Mercury and Venus

Planetary Astrophysics
AST6112, Fall 2013
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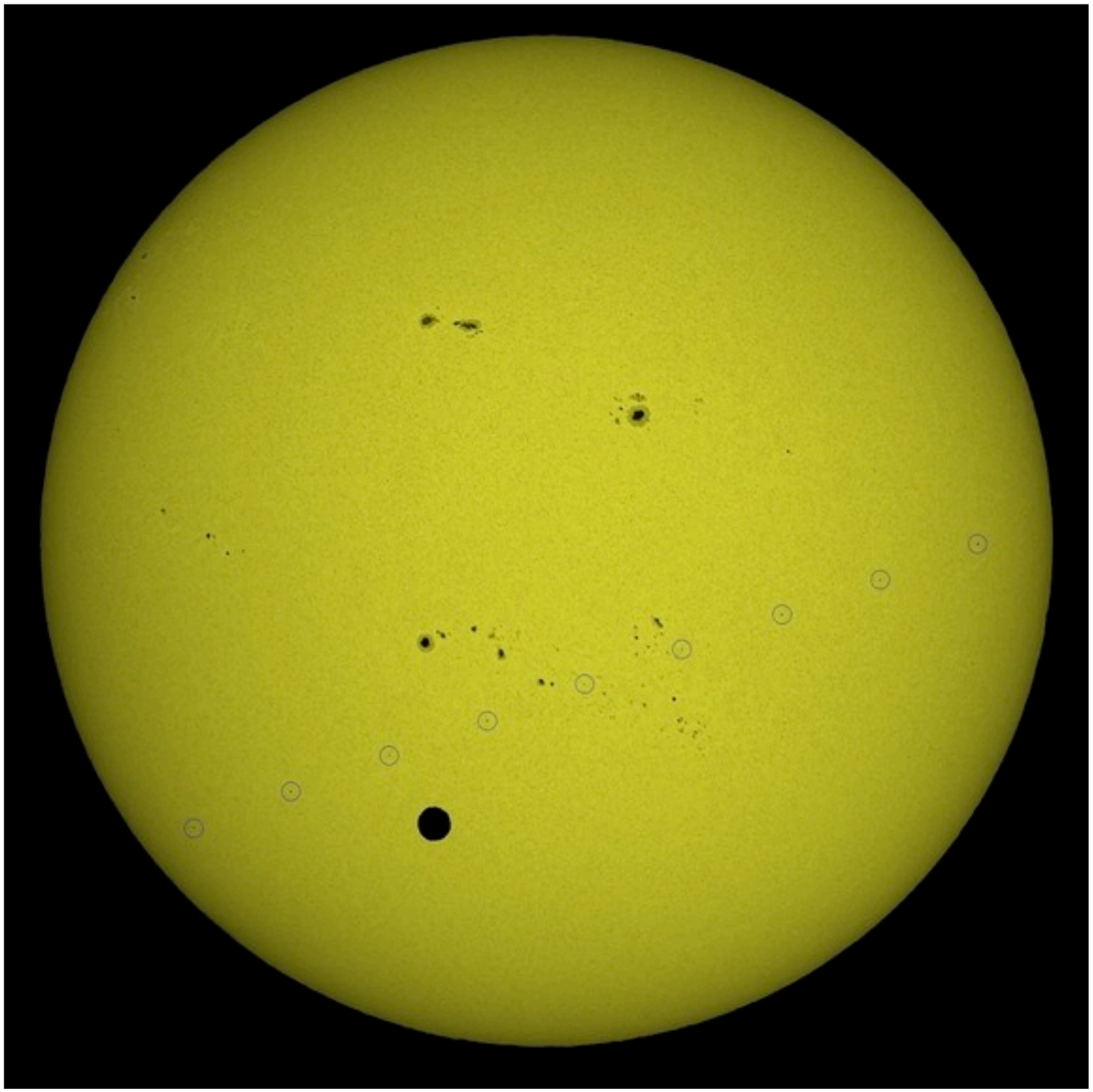
Interesting Facts

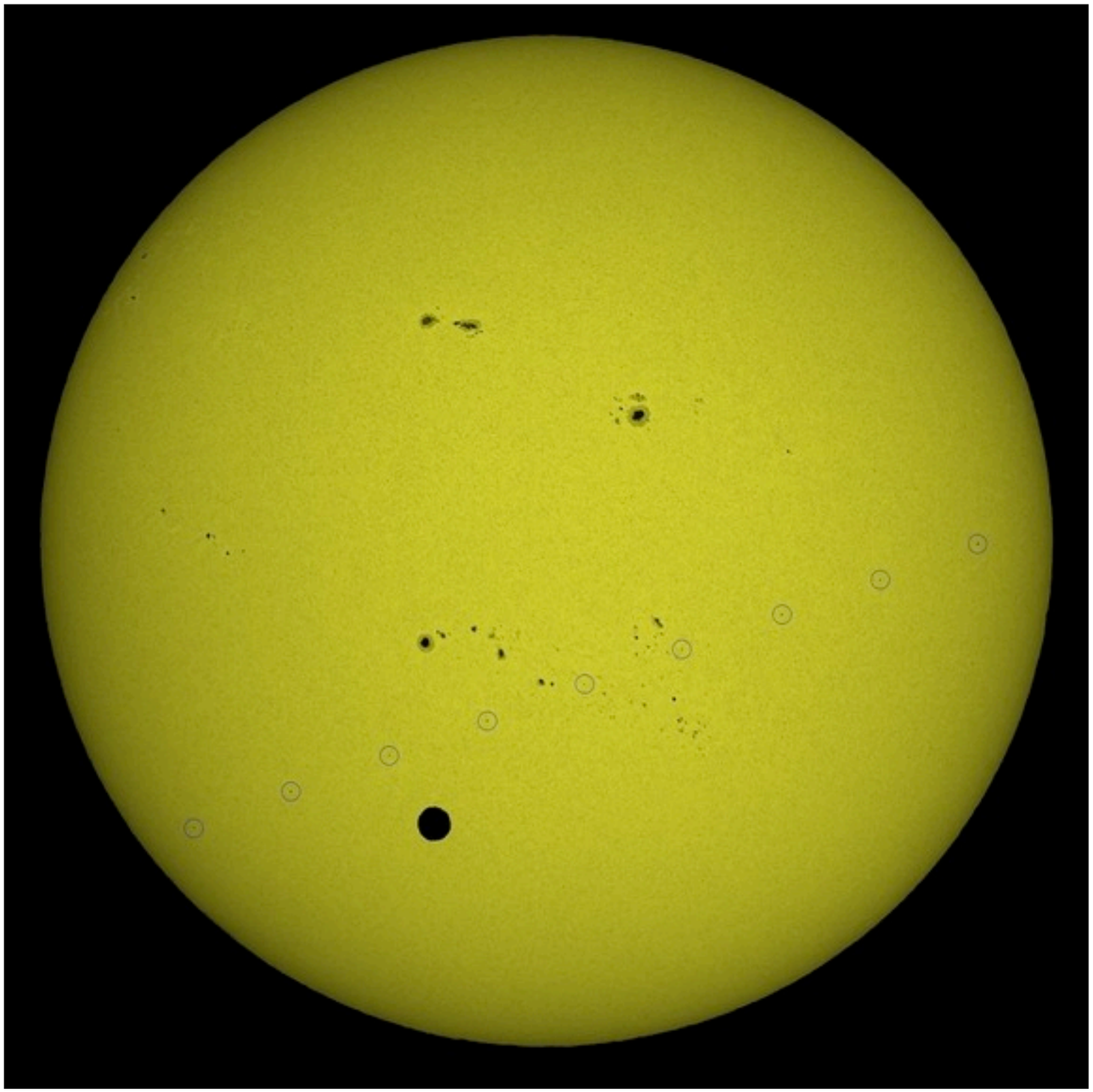
- The only two planets interior to Earth's orbit
  - Only two planets known to transit the Sun as seen from the Earth
- Only visible during day, dawn, or dusk
-

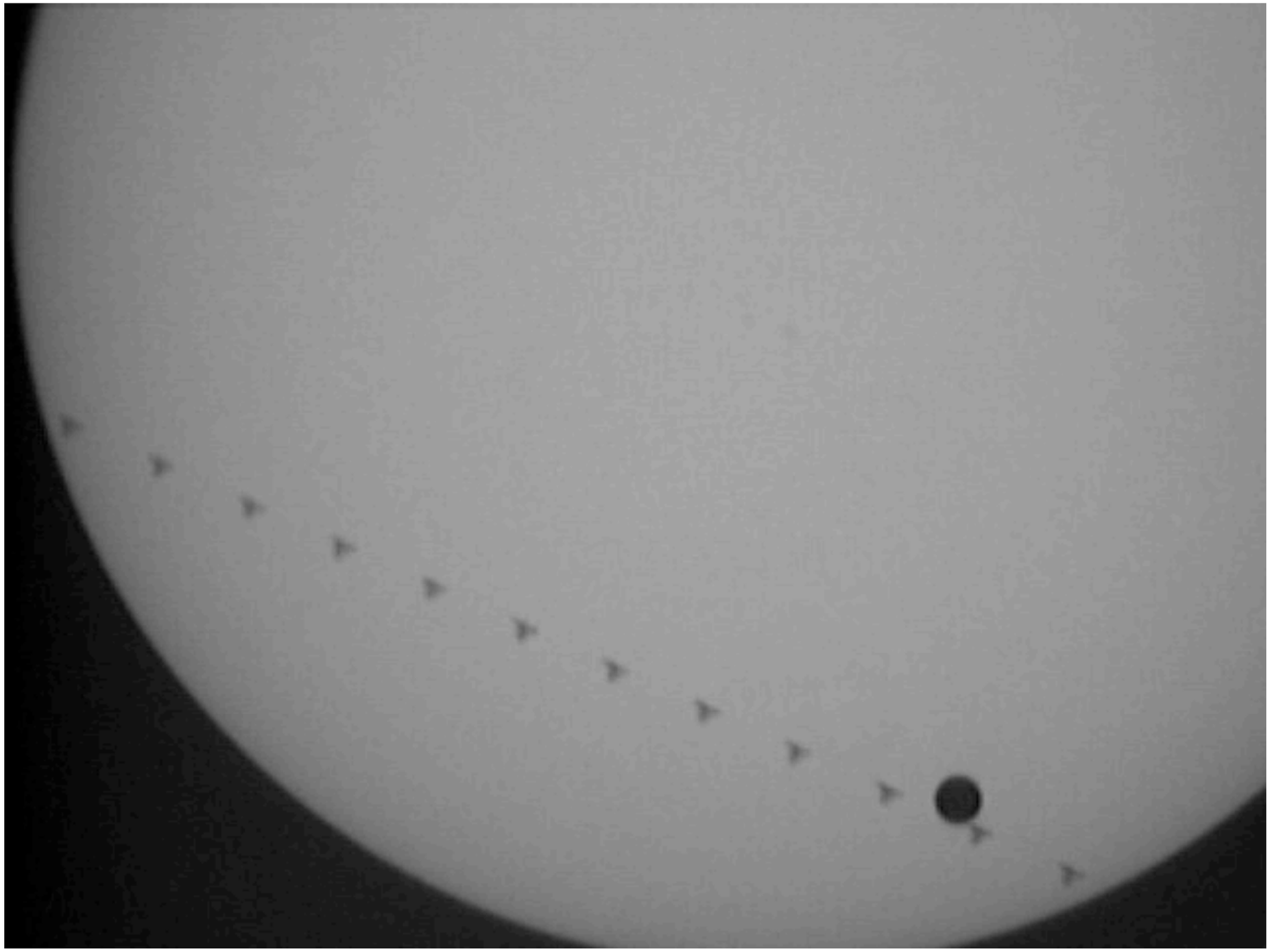
Venus Orbit and Transits

- As seen from the Earth:
  - transits every 243 years in a pair separated by ~8 years
    - Earth-Venus close to 8:13 and 243:395 period ratio
    - transit duration ~ hours
    - transits of this century 2004 and 2012
- Orbital period ~ 225 day

