CeeCee Bishop will not have office hours this week.

Instead, **Prof. Seth Aubin** will have additional formal office hours during this time (Thursday: 8:30-10:30am).

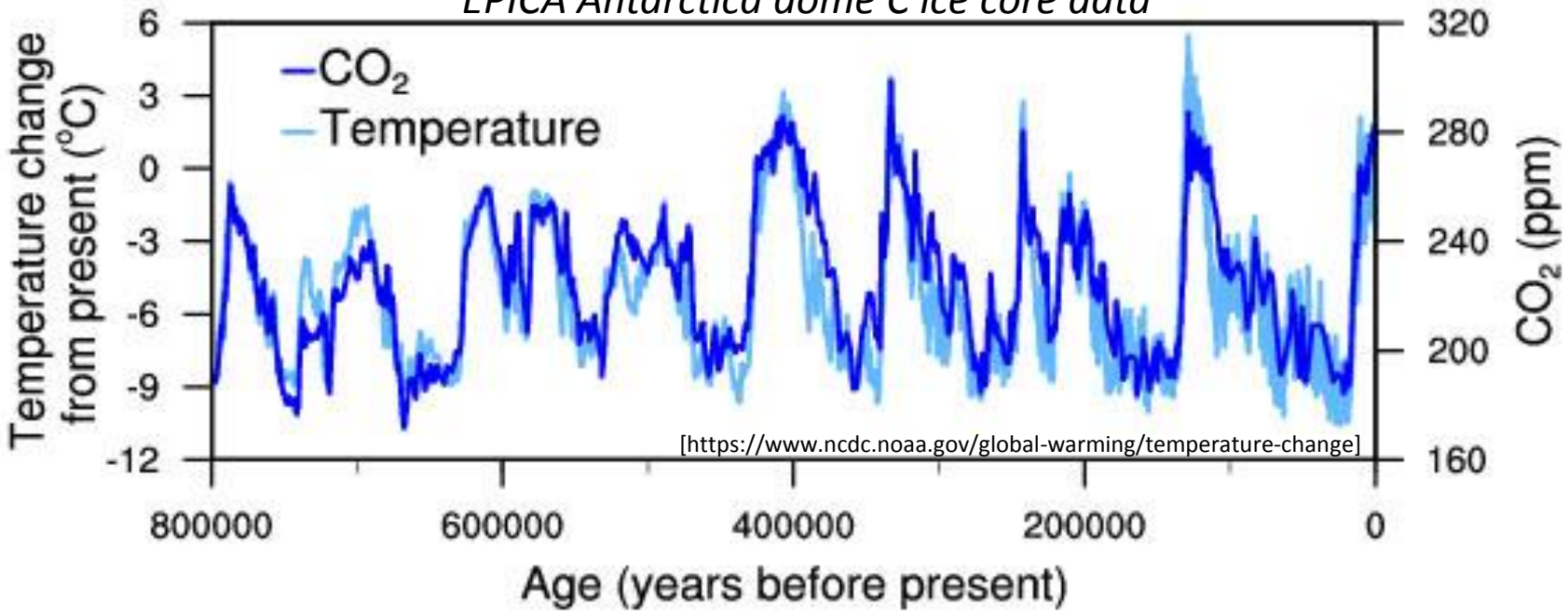
Today's Topics

Wednesday, October 16, 2019 (Week 7, lecture 19) – Chapters 9 & 10.

1. Temperature of Earth
2. The Moon
3. Mercury
4. Venus
5. Mars

Temperature of the Earth: past 800k years

EPICA Antarctica dome C ice core data



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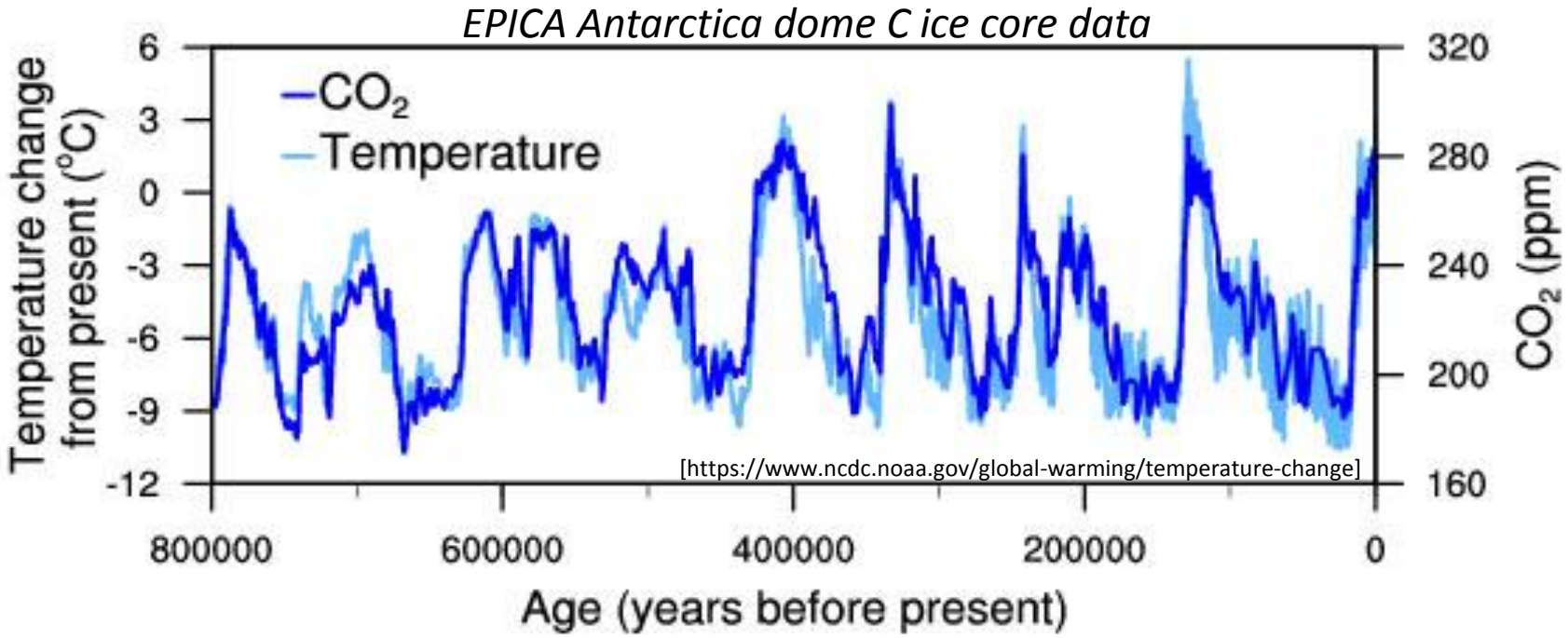


- The average temperature of the Earth has varied by **$\Delta T \approx 12°$ C** over the past 800,000 years.

