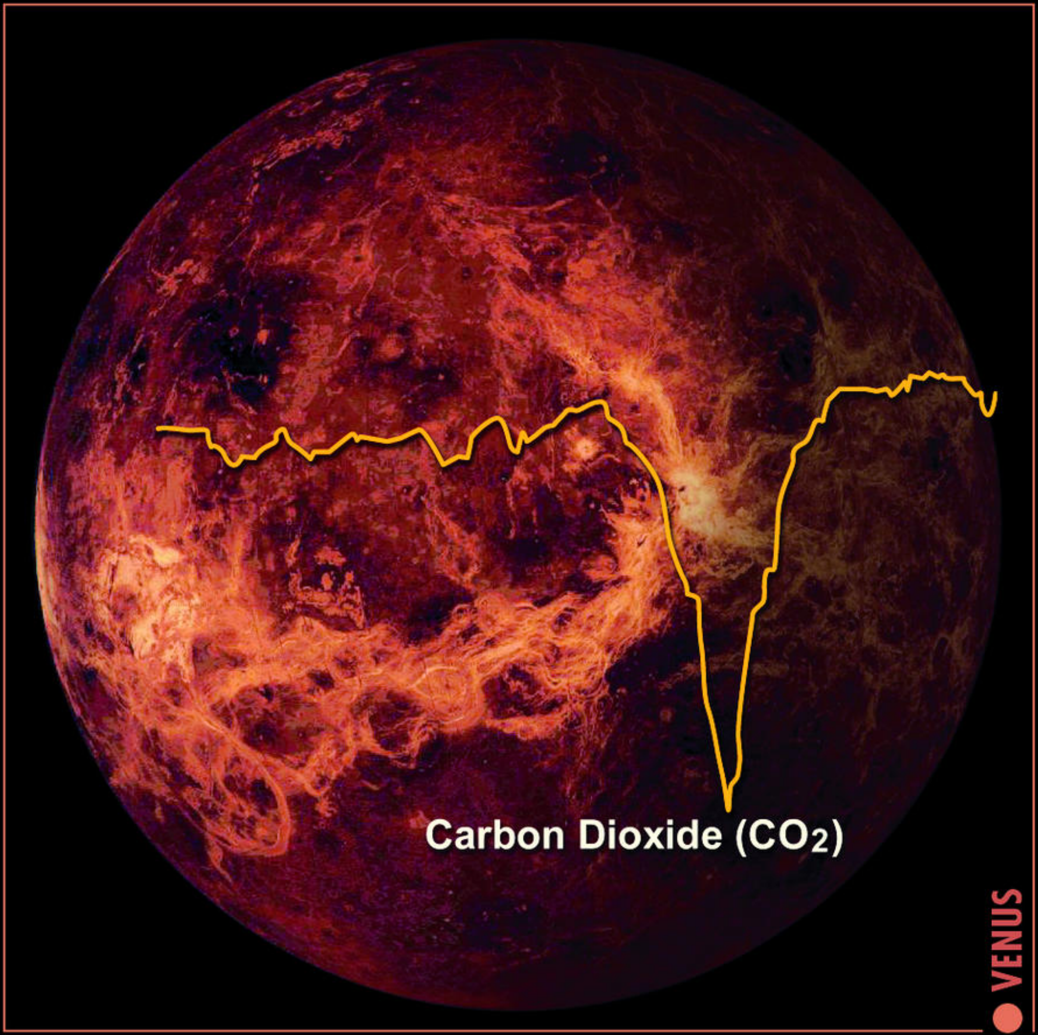
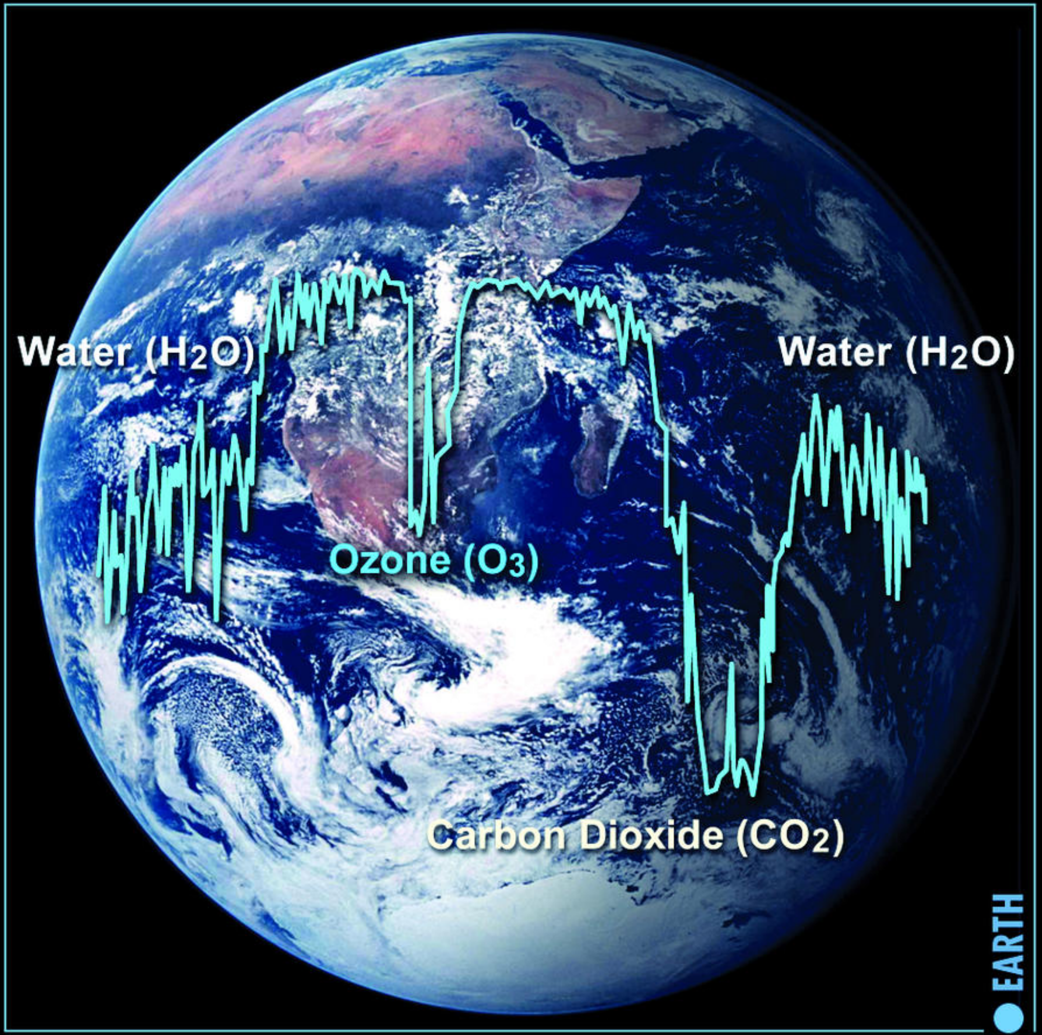
Planetary Habitability





Stephen Kane

UNIVERSITY OF CALIFORNIA
UC RIVERSIDE

Topics

- **Lecture 1 – Introduction**
- **Lecture 2 – Habitability Factors**
- **Lecture 3 - Stars**
- **Lecture 4 – Planetary Atmospheres**
- **Lecture 5 – Planetary Interiors**
- **Lecture 6 – Planetary Energy Balance**
- **Lecture 7 – Habitable Zone I**
- **Lecture 8 – Habitable Zone II**
- **Lecture 9 – Earth as a Living Planet**
- **Lecture 10 – Mars**
- **Lecture 11 – Icy Moons**
- **Lecture 12 – Venus**
- **Lecture 13 – Mercury & the Moon**
- **Lecture 14 – The Role of Giant Planets**
- **Lecture 15 – Stellar Influences**
- **Lecture 16 – Magnetic Fields**
- **Lecture 17 – Milankovitch Cycles**
- **Lecture 18 – Geological Cycles**
- **Lecture 19 – The Next Steps**
- **Lecture 20 – Summary/Discussion**

The Venus Exploration Analysis Group

Unveil Venus: Why is Earth's sister planet so different?

VEXAG was established by NASA in 2005 to identify scientific priorities and opportunities for the exploration of Venus, Earth's sister planet. The group has an open membership and an 7-person Executive Committee, 3 Focus Groups, and 2 Topical Analysis Groups. Input from the scientific community is actively sought. The VEXAG provides findings to NASA Headquarters, but does not make recommendations. Stay in touch by visiting our Twitter and Facebook pages!

VEXAG Charter

The Venus Exploration Analysis Group is NASA's community-based forum designed to provide scientific input and technology development plans for planning and prioritizing the exploration of Venus over the next several decades. VEXAG is chartered by NASA's Solar System Exploration Division and reports its findings to NASA. Open to all interested scientists, VEXAG regularly evaluates Venus exploration goals, scientific objectives, investigations, and critical measurement requirements, including especially recommendations in the NRC Decadal Survey and the Solar System Exploration Strategic Roadmap.

Guiding Documents

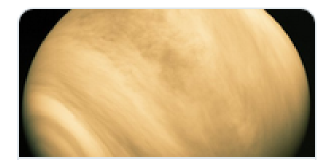
Goals, Objectives and Investigations for Venus Exploration: 2016

Roadmap for Venus Exploration: 2014

Tweets by @unveilvenus

VEXAG Venus @unveilvenus

Could Life Be Floating in Venus's Clouds? eos.org/articles/could… @unveilvenus



Could Life Be Floating in V…
If present, microbes could e…
eos.org

Nov 9, 2018

VEXAG Venus Retweeted

Paul Byrne @ThePlanetaryGuy

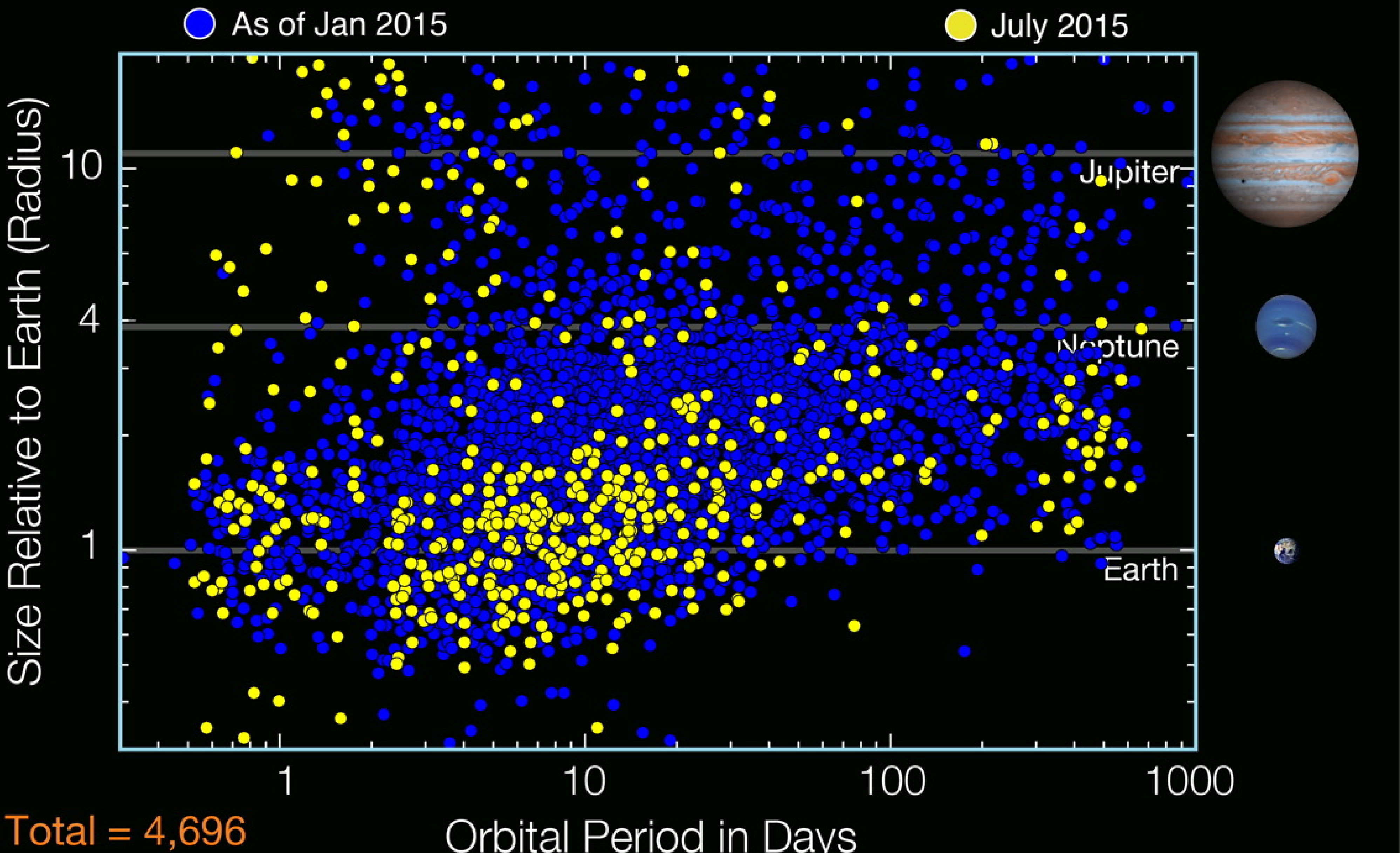
Following his talk from this morning, Sanjay Limaye's hypothesis of life in the Venusian clouds features in this @AGU_Eos article:eos.org/articles/could …#VEXAG2018 @unveilvenus

Venus

- Importance of Venus to astrobiology
- Present day Venus
- Outstanding questions
- The Venus Zone
- Climate models of Venus and Venus analogs
- Expected exoVenus yield
- Planned Venus missions

