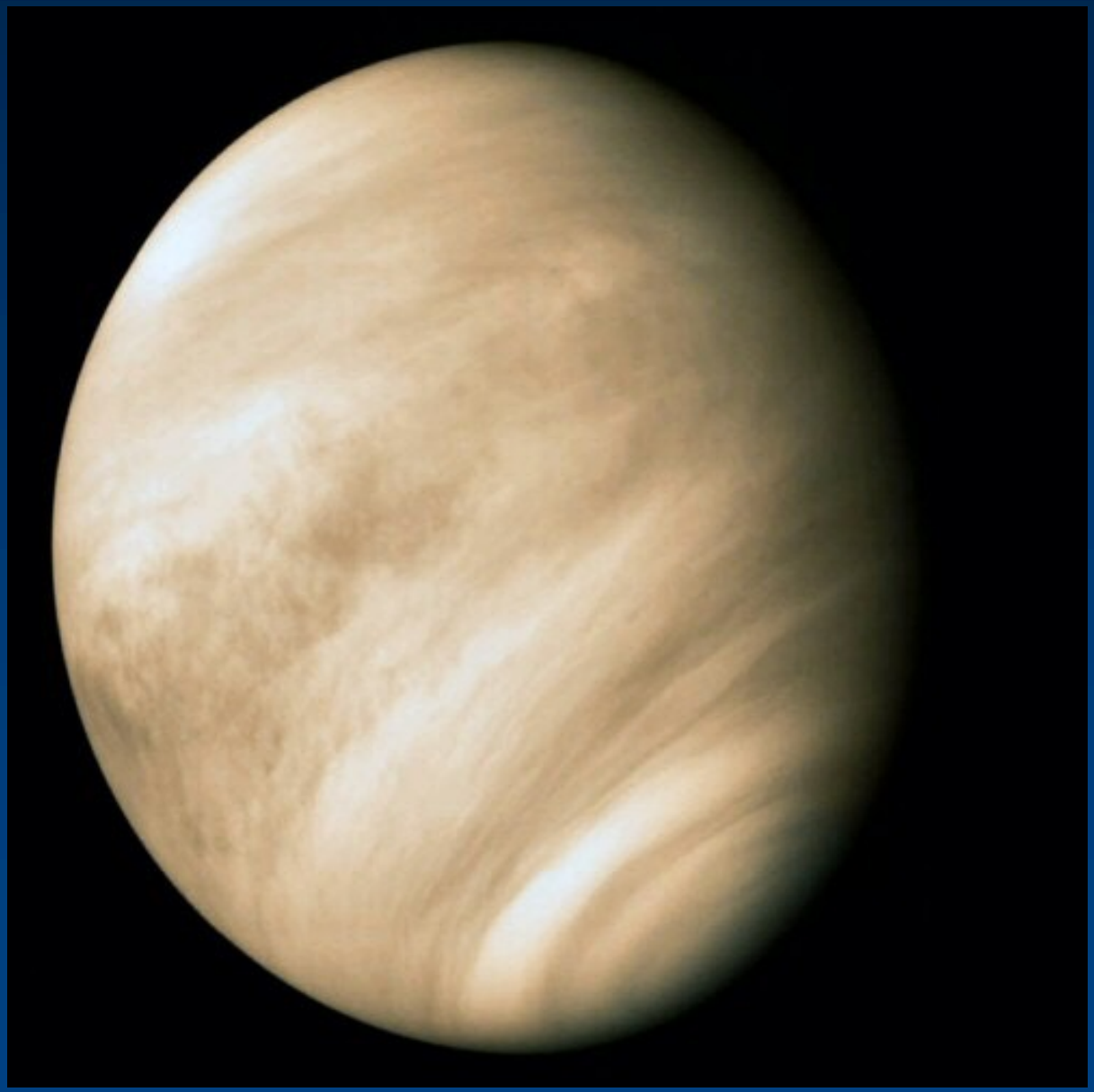
Announcements

- Final Project – see handout for instructions or retrieve from class web pages – be consistent on data sheet!
- HW8 is due next Thursday
- Physics Day is April 13, student talks, free lunch

Register before April 8:
https://physics.unm.edu/pandaweb/undergraduate/day2024/index.php

Venus



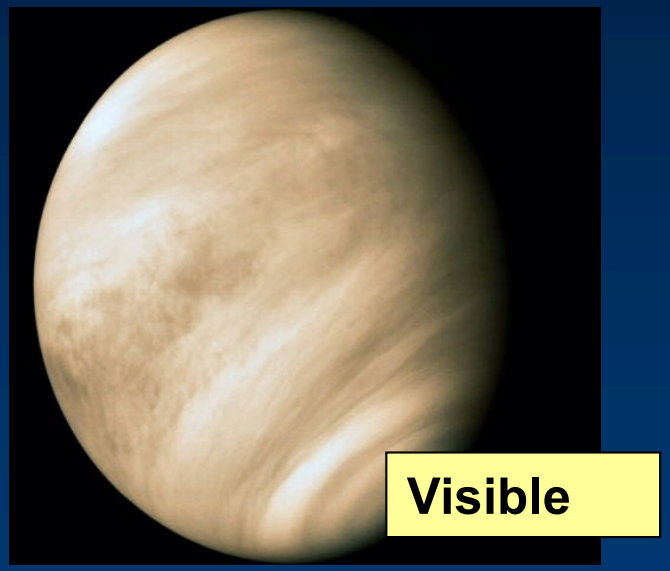
Moon and Venus over Geneva, Switzerland, 13 June 2002

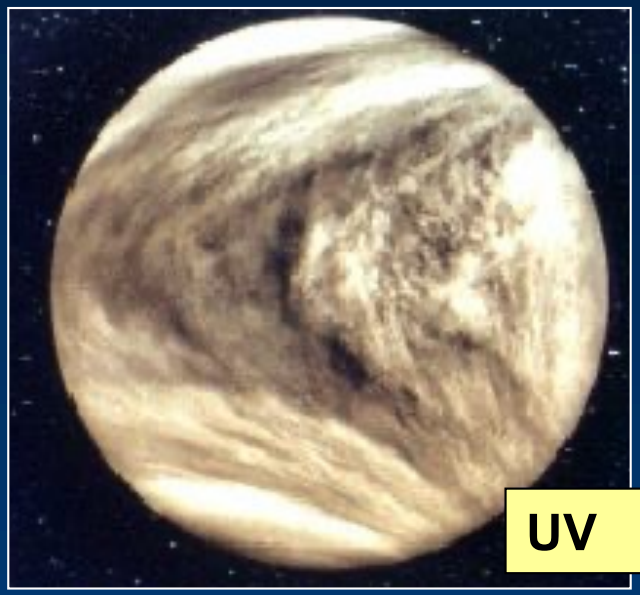
Would you ever see Venus next to the full moon?

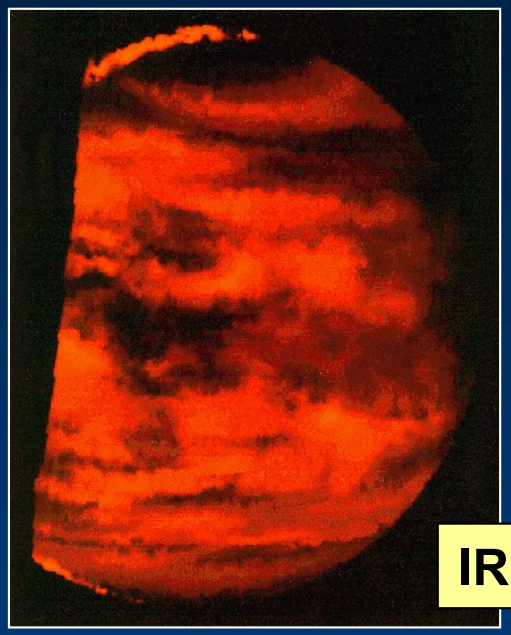
Venus basic data

Semi-major axis	0.72 AU
Eccentricity	0.0068
Tilt of orbit	3.39°
Orbital Period	225 Earth days
Rotation Period	243 Earth days (retrograde)
Diameter	95% Earth's
Mass	82% Earth's
Density	5.2 g/cm^3
V_{esc}	10.4 km/s
Atmospheric Pressure	90 atm at surface
Temp	733 K
Albedo	0.59

- Atmosphere so thick, can't see surface, at visible, UV or even IR wavelengths

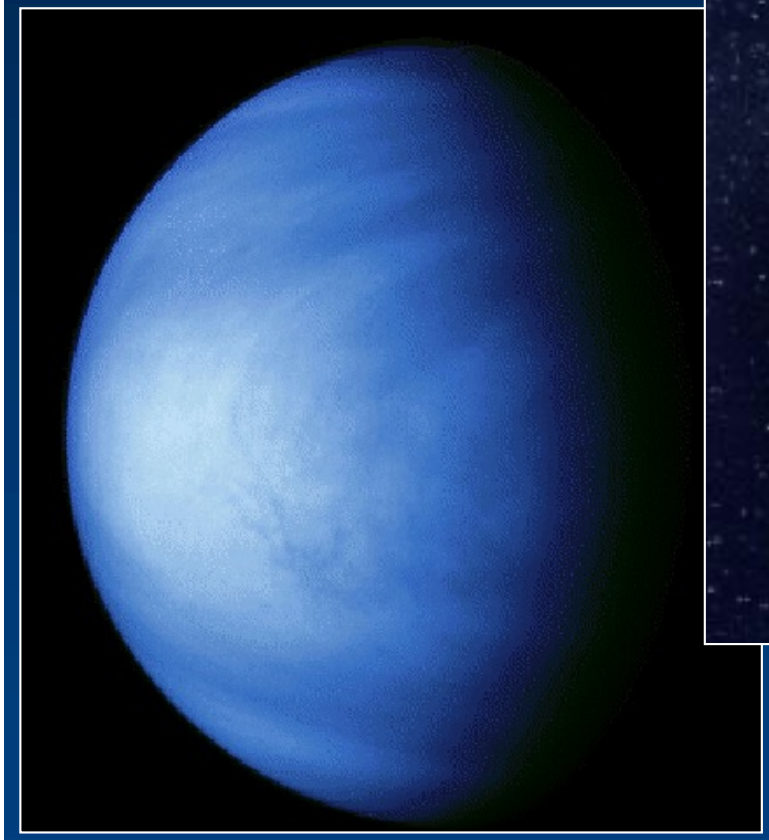




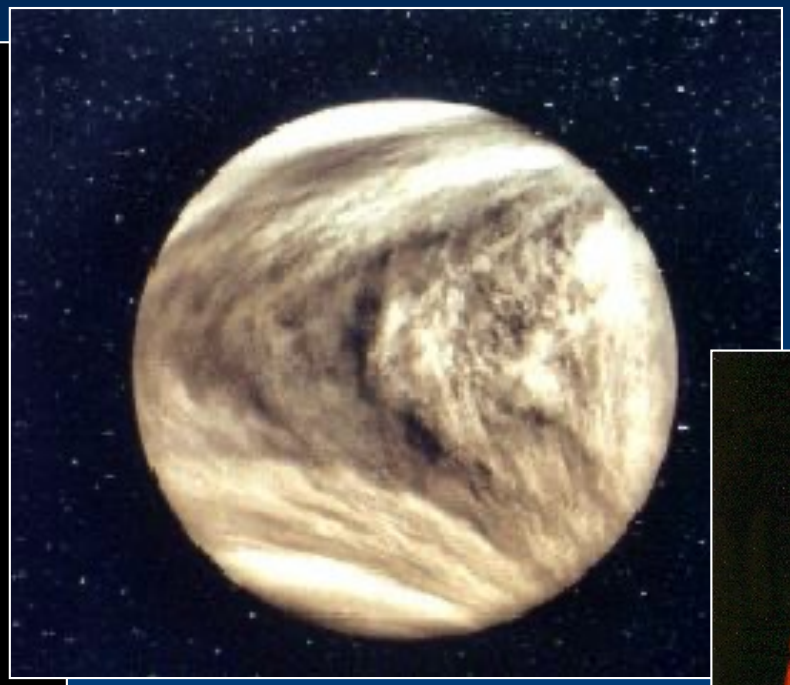


- Strong upper level winds of up to 350 km/h
- Convection: hot air from equatorial regions to poles, cools, returns to equator. Keeps T very constant. Convection and winds give V-shape appearance.
- Yet at surface winds are only < 5 km/h due to intense pressure.

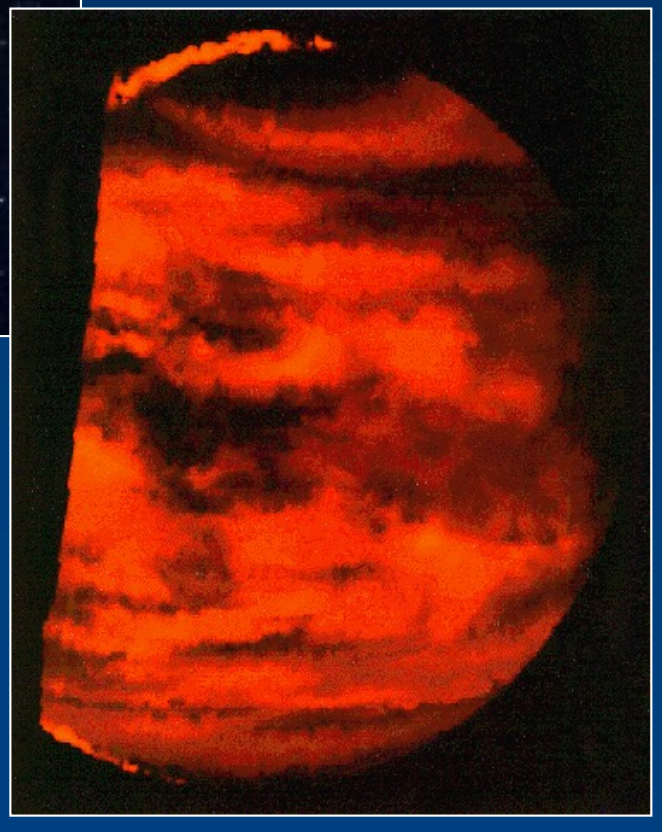
- Different wavelengths penetrate the atmosphere to different depths => study different layers



Visible



UV



IR

Missions to Venus

Soviet Venera 4 -18 (1967 - 1983)

Mariner 2, 5 and 10 (1962, 1967 and 1974)

Pioneer Venus (1978)

Magellan (1989)

Venus Express (ESA, launched 9 Nov 2005), in orbit since May 2006. Ended in 2014 (extended mission).

Venus' atmosphere

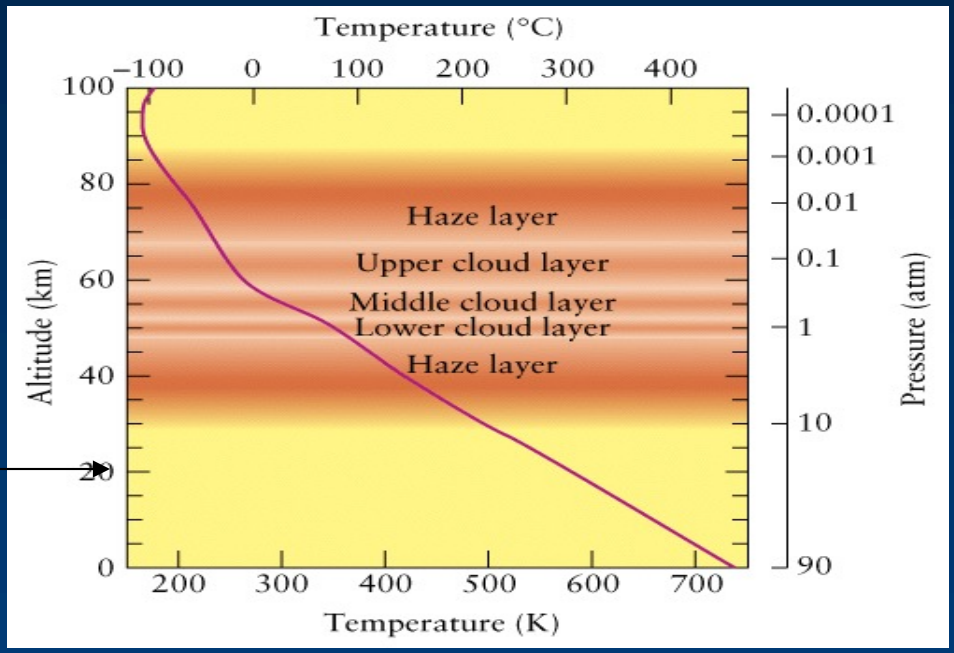
Table 9-4 Chemical Compositions of Three Planetary Atmospheres

	Venus	Earth	Mars
Nitrogen (N_2)	3.5%	78.08%	2.7%
Oxygen (O_2)	almost zero	20.95%	almost zero
Carbon dioxide (CO_2)	96.5%	~~0.035%~~	95.3%
Water vapor (H_2O)	0.003%	about 1%	0.03%
Other gases	almost zero	almost zero	2%

0.042%

- Hot, dry, dense: so hot at surface (~733K) it almost melts rock
- Very thick CO_2 atmosphere (strong greenhouse effect => high temps)
- 0.15% sulfuric acid (H_2SO_4) clouds and haze

The clouds are composed of sulfuric acid droplets. These start at about 30 km altitude and extend up to 85 km.



Max height of Earth's clouds

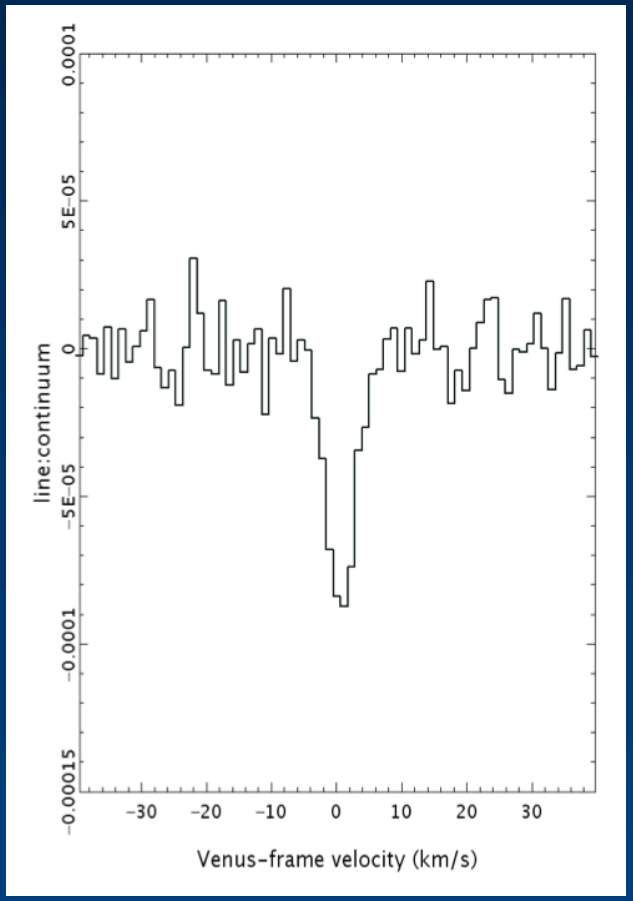
Enormous pressure at surface (like ocean depth ~1km at Earth): much more gas in atmosphere.

No oceans: water stays in vapor form, breaks into H and O by UV photons, H escapes => very dry.

Life on Venus?

- Phosphine (PH_3) claimed to be detected in the atmosphere
  - No obvious chemical source
  - Temperatures in the middle cloud layer ~270 K, ok for life

- Probably a calibration error
- Two new missions to Venus in the works – DAVINCI and VERITAS



ALMA observations from Greaves et al 2020

How can we study surface through the thick clouds?

Use radar ⇒ long wavelength radio waves will pass through clouds.

Idea: EM radiation will pass through if $\lambda >$ size of cloud particles.

