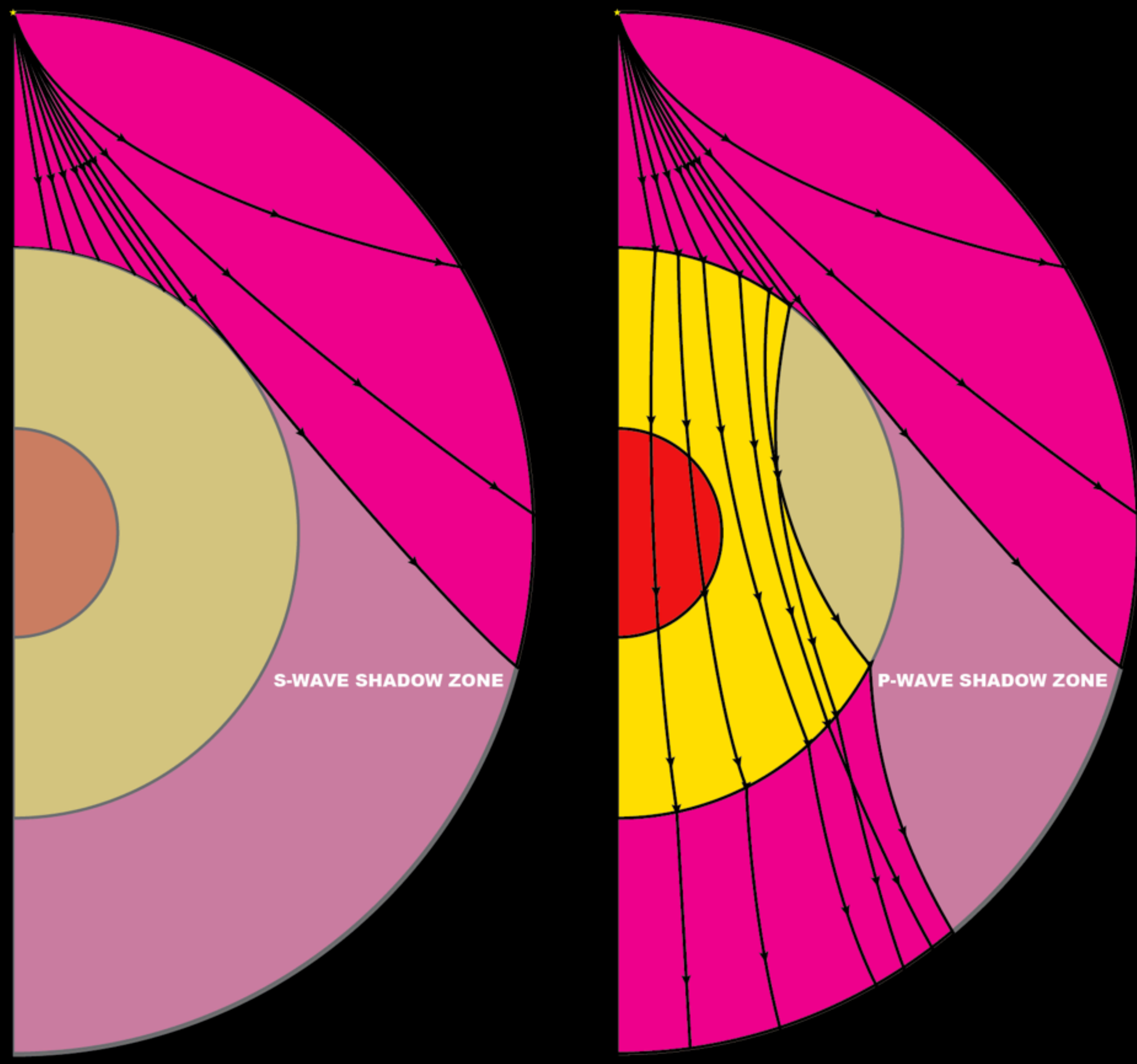


Seismology

These waves interact with the material in the Earth differently.

S-waves appear unable to transmit through the Earth, while P-waves appear to refract from the same place that S-waves are stopped.

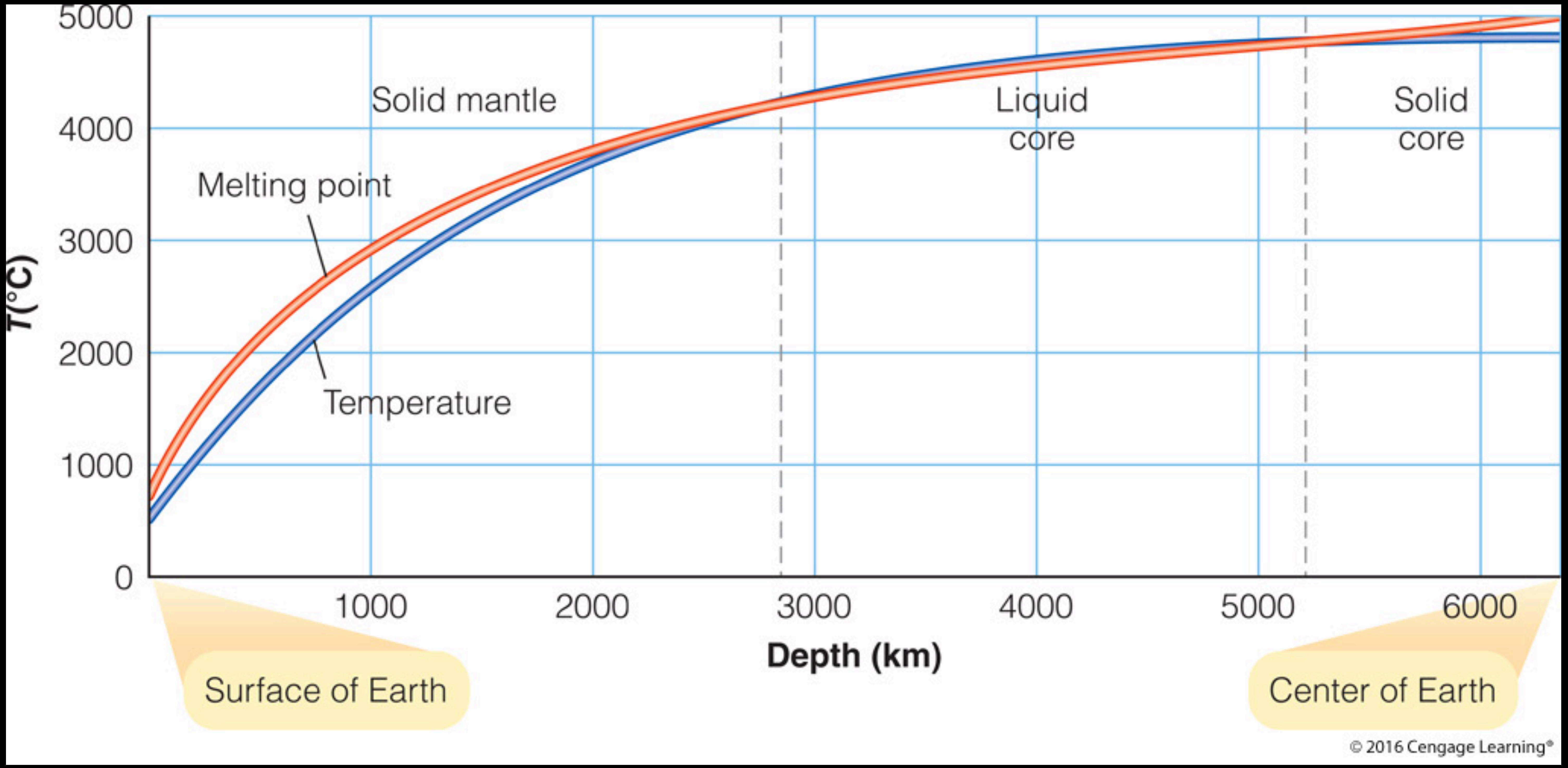
This tells us about the density and state of the material inside the Earth.



The Layers of the Earth

By knowing the density of the material, we can deduce its composition, and calculate the temperature as a function of depth.

By comparing this to the melting temperature of the material, we can see where there must be a liquid layer.

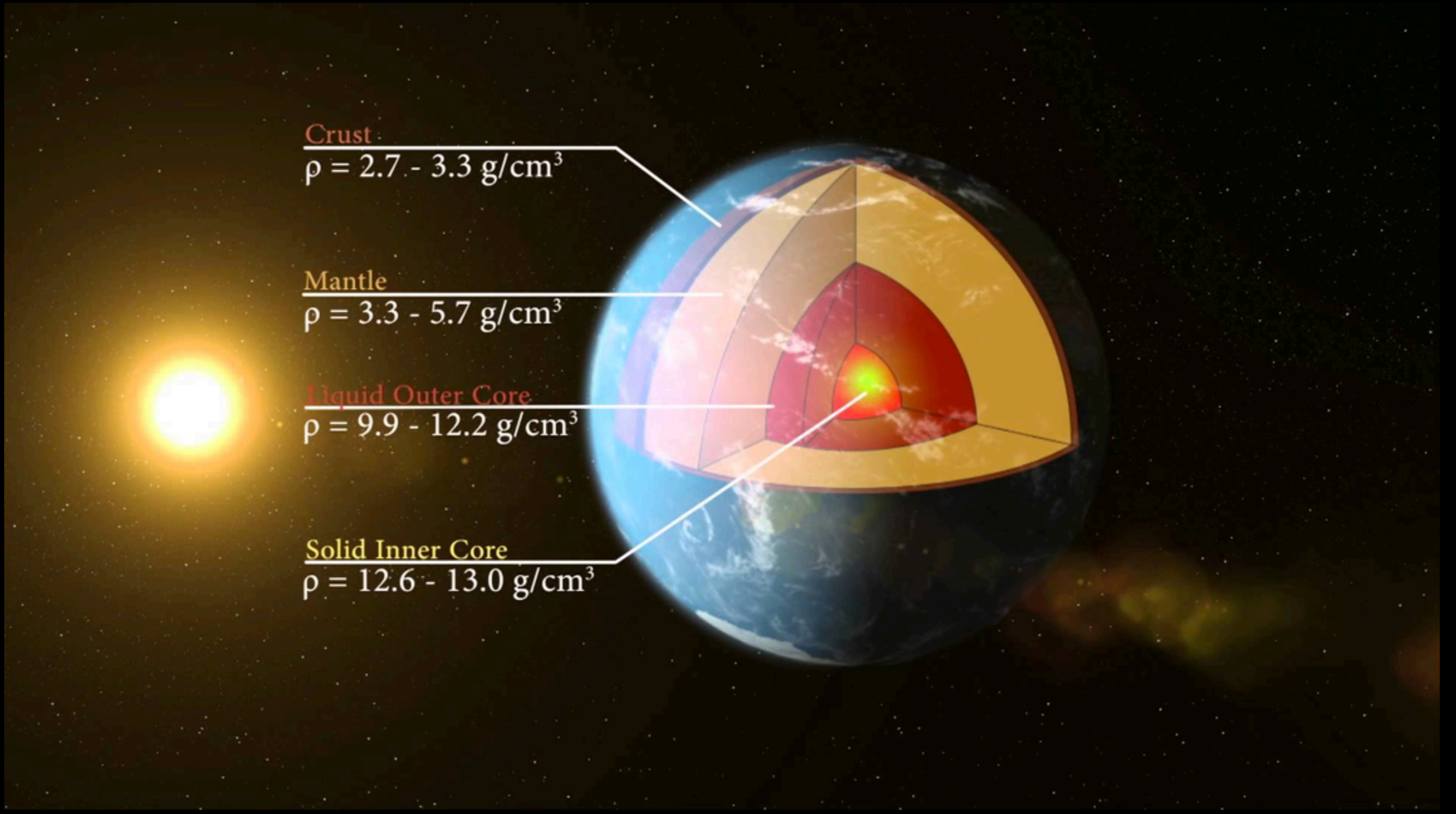


The Layers of the Earth

By examining lava, seismograph data, and studying the surface of the Earth, we can deduce with confidence that the Earth is highly differentiated.

At some point in Earth's past, the Earth must have been hot enough that it was all liquid.

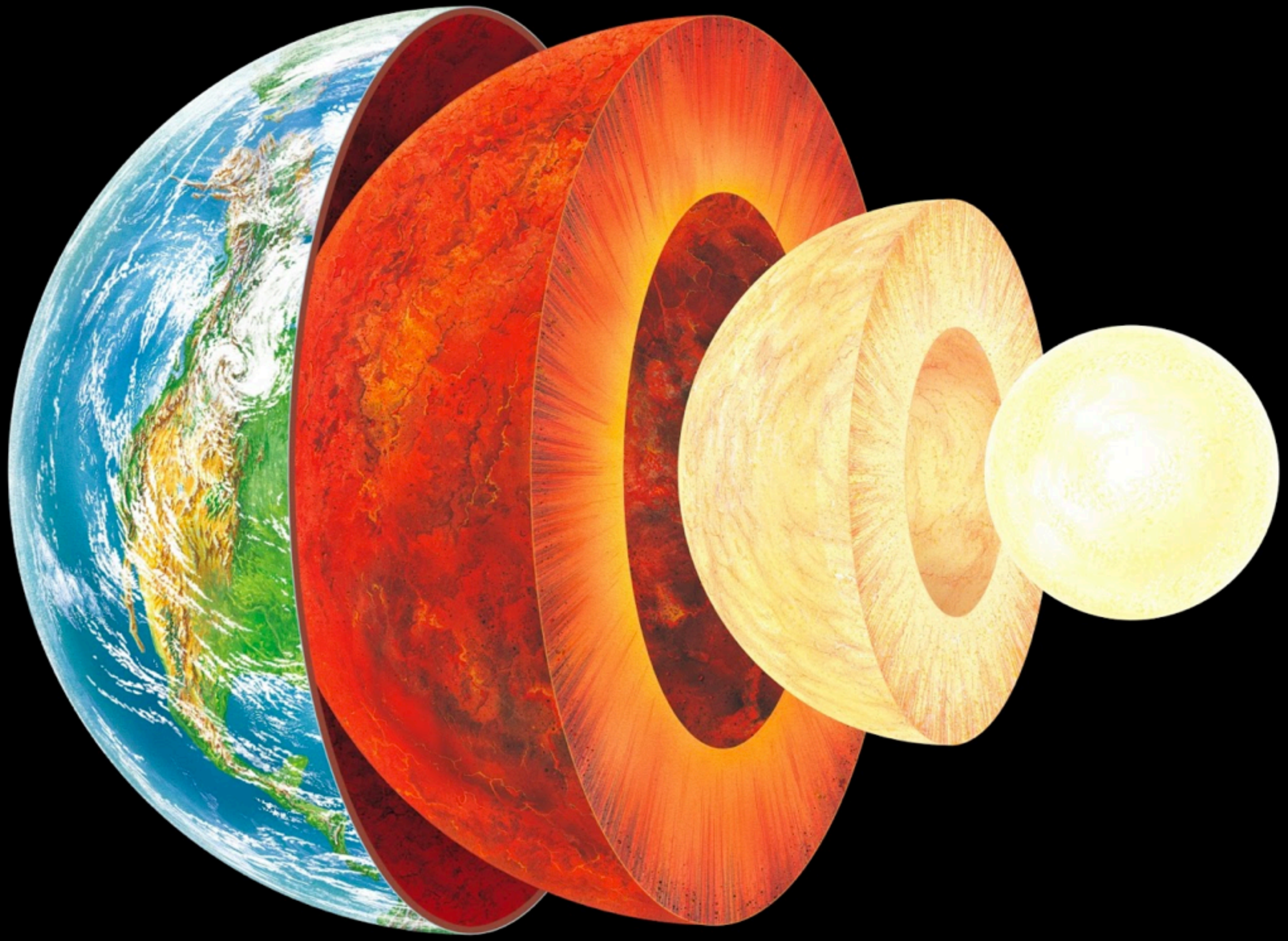
Denser materials decended to the centre, lighter materials floated to the top.



The Layers of the Earth

This is our current model for the insides of the Earth, as determined from seismic and lab data.

There is a solid inner core, a liquid outer core, a plastic mantle, and a solid crust.



The Surface

Earth’s Surface

The surface is comprised of the crust and the hydrosphere.

The surface of the Earth is constantly, rapidly changing.

This is why Earth is known as the “Active Planet”.

By what mechanisms is the surface changing?

Carsten Peter/National Geographic Creative

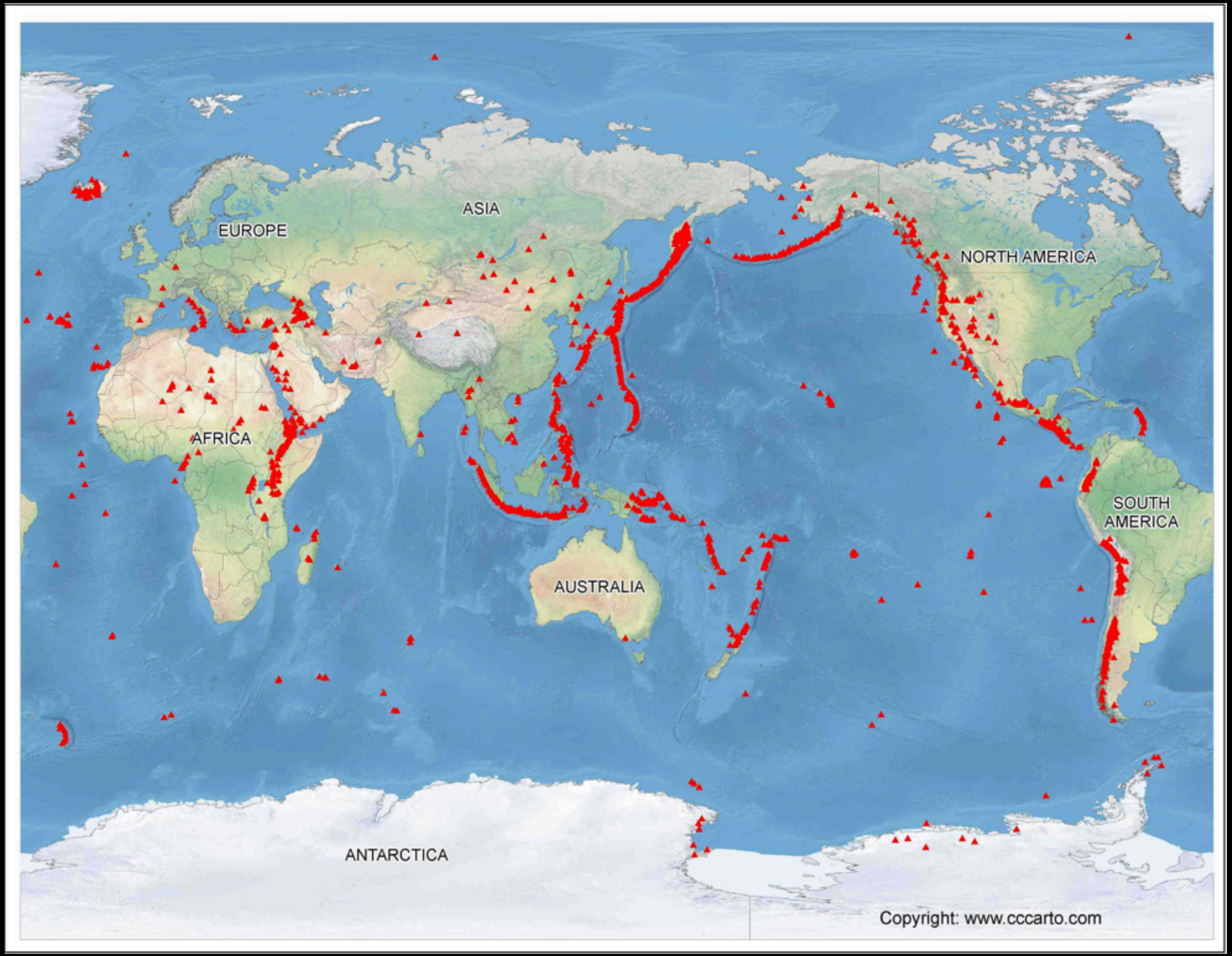
Active Planet - Volcanism

Volcanoes bring material from just beneath the crust to the surface.

The outgassing of volcanoes adds more CO_2, along with other gases into our atmosphere.

This CO_2 helped maintain warmth on the planet over its history.

Volcanic output of CO_2 is 65-319 million tonnes per year. Human fossil fuel use is 20 billion tonnes pear year.

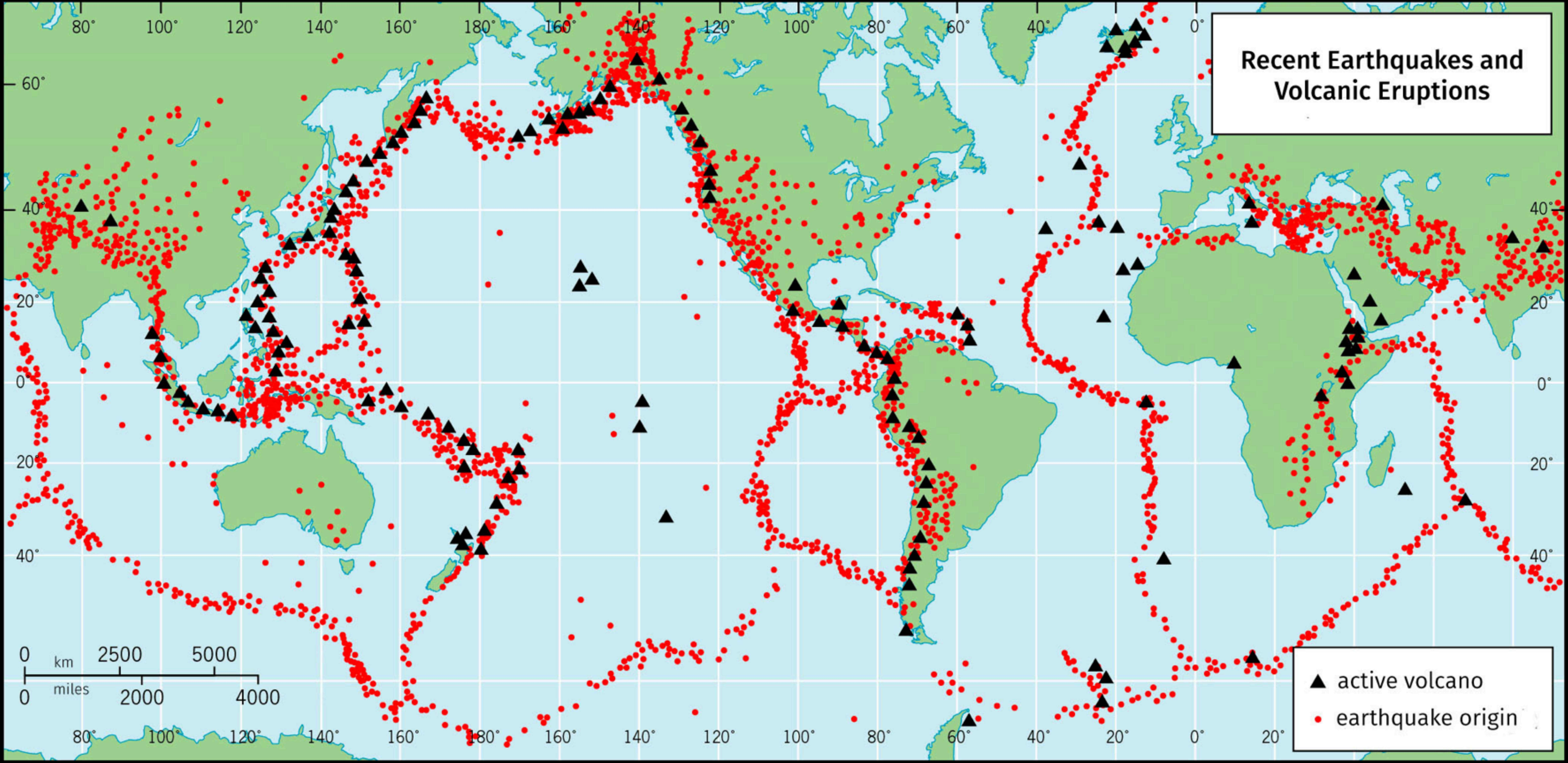


Active Planet - Erosion

Water constantly erodes the shores, riverbanks, and changes the surface of the Earth over long periods of time.

