



Our Climate: **A Global Challenge**

Academy for Lifelong Learning
Denver, CO
March 5, 2015

Notices

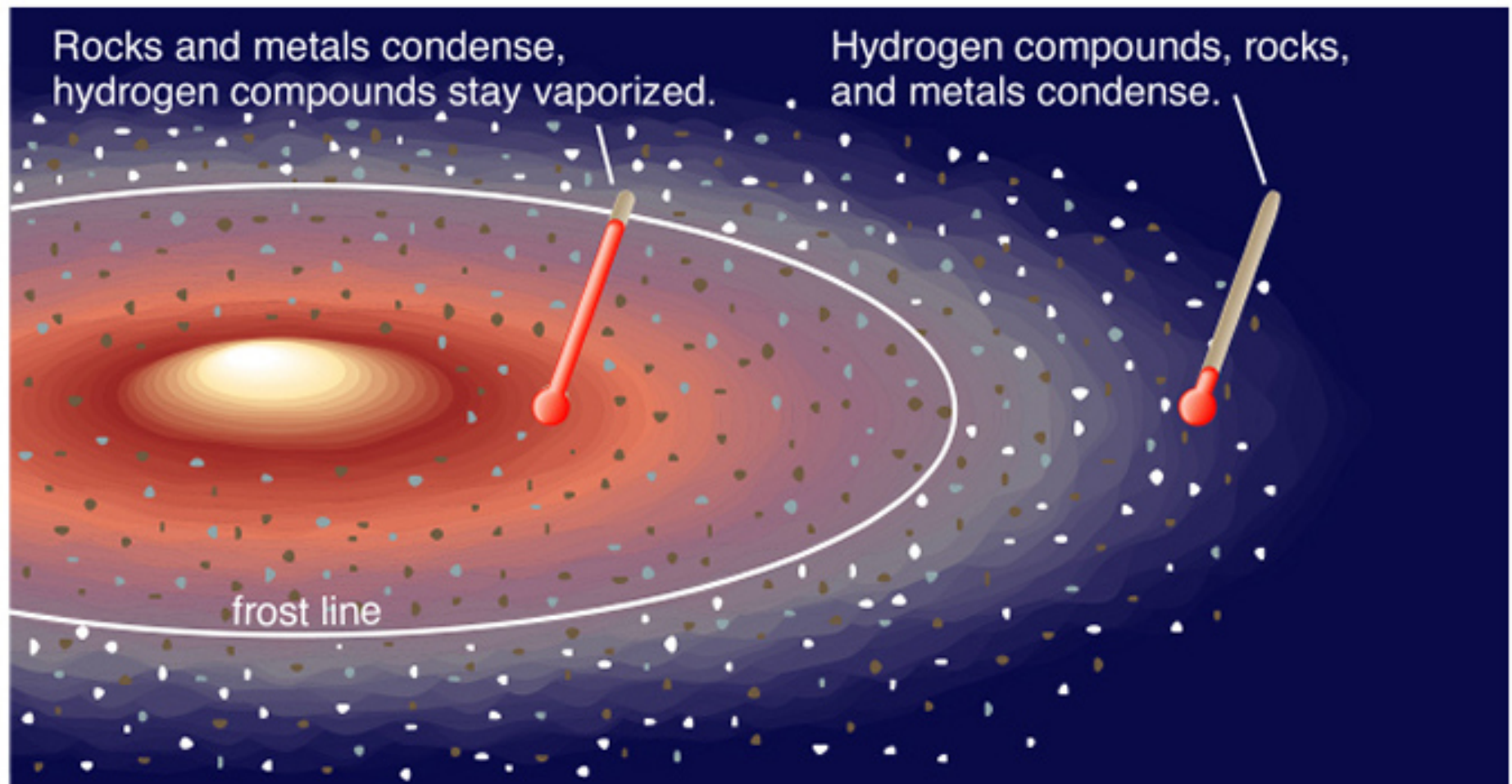
- A corrected version of the handout entitled “Units of Energy” is available from the DU web site I mentioned last time and there are some copies in the back of the room.
- Instructions for the tour of the NICL on April 2 are also available.

A Star is Born

Pretty, but not Judy Garland.