New Kepler Planet Candidates

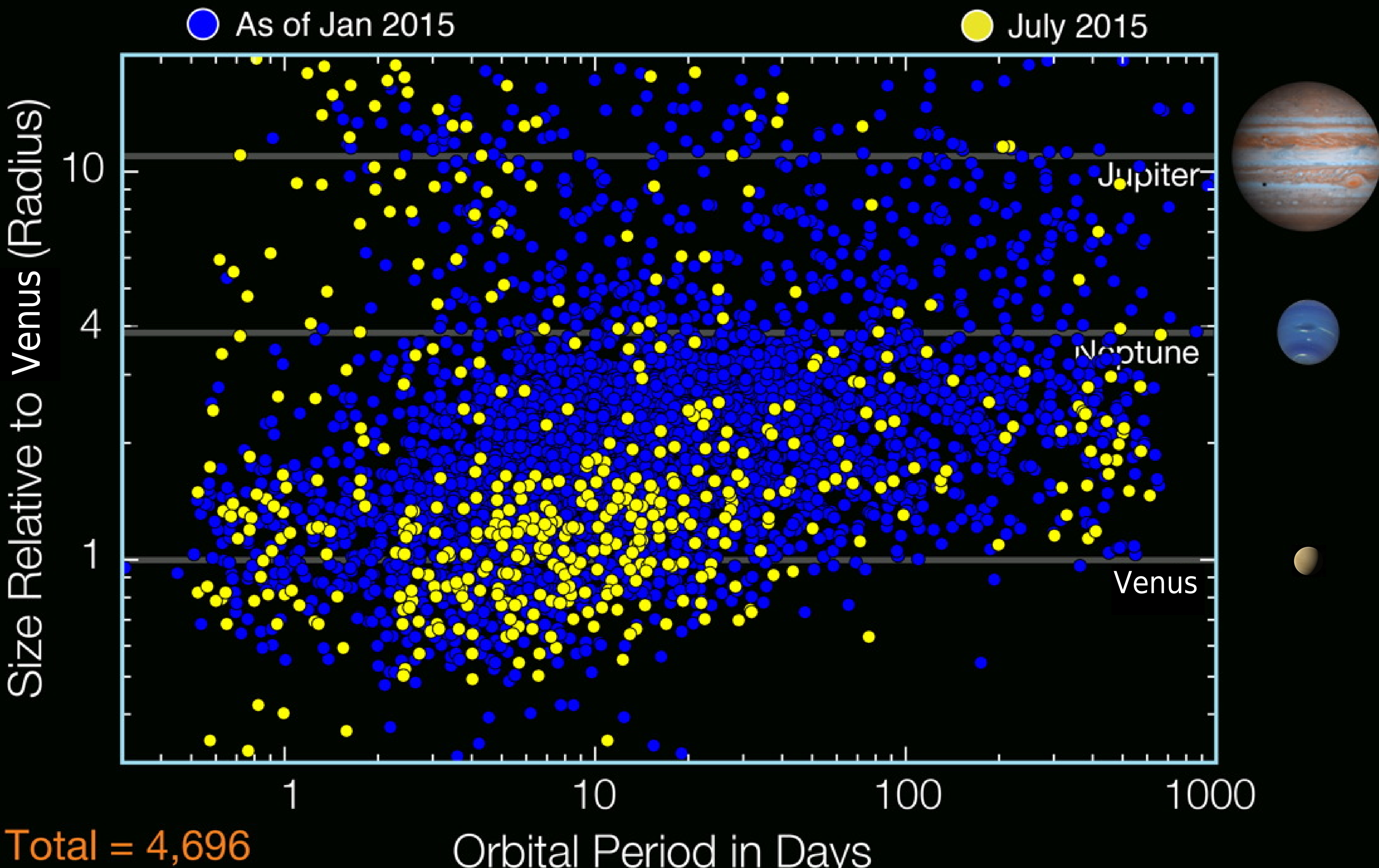
As of July 23, 2015



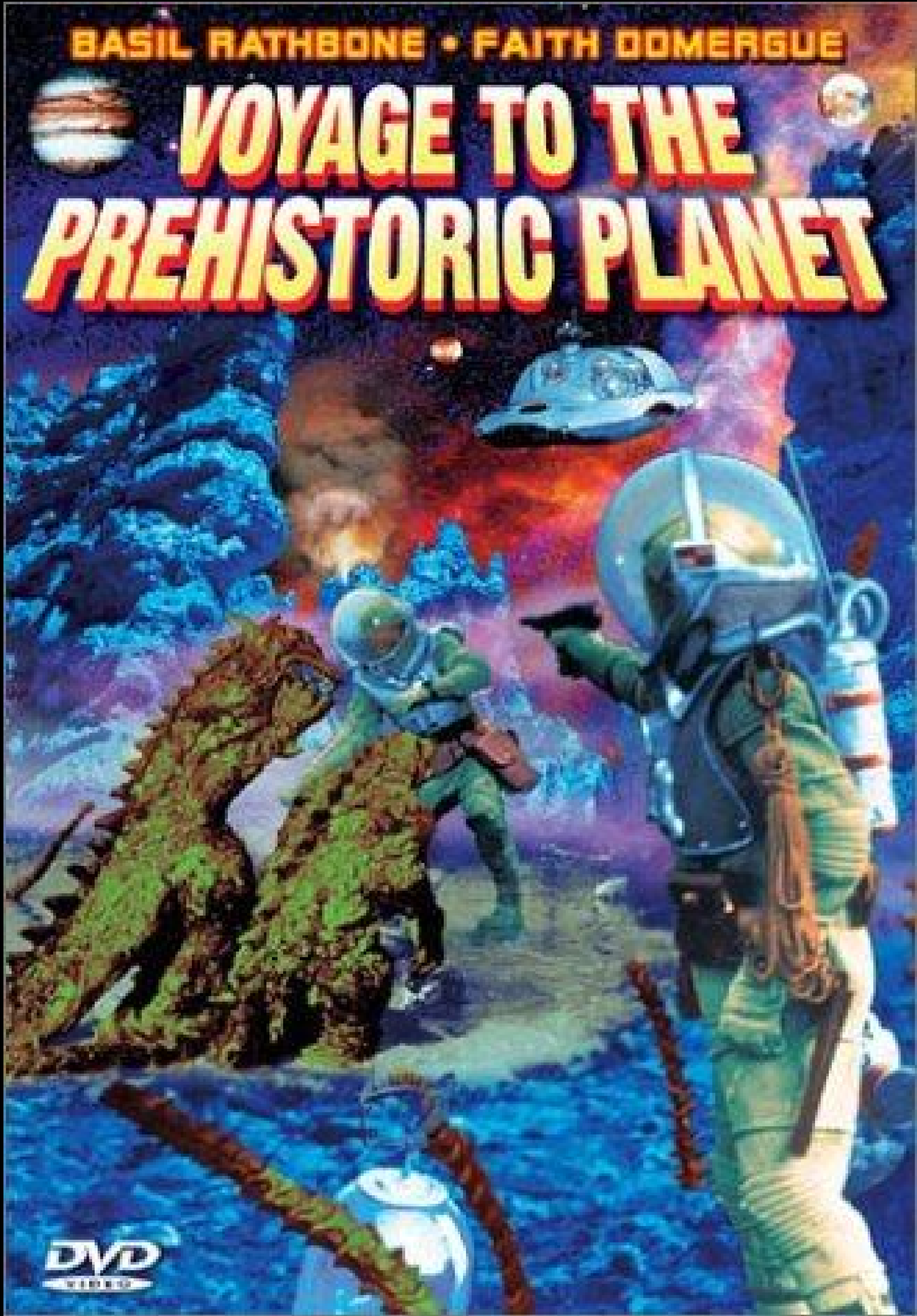
Total = 4,696

New Kepler Planet Candidates

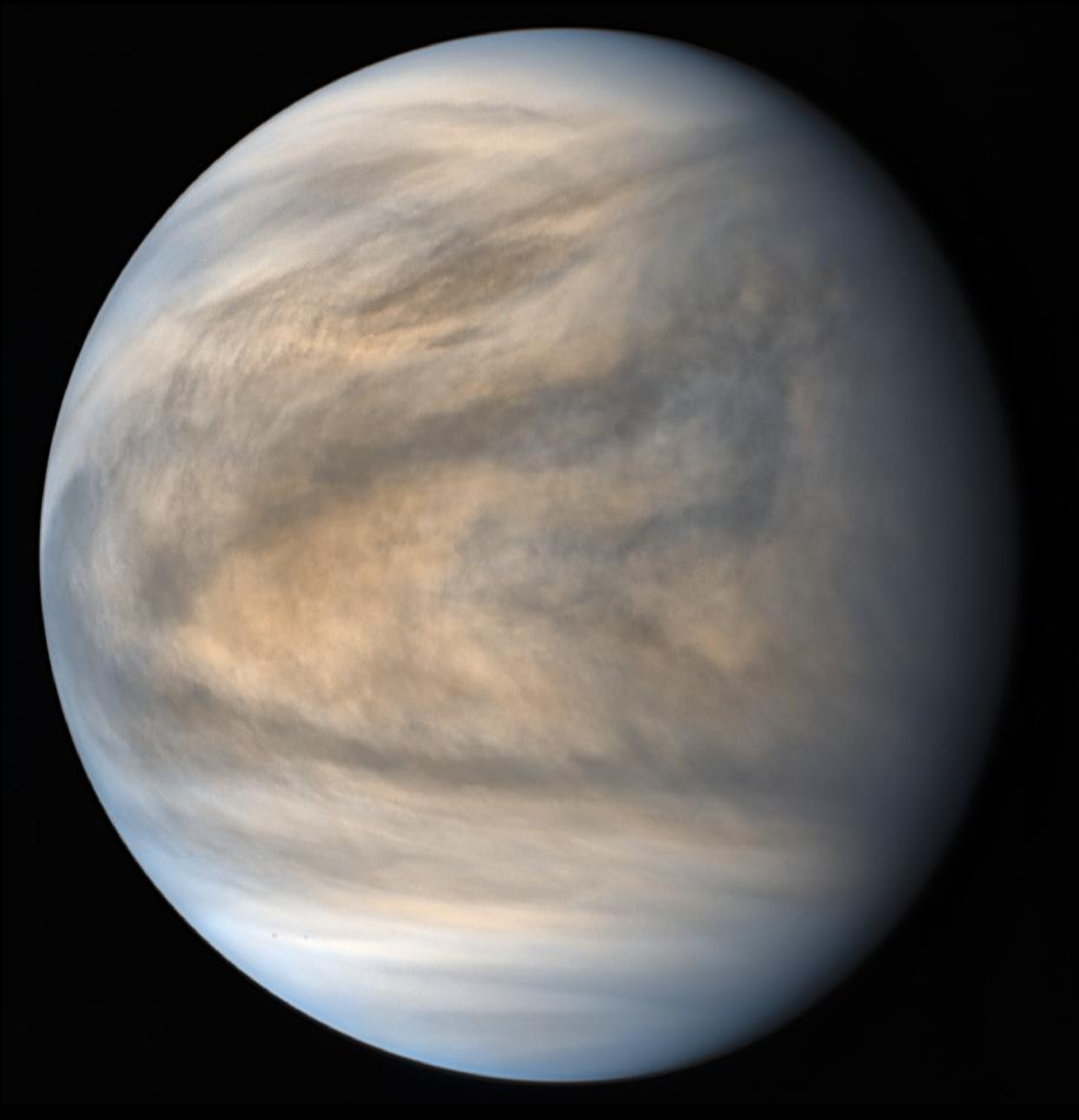
As of July 23, 2015

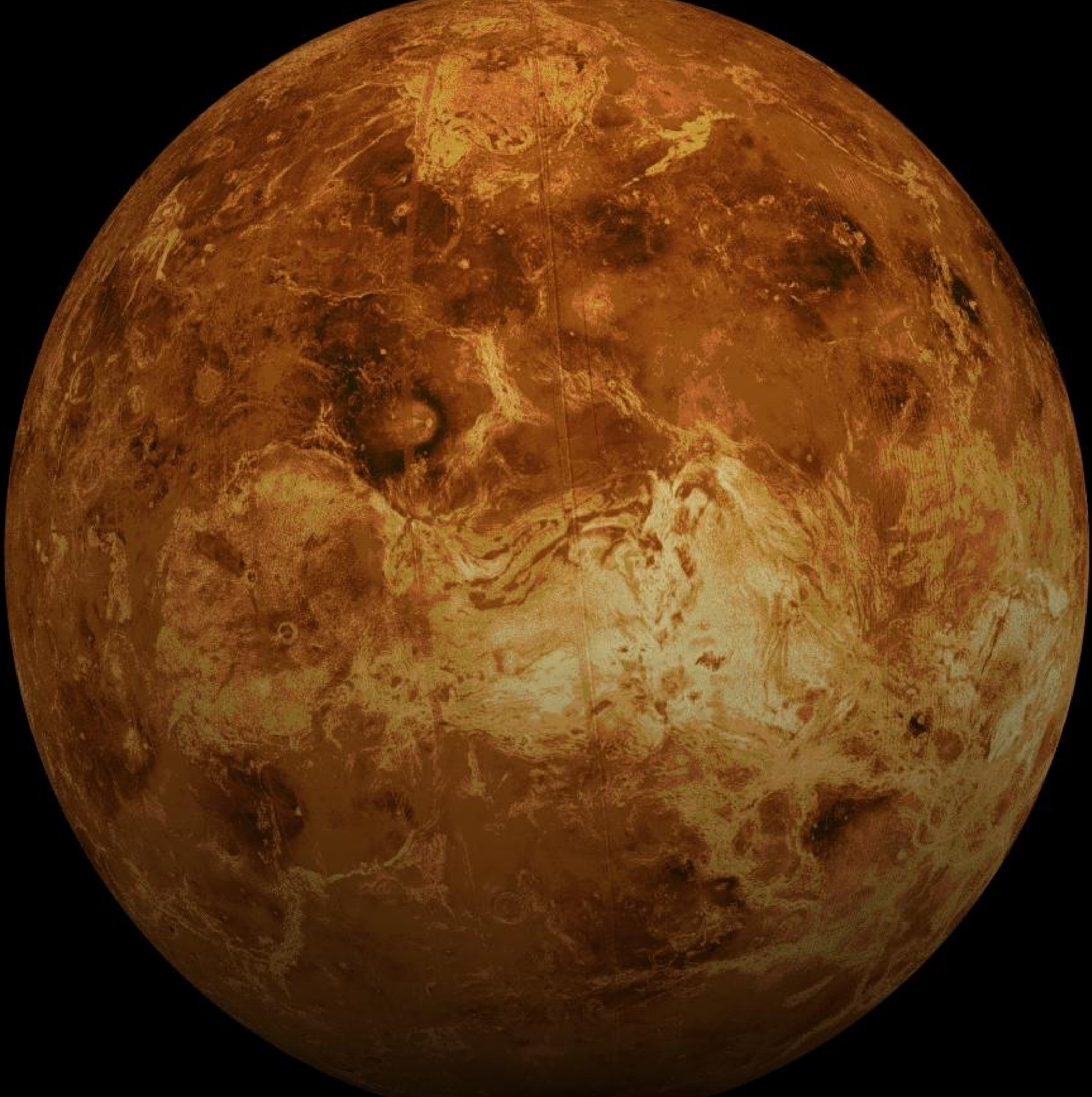


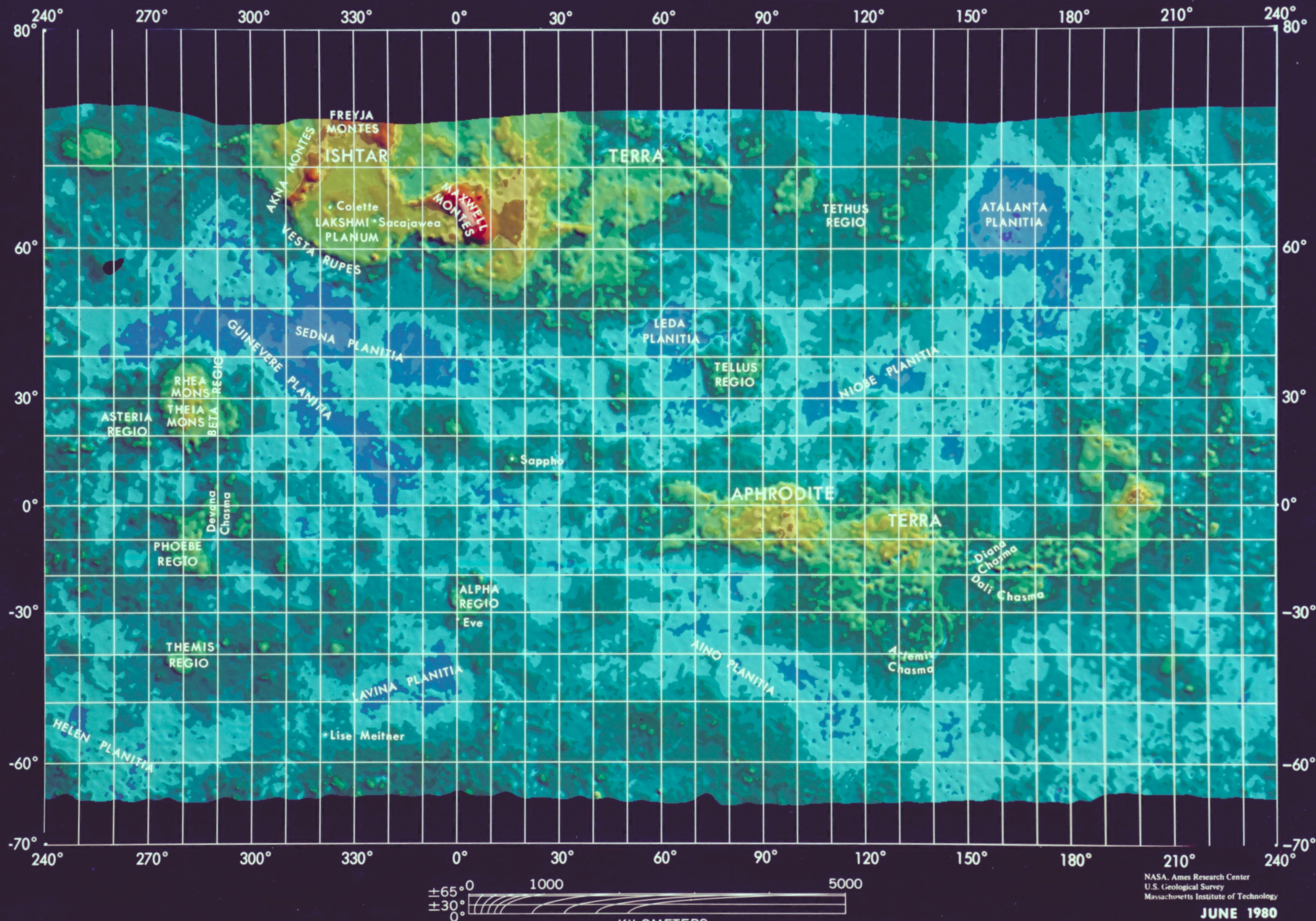

THE THREE STOOGES
HAVE ROCKET, WILL TRAVEL
THEIR FIRST FULL LENGTH FEATURE MOTION PICTURE!
with JEROME COWAN · ANNA-LISA · BOB COLBERT · Written by RAPHAEL HAYES · Produced by HARRY ROMM · Directed by DAVID LOWELL RICH
A COLUMBIA PICTURE


BASIL RATHBONE · FAITH DOMERGUE
VOYAGE TO THE PREHISTORIC PLANET
DVD
VIDEO

Akatsuki (2010)