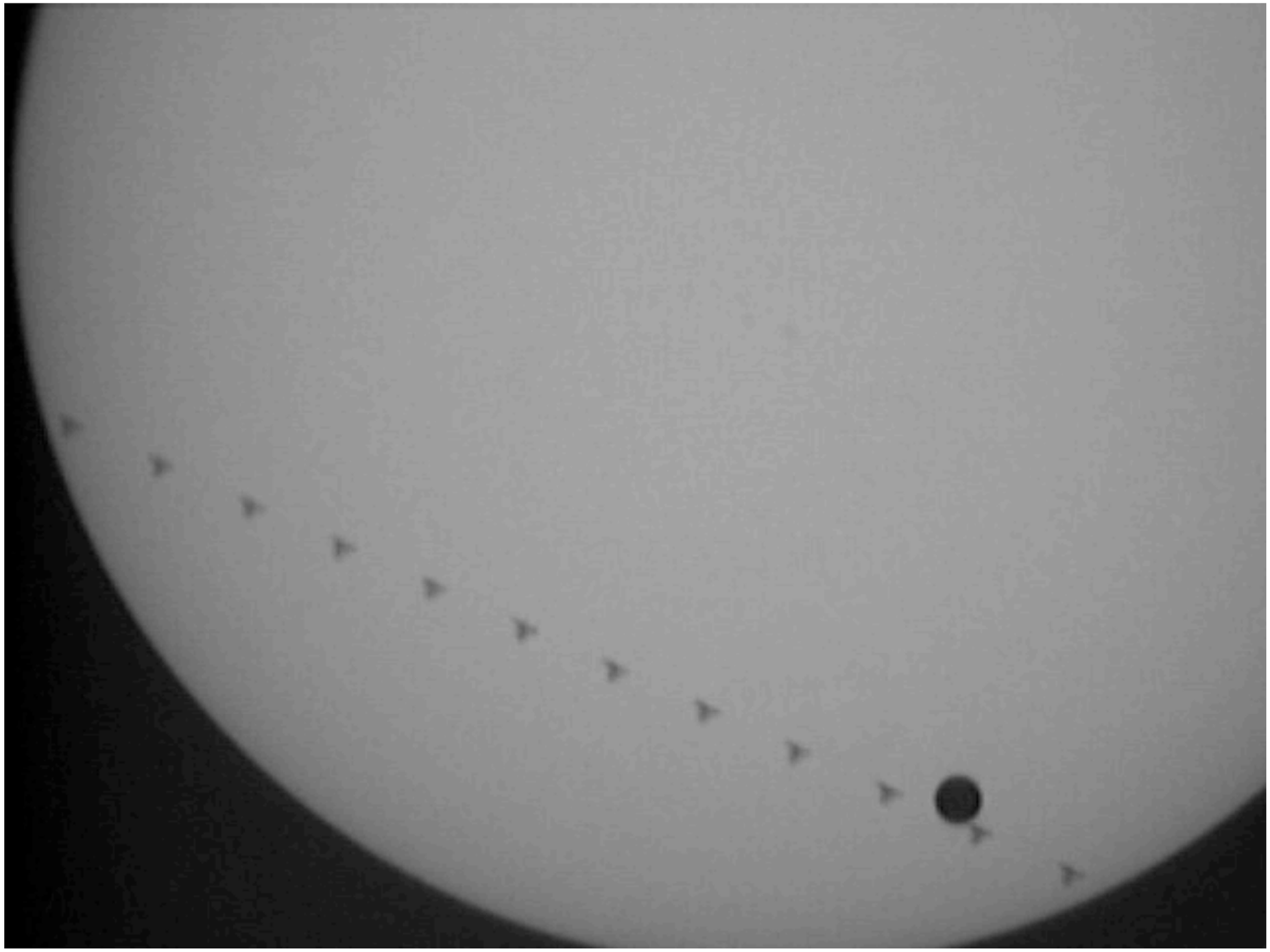


2012 Venus Transit
Hubble Space Telescope also transiting!



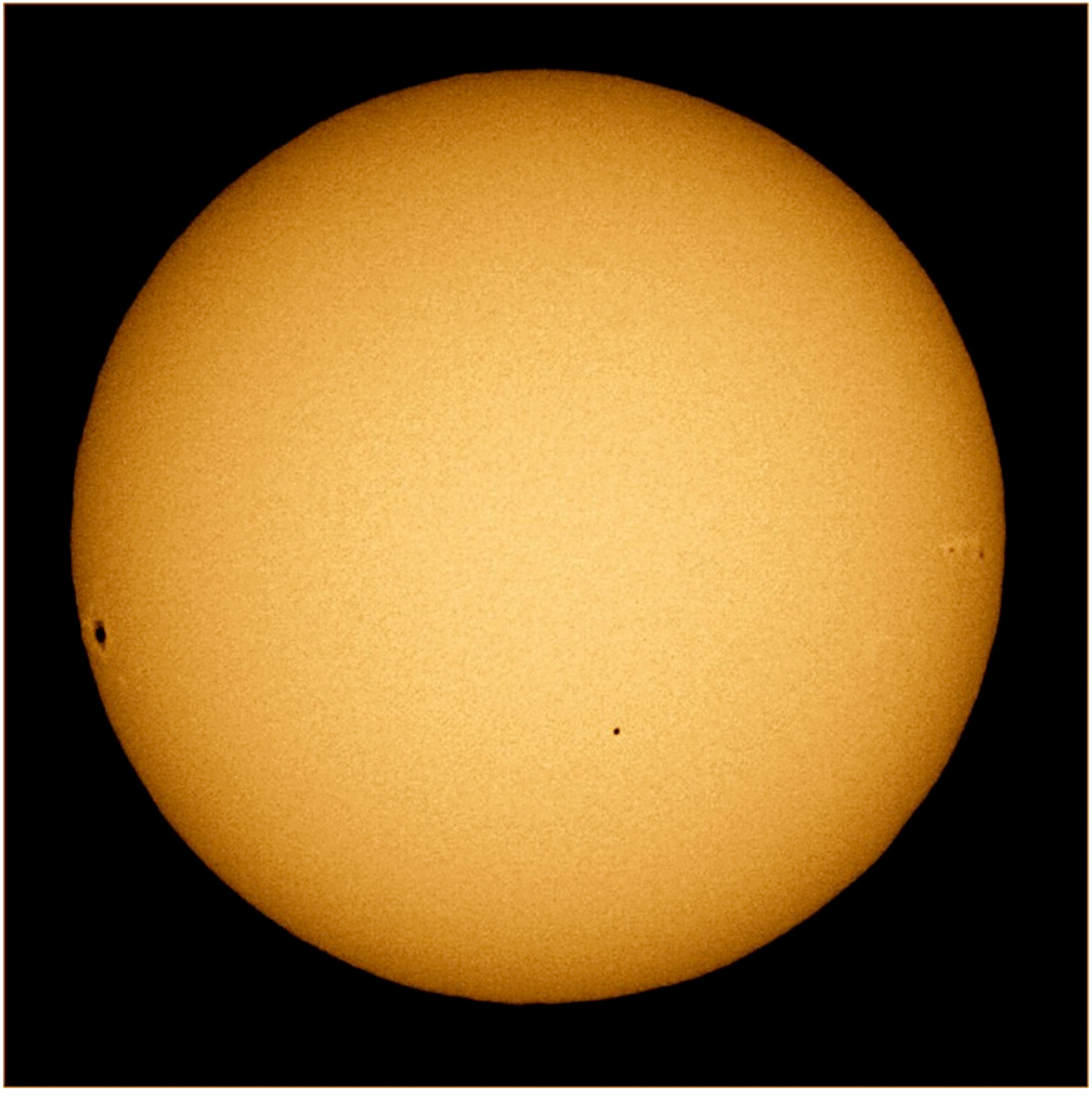


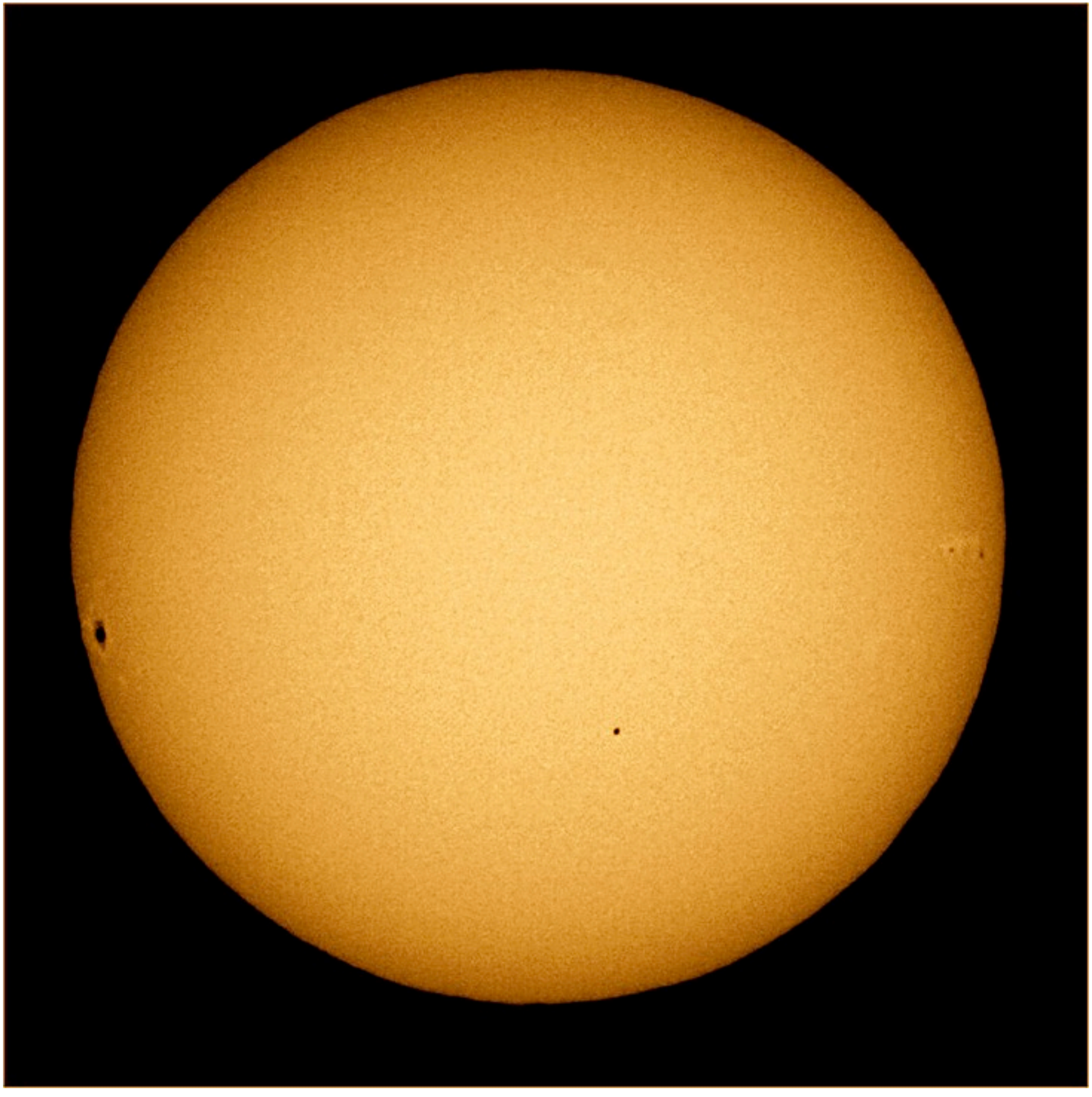
2004 Venus Transit
International Space Station is also transiting!



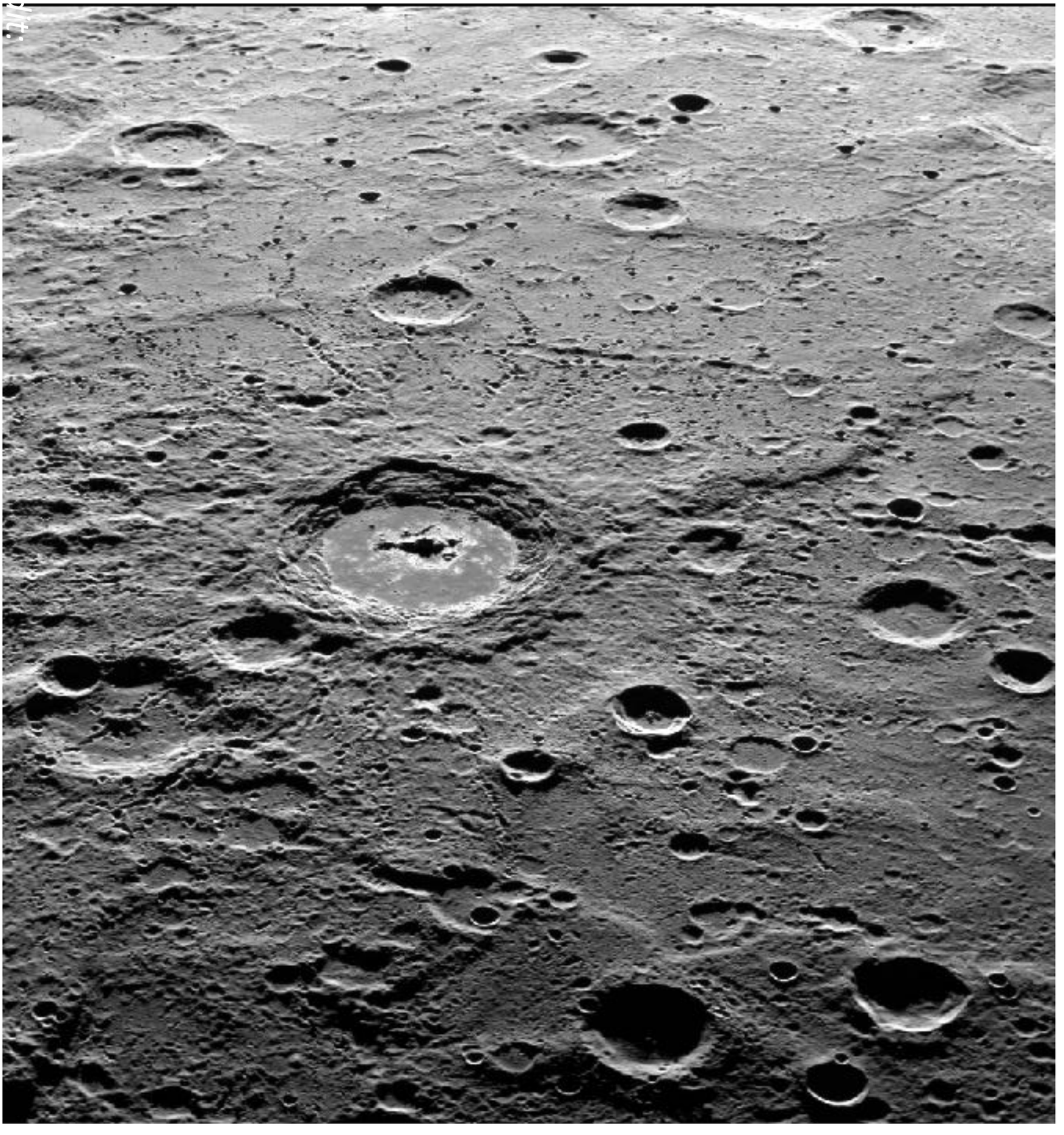
Mercury Orbit and Transits

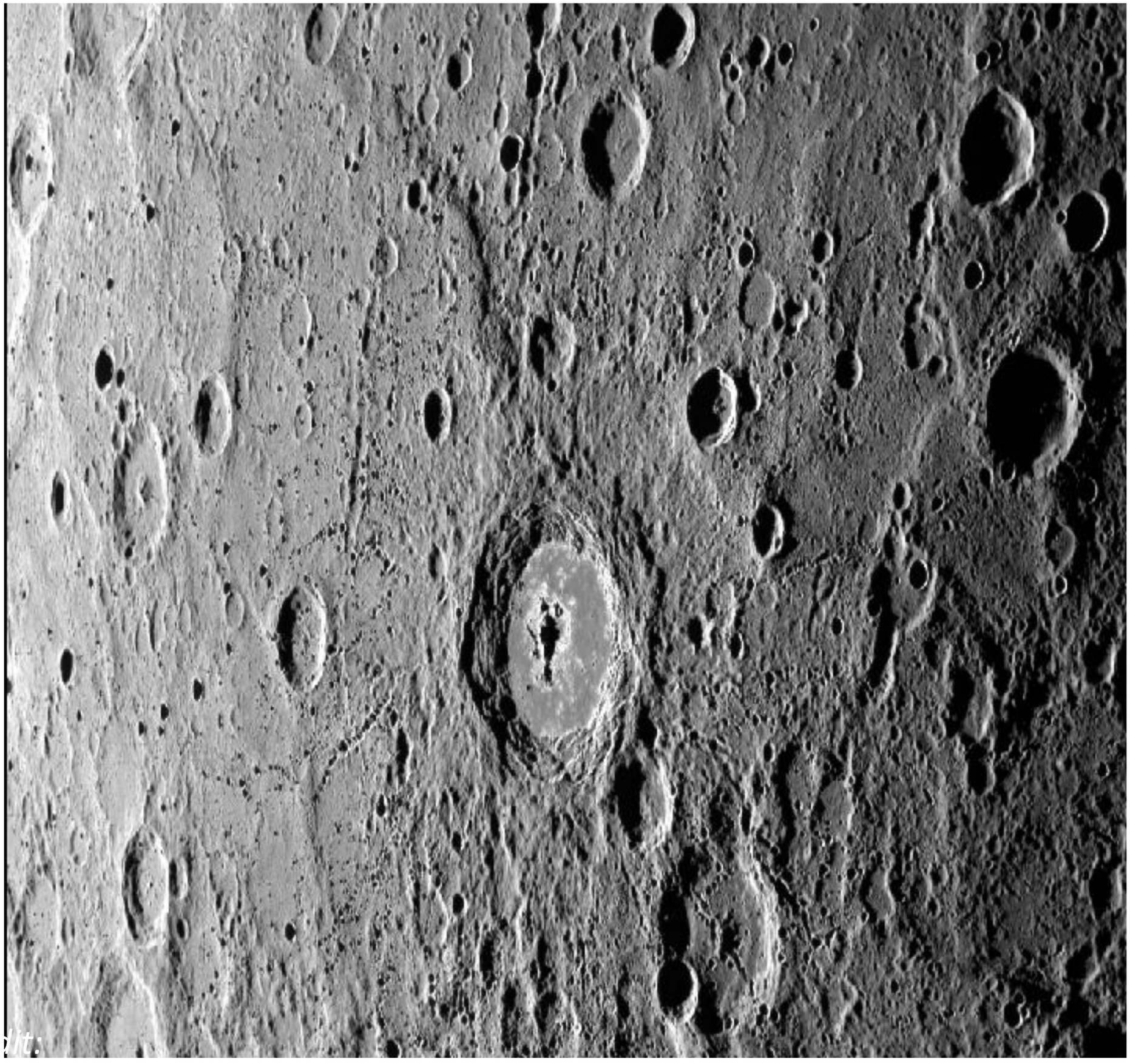
- As seen from the Earth:
  - transits during two seasons: May or November
    - May transits can be separated by 13 or 33 years
    - November transits can be separated by 7, 13, or 33 years
    - Mercury is near aphelion during May and perihelion during November
- Orbital period ~ 88 day
- Mean Solar day ~ 176 days (see Table 1.1, 1.2 in dP&L)