Example: Water droplets in Earth's atmosphere have average size of 20 μm = 20,000 nm.

Compare to visible: 400 –700 nm.

Clouds block light, but your cell phone still works on a cloudy day!

Goldstone/VLA radar

VENUS

Observations of Venus in 1990 and 1993 allowed for multi-polarization mapping of several bright volcanic regions [10]. Fig. 2 shows an image of the SC radar echo mapped with the Goldstone/VLA radar on August 23, 1991.

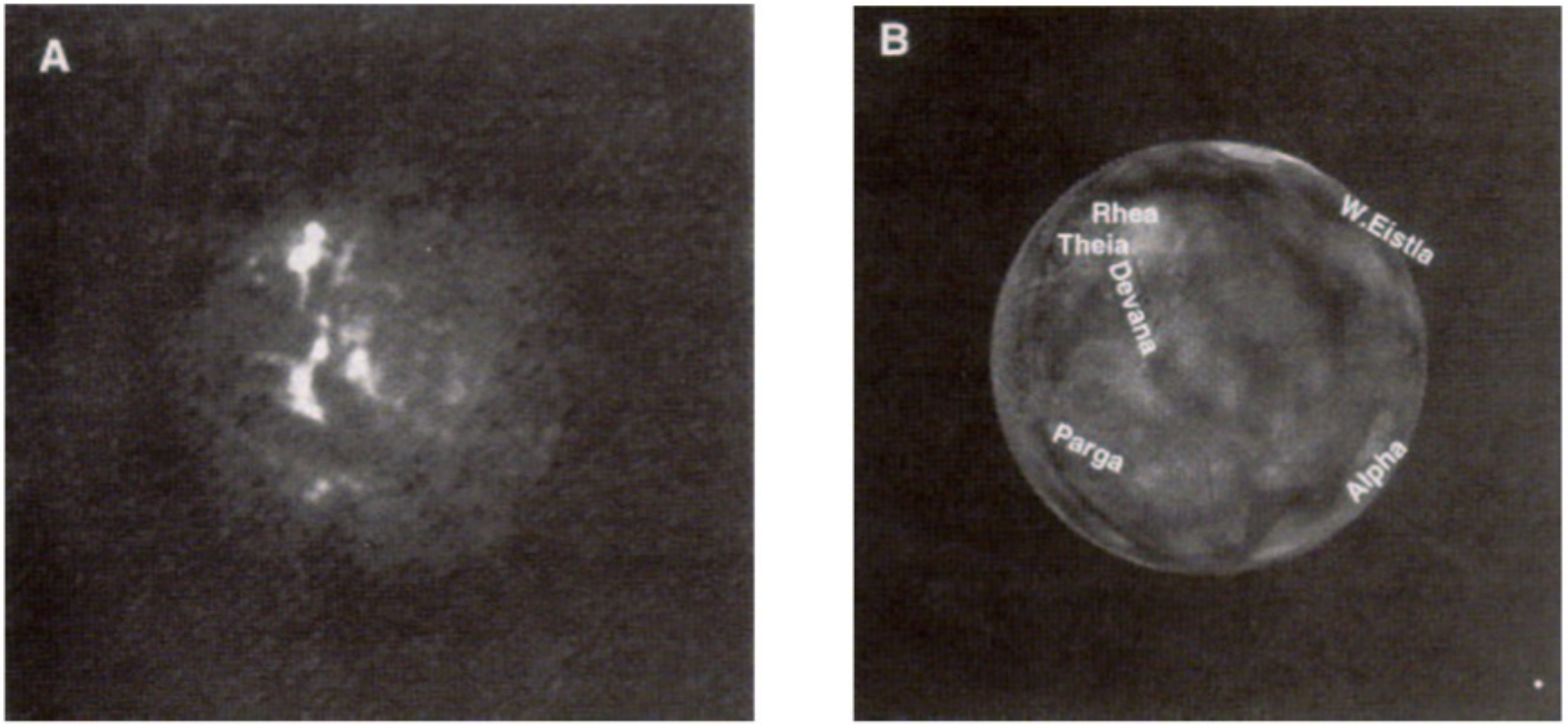
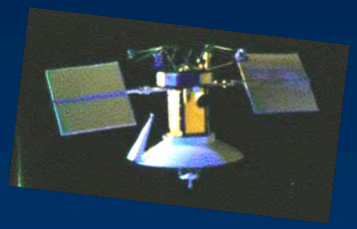


Figure 2: Radar reflectivity of Venus as mapped with the combined Goldstone/VLA radar on March 4, 1993. Sub-Earth latitude and longitude were -7.3° and 302.5°. Actual SC reflectivity is shown on left, topography and feature names are shown on the right. From [10].

Butler et al.

Radar echo measures altitude



space probe

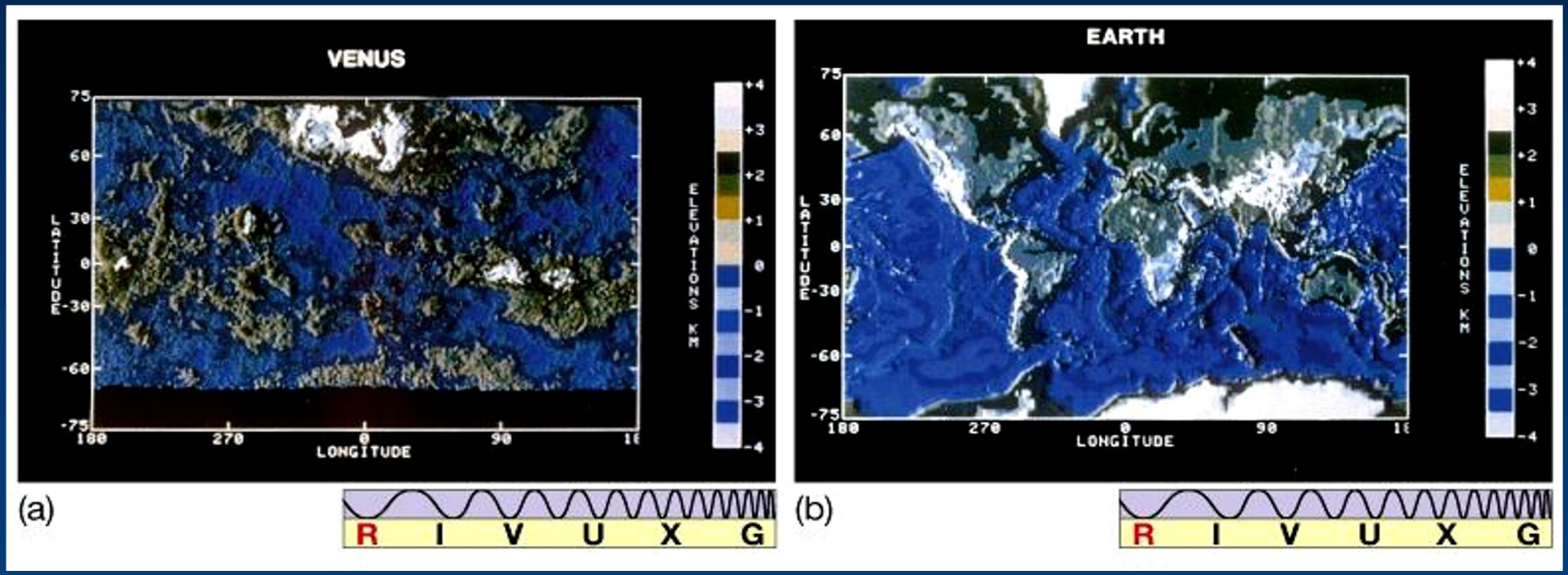
time for signal to return tells you the altitude of surface feature.

Planet Surface

Topographic map of Venus

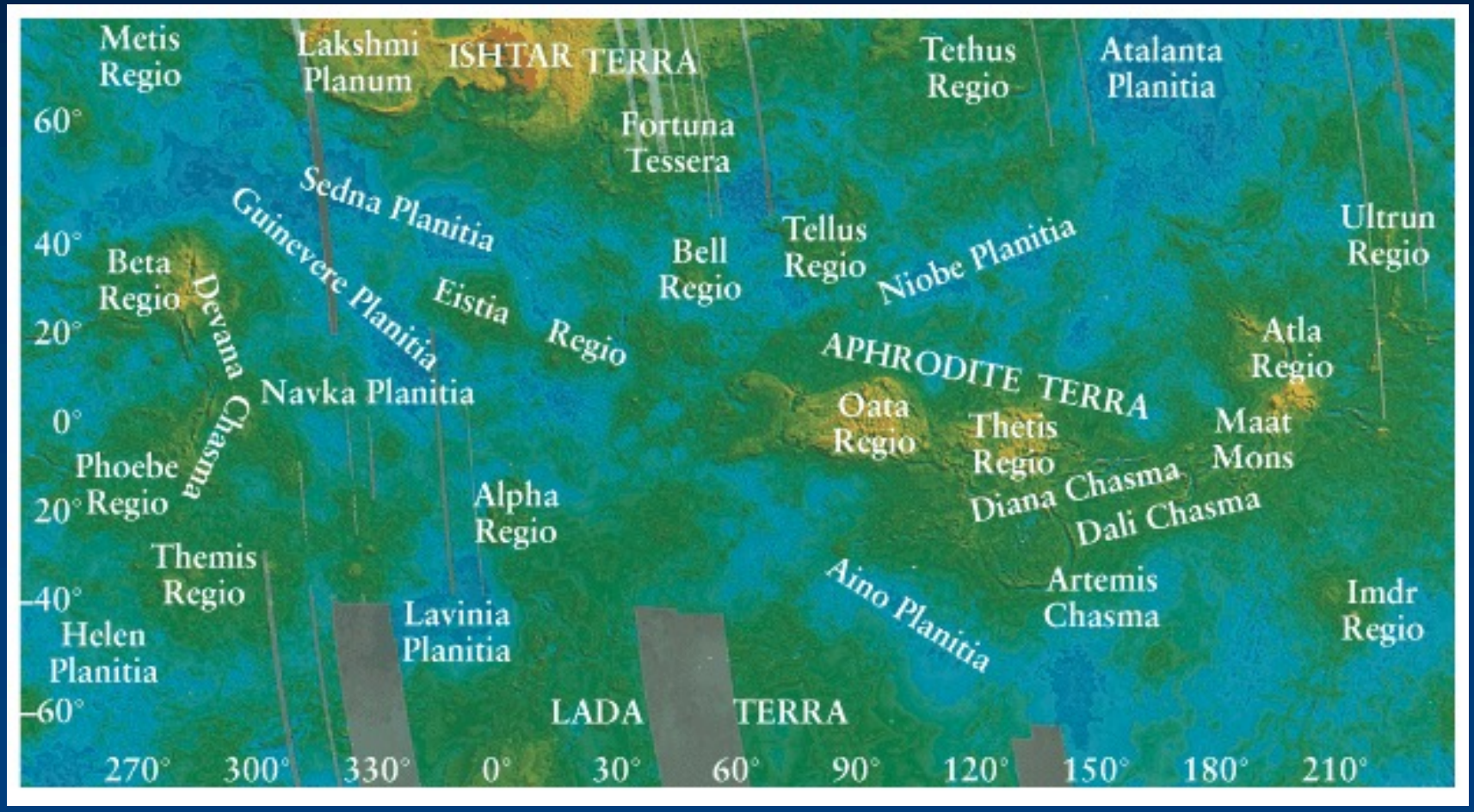
Flatter than Earth, no evidence of plate boundaries.

⇒No large scale plate tectonics



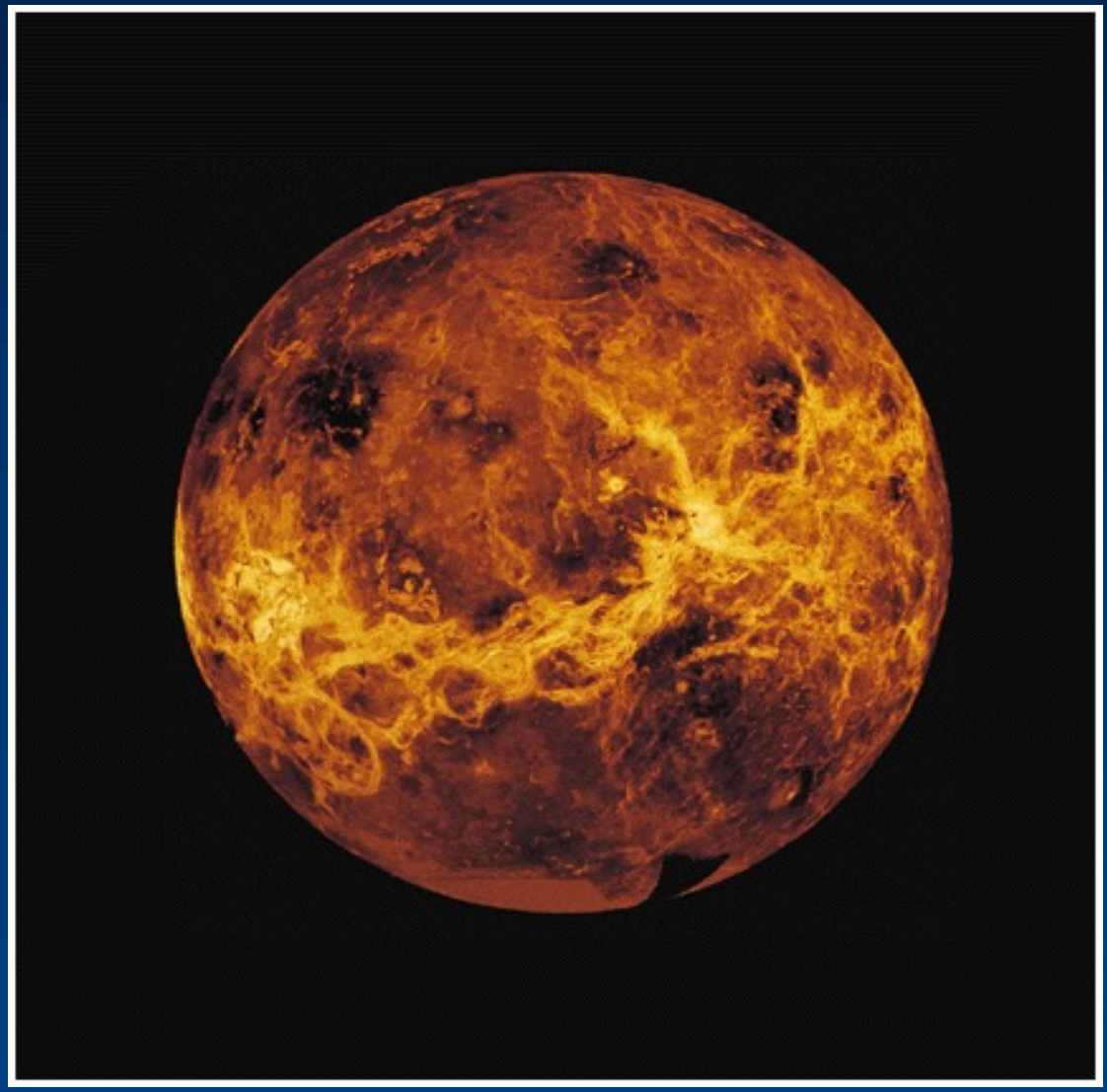
85% plains

15% highland plateaus (Ishtar Terra and Aphrodite Terra)

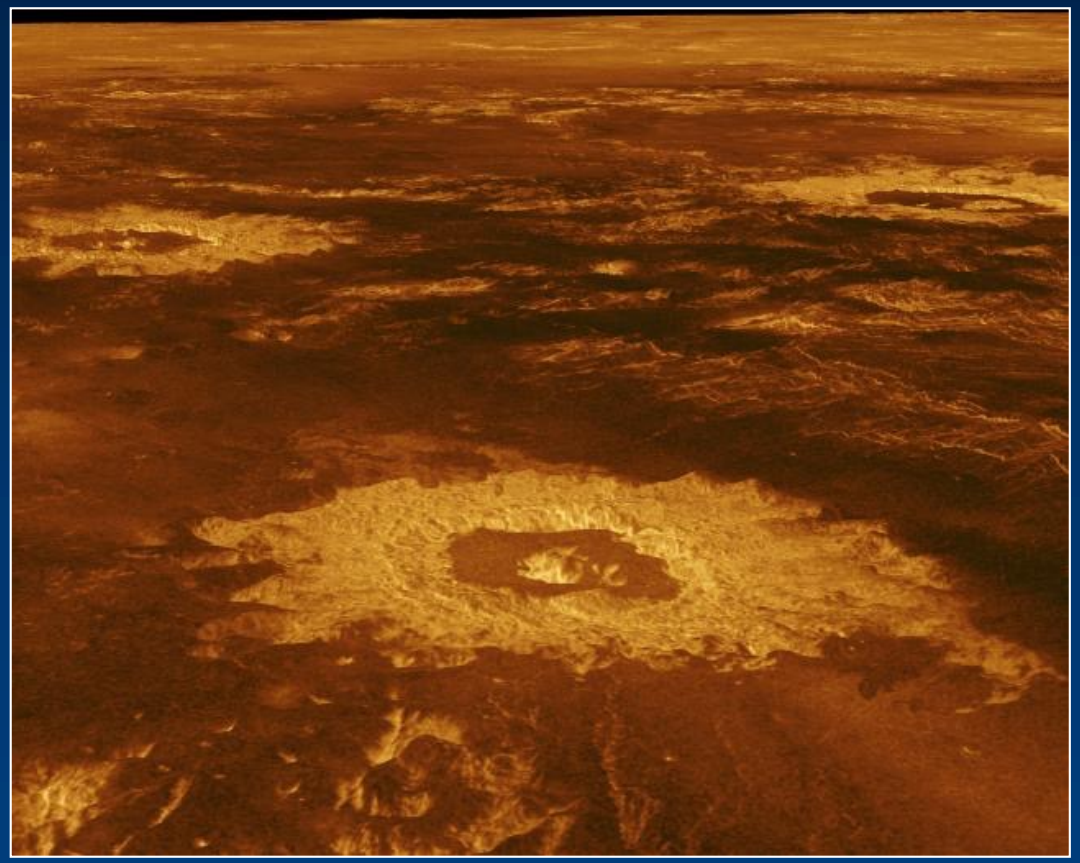

Metis Regio
Lakshmi Planum
ISHTAR TERRA
Tethus Regio
Atalanta Planitia
60°
Fortuna Tessera
Sedna Planitia
Guinevere Planitia
40°
Beta Regio
Devana Chasma
Eistia Regio
Bell Regio
Tellus Regio
Niobe Planitia
Ultrun Regio
20°
Atla Regio
APHRODITE TERRA
Navka Planitia
0°
Oata Regio
Thetis Regio
Maat Mons
Phoebe Regio
20°
Alpha Regio
Diana Chasma
Dali Chasma
Themis Regio
Aino Planitia
Artemis Chasma
40°
Lavinia Planitia
Imdr Regio
Helen Planitia
60°
LADA TERRA
270°
300°
330°
0°
30°
60°
90°
120°
150°
180°
210°

The surface of Venus: Magellan radar images

- Mountains (but not chains), rift valleys, volcanoes and lava flows. How young?