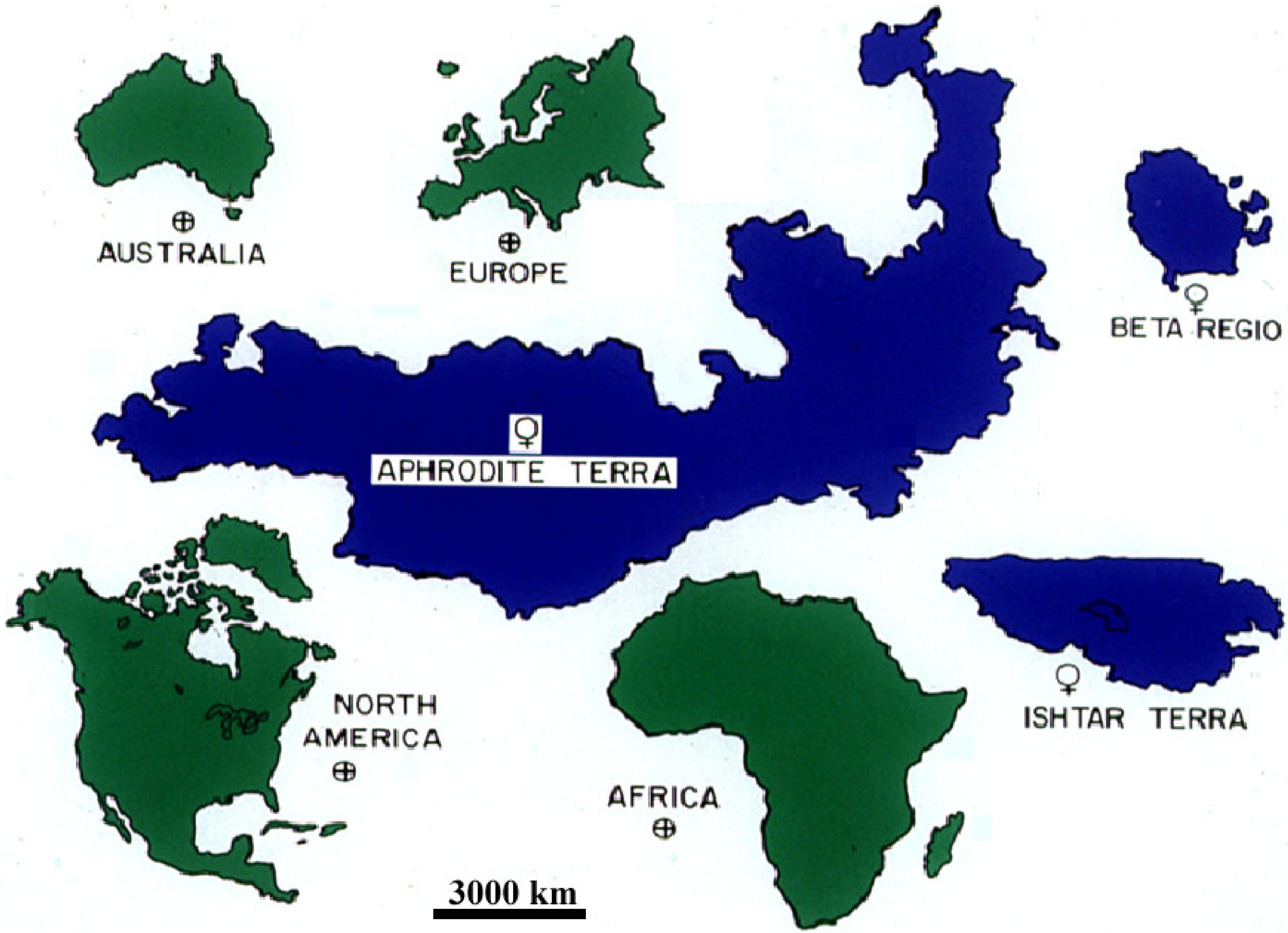


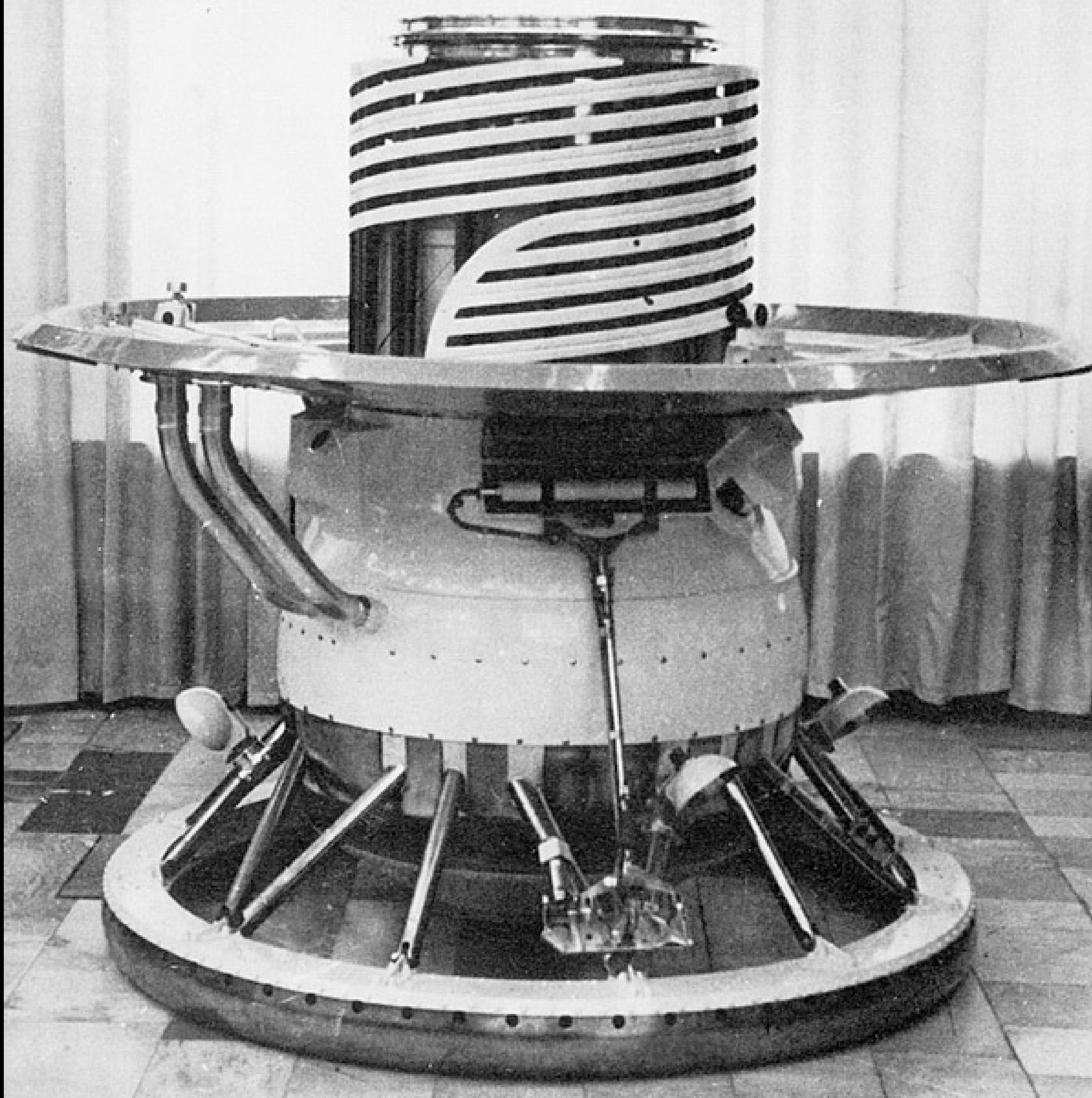


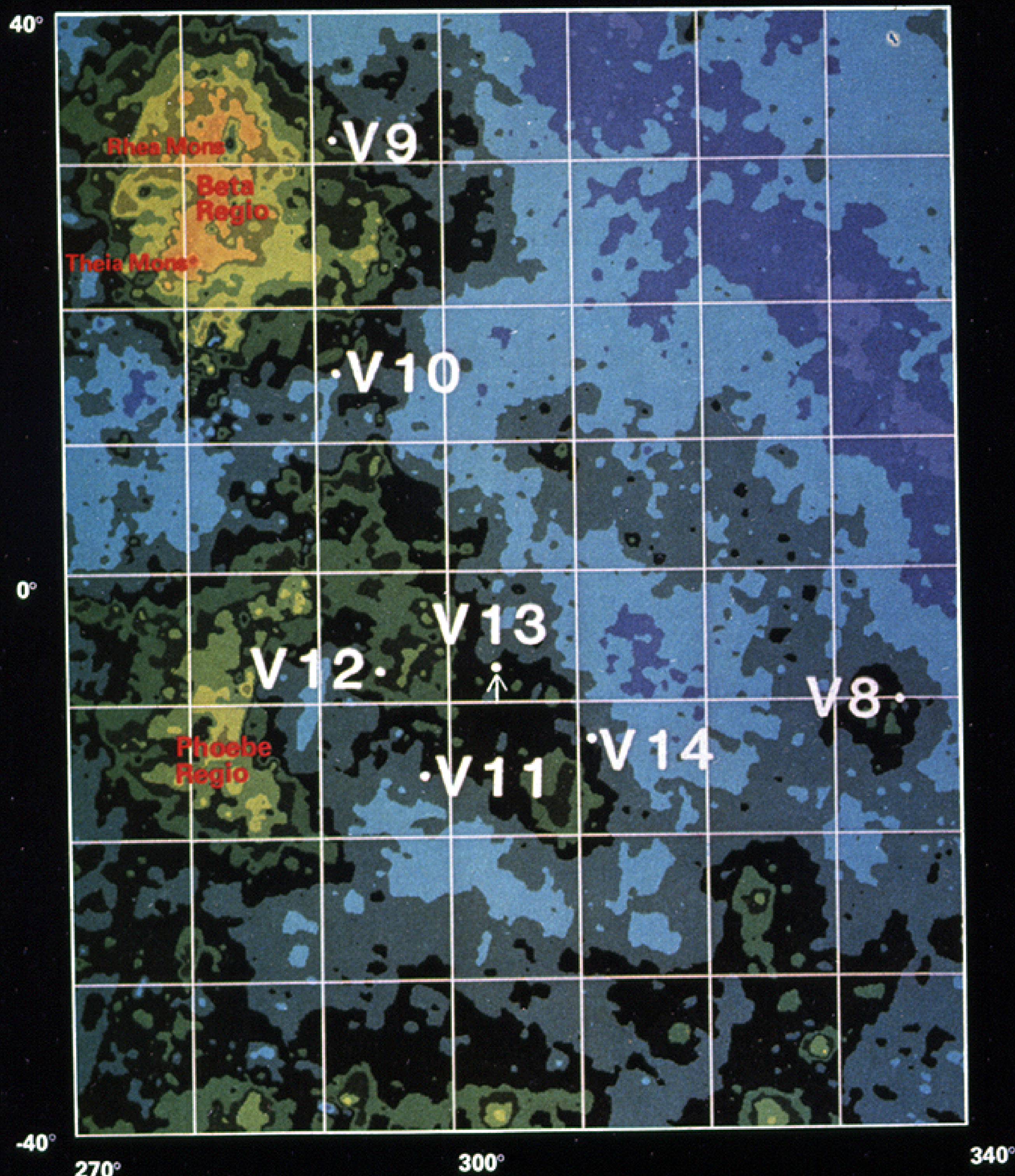
VENUS

NASA, Ames Research Center
U.S. Geological Survey
Massachusetts Institute of Technology

JUNE 1980


AUSTRALIA
EUROPE
BETA REGIO
APHRODITE TERRA
NORTH AMERICA
AFRICA
ISHTAR TERRA
3000 km





40°
0°
-40°
270°
300°
340°
Rhea Mons
Beta Regio
Theia Mons
Phoebe Regio
V9
V10
V13
V12
V8
V14
V11


ВЕНЕРА-14 ОБРАБОТКА ИППИ АН СССР И ЦДКС
ВЕНЕРА-14 ОБРАБОТКА ИППИ АН СССР И ЦДКС

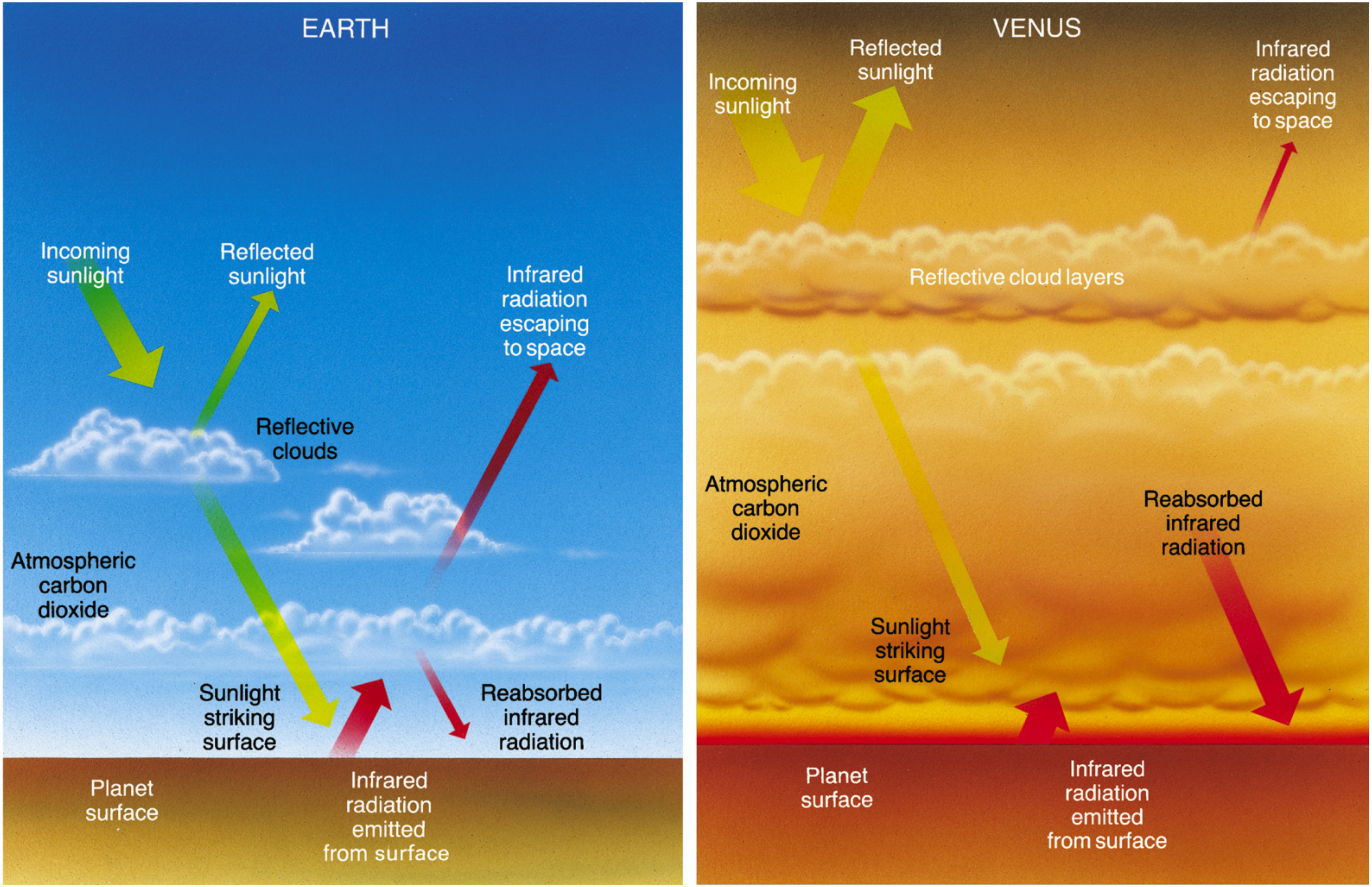
Table 13.1 Planetary characteristics of Venus. (Source: Fegley (2014).)

Parameter	*Value*	*Value relative to Earth*
Mass	4.8685×10^{24} kg	0.815
Mean radius	6052 km	0.95
Mean density	5243 kg m^{-3}	0.95
Mean surface gravity	8.87 m s^{-2}	0.904
Semi-major axis	108 208 930 km	0.723
Orbital eccentricity	0.0067	
Sidereal orbital period	224.701 d*	0.615
Rotation period	243 d* (retrograde)	243
Daylength (noon to noon)	116.75 d*	116.75
Surface temperature at the mean radius	737 K	2.6
Surface pressure at the mean radius	93.3 bar	93.3
Bond albedo	0.76	2.53

* Units are in Earth days.

Table 13.2 Composition of Venus' atmosphere. (Source: Fegley (2014) and references therein.)

Gas	Abundance by volume
CO_2	$96.5 \pm 0.8\%$
N_2	$3.5 \pm 0.8\%$
SO_2	150 ± 30 ppm (22–42 km)
	30–150 ppm (12–22 km)
Ar	66 (+40, –20) ppm
H_2O	30 ± 15 ppm (0–45 km)
CO	17 ± 1 ppm (12 km)



EARTH
Incoming sunlight
Reflected sunlight
Infrared radiation escaping to space
Reflective clouds
Atmospheric carbon dioxide
Sunlight striking surface
Reabsorbed infrared radiation
Planet surface
Infrared radiation emitted from surface
VENUS
Incoming sunlight
Reflected sunlight
Infrared radiation escaping to space
Reflective cloud layers
Atmospheric carbon dioxide
Reabsorbed infrared radiation
Sunlight striking surface
Planet surface
Infrared radiation emitted from surface

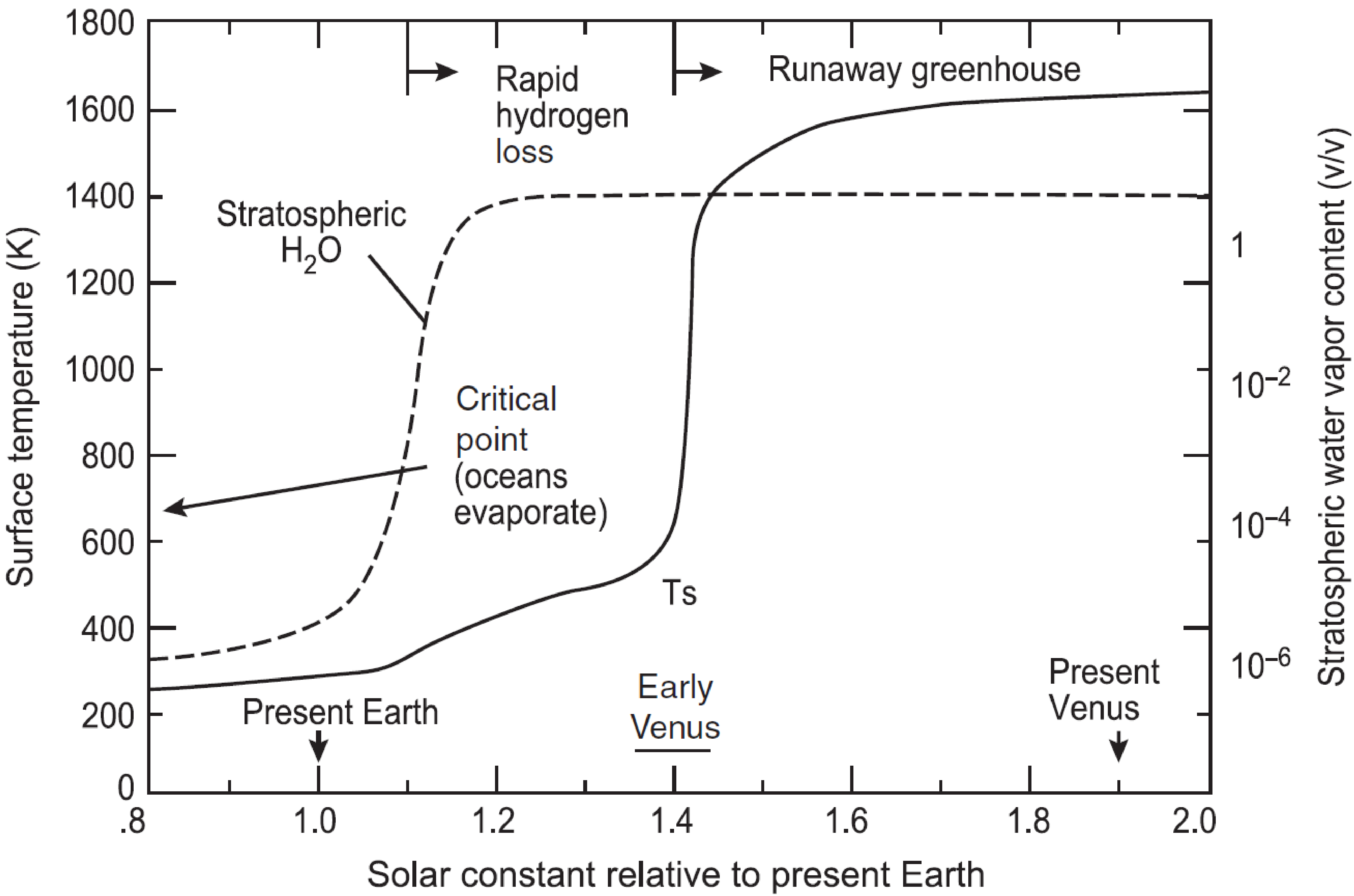
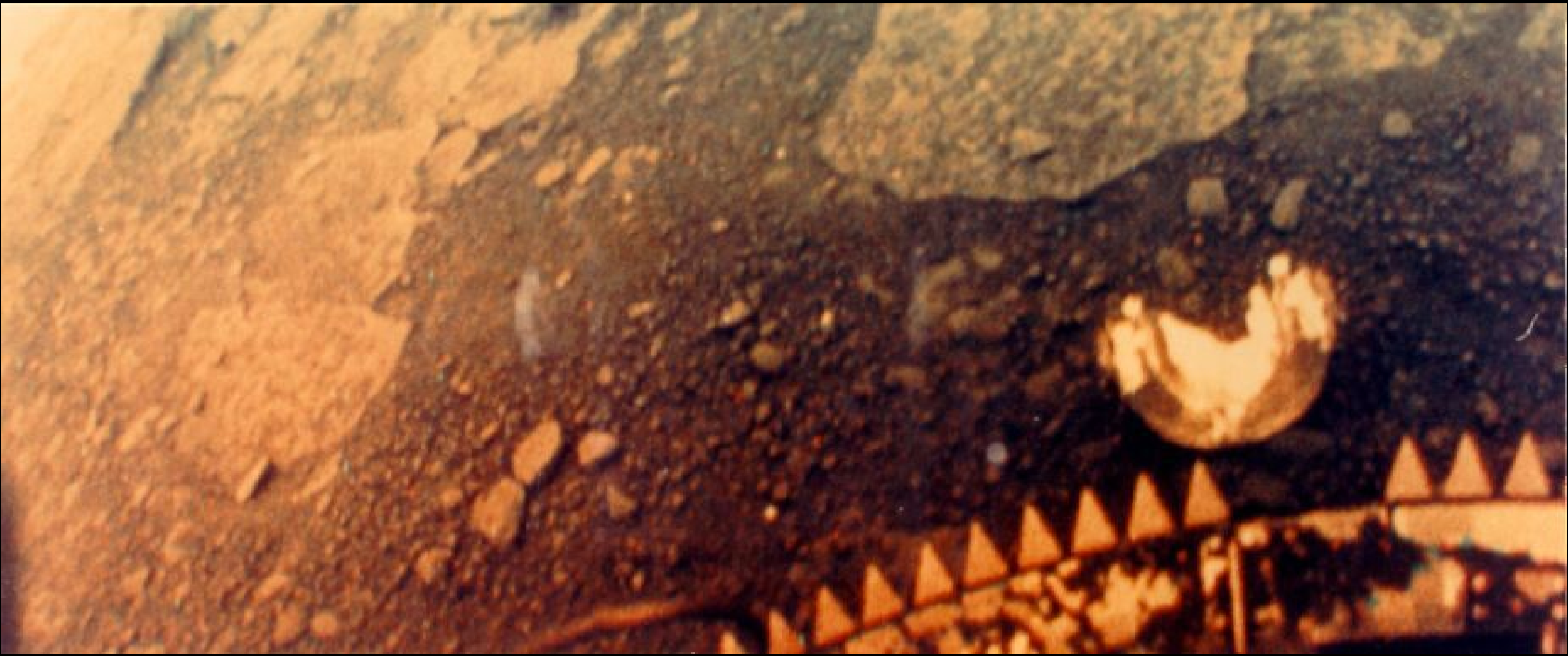


