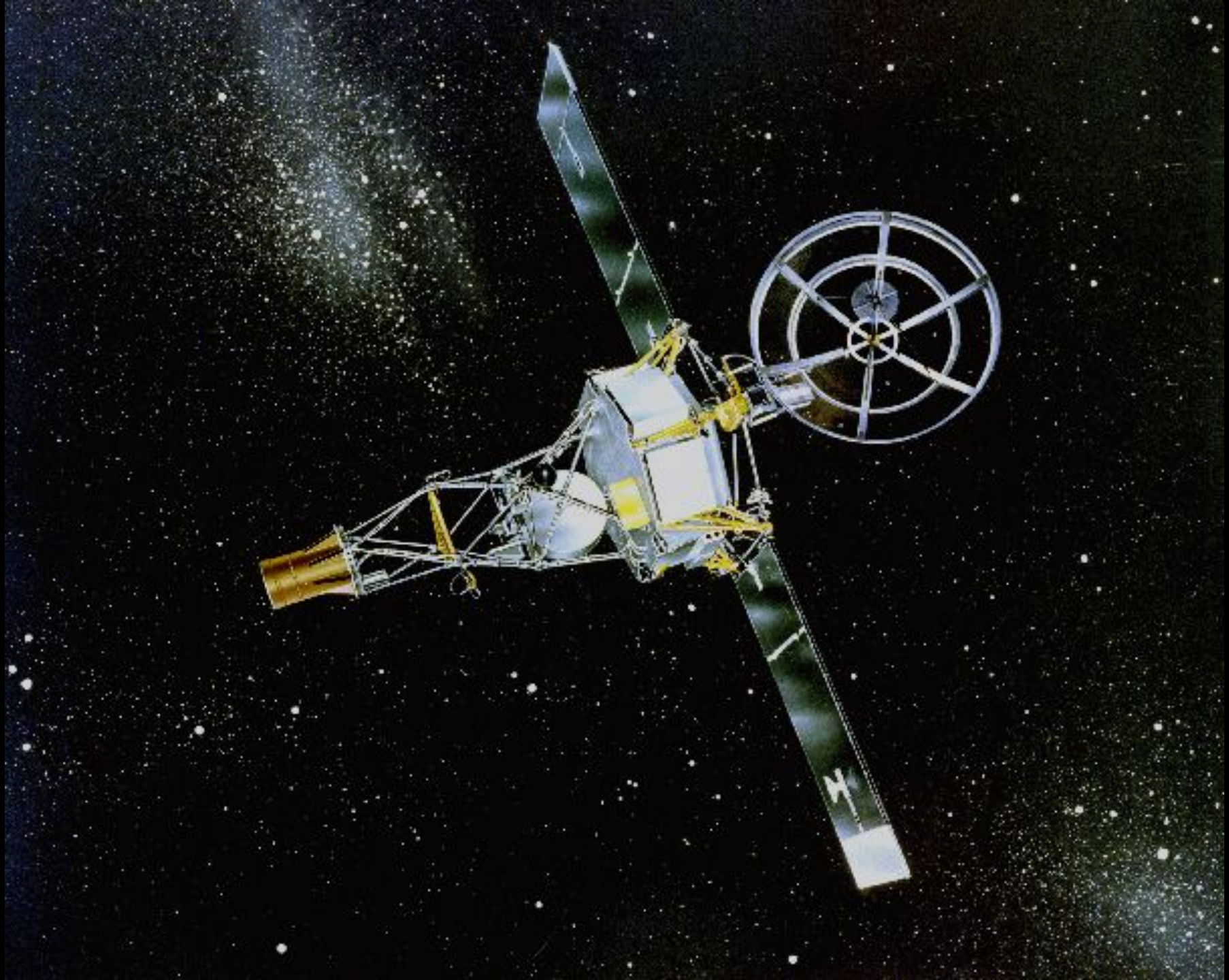
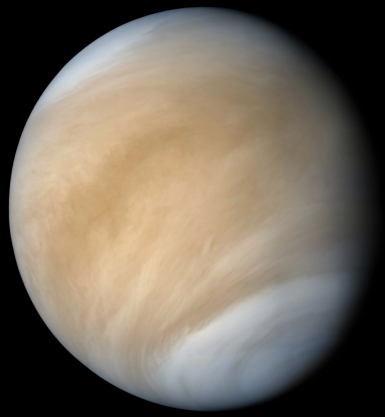
HOT SCIENCE AT VENUS

David Grinspoon
Planetary Science Institute

KISS 7/20/22

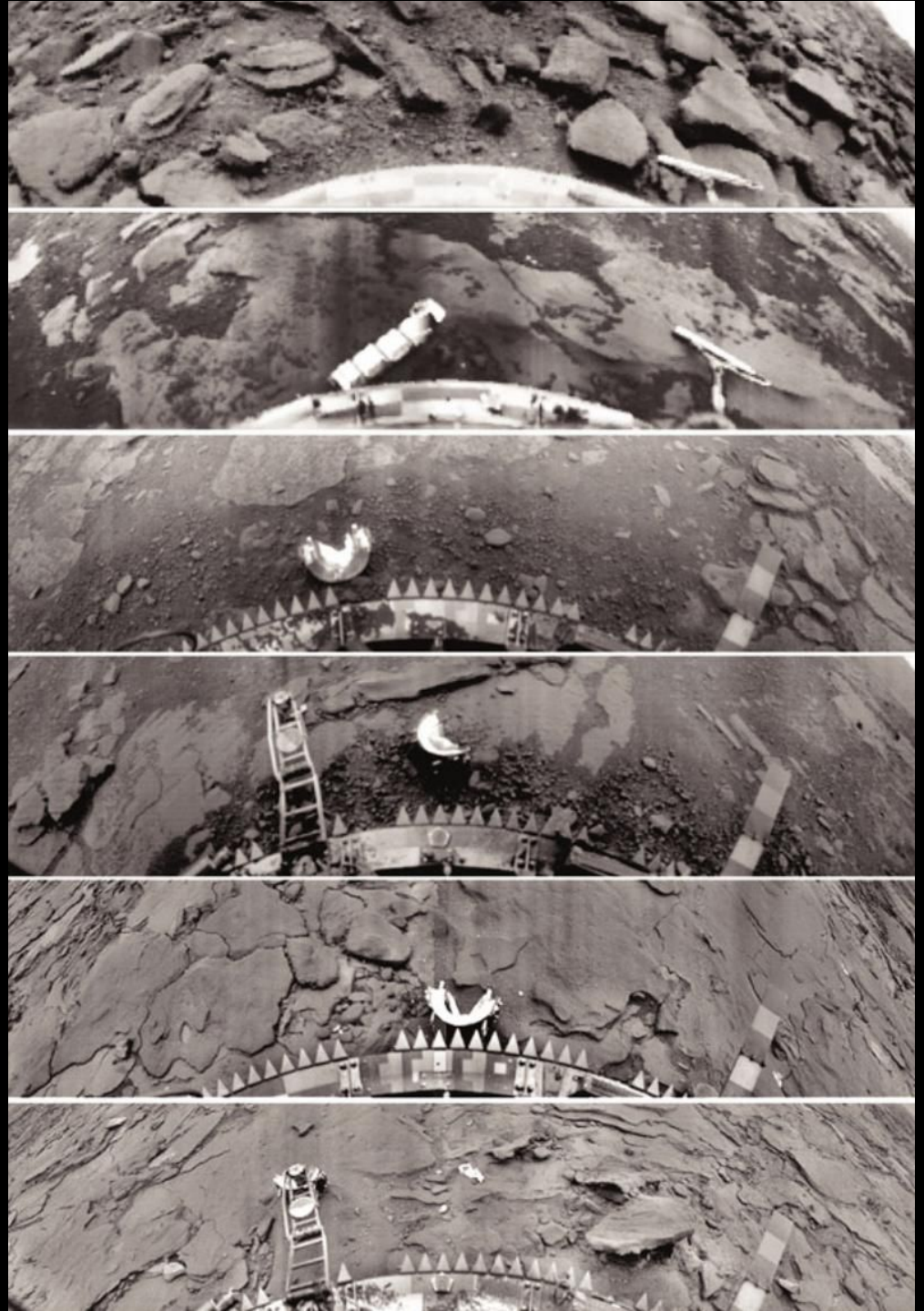


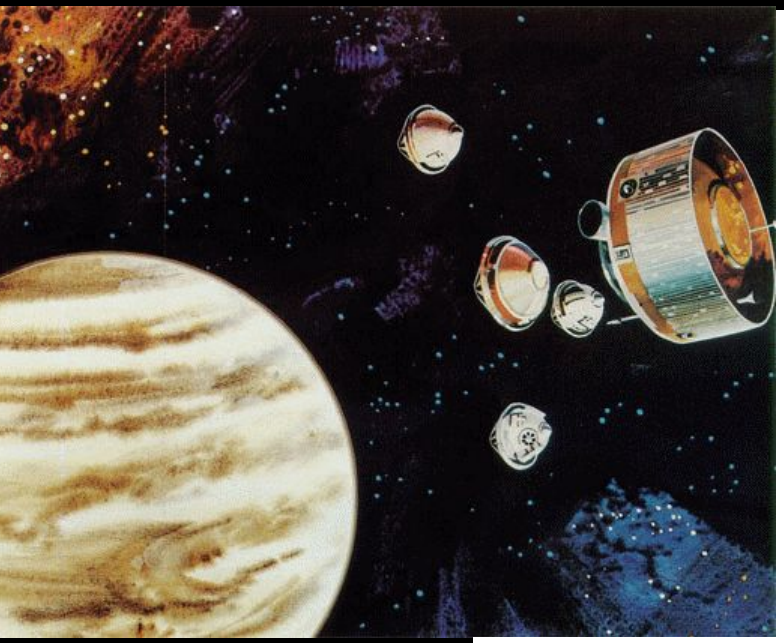


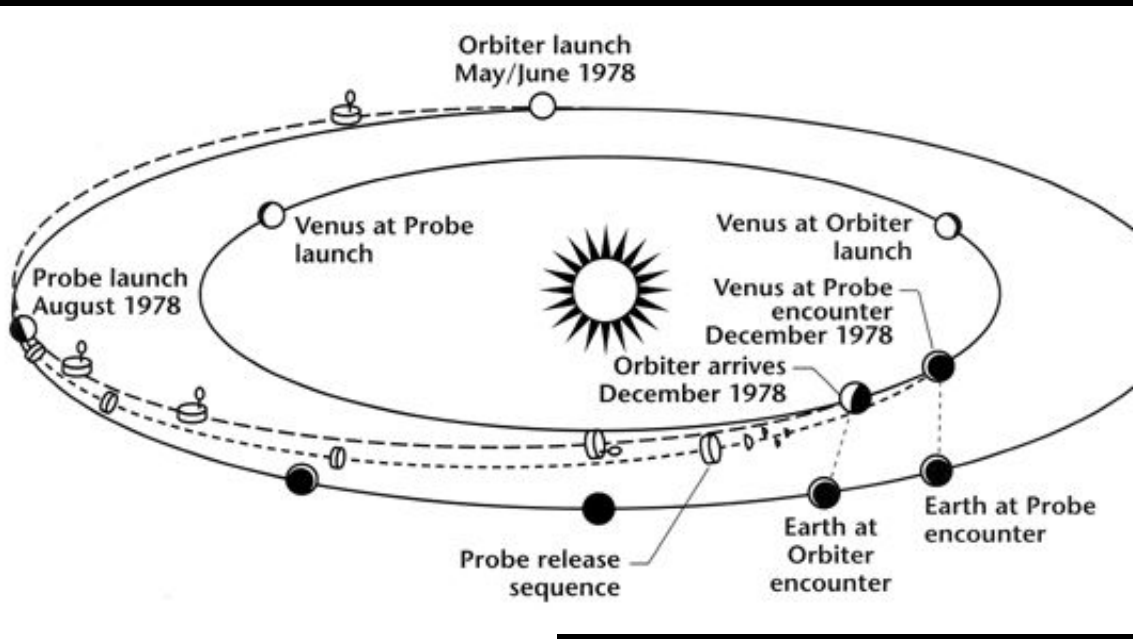
	Venus	Earth
D (km)	12,104	12,756
M (10^{24} kg)	4.86	5.97
V_e (km/s)	10.4	11.2
P (bars)	92	1
T_s (C)	477	20
H_2O (kg)	5.9×10^{16}	1.4×10^{21}