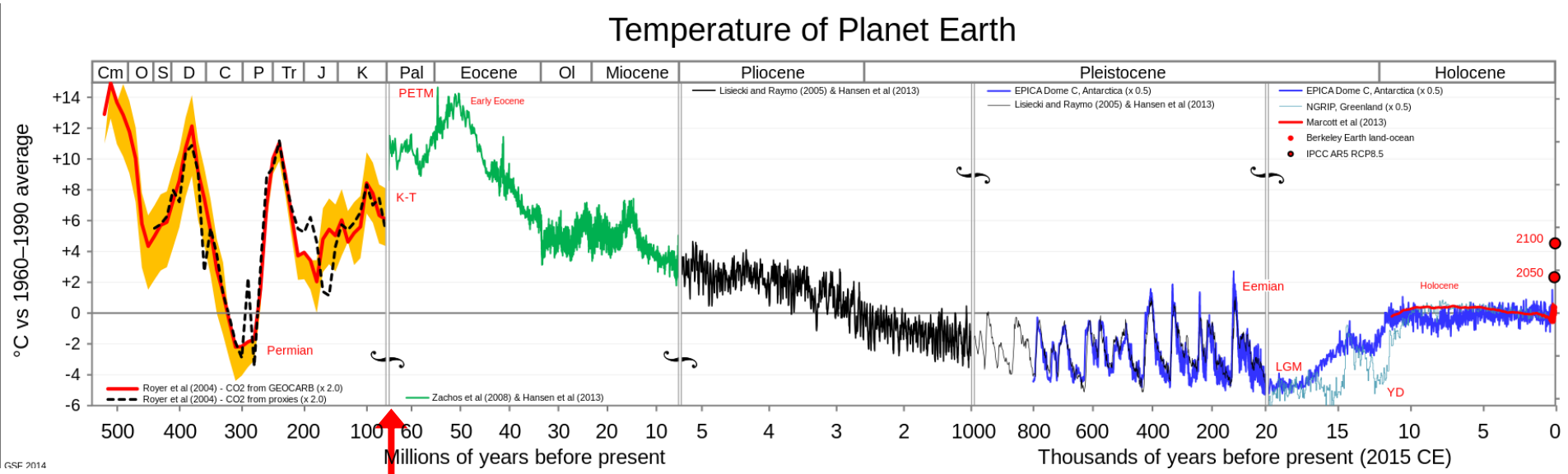
  → *The temperature of the Earth is relatively stable.*

- The temperature **varies on a 100,000 year** characteristic timescale.

  → *Temperature cycle <u>probably</u> due in part to variations in the Earth's orbit.*

- **Relative isotope abundances** in ice from ice cores (^{18}O vs ^{16}O and ^{2}H vs ^{1}H) can serve as **proxies for global temperature**.

Temperature of the Earth: past 540 M years



[Wikipedia: By Glen Fergus - Own work; data sources are cited]

end of the dinosaurs

Hypothesis: giant asteroid impact on Yucatan peninsula (Mexico)

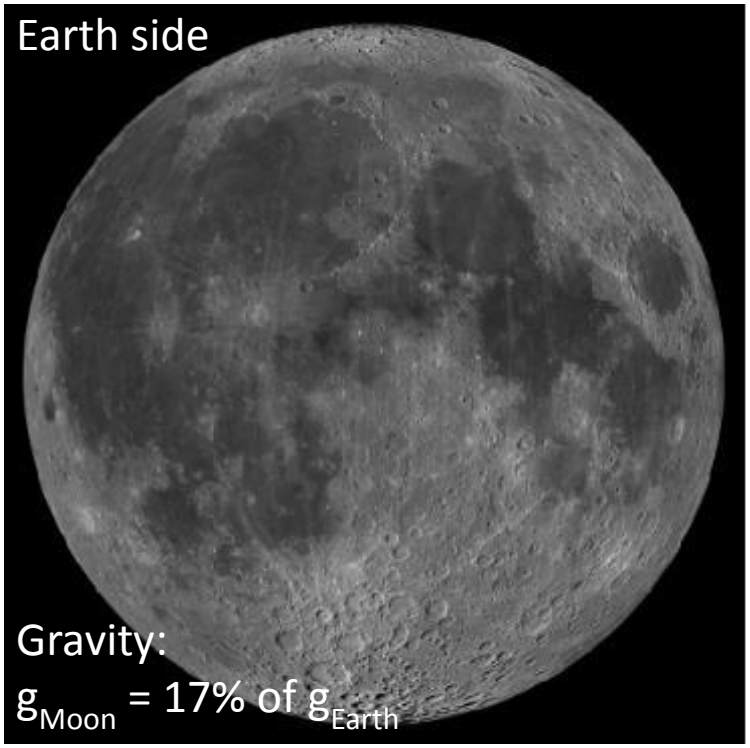
- Temperature estimates for the past 0.5 billion years are harder to measure.
- Less short term fluctuations, but also larger long term changes.

  → **$\Delta T \sim 18°$ C.**

The Moon

This image shows the far side of the moon, illuminated by the sun, as it crosses between the DSCOVR spacecraft's Earth Polychromatic Imaging Camera (EPIC) camera and telescope, and the Earth - one million miles away.

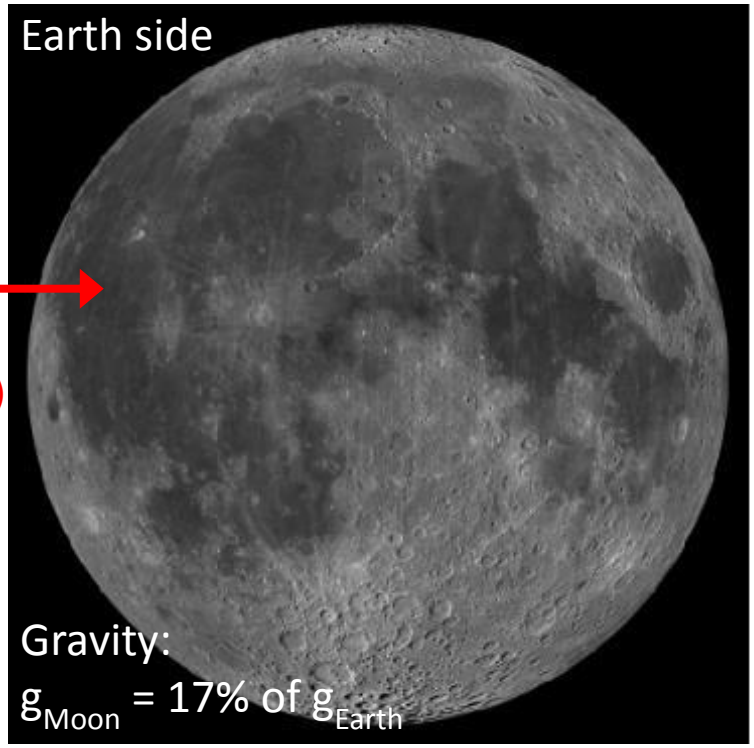
The Moon


Earth side
Gravity:
g_{Moon} = 17% of g_{Earth}


Far side
[OpenStax; NASA]

The Moon

lunar maria: volcanic basalt (3.8 billon years)



- Mass = 1.2% of Earth's, radius = 27% of Earth's, relatively circular orbit (ε=0.05).
- Geologically inactive (very old craters) with small iron core.
- Same side always faces Earth: **tidal locking**.
- Age of Moon rocks (Apollo): 3.3 - 4.4 billions years old.
- Rocks are mostly **silicates.**
- Average density of Moon: 3.3 g/cm3
- Water ice in craters is probably due to comets, meteorites.

