VEXAG for CAPS NF Meeting #3

Noam R. Izenberg,
Johns Hopkins University Applied Physics Laboratory
for the Venus Exploration Analysis Group Steering Committee

Committee on Astrobiology and Planetary Sciences Meeting No. 3 on New Frontiers Mission List Review
May 20, 202

VENUS In Situ Explorer

VISE in V&V (NF 5)

1. Understand the physics and chemistry of Venus's atmosphere; abundances of its trace gases, sulfur, light stable isotopes, and noble gas isotopes;
2. Constrain the coupling of thermochemical, photochemical, and dynamical processes in Venus's atmosphere and between the surface and atmosphere to understand radiative balance, climate, dynamics, and chemical cycles;
3. Understand the physics and chemistry of Venus's crust;
4. Understand the properties of Venus's atmosphere down to the surface and improve our understanding of Venus's zonal cloud-level winds;
5. Understand the weathering environment of the crust of Venus in the context of the dynamics of the atmosphere and the composition and texture of its surface materials
6. Look for planetary-scale evidence of past hydrological cycles, oceans, and life and for constraints on the evolution of the atmosphere of Venus.

VISE in OWL (NF 6)

A. Characterize past or present large-scale spatial and temporal (global, longitudinal and/or diurnal) processes within Venus's atmosphere.

B. Investigate past or present surface-atmosphere interactions at Venus.

C. Establish past or present physical and chemical properties of the Venus surface and/or interior.

Numbers/letters do not denote priority

CAPS Statement of Task

1. Has scientific understanding or external factors, such as programmatic developments or technological advances, significantly changed since the New Frontiers 5 (NF-5) mission themes or New Frontiers 6 (NF-6) mission themes were evaluated by most recent planetary science and astrobiology decadal survey, Origins, Worlds, and Life (OWL)?

2. Has scientific understanding or external factors, such as programmatic developments or technological advances, been sufficiently substantial since OWL to warrant reconsidering or removing any of these mission themes?

3. Given that NASA anticipates the next New Frontiers Announcement of Opportunity (AO) will be released no earlier than 2026, should NASA use the mission themes provided in the draft NF-5 AO (released 1 September 2023), the NF-6 mission themes as provided in OWL, or a hybrid of the these?

Statement of Task

1. Has scientific understanding or external factors, such as programmatic developments or technological advances, significantly changed since the New Frontiers 5 (NF-5) mission themes or New Frontiers 6 (NF-6) mission themes were evaluated by most recent planetary science and astrobiology decadal survey, Origins, Worlds, and Life (OWL)?

The OWL decadal recognizes the cross-cutting science case for Venus

The VISE mission remains a considered, logical follow-on to the current upcoming Venus missions

DAVINCI and VERITAS, and the ESA Venus mission EnVision will be complete or in late operational phase by the next plausible New Frontiers Launch date.

Statement of Task

2. Has scientific understanding or external factors, such as programmatic developments or technological advances, been sufficiently substantial since OWL to warrant reconsidering or removing any of these mission themes?

VEXAG retains the position that there is neither scientific nor programmatic reason to change or remove the OWL decadal themes.

There are few enough competitive major mission opportunities in the foreseeable future.

Statement of Task

3. Given that NASA anticipates the next New Frontiers Announcement of Opportunity (AO) will be released no earlier than 2026, should NASA use the mission themes provided in the draft NF-5 AO (released 1 September 2023), the NF-6 mission themes as provided in OWL, or a hybrid of the these?

VEXAG advocates retaining the NF 6 mission themes, possibly augmenting them with OWL-updated versions of the NF 5 themes not currently included.

No theme that addresses multiple crosscutting Questions of the OWL decadal should be considered for removal.

Advancements (Science)

- Continuing new atmospheric observations and analyses from Akatsuki
  - Horinouchi et al. (2024), Espadinha et al. (2024)
- Mining of new science from old datasets
  - Venus as an active world (Venus Express, Magellan)
  - Herrick & Hensley (2023)
- Venus as key to exoplanets and habitability.
  - Kane & Byrne (2024)
  - Seager et al. (2023)

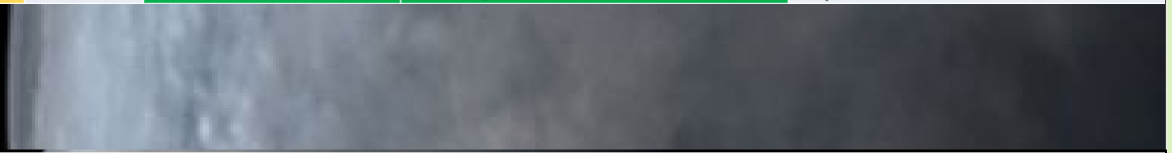
Advancements (Science)

Selected Venus missions

- DAVINCI – Deep atmosphere probe
  - Launch ~2031; Completion ~2033
- VERITAS – Radar Orbiter
  - Launch ~2031; Completion ~2036
- EnVision – ESA/NASA – Radar Orbiter
  - Launch ~2031; Completion ~2036

Rocket Lab Venus mission (~2025)

Goal	Objective	Investigation	Achieved by end of V3NUS	Future Achievement
I. Understand Venus' early evolution and potential habitability to constrain the evolution of Venus-size (exo)planets.	A. Did Venus have temperate surface conditions and liquid water at early times?	HO. Hydrous Origins	Near-IR emissivity maps, searching for widespread felsic crust.	**Measurement of surface rock composition in situ (e.g. XRF, GRS, LIBS), particularly in tesserae**
		RE. Recycling	Radar maps, subsurface sounding, Near-IR emissivity maps.	**Measurement of surface rock composition in situ (e.g. XRF, GRS, LIBS).** Follow-up high-res radar & high res NIR surface imaging
		AL. Atmospheric Losses	-	Orbital measurements of ionosphere & solar wind interaction; sub-mm sounder to measure winds and transport through lower thermosphere
		MA. Magnetism	-	**Magnetic fields** measured from orbit **and/or balloon**
	B. How does Venus elucidate possible pathways for planetary evolution in general?	IS. Isotopes	Comprehensively addressed by DAVINCI.	**Next generation MS instruments on long-lived cloud platform** may be able to achieve even higher sensitivity
		LI. Lithosphere	Comprehensively addressed by VERITAS & EnVision's SAR & gravity.	Seismometry; Magnetotelluric sounding; **In situ measurements of surface material composition.** Follow-up high-res radar & high res NIR surface imaging
		HF. Heat flow	Constraints from gravity/ topography calcs; also from detection & characterization of volcanism & tectonism.	***Seismometry***; in situ heat flow
		CO. Core	Strongly constrained by gravity measurements & spin vector variation monitoring.	***Seismometry*. Higher accuracy gravity. Magnetic field measurements from orbit and/or aerobot**



