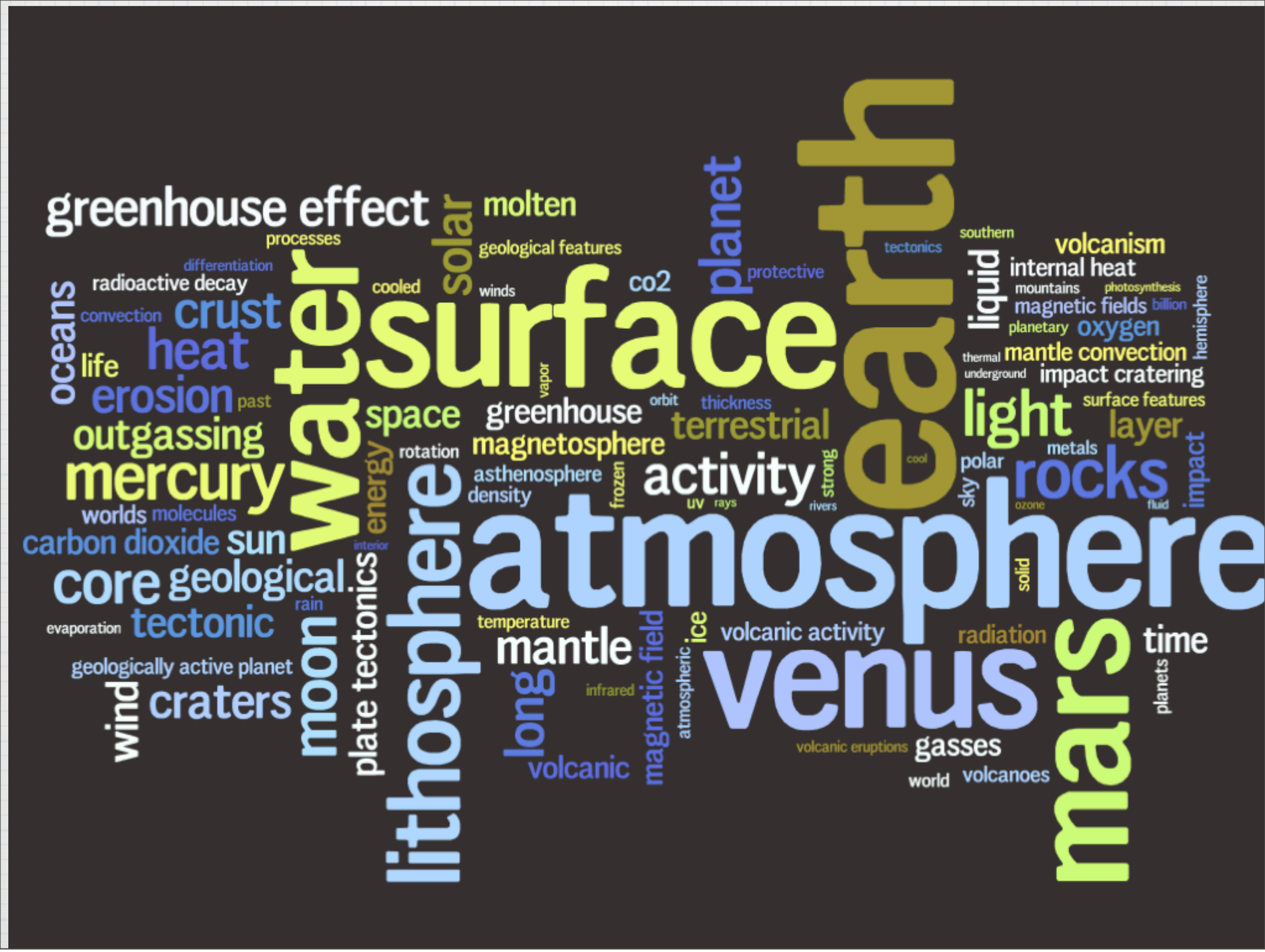
Earth & the Terrestrial Planets

Chapter 7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planets
volcanic eruptions
gasses
world
volcanoes

Four Terrestrial Planets All Unique

* We covered the formation of the Solar System and saw how the terrestrial planets formed with their rocks and metals contents
* 4.6 billion years later, these four planets have evolved into unique worlds of their own
* and only one can sustain life

Luck or Fate?

* Mercury: airless and barren
* Venus: searing hothouse and crushing atmospheric pressures
* Earth: abundant water, a protective atmosphere, and a stable climate
* Mars: thin and cold atmosphere
* Are those characteristics accidents or are they due to other factors?

Earth

* Let's look at the Earth first as we know it better than any other worlds
* Note here, however, that we barely have explored Earth's sub-oceanic floors
* Now, let's look at the Earth's surface and notice what brings about natural changes

Earth: geologically active planet

1. Weathering (erosion) cause surface changes
   - rain ⇒ rivers ⇒ oceans ⇒ evaporation ⇒ clouds ⇒ rain
2. And on a slower time scale:
   - rain ⇒ snow ⇒ glaciers ⇒ melt ⇒ rivers ⇒ oceans ⇒ evaporation ⇒ clouds ⇒ rain

Earth: geologically active planet...

* Rains bring yearly landslides and rivers can overflow and cover huge areas with silt
* Rivers can carve, given time, deep canyons such as the Grand Canyon and also create more costal lands by alluvion deposits
* Oceans carve some coastal areas and add lands on others
* Glaciers scar the upper crust as they form and retreat

Earth: geologically active planet...

* Winds on Earth are caused primarily by our planet's rotation and its effects on the atmosphere
* With the wind, the atmosphere moves heat around
* Given enough time, the wind and rain erodes huge mountains down to hills

Earth: geologically active planet...

2. Tectonic activity causes

* on a slow time scale: the land masses on Earth to move: the continental drift
* on a faster time scale:
  1. earthquakes
  2. volcanic eruptions

Other phenomena affecting the Earth's surface

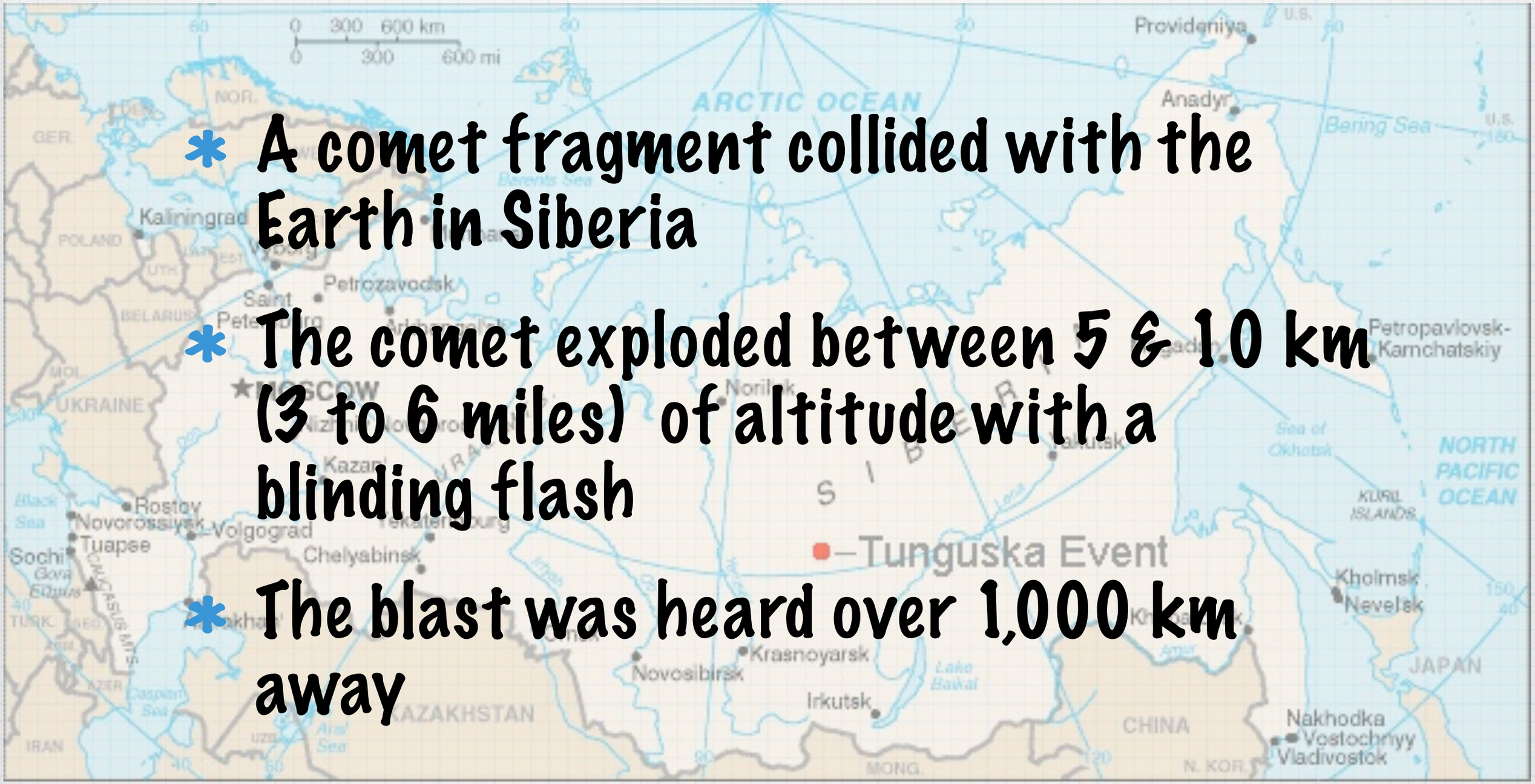
3. Impact from space

* The most dramatic events which can cause **much geological changes** and **destroy life on a large scale**:

* when an **asteroid** or a **comet** slams into the Earth

* This is not so rare as you think...

Tunguska, Siberia June 30, 1908



* A comet fragment collided with the Earth in Siberia
* The comet exploded between 5 & 10 km (3 to 6 miles) of altitude with a blinding flash
* The blast was heard over 1,000 km away

Tunguska, Siberia June 30, 1908...

Tunguska, Siberia June 30, 1908...

* The blast was equivalent to be between 10 & 15 megatons of TNT
* 60 million trees fell over an area of about 2,150 square km (830 sq. miles)
* No crater was found but a lake may be hiding it. We should know more by 2013

Lima, Peru
Sept 15, 2007

A 5-feet wide meteorite fell in southern Peru:
its crater is about 50 feet wide and 15 feet deep

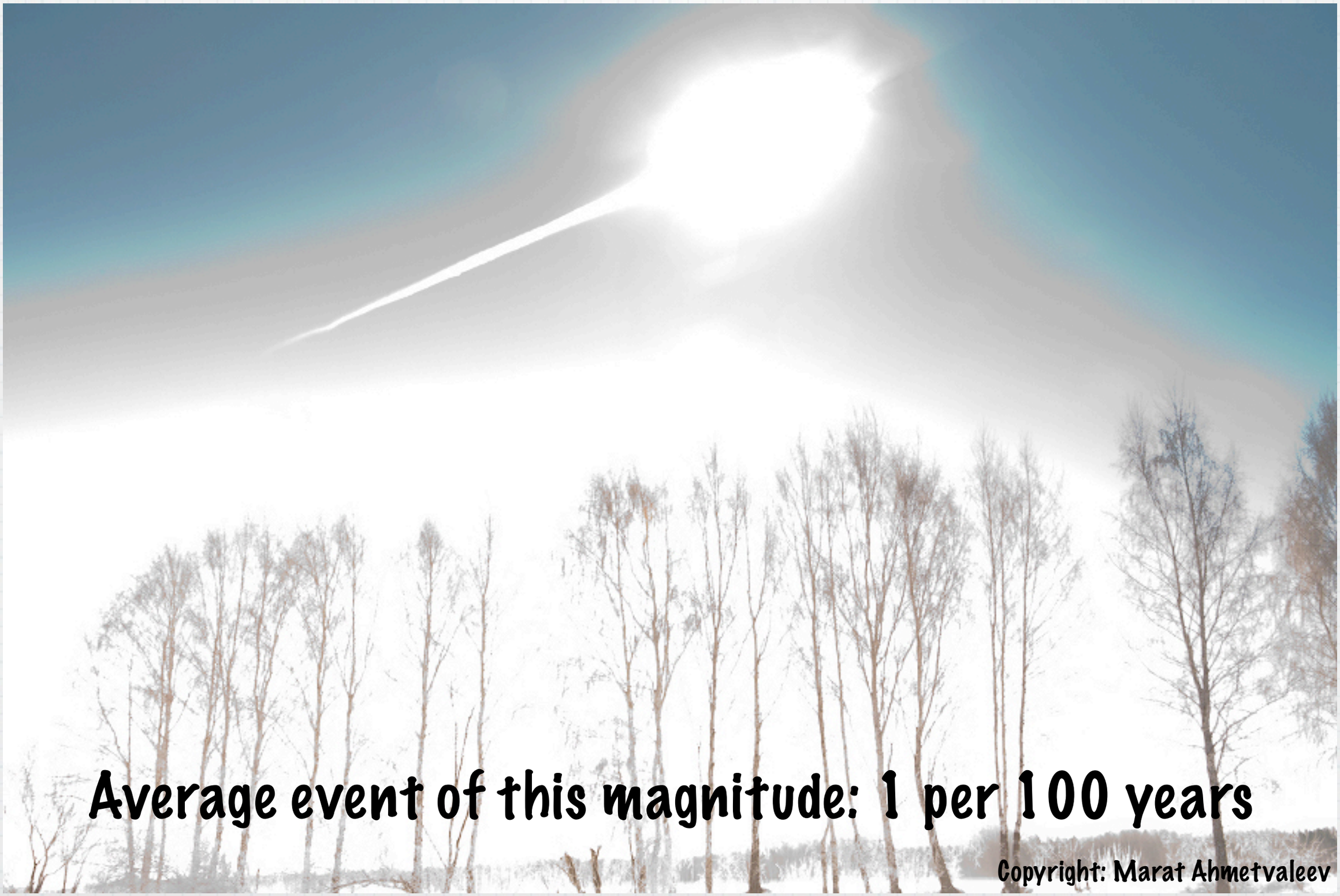
Fireball Meteor over Groningen, Holland

It was accompanied by sonic booms & rumbling sounds

The Peekskill meteorite

Perseid meteor as seen from ISS

And, of course, the Chelyabinsk Meteor (Feb 15, 2013 - Russia)



* The Earth we see today is not the young Earth it used to be
* Mercury, Venus, Earth, Mars and the Moon must have looked similar when they were young (after accretion)
* All were made of rocky materials and they were all subjected to the same Heavy Bombardment period

➡ We can then assume that Mercury, Venus, Mars and the Moon changed as well

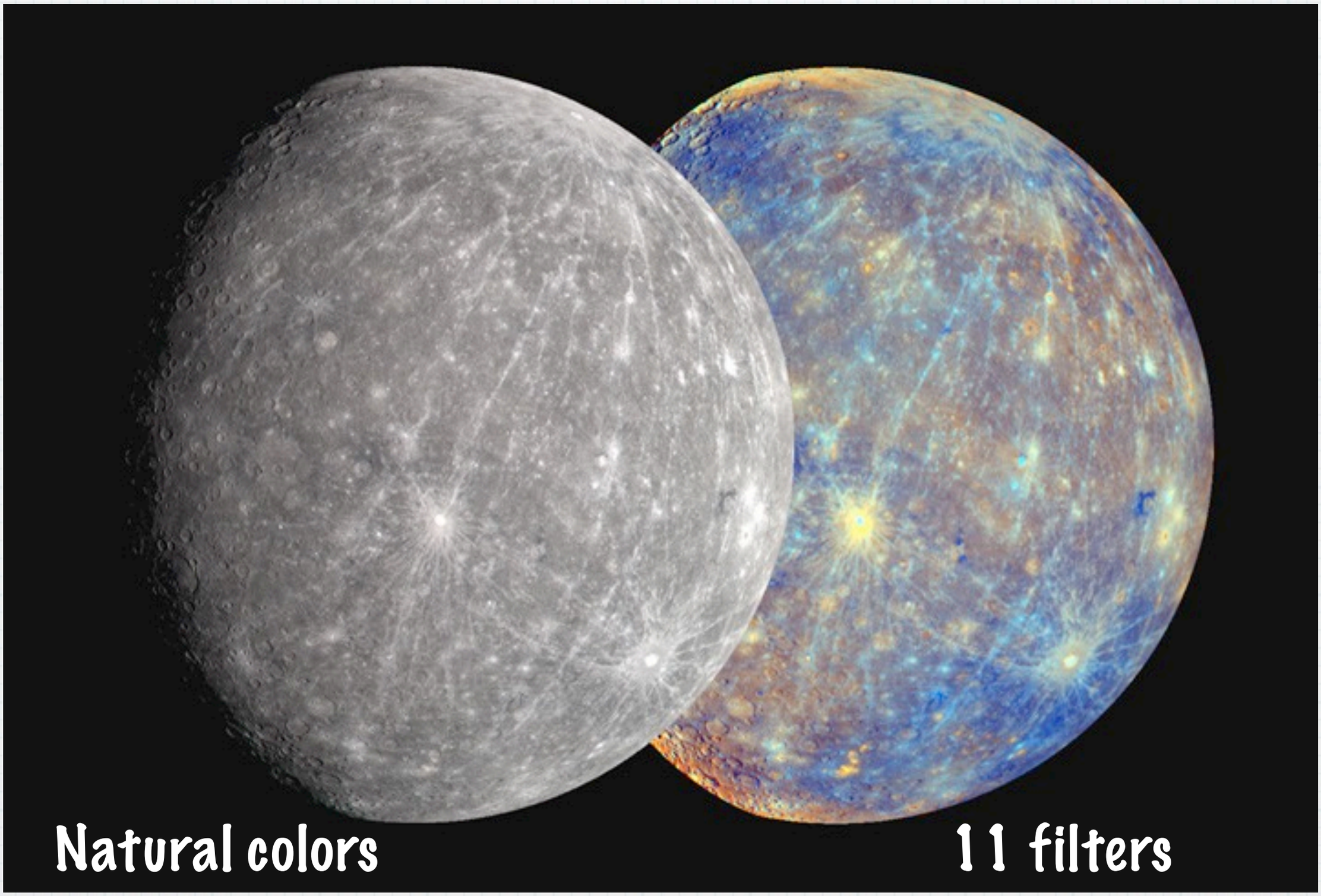
World Evolutions

* The changes that occurred to each have been due to each world's fundamental and unique properties
* Let's look at each terrestrial body in turn from space and look for similarities and differences

Mercury

* Heavily cratered
* But some areas appear to be volcanic plains
* Has long steep cliffs some of which are more than a mile in height, extend for hundreds of miles, and cut through craters and other surface features

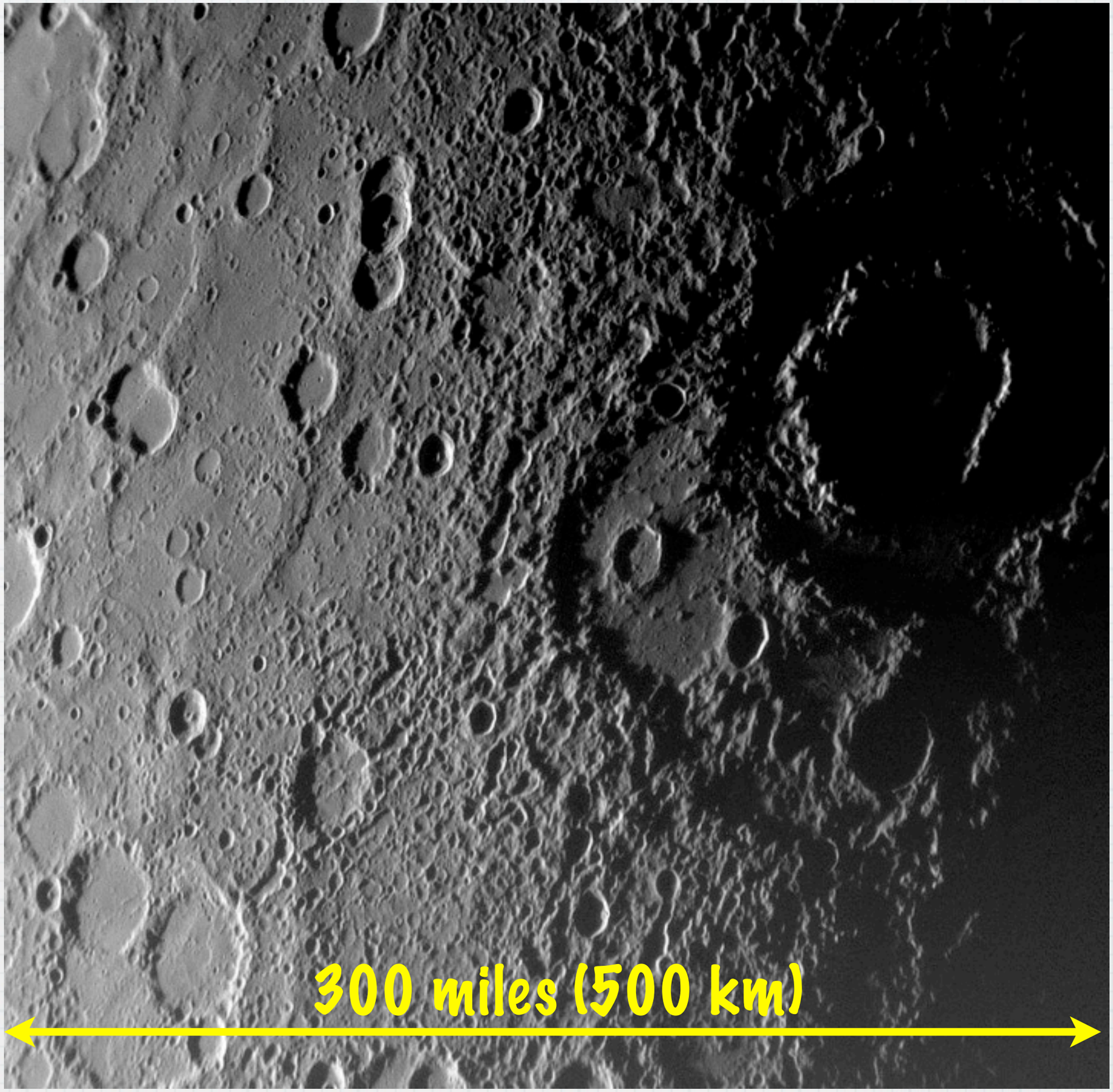
Picture of Mercury taken from 27,000 km away by MESSENGER Oct 6, 2008



Credit: NASA/Johns Hopkins University Applied Physics Laboratory/Carnegie Institution of Washington

Surface of Mercury

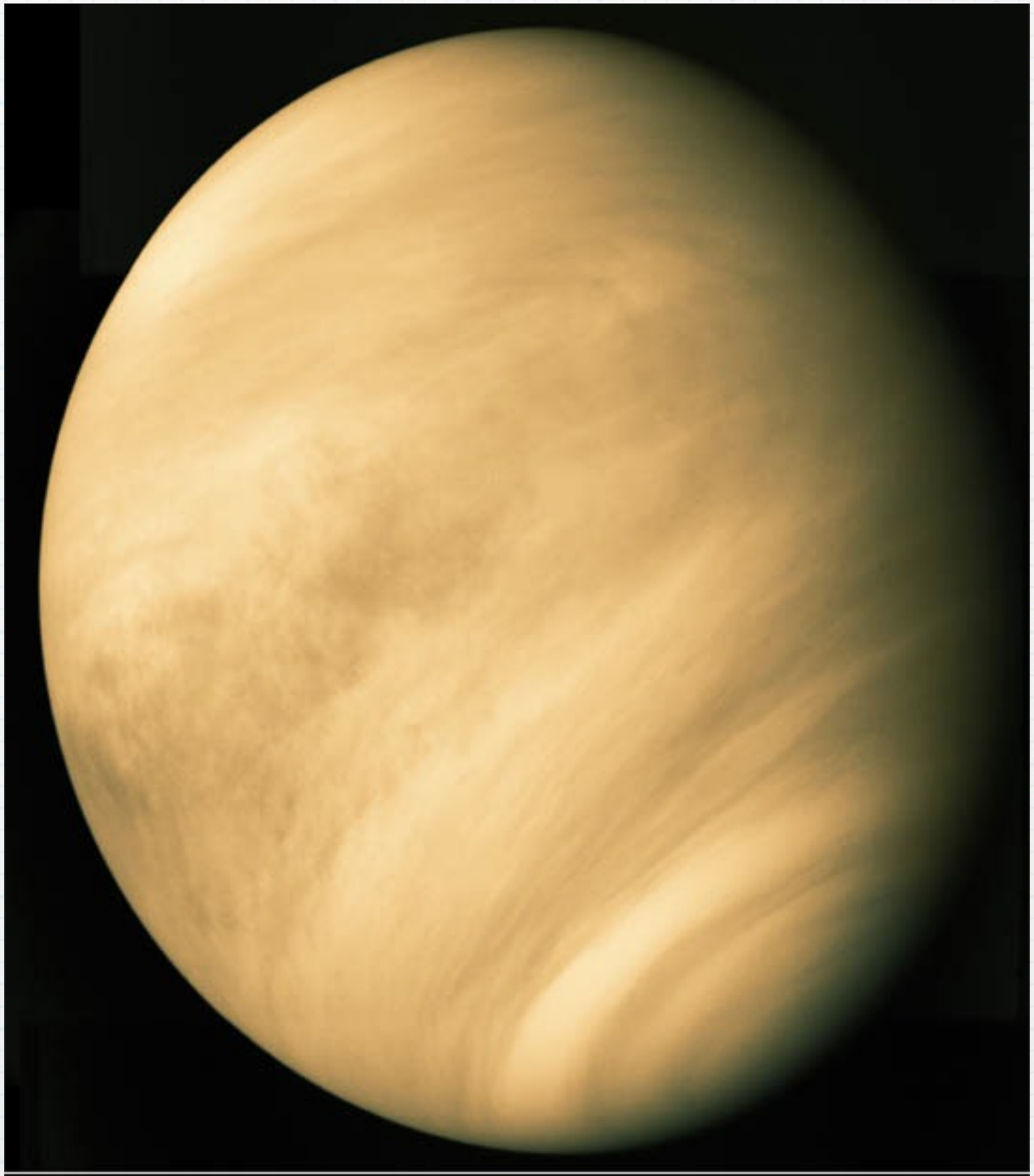
Looks a lot like the Moon floor...



Venus

* Radar data of Venus' surface show that Venus has tall volcanoes
* The atmosphere is primarily carbon dioxide gas (CO_2) and is crushingly dense
* The surface is scorchingly hot

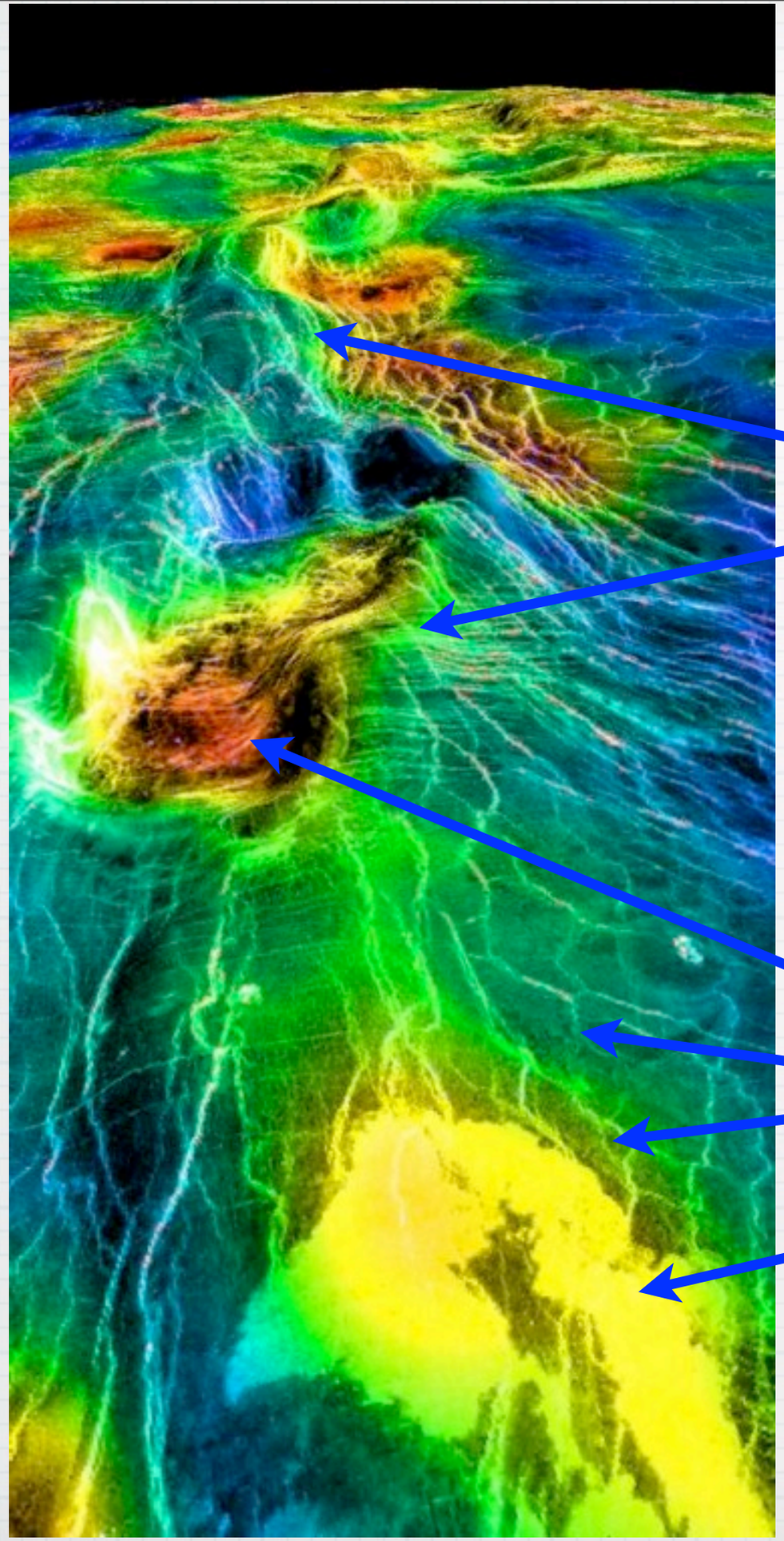
A Mariner 10 image of Venus



Venus (radar mapping)

Image Credit: NASA/JPL

Radar data of Venus, coded with emissivity



Tectonic belt

Vertical exaggeration: 20

Elevation of viewpoint (km): 300

Image resolution: 225 m

Coronae

Arachnoids

Lava flow

Image Credit: NASA/JPL/USGS

Earth

* Earth shows a variety of geological features that are easily visible from orbit:

➡ clouds, oceans, mountains, plains, ice caps, glaciers, ...