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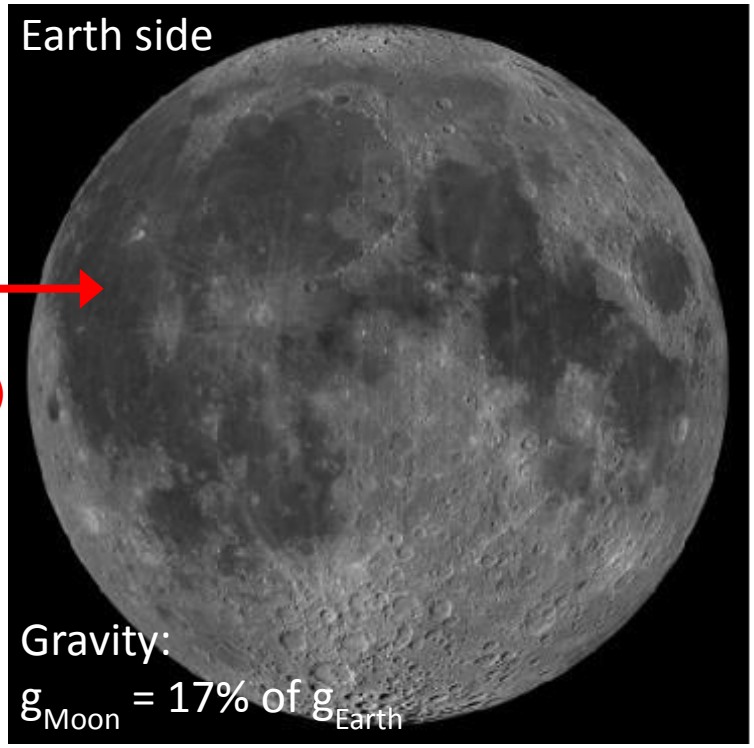

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very similar to Earth's mantle

Giant Impact Hypothesis

- Earth cannot do an orbital capture of an external moon

  → *prevented by 2-body physics.*

- Similarities between Moon and Earth's mantle suggest a common origin.

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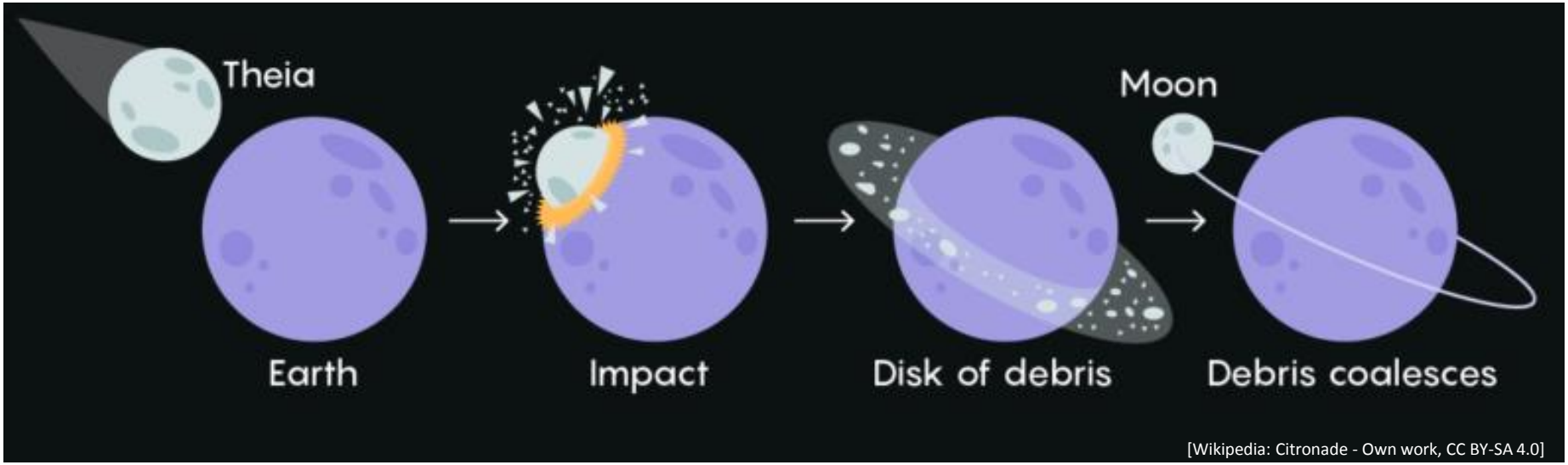
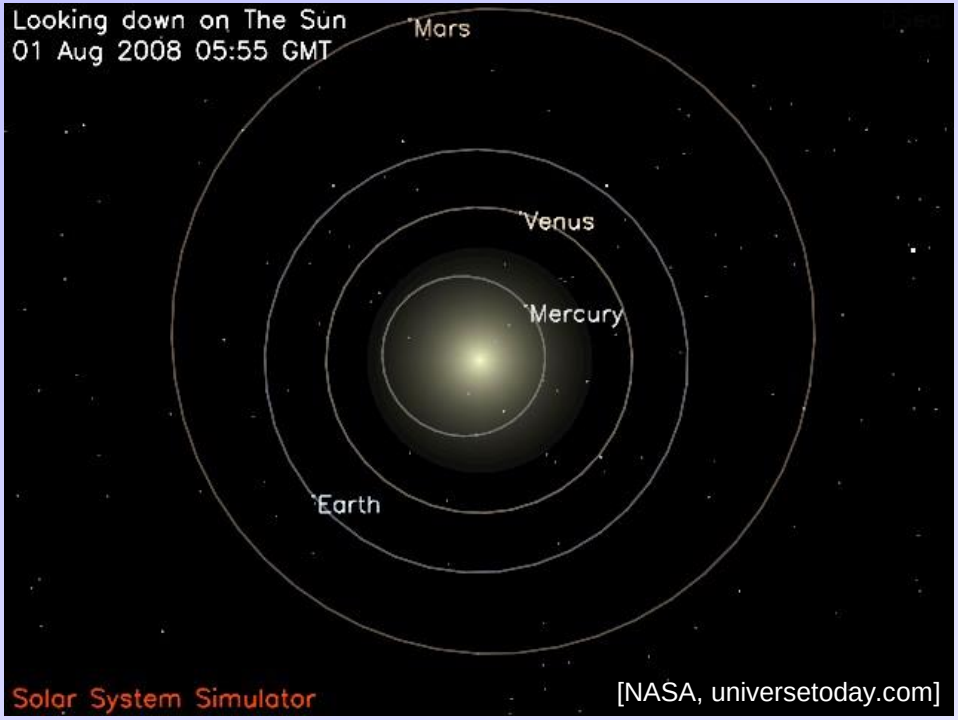
- Giant impact hypothesis

  1. External Mars-sized proto-planet (Theia) smashed into Earth about 4.5 billion years ago.
  2. Debris disk from impact forms around Earth *(some debris escapes the Earth forever)*.
  3. Debris disk coalesces into Moon.