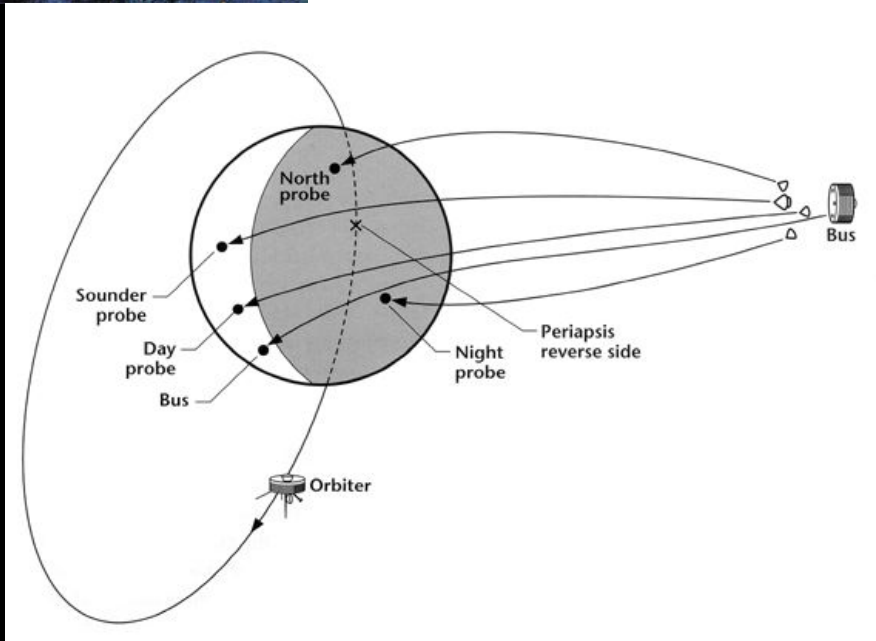
Earth has 100,000 times as much water as Venus!


СССР
СССР СССР СССР СССР



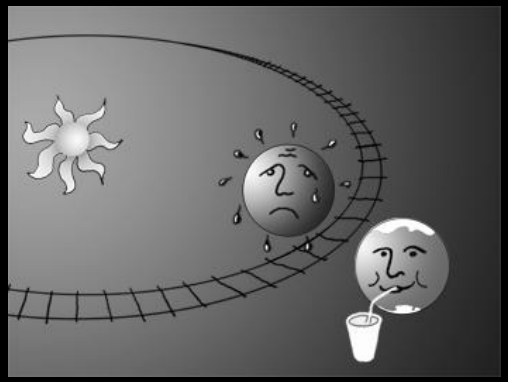



Orbiter launch
May/June 1978
Venus at Probe
launch
Venus at Orbiter
launch
Probe launch
August 1978
Venus at Probe
encounter
December 1978
Orbiter arrives
December 1978
Earth at Probe
encounter
Earth at
Orbiter
encounter
Probe release
sequence


North
probe
Bus
Sounder
probe
Day
probe
Bus
Periapsis
reverse side
Night
probe
Orbiter

IDENTICAL TWINS: WHERE DID VENUS GO WRONG?

Born too close to the sun.



Too much sun. Runaway Greenhouse

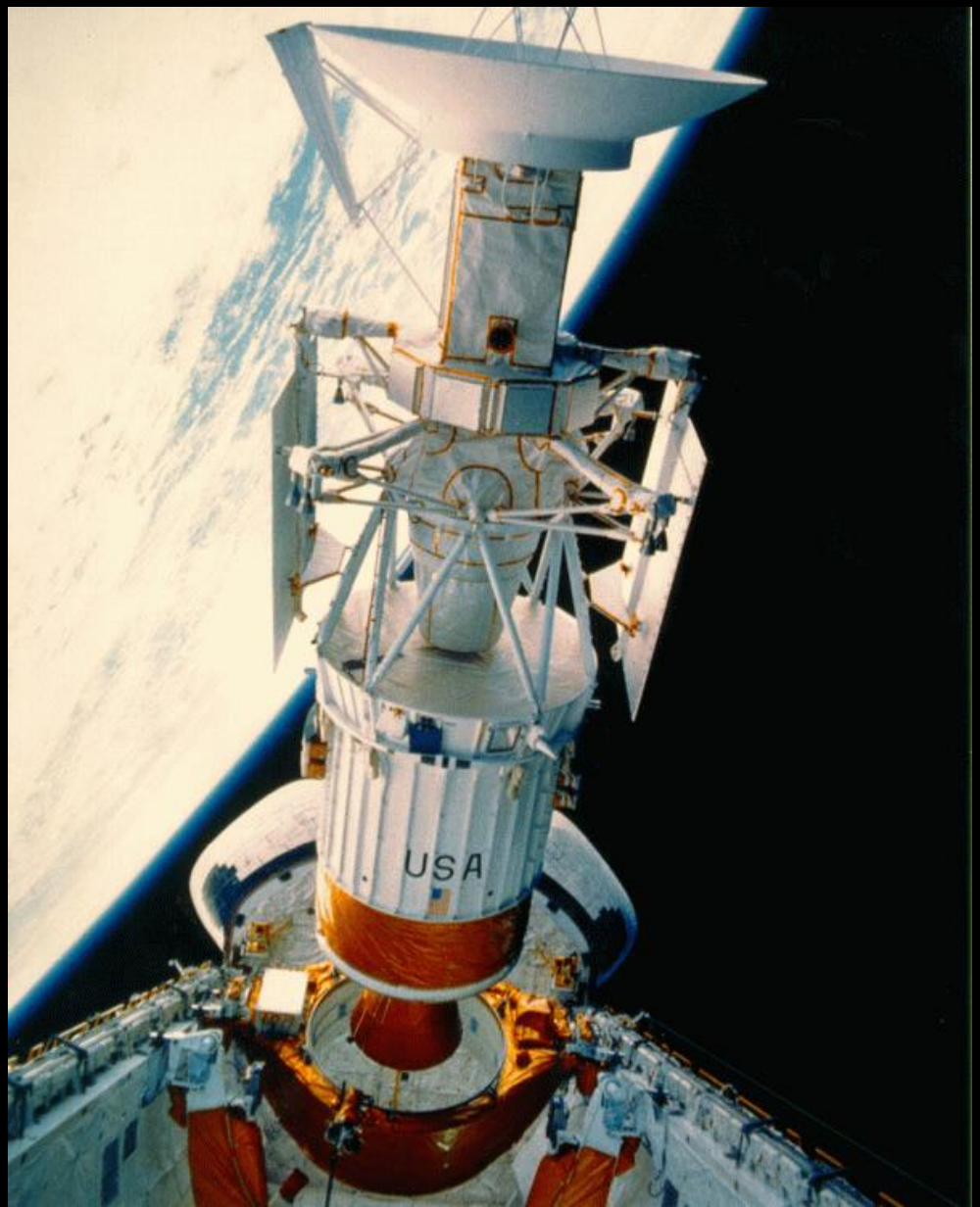
powerful positive **feedback**:

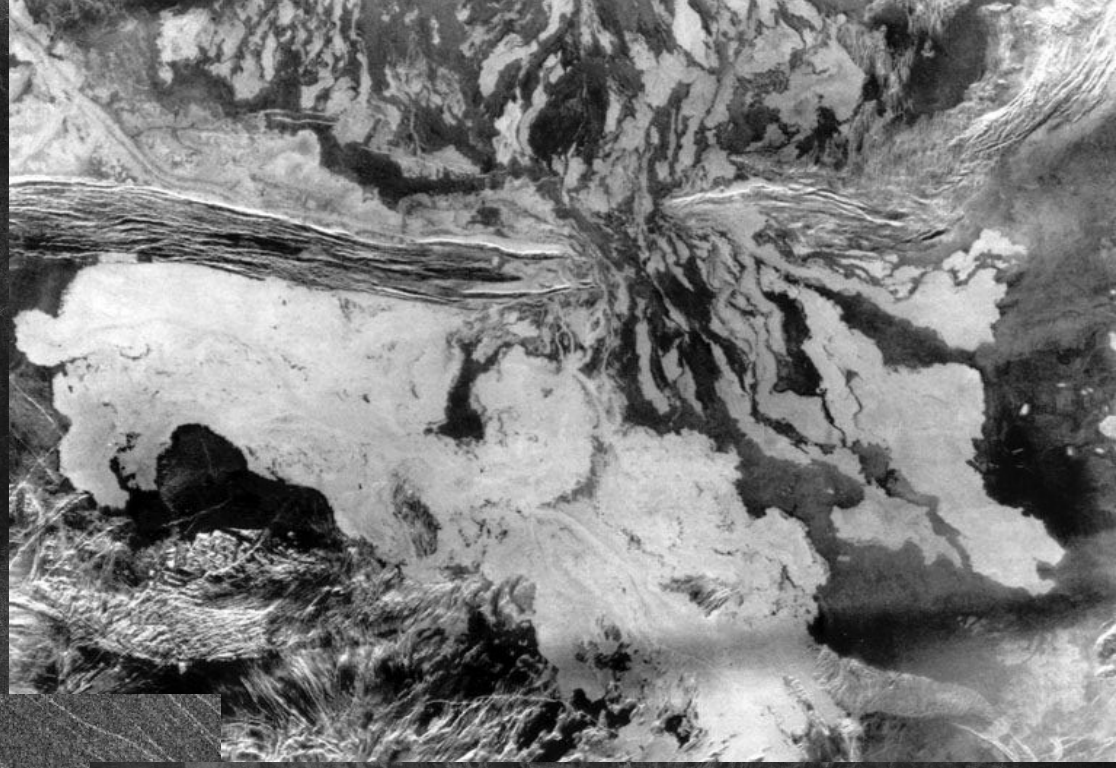
higher surface T → more water vapor in atmosphere → greater IR opacity → higher surface T

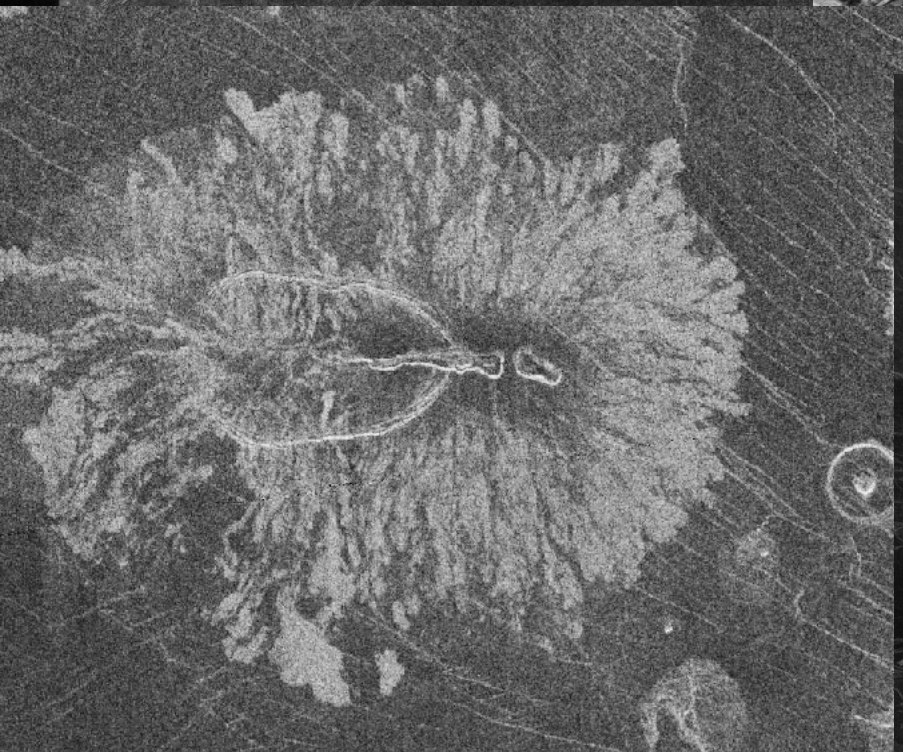
Steam atmosphere H escapes.