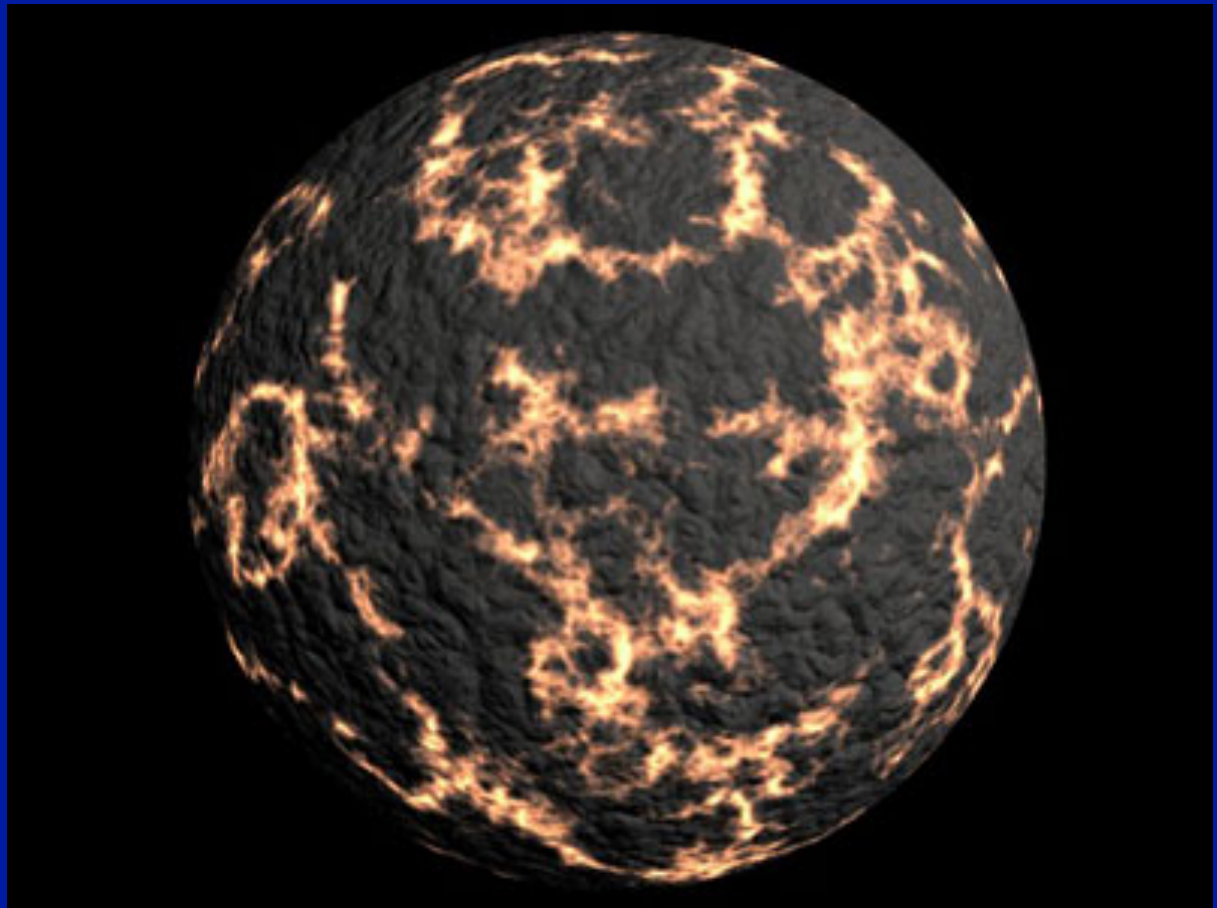


Frost line

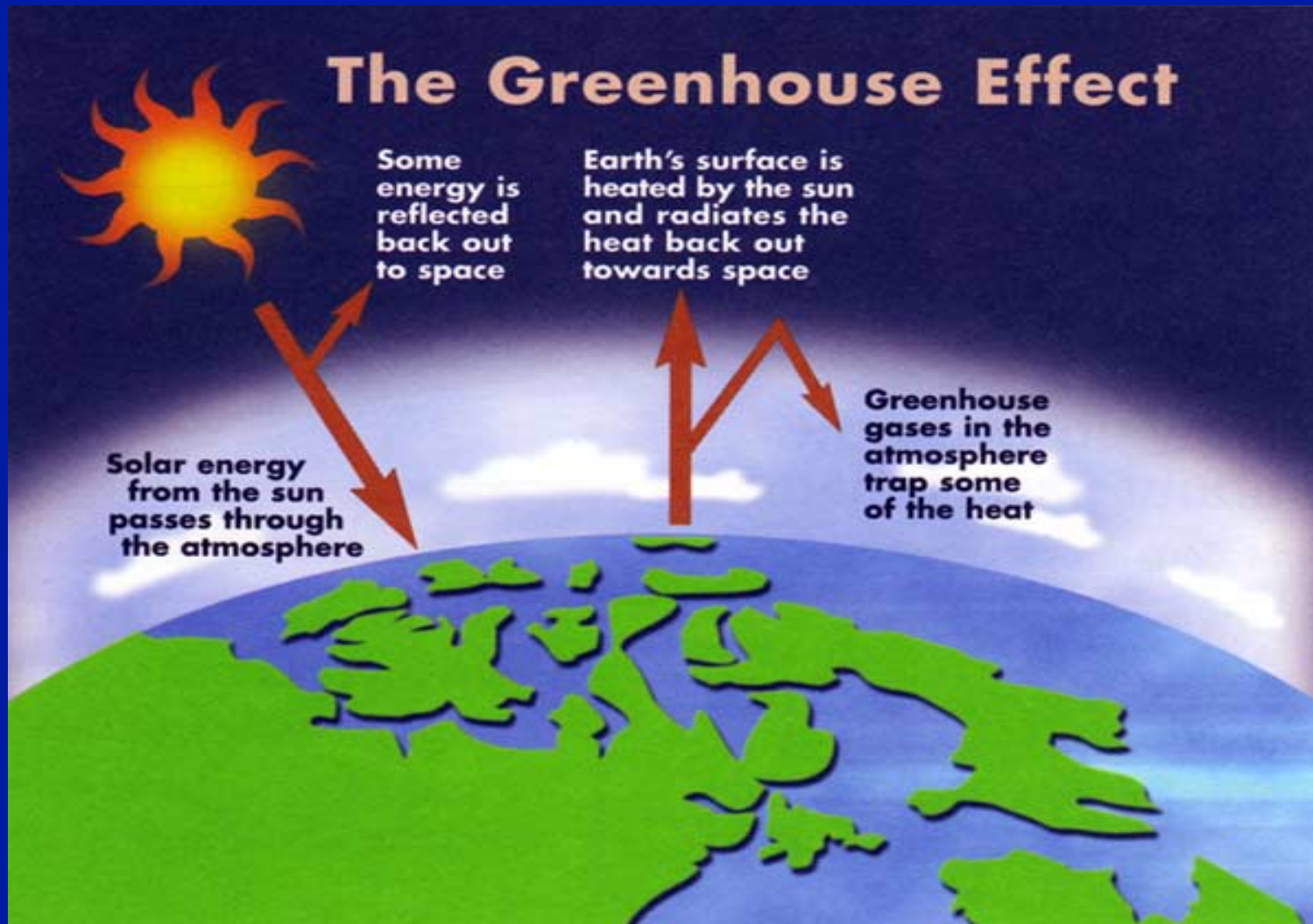


Primordial Earth 4.5 Bya

Sun 30% cooler than today
Earth hot and constantly bombarded
Accretion was still going on.



CO₂ keeps the planet warm.
Without it, Earth would be an iceball.

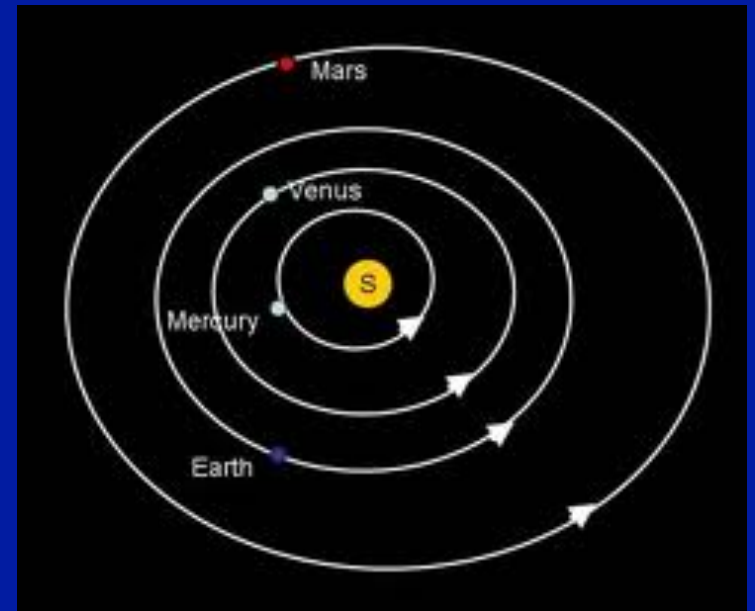


Comparative Planetology

Mercury, Venus, Earth, and Mars

Inner Planets: Comparative Planetology

"Rocky" planets



origin of the moon

Early Earth suffered, for almost 0.5 billion years, from an extensive meteoroid bombardment (until 3.9 Byrs ago??).

The moon was probably created in some kind of impact

- A. a Mars sized object making a glancing blow of proto-Earth
- B. a collision of two larger objects that pulverized the protoplanets leaving behind debris out of which the Earth and moon coalesced.

Preferred explanation is A. (The object is called Theia after the mother of Selene, the Greek goddess of the moon.

This explains lack of volatiles and iron, while preserving other Earth-moon similarities.

Lunar mare created 3–3.5 Byrs ago:
Later large impacts fractured the lunar crust.
Produced massive lava flows from interior.



Formation of the oceans

Comets brought water
3.8 Bya when Earth
was 0.8 billion years old

Meteorites brought iron
other metals (and probably
some of the water)

