DAVINCI

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

Becoming a Science Mission PI

Dr. Jim Garvin

NASA Goddard

PI: DAVINCI

June 20, 2024: PI Masters for ESE Program

Goddard Space Flight Center · Lockheed Martin · NASA Langley Research Center · JPL Jet Propulsion Laboratory, California Institute of Technology · Malin Space Science Systems · KinetX Aerospace · APL · University of Michigan · Ames Research Center

OUTLINE

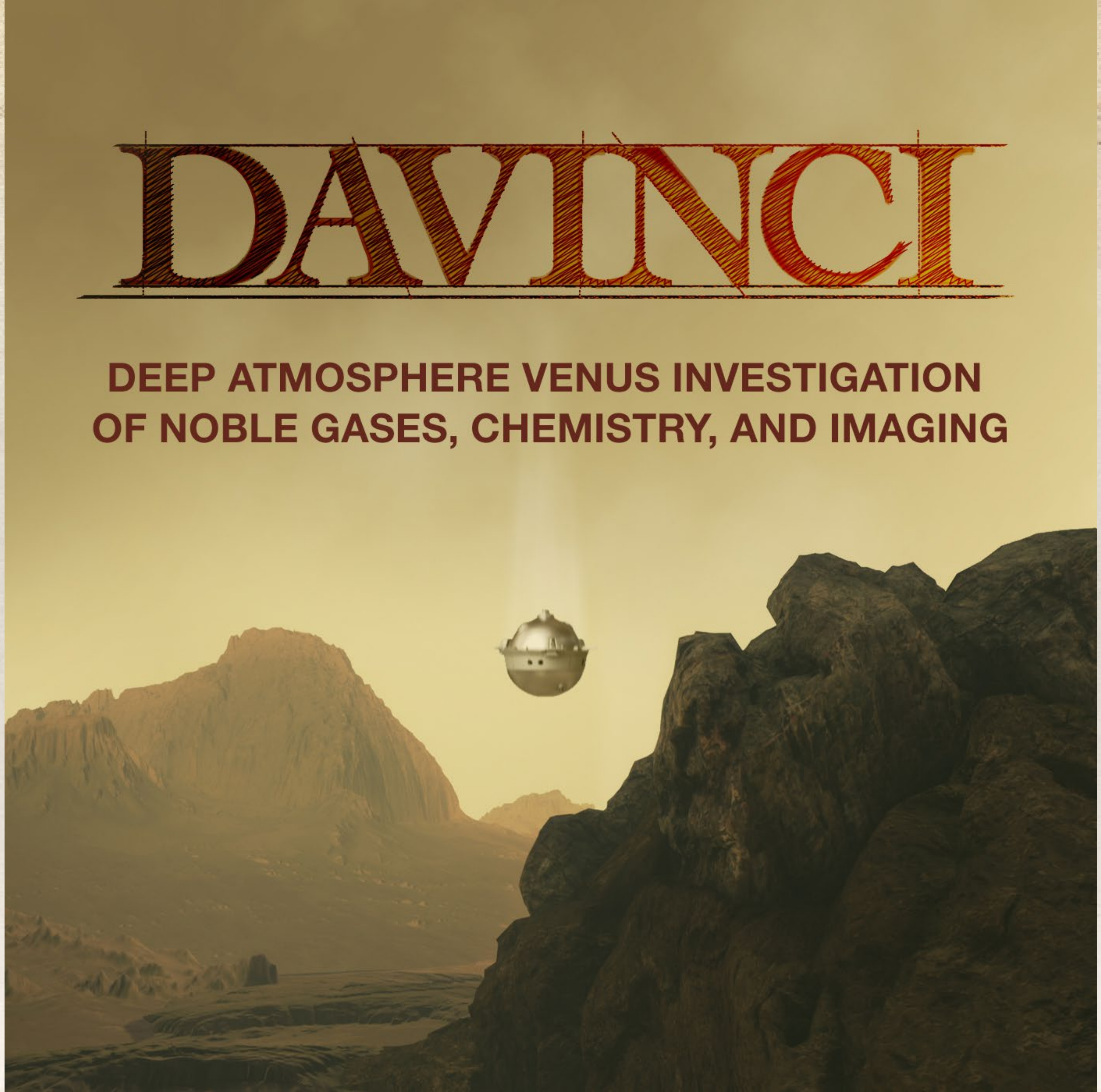
- **Becoming a competed science mission PI**
- Case example *from* **DAVINCI** mission to Venus (*NASA Discovery*)
- **THEMES to be addressed:**
  - Knowing and connecting Science Goals and Objectives to a Mission
  - Building a TEAM
  - Developing a mission concept
  - Establishing guiding principles
  - Realities of Mission systems engineering
  - Proposing (typically 2 steps)
  - Selection and implications
  - Implementation with science activities
  - Flight with science deliverables
  - ***WHY all this matters?***

This is our topic:

Returning NASA to Venus atmosphere & surface after 50+ years (DAVINCI)

<u>**Not**</u> **Earth Sciences**, *but* the Planetary *Discovery* program now has the **ESE** program at NASA which is similar !

I am **PI** of DAVINCI and was Project Scientist for ESSP (for GRACE, Calipso *etc.)*



DAVINCI

For more details on the ***science,*** please see our recently published paper (**AAS PSJ**) ➔

See also our ***science web site*** at:

https://ssed.gsfc.nasa.gov/davinci

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Revealing the Mysteries of Venus: The DAVINCI Mission

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Abstract

The Deep Atmosphere Venus Investigation of Noble gases, Chemistry, and Imaging (DAVINCI) mission described herein has been selected for flight to Venus as part of the NASA Discovery Program. DAVINCI will be the first mission to Venus to incorporate science-driven flybys and an instrumented descent sphere into a unified architecture. The anticipated scientific outcome will be a new understanding of the atmosphere, surface, and evolutionary path of Venus as a possibly once-habitable planet and analog to hot terrestrial exoplanets. The primary mission design for DAVINCI as selected features a preferred launch in summer/fall 2029, two flybys in 2030, and descent-sphere atmospheric entry by the end of 2031. The in situ atmospheric descent phase subsequently delivers definitive chemical and isotopic composition of the Venus atmosphere during an atmospheric transect above Alpha Regio. These in situ investigations of the atmosphere and near-infrared (NIR) descent imaging of the surface will complement remote flyby observations of the dynamic atmosphere, cloud deck, and surface NIR emissivity. The overall mission yield will be at least 60 Gbits (compressed) new data about the atmosphere and near surface, as well as the first unique characterization of the deep atmosphere environment and chemistry, including trace gases, key stable isotopes, oxygen fugacity, constraints on local rock compositions, and topography of a tessera.

Unified Astronomy Thesaurus concepts: Venus (1763); Planetary science (1255); Planetary probes (1252); Flyby missions (545); Planetary atmospheres (1244); Planetary surfaces (2113)

URL for doi: *https://doi.org/10.3847/PSJ/ac63c2*

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NOTE: *it takes tenacity (at least sometimes) to be a mission* ***PI***

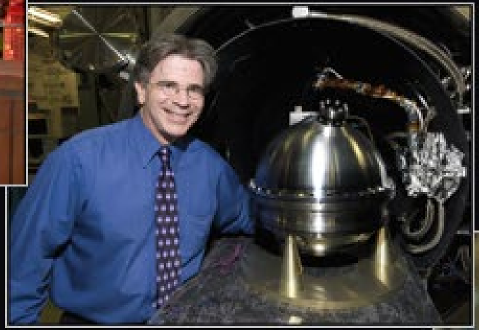
PI : *from* **Grad School** *to* Venus … *in* ~ 42 years

Selection for flight in June 2021 !