Mercury

- Inner most planet, closest to Sun.
  → 88 day orbit.
- Comparable density to Earth's.
  → 5.4 g/cm^3.
- Smallest planet.
  → $R_{mercury}$= 38% of Earth's.
  → $g_{Mercury}$ = 38% of Earth's.
- Most eccentric orbit: ε = 0.206
- Vast surface temperature variations:
  → Max: 700 K (~420° C).
  → Min: 100 K (-170 ° C).
  → At poles:180 K (water ice in crater shadows).



[NASA, universetoday.com]

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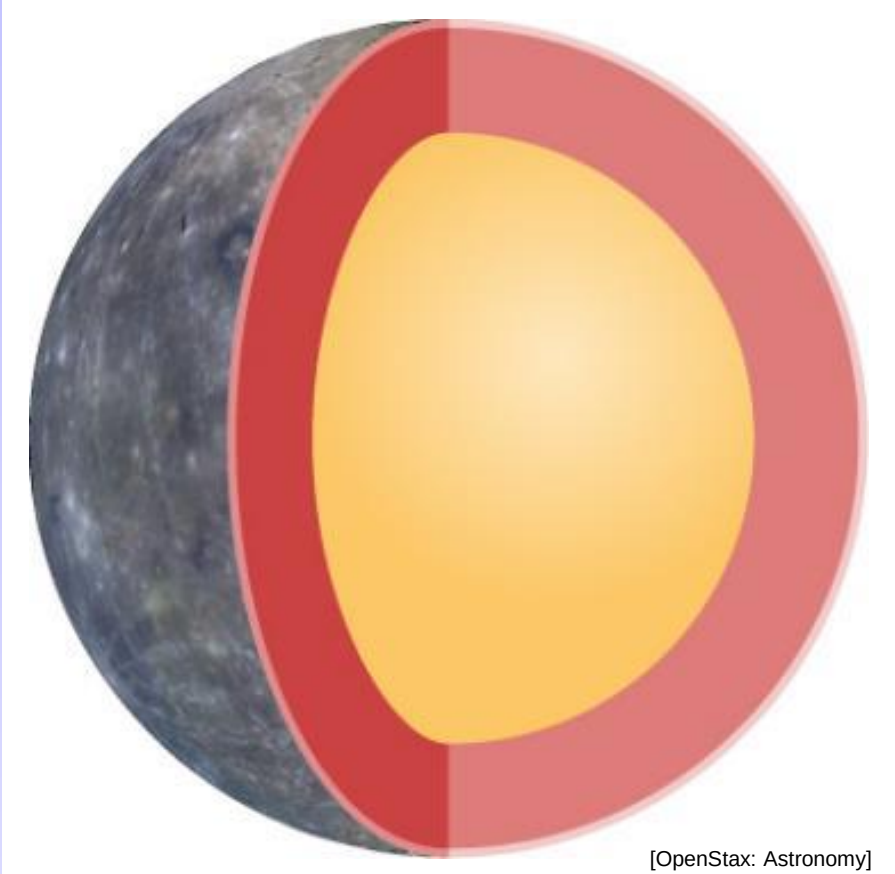

[OpenStax: Astronomy]

Mercury's Internal Structure. The interior is dominated by a metallic core about the same size as our Moon.

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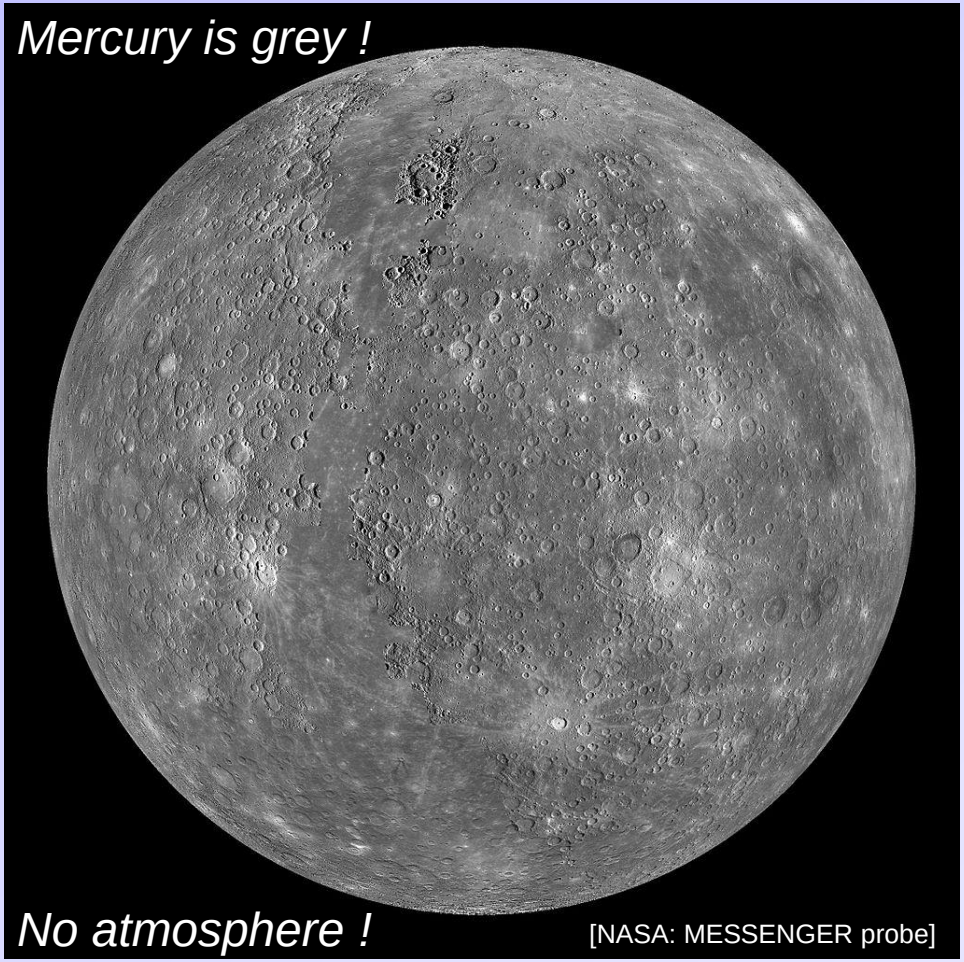

