Venus: a "thermal" frontier for Science

Dr. Jim Garvin

NASA Goddard *Chief Scientist*

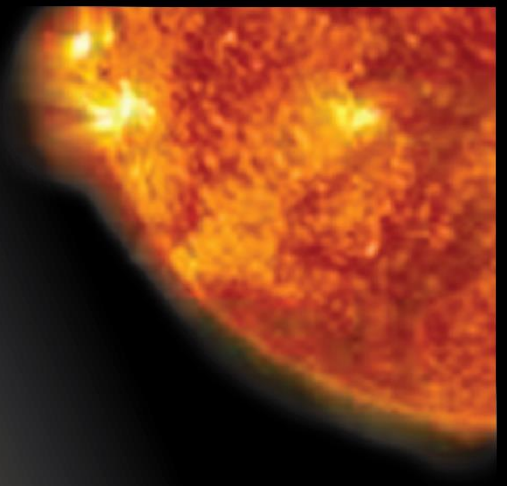
PI, **DAVINCI** mission to Venus

TFAWS: ***Aug. 23, 2023***

Why Venus?

Venus holds the clues to how stable habitability may be in our solar system and beyond

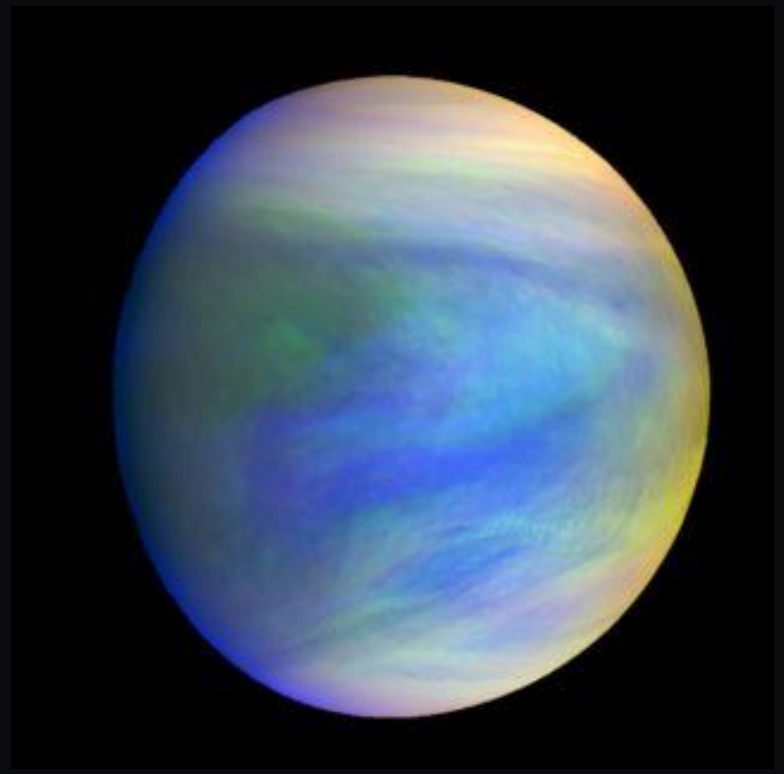
Venus informs our understanding of how stellar evolution governs climate



Venus is our “ground-truth” as we move into investigation of exoplanetary habitability

Planetary *Atmospheres (**VENUS**)* are “chemical fossil records” of climate evolution & habitability

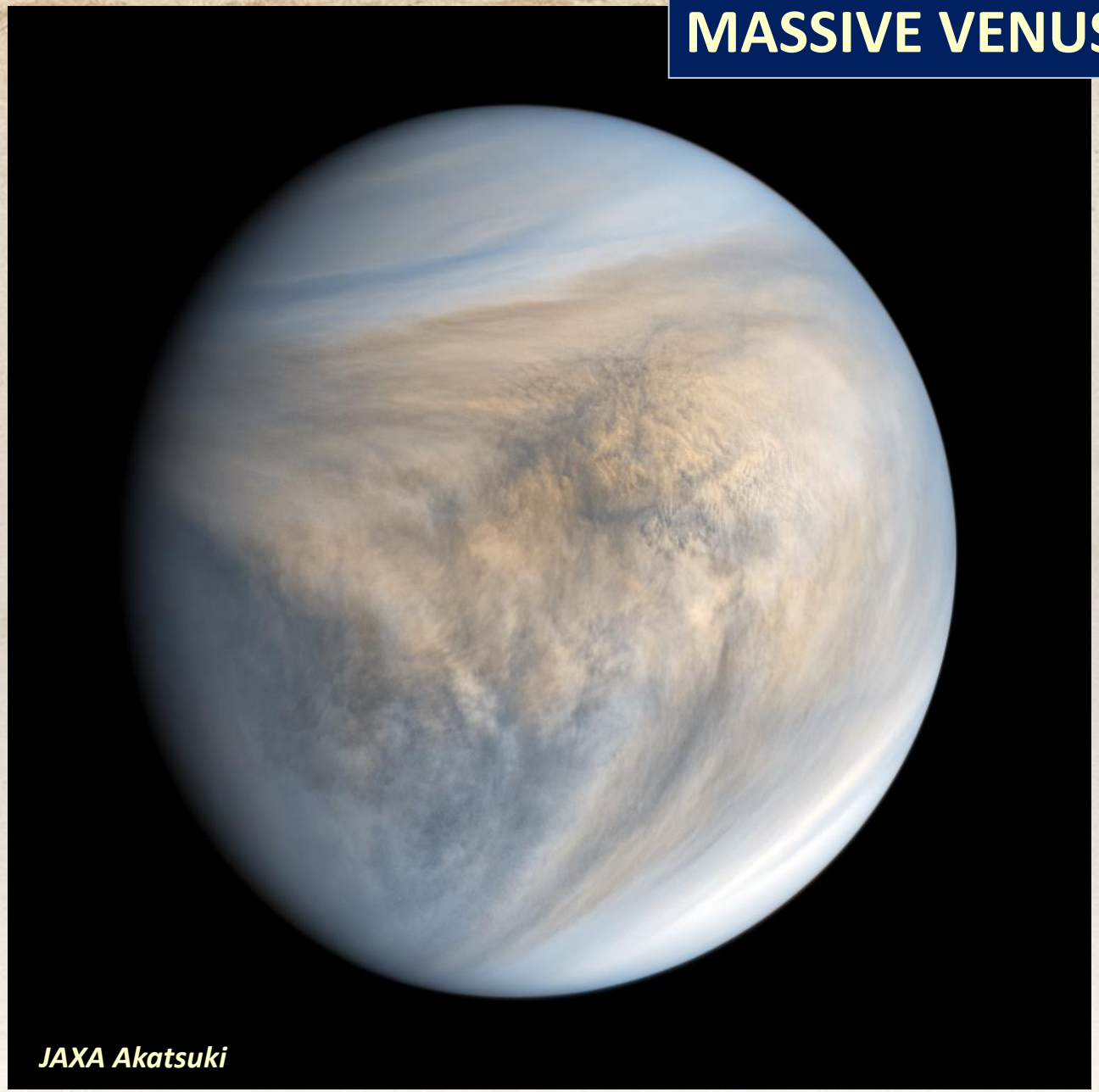
Venus from Earth as a crescent



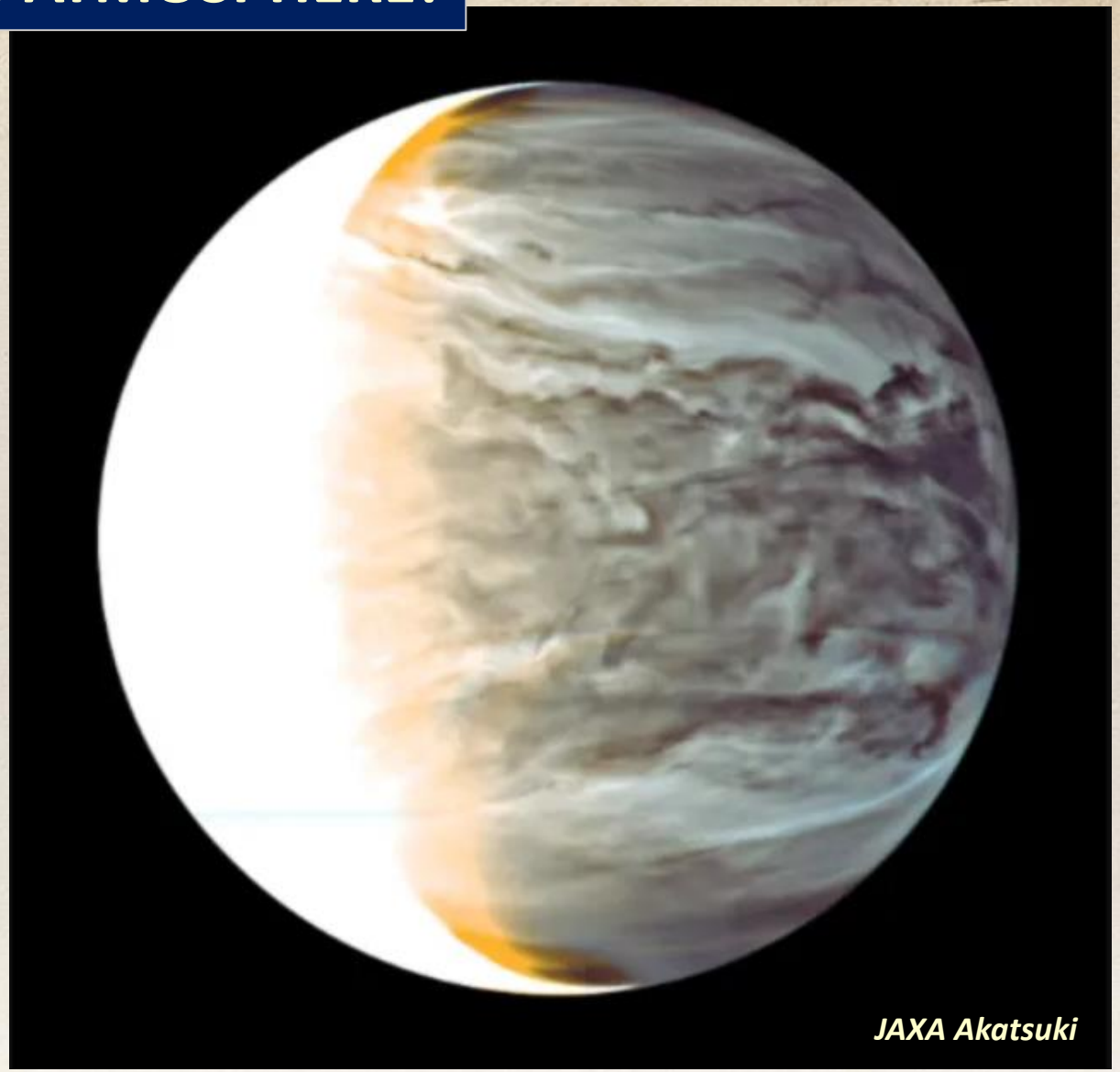
Venus from orbit (JAXA *Akatsuki*)

Venus beckons in the 2030's and beyond !

MASSIVE VENUS ATMOSPHERE!



JAXA Akatsuki

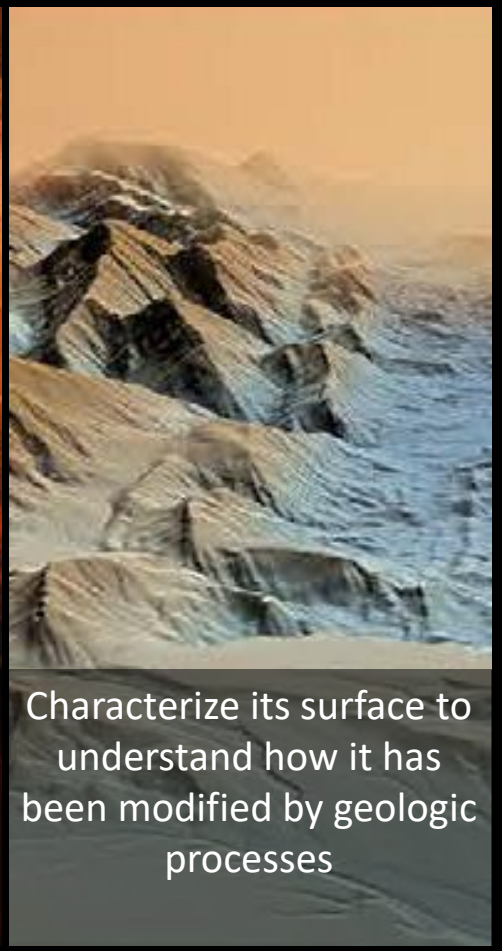


JAXA Akatsuki

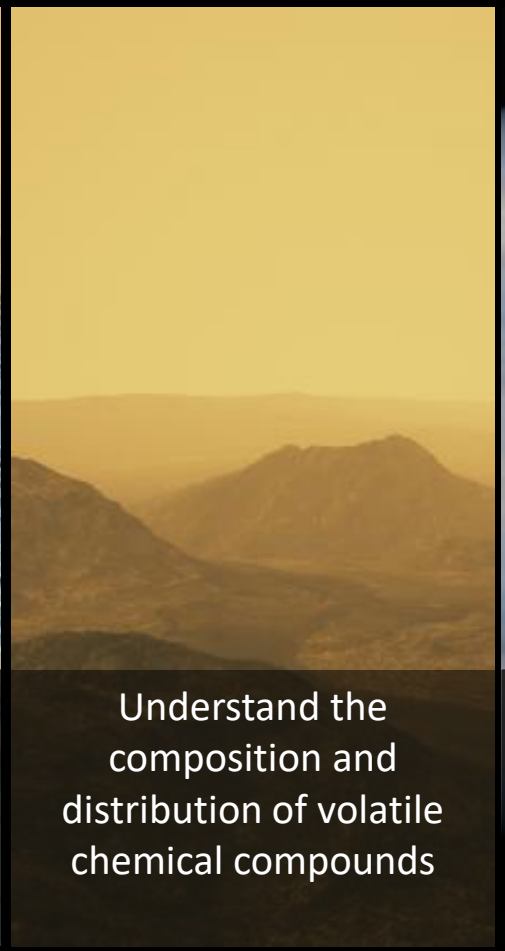
To understand Venus

Planetary Decadal Inner Planet Fundamental Science Objectives: *Origins Worlds + Life*

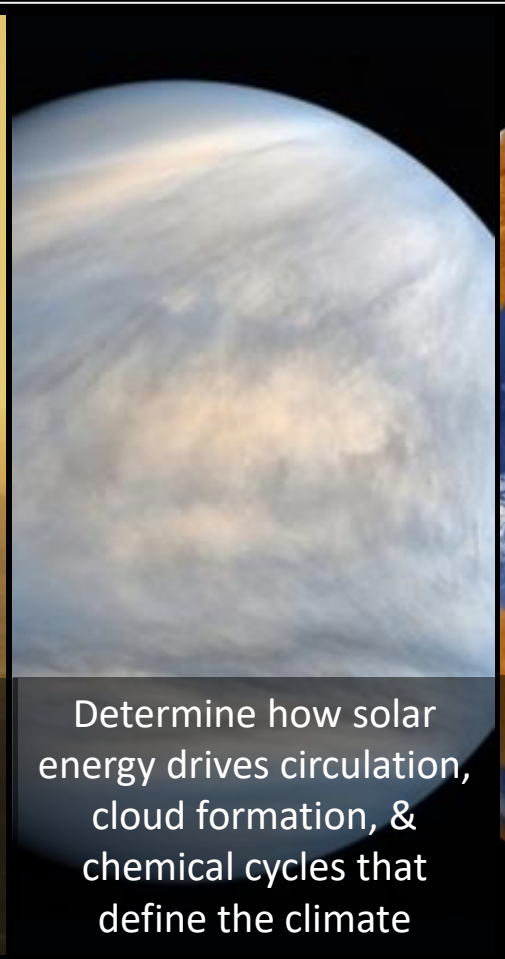
Understand its formation from the solar nebula and controls on its subsequent evolution



Characterize its surface to understand how it has been modified by geologic processes



Understand the composition and distribution of volatile chemical compounds



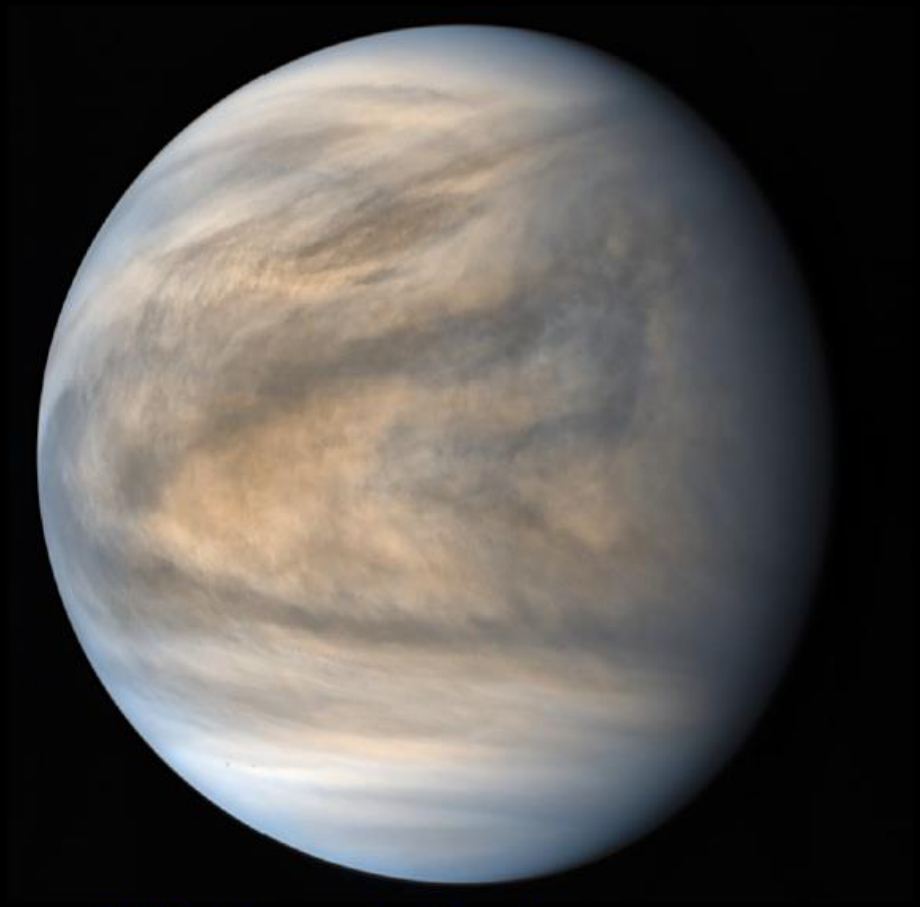
Determine how solar energy drives circulation, cloud formation, & chemical cycles that define the climate

Characterize the record of and mechanisms for climate evolution, with the goal of understanding climate change

*is to **understand** how* **planetary habitability** forms, endures, and is **lost**