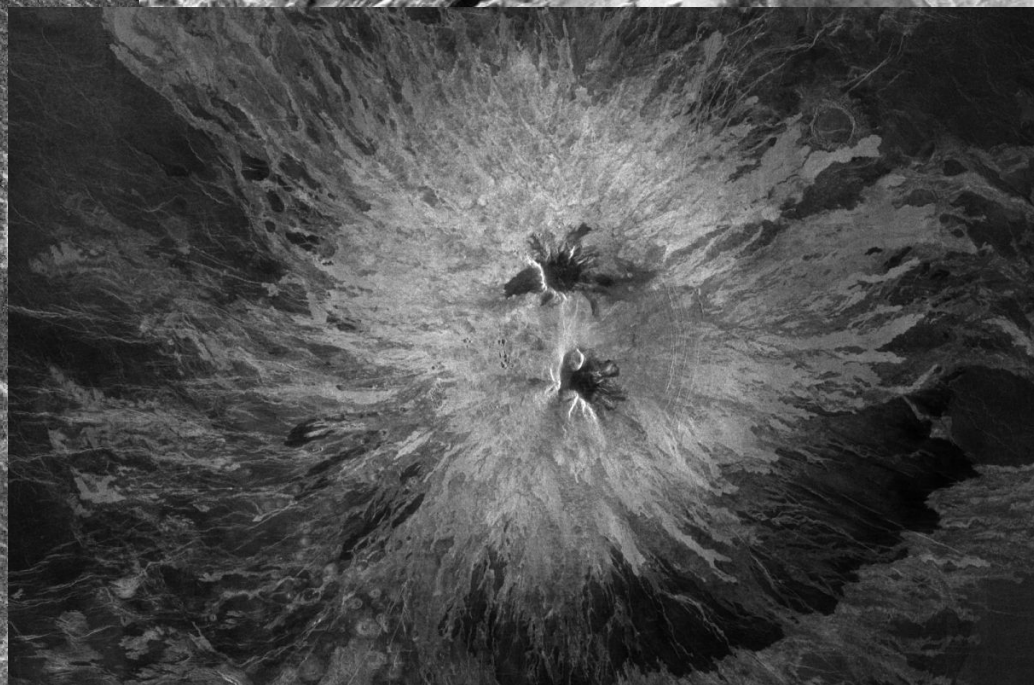
Result: Today Venus has only 10^{-5} Earth's water inventory.

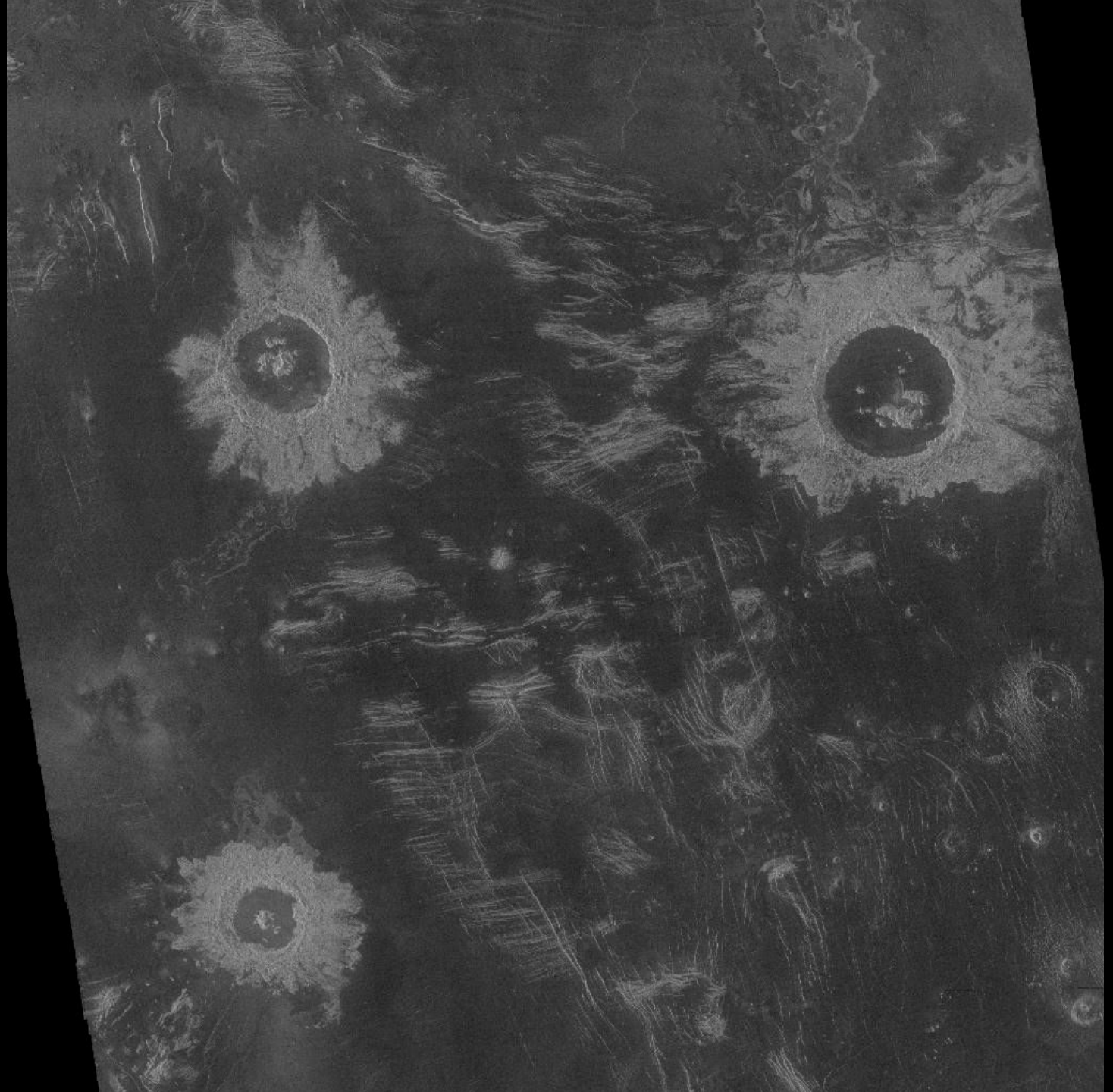
Magellan:
”the Mariner 9 of Venus”