The "blue marble" - "western view"

http://www.flickr.com/photos/gsfc/6760135001/sizes/l/in/photostream/

The "blue marble" - "eastern view"

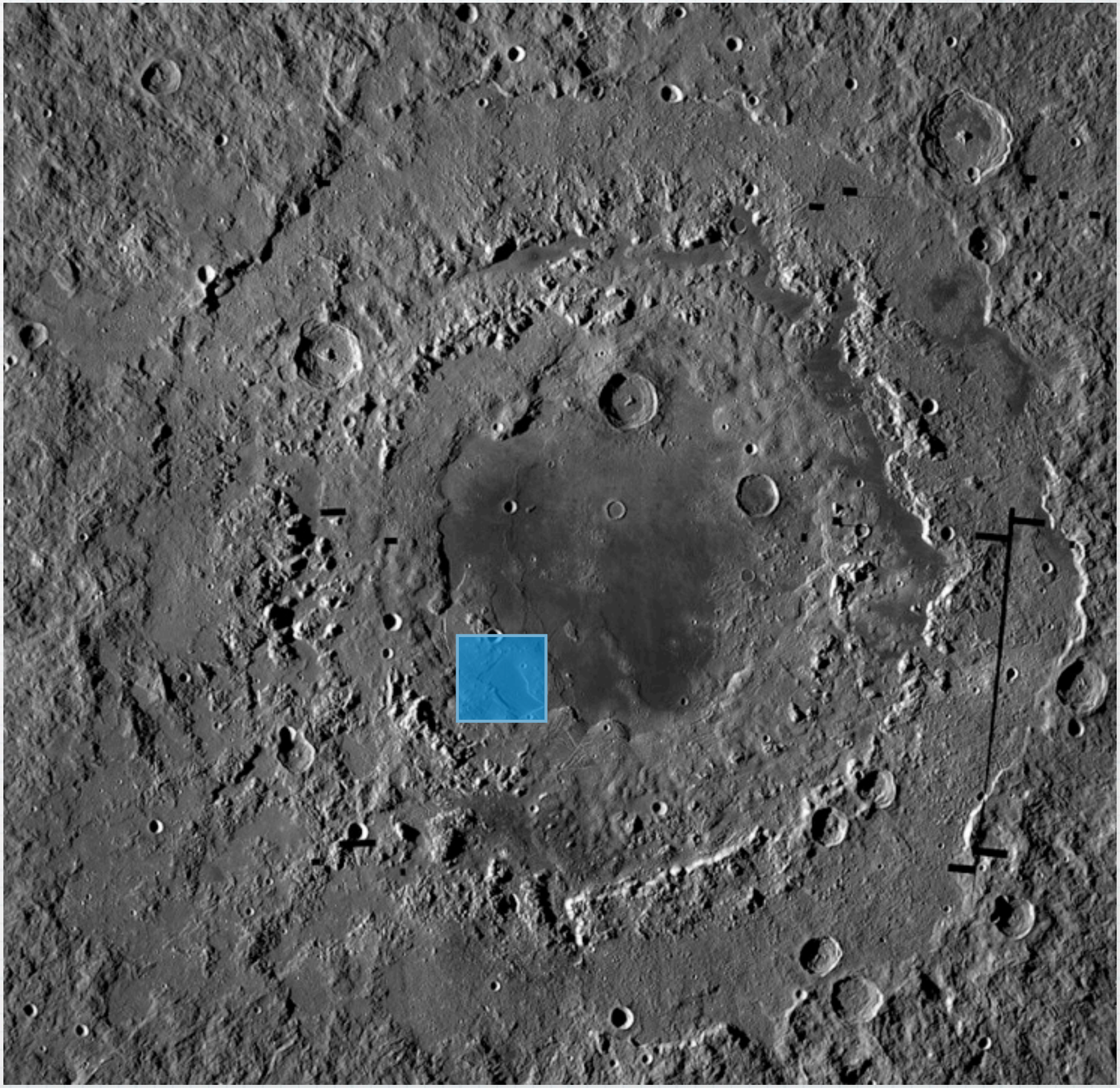
https://secure.flickr.com/photos/gsfc/6806922559/sizes/l/in/set-72157627439487497/

The Moon

* A heavily cratered surface
* Many areas appearing to be volcanic plains
* It looks a lot like Mercury

Moon detail:
The Orientale Basin (Mare)

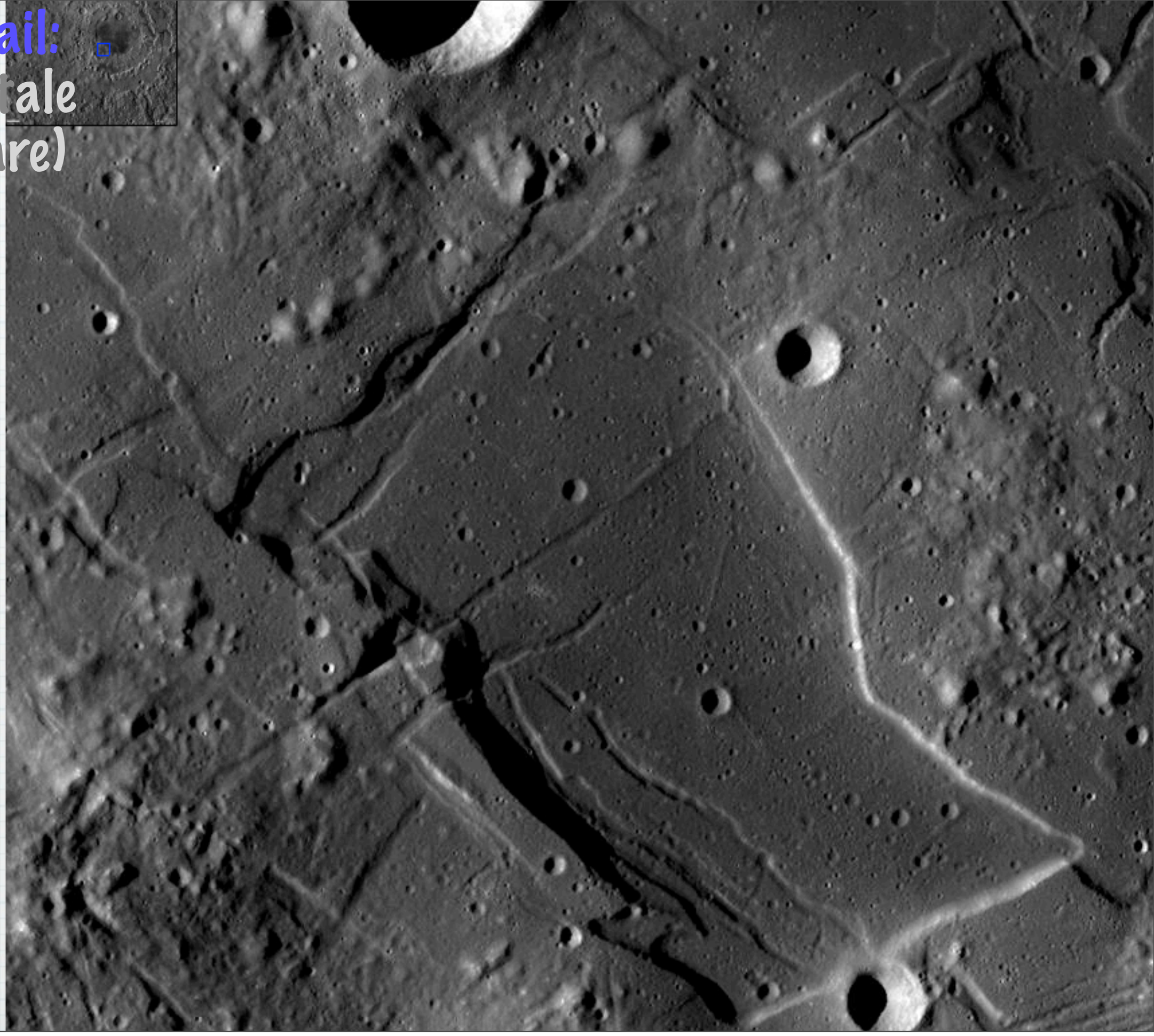
3 billion years old
600 miles (950 km) across
Formed by the impact of an asteroid sized object



Moon detail:

The Orientale Basin (Mare)

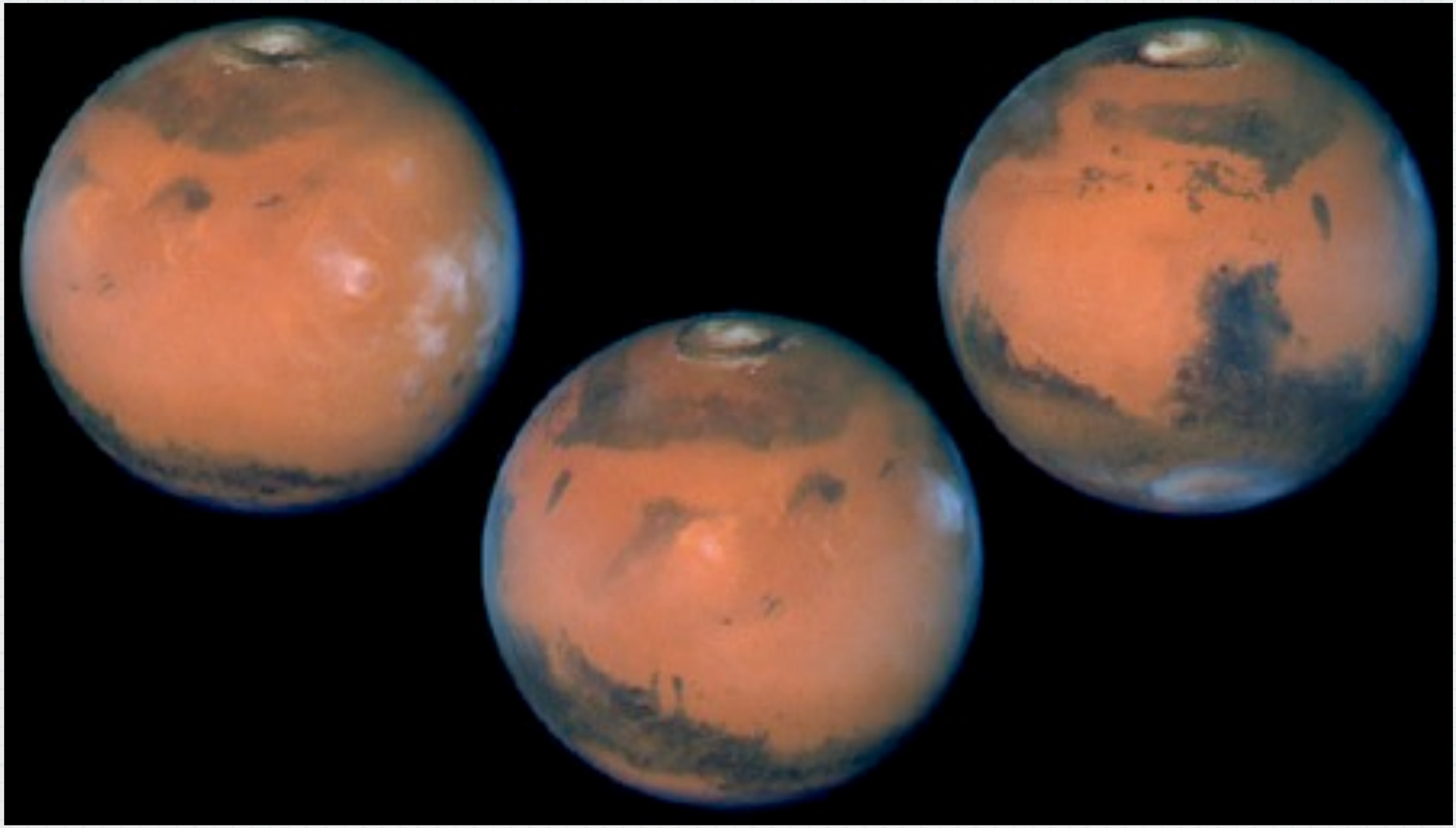
100 meter resolution per pixel



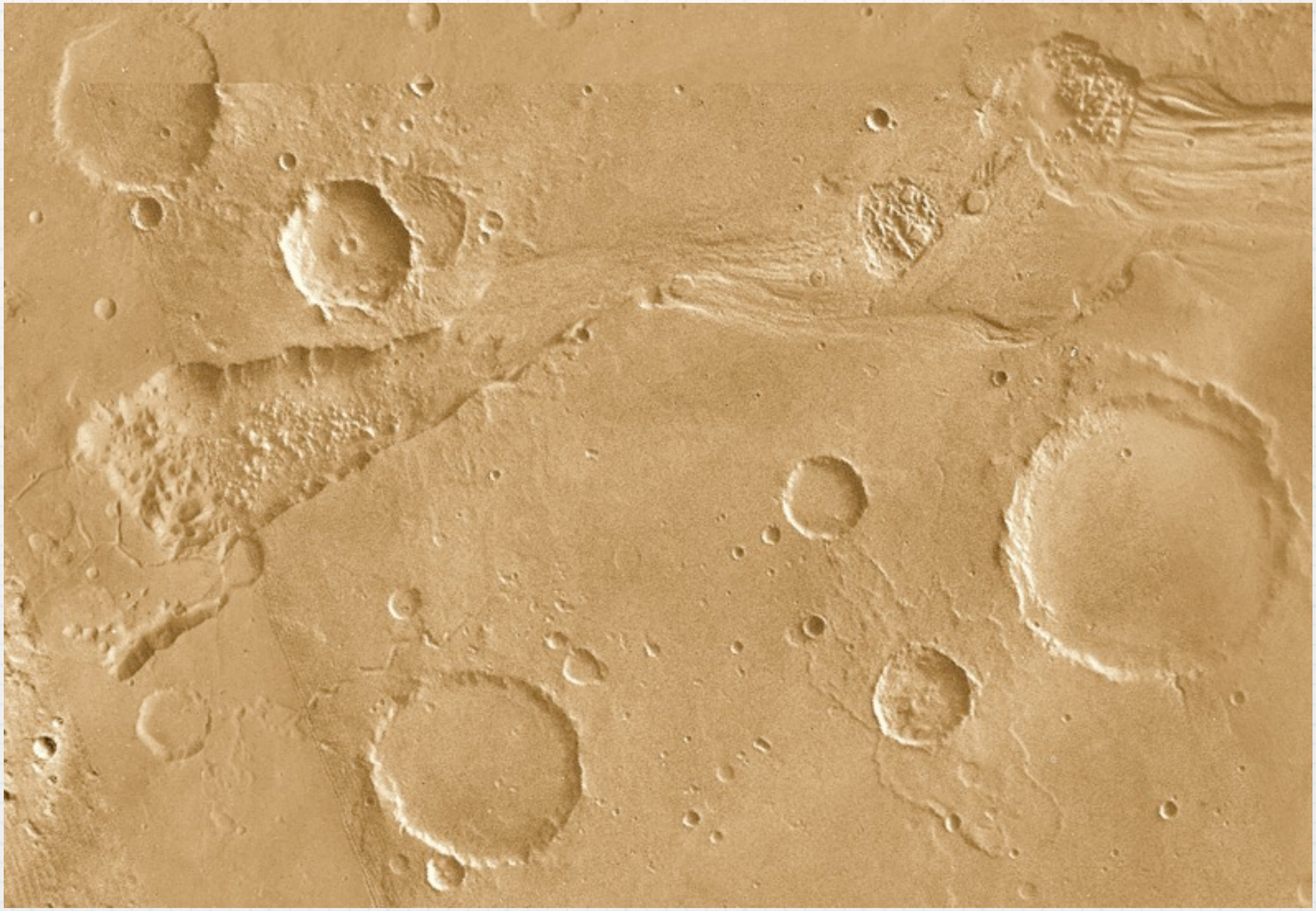
Mars

* Craters, mountains, ice caps, the largest volcanoes in the solar system,
* a huge canyon cutting its surface
* and numerous features that appear to have been shaped by running water

The Hubble Space Telescope captures a full rotation of Mars



Outflow Source of Channel Ravi Vallis



Very Different Worlds

* They started the same way
* They are issued of the same solar nebula and formed at the same time at nearly the same region of space
* **Why are the terrestrial planetary bodies so different now?**
* Let's start with the Earth

Geologically Active

* Geological activity changes the surface
* This activity is driven from within
* By events such as:
  * volcanic eruptions,
  * earthquakes, and
  * continental drifts

Cutaway of the Earth

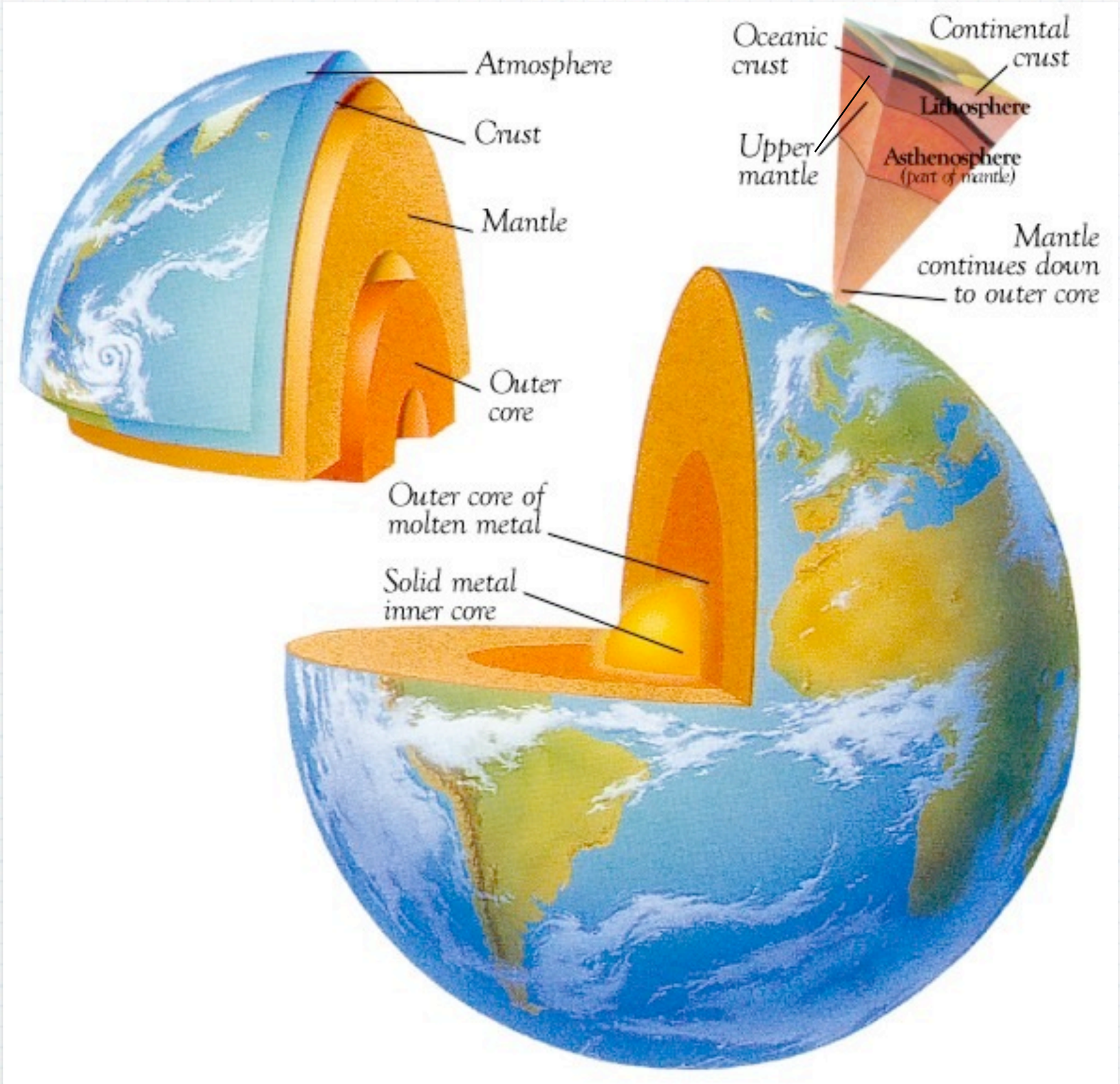


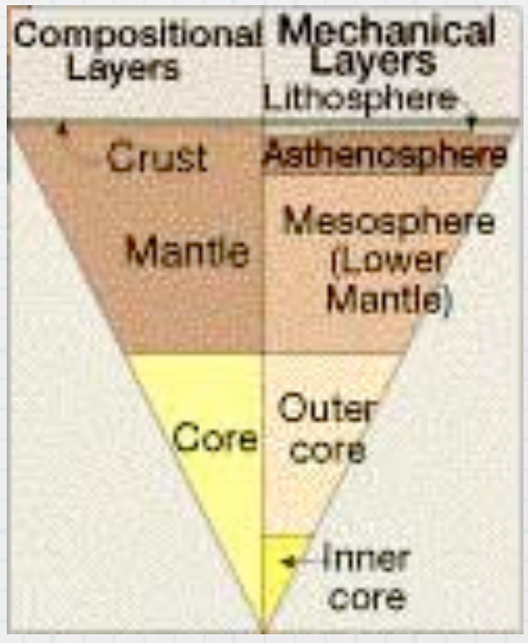
image from Colin Rose & Dorling Kindersley

Internal Structure of the Earth

* The core: highest density material made of metals such as iron and nickel

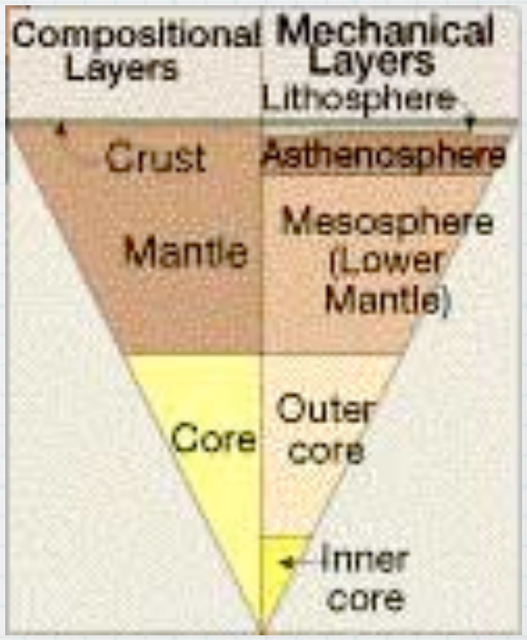
* Earth's core has two distinct regions

1. solid inner core
2. molten outer core

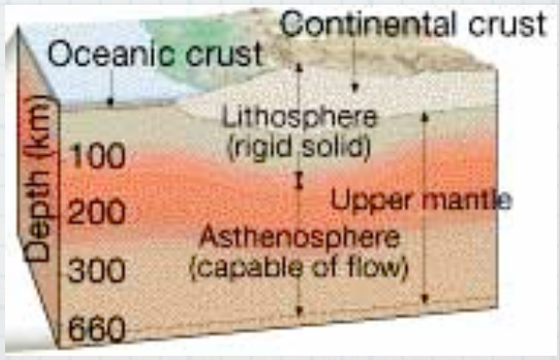


Internal Structure of the Earth...

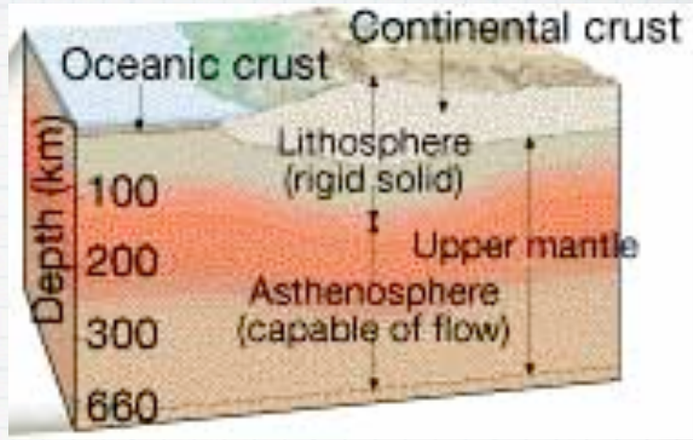
* The **mantle**: a thick moderate density layer **made of rocky materials** surrounds the core. Further subdivided in a **thicker inner mantle zone** and a **thiner outer mantle shell**



* The **crust**: a thin lower density rock layer **represents the world's outer skin**
  * continental crust & oceanic crust



Internal Structure of the Earth...

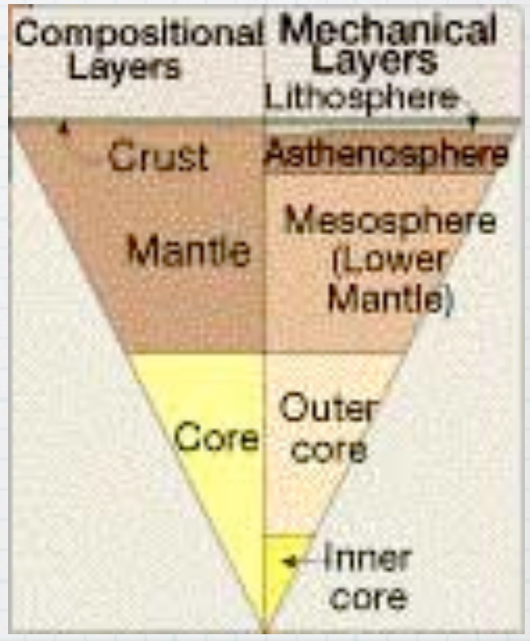


* The lithosphere is a layer which includes the crust plus part of the upper mantle and acts as an insulation layer
* That layer floats on top of the mantle situated below (asthenosphere)
* The thickness of the lithosphere indicates if a terrestrial world is still geologically active or not: a very thick lithosphere indicating a dead or dying world (it resists deformation)

Density, Temperature, and Location

* To summarize, from top to center:

1. the lithosphere is the coolest and most rigid layer of rocks. Its top is the surface of the planet (the crust)
2. then the mantle is a warm, elastic layer of molten rocks
3. lastly, we have the core with the hottest and densest metal materials



Differentiation and Internal Heat

* The reason for the clear layering is called differentiation:
  * liquids of different densities do not mix and are separated by gravity

Question

* Why do water and oil separate?

A. Water molecules repel oil molecules electrically

B. Water is denser than oil, so oil floats on water

C. Oil is more slippery than water, so it slides to the surface of the water

D. Oil molecules are bigger than the spaces between water molecules

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Differentiation and Internal Heat...