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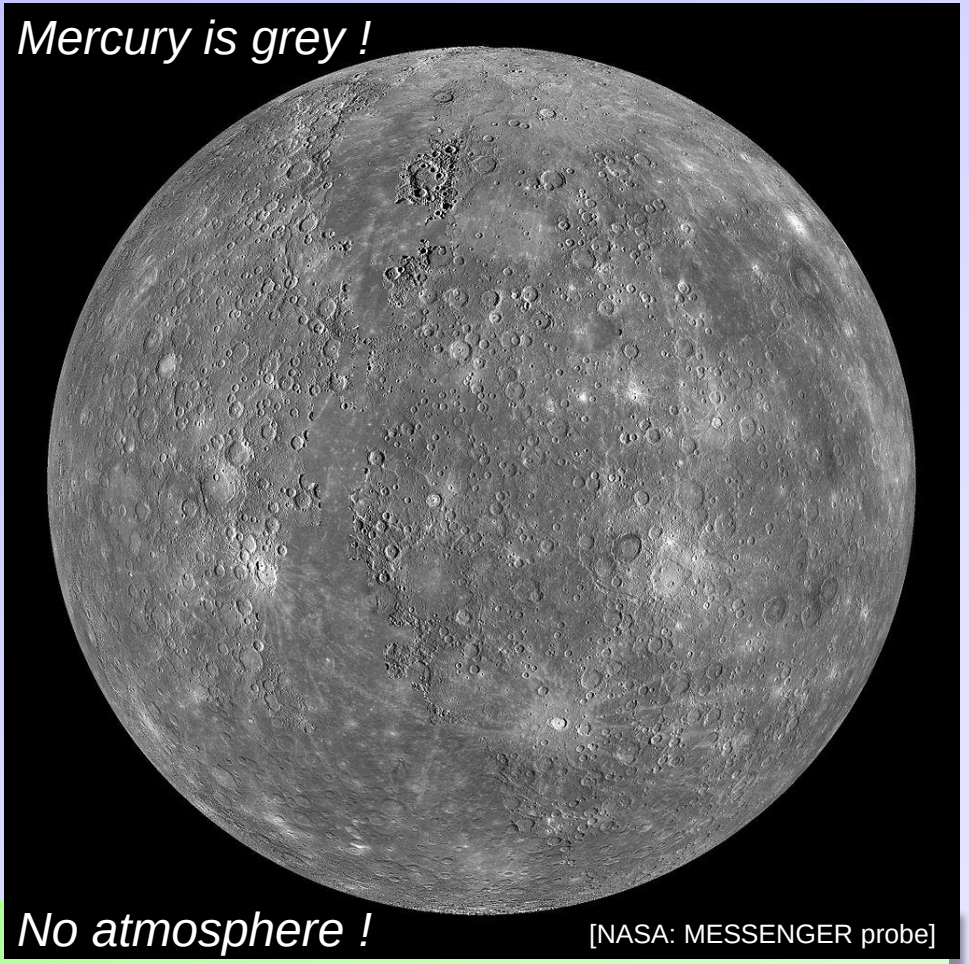
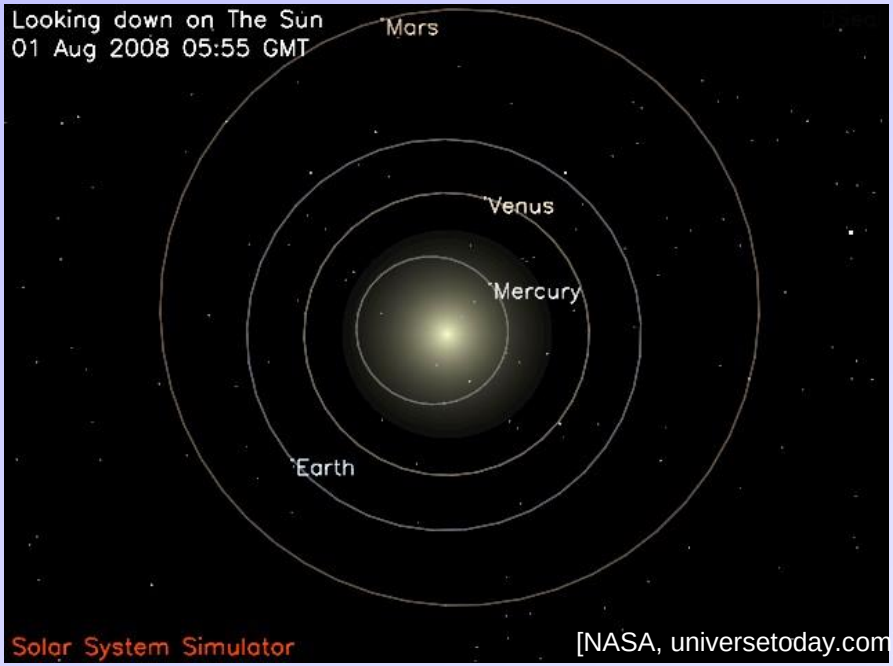


Mercury's strange rotation

- Mercury rotates 3 times (with respect to stars) for every 2 orbits around the Sun.
- Example of **tidal locking** (called a "3:2 spin-orbit resonance").
- Mercury's experiences **"tides"** (deformation from Sun's gravity gradient).
  → to be measured by BepiColombo probe (ESA & JAXA).

Venus

- Second planet from Sun.
- 224 day orbit, low eccentricity $\varepsilon = 0.007$
- **Earth-like features:**
  - → R_{Venus}= 95% of Earth's.
  - → M_{Venus}= 82% of Earth's.
  - → $g_{Mercury}$ = 90% of Earth's.
  - → Density: 5.24 g/cm^3.



