VEXAG Venus Bridge Study

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and the Venus Bridge Focus Group

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Venus Bridge Charter

- NASA SMD AA asked VEXAG to assess viable mission concepts that could fit within a $200 M cost cap.
- This program envisions 2-3 small, competitively selected missions within the cost cap that could launch in the early to mid 2020s.
- Venus Bridge could provide Decadal science that also potentially enables simultaneous and future Venus missions in the late 2020s or 2030s.

Focus Group Members

- Robert Grimm, Southwest Research Institute, VEXAG Chair
- Martha Gilmore, Wesleyan Univ., VEXAG Deputy Chair
- Jim Cutts, JPL Study Lead
- Robert Herrick, Univ. Alaska, Fairbanks
- Gary Hunter, GRC Study Lead
- Noam Izenberg, APL
- Kandis Lea Jessup, SwRI
- Damon Landau, JPL Technical Lead
- Rob Lillis, UC Berkeley
- Steve Oleson, GRC Technical Lead
- Thomas Thompson, JPL, VEXAG executive secretary

- Input from the PSDS3 Venus PIs and staff at GRC and JPL is gratefully acknowledged.

Focus Group Process

- Focus group initially formed of volunteers from Venus community.
- Solicited mission concepts, these were categorized in terms of architecture (e.g., orbiter, in situ, lander).
- Identified science goals and initial broad instrument compliment utilizing each architecture.
- Commissioned two studies: one at GRC COMPASS and one at JPL Team X. Focus group members in attendance at each. Total funding $330K.
- Emphasized importance of LINKED two-element mission.
  - GRC would study orbiter + lander, JPL would study orbiter + atmospheric element.
  - Did not study single $200M element.
- Two studies independent of each other to maximize range of viable mission concepts.
- Integration and summary of study results.

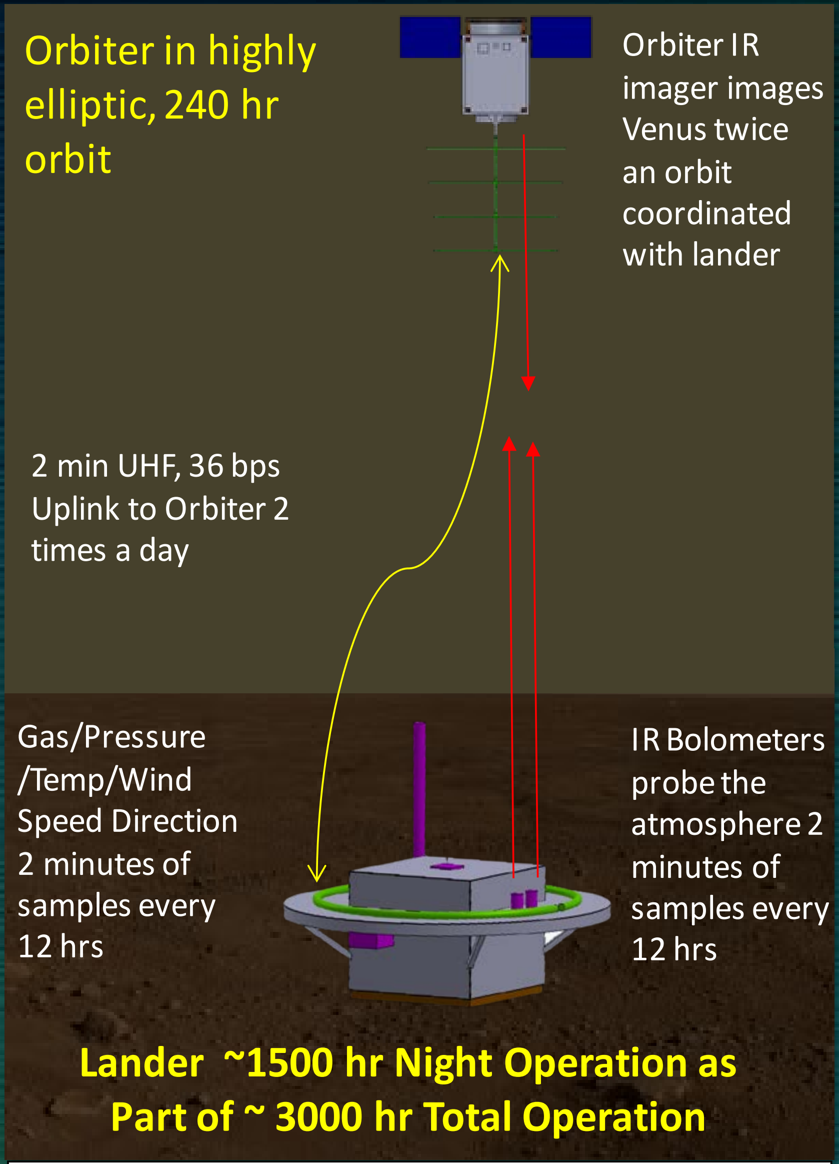
Principal Element	Variation	Purpose	VEXAG Science Goals, Object., & Investig. (GOI)	VEXAG Technology Plan	VEXAG Roadmap	Bridge Concepts PSDS3 Sel.
Science Orbiter with Telecom Relay	Surface (IR)	Surface composition & weathering. Does Venus have granites? Is there evidence of recent volcanism or past water?	II.A.4, II.B.1,2; III.A.2, 3; III.B.2.	Smallsat & cubesat assessment identified for next technol. plan	Orbital Remote Sensing	V-BOSS
	Atm (IR)	Middle circulation, planetary waves, airglow. How does the atm. circulate? Are there large quakes?	I.B.1,2,3; II.A.3,4.			VB-IRO, SMO, RSOC VAMOS
	Atm (UV)	Upper circulation & composition. What is the origin of the UV absorber and energy balance of the atm.?	I.B.2; I.C.1,2,4.			VB-UVO CUVE
	Ionosphere	Ion escape & precipitation What is the current escape rate of the atmosphere?	I.A.2.			VB-PFO
Probe	Skimmer	Atmospheric sample below homopause. Isotopes of noble gases What is the origin of the atmosphere?	I.A.1,2; II.A.2; III.A.1.	TPS	≈ Deep Probe	VB-Skim Cupid's Arrow
	Descender	Profile of atmospheric state and composition. How did the atmosphere form? What is the structure of the atmosphere?	I.A.1,2; I.B.1-3; I.C.4; II.A.2; III.A.1,4.	TPS	Deep Probe	V-BOSS, VB-Probe
Aerial Platform	Balloon or Airplane	Global measurements of cloud-level circulation and composition. Investigate seismicity and interior. *Questions mirror probe and lander but global scale.*	I.A.1,2; 1.B.1,3; I.C.1-4; II.A.2,3; III.A.1, III.B.2,3.	TPS, Aerial Platforms	Sustained Aerial Platform	VB-Balloon
Lander		Atmospheric & geophysical measurements. Imaging. What is the boundary-layer environment and origin of super-rotation? Is there seismic activity?	I.B.1,2; II.A.3; III.B.2-3.	TPS, HTE	Long-Lived Lander	V-BOSS SAEVe