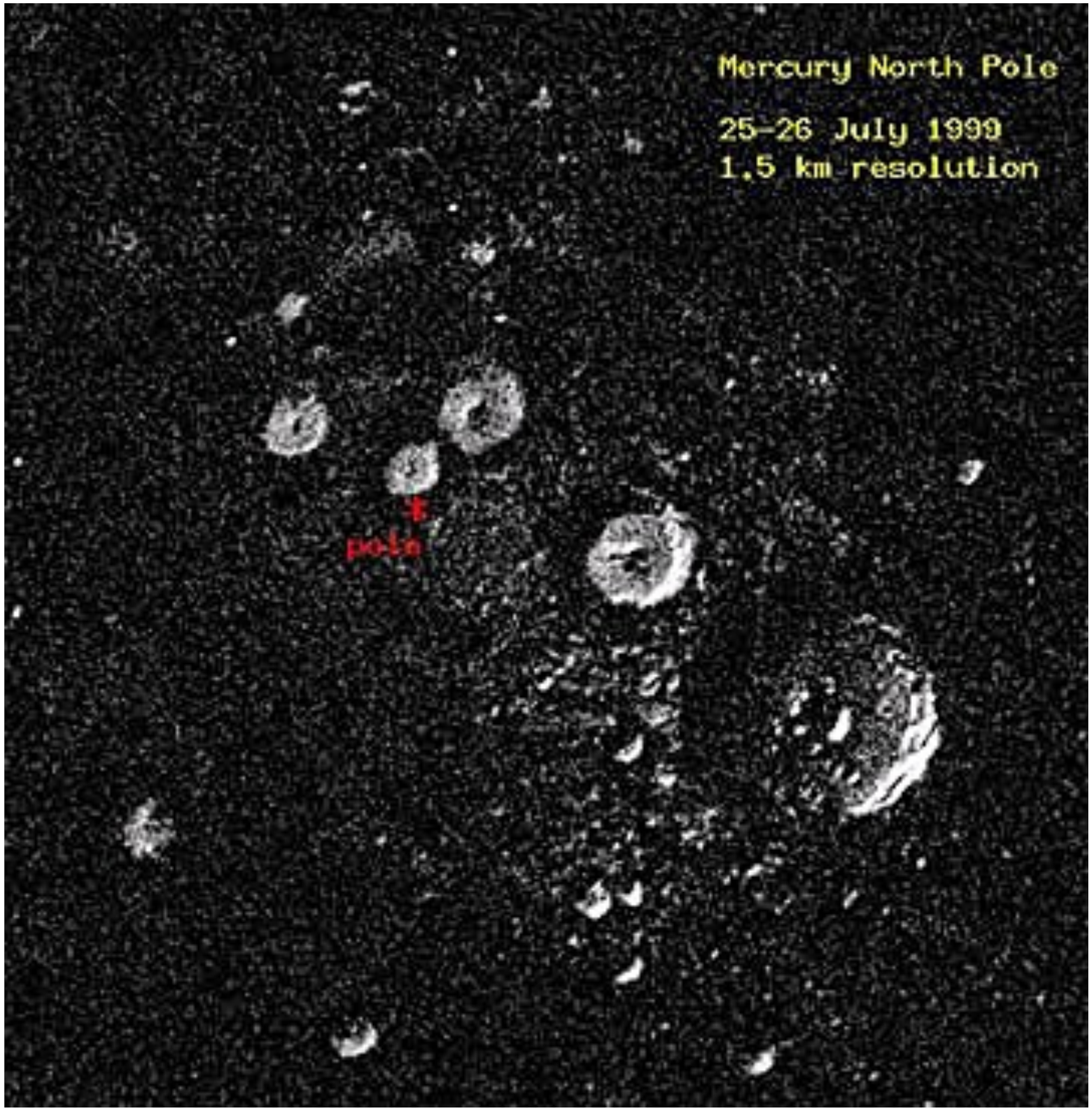


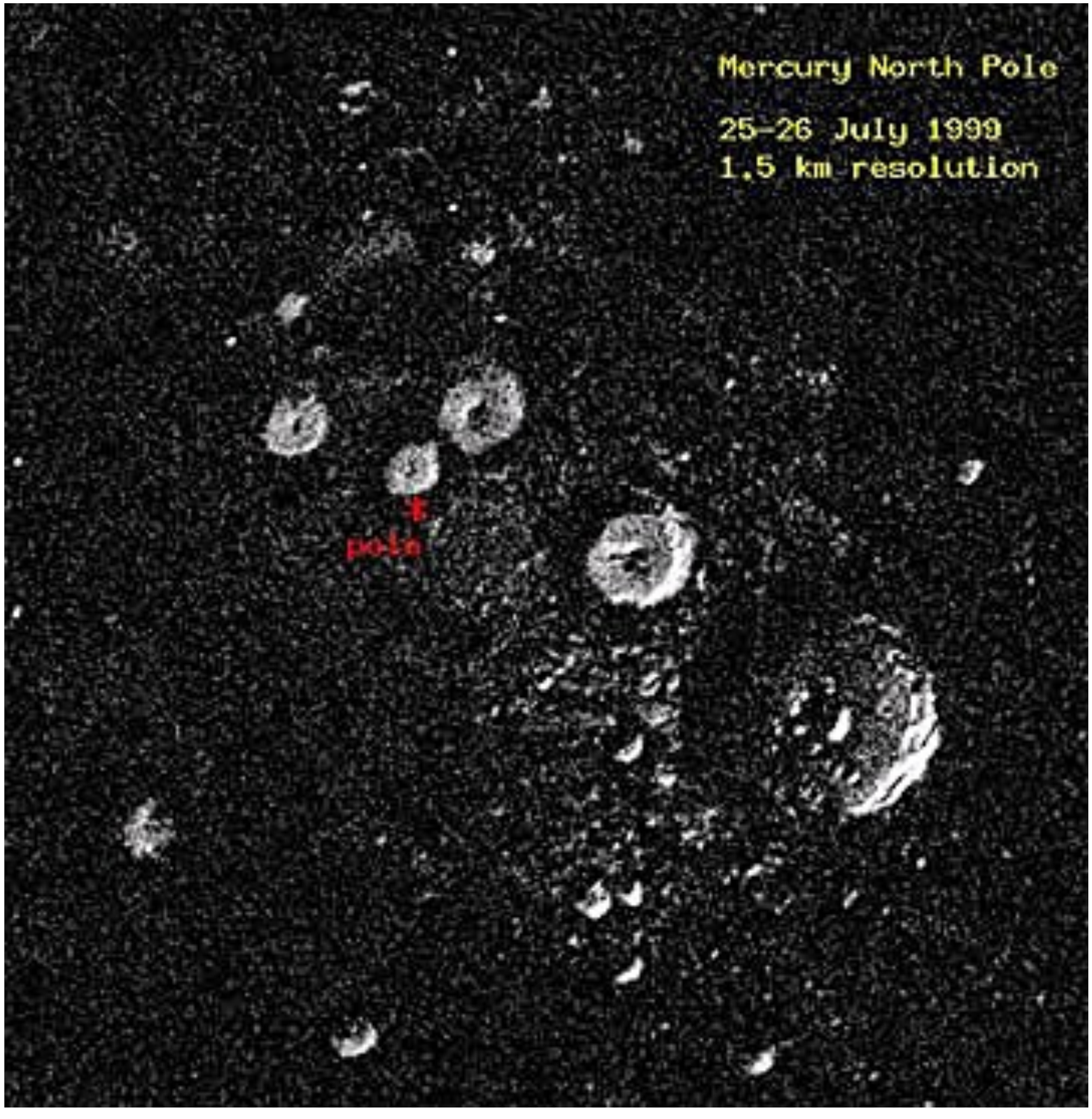
2006 Mercury transit



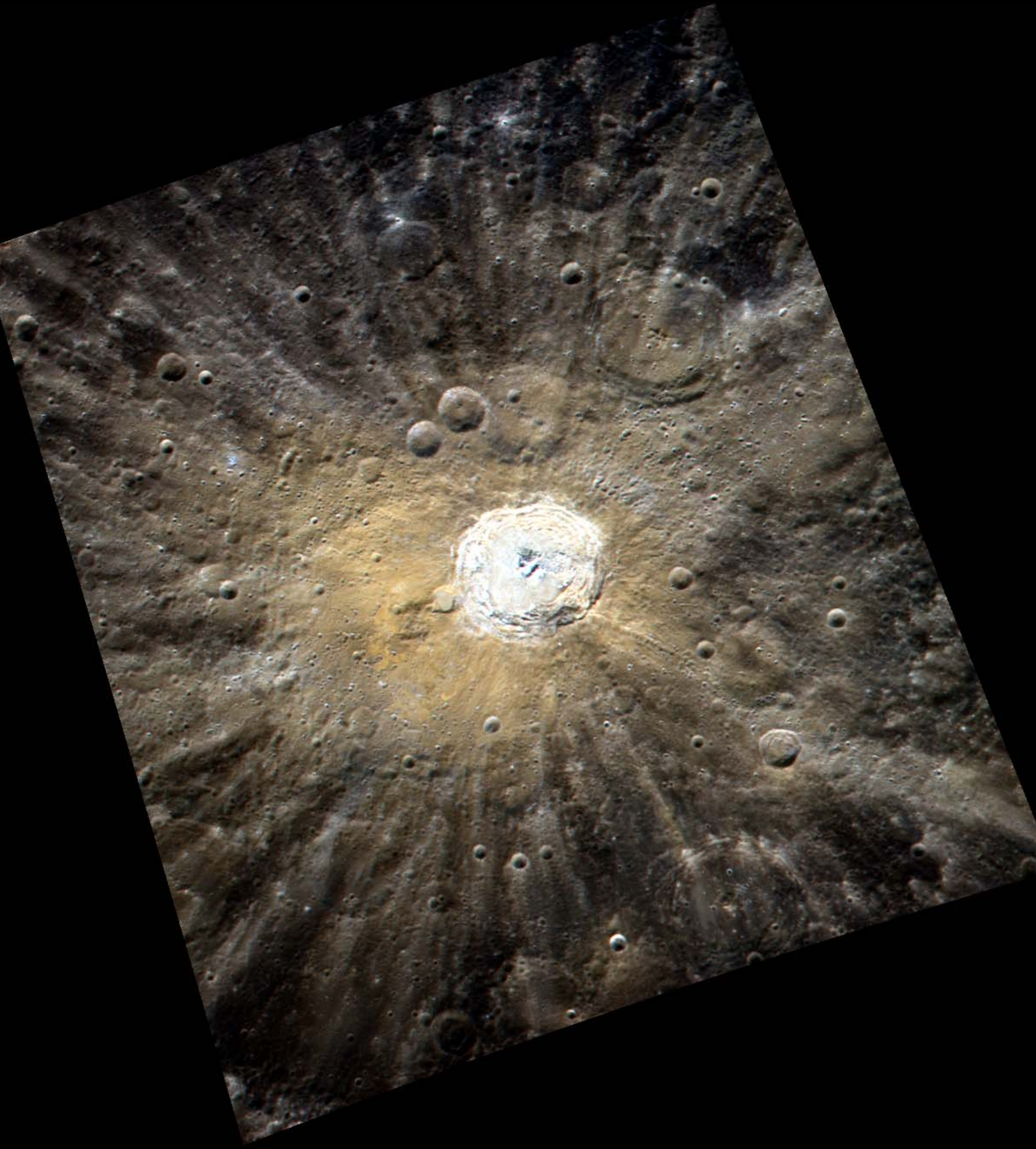


Mercury surface; Image credit NASA


Mercury North Pole
25-26 July 1999
1.5 km resolution
pole



Mercury surface; Image credit NASA



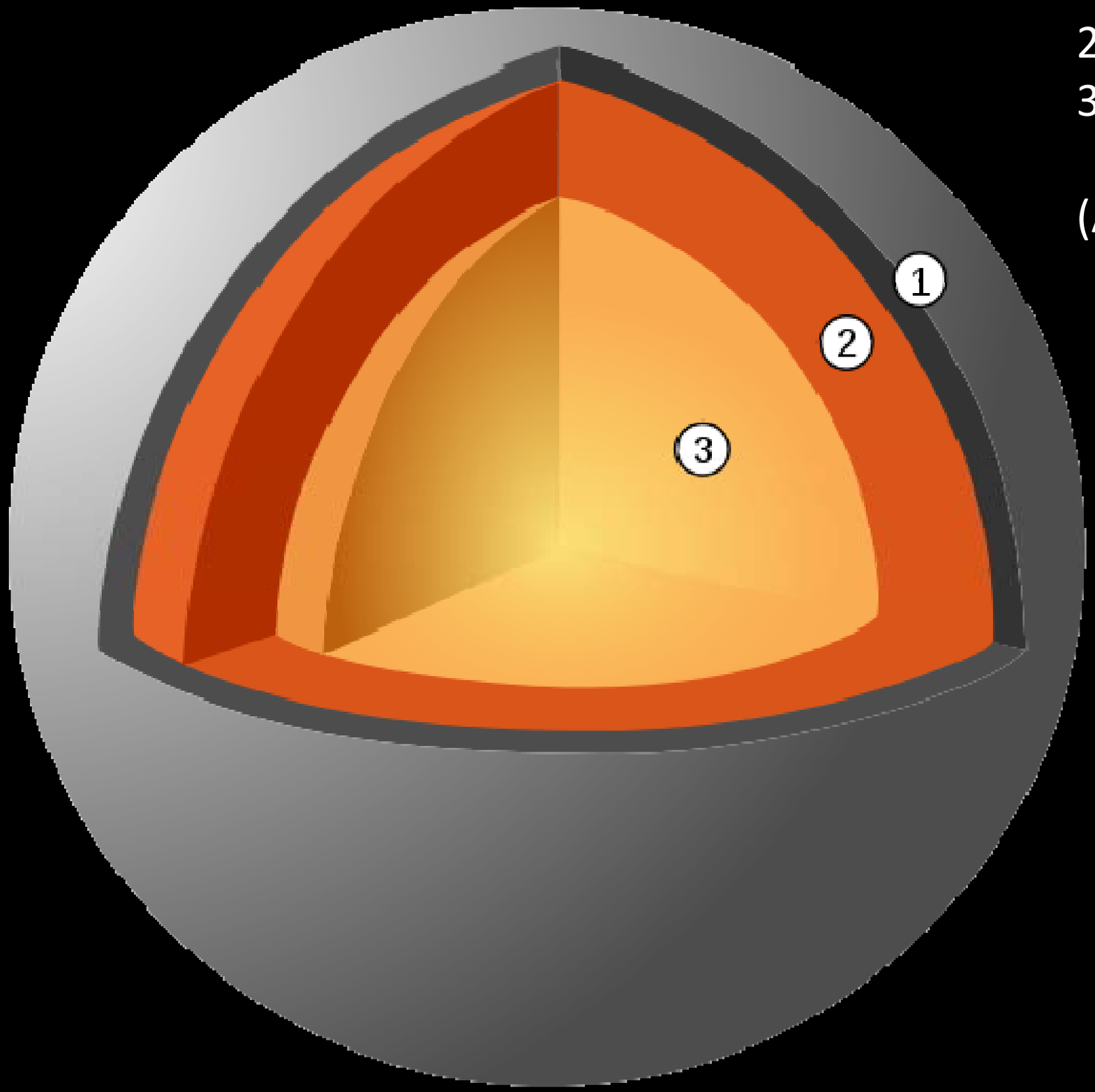
Iron core

- Mean density $\rho=5.43$ g cm^{-3}
- If only rock ($\rho=3.3$ g cm^{-3}) and iron ($\rho=7.95$ g cm^{-3})
- ~ 60% of the mass are iron
- ~ 75% of the radius is inner iron core

Suppose a two-component “spherical” pie…

Mercury Temperature Variance

- Equatorial: 100 K (night) to 700 K (day)
- Polar: constantly below 180 K
- Rotation is locked in a gravitational resonance
    - 3 rotations for each revolution