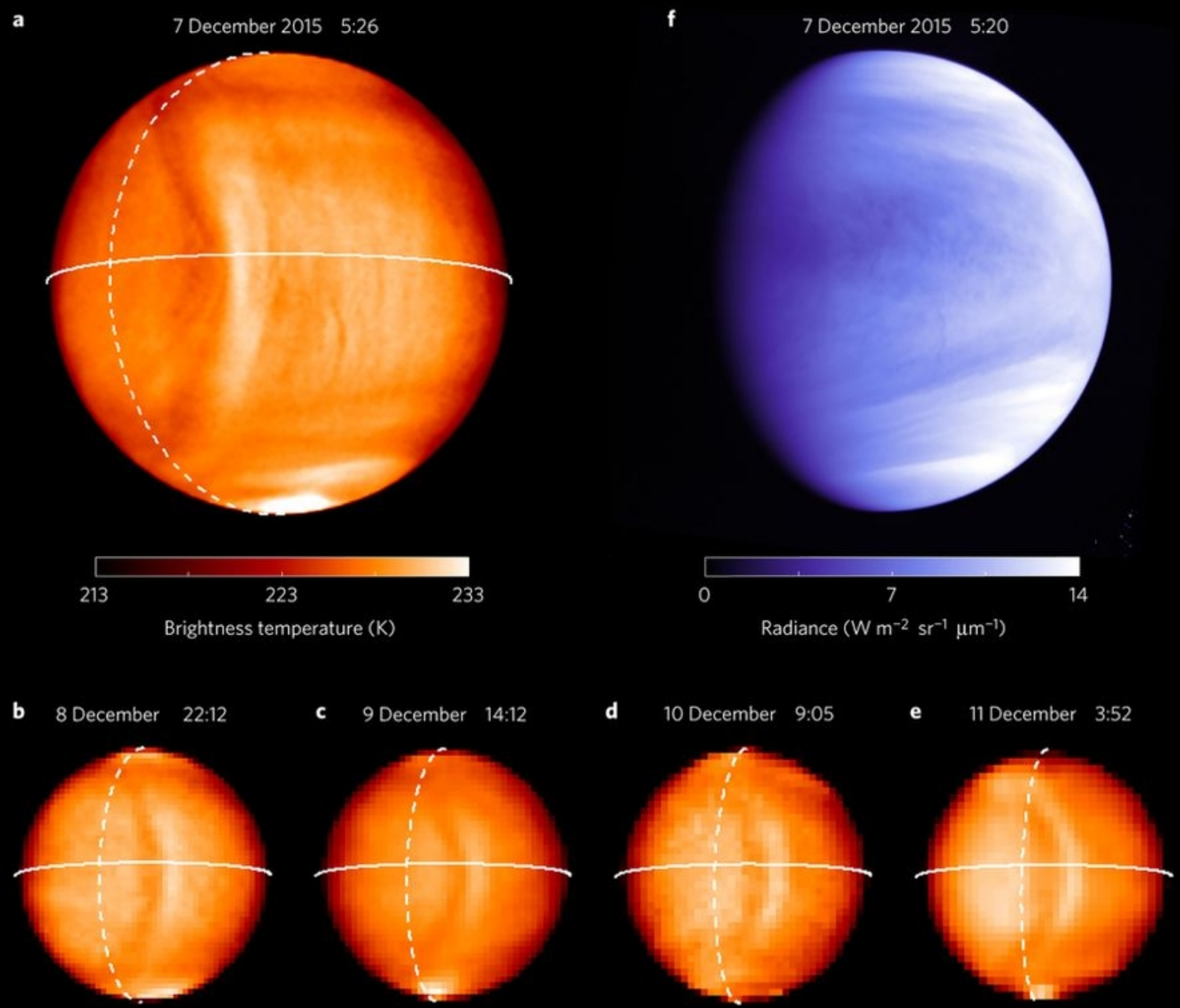
Figure 13.15: Catling & Kasting

Venera 13 (1982)



“If Venus did not exist in our solar system, we would not dare to imagine it” - Francois Forget

Atmospheric dynamics on Venus

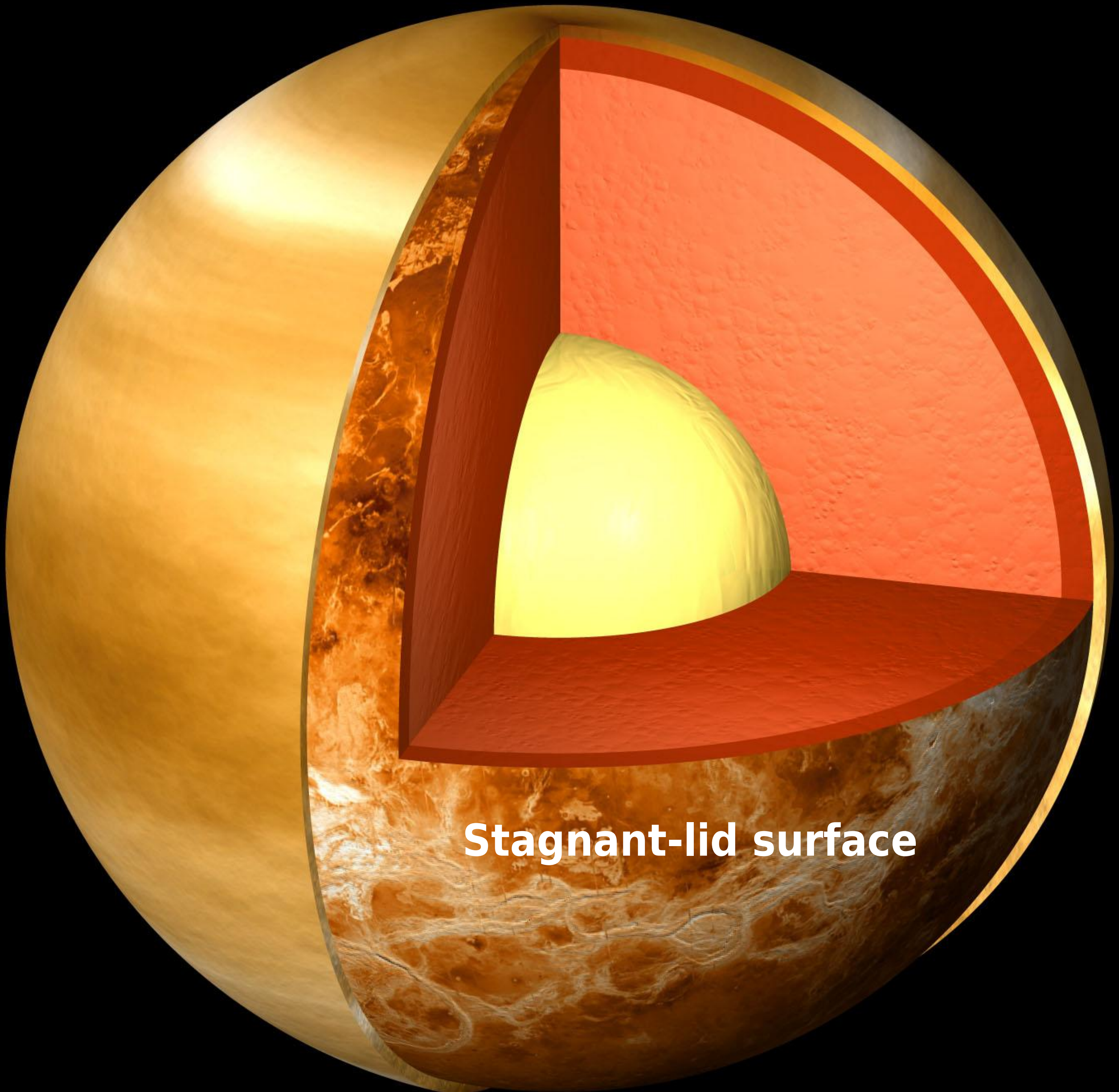


- The atmosphere of Venus is ~2 orders of magnitude more massive than that of Earth's atmosphere.

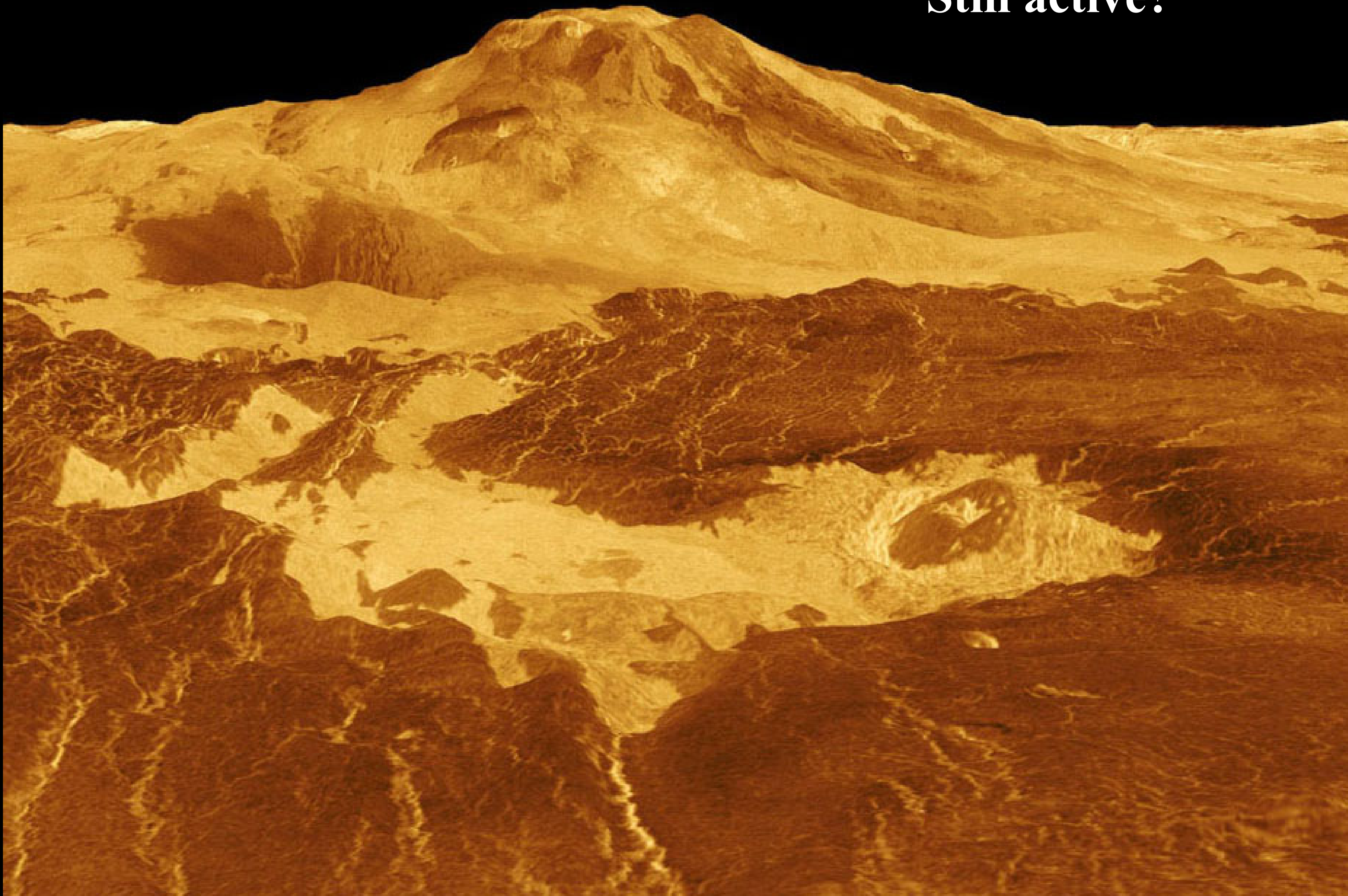
- Approximately 3% of sunlight incident at the top of the Venusian atmosphere reaches the surface. Thus, almost all of the solar energy absorbed by the planet is deposited into the atmosphere.

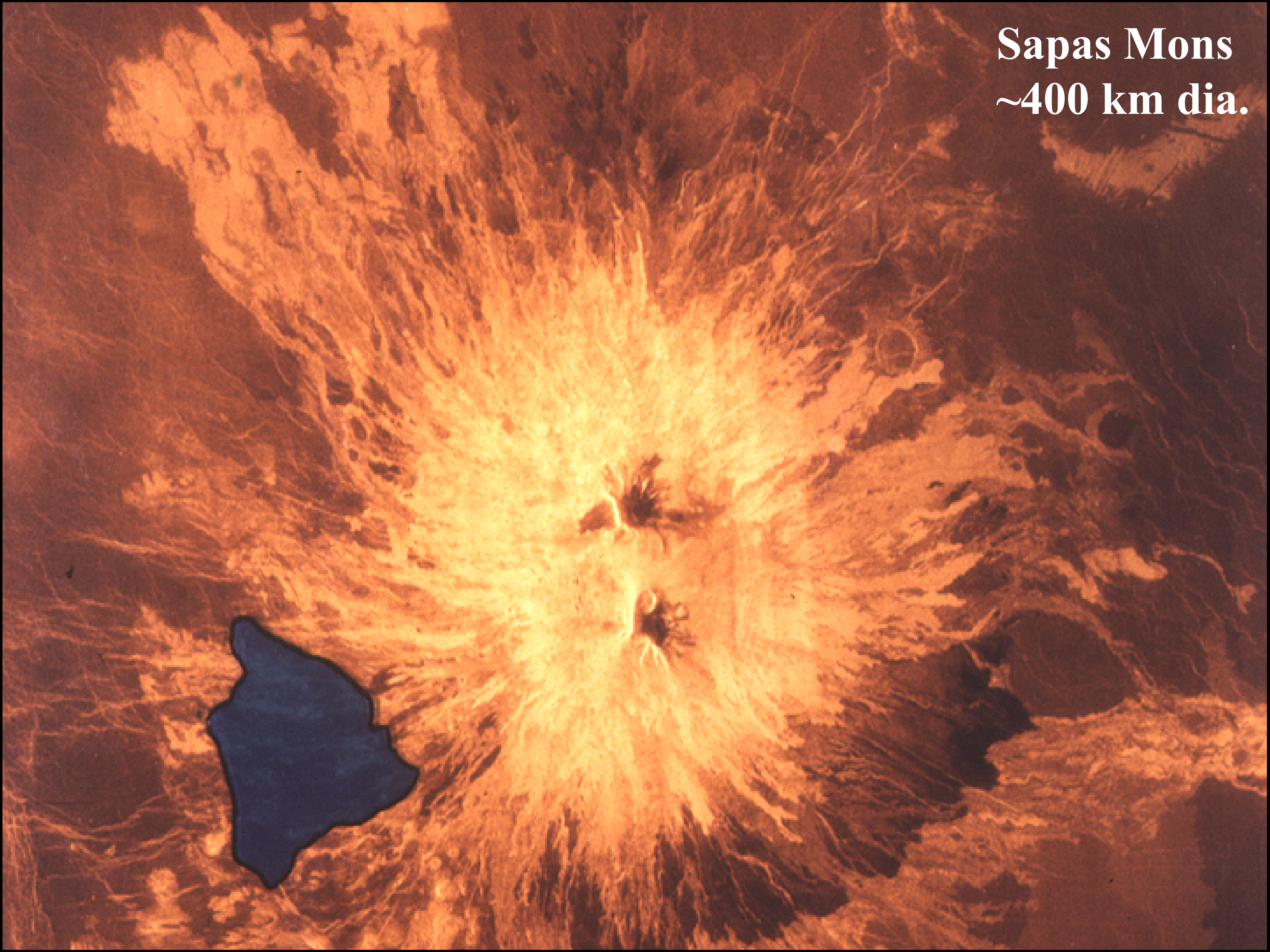
- This, in turn, produces a turbulent atmosphere with a dramatic velocity gradient (super-rotation), that interacts strongly with the surface topography. Such interactions can transfer angular momentum between the atmosphere and solid planet.

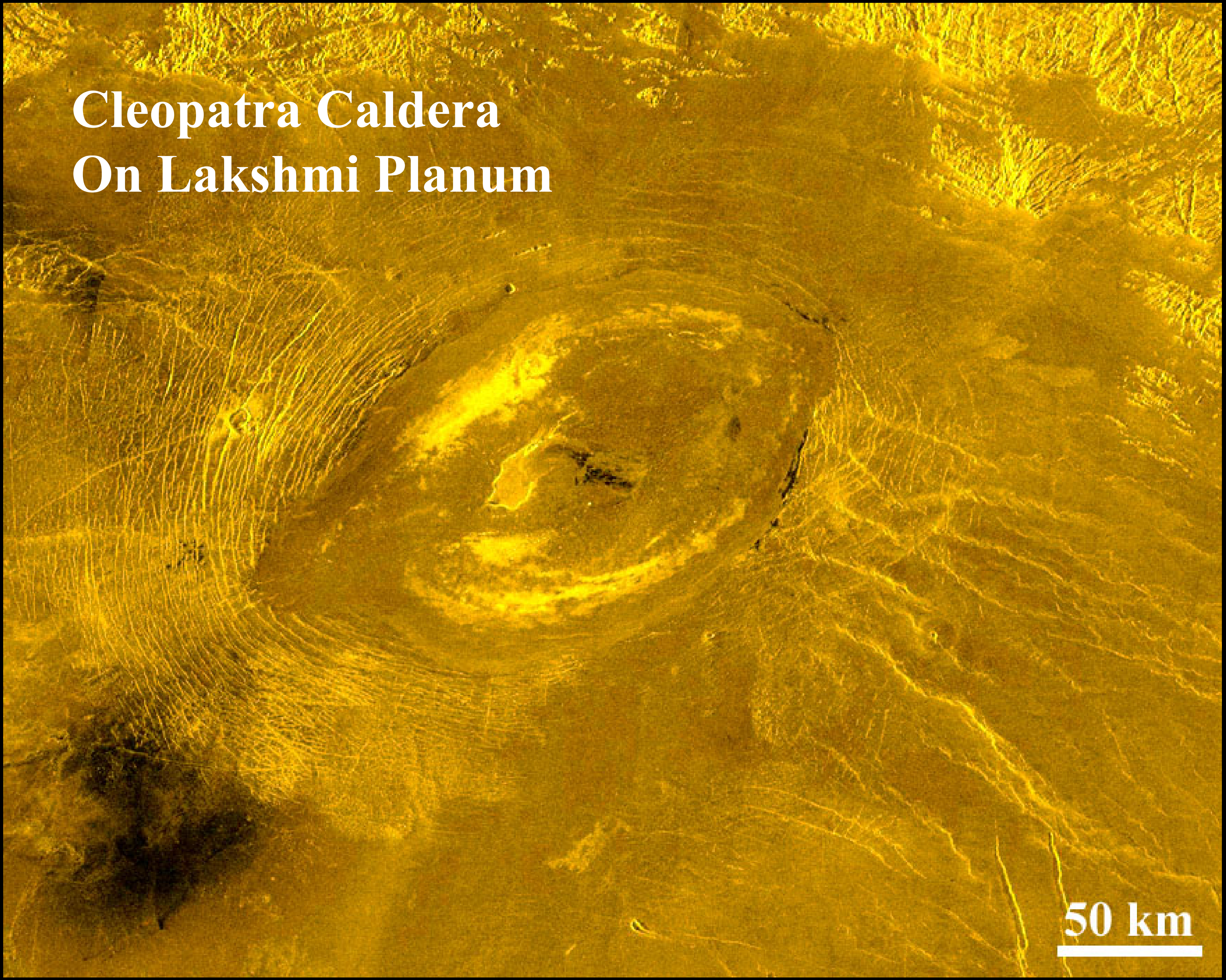
Fukuhara et al. 2017, Nature Geoscience, 10, 85
Margot et al. 2021, Nature Astronomy, 5, 676
Kane. 2022, Nature Astronomy, 6, 420