Venus & Earth: Habitability Factors

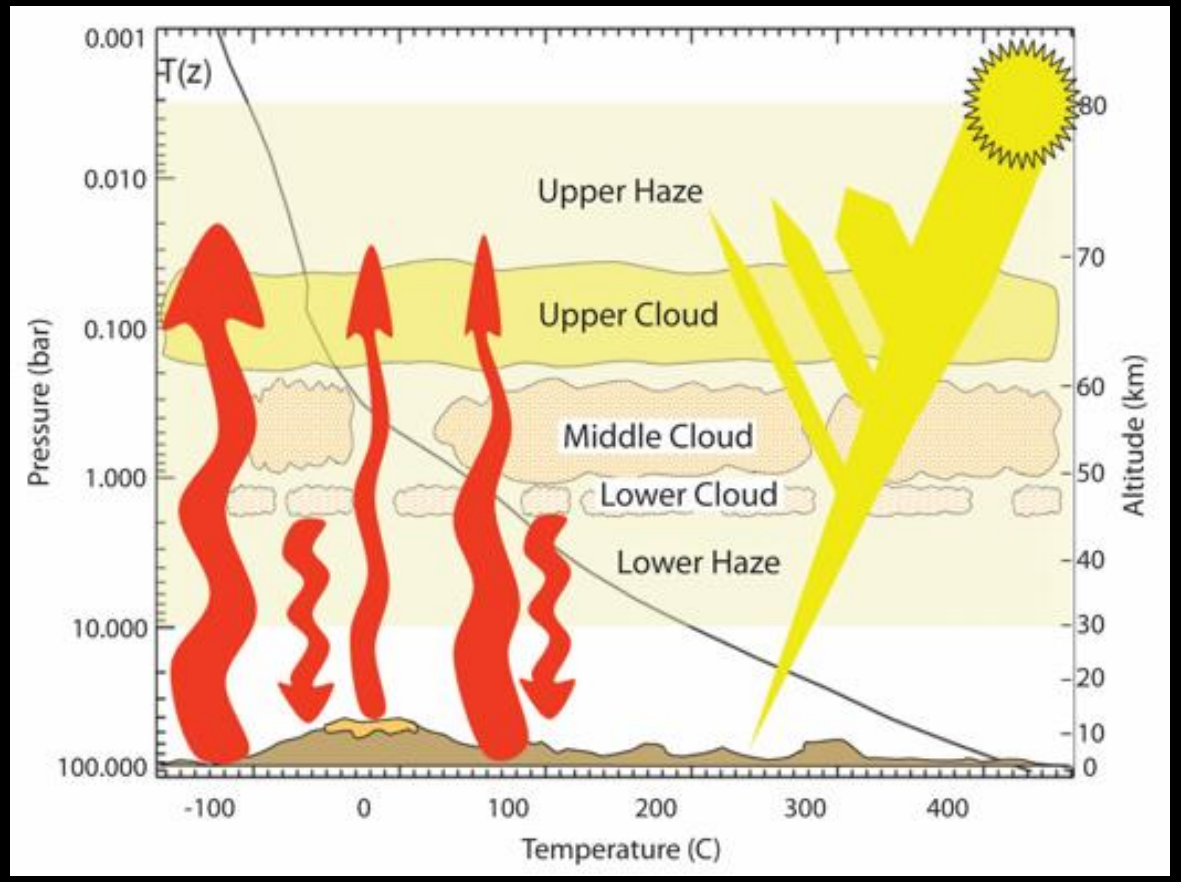
CO_2
atmosphere



N_2, O_2
atmosphere

- **30% closer to the Sun.**
- **Receives twice the amount of solar energy.**
- **Rotates very slowly backwards.**
- **Almost vertical rotational axis.**
- **Little to no surface subduction.**
- **Negligible magnetic field.**
- **No substantial moon.**

Venus of today is a *planet of extremes*



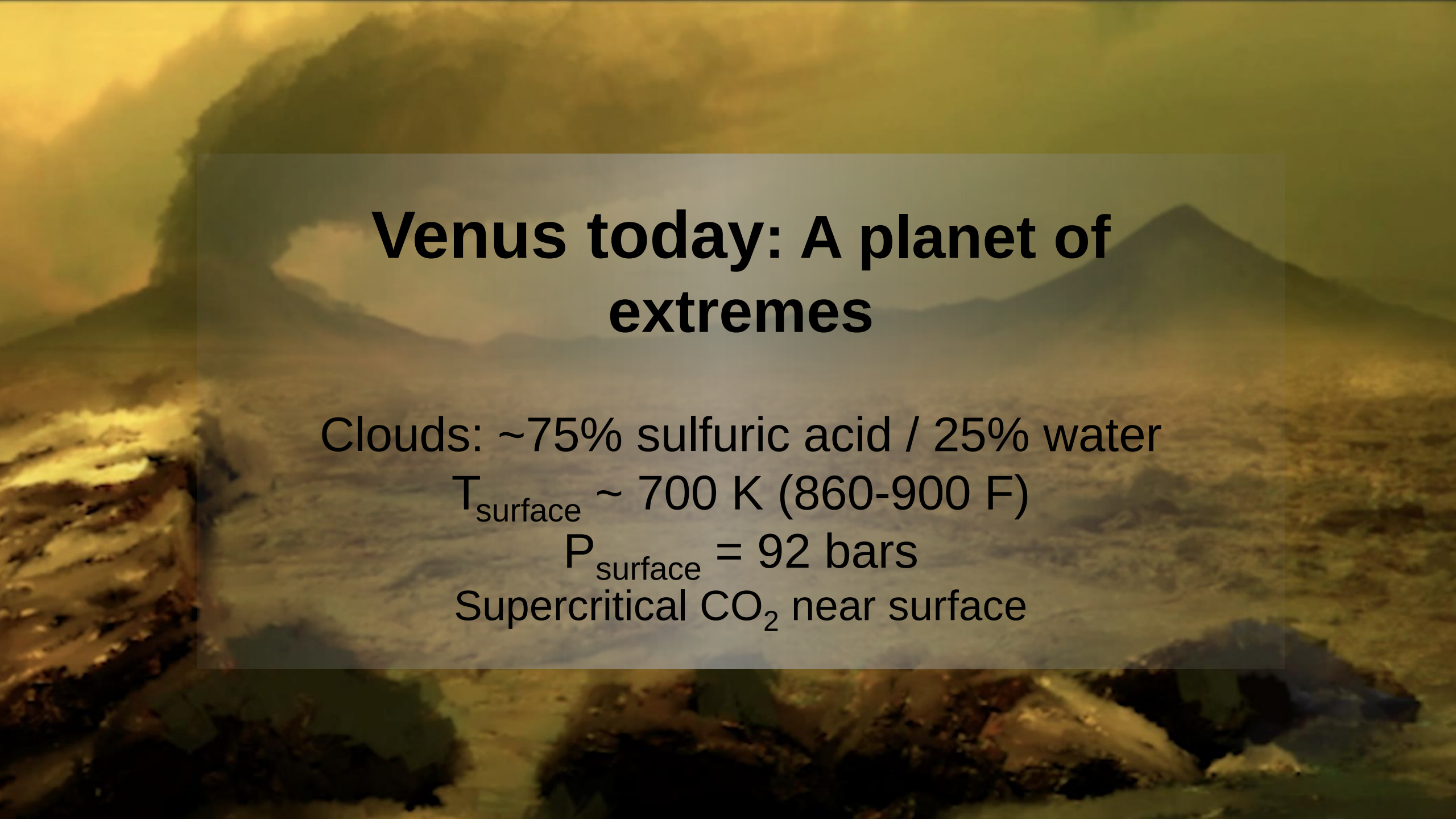
Extremely strong greenhouse effect

- Atmosphere is 96.5% CO_2

Harsh environment (deep atmos.)

- Surface temperature 460°C
- Surface pressure ~92 bar
- 250 mph winds in the clouds; calm at the surface (1-2 m/s)
- Clouds - 30 km thick - consisting of sulfuric acid and unknowns (aerosols)

James B. Garvin/NASA



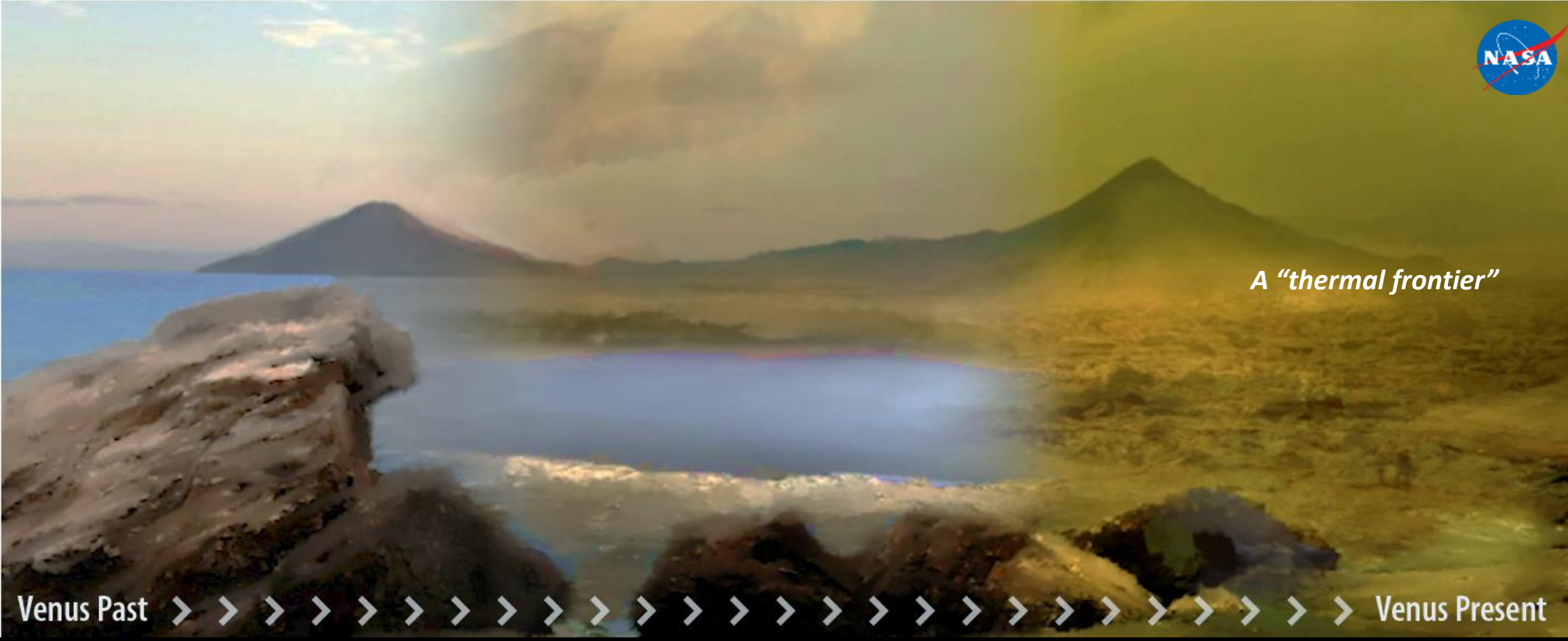
Venus today: A planet of extremes

Clouds: ~75% sulfuric acid / 25% water

$T_{surface}$ ~ 700 K (860-900 F)

$P_{surface}$ = 92 bars

Supercritical CO_2 near surface

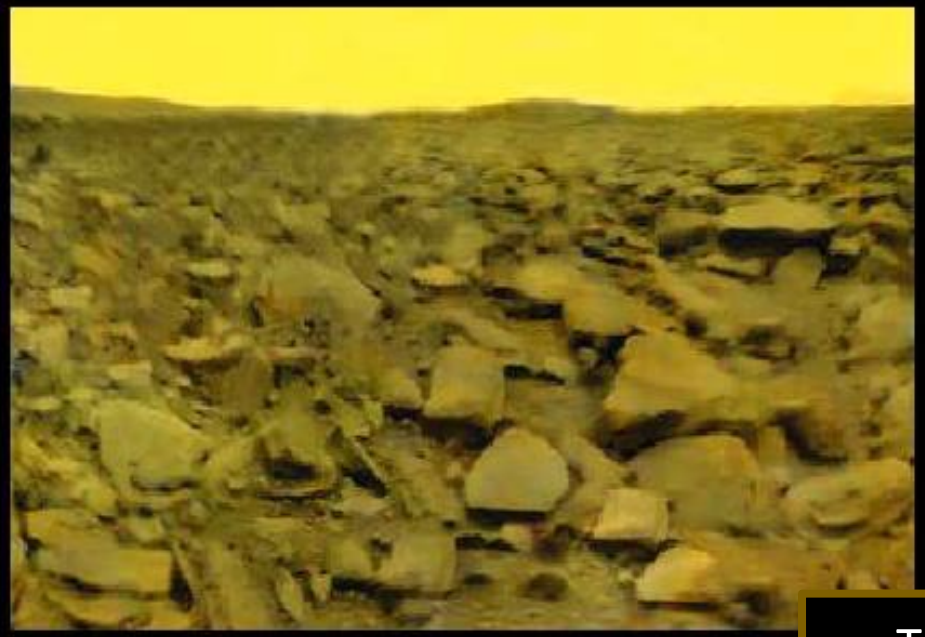


“Ultimately, the assessment of whether or not a planet is habitable will need to be embedded in the context of the outcomes of terrestrial exoplanet evolution.”

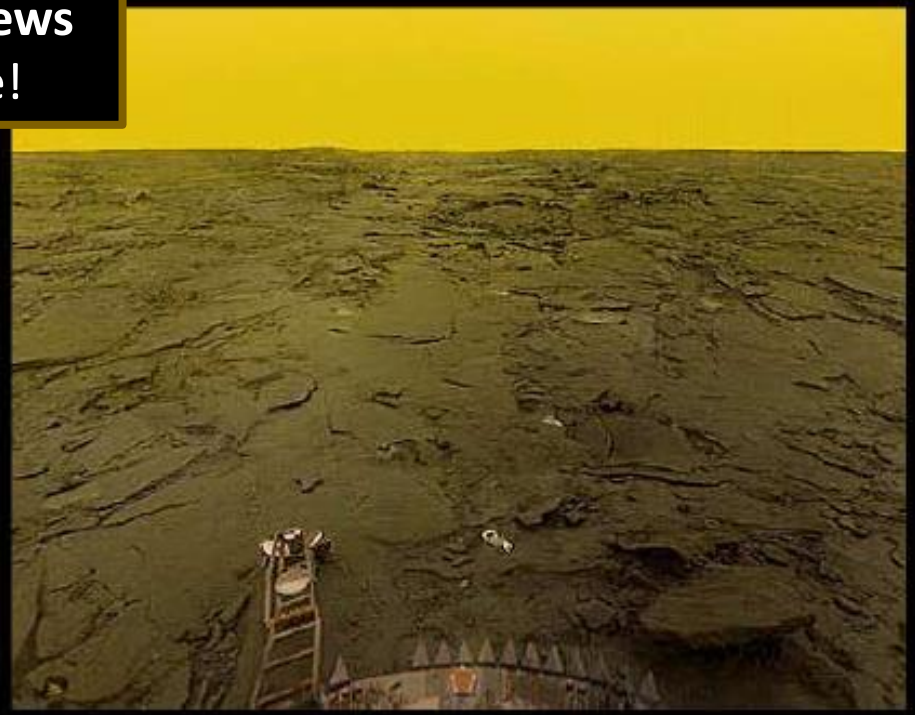
- 2018 *Exoplanet Science Strategy* report

USSR *Venera* views *of* Venus:

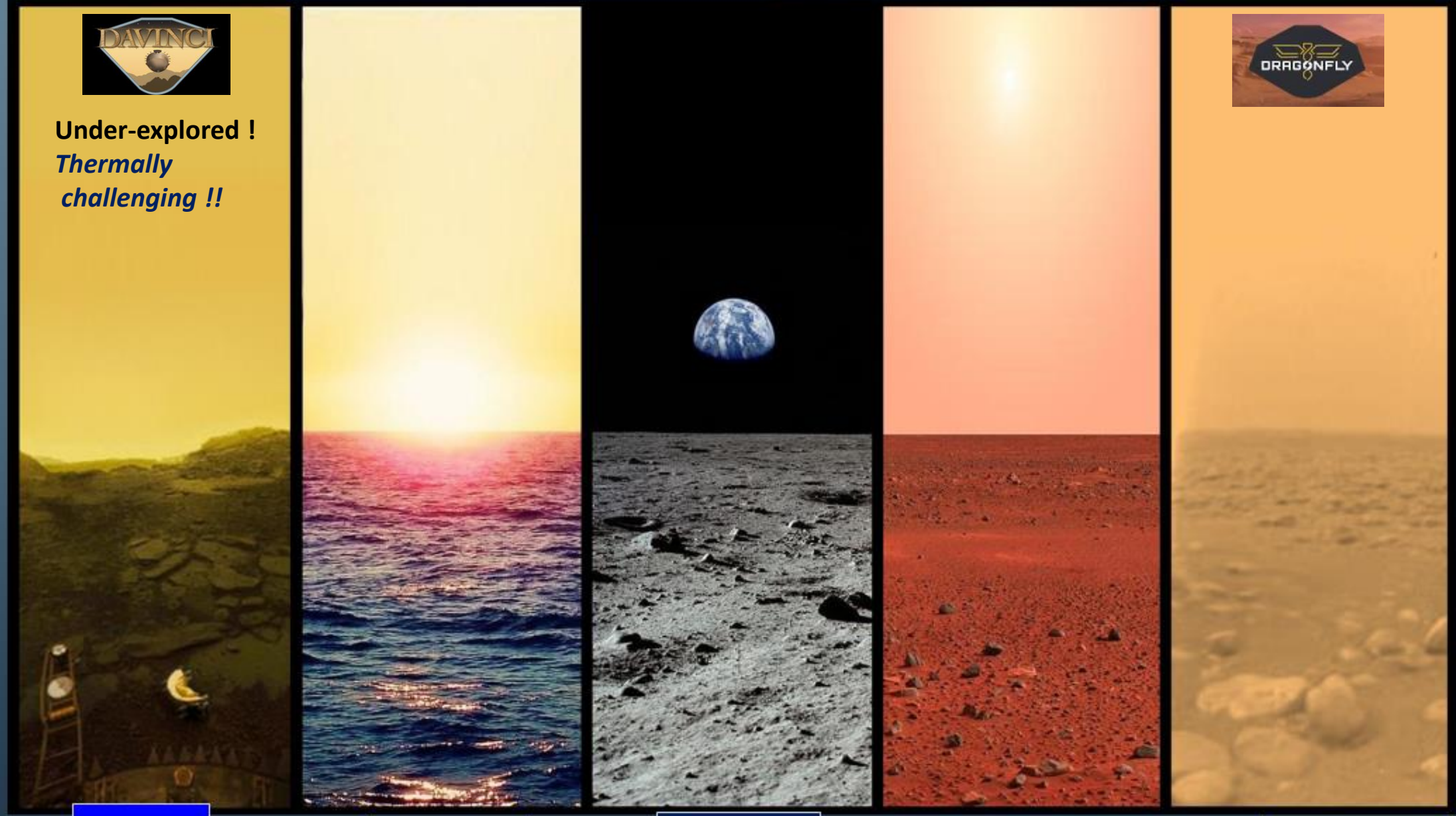
1975-82



The **only surface views** we have!