Goal	Objective	Investigation	Achieved by end of V3NUS	Future Achievement
III. Understand the geologic history preserved on the surface of Venus and the present-day couplings between the surface and atmosphere	A. What geologic processes have shaped the surface of Venus?	GH. Geologic History	global SAR imaging & topography, nIR emissivity, gravity & subsurface mapping including high-res imaging follow-up.	**In situ measurement of surface composition (multiple locations?).** Follow-up high-res radar & **high res NIR surface imaging**
		GC. Geochemistry	Constraints from nIR emissivity maps (& SAR & radiometry).	**In situ measurement of surface composition**
		GA. Geologic Activity	Change detection in repeated SAR imagery [with limited repeat-pass InSAR for cm-scale changes], nIR & RF thermal anomaly search, volcanic plume search (EnVision), volcanic tracer search (DAVINCI).	Systematic surface monitoring with repeat-pass InSAR & radiometry (NIR & RF). Seismometry (surface aerobot, or orbital)
		CR. Crust	Addressed by VERITAS & EnVision's SAR & gravity, and EnVision's Sub-surface sounding, and DAVINCI descent imaging.	***Seismometry***; Magnetotelluric sounding; **In situ measurements of surface material composition.**
	B. How do the atmosphere and surface of Venus interact?	LW. Local Weathering	Constraints from nIR emissivity maps (& SAR & radiometry) *[but see text – this really targets lander measurements]*. Also DAVINCI measurements of near-surface atmospheric composition.	**In situ measurement of surface & atmosphere composition (at multiple localities)**
		GW. Global Weathering	Constraints from nIR emissivity maps (& SAR & radiometry) & SAR imagery.	**In situ measurement of surface & atmosphere composition, global patterns**
		CI. Chemical Interactions	DAVINCI measurements of near-surface atmospheric composition. EnVision measurements of tropospheric gas abundances. VERITAS & EnVision maps of clouds & low-altitude water vapour. Study of radar anomaly.	Surface landers & meteorological stations. Follow-up high res radar and other surface mapping

Goal	Objective	Investigation	Achieved by end of V3NUS	Future Achievement
II. Understand atmospheric dynamics and composition on Venus.	A. What processes drive the global atmospheric dynamics of Venus?	DD. Deep Dynamics	Vertical profile of P, T, wind, from DAVINCI; cloud-level winds & waves from cloud tracking particularly from Akatsuki; gas mapping & radio occultation from EnVision; surface winds from Aeolian features from SAR.	**Cloud-level 3-D winds & waves from aerobot.** Long-life surface meteorological station. Next-generation cloud tracking from orbit. Sat-to-Sat radio occultations for frequent T profiles at 40 – 90 km
		UD. Upper Dynamics	Imaging of upper atmosphere in different wavelengths from all 3 missions.	Ionosphere / magnetosphere / plasma / solar wind interaction orbital measurements. Sub-mm heterodyne to measure winds & transport at 70 – 140 km, or thermal IR sounding of mesosphere (60 – 100 km)
		MP. Mesoscale Processes	Constraints on winds & waves from Akatsuki & Envision. VERITAS, DAVINCI camera elements.	**Cloud-level 3-D winds & waves from aerobot. Simultaneous orbital & in situ atmospheric observations.** Long-life meteorological station
	B. What processes determine the baseline and variations in Venus atmospheric composition and global and local radiative balance?	RB. Radiative Balance	Radiative flux measurement from DAVINCI+ descent probe. New spectroscopy from orbit by EnVision.	Radiative flux measurements from descent probe. **Cloud-level radiative flux measurements from aerobot**. Long-life radiometric/meteorological station
		IN. Interactions	DAVINCI chemical profiles, and EnVision's maps of key volatile gases, and links to volcanic activity as studied by VERITAS & EnVision.	**In situ characterization of cloud particles, radiation, microphysics. Search for lighting** (**aerobot**, orbiter). Aeolian processes (lander, orbiter)
		AE. Aerosols	VERITAS/VEM, and EnVision/VenSpec will map aerosol distributions. DAVINCI+ will measure the gaseous volatile species which participate in condensational cloud formation.	**In situ cloud-level aerobot measuring cloud and gas composition, and particle size & shape. Characterization of dust at surface**
		UA. Unknown Absorber	VenSpec-U and CUVIS will contribute new UV observations. DAVINCI contributes to understanding of chemical inventory in clouds.	**In situ cloud-level aerobot measuring cloud, gas, aerosol composition, especially at altitudes > 60 km, and UV/blue fluxes**
		OG. Outgassing	DAVINCI will obtain a vertical profile of composition including volcanically outgassed volatiles; EnVision-VenSpec will map major outgassed volatile species.	**In situ measurements of surface and cloud materials to search for signatures of outgassed volatiles**

- Evaluation of expected accomplishments of "V3NUS" vs. what is missing and what is next.

e.g. VISE

Advancements (Technology)

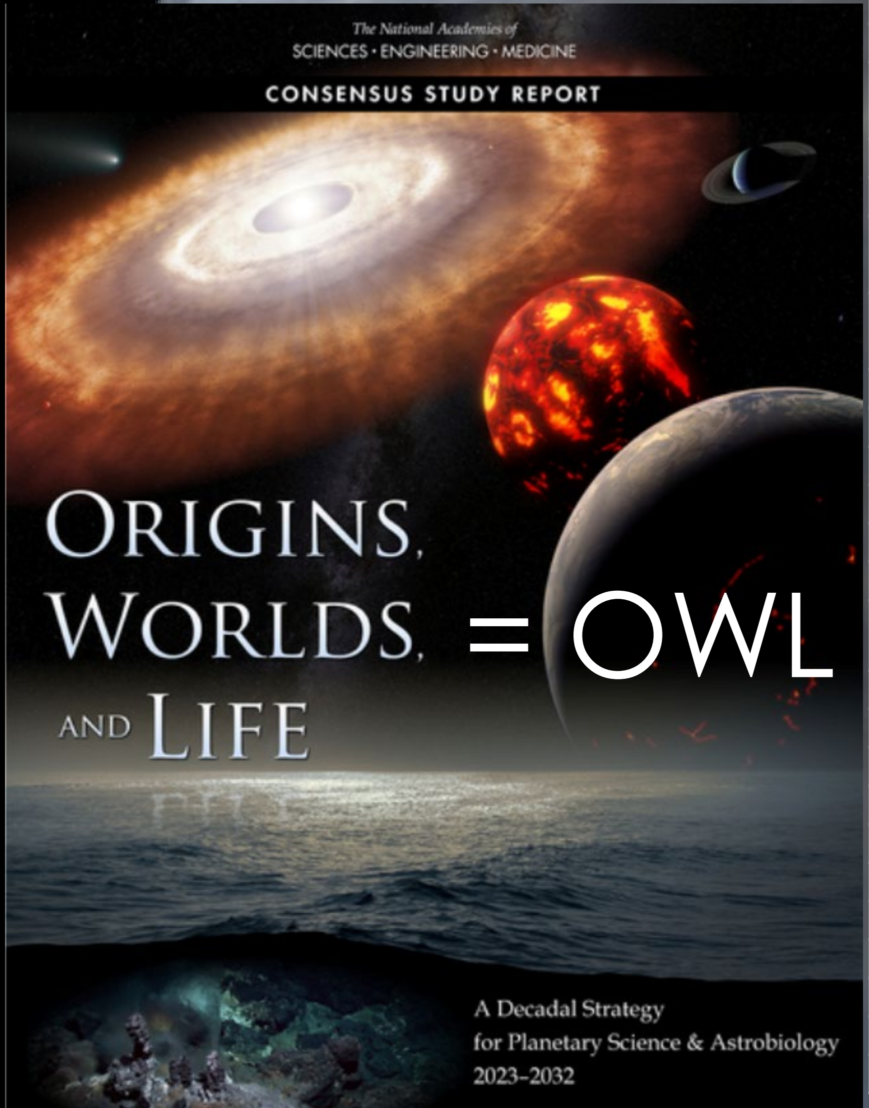
- Aerial Platforms
  - Balloon technology
  - Infrasound,
  - Atmospheric instrumentation
- Surface Platforms
  - High temperature electronics/power
  - Venus simulation (laboratory)
- Modeling
  - Venus climate models

It is currently unclear what the true cadence of New Frontiers – and Discovery – missions can be for the the next decade.