Stagnant-lid surface

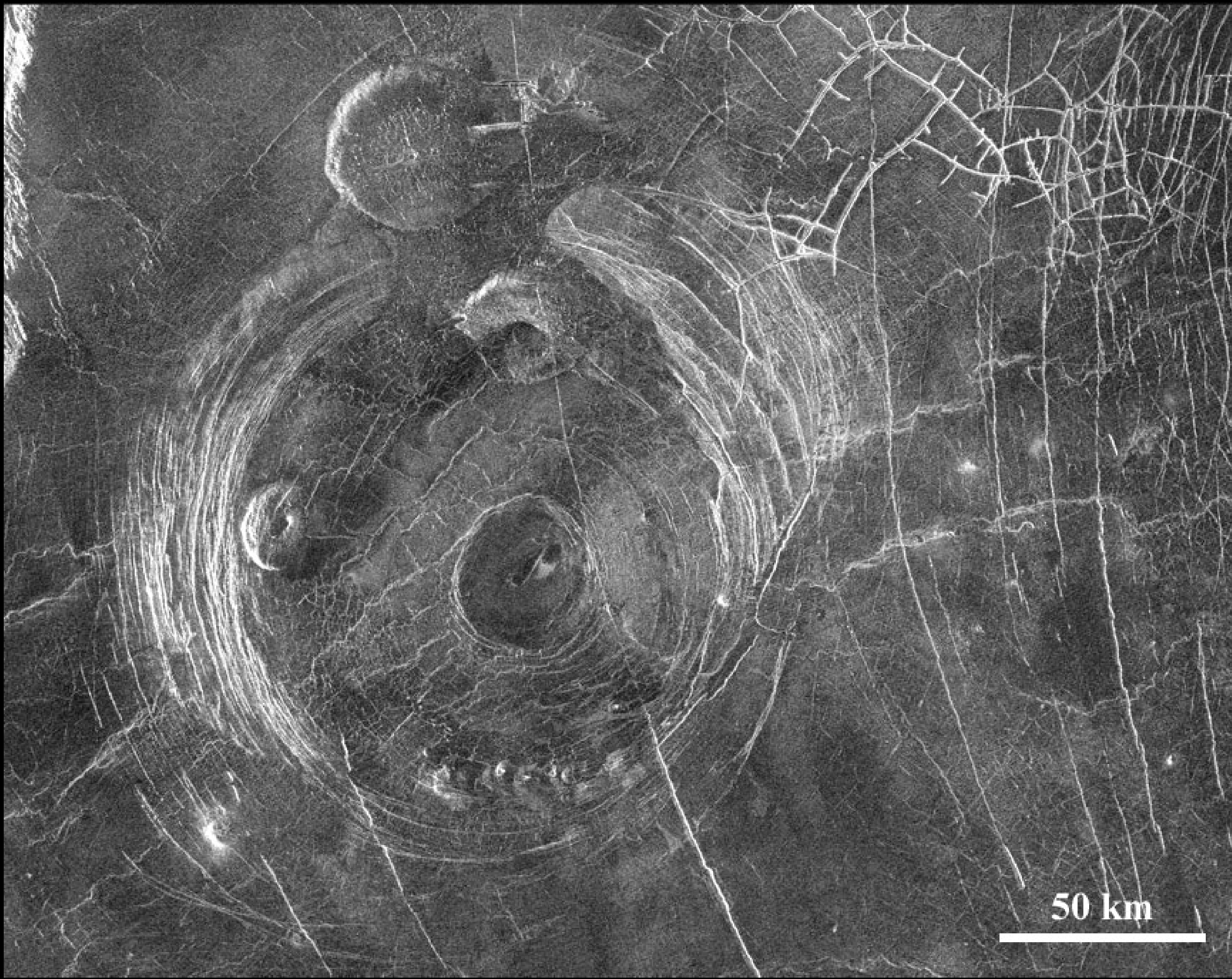
Maat Mons ~8 km high
Still active?



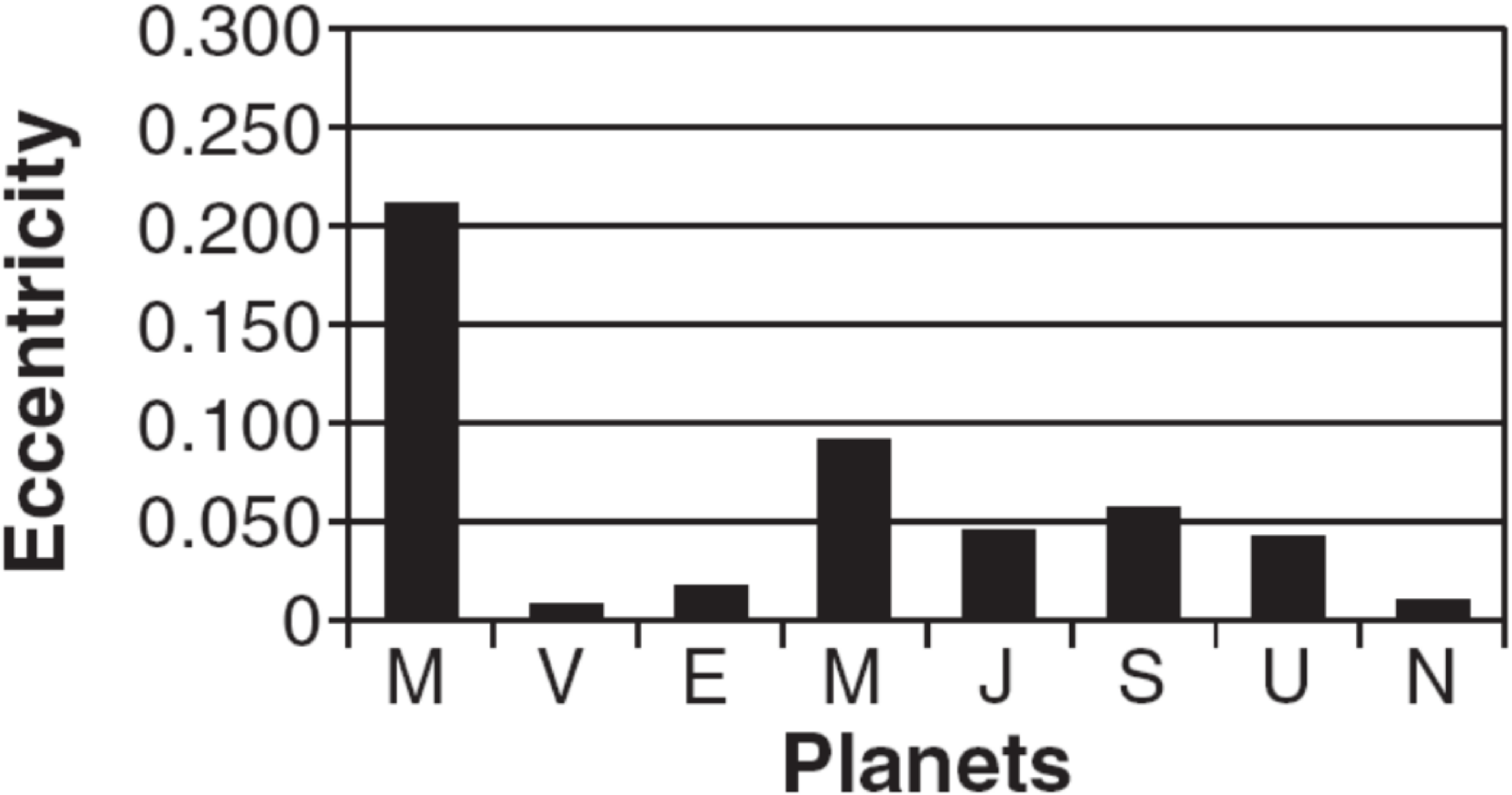

Sapas Mons
~400 km dia.


Cleopatra Caldera
On Lakshmi Planum
50 km

Tectonic features: Fotla Corona S.E. of Aphrodite Terra

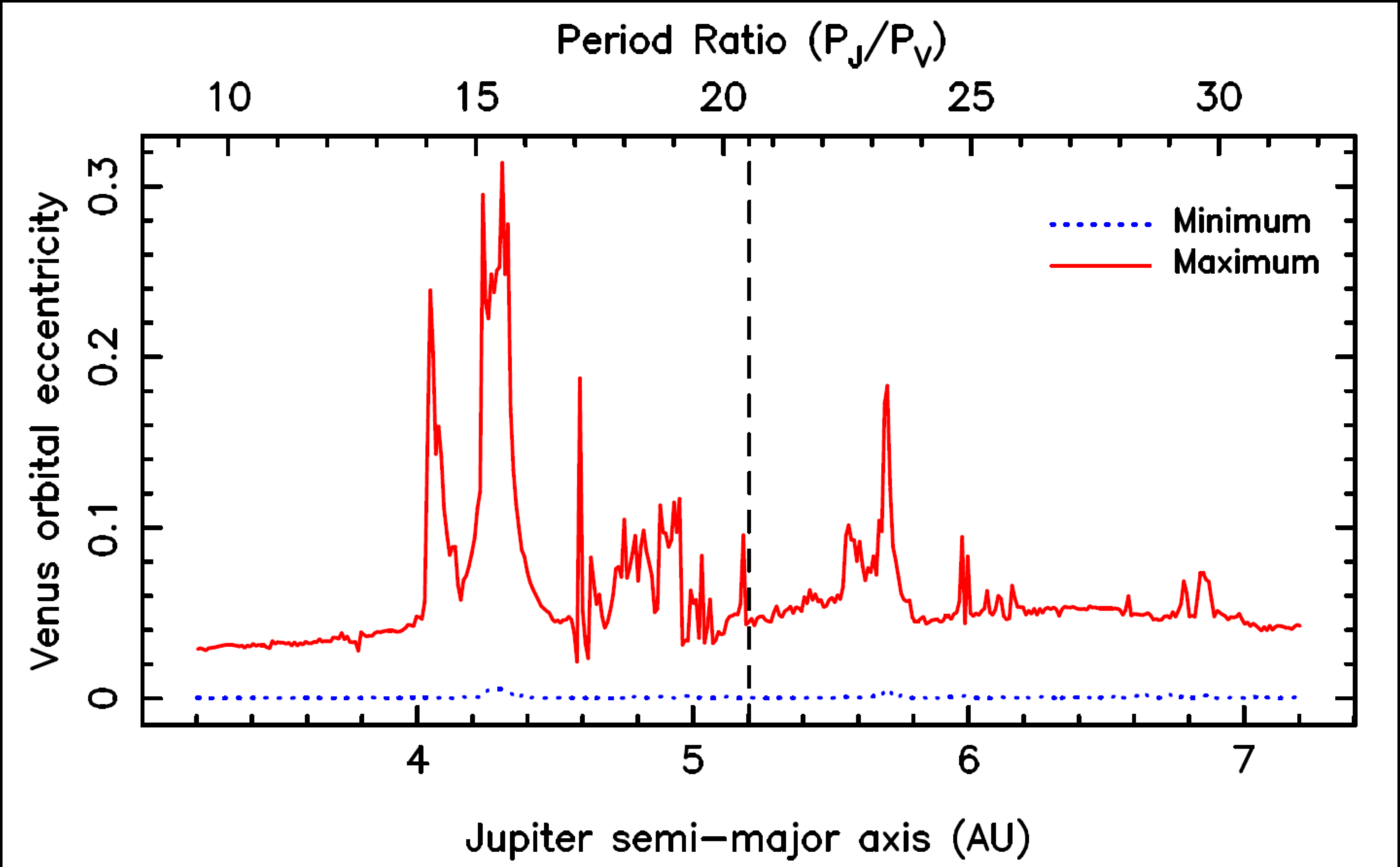


Venus: Orbital Eccentricity



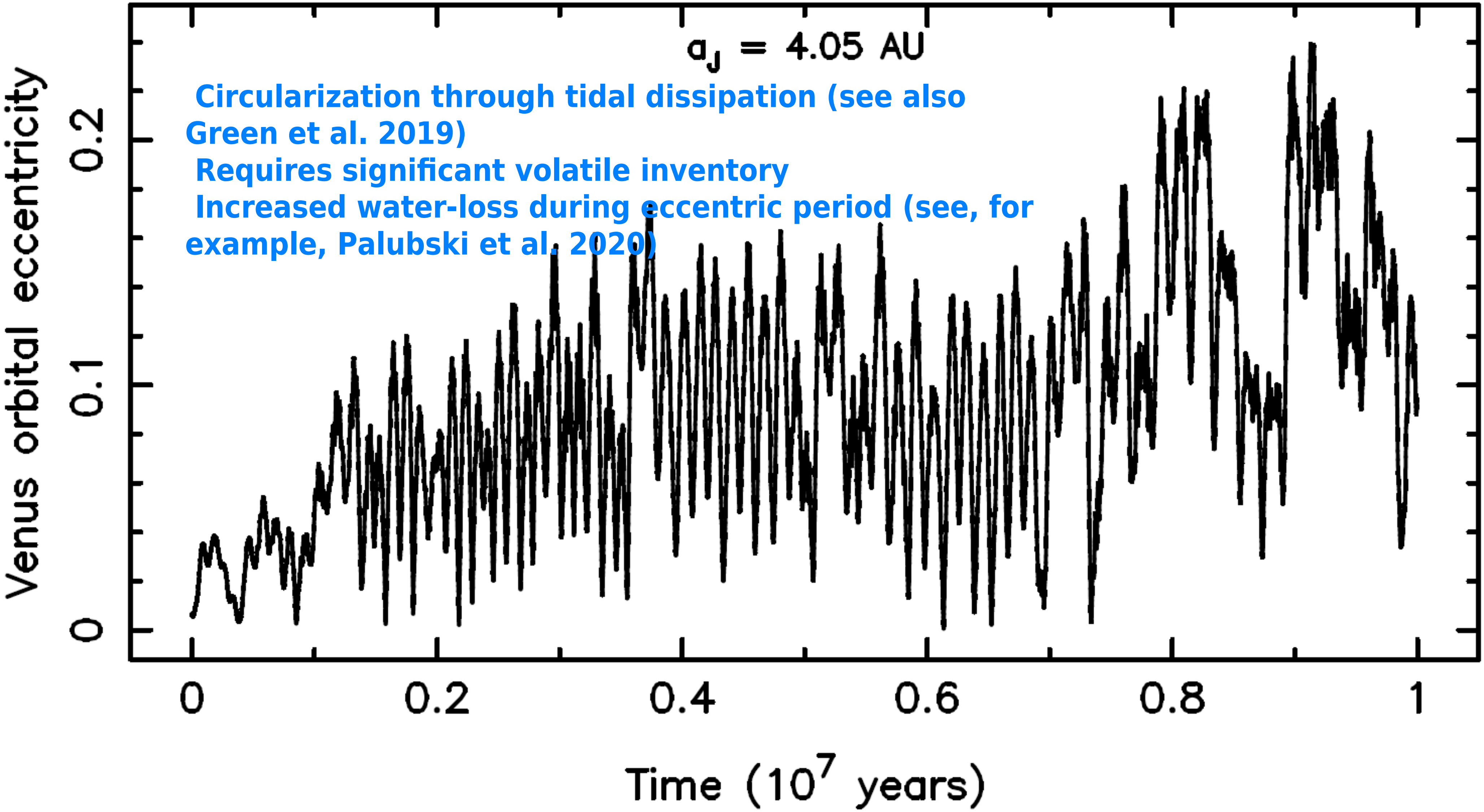
Kane et al. “Could the Migration of Jupiter Have Accelerated the Atmospheric Evolution of Venus?”, 2020, PSJ, 1, 42

Venus: Orbital Eccentricity



Kane et al. "Could the Migration of Jupiter Have Accelerated the Atmospheric Evolution of Venus?", 2020, PSJ, 1, 42

Venus: Orbital Eccentricity

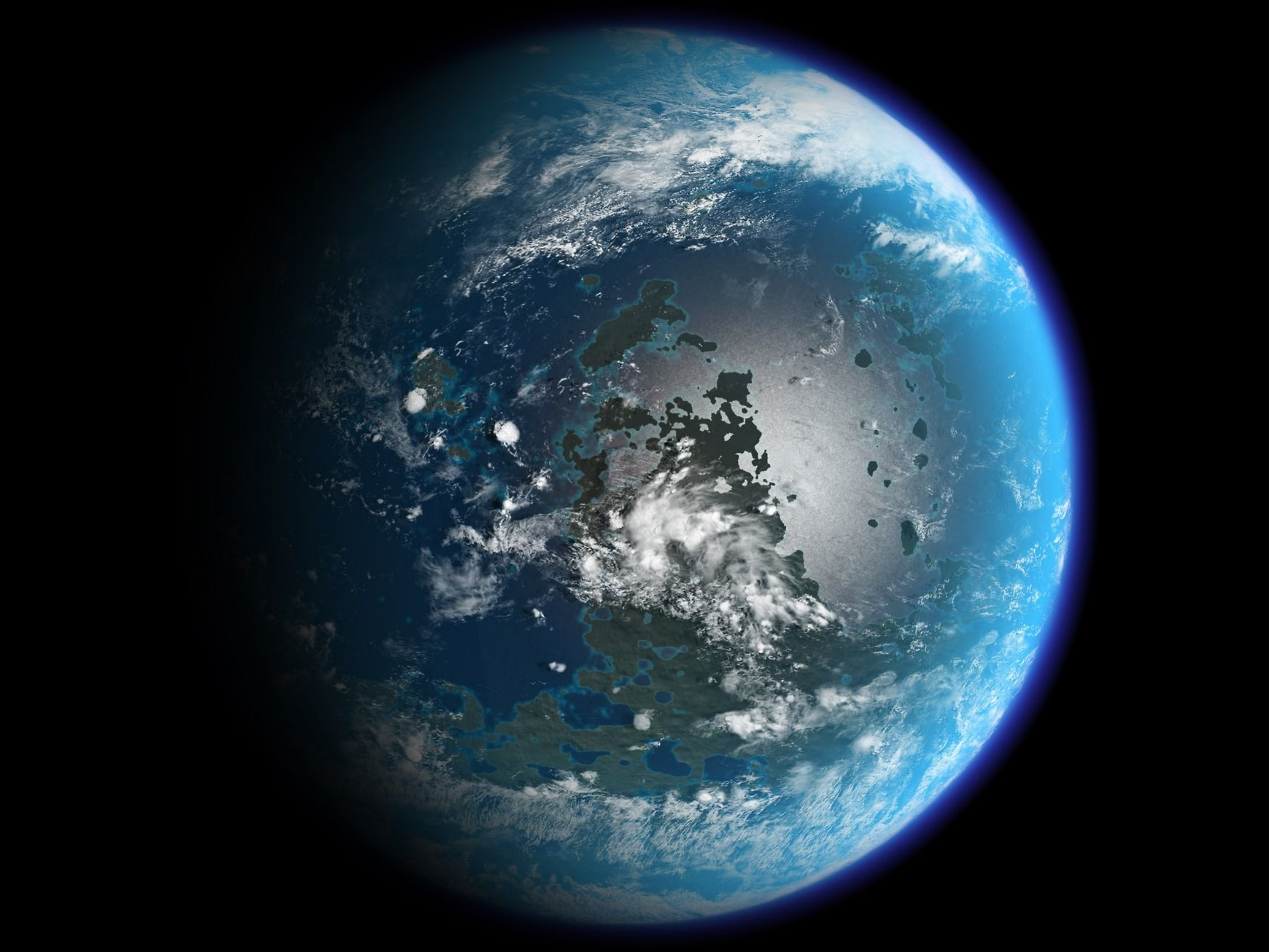


Circularization through tidal dissipation (see also Green et al. 2019)

Requires significant volatile inventory

Increased water-loss during eccentric period (see, for example, Palubski et al. 2020)

Kane et al. "Could the Migration of Jupiter Have Accelerated the Atmospheric Evolution of Venus?", 2020, PSJ, 1, 42



Venus: Habitability Factors

• What is the interior structure and composition of Venus? How much does it differ from the Earth and the Sun?

• What has been the history of tectonics, volatile cycling, and volcanic resurfacing (Ivanov & Head 2011)? Does any subduction occur today (Smrekar et al. 2018)?