Internal heating of the Earth

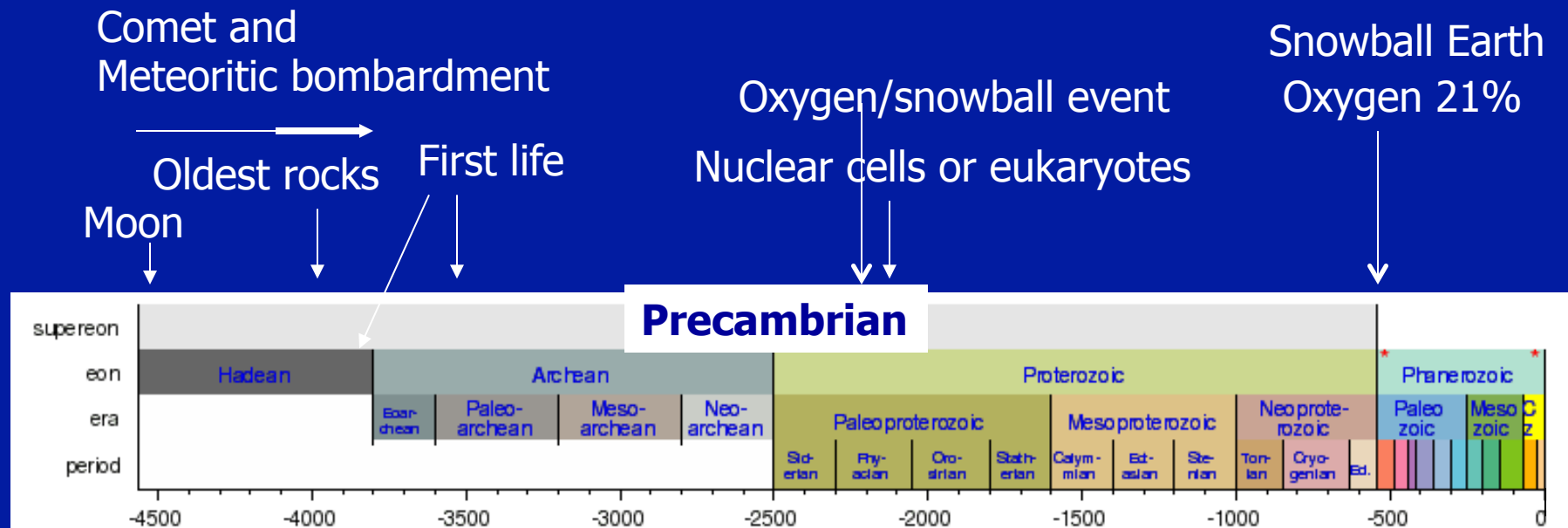
- bombardment
- gravitational collapse
- radioactive decay

Now internal heat is a minor contribution
Primordial Earth it would have been greater



Earth's history

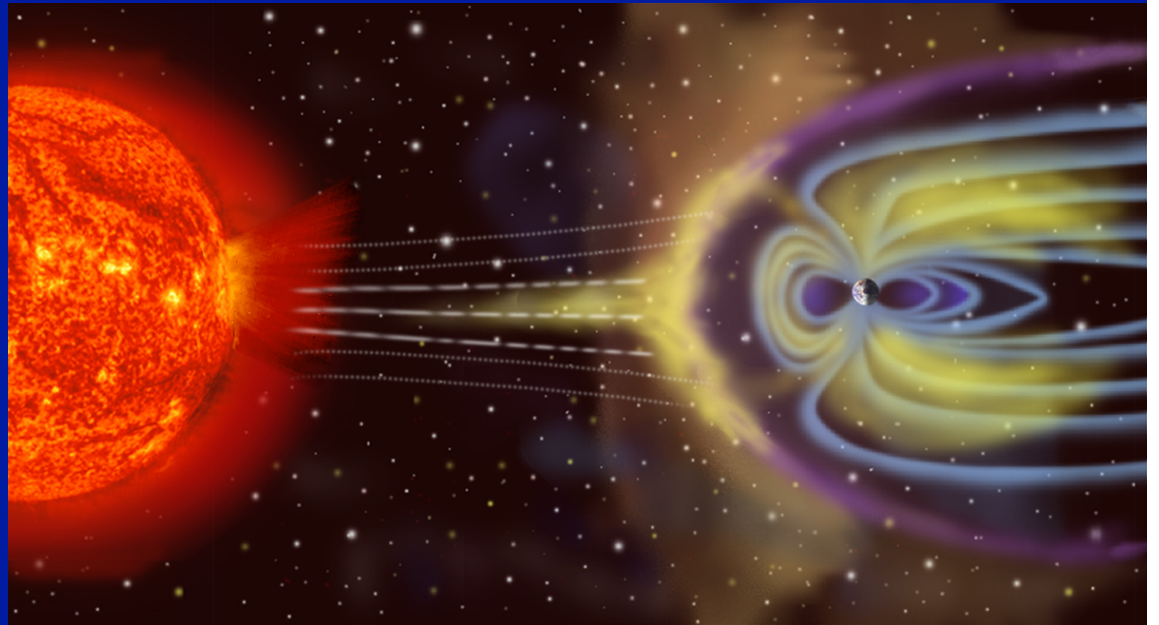
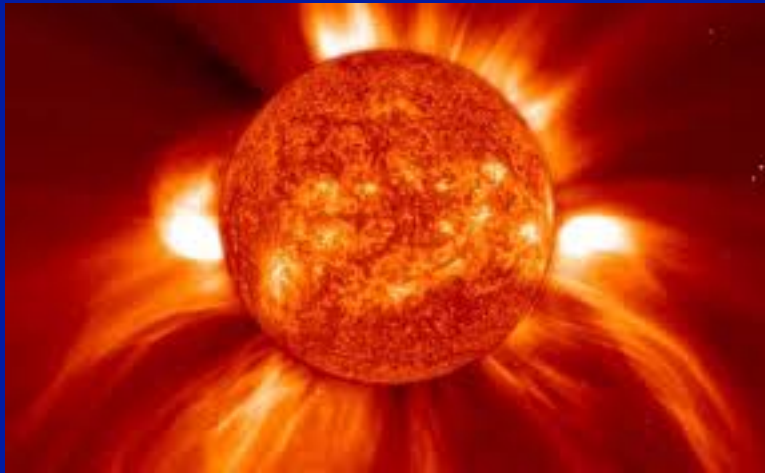
Planets formed in few million years