Humans fight erosion in various ways, but it can't be completely stopped.

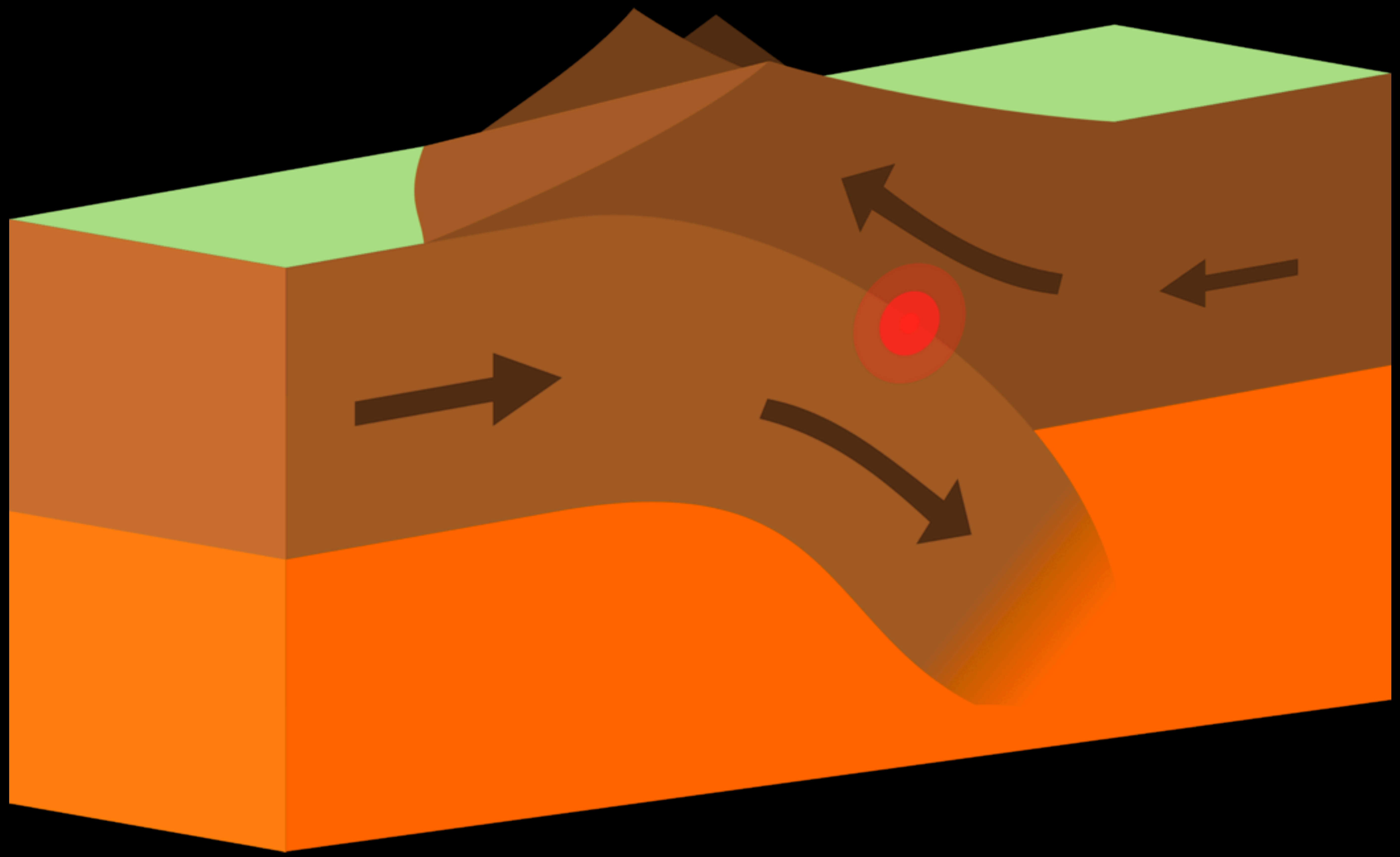
Active Planet - Plate Tectonics



Active Planet - Plate Tectonics

Mapping out Earthquake locations and volcanoes shows us very clearly that they primarily occur on the edges of large sections of the crust.

These are the plates that form the crust.

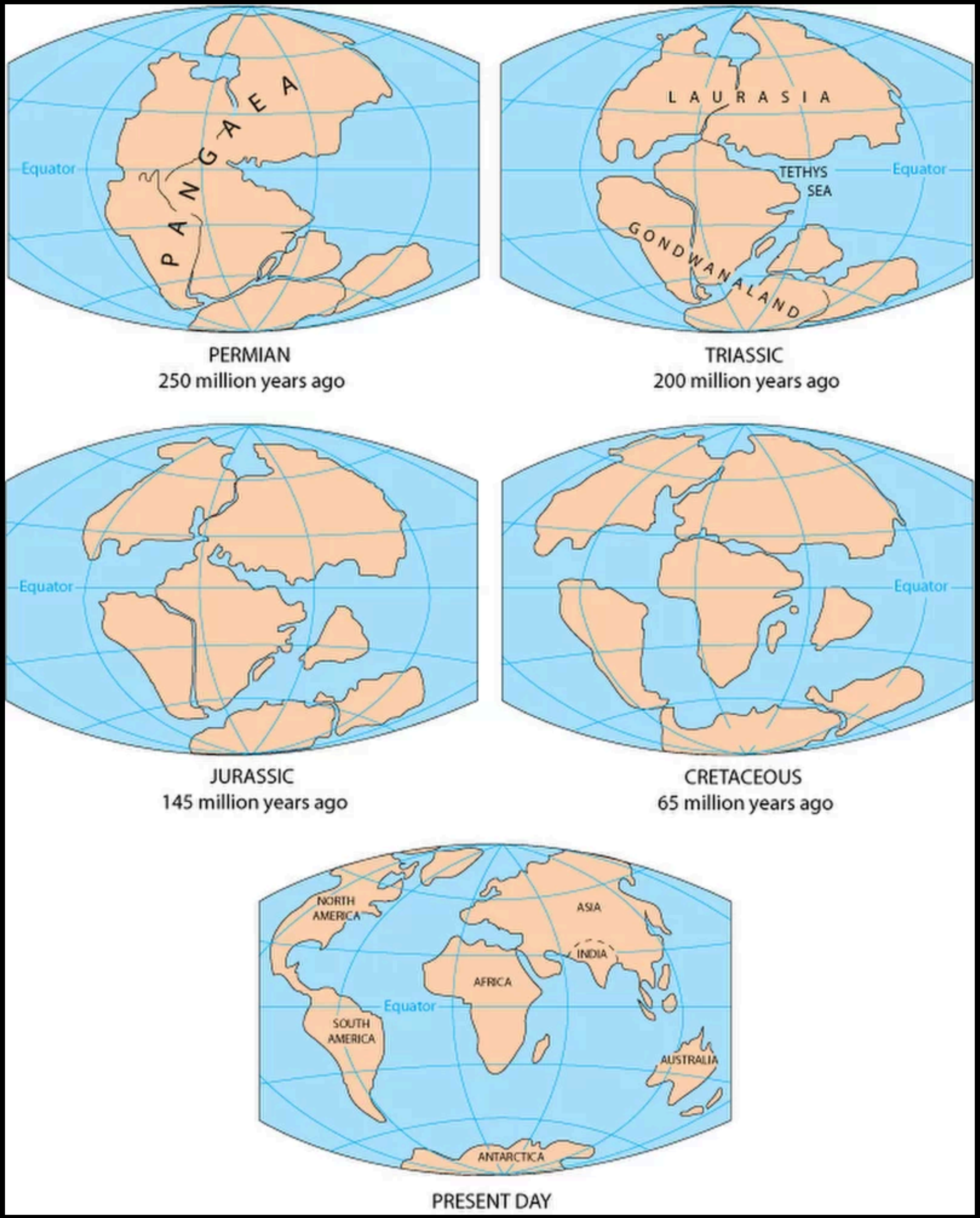


Where they meet, one is pushed down into the mantle while the other is pushed up to form mountains

Active Planet - History

Fossil and geological links indicate that the continents used to be linked together in a pangaea, which drifted apart.

e.g. Species of animals existed at one time in both Africa and South America that would have otherwise had no way to cross the ocean. Only one conclusion, the continents used to be closer!



The Atmosphere

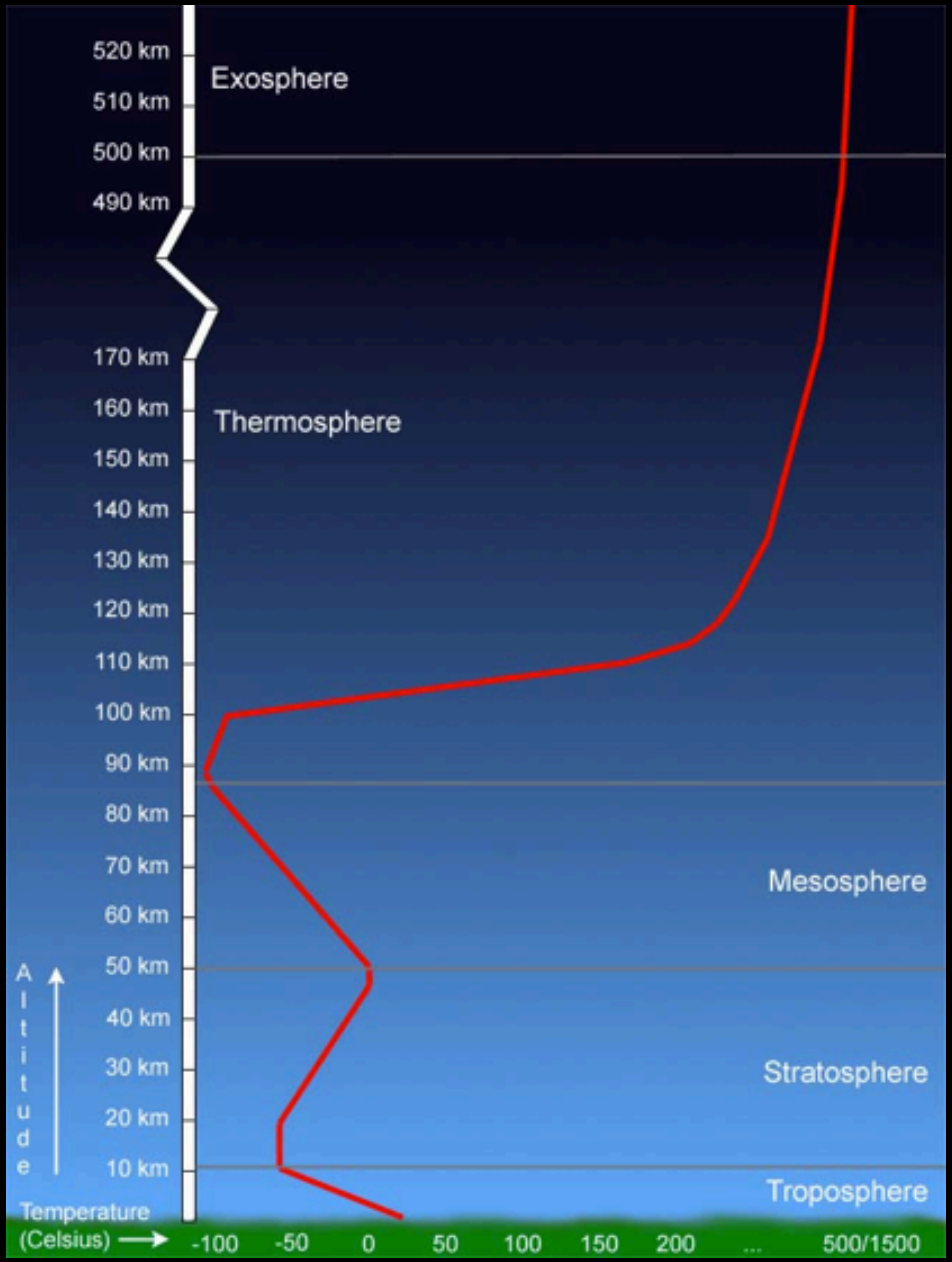
Layers

Troposphere - the layer where almost all the turbulence (weather) occurs

Stratosphere - increases in temperature due to absorption of UV light by ozone

Mesosphere - the middle layer, varies in height over the seasons

Ionosphere - the upper layers combined, highly ionized by solar radiation

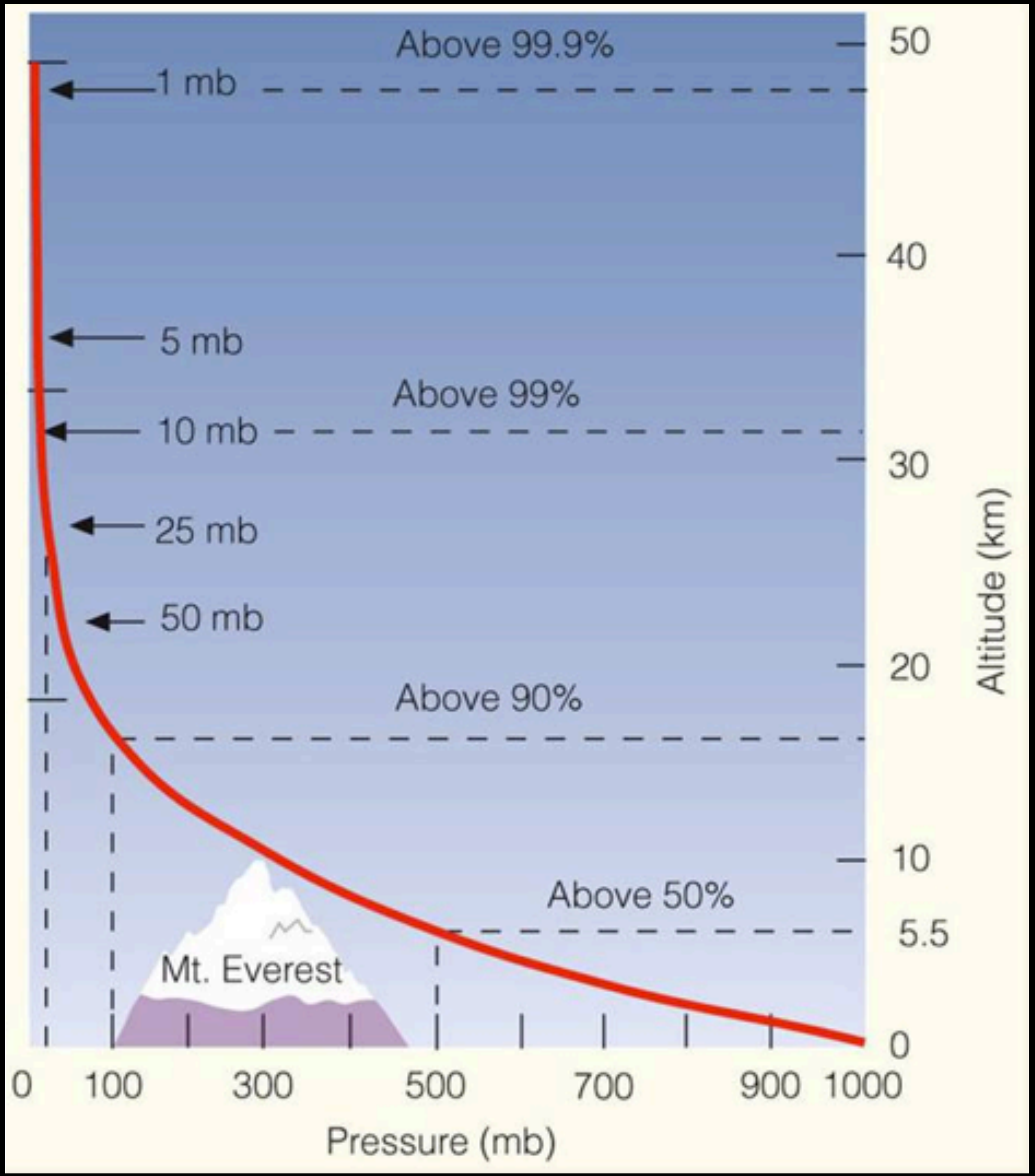


Layers

Troposphere contains 75% of the mass of the atmosphere, and 99% of water.

Stratosphere contains about 20% of the mass of the atmosphere.

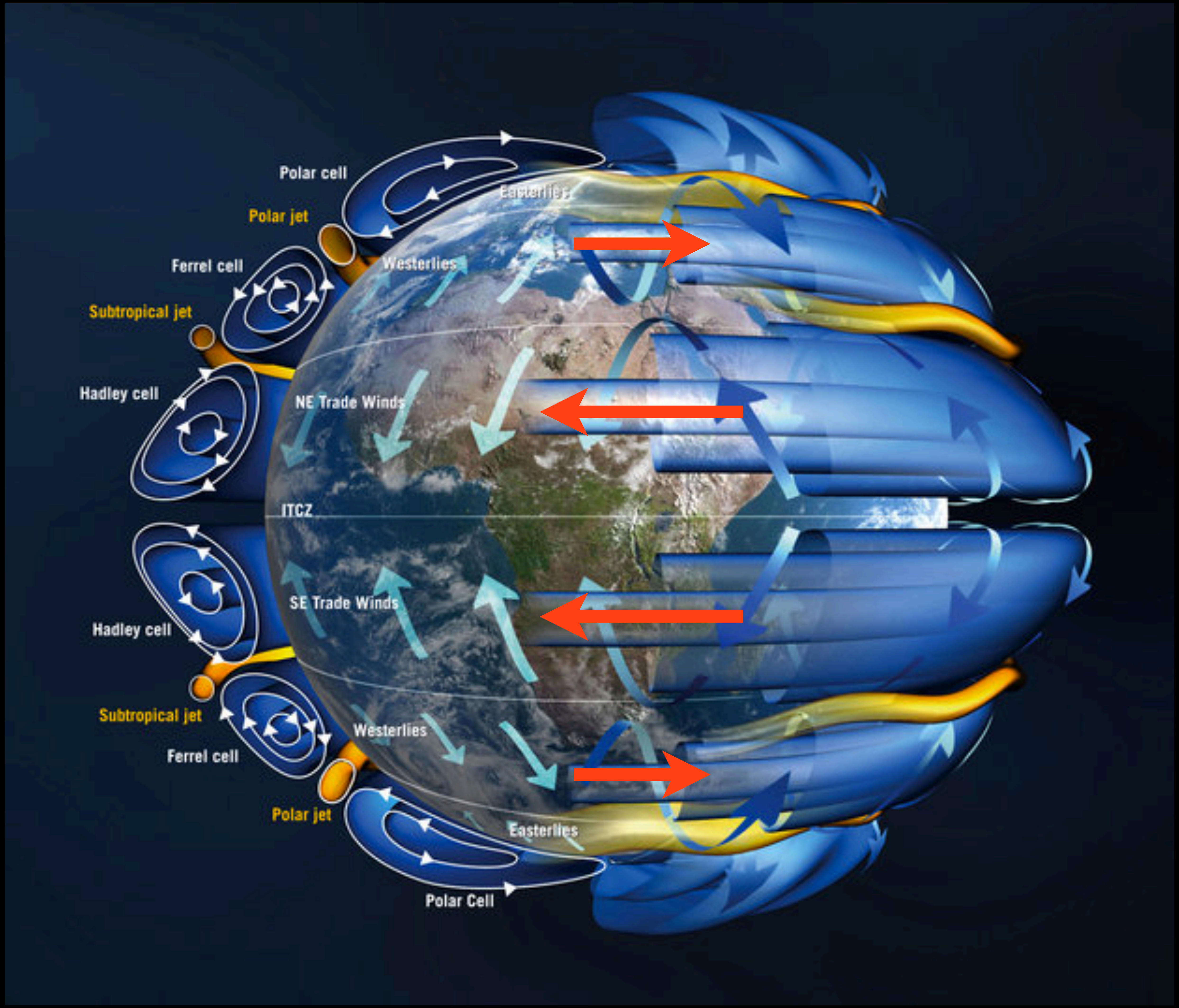
Pressure decreases uniformly, unlike the temperature.



Atmospheric Flow

There are some over-arching flow patterns.

Atmospheric flow is separated into bands/cells that counter-circulate.



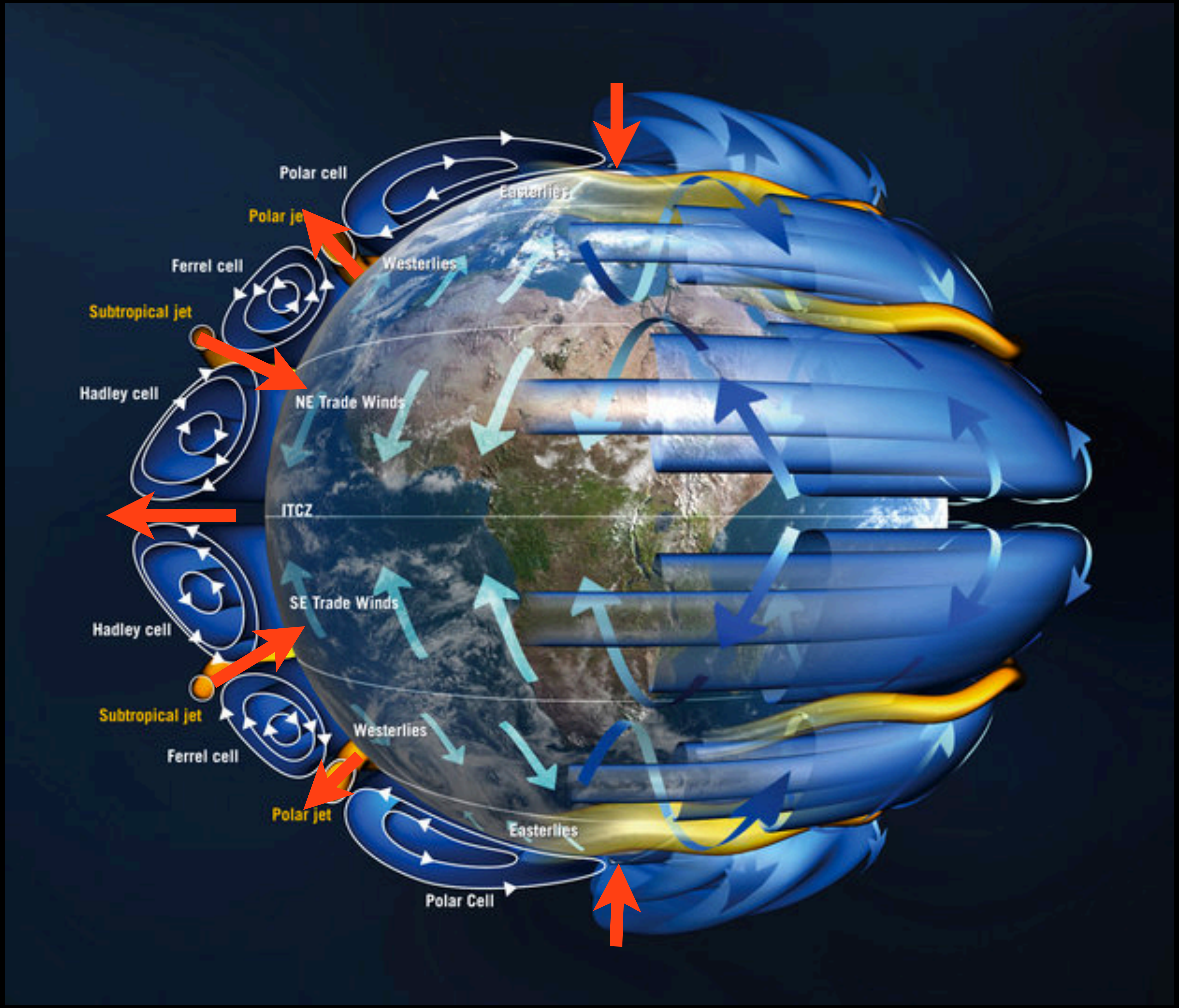
These winds influence the air travel, such that flying E-W takes different amounts of time than flying W-E!