• What is the detailed composition and atmospheric chemistry that exists within the Venusian middle and deep atmosphere and how does it interact with the surface?

• Where did the water go (Kane et al. 2020)? Was hydrogen loss and abiotic oxygen production prevalent, or did surface hydration dominate?

• Did Venus have a habitable period (Way et al. 2016)? That is, did Venus ever cool after formation (Hamano et al. 2013)? If Venus had a habitable period, how long did it last (Kane et al. 2019)?

• What are the major factors that have caused a divergence in the evolutionary history of Venus and Earth (insolation flux, rotation, volatile inventory, lack of a significant moon, etc)?

Astrobiology, Vol. 18, No. 9 | Hypothesis Articles

Venus' Spectral Signatures and the Potential for Life in the Clouds

Sanjay S. Limaye, Rakesh Mogul, David J. Smith, Arif H. Ansari, Grzegorz P. Słowik, and Parag Vaishampayan

Published Online: 12 Sep 2018 | https://doi.org/10.1089/ast.2017.1783

Abstract

The lower cloud layer of Venus (47.5–50.5 km) is an exceptional target for exploration due to the favorable conditions for microbial life, including moderate temperatures and pressures (~60°C and 1 atm), and the presence of micron-sized sulfuric acid aerosols. Nearly a century after the ultraviolet (UV) contrasts of Venus' cloud layer were discovered with Earth-based photographs, the substances and mechanisms responsible for the changes in Venus' contrasts and albedo are still unknown. While current models include sulfur dioxide and iron chloride as the UV absorbers, the temporal and spatial changes in contrasts, and albedo, between 330 and 500 nm, remain to be fully explained. Within this context, we present a discussion regarding the potential for microorganisms to survive in Venus' lower clouds and contribute to the observed bulk spectra. In this article, we provide an overview of relevant Venus observations, compare the spectral and physical properties of Venus' clouds to terrestrial biological materials, review the potential for an iron- and sulfur-centered metabolism in the clouds, discuss conceivable mechanisms of transport from the surface toward a more habitable zone in the clouds, and identify spectral and biological experiments that could measure the habitability of Venus' clouds and terrestrial analogues. Together, our lines of reasoning suggest that particles in Venus' lower clouds contain sufficient mass balance to harbor microorganisms, water, and solutes, and potentially sufficient biomass to be detected by optical methods. As such, the comparisons presented in this article warrant further investigations into the prospect of biosignatures in Venus' clouds.

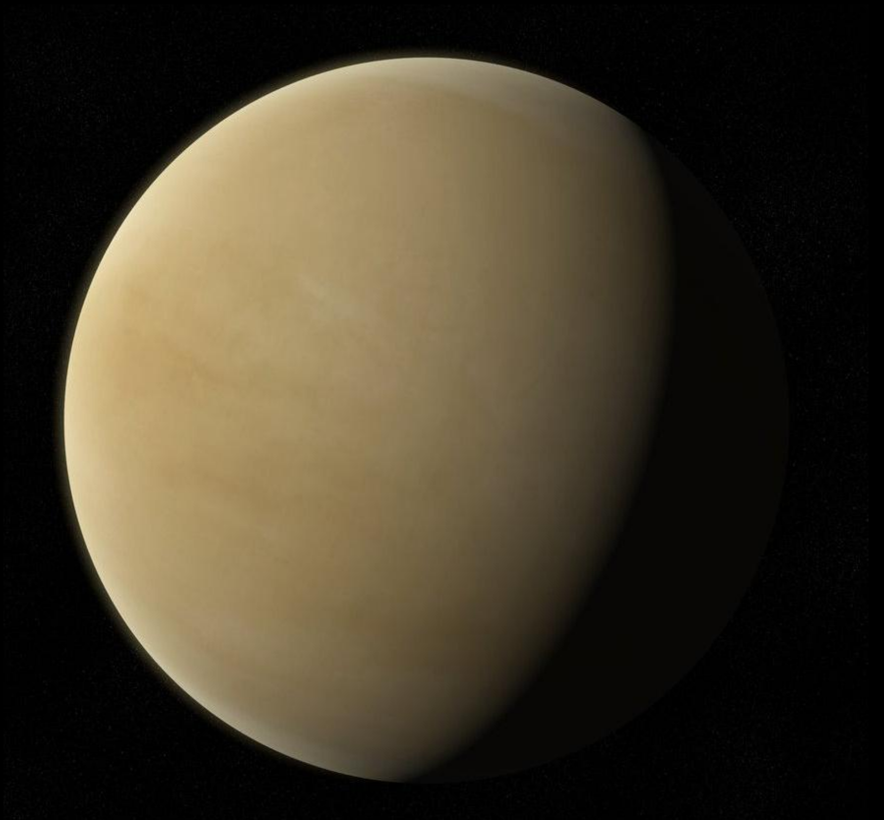
1. Introduction

The habitability of Venus' clouds has been a subject of discussion for several decades (Morowitz and Sagan, 1967; Grinspoon, 1997) yet has gained limited traction as a popular target in astrobiology research. Initially stirring excitement,

Why do we need a "Venus Zone"?

- The transit method is biased toward short-period planets.
- We know that it's possible for planets of Earth-size to produce radically different atmospheres.
- What is the frequency of Venus analogs? How often does Dr Jekyll become Mr Hyde?

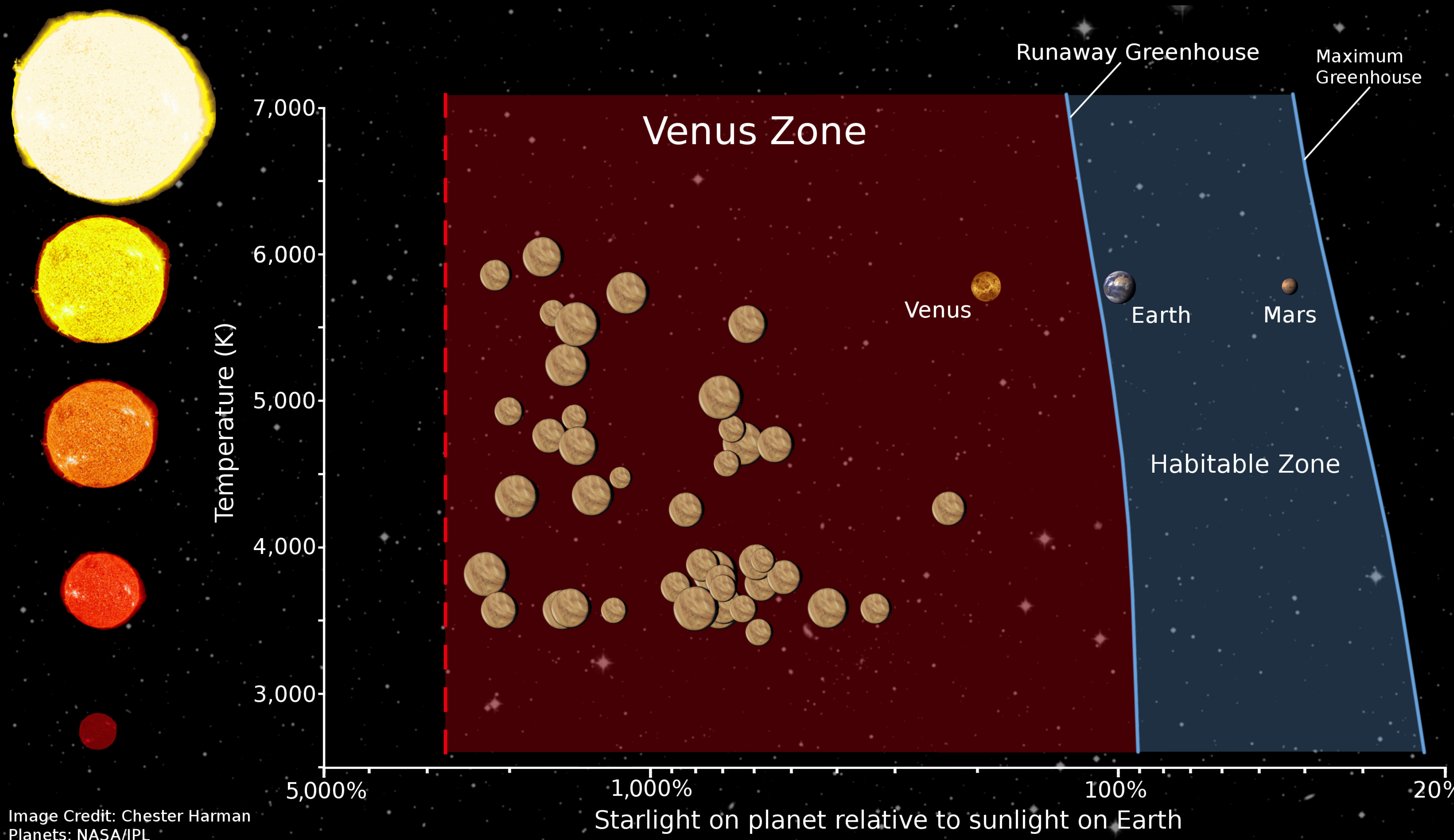
TARGET SELECTION!



Kane, Kopparapu, Domagal-Goldman. 2014, ApJ, 794, L5

The Venus Zone

- Outer edge defined by runway greenhouse
- Inner edge defined by atmospheric mass loss



Kane, Kopparapu, Domagal-Goldman. 2014, ApJ, 794, L5

The Venus Zone

- Define η(Venus) as fraction of stars with at least one terrestrial planet within the Venus Zone

- For M stars: η(Venus) = 0.32 +0.05/-0.07
  For GK stars: η(Venus) = 0.45 +0.06/-0.09

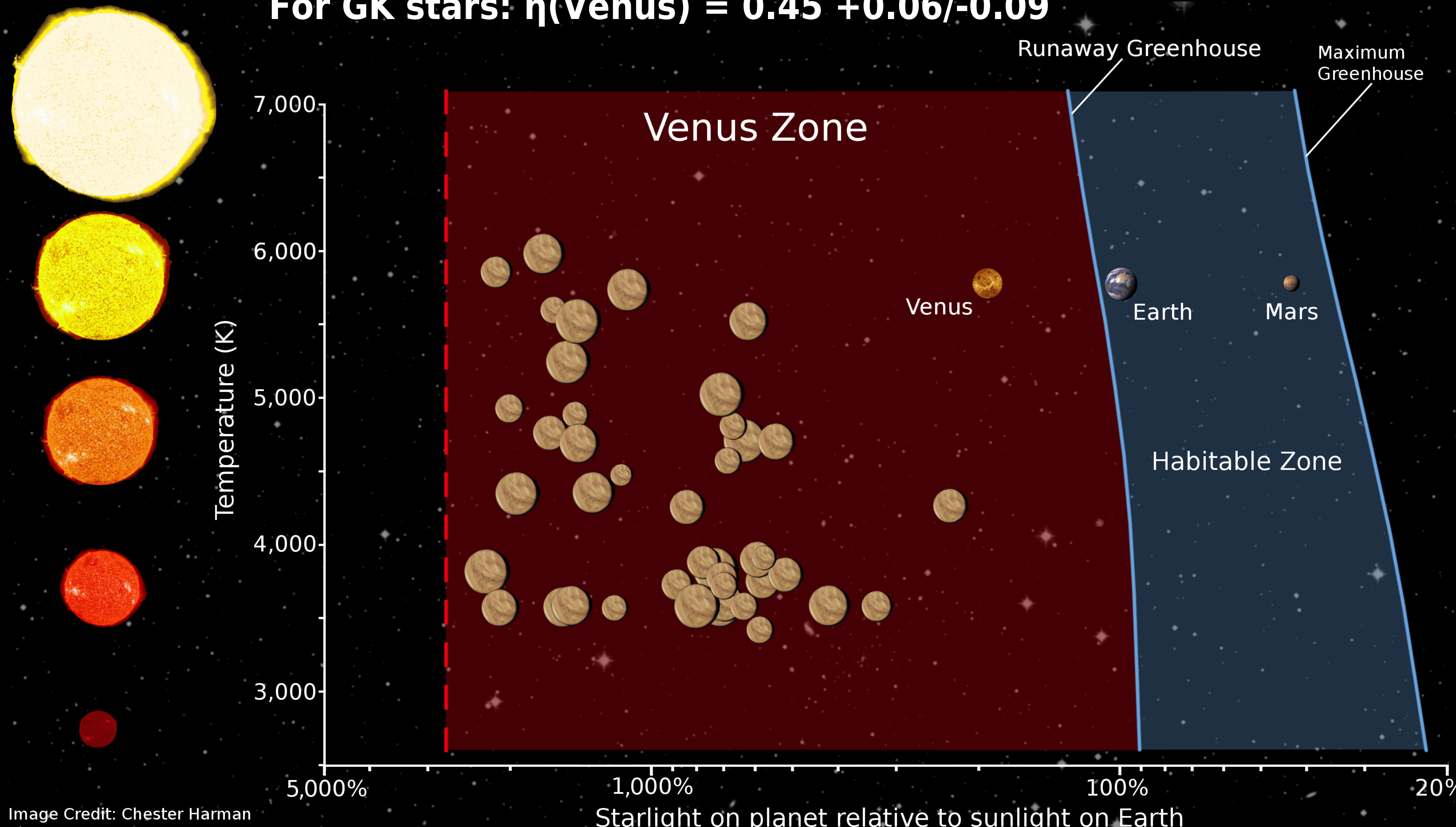


Image Credit: Chester Harman
Planets: NASA/JPL

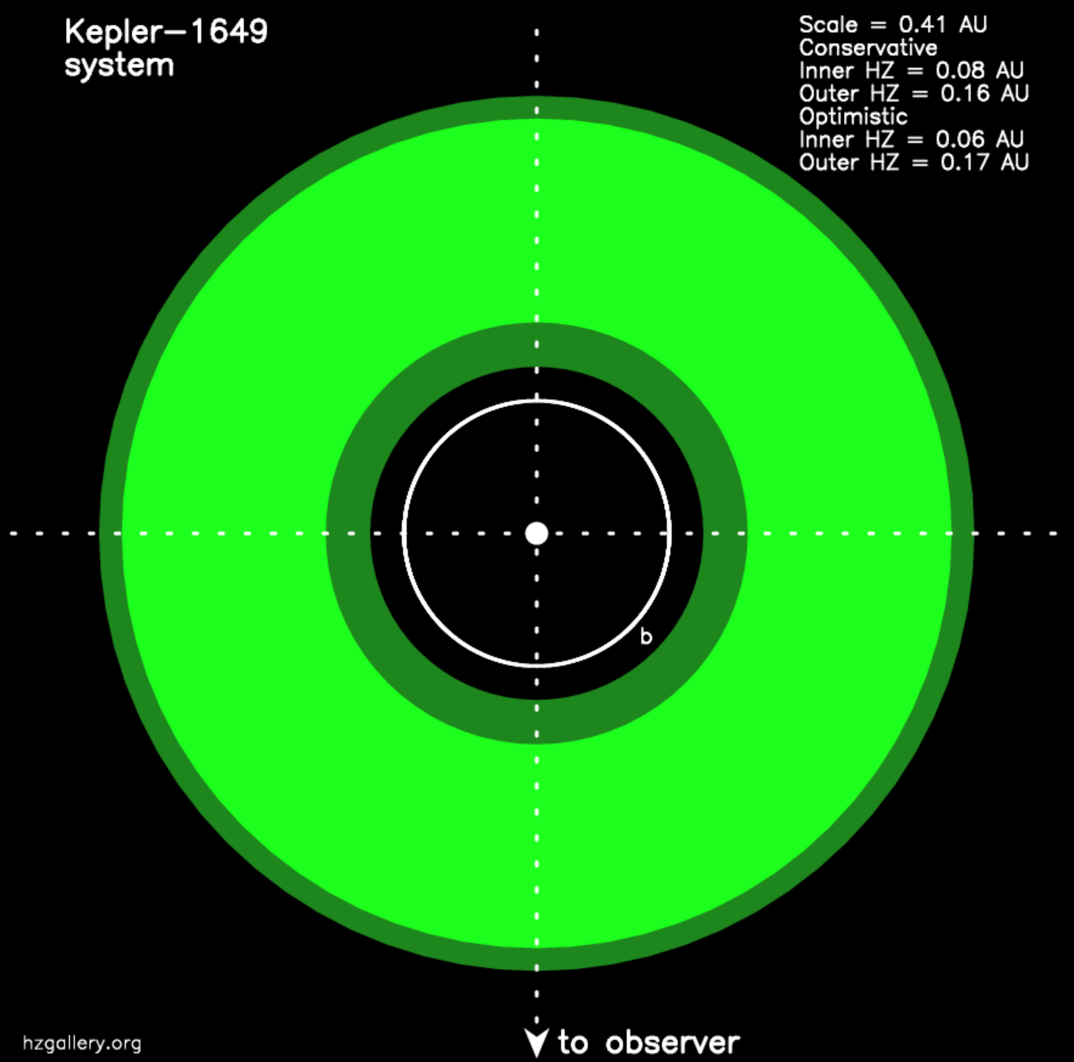
Kane, Kopparapu, Domagal-Goldman. 2014, ApJ, 794, L5

Kepler-1649b: A Possible Venus Analog

Table 1
System Parameters for Kepler-1649

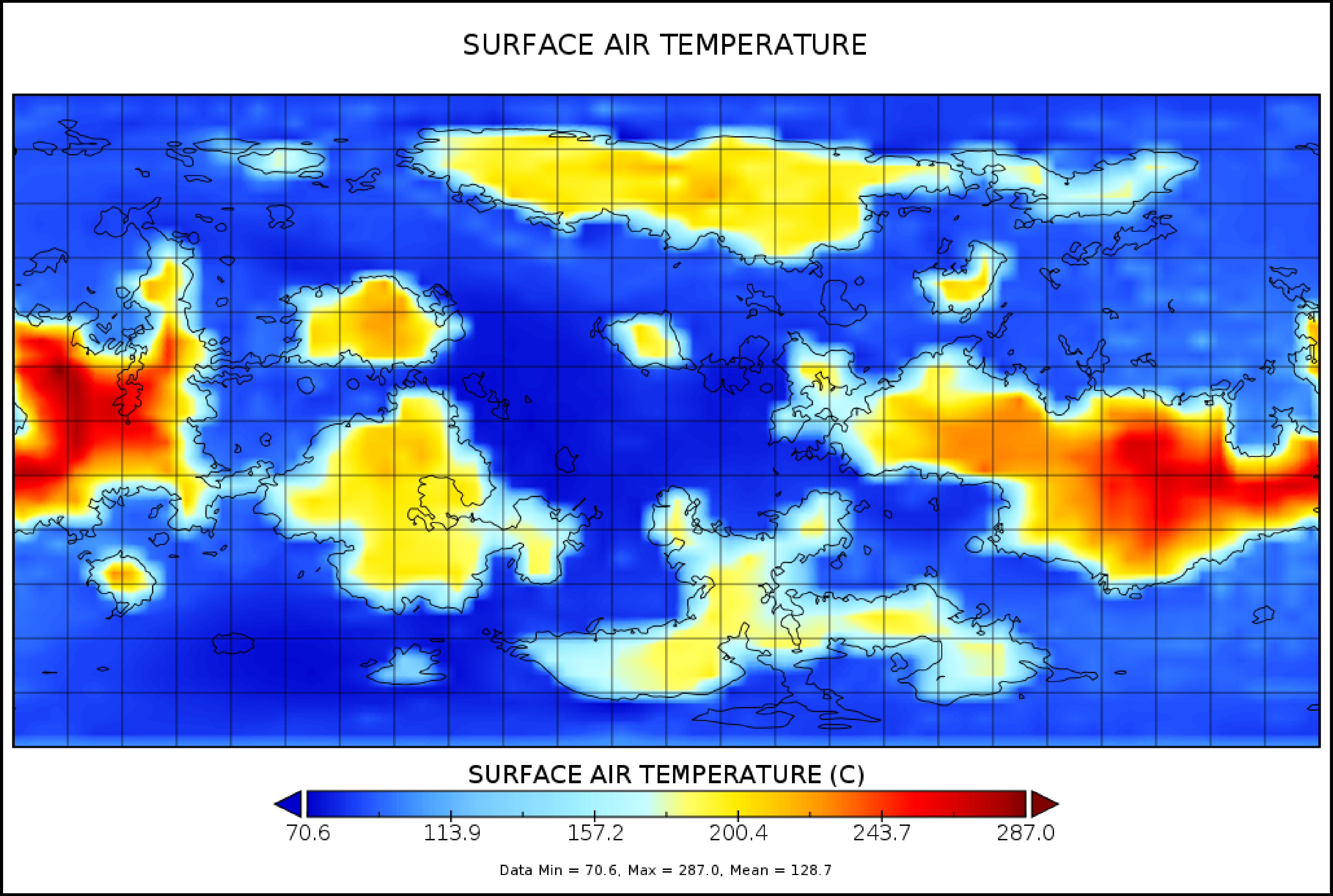
Parameter	Value	Notes
Transit and Orbital Parameters		
Orbital period P (d)	8.689090 ± 0.000024	A
Midtransit time E (HJD)	2454966.2348 ± 0.0026	A
Scaled semimajor axis $a/R_\star$	60.6 ± 8.1	A
Scaled planet radius $R_p/R_\star$	$0.0391^{+0.0014}_{-0.0022}$	A
Impact parameter $b \equiv a\cos i/R_\star$	$0.34^{+0.15}_{-0.34}$	A
Orbital inclination i (deg)	89.57 ± 0.32	A
Derived stellar parameters		
Effective temperature T_{eff} (K)	3240 ± 61	B
Spectroscopic gravity $\log g$ (cgs)	4.98 ± 0.22	B
Metallicity [Fe/H]	-0.15 ± 0.11	B
Mass $M_\star(M_\odot)$	0.219 ± 0.022	C
Radius $R_\star(R_\odot)$	0.252 ± 0.039	C
Planetary parameters		
Radius R_p ($R_\oplus$, equatorial)	1.08 ± 0.15	A,B,C
Orbital semimajor axis a (AU)	0.0514 ± 0.0028	D
Incident Flux ($S_\oplus$)	2.30 ± 0.65	D

Note. —
A: Based on *Kepler* photometry.
B: Based on an analysis of the Palomar spectra.
C: Based on stellar evolution tracks.
D: Based on Newton's version of Kepler's Third Law and total mass.