1. Crust: 100–300 km thick
2. Mantle: 600 km thick
3. Core: 1,800 km radius

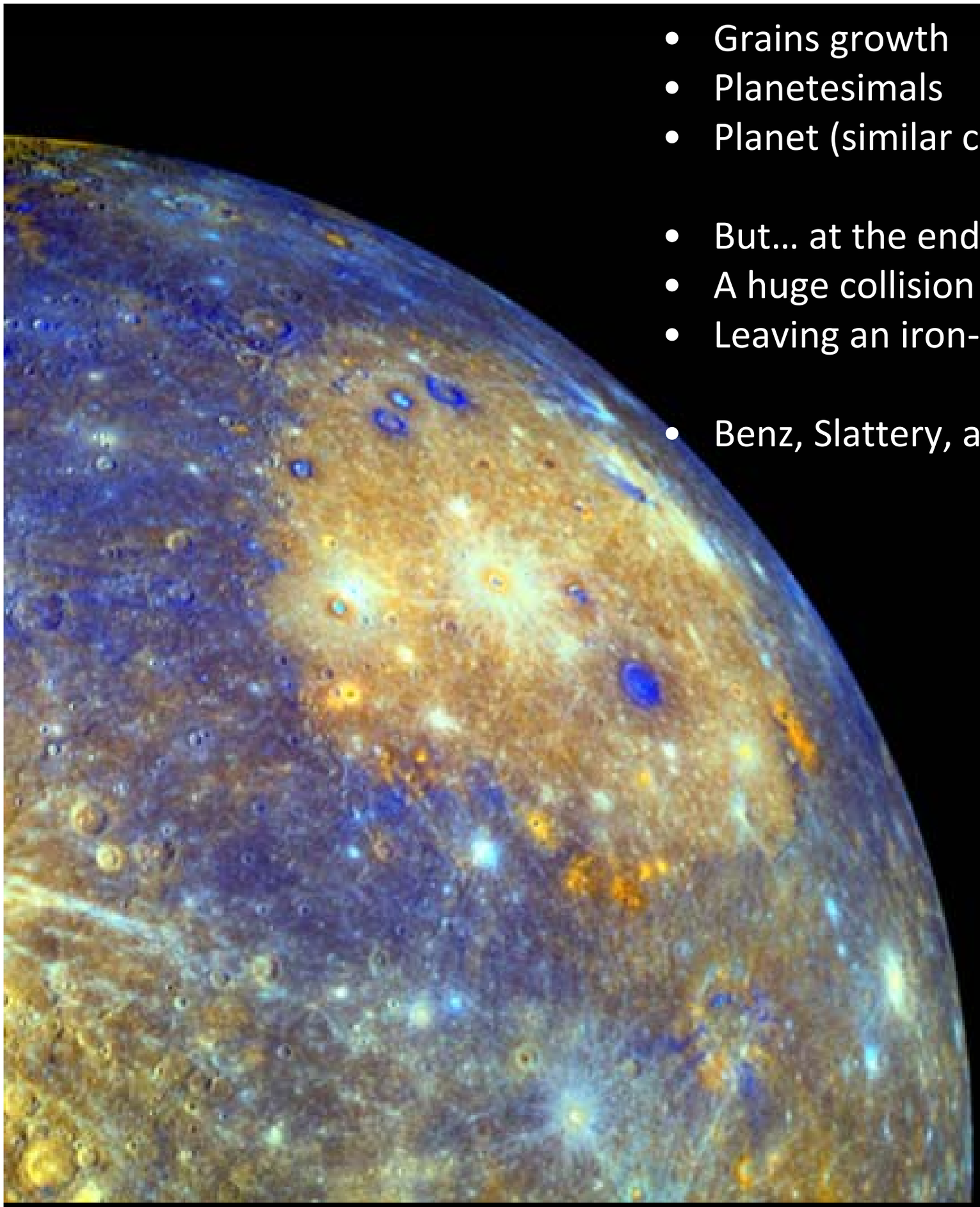
(Another sketch in Fig. 6.21)

Credit: Joel Holdsworth from Wikipedia

Why do we care?

- Strong constraint on formation model
- Solar system formation & evolution?

- Remember ~ 60% mass fraction
- Twice the chondritic percentage
- This led to the “impact model”



- Grains growth
- Planetesimals
- Planet (similar chemical composition as chondrites?)

- But… at the end of Mercury formation…
- A huge collision removed much of its mantle
- Leaving an iron-rich Mercury

- Benz, Slattery, and Cameron 1988 [1]

Stable orbit?
Stress and Strain?
Timescale?
Composition?

Credit: NASA

Solar evaporation

Cameron 1985 [2]

- Protomercury formed in Solar nebula
- Late stage inner Solar System very hot
- At the position of Mercury ~3000K
- Rocky mantle → vaporized & mixed into nebula → carried away

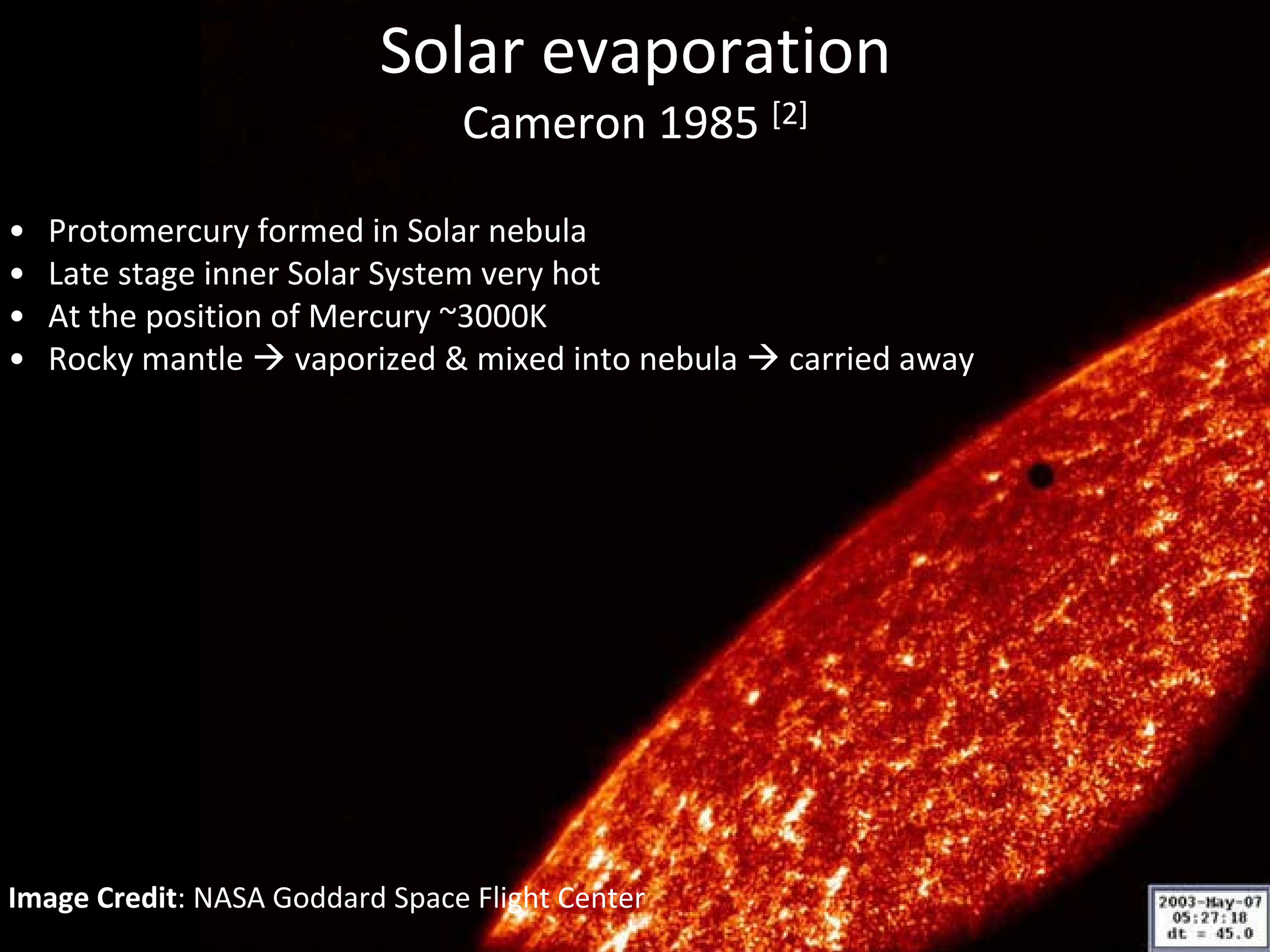


Image Credit: NASA Goddard Space Flight Center

Gas drag[3]

- Inner solar nebula
- Removal process
- Slightly less effective for iron than silicate
- Planetesimals with high iron-to-silicate ratio

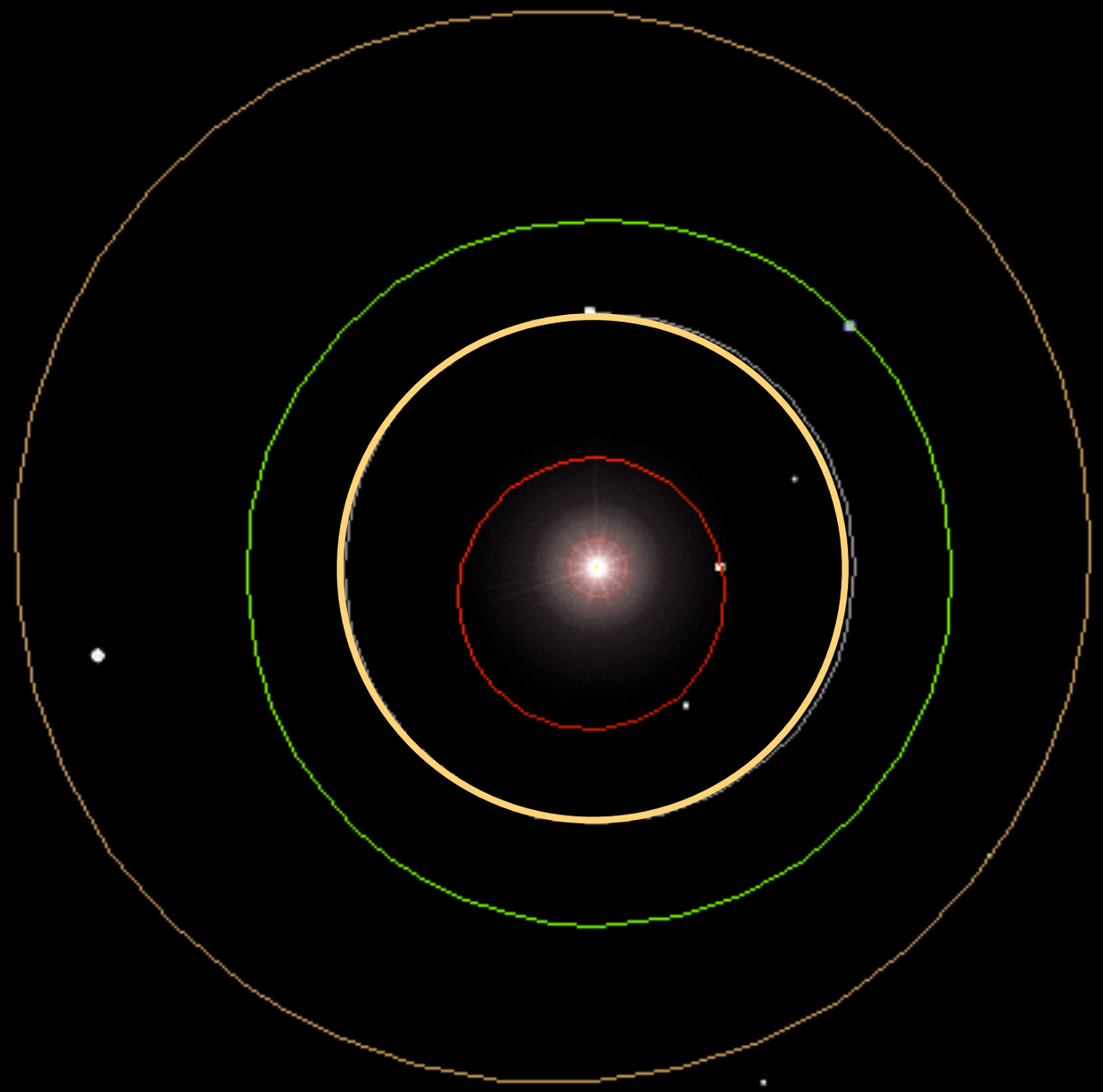
In situ or Migration?

- The last two model

- The first model

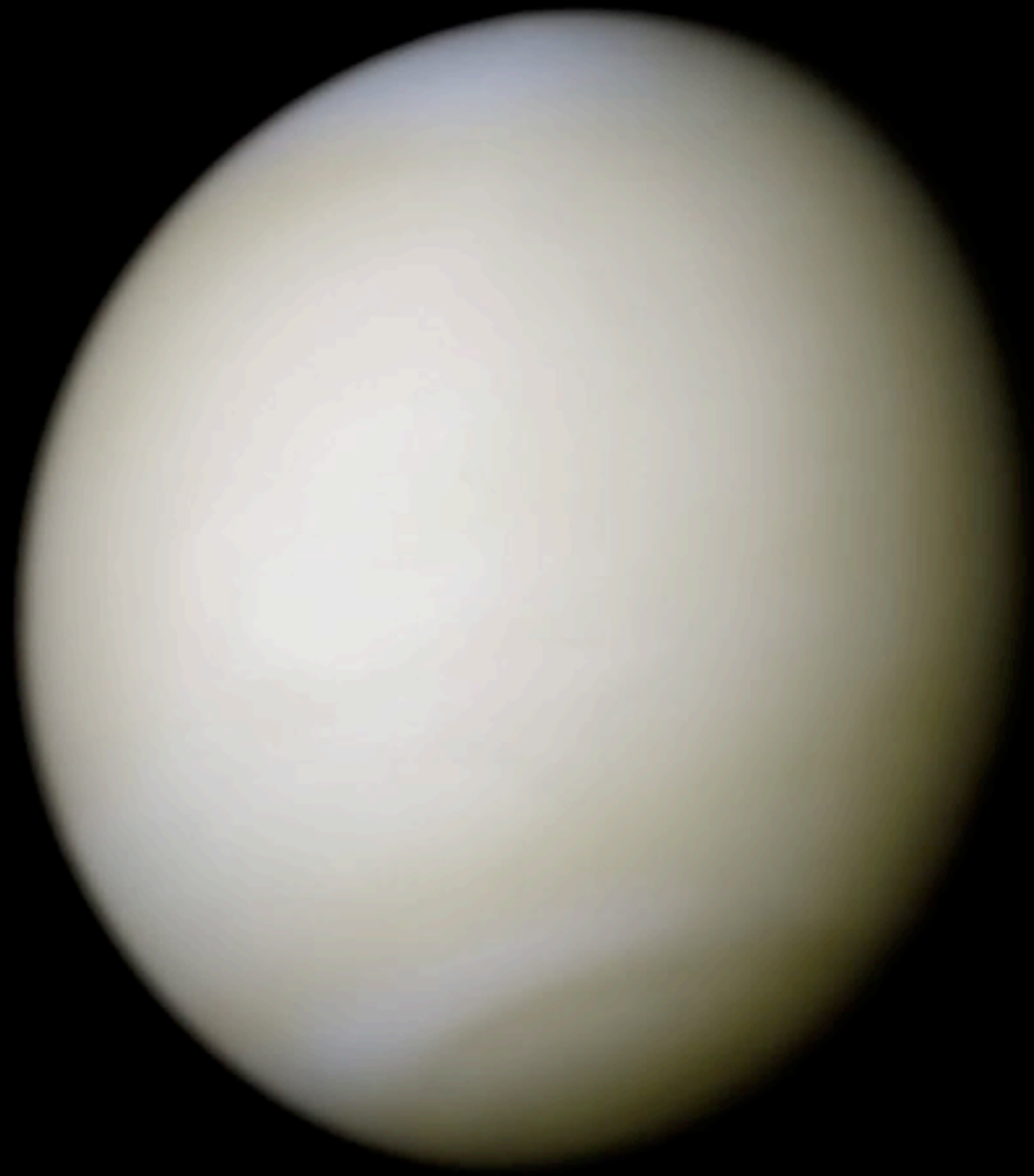
Properties of Venus

- <u>Orbital Data</u>
- a = 0.723 AU
- P = 224.7 days
- e = 0.007
- tilted by 3.39º
- Most circular orbit among the planets.



Properties of Venus

Properties of Venus



- Planetary Data
- Radius: 6052 km
  - –(0.949 R_{Earth})
- Mass: 0.815 M_{Earth}
- Rotation: 243.02 days
  - –Retrograde!
- Axis Tilt: 177.4º
  - –Upside down!