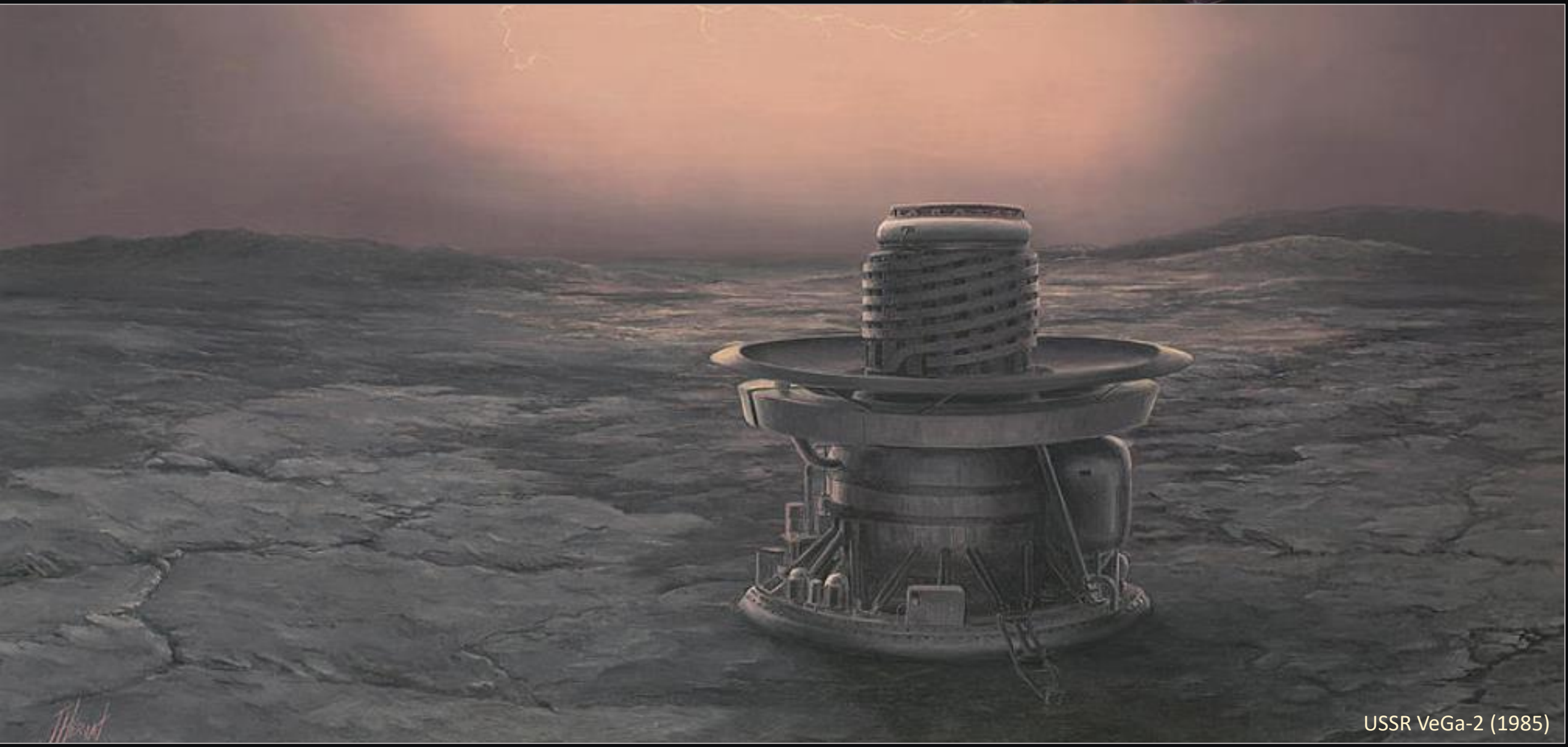
Garvin *et al*. 1984
(JGR 89 paper, PhD)


DAVINCI
Under-explored !
Thermally challenging !!
DRAGONFLY
NASA
VENUS
Ancient oceans ?
Earth
(Oceans!)
MOON
First humans off planet
Mars
Life?
TITAN
Weird oceans

DAVINCI

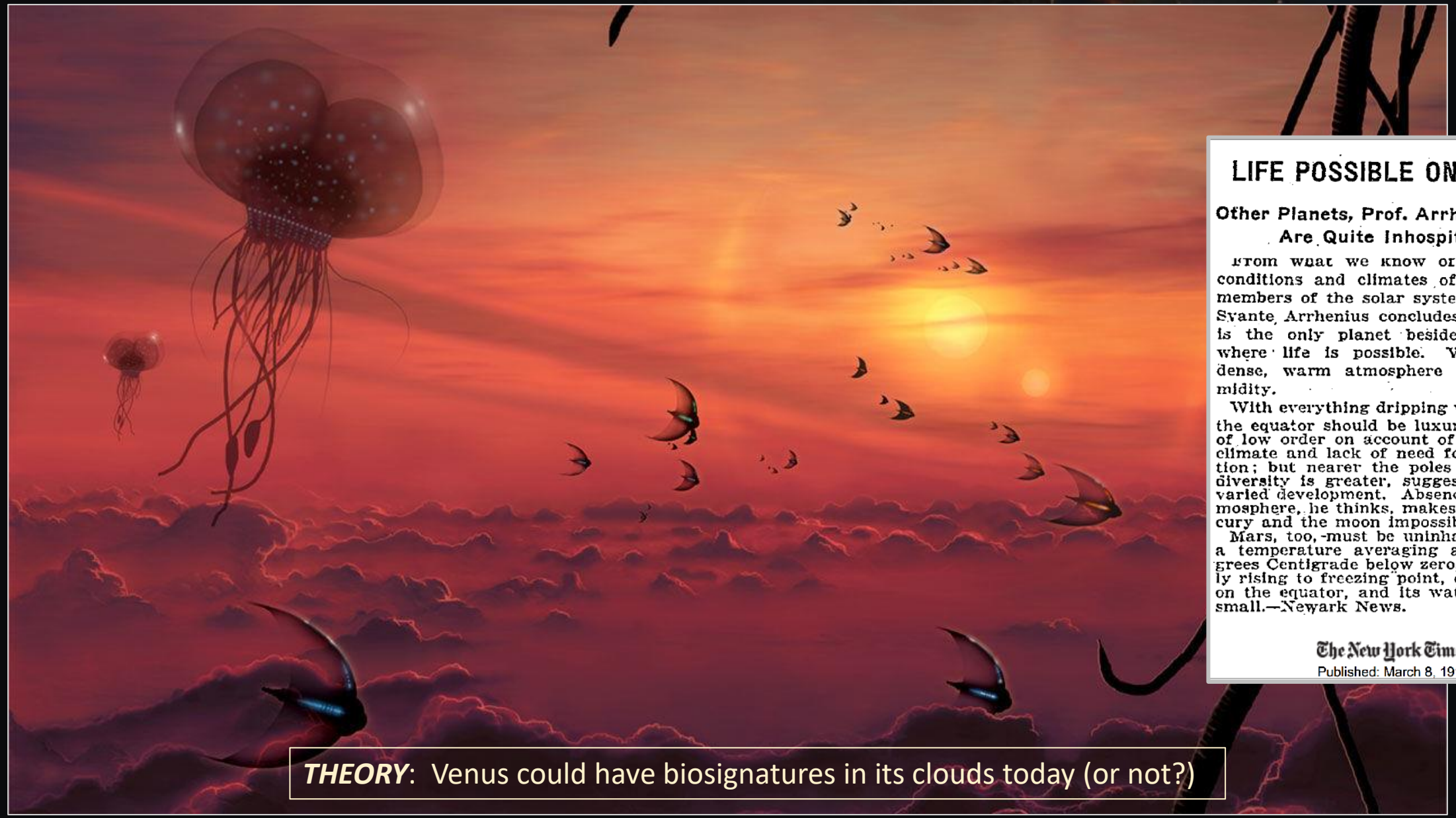
… so we have a plan to go there to explore …

Venus : *last visit by Earthlings was in **1985***



USSR VeGa-2 (1985)

What if *Venus* had past oceans & pathways for *life* ?



LIFE POSSIBLE ON VENUS.

Other Planets, Prof. Arrhenius Says, Are Quite Inhospitable.

From what we know of the surface conditions and climates of the various members of the solar system, Professor Svante Arrhenius concludes that Venus is the only planet besides the earth where life is possible. Venus has a dense, warm atmosphere of high humidity.

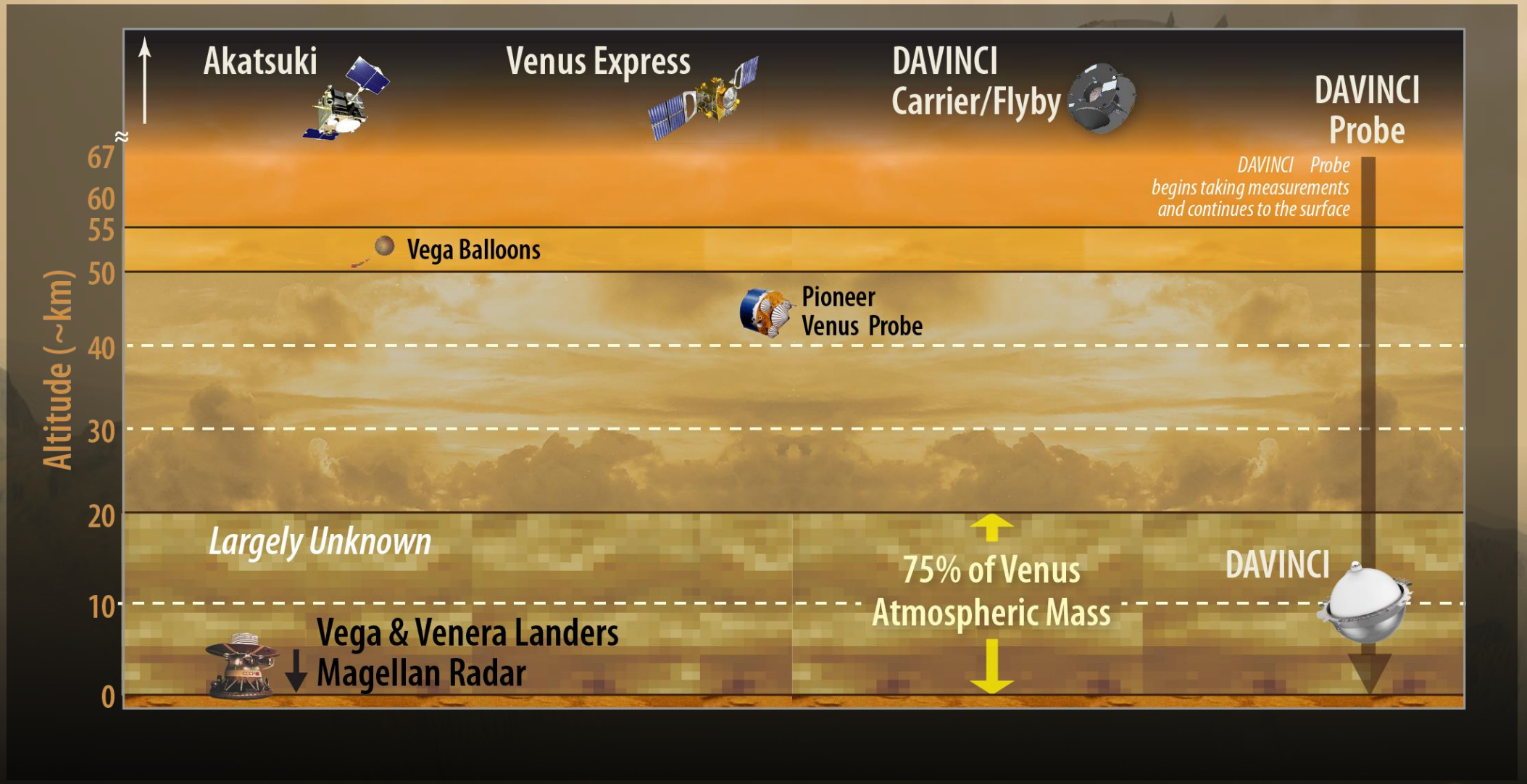
With everything dripping wet, life near the equator should be luxuriant, though of low order on account of the uniform climate and lack of need for specialization; but nearer the poles the climatic diversity is greater, suggesting a more varied development. Absence of any atmosphere, he thinks, makes life on Mercury and the moon impossible.

Mars, too, must be uninhabitable with a temperature averaging about 37 degrees Centigrade below zero, and scarcely rising to freezing point, even at noon on the equator, and its water supply is small.—Newark News.

The New York Times
Published: March 8, 1919

THEORY: Venus could have biosignatures in its clouds today (or not?)

The **deep atmosphere** is essentially **unknown** right now



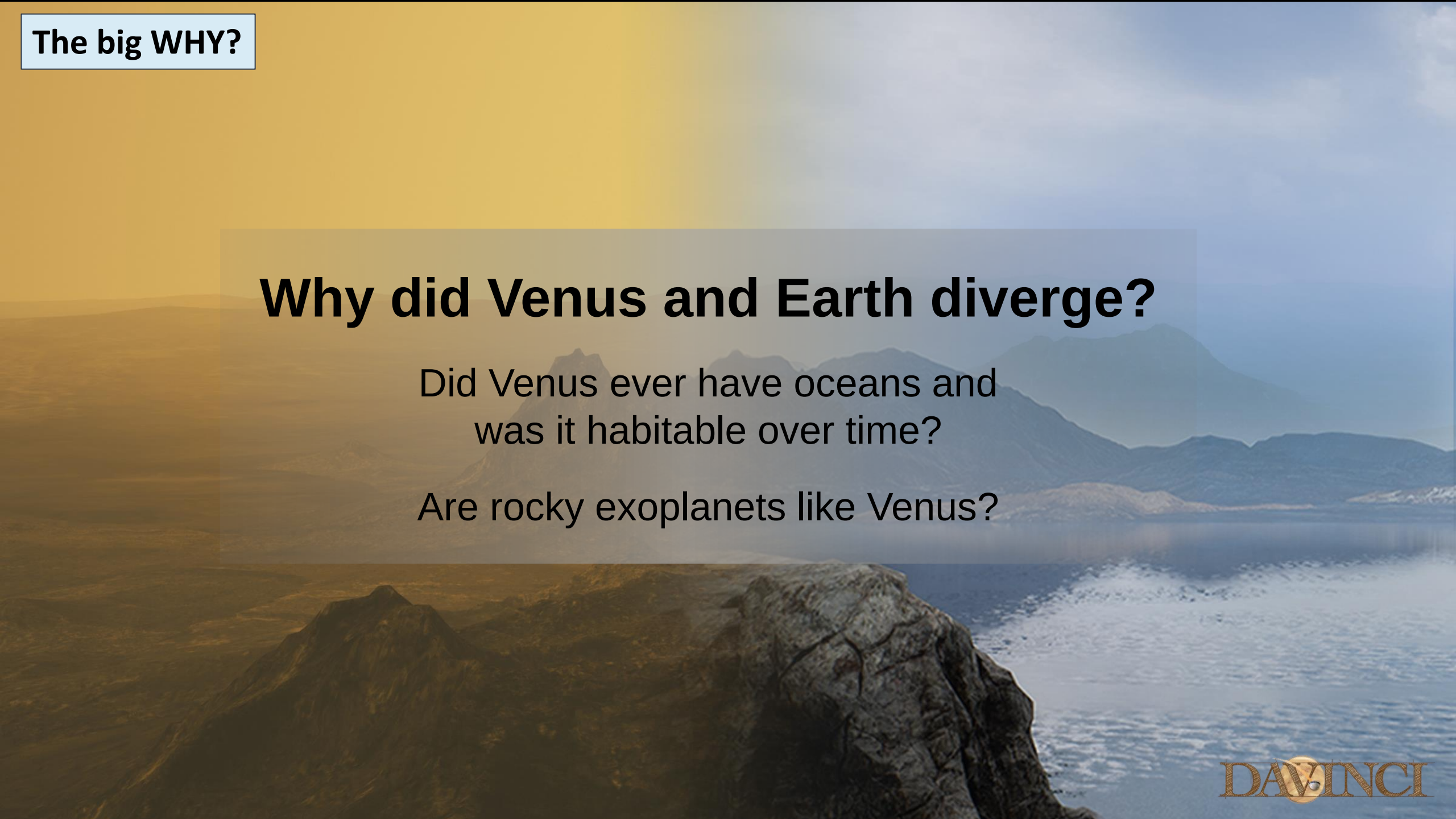
Supercrit. CO_2

The big WHY?

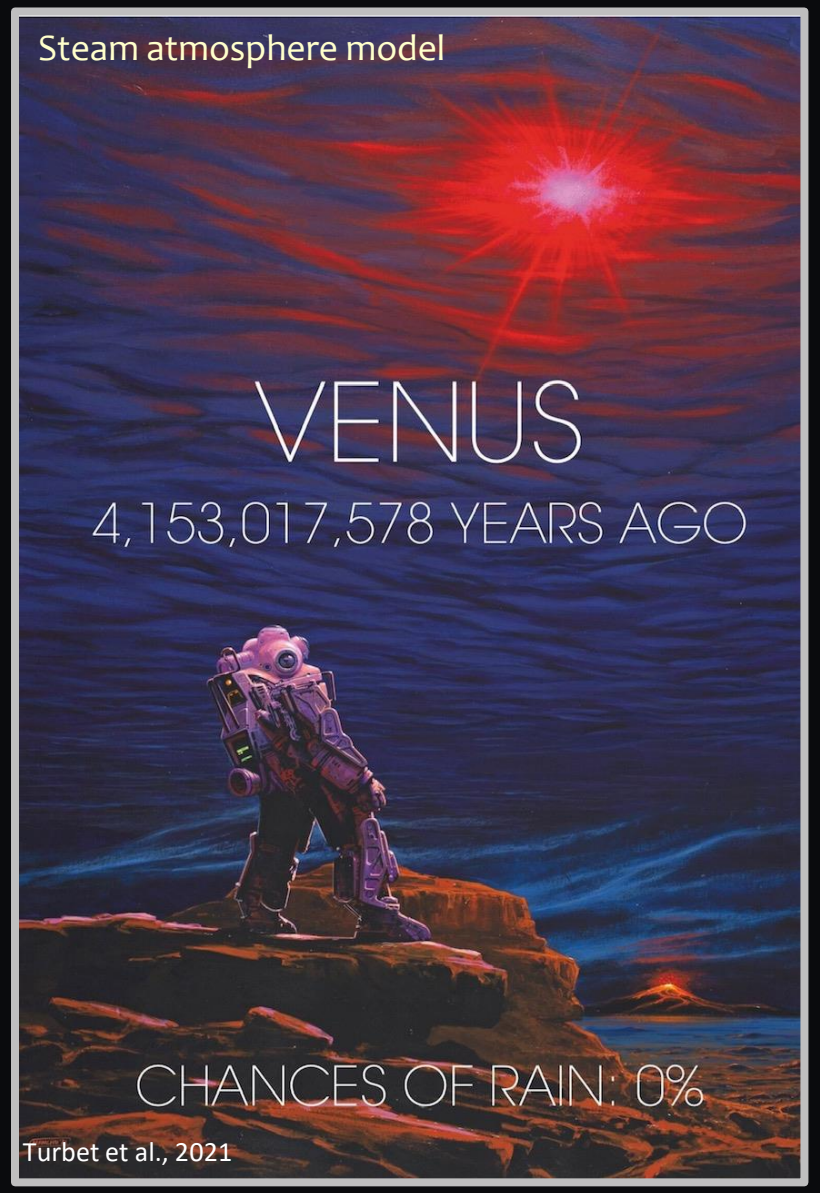
Why did Venus and Earth diverge?