time →

What matters

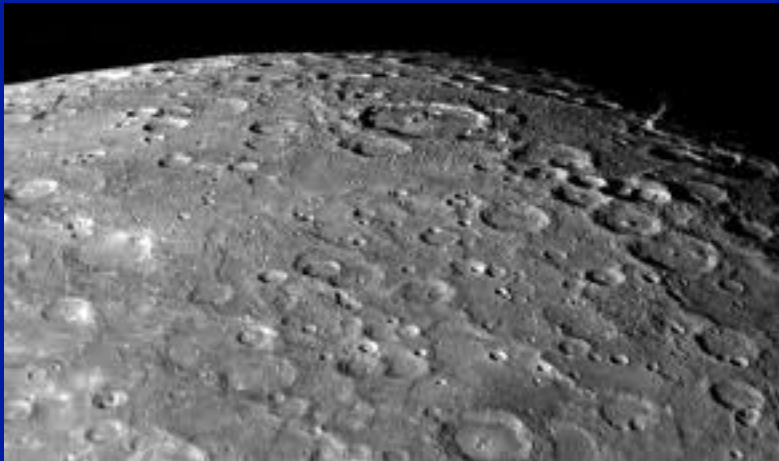
- Atmosphere
- Rate of rotation
- Tidal disruption
- Magnetic field
- Sputtering



Consider Mercury



- Rotation: 58 Earth days
- Mercuric year: 88 days
- Surface temperature highly variable, at equator
 - towards the sun: 430 °C (800 °F)
 - Side away from sun: - 170 °C (-274 °F or 100 K)

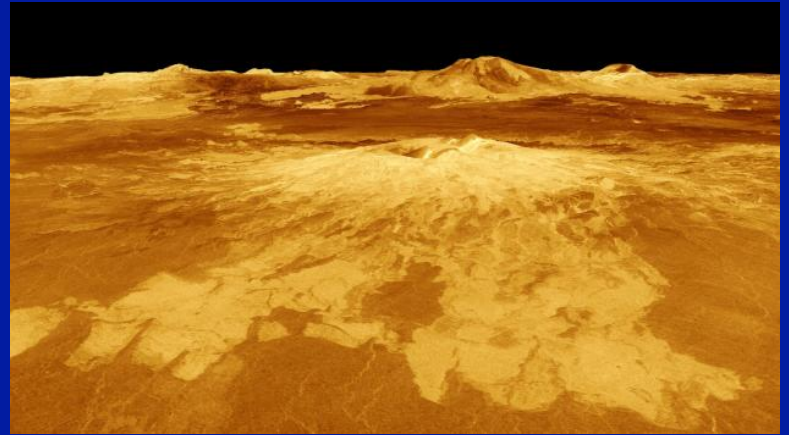


Why? – Hot side faces the nearby sun. Cold side quickly radiates its heat to space and the planet has **no atmosphere** to trap the heat.

Other Mercurial facts

- Slow rotation: local observer on Mercury sees 1 day per two years (orbits around the sun)
- Heavily cratered
 - Geologically inactive for billions of years
- Has dipole magnetic field
 - Weak compared to Earth's
 - Implies planet has molten core (solar tidal forces)
- Water ice and organic compounds found in permanently shadowed craters near the north pole of Mercury.