Atmospheric Flow

This is Earth's differential rotation.

Sun heats the Earth, the air expands, rises higher in the atmosphere.

There, it cools down and sinks again.



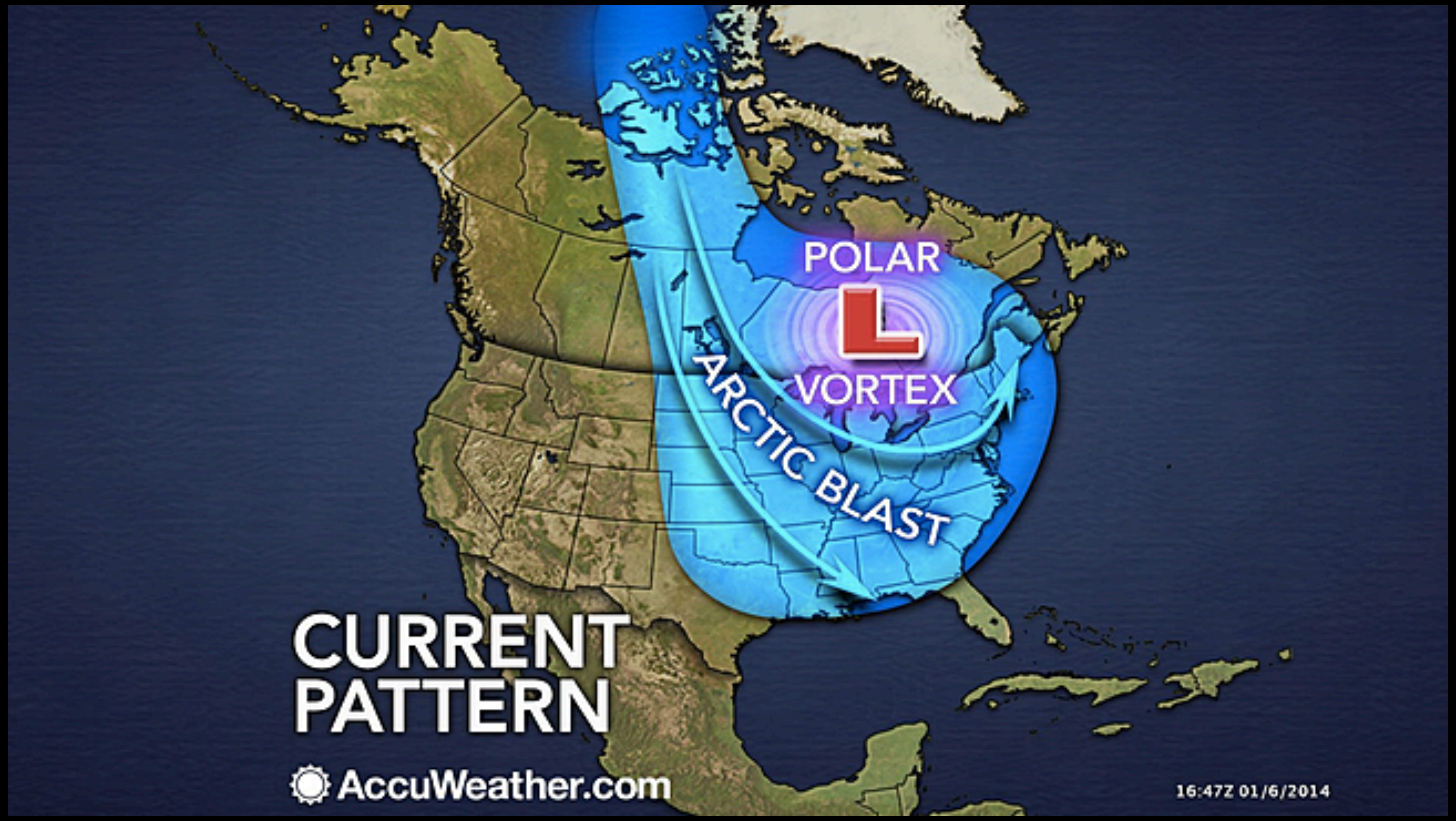
Earth's rotation and eddy currents helps explain the other patterns.

Polar Vortex

Like all planets with atmospheres, Earth has a distinctive polar vortex.

It is the net circular flow of atmosphere at the poles.

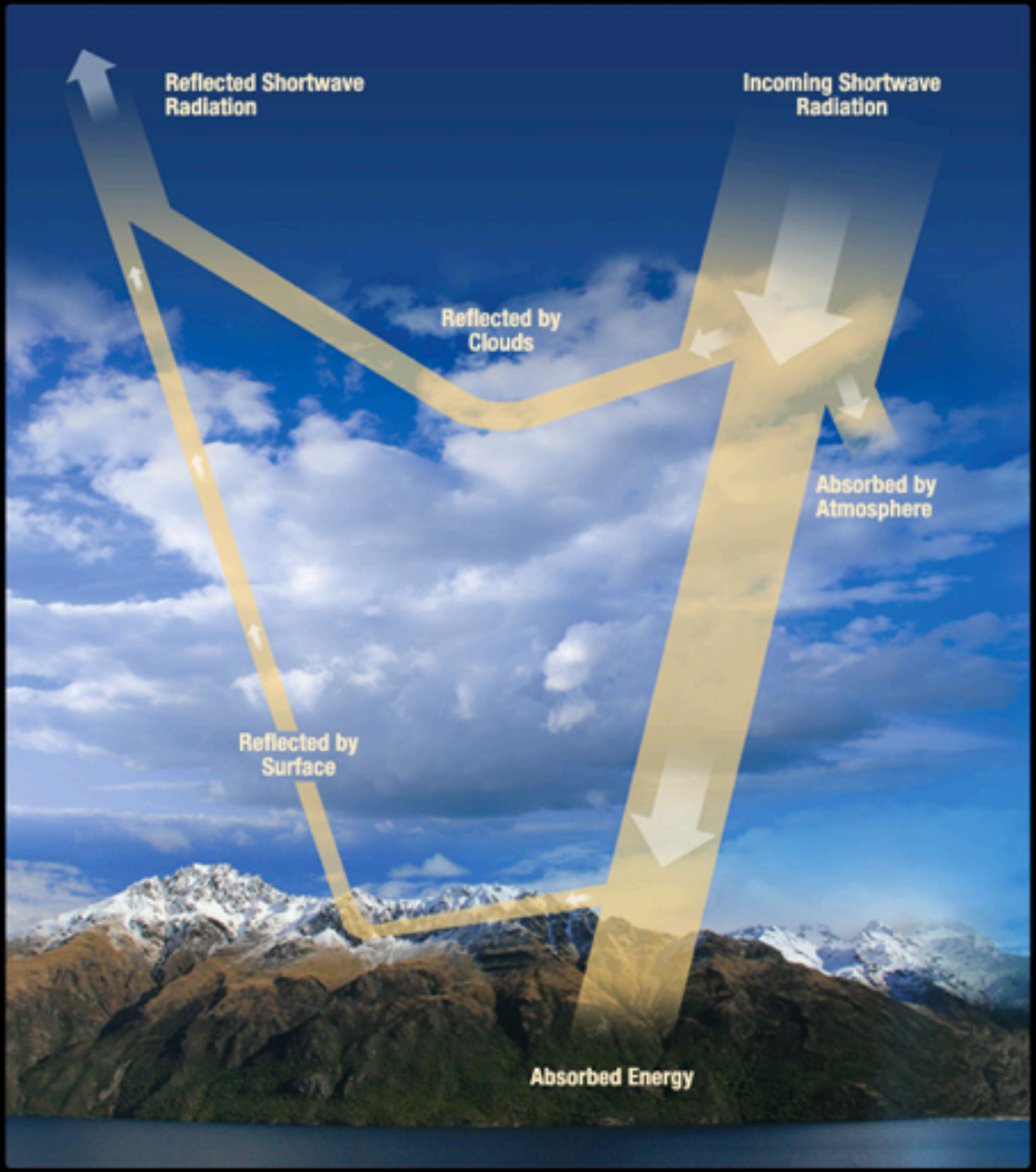
Earth's polar vortex is not very stable, and it can periodically move into Canada, Europe or Russia, bringing extreme cold spells with it.

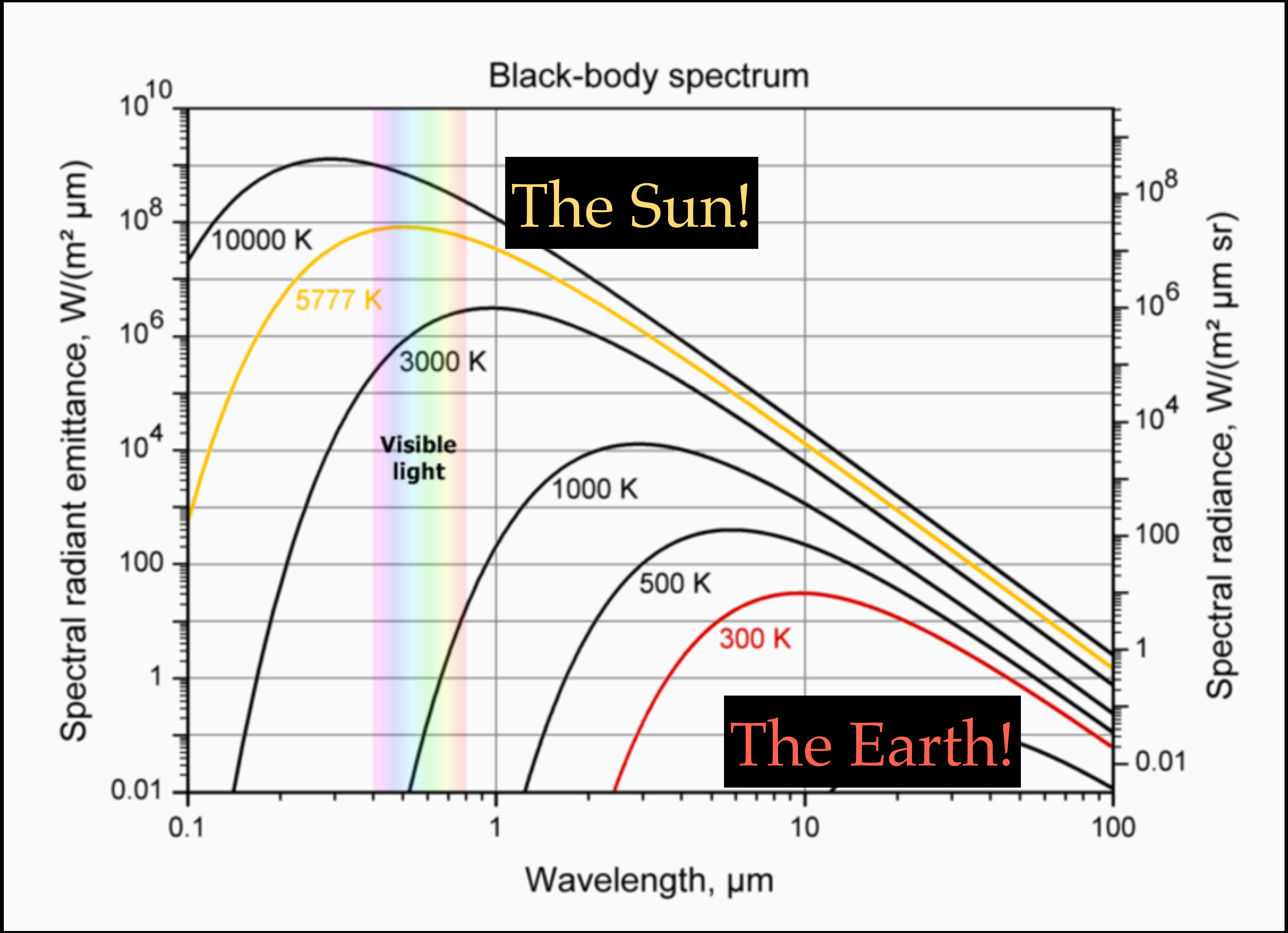


Transport of Light

Atmosphere directly absorbs some of light from the Sun.

The light that passes through (about 70%) is mostly absorbed by the ground, where it is converted into heat, which is then re-emitted as infrared radiation.



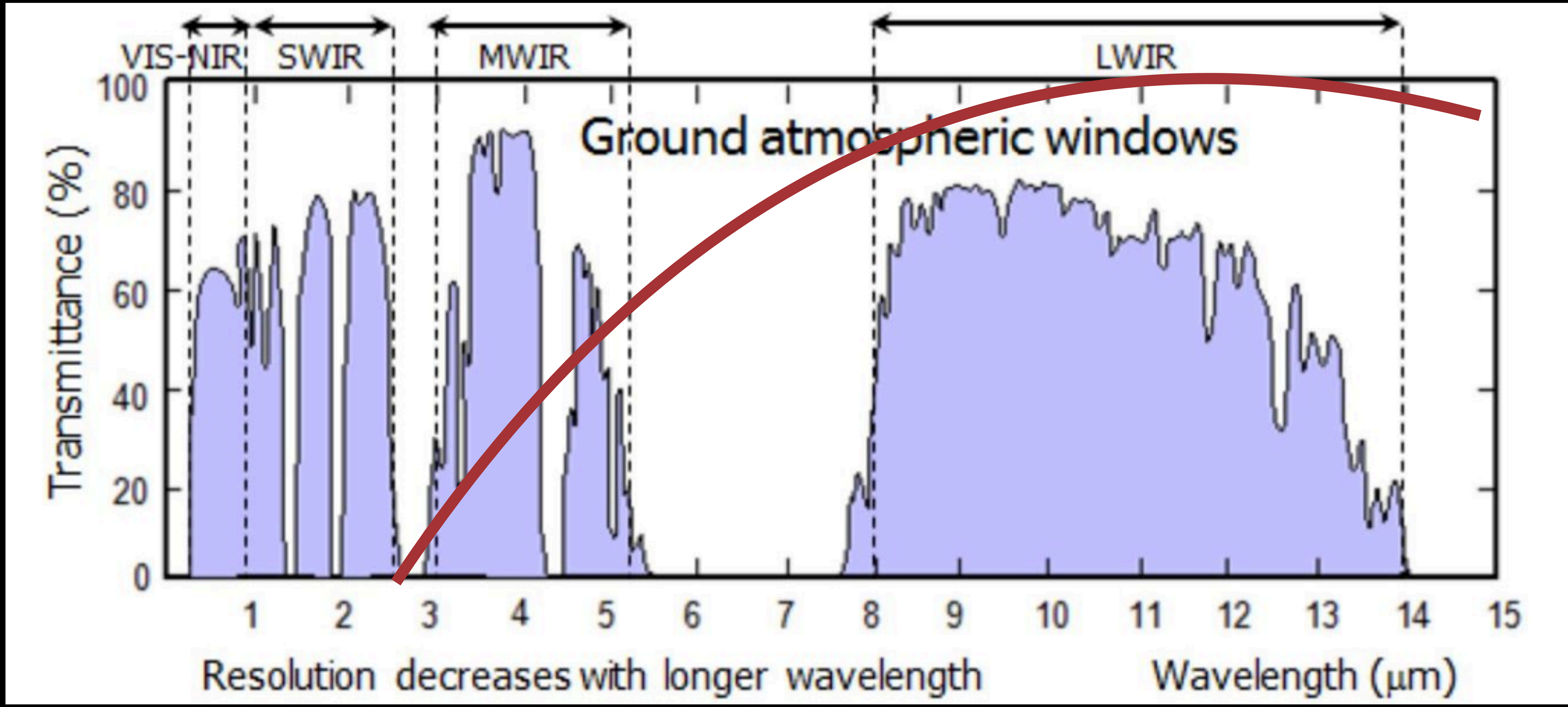


Black-body spectrum
The Sun!
The Earth!
10000 K
5777 K
3000 K
1000 K
500 K
300 K
Visible light
Spectral radiant emittance, W/(m² μm)
Spectral radiance, W/(m² μm sr)
Wavelength, μm
0.1
1
10
100
10^10
10^8
10^6
10^4
100
1
0.01

Transport of Light

The infrared light that makes up Earth's blackbody spectrum is spread out over the IR range, with the peak around 10μm.

About 59% of the heat is radiated back into space directly, while the remaining 41% works to keep our planet warm.

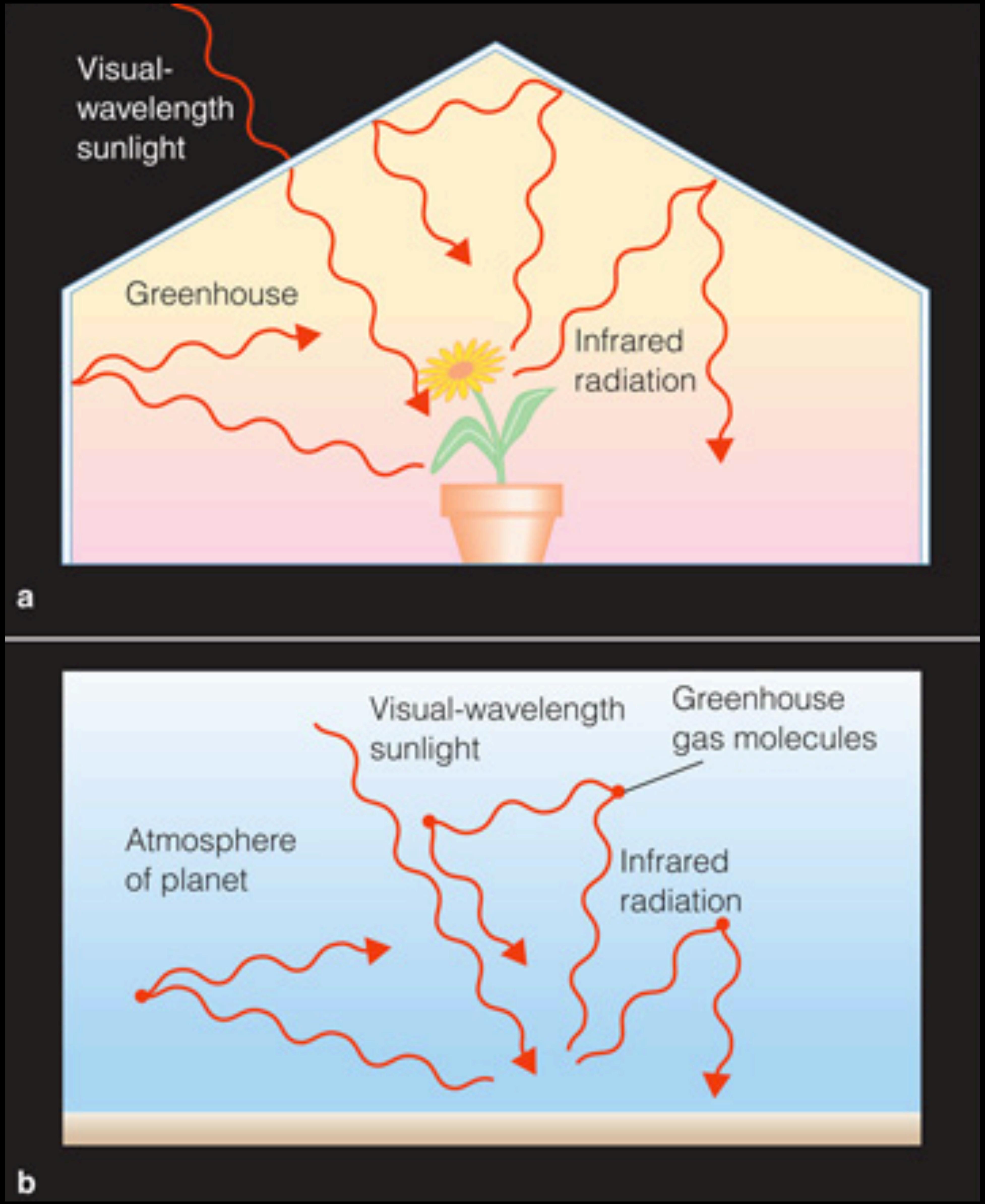


This is why it is not freezing cold at night!

Greenhouse Effect

One frequency passes through a barrier and is converted to another frequency that is reflected by the barrier.

The atmosphere that was transparent to the visible light is opaque/reflective to the infrared light.