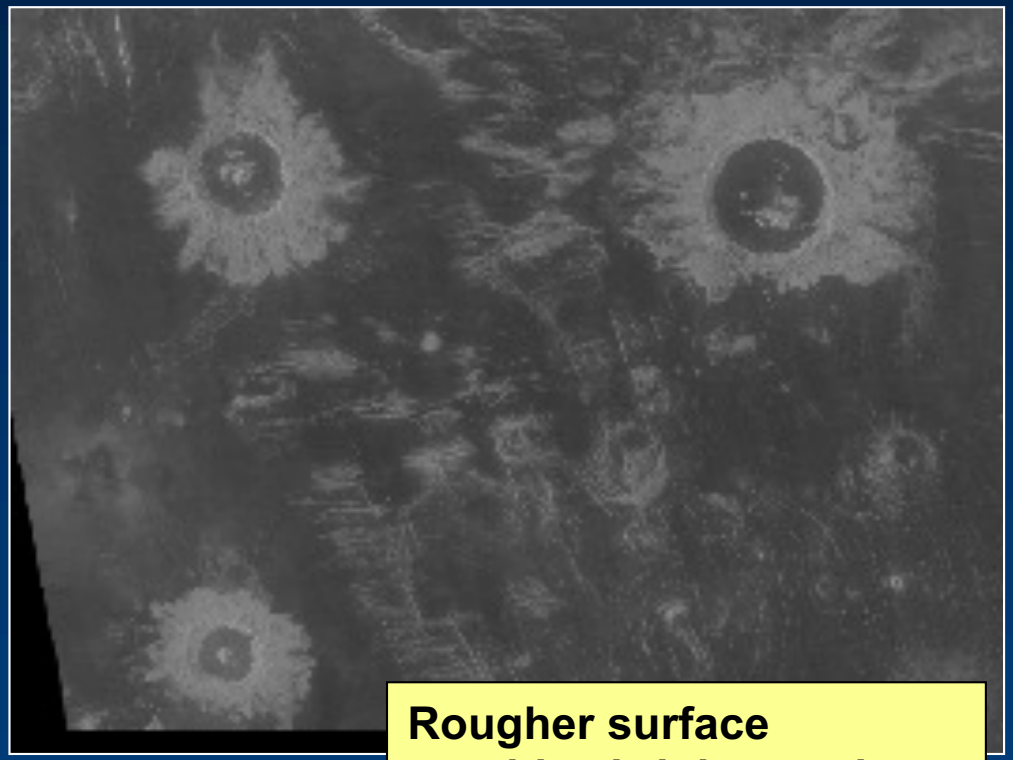
Craters on Venus



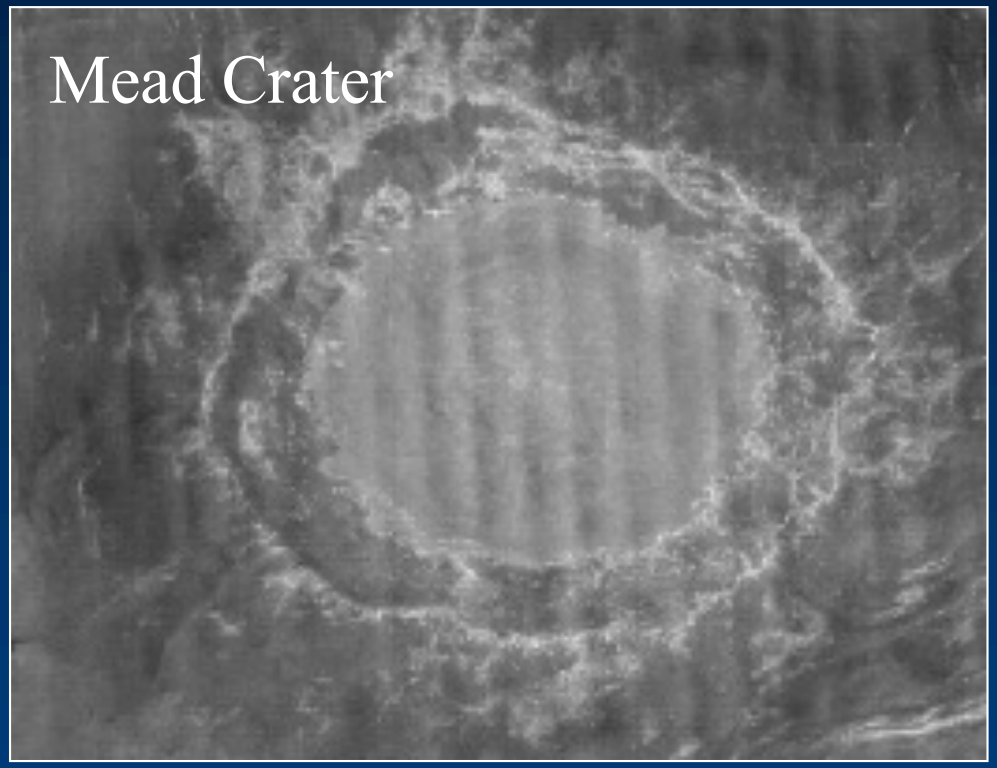
- Only ~1000 seen, spread randomly (unlike the Moon): All parts have about the same age.
- None < 3 km across (no meteor impacts < 30 m), smaller ones burn up in atmosphere

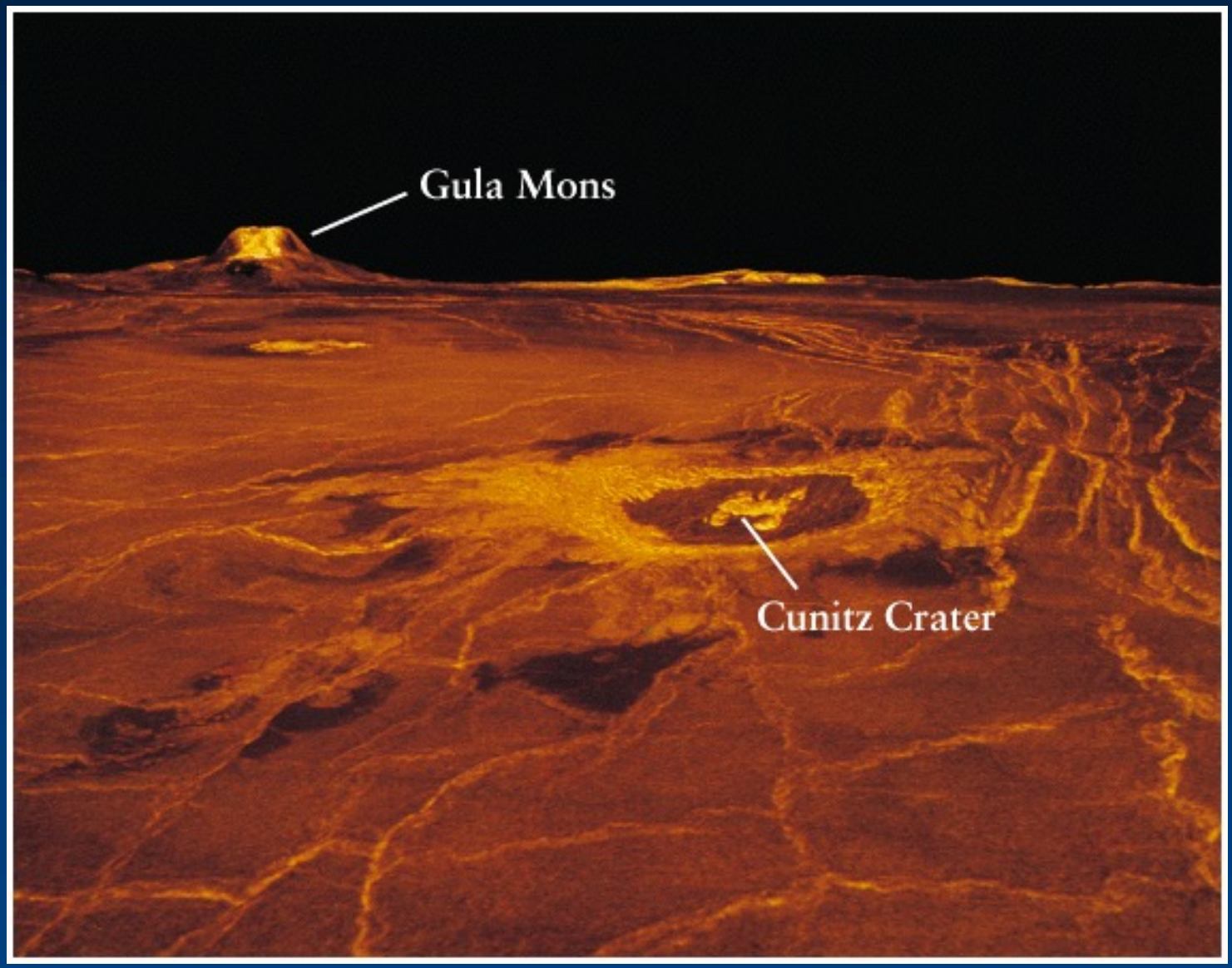
Sparseness of impact craters (doesn't look like Moon or Mercury!) implies that the surface is young, ~500 million years

Field of craters and the largest crater found on Venus (280 km diameter)

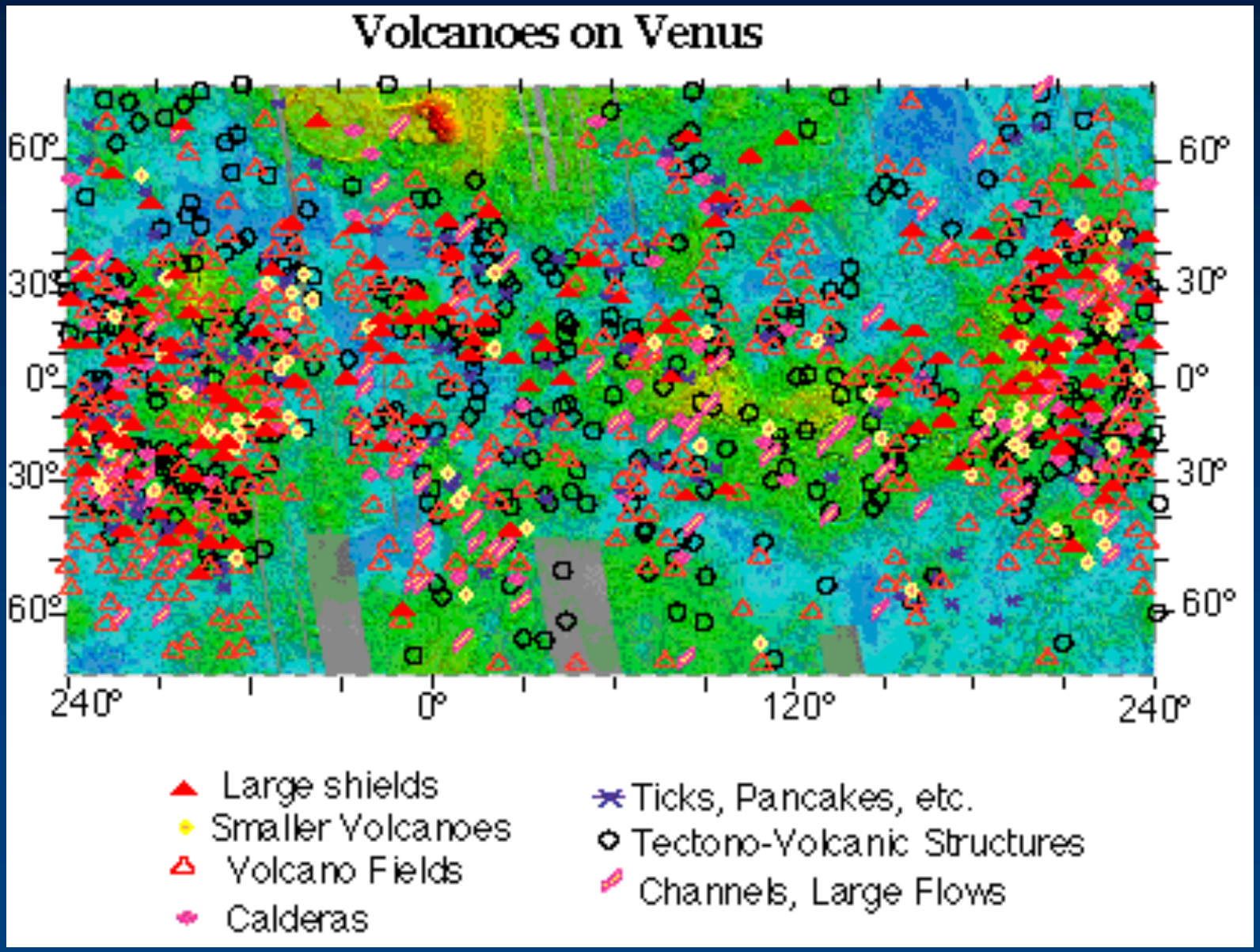


Rougher surface provides brighter radar echo => recent, unweathered event



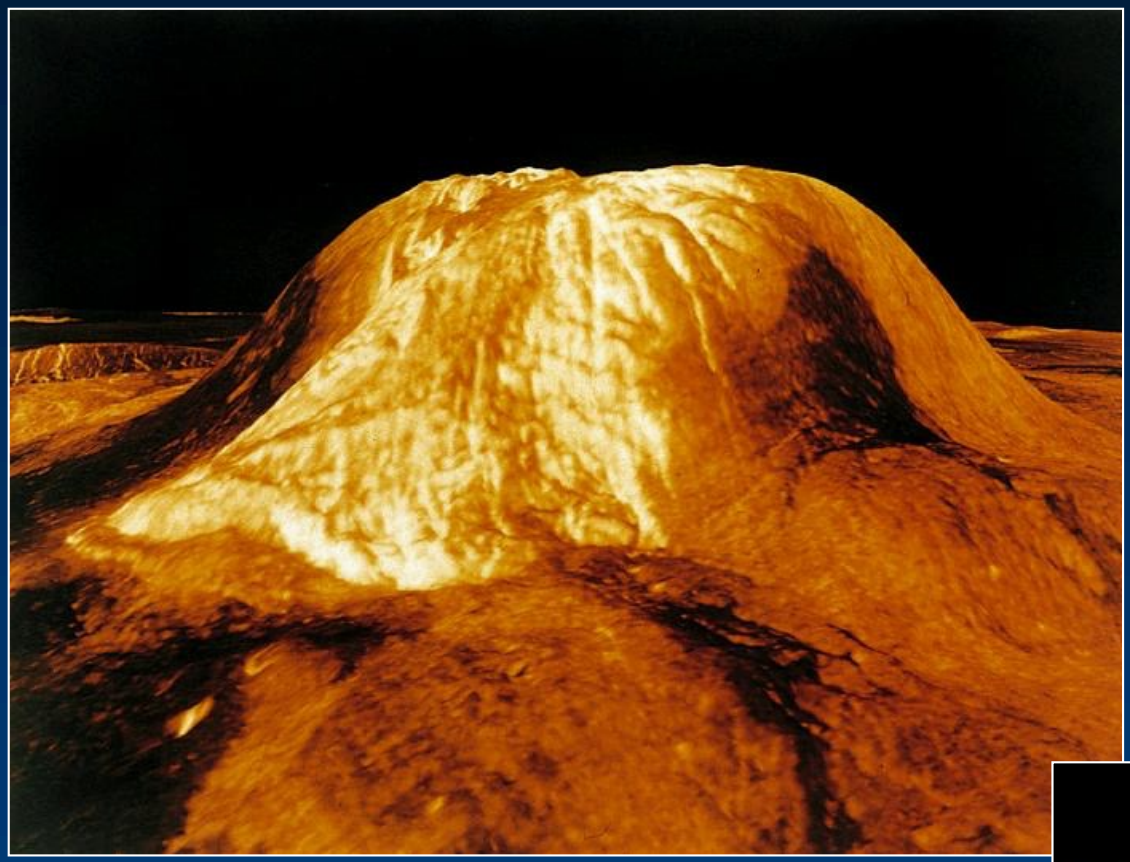

Gula Mons
Cunitz Crater

Volcanism

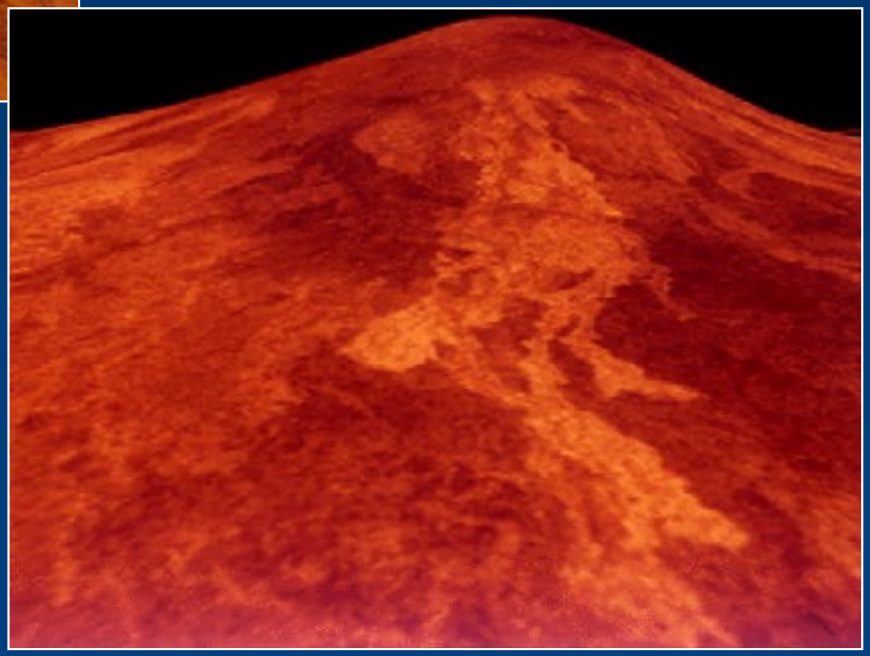


Volcanoes also randomly distributed – no plate tectonics.

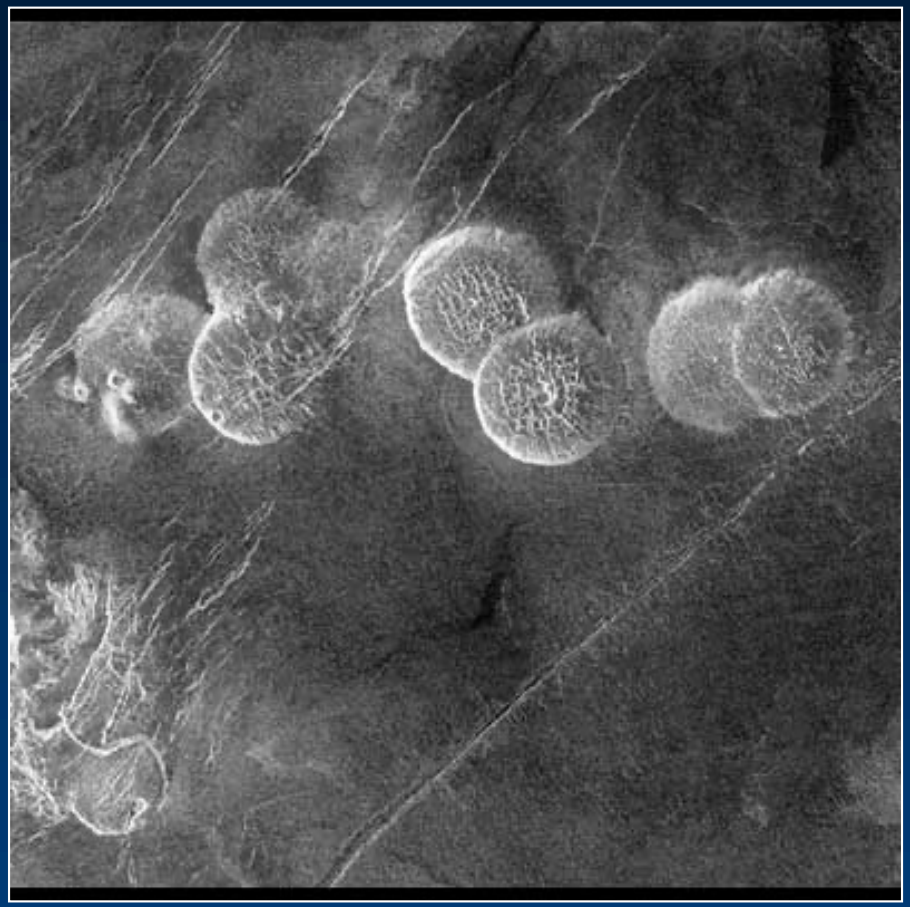
Recent volcanism suggested by varying SO_2 levels in atmosphere, and youngest lava < 10 million years (but very little resurfacing in the past 200-500 million years).