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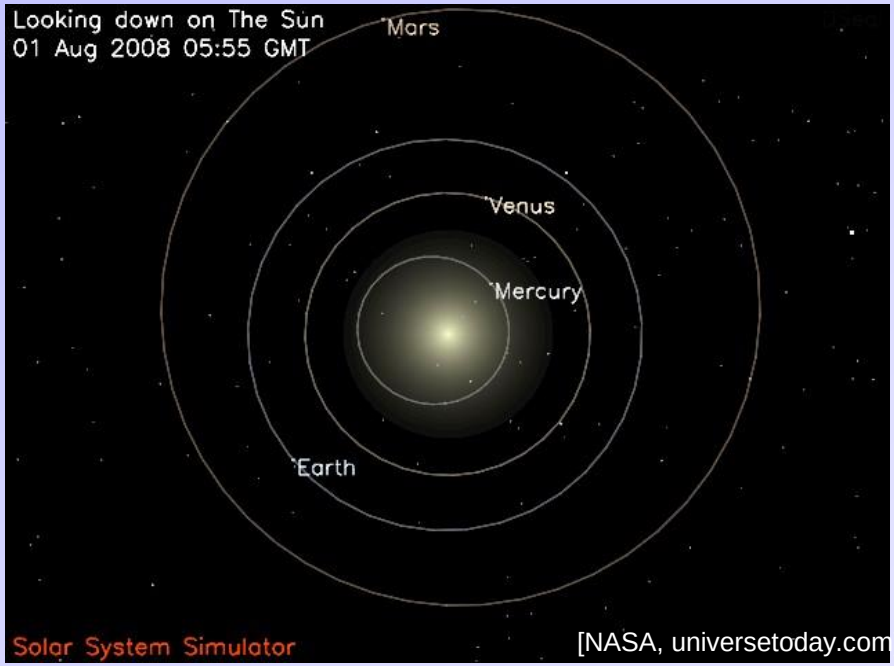
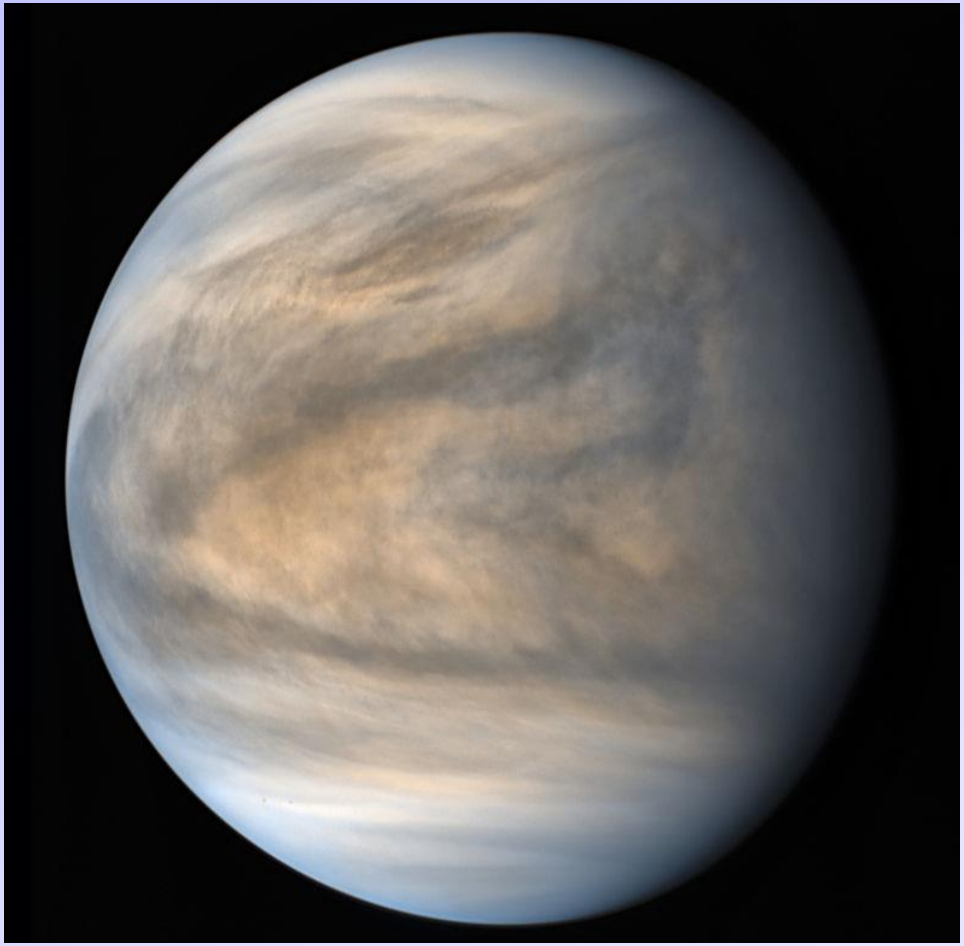


Very non-Earth features

- Planet **rotates backwards** (opposite Earth's).
- Planet **rotates very slowly**: 1 Venus rotation = -243 Earth days.
- **Very hot** → Surface temperature: T = 730 K = **460° C** *(hotter than Mercury)*.
- High pressure **atmosphere: 90 times Earth's.**
  → mostly CO_2 with a little N_2, and **no water**.
- Very weak magnetic field.

Venus

Visible light image (by Mariner 10, 1974).



[Source: JAXA, ISAS, DARTS, Damia Bouic]

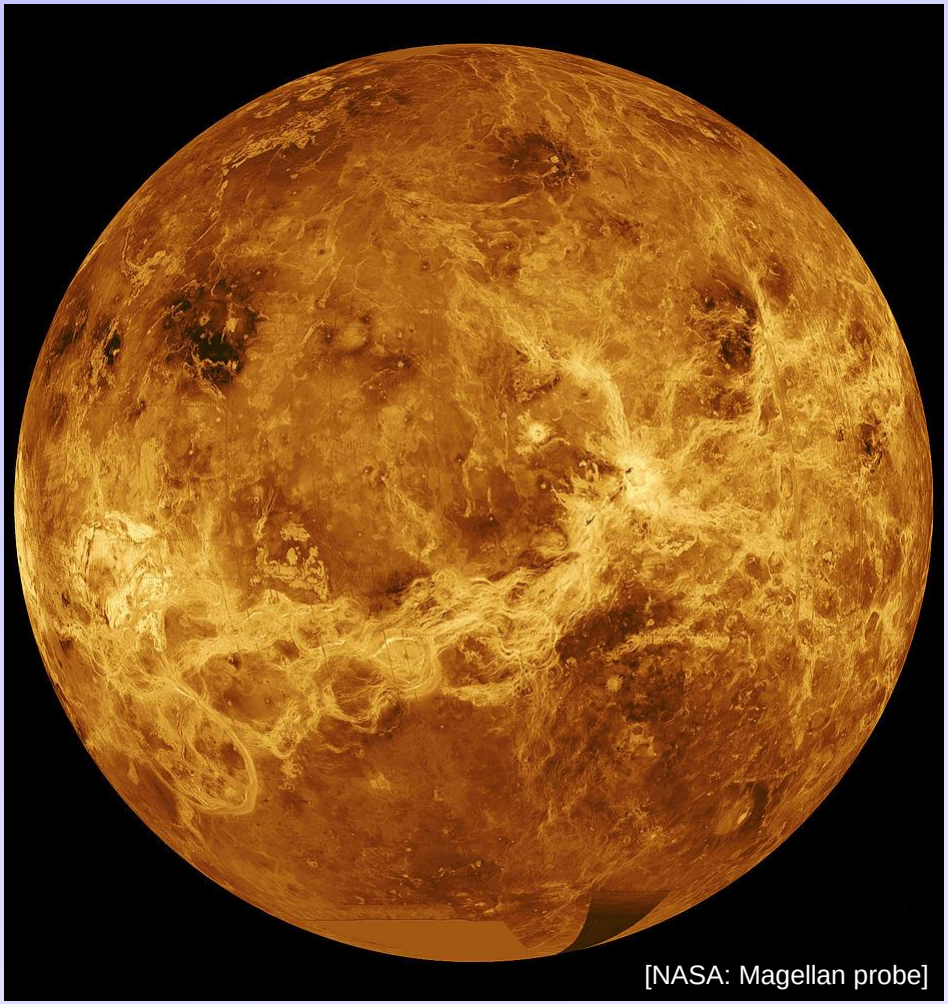
False color UV image (by Akatsuki probe, 2016).

The surface is completely obscured by **sulfuric acid clouds** !!!

Venus with Radar Imaging

Radar Imaging/mapping

Radar images are collected by directing microwaves at 2.4 GHz onto surface (through clouds) and imaging the scattered return waves.