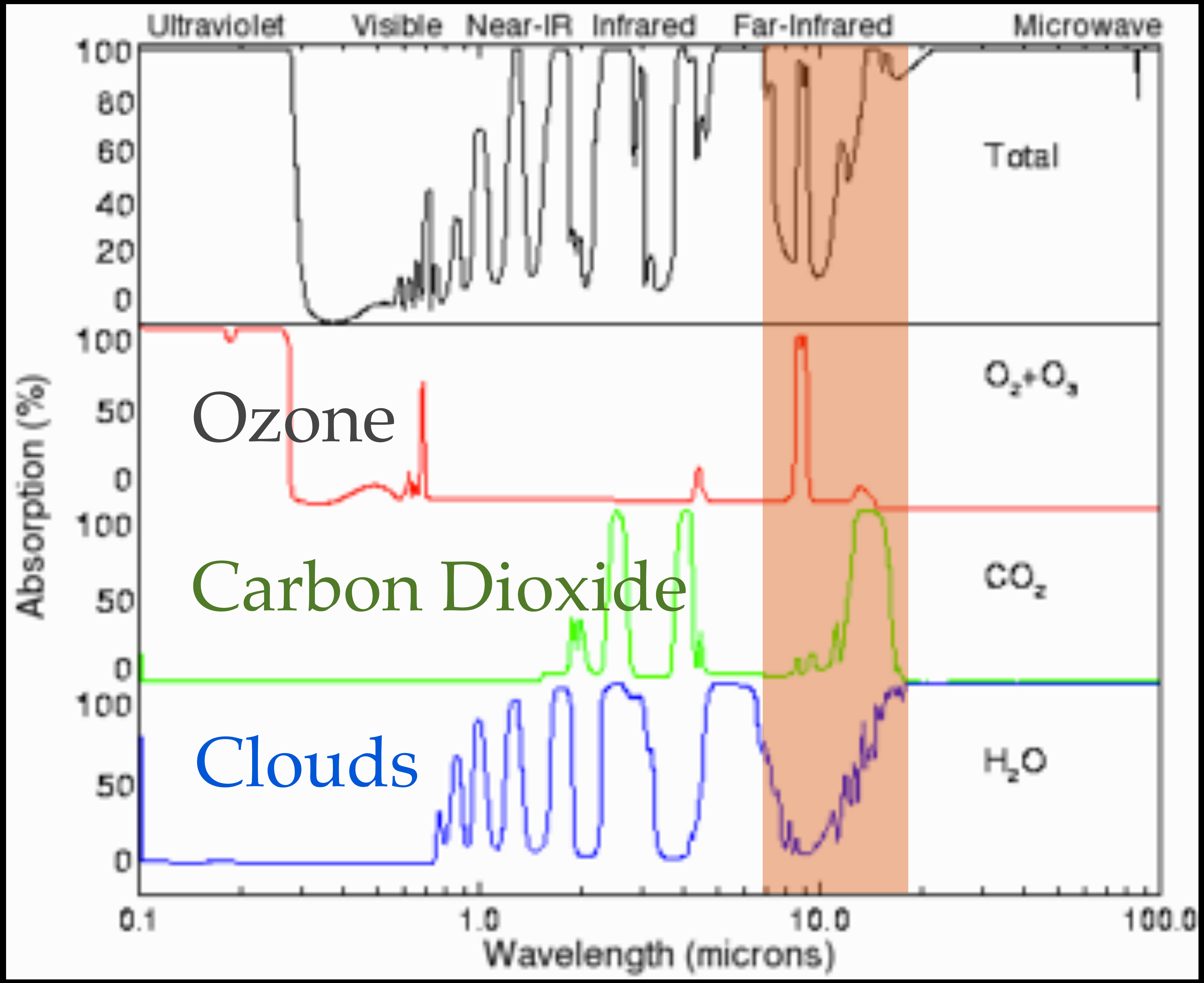


Greenhouse Effect

In Earth's atmosphere, CO_2, O_2, O_3 and water vapour all act as greenhouse gases.

As Earth's temperature increases, the blackbody radiation shifts to smaller wavelengths.

This is dangerous, as the Earth is a good greenhouse at small wavelengths!



Earth's Infrared

Disturbing Content Warning

The next slide contains content that may be disturbing for some students.
However, this content reflects the harsh reality of the world we live in.

If you wish to turn away, you may.
But turning our backs on reality won't make things better.

Climate Change

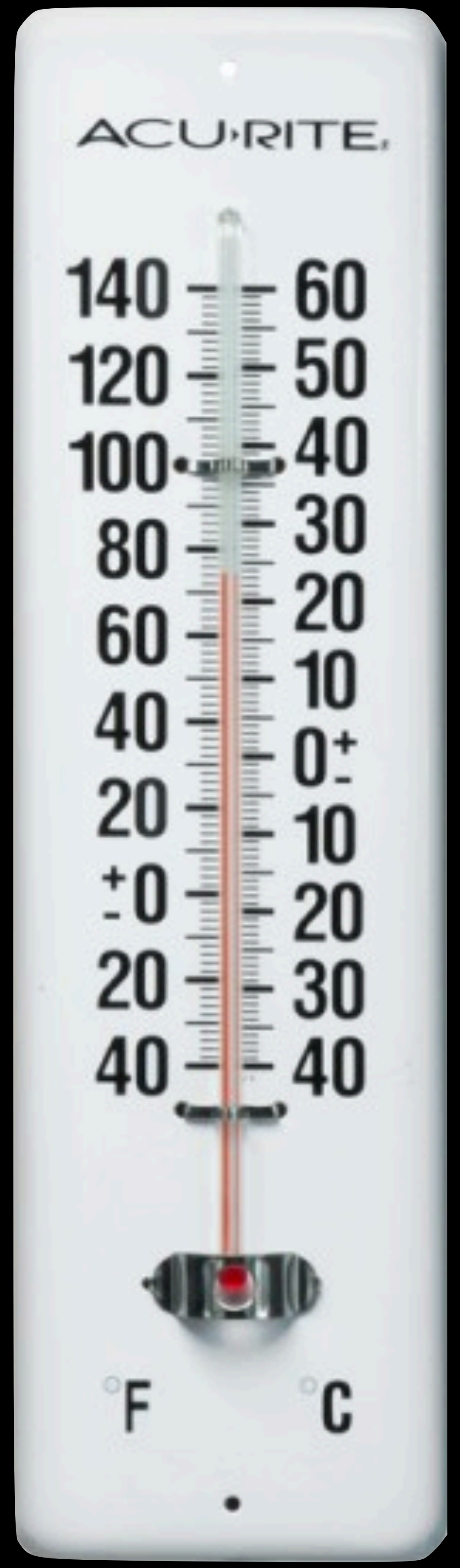
"Global Warming" is a misnomer.

The greenhouse effect will cause the average temperature of Earth to increase a few degrees.

The noticeable effects of climate change include more convection, causing more storms and destructive weather patterns, as well as a distinctive change in the habitats and ecosystems of the world.

Water Expansion

The ice caps melting is not the only reason why water levels on Earth will rise: materials expand as they heat (e.g. classic liquid thermometers).



Total Volume of Water on Earth: $V=1.386\text{x}10^{18}\text{m}^3$

Volumetric Expansion Coefficient: $\alpha=0.000214\text{K}^{-1}$

Increase in Water Volume: $\Delta V = \alpha V(\Delta T) = 2.97\text{x}10^{14}\text{m}^3/\text{K}\ (\Delta T)$

Surface Area of Water on Earth: $SA=510\text{x}10^{12}\text{m}^2$

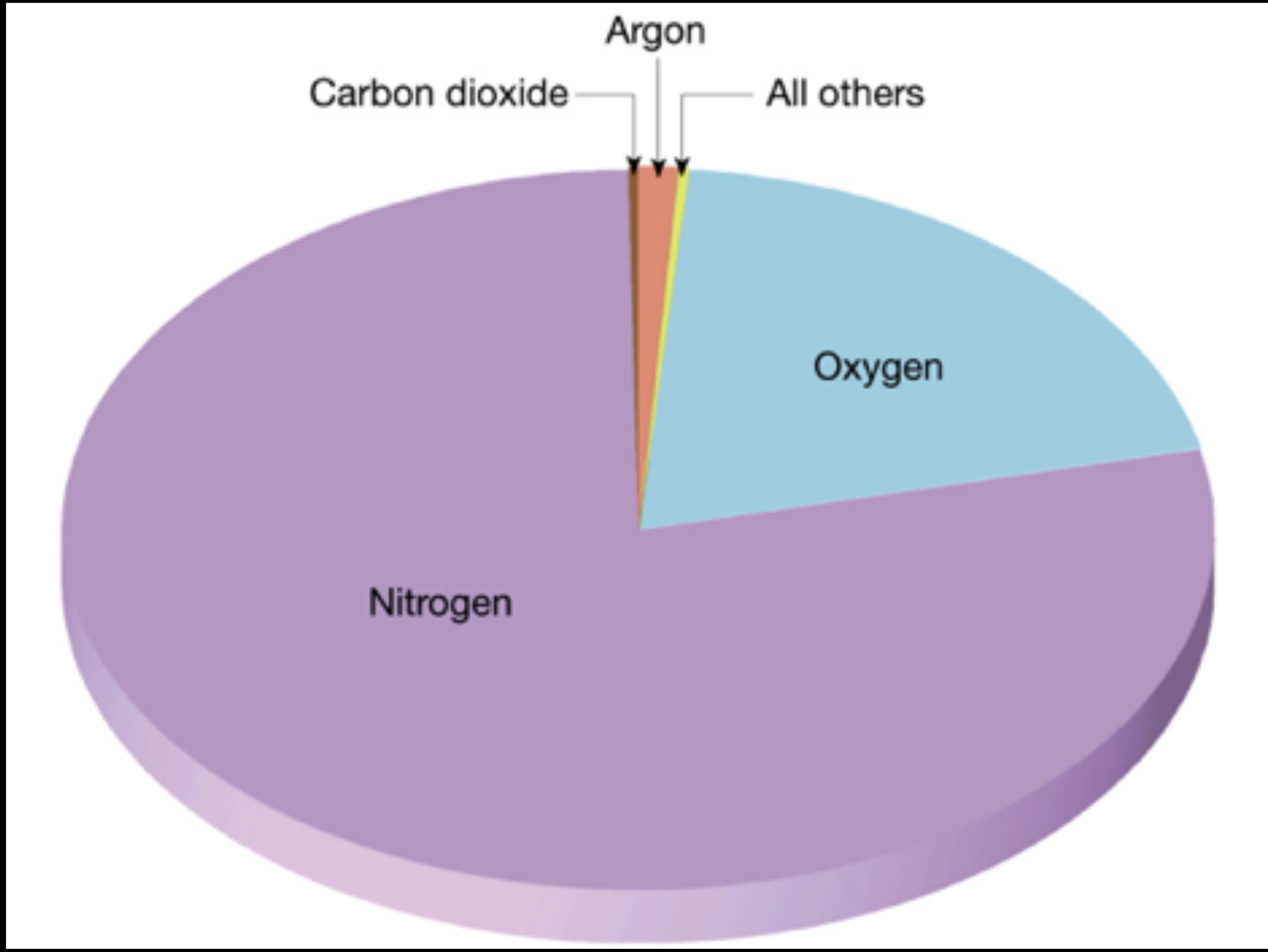
Increase in Water Height: $\Delta h = \Delta V/SA = 0.581\ (\Delta T)$

Composition

78% nitrogen, 21% oxygen, 0.9% argon

CO_2 and others make up very small fraction, yet have a huge impact.

Oxygen is a highly reactive substance, and does not occur in any large quantity on any other object ever found by humans.



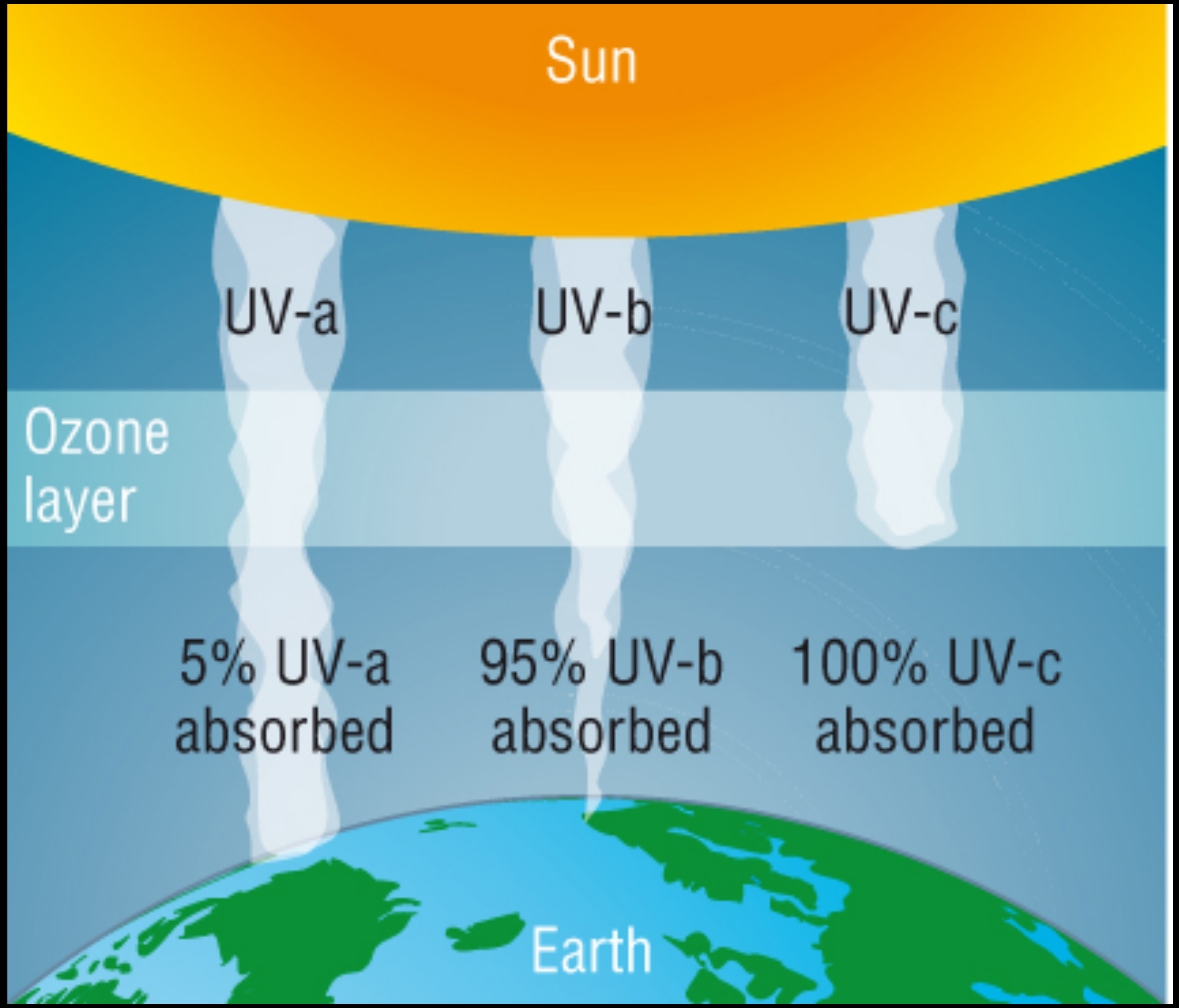
Oxygen must be constantly replenished in our atmosphere

Ozone

Ozone is O_3, produced naturally by interactions of UV light with O_2.

The ozone layer blocks a significant amount of dangerous UV light.

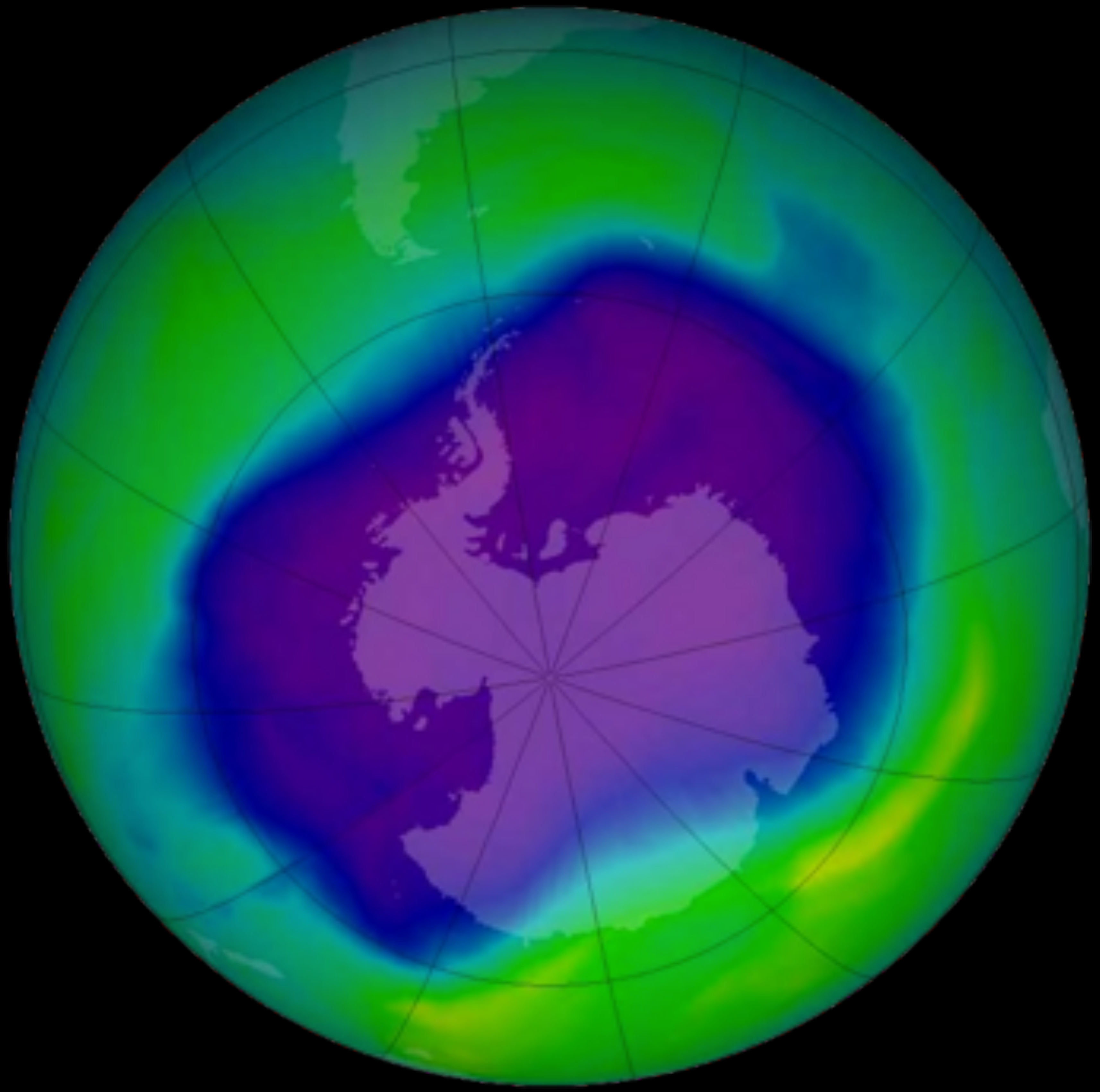
Ozone is also a potent greenhouse gas that reflects infrared light.



Ozone

There is a large hole in our ozone layer due to the use of CFCs in aerosols and refrigerators.

This is the first evidence of human-caused, global-scale environmental impact.



Question: Is it a good idea to counter global climate change by decreasing the ozone layer, since ozone is a greenhouse gas?

a. Yes

b. No

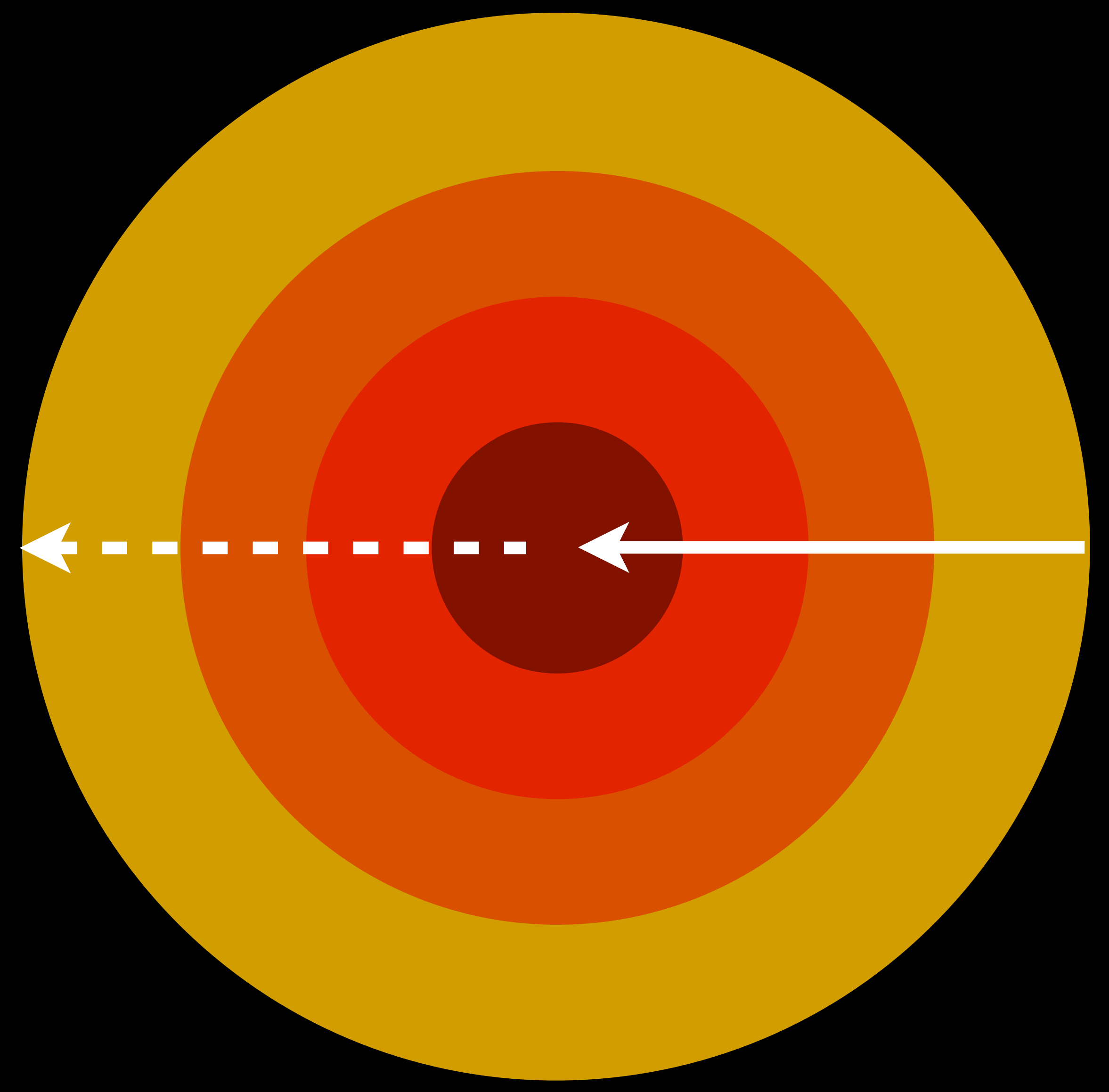
c. Only very carefully

Planetary Evolution

First Stage of Development

The Earth is highly differentiated - the densest material resides in the centre, with density increasing with depth.

Thus, at one point, the material must have been fluid enough to move around.