* In the planetary formation early stages, all these materials were mixed and very hot

* They were fluid: the dense metals like iron sank toward the center and less dense materials such as the rocks floated toward the surface. This process released heat

Internal Heat

* There are three main reasons for that internal heat

1. The terrestrial worlds gained heat from

a) the formation process itself

b) accretion during the Heavy Bombardment period

2. Heat was also gained due to differentiation process

material friction

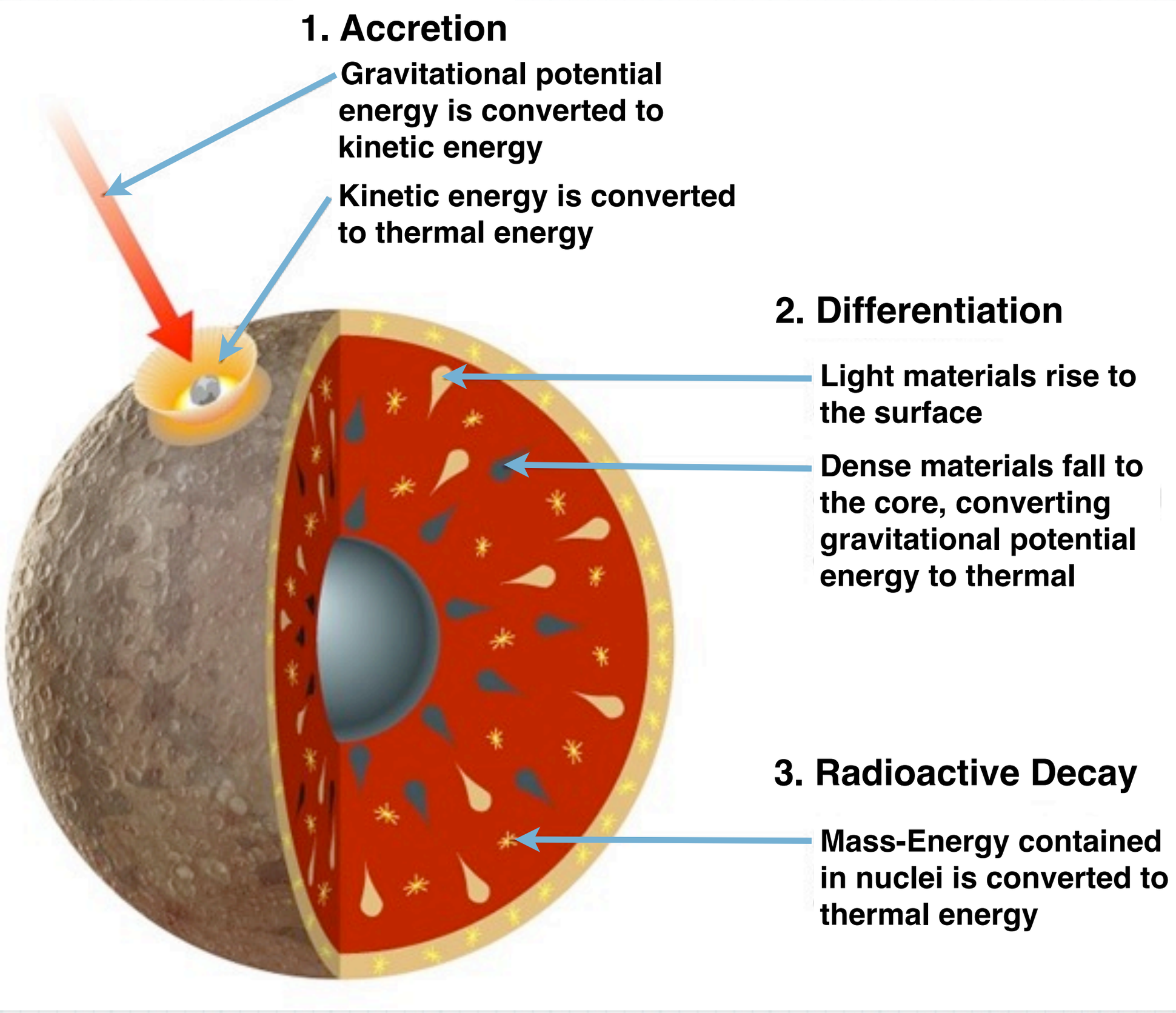
Internal Heat...

3. Radioactivity

Metals and rocks have a fraction of radioactive isotopes. As these decay, they release heat directly into the planetary interiors

Radioactive "heating" is still happening as of today

Internal Heat Processes



Internal Heat...

* The terrestrial worlds differ considerably in the amount of internal heat they still have

1. The most important factor for that amount of remaining heat, that is for how long it takes for a world to cool off, is the size of that world

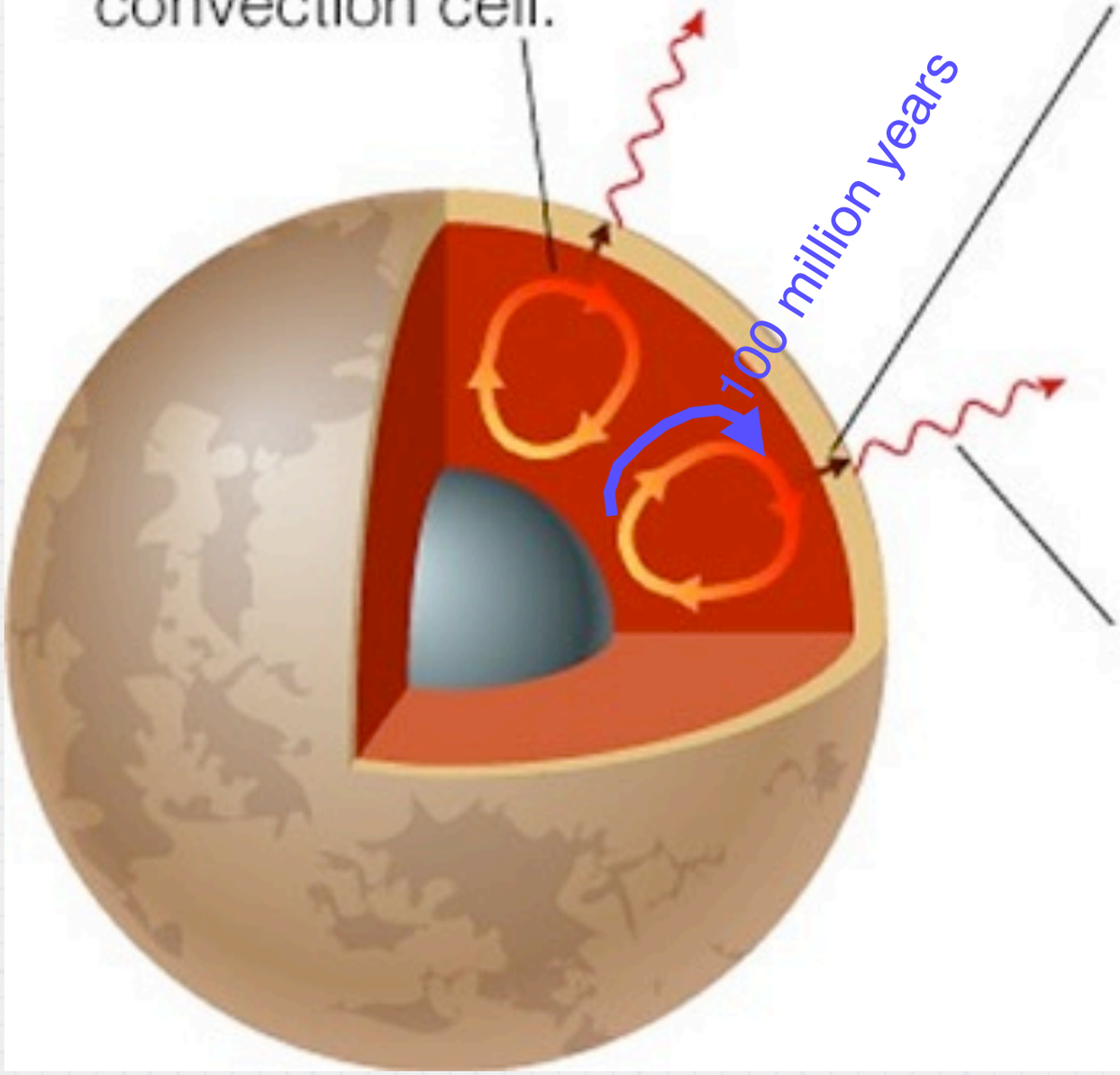
2. The second most important factor is the thickness of the lithosphere, as it acts as an insulation layer

Internal Heat Drives Geological Activity

* The internal heat gives out the energy needed to drive the geological activity

* If the interior of the planet is deep enough and hot enough, a convection process is started and hot rocks rise as they expand and cooler rocks sink

1. Convection
Hot rock rises and cooler rock falls in a mantle convection cell.



2. Conduction
After convection brings heat to the base of the lithosphere, conduction carries heat through the rigid lithosphere to the surface.

3. Radiation
At the surface, energy is radiated into space.

Internal Heat Drives Geological Activity...

* Note that while the rocks are hot they are not molten; they remain solid, but are plastic (the asthenosphere has the most plastic, or fluid, region)

* Convection is a very slow process and it can take 100 million years for rocks to be carried from the base of the mantle to the top

Heat Latency

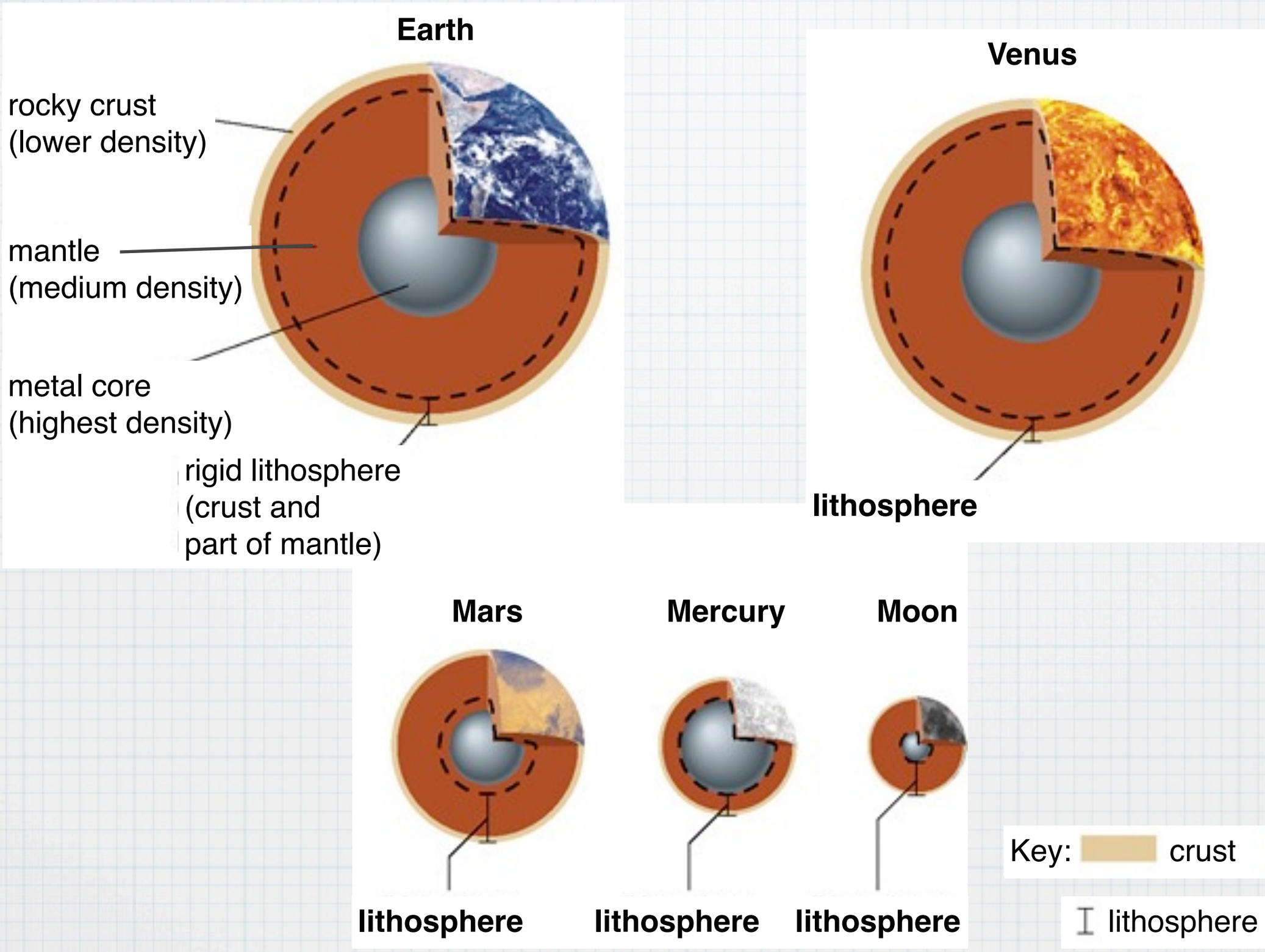
* Just as a big glass of hot water remains warm longer than a small one,
  * a planetary size (radius, volume) determines how long a planet stays hot
    a. which drives the strength of the convection in the mantle
    b. and is responsible for the thickness of the lithosphere

Cooling Off

* When a planet's interior cools off, the lithosphere becomes thicker
* A thick lithosphere resists distortions (inhibits tectonic and volcanic activities)

➡ When the planet is cool enough, convection stop and the planet is said to be geologically dead (although the core is still quite hot)

Planet Cutaways (to scale)



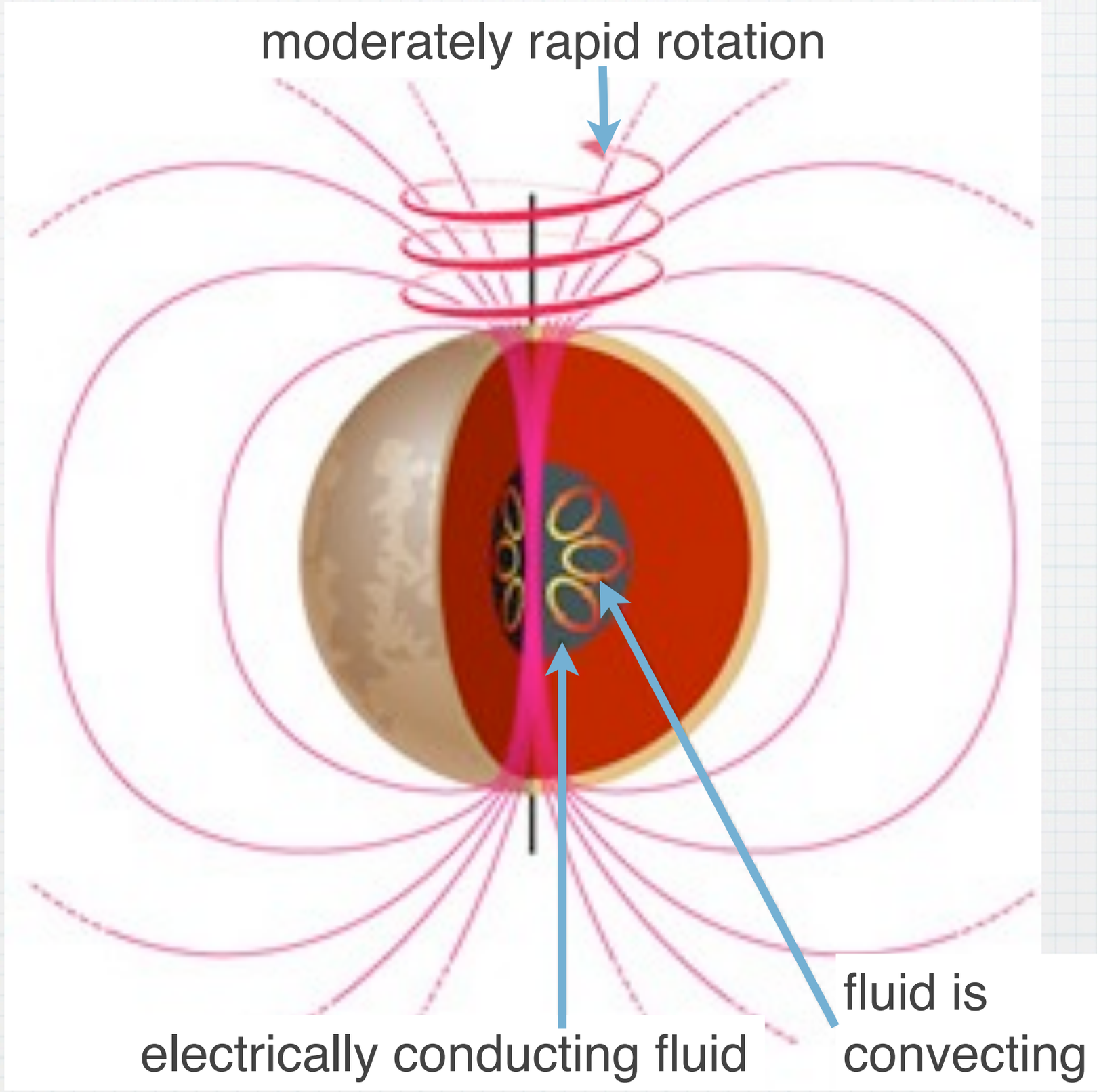
Earth's Magnetic Field

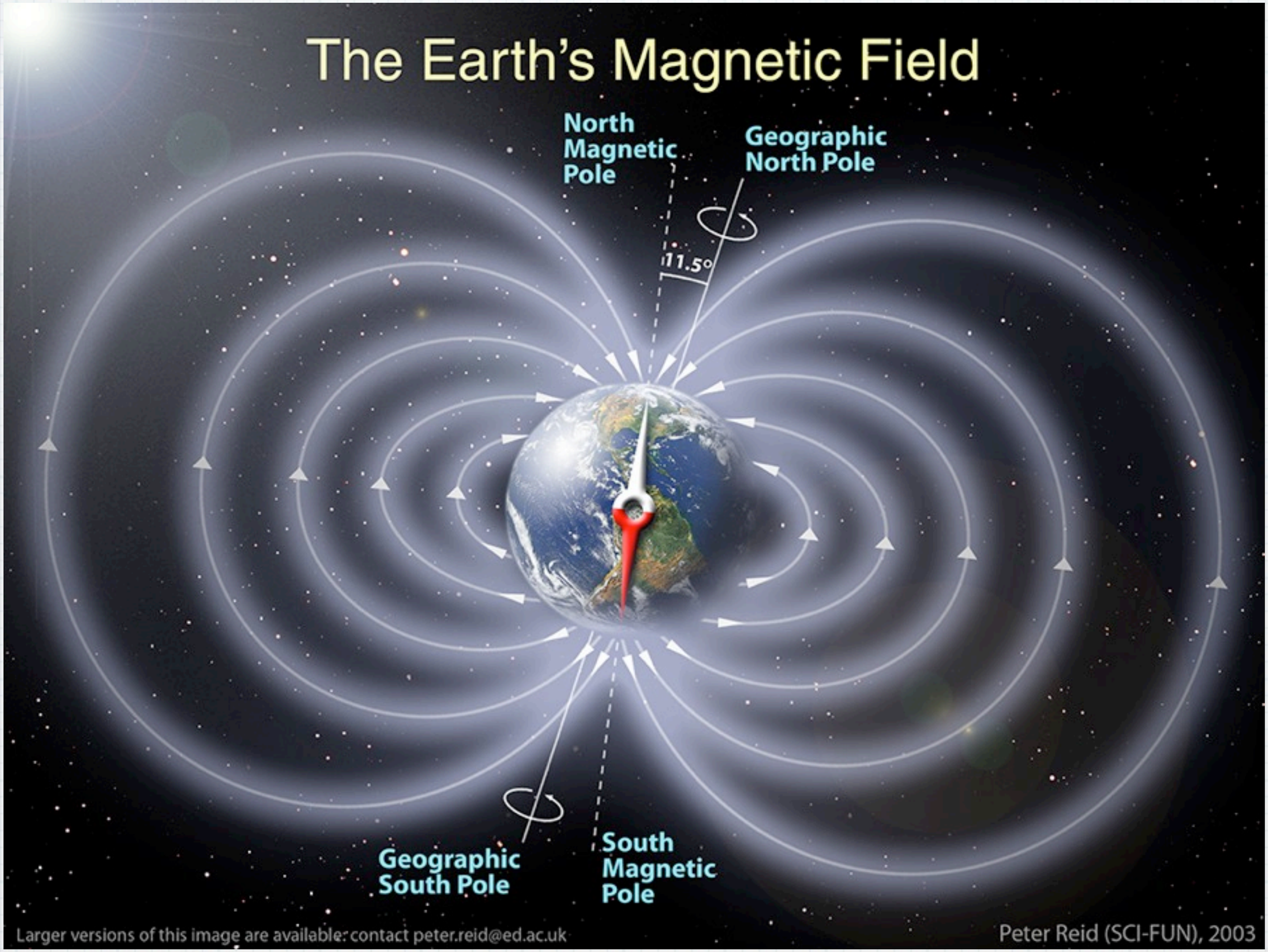
* The Earth has a magnetic field
* It protects the surface from the solar wind (charged energetic particles such as protons and electrons)
* Without the magnetic field, the atmosphere would be thinner and living organisms would be genetically damaged by the solar wind

Earth's Magnetic Field...

* The magnetic field is generated by the motions of the molten metals in the liquid outer core:

* the internal heat causes liquid metals to rise and fall via a convection mechanism in the liquid outer core and the daily rotation of the Earth twists and distorts the convection flows

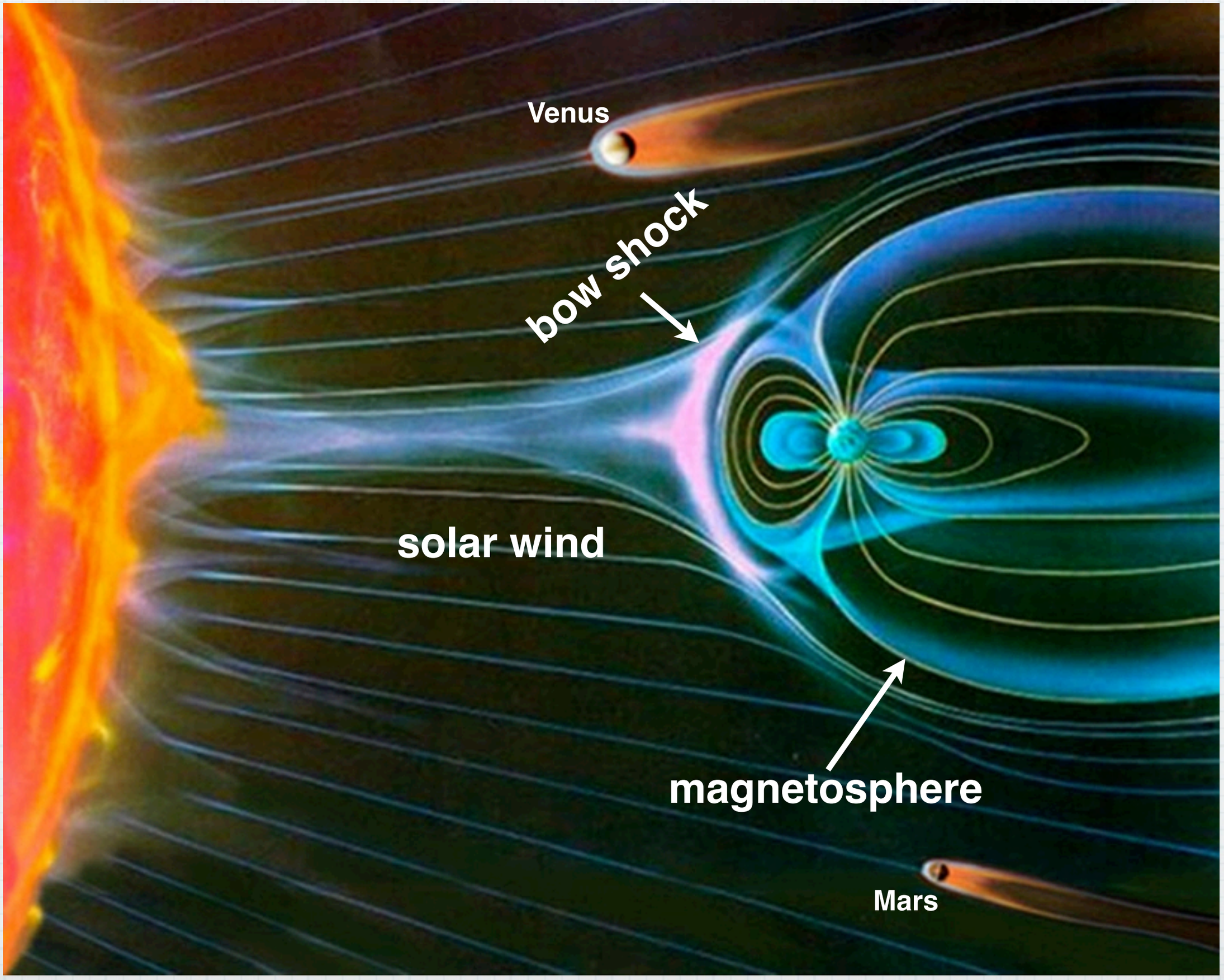

moderately rapid rotation
electrically conducting fluid
fluid is convecting


The Earth's Magnetic Field
North Magnetic Pole
Geographic North Pole
11.5°
Geographic South Pole
South Magnetic Pole
Larger versions of this image are available: contact peter.reid@ed.ac.uk
Peter Reid (SCI-FUN), 2003

The Magnetosphere

* The Earth's magnetic field deflects the solar wind before it hits the atmosphere
* This protective "bubble" is called the magnetosphere
* Most of the solar wind charged particles are deflected but some come in via the poles

Earth magnetosphere deflects the solar wind



Auroras

The charged particles from the solar wind which make it through collide with molecules in the atmosphere (mostly at the polar regions)

These molecules lose electrons. When the molecules get an electron back, they emit the light we call aurora

A Strong Magnetosphere

* This is a unique characteristic of Earth (for the terrestrial planets)
* Mercury, Venus, Mars and the Moon's own magnetic fields are much weaker
* They lack a protective magnetosphere
* We will see later what that did to Venus and Mars planetary histories

Question

* If the planet core is cold, do you expect it to have magnetic fields?

A. Yes, refrigerator magnets are cold, and they have a magnetic field

B. No, planetary magnetic fields are generated by moving charges around, and if the core is cold, nothing is moving

Question

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Shaping the Earth' Surface

Four major geological processes can virtually explain all surface features of a planet :

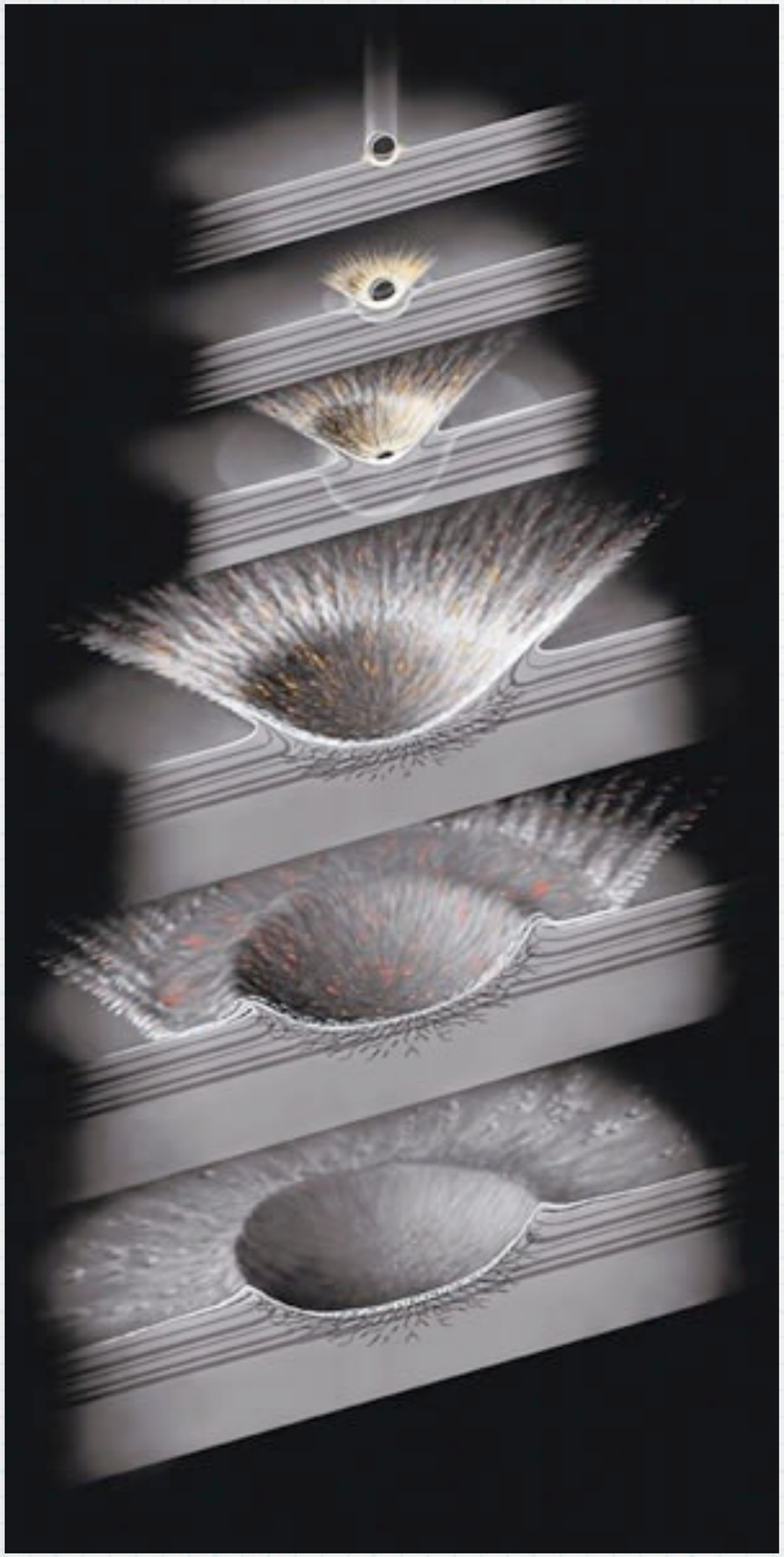
1. Impact cratering
2. Volcanism
3. Tectonics
4. Erosion

1. Impact Cratering

* This is an external mechanism
* When a comet or an asteroid strikes a planet's surface, it creates a bowl-shaped impact crater

1. Impact Cratering...

* A typical impact speed is between 40,000 to 250,000 km/hr
* Kinetic energy is proportional to the square of the velocity
* With that speed, at time of impact massive amounts of rocks are simply vaporized and a crater is formed



1. Impact Cratering...

* A crater is usually circular no matter the original direction of the object

* A crater is usually 10 times wider than the object that created it and about 10 to 20% as deep as they are wide

  (so a 1-mile wide asteroid would create a hole 10 mile wide and 1 to 2 mile deep)

Earth vs. Moon

* The Moon, our neighbor born from our planet, is scarred by craters
* Few are left on Earth

* Numerically, the Earth should have had more impact craters than the Moon

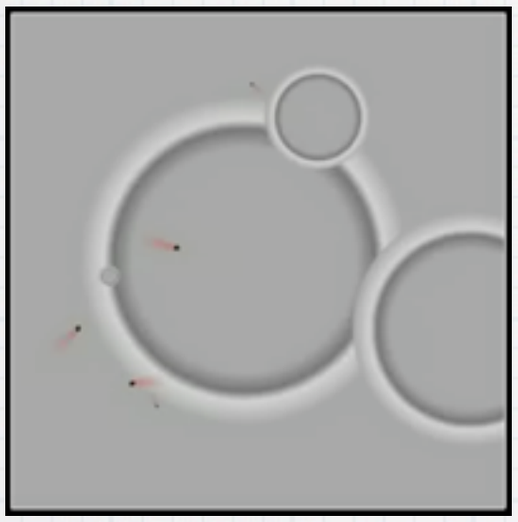
➡ Earth's craters have been erased by geologic activity such as volcanism and erosion

Known Impact Crater Distribution

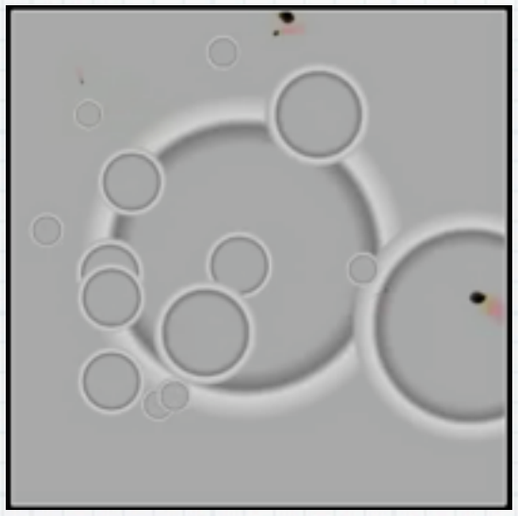
Earth vs. Moon...