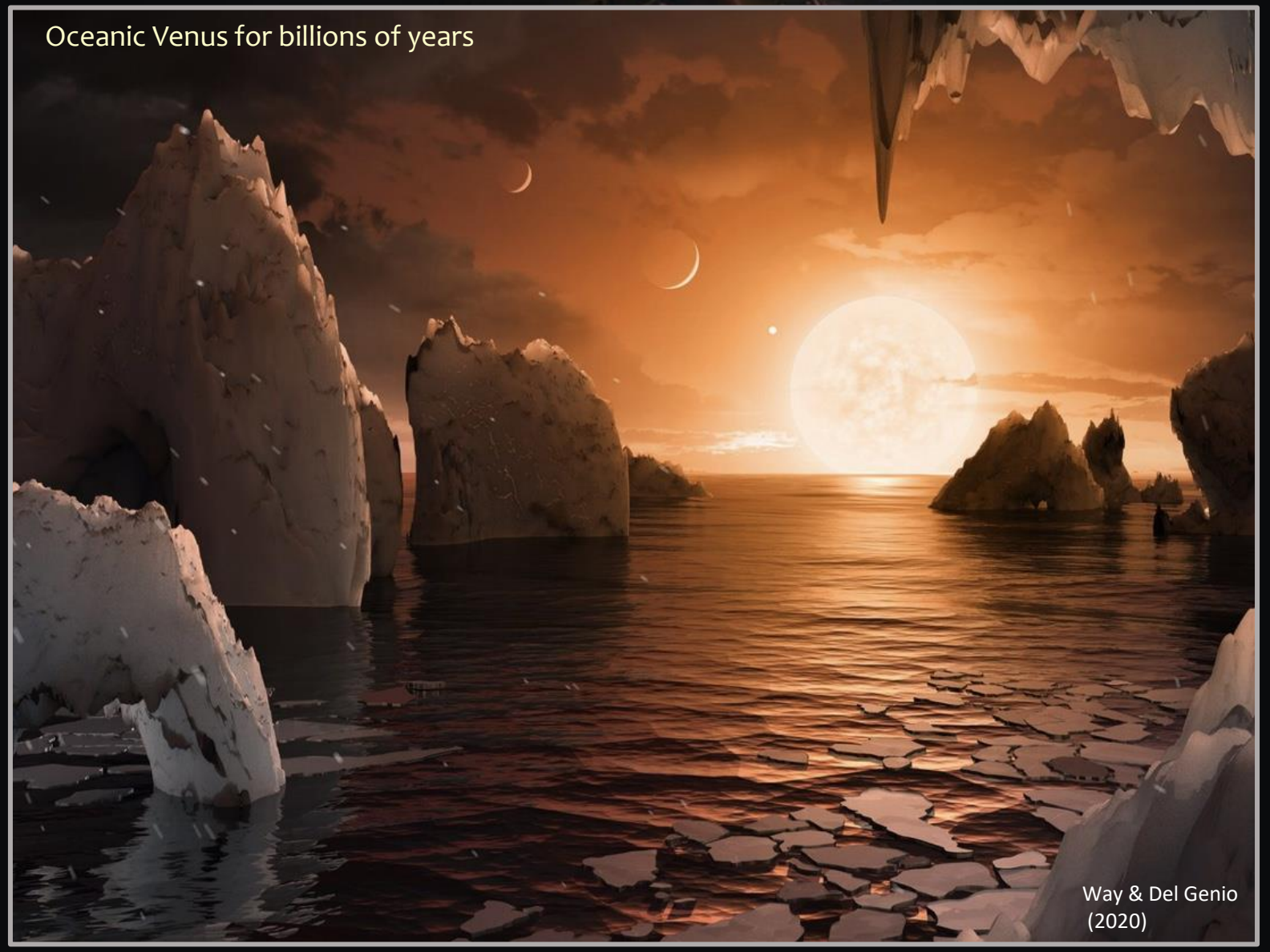
Did Venus ever have oceans and
was it habitable over time?

Are rocky exoplanets like Venus?



How can we tell which of these is the “real” *early* Venus story?





DAVINCI will explore past and present Venus

Deep Atmosphere Venus Investigation of Noble Gases, Chemistry, and Imaging

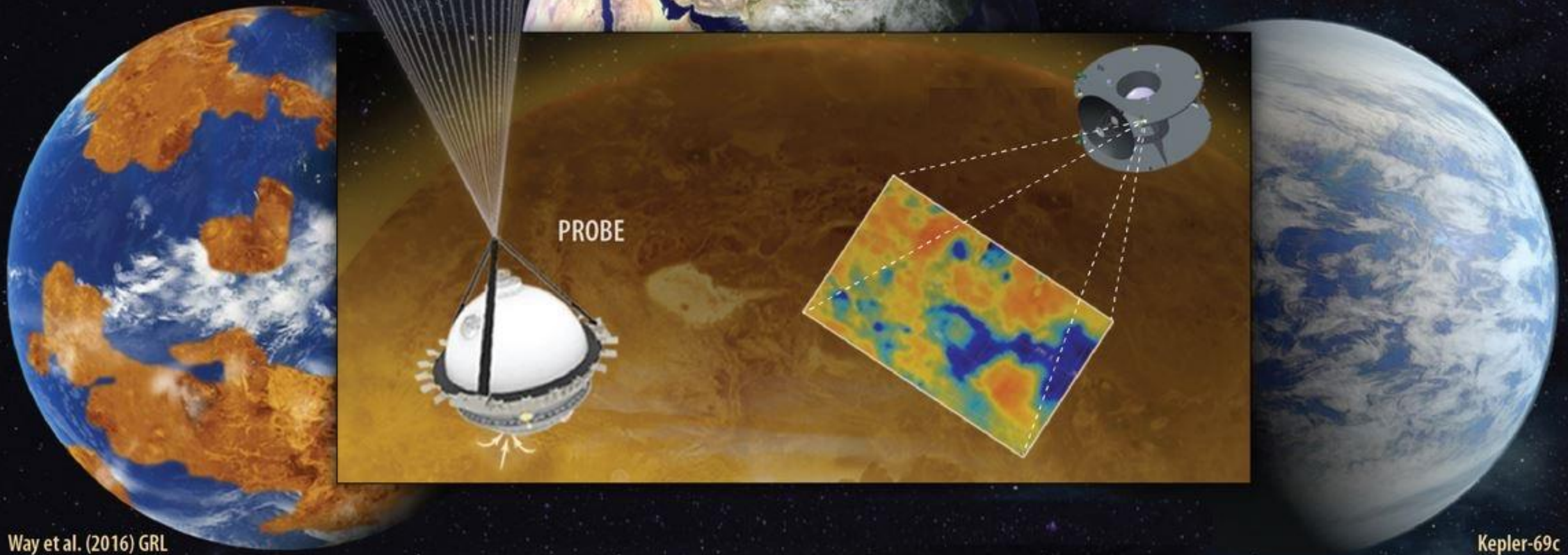
Establishing Venus' place in our Solar System

Enabling exploration of Venus-like exoplanets and Earths

Ancient Oceans on Venus?

Evolution of Habitability

Venus-like Exoplanets



Way et al. (2016) GRL

Kepler-69c

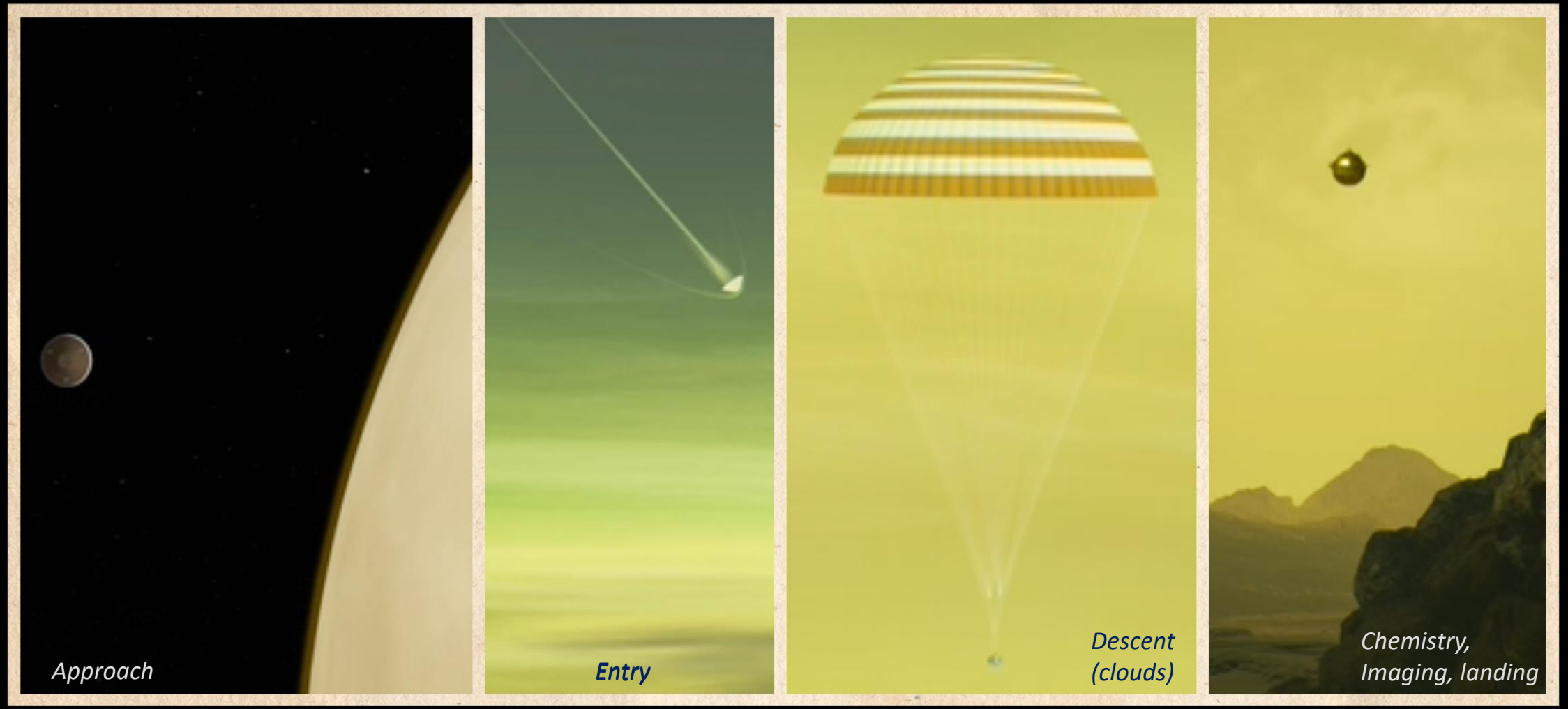
DAVINCI will make critical, missing measurements with flight-proven instruments to answer these fundamental unknowns:

Atmosphere → *Did the inner planets form from similar materials? Did Venus have an early ocean? Why did Venus become dry and hot? How did volcanism proceed over time?*

Geology/interactions → *Do the compositions and deformation of the crust reveal past continents? What is the weathering regime at the surface?*


DAVINCI
Building a pathway to Venus for all interested!
NASA

Probe-based Chemistry, Environments, Dynamics, and Descent Imaging of Venus atmosphere



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Venus is a long-overlooked frontier in our solar system

Ancient continents?

Chemistry, Environments … climate change… water

Measurement Driven:

From above (on flybys):

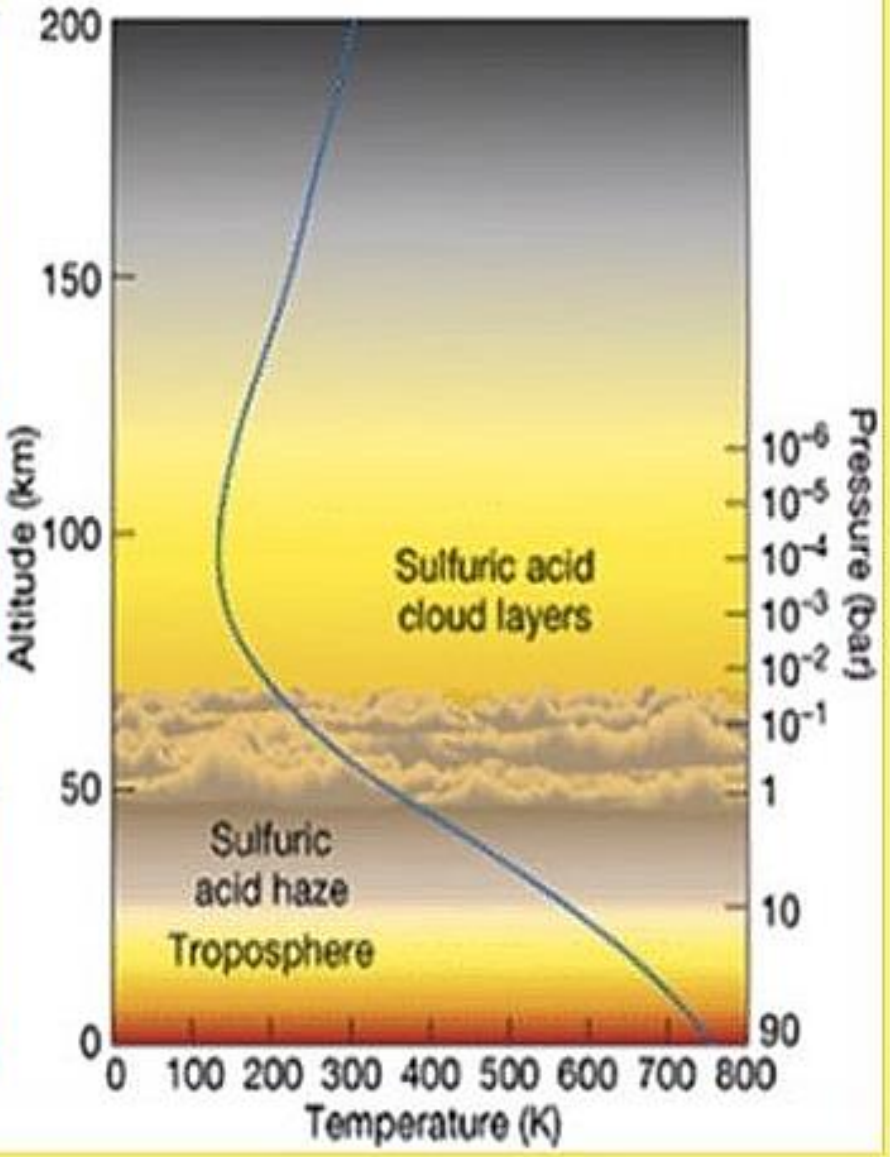
- *UV observations – clouds*
- *NIR observations – surface composition*

From *below* (in atmosphere!):

- *Noble Gases*
- *Key isotopic Ratios*
- *History of Water (via D/H)*
- *Lower Atmosphere Composition*
- *Temperature, Pressure, Winds*
- *Local-scale composition*
- *Landscapes at 'people' scales*

VENUS: key unanswered questions abound from top of atmosphere to the hot surface

- > 130 km : Thermosphere
  - Thermal neutral escape not measured
- 70 - 130 km : Mesosphere
  - VEx: excellent profiling, mapping only of few species
  - Thermal infrared mapping (on nightside only)
- 48 – 70 km : Main Cloud layer
  - VEx cannot resolve vertical structure
  - VEx cannot identify composition of clouds
- 0 – 48 km : Below the clouds
  - Only some gas species measured by VEX
  - Vertical profiles only for H_2O.
  - Surface- atmosphere exchange still unknown.
- Surface :
  - Emissivity mapping at 1 µm only; 50 km spatial resolution; low sensitivity; coverage mainly in S hemisphere.
- Interior :
  - No constraints at all on interior structure or heat flow



Mission Summary: *Measurement-rich*

Venus Express
Akatsuki
DAVINCI Orbiter

DAVINCI Probe

DAVINCI Probe begins taking measurements & continues to the surface

Vega Balloons

Pioneer Venus Probe

Largely Unknown

75% of Venus Atmospheric Mass

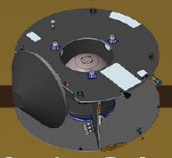
DAVINCI

Vega & Venera Landers

Magellan Radar

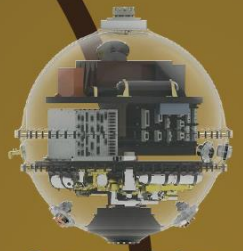
Spacecraft with Probe

Descent



Carrier, Relay, Imaging Spacecraft

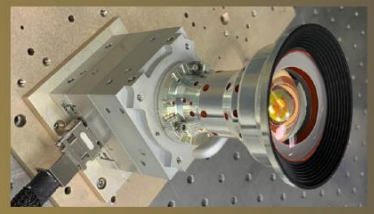
Probe Flight System



Descent Sphere

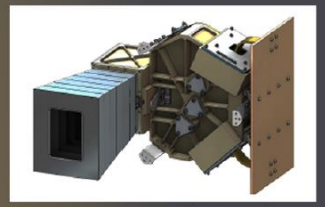
Carrier Flyby Instruments

VISOR (Venus Imaging System for Observational Reconnaissance)



Based on OSIRIS-REx/ECAM

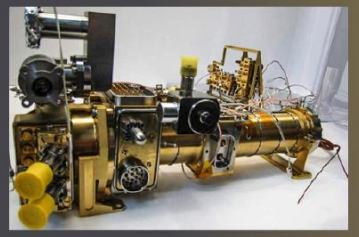
CUVIS (Compact Ultraviolet to Visible Imaging Spectrometer)



Hyperspectral UV Imaging Spectrometer
0.20 nm spectra (UV)

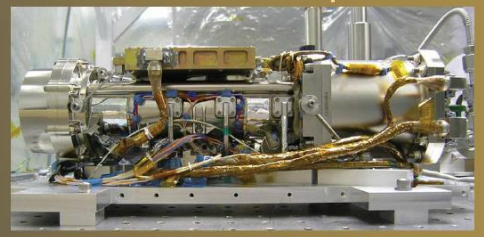
Probe Instruments (in the atmosphere)

VMS (Venus Mass Spectrometer)



Based on MSL/SAM QMS

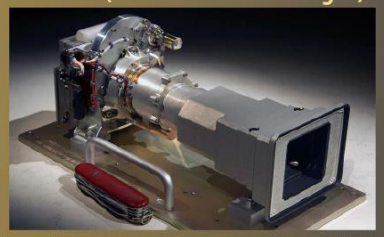
VTLS (Venus Tunable Laser Spectrometer)



Based on MSL/SAM TLS

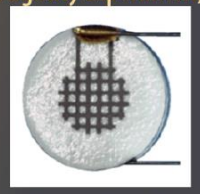
VASI (Venus Atmospheric Structure Investigation)

VenDI (Venus Descent Imager)