Venus Bridge Study Approaches

- GRC study is a point design with strong linkages between an orbiter and lander.
  - Concept Maturity Level 4.
    - CML 4: pre-Step 1, preferred design to subsystem level.
- JPL studied 8 mission architectures that can be combined if desired.
  - Concept Maturity Levels 2-4
    - CML 2: Initial feasibility, ballpark mass and cost.

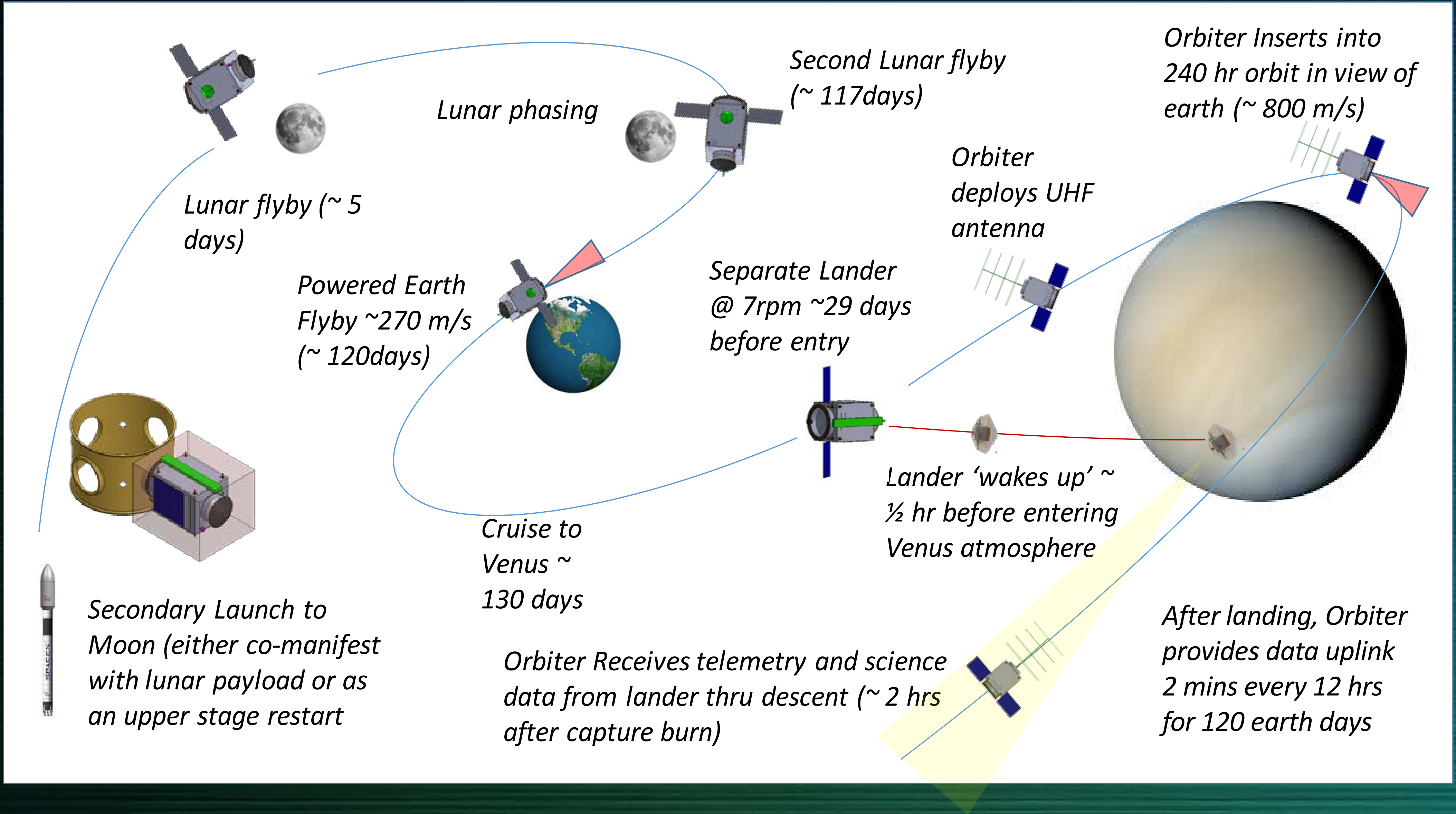
GRC Point Design Venus Bridge Orbiter and Surface Study (V-BOSS)

- Orbiter/Descent Science/Lander, CML 4
- 117 Earth day landed mission, 2025 Launch
- Leverages prior investments in Long-Lived In-Situ Solar System Explorer (LLISSE)
- Synergistic observations enhance science return
- This architecture allows a range of science investigations through modification of Orbiter-Lander platforms through choice of other instruments, science themes, or operational modes.



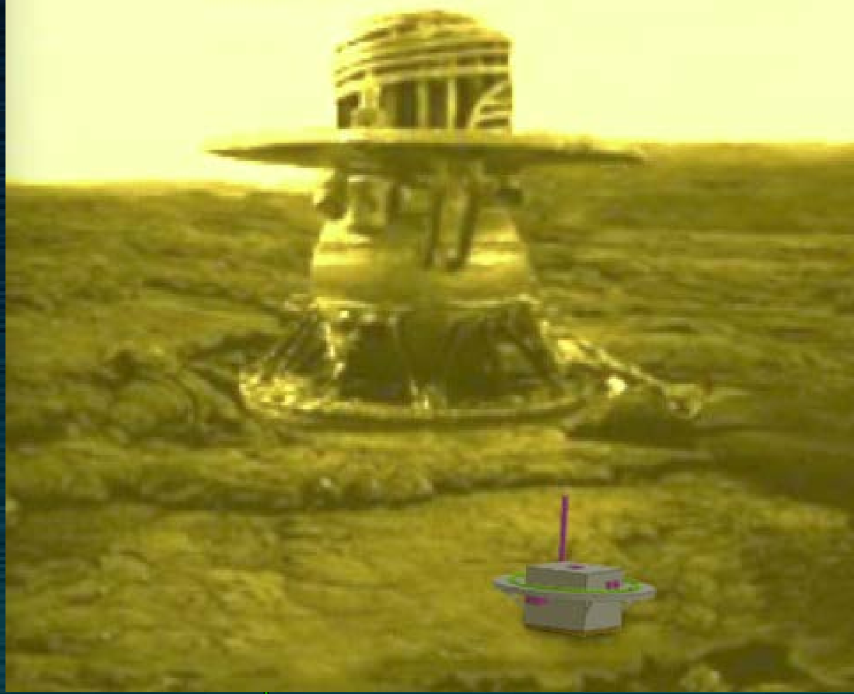
V-BOSS Coupled Orbiter-Lander Concept. Daytime measurements identical except without IR.