It appears it will remain unclear for at least the next budget cycle or two.

Competed missions are never guaranteed

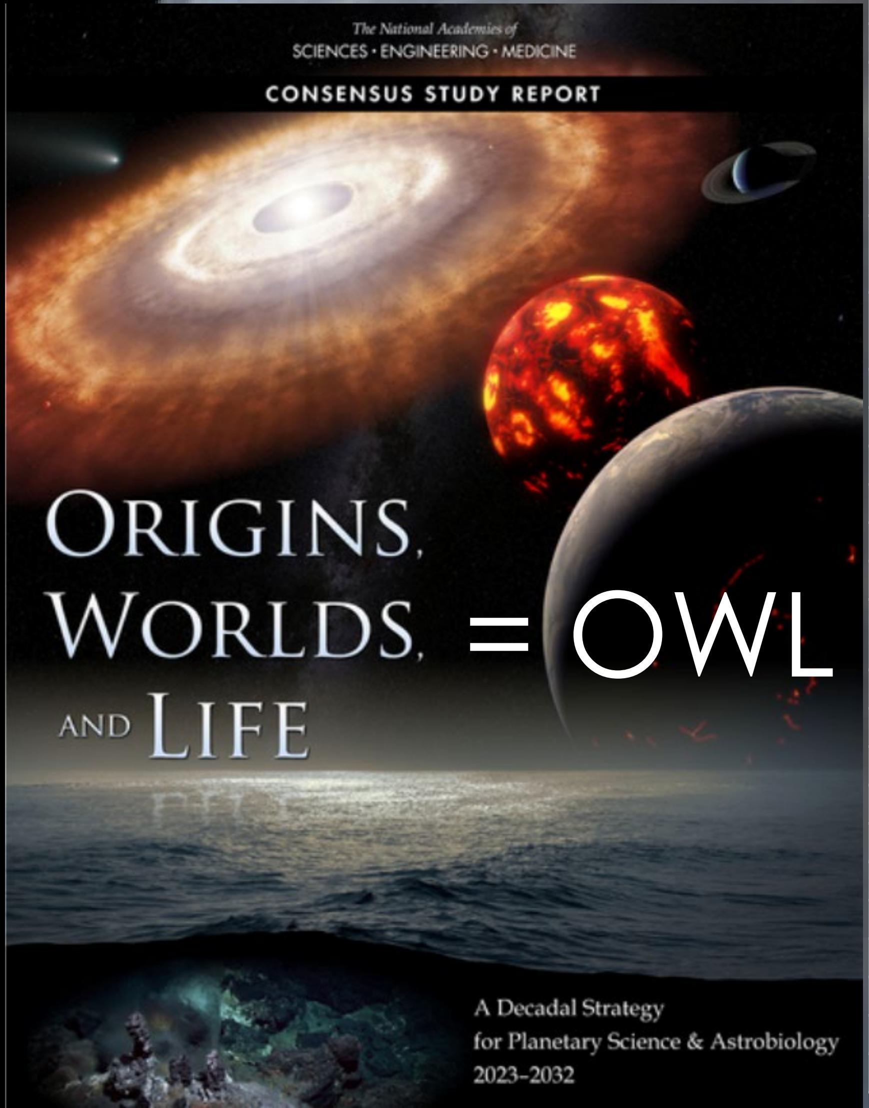
Venus in the Decadal Survey



= OWL

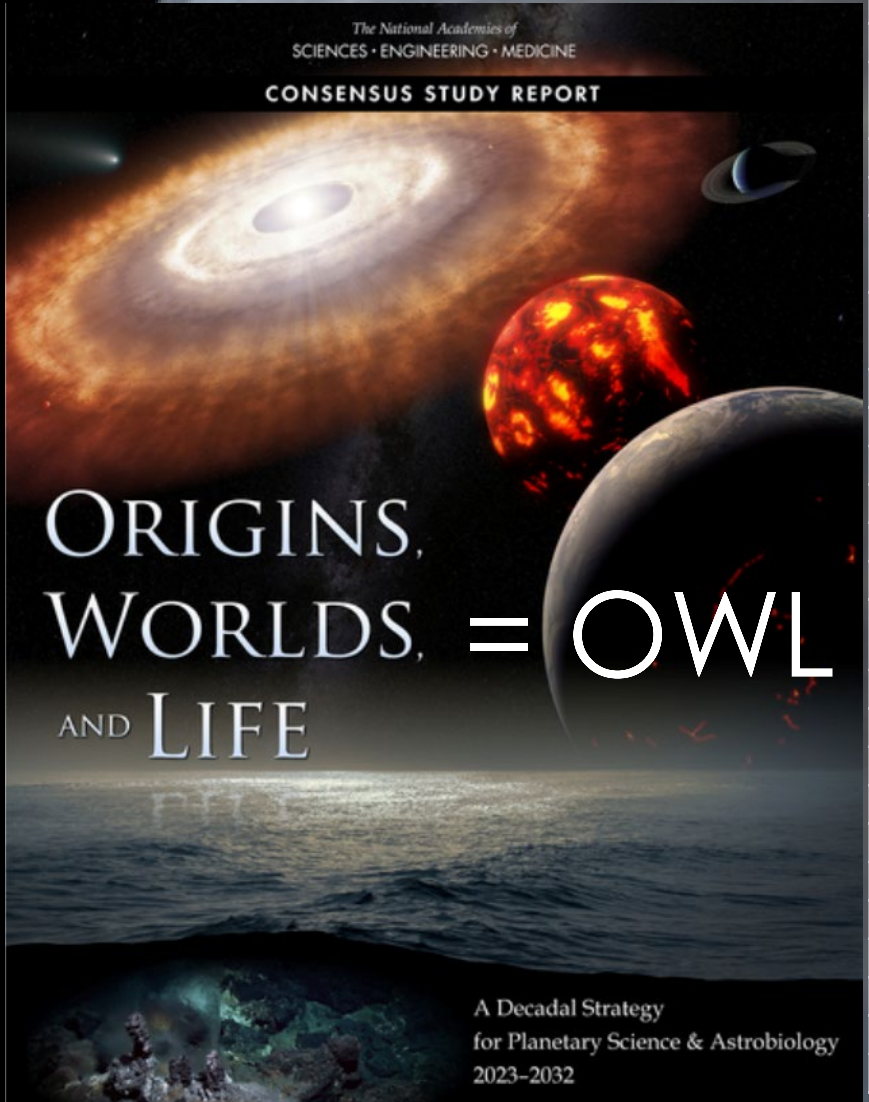
Q #	OWL Theme with Venus Relevance
1.1	What Were the Initial Conditions in the Solar System?
1.2	How Did Distinct Reservoirs of Gas and Solids Form and Evolve in the Protoplanetary Disk?
1.3	What Processes Led to the Production of Planetary Building Blocks?
3.1	How and When Did Asteroids and Inner Solar System Protoplanets Form?
3.3	How Did the Earth-Moon System Form?
3.4	What Processes Yielded Mars, Venus, and Mercury and Their Varied Initial States?
3.5	How and When Did the Terrestrial Planets and Moon Differentiate?
3.6	What Established the Primordial Inventories of Volatile Elements and Compounds in the Inner Solar System?
4.2	How Did Impact Bombardment Vary with Time and Location in the Solar System?
4.4	How Do the Physics and Mechanics of Impacts Produce Disruption of and Cratering on Planetary Bodies?
5.1	How Diverse Are the Compositions and Internal Structures Within and Among Solid Bodies?
5.2	How Have the Interiors of Solid Bodies Evolved?
5.3	How Have Surface/Near-Surface Characteristics and Compositions of Solid Bodies Been Modified by, and Recorded, Interior Processes?
5.4	How Have Surface Characteristics and Compositions of Solid Bodies Been Modified by, and Recorded, Surface Processes and Atmospheric Interactions?
5.6	What Drives Active Processes Occurring in the Interiors and on the Surfaces of Solid Bodies?
6.1	How Do Solid-Body Atmospheres Form and What Was Their State During and Shortly after Accretion?
6.2	What Processes Govern the Evolution of Planetary Atmospheres and Climates Over Geologic Timescales?
6.3	What Processes Drive the Dynamics and Energetics of Atmospheres on Solid Bodies?
6.4	How Do Planetary Surfaces and Interiors Influence and Interact with Their Host Atmospheres?
6.5	What Processes Govern Atmospheric Loss to Space?
6.6	What Chemical and Microphysical Processes Govern the Clouds, Hazes, Chemistry and Trace Gas Composition of Solid Body Atmospheres?
10.1	What Is “Habitability”?
10.3	Water Availability: What Controls the Amount of Available Water on a Body Over Time?
10.5	What Is the Availability of Nutrients and Other Inorganic Ingredients to Support Life?
11.3	Life Detection: Is or Was There Life Elsewhere in the Solar System?
11.4	Life Characterization: What Is the Nature of Life Elsewhere, If It Exists?
12.1	Evolution of the Protoplanetary Disk
12.2	Accretion in the Outer Solar System
12.3	Origin of Earth and Inner Solar System Bodies
12.6	Atmosphere and Climate Evolution on Solid Bodies
12.10	Dynamic Habitability
12.11	Search for Life Elsewhere