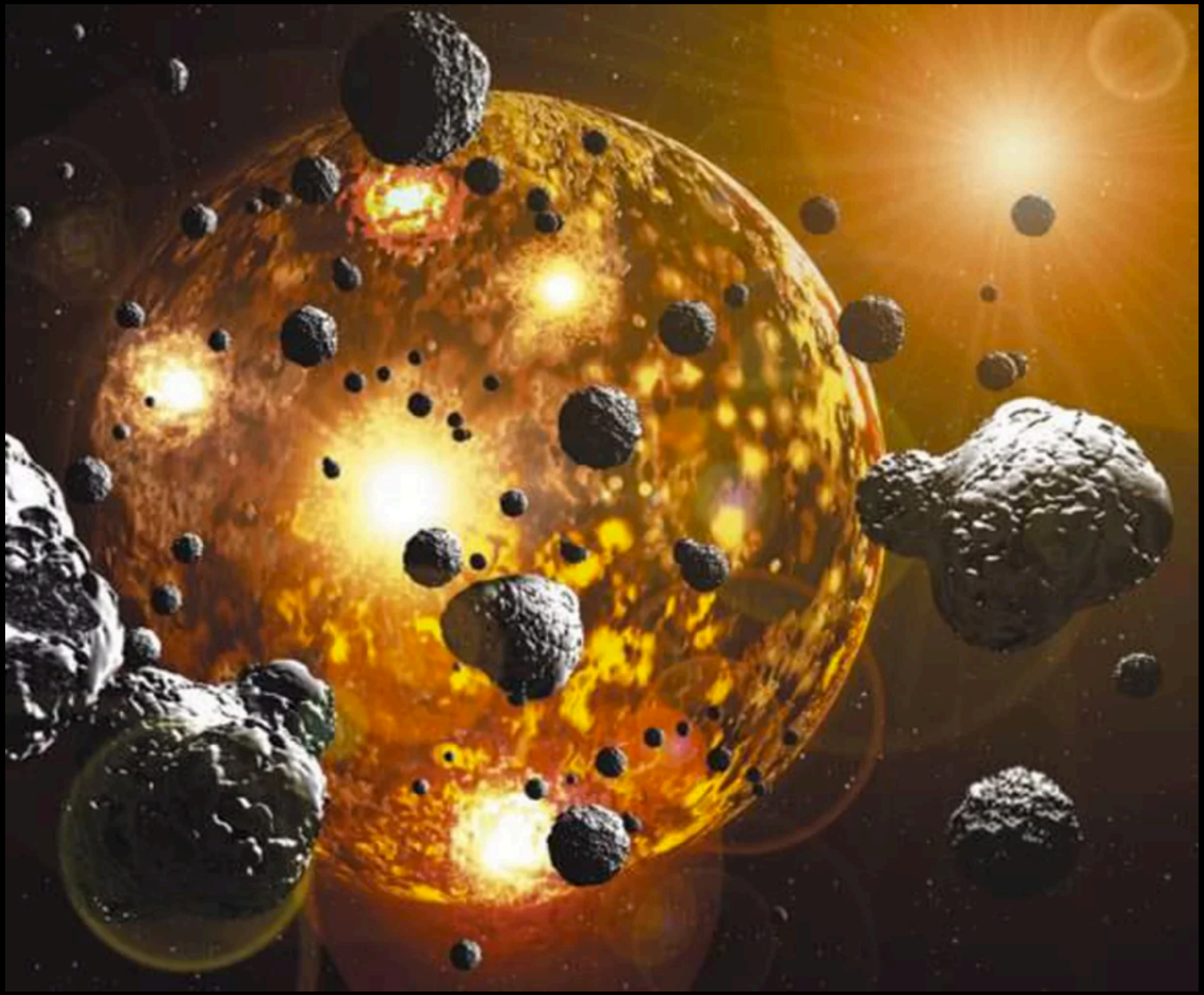


The first stage of development is called Differentiation, and suggests that Earth started out as a molten object.

First Stage of Development

The best explanation is continual bombardment of the planet from asteroids. (Accretion)

Earth isn't special - all planets likely experienced this bombardment!



Second Stage of Development

Bombardment slows over time.

Crust forms on the cooling surface.

Remaining asteroids continue to collide, but now leave craters in solid crust.

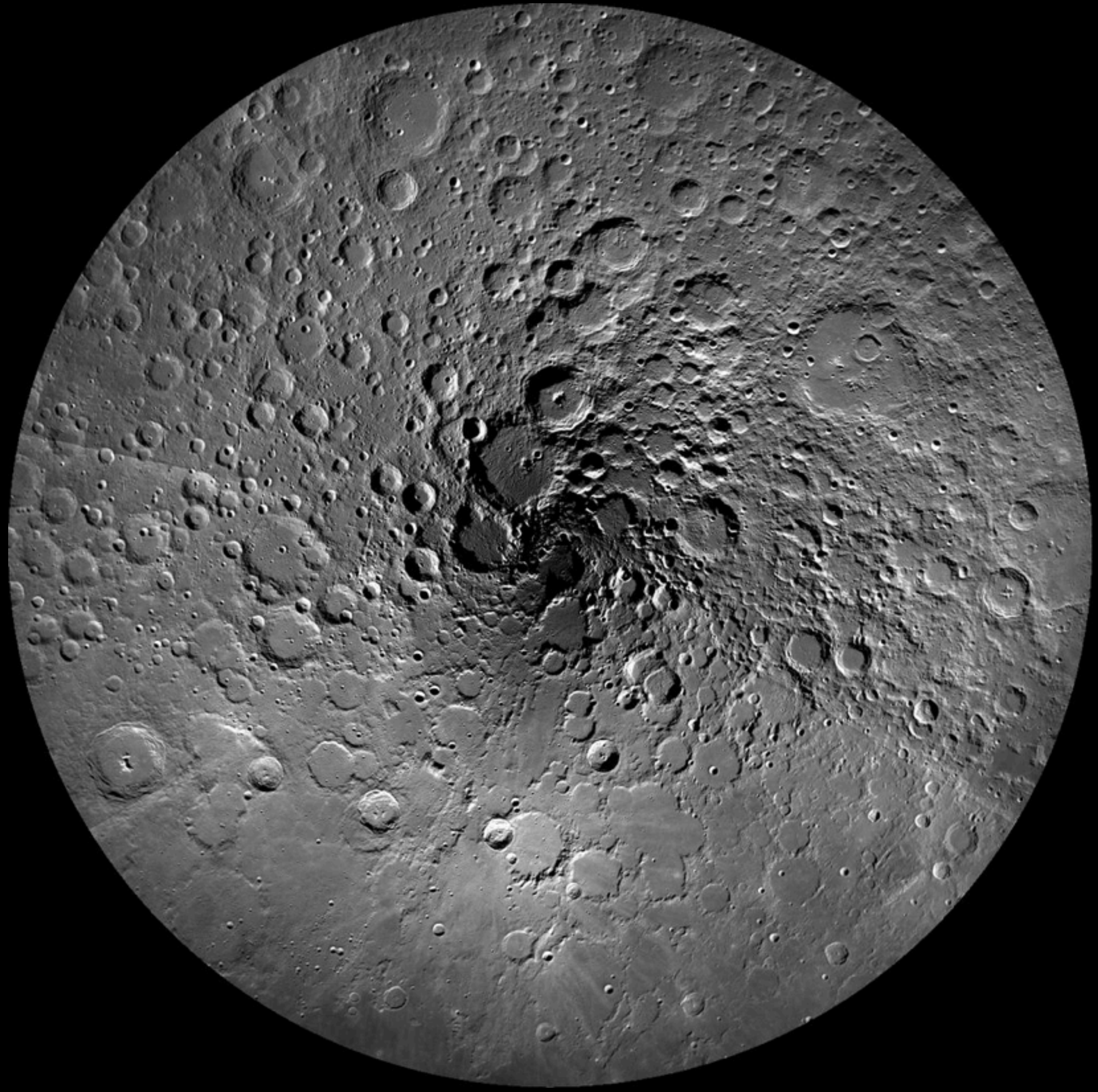
This stage is called “Cratering”.
(Big surprise, I know.)

Second Stage of Development

Earth's surface is changing too much to see the craters after so long.

But we can look to the Moon for confirmation!

The Moon's surface, clearly visible from Earth, shows this period of continued cratering.



Third Stage of Development

Earth would have been large enough by this point to support an atmosphere.

The early atmosphere likely contained methane, ammonia, water vapour.

Third Stage of Development

Mantle mostly liquid, and outgassing continues from lava produced from volcanoes and impact craters.

This stage is called Flooding.

Outgassed material includes methane, CO_2, SO_2, and various nitrogen compounds.

Fourth Stage of Development

UV light from the Sun plays
an important role in the fourth stage.

The Slow Surface Evolution includes
tectonic activity, but also the effect
of UV light on the atmosphere.

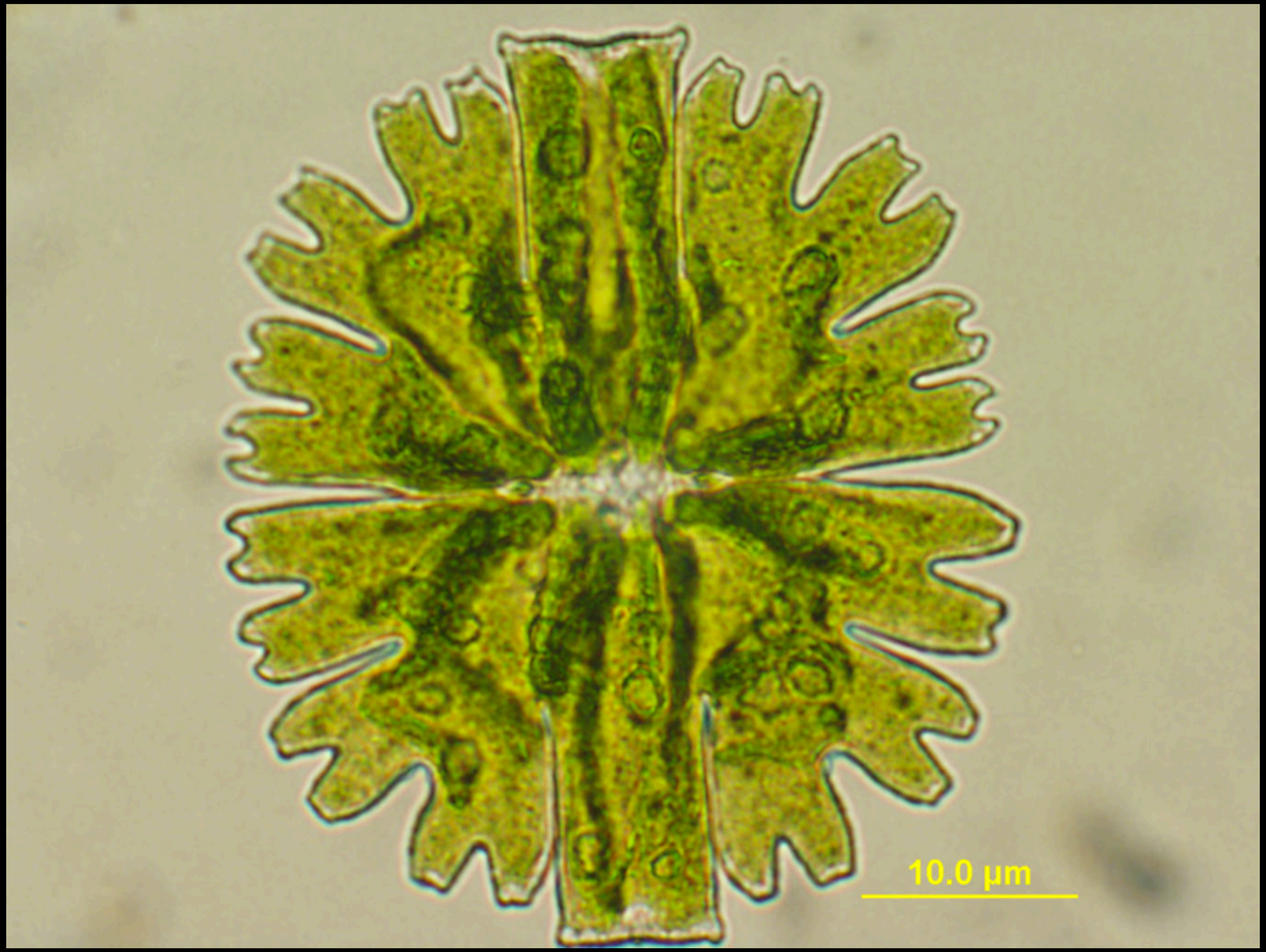
UV light separates nitrogen compounds
and produces N_2. This is the origin of
our nitrogen.

Fourth Stage of Development

Temperatures drop and water condenses to form liquid oceans.

CO_2 dissolves into oceans, reducing the greenhouse gas and allowing further cooling.

Eventually, basic life formed in the oceans, and evolved the ability to photosynthesize.



Fourth Stage of Development

Early forms of life used up the dissolved carbon, allowing more CO_2 to be dissolved, and produced O_2.

This O_2 then reacted with UV light to produce O_3, which formed the ozone layer.

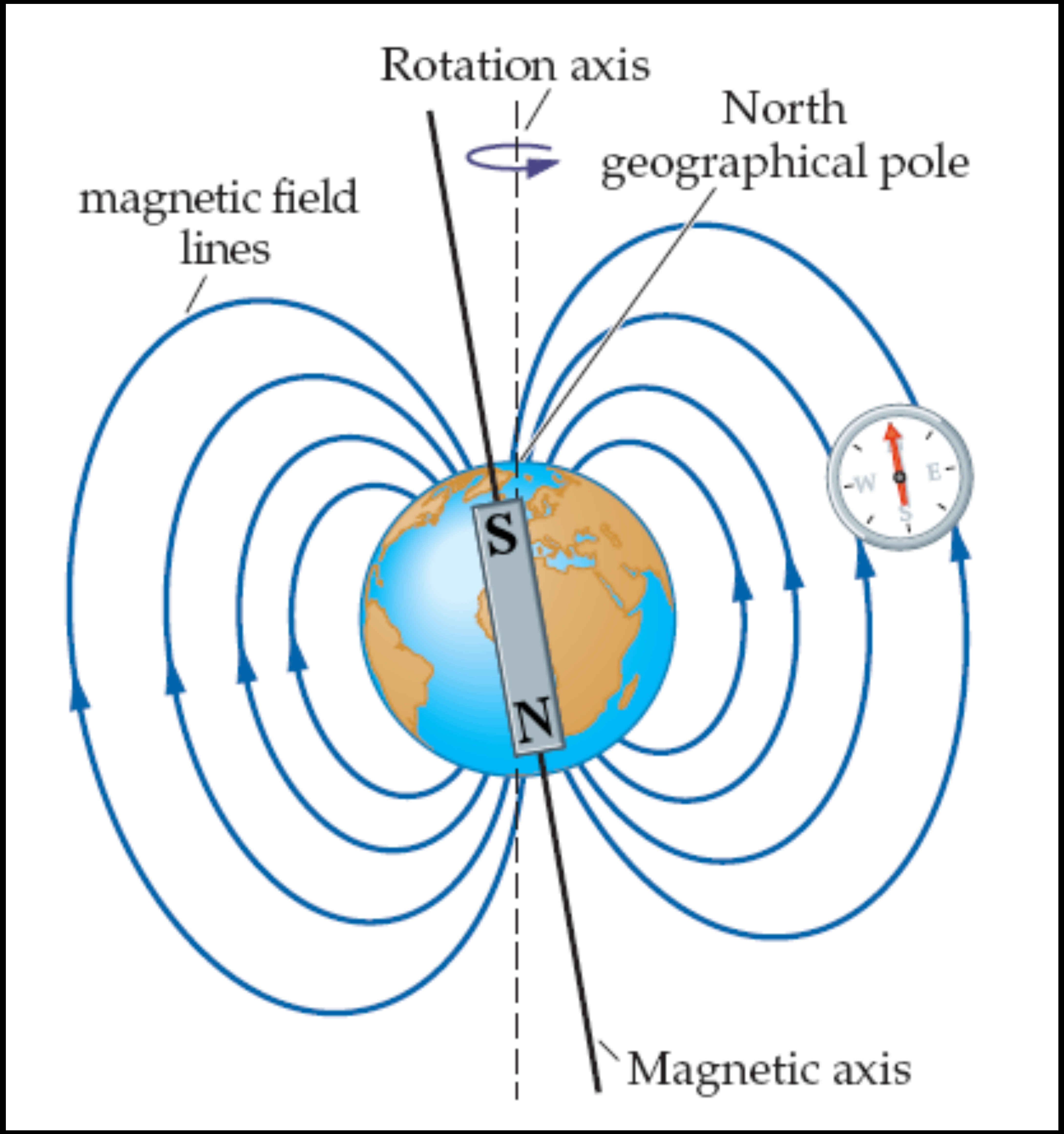
This shielded the land from the harmful UV light and allowed life on land.

Fields: Earth’s Magnetic Field

Compass

The compass was used for navigational purposes as early as about 1000 CE.

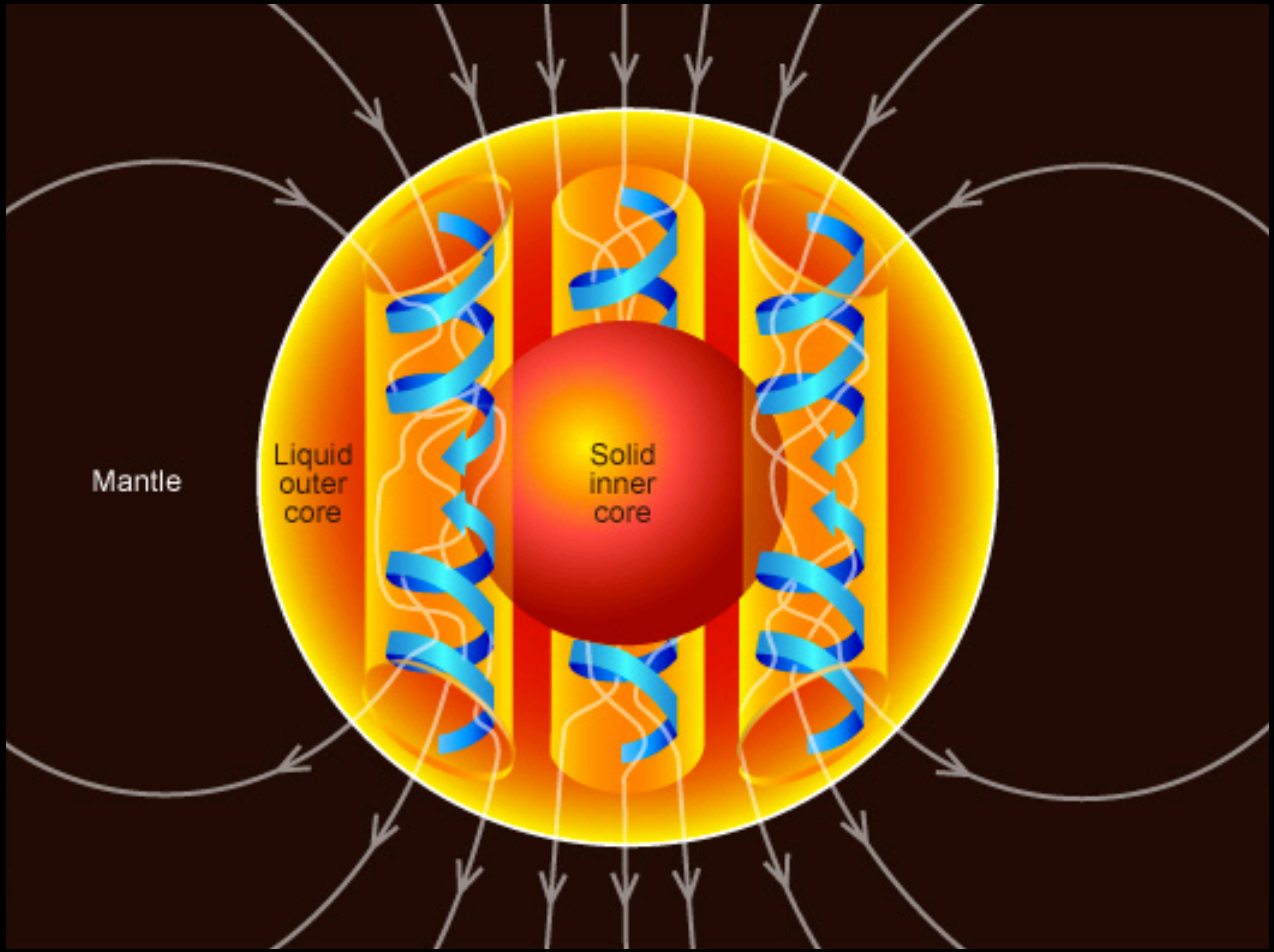
In the 1600s, it was proposed
that the Earth’s field was
due to permanent magnetization
in Earth’s core (like a bar magnet).



Magnetosphere

In 1919, it was first proposed that the Earth's rotational axis and magnetic axis were too coincidental - there must be a link.

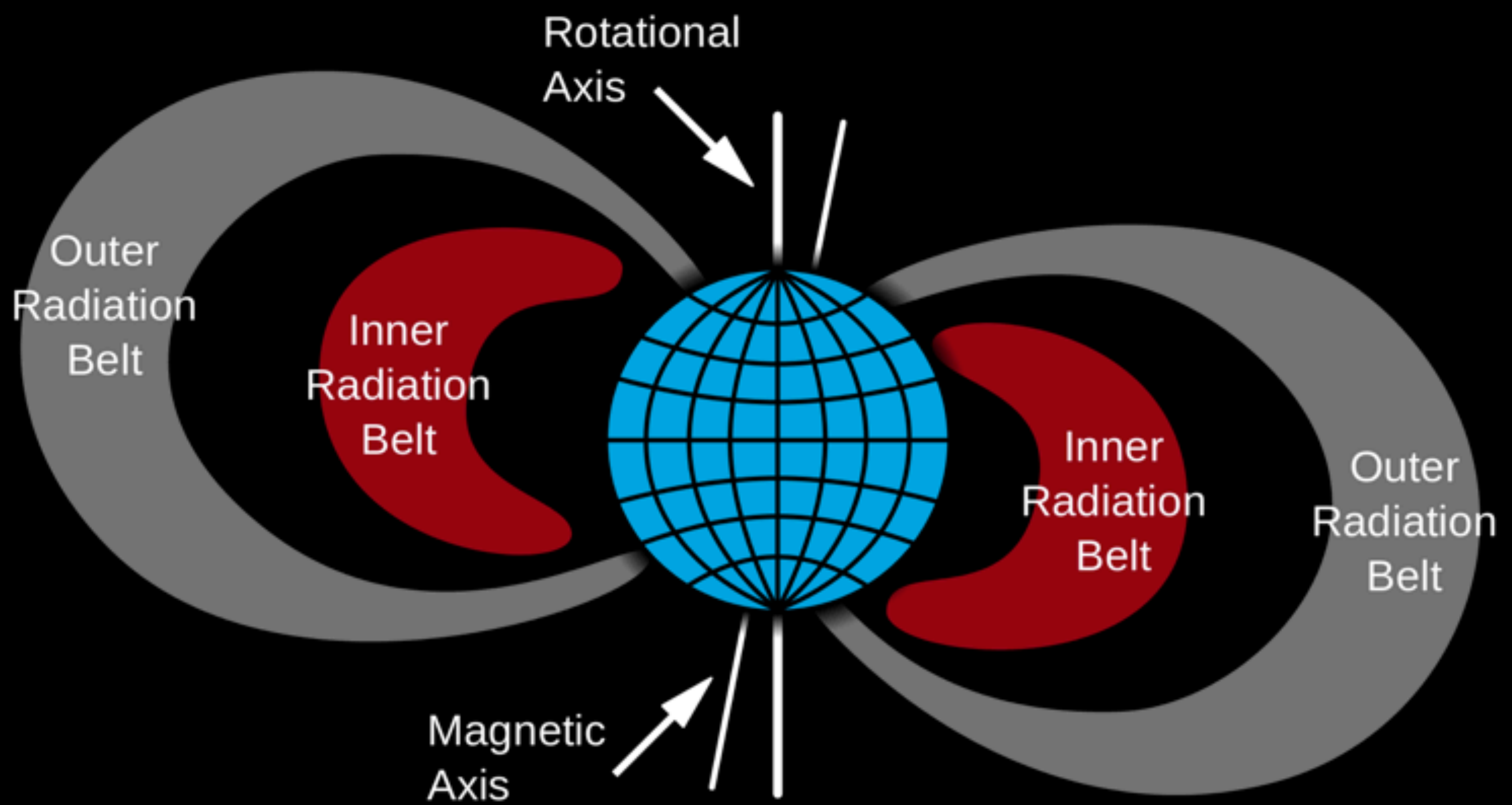
Dynamo theory - well studied in electromagnetism - was proposed as the origin of Earth's magnetic field.