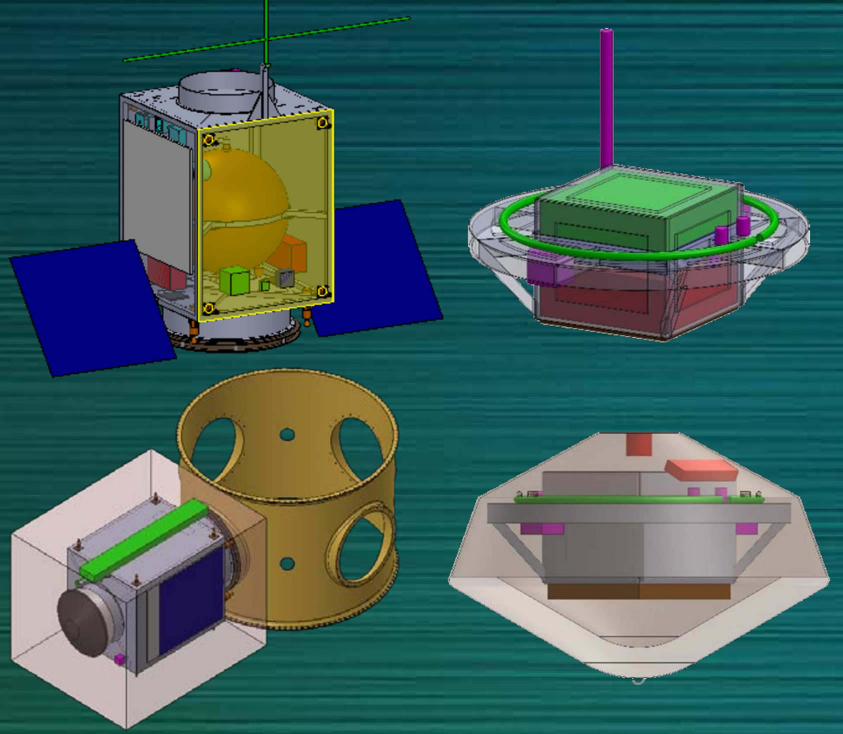
V-BOSS Mission Overview



V-BOSS Architecture

- Lander: ~ 15 kg, ~ 20 cm cube with drag flap, high temp electronics and battery, UHF communications through 1/3 wavelength loop antenna.
- Entry/Descent/Landing System: ~ 12 kg, Heritage 0.5m Aeroshell, passive separation systems, lander provides telemetry.
- Orbiter: 200 kg (wet) Smallsat with ~ 90 kg monopropellant to provide burns at Earth and to capture at Venus (total ~ 1000 m/s), ~ 200 W solar arrays, UHF uplink from lander, X-band data return to Earth. High elliptical orbit was chosen to maximize ‘listening’ time for lander uplinks and to minimize capture propellant.





V-BOSS Science Traceability

VEXAG Goals	Mission Goals	Instrument
Understand what the chemistry and mineralogy of the crust tell us about processes that shaped the surface of Venus over time.	Constrain surface mineralogy	**MIREM**: Multispectral IR Emissivity Mapper (4 channels) **V-Rad** Radiance (IR Bolometers) (on lander) 2 looking up and 1 looking down
Understand atmospheric evolution; Characterize the Venus Greenhouse	Determine atmospheric composition at lowest scale height	**V-Chem** (on Descent): Atmospheric Chemical sensor suite: fO2, CO, SOx, H2O, OCS, HCl, HF, NO, Pressure, Temp
	Radiance (IR Bolometers)	**V-Rad** (On descent) Radiance (IR Bolometers) (on lander) 2 looking up and 1 looking down
Characterize how the interior, surface, and atmosphere interact	Constrain surface-atmosphere interactions	**V-Chem**: Long duration Atmospheric Chemical sensor suite: fO2, CO, SOx, H2O, OCS, HCl, HF, NO, Pressure, Temp **V-Lab**: Reaction chemistry samples Measure electrochem (IV,CV)
Characterize current processes in the atmosphere	Measure wind speed and direction over several months	**V-Wind**: Long-duration wind sensor