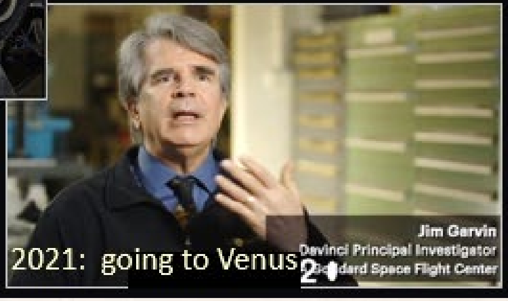
1980: searching for Venus

1983: landing on Venus

2004: talking Venus



2009: proposing Venus



2021: going to Venus

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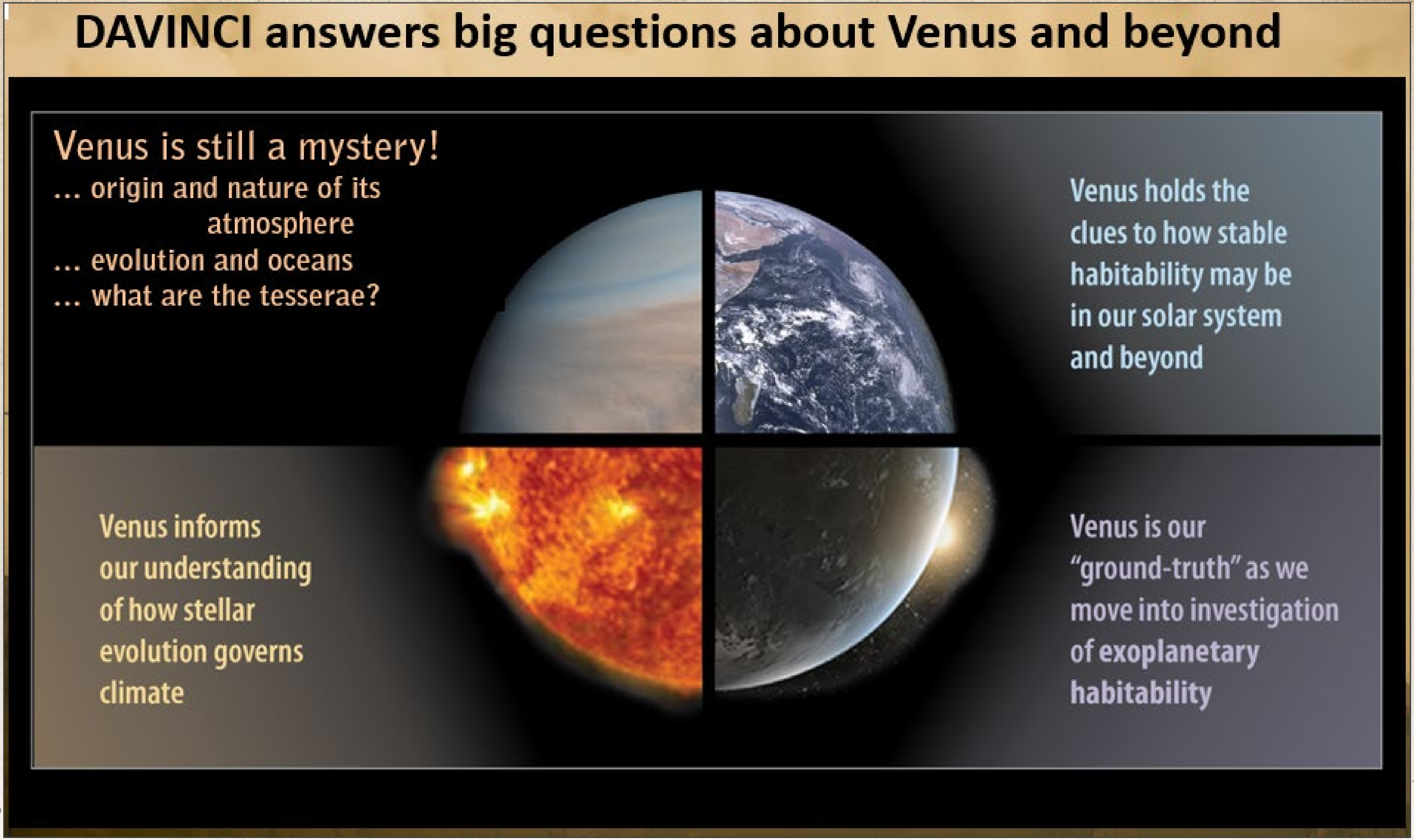
KEY Point #1: PI *and* Deputy PI(s) & Project Scientists are the **Science Leaders**, *plus* PEL's (instruments)

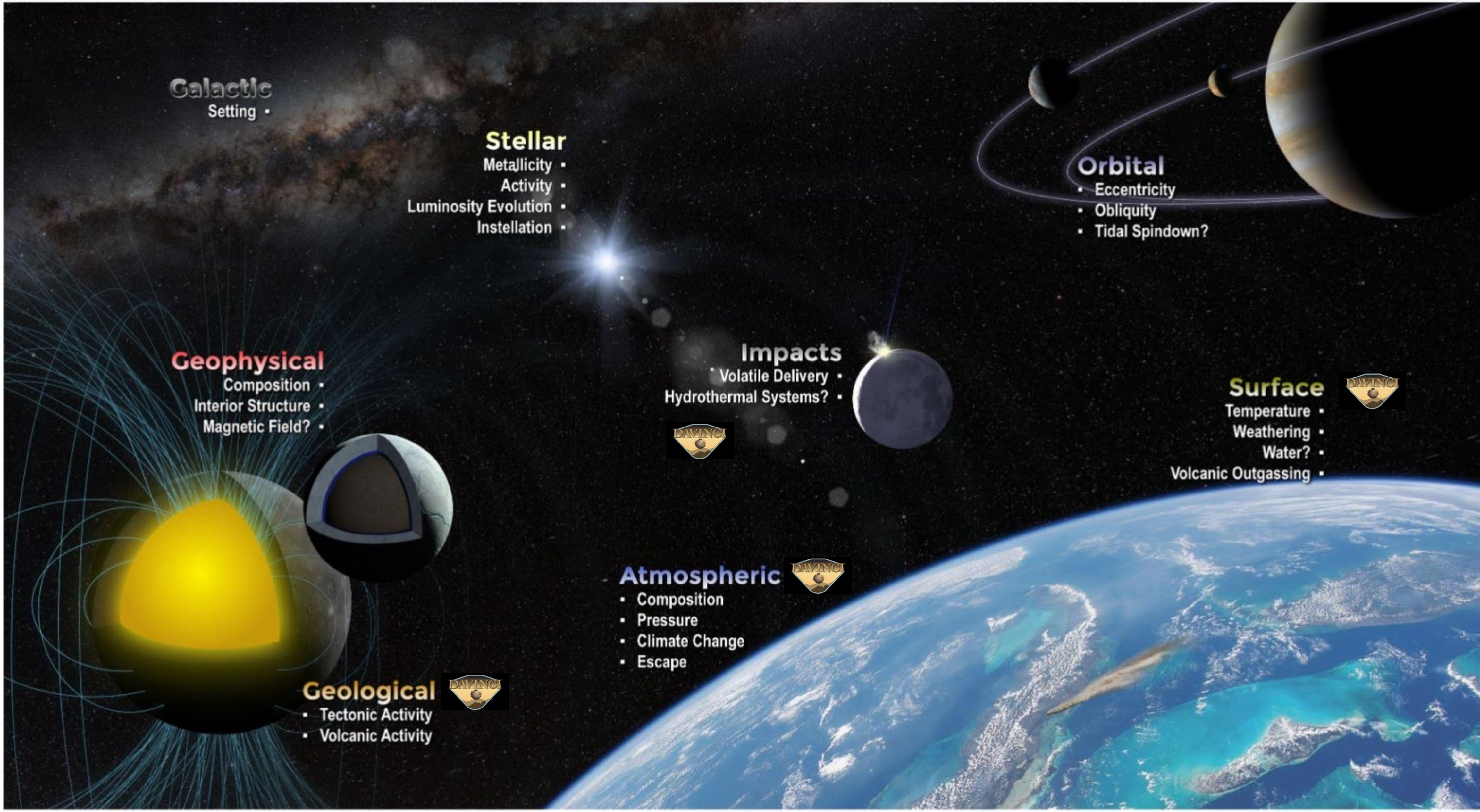
NOTE: our model is a **PI + 2 DPI's** variant as the key interface with **PM/PSE** teammates

WHERE TO START: *SCIENCE GOALS & OBJECTIVES in “BIG” CONTEXT*

KNOW WHY
your target science area matters across disciplines even if your mission focuses on one key area (or two as in ESE TO’s)



Why Venus is key to HABITABLITY beyond – the perfect "Exo-planet next door" to Earth



KEY #2: establish the big WHY's

(for elevator speeches)

Why did Venus and Earth diverge?

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

Are rocky exoplanets like Venus?

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Where DAVINCI fits into 2022 Planetary Decadal Survey

KEY #3: *map mission science goals & objectives into multi-level NASEM Decadal Survey questions and priorities (it is an AO req't!)*

Themes	Priority Science Question Topic and Scope
A) Origins	**Q1. Evolution of the protoplanetary disk** What were the initial conditions in the Solar System? What processes led to the production of planetary building blocks, and what was the nature and evolution of these materials?
	Q2. Accretion in the outer solar system How and when did the giant planets and their satellite systems originate, and did their orbits migrate early in their history? How and when did dwarf planets and cometary bodies orbiting beyond the giant planets form, and how were they affected by the early evolution of the solar system?
	Q3. Origin of Earth and inner solar system bodies How and when did the terrestrial planets, their moons, and the asteroids accrete, and what processes determined their initial properties? To what extent were outer Solar System materials incorporated? *DAVINCI*
B) Worlds & Processes	**Q4. Impacts and dynamics** How has the population of Solar System bodies changed through time, and how has bombardment varied across the Solar System? How have collisions affected the evolution of planetary bodies?
	Q5. Solid body interiors and surfaces How do the interiors of solid bodies evolve, and how is this evolution recorded in a body's physical and chemical properties? How are solid surfaces shaped by subsurface, surface, and external processes? *DAVINCI*
	Q6. Solid body atmospheres, exospheres, magnetospheres, and climate evolution What establishes the properties and dynamics of solid body atmospheres and exospheres, and what governs material loss to space and exchange between the atmosphere and the surface and interior? Why did planetary climates evolve to their current varied states? *DAVINCI*
	Q7. Giant planet structure and evolution What processes influence the structure, evolution, and dynamics of giant planet interiors, atmospheres, and magnetospheres?
	Q8. Circumplanetary systems What processes and interactions establish the diverse properties of satellite and ring systems, and how do these systems interact with the host planet and the external environment?
C) Life & Habitability	**Q9. Insights from Terrestrial Life** What conditions and processes led to the emergence and evolution of life on Earth, what is the range of possible metabolisms in the surface, subsurface and/or atmosphere, and how can this inform our understanding of the likelihood of life elsewhere?
	Q10. Dynamic Habitability Where in the solar system do potentially habitable environments exist, what processes led to their formation, and how do planetary environments and habitable conditions co-evolve over time? *DAVINCI*
	Q11. Search for life elsewhere Is there evidence of past or present life in the solar system beyond Earth and how do we detect it?
All Themes	**Q12. Exoplanets** What does our planetary system and its circumplanetary systems of satellites and rings reveal about exoplanetary systems, and what can circumstellar disks and exoplanetary systems teach us about the solar system? *DAVINCI*