Radar image map of Venus
(by Magellan probe, 1990-1994)

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Radar Imaging/mapping
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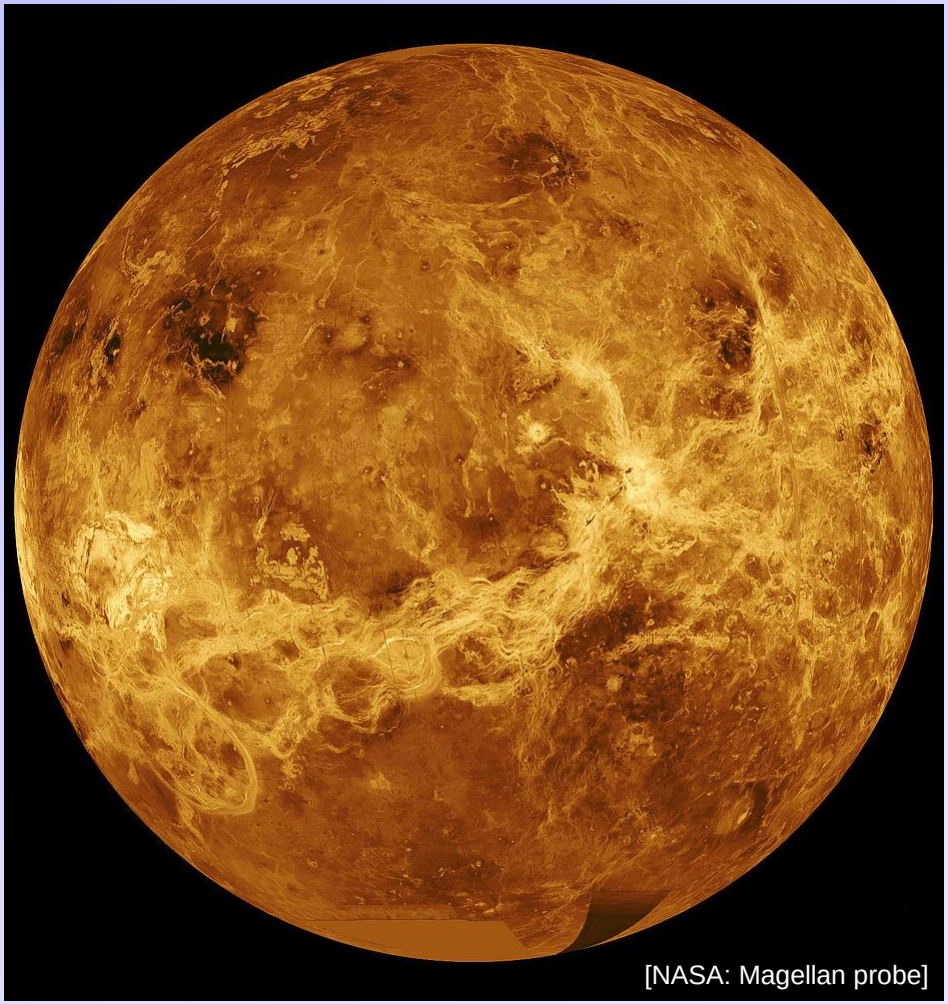
Many features from mapping:

- volcanoes (dormant).
- large solid lava plains (70% of planet).
- Mountains.
- Highlands that form two “continents”.
- Craters.
- But **no** tectonic plates.

→ not much geologic activity.



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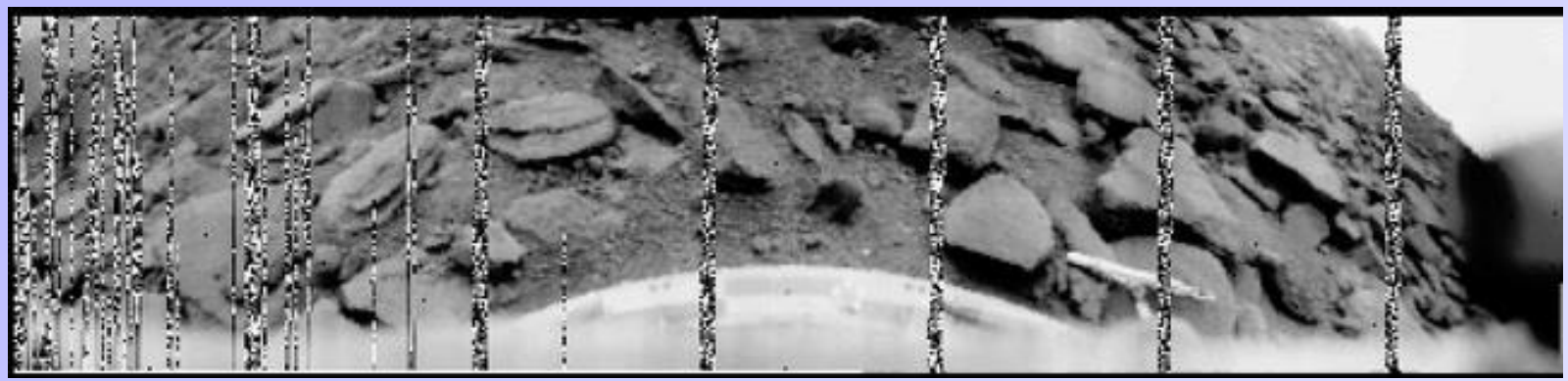
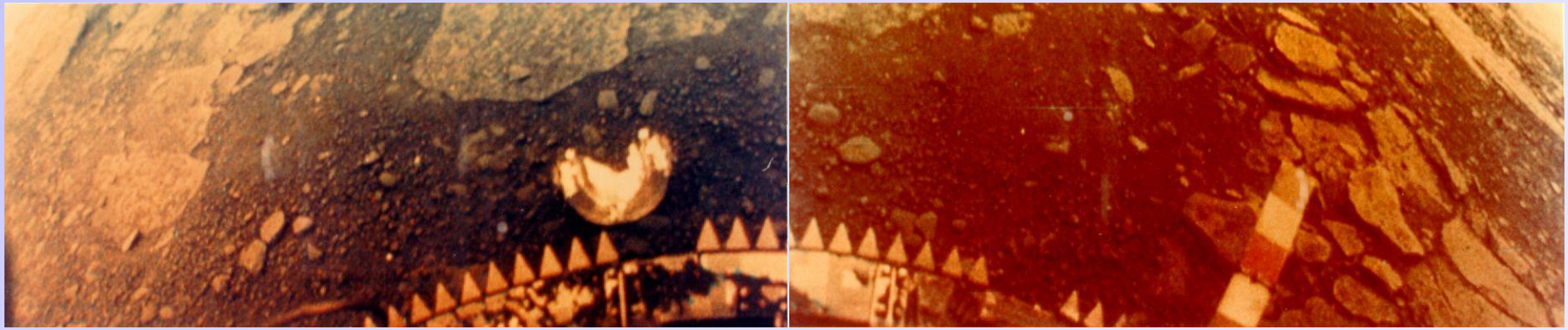
Venusian Surface

Venera 9 probe (1975)