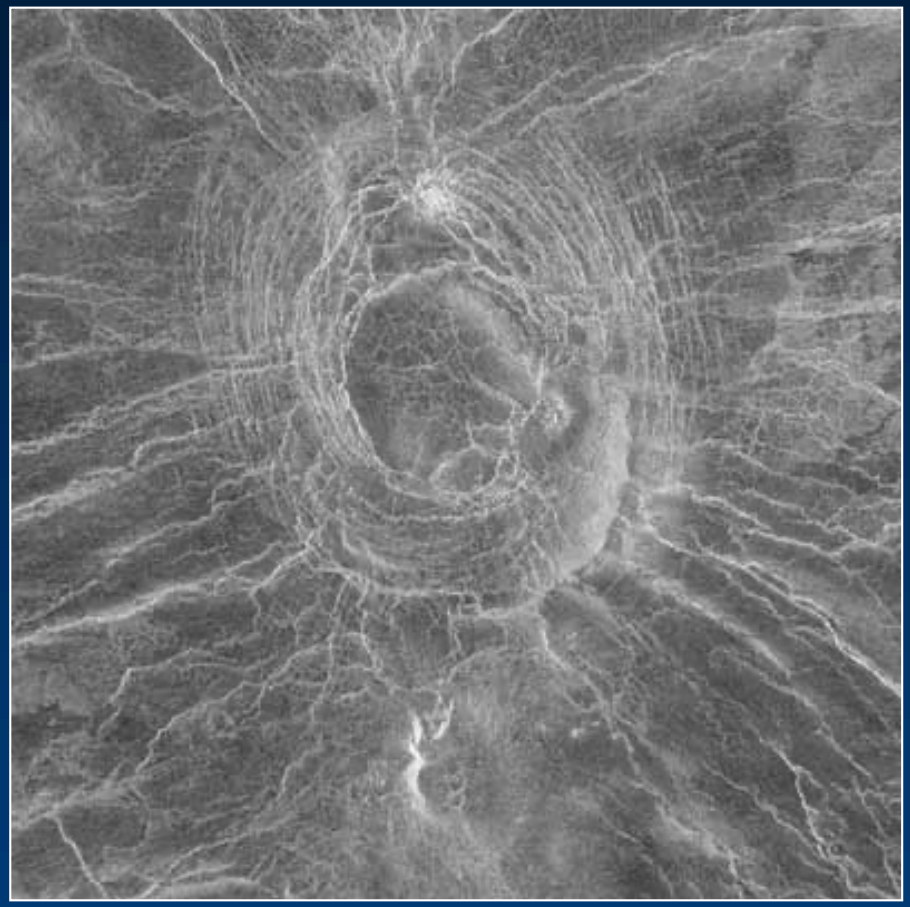


Shield volcano elevation map from Magellan radar data. About 100 km across.



Sif Mons, and a ~5 km long lava flow. Estimate lava flows within 10 million years.

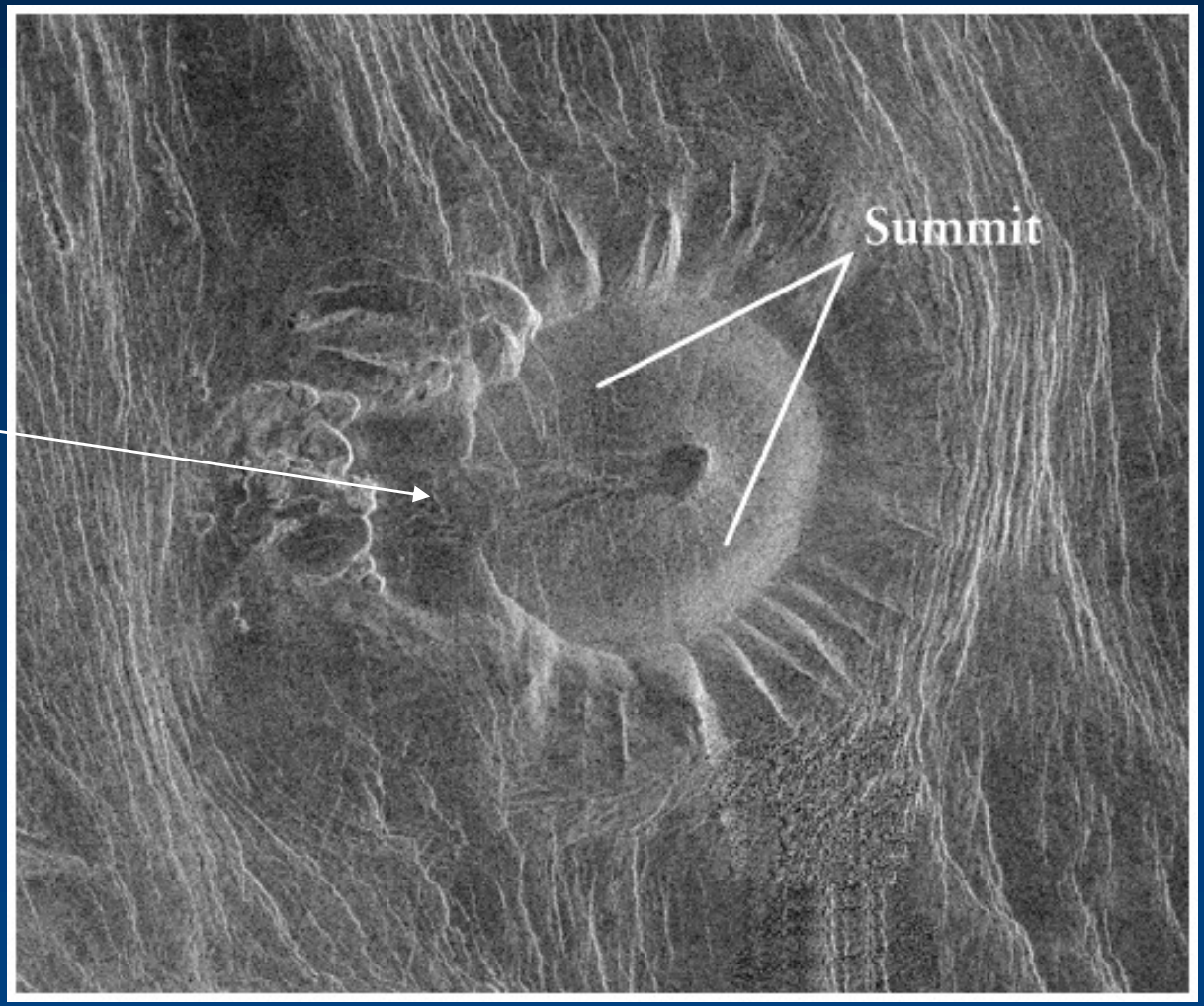




"Pancake volcanoes" - eruptions of lava through vents close to ground.
"Corona structures" - Concentric pattern, with a radial fracture => lava from inside caused surface to stretch.

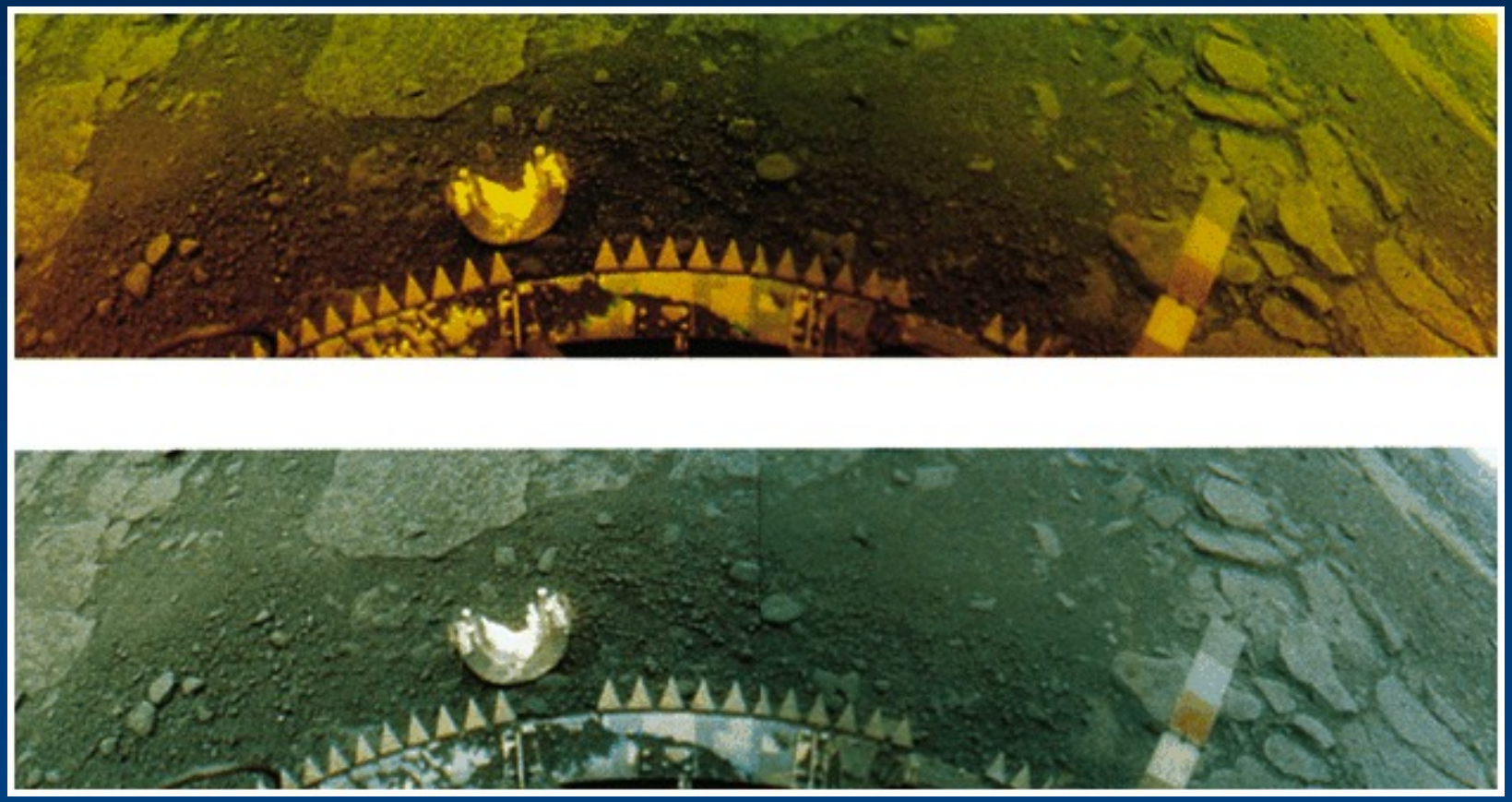
Another type of volcano: “tick volcano”, with ridges and valleys. A flat summit ~22 mi diameter.

Rim appears breached by lava flow

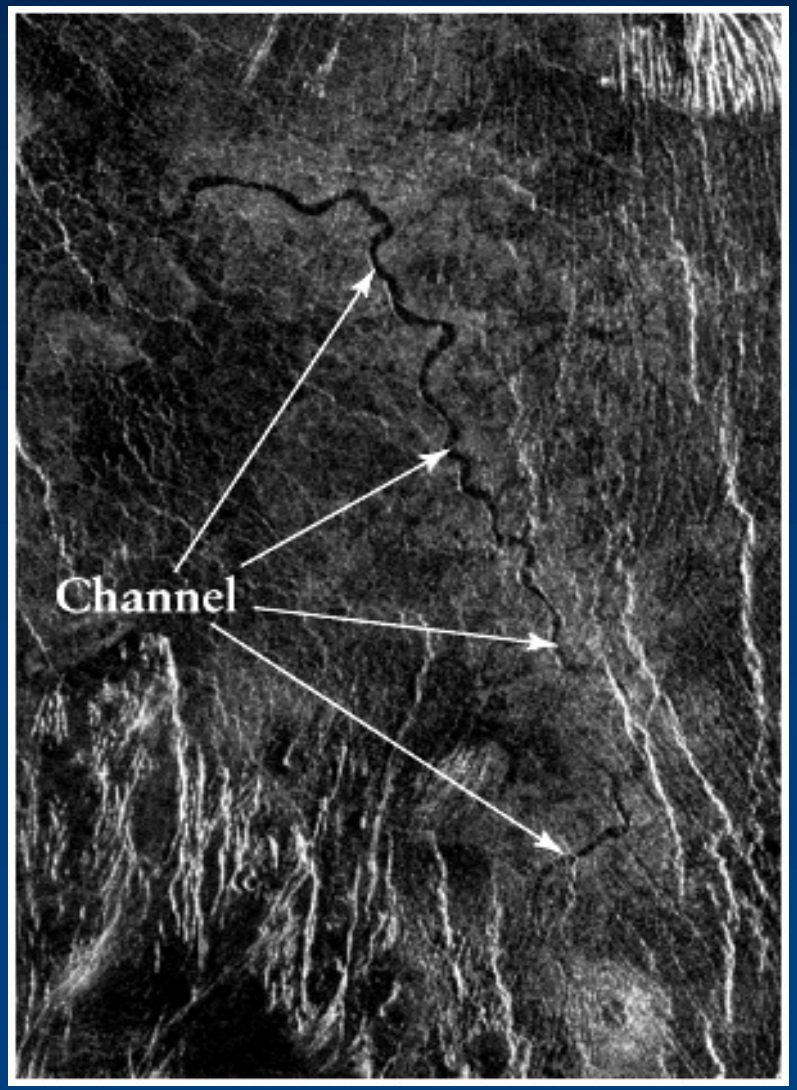


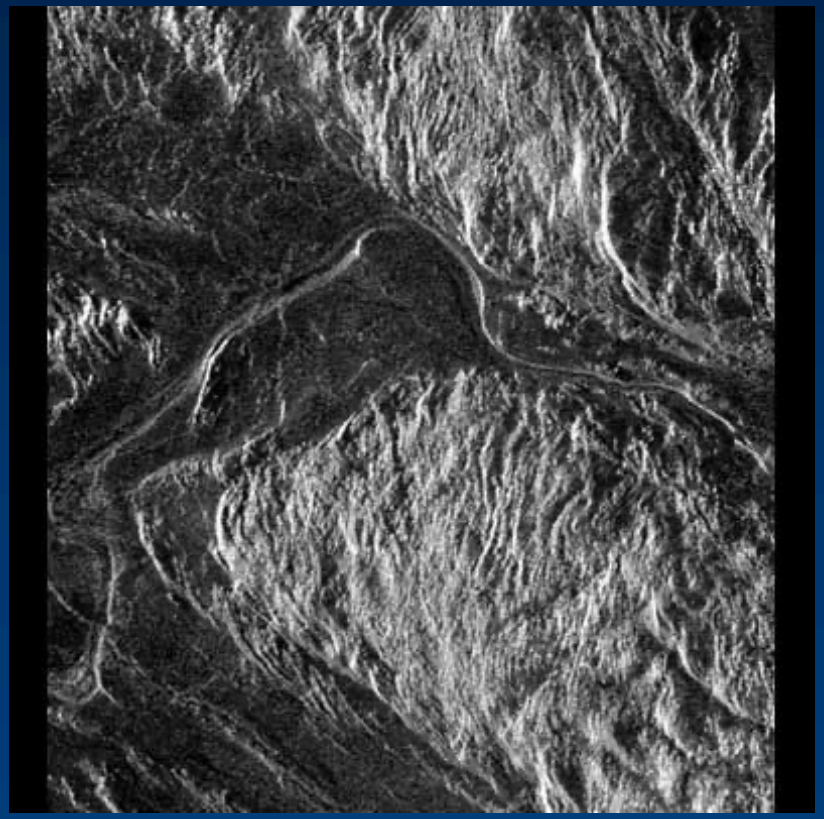
More evidence for past (?) volcanic activity:

Venera 13 (Soviet lander 1981) found rocks similar to Earth's basalt.



A 2 km-wide channel, caused by lava.
Total length is 6800 km (= 4200 miles).
Compare to Nile at 6600 km.

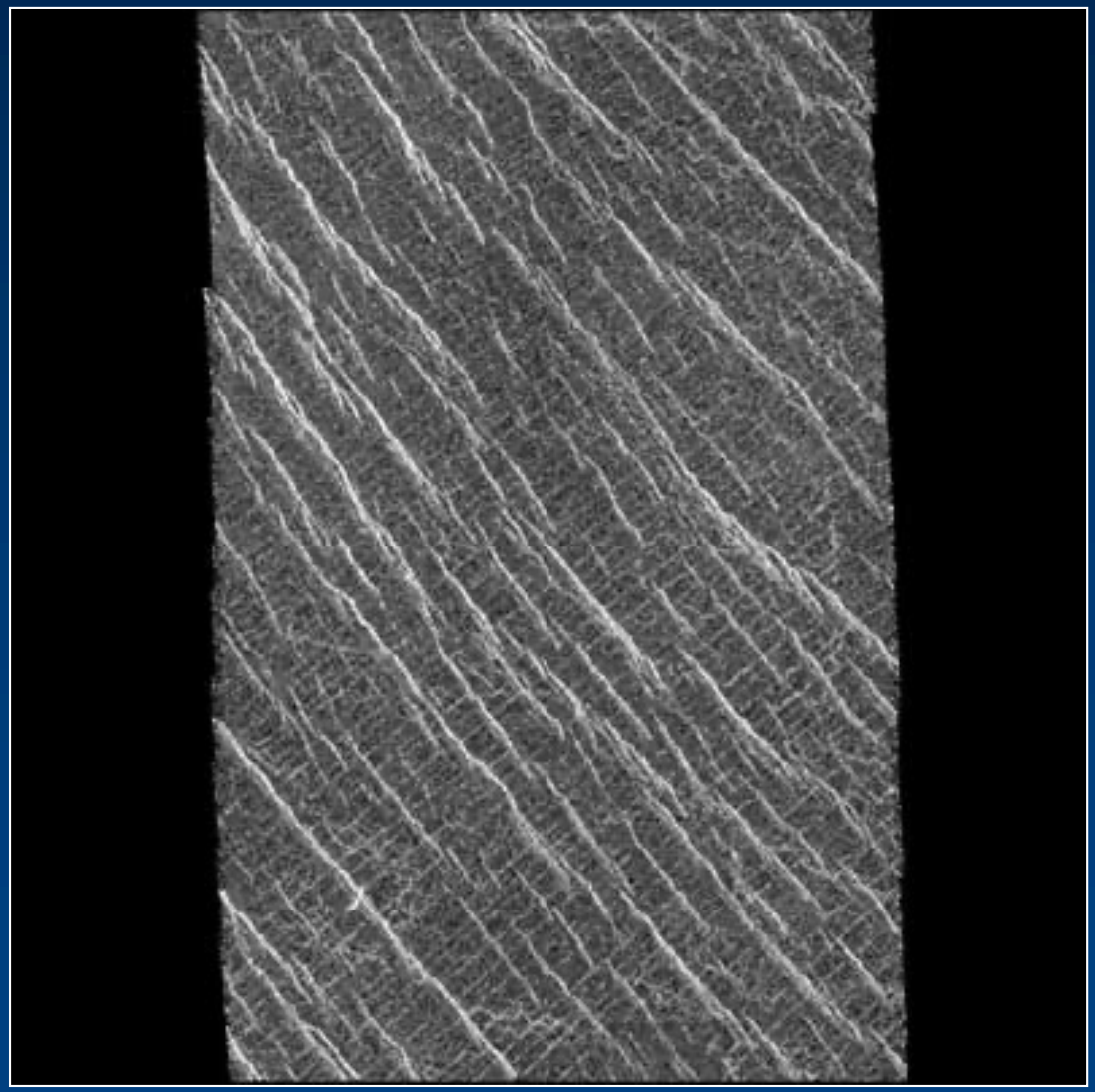




Carved by hot lava, which should remain liquid for a long time due to extreme surface temperatures