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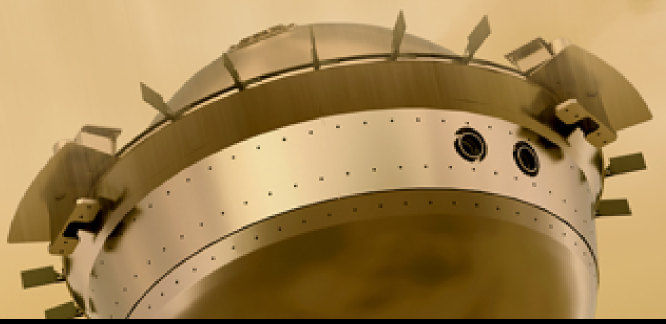
KEY: demonstrating traceability to **Decadal Survey** : from ***questions*** to ***measurements*** to ***mission***

High level traceability → connections to *PAS-Decadal, 2022* via *Questions #*: 3, 5, 6, 10, 12



NOTE: *DAVINCI key questions are derived from latest Decadal & VEXAG goals docs (2022)*

DAVINCI Goals Address Key Questions

Key Science Questions	*Traceability of DAVINCI Measurements*	VMS	VTLS	VASI	VfOx	VenDI	VISOR	CUVIS
What is the origin of the Venus atmosphere and how has it evolved? How and why is Venus different from Earth and Mars, and how does it compare to Earth-sized exoplanets?	**VMS**: noble gas abundance and isotope ratios to test current hypotheses of origin and evolution **VMS & VTLS**: atmospheric and isotopic composition, search for exotic chemistry, constrain mineralogy by constraining surface-atmosphere exchange **VfOx**: oxygen abundance near the surface **VISOR & CUVIS**: UV absorbers in the upper clouds and dynamics from flybys							
Was there an early ocean on Venus? If so, when and where did it go? What is the rate of volcanic activity on Venus?	**VMS, VTLS, & VASI**: D/H and other key trace gases above and below the clouds down to the surface; history of water **VMS**: radioactive decay products ^{40}Ar and ^{4}He to determine long-term and recent volcanism rate **VenDI & VISOR**: compositional insights into past water-rock interaction							
What exactly are the tesserae highlands? What is their origin and history? How do they compare with major highlands?	**VenDI**: high-resolution morphology, composition, and role of crustal water in igneous rock formation and erosional processes at Alpha Regio **VfOx**: constrain surface redox state through oxygen measurements near the surface-atmosphere interface **VISOR & VenDI**: IR emissivity for composition at scales of 5-200 m (VenDI) and ~70 km (VISOR) to constrain regional composition of mountains on Venus							

Science Objectives - *Level 1* Requirements

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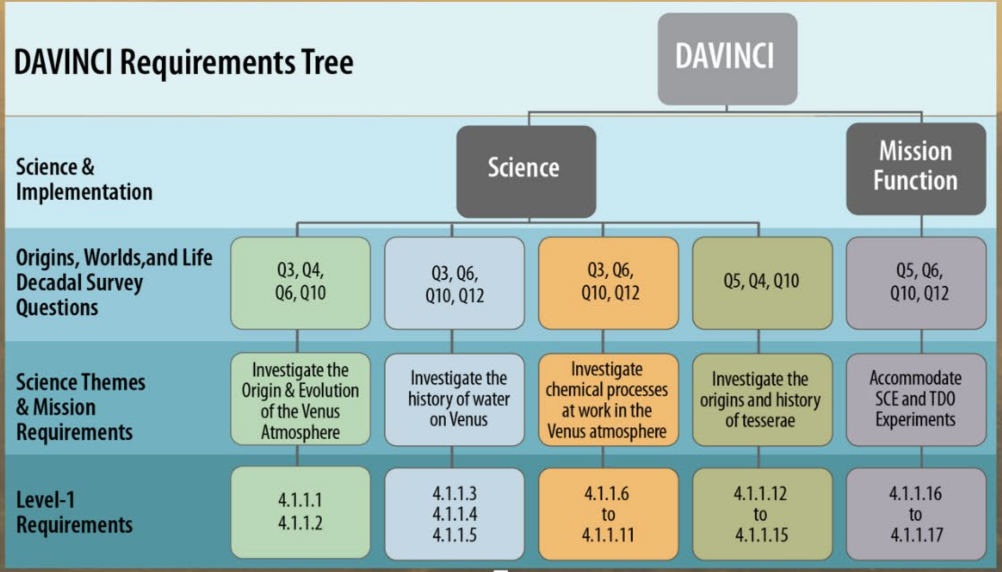
How we connect DAVINCI to Decadal Survey questions with L-1 deliverables to **NASA**

17 PLRA L-1's w/ rationales & connectivity to planetary *Decadal*



Short Form L-1's with Themes and Baseline Requirements

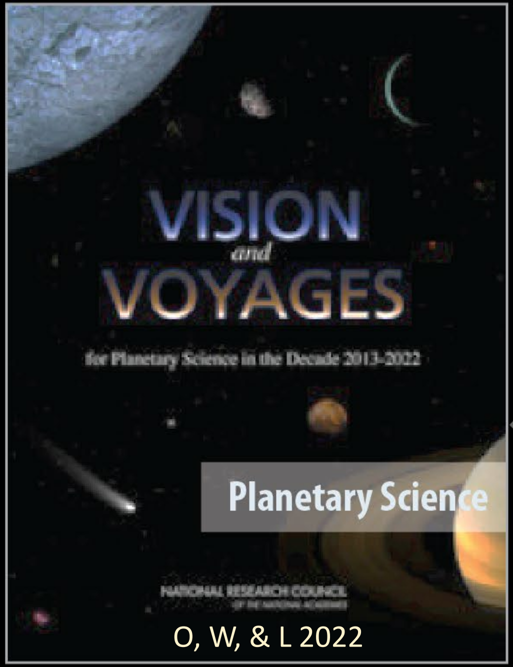
PLRA ID	Science Theme	Baseline
4.1.1.1	Origin & Evolution of the Atmosphere	Concentration of N_2, He, Ne, Ar, Kr, Xe from a sample below the homopause
4.1.1.2	Origin & Evolution of the Atmosphere	Precision of nXe/132Xe, nKr/84Kr, 40Ar/36Ar, 38Ar/36Ar, 20Ne/22Ne, 21Ne/22Ne , 3He/4He, 15N/14N from a sample below the homopause
4.1.1.3	History of Water	Precision of D/H; one sample > 55 km; at least 5 < 35 km, including 3 below 15 km w/ >5 km spacing at > 15 km & > 1km spacing at < 15 km
4.1.1.4	History of Water	Precision of $^{18}O/^{16}O$ in H_2O; vertical spacing > 5 km above 15 km, > 1 km below 15 km
4.1.1.5	History of Water	Concentrations of 40Ar, 4He, 136Xe, 129Xe and precision of the 3He/4He below the homopause
4.1.1.6	Chemical Processes	Concentrations of H2O, SO2, OCS, and CO; at least 5 samples < 35 km, incl. 3 below 15 km w/ >5 km spacing at > 15 km & > 1km spacing at < 15 km
4.1.1.7	Chemical Processes	Precisions of 13C/12C in CO2, and 34S/32S and 33S/32S in SO2 and OCS; samples spaced > 5km at > 15 km & > 1km spacing at < 15 km
4.1.1.8	Chemical Processes	Concentrations of H2O, SO2, and OCS, and 34S/32S in SO2 sampled at least once > 55 km and once/km < 30 km
4.1.1.9	Chemical Processes	Mass & concentration of species containing at ≥ 1 and ≤ 8 sulfur atoms up to 272 Da; sampling once > 55 km and once/km < 30 km
4.1.1.10	Chemical Processes	Measure pressure and temperature after aeroshell separation at altitudes < 60 km
4.1.1.11	Chemical Processes	UV images; spatial resolution < 20 km/pixel and solar phase angle < 60 degrees at two or more epochs
4.1.1.12	Origins & History of Tesserae	2 digital topographic maps from ≥ 5 overlapping sub-cloud NIR images at Western Alpha Regio. One at > 30 km^2 and one at ≥ 9 km^2 scales
4.1.1.13	Origins & History of Tesserae	1 sub-cloud NIR image of Western Alpha Regio with res 1.5 (+/- 0.05) m/pixel over an area of > 0.25 km^2
4.1.1.14	Origins & History of Tesserae	3 band ratio maps at Western Alpha Regio at 3 spatial resolutions between 10 m and 150 m; 5 sigma separation between basalt and granite surfaces
4.1.1.15	Origins & History of Tesserae	NIR images of 3 highlands including Alpha Regio or similar; 3 sigma separation between basalt and granite surfaces
4.1.1.16	SCE & Tech Demo	Accommodate CUVIS technology demonstration instrument
4.1.1.17	SCE & Tech Demo	Accommodate VfOx student collaboration experiment

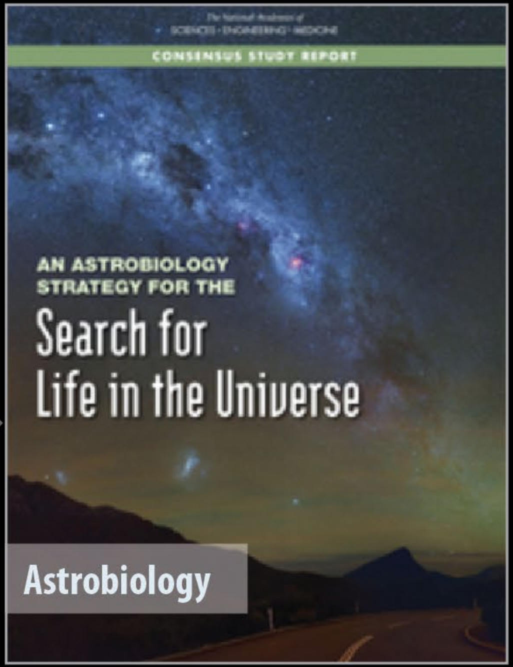
Signed by SMD AA in DAVINCI PLRA Dec. 2023

High discovery potential & impact →

Key: know how your mission connects!