Venus in the Decadal Survey



Q #	OWL Theme with Venus Relevance
1.1	EVOLUTION OF THE PROTOPLANETARY DISK
1.2	
1.3	
3.1	ORIGIN OF EARTH AND INNER SOLAR SYSTEM BODIES
3.3	
3.4	
3.5	
3.6	
4.2	IMPACTS AND DYNAMICS
4.4	
5.1	SOLID BODY INTERIORS AND SURFACES
5.2	
5.3	
5.4	
5.6	
6.1	SOLID BODY ATMOSPHERES, EXOSPHERES, MAGNETOSPHERES, AND CLIMATE EVOLUTION
6.2	
6.3	
6.4	
6.5	
6.6	
10.1	DYNAMIC HABITABILITY
10.3	
10.5	
11.3	SEARCH FOR LIFE ELSEWHERE
11.4	
12.1	EXOPLANETS
12.2	
12.3	
12.6	
12.10	
12.11	

Venus in the Decadal Survey



= OWL

Q #	OWL Theme with Venus Relevance
1.1	What Were the Initial Conditions in the Solar System?
1.2	
1.3	
3.1	
3.3	
3.4	
3.5	
3.6	
4.2	
4.4	
5.1	
5.2	
5.3	
5.4	
5.6	
6.1	
6.2	
6.3	
6.4	
6.5	
6.6	
10.1	
10.3	
10.5	
11.3	
11.4	
12.1	
12.2	
12.3	
12.6	
12.10	
12.11	Search for Life Elsewhere

Venus is critically woven throughout the process-oriented themes of the 2023-2032 Decadal Survey

VISE in V&V

1. Understand the physics and chemistry of Venus's atmosphere; abundances of its trace gases, sulfur, light stable isotopes, and noble gas isotopes;
2. **Constrain the coupling of thermochemical, photochemical, and dynamical processes in Venus's atmosphere and between the surface and atmosphere to understand radiative balance, climate, dynamics, and chemical cycles;**
3. **Understand the physics and chemistry of Venus's crust;**
4. **Understand the properties of Venus's atmosphere down to the surface and improve our understanding of Venus's zonal cloud-level winds;**
5. **Understand the weathering environment of the crust of Venus in the context of the dynamics of the atmosphere and the composition and texture of its surface materials**
6. Look for planetary-scale evidence of past hydrological cycles, oceans, and life and for constraints on the evolution of the atmosphere of Venus.

V&V VISE Objectives	OWL Q	OWL VISE Objectives
1, 2, 3, 4	1.1	B, C
1, 3	1.2	A, B, C
2, 5	1.3	B, C
1, 2, 3, 4, 5	3.1	B, C
1	3.3	B
1	3.4	B, C
3, 5	3.5	C
1, 2, 3	3.6	A, B, C
2,3	4.2	B
2,3	4.4	B, C
3	5.1	A, C
2, 3	5.2	C
3	5.3	B, C
3, 5, 6	5.4	A, B
3	5.6	B, C
1, 2, 4, 6	6.1	A, C
3, 4, 6	6.2	A, B, C
1, 2, 3, 4, 5, 6	6.3	A, B
1, 2, 3, 4, 5, 6	6.4	A, B, C
1, 2, 4, 6	6.5	A
1, 2, 4	6.6	A, B, C
1, 2, 3, 4, 5, 6	10.1	A, B
1, 2, 3, 4, 5, 6	10.3	A, B, C
1, 2, 4, 6	10.5	A, B, C
6	11.3	B
2	11.4	B, C
1, 2, 4, 5, 6	12.1	A, B, C
1, 2, 4, 5, 6	12.2	C
1, 2, 5	12.3	B, C
1, 2, 4, 5, 6	12.6	A, B, C
3, 5, 6	12.10	A, B
6	12.11	A, B, C

1. EXOPLANETS

VISE in OWL

A. **Characterize past or present large-scale spatial and temporal (global, longitudinal and/or diurnal) processes within Venus's atmosphere.**
B. **Investigate past or present surface-atmosphere interactions at Venus.**
C. **Establish past or present physical and chemical properties of the Venus** surface **and/or interior.**