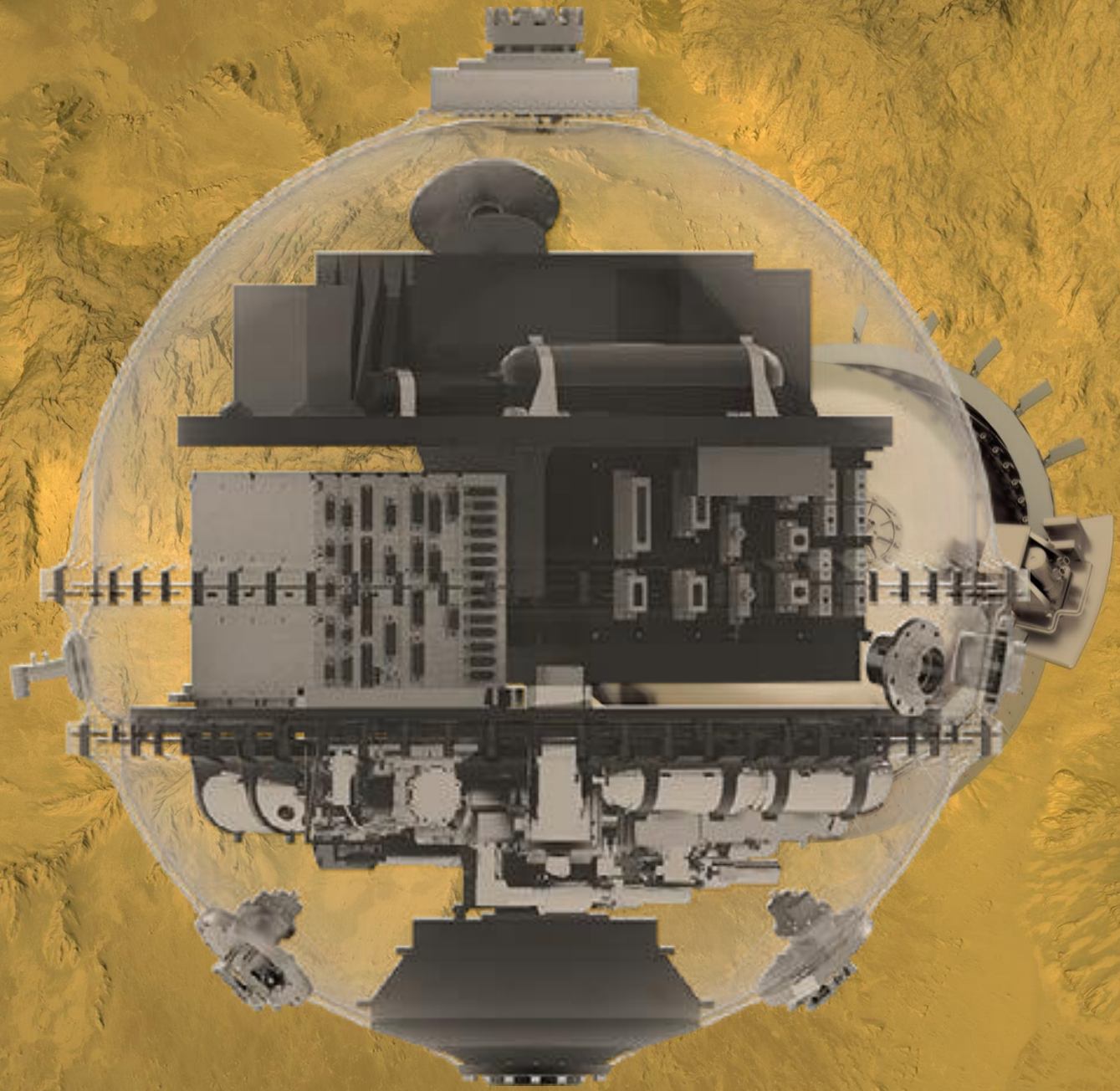
Based on MSL/MastCam, MARDI, MAHLI

VfOx (Venus Oxygen Fugacity Experiment)



Deep Atmosphere Oxygen
fO_2 near surface

New Flight systems ….
take us there with
“thermal engineering”



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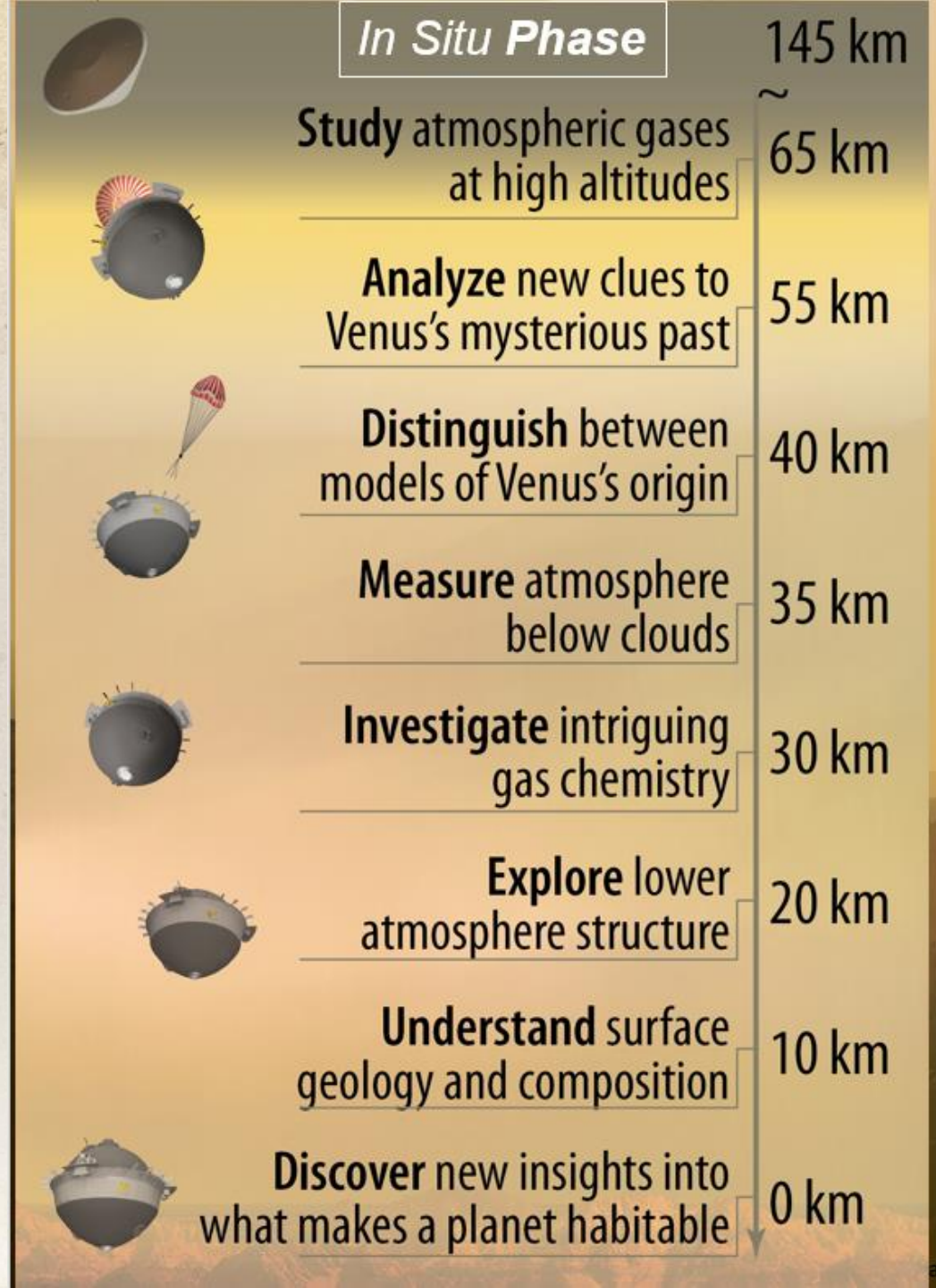
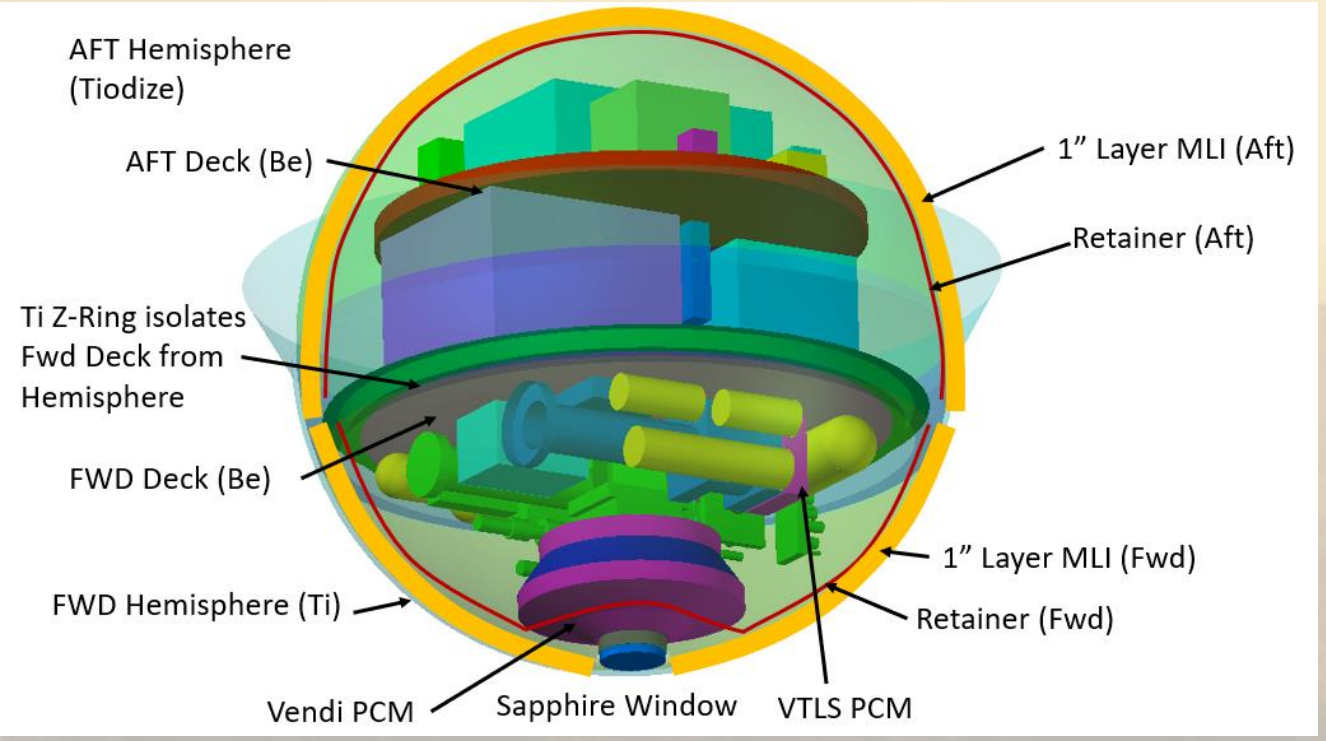
KEY: flying a chemistry laboratory down through Venus atmosphere in ~ 1 hr to make 1000's of new measurements with 1st imaging under the clouds in a thermally stable environment !!



Thermal Design Overview (*PSE Team*)



- The *Zephyr* thermal design utilizes passive methods to maximize the thermal time constant during the descent into the hot Venusian atmosphere very similar to *the Pioneer Venus Large Probe* (PVLP).
- High thermal capacitance Beryllium Aft and Forward Decks serve as large heat sinks for components and instruments
- 2.5 cm of high temperature MLI radiatively insulates the internal components from the hot outer surface of the Descent Sphere
- One-inch-tall titanium Isolators between the forward deck and the mid hemisphere minimize conductive heat transfer into the system
- Phase Change Material (PCM) around the VENDI and VTLS serve as local heat sinks.
- High emissivity tiodize on the outer surface of the Descent Sphere maintain a cold starting temperature (-20°C to 5°C) prior to descent
- Operational and Survival heaters maintain component temperatures during the cold phases of the mission

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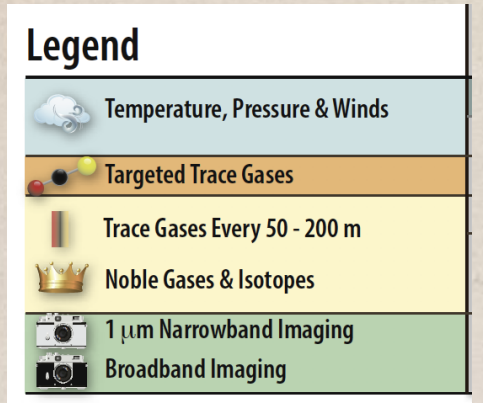
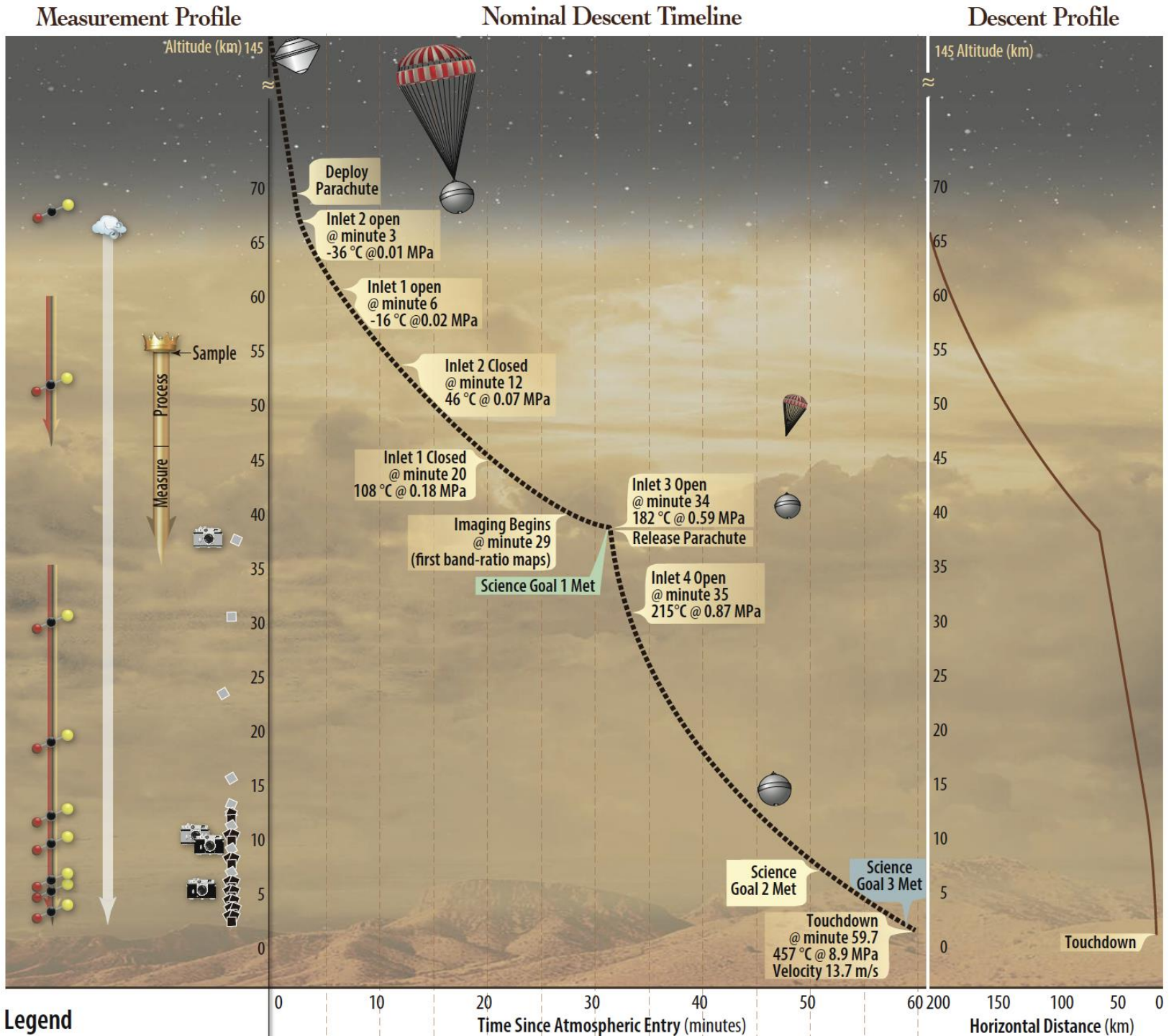
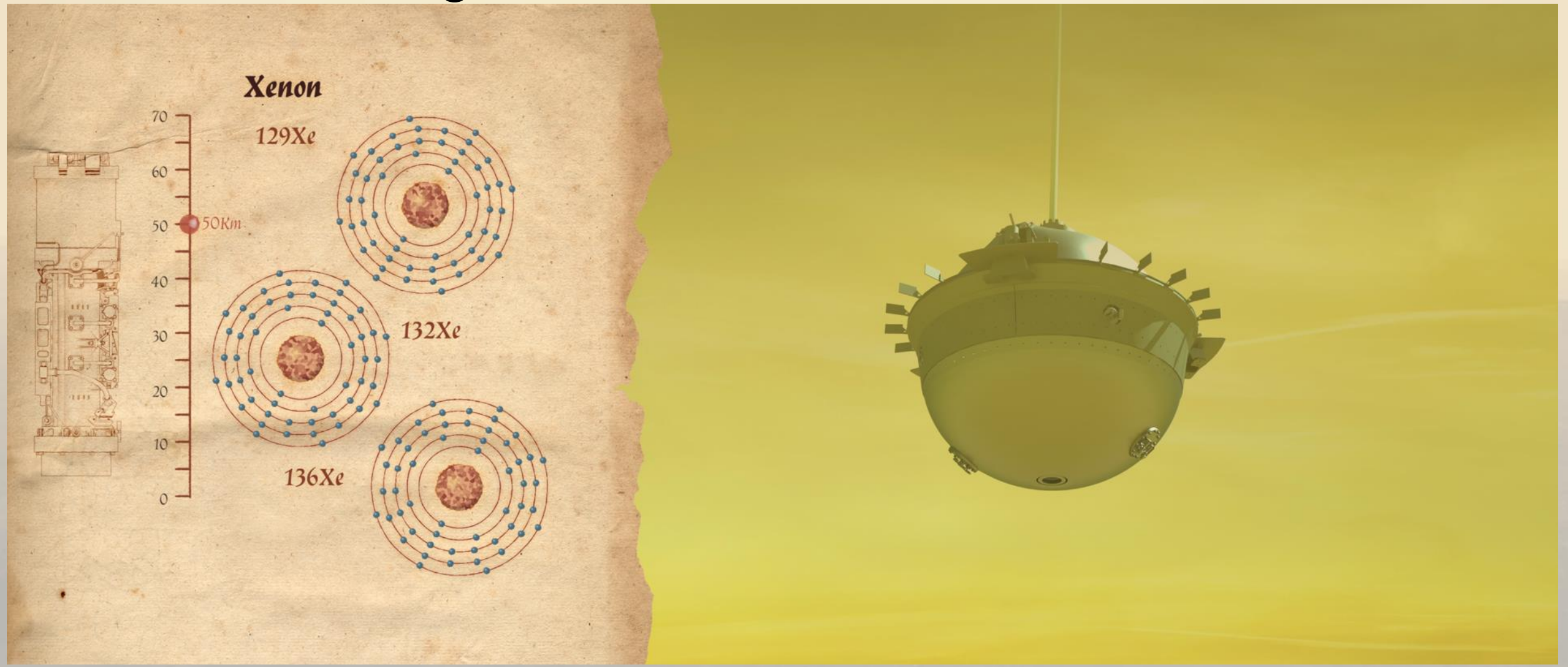
~ 60 minutes of new science (0.9 *Gbits*): *Thermal Stability !*





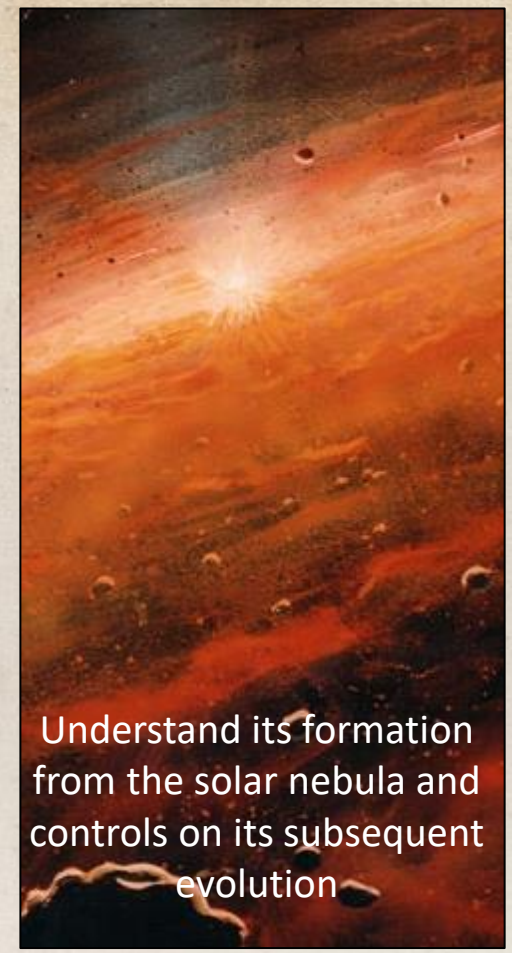
Using “elemental fossils” *such as* Xenon