V-BOSS Instrument Maturity

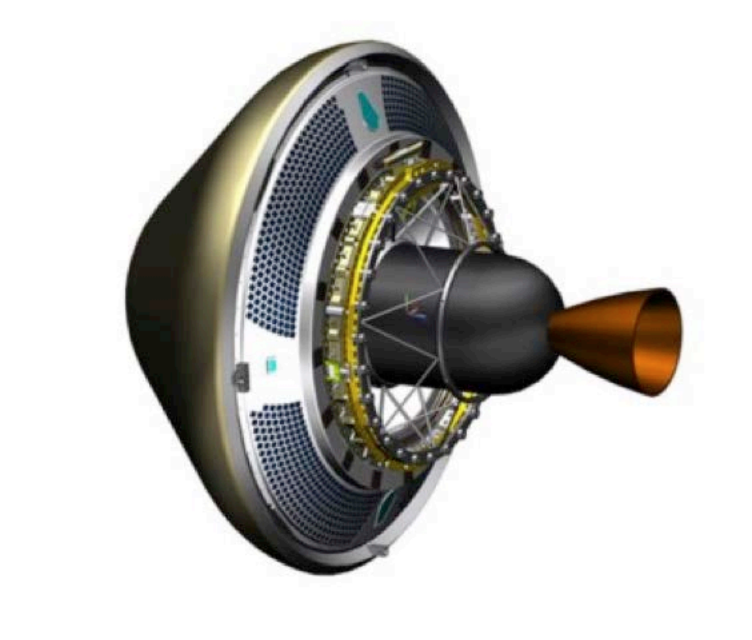
Technology	Current TRL	Estimated Component TRL 6	Modification from LLISSE for V-BOSS	Funding Source: Ongoing (O) and Potential (P)
Electronic circuits (SiC): sensors and data handling	4-5	Aug 2019	None	LLISSE (O)
Electronic circuits (SiC): power management	3-4	Sept 2021	None	LLISSE (O)
Communications (100 MHz)	3-4	Sept 2021	None	LLISSE (O)
MIREM Spectral Imager	3-4	2021-2022	None	IRAD/MatIISE(P)
Wind Sensor	4	Aug 2019	None	LLISSE (O)
Temperature Sensor	4-5	Aug 2019	None	LLISSE (O)
Pressure Sensor	4-5	Aug 2019	None	LLISSE (O)
Chemical Sensors	5	Aug 2019	None	LLISSE/ HOTTech (O)
LLISSE Bolometer	3-4	Sept 2021	None	LLISSE (O)
V-Rad (V-BOSS IR Bolometer)	3-4	TBD	• Modify LLISSE Bolometer Structure for Specific Filters • Verify System Operation with Filters	MatISSE (P)
V-Lab (V-BOSS Surface Reaction Measurement)	4	TBD	• Identify high temperature measurement approach for minerals in existing platform • Modify high temperature circuits as needed.	MatISSE (P)

V-BOSS Lessons Learned

- $200M cost cap very restricting for an orbiter and lander.
  - Can be done with a 'free' secondary launch, a smallsat and a simple, high temp lander.
  - Science Value based on duration:
    - Chosen path: Simple instruments periodically sense environment for the 'duration' on surface (single Venus night/day cycle).
    - Alternate path: Shorter 10's of hours continuous science possible but at the expense of duration.
  - Science data high value but small volume (<1Gb) – helps keep costs down.
  - Lander and Orbiter a "science team" (orbiter more than just a relay): IR sensing tie between lander and orbiter.
- **Cost split between orbiter and lander/EDL ~ 70:30.**

JPL – Venus Bridge Concept Study Approach

- Architecture studies of 8 concepts
  - 5 orbiters
  - 3 in situ elements (skimmer, probes and balloon).
- Drew on studies of two Venus missions funded at JPL under NASA's Planetary Science Deep Space SmallSat (PSDS3) program
  - Also info from external PSDS3 for Venus UV orbiter, Mars aeronomy orbiter, and planetary small probe.



VB-Skimmer with solid rocket

JPL Lessons Learned

- **Overall, the aggregate mission set is less complex when the orbiter and atmospheric element find their own way to Venus.**
  - Co-development and launch of orbiter and atmospheric element could result in reduction of costs but were not quantified.
- Enabling technologies
  - highly capable miniaturized instruments.
  - new mission architectures (e.g., skimmers).
  - accommodation of limited data rates.
- None of the missions require technologies beyond those that are being developed under existing NASA programs.
  - HEEET required for probe and balloon (can use PICA for skimmer).

JPL Launch Options from GTO

	Launch (wet) mass (kg) by Venus orbit type				Flight time (yr) by Venus orbit type			
	N/A	6 hr ellip-tical	24 hr circu-lar	2 hr circu-lar (req. A/B)	N/A	6 hr ellip-tical	24 hr circu-lar	2 hr circu-lar (req. A/B)
Chemical Orbiter		205	230	205		>0.7	>0.7	>1.2
SEP Orbiter		135	135	125		>2.6	>2.1	>2.6
Atm Element	185				>1.0			

Linkage of Specific Concepts to VEXAG Goals, Objectives, and Investigations

- Each Venus Bridge concepts significantly addresses at least one VEXAG investigation.
- Majority in atmosphere.

Goals	Objectives	Investigations	GOI Code	Atmospheric Element			Orbital Element					V-BOSS
				VB-Skim	VB-Probe	VB-Balloon	VB-PFO	VB-UVO	VB-IRO	VB-SMO	VB-RSO	
Atmosphere	Atmospheric Evolution	Solar Nebula	I.A.1									
		Atmospheric Escape	I.A.2									
	Radiative balance, climate, and superrotation	Global Circulation	I.B.1									
		Radiative Balance	I.B.2									
		Vertical Motion	I.B.3									
	Clouds and hazes	Cloud Chemistry	I.C.1									
		Greenhouse Constituents	I.C.2									
		Lightning	I.C.3									
		Biologically relevant chemistry	I.C.4									
Surface and Interior	Geodynamics	Stratigraphy/deformation	II.A.1									
		Outgassing	II.A.2									
		Interior	II.A.3									
		Active volcanism and tectonism	II.A.4									
		Absolute rock ages	II.A.5									
	Differentiation	Local surface composition	II.B.1									
		Large scale compositional variations	II.B.2									
		Structure of crust	II.B.3									
		Core and mantle structure	II.B. 4									
		Radiogenic crustal elements	II.B.5									
		Subsurface layering	II.B.6									
Interior/Surface/Atmosphere	Liquid water and the greenhouse effect	History of water from isotopes	III.A.1									
		Role of water in tesserae	III.A.2									
	Interaction of interior-surface and atmosphere over time	Evidence of hydrous minerals & sediments	III.A.3									
		Atmospheric sources & sinks	III.B.1									
		Rock weathering investigations	III.B.2									
		Altitude profiles of reactive species	III.B.3									
		Sulfur outgassing from the surface	III.B.4									

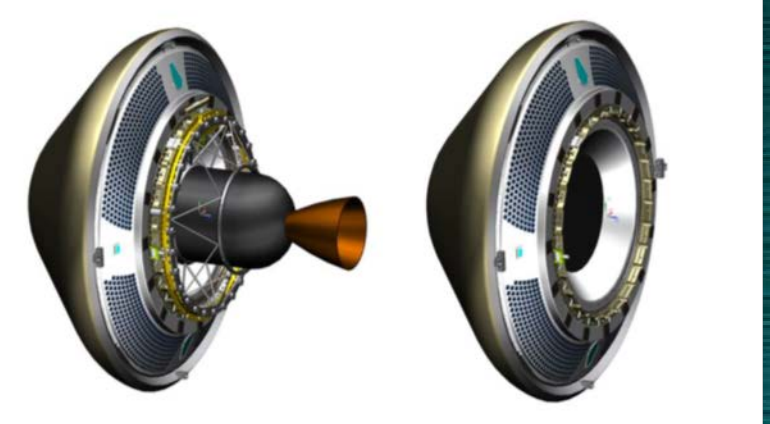
Significantly Addresses
Partially Addresses