The convective motion of the liquid outer core produces the field.

Van Allen Belts

Magnetic field around Earth has an effect on solar winds.



Electrons are lighter and collect in the outer radiation belt.

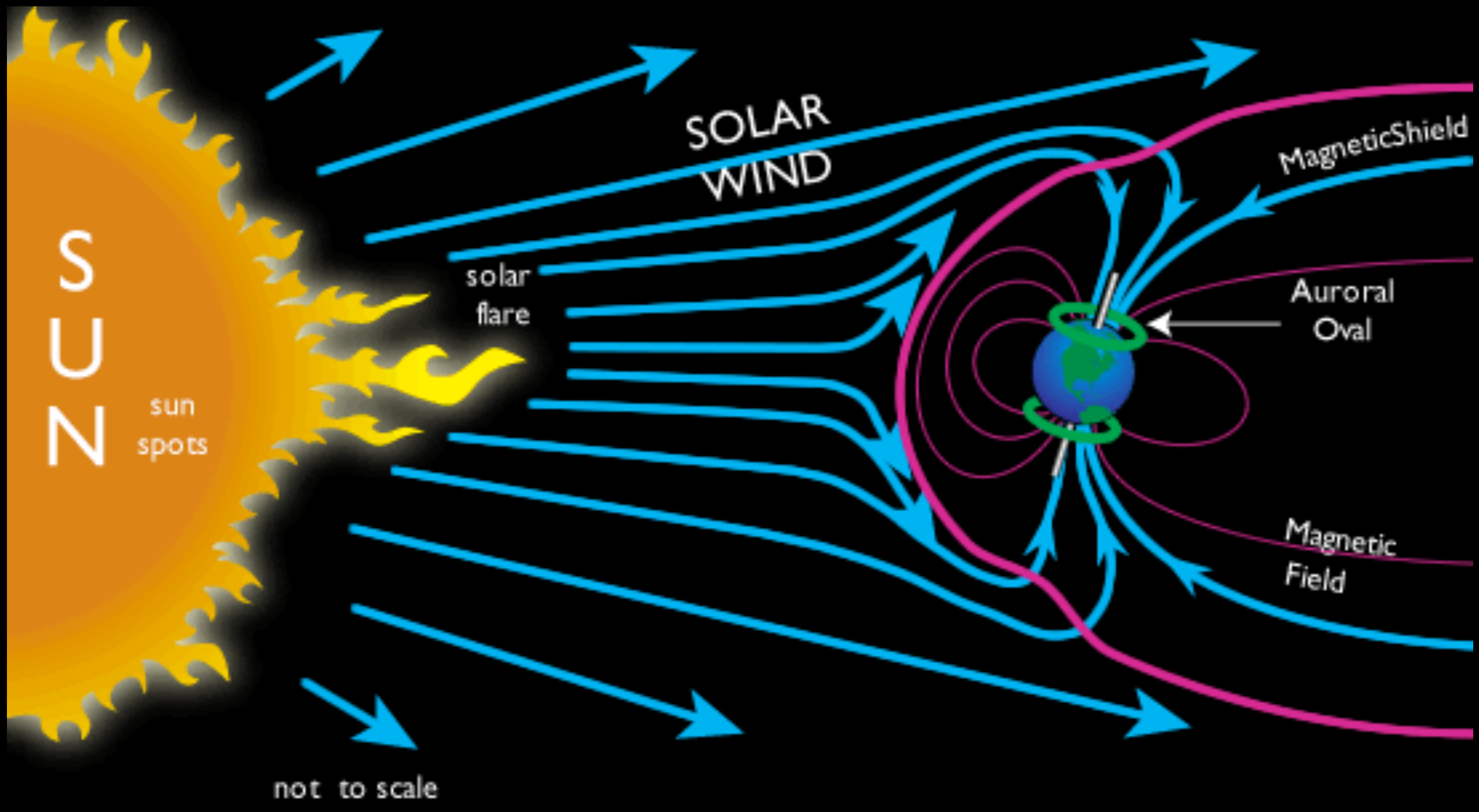
Protons are heavier, have more momentum, collect in the inner belt.

Recall: a=F/m, so if m is larger then acceleration is smaller and it takes longer to slow down.

Van Allen Belts

The charged particles spiral towards the poles of the magnetic field and are observable from Earth as aurorae.

The nothern aurora is called Aurora Borealis and the southern is Aurora Australis.



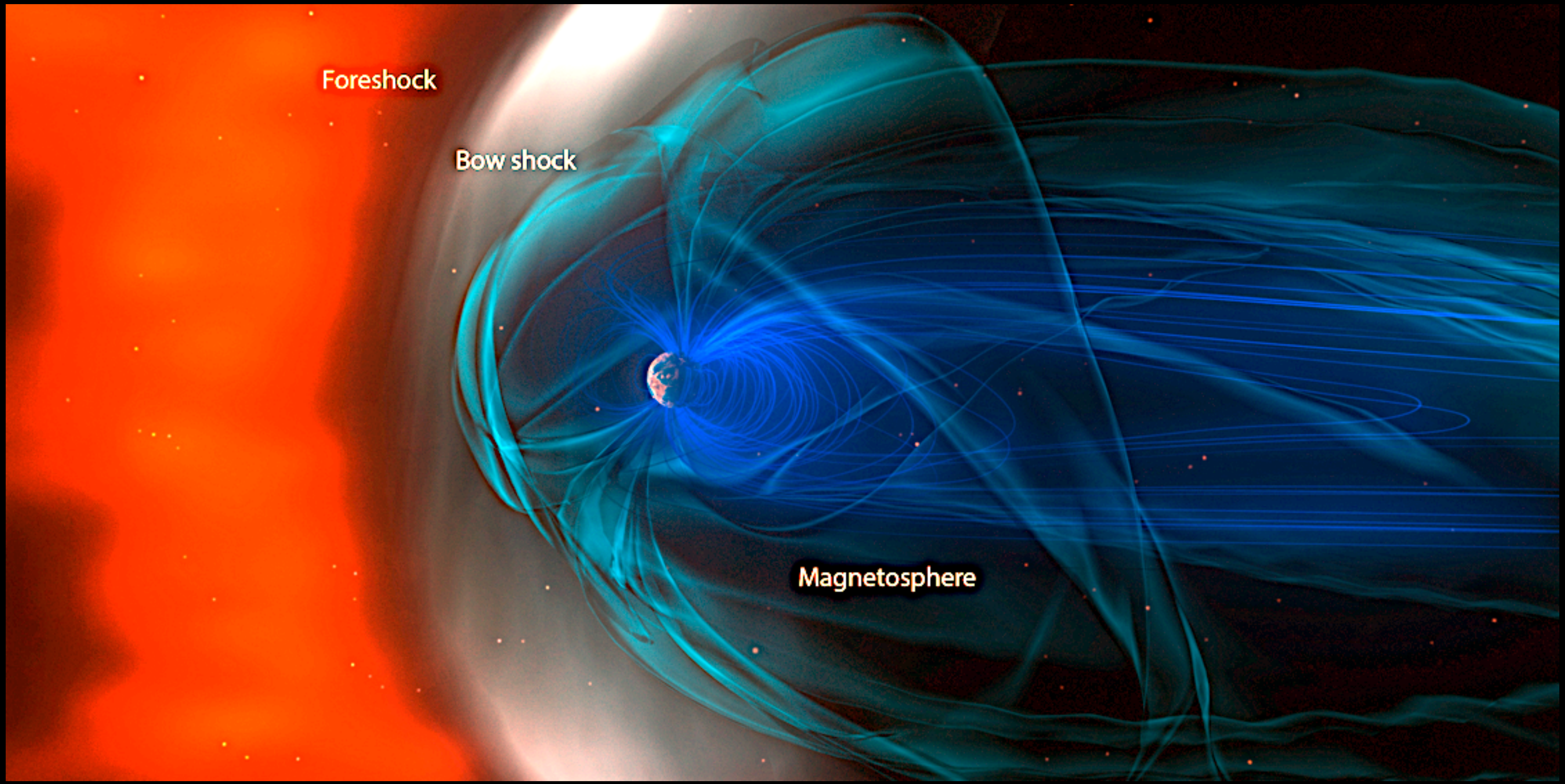
Interaction with Solar Wind

The solar wind can have a huge impact on the Earth's magnetosphere.

The Bow Shock is where the two meet in space.

Just behind that is the Magnetopause, where the two battle for dominance.

Trailing behind the Earth is the magnetotail.



https://www.youtube.com/watch?v=WOnz7IztubE

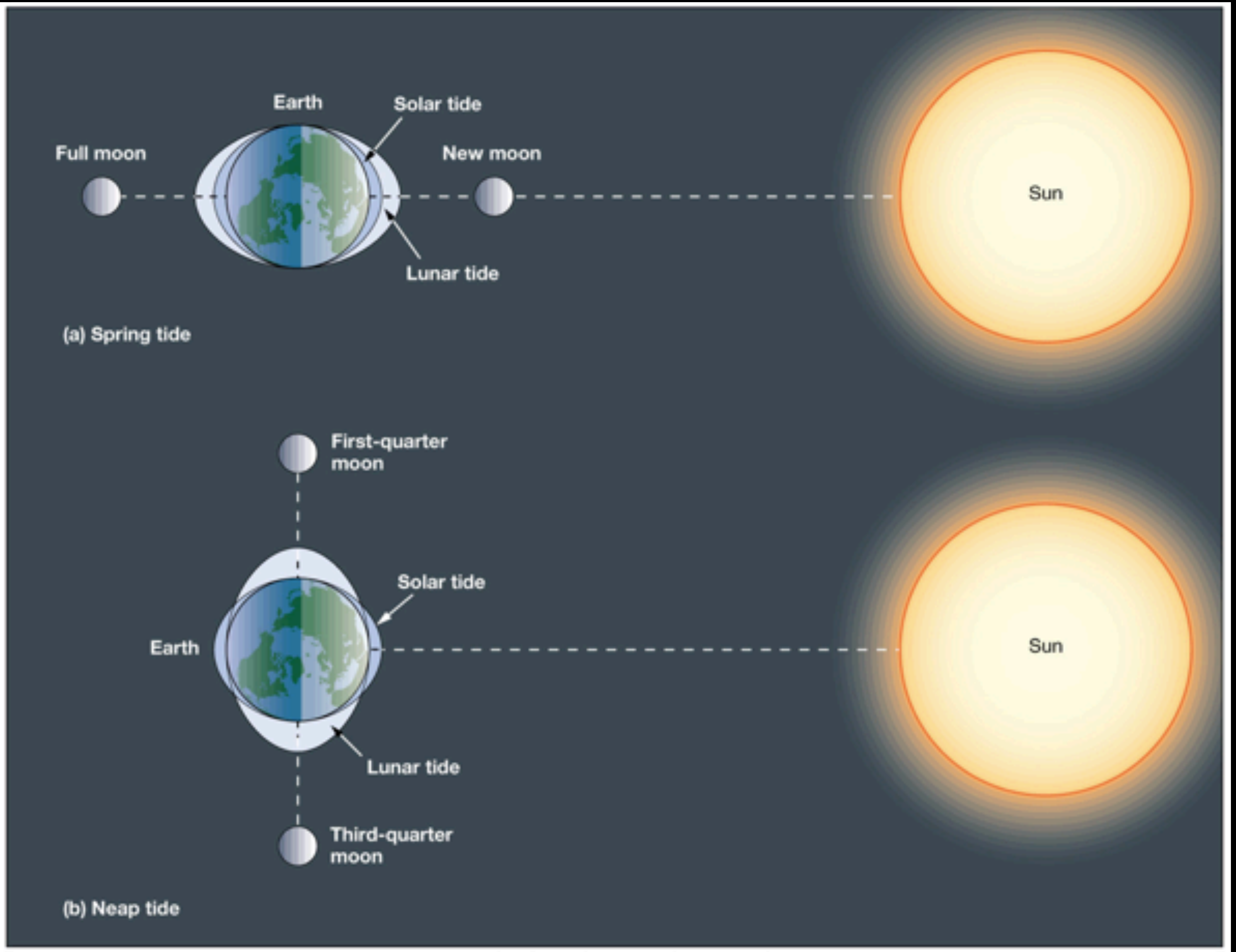
Fields: Tidal Gravitational Fields

Tidal Forces

Tidal forces are directional forces that change with distance, such as the gravity from a distant object.

Earth actually experiences two primary tidal forces.

The Moon produces the largest tidal effect, but the Sun produces a noticeable effect as well.

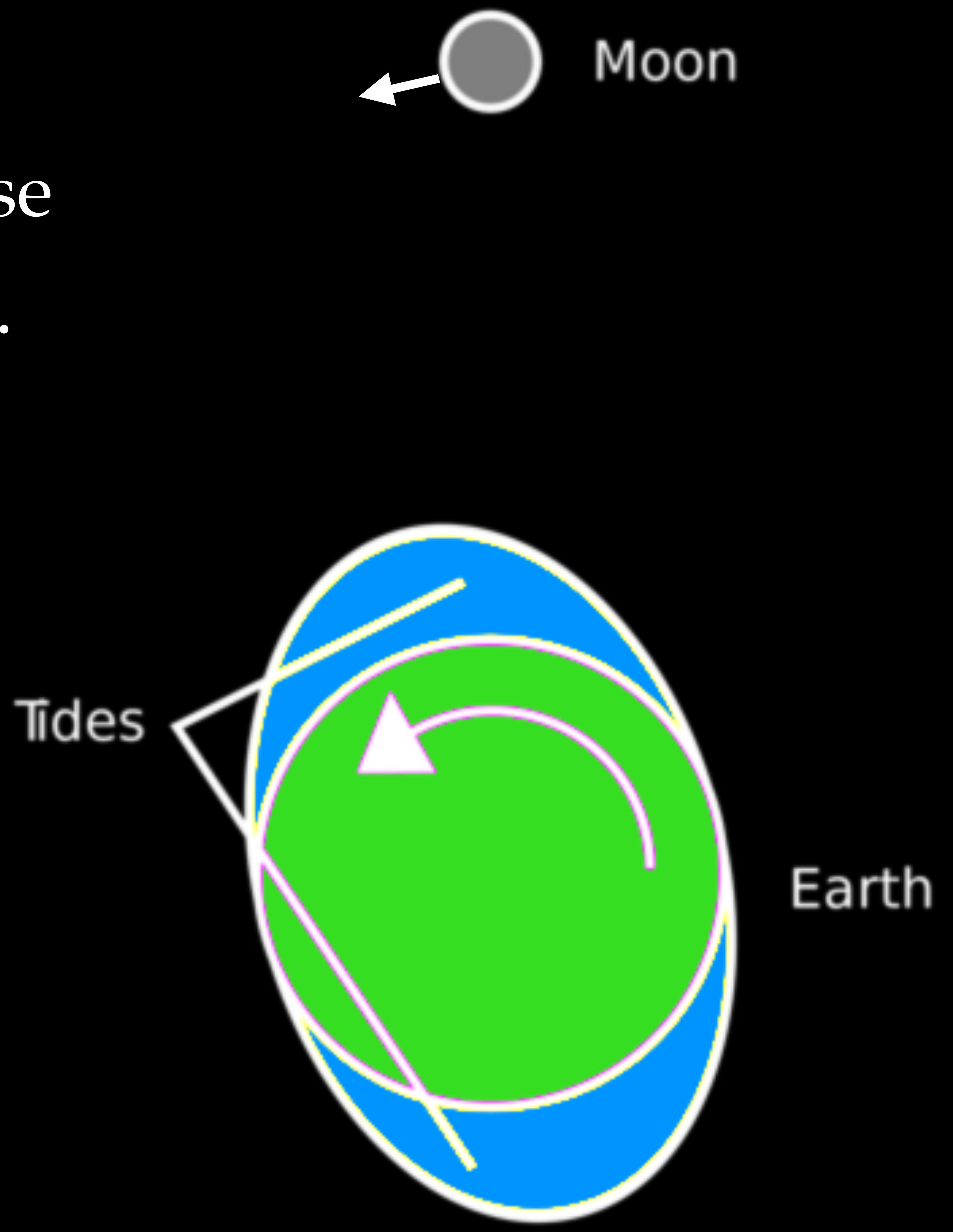


Tidal Forces

The tides lead the orbit of the Moon because Earth's faster rotation pulls the tide with it.

The Moon causes two high tides: When the Moon is approx. at your zenith and when it is at approx. at your nadir.

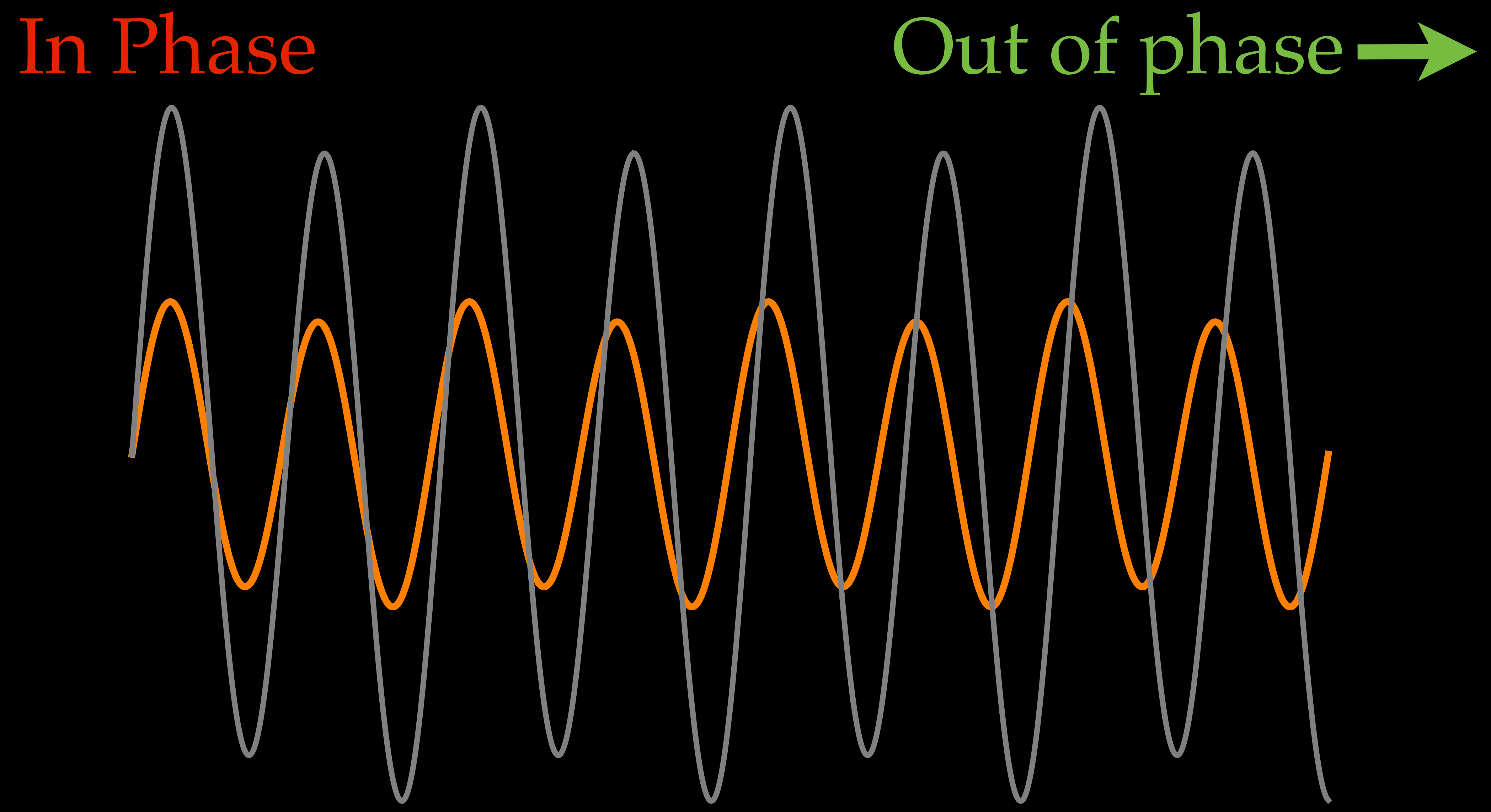
The same thing happens with the Sun.

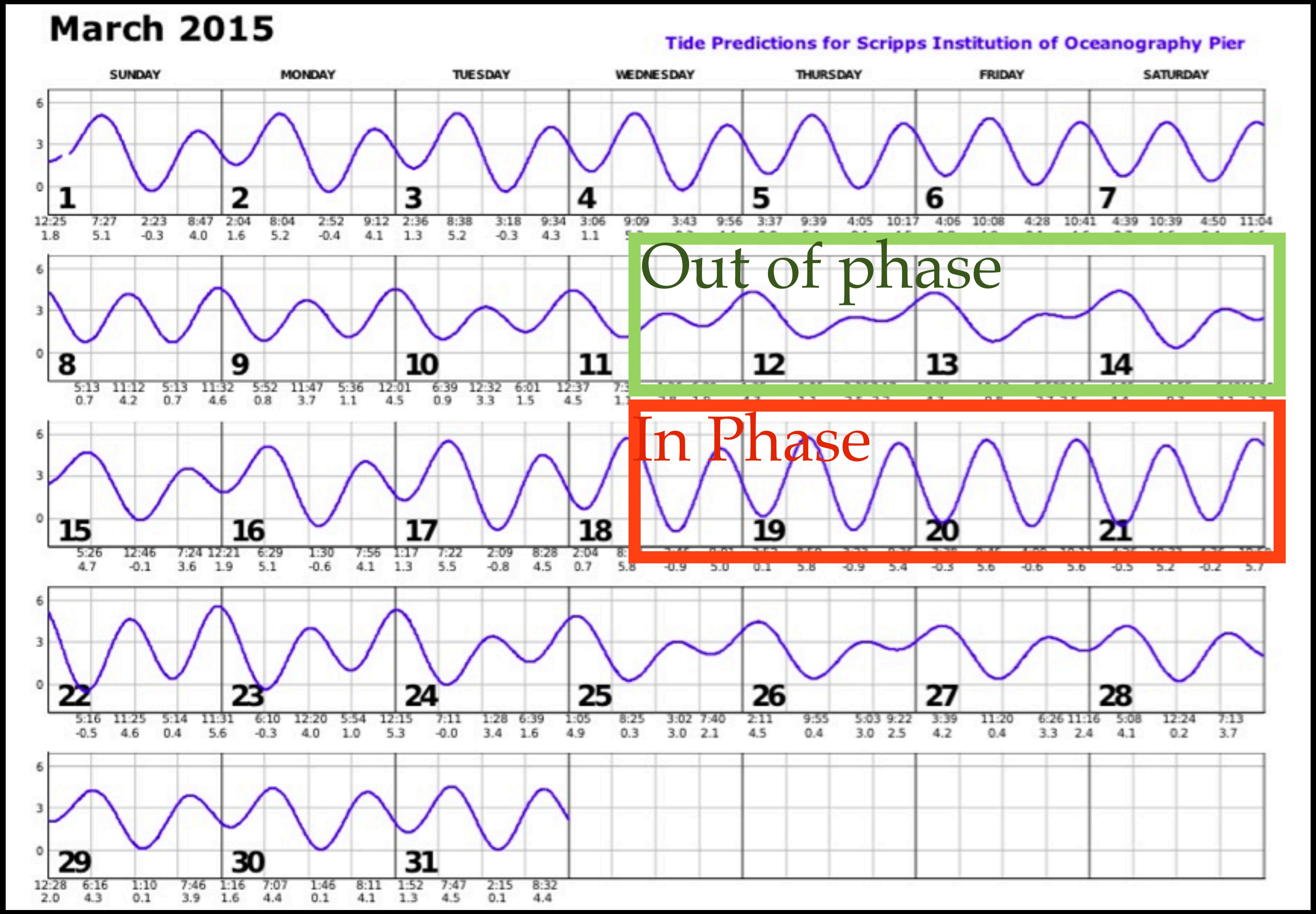


Tides

The Moon’s tidal day is 24h 50m, while the Sun’s tidal day is 24h.