Measuring the clues to past evolution, oceans, context

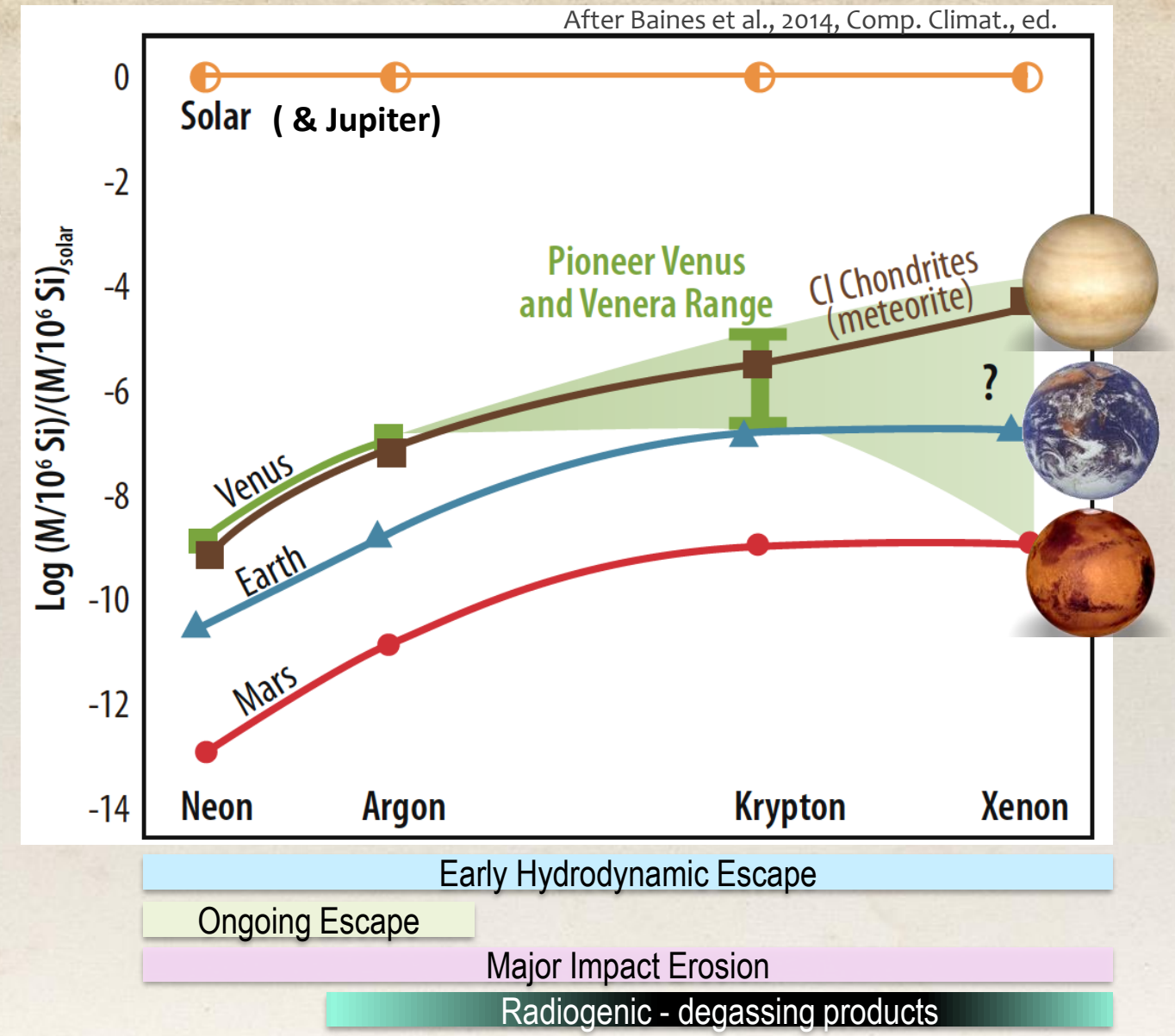
[DAVINCI 2022]

To understand Venus … *and its formation →*



Understand its formation from the solar nebula and controls on its subsequent evolution

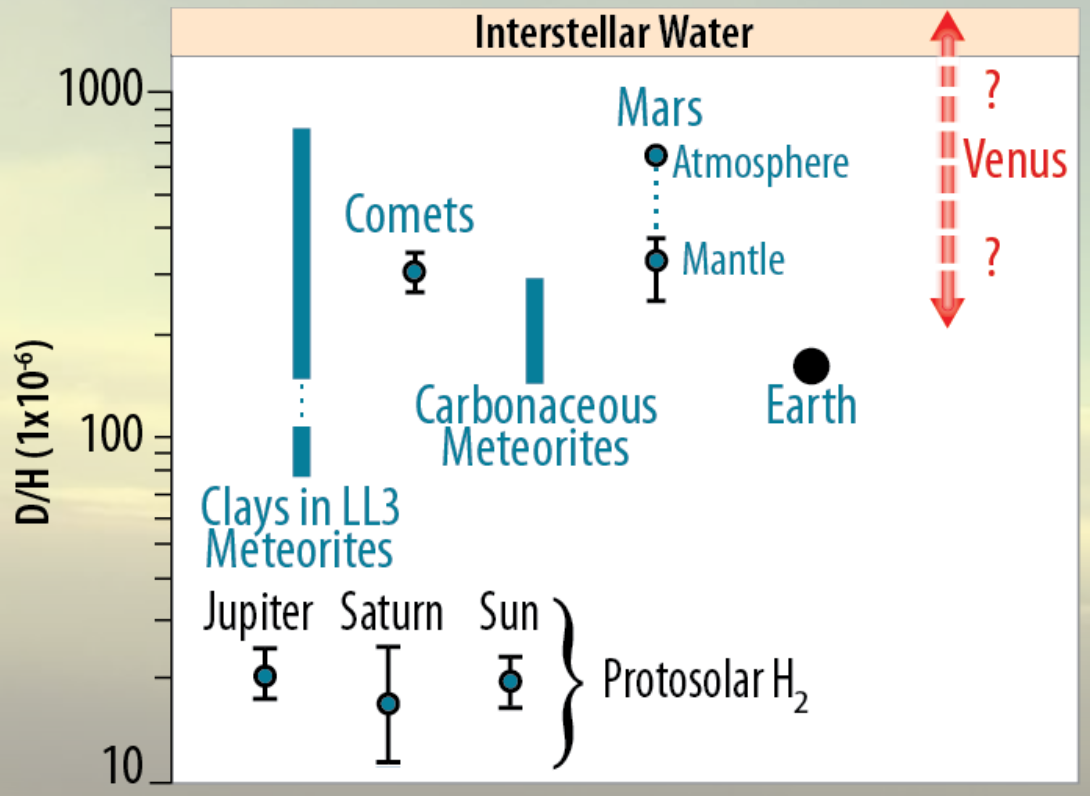
After Baines et al., 2014, Comp. Climat., ed.



Noble gas isotopes reveal the origin and evolution of the materials that built Venus

Especially **Xe**

Loss: Is ***high*** D/H a signature of past oceans?



Prior measurements indicate

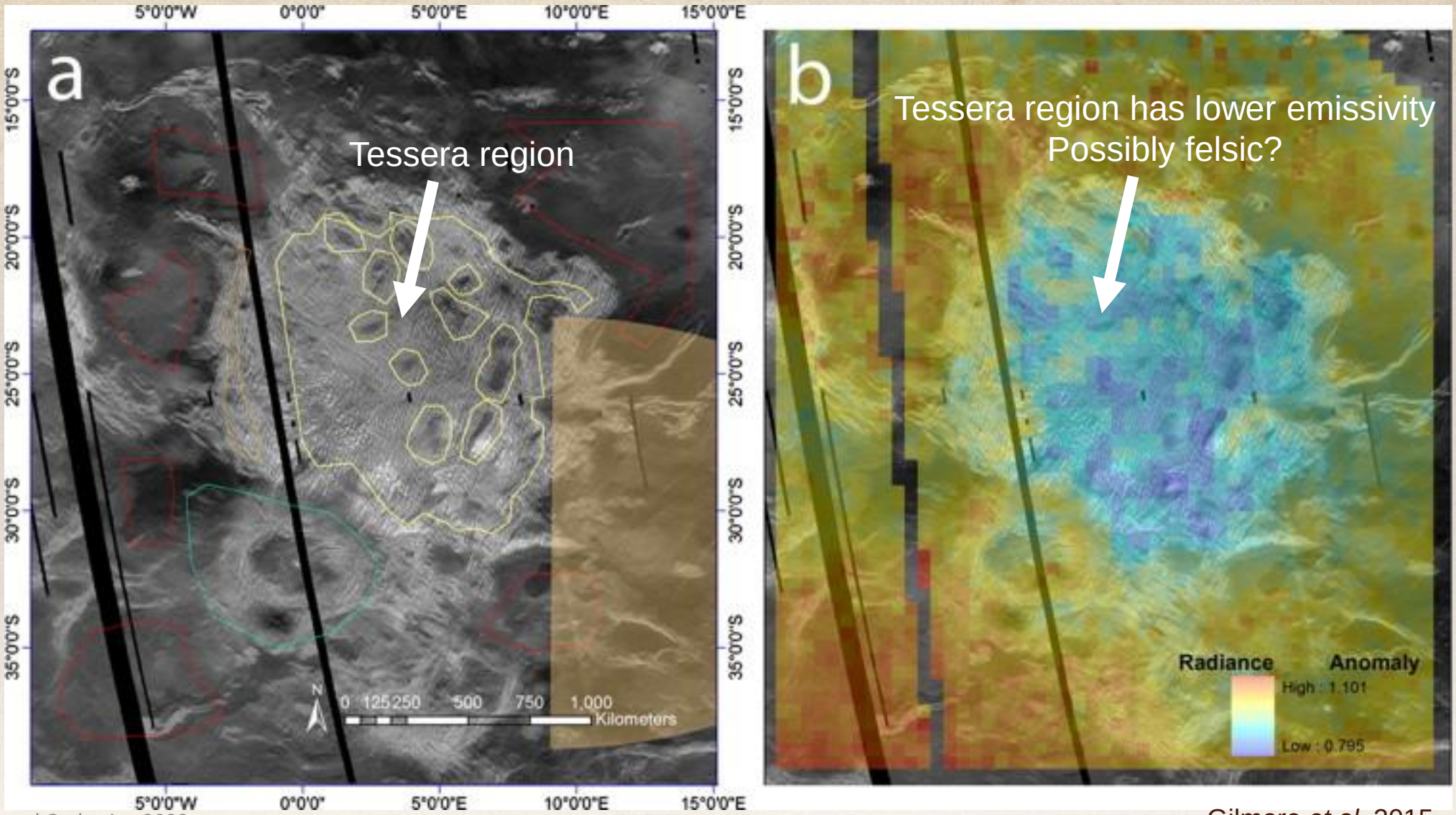
- Anomalously high D/H
- Gradients in D/H from the upper atmosphere to the cloud region

VTLS will make… 10 altitude-resolved, definitive measurements of D/H in water from above the clouds to the near-surface

… a major breakthrough

DAVINCI will confirm ***past oceans*** and the timing of the loss

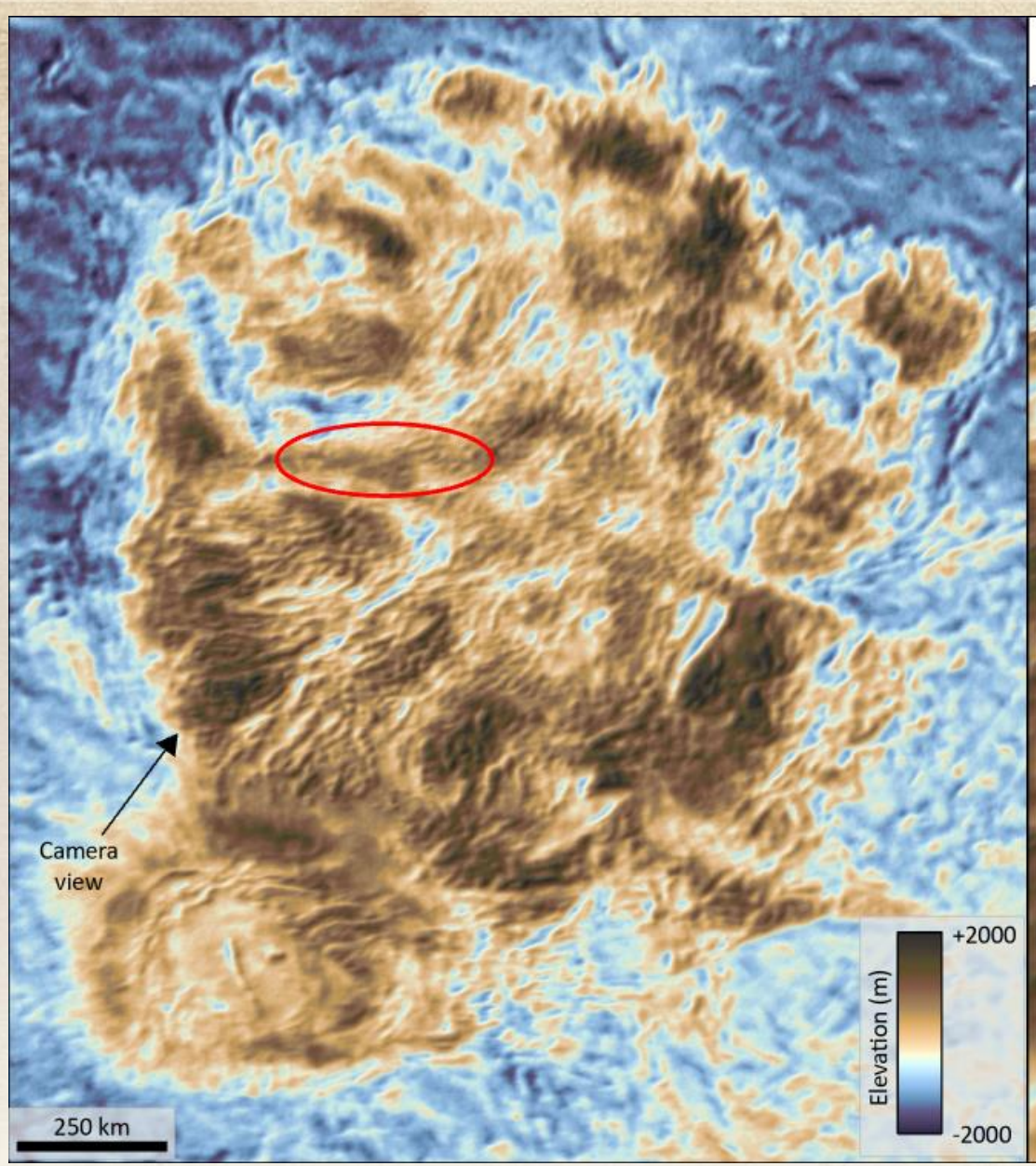
Alpha Regio: hints of felsic rocks through prior emissivity measurements

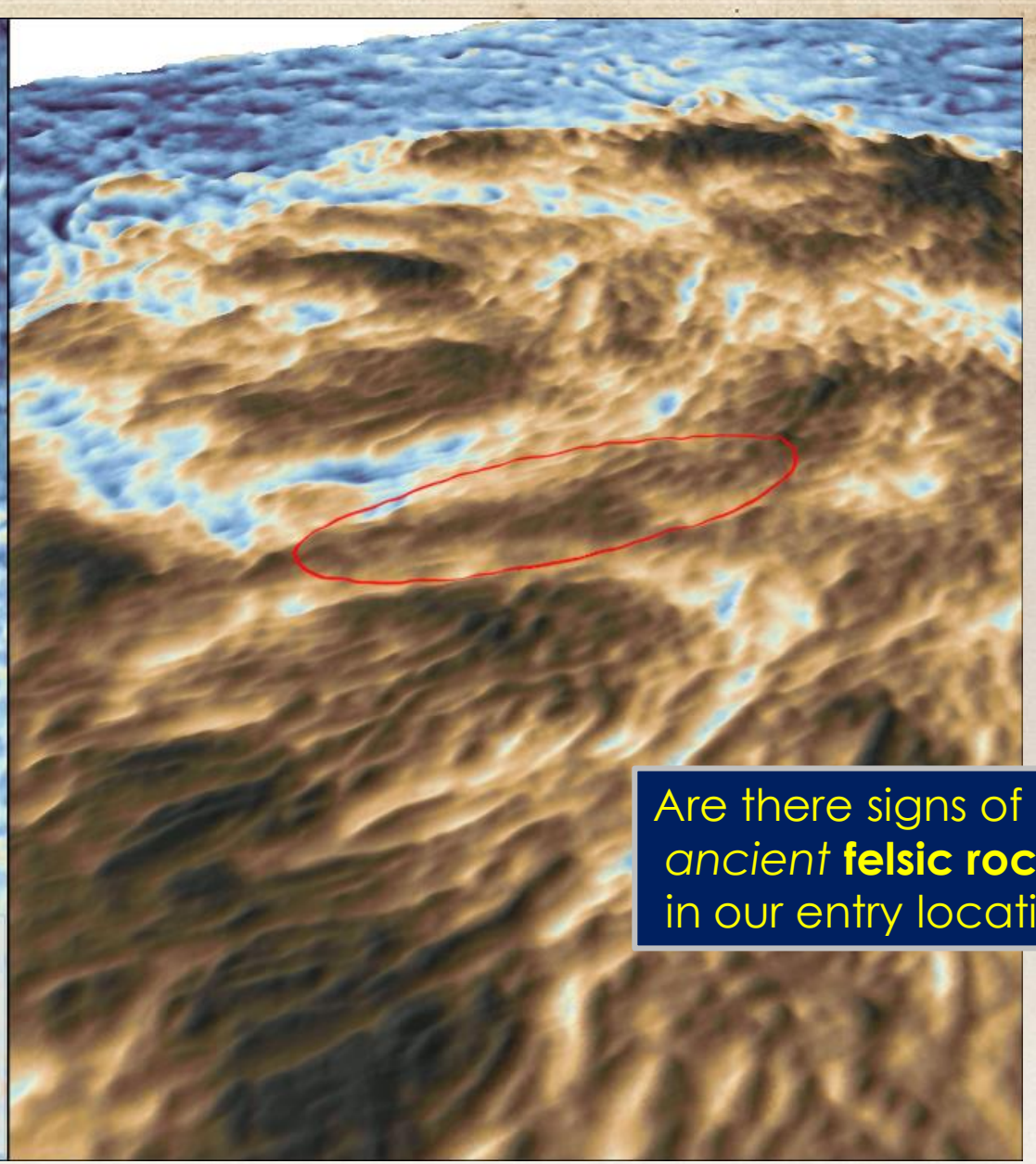


Gilmore *et al*. 2015

Entry target : ALPHA REGIO = mountains !