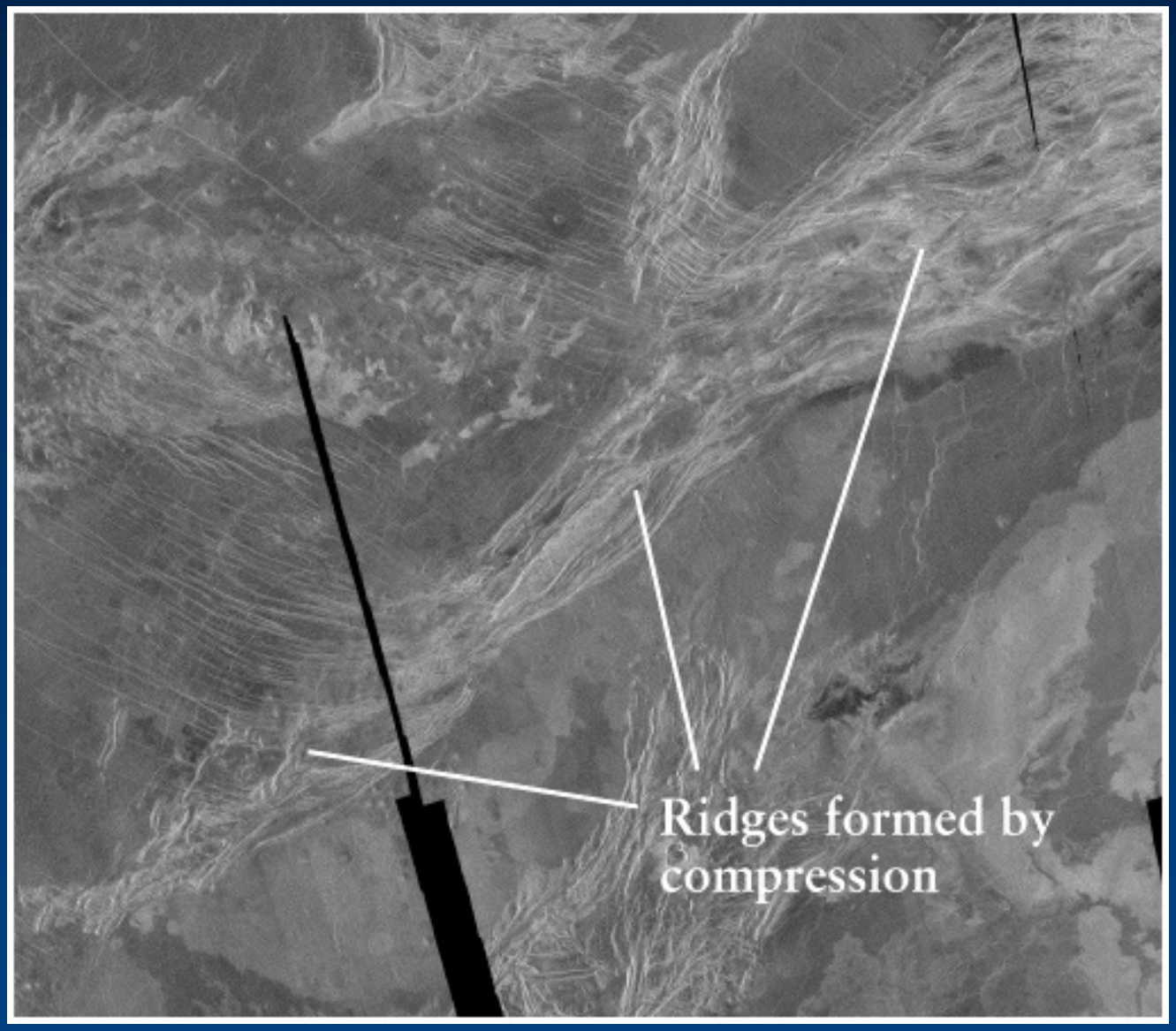
More evidence of small-scale surface deformation

1 km



- Faults and fractures? Details not known.

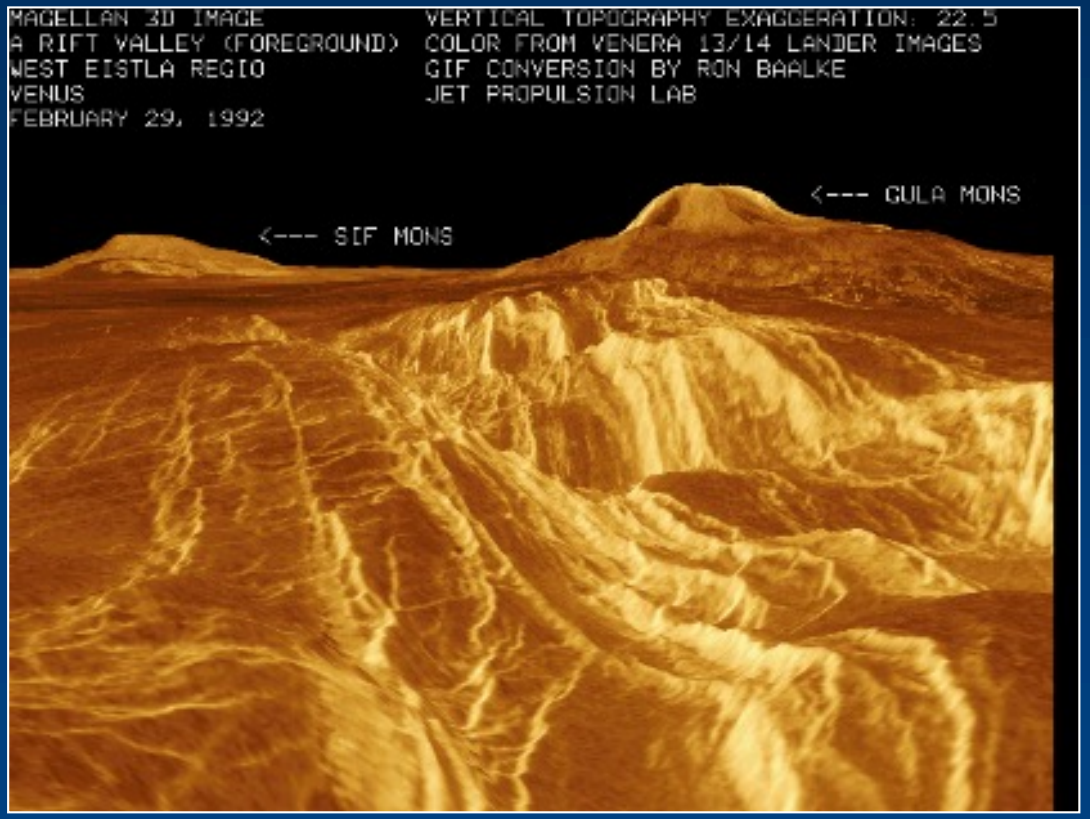
Compression folding



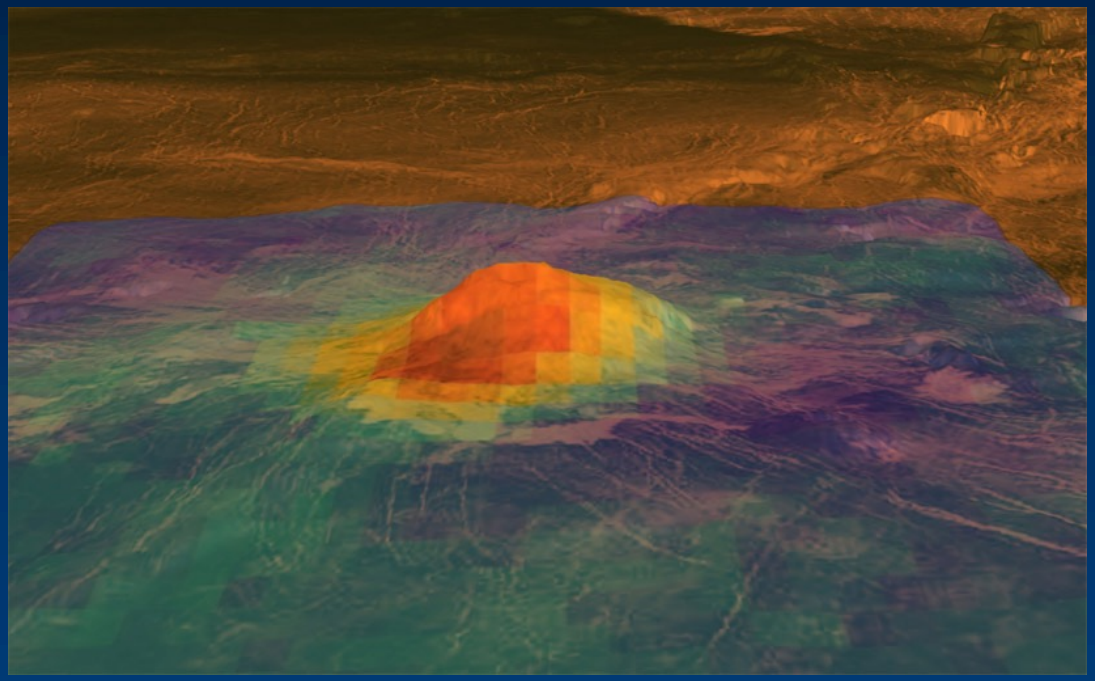
Rift valleys

- Similar in size to East African Rift (largest on Earth, tectonic motion between African and Eurasian plates).

- On Venus, rift valleys consequence of local activity since surface appear to be a single plate.



Is volcanism still ongoing?



- Venus Express infrared imaging in an atmospheric window at 1.02 microns reveals nine sites of hot-spot volcanism within past 2.5 million years and possibly 250,000 years

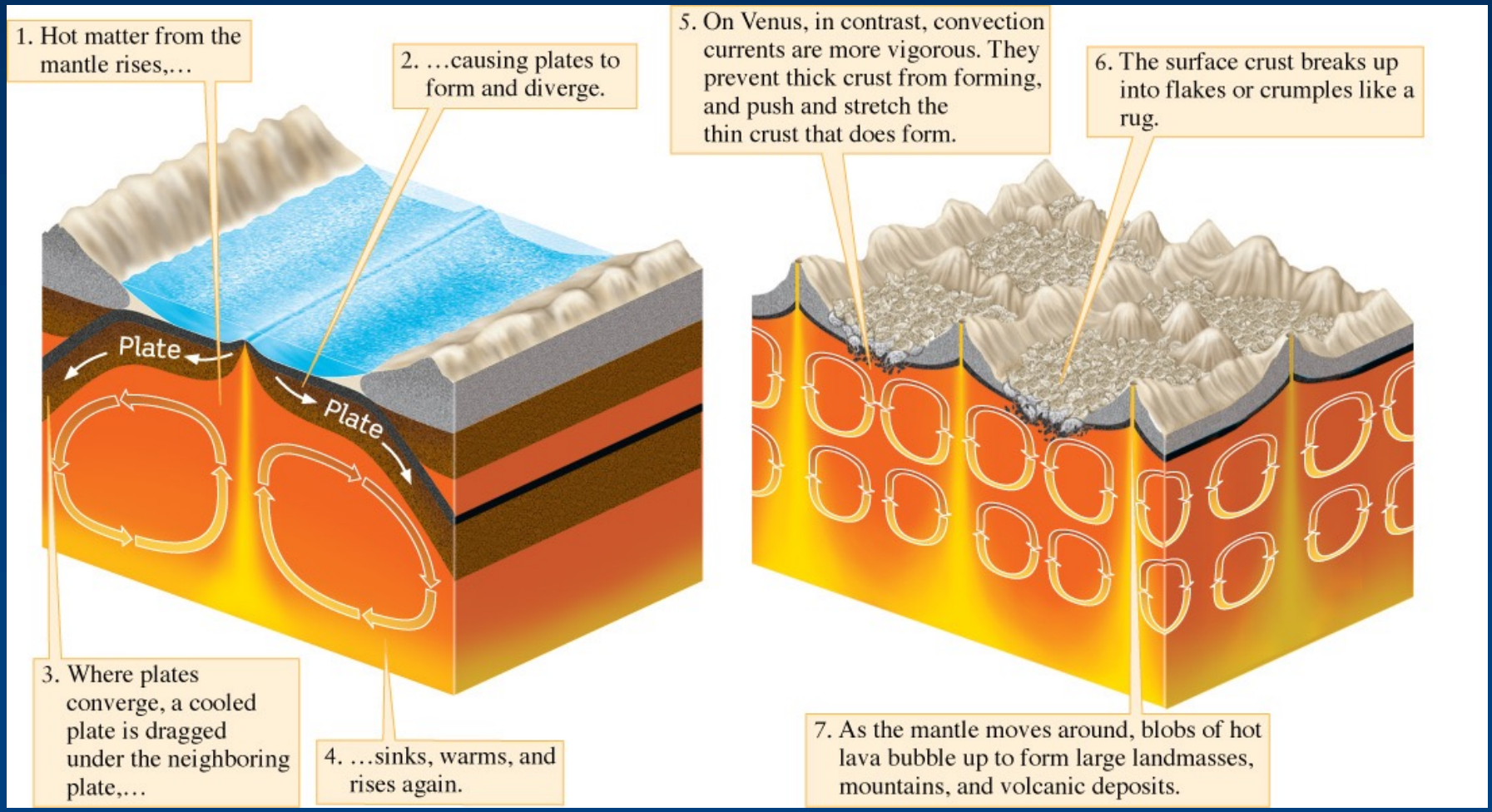
- $S0_2$ levels in atmosphere indicate recent volcanism, but may not constrain time to < 10 million years ago.

Volcanism Summary

- No volcanoes in chains => no plate tectonics
- Evidence for localized upwelling and fracturing
- Volcanoes *may* still be active today
- Surface is relatively young, ~500 million years, and entire planet about the same age. Contrast Earth.

Why different from Earth?

- One idea: <u>more</u> active volcanism keeps crust thin, continually covers up craters. Rock may even be soft due to surface heat. Easy to break through ("flake tectonics").

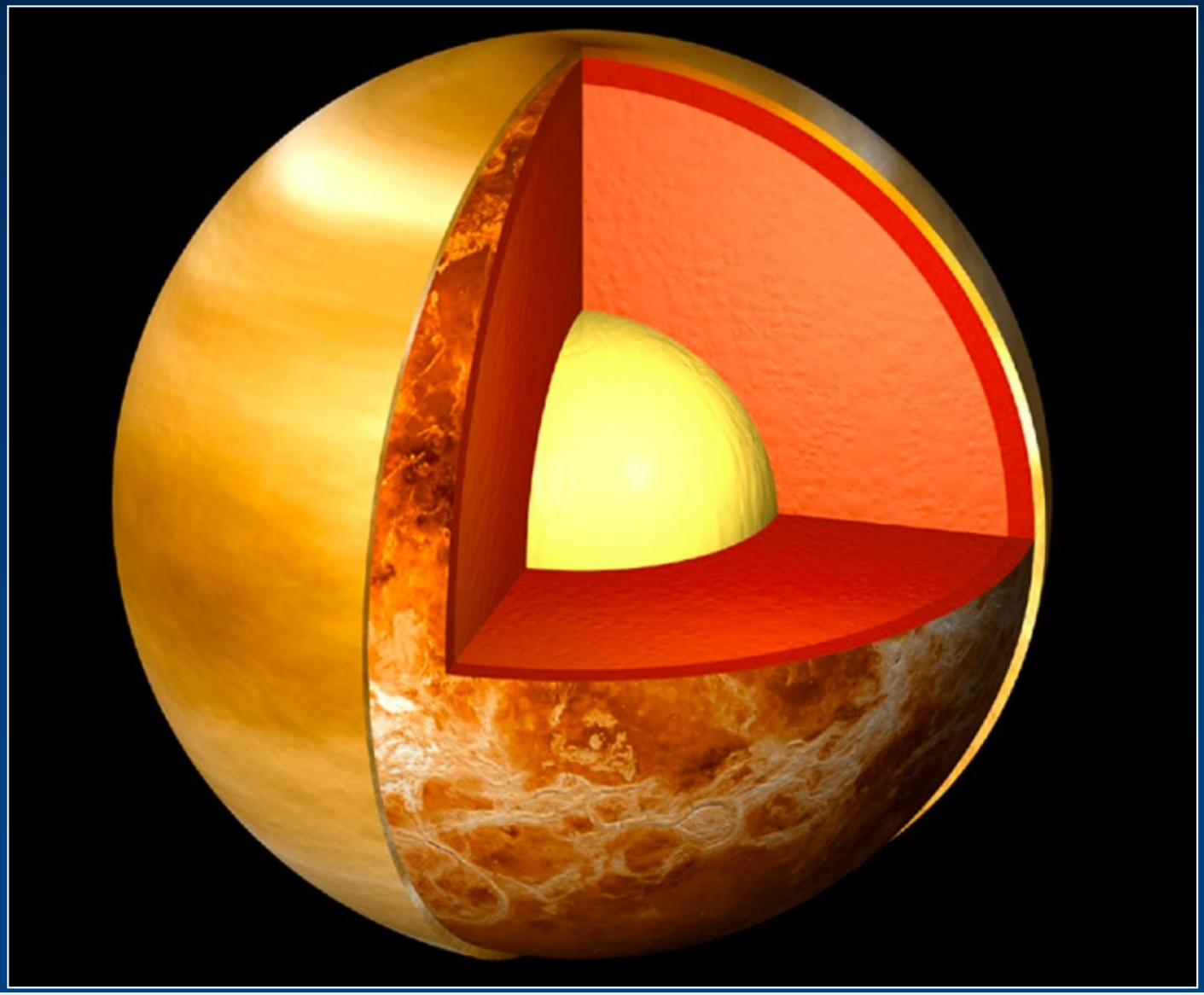


- Second idea: the surface undergoes uniform upheaval about every ½ billion years. Heat builds up under thick, dead lithosphere until catastrophic surface meltdown.

- Is lithosphere thick or thin??? Evidence of young volcanoes favors thin crust.

Seismometers would be very nice to have on Venus…

Interior presumably like Earth's (iron core, mantle, crust), but no magnetic field. Why?



Climate History of Venus

- Like Earth, started with outgassing from volcanoes (mostly H_2O, CO_2, SO_2) and perhaps additional water from cometary impacts.

- Young Sun only 70% as luminous as now, so Venus' early atmosphere would have been cooler. Probably liquid water? At least some water would have been gaseous. CO_2 dissolved in water and rocks.

- Water vapor is greenhouse gas, so T would rise. Plus aging Sun got brighter.