Sometimes the two tides are in-phase, others they are out-of-phase.





http://scienceprimer.com/lunar-and-solar-tides

Long Term Effects

The tides act as a form of friction on Earth's rotation, drawing energy from the Earth-Moon gravitational system.

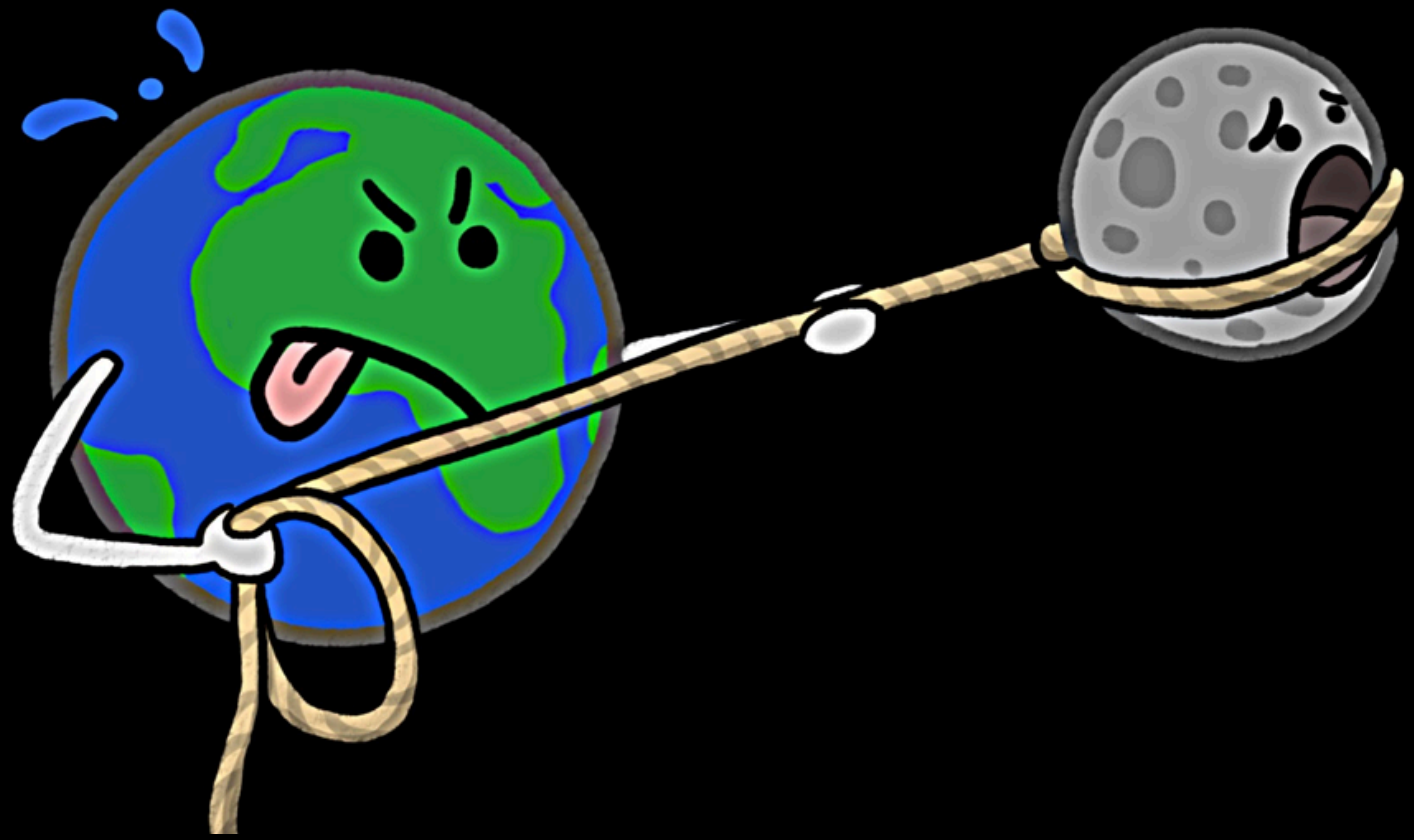
As a result of the tides, the Earth's rotation is slowing down, and the Moon is moving further away (speeding up!).

500M years ago, Earth's solar day was about 22h, resulting in a 397 day year, as evidenced by coral fossil records

Long Term Effects

In about 10B years, the Earth will become Tidal Locked to the Moon, meaning that the Moon will orbit at the same rate as Earth rotates.

But don't worry:
In 1B years, all Earth's water will have boiled away into space.
In 7B years, the Sun will balloon past Earth's orbit.



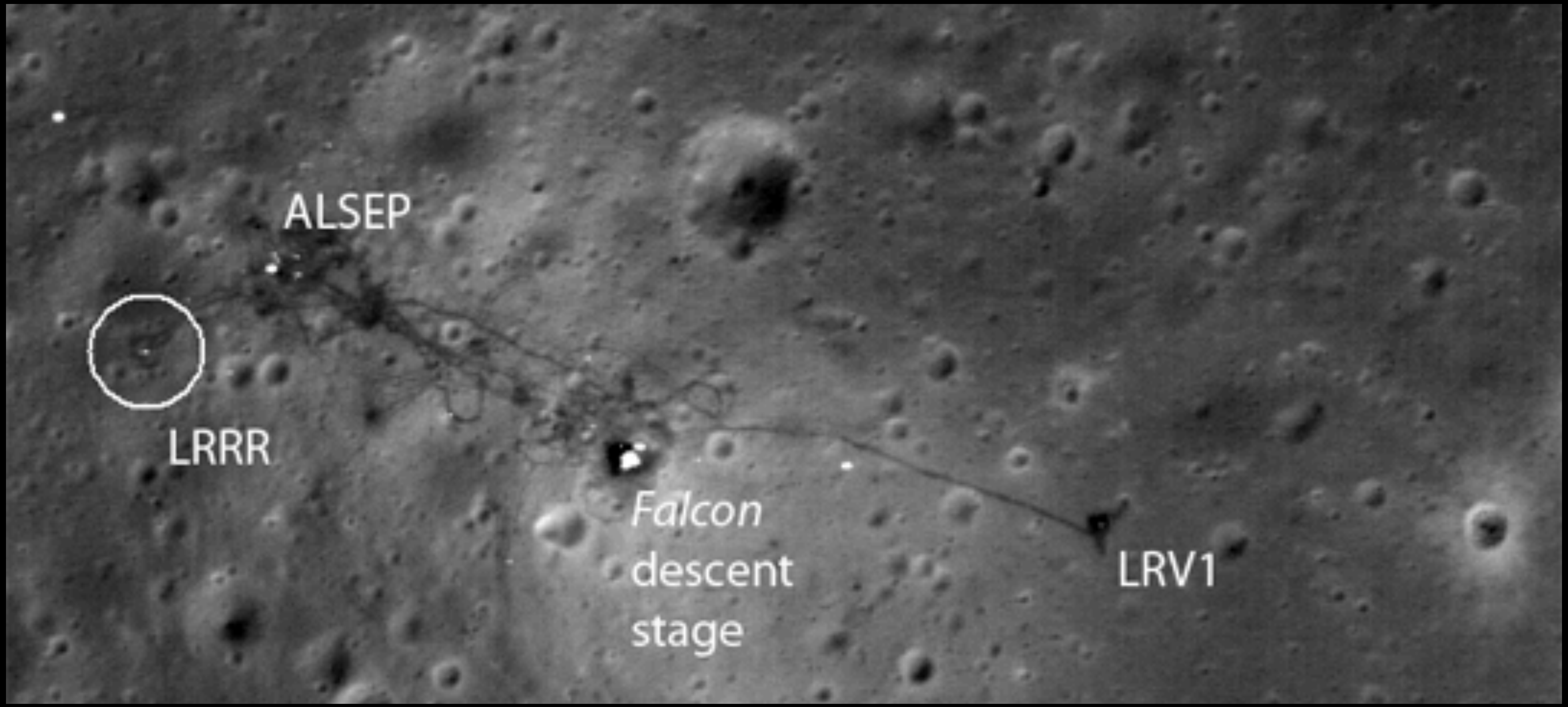
The Moon

Orbital Properties

The Moon's orbital period is 27.3d (relative to stars - sidereal month).

Its perigee is 362 600 km, and apogee is 405 400 km.

This is known accurately due to laser reflectors left on the Moon by visiting humans.

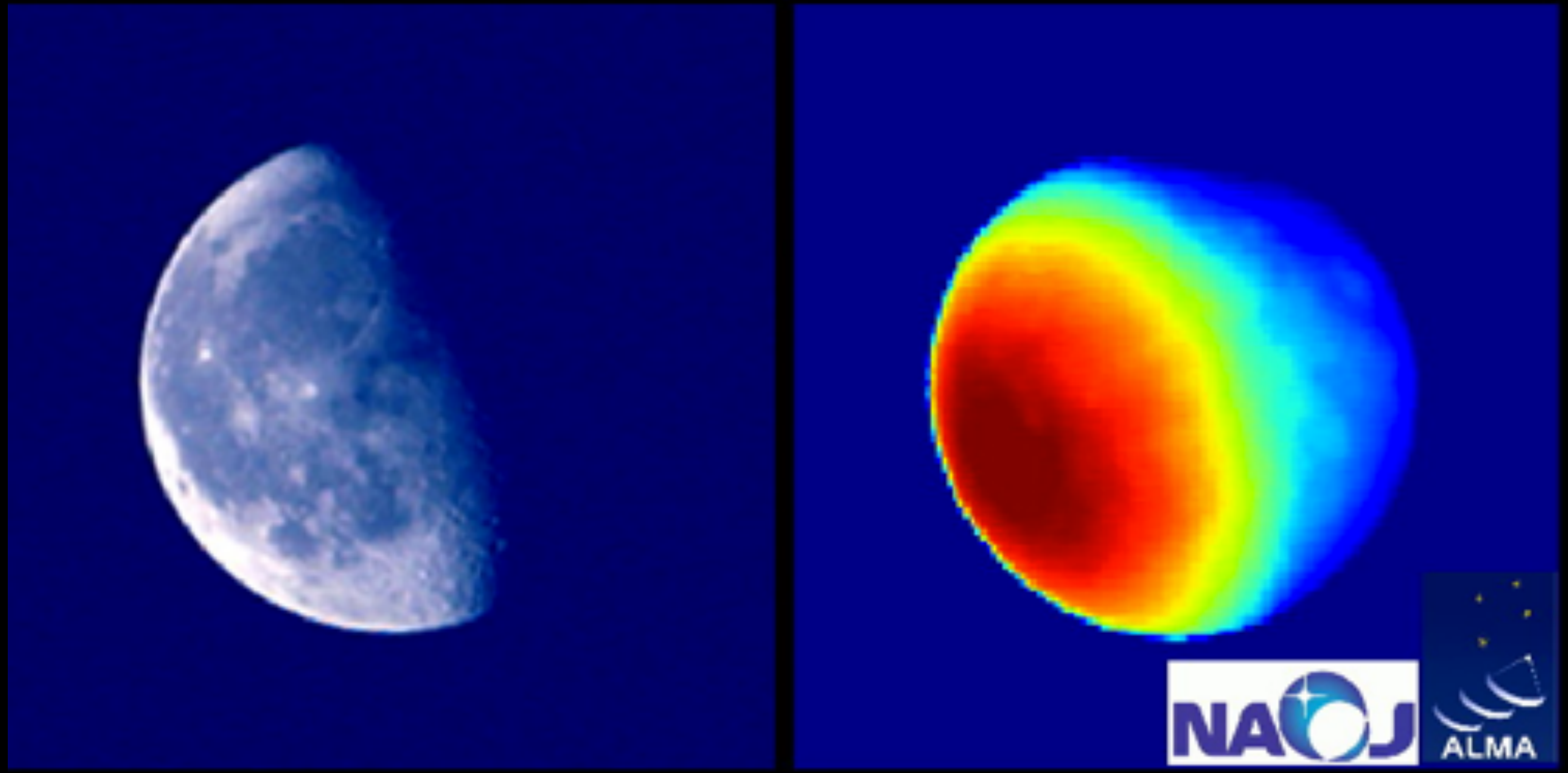


Proof that humans visited the Moon!


APOLLO 12
1969
OCEANUS PROCELLARUM
APOLLO 15
1971
HADLEY RILLE
APOLLO 14
1971
FRA MAURO
APOLLO 17
1972
TAURUS-LITTROW
APOLLO 16
1972
DESCARTES
APOLLO 11
1969
MARE TRANQUILITATIS
GALACTIC HUNTER
GALACTIC-HUNTER.COM

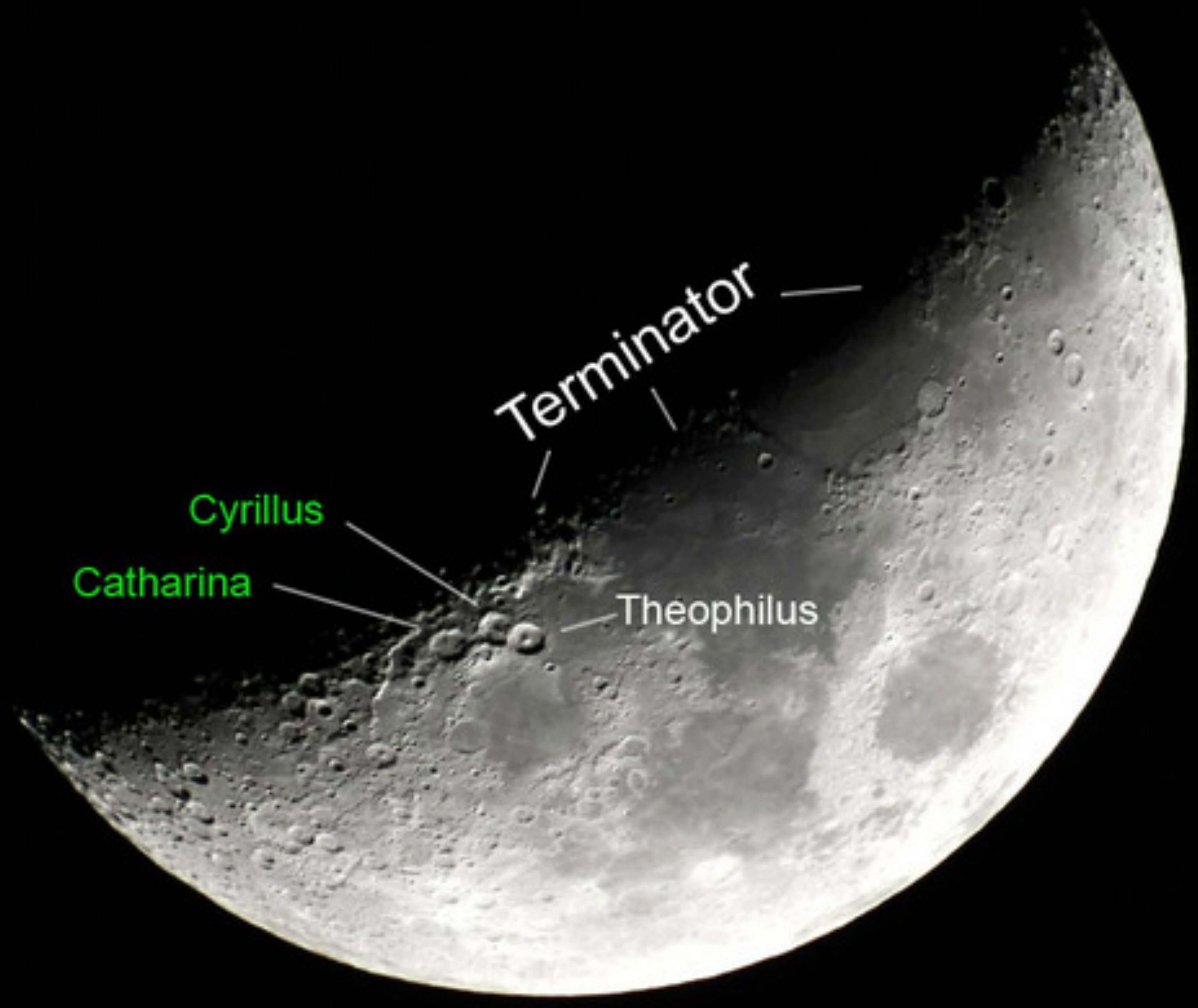
Surface Conditions

Temperatures range from -173^{o}C to $+130^{o}$C depending on the location of the Sun.



Between night and day is the Lunar Terminator - the best way to see surface features on the Moon.

With an amateur telescope, objects the size of about 1km can be observed at the terminator.



Tidal Lock

A quick look at the phases of the Moon clearly shows that its rotation is tidally locked.

Since Earth's gravitational effect on the Moon is 20x larger than the Moon's gravitational effect on Earth, tidal forces slowed the Moon's rotation quicker.

Lunar Tidal Bulge

The Moon is not perfectly spherical.

Like Earth, the Moon has a tidal bulge which has been locked in to the rock permanently.

However, the Moon’s tidal bulge is larger than it should be.

This is further evidence that the Moon used to be closer to the Earth, and gives a timeline of how long ago it stopped rotating.

Lunar Composition

Lunar Terrain

Two distinct types of surface:

Mare - the dark regions (seas)

Terrae - the lighter regions (highlands)

There are 14 total maria.

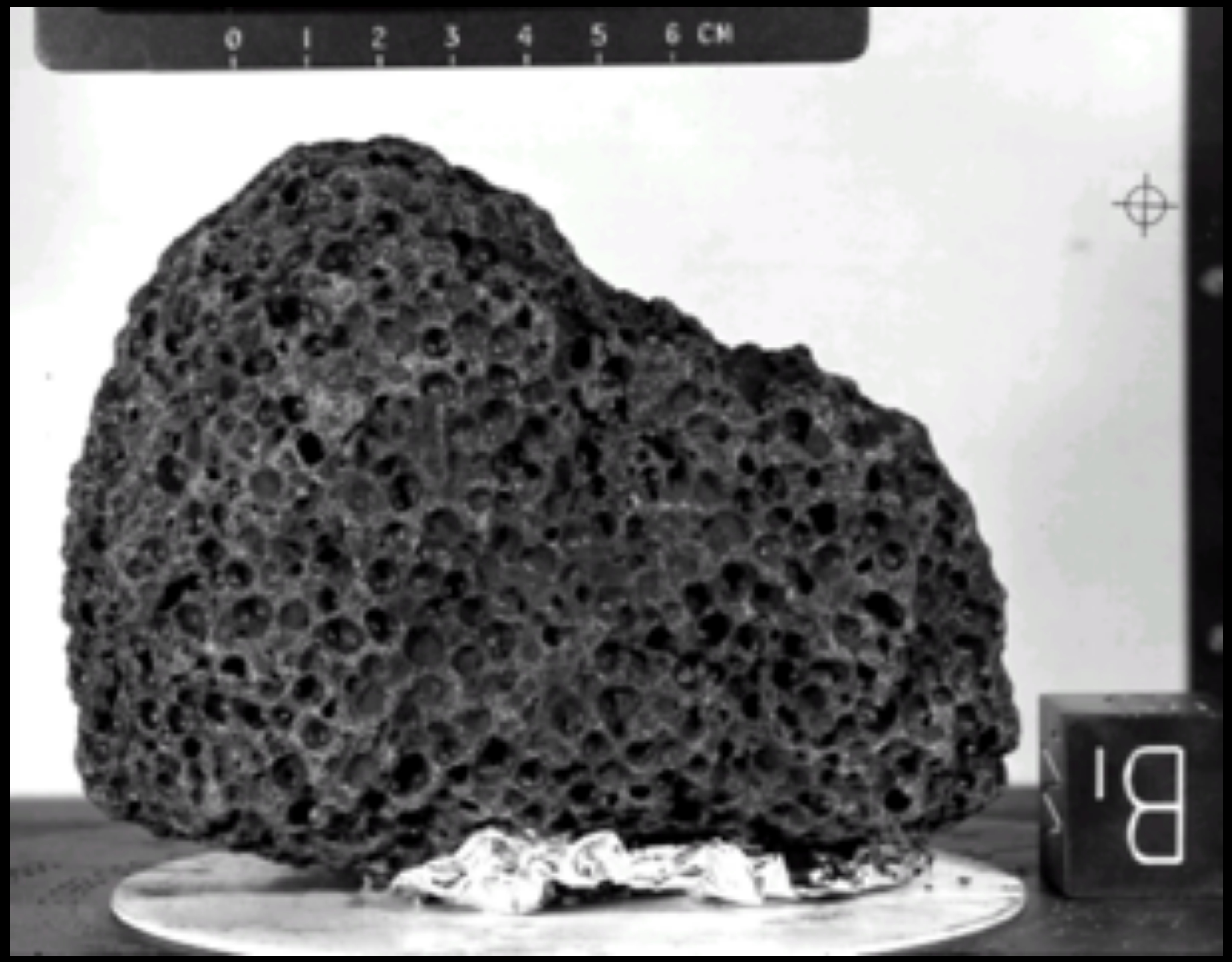
The highlands have distinctly more craters, indicating that they are much older.