Consider Venus

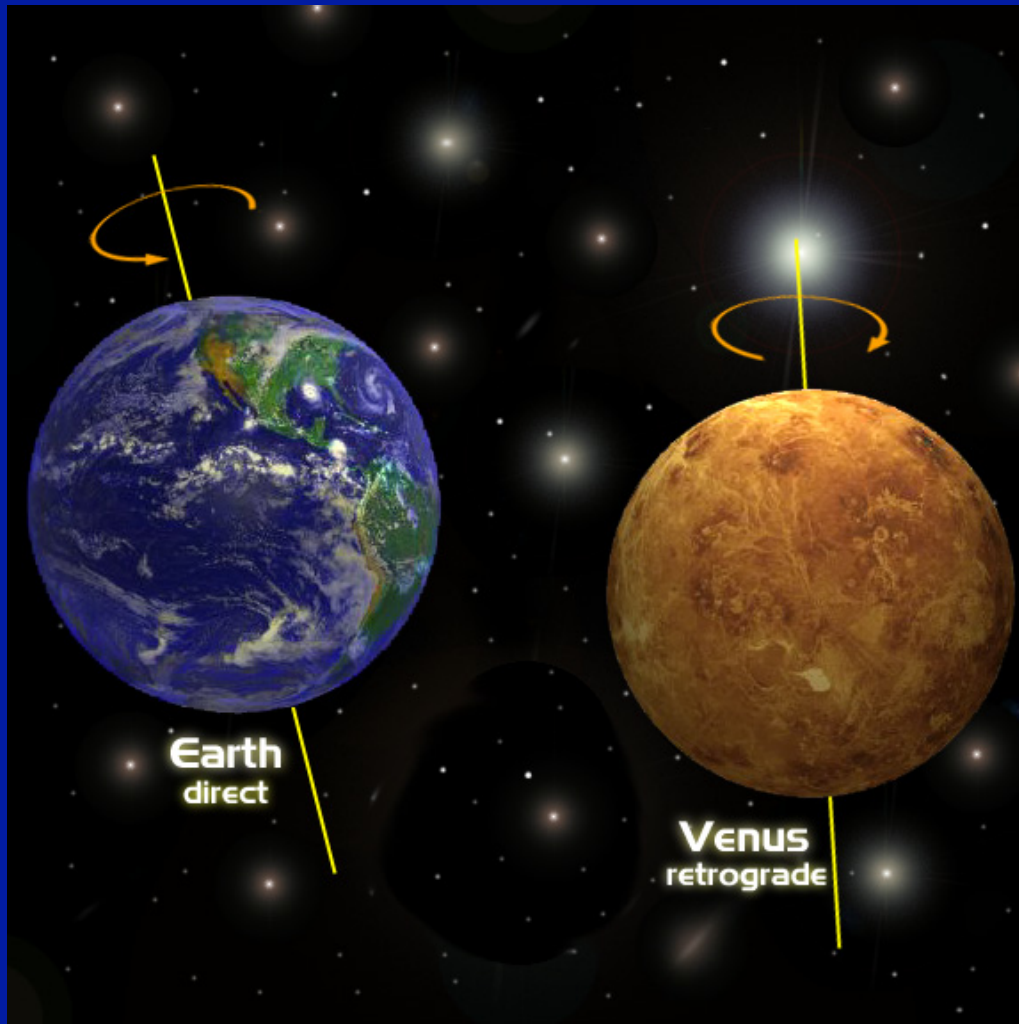


Radar image of the surface of Venus
from the Magellan Spacecraft

- Rotation period (retrograde): 243 Earth days
- Venusian year: 224.7 Earth days
- Surface temperature highest in solar system at 462 °C (860 °F)
- Shield volcanoes (like Hawaii in the middle of plates) – apparently plates are not moving
- No magnetic field now
- Almost 2 x higher heat input from the sun (1.91 x Earth)

Retrograde (backward) rotation

Sun rises in the west.



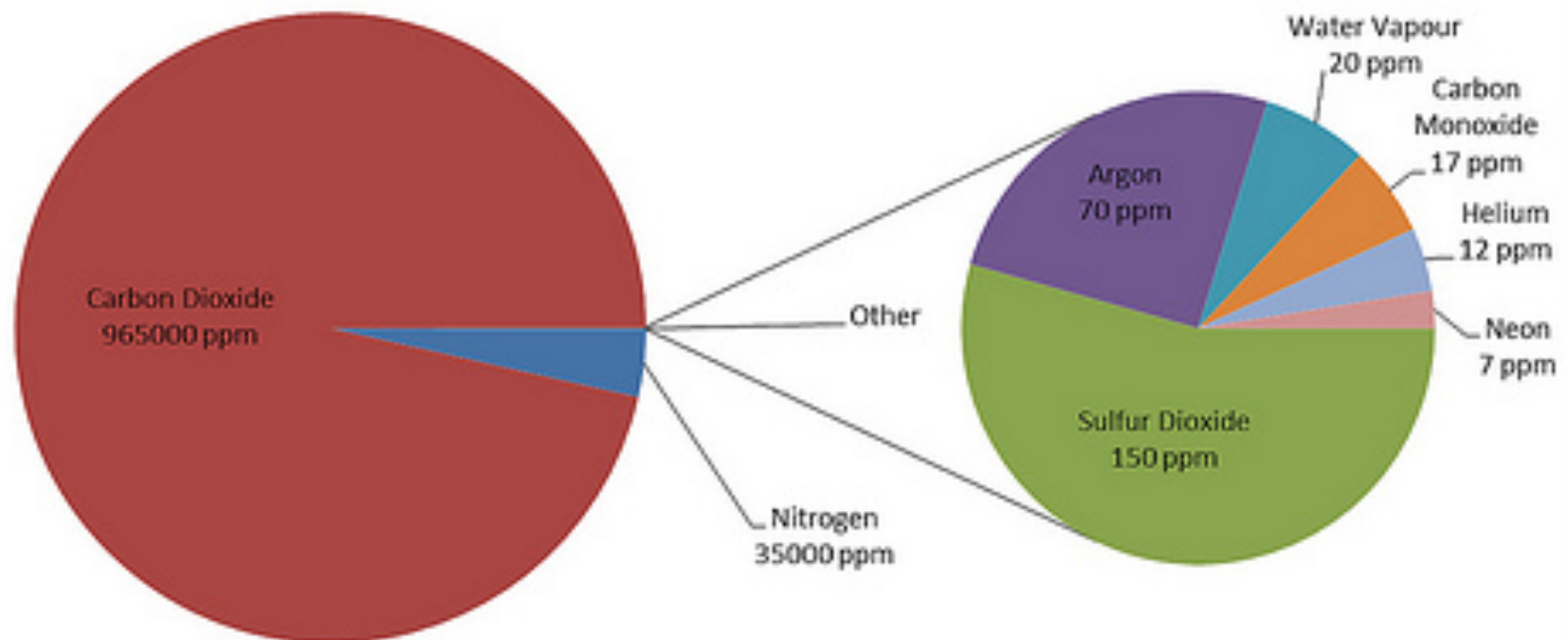
Fast rotation (Earth)
more surface wind
more weather
more erosion
crust moves