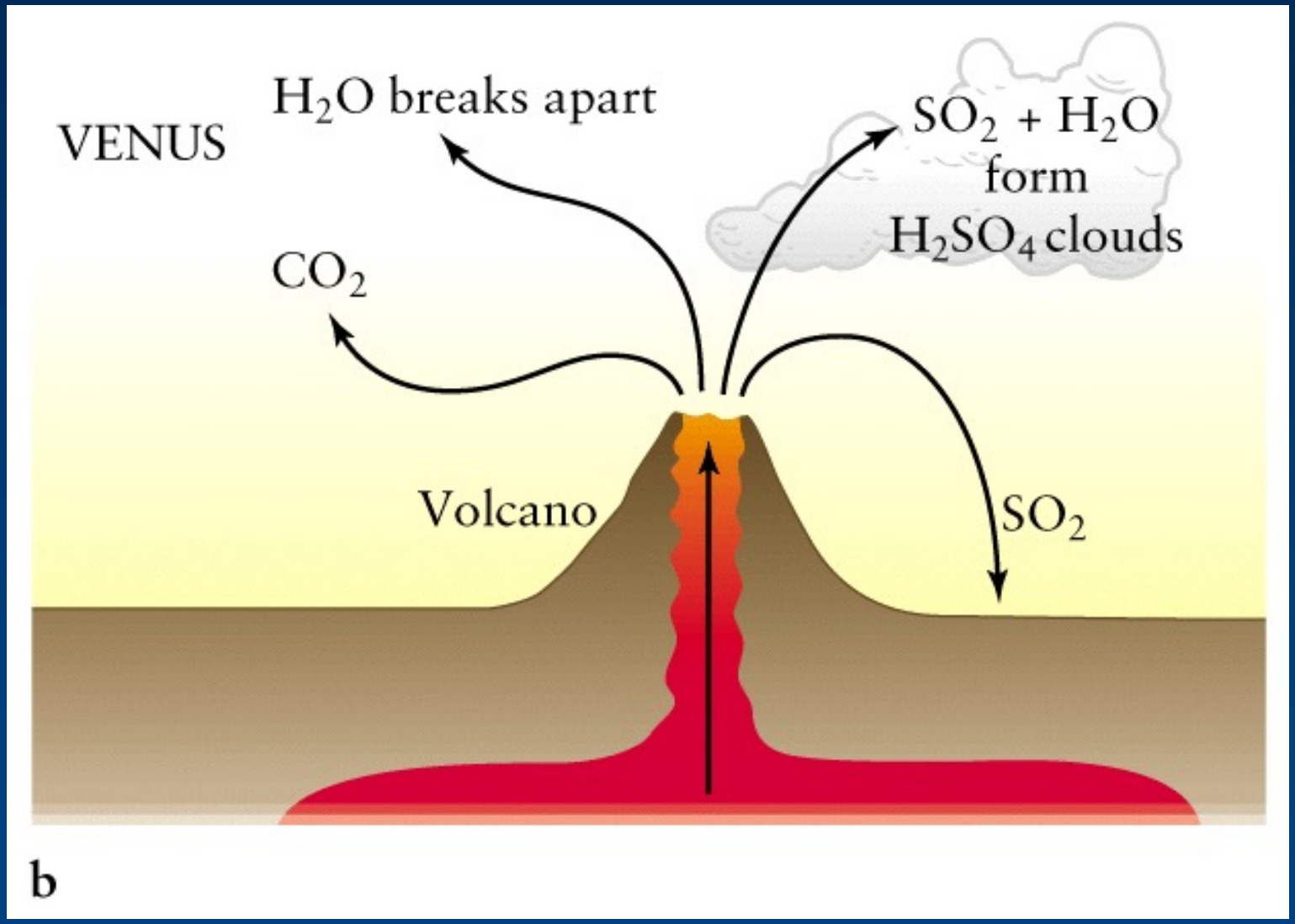
- Hotter Sun + water vapor increases atmospheric temperature.

- Water could no longer be liquid as Sun got hotter (~ few 100 million years). Oceans start to evaporate, adding more H_2O and CO_2 (and SO_2) to atmosphere.

- Stronger Greenhouse effect => further evaporation => stronger Greenhouse effect, etc. Eventually, CO_2 even baked out of rocks into atmosphere. Temperature stops rising when all CO_2 removed.

Runaway Greenhouse Effect!

Eventually, solar UV radiation would have broken H_2O apart. Hydrogen lost, O reacts to form molecules, atmosphere becomes dry.

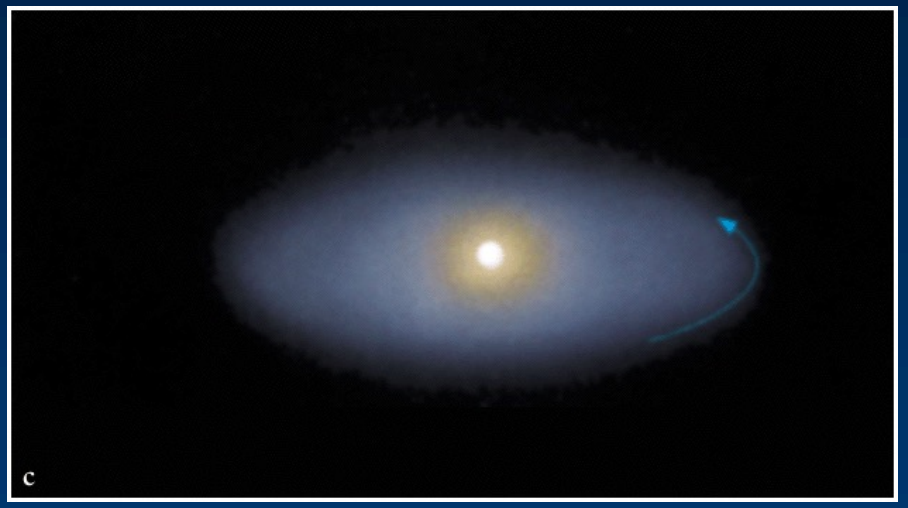


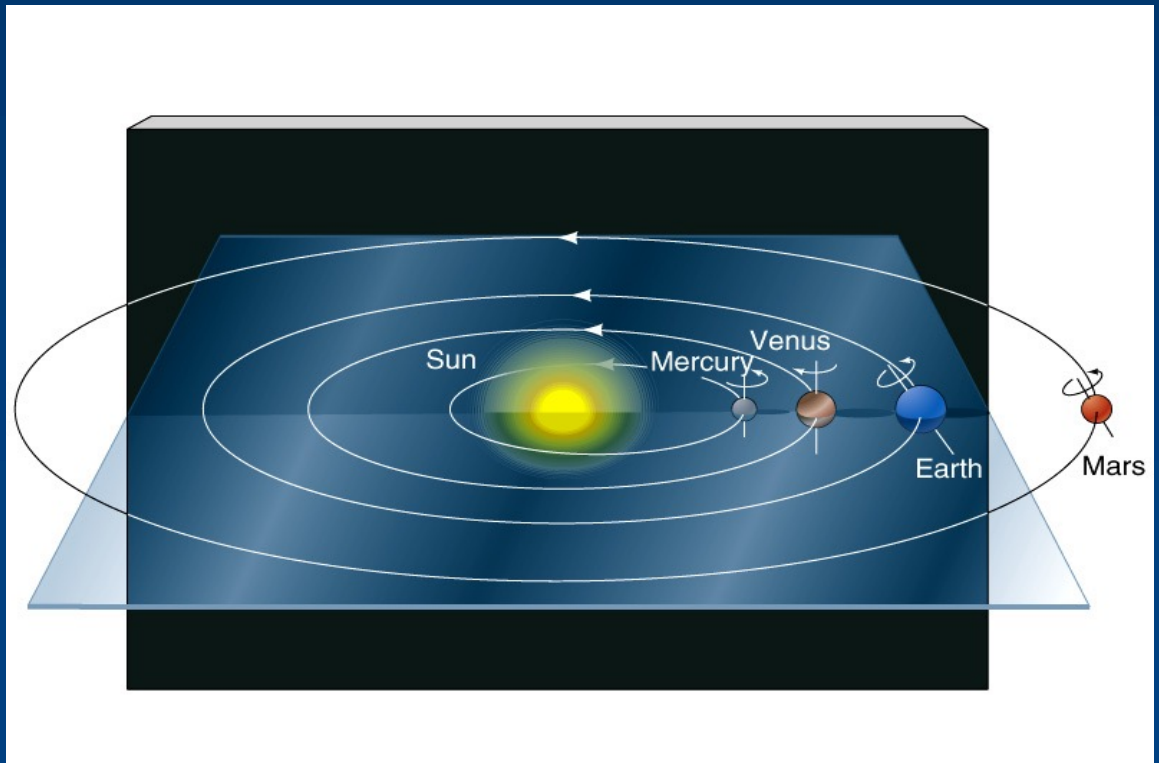
Comparison of Venus and Earth

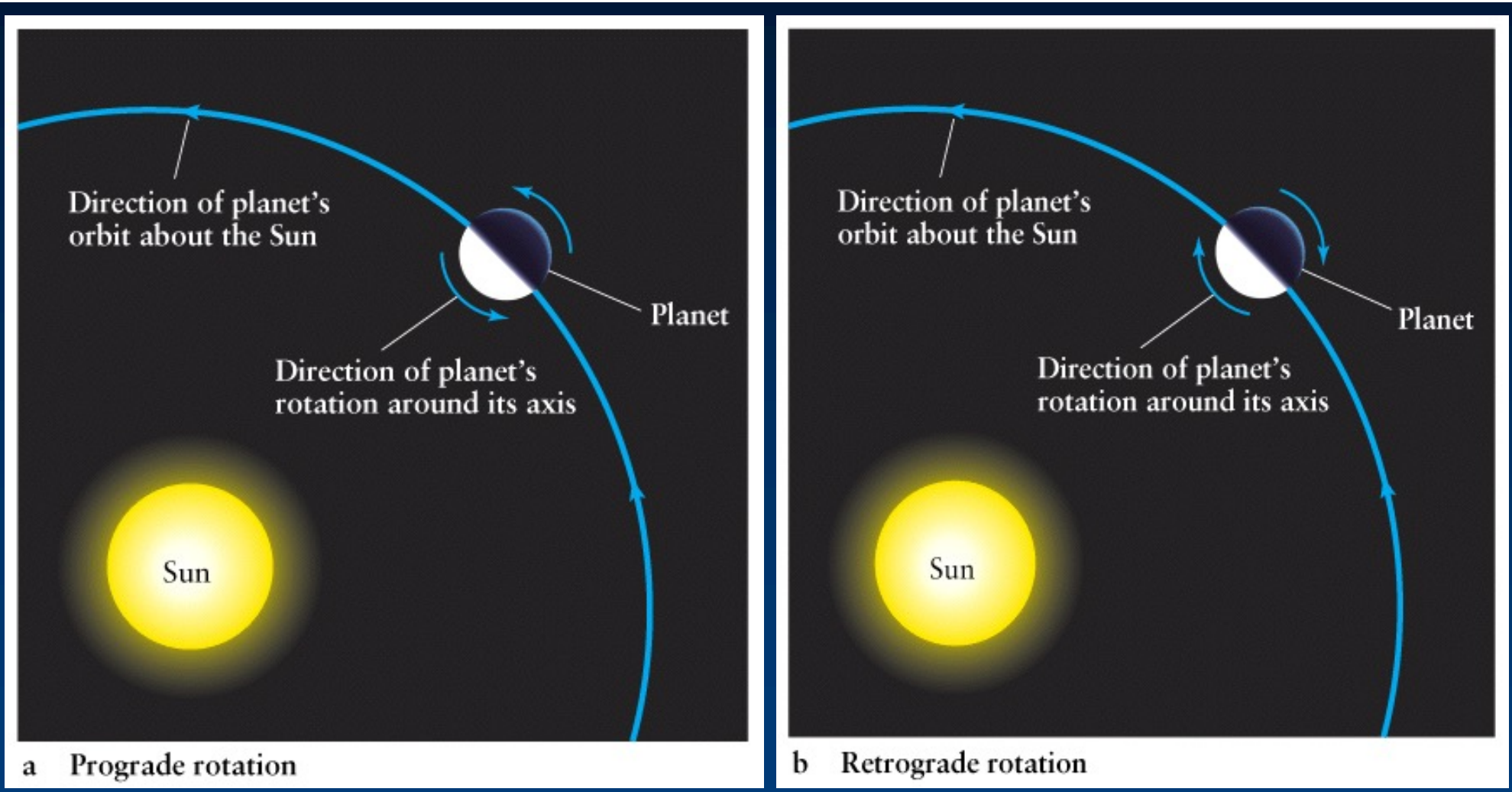
- Both display volcanism and geological activity, BUT Venus has:
  - Slow rotational period
  - No magnetic field
  - No plate tectonics
  - No moon
  - No water
  - High surface temperature and dense atmosphere

Finally – what to make of retrograde rotation?

Retrograde rotation is hard to understand just from planetary formation from pre-solar system nebula



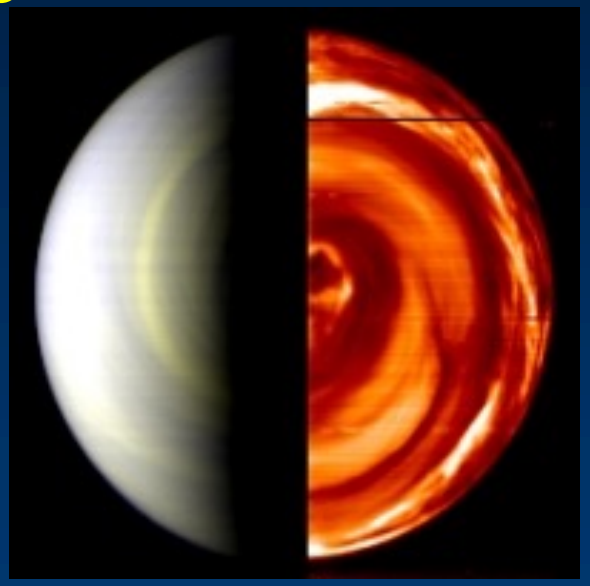




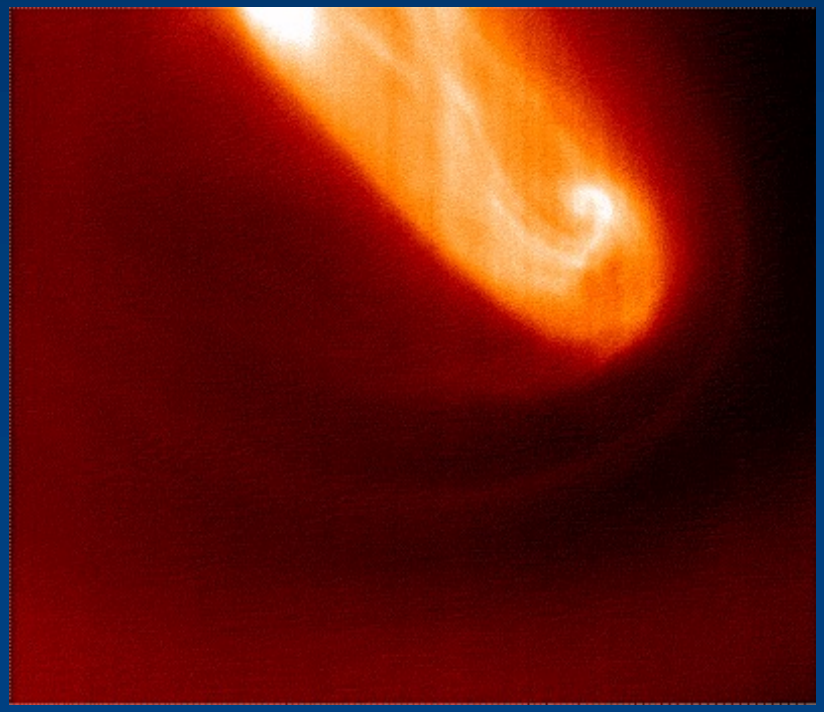
Massive impact reversed Venus's rotation??? Or complex mechanism involving tidal interaction between Venus, Sun & Earth, and atmospheric braking? Unknown.

Venus Express

- Aim: to study atmosphere
  - Interactions with surface
  - Interactions with solar wind
  - Circulation and composition as a function of depth
  - Radiative balance