* A cratered surface can be dated as the rate at which craters were made has slowed down
* Radiometric data from the Moon told us the rate

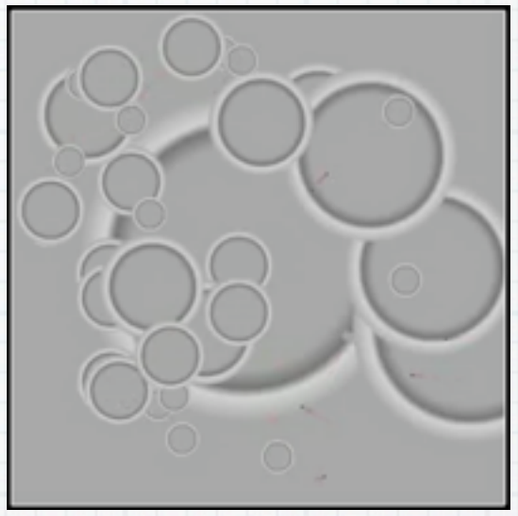
History of Cratering Density



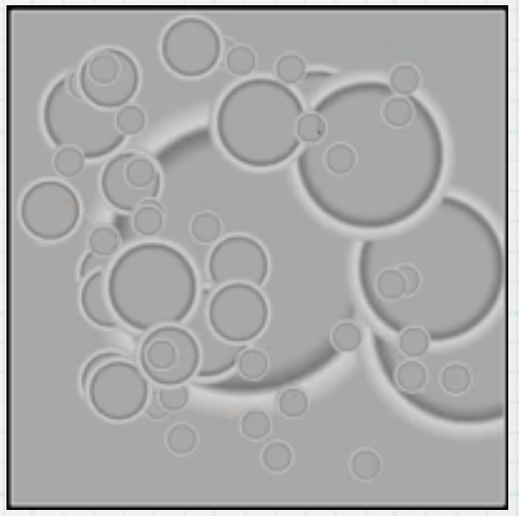
0.0 Gyr



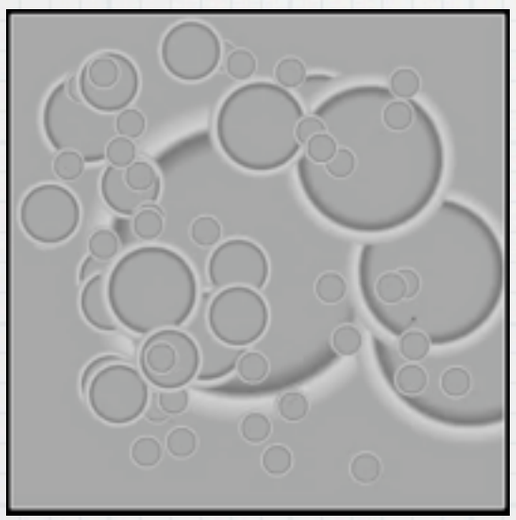
0.2 Gyr



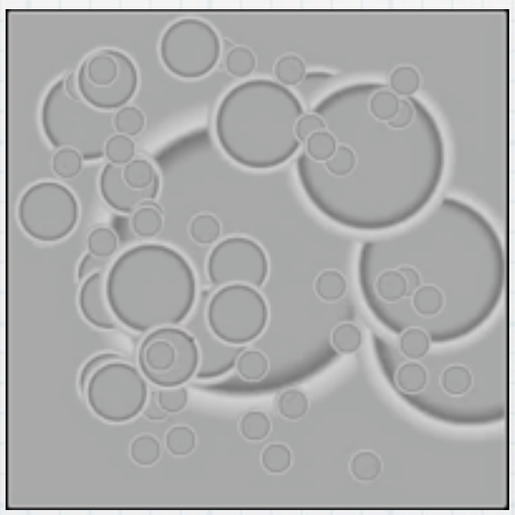
0.4 Gyr



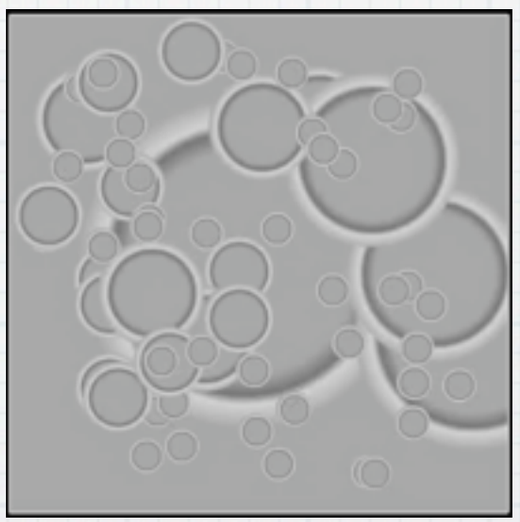
0.6 Gyr



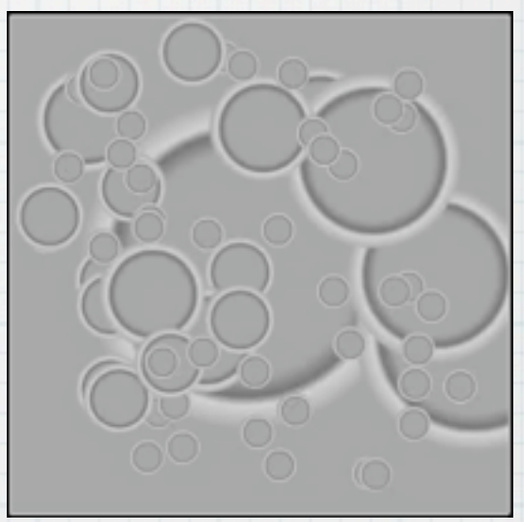
0.8 Gyr



1.0 Gyr



2.0 Gyr



3.0 Gyr

Near-Earth Asteroids larger than 330 feet

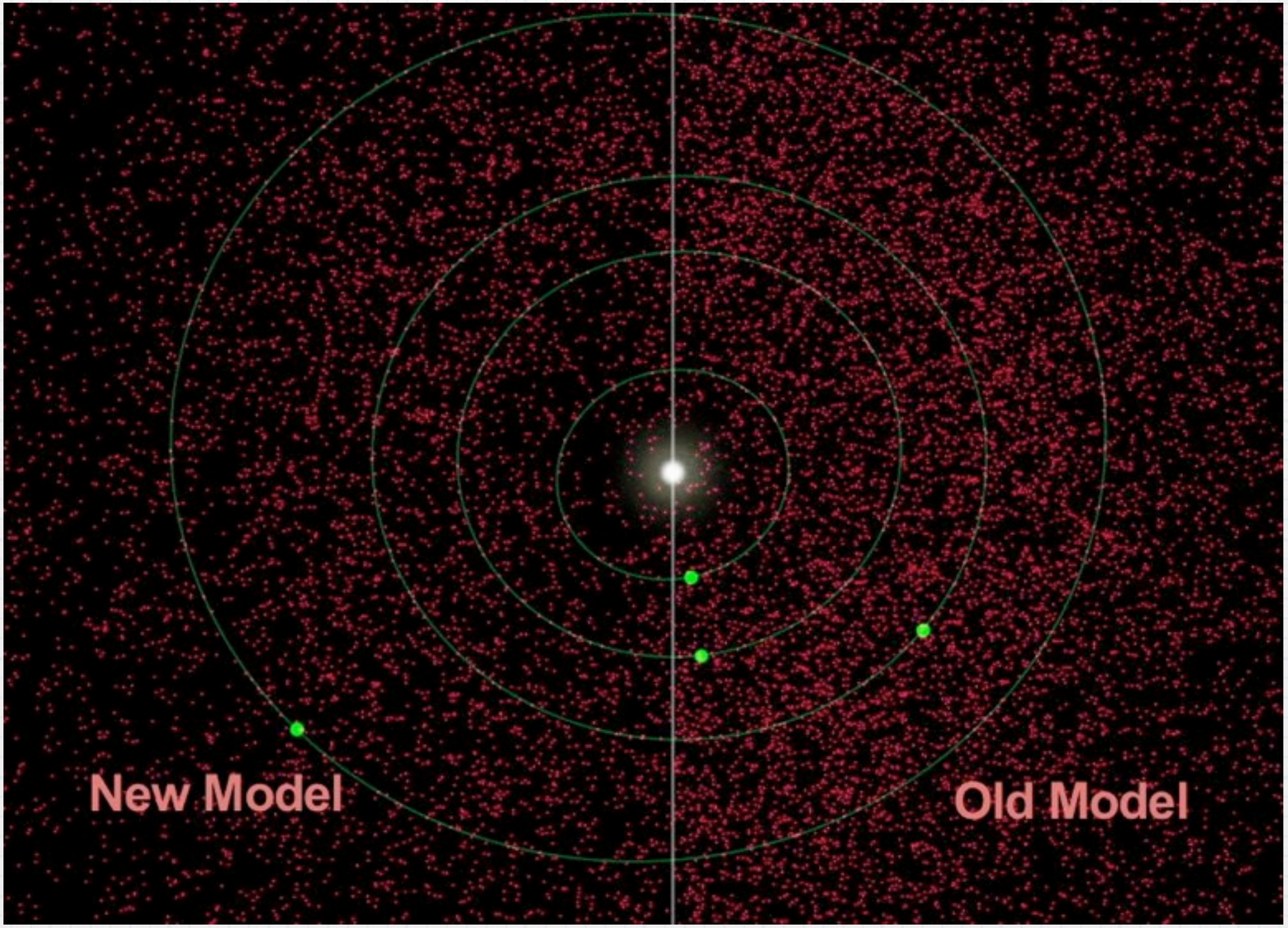


Illustration Credit: NASA, JPL-Caltech, WISE

The good news: less than we thought (less than 20,000)

The bad news: future collisions will happen

2. Volcanism

* The reason for Earth's ongoing volcanic activity is its large terrestrial size
* Had it been smaller, volcanic activity would have stopped long ago
* Volcanic activity occurs through cracks in the lithosphere as the molten rocks (**magma**) rise

2. Volcanism...

Volcanism is driven by 3 mechanisms

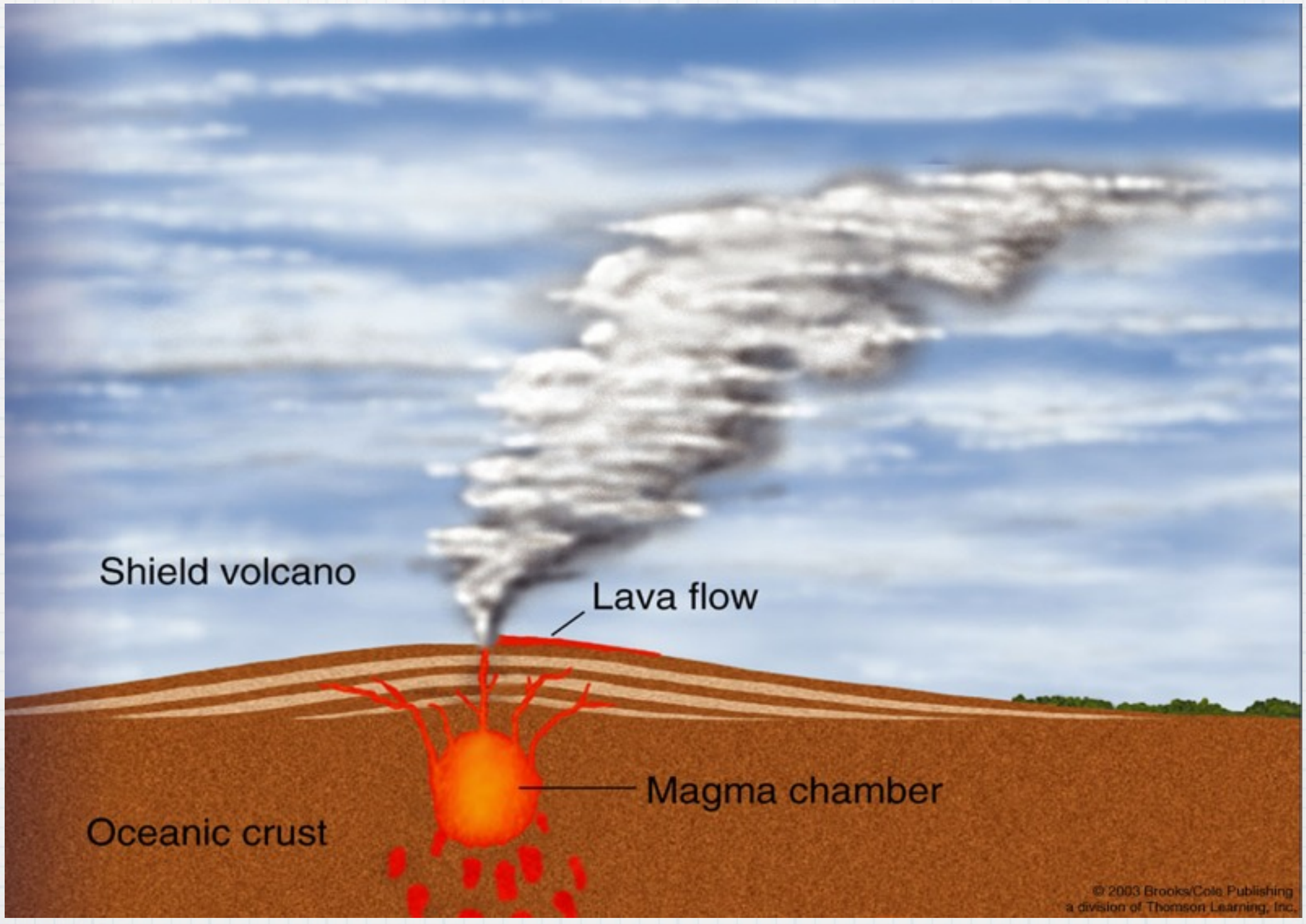
1. molten (hot) rocks are less dense than solid rocks and rise naturally
2. most of the Earth's interior is not molten but solid, and a pocket of molten rock will be squeezed upward due to pressure
3. molten rocks contain trapped gases that expand as the rocks rise and lead to (possibly dramatic) eruptions

Outgassing

* Volcanic activity is the main reason why we have oceans and an atmosphere
* Recall that water and other ices were brought during the Heavy Bombardment period
* Volcanism released some of these materials as gasses in the atmosphere in a process we call outgassing

Volcanic activity and outgassing

Volcanic activity and outgassing



Outgassing...

* The most prevalent elements which were outgassed were water vapor, carbon dioxide, nitrogen, and sulfur-bearing gasses
* Water vapor rained down and formed the oceans, the others helped make our atmosphere: 77% of Earth's air is nitrogen

3. Tectonics

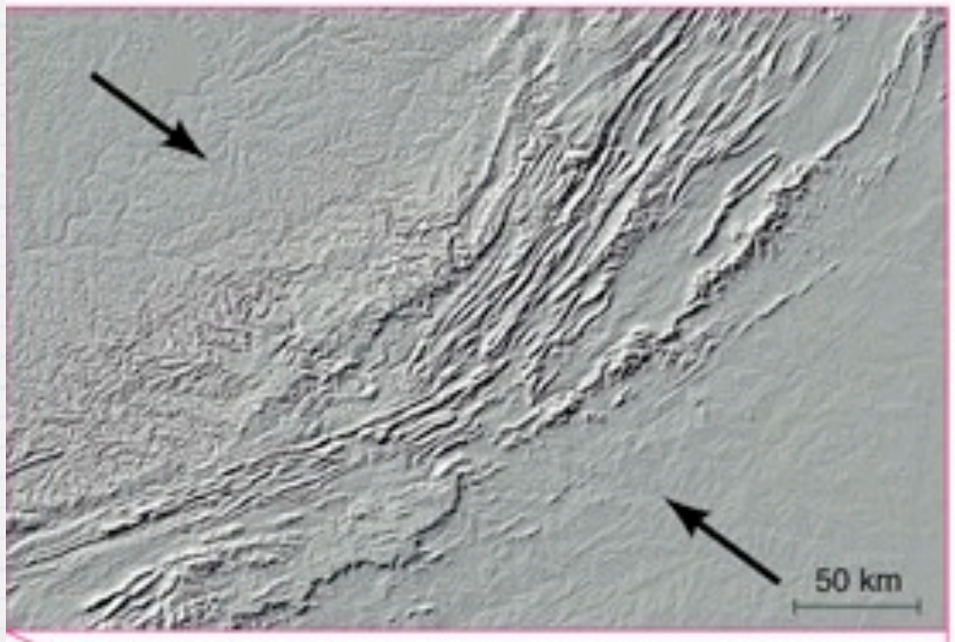
* Tectonic activity is surface reshaping resulting from stretching, compressing, or other forces acting on the lithosphere

* Mantle convection drives tectonic activity
* The convections fractured the lithosphere in pieces we call plates

3. Plate Tectonics

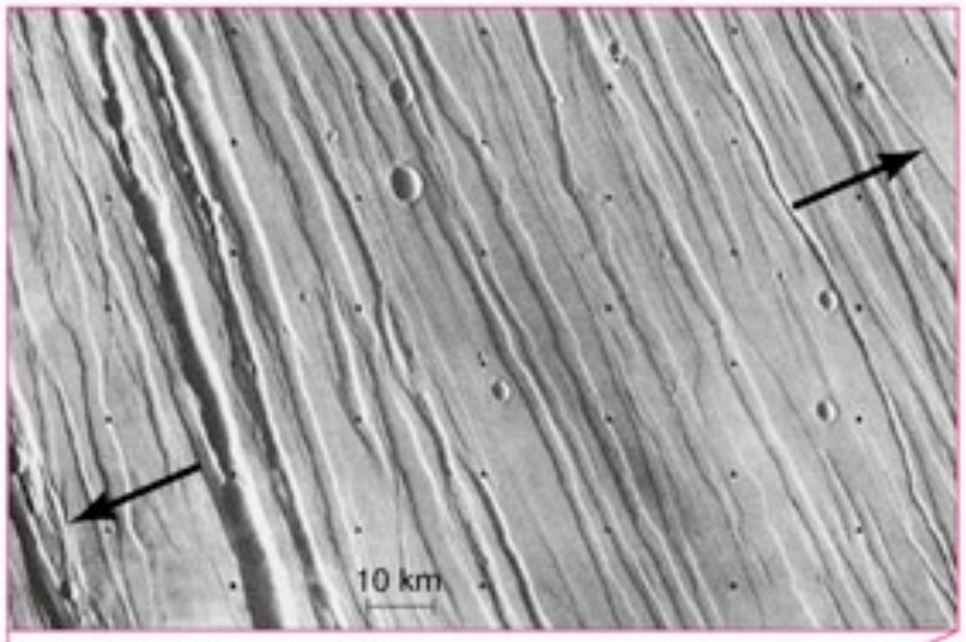
* These plates now move over, under and around each others
* This is called plate tectonics
* Surface compression makes mountains
* Surface stretching makes valleys and (room for the) seas

compression

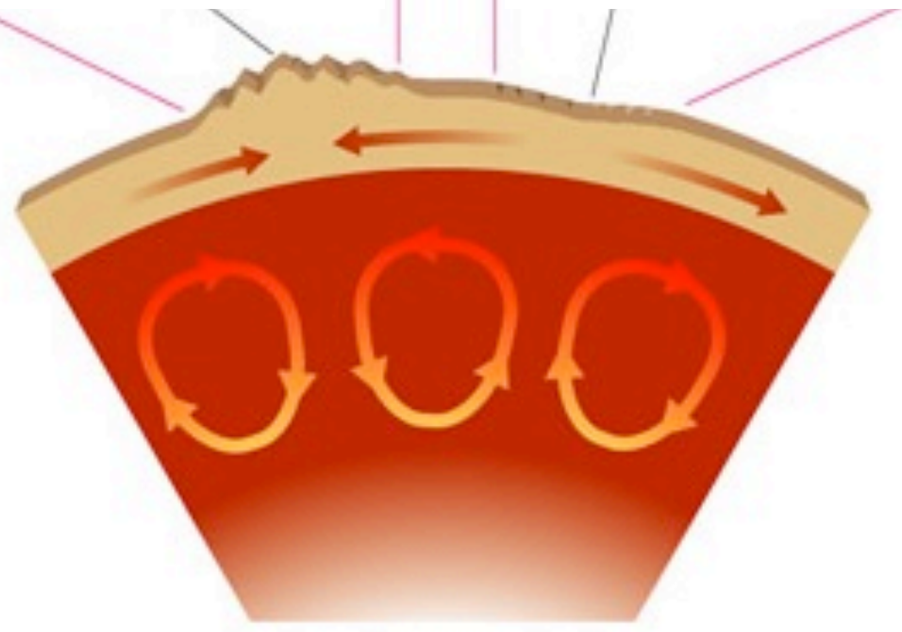


Internal stresses can cause compression in crust, which can make mountains

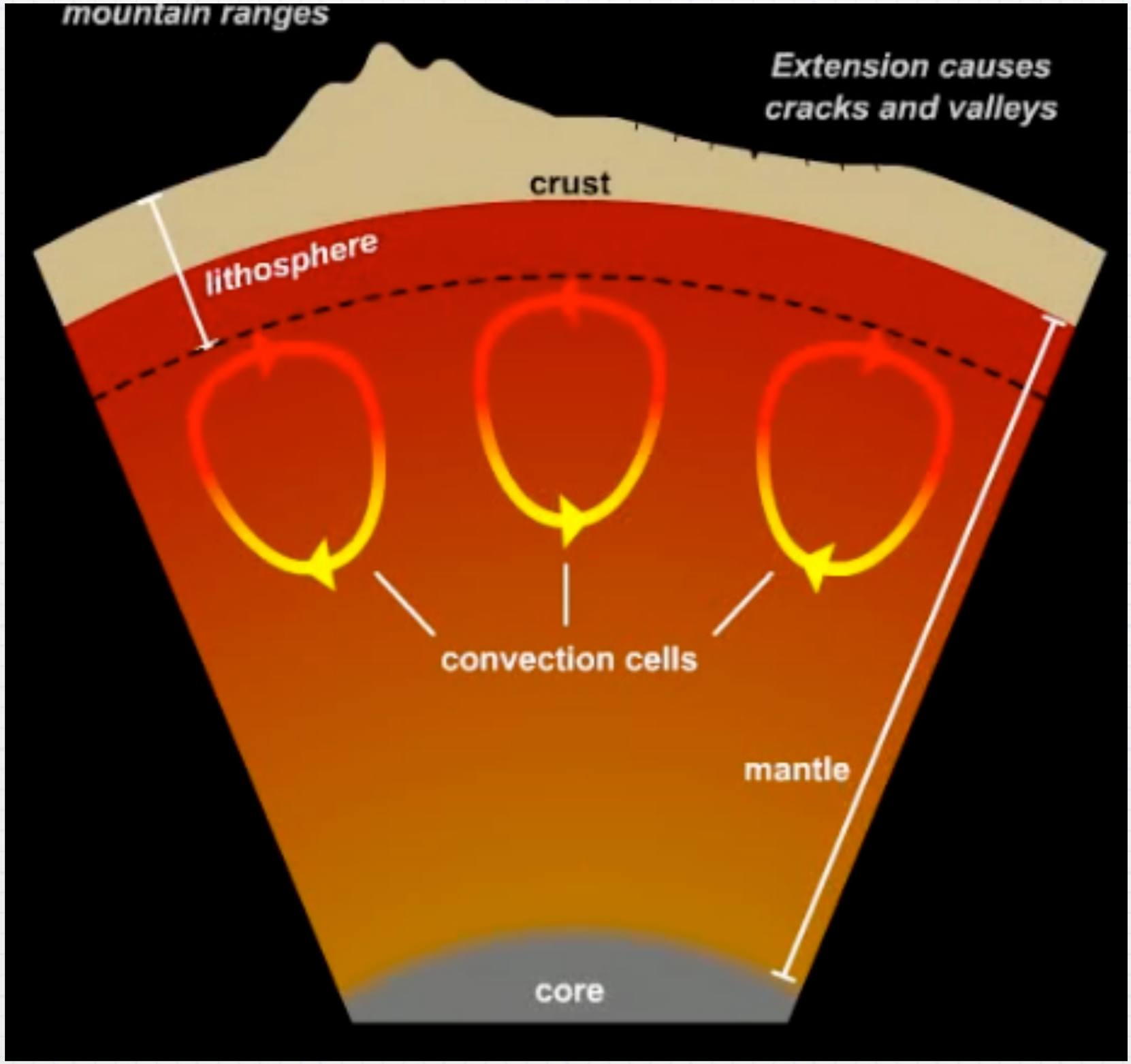
stretching



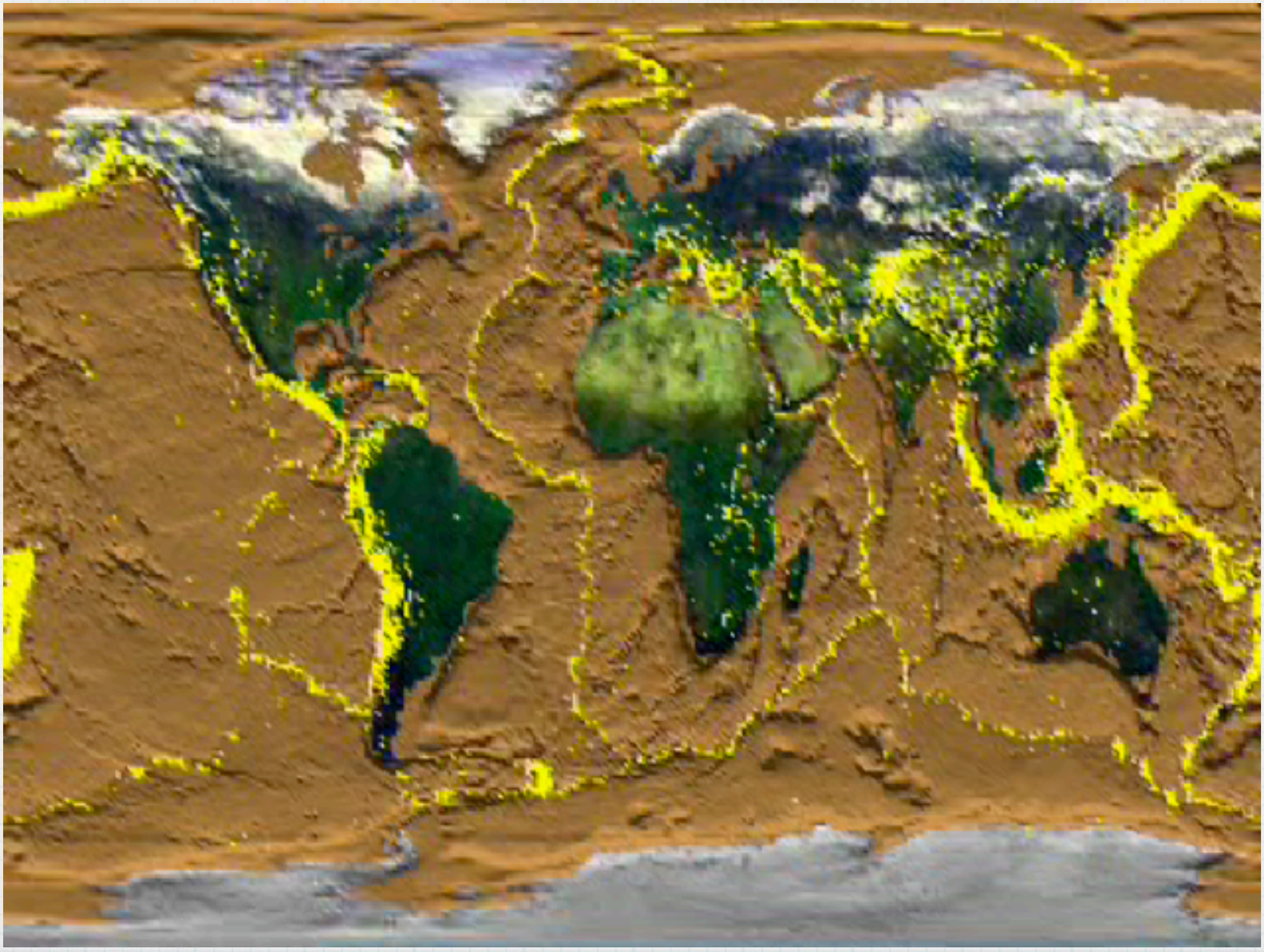
Internal stresses can pull the crust apart, which extends it and makes cracks and valleys