Slow rotation (Venus)
less surface wind
less weather
less erosion
crust stable

Venus has a CO₂ atmosphere

Atmospheric pressure 90 x that of Earth

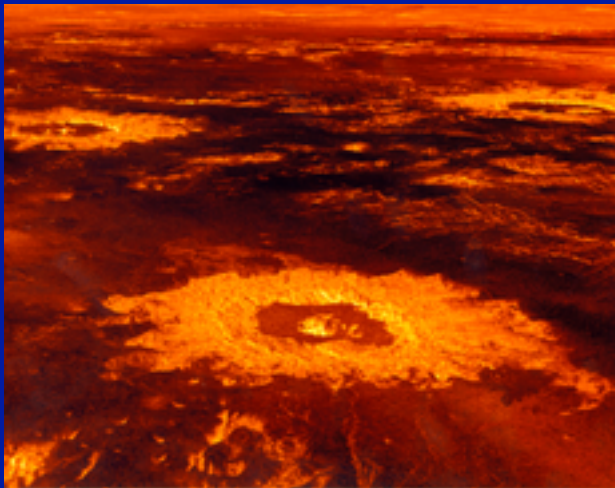
Venus' Atmospheric Composition in Parts per Million



Impact craters on Venus

Almost a thousand impact craters on Venus are evenly distributed across its surface.

On other cratered bodies, such as Earth and the Moon, craters show a range of states of degradation. On the Moon, degradation is caused by subsequent impacts, whereas on Earth it is caused by wind and rain erosion. On Venus, about 85% of the craters are in pristine condition.



Crust does not change continuously as does that of Earth. Instead pressure builds and there are sudden episodes of planet wide crustal overturning. The last such episode was 300-600 Mya.

Active volcanism:

In March of 2014, Venus had “hot flashes” from spots where the temperature surged 40-320°C above ambient – which is already hot!

History of Venus

(first 1-3 billion yrs of 4.5 billion)

- Originally like primitive Earth with a molten core, a magnetic field and water (in oceans)
- Major early impact &/or extreme tides caused retrograde spin
- Slow spin and lack of a moon allowed the internal dynamo currents to decay and the magnetic field to disappear
- Maybe Venus had primitive forms of life as did Earth

History of Venus (next 1-2 billion yrs)

- On primitive Venus and Earth lots of volcanic activity emitted CO_2 into the atmosphere.
- Planet was hotter than Earth and had lots of water vapor in the atmosphere.
- Energetic particles from the sun could reach the planet (no magnetic field) & break up the H_2O
- No H_2O , there is no “weathering” to remove CO_2
- H is light-weight. It has evaporated off the atmosphere (Earth’s too), leaving O behind, gradually removing all the planet’s water.

History of Venus (next 1-2 billion yrs, cont. 1)

- On Earth, the C is absorbed into the oceans, where it is used by living organisms and becomes deposited as limestone (aka, the carbon cycle).
- On Venus, the oceans evaporated away, so the carbon cycle won't start. Instead C finds the O in the atmosphere, makes still more CO₂, and traps more heat. As the heat went up, this process got easier, and continued until all the C was used.
- In addition, the atmosphere grew, increasing the pressure on the surface.

History of Venus (next 1-2 billion yrs, cont. 2)

- The volcanoes also emit sulfur (S).
- On Earth, S solidifies on the surface or becomes incorporated into surface minerals. On Venus, temperatures rose above the level at which S not merely melted, but evaporated & combined with dissociated H_2O atoms to form SO_2 , and clouds of sulfuric acid - H_2SO_4 .
- SO_2 absorbs at different wavelengths than CO_2 , further exacerbating the greenhouse effect.

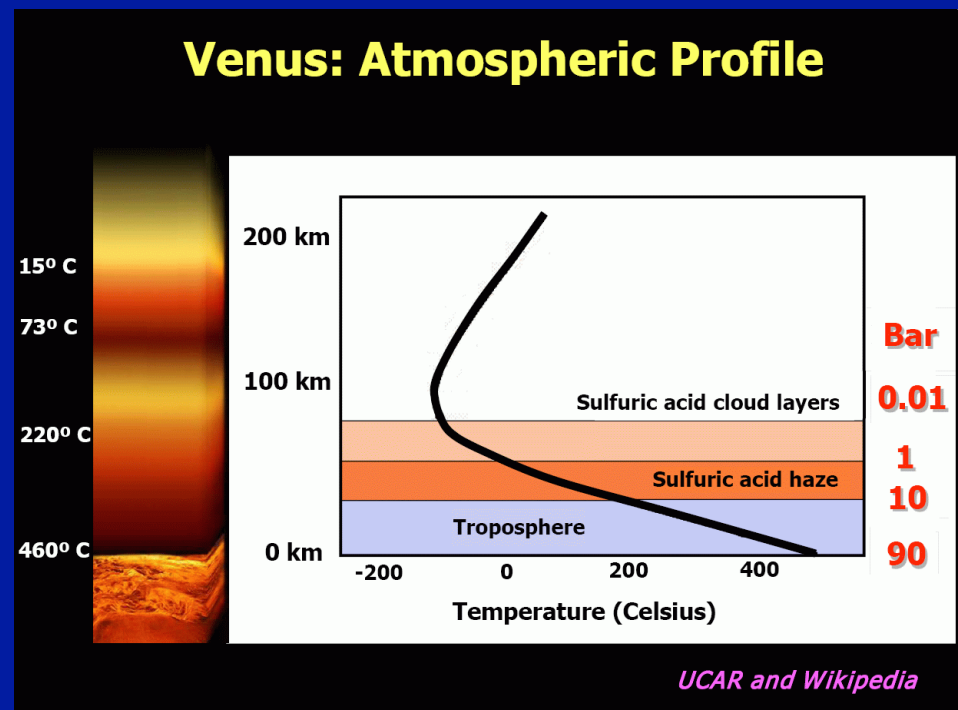
Runaway greenhouse boiled away the oceans.