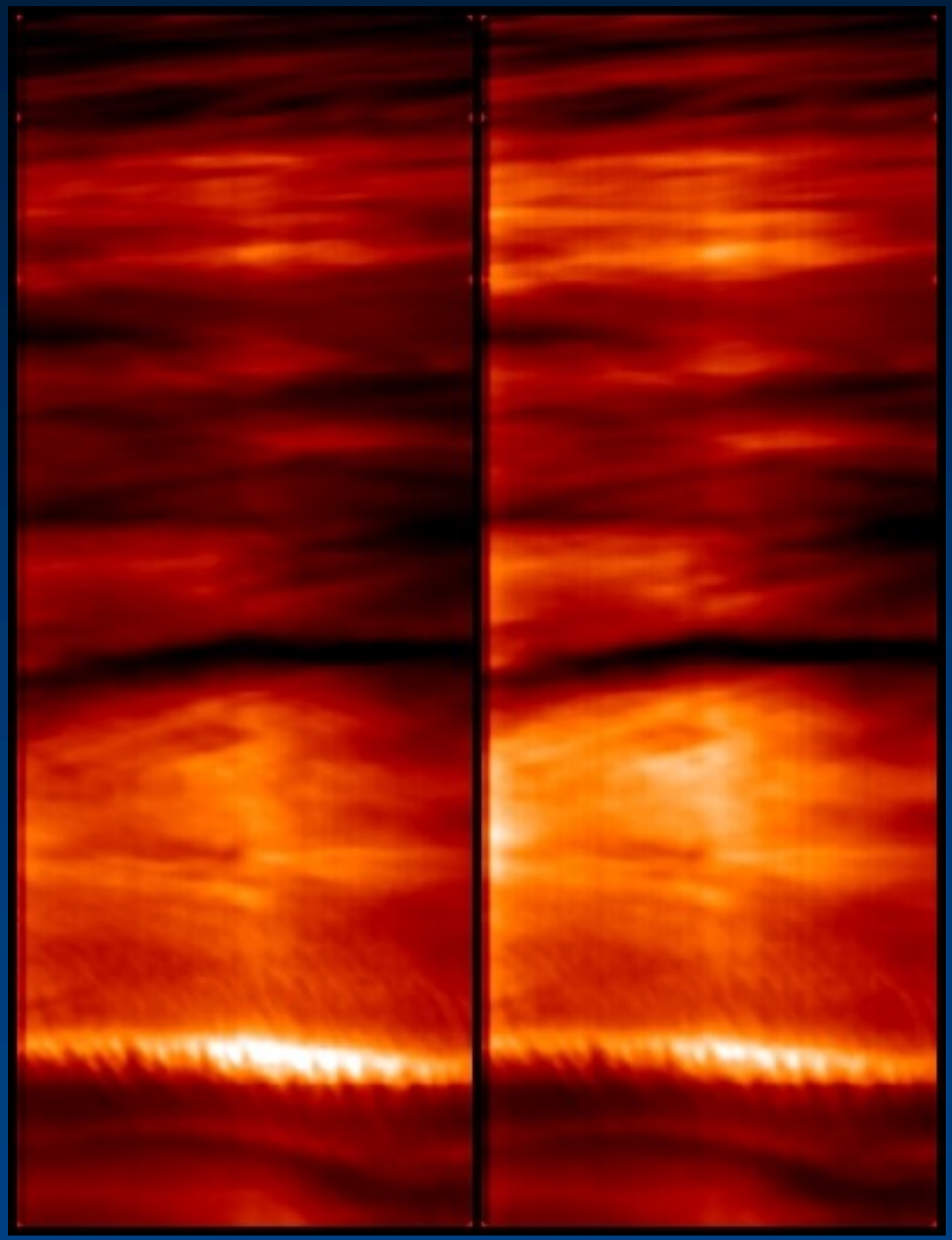


- IR image of doubled-eyed vortex at south pole



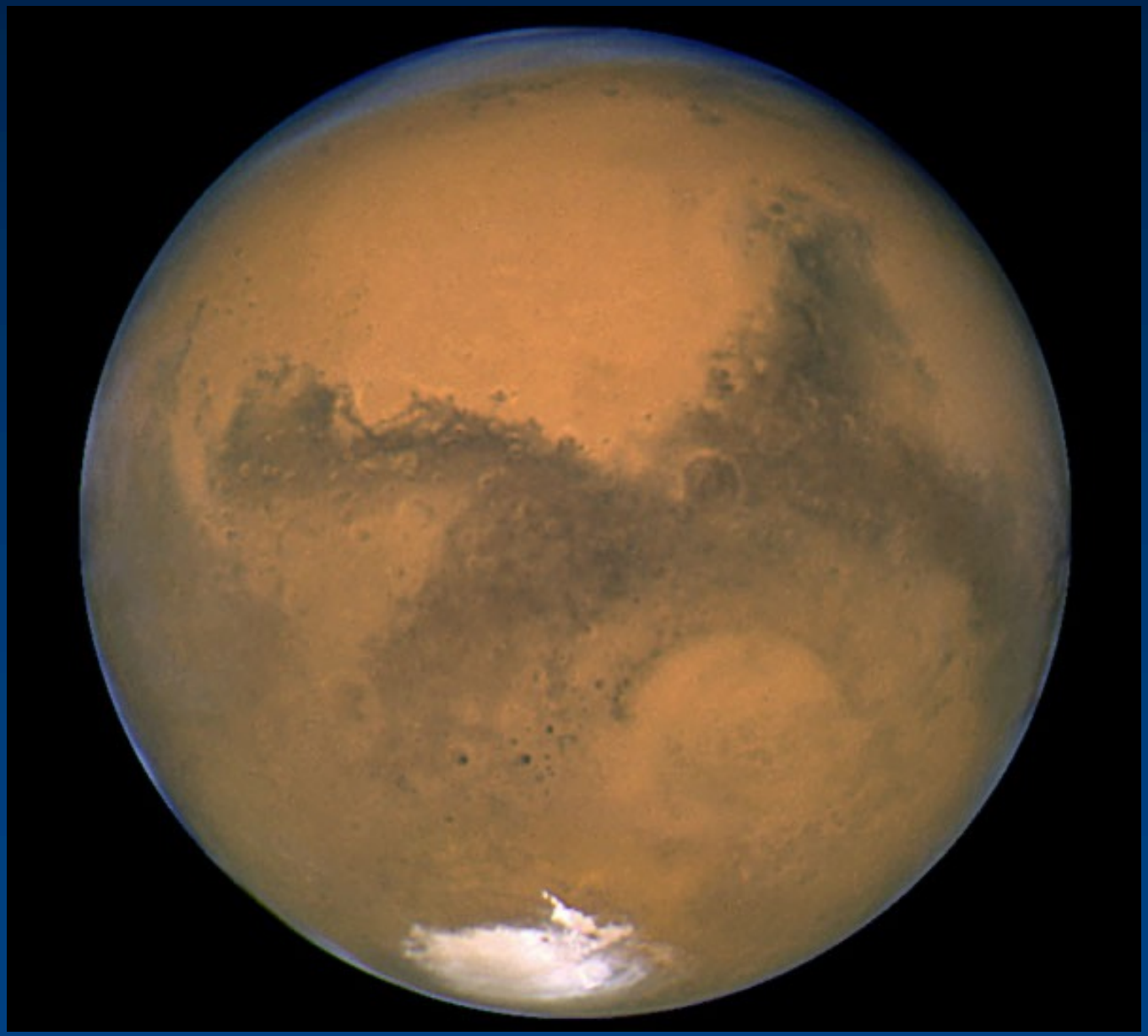
- Evidence that Venus is slowing down

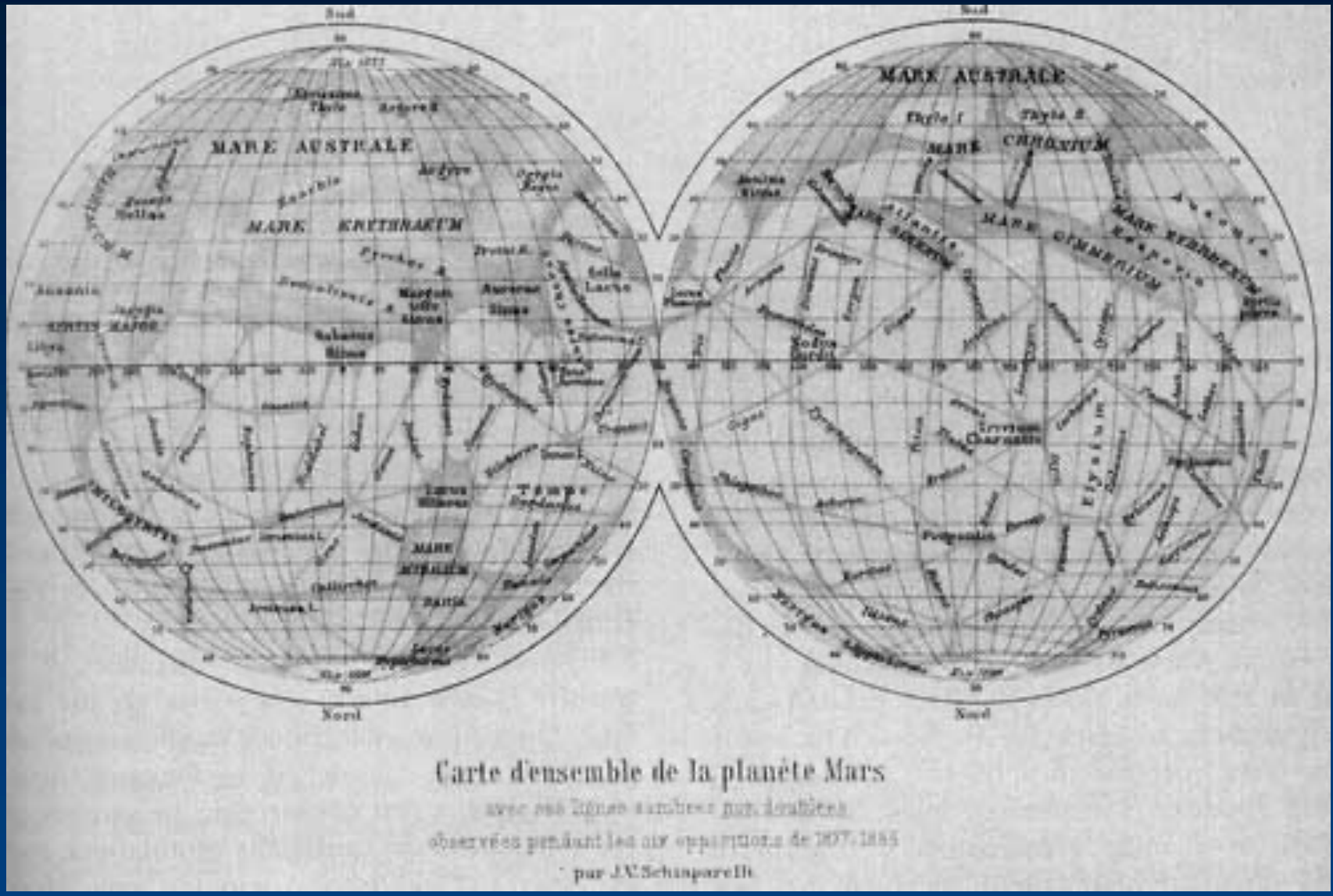
- Ended on Dec. 2014



- IR images
- 2.3 and 1.7μm
- Atmospheric structure at 35 and 20 km altitude respectively
- Stripes: wave-like atmospheric motion (tidal forces?) but nature still unknown.

Mars





Carte d'ensemble de la planète Mars

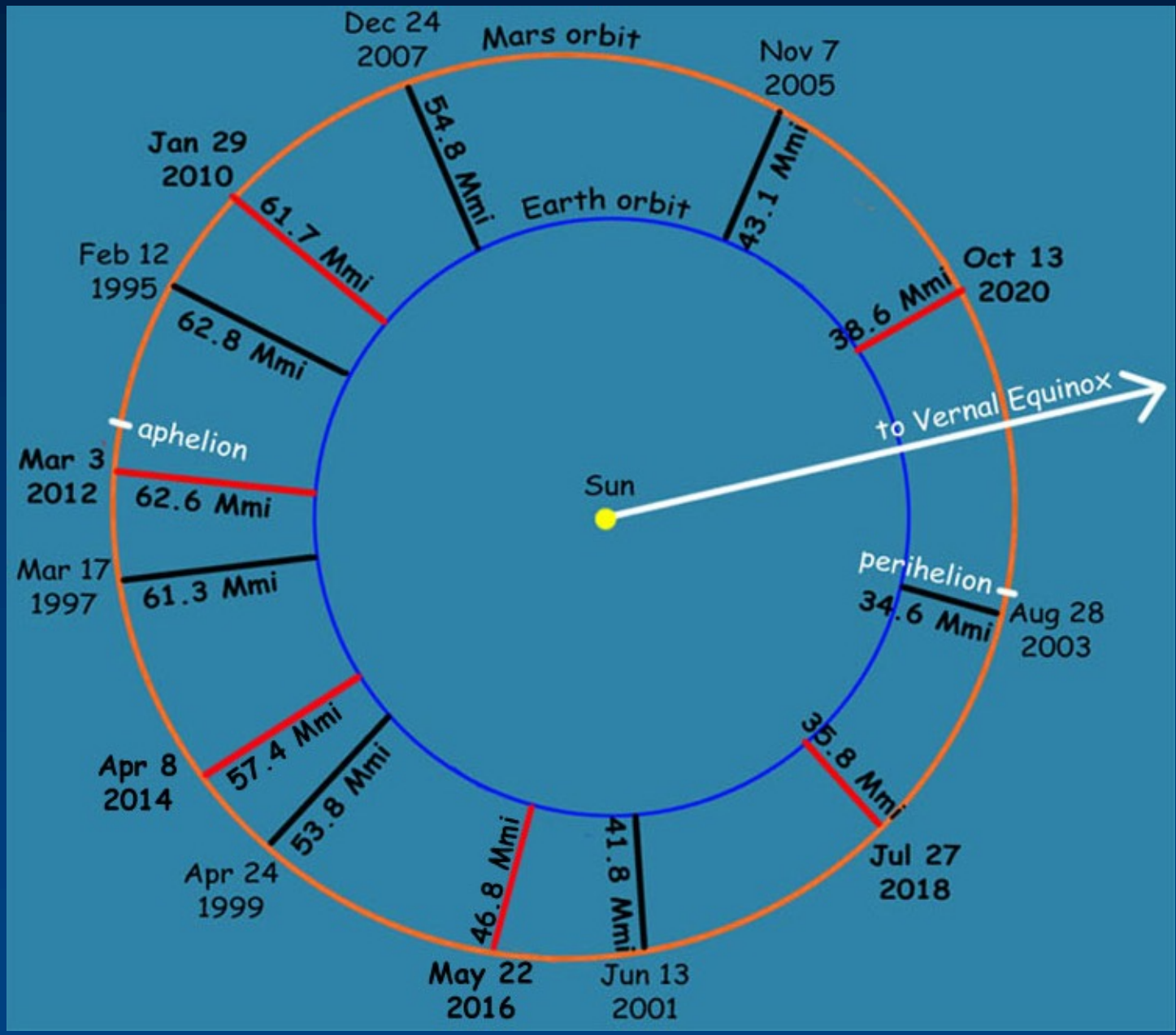
par J.V. Schiaparelli

"Canali" on Mars circa 1880

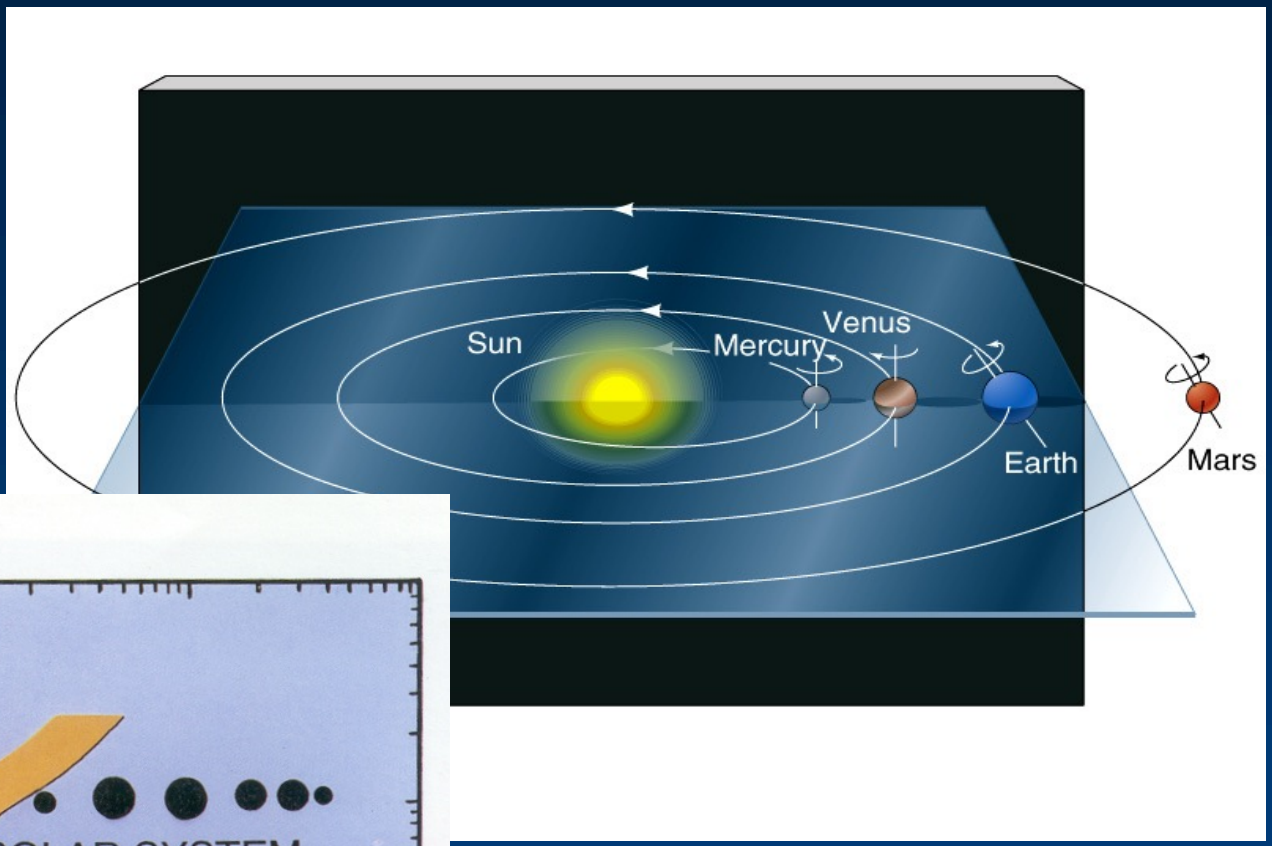
It will be possible to see cities on Mars, to detect navies in [its] harbors, and the smoke of great manufacturing cities and towns... Is Mars inhabited? There can be little doubt of it ... conditions are all favorable for life, and life, too, of a high order. Is it possible to know this of a certainty? Certainly.

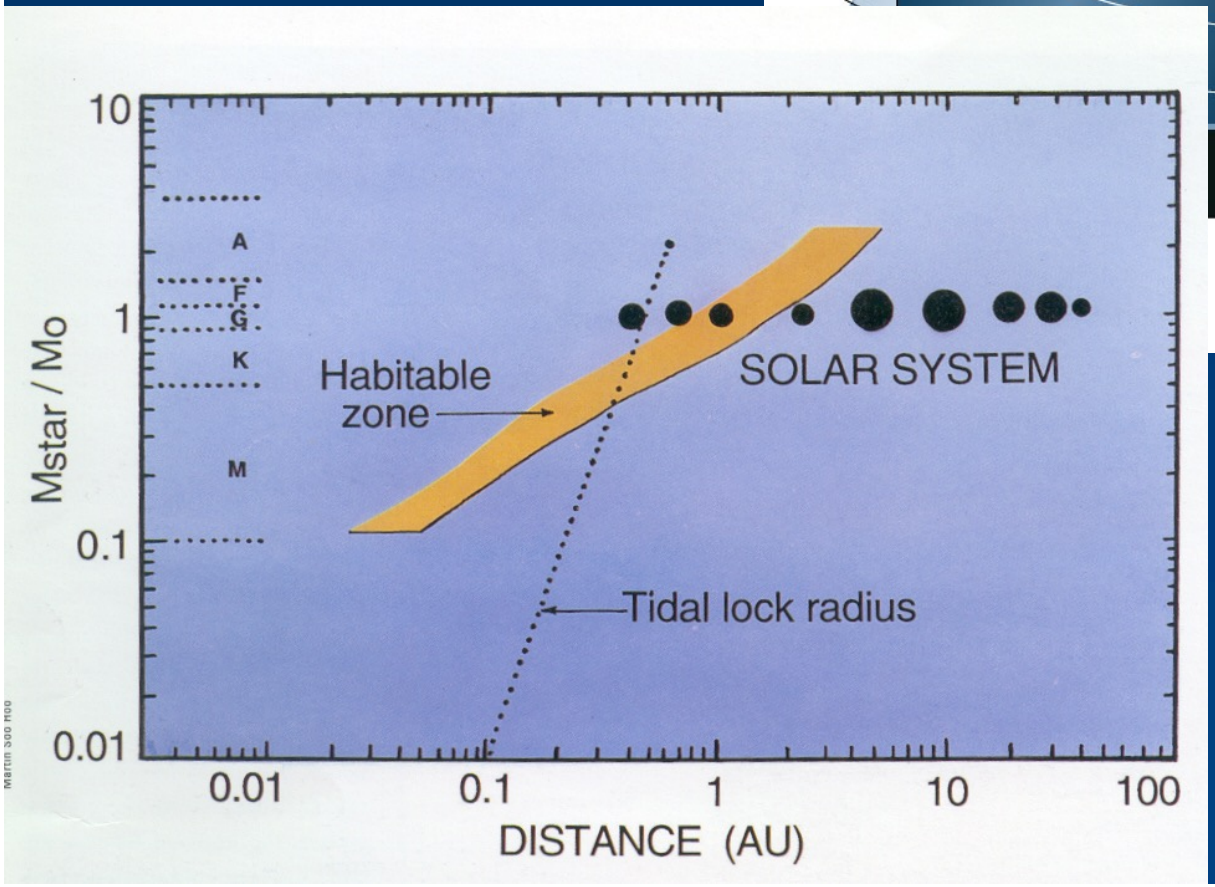
1895 Samuel Leland Phelps, Professor in Astronomy regarding the construction of a 40 inch telescope at the University of Chicago.