Sub-km topography of **ALPHA REGIO**

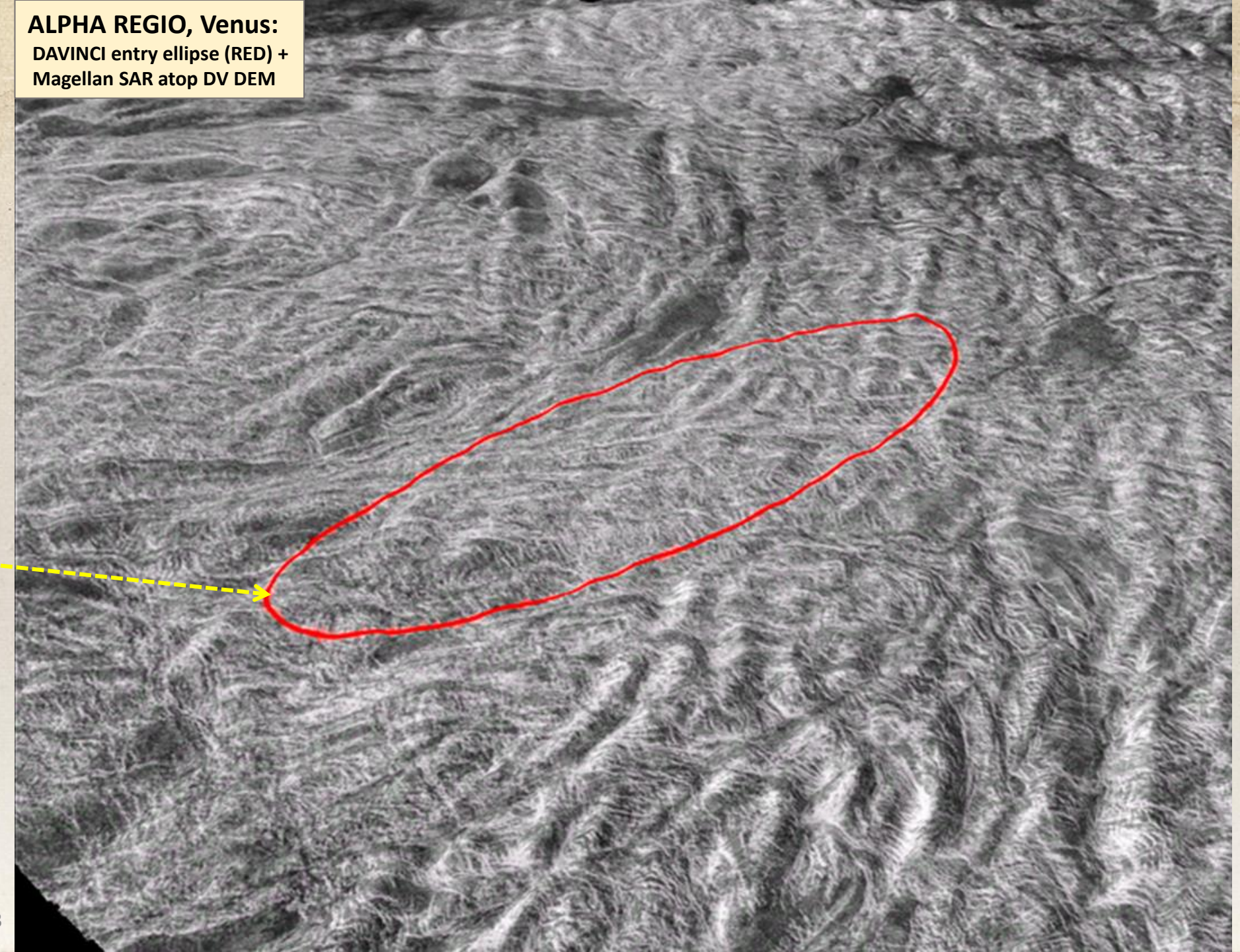




Are there signs of *ancient* **felsic rocks** in our entry location?

DAVINCI

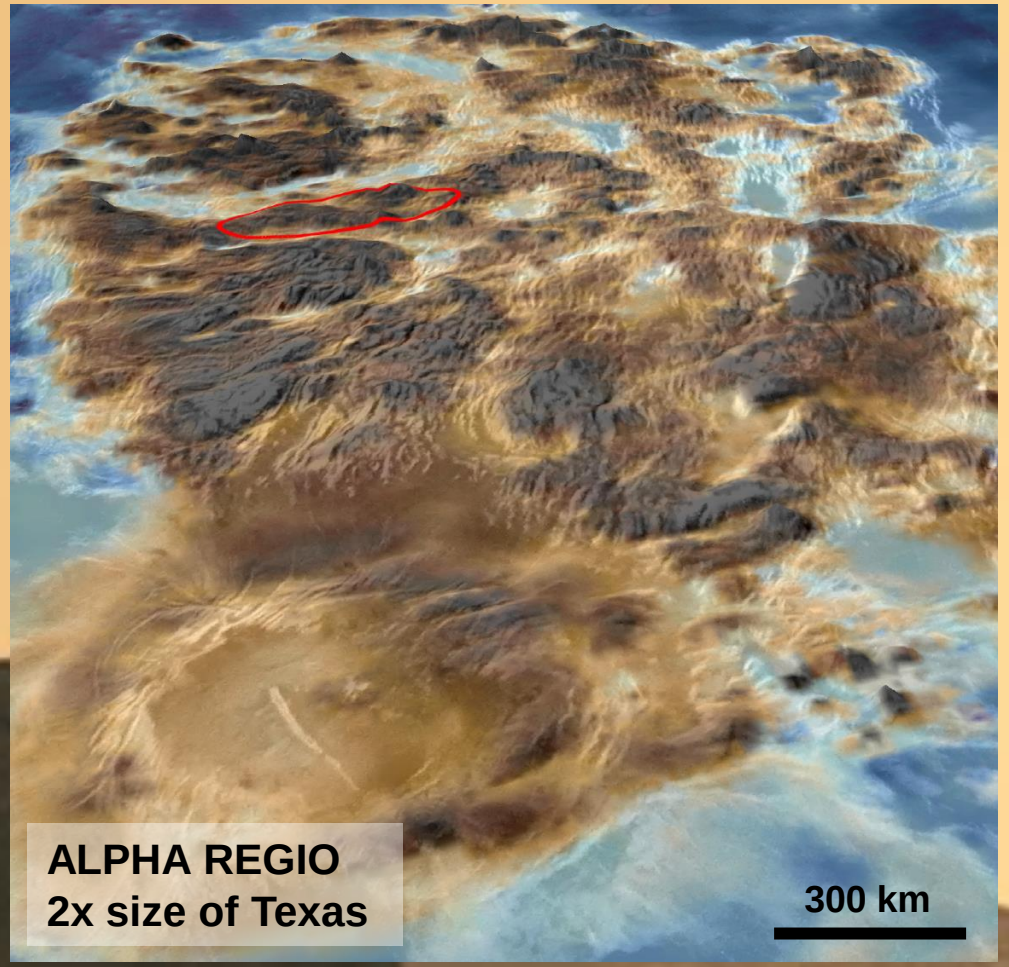
ALPHA REGIO, Venus:
DAVINCI entry ellipse (RED) + Magellan SAR atop DV DEM



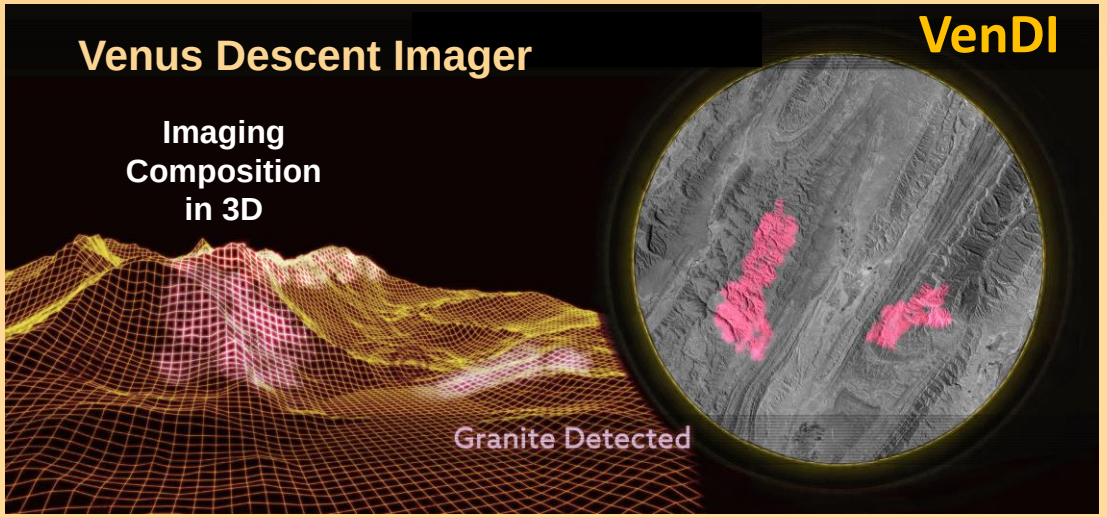
Mountain ridges and valleys in Venus ***tesserae*** : unique new solar system landscapes

Contextual Evidence for Oceans Revealed by…

Descent over a Possible Ancient Continent, Alpha Regio



Arecibo radar backscatter atop Magellan altimetry



NIR imaging *from below the clouds* ➔ *big sapphire window*

Multi-scale, *different* FOV views from NIR imaging by **VenDI** for composition and relief at **multiple *spatial scales***

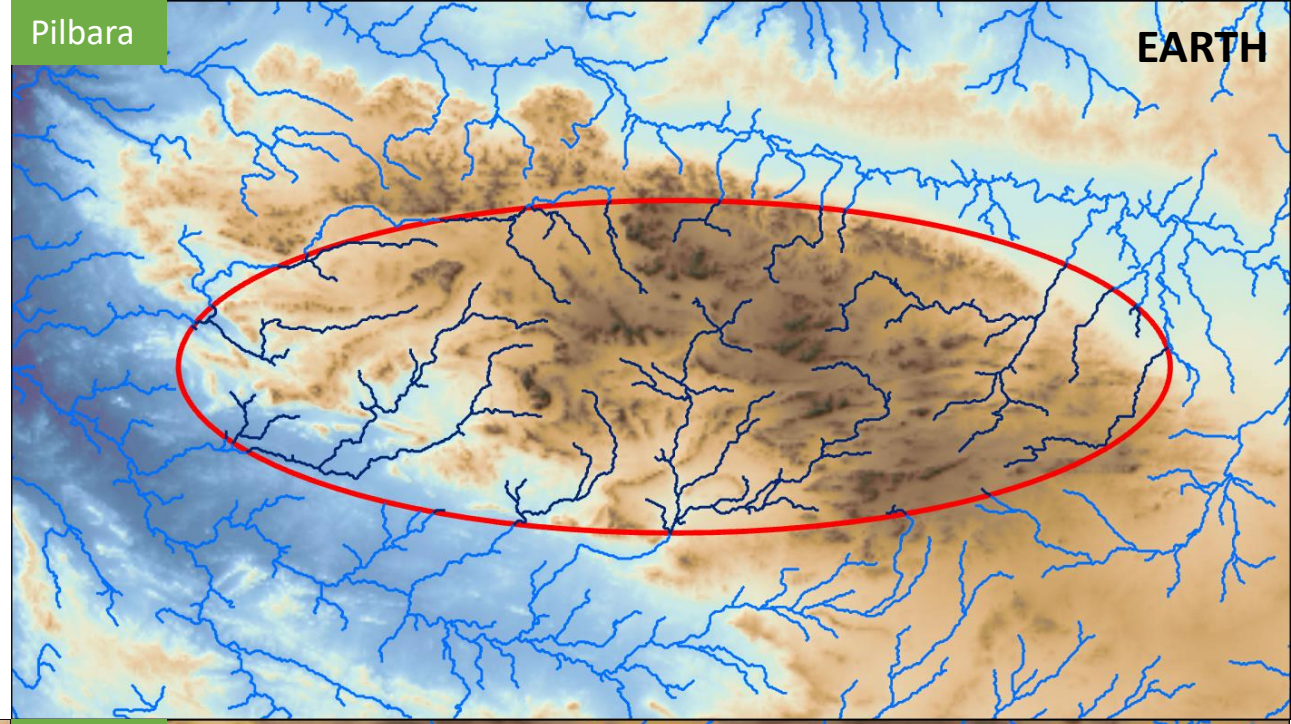
A unique terrain's **topography** to be revealed at **unprecedented** resolution

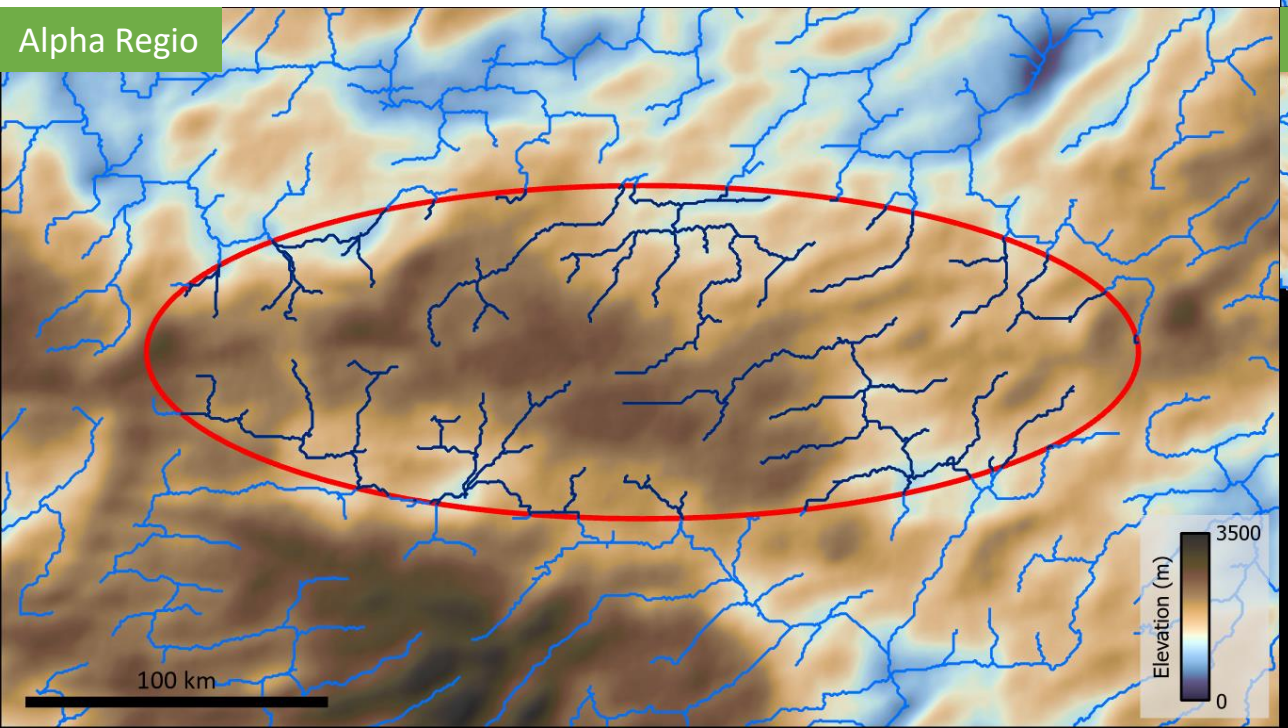
VenDI will allow topography & composition to be considered together in integrated maps formed through digital elevation models & band ratio composition measurements

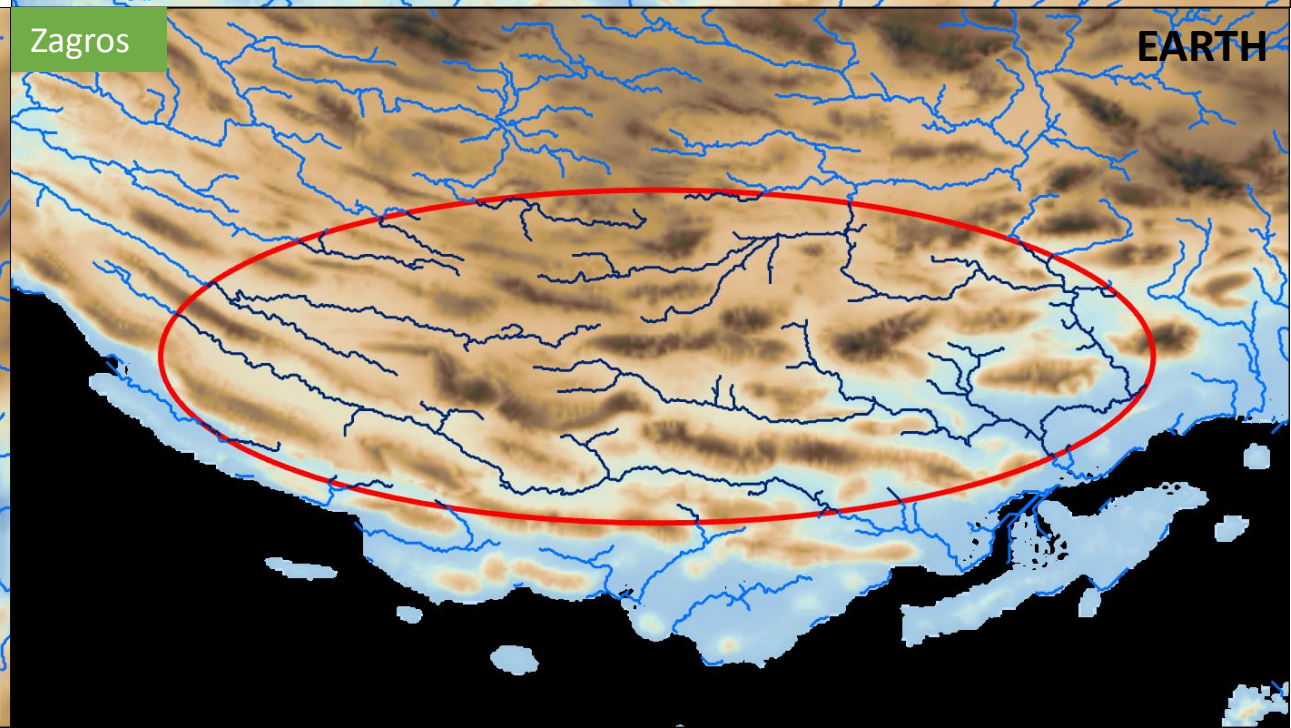
Stream networks: *Alpha Regio (Venus)* *vs* Pilbara, Zagros

DEM (topography): 500 m x,y scale
Criteria: 100 km^2 upstream area
Total Length within 348 x 140 km ellipse (DAVINCI scale):
- Alpha Regio: 1972 km
- Pilbara: 2035 km
- Zagros: 2055 km

Could there have been hydrology on **Venus**?





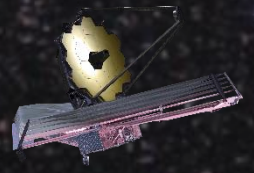


DAVINCI will provide a definitive, new understanding of **Venus**
to reveal the extent of habitability in our inner solar system & beyond

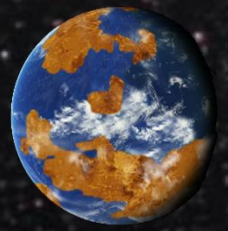
Venus is the exoplanet next door

Garvin/NASA

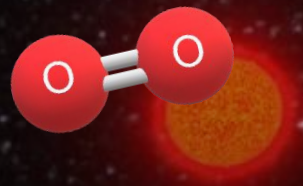
DAVINCI makes connections to exoplanets directly!