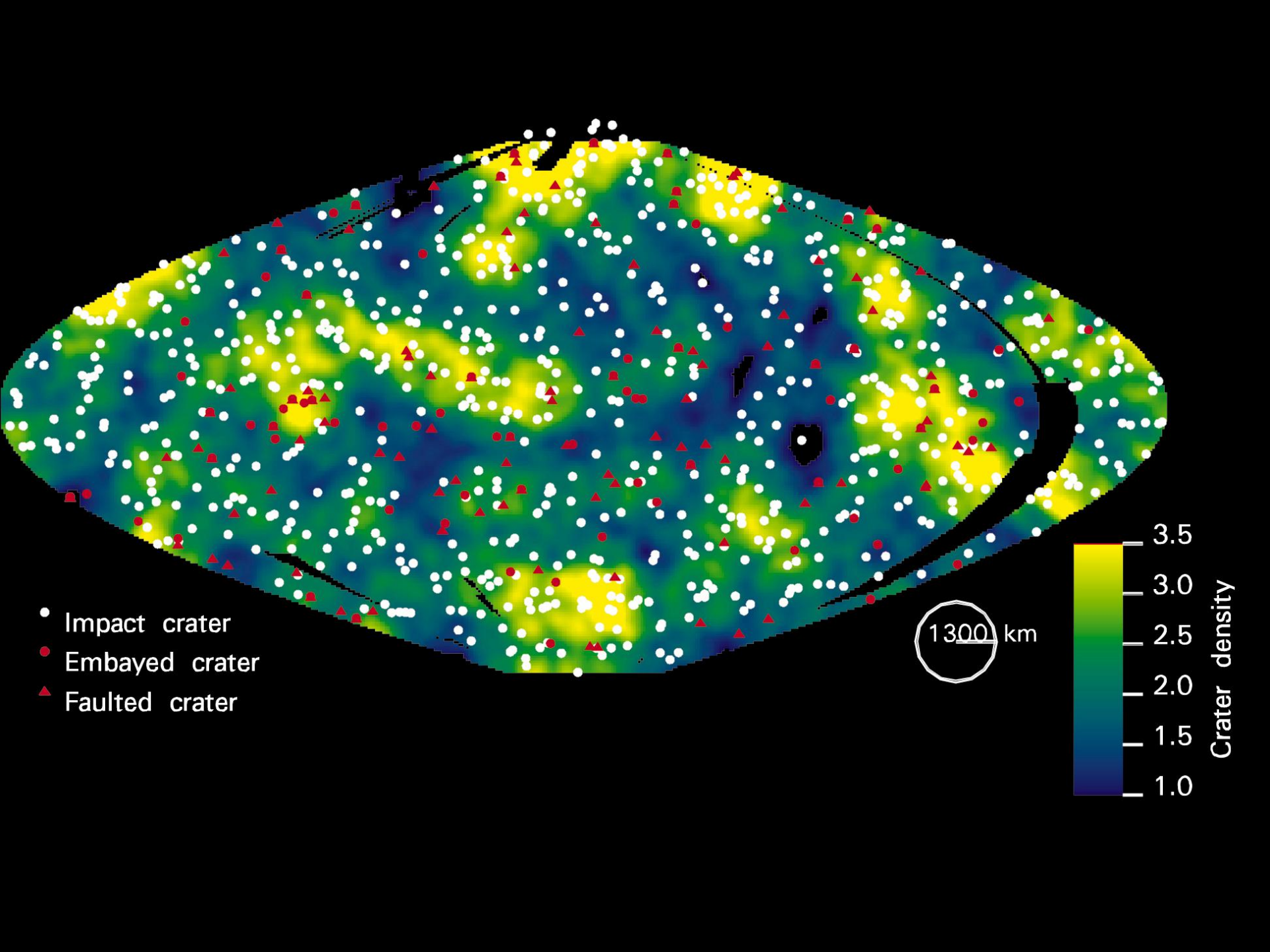


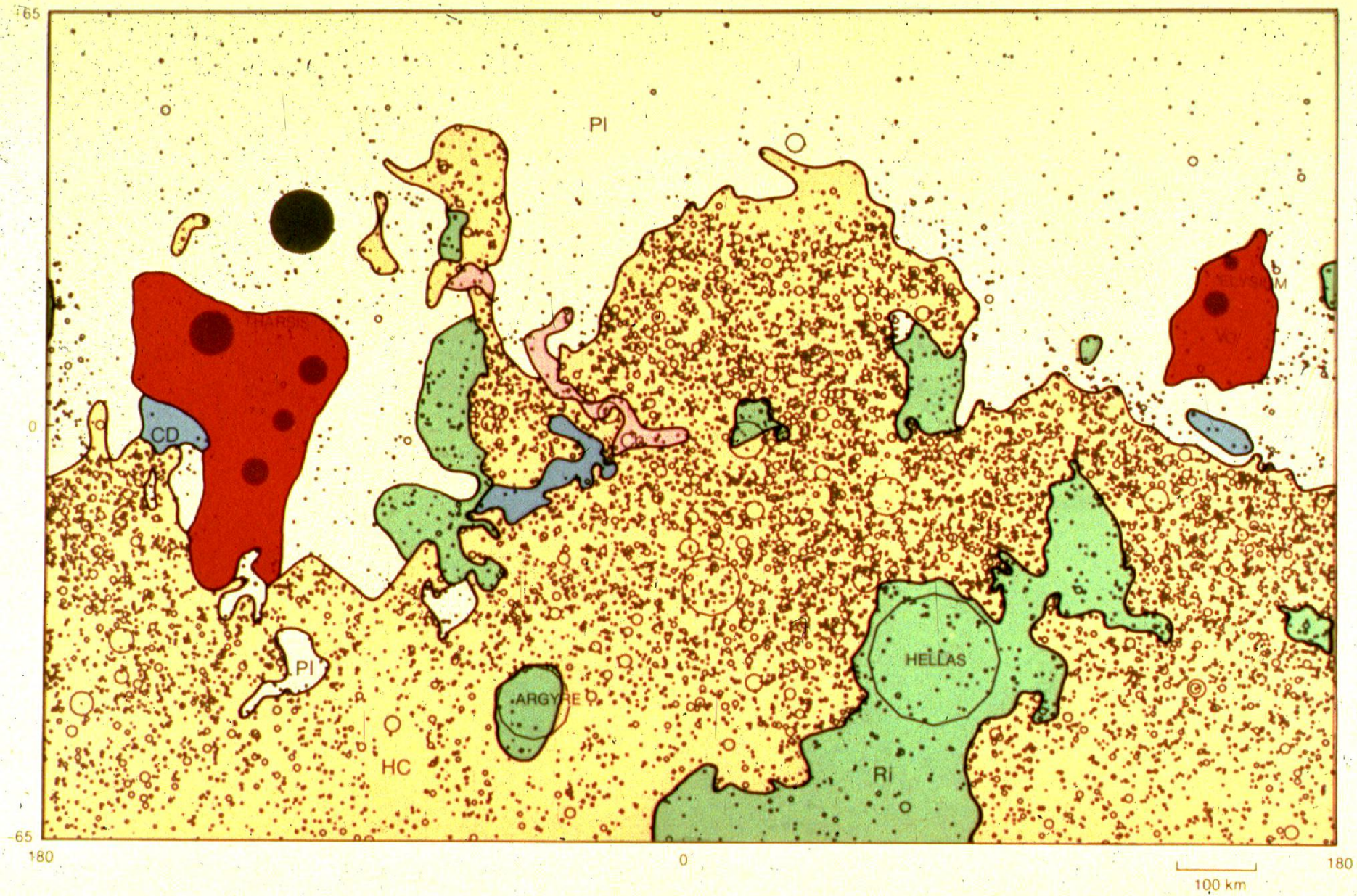




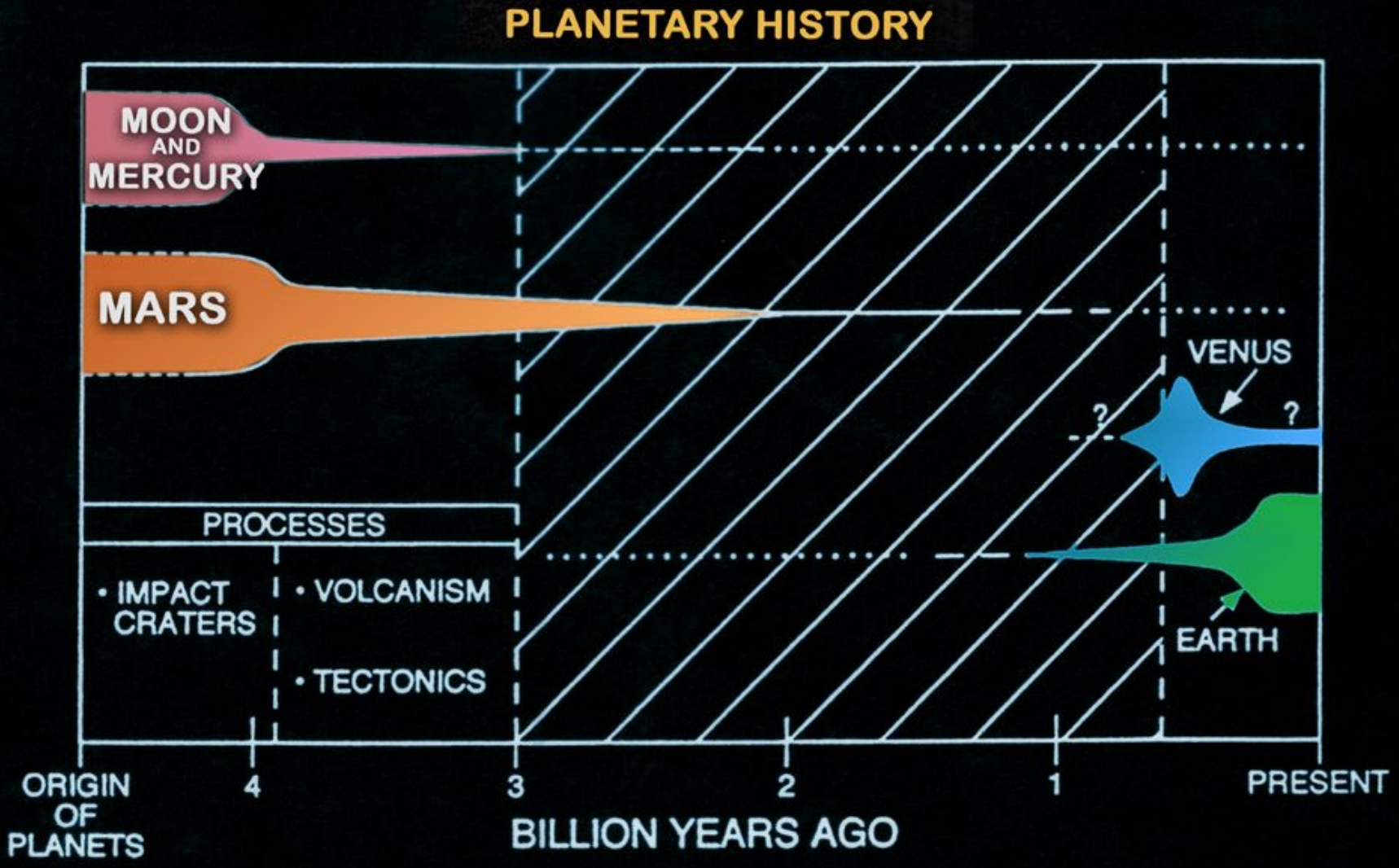


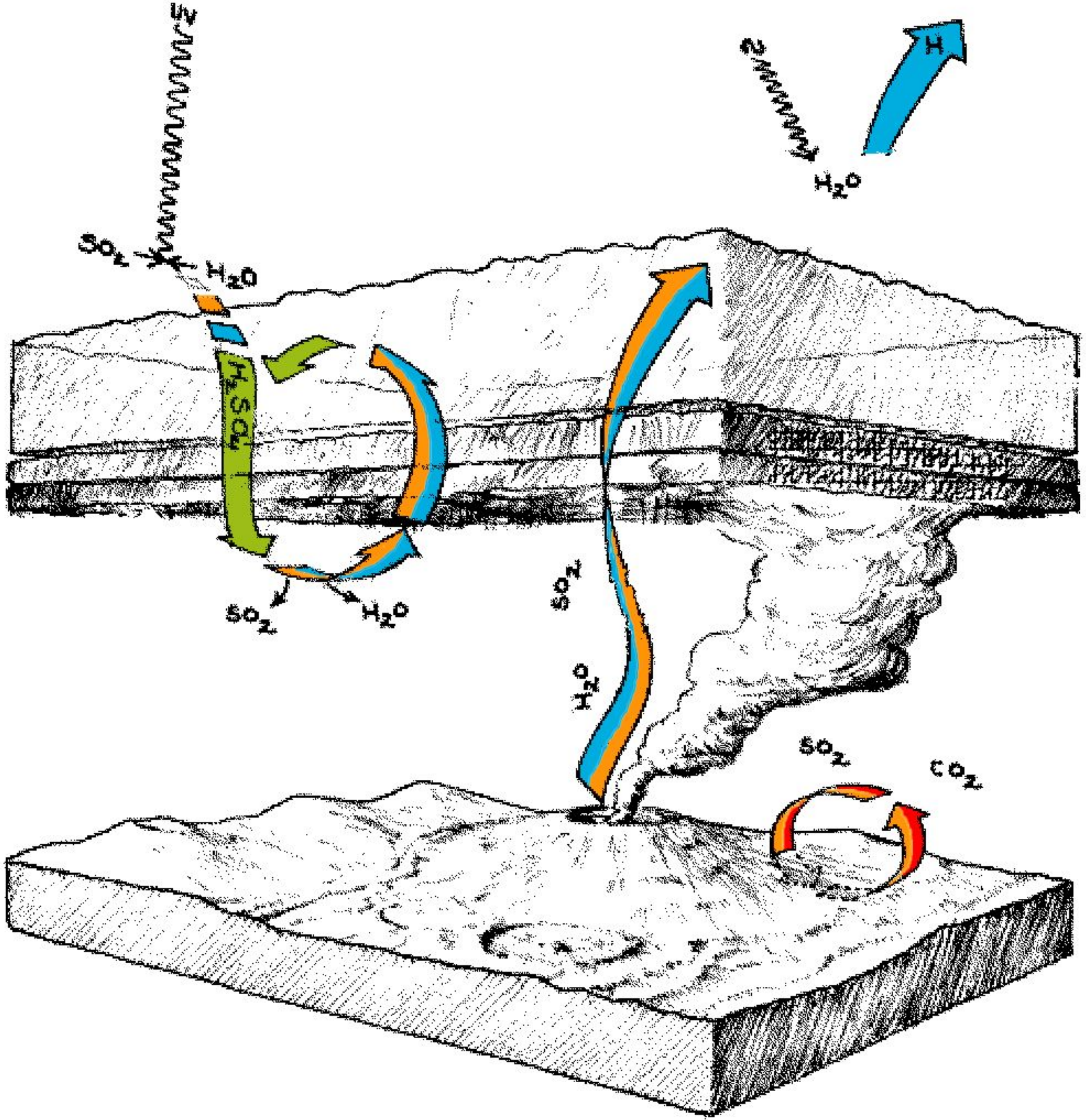



Impact crater
Embayed crater
Faulted crater
1300 km
3.5
3.0
2.5
2.0
1.5
1.0
Crater density


65
0
-65
180
0
180
100 km
Pl
THARSIS
CD
Pl
HC
ARGYRE
HELLAS
Ri
Ch
ELYSIUM
Vo
PLAINS—Pl
HEAVILY CRATERED—HC
RIDGED PLAINS—Ri
VOLCANIC PLAINS—Vo
CANYON/DEPOSITS—CD
CHANNELS/CHAOTIC—Ch

LUNAR AND PLANETARY PERSPECTIVES



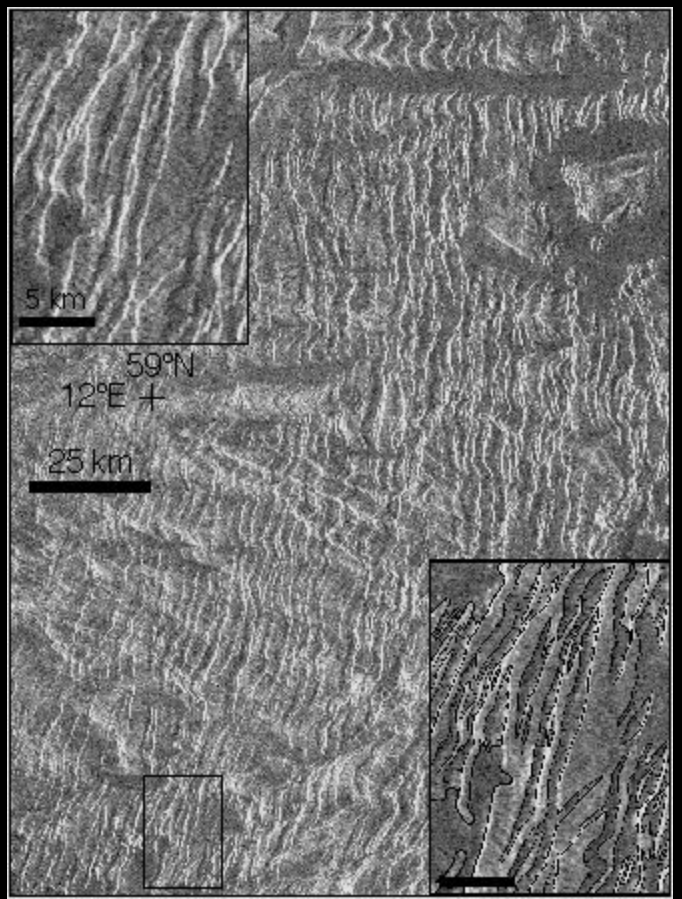


H
H_2O
SO_2
H_2O
H_2SO_4
SO_2
H_2O
SO_2
H_2O
SO_2
CO_2

Magellan – canali terminus

Some surface features from Magellan hint at climate change

Magellan – Tessera terrain



Is there evidence for climate change at the surface?