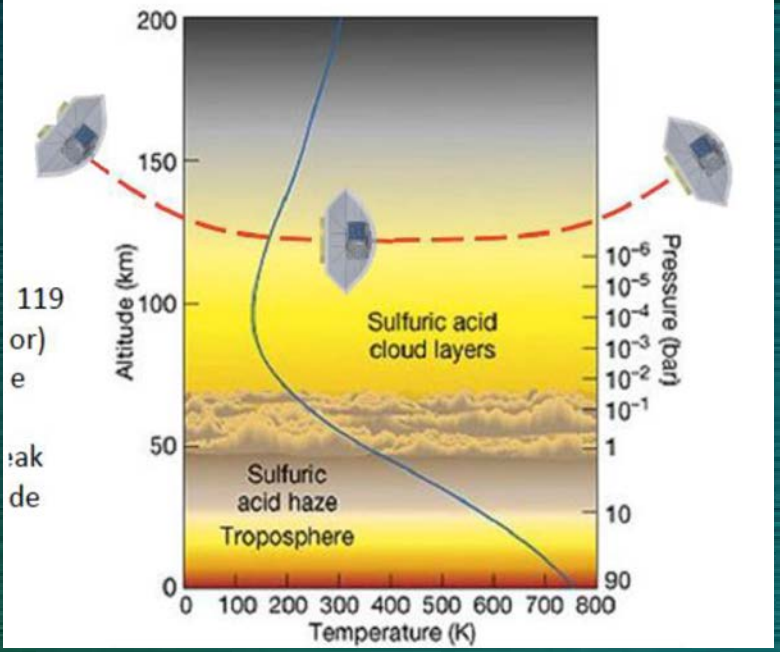
Atmospheric Skimmer (VB-Skim)

Science Objectives:
- Measure the relative abundances of noble gases and their isotopic ratios
- Determine if Venus and Earth formed from the same mix of solar nebular ingredients.
- Identify the very different processes that have shaped the two sister planets.
- Ascertain if large, cold comets played a substantial role in delivering volatiles to Venus.

Instruments
- Quadrupole Ion Trap Mass Spectrometer (QITMS).

Mission Concept **CML 4+**
- Probe (1-m diameter) is integrated with cruise stage.
- Multiple samples at different altitudes as skimmer descends below homopause.
- Samples analyzed after probe exits atmosphere and then telemeters to Earth.





Atmospheric Probe (VB-Probe)

Science Objectives:

- Characterize the aerosol layers including an investigation of the unknown UV absorber.
- Measure wind velocity in the altitude range 70 to 45 km at one location on the planet.

Instruments

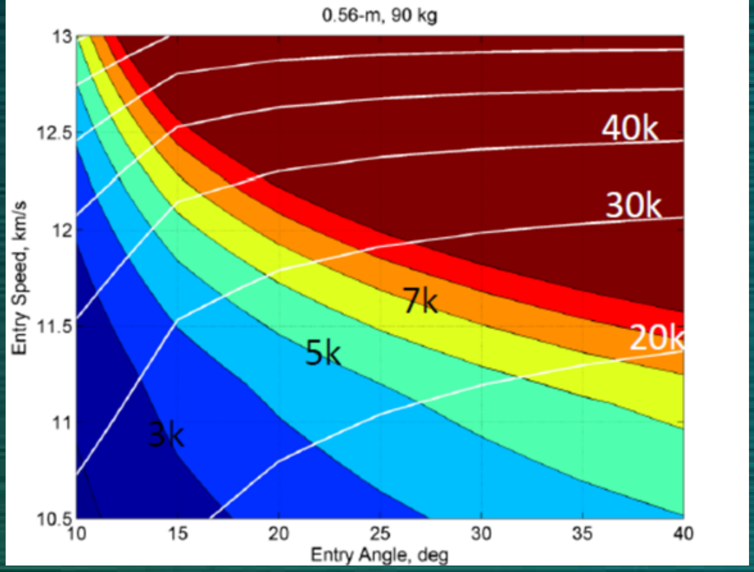
- Nephelometer: Study clouds and haze.
- NanoChem: Detect cloud forming molecules.
- Ultra Stable Oscillator: Wind velocity.
- Atmospheric Structure Instrument: Stratification.

Mission Concept **CML 2**

- Probe (0.5m diameter) with advanced technology thermal protection system (HEEET).
- Sampling extends from the point at which the probe becomes subsonic (70 km altitude) to close to the cloud base at 45 km.
- Track from earth with Delta DOR and DVLBI and Venus Bridge orbiter .

Probe with diameter of 0.56m compatible with Standard ESPA ring dimensions and Venus entry environments

Peak heat flux, W/cm² (colors by 1k)
Total heat load, J/cm² (white lines by 10k)



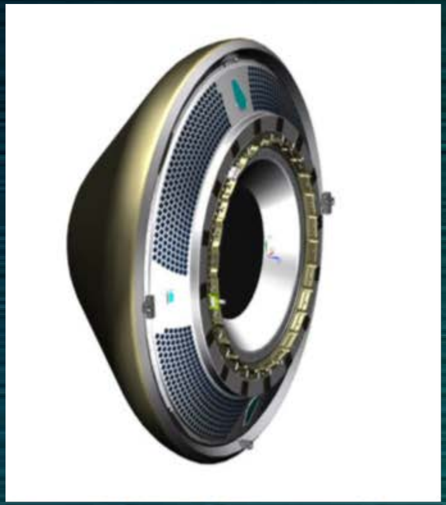
Balloon (VB-Balloon)

Science Objectives:
- Track the balloon through at least three circumnavigations of Venus,
- Characterize the particulate content of the clouds and cloud-forming species.
- Measure convective activity, turbulence and the infrasound activity.

Instruments:
- Nephelometer: Study clouds and haze.
- NanoChem: Detect cloud forming molecules.
- Infrasound: Detect seismic & volcanic activity.

Mission Concept: **CML 2**
- Probe (1.0-m diameter) with advanced technology thermal protection system (HEEET).
- Superpressure balloon is deployed at 53 km altitude and circumnavigates the planet every four to five days.
- Track from Earth and relay data through a Venus Bridge orbiter.