Numbers/letters do not denote priority

Repeated themes for VISE-like mission objectives/investigations

- In situ – atmosphere and surface
- Long lived (days to months)
- Multiple platforms
  - Satellite pairs
  - Orbit-atmosphere-ground pairings
  - Multiple stations

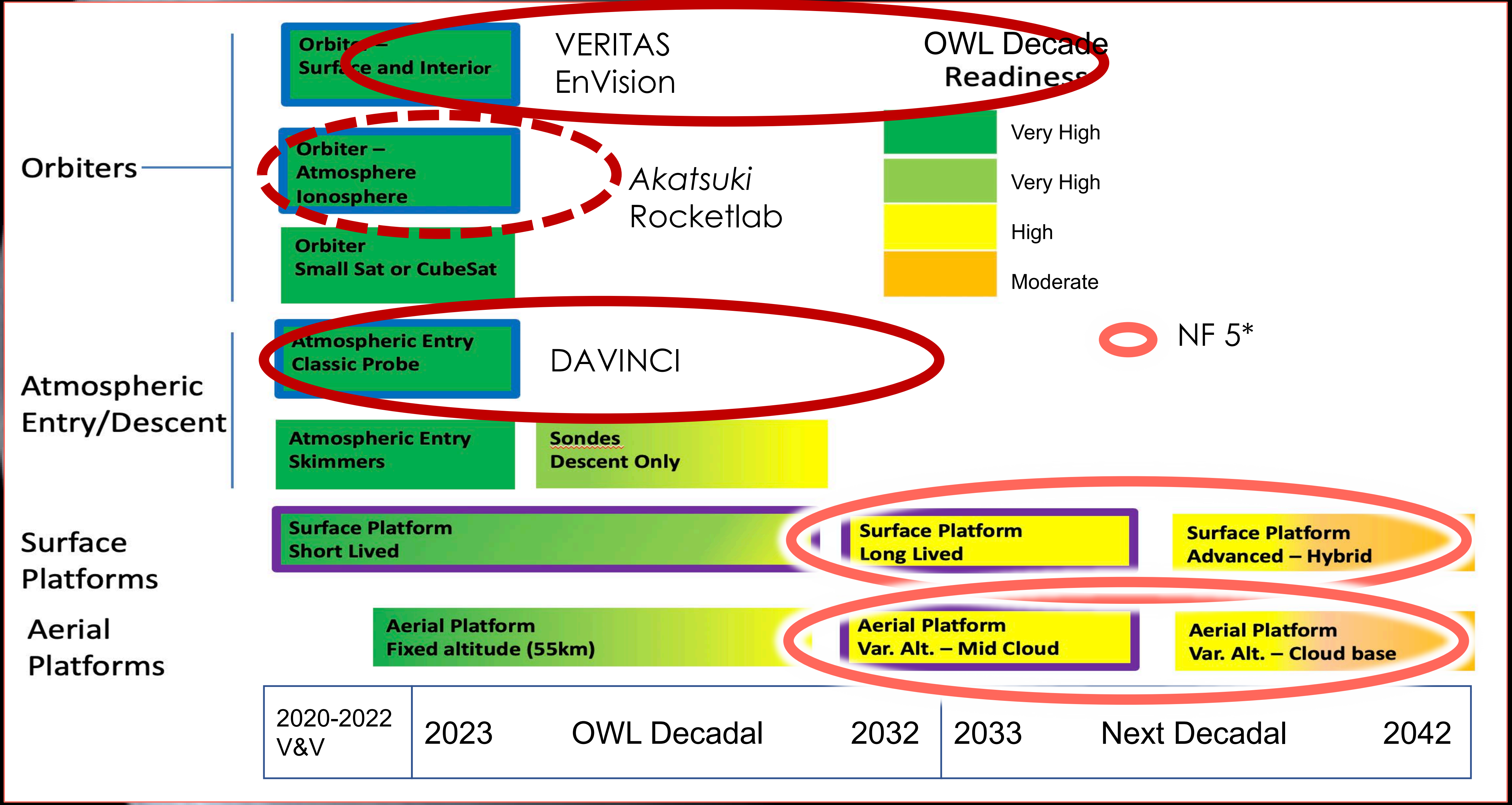
What is "feasible" by/in the 2030s?

- Many investigations not covered by the next NASA/ESA Venus missions (e.g. multiple conceptions of VISE) could be undertaken now, with no additional technical advancement, and no returns from the current selected missions required.
- Many more not-quite ready now (e.g. long duration aerial or surface stations) can be made ready over the next decade with modest technical advancement resources.

- Technical vs. programmatic feasibility: The Venus Exploration Strategy advocates for a Venus Exploration Program to be a consideration for the *next* Decadal Survey

Backup

Venus Roadmap, extended



Redefining the Obtainable with V3NUS = DAVINCI, VERITAS, EnVision +

"Partially to Substantially Addressed"

The Investigation will or could be be substantially incremented/revised after V3NUS completion. Does not mean completed or resolved

"First Look"

The V3NUS missions will minimally or not at all increment these investigations.

Future Investigations for GOI

Most future investigations have strong in-situ components – key themes of a VISE-like mission (V&V or OWL Decadal version).

New data all areas will expose new questions in most categories.

I. Understand Venus' early evolution, potential habitability, constrain evolution of Venus planets

HO. Hydrous Origins	Near-IR emissivity maps, search for felsic crust.	Multilocation measurement of surface rock composition, particularly in tesserae.
RE. Recycling	Radar maps, subsurface sounding, Near-IR emissivity maps.	Multilocation measurement of surface rock composition. Follow-up high-res radar & high res NIR surface imaging. Age dating.
AL. Atmospheric Losses	-	Orbital measurements of ionosphere & solar wind interaction; measure winds and transport through lower thermosphere.
MA. Magnetism	-	Magnetic fields from orbit, balloon, near surface
IS. Isotopes	Comprehensively addressed by DAVINCI.	Next generation MS instruments on long-lived cloud platform to achieve even higher sensitivity
LI. Lithosphere	Comprehensively addressed by VERITAS & EnVision's SAR & gravity.	Seismometry; Magnetotelluric sounding; Multi-location measurements of surface material & bulk composition. Follow-up high-res radar & high res NIR surface imaging. Age dating.
HF. Heat flow	Constraints from gravity/ topography & from detection, characterization of volcanism & tectonism.	Seismometry; in situ heat flow in different provinces.
CO. Core	Strongly constrained by gravity measurements & spin vector variation monitoring.	Seismometry. Higher accuracy gravity from e.g. gradiometry. Magnetic field measurements from orbit and/or aerobot.