DAVINCI science connects to multiple guiding documents





Addressing planetary goals & priorities

Evolution of habitability & false positives

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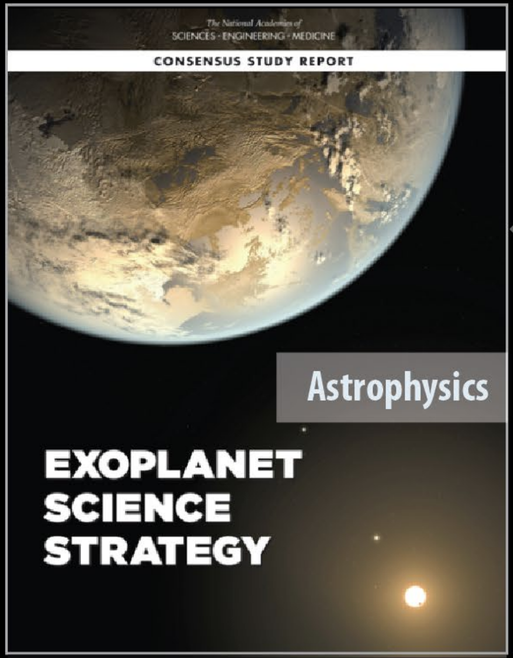
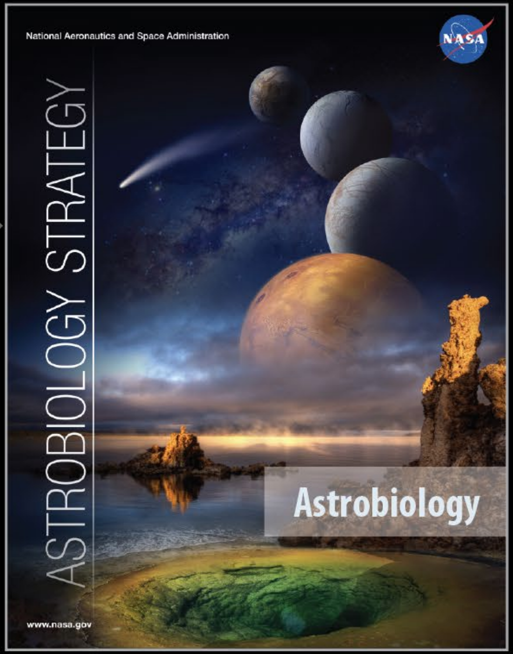
Deep Atmosphere Venus Investigation of Noble gases, Chemistry, and Imaging

Interpretation of JWST observations

Habitability and intersection of sciences





DAVINCI is at the center of interdisciplinary community needs

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KEY: <u>simple mapping</u> of **macro-science** goals into themes that connect to NASA strategic priorities (solar system)

This approach helps in some cases (used for *Europa Lander* SDT and DAVINCI, for example)

[DAVINCI : PI Masters 2024]

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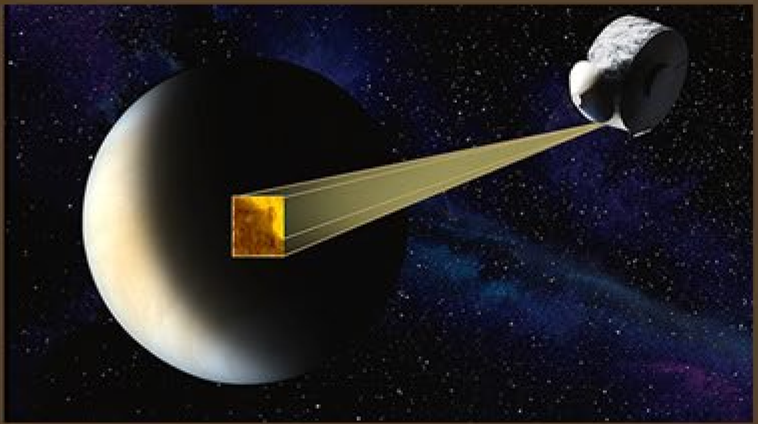
Deputy Principal Investigators
Dr. Stephanie A. Getty, NASA's GSFC
Dr. Giada N. Arney, NASA's GSFC



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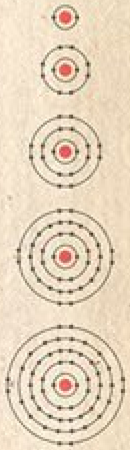
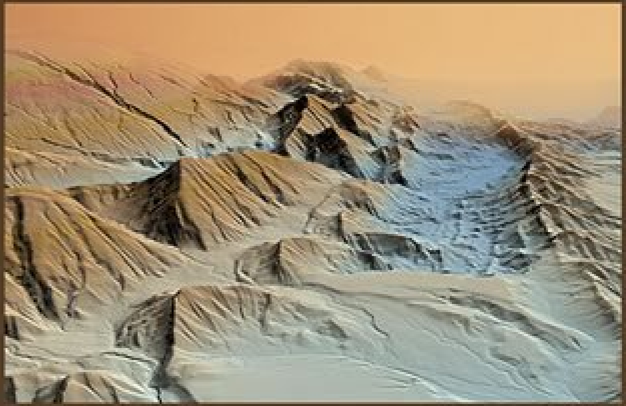
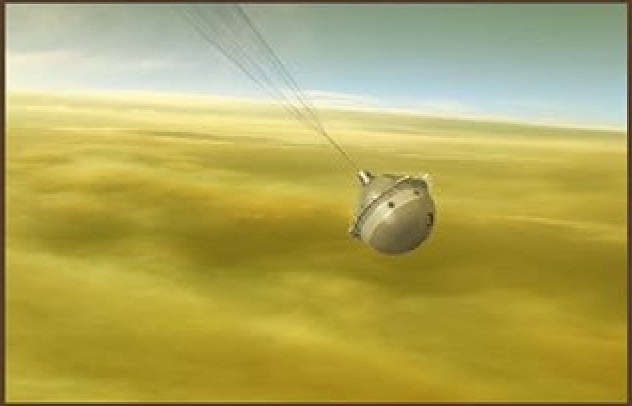
Deep Atmosphere Venus Investigation of Noble gases, Chemistry, and Imaging







Showcase the mission with its science !

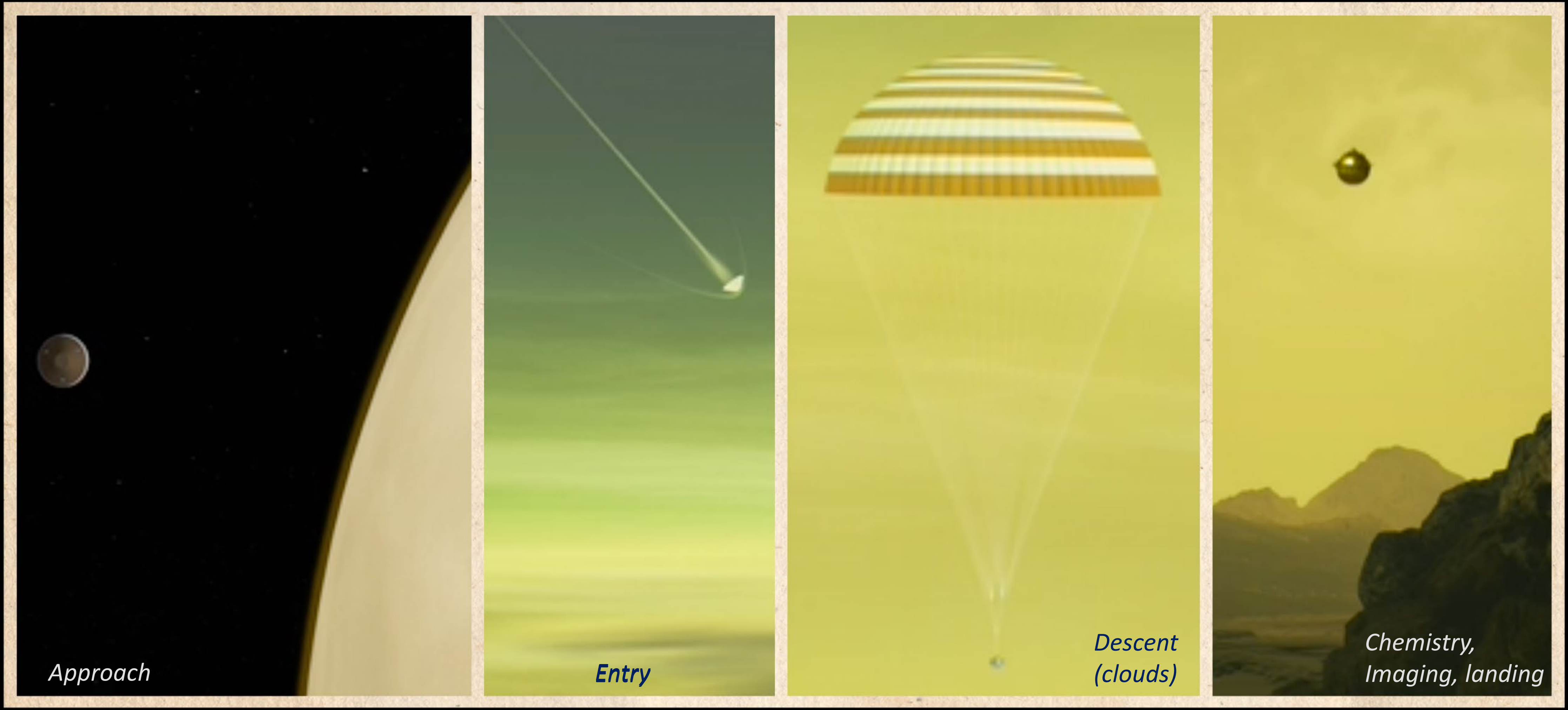
NASA

LOCKHEED MARTIN

NASA's Goddard Space Flight Center
in partnership with Lockheed Martin
and
Jet Propulsion Laboratory
Malin Space Science Systems
NASA's Langley Research Center
NASA's Ames Research Center
KinetX
University of Michigan
JHU Applied Physics Laboratory