Retrograde Rotation

- Venus has a slow, retrograde (east-to-west) rotation.
  - Rotation Period is 243 days
  - This is surprisingly slow!
- Possible Causes:
  - Tidal interaction between Venus, Sun, & Earth with complex braking by the atmosphere.
  - Massive glancing impact virtually de-spinning Venus and making it go slowly backwards.
- No magnetic field

Venus' Atmosphere

- Composition:
  - 96% Carbon Dioxide (CO_2)
  - 3.5% N_2
  - 0.15% Sulfur Dioxide (SO_2)
  - <0.1% Water Vapor (bone dry!)
- Surface Pressure: 90 atmospheres
  - Like the ocean at a depth of ~1 km!
- Surface Temperature: uniform 750 K (891º F)

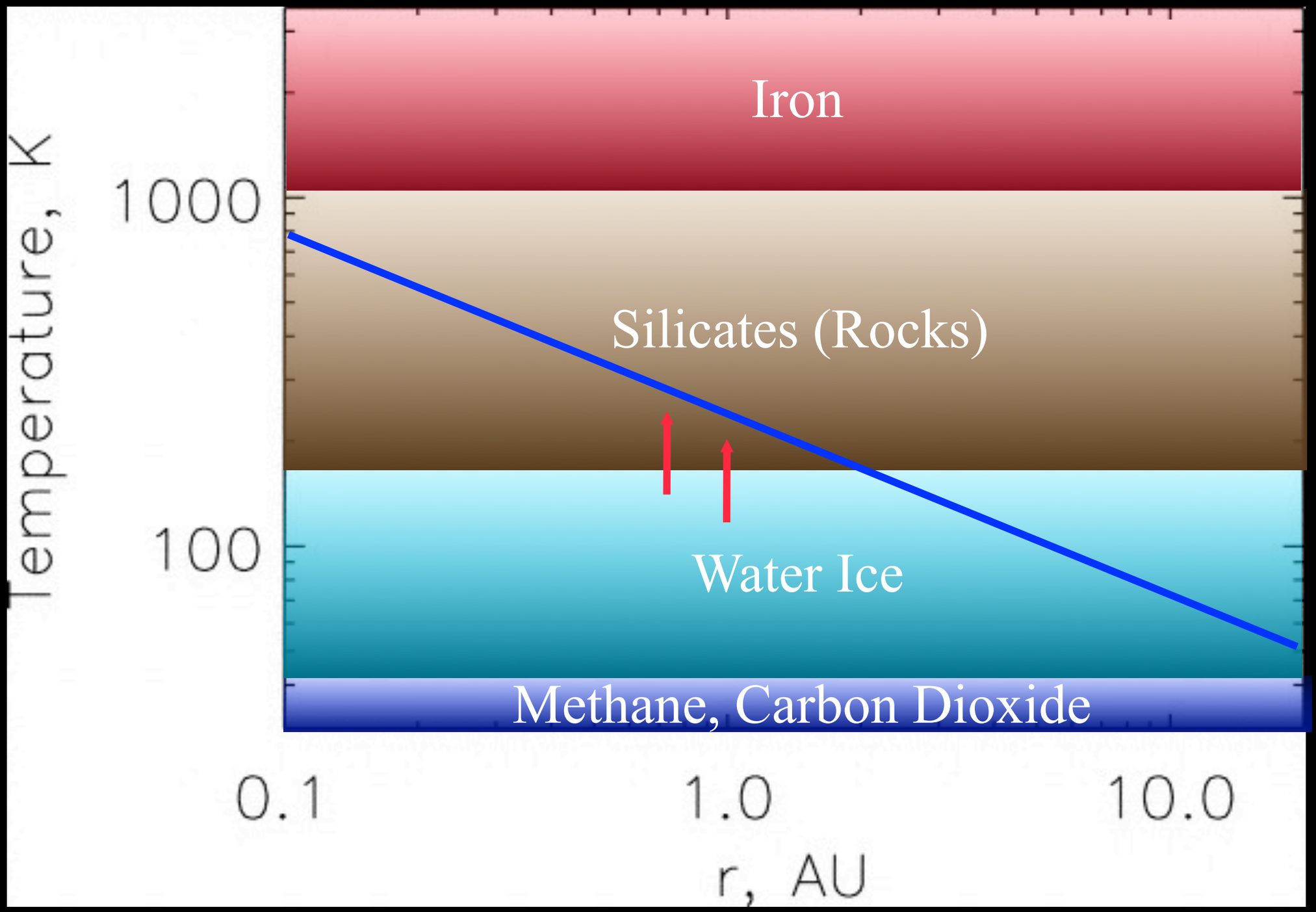
Atmospheres of Earth & Venus

- Earth:
  - Warm, light, moist, N_2 & O_2 atmosphere
- Venus:
  - Hot, heavy, very dry CO_2 atmosphere

- Why so different?

Compositional Gradients

- Venus and Earth should be made of the same stuff



Cooling Time

$$\text{Cooling Time} = \text{constant} \times \frac{R}{T_{initial}^3}$$

95% of Earth's

Atmosphere

$$v_E = \sqrt{\frac{2GM}{R}}$$

v_E = 93% of Earth's

$$v = \sqrt{\frac{3kT}{m}}$$

v = 108% of Earth's

Artist’s conception of Venus in 1918

Sulfuric Acid Clouds

- The clouds of Venus are not water vapor clouds like on Earth:
  - Mostly droplets of Sulfuric Acid (H_2SO_4).
  - Form a thick layer between 48 & 58 km altitude
- Lower atmosphere and surface are clear below the H_2SO_4 cloud deck.

Spacecraft Visits

- Flybys: Mariner & Pioneer satellites (1962)
- Landers:
  - –Venera 7 (1970 - USSR) - first soft landing
- Atmospheric Probes:
  - –Pioneer Venus (US: 1978)
  - –Vega 1 & 2 balloon probes (USSR: 1985)
- Orbiters:
  - –Venera 15 & 16 (USSR: 1983)
  - –Magellan (US: 1990-1994)
  - –Venus Express (ESA: 2005-2006)

The Surface of Venus
Venera 14, 1982 (lasted 60 minutes)

Artist’s conception of the surface of Venus

What Went Wrong?

VIRTIS temperature map
(ESA Venus Express)

modelled data
based on Magellan (NASA)

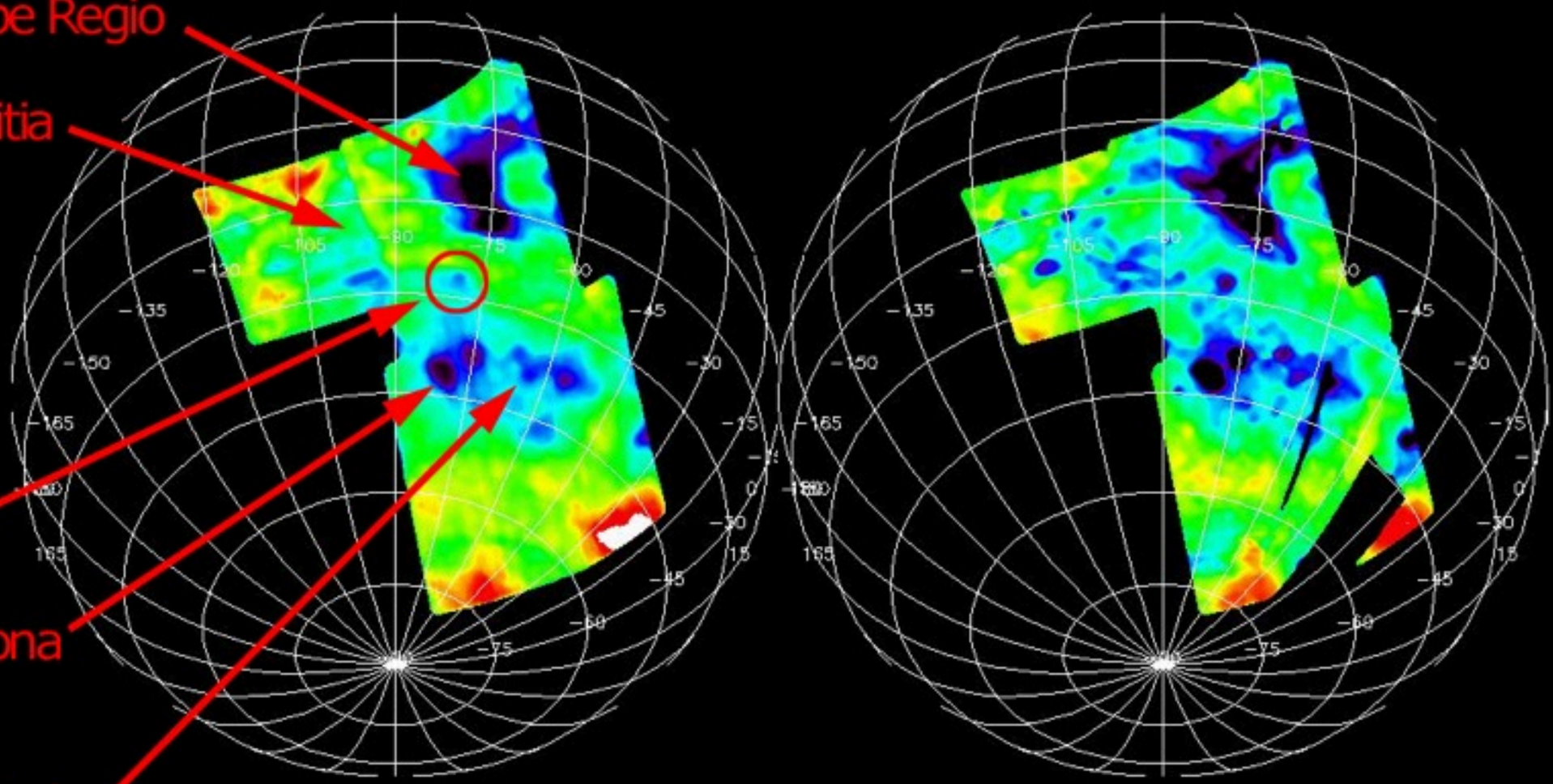
Phoebe Regio

Gunda Planitia

Mielikki Mons

Shiwanokia Corona

Themis Regio



Equilibrium Temperature at Venus

$$T \sim 278\mathrm{K}\left(\frac{a}{\mathrm{AU}}\right)^{-1/2}$$

$$a = 0.723\mathrm{AU}$$

$$T \sim 327\mathrm{K} = 54^\circ\mathrm{C} = 130^\circ\mathrm{F}$$

Warm, *but reasonable.*

Equilibrium Temperature at Venus

$$T \sim 278\mathrm{K}\left(\frac{a}{\mathrm{AU}}\right)^{-1/2}$$

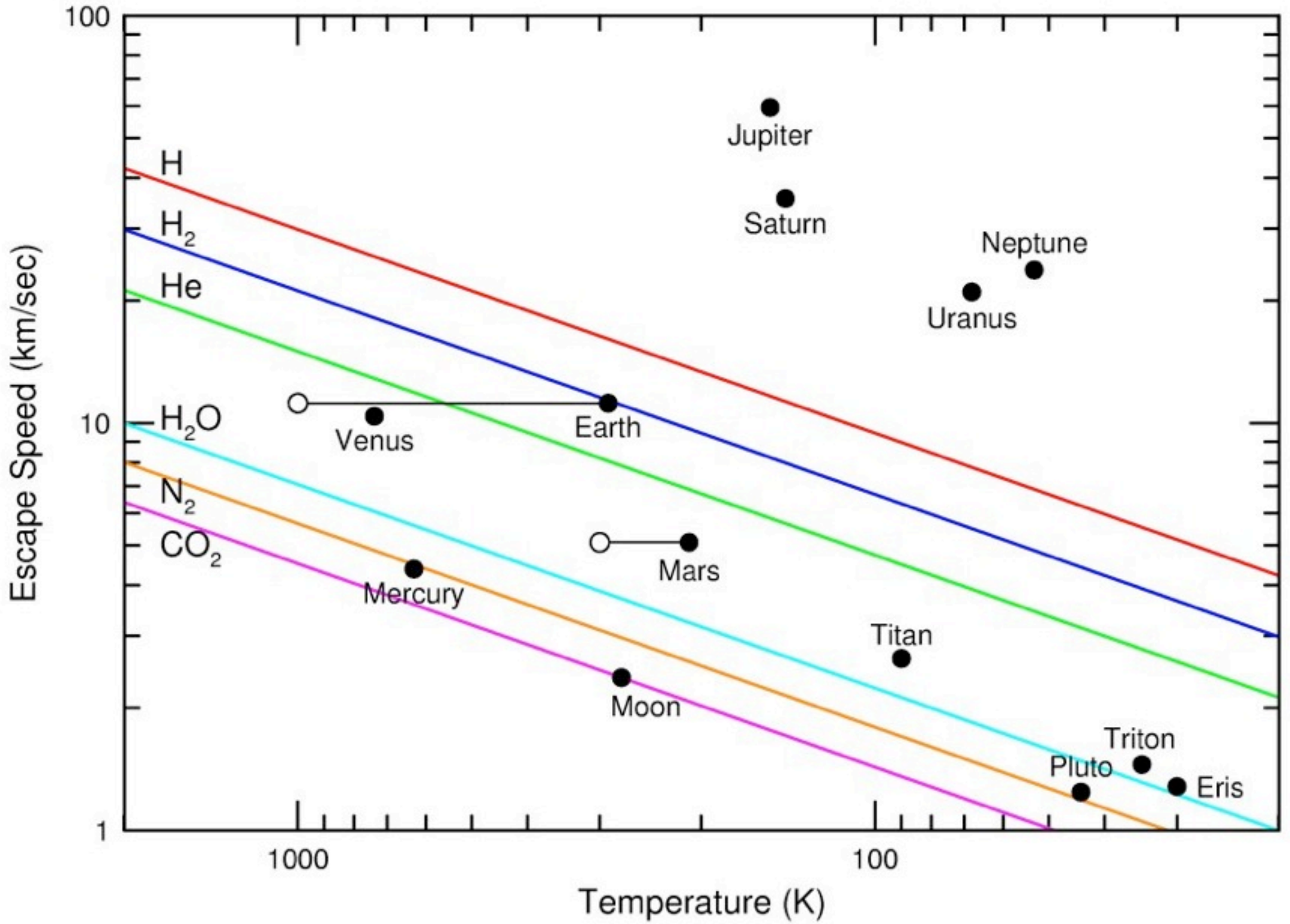
$$a = 0.723\mathrm{AU}$$

Warm, *but reasonable.*

Why Is Venus So Hot?

Why Is Venus So Hot?