Investigation	Achieved by end of V3NUS +	Future Achievement
HO. Hydrous Origins	Near-IR emissivity maps, search for felsic crust.	**Multilocation** measurement of **surface** rock composition, particularly in tesserae.
RE. Recycling	Radar maps, subsurface sounding, Near-IR emissivity maps.	**Multilocation** measurement of **surface** rock composition. Follow-up high-res radar & high res NIR surface imaging. Age dating.
AL. Atmospheric Losses	-	Orbital measurements of ionosphere & solar wind interaction; **measure winds and transport** through lower thermosphere.
MA. Magnetism	-	Magnetic fields from orbit, **balloon, near surface**
IS. Isotopes	Comprehensively addressed by DAVINCI.	Next generation MS instruments on **long-lived cloud platform** to achieve even higher sensitivity
LI. Lithosphere	Comprehensively addressed by VERITAS & EnVision's SAR & gravity.	**Seismometry**; Magnetotelluric sounding; **Multilocation** measurements of **surface** material & bulk composition. Follow-up high-res radar & high res NIR surface imaging. Age dating.
HF. Heat flow	Constraints from gravity/ topography & from detection, characterization of volcanism & tectonism.	**Seismometry**; **in situ** heat flow in different provinces.
CO. Core	Strongly constrained by gravity measurements & spin vector variation monitoring.	**Seismometry**. Higher accuracy gravity from e.g. gradiometry. Magnetic field measurements from orbit and/or **aerobot**.

Future Achievement	Orbit	Aerial	Surface	Long	Multi	When?
Multilocation measurement of surface rock composition, particularly in tesserae.		✓-	✓		✓	Now
Multilocation measurement of surface rock composition. Follow-up high-res radar & high res NIR surface imaging. Age dating.	✓	✓	✓		✓	Now-10+ yr
Orbital measurements of ionosphere & solar wind interaction; measure winds and transport through lower thermosphere.	✓	✓		✓-		Now
Magnetic fields from orbit, balloon, *near surface*.	✓	✓				Now-*10 yr*
Next generation MS instruments on long-lived cloud platform to achieve even higher sensitivity		✓		✓		<10 yr
Seismometry; Magnetotelluric sounding; Multi-location measurements of surface material & bulk composition. Follow-up high-res radar & high res NIR surface imaging. Age dating.		✓	✓	✓-	✓	Now-<10yr
Seismometry; in situ heat flow in different provinces.		✓	✓	✓		<10yr
Seismometry. Higher accuracy gravity from e.g. gradiometry. Magnetic field measurements from orbit and/or aerobot.	✓	✓	✓	✓		<10yr

II. Understand atmospheric dynamics and composition on Venus		
DD. Deep Dynamics	Vertical profile of P, T, cloud-level winds & waves from cloud tracking; gas mapping & radio occultation, surface winds from aeolian features	Cloud-level 3-D winds & waves from aerobot. Long-life surface meteorological station. Next-generation cloud tracking from orbit. Sat-to-Sat radio occultations for frequent T profiles at 40 – 90 km.
UD. Upper Dynamics	-	Ionosphere, magnetosphere, plasma, solar wind interaction from orbit. Sub-mm heterodyne to measure winds & transport (70 – 140 km), thermal IR magnetosphere sounding (60 – 100 km).
MP. Mesoscale Processes	Constraints on winds & waves. Winds from camera elements.	Cloud-level 3-D winds & waves from aerobot. Simultaneous orbital & in situ atmospheric observations.
RB. Radiative Balance	Radiative flux measurement from descent probe. New spectroscopy from orbit.	Radiative flux measurements from descent probes. Cloud-level radiative flux from aerobot
IN. Interactions	Chemical profiles, maps of volatile gases, links to volcanic activity.	In situ characterization of cloud particles, radiation, microphysics. Search for lighting. Aeolian processes.
AE. Aerosols	Orbital mapping of aerosol distributions. Measurement of gas volatile species which participate in condensational cloud formation.	In situ cloud-level aerobot measuring cloud and gas composition, and particle size & shape. Characterization of dust at surface.
UA. Unknown Absorber	Orbital UV observations. In-situ chemical inventory in clouds.	In situ cloud-level aerobot measuring cloud, gas, aerosol composition, esp, at altitudes > 60 km, & UV/blue fluxes.
OG. Outgassing	Vertical profile of composition including outgassed volatiles; Mapping outgassed volatile species.	In situ measurements of surface and cloud materials to search for signatures of outgassed volatiles.

Investigation	Achieved by end of V3NUS	Future Achievement
DD. Deep Dynamics	Vertical profile of P, T, cloud-level winds & waves from cloud tracking; gas mapping & radio occultation, surface winds from aeolian features	Cloud-level 3-D winds & waves from **aerobot**. **Long-life** surface meteorological **station**. Next-generation cloud tracking from orbit. **Sat-to-Sat** radio occultations for frequent T profiles at 40 – 90 km.
UD. Upper Dynamics	-	Ionosphere, magnetosphere, plasma, solar wind interaction from orbit. Sub-mm heterodyne to measure winds & transport (70 – 140 km), thermal IR magnetosphere sounding (60 – 100 km).
MP. Mesoscale Processes	Constraints on winds & waves. Winds from camera elements.	Cloud-level 3-D winds & waves from **aerobot**. **Simultaneous** orbital & **in situ** atmospheric observations.
RB. Radiative Balance	Radiative flux measurement from descent probe. New spectroscopy from orbit.	Radiative flux measurements from descent **probes**. Cloud-level radiative flux from **aerobot**
IN. Interactions	Chemical profiles, maps of volatile gases, links to volcanic activity.	**In situ** characterization of cloud particles, radiation, microphysics. **Search** for lighting. Aeolian **processes**.
AE. Aerosols	Orbital mapping of aerosol distributions. Measurement of gas volatile species which participate in condensational cloud formation.	**In situ** cloud-level **aerobot** measuring cloud and gas composition, and particle size & shape. Characterization of dust at **surface**.
UA. Unknown Absorber	Orbital UV observations. In-situ chemical inventory in clouds.	**In situ** cloud-level **aerobot** measuring cloud, gas, aerosol composition, esp, at altitudes > 60 km, & UV/blue fluxes.
OG. Outgassing	Vertical profile of composition including outgassed volatiles; Mapping outgassed volatile species.	**In situ** measurements of **surface** and **cloud** materials to search for signatures of outgassed volatiles.

Future Achievement	Orbit	Aerial	Surface	Long	Multi	When?
Cloud-level 3-D winds & waves from aerobot. Long-life surface meteorological station. Next-generation cloud tracking from orbit. Sat-to-Sat radio occultations for frequent T profiles at 40 – 90 km.	✓	✓	✓	✓	✓	<10yr
Ionosphere, magnetosphere, plasma, solar wind interaction from orbit. Sub-mm heterodyne to measure winds & transport (70 – 140 km), thermal IR magnetosphere sounding (60 – 100 km).	✓					Now
Cloud-level 3-D winds & waves from aerobot. Simultaneous orbital & in situ atmospheric observations.	✓	✓		✓	✓	<10yr
Radiative flux measurements from descent probes. Cloud-level radiative flux from aerobot		✓	✓		✓	Now
In situ characterization of cloud particles, radiation, microphysics. Search for lighting. Aeolian processes.		✓	✓	✓	✓-	Now
In situ cloud-level aerobot measuring cloud and gas composition, and particle size & shape. Characterization of dust at surface.		✓	✓		✓	<10yr
In situ cloud-level aerobot measuring cloud, gas, aerosol composition, esp, at altitudes > 60 km, & UV/blue fluxes.		✓		✓	✓-	<10yr
In situ measurements of surface and cloud materials to search for signatures of outgassed volatiles.		✓	✓	✓	✓	<10yr