Aeroshell for VB-Balloon is same diameter as for VB-Skimmer but is protected with high performance thermal protection system (HEEET)



Balloon is about the same size as the 3.5m Soviet VeGa balloon from 1985. This balloon is longer duration and benefits from 40 years of technology advancements

Particles and Fields Orbiter (VB-PFO)

Science Objectives:

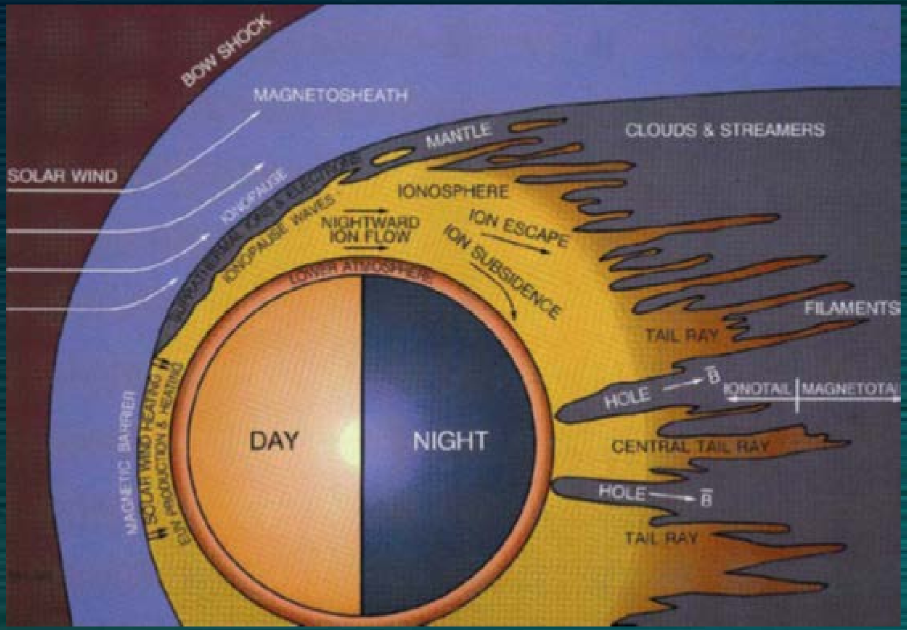
- Characterize the processes that determine atmospheric escape .
- Measure neutral and ionized species and magnetic fields under a variety of solar activity conditions.

Instruments

- Ion mass & electron analyzer.
- Magnetometer & boom.
- Langmuir probe.
- Electric field antenna.
- Radio occultations with cubesat possible (See RSOC concept).

Mission Concept **CML 3**

- Single spacecraft.
- Solar electric propulsion.
- Highly inclined eccentric orbit.
- Periapsis ideally < 250 m.
- Limited data volume needed.



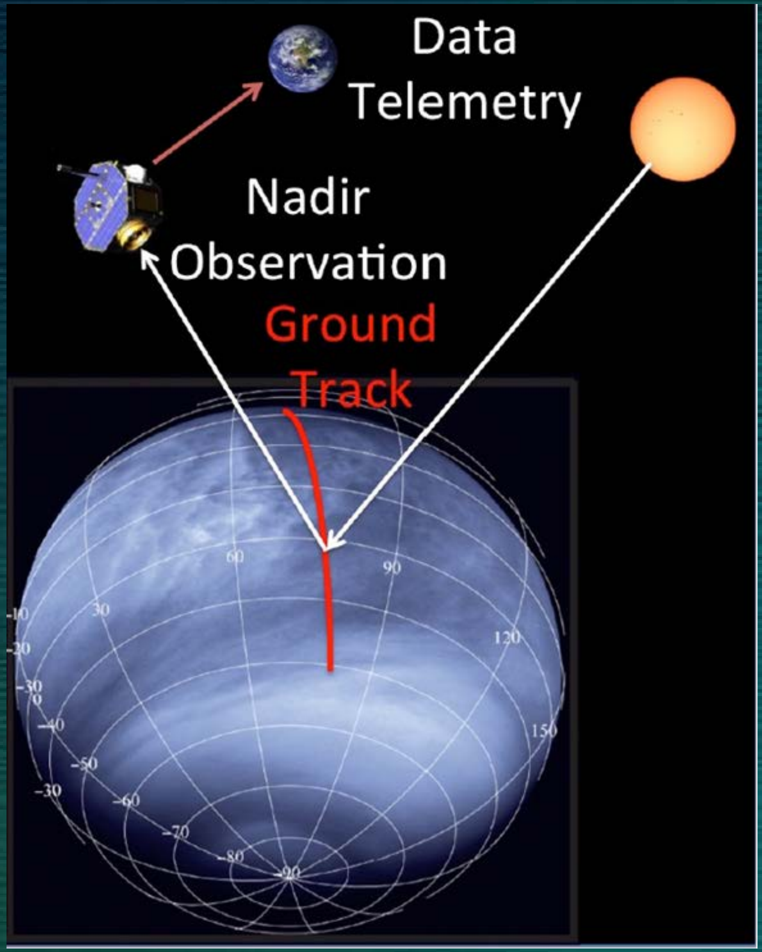
“MAVEN at Venus”

Ultraviolet Orbiter (VB-UVO)

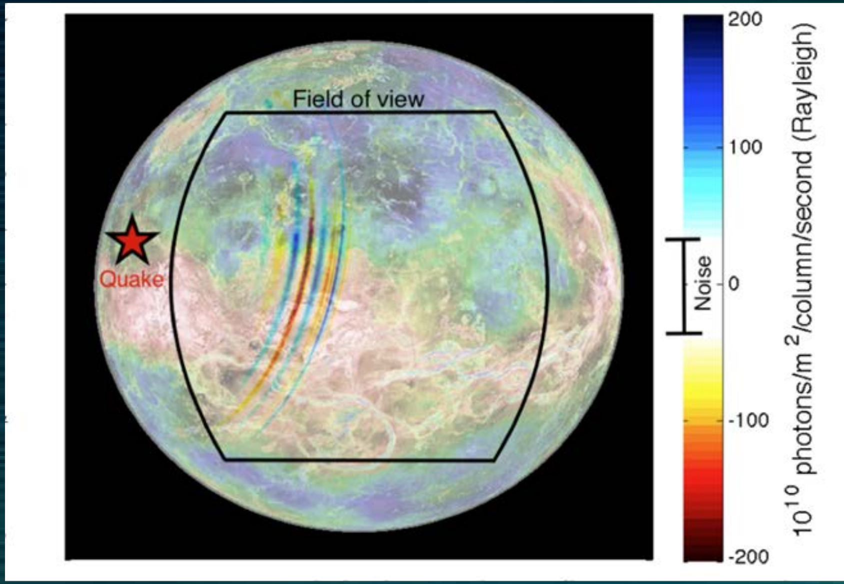
Science Objectives:
- Characterize Venus UV absorber(s) and understand its upper clouds dynamics and chemistry and the planet's energy balance.