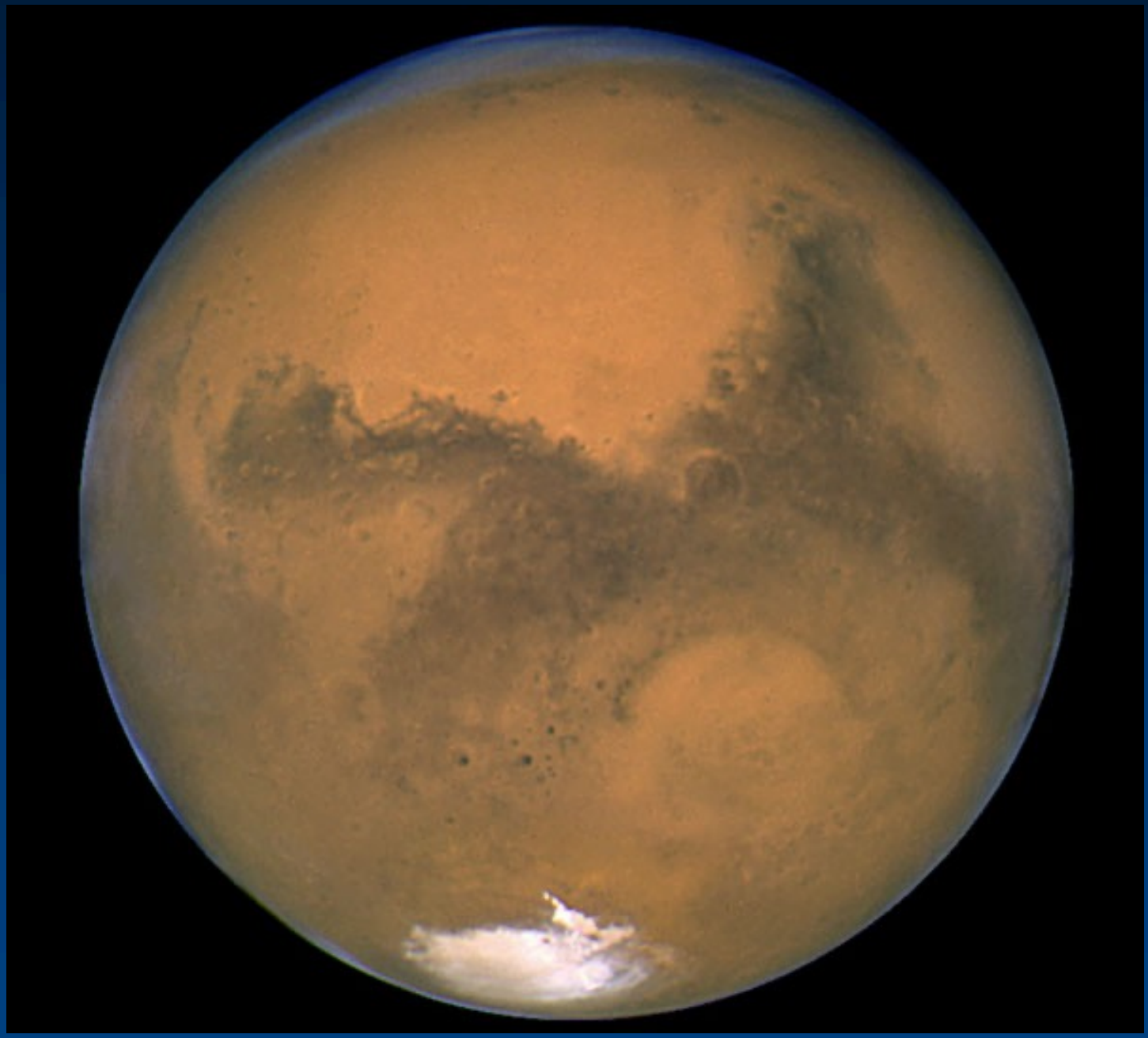
dates of opposition



Terrestrial Planets' Spin, Habitability



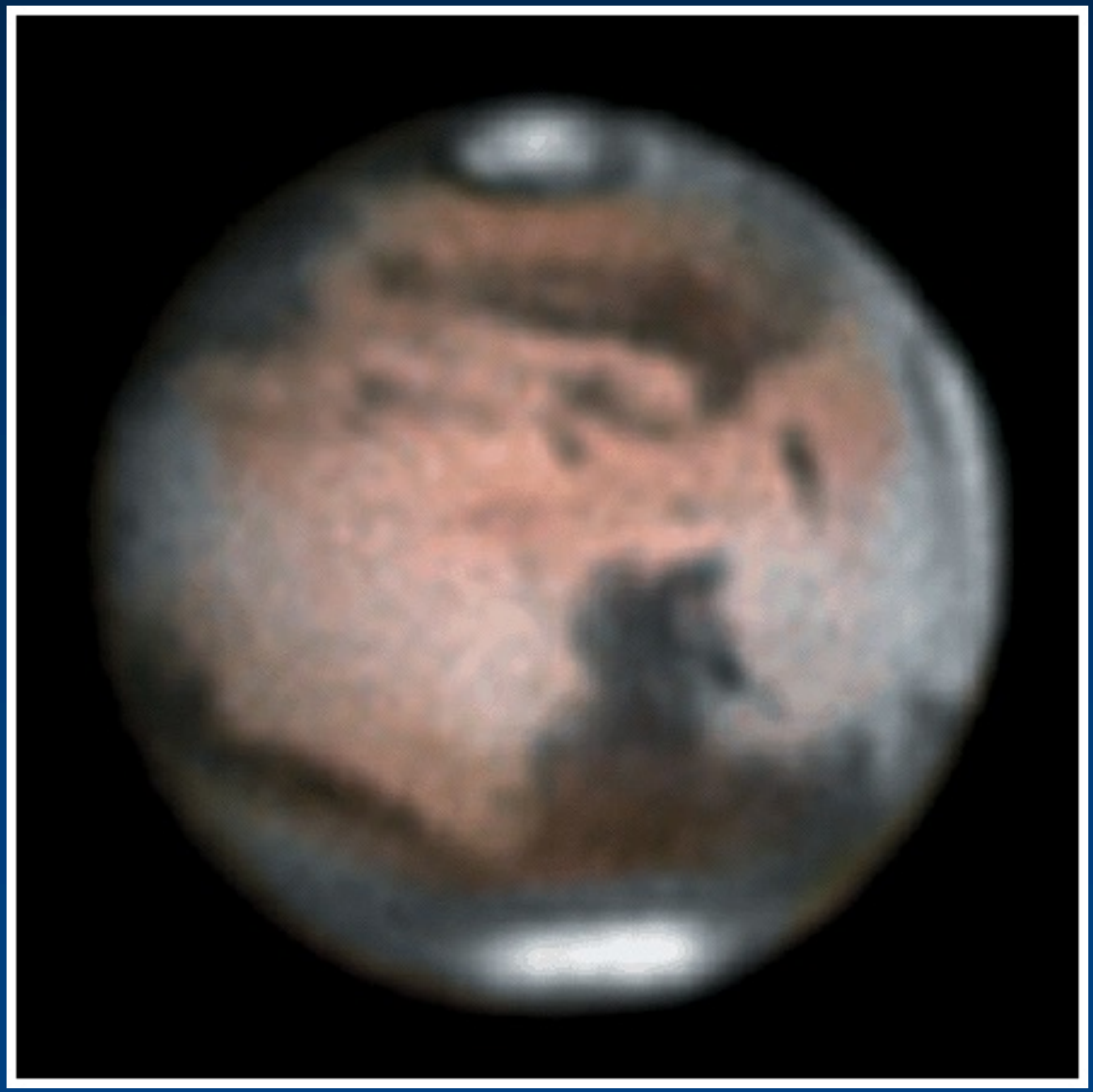




HST image of Mars taken August 2003

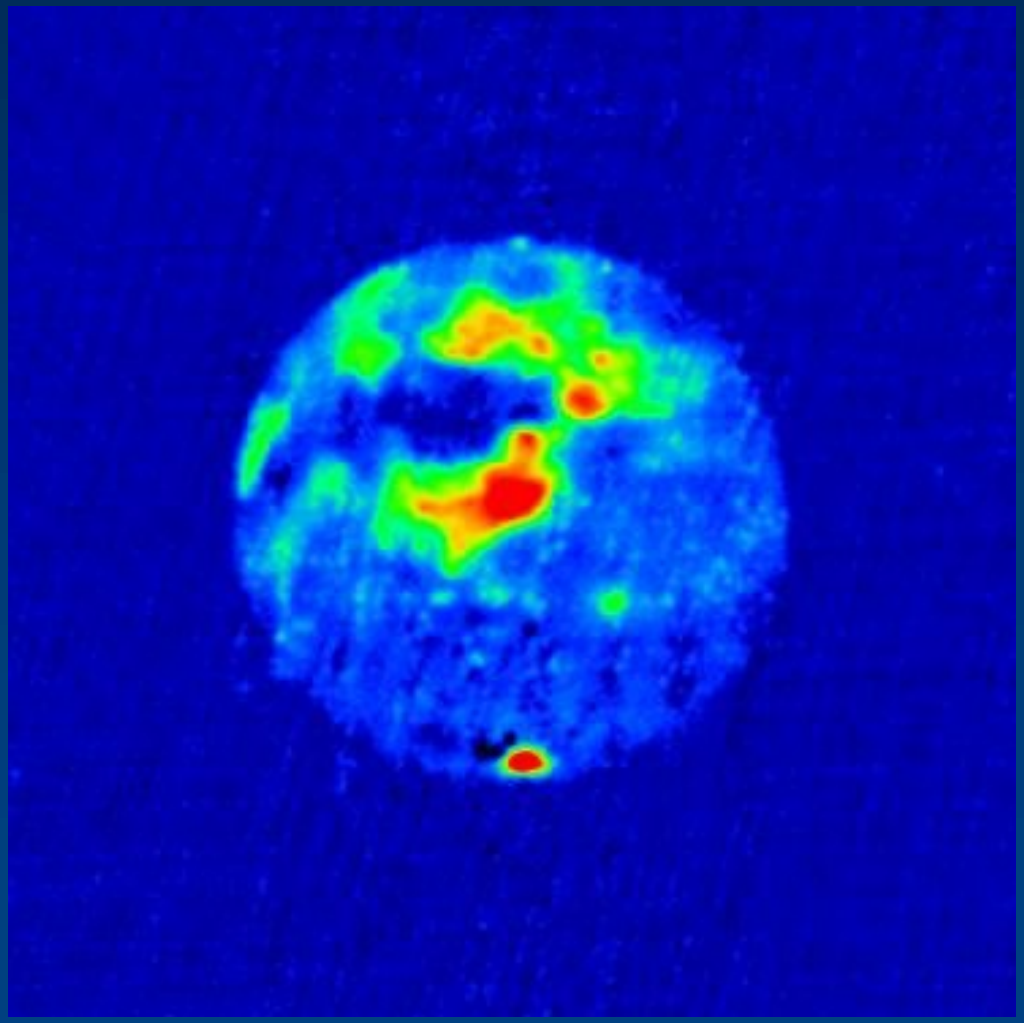
Images - from Earth

Reddish, polar caps, seasonally changing patchiness



Radar Image - from Earth

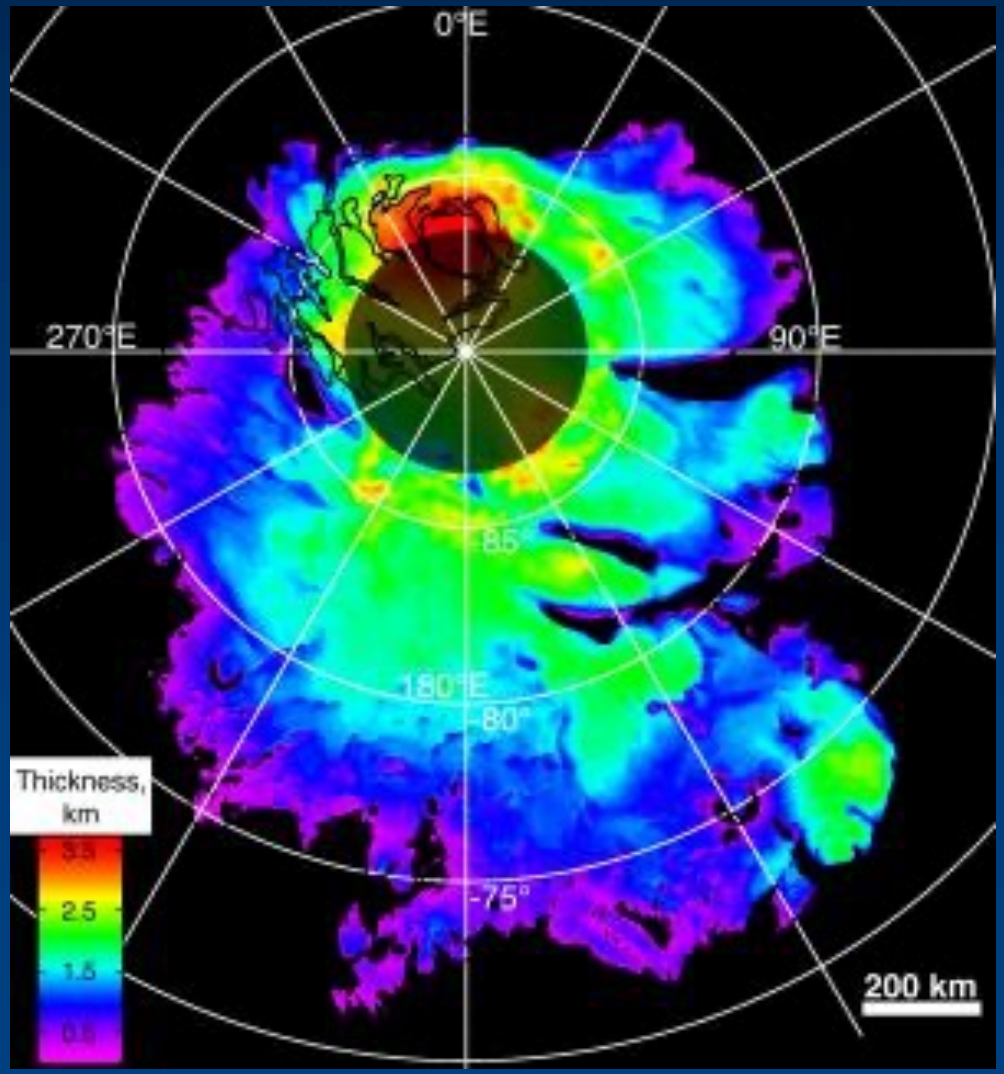
Ices are highly reflective



Goldstone
to
VLA

Radar Image - from Mars (Mars Express)

Depth of Ice at the South Pole



Space missions

- 58 missions as of Oct, 2021
- 26 successes and 30 failures
- 1M No.1 (USSR) failed to launch in 1960
- Mariner 4 (1965) first successful fly-by

  Viking Orbiters (1976)

  Mars Global Surveyor (1998-pres)

  Mars Climate Orbiter (1998-99, burned up, units! -2)

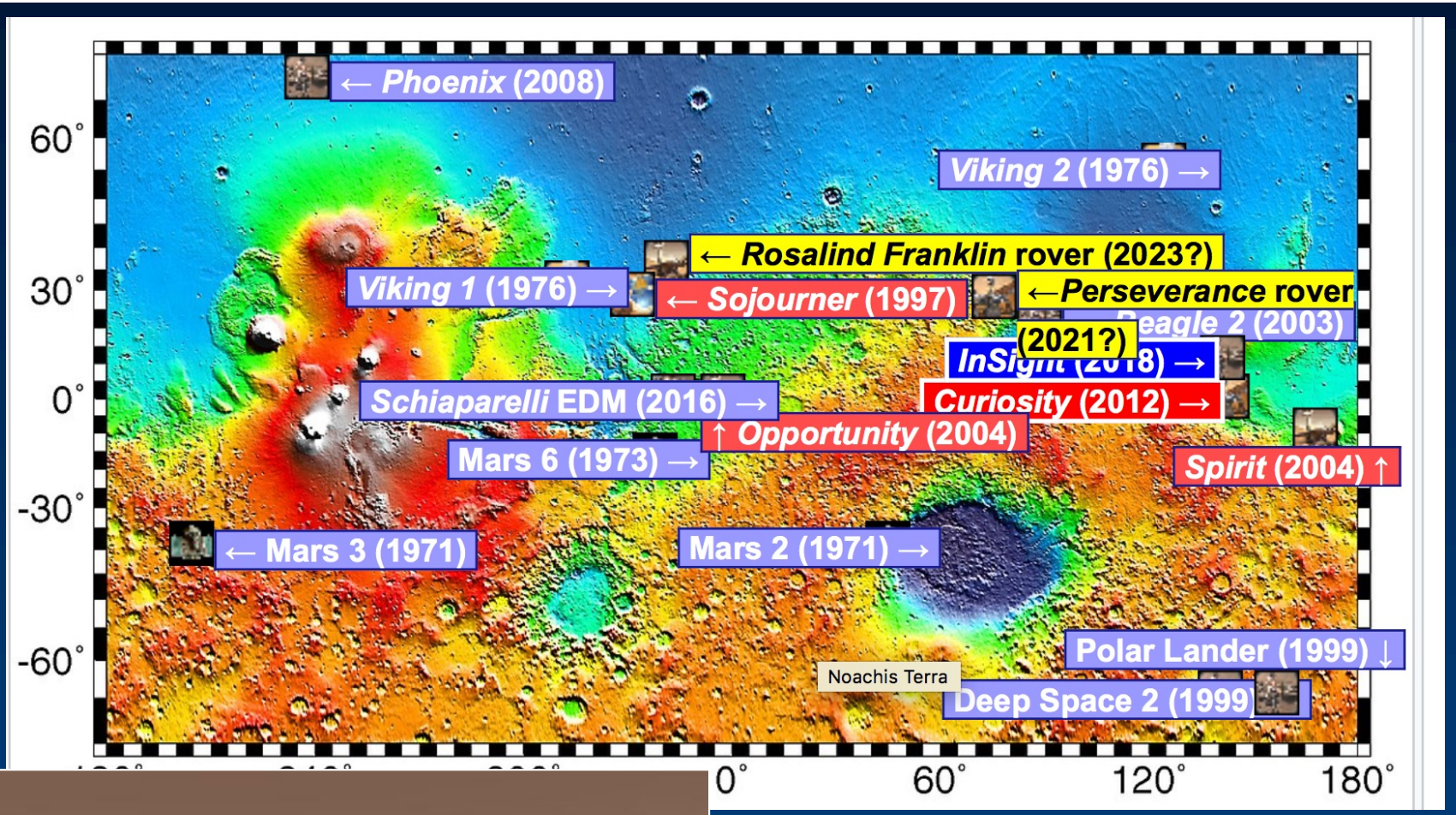
  Mars Odyssey Orbiter (2001-pres)

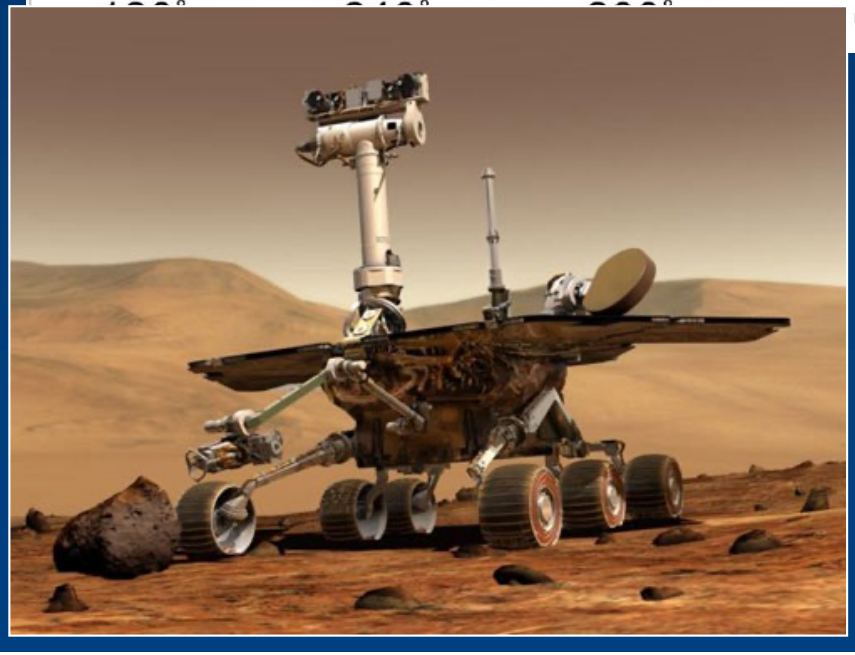
  Nozomi (Japan 2003, failed to go into orbit)

  Mars Express (ESA, 2003-present)

  Mars Reconnaissance Orbiter (NASA, 2006-pres)

Currently: 1 lander (Insight), 5 rovers, 6 orbiters, 1 drone


← Phoenix (2008)
Viking 2 (1976) →
← Rosalind Franklin rover (2023?)
Viking 1 (1976) →
← Sojourner (1997)
←Perseverance rover (2021?)
Beagle 2 (2003)
InSight (2018) →
Schiaparelli EDM (2016) →
Curiosity (2012) →
↑ Opportunity (2004)
Mars 6 (1973) →
Spirit (2004) ↑
← Mars 3 (1971)
Mars 2 (1971) →
Polar Lander (1999) ↓
Noachis Terra
Deep Space 2 (1999
60°
30°
0°
-30°
-60°
0°
60°
120°
180°



Mars basic data

Semi-major axis	1.52 AU
Period	1.88 Earth years
Rotation	$24^h\ 37^m$
Inclination	25.19°
Diameter	0.533 Earth
Mass	0.107 Earth
Density	3934 kg/m^3 = 3.94 g/cm^3
V_{esc}	5.0 km/s
Temp	-220 to +70° F or 133 to 293K
Albedo	0.15
Atmospheric pressure level)	0.087 psi (0.6% Earth at sea