

VENUS FLAGSHIP MISSION PLANETARY DECADAL STUDY

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AND THE VENUS FLAGSHIP MISSION STUDY TEAM

Planetary and Astrobiology Decadal Survey
October 13, 2020



VENUS FLAGSHIP MISSION CONCEPT SCIENCE TEAM

Study Team

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Mission Design at GSFC, Richard Lynch, Lead, M. Amato; Adriana Ocampo, NASA HQ liaison

Host of generous domestic and international colleagues, collaboration between several NASA centers sharing science, instrument and engineering expertise – THANK YOU!

Erica Aguirre, Abby Allwood, Chi Ao, Shahid Aslam, Sami Asmar, Kevin Baines, Charles Baker, Don Banfield, Bruce Bills, Dave Blake, Jeremy Brossier, Paul Byrne, Gordon Chin, Sam Clegg, Glynn Collinson, Jim Cutts, Doris Daou, Darby Dyar, Larry Esposito, Sabrina Feldman, Justin Filiberto, Stephanie Getty, Jim Greenwood, Jeff Hall, Paul Hartogh, Chris Heirwegh, Joern Helbert, Scott Hensley, Laurie Higa, Gary Hunter, Noam Izenberg, Jacob Izraelevitz, Andrew Johnson, Kandis-Lea Jessup, Attila Komjathy, Tibor Kremic, Siddharth Krishnamoorthy, Sebastian Lebonnois, Yang Liu, Earl Maize, Darby Makel, Larry Matthies, Suman Muppidi, Dragan Nikolic, Adriana Ocampo, Joe O'Rourke, Bob Pappalardo, Brian Paczkowski, Richard Quinn, Ann Parsons, Michael Pauken, Jason Rabinovitch, Bruce Milam, Miguel San Martin, Dave Senske, Rainee Simons, Suzanne Smrekar, Christophe Sotin, Eric Sunada, Melissa Trainer, Allan Treiman, Ethiraj Venkatapathy, Panagiotis Vergados, Larry Wade, Michael Way, Chris Webster, Thomas Widemann.₁

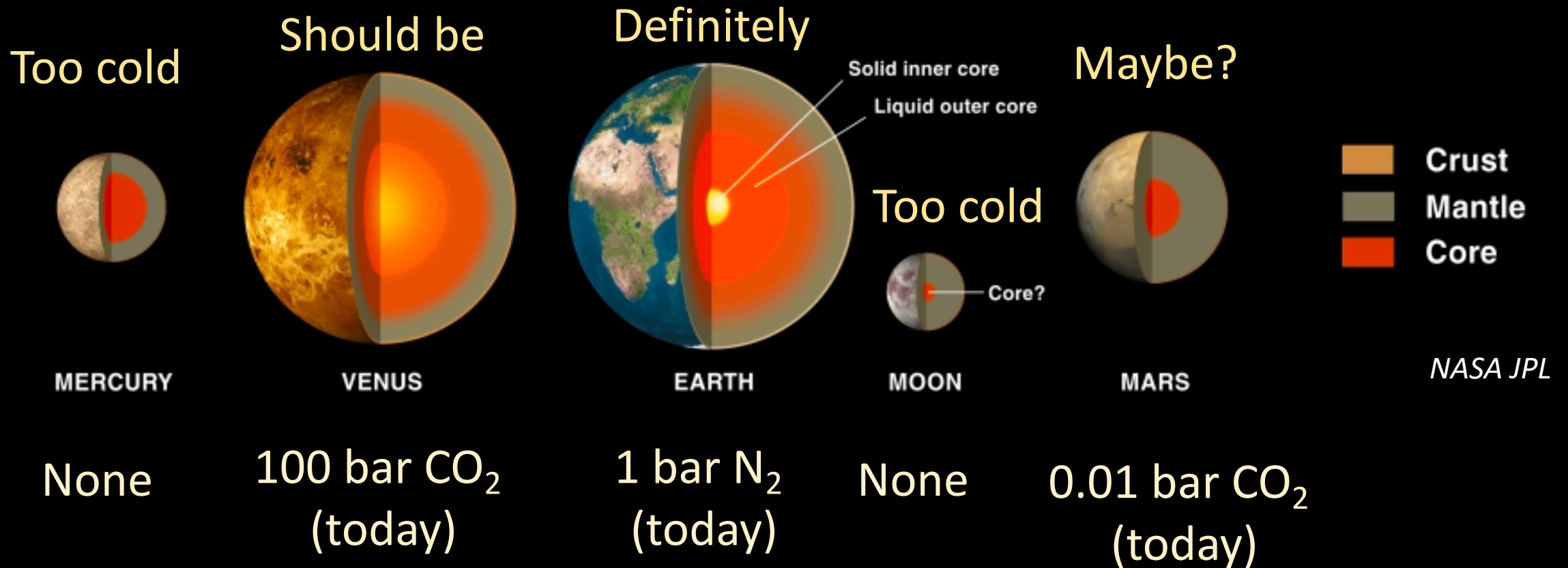
Science/Engineering Team meetings 2-4x/week, 2.5 days at GSFC Feb, 2 week Design run virtually in April