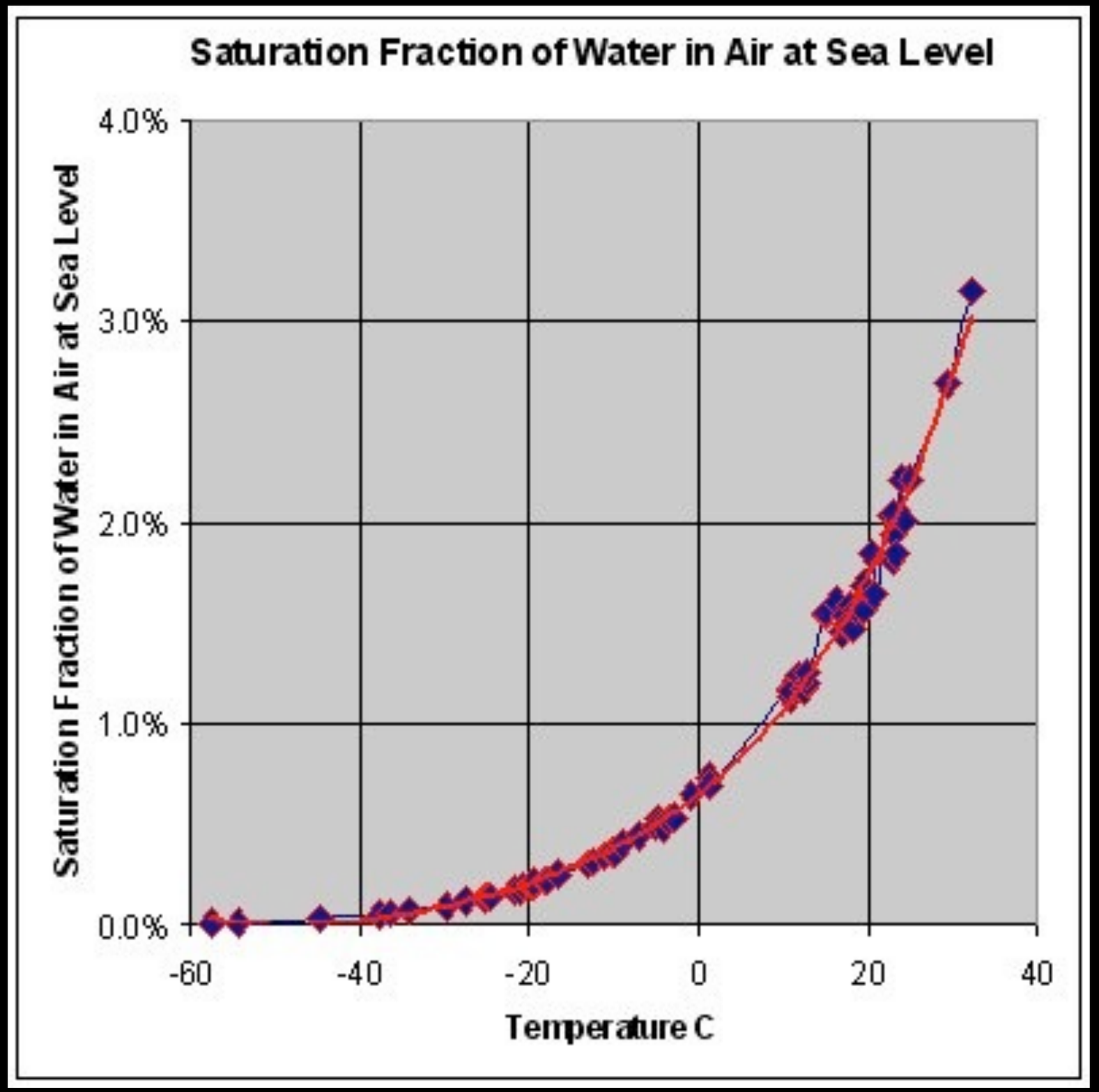
- Venus is so hot (750K) because of the greenhouse effect:
  - Hot, heavy CO_2 atmosphere
  - Heat trapping makes Venus 500K *hotter* than it would be with no atmosphere.


100
10
1
Escape Speed (km/sec)
1000
100
Temperature (K)
H
H_2
He
H_2O
N_2
CO_2
Jupiter
Saturn
Neptune
Uranus
Venus
Earth
Mars
Mercury
Titan
Moon
Triton
Pluto
Eris

Early Atmospheres Similar

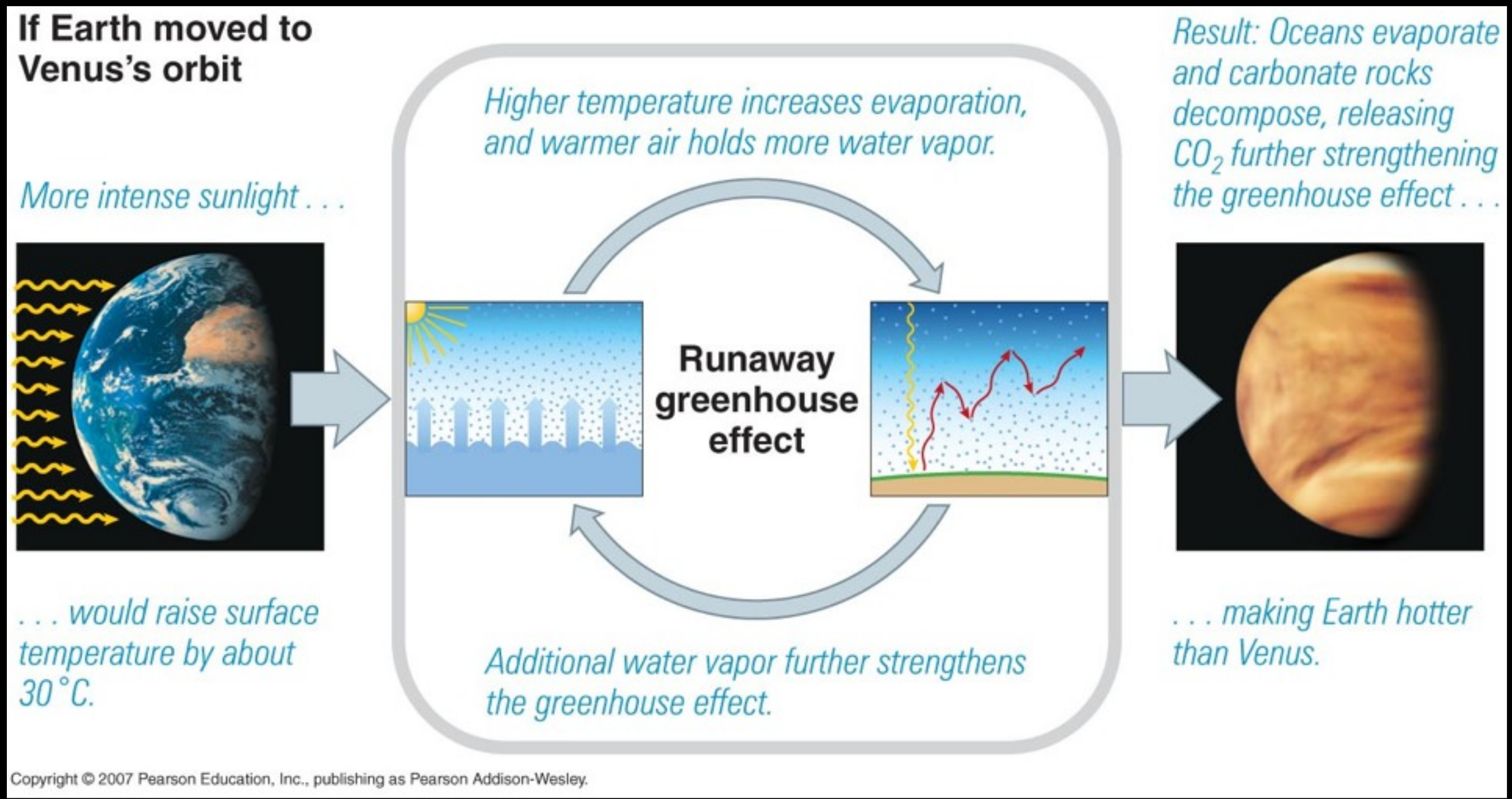
- Volatiles from outer solar system
- Nearly the same amount of CO_2 on Earth & Venus
  - –On Venus, CO_2 is in the atmosphere
  - –On Earth, CO_2 is locked up on rocks
- Likely had a similar amount of water

Hotter temperatures allow more water in atmosphere



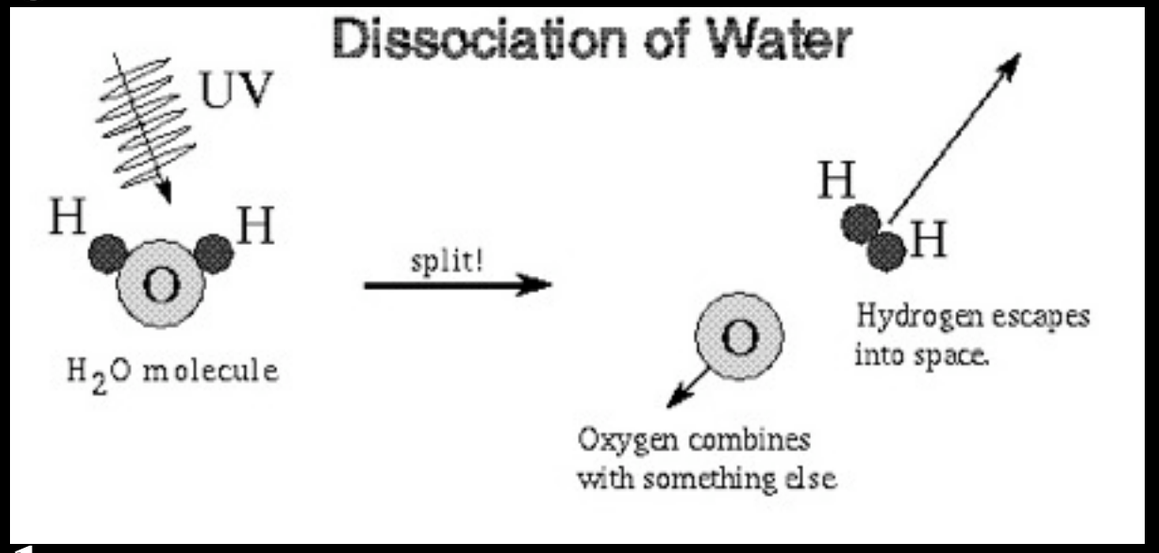
Runaway Greenhouse Effect

slightly closer distance leads to a *runaway greenhouse effect*



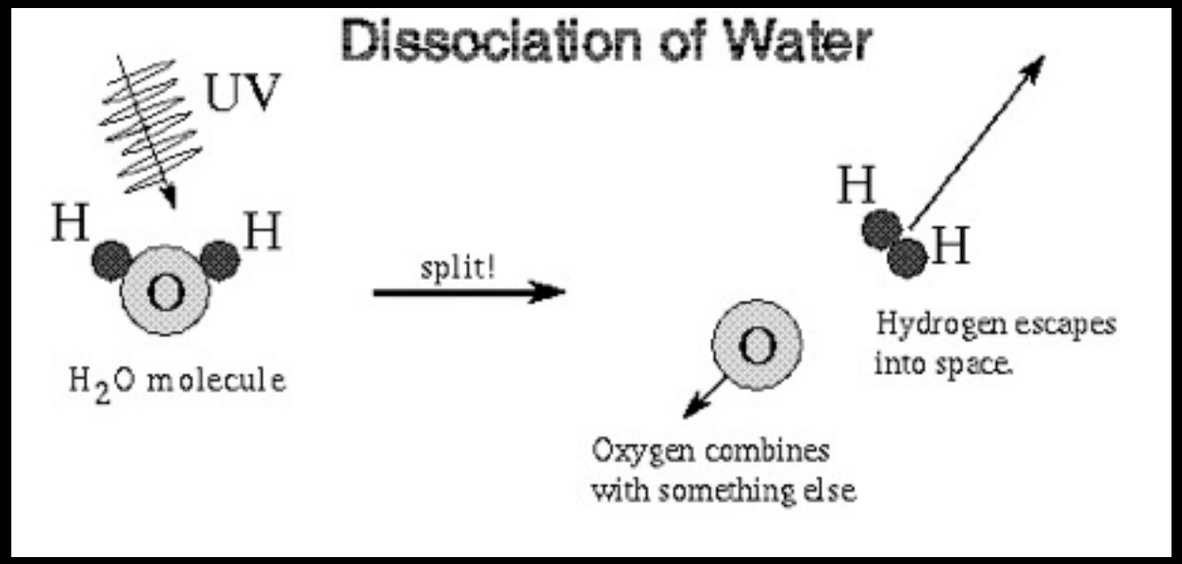
Venus has very little water

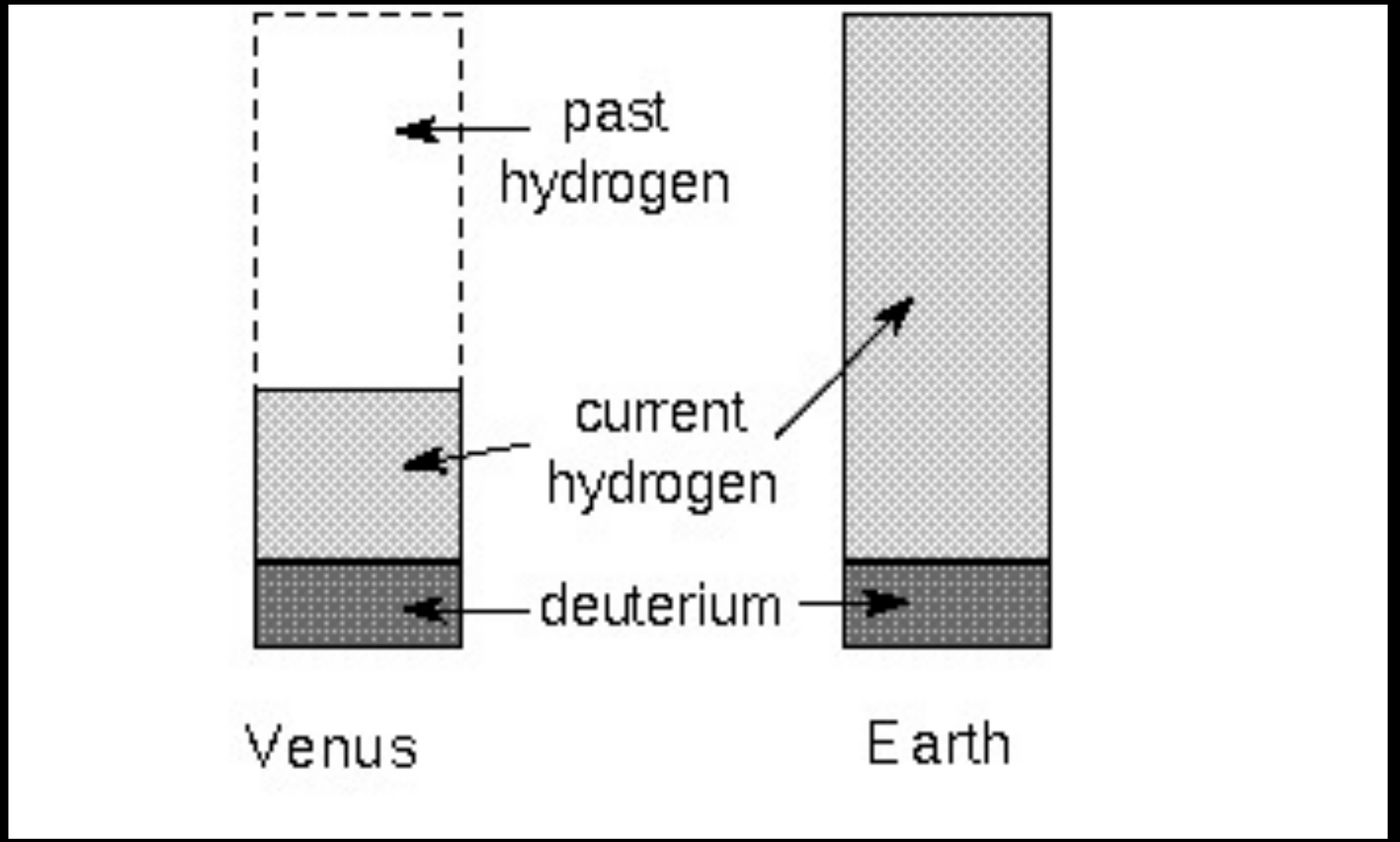
- Because Venus is so hot, water stays as a vapor
- Water vapor gets broken into H_2 and O by UV photons.
- H_2 escapes into space
- Water is constantly removed