[Wikipedia: By Government of the USSR / Venera 9 mission, copyright presumably held by the Russian space agency - www.mentallandscape.com, website owned by Don Mitchell]

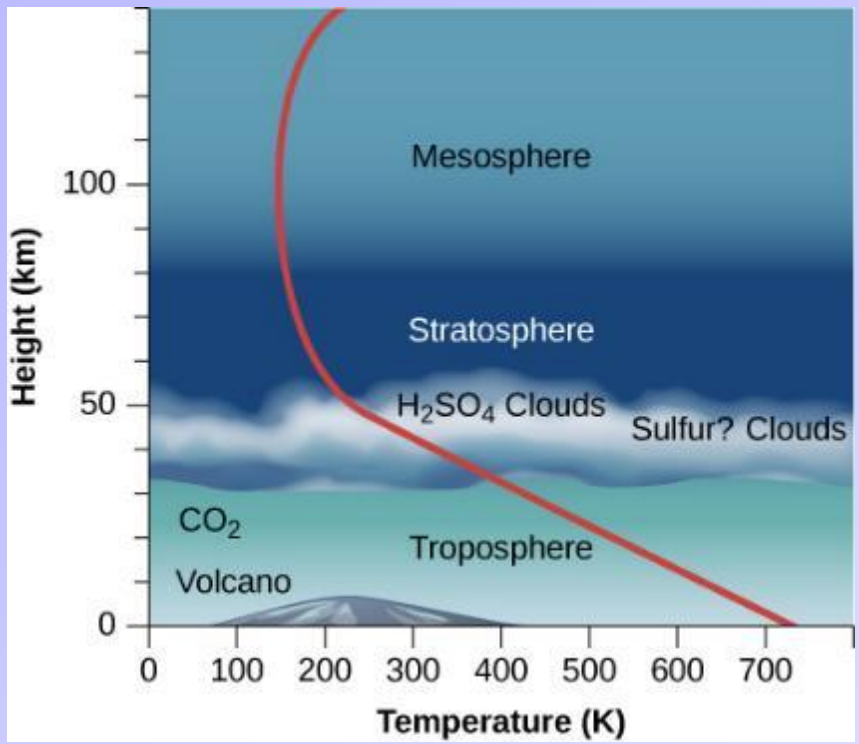
Venera 13 probe (1982)



[Source: https://nssdc.gsfc.nasa.gov/photo_gallery/photogallery-venus.html]

Venus's Atmosphere

Runaway Greenhouse Effect



Carbon dioxide (CO_2): 96.5 %.

Nitrogen (N_2): 3.5 %.

- Once sunlight enters the atmosphere it is repeatedly scattered (e.g. clouds) and converted to heat at the surface.
- The surface re-radiates this energy in the infrared, which is easily retained by the CO_2 atmosphere.

Note: a significant fraction of the Sun's light is reflected by the clouds (90%) .

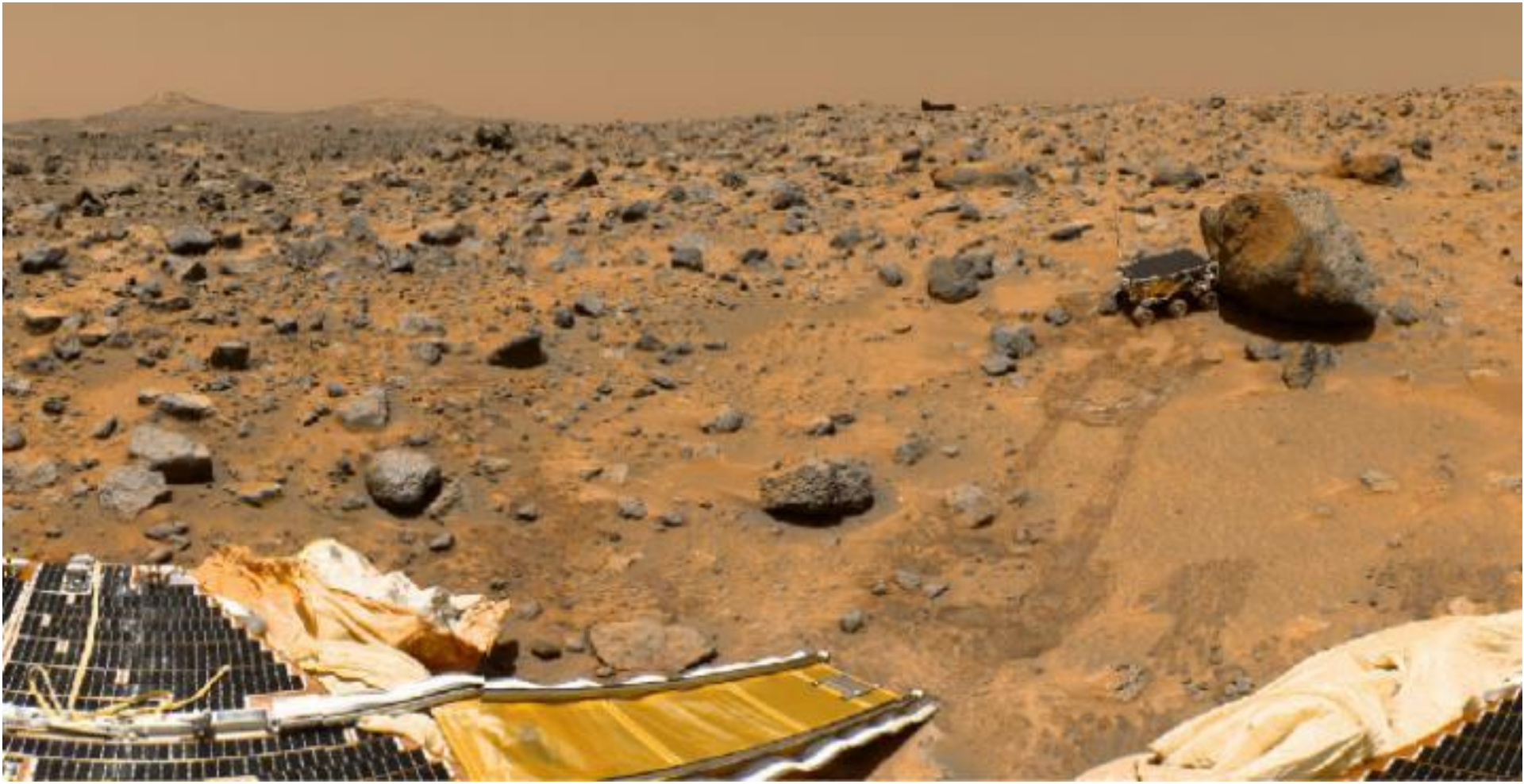
High Wind: The surface is relatively calm, but the clouds circulate at 300 km/h !

Venus: Stratospheric Colony ?

[NASA - http://sacd.larc.nasa.gov/branches/space-mission-analysis-branch-smab/smab-projects/havoc/]

At an altitude of 55 km, the temperature is 20-30° C (if you can handle the wind !)

Mars



[NASA:Pathfinder mission + sojourner]