Mantle Convection & Plate Tectonics



Mapping Plate Boundaries with Earthquakes



3. Plate Tectonics...

* Earth seems to be the only terrestrial planet having a currently active plate tectonic system
* Venus does not show obvious features from space that would indicate such a system exists there now although we suspect limited volcanism currently happens
* Mars has tried to start its plate tectonic cycle, but failed to keep it going

4. Erosion

* Erasing action: any process which breaks down or transports rocks via the action of ice, liquid, or gas is an example of erosion
* Building action: erosion also build features such as sand dunes, river deltas, lake-bed deposits
* Sedimentary rocks were built over large periods of time by erosion which piled up sediments layers upon layers on the ocean floors

4. Erosion...

* The Grand Canyon is made of sedimentary rock which was uplifted by tectonic activity and then eroded by water
* Our planet has strong winds. The winds are primarily driven by the Earth's rotation
* Winds are an important part of erosion on Earth because they are strong and an abundant supply of water exists in 3 forms: gas, liquid and solid

Carving with water

Carving with ice

Carving with winds

Erosional debris builds land in this river delta

The Role of an Atmosphere

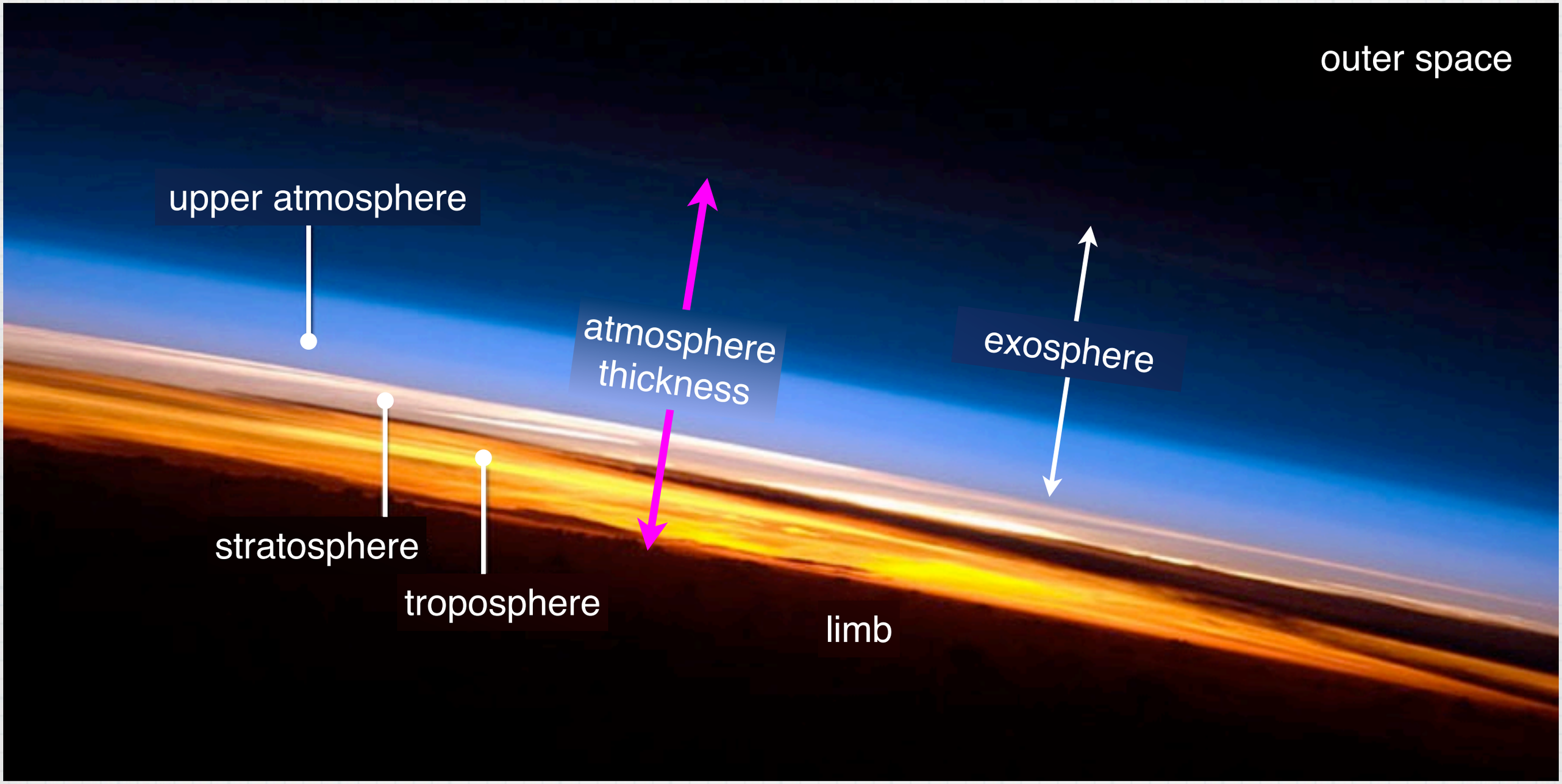
* Without an atmosphere, there would be little erosion, no liquid water, and no possibility for life on the surface

* Further more, there would be no barrier to filter out dangerous radiation (solar and cosmic)

The Role of an Atmosphere...

* Thin but effective: the atmosphere thins out rapidly with altitude
* 2/3 of its volume is contained within 10 km (6 miles) of the oceans' surface
* On a regular sized classroom globe, the atmosphere's thickness is one sheet of paper thin

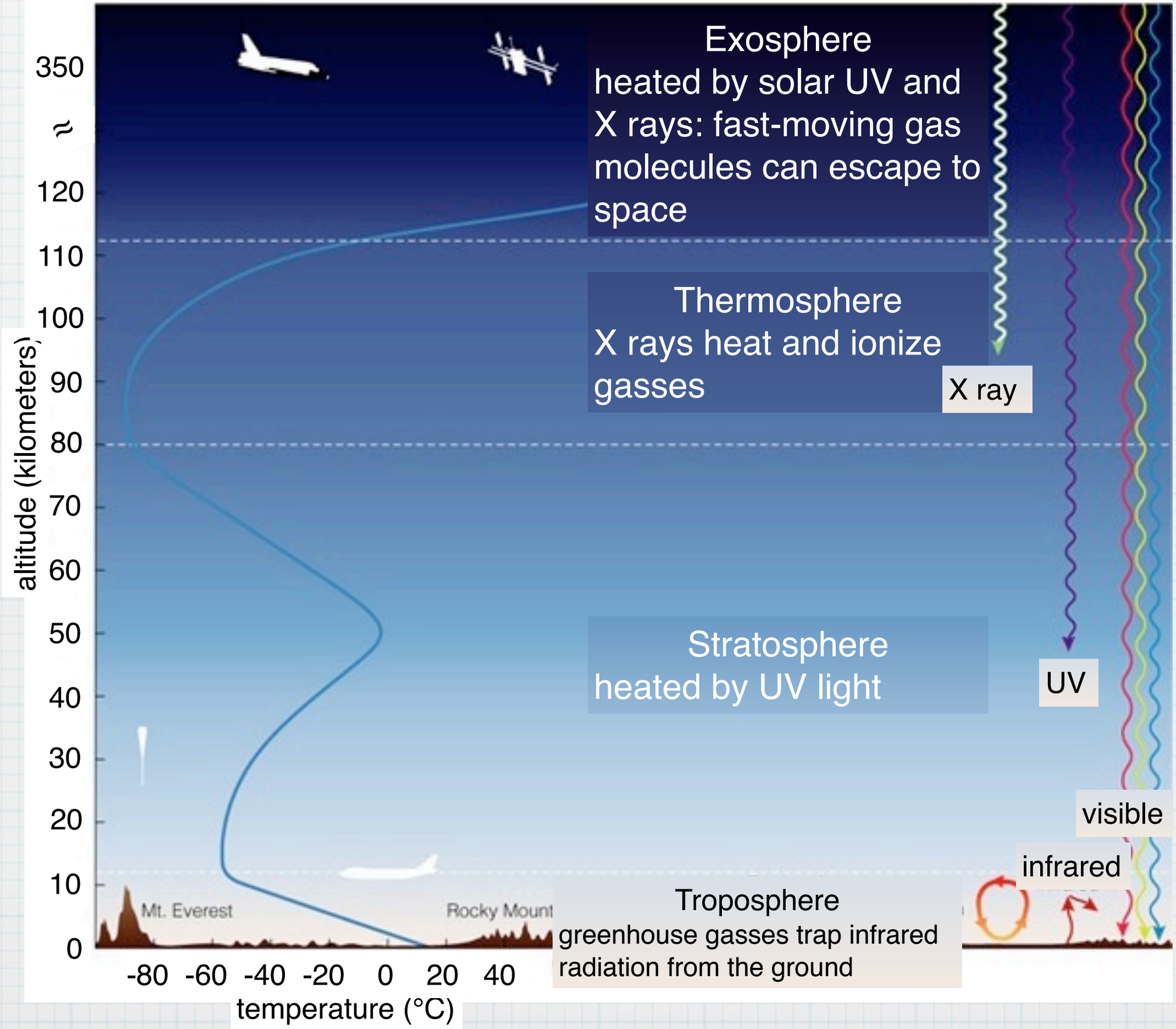
Airglow of Earth's upper atmosphere



NASA: ISS

Surface Protection

* The Sun emits more than visible light: ultraviolet and X rays are deadly to life
* Our atmosphere blocks the X-rays quite easily at the top layer
* UVs are mostly blocked in the middle atmosphere layer (called the stratosphere) by a rare gas called ozone (O_3)


Exosphere
heated by solar UV and X rays: fast-moving gas molecules can escape to space
Thermosphere
X rays heat and ionize gasses
X ray
Stratosphere
heated by UV light
UV
visible
infrared
Troposphere
greenhouse gasses trap infrared radiation from the ground
Mt. Everest
Rocky Mount
altitude (kilometers)
350
≈
120
110
100
90
80
70
60
50
40
30
20
10
0
-80 -60 -40 -20 0 20 40
temperature (°C)

Light Reaching the Surface

* About half of the light emitted by the Sun reaching the surface is the type we call "visible"
* Plants "see" it too. Without photosynthesis, there would be no animal life on Earth (nor oxygen...)
* The primary source of heat for the surface is due to absorbed visible light

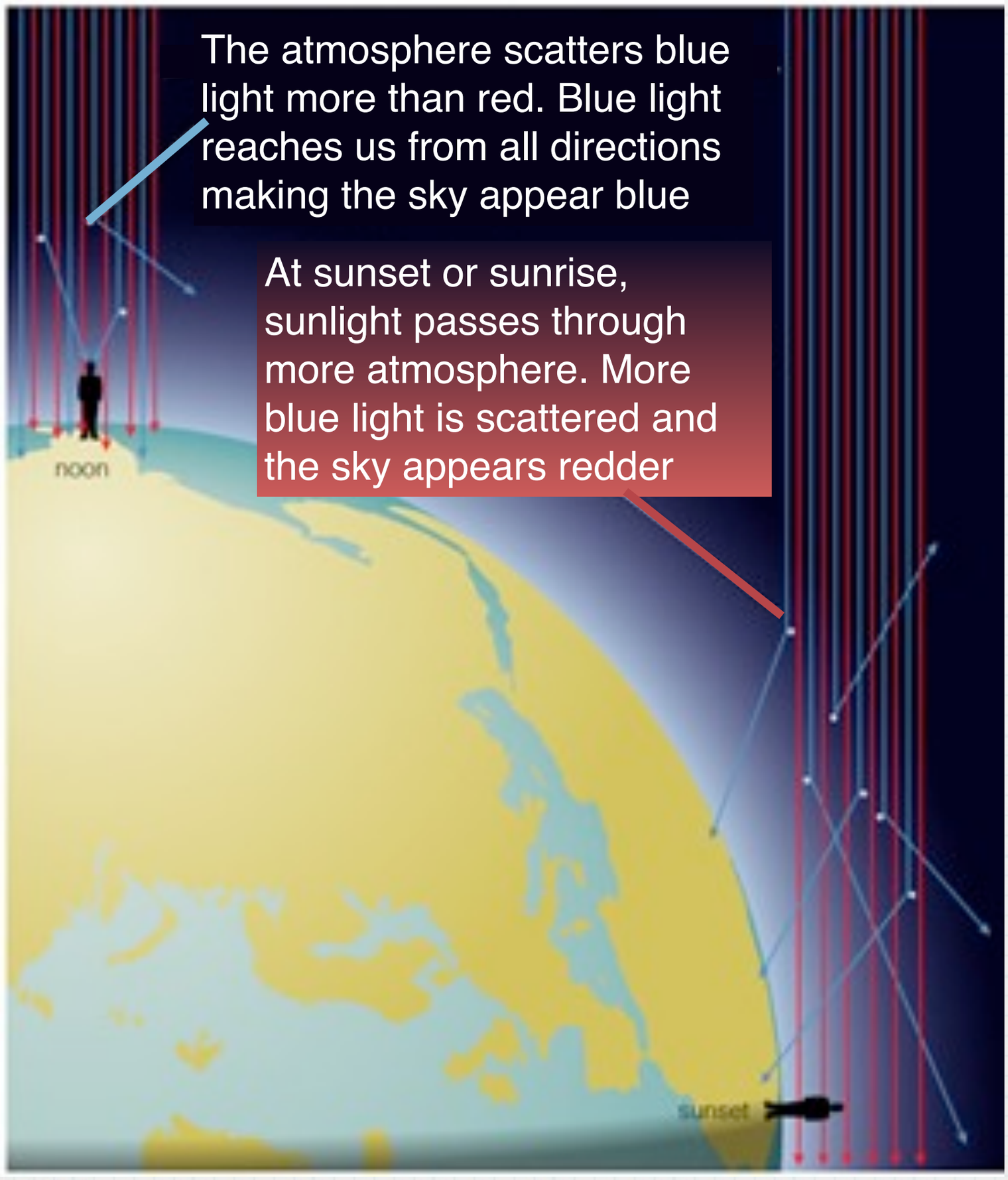
Why is the Sky Blue?

* Visible light, as we know, is composed of a range of frequencies (400 nm to 800 nm) from what we call indigo to red
  * Indigo is more energetic than red
  * Our atmospheric gas composition scatters the more energetic photons than the lesser ones

Why is the Sky Blue?...

* Since it is scattered more, blue light reaches us from the sky in all directions and the sky then appears blue during the day

* At sunrise or sunset, sunlight must pass through a thicker layer of atmosphere and most of the blue is scattered further away and the sky appears redder



The Greenhouse Effect

* Visible light warms the Earth's surface
* Once the ground absorbs visible light, the ground re-emits that energy as infra-red light
* Our atmosphere then traps that light with gasses that absorb infra-red
* These gasses are called greenhouse gasses

The Greenhouse Effect...

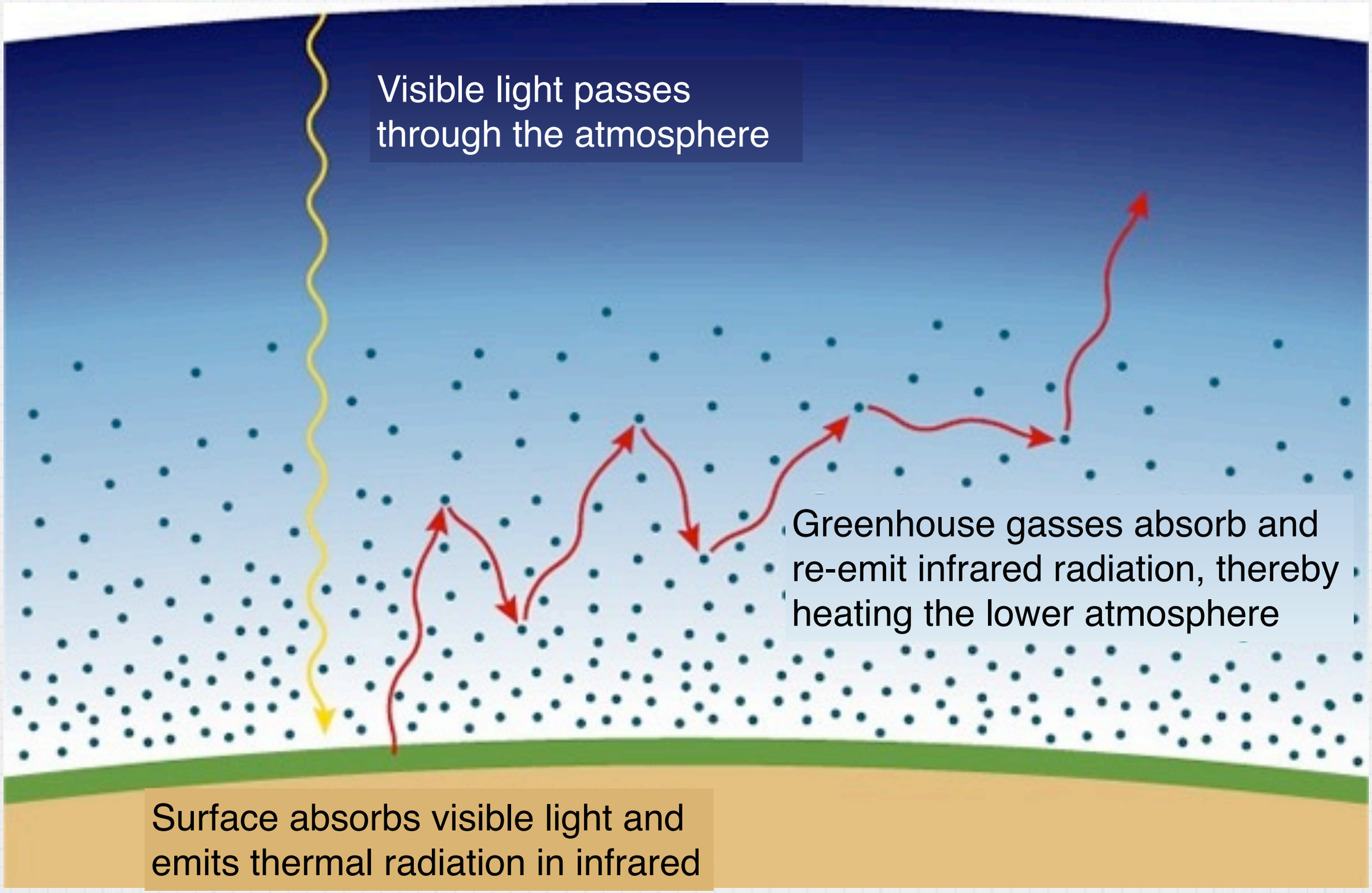
1. A greenhouse gas molecule absorbs an IR photon which makes it rotate and vibrate
2. Another IR photon is then re-emitted and then re-absorbed by another greenhouse gas molecule and so on

➡ Greenhouse gasses slow down IR energy from escaping into space by heating the surrounding air

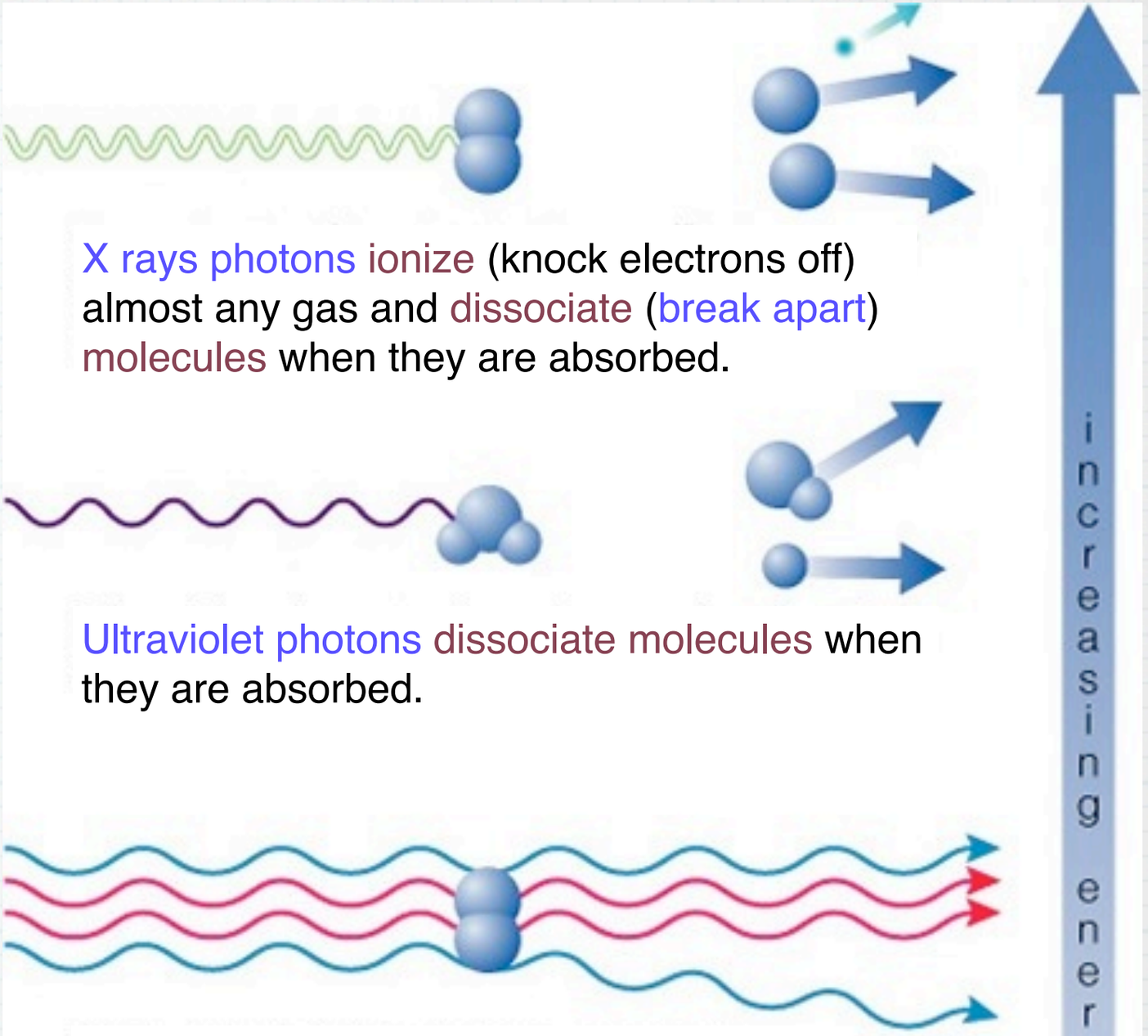
The Greenhouse Effect...

* Greenhouse gasses are water vapor, carbon dioxide and methane
* They are found in the lower atmosphere (called Troposphere)
* Too much of a good thing can be a bad thing
* Too much greenhouse gases mean that the atmosphere could warm up a lot and then affect life negatively

Greenhouse Effect



Photonic energy and impact on different atmospheric molecules



X rays photons ionize (knock electrons off) almost any gas and dissociate (break apart) molecules when they are absorbed.

Ultraviolet photons dissociate molecules when they are absorbed.

Most visible-light photons are simply transmitted, though some are scattered.

Infrared photons are absorbed by molecules, causing them to vibrate and rotate.

Oxygen in the Atmosphere

* Oxygen (O_2) is not a product of volcanic outgassing
* O_2 is highly reactive and quickly combines with other elements so something must constantly resupply the oxygen we need to breathe. What is it?
* **Photosynthesis!**

Photosynthesis

* Photosynthesis is the process by which plant life absorbs CO_2 and releases O_2
* Virtually all oxygen on Earth is created from photosynthetic life
* Ozone, O_3, comes from O_2 and protects us from UV radiation
* Plant life produces about the same amount of oxygen as it is consumed by animal life

Snapshot

* Why is Earth geologically active?
* Internal heat drives geological activity, and Earth retains plenty of internal heat because of its relatively large size for a terrestrial world. This heat causes mantle convection and keeps Earth's lithosphere thin, ensuring active surface geology. It also keeps part of Earth's core melted, and the circulation of this molten metal creates Earth's magnetic field

Snapshot

* What processes shape Earth's surface?
* The four major geological processes are impact cratering, volcanism, tectonics, and erosion. Earth has experienced many impacts, but most craters have been erased by other processes. We owe the existence of our atmosphere and oceans to volcanic outgassing. A special brand of tectonics—plate tectonics—shapes much of Earth's surface. Ice, water, and wind drive rampant erosion on our planet

Snapshot

* How does Earth's atmosphere affect the planet?
* Two crucial effects are (1) protecting the surface from dangerous solar radiation—ultraviolet is absorbed by ozone and X rays are absorbed high in the atmosphere— and (2) the greenhouse effect, without which the surface temperature would be below freezing

The Other Terrestrial Planets

* Let's now look at Mercury, the Moon, Mars and Venus in that order
* We will then understand what makes Earth unique in the Solar System

Mercury & the Moon

* They have the simplest histories
* It is a direct consequence of their small sizes
* They have lost large amount of their internal heat and cannot power surface geological activity as their lithosphere is too thick to permit outgassing

Mercury & the Moon...