III. Understand Venus geologic history and couplings between the surface and atmosphere		
GH. Geologic History	Global SAR imaging & topography, NIR emissivity, gravity & subsurface mapping + high-res imaging.	Multiple location surface properties & composition. Follow-up high-res radar & high res NIR surface imaging.
GC. Geochemistry	Constraints from NIR emissivity maps (& SAR & radiometry).	Multisite surface composition.
GA. Geologic Activity	Change detection (repeat SAR imagery), searches for NIR & RF thermal anomalies, volcanic plumes, volcanic tracers.	Systematic surface monitoring w. repeat-pass InSAR & radiometry (NIR & RF). Seismometry (in-situ, or orbital).
CR. Crust	Addressed by SAR & gravity, sub-surface sounding, and descent imaging.	Seismometry; Magnetotelluric sounding; In situ measurements of surface material composition.
LW. Local Weathering	Constraints from NIR emissivity maps (& SAR & radiometry). Also measurements of near-surface atmospheric composition.	Measurement of surface & near-surface atmosphere composition at multiple localities.
GW. Global Weathering	Constraints from NIR emissivity maps (& SAR & radiometry) & SAR imagery.	Measurement of surface & atmo. composition, global patterns.
CI. Chemical Interactions	Near-surface atmospheric composition. Tropospheric gas abundances. Cloud & low-alt, water vapor maps. Radar anomaly.	Surface landers & meteorological stations. Follow-up high res radar and other surface mapping.

Investigation	Achieved by end of V3NUS	Future Achievement
GH. Geologic History	Global SAR imaging & topography, NIR emissivity, gravity & subsurface mapping + high-res imaging.	**Multiple** location **surface** properties & composition. Follow-up high-res radar & high res NIR surface imaging.
GC. Geochemistry	Constraints from NIR emissivity maps (& SAR & radiometry).	**Multisite** **surface** composition.
GA. Geologic Activity	Change detection (repeat SAR imagery), searches for NIR & RF thermal anomalies, volcanic plumes, volcanic tracers.	Systematic **surface monitoring** w. repeat-pass InSAR & radiometry (NIR & RF). Seismometry (**in-situ** / orbital).
CR. Crust	Addressed by SAR & gravity, sub-surface sounding, and descent imaging.	**Seismometry**; Magnetotelluric sounding; **In situ** measurements of surface material composition.
LW. Local Weathering	Constraints from NIR emissivity maps (& SAR & radiometry). Also measurements of near-surface atmospheric composition.	Measurement of **surface & near-surface** atmosphere composition at **multiple** localities.
GW. Global Weathering	Constraints from NIR emissivity maps (& SAR & radiometry) & SAR imagery.	Measurement of surface & atmo. composition, **global patterns**.
CI. Chemical Interactions	Near-surface atmospheric composition. Tropospheric gas abundances. Cloud & low-alt, water vapor maps. Radar anomaly.	Surface **landers** & **meteorological stations**. Follow-up high res radar and other surface mapping.

Goal	Objective	Investigation	Achieved by end of V3NUS
III. Understand the geologic history preserved on the surface of Venus and the present-day couplings between the surface and atmosphere	A. What geologic processes have shaped the surface of Venus? BP2,3,5	GH. Geologic History	Global SAR imaging & topography, NIR emissivity, gravity & subsurface mapping + high-res imaging.
		GC. Geochemistry	Constraints from NIR emissivity maps +SAR +radiometry.
		GA. Geologic Activity	Change detection (repeat SAR imagery), searches for NIR & RF thermal anomalies, volcanic plumes, volcanic tracers.
		CR. Crust	Addressed by SAR & gravity, sub-surface sounding, and descent imaging.
	B. How do the atmosphere and surface of Venus interact? BP3,5	LW. Local Weathering	Constraints from NIR emissivity maps +SAR +radiometry. Near-surface atmospheric composition.
		GW. Global Weathering	Constraints from NIR emissivity maps (& SAR & radiometry) & SAR imagery.
		CI. Chemical Interactions	Measurements of near-surface atmospheric composition. Measurements of tropospheric gas abundances. Maps of clouds & low-altitude water vapor. Radar anomaly.

Future Achievement	Orbit	Aerial	Surface	Long	Multi	When?
Multiple location surface properties & composition. Follow-up high-res radar & high res NIR surface imaging.	✓	✓	✓		✓	Now
Multisite surface composition.			✓		✓	Now
Systematic surface monitoring w. repeat-pass InSAR & radiometry (NIR & RF). Seismometry (in-situ, or orbital).	✓	✓	✓	✓	✓	<10yr
Seismometry; Magnetotelluric sounding; In situ measurements of surface material composition.		✓	✓		✓	<10yr
Measurement of surface & near-surface atmosphere composition at multiple localities.		✓	✓		✓ -	Now
Measurement of surface & atmo. composition, global patterns.		✓	✓		✓	Now
Surface landers & meteorological stations. Follow-up high res radar and other surface mapping.	✓		✓	✓	✓ -	Now

VISE in V&V

Venus In Situ Explorer Theme remains new, compelling science, independent of V3NUS