DAVINCI will explore past and present Venus
Deep Atmosphere Venus Investigation of Noble Gases, Chemistry, and Imaging [redacted]
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
PROBE
Way et al. (2016) GRL
Kepler-69c
KEY: simple one-page descriptions help at Step 1→ 2 (with NASA HQ)

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



KEY: flight mission systems engineering tied to required vantage point(s) and known risks

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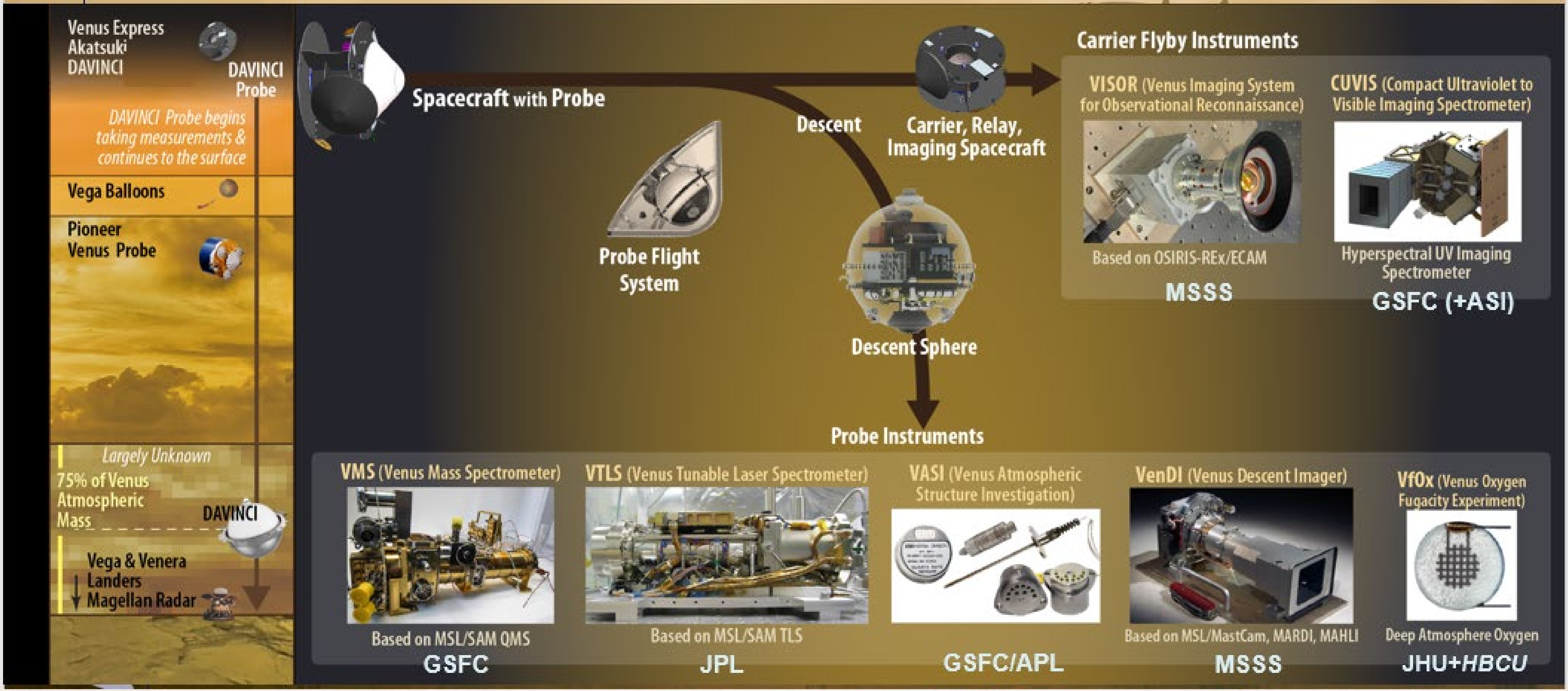
KEY: developing **partnerships** for spacecraft and instruments with breadth (and **trust**)



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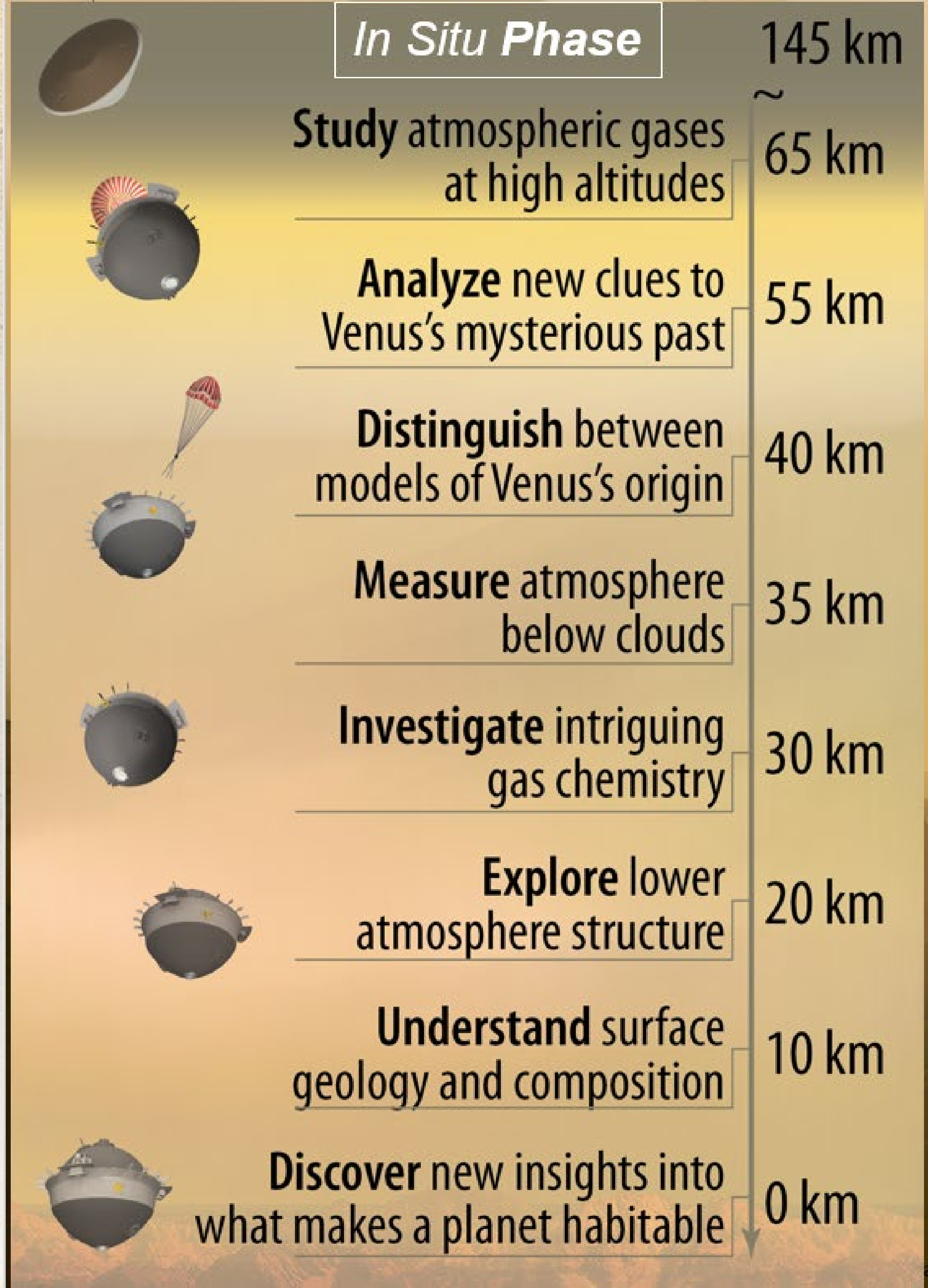
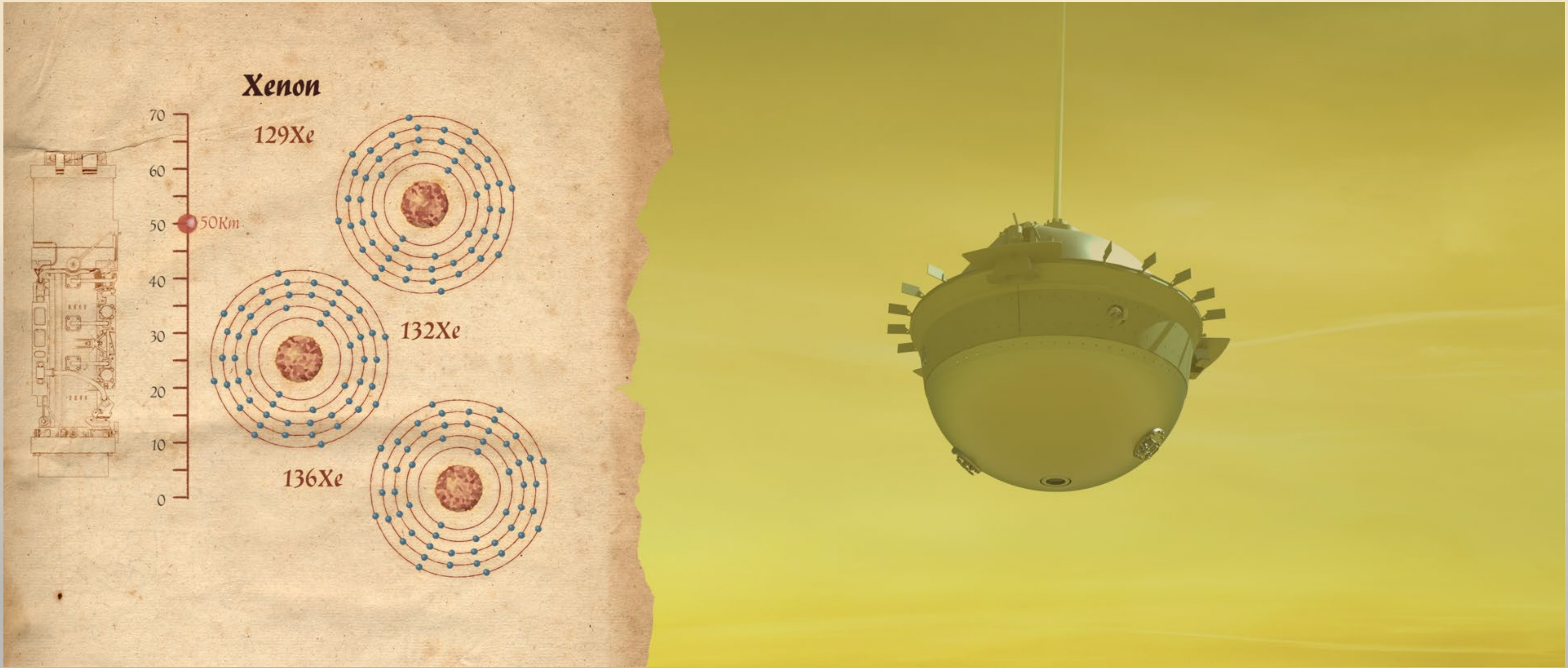
KEY: understanding the design reference mission and its scientific deliverables and margins