* Small also means their gravity is too weak to hold an atmosphere for long periods of time

➡ And since these worlds are not outgassing any longer, there is no atmosphere at all: it evaporated into space

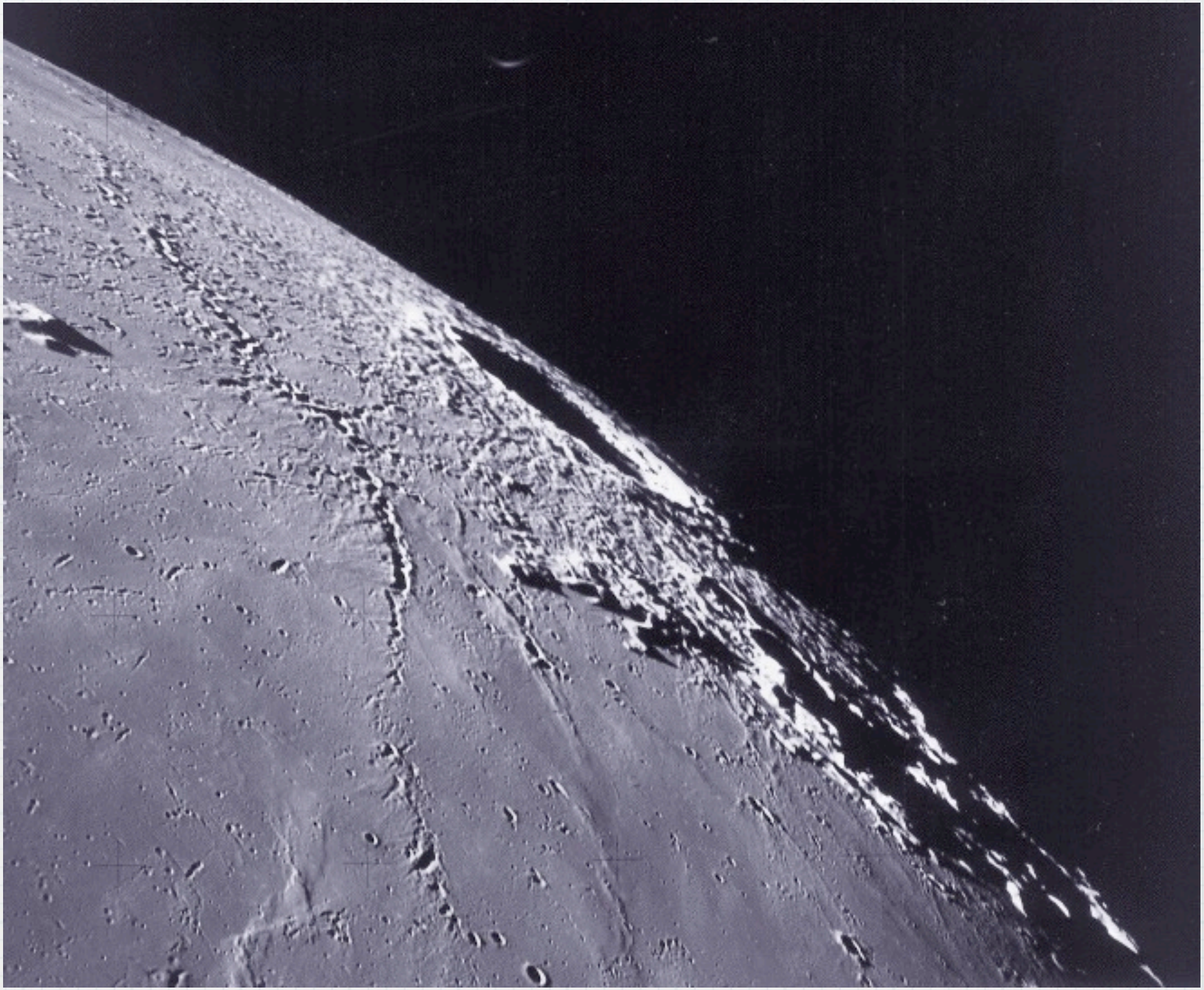
Surface Features

* Many craters exists on both Mercury and the Moon
* It is not easy to distinguish one from the other

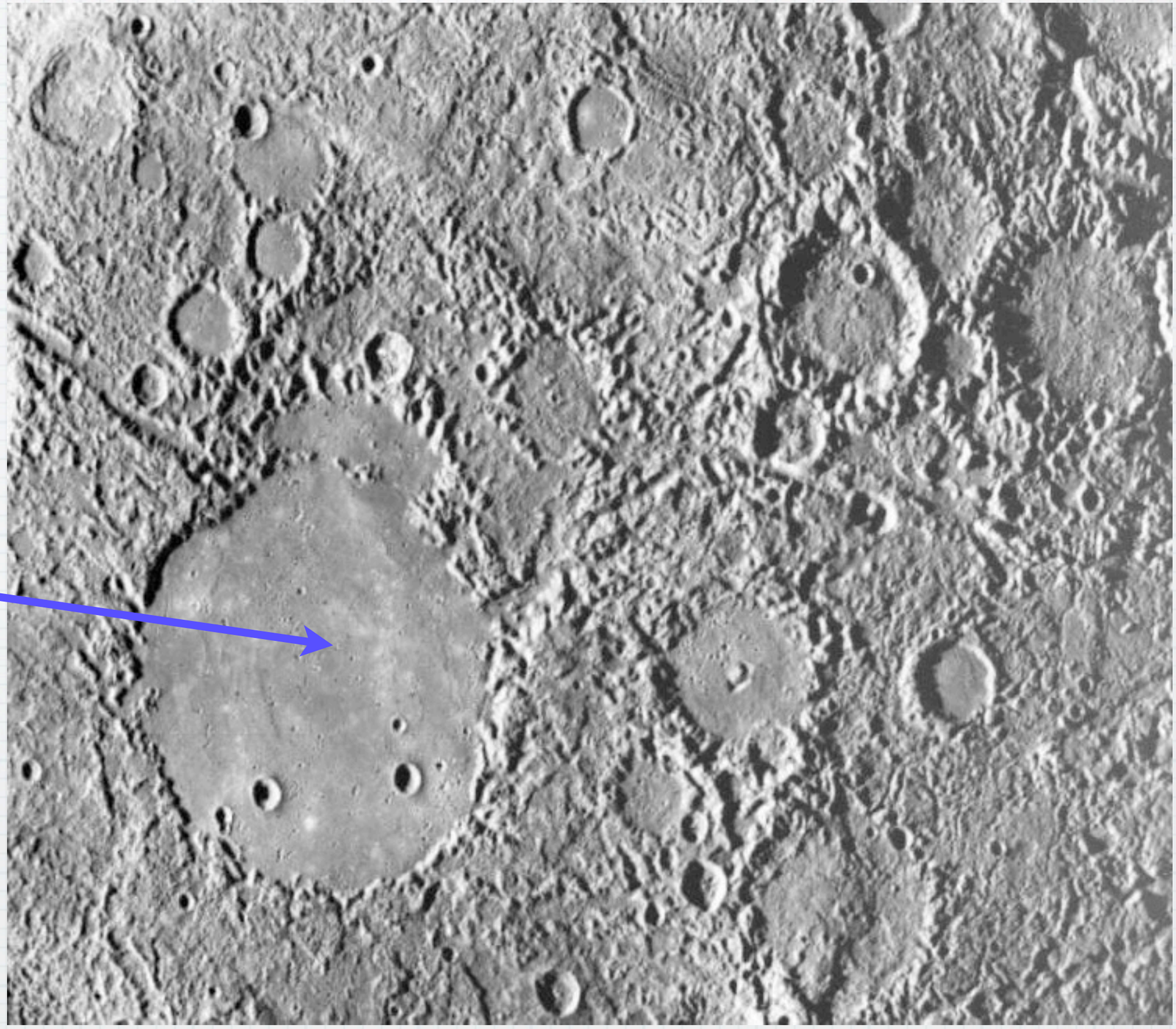
Surface Features...

* Long ago, before they cooled, these worlds were hot enough inside to power tectonic and volcanic activity
* Both worlds show marias (basins) which were made by floods of molten lava billions of years ago

Maria and craters on the Moon

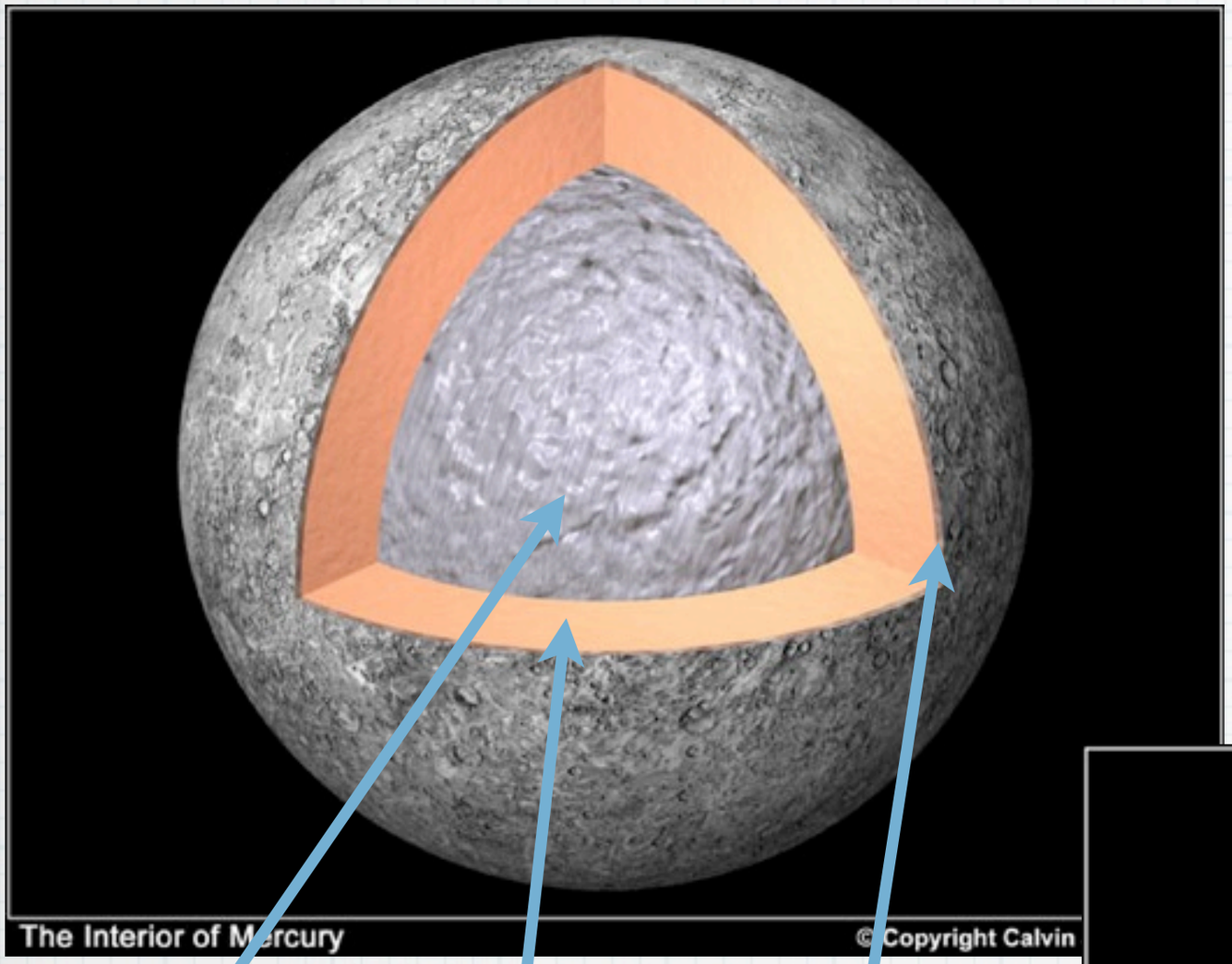


Maria and craters on Mercury



Mercury and the shrinking planet

* Unique on Mercury are long and impressive cliffs with vertical faces up to 3 or more km high (about 2 miles) which run for hundreds of km on the surface
* The planet shrank when its big core cooled; its lithosphere contracted and cracked
* (interestingly enough, that phenomena may now happen on the Moon)



huge core

lithosphere

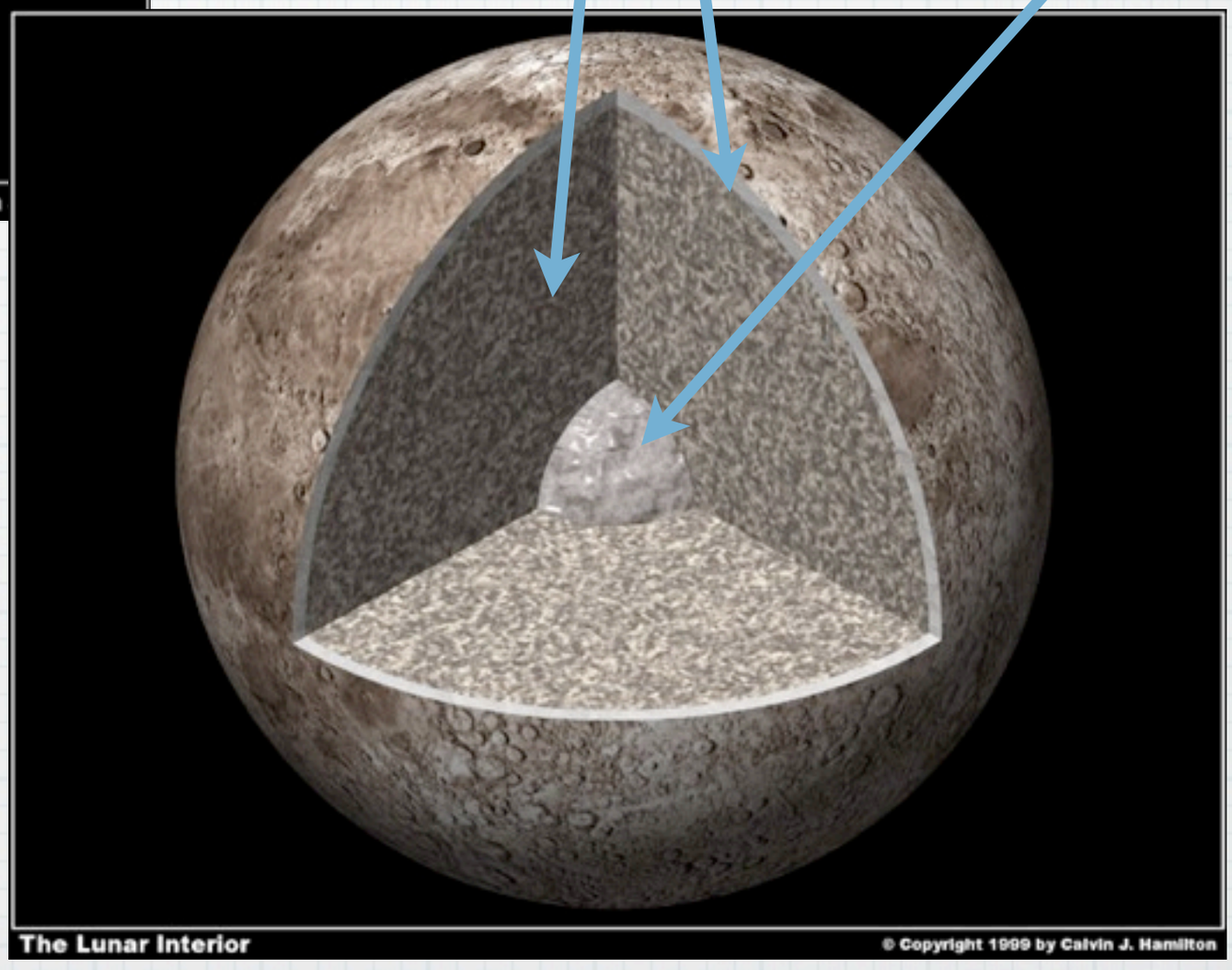
crust

Inside Mercury

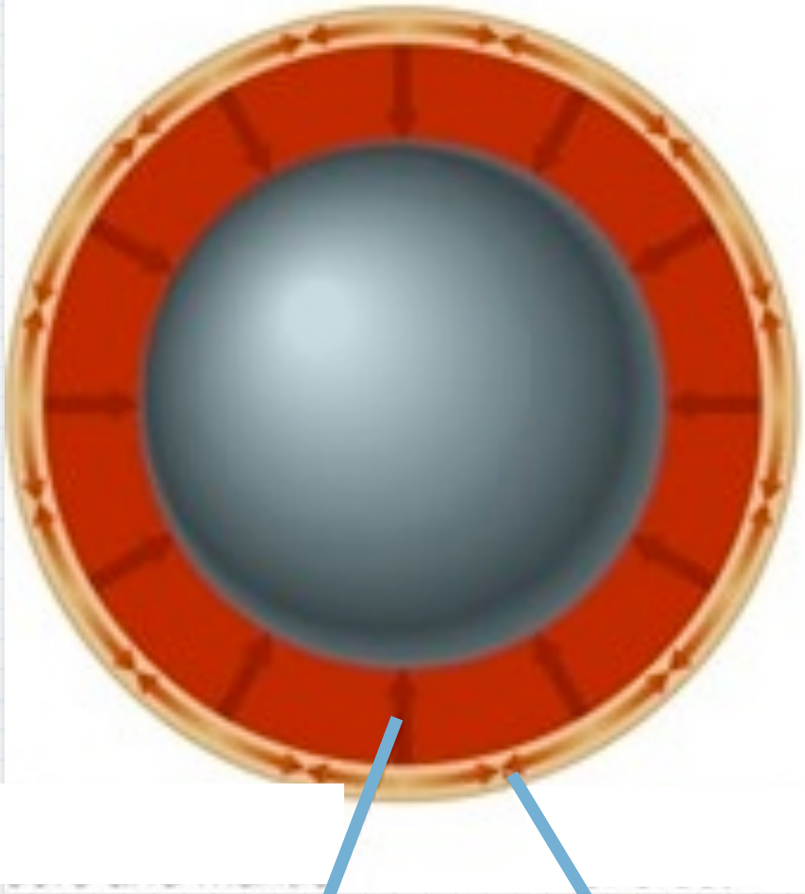
Inside the Moon

thick lithosphere and crust

tiny core



Mercury shrank in size as its core and mantle cooled



compression of crust

shrinking of core and mantle

Some portions of the crust were forced to slide under others

Today we see long steep cliffs created by this crustal movement

Snapshot

* Was there ever geological activity on the Moon or Mercury?
* Both the Moon and Mercury had some volcanism and tectonics when they were young. However, because of their small sizes, their interiors long ago cooled too much for ongoing geological activity

Mars

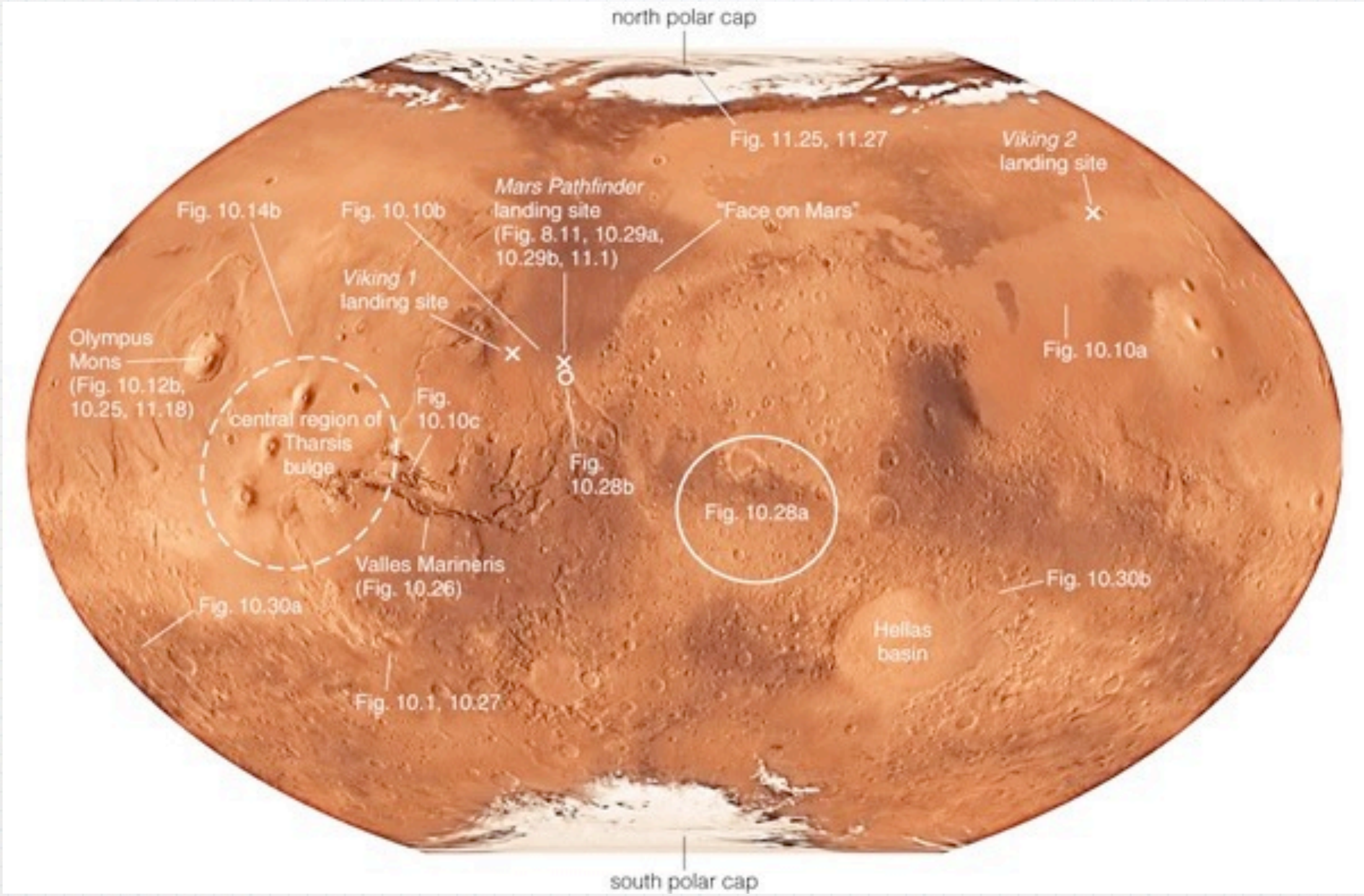
1. Much larger than Mercury & the Moon
2. Smaller than the Earth
   * 1/2 the radius
   * 1/10th the mass
3. 1.5 A.U. from the Sun

➡ Its geological history is written from these "genes"

Similarities with Earth

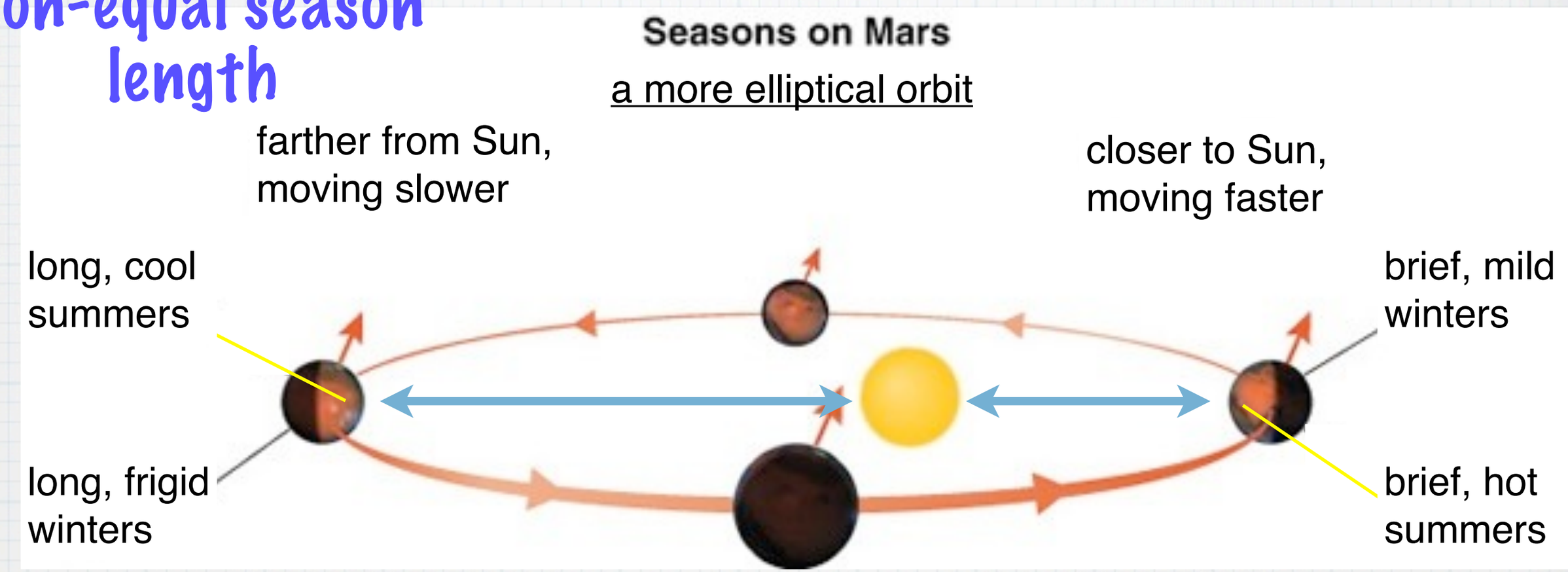
1. A Martian day is 24 hr and 36 min long
2. Mars has 2 polar caps (mostly frozen water and frozen carbon dioxide)
3. Similar tilt than Earth
4. Similar season patterns but they last twice as long
5. Present-day surface features are like a desert or volcanic plain on Earth

Present-day surface features are like a desert or volcanic plain on Earth

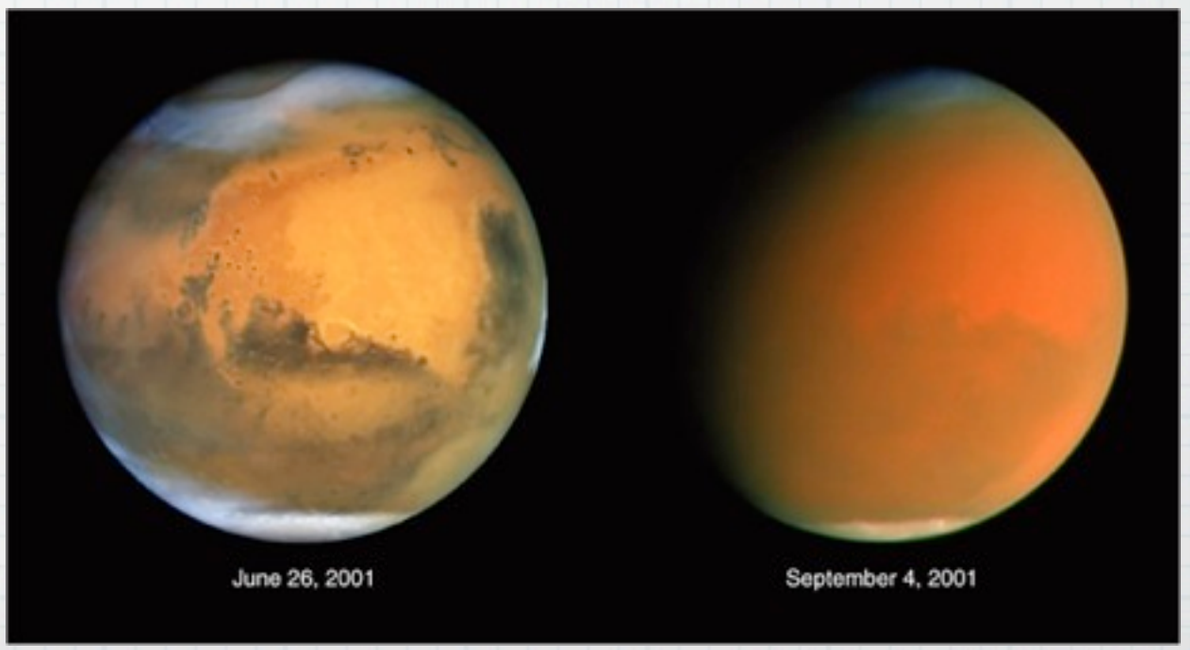


Differences with Earth

Non-equal season length



Huge martian storms are the results



Differences with Earth...

* Mars has a very thin atmosphere
* Mostly composed carbon dioxide (a greenhouse gas!) ... but a very weak greenhouse effect due to its thinness

➡ Temperature below freezing

* Atmospheric pressure is less than 1% that of Earth's surface

Differences with Earth...