This probably cannot happen on Earth, but studying Venus is what got Jim Hansen wondering what would happen here.

Conclusion from Venus

- All this can be tied in with the geologic evidence from the surface of Venus, making the Venusian surface a great model for what **hell** must be like.

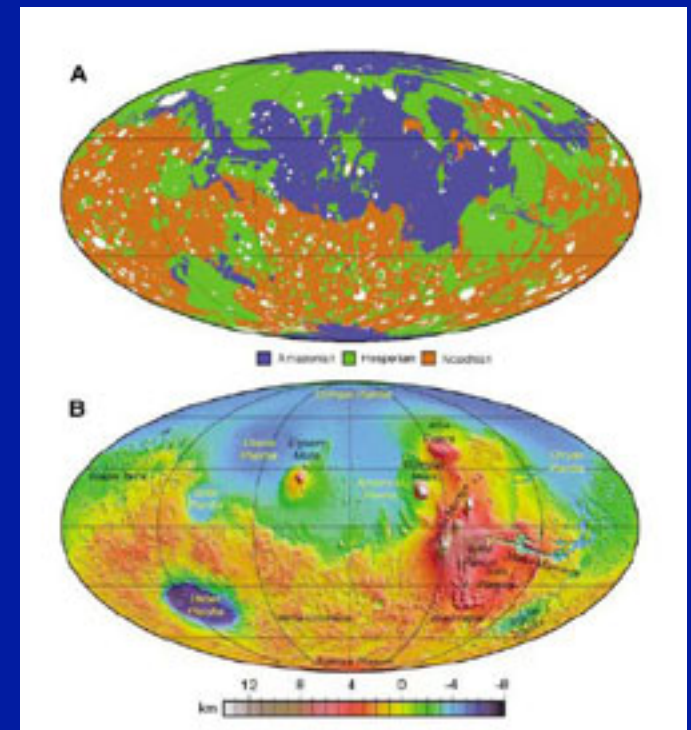
A slightly different planet and no moon leading to a very different result, caused by a *runaway* greenhouse effect!



Martian geologic history

As inferred from studies of meteoritic impact distributions

- Noachian era: 4.5-3.7 Bya
 - warmer climate
 - denser atmosphere
 - volcanic activity
 - oceans and lakes
- Hesperian era: 3.7-3.0 BYA
 - magnetic dynamo weakens and dies
 - climate changed to dryer and dustier
 - water frozen underground
- Amazonian era: 3.0 Bya to present
 - occasional sudden releases of water



Mars

- Atmosphere is 95% CO₂ (traces of methane)
 - 0.6% the pressure of Earth's atmosphere
 - Column density of CO₂ too small to have much effect.
 - Greenhouse equilibrium is about 7 °F (4 °C) above expected temperature.
- Loss of atmosphere
 - No magnetic field
 - Erosion by solar wind
 - sputtering
 - Evaporation
 - Collision

Life on Mars?
Traces of methane
Once upon a time had water



Put Earth at orbit of Venus – how hot??

Sun is $1/(0.72)^2 = 1.93$ times brighter at the orbit of Venus.

- If the Sun were twice as bright the temperatures on Earth would be much greater, but how do you calculate this?
- E goes as T^4 ; therefore T goes as $E^{1/4}$ (T in Kelvin).
 - Stefan-Boltzmann Law
 - To get from Kelvin to °C, subtract 273.
- So if E doubles, then temperature increases by $2^{0.25} = 1.19$ times, so the temperature on Earth would be about $(273+15^\circ\text{C}) \times 1.19 = 343$ Kelvin or 70°C .
 - The boiling point of water is 100°C or 373 Kelvin at 1 bar.
- At 90 bars (the atmospheric pressure on Venus), water boils at 303°C or 576 Kelvin. The surface temperature on Venus is 465°C .
- Venus is a LOT hotter than Earth because of the enhanced greenhouse effect from its thick CO_2 atmosphere, and its oceans have boiled away.

Summary

- CO₂ (or lack thereof) controls the temperature of all 4 of the solar system's inner planets: Mercury, Venus, Earth and Mars
- Good news: runaway greenhouse that boils away oceans is very unlikely on Earth
 - A gedanken (thought) experiment
 - Assuming we don't quit burning fossil fuels voluntarily or don't run out of them
 - Ultimately it would be too hot for human life and that will cut off the burning of fossil fuels

Video from NASA

<https://www.youtube.com/watch?v=oC31pqk9sak>

10 minutes

Olympus Mons, a shield volcano, is the largest volcano in the solar system.

It is 22 km (14 miles) high.

Its area is about that of Arizona.