We describe our in situ mission as a science "submarine" to take the plunge into Venus' "ocean of air"



at MSFC

Using “molecular fossils” like Xenon



KEY: measurements that <u>change the current state of knowledge</u> (traceable to latest ***DECADAL SURVEY***)

[DAVINCI : PI Masters 2024]

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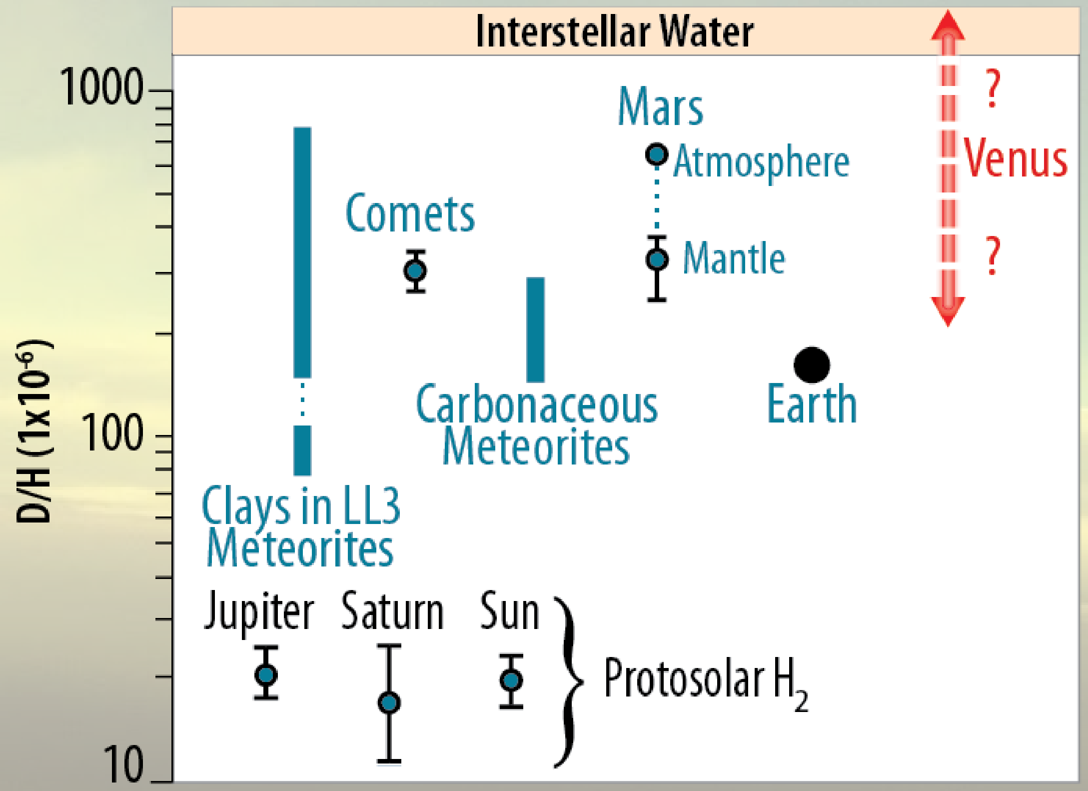
How much water did Venus have?
Where did it come from? What happened to it?

The answer is revealed by understanding the balance between **sources** and **loss**

Atmospheric origins	Noble gases and isotopic signatures
Delivery of volatiles	
Degassing over time	Noble gas abundances
Atmosphere & Ocean Loss	D/H in water

DAVINCI will make direct measurements to provide answers

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



Prior measurements indicate

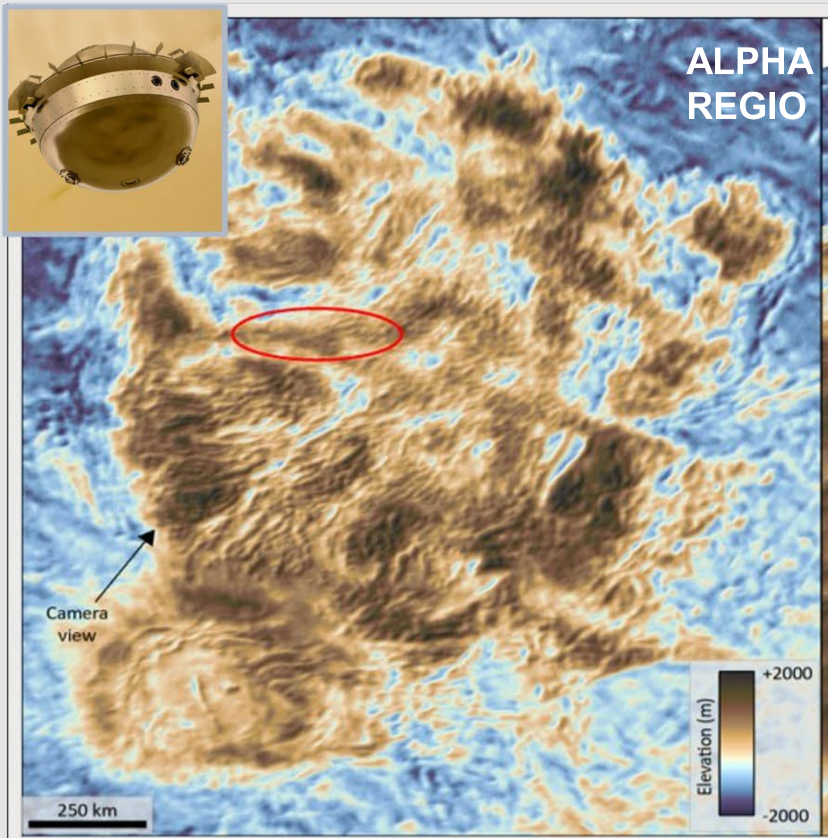
- Anomalously high D/H
- Gradients in D/H from the upper atmosphere to the cloud region

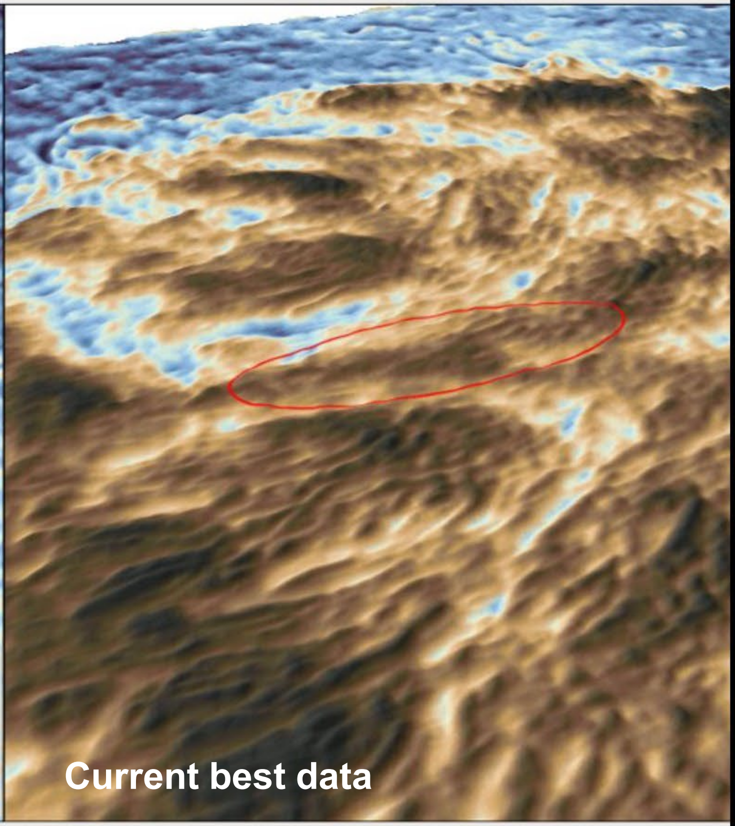
VTLS will make… 10 altitude-resolved, definitive measurements of D/H in water from above the clouds to the near-surface