Lunar Terrain

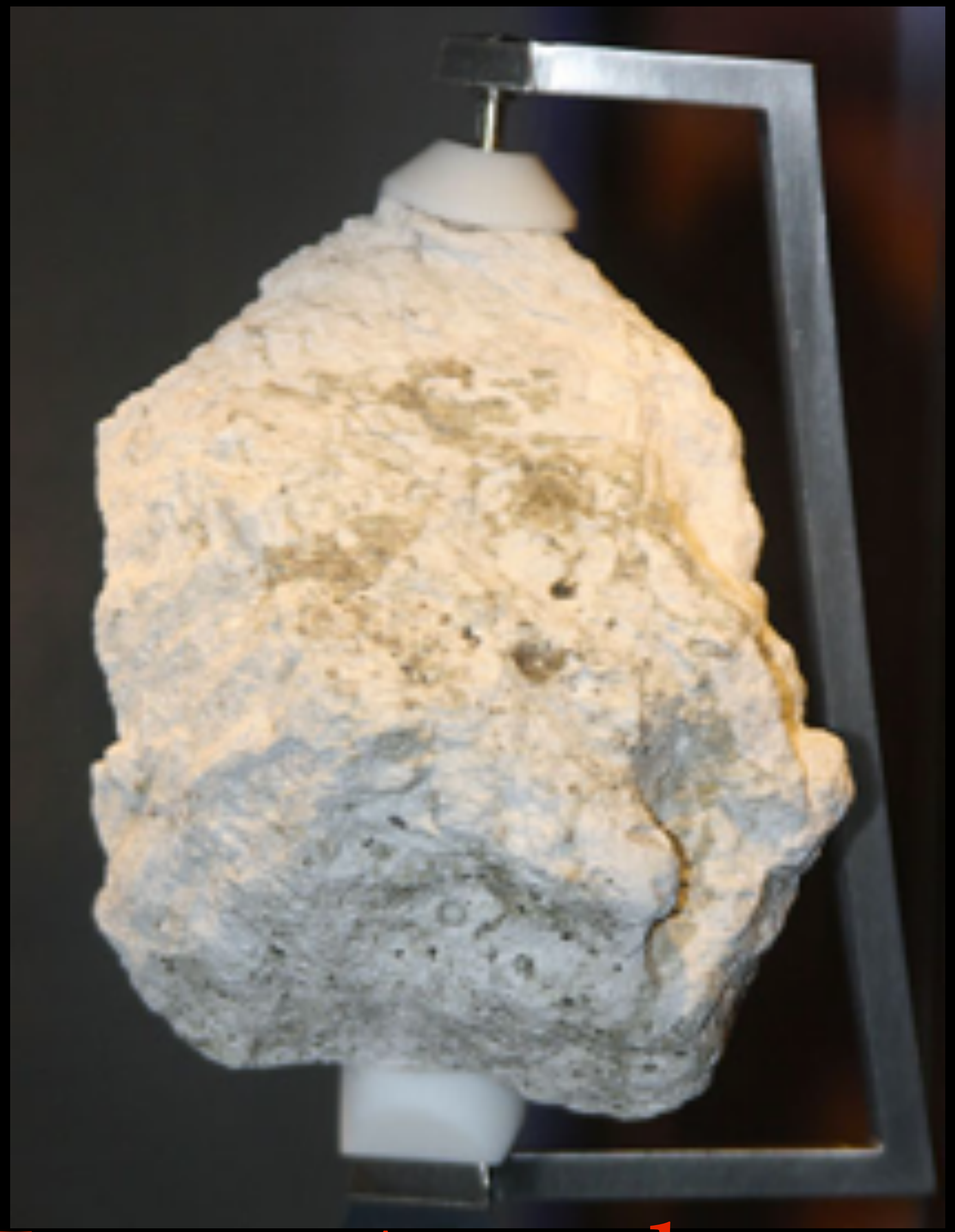
The darker maria terrain is due to the rock type: Basalt. The mare basalt contains a higher iron content, and shows the distinctive traits of being formed as lava (also explains the flatness).

The lighter anorthosite contains a higher aluminum content.

Samples indicate that the anorthosite formed 4-4.4B years ago, while basalt around 3.2-3.9B years ago.



Mare Basalt



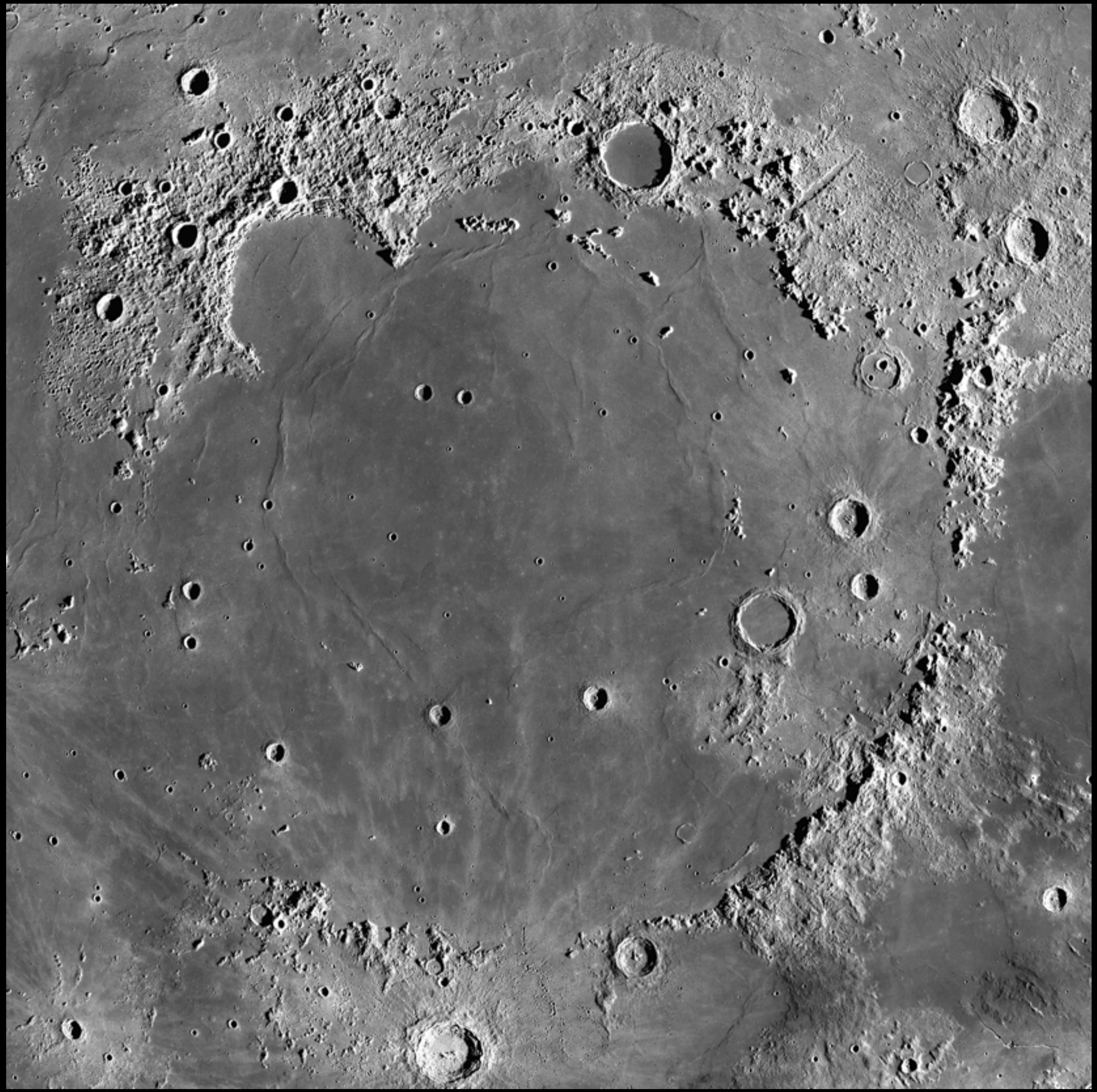
Lunar Anorthosite

Early Moon

Mare vs Highlands structures strongly indicate that the Moon experienced very high bombardment early after formation (highlands).

Intense bombardment occurred prior to 4B years ago.

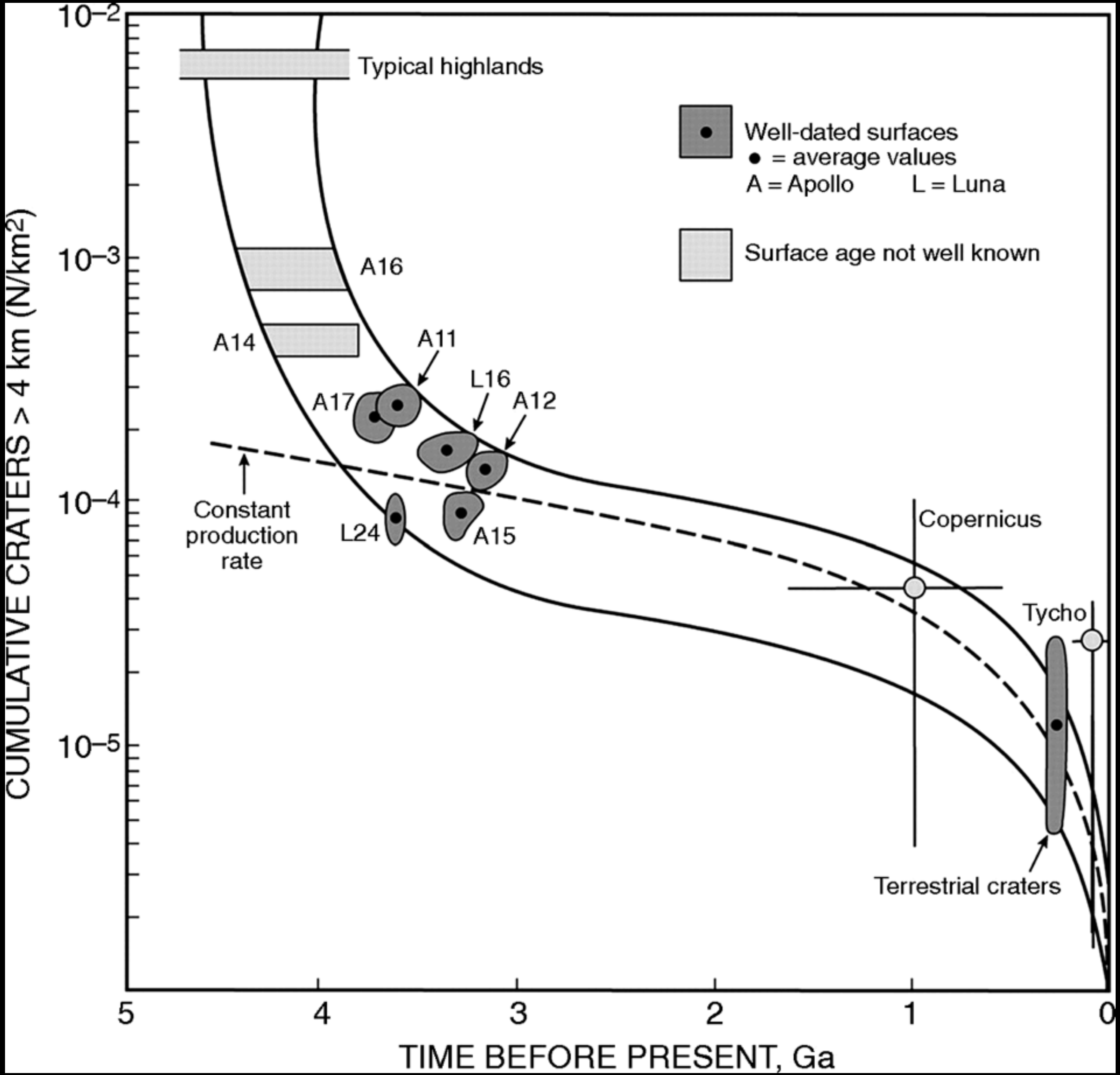
Current crater rates:
10km/10My, 1m/month, 1cm/minute



Crater Rates

By visiting the Moon and measuring the age of the rocks, we are able to understand a significant part of the history of our solar system.

This data will be important when we discuss the formation theories for the solar system.

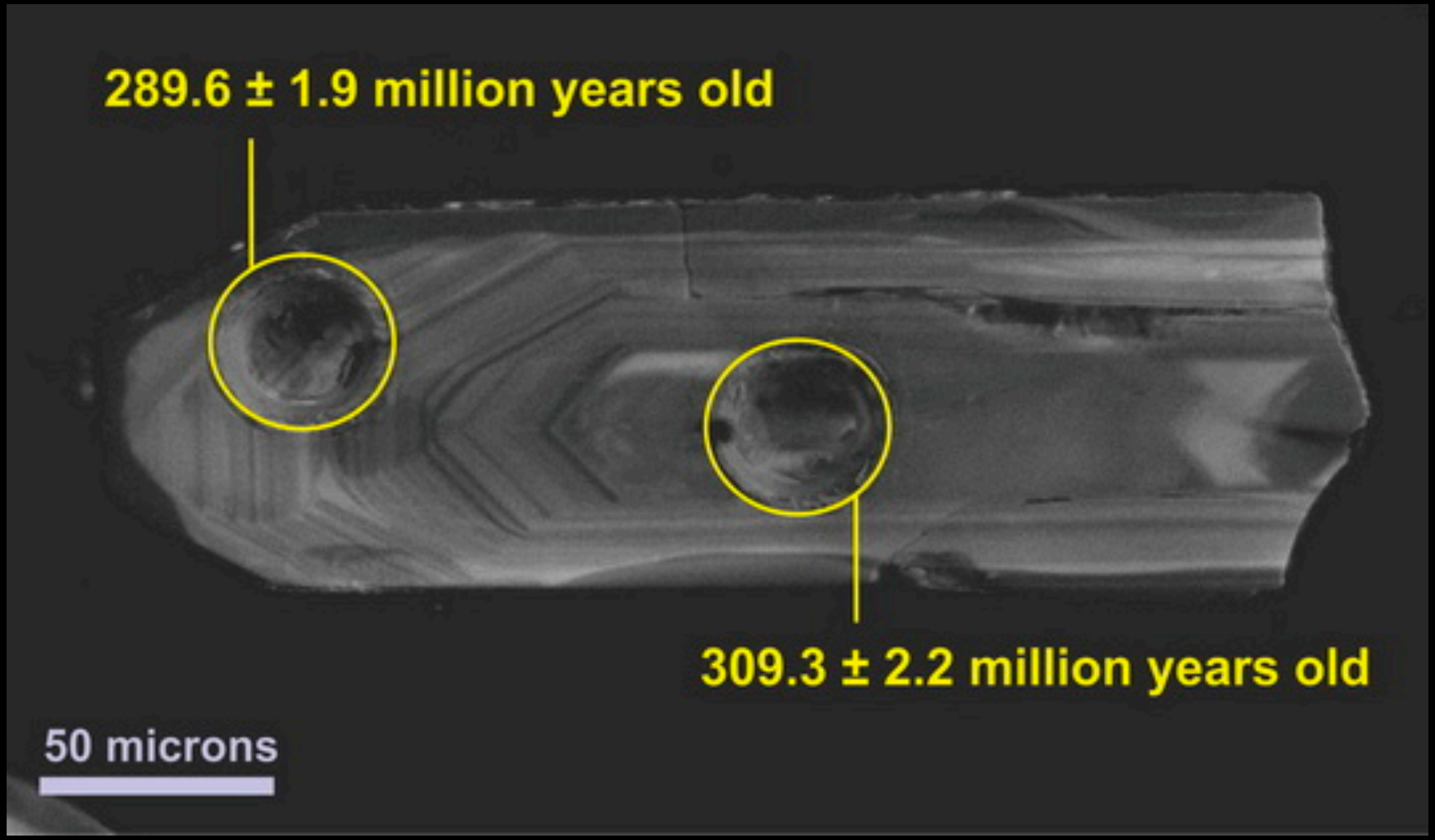


Radiometric Aging

e.g. Zircon crystals can form in the presence of uranium, but not lead

All lead in zircon must have been produced by the radioactive decay of uranium.

Knowing the half-life of uranium, test a sample of zircon crystals and look for the fraction of uranium and lead atoms.



Accuracy of 0.1-1%.

Regolith

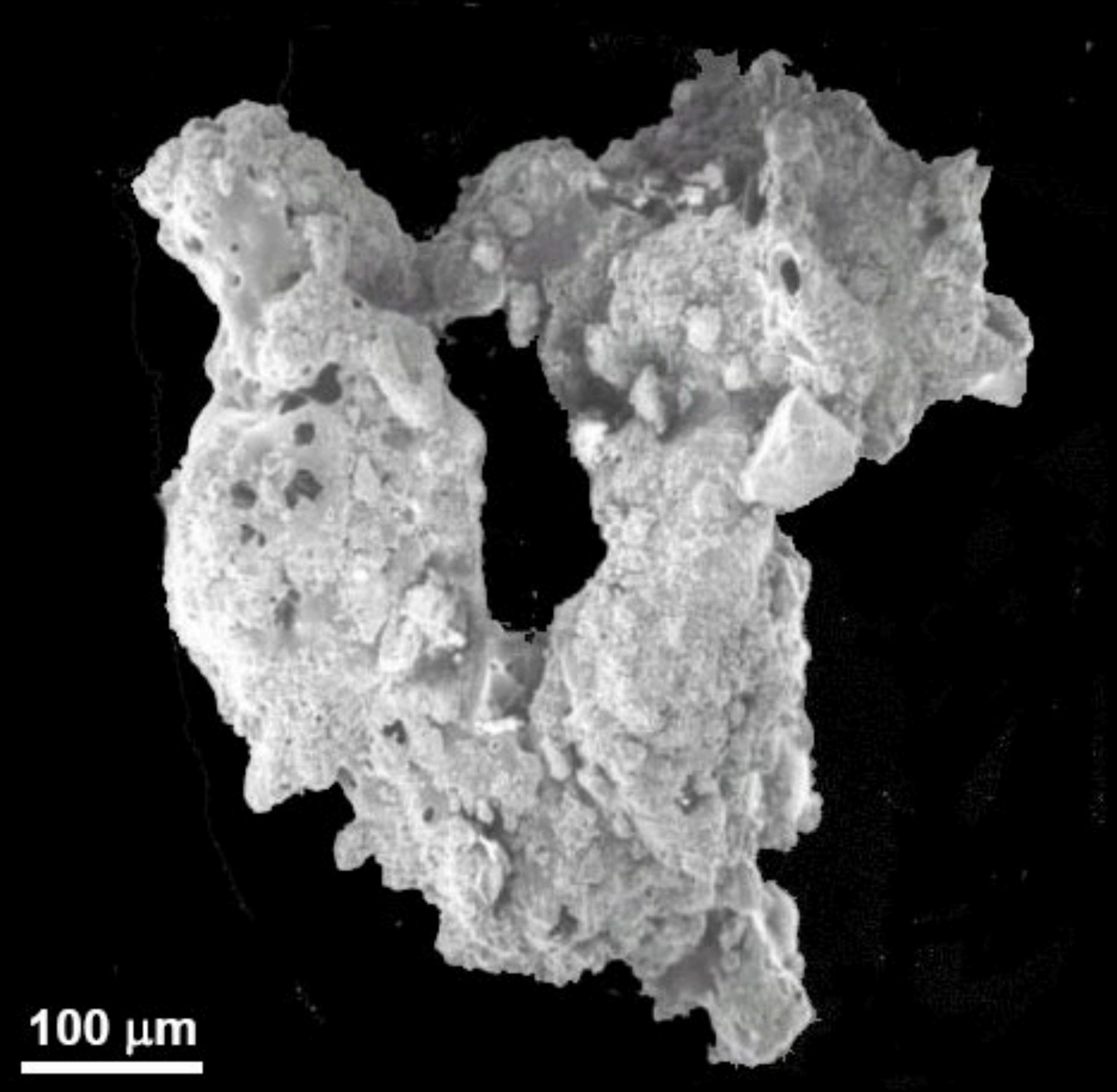
The surface of the Moon is comprised of the debris (ejecta) from multitude of collisions.

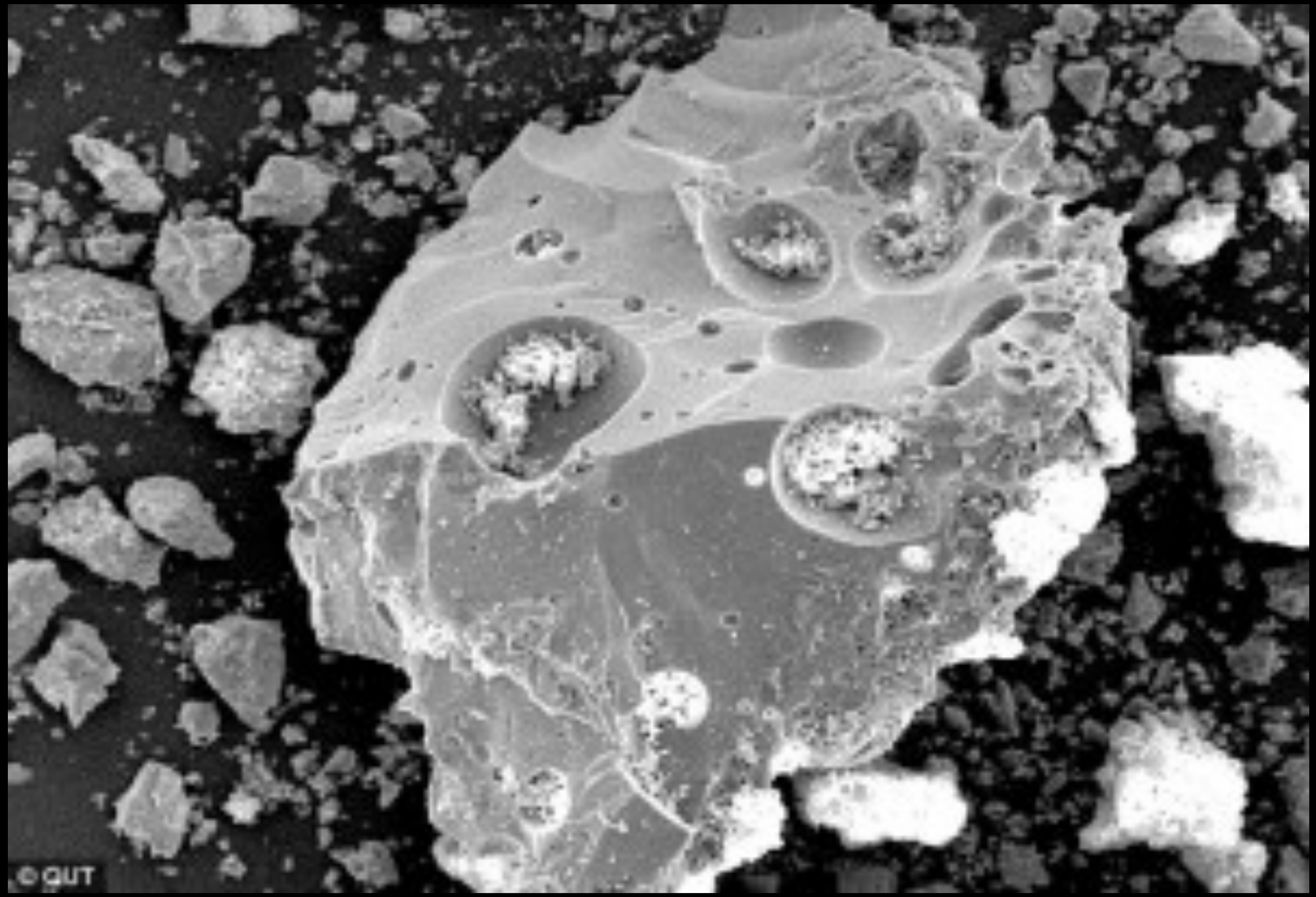
Regolith is the term for all the loose material on the surface.

The regolith averages 20m deep and can be as much as 100m deep in some regions.

Regolith

Tiny meteoroid strikes erode large rock, but nothing provides erosion to the lunar dust, leaving it jagged and sharp.





Lunar Dust

Dust was ranked the #1 danger for repeated missions to the Moon.

> These particles can wreak havoc on space suits and other equipment. During the Apollo 17 mission, for example, crew members Harrison “Jack” Schmitt and Gene Cernan had trouble moving their arms during moonwalks because dust had gummed up the joints. “The dust was so abrasive that it actually wore through three layers of Kevlar-like material on Jack’s boot.”

Dust has sharp edges, cutting into seals, gaskets, lenses, solar panels, wiring

Lunar Dust

Solar wind electrically charges the dust, creating a fine dust cloud that statically clings to any astronaut/equipment.

It was brought into landers on the suits of the astronauts, breathed in, eroded all the seals of all samples brought back.

Posed an extreme risk to lungs and organs if breathed in, on the level of asbestos or worse.

Lunar Composition

The elemental composition of the Moon is similar to that of the Earth's surface, but differs from the Earth's core.

This indicates a common origin.

So where is the water? All surface samples completely devoid of water - in contrast, Earth rocks contain about 1-2% water.

We will discuss this in the next topic.