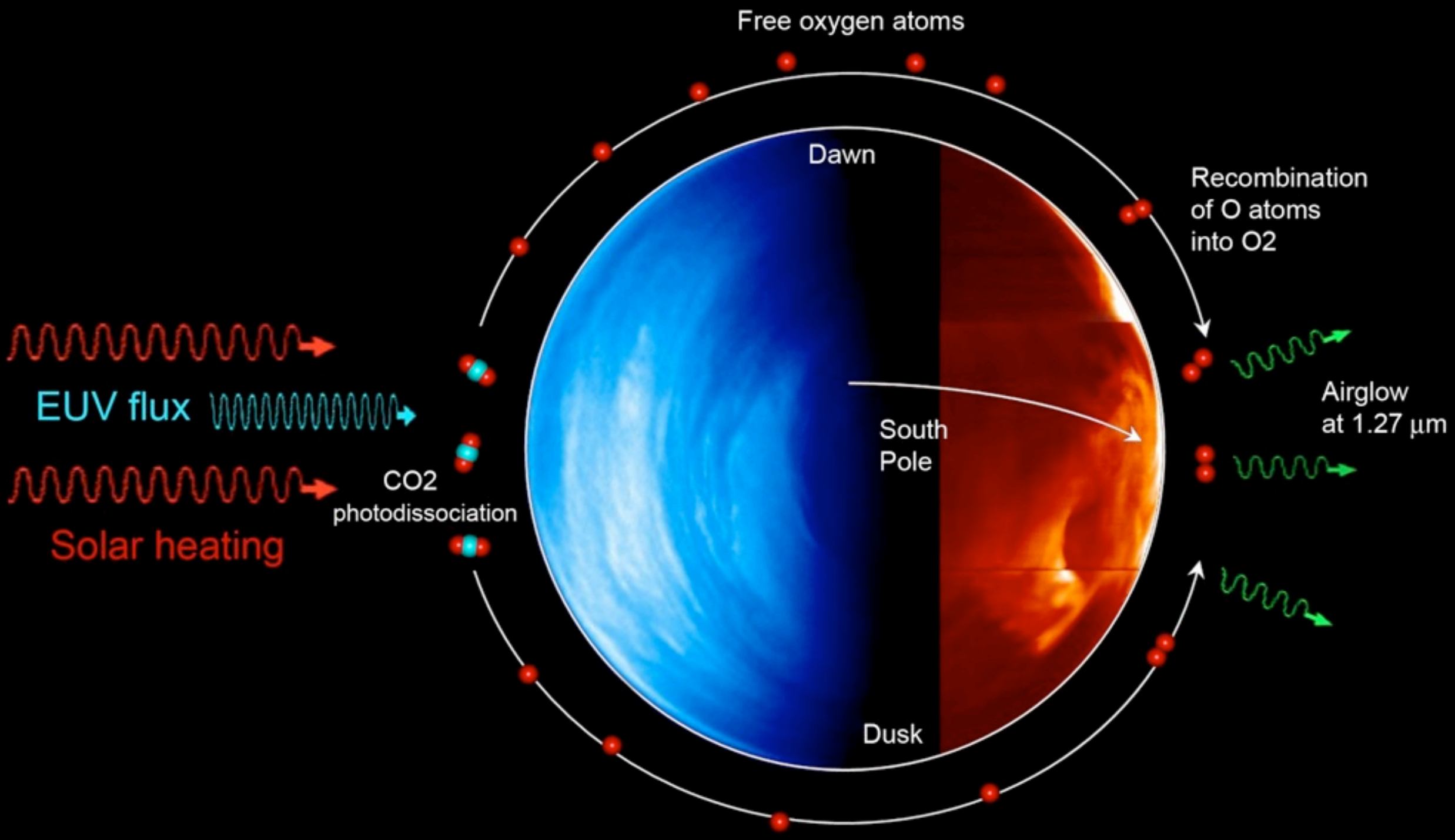
This makes Venus extremely dry today!

Evidence for Water on Venus

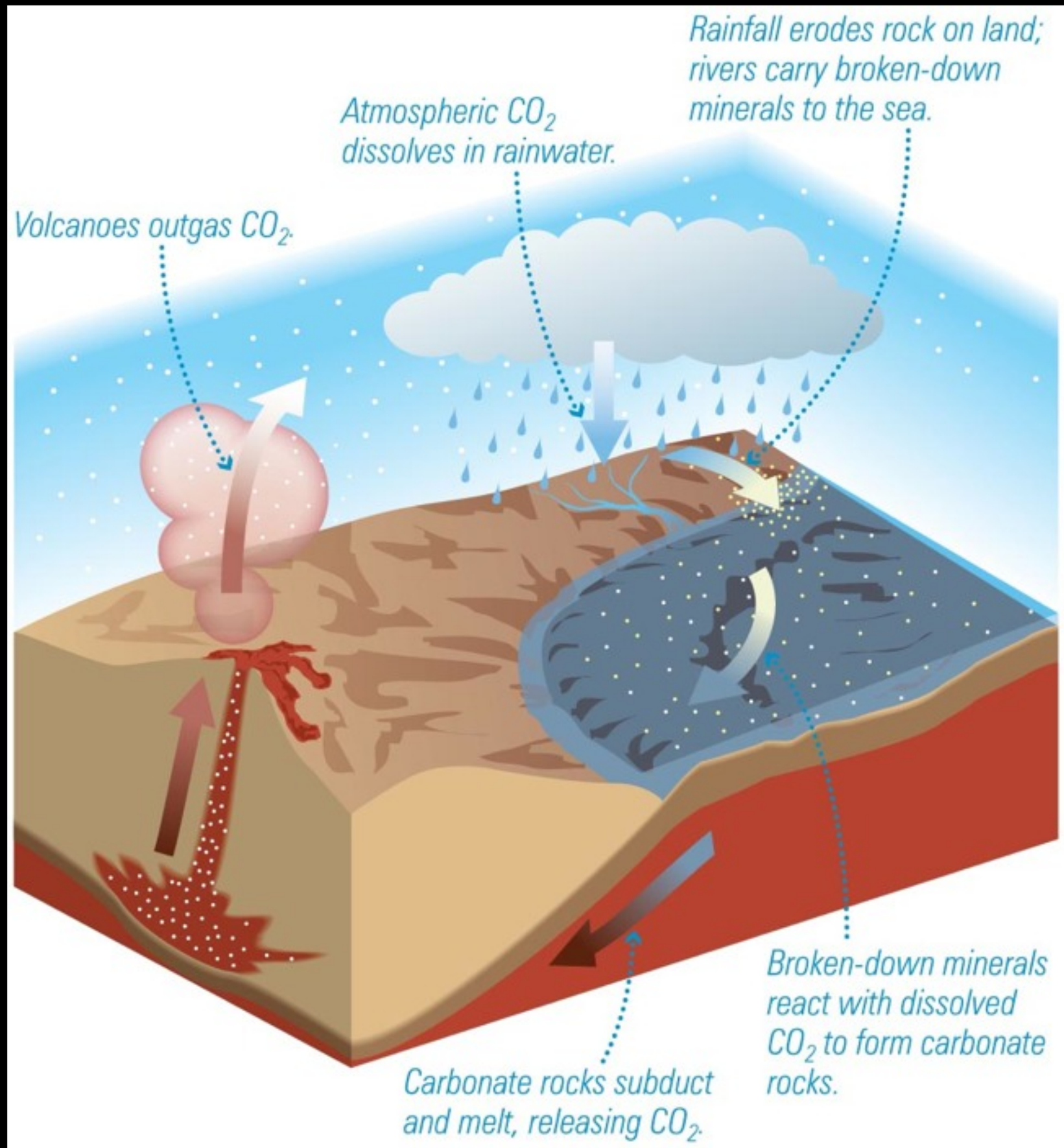




Oxygen Airglow

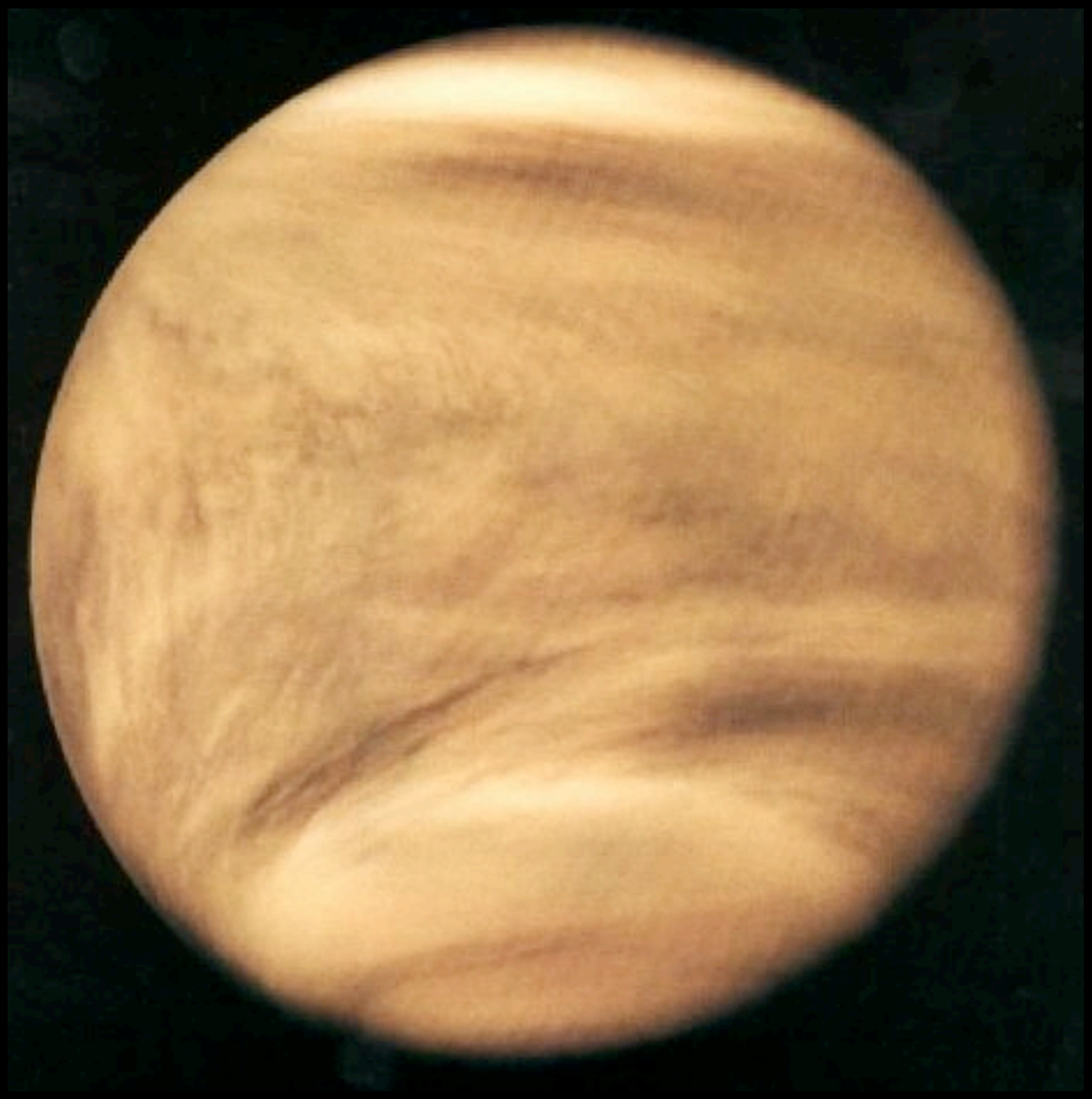


Water: a CO_2 Sink

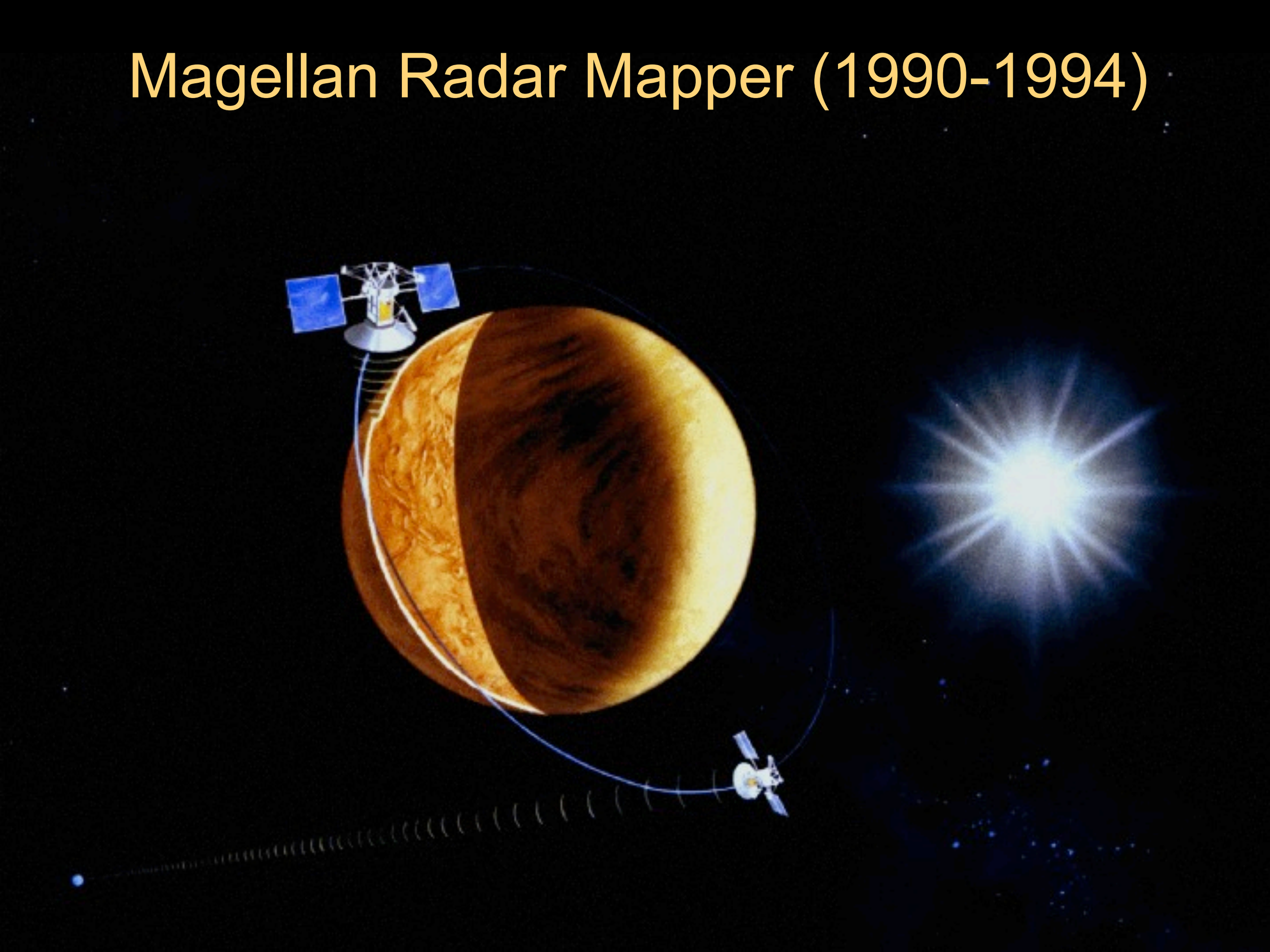


Water:
a CO_2 Sink

Venus Unveiled

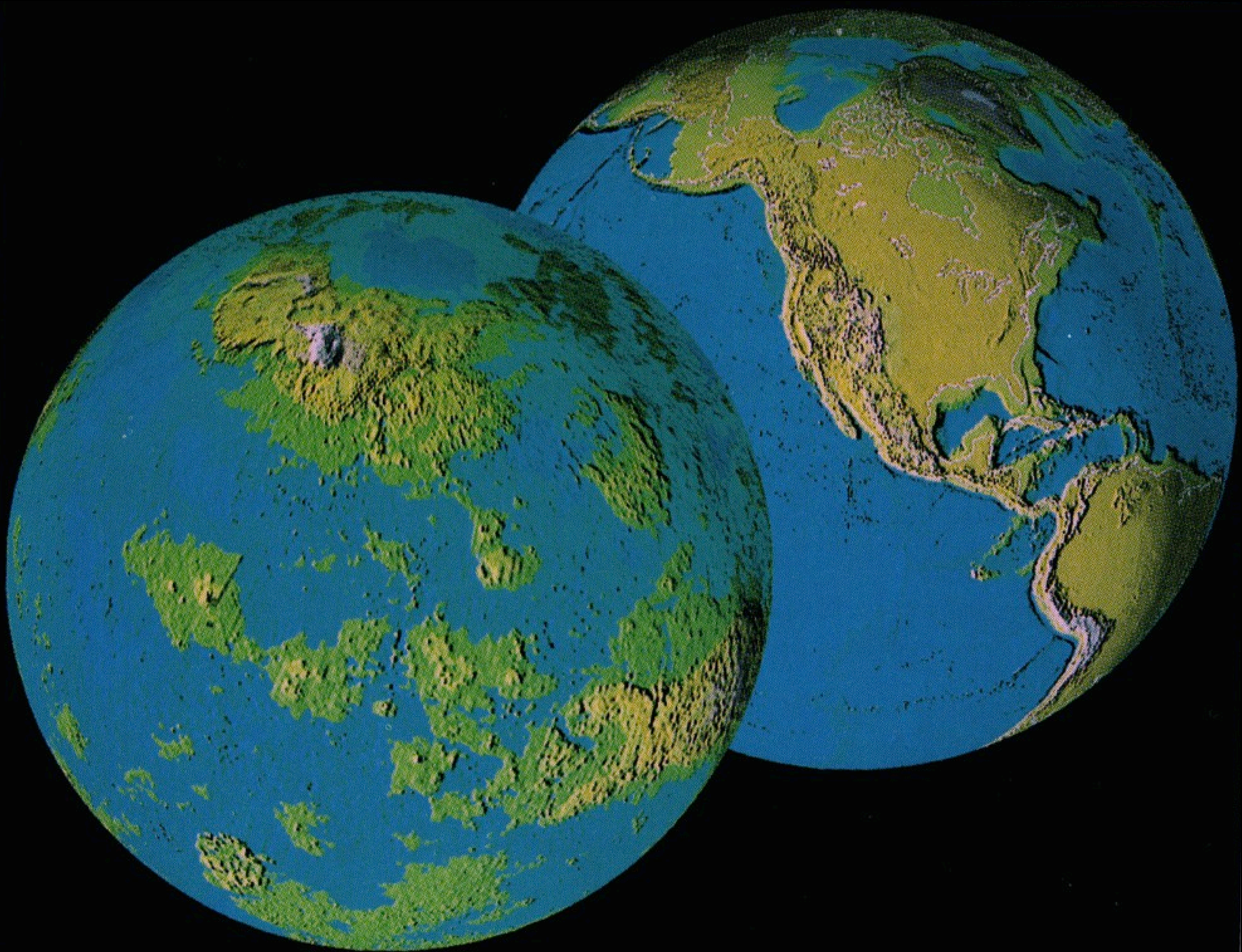


Magellan Radar Mapper (1990-1994)