* No oxygen so no ozone → damaging UV radiation hits the surface
* Winds are driven differently than Earth: they are powered by the extreme seasonal changes and huge dust storms can encompass the entire planet for months

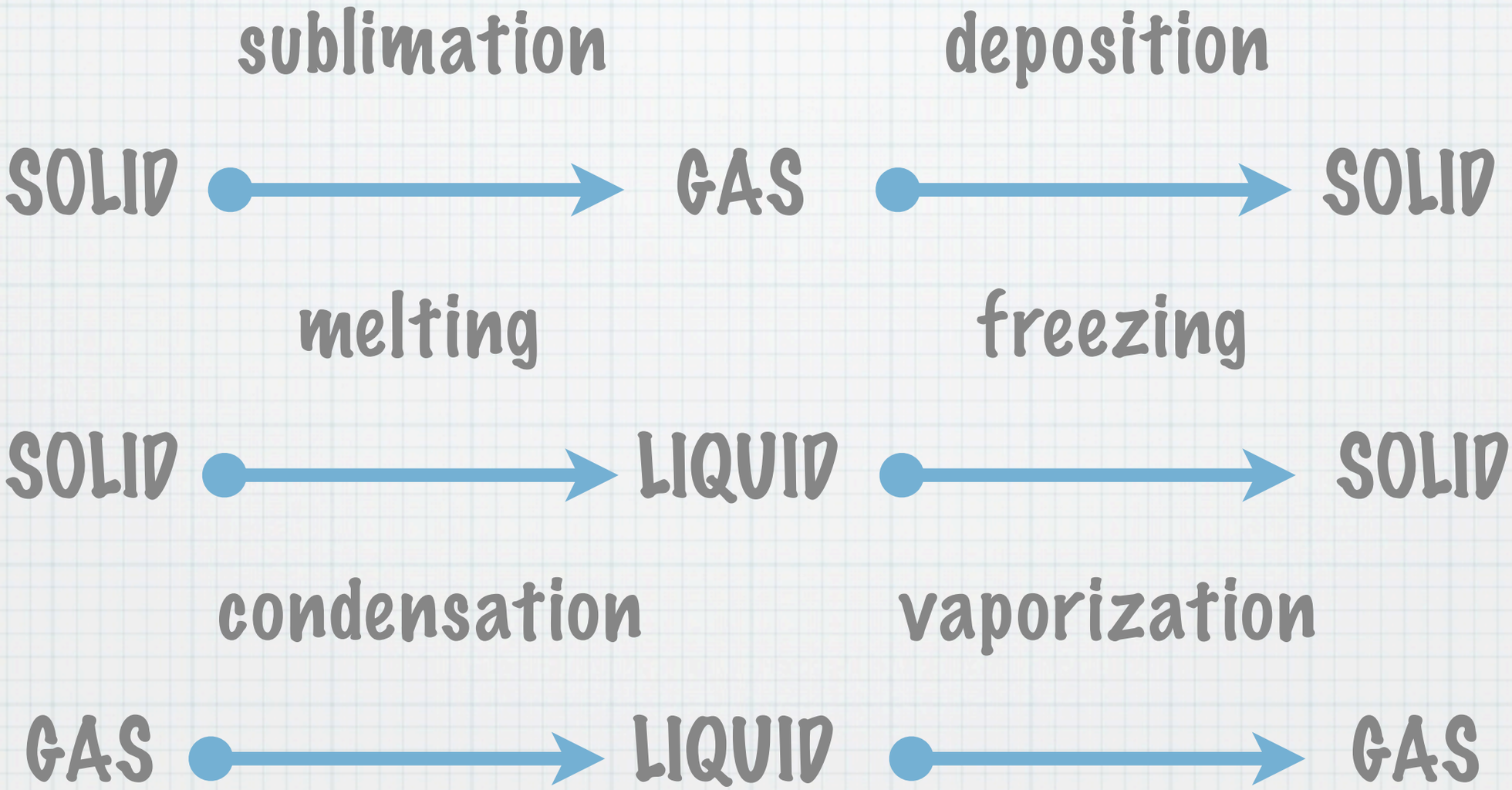
Differences with Earth...

* Due to the weak atmospheric pressure, liquid state is not possible

➡ Carbon dioxide and water only exist in two forms: frozen or gas

* Sublimation is the scientific name of the process of a solid turning into a gas bypassing the liquid phase

The Science Corner

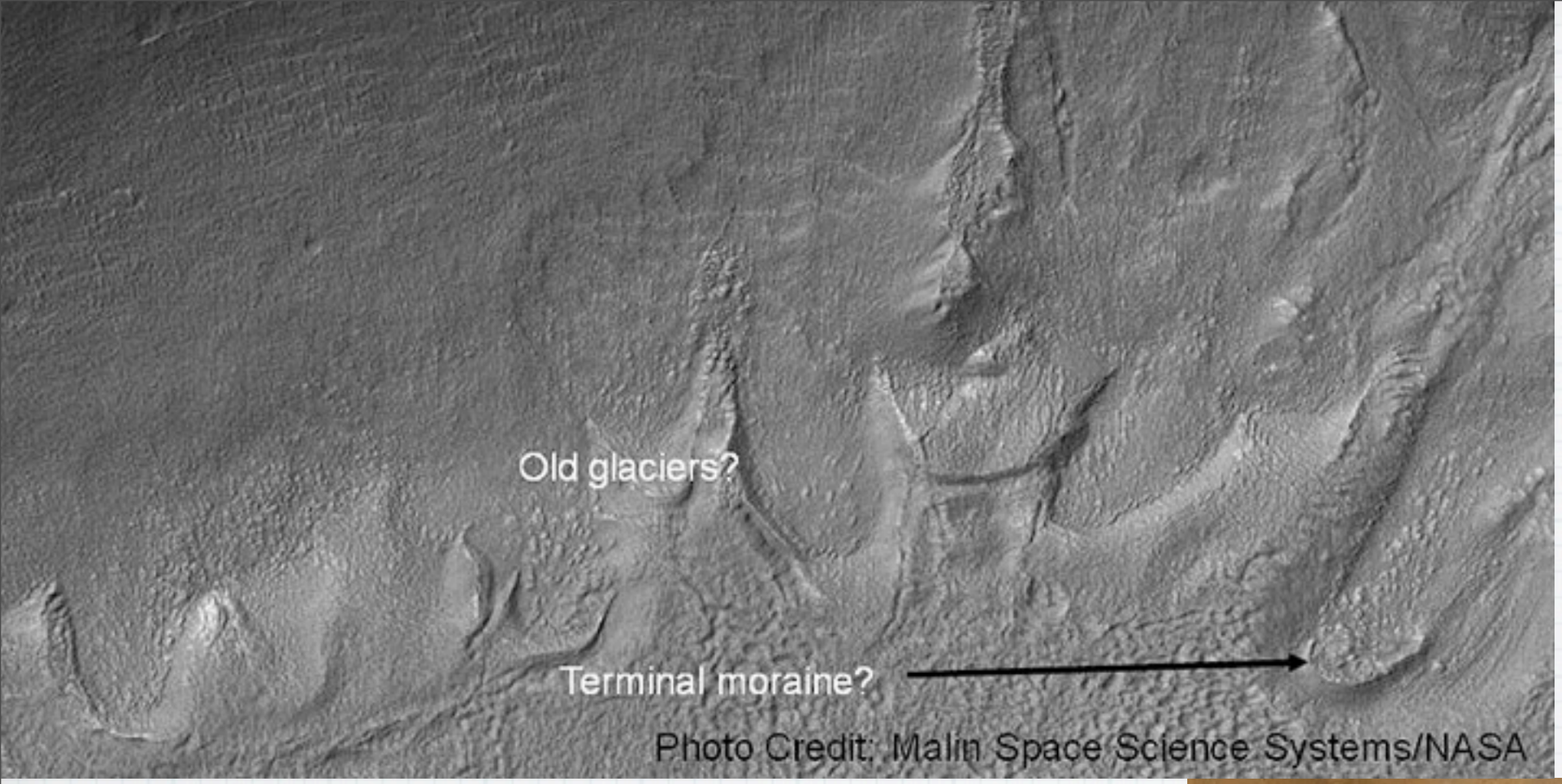


Was Mars always like that?

* Geological evidence show that Mars was in the past much warmer and wetter than it is now

* Ample evidence of past water flows exist

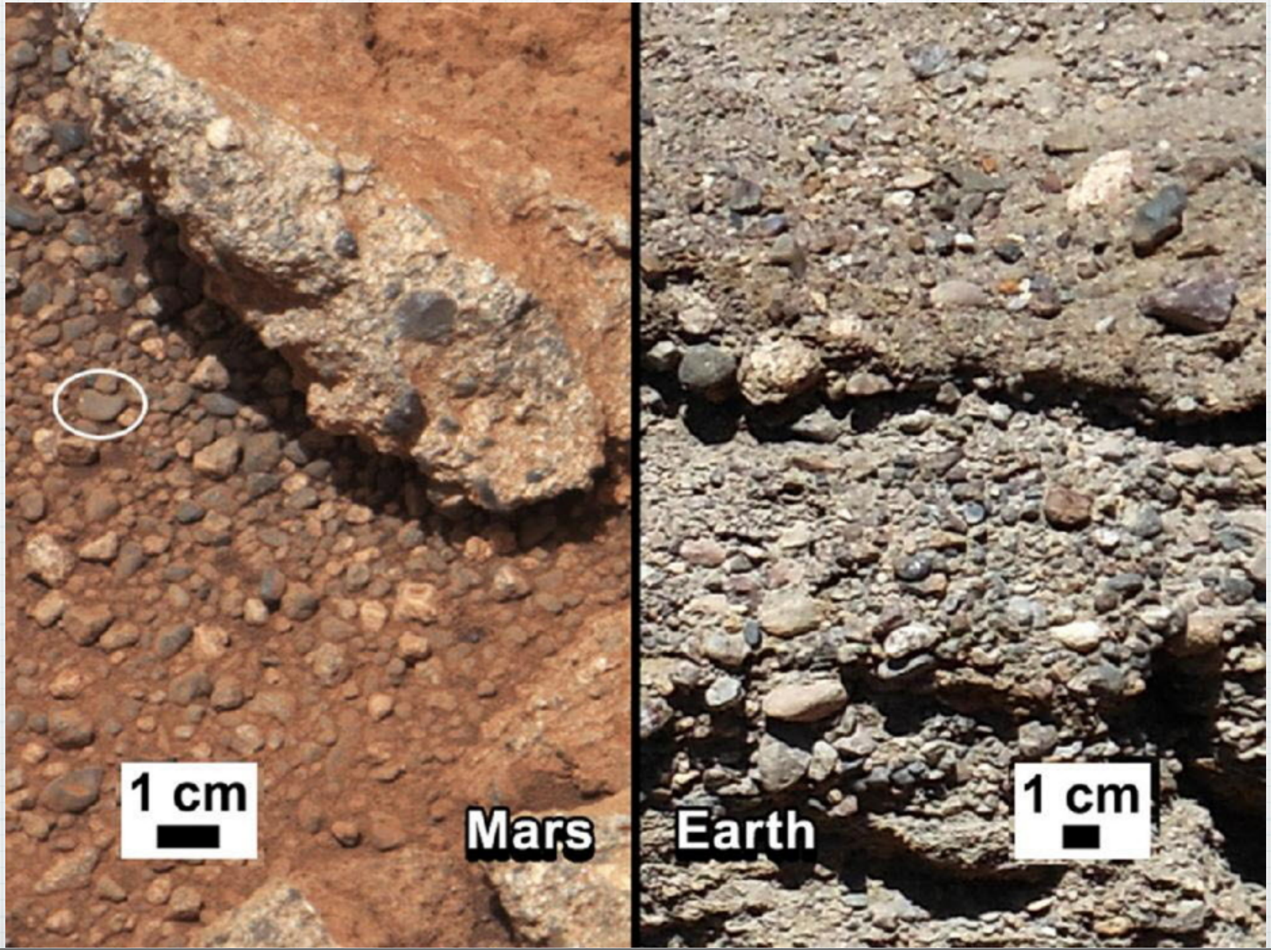
➡ This dictates that the atmosphere was thicker and warmer in the past



Evidence of glaciers?

Evidence of gullies?

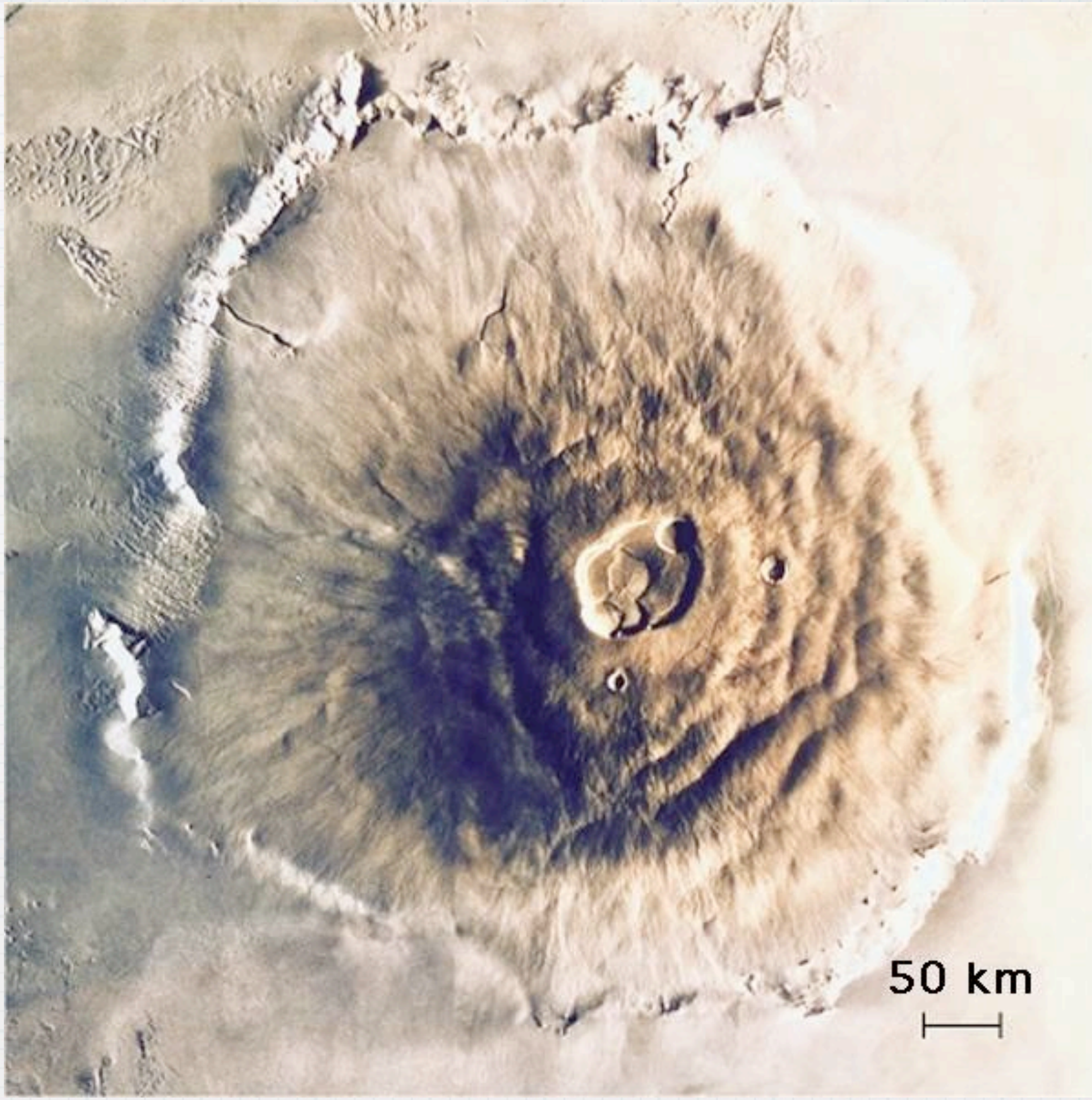
Rounded shape of pebbles = water transport



Mars Geology

* Olympus Mons is the largest volcano in the Solar System (600 km across, 26 km high!)
* Many other volcanoes exist
* We believe they are all extinct (since all the volcanoes show impact craters on their slopes)

600 km across and 26 km high: Mons Olympus



Mars Geology...

* Tectonic features appears as well although not as globally as Earth's tectonic plates

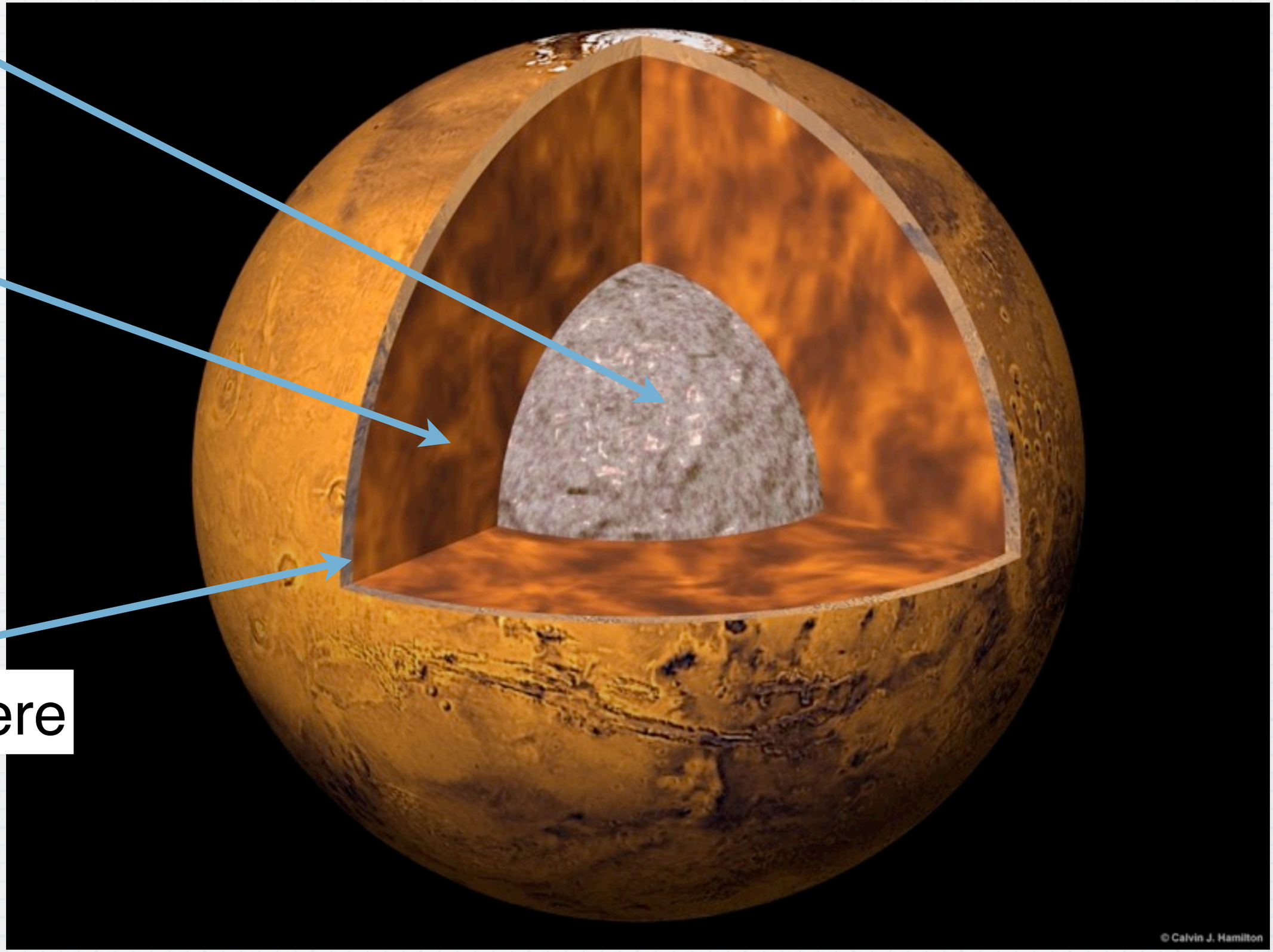
* Mar's interior is cooling and its lithosphere is thickening

➡ Mars will be geologically dead in a few billion years

core

thick mantle

lithosphere

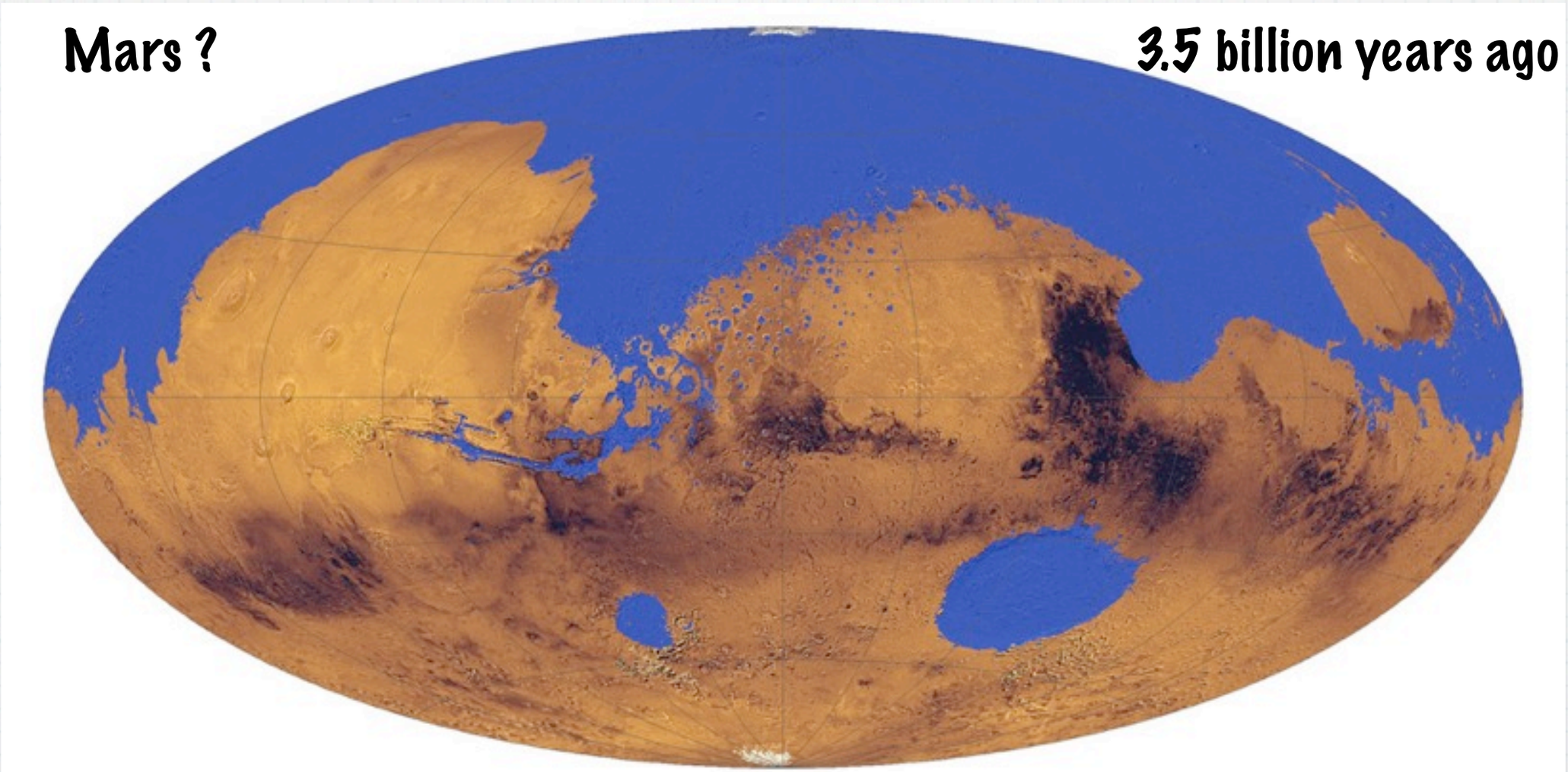


Liquid Water on Mars

* Dried up riverbeds and many other erosion signs indicate that Mars had water flowing in the distant past
* An ocean may have filled the low-lying regions in the northern hemisphere
* In its first billion years, liquid water was plentiful on Mars

New study indicates an ancient ocean may have covered one-third of Mars

The study implies that at one time the Red Planet had an earth-like hydrological cycle, including precipitation, runoff, cloud formation, and ice and groundwater accumulation



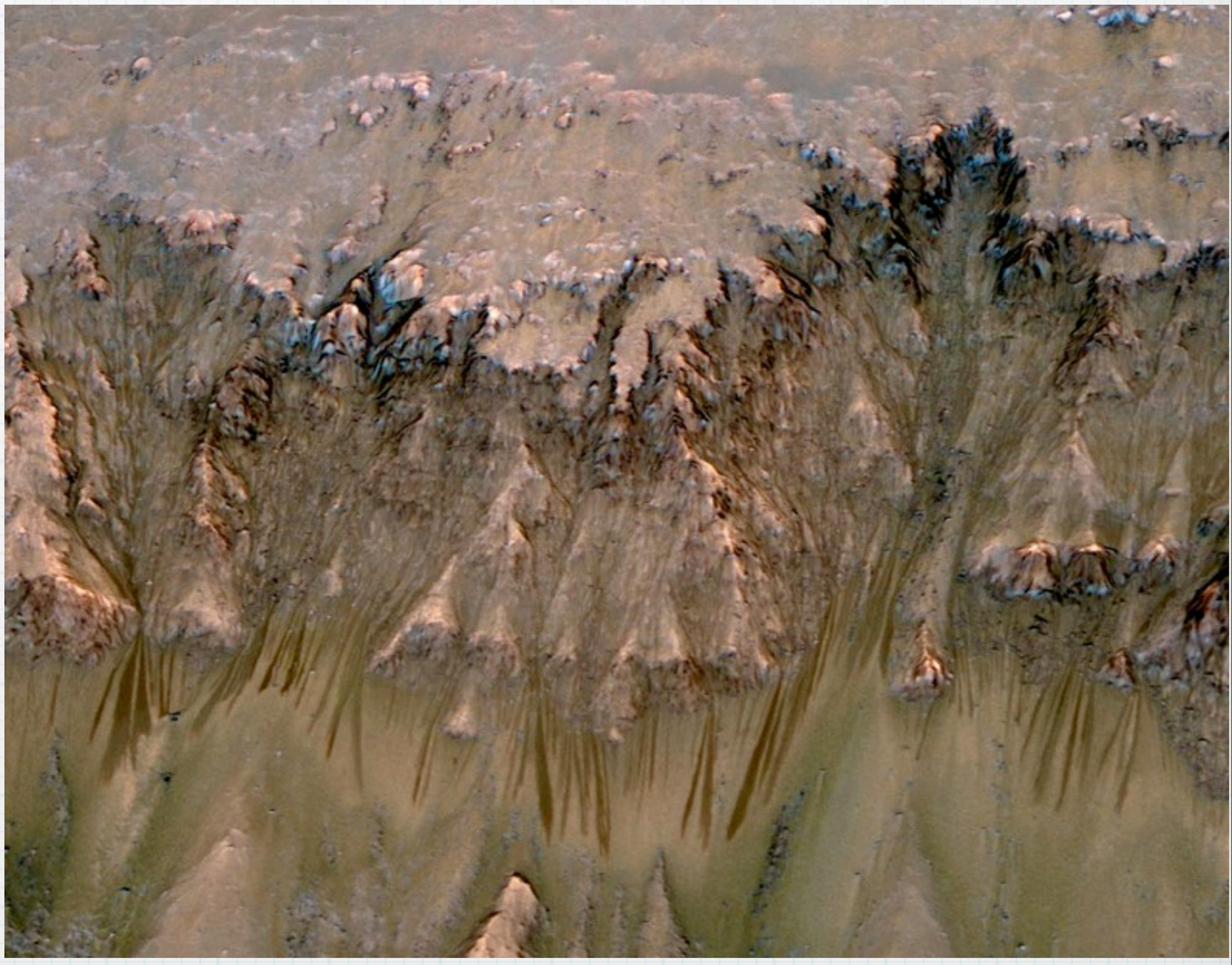
Where is the Water now?

* Most was lost in space due to the evaporation of the atmosphere
* Significant amounts apparently still remain frozen at the polar caps and in the top meter or so of the surface soil

➡ So a lot more probably lies deeper underground

Evidence for current water flows on Mars

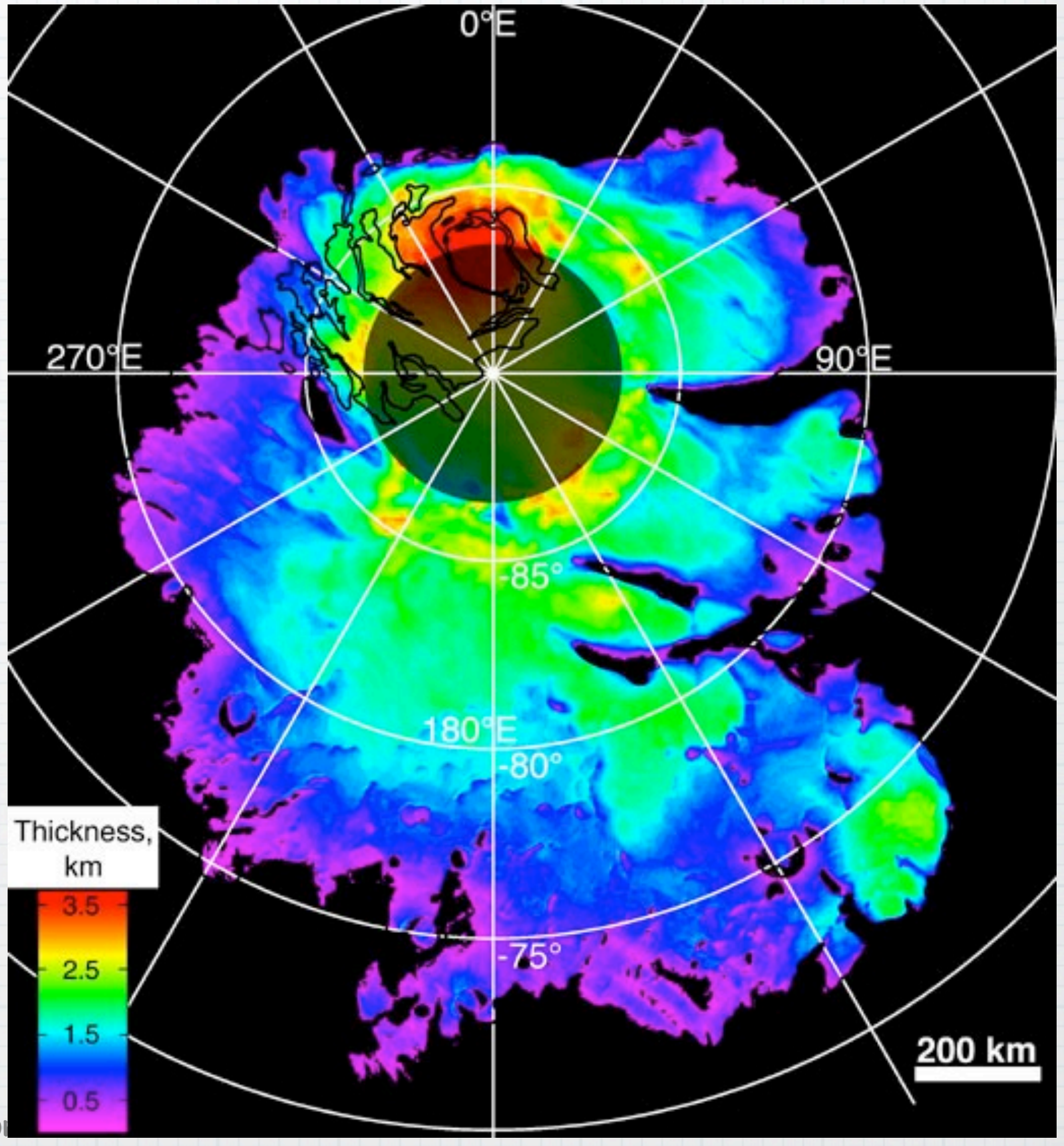
The dark zones show salty water evaporating during martian summer times



Martian Southern Polar Cap

This region contains enough frozen water to cover the whole planet in a liquid layer approximately 11 meters (36 feet) deep

Thickness of Mars' South Polar Layered Deposits



Why did Mars change?