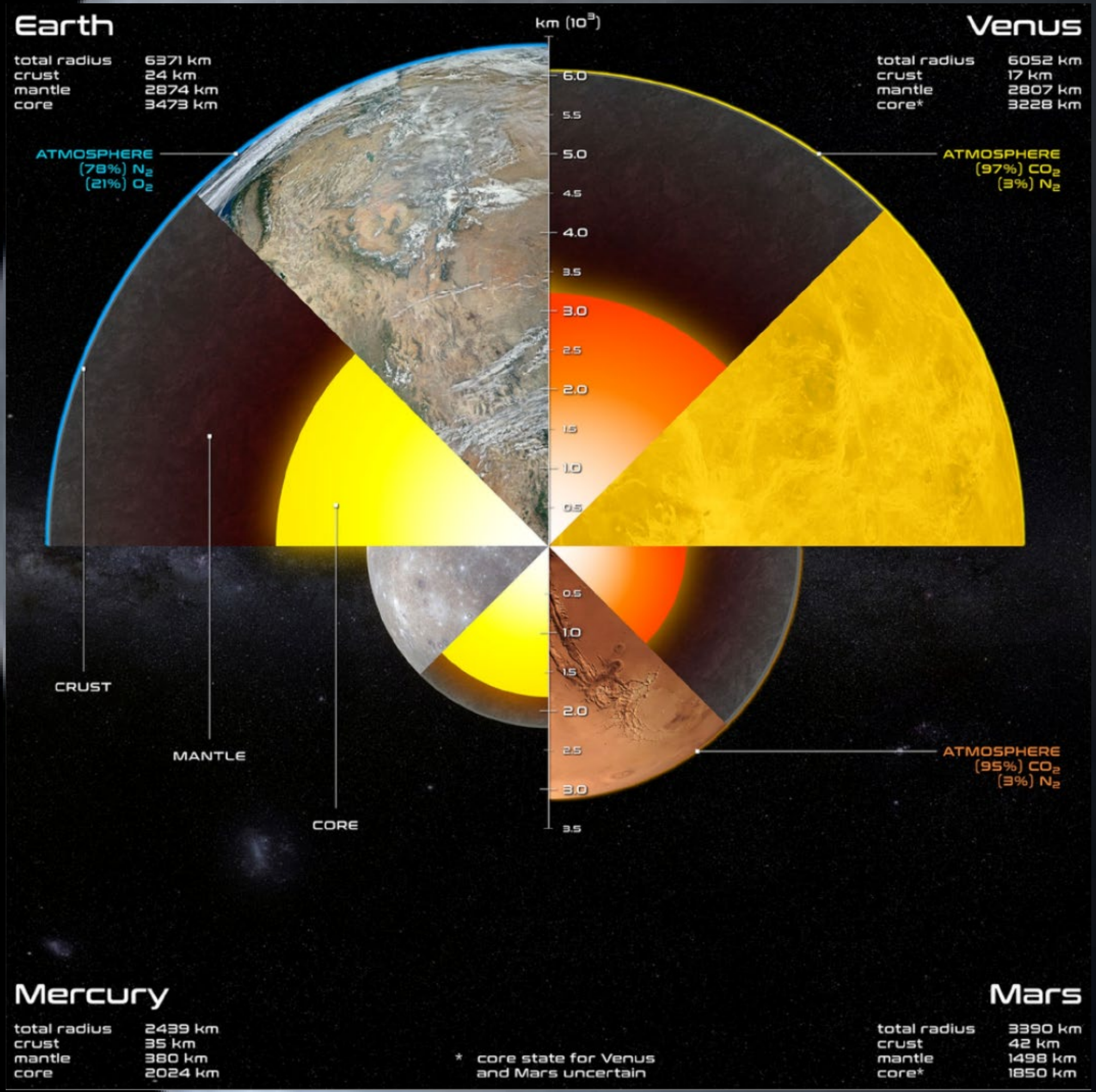
V&V VISE Objectives	OWL Q	OWL VISE Objectives
1, 2, 3, 4	1.1	B, C
1, 3	1.2	A, B, C
2, 5	1.3	B, C
1, 2, 3, 4, 5	3.1	B, C
1	3.3	B
1	3.4	B, C
3, 5	3.5	C
1, 2, 3	3.6	A, B, C
2,3	4.2	B
2,3	4.4	B, C
3	5.1	A, C
2, 3	5.2	C
3	5.3	B, C
3, 5, 6	5.4	A, B
3	5.6	B, C
1, 2, 4, 6	6.1	A, C
3, 4, 6	6.2	A, B, C
1, 2, 3, 4, 5, 6	6.3	A, B
1, 2, 3, 4, 5, 6	6.4	A, B, C
1, 2, 4, 6	6.5	A
1, 2, 4	6.6	A, B, C
1, 2, 3, 4, 5, 6	10.1	A, B
1, 2, 3, 4, 5, 6	10.3	A, B, C
1, 2, 4, 6	10.5	A, B, C
6	11.3	B
2	11.4	B, C
1, 2, 4, 5, 6	12.1	A, B, C
1, 2, 4, 5, 6	12.2	C
1, 2, 5	12.3	B, C
1, 2, 4, 5, 6	12.6	A, B, C
3, 5, 6	12.10	A, B
6	12.11	A, B, C

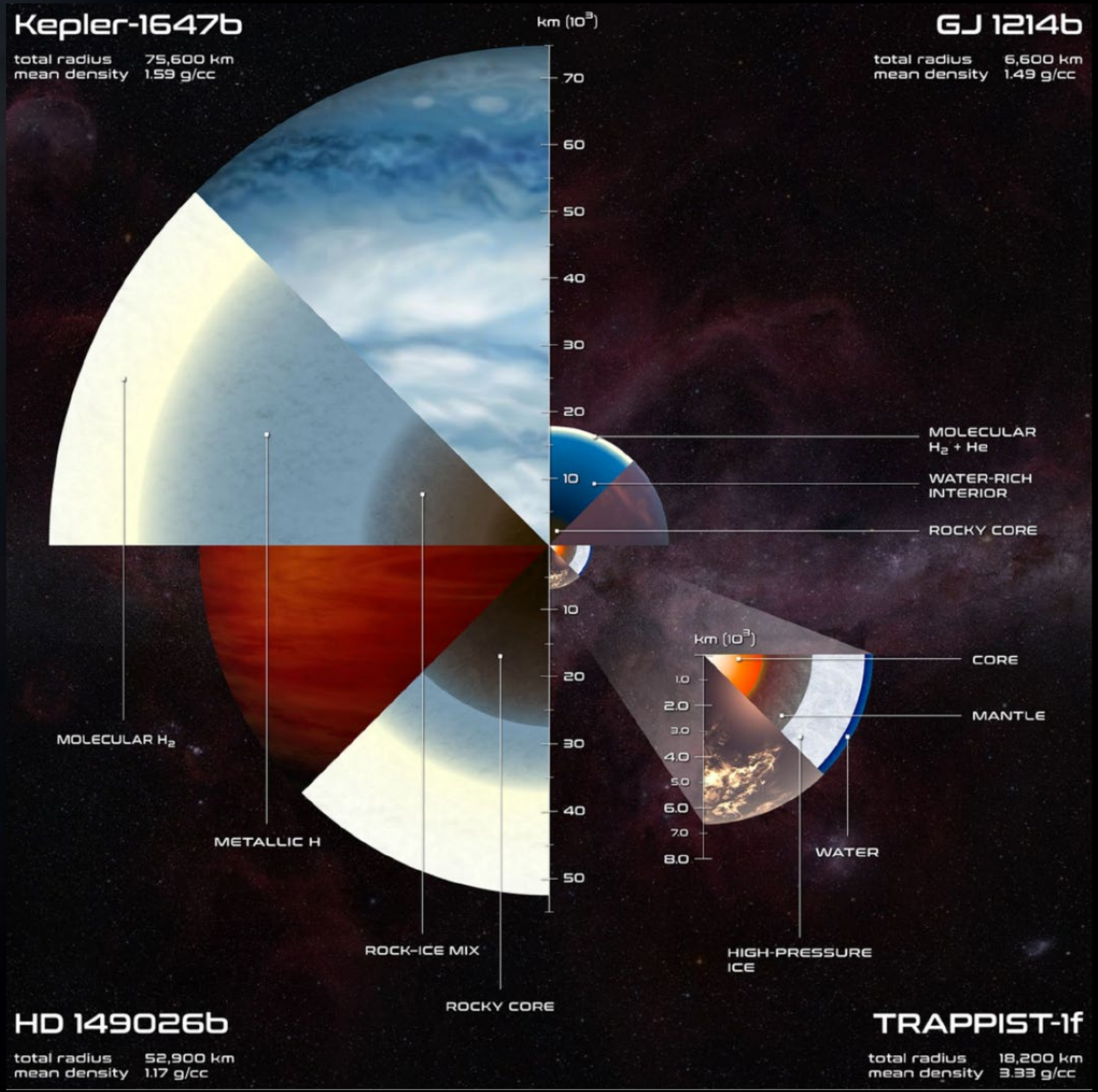
"Substantially Addressed" "First Look"

VISE in OWL

In the new Decadal as well as the old

Solar System as Key to Exoplanets





Kane et al., 2021