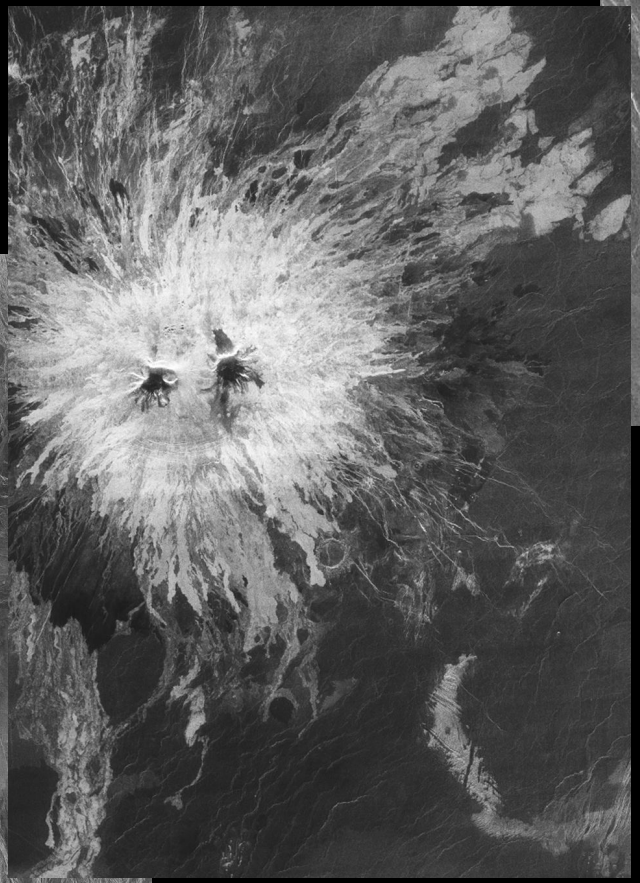
Processed Venera 13 panorama

Weathered rock may hold the chemical clues

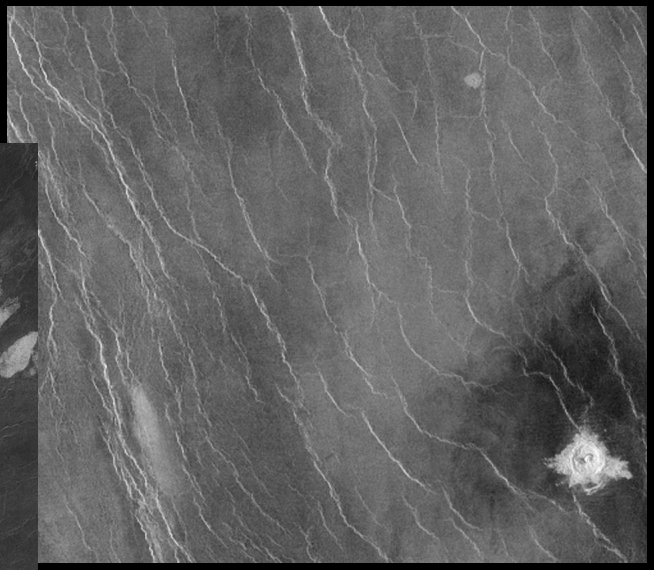
How Geologically Active Is Venus ?

Magellan saw young volcanic features

Volcanoes

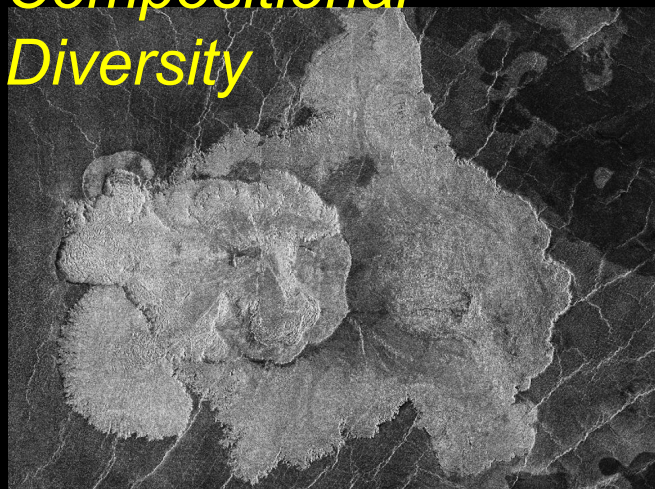


Plains



Tessera

Compositional Diversity



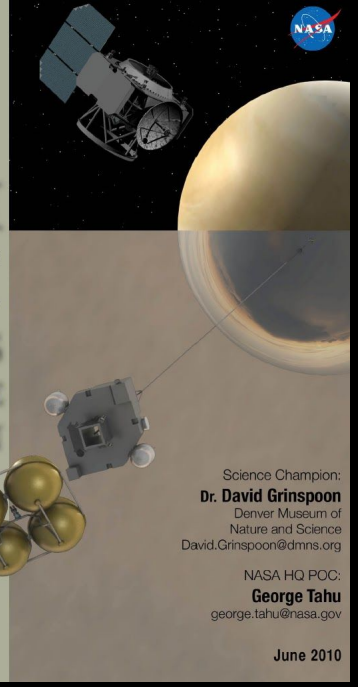
National Aeronautics and Space Administration

VCM

Mission Concept Study

Planetary Science
Decadal Survey

VENUS CLIMATE MISSION

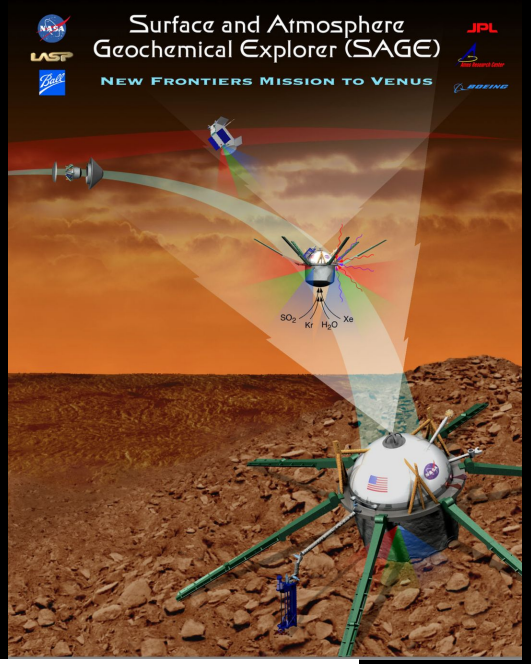


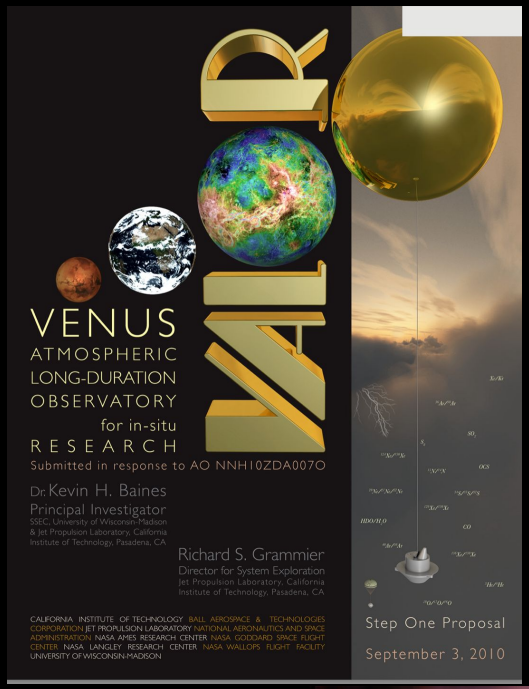
Science Champion:
Dr. David Grinspoon
Denver Museum of
Nature and Science
David.Grinspoon@dmns.org

NASA HQ POC:
George Tahu
george.tahu@nasa.gov

June 2010

www.nasa.gov





Vesper

Executive Summary

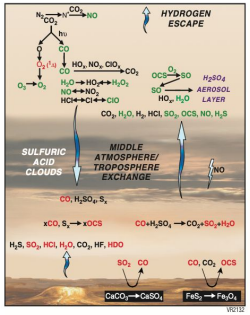
Venus and Earth are often called "sister worlds." They have similar size and density, formed at the same time in the pre-solar nebula from a similar inventory of materials, and have orbits where liquid water might exist. It remains a mystery why Venus is now so vastly different from Earth. Venus has a dense atmosphere whose 90 bar surface pressure is equal to Earth's ocean pressure at 1 km depth. Its 700 K surface temperature is hot enough to melt lead. It has clouds that super-rotate at sixty times the surface rate, yet it has a middle atmosphere that is surprisingly similar to the same regions on Earth and Mars.

The Vesper mission will answer fundamental questions about the chemistry and dynamics of the atmosphere and the surface-atmosphere interaction; questions that have not and cannot be addressed by any previous or present Venus mission. Vesper (Latin for "Evening Star") will inaugurate a new era of Solar System and extrasolar comparative planetology. It will yield revolutionary science by conducting an orbital mission using a spacecraft based on the highly successful (and still operating) Mars Odyssey bus, incorporating lessons learned from the Venus Magellan orbital radar mission and instrumentation based on flight-proven designs specifically adapted to focused goals.

Vesper has two Level 1 Venus science goals: (1) to understand the chemical processes operating in the atmosphere and (2) to understand its dynamical structure. The mission will perform a detailed, global study of the coupled chemistry and dynamics of the atmosphere over two Venus sidereal days (486 Earth days). Vesper is the right next step in Venus exploration, providing the necessary bridge between current understanding of the atmosphere and the new science generated by future surface explorations.

1.0 SCIENCE OBJECTIVES

The 2003 NRC Solar System Decadal Survey Report describes the "Sharp Contrast Between Earth and Venus" as one of the six most significant, continuing mysteries about the Solar System. NASA's 2006 Solar System Exploration Roadmap, which embraces key elements of the



Vesper will directly measure the atmospheric dynamics and chemistry of Venus. Constituents in green will be measured by SLS, in red by DASC and in purple by NUVI.

of Habitability as a major driver in Science and Exploration. The science themes of Vesper embrace and expand upon these studies.

Habitability

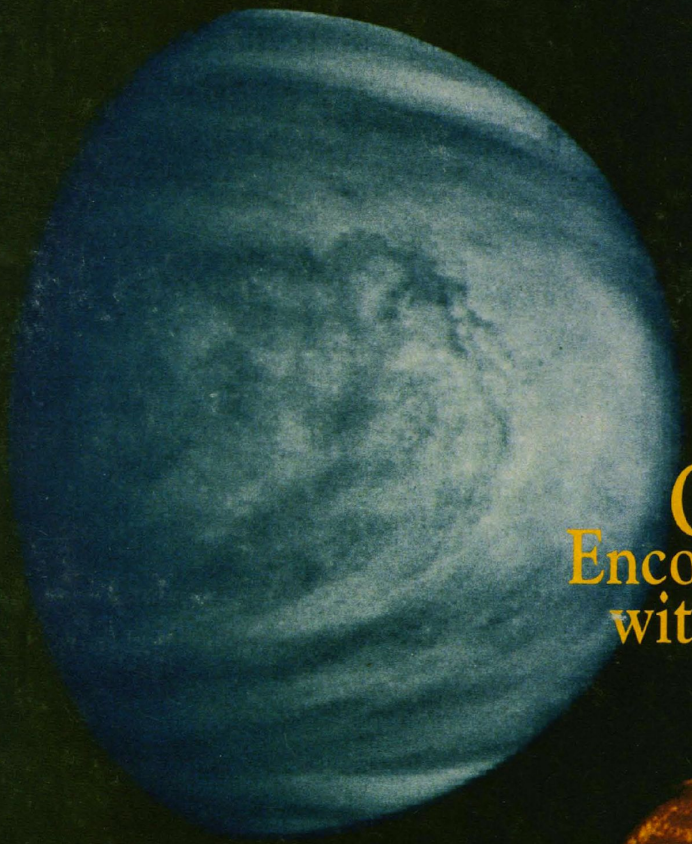
Habitability on the Earth–In a time of global climate change on Earth, what does the Venus runaway greenhouse effect tell us about the future destiny of Earth? What other mechanisms exist that may induce long-term effects? The study of the middle and lower atmosphere of Venus will reveal an alternate evolutionary pathway for terrestrial type planets. Vesper is uniquely suited to providing an understanding of these atmospheric regions.