… a major breakthrough

DAVINCI will confirm past oceans and the timing of the loss

Exploring Venus' *Alpha Regio* highlands





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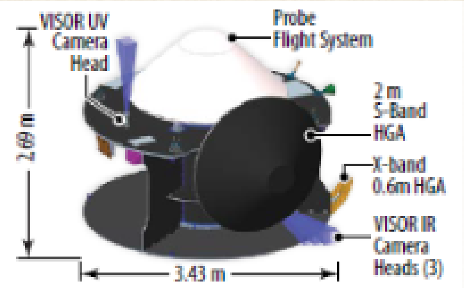
GENERAL MISSION OVERVIEW (HQ and GAO) with a few details: 2021 to 2033

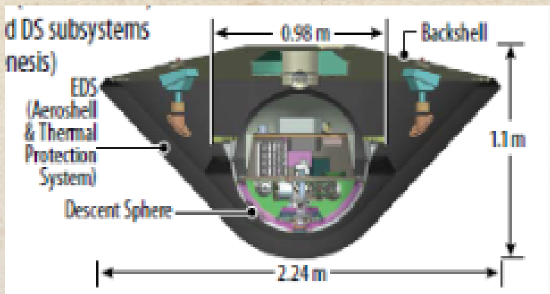
Science Description

DAVINCI will measure the composition of Venus' atmosphere to understand how it formed and evolved, as well as determine whether the planet ever had an ocean. The mission consists of a **Descent Sphere** that will plunge through the planet's thick atmosphere, making precise measurements of noble gases and other compounds to understand why Venus' atmosphere is a runaway hothouse compared the Earth's. It also includes Venus flybys for remote sensing of the composition and dynamics of the upper clouds, as well as of the nightside emissivity of highlands including the target area for descent sphere entry, descent, and imaging (Alpha Regio).

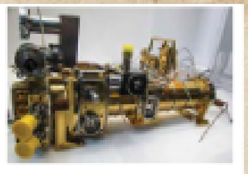
Spacecraft (CRIS):



Probe Flight System:



VMS:



VTLS:

VASI:

VenDI:

VISOR:

DS:

VfOx CUVIS

Project Description

DAVINCI will launch in CY2029, perform two Venus flybys and image the planet's upper clouds & surface with VISOR and CUVIS, then release its Descent Sphere to conduct an in situ science of the atmospheric chemistry over 59 minutes, descending over the Alpha Regio highlands.

Key Information

Mission Phase: B
Launch Date: 2030
Mission Life: 2 yrs
Category: 2
Class: C
Launch Vehicle: TBD

LCC *~ $964M (without LV, UFE)*

Instruments

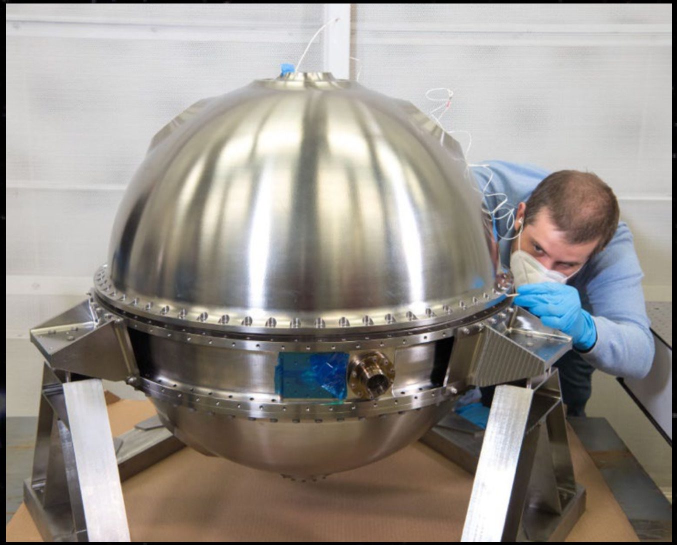
VenDI (Venus Descent Imager): MSSS
VMS (Venus Mass Spectrometer): NASA GSFC
VASI (Venus Atmospheric Struct. Invest): NASA GSFC
VTLS (Venus Tunable Laser Spectrometer): NASA JPL
VISOR (Venus Imaging Sys for Observ Recon): MSSS
CUVIS (Compact Ultraviolet to Visible Imaging Spectrometer): NASA GSFC
VfOX Student Collaboration: JHU/APL

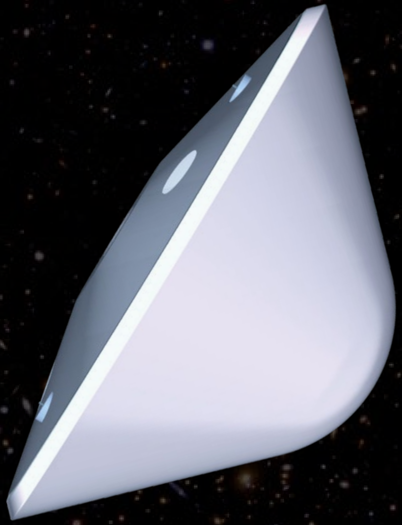
Partners & Contractors

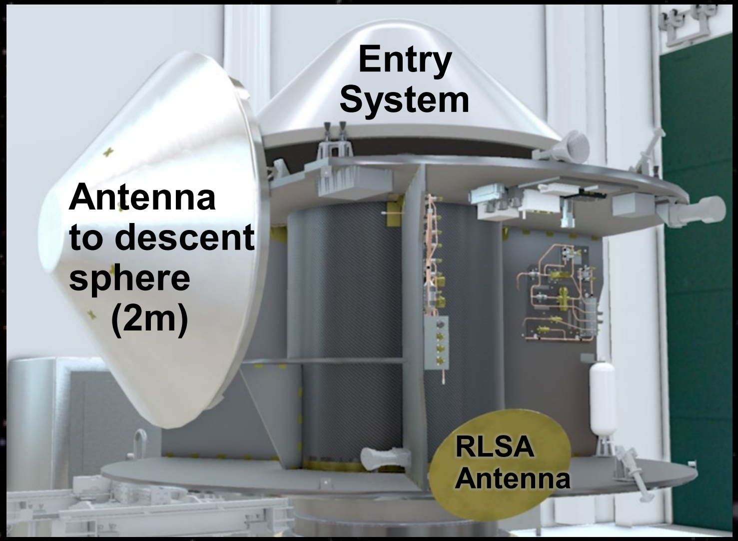
NASA GSFC – PI Institution, Project Management, Systems, Mission Assurance, VMS, VASI, Descent Sphere (DS), SOC, Flight Dynamics [with APL for Frontier Radio]
Lockheed Martin Space – Spacecraft (CRIS), Ground System, Mission Operations Center, Probe Flight System (aeroshell)
NASA JPL - VTLS
MSSS (Malin Space Science Systems) – VenDI, VISOR
NASA KSC – Launch Services
KinetX – Navigation

From **Selection** (6/2021) to **key gates** (PDR, CDR, LRR) to **Launch** to *on target* science observations …

DAVINCI flight systems are ready to go!







Descent Sphere (DS)

Entry System (ES)

Spacecraft [CRIS]
(with entry system attached)

DAVINCI

DAVINCI is made possible through partnerships

NASA Centers

GSFC – Lead
LaRC – entry analysis
ARC – thermal protection
KSC – Launch

Industry

Lockheed Martin – Spacecraft, Entry Systems
Malin Space Science Systems – Cameras
KinetX – navigation
NTS – Venus Test Chamber

FFRDCs/UARCs

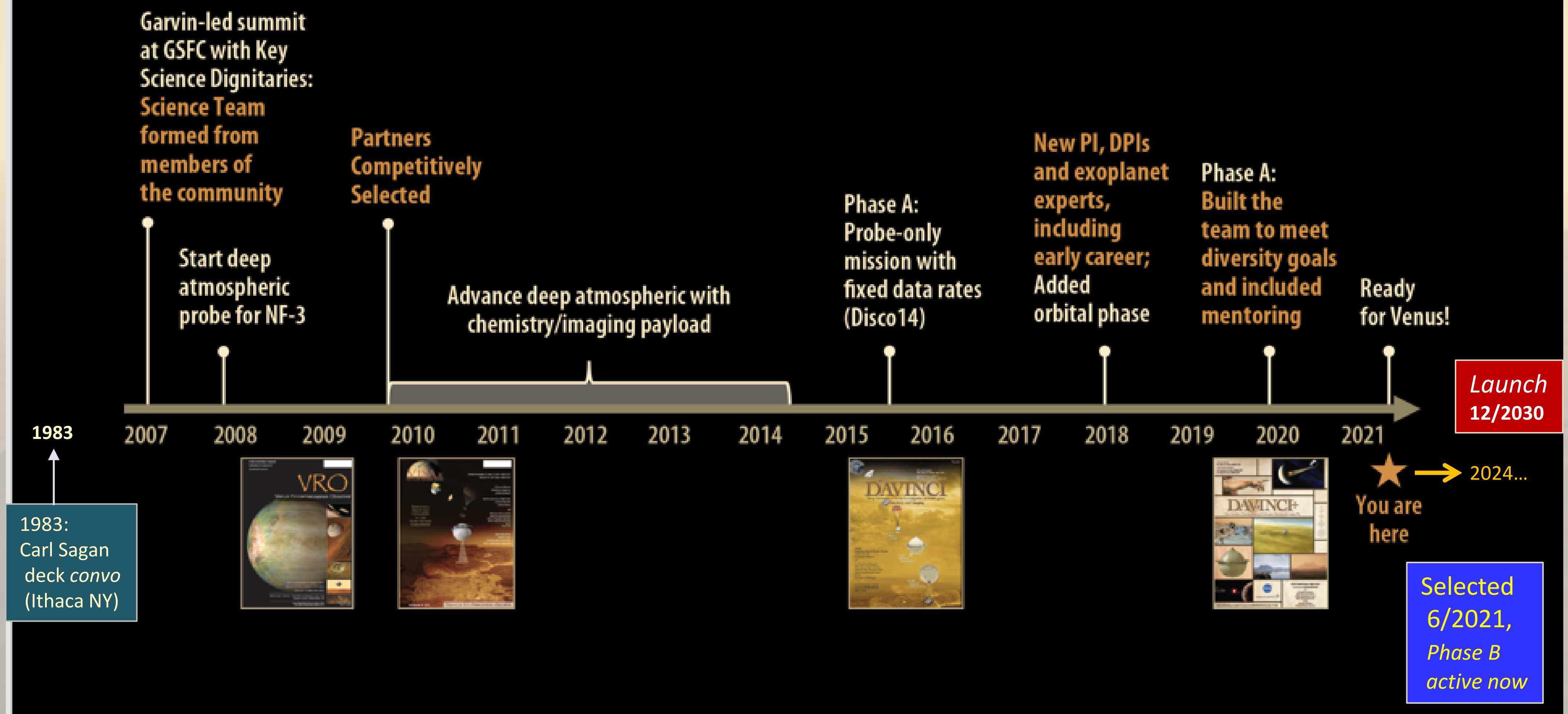
JPL – VTLS, DSN
APL – VASI, Communications