Instruments
- UV Spectrometer 200 to 400nm with 0.2 nm resolution.
- UV multispectral imager 320 to 570nm with 4 nm resolution.

Mission Concept **CML 4**
- Single spacecraft
- Solar electric propulsion
- High altitude polar orbit providing nadir observations



Infrared Orbiter (VB-IRO)

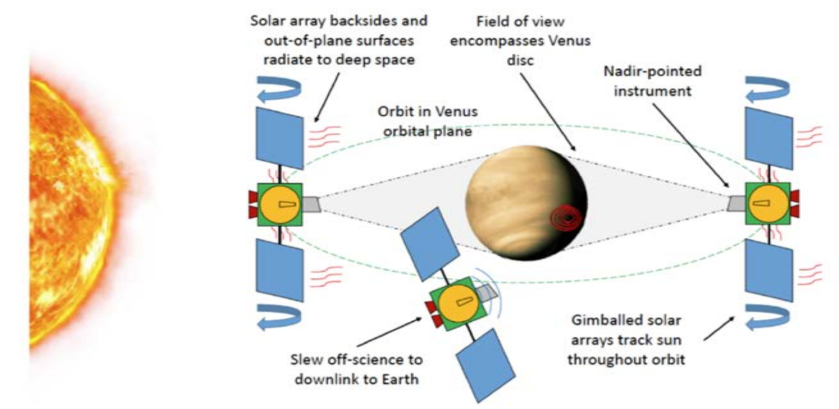


Science Objectives:

- Measure atmospheric perturbations in airglow in order to characterize seismic-wave propagation and seismicity. Determine crustal thickness.
- Characterize gravity waves in the upper atmosphere.

Instrument:

- Two channel infrared imager at 1.27µm and 4.3 µm.



Mission Concept **CML 4**

- Observe Venus from a high circular orbit with 24 hour period.
- Stare at the full disc using 1.27µm on the nightside and 4.3 µm on the dayside.
- Recording of data is triggered when waves traveling across the disc at seismic velocities are observed.

Note this concept for two-channel infrared observation of the atmosphere is distinct from the 4-channel V-BOSS imager for joint atmospheric & surface observations.

Submillimeter Orbiter (VB-SMO)

Science Objectives:

- Investigate the chemistry and dynamics of the middle atmosphere from the cloud base to the lower thermosphere.
- Identify the processes that controls the superrotation.

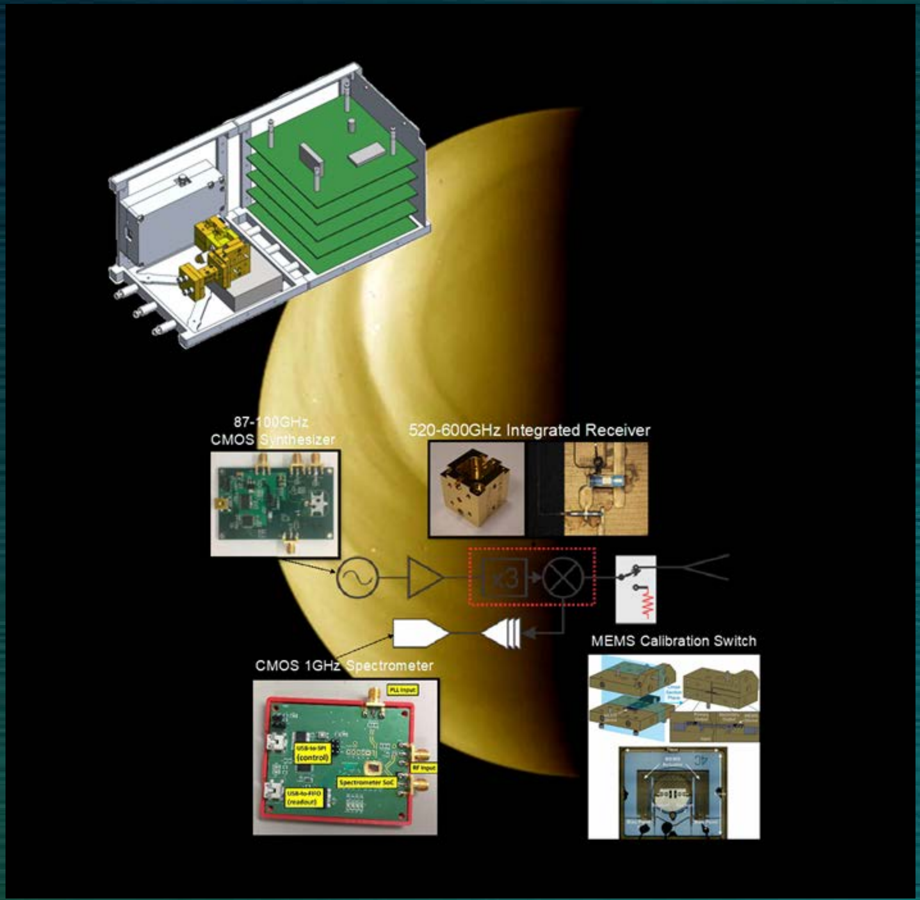
Instruments

- Miniaturized JPL submillimeter wave spectrometer/limb sounder.

- Sensitivities: some molecular species (pp-trillion) .
- winds- meters per second.

Mission Concept **CML 2**

- SmallSat less than 100 kg dry mass.
- 500 x 4,000 km elliptical polar orbit.