Habitability in planetary environments–How did

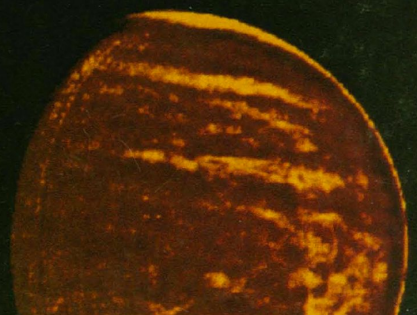
American Association for the Advancement of Science

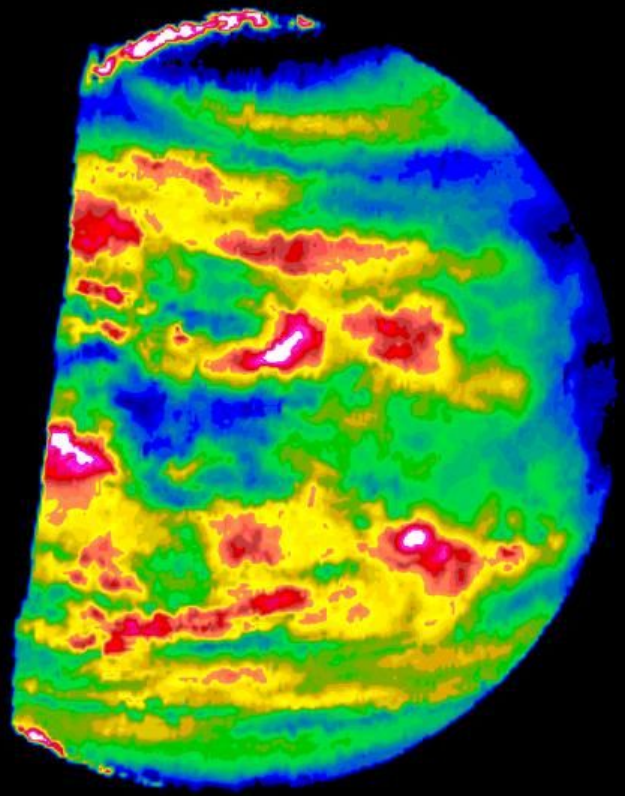
SCIENCE

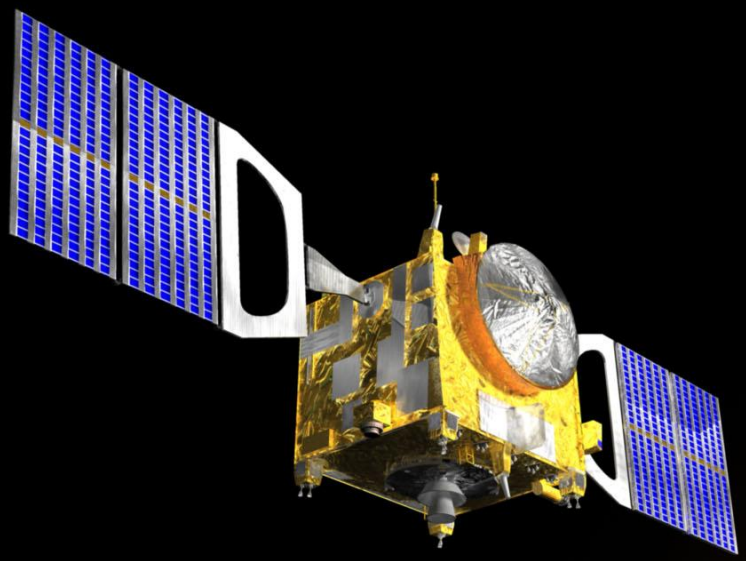
27 September 1991 $6.00
Vol. 253 ■ Pages 1457–1612



Galileo's Encounter with Venus





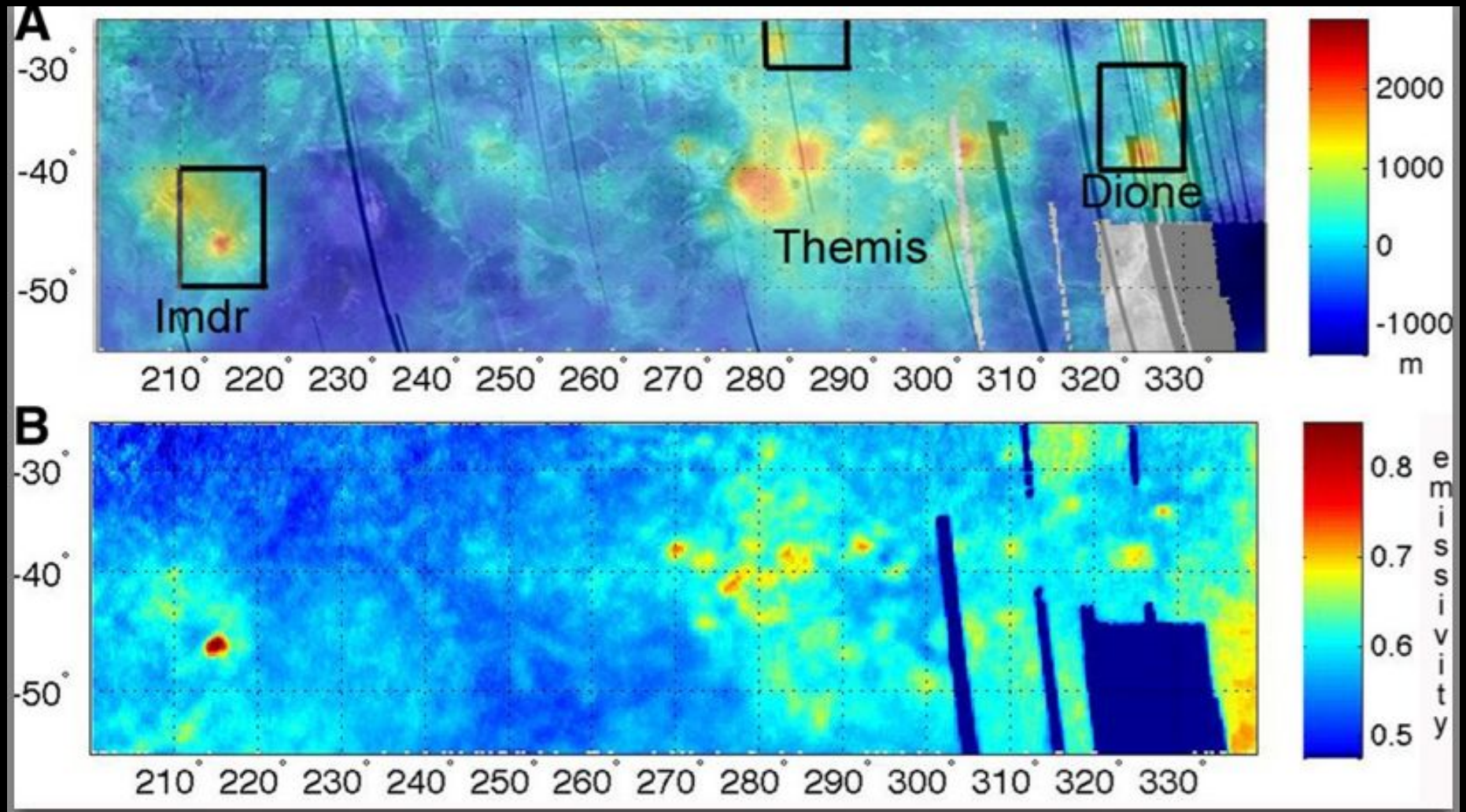



esa
Venus
Express

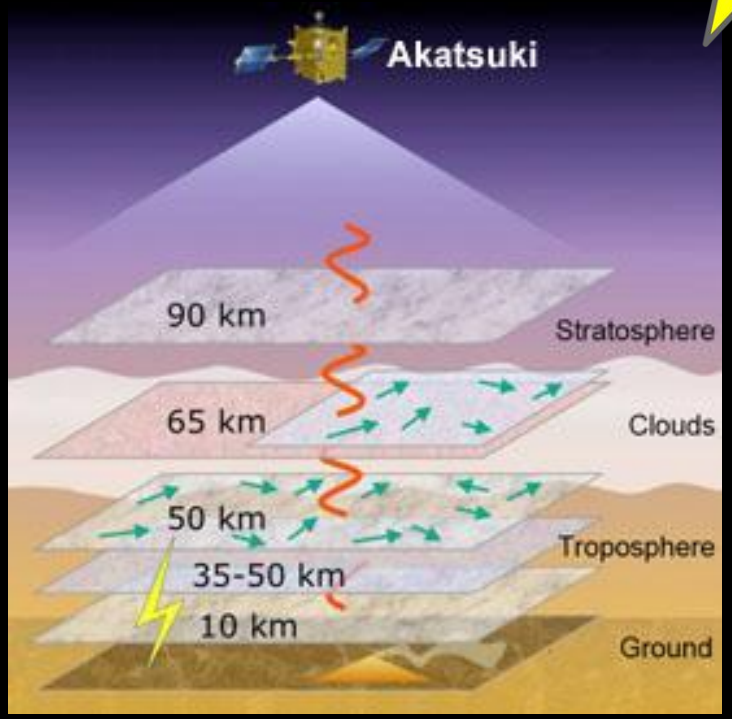
Sciencexpress Report

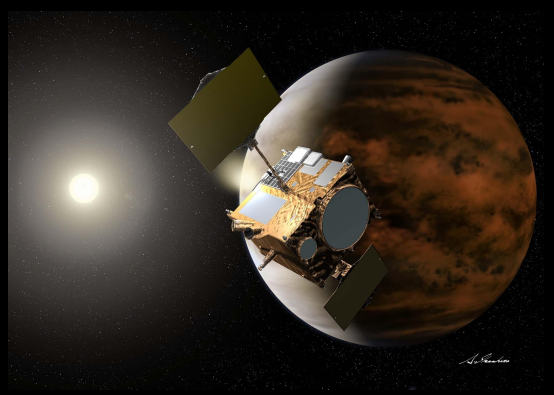
Recent Hot-Spot Volcanism on Venus from VIRTIS Emissivity Data

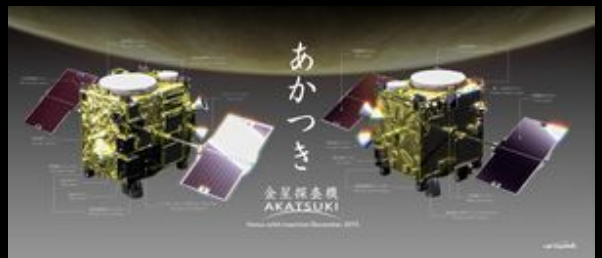
Suzanne E. Smrekar,[1]* Ellen R. Stofan,[2] Nils Mueller,[3,6] Allan Treiman,[4] Linda Elkins-Tanton,[5] Joern Helbert[6]