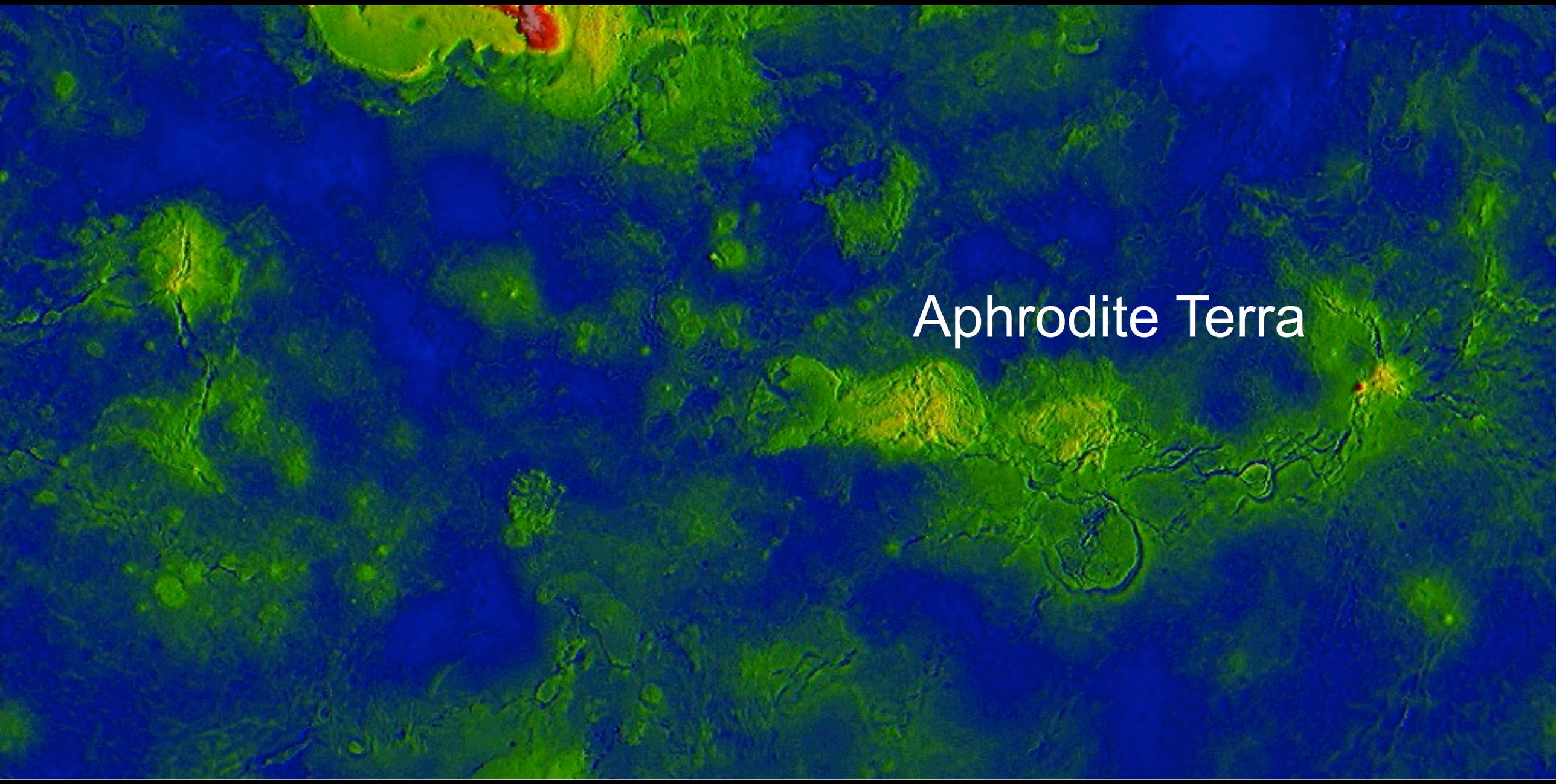


The Surface of Venus

- Terrain:
  - ~85% rolling plains
  - ~15% highland plateaus & mountain belts
- Highlands are concentrated into two regions:
  - Ishtar Terra
  - Aphrodite Terra
- Also see impact craters, volcanoes, and other geological features.



Ishtar Terra



Venus Surface Topography

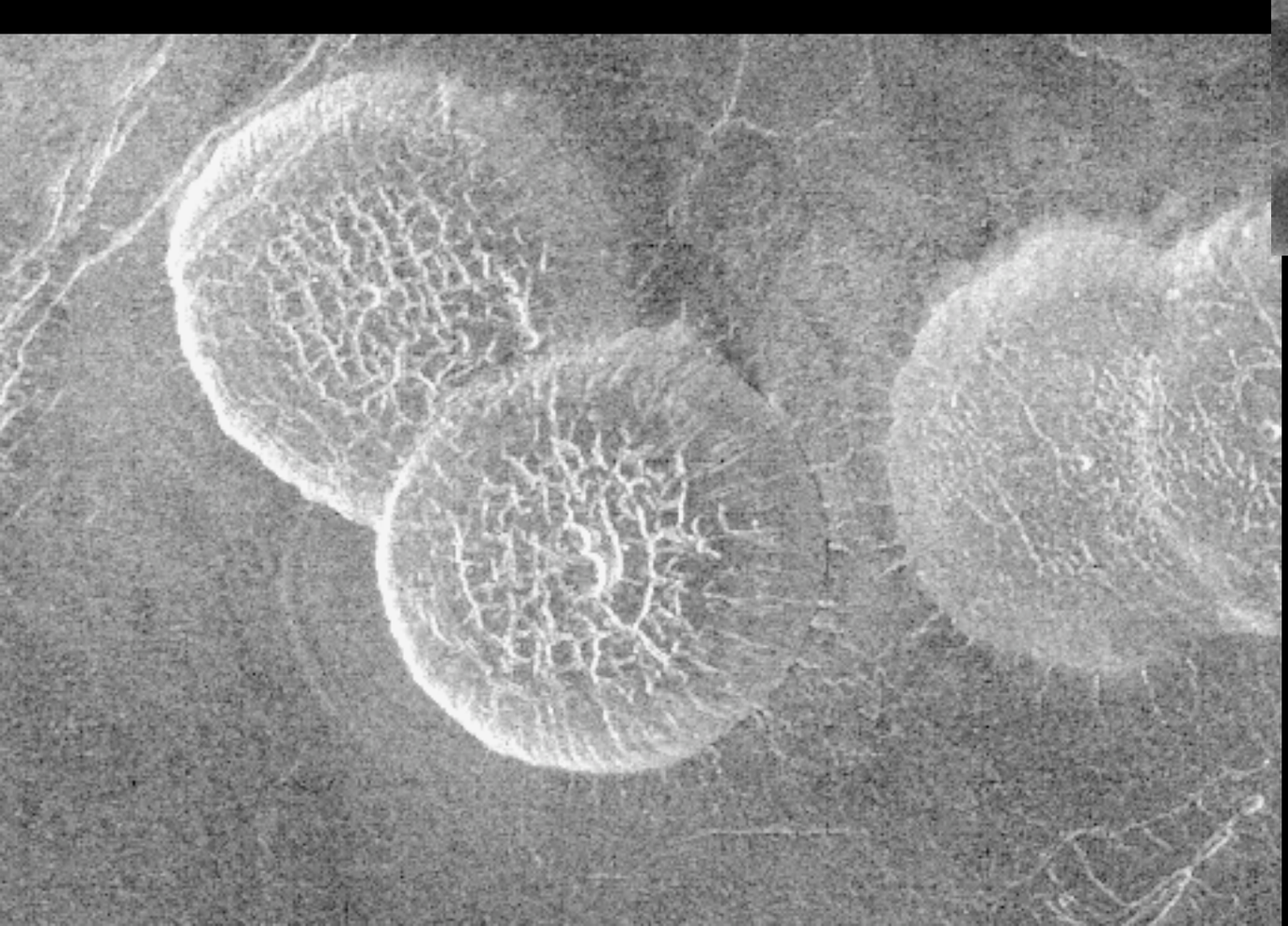
Impact Crater (Danilova)

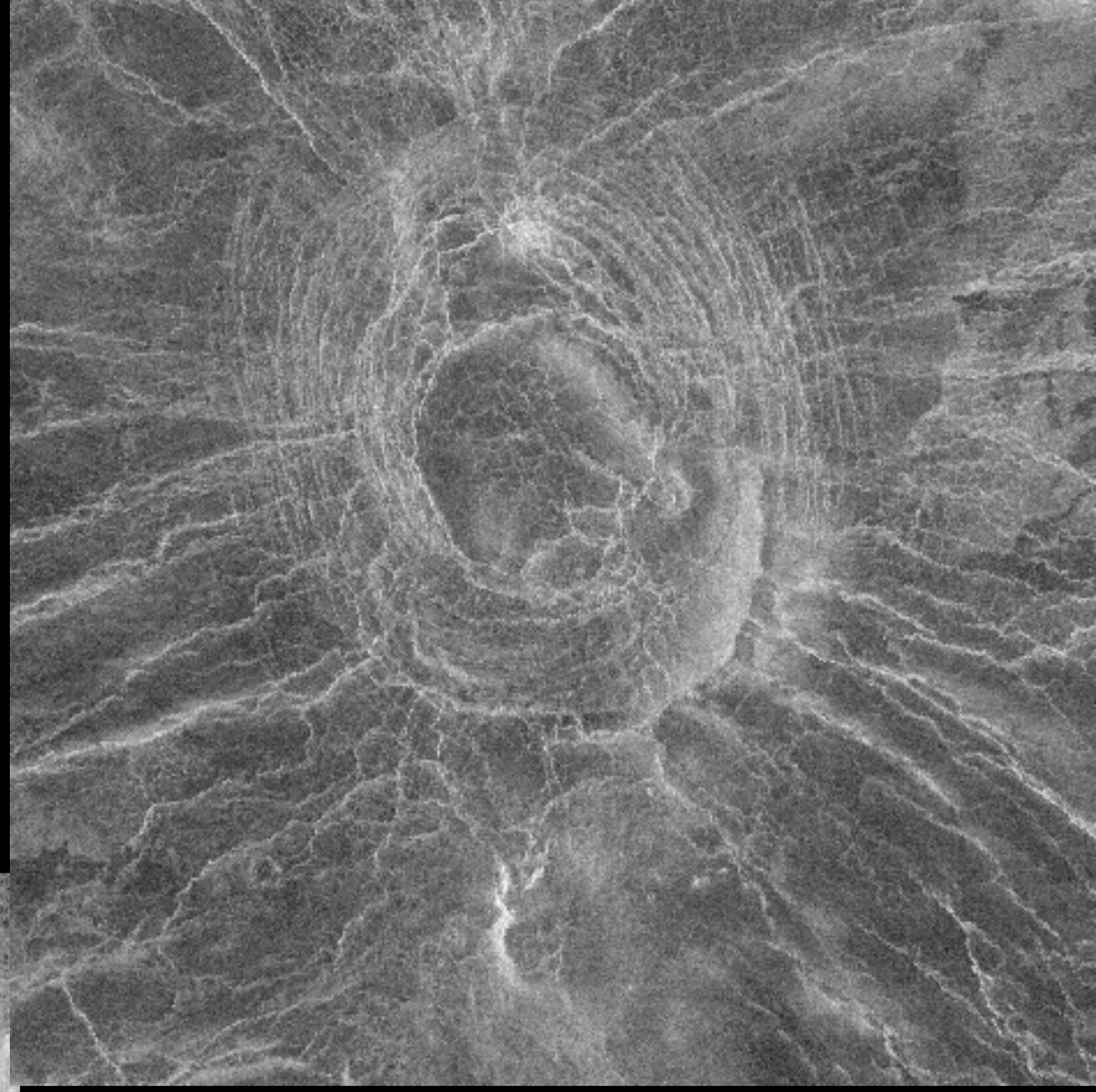
Impact Craters

- Only ~1000 impact craters are seen on Venus:
  - Randomly scattered around the surface.
  - None < 3 km across (no meteors <30m across)
  - ~80% of the surface has been repaved in the last 500 Myr.
- Two competing ideas:
  - Craters get very quickly filled in by volcanism.
  - Catastrophic volcanic repaving of the entire surface ~500 Myr ago.

Small Volcanic Features

Pancake Domes





Corona

Volcanism & Geologic Activity

- Volcanoes are a common terrain feature:
  - None in chains, suggesting no plate tectonics
  - Are some volcanoes active today??

- Tectonics, but *not* plate tectonics:
  - High temperatures makes the crustal rock soft.
  - Upwelling of material from the mantle.
  - Downwelling causing compression.

Venus & Earth

- Volcanic & tectonic repaving:
  - Earth: on-going process
  - Venus: most repaving occurred ~500 Myr ago
- Tectonic activity is different:
  - Earth: *lateral* recycling by sliding motions of tectonic plates.
  - Venus: *vertical* recycling via upwelling & downwelling.
- Lack of plate tectonics on Venus?
  - May be related to lack of water in Venus' crust

Key Ideas:

- In many ways Venus "should" be similar to Earth
  - Nearly the same size & mass
  - Has an atmosphere
  - Equilibrium temperature would support liquid water
- Venus has a hot, heavy CO_2 atmosphere with very little water.
- The surface temperature of Venus is 743 K (878º F)!
- What went wrong?
  - No carbon dioxide sink
  - Probably lost all of its water in a 'runaway greenhouse'
- Venus has implications for the range of habitability

- Retrograde rotation: tides or late-stage impact?
- The surface of Venus is ~500 million years old
  - No large-scale plate tectonics
  - Entire surface repaved by large-scale volcanic activity?

Concept Test

Today, Venus has a thick atmosphere that keeps the surface very hot and has result in Venus losing most of its water.

However, we believe that Venus and Earth were once quite similar. Why is Venus's atmosphere mostly of carbon dioxide and much thicker that Earth's?

A. *Because Venus was closer to the Sun, more carbon dioxide was able to condense out of the protoplanetary nebula.*

B. *Because Venus was closer to the Sun, less water was able to condense out of the protoplanetary nebula.*

C. *Because Venus was less massive than the Earth, it retained a larger fraction of its initial carbon dioxide than water.*

D. *On Earth, most of the carbon dioxide dissolved into the oceans and became incorporated into rocks.*

E. *On Earth, the giant collision that created the moon removed most of the Earth's carbon dioxide.*