* Early in its history, Mars outgassed and had a dense atmosphere

* Scientists think that Mars' carbon dioxide gas was lost due to the solar wind when its magnetic field weakened early due to Mars' small size

➡ the greenhouse effect died

Mars' Magnetic Field

* Then the atmosphere naturally dissipated in space

➡ the surface cooled

* The hydrogen then escaped toward space, the oxygen rusted the surface rocks

➡ the surface became red

In Conclusion

* To summarize, Mars current look is due to its smaller terrestrial size
* Big enough to have volcanism and develop a thick atmosphere...
* But too small to maintain its internal heat and the atmosphere generation process stopped while the protective magnetosphere disappeared

In Conclusion...

* Its gravitational field (weaker than Earth's) was not strong enough to keep the atmosphere without a magnetosphere present
* Lastly, Mars is 1.5 times away farther from the Sun than Earth, it then receives less heat from it
* The extra warmth, if Mars were closer, could melt the water which is locked in the polar caps and frozen underground

Snapshot

* What geological features tell us that water once flowed on Mars?
* Dry river channels, rock-strewn floodplains, and eroded craters all show that water once flowed on Mars, though any periods of rainfall seem to have ended at least 3 billion years ago. Mars today still has water ice underground and in its polar caps, and could possibly have pockets of underground liquid water

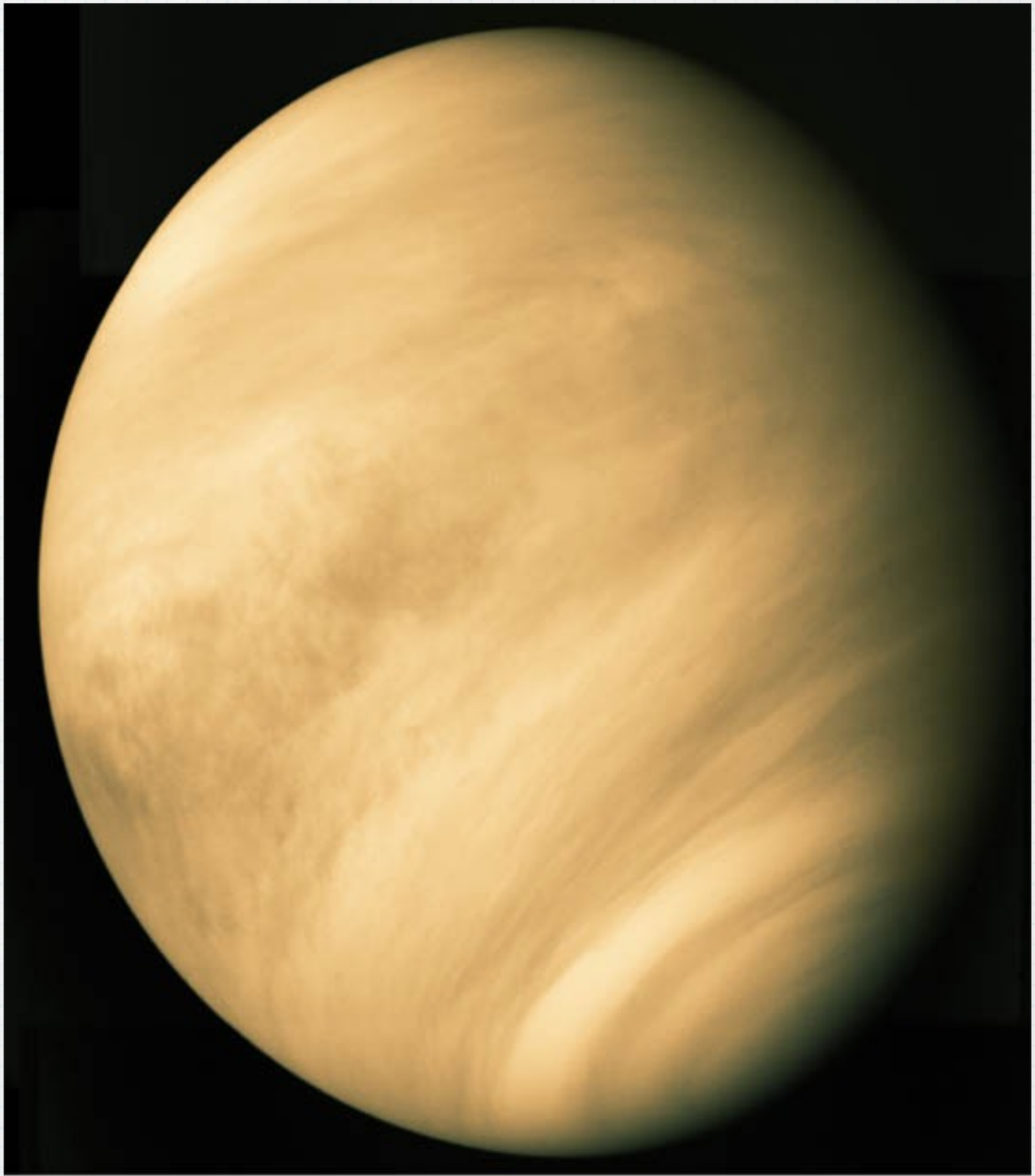
Snapshot

* Why did Mars change?
* Mars' atmosphere must once have been much thicker with a much stronger greenhouse effect, so change must have occurred due to loss of atmospheric gas. Much of the lost gas probably was stripped away by the solar wind, which was able to reach the atmosphere as Mars cooled and lost its magnetic field and protective magnetosphere. Water was probably also lost because ultraviolet light could break apart water molecules in the atmosphere, and the lightweight hydrogen then escaped to space

Venus

* Venus' radius is 5% smaller than Earth's
* We should expect that Venus and Earth look similar
* But we know that Venus is a searing hothouse with a crushing atmosphere...

Venus: a thick atmosphere prevents a direct surface picture from space



Venus' Surface

* A permanent thick cloud cover prevents direct surface observations
* We can study geological features via the use of radar waves which can create 3-D images of the surface

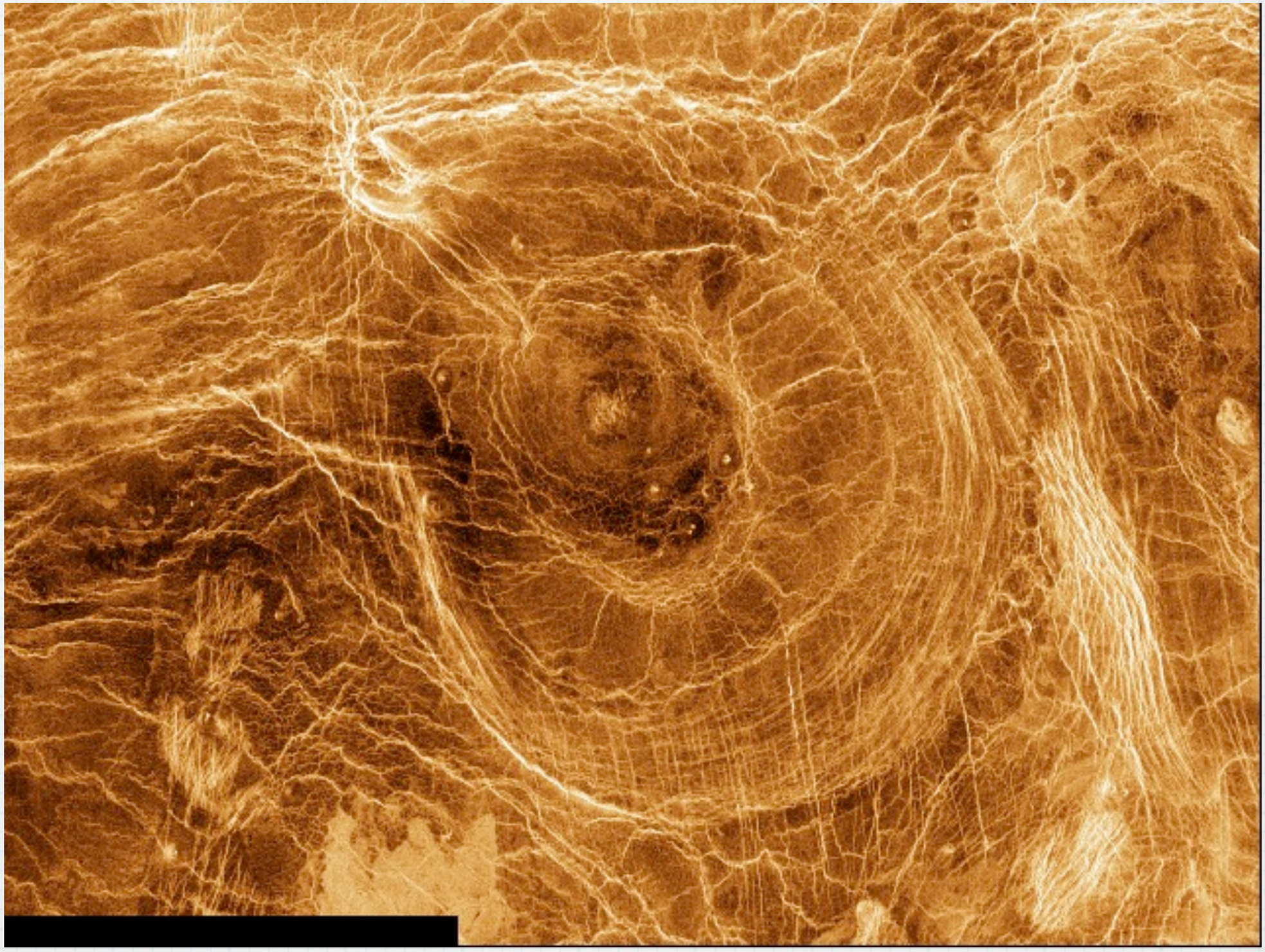
Geological Features

* Impact craters, volcanoes, and a lithosphere which has been shaped by tectonic forces are seen just like on Earth

* A circular feature called a corona (crown in Latin) surrounded by "arachnoids" is unique to Venus but can be explained if we assume the planet has a convecting mantle

A volcanic site:

A corona surrounded by tectonic stress marks called arachnoids



Geological Features...

* We think Venus is still geologically active but we have no direct observations of active volcanoes
* However we see few impact craters and this tells us the surface is geologically young
* The atmosphere contains sulfuric acid and comes from sulfur dioxide (SO_2) which can only come from current outgassing (volcanic activity)

Geological Features...

- However there is no erosion on Venus because
  - there is no rain or ice as Venus is too hot
    - Venus rotates so slowly (once every 243 days) there is no surface wind
      - (there are, however, very high winds at higher altitudes)

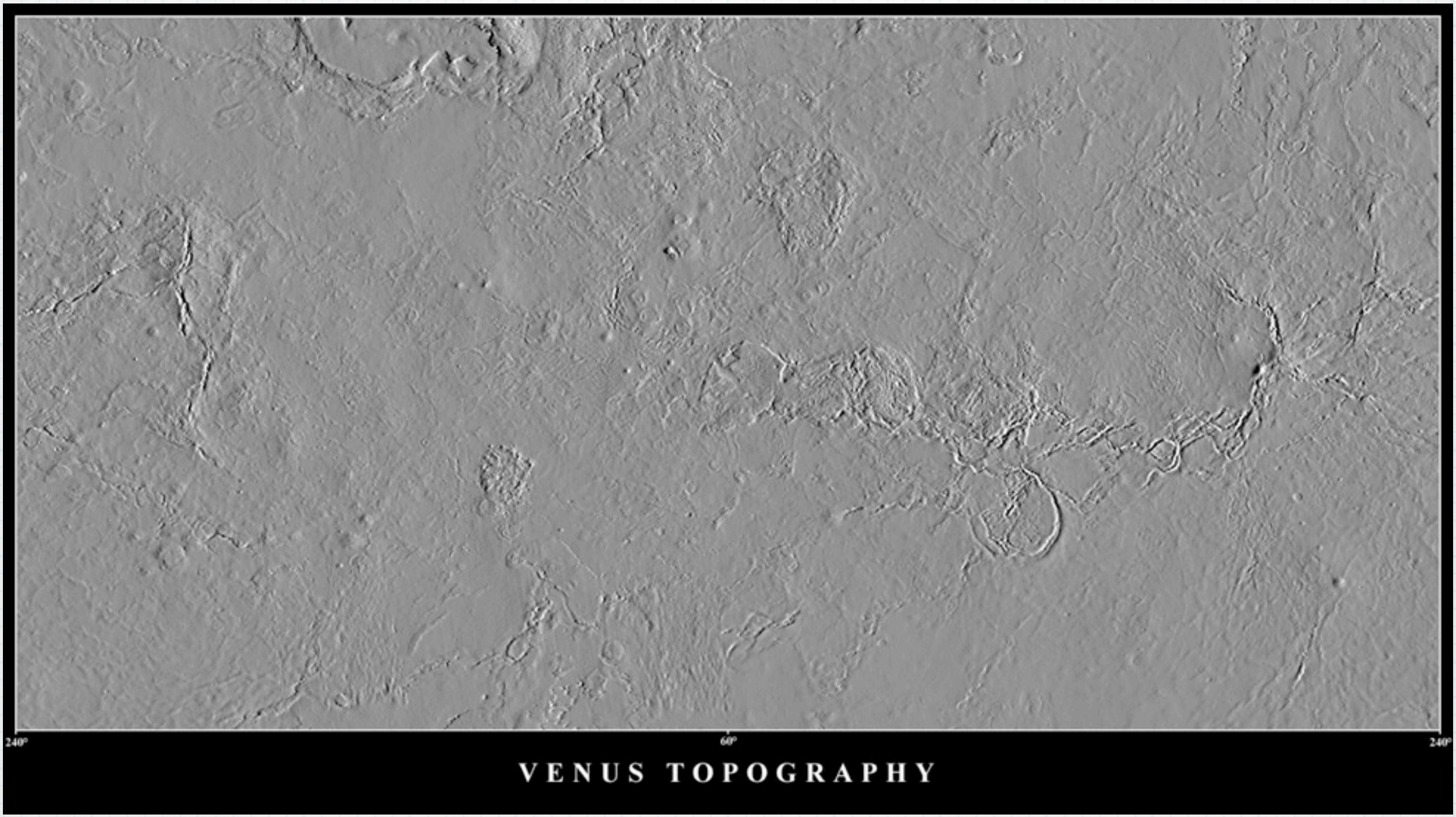
Different Plate Tectonics

* With its surface temperature near to 750 K, its lithosphere is almost certainly buoyant, in contrast to Earth's oceanic lithosphere
* The surface of Venus has much more in common with Earth's continents with examples of rift zones, mountain belts, and strike-slip systems

Different Plate Tectonics...

* Venus, not having oceans, lacks examples of spreading ridges, subduction zones and transform faults
* Venus displays evidence of plate tectonic-like behavior that is different to Earth's oceans, and points towards a more general model of plate tectonics

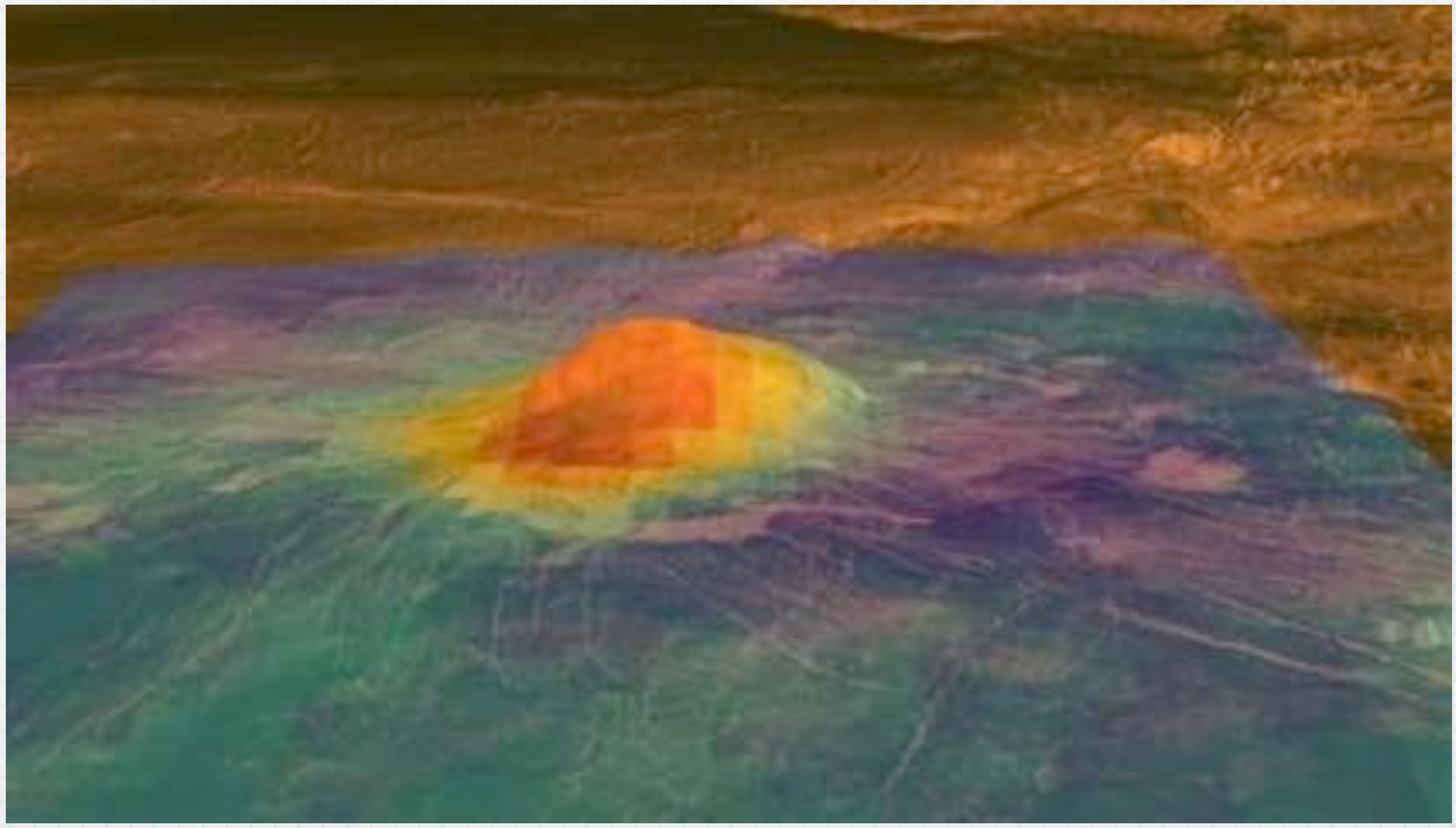
750 million year-old "new" surface (dated from sizes & numbers of craters)



Different Plate Tectonics...

* Venusian unproven plate tectonics processes are hard to discern from space
* Weak mantle convection is doubted as Venus is similar in size as Earth
* Scientists thinks that volcanic activity occurs but the thick clouds hide their discoveries

Volcanoes on Venus may be young ... and hot!



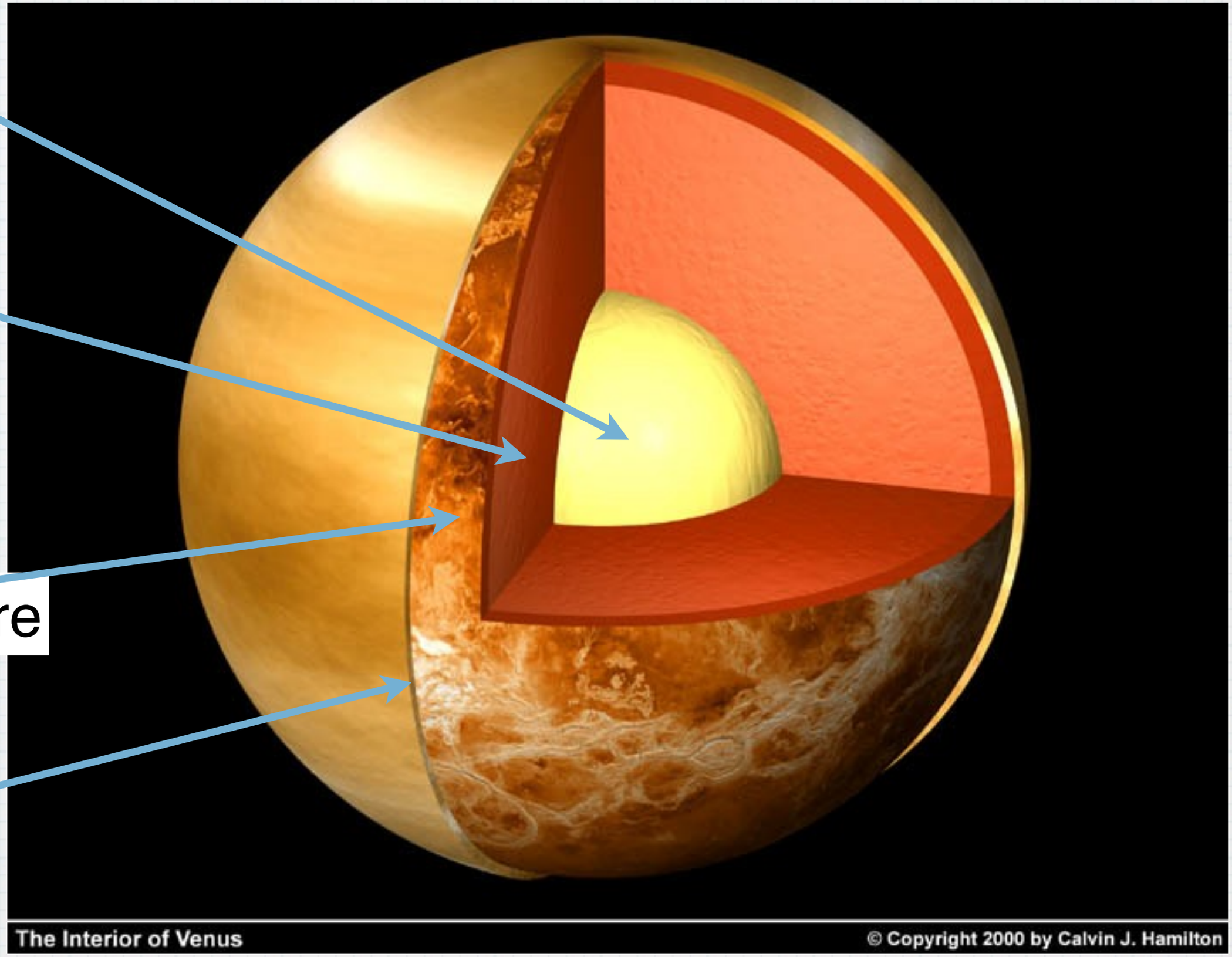
The colored overlay of the the volcanic peak Idunn Mons shows emission levels derived from surface brightness data, acquired by the Venus Express mission. The high-emission area (shown in red and yellow) is centered on the summit and the bright flows that originate there

core

mantle

lithosphere

crust



The Interior of Venus

Why is Venus so Hot?

* Venus is closer to the Sun than Earth
* Yet its surface absorbs less light that Earth
* The reason is the clouds reflect much sunlight into space

Major Greenhouse Effect

* Venus however has a huge greenhouse effect because its atmosphere is thick in carbon dioxide (96% CO_2)
* That is 200,000 times the amount of CO_2 Earth has
* But why? After all Venus & Earth have similar sizes and compositions
* So why are their atmospheres so different?

Where is Venus' Water?

* We expect huge amounts of H_2O and CO_2 to have outgassed on both planets
* On Earth
  * most of the water is in the oceans
  * most of the CO_2 dissolved in them
  * then chemically reacted to form all the carbonate rocks

Where is Venus' Water?...

* There are no oceans on Venus, any water in the crust would have evaporated in the atmosphere long ago

* Yet the atmosphere contains little water

➡ There is so much CO_2 in the atmosphere precisely because it could not dissolve and be locked in rocks due to the lack of water

Where is Venus' Water?...

* Like Mars, Venus lacks a protective magnetosphere (too slow of a rotation)
* The leading hypothesis is that UV radiation broke the water molecules down: the hydrogen escaped and the oxygen is likely to have been stripped away by the solar wind
* For that to have happened, the water was in the atmosphere and there were no oceans

Runaway Greenhouse Effect

* The reason for the lack of oceans is that they evaporated (or never formed)

* Water is also a greenhouse gas

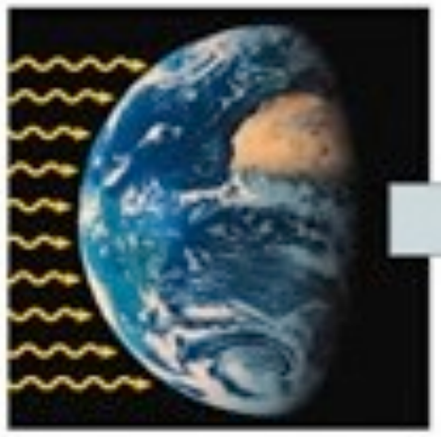
* Being closer to the Sun, Venus was naturally receiving more heat from the Sun

* This H_2O evaporation added a major greenhouse effect to the already present CO_2 driven one

Runaway Greenhouse Effect...

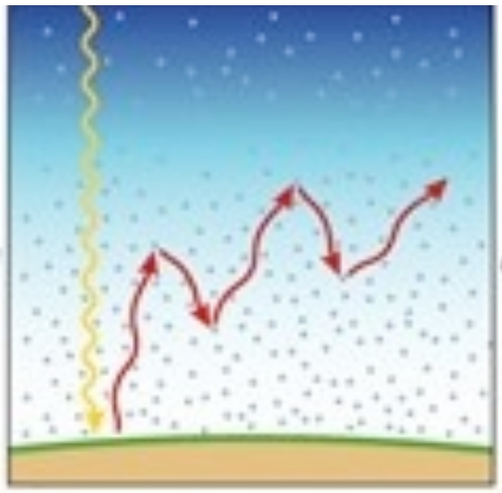
* The two greenhouse effects created a positive feedback loop, each one re-enforcing the other
* And the result was a runaway greenhouse effect
* If Earth had formed a little closer to the Sun or if the Sun had been a bit warmer, Earth might have undergone the same Venus look

If Earth moved toward Venus' orbit...



More intense sunlight immediately raises Earth's surface temperature by about 30°C (86°F)

Water vapor increases greenhouse effect raising temperature further



Runaway Greenhouse

Greater warmth increases evaporation and warmer air holds more water vapor

As the oceans finish evaporating, carbonate rocks decompose releasing CO_2, Earth becomes hotter than Venus

Snapshot

* Is Venus geologically active?
* Venus almost certainly remains geologically active today. Its surface shows evidence of major volcanic or tectonic activity in the past billion years, and it should retain nearly as much internal heat as Earth. However, geological activity on Venus differs from that on Earth in at least two key ways: lack of erosion and lack of plate tectonics

Snapshot

* Why is Venus so hot?
* Venus' extreme surface heat is a result of its thick, carbon dioxide atmosphere, which creates a very strong greenhouse effect. The reason Venus has such a thick atmosphere is its distance from the Sun: It was too close to develop liquid oceans like those on Earth, where most of the outgassed carbon dioxide dissolved in water and became locked away in rock. Thus, the carbon dioxide remained in the atmosphere, creating the strong greenhouse effect

Movies & more

* http://apod.nasa.gov/apod/ap110328.html
* http://www.mnn.com/earth-matters/translating-uncle-sam/stories/interactive-explore-the-surface-of-mars
* http://www.youtube.com/watch?v=74mhQyuyELQ
* http://www.youtube.com/watch?v=ev9oPUNaqXE
* http://www.nasa.gov/mov/171470main_Columbia640.mov
* http://science.nasa.gov/science-news/science-at-nasa/2011/04aug_marsflows/
* http://hirise.lpl.arizona.edu/