Radioscience Orbiter with Cubesats (VB-RSOC)

Science Objectives:

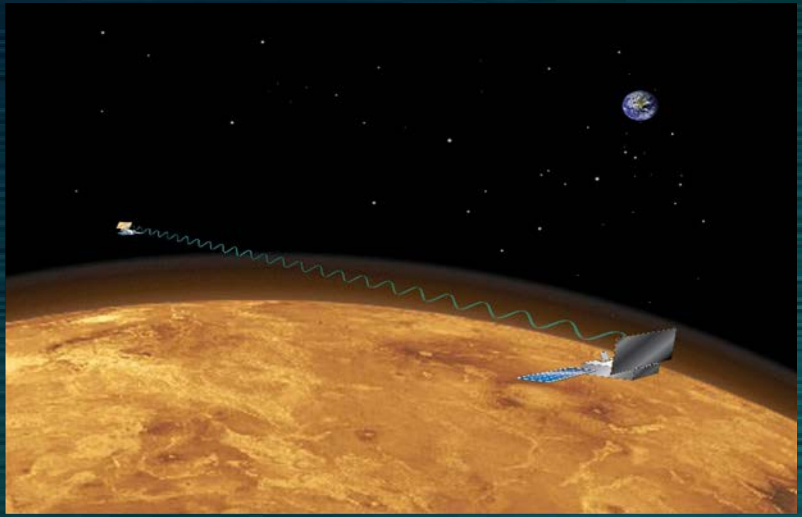
- Probe global structure of Venusian atmosphere and surface-atmosphere coupling by measuring gravity and planetary waves.
- Use radio occultations of smallsat/cubesat cross-links to generate temperature and pressure profiles to ~ 45 km altitude as function of latitude, longitude, time of day.

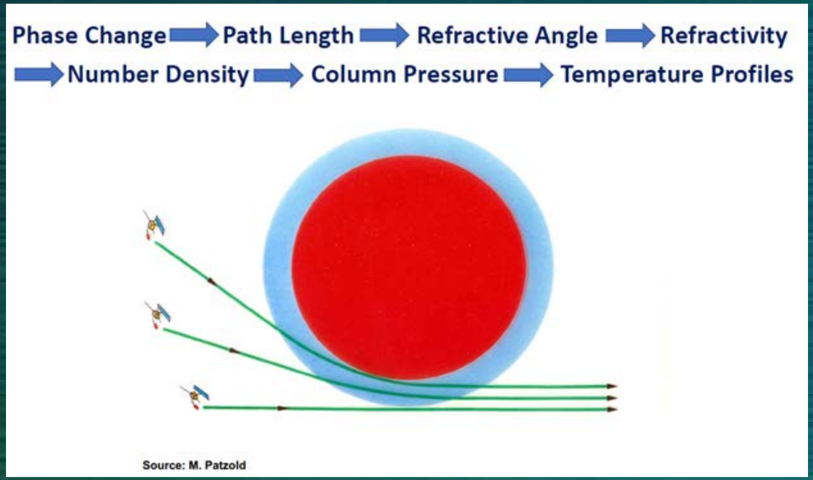
Instruments

- Dual-purpose radio, conducts both science measurement cross-links and data telemetry.

Mission Concept **CML 2**

- Smallsat deploys cubesats, placing them in different orbits.
- Crosslink geometry provides much improved latitude-longitude-time coverage over traditional Earth-spacecraft occultations.





JPL Possible Linkages

- Science
  - Skimmer + particles & fields orbiter to assess atmospheric origin & loss.
  - High-altitude probe + orbiter to determine nature of ultraviolet absorber.
  - Balloon + orbiter to assess seismicity.
- Telecom
  - Skimmer requires no relay as it can return all data after exiting atmosphere.
  - Probe survives <1 hr and has very limited direct-to-Earth data return capability. An orbital relay offers major advantages.
  - For a balloon mission, as for the long-lived lander in the companion study, an orbital relay is vital.

Venus Bridge Study Summary

- **GRC provided a fully scientifically and technically linked orbiter and lander.**
  - Concept Maturity Level 4 (achieved preferred design)
  - Conservative approach using major aerospace providers.
  - Two-element mission priced at $201M, including 25% reserves on Phases A-D but not including some required technology development to TRL 6 nor launch, operations, or communications. Class D no redundancy.
- **JPL provided a wide range of missions.**
  - CML 2-4+ (varies from initial feasibility to preferred design).
  - Favors separate transfer for each element due to volume and complexity.
  - Single-element concepts were typically <$100M including ~30% reserves, launch, and operations; some tech development not included.
  - Aggressive approach assumes unproven university or smallsat providers to meet cost cap. Class D minimal redundancy.
- **For $200M, can probably do a couple of smallsat missions, with significant risk.**

Venus is a cornerstone of comparative planetology.

It is the key to understanding where Earth-sized means Earth-like in the Universe.

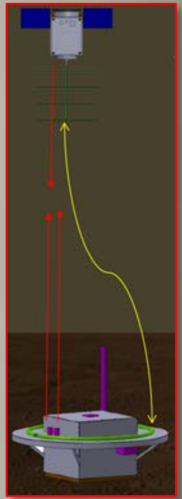
Venus records both the origin and fate of habitable planets.

US Missions

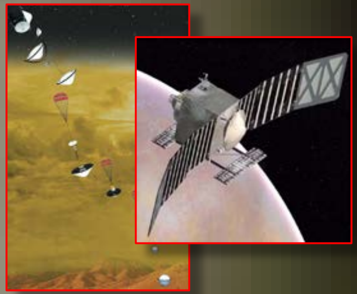
NASA Magellan 1989-1994

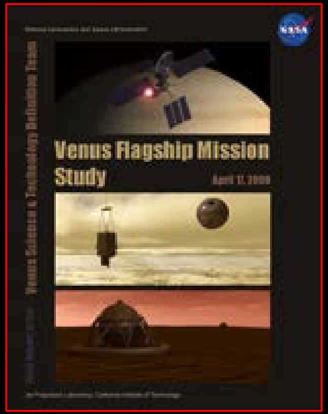
SmallSats?

Venus Bridge 2025?



Discovery New Frontiers 2026-2028?



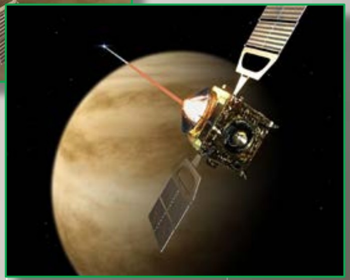


Venus Flagship?

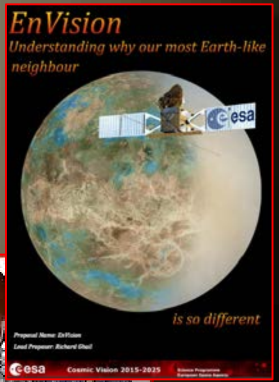
International Missions

ESA Venus Express 2005-2014

JAXA Akatsuki 2010-present



RSA Venera D 2026+?



ESA Envision 2031?

1990 1995 2000 2005 2010 2015 2020 2025 2030 2035 2040 2045