JWST is searching for exo-Venus analogs. **DAVINCI** data can provide ground-truth to interpret these observations



Venus possible past habitability may mean that some "**Venus-like**" exoplanets are habitable too – DAVINCI helps to reveal this story

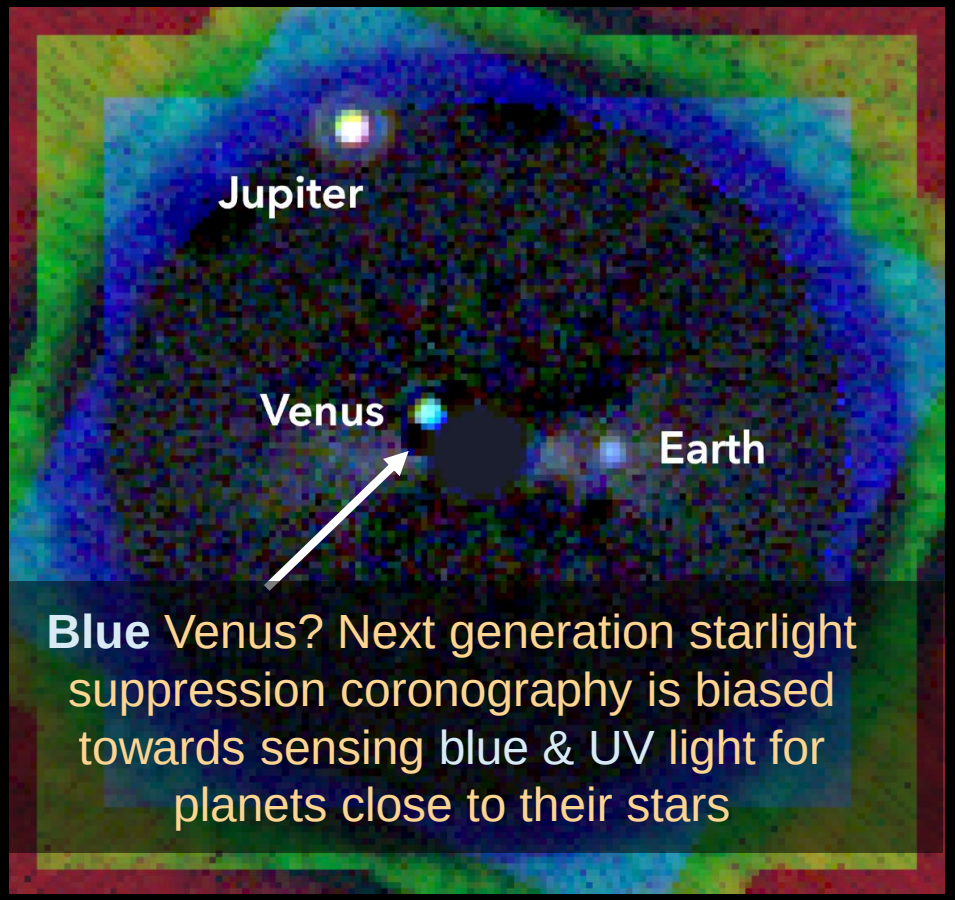


Oxygen false positive biosignatures will be relevant to JWST, which will study exoplanets around active low mass stars

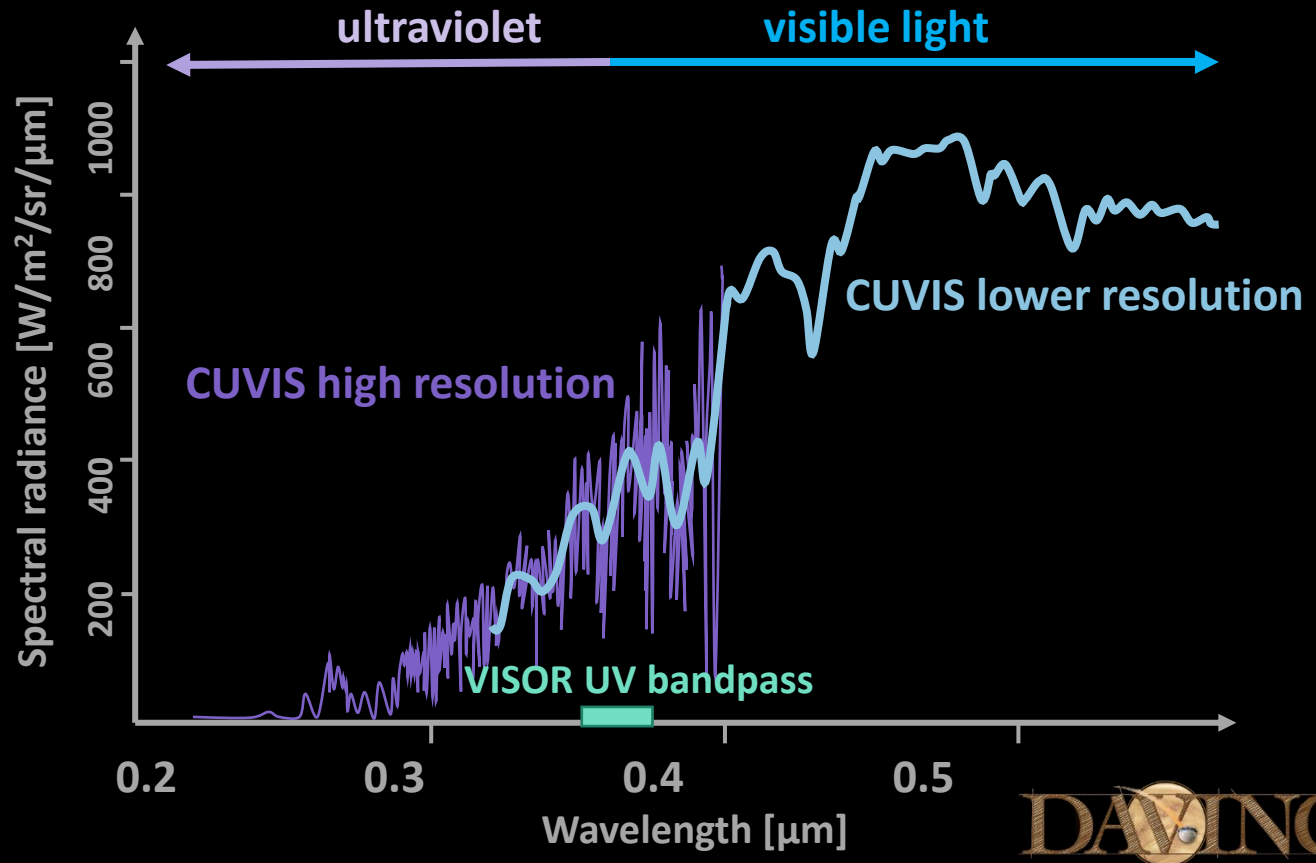
DAVINCI

Venus is relevant to the *next generation of exoplanet observatories* beyond JWST like Habitable Worlds Observatory (HWO)

Simulation of our solar system in reflected light viewed with a coronagraphic observatory like HWO



CUVIS and VISOR measurements of Venus at blue and UV wavelengths can inform coronagraphic measurements of exo-Venuses in reflected light



DAVINCI remote sensing can constrain predictions of HWO observations of exo-Venus planets

Mission timeline

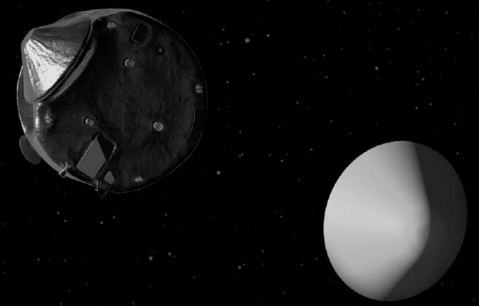
2029

Launch Period
June 2029

2030

Flyby 1 January 2030
Flyby 2 November 2030

Probe Release
June 2031



2031

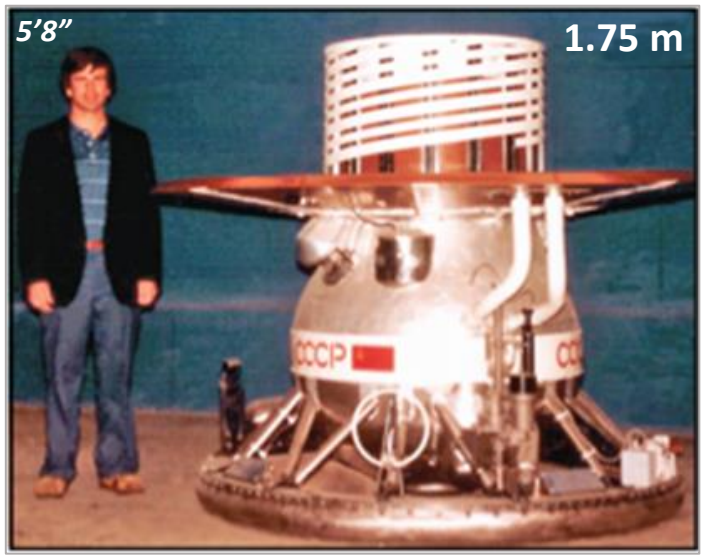
Probe Descent
1 hour in June 2031

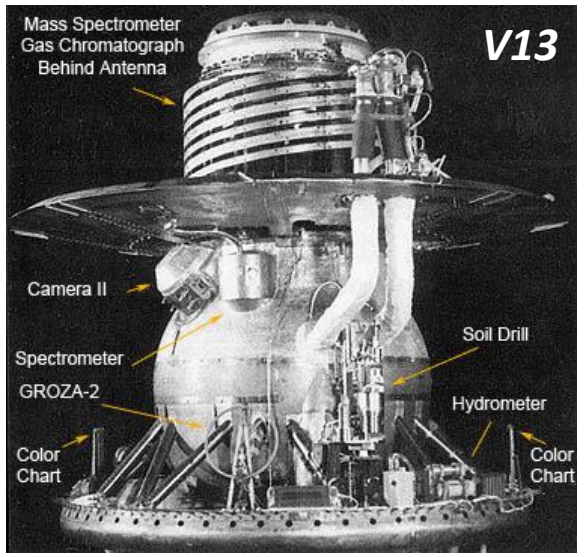
513 Gigabits of new science data about **Venus**

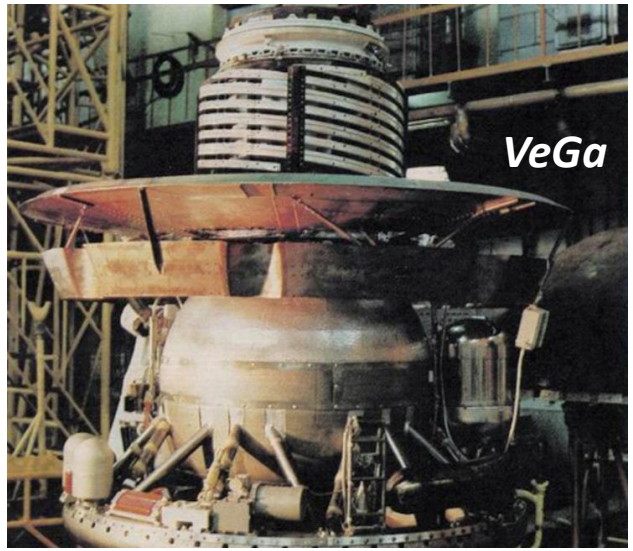
Venus Spacecraft Comparisons

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

Venera/VeGa 1980s

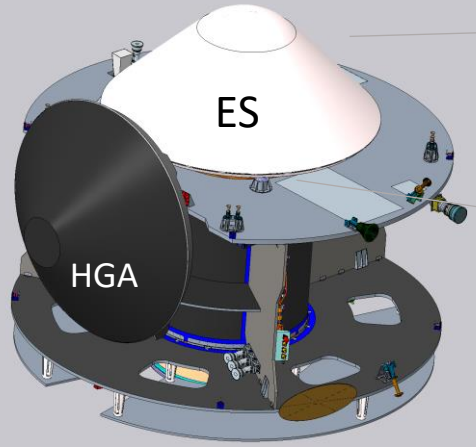




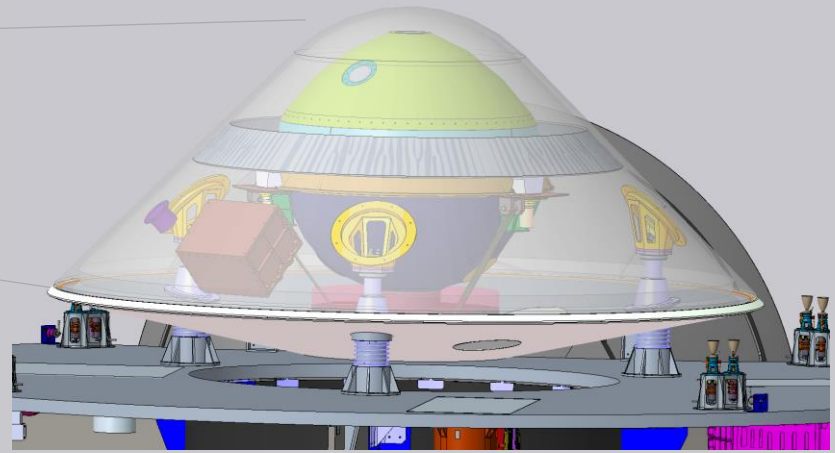


DAVINCI 2029

Spacecraft Diameter = ~3.5 m (11 ft)

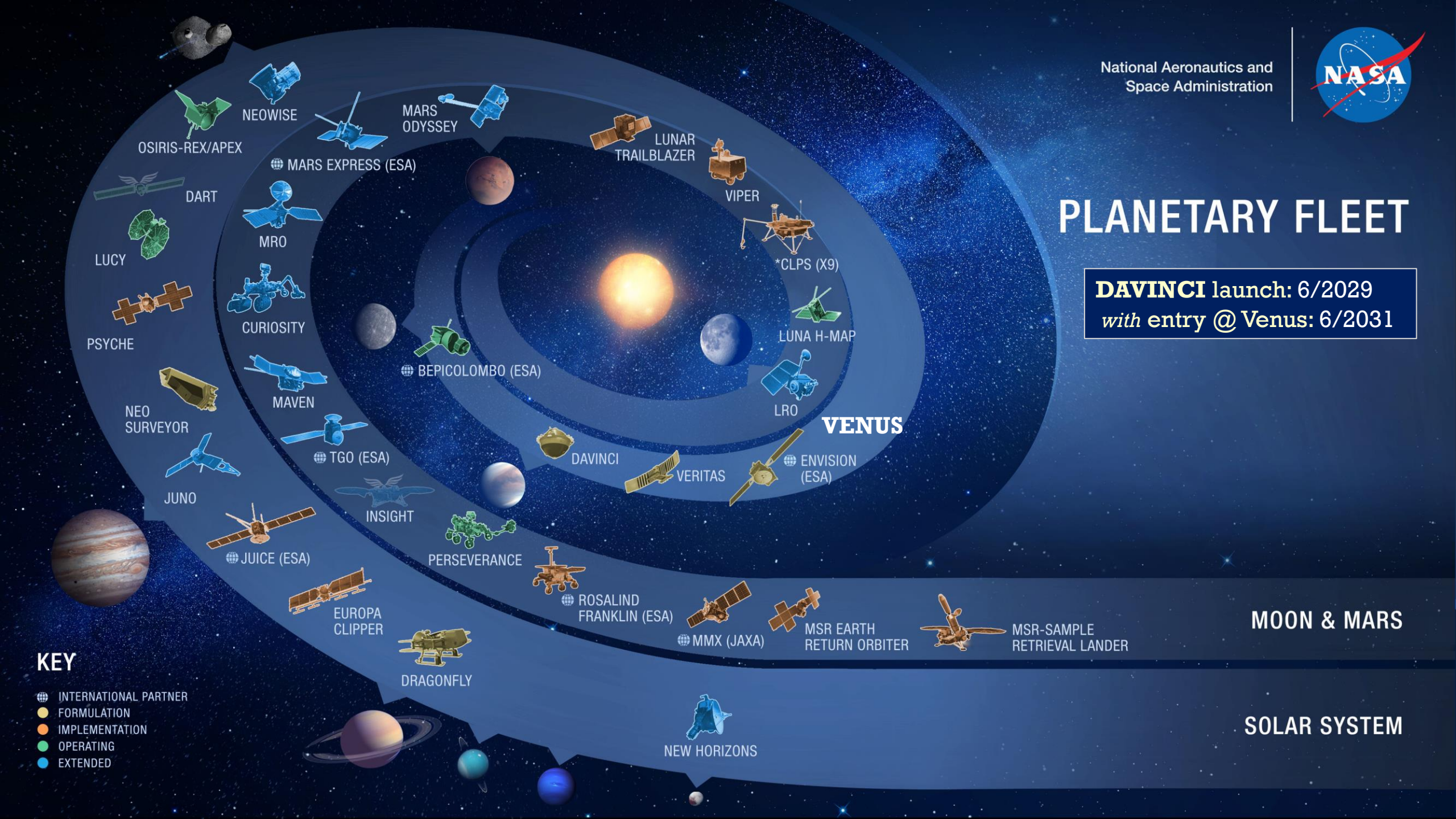


Probe Diameter = 1+ m (3.5 ft)



First visit to Venus deep atmosphere and surface in tesserae !

Help us get to this unique environment to *RELISH the Hellish*


National Aeronautics and Space Administration
NASA
PLANETARY FLEET
DAVINCI launch: 6/2029
with entry @ Venus: 6/2031
NEOWISE
OSIRIS-REX/APEX
MARS ODYSSEY
MARS EXPRESS (ESA)
LUNAR TRAILBLAZER
VIPER
DART
MRO
*CLPS (X9)
LUCY
CURIOSITY
LUNA H-MAP
PSYCHE
BEPICOLOMBO (ESA)
LRO
MAVEN
NEO SURVEYOR
VENUS
TGO (ESA)
DAVINCI
ENVISION (ESA)
VERITAS
JUNO
INSIGHT
JUICE (ESA)
PERSEVERANCE
EUROPA CLIPPER
ROSALIND FRANKLIN (ESA)
MMX (JAXA)
MSR EARTH RETURN ORBITER
MSR-SAMPLE RETRIEVAL LANDER
MOON & MARS
DRAGONFLY
NEW HORIZONS
SOLAR SYSTEM
KEY
INTERNATIONAL PARTNER
FORMULATION
IMPLEMENTATION
OPERATING
EXTENDED

Vision of a New Venus from DAVINCI

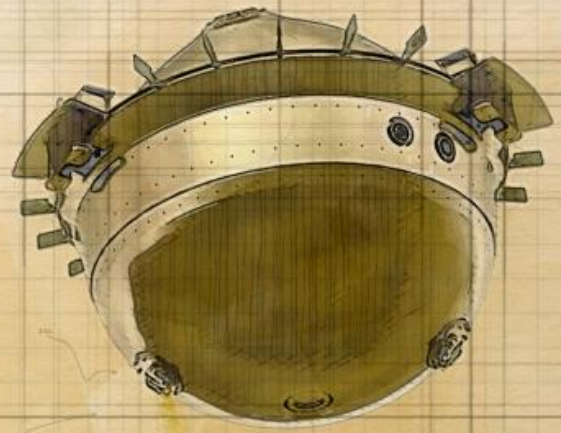
FOR SCIENCE AND FUTURE GENERATIONS

But TFAWS engineering matters!!


The DAVINCI team

DAVINCI

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



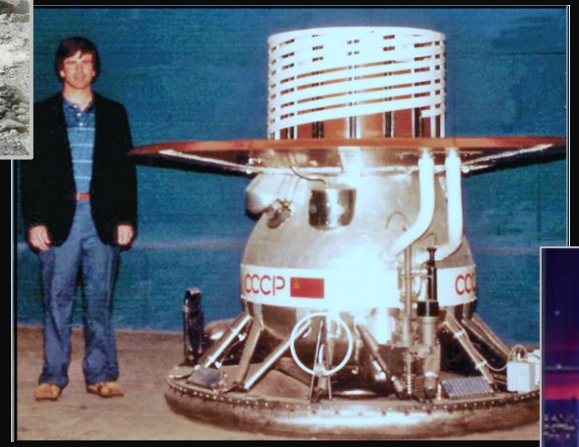
QUESTIONS *or* Comments?

First *in situ* mission to Venus since 1985: help us do this in 2029-2031!

BACKUPS

PI *: from* Grad School *to* Venus … *in* ~ 42 years

1980: searching for Venus



1983: landing on Venus

2004: talking Venus

2009: proposing Venus

Selection for flight in June 2021 !

2021: going to Venus !