Universities and Science Organizations

Arizona State University
Italian Space Agency, Italy
Lunar and Planetary Institute
Planetary Science Institute
Smithsonian Institution
Univ. California Riverside
University of Arizona
University of Michigan – VMS electronics
Wesleyan University
University Pierre et Marie Curie, France

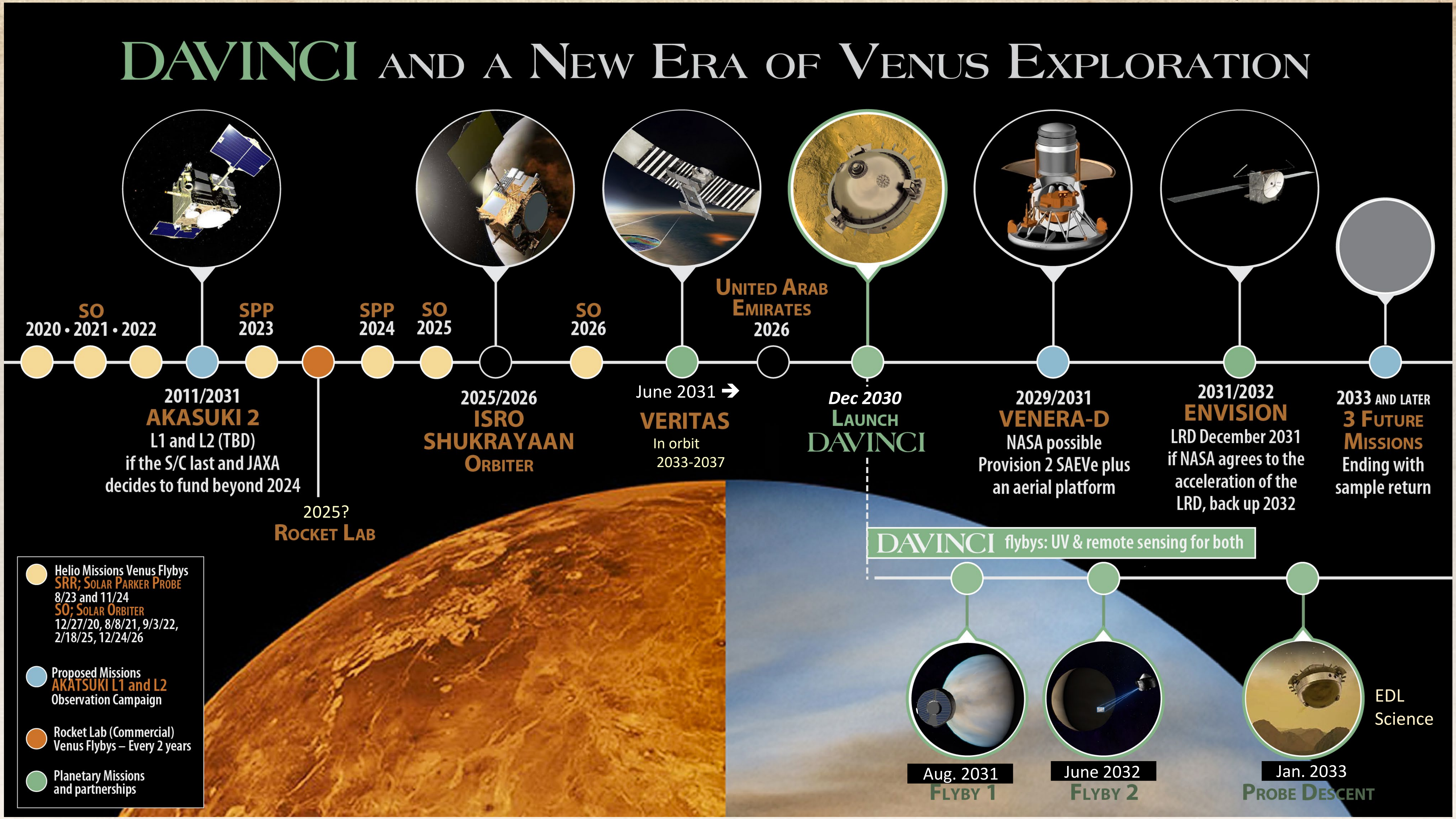
The Team MATTERS *in all phases*

Building the DAVINCI Team



DAVINCI

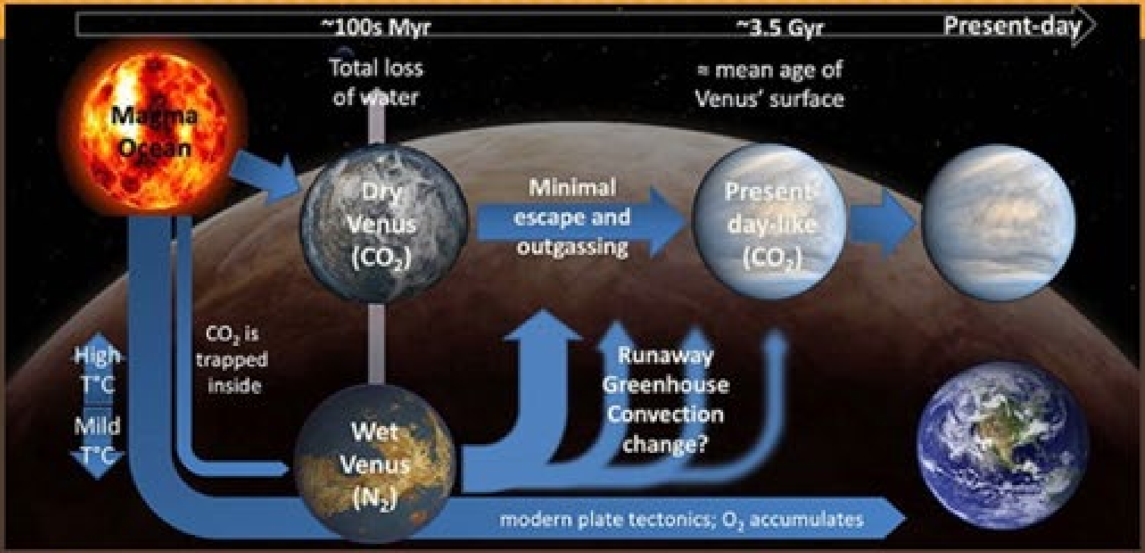
KEY: *Connecting* to **larger** programs of scientific investigation at NASA *in science context*



** launch dates are current best estimates **

KEY: science connectivity matters, especially in **Planetary and Earth Sciences** *at* NASA

Three Venus Missions Working Together to Reconstruct Venus History: DAVINCI *role*



Geologically active present? : DAVINCI volcano signature trace gases (He) + VERITAS & EnVision search for volcanic change, thermal anomalies, gas plumes

Aqueous past? : DAVINCI isotope geochemistry (D/H) + all three missions felsic highland search (*multi-scale: 70 km to 5 m*)

Formation & Early evolution : DAVINCI isotope geochemistry (nobles) & trace gas chemistry + VERITAS & EnVision interior structure science

DAVINCI

KEY: *science guides, but realistic systems engineering and cost management by experienced DPMR and business team are* ***ESSENTIAL*** *!!!*

SUMMARY

- Being a **PI** is a **full-time job** (and a privilege <u>beyond words</u> given $$ invested by US)
- Working as PI to succeed in a ~2 year Step 1 *to* CSR to Selection cycle is a complex process – build on what has worked and tailor to your context (specific AO)
- ***PI*** must work seamlessly with business team and Project systems engineering team to propose effectively (with DPI(s) and others, including PEL's for instruments)
- Strong *Proposal Manager* matters – **PI** has to work with *Prop. Mgr.* so that the vision for the proposal (especially in CSR = Phase A) is realized [1379 pages + appendices]
- Build partnerships and keep mission scope fixed and realistic with reserves $\geq$ 30%
- Strong business/cost team (led by DPMR) is a **key ingredient** (experience matters)
- Spread the wealth of science across the community (instruments, Co-I's *etc.*)!

“EDL/Science” in Jan 2033

Dreams can come true!

Communicating *our story* with our Administrator

DAVINCI
Probe ETU
with NASA
Admininsitrator
(Sen. Nelson))

QUESTIONS?