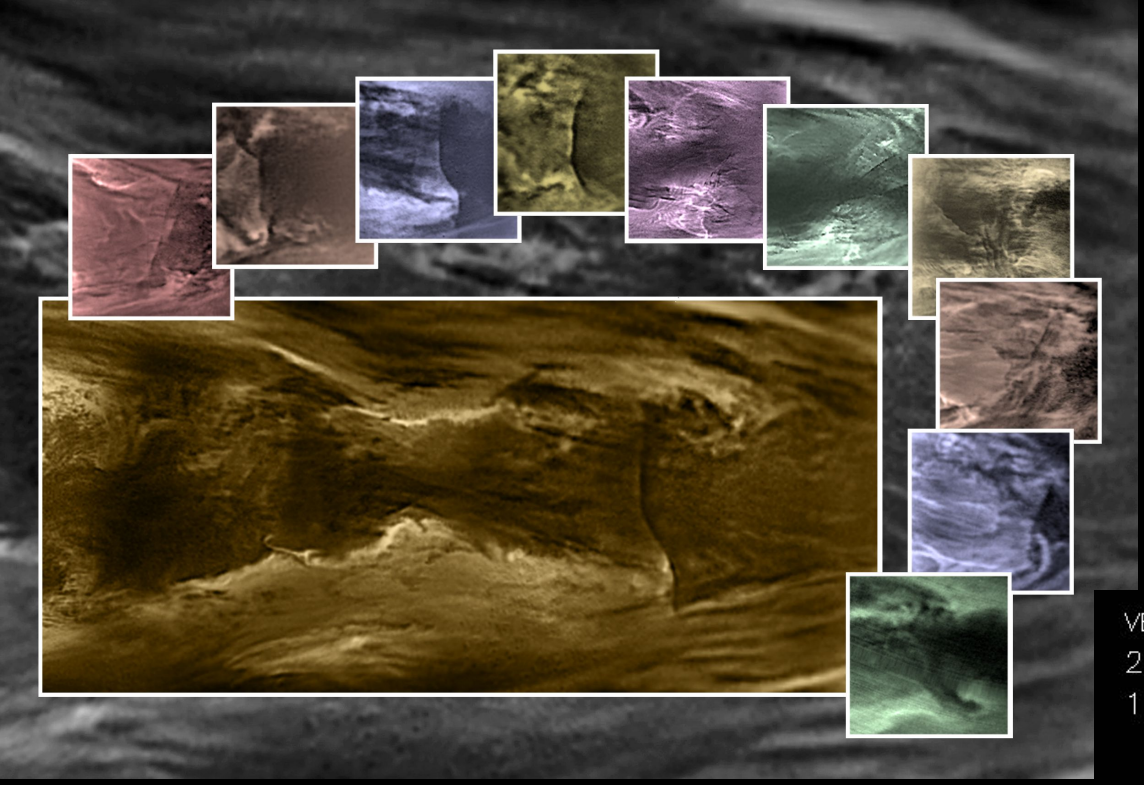


Akatsuki
First Japanese Mission to Venus









VENUS 2.26 μm (AKATSUKI/IR2)
2016–08–15
11:33:34

CREDITS: J. Peralta

Modelling result:

Including clouds in global climate models *greatly* increases stability of oceans on early Venus against the warming sun, essentially delaying the runaway greenhouse, possibly by billions of years. (Grinspoon & Bullock 2007; Way et al. 2016)

Geophysical Research Letters

RESEARCH LETTER
10.1002/2016GL069790

Key Points:
- Venus may have had a climate with liquid water on its surface for approximately two billion years
- The rotation rate and topography of Venus play crucial roles in its surface temperature and moisture
- Young Venus-like exoplanets may be considered candidates for the search for life beyond Earth

Correspondence to:
M. J. Way,
michael.j.way@nasa.gov

Citation:
Way, M. J., A. D. Del Genio, N. Y. Kiang, L. E. Sohl, D. H. Grinspoon, I. Aleinov, M. Kelley, and T. Clune (2016), Was Venus the first habitable world of our solar system?, *Geophys. Res. Lett.*, *43*, doi:10.1002/2016GL069790.

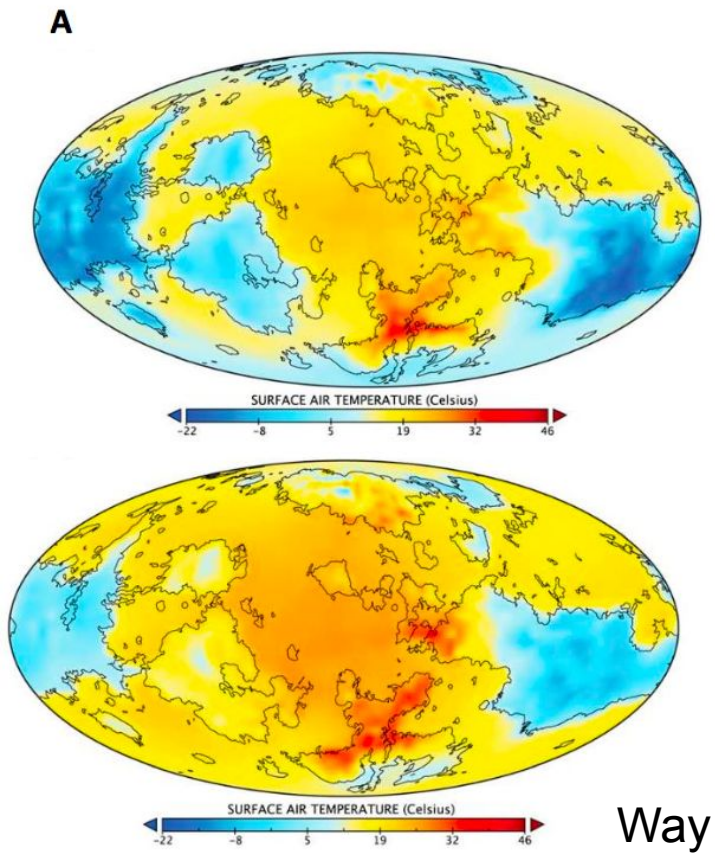
Was Venus the first habitable world of our solar system?

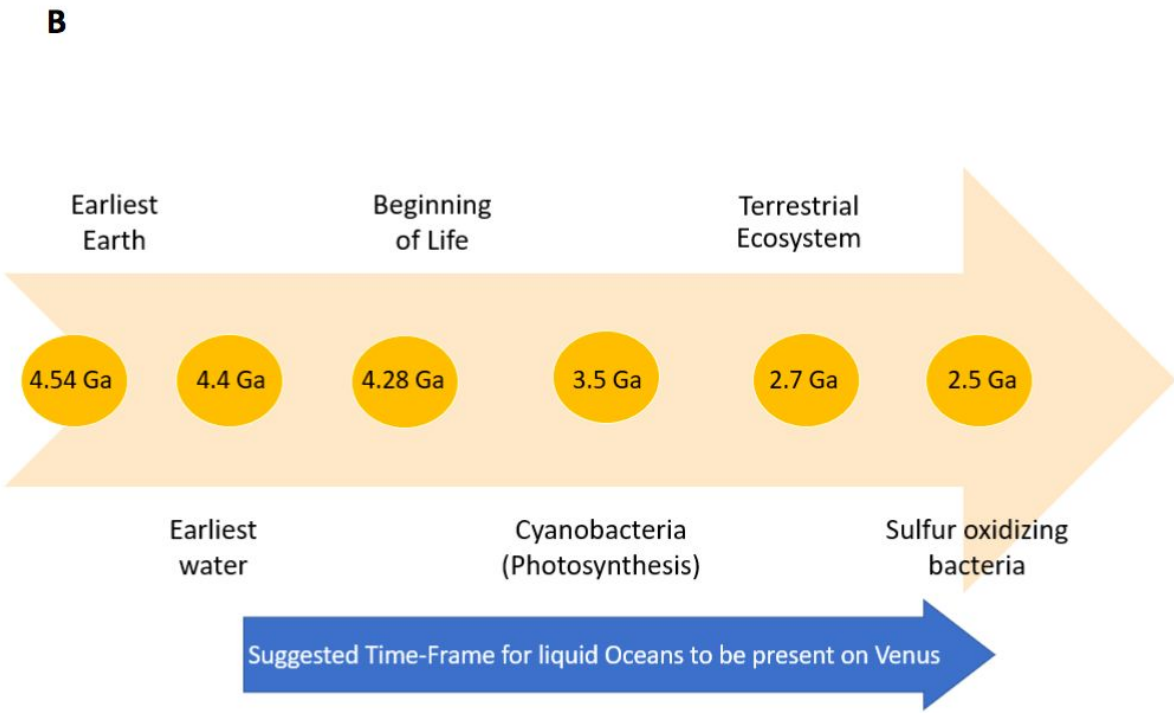
M. J. Way[1,2], Anthony D. Del Genio[1], Nancy Y. Kiang[1], Linda E. Sohl[1,3], David H. Grinspoon[4], Igor Aleinov[1,3], Maxwell Kelley[1], and Thomas Clune[5]

[1]NASA Goddard Institute for Space Studies, New York, New York, USA, [2]Department of Astronomy and Space Physics, Uppsala University, Uppsala, Sweden, [3]Center for Climate Systems Research, Columbia University, New York, New York, USA, [4]Planetary Science Institute, Tucson, Arizona, USA, [5]Global Modeling and Assimilation Office, NASA Goddard Space Flight Center, Greenbelt, Maryland, USA

Abstract Present-day Venus is an inhospitable place with surface temperatures approaching 750 K and an atmosphere 90 times as thick as Earth's. Billions of years ago the picture may have been very different. We have created a suite of 3-D climate simulations using topographic data from the Magellan mission, solar spectral irradiance estimates for 2.9 and 0.715 Gya, present-day Venus orbital parameters, an ocean volume consistent with current theory, and an atmospheric composition estimated for early Venus. Using these parameters we find that such a world could have had moderate temperatures if Venus had a prograde rotation period slower than ~16 Earth days, despite an incident solar flux 46–70% higher than Earth receives. At its current rotation period, Venus's climate could have remained habitable until at least 0.715 Gya. These results demonstrate the role rotation and topography play in understanding the climatic history of Venus-like exoplanets discovered in the present epoch.

For over three billion years our solar system may have contained two neighboring terrestrial planets with habitable surface oceans.





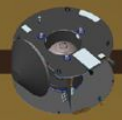
Way et al. 2016

Neira et al. 2018

DAVINCI

Spacecraft with Probe

Descent



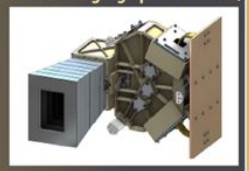
Carrier

Carrier instruments

VISOR (Venus Imaging System from Orbit for Reconnaissance)

Based on OSIRIS-REx/ECAM

CUVIS (Compact Ultraviolet to Visible Imaging Spectrometer)



Probe Flight System

Descent Sphere

Probe Instruments

VMS (Venus Mass Spectrometer)

Based on MSL/SAM QMS

VTLS (Venus Tunable Laser Spectrometer)

Based on MSL/SAM TLS

VASI (Venus Atmospheric Structure Investigation)

VenDI (Venus Descent Imager)

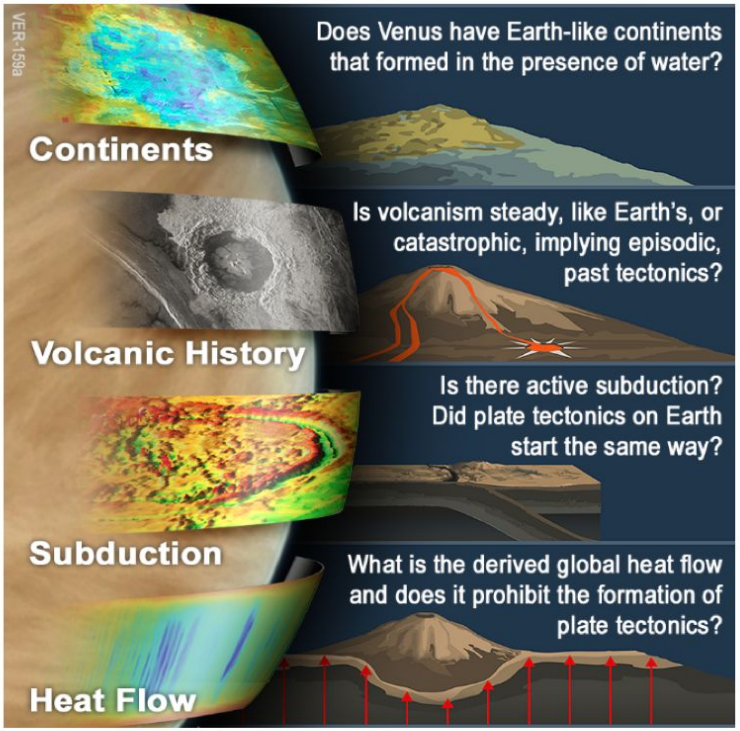
Based on MSL/MastCam, MARDI, MAHLI

VfOx (Venus Oxygen Fugacity Experiment)

VERITAS (Venus Emissivity Radio science, InSAR, Topography And Spectroscopy)

Mission overview:
Low polar orbiter
Timeline is TBC:
Launch: ~2028
>3 yr science mission beginning ~ 2030

Partners:
JPL lead institution
Lockheed Martin
Italian Space Agency
German Space Agency
French Space Agency



INSTRUMENTATION:

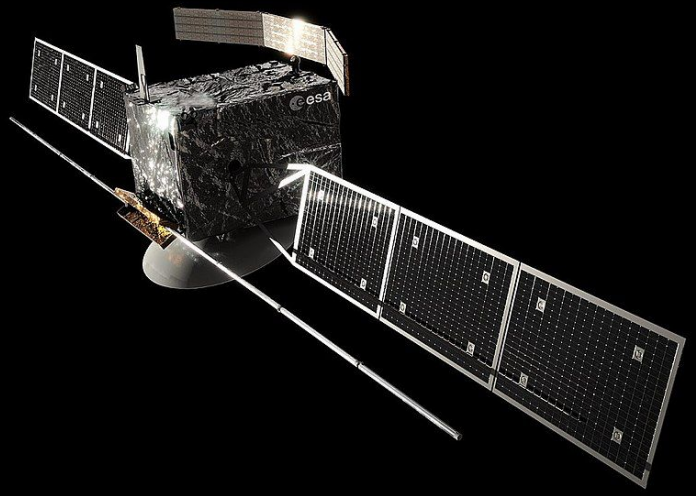
VISAR
(Venus Interferometric Synthetic Aperture Radar)
First global, high-resolution topography
First planetary active deformation maps
- Global data sets:
  - Topography: 5.9 m vertical, 250 m horizontal
  - SAR imaging: 30 m
- Targeted data sets:
  - SAR imaging: 15 m
  - Surface deformation: 1.5 cm vertical

VEM
(Venus Emissivity Mapper)
First near-global map of rock type and surface weathering
First search for volcanically outgassed water
- 6 NIR surface bands with robust SNR
- 8 atmospheric bands for calibration/ water vapor

GRAVITY SCIENCE INVESTIGATION
First global maps of derived elastic thickness and heat flow
First determination of core size and state

Discovering the secrets of a lost habitable world

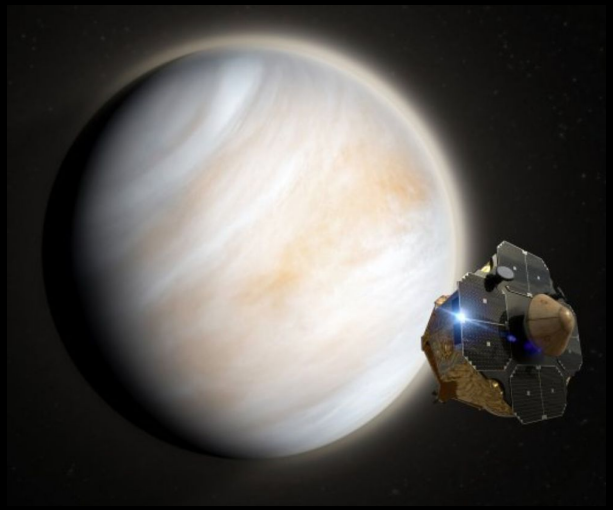
EnVision



ROCKETLAB

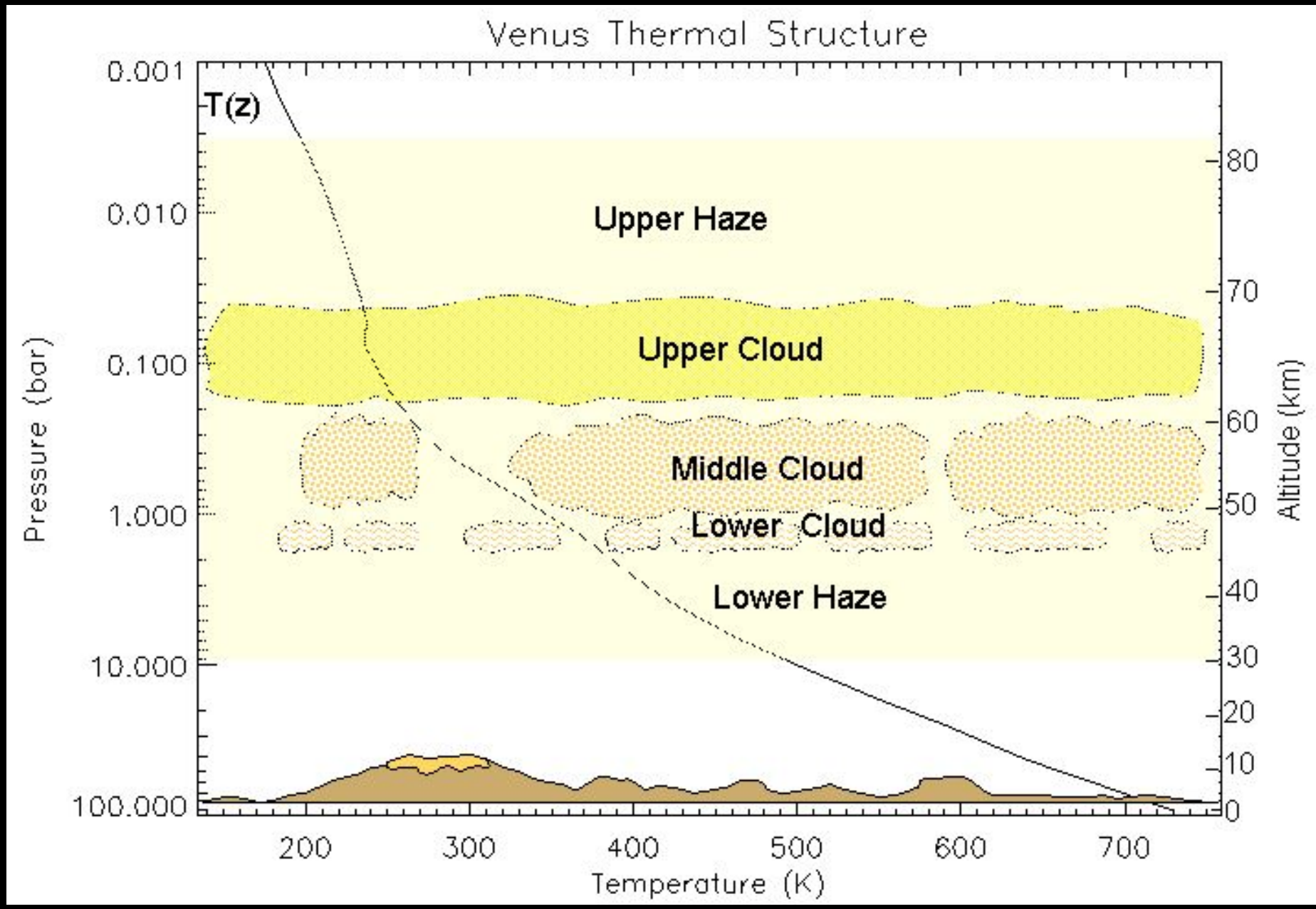
FIRST PRIVATE MISSION TO VENUS

Supporting the search for life off Earth



Why is Venus so different from Earth? How and why did they diverge?

- What does the Venus greenhouse tell us about climate change?
  - How do clouds and chemical cycles affect atmospheric energy balance?
  - What drives the atmospheric superrotation?
  - What is the history of climate?
- When and where did the water go?
  - How did the early atmosphere evolve?
  - Did Venus have an ocean and if so, when was it lost?
  - Was Venus habitable? Was it inhabited?
  - Could there be life in the clouds today?


Venus Thermal Structure
T(z)
Upper Haze
Upper Cloud
Middle Cloud
Lower Cloud
Lower Haze
Pressure (bar)
0.001
0.010
0.100
1.000
10.000
100.000
Altitude (km)
80
70
60
50
40
30
20
10
0
200
300
400
500
600
700
Temperature (K)

Why is Venus so different from Earth? How and why did they diverge?

- What is the history of geological activity?
  - How active is Venus geologically?
  - What is the volcanic and tectonic resurfacing history?
  - What are the ages and compositions of different surface units?
  - Did Venus ever have plate tectonics. When did it cease?
  - How are geology and climate connected?
- What is the interior structure?
  - What is the structure of the Venus lithosphere?
  - How does mantle convection work on Venus?
  - What is the size and physical state of the core?
  - Does Venus have Earth-like continents?
  - Why no magnetic dynamo?

Why is Venus so different from Earth? How and why did they diverge?

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Moon forming impact?

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One final thought:

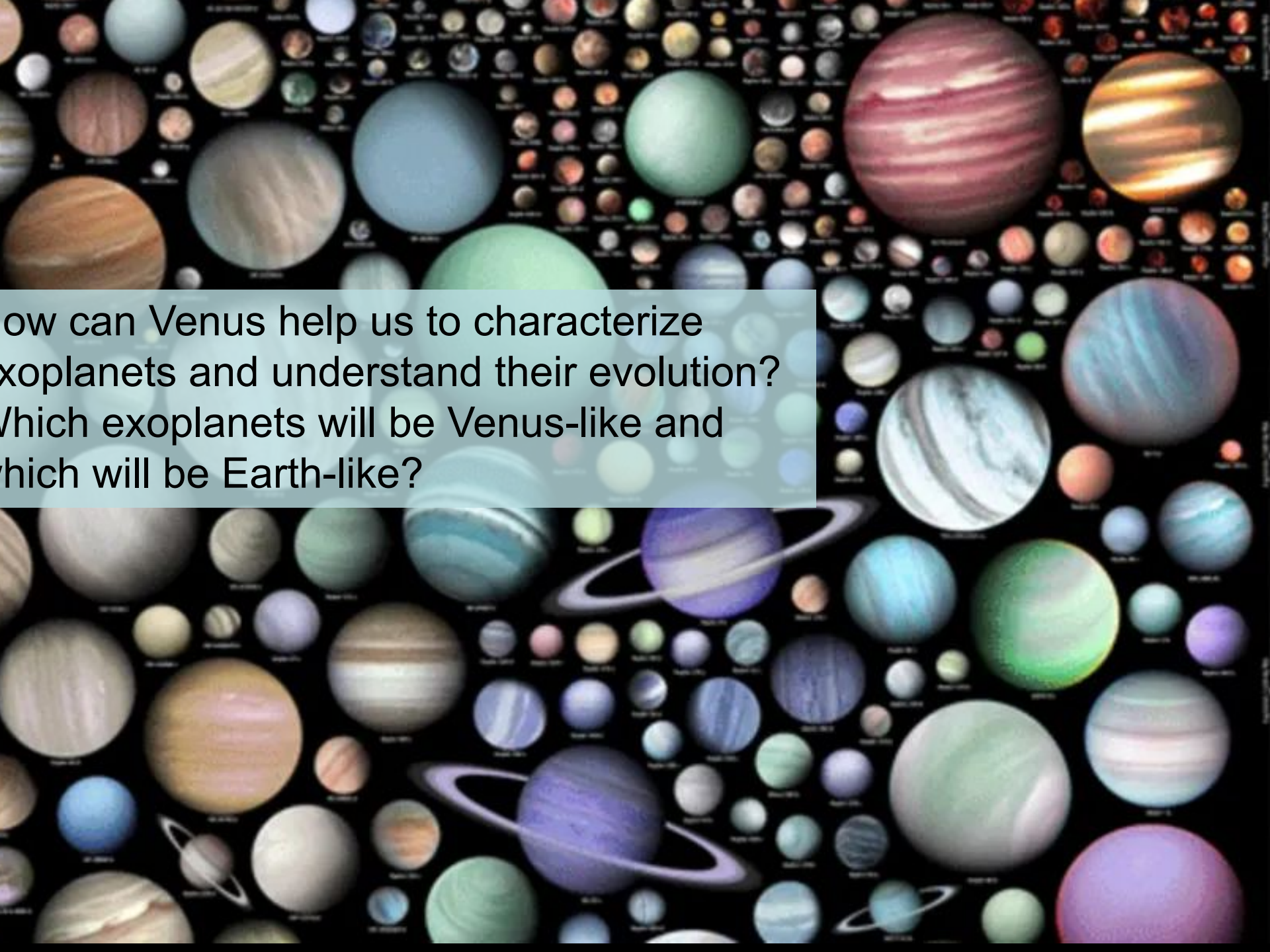
In discussions like this we tend to focus on the question of *science value*.
But there is also huge *exploration value* - related, but not quite the same thing.

Venus is a vast, unexplored world of great beauty, variety and mystery, so like our Earth, and yet so distinct.

In many ways the most Earthlike world and Earth-relevant world we* will ever get to explore up close.

The potential for public fascination and serendipitous discovery is unlimited.

* "We" here meaning 21st century humans.


ow can Venus help us to characterize
xoplanets and understand their evolution?
Which exoplanets will be Venus-like and
hich will be Earth-like?