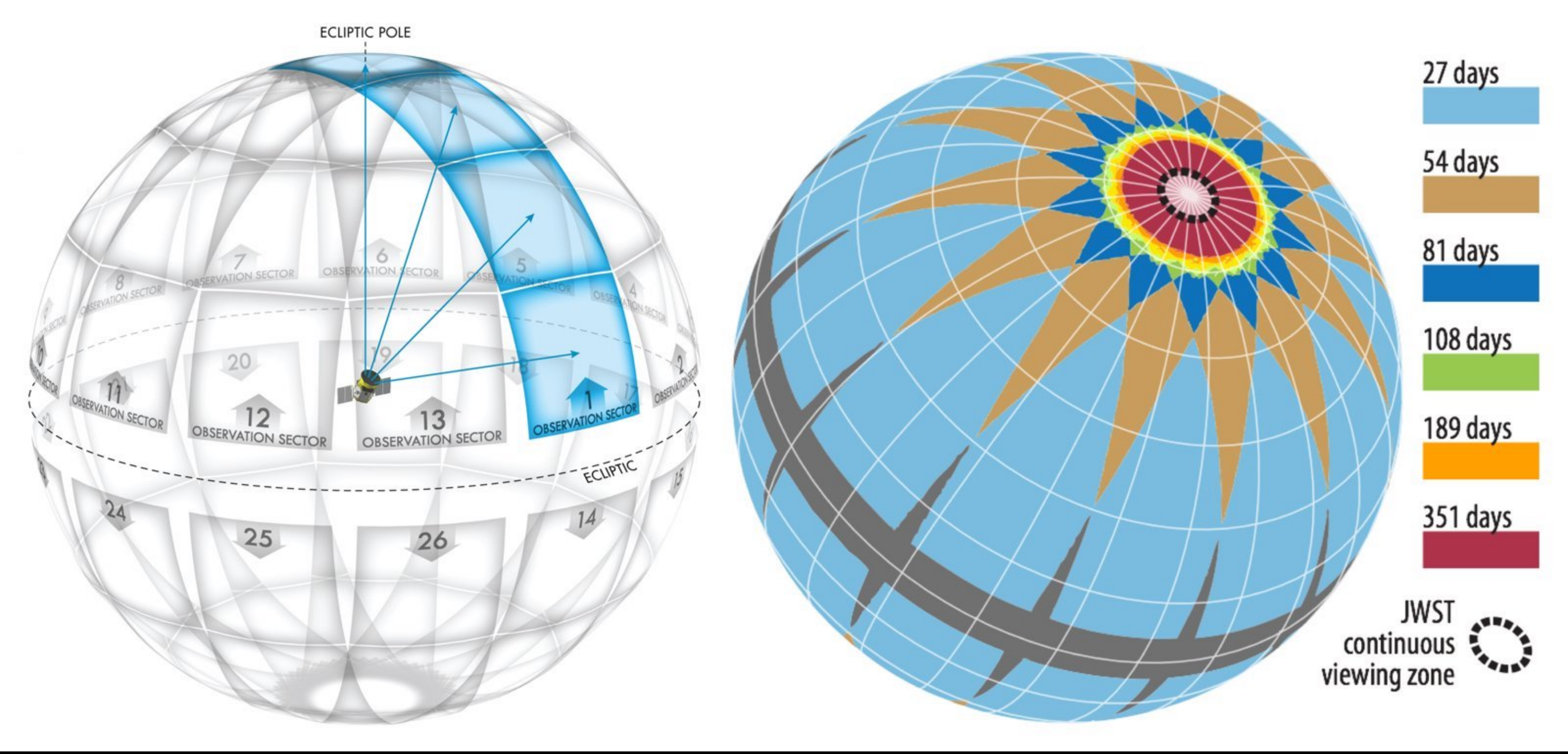
Angelo et al. 2017, AJ, 153, 162

Kepler-1649b: A Possible Venus Analog



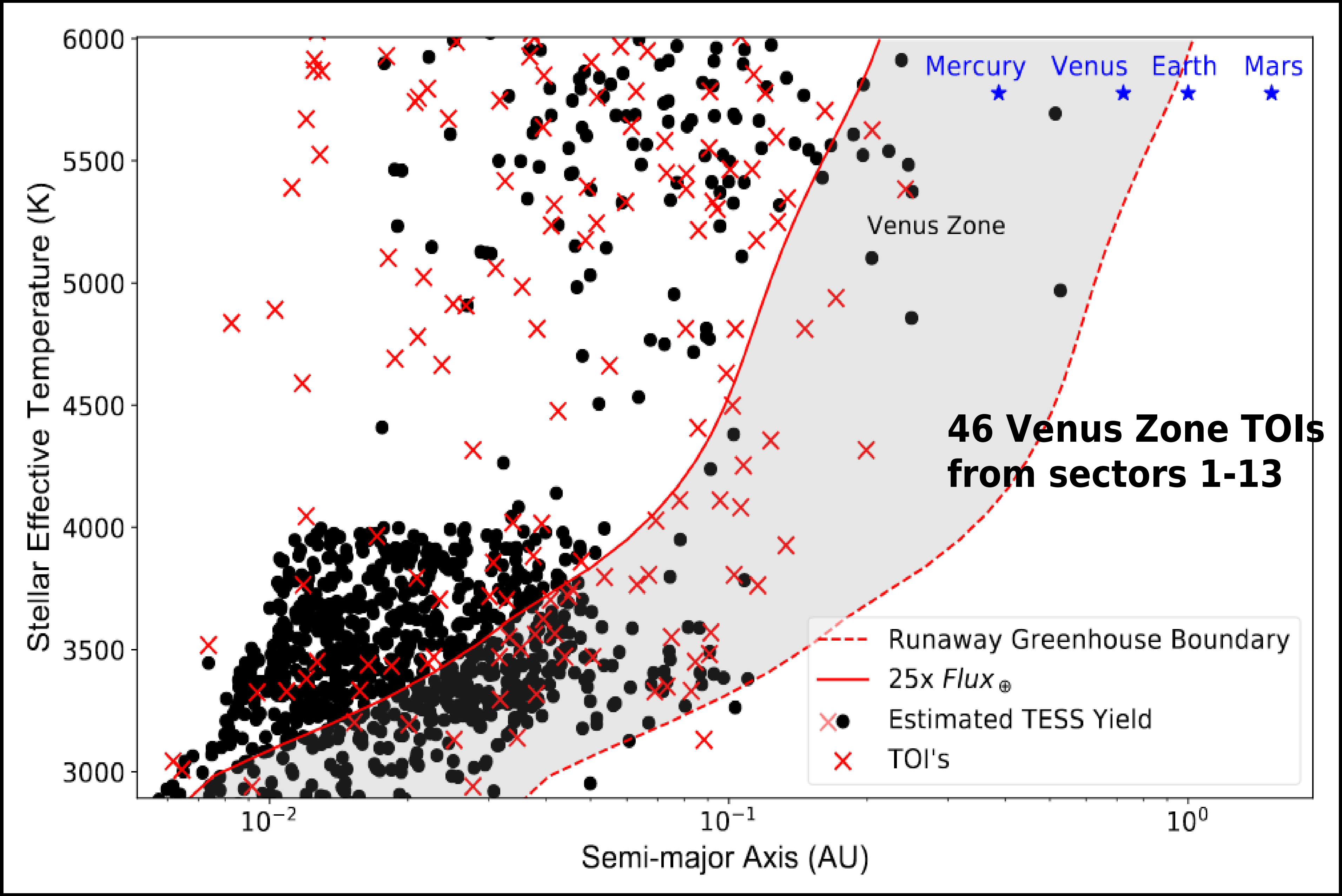
Kane, Ceja, Way, Quintana. 2018, ApJ, in press (arXiv:1810.10072)

Transiting Exoplanet Survey Satellite (TESS)



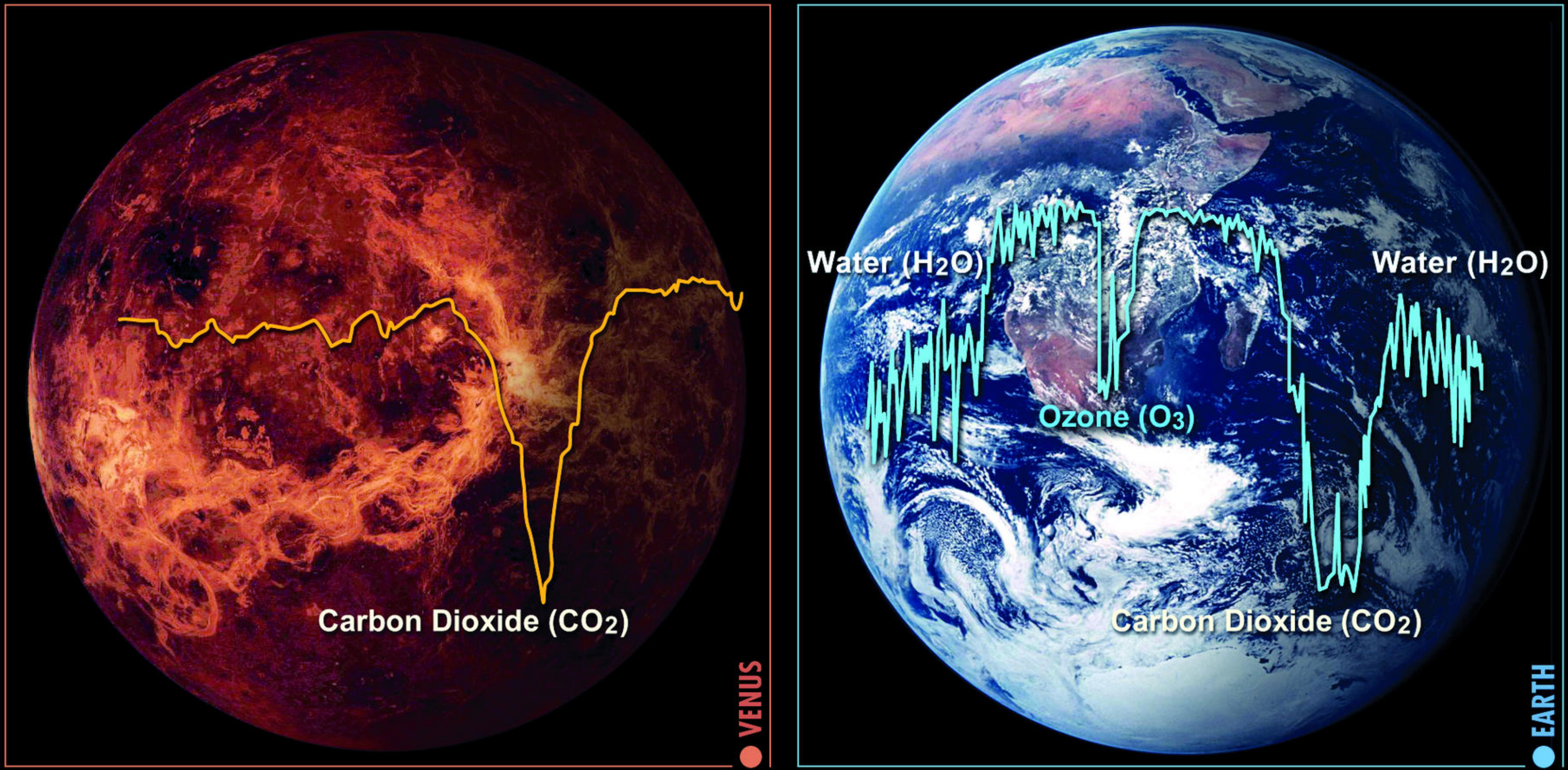
Aims to measure masses for at least 50 planets smaller than Neptune over primary mission (TESS-Keck Survey).

Transiting Exoplanet Survey Satellite (TESS)



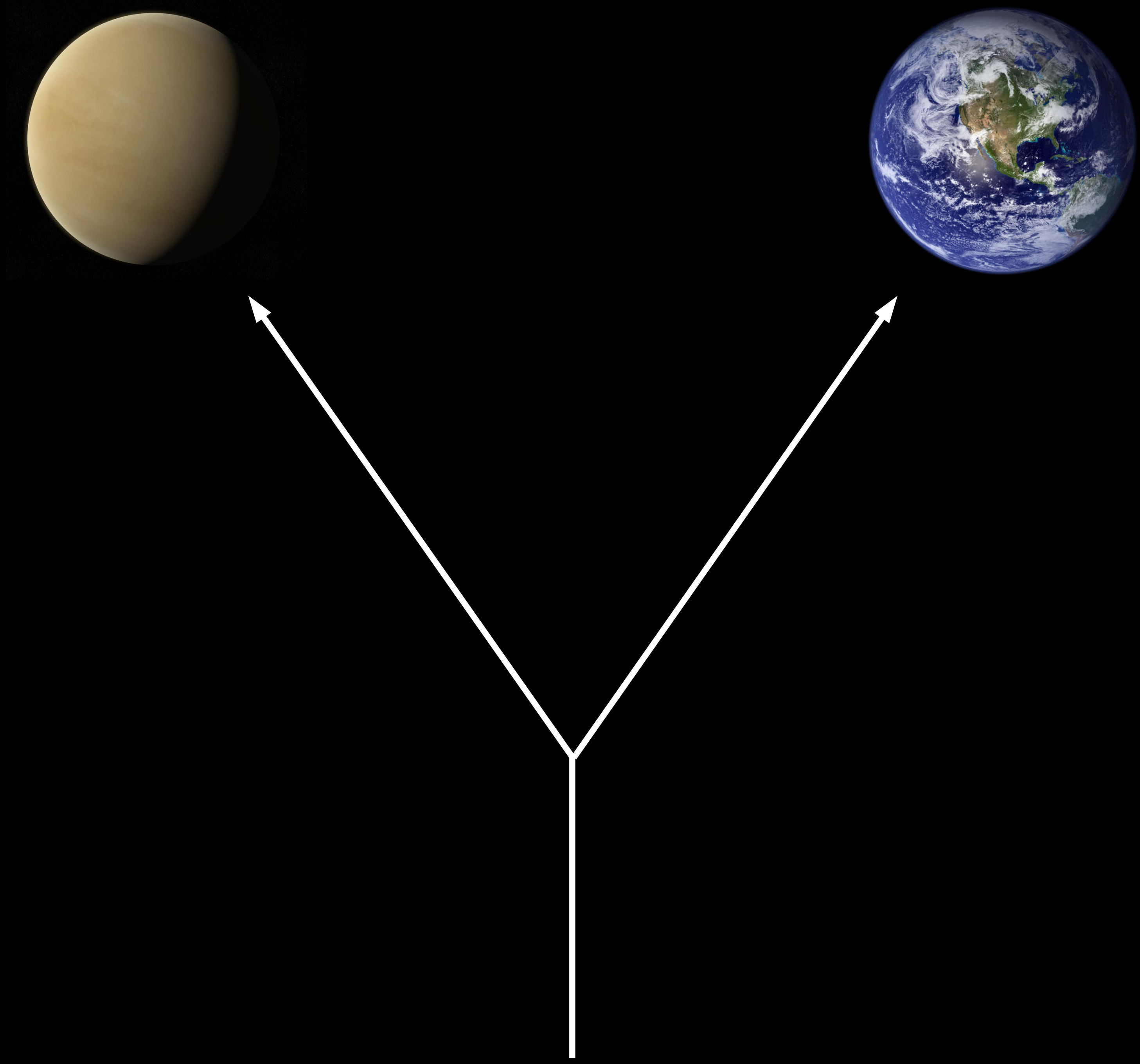
Huang et al. 2018, arXiv:1807.11129
Ostberg & Kane, 2019, AJ, 158, 195

Comparative Atmospheric Planetology

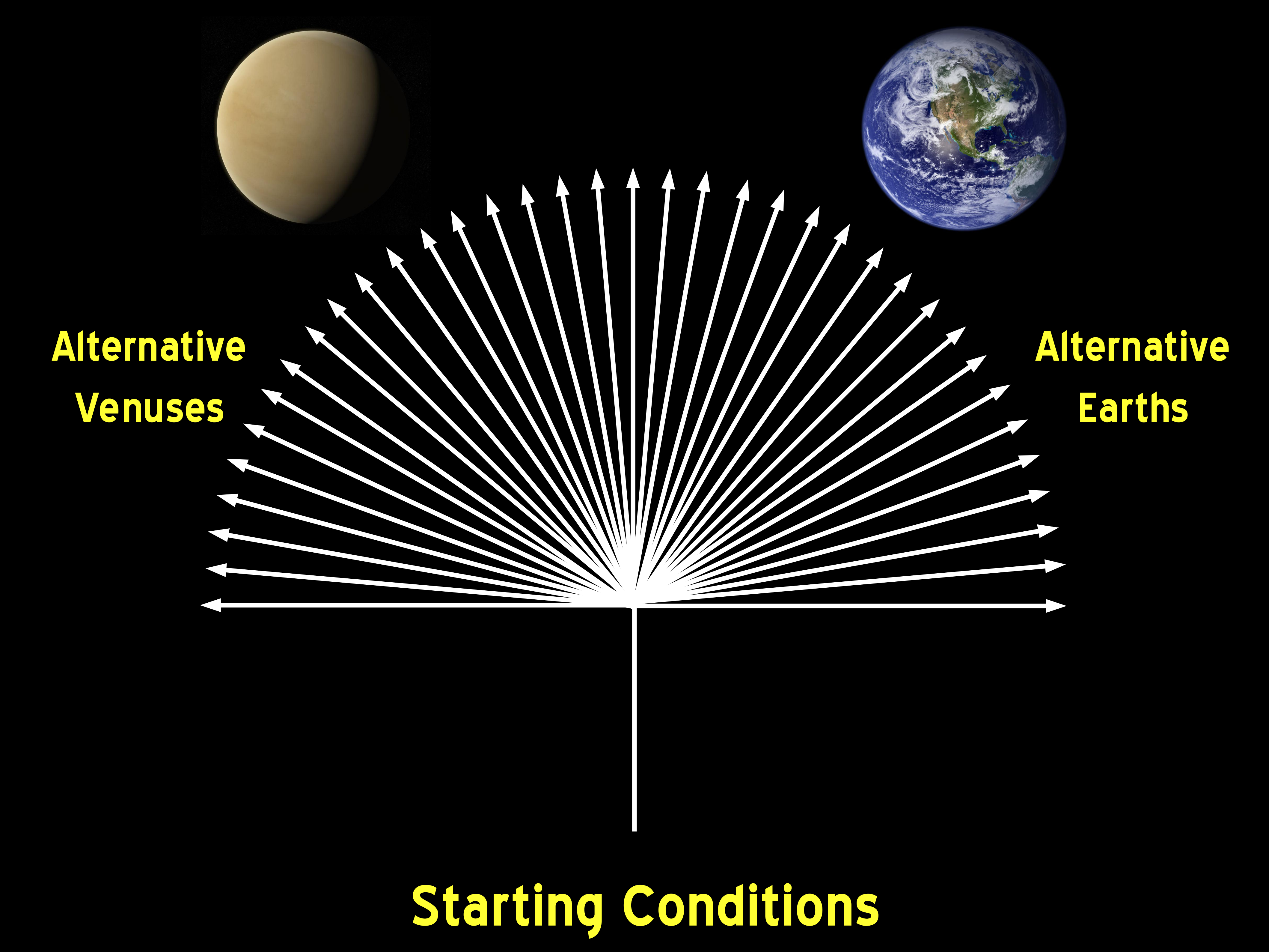


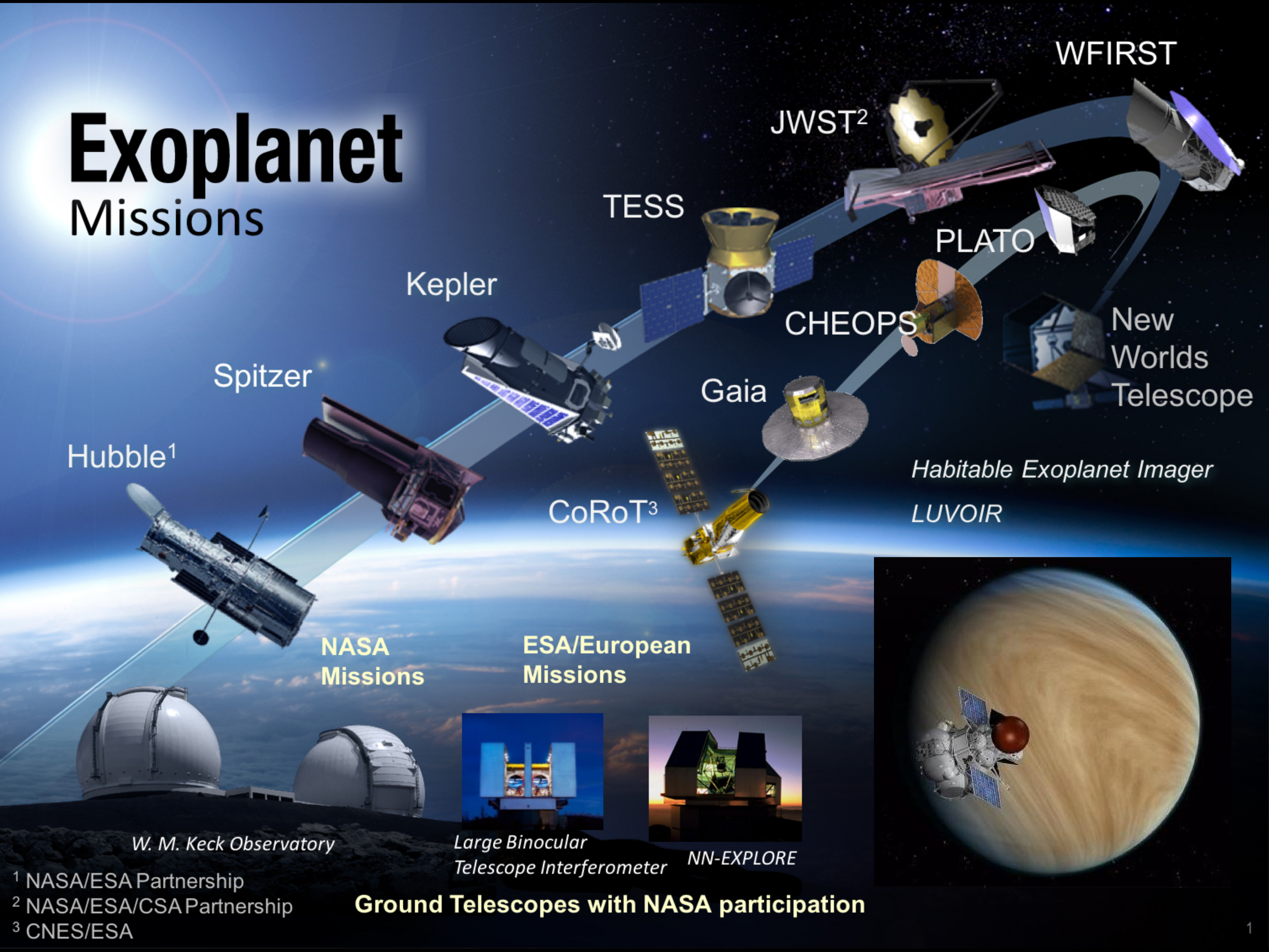
- Ratios of terrestrial planet atmospheres within the same system.
- Simulation of transmission/emission spectra with/without clouds.

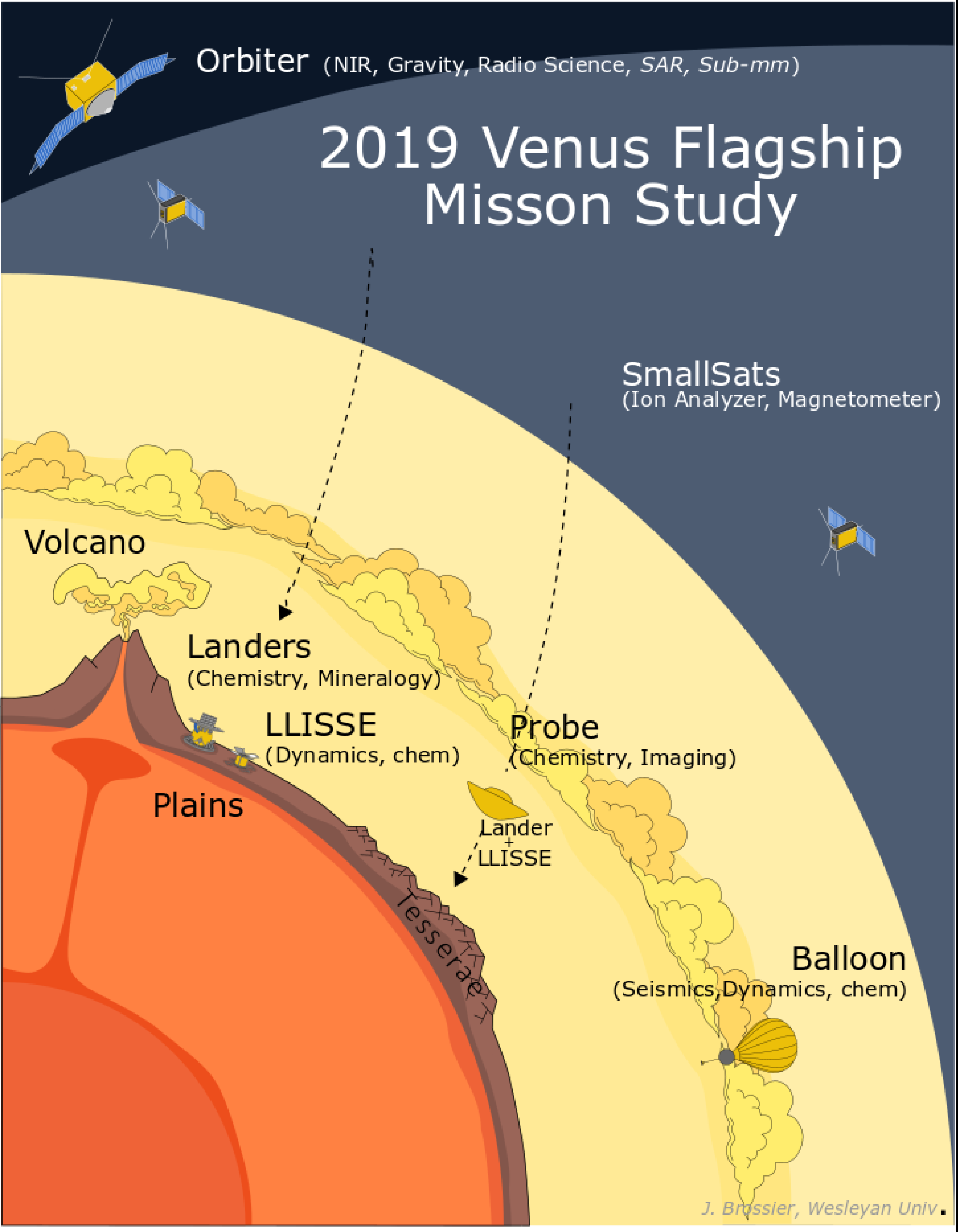
Kane, Kopparapu, Domagal-Goldman. 2014, ApJ, 794, L5
Ostberg & Kane, 2019, AJ, 158, 195



Starting Conditions


Alternative
Venuses
Alternative
Earths
Starting Conditions


Exoplanet
Missions
WFIRST
JWST[2]
TESS
PLATO
Kepler
CHEOPS
New Worlds Telescope
Spitzer
Gaia
Hubble[1]
Habitable Exoplanet Imager
CoRoT[3]
LUVOIR
NASA Missions
ESA/European Missions
W. M. Keck Observatory
Large Binocular Telescope Interferometer
NN-EXPLORE
[1] NASA/ESA Partnership
[2] NASA/ESA/CSA Partnership
[3] CNES/ESA
Ground Telescopes with NASA participation
1



Selected for Planetary Mission Concept Study

PI:
Martha Gilmore

Co-Is:
Sushil Atreya
Patricia Beauchamp
Penelope Boston
Mark Bullock
Shannon Curry
Robert Herrick
Jennifer Jackson
Stephen Kane
Alison Santos
David Stevenson
Colin Wilson

DAVINCI+

Deep Atmosphere Venus Investigation of Noble gases, Chemistry, and Imaging Plus

Dr. James Garvin, NASA GSFC Principal Investigator

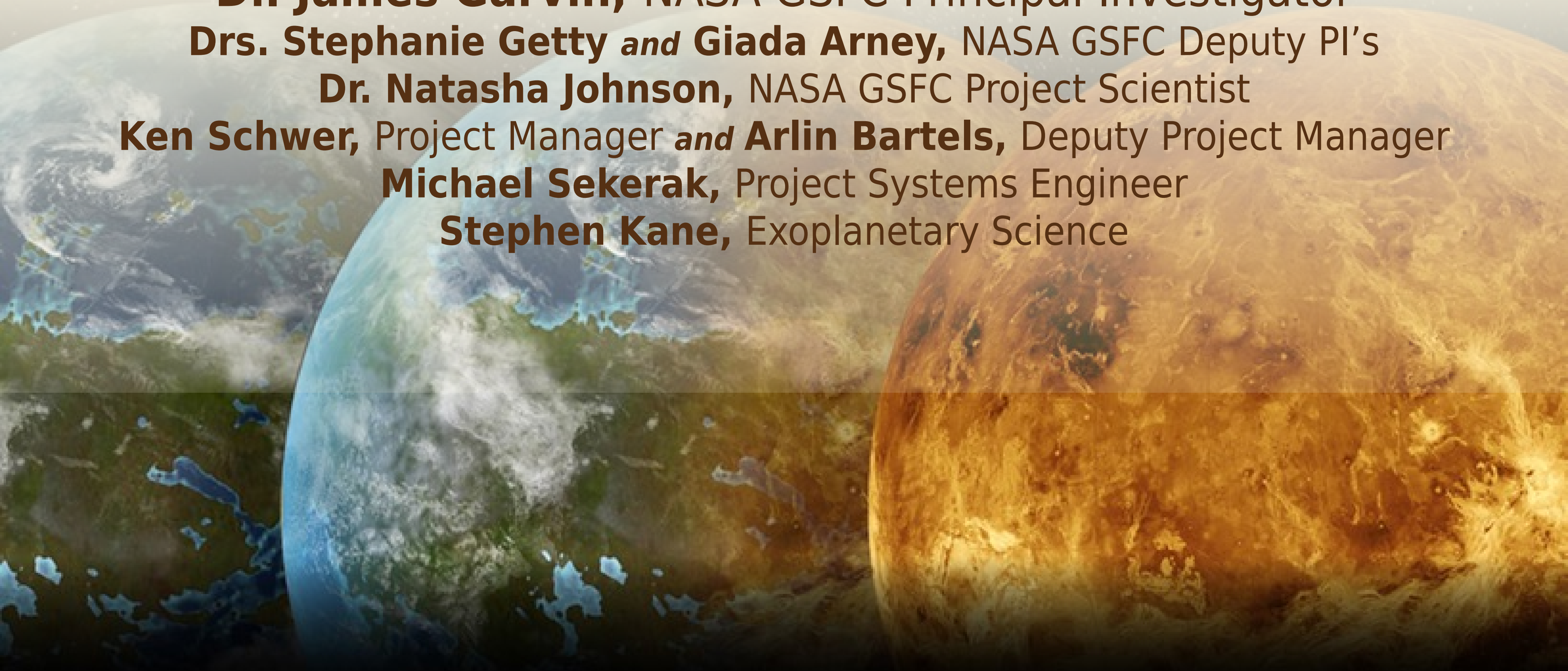
Drs. Stephanie Getty ***and*** **Giada Arney,** NASA GSFC Deputy PI's

Dr. Natasha Johnson, NASA GSFC Project Scientist

Ken Schwer, Project Manager ***and*** **Arlin Bartels,** Deputy Project Manager

Michael Sekerak, Project Systems Engineer

Stephen Kane, Exoplanetary Science

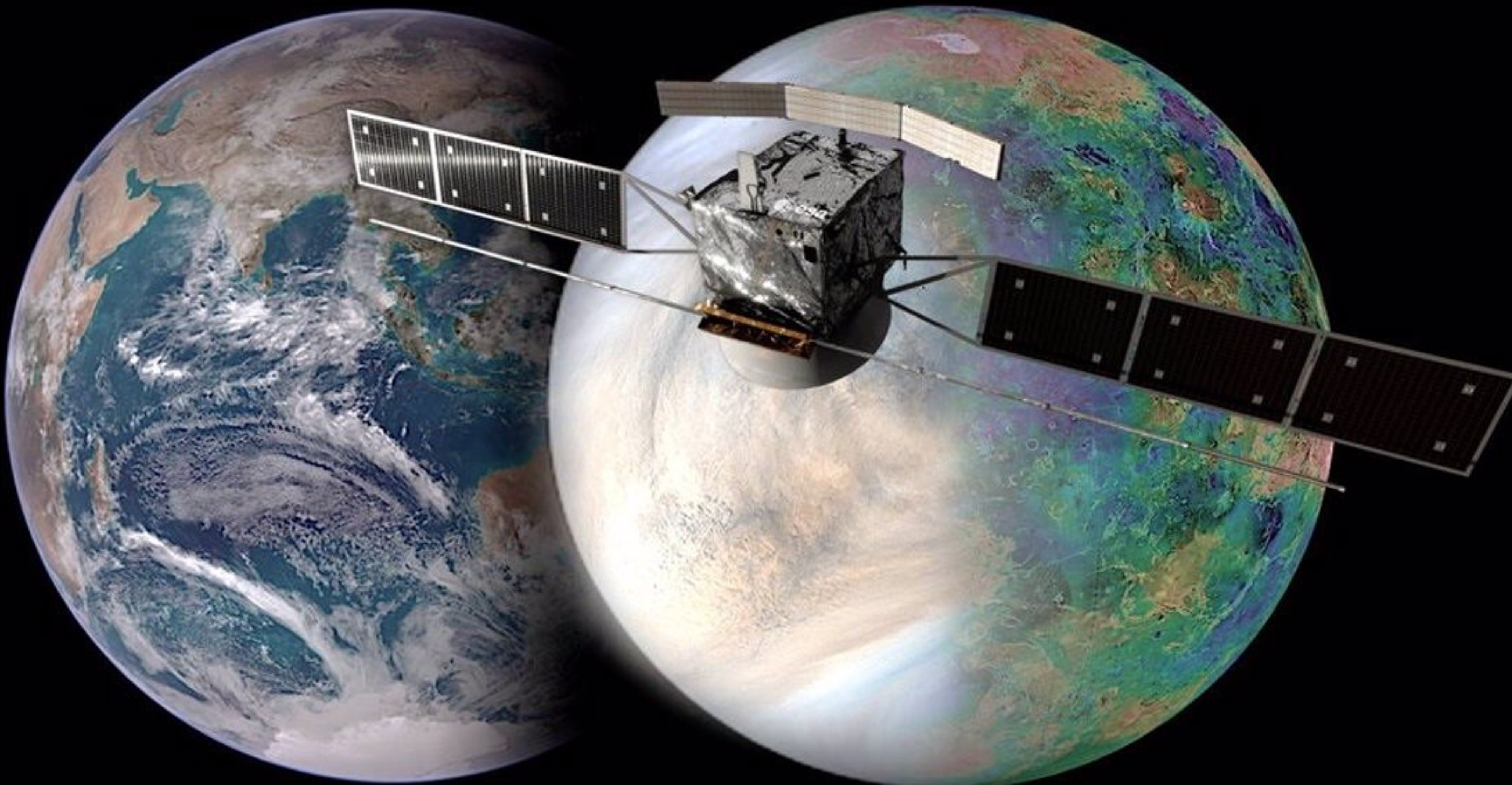


Ancient oceans | Evolution of habitability | Venus-like exoplanets

Two NASA Venus missions selected as Discovery class planetary missions. Current anticipated launches are early 2030s.

The missions are complementary: DAVINCI will study the atmosphere, whilst VERITAS will investigate the surface and interior. Both aspects are critical pieces of the habitability and evolution narrative.

The European Space Agency (ESA) has selected EnVision as a medium-class planetary probe. Expected launch is early-mid 2030s.



EnVision will be an orbiter that maps the surface, with particular attention to the “tesserae”, revealing basaltic versus granitic compositions, indicative of past surface water.