SCIENCE RATIONALE

*Astronaut photograph ISS020-E-9048 acquired on June 12, 2009
Nikon D2XS digital camera fitted with a 400 mm lens
Expedition 20, Sarychev Peak, Kuril Islands, NE Japan*

Habitable planets must be large enough to:

Stay geologically active (long enough for life to develop)



Venus Flagship Mission

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Generate and maintain an atmosphere (long enough for life to develop)

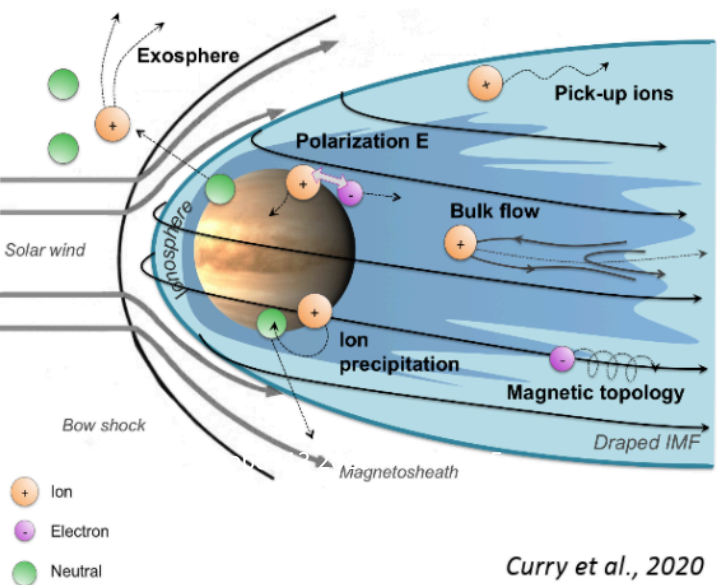
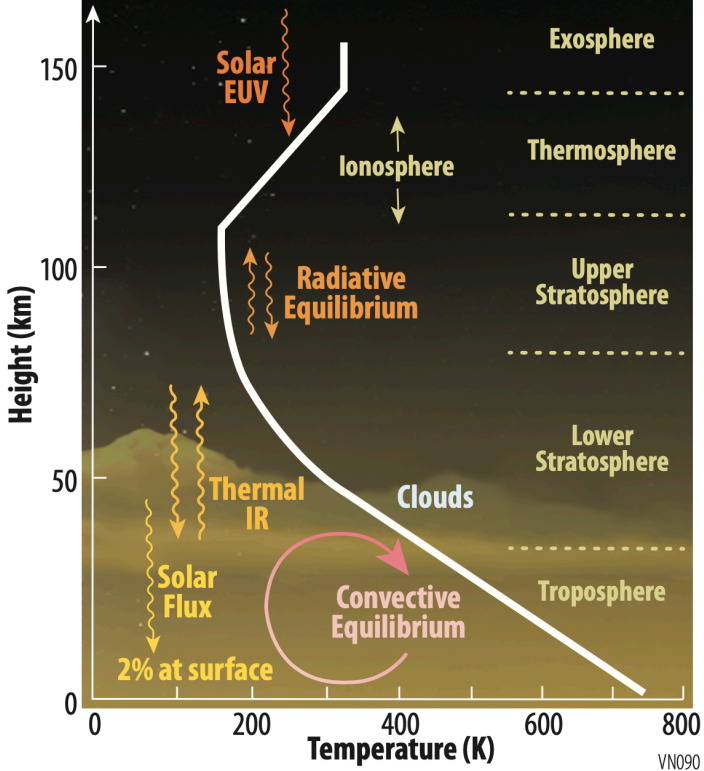
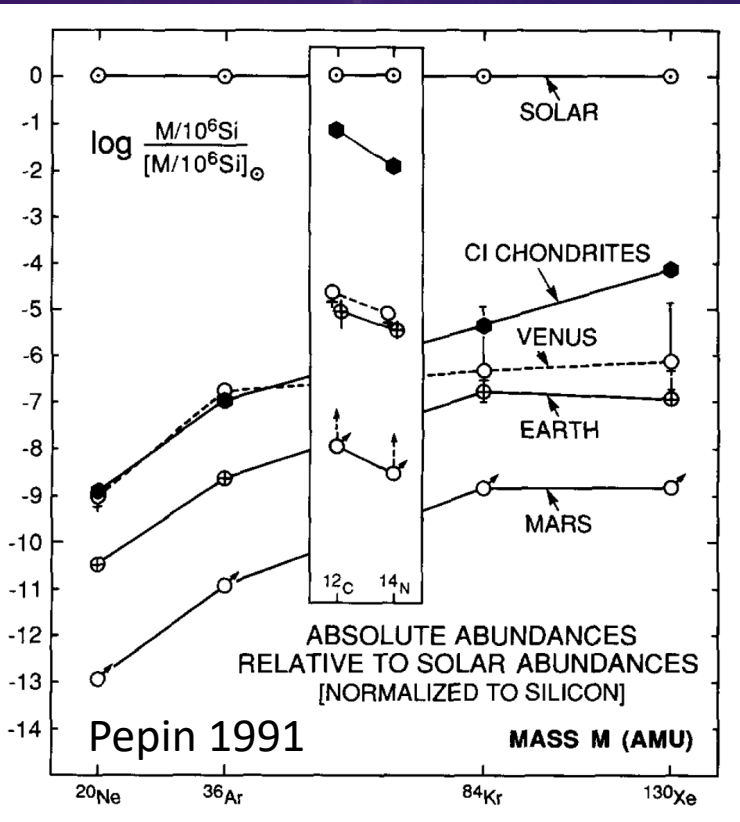
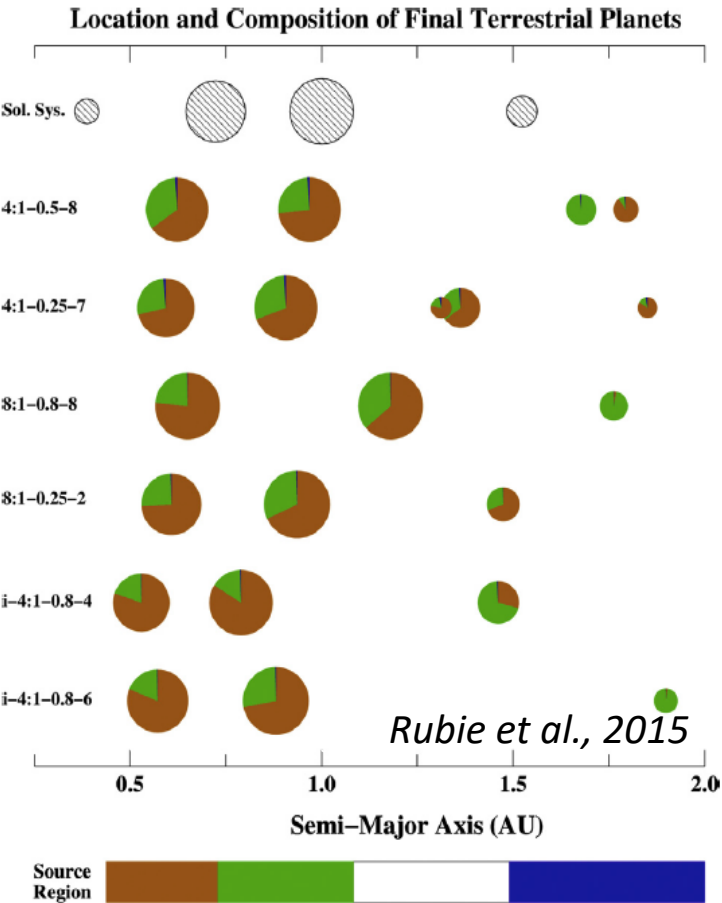
Deuterium on Venus: Observations From Earth

CATHERINE DE BERGH, BRUNO BÉZARD, TOBIAS OWEN,
DAVID CRISP, JEAN-PIERRE MAILLARD, BARRY L. LUTZ

Absorption lines of HDO and H₂O have been detected in a 0.23-wave number resolution spectrum of the dark side of Venus in the interval 2.34 to 2.43 micrometers, where the atmosphere is sounded in the altitude range from 32 to 42 kilometers (8 to 3 bars). The resulting value of the deuterium-to-hydrogen ratio (D/H) is 120 ± 40 times the telluric ratio, providing unequivocal confirmation of in situ Pioneer Venus mass spectrometer measurements that were in apparent conflict with an upper limit set from International Ultraviolet Explorer spectra. The 100-fold enrichment of the D/H ratio on Venus compared to Earth is thus a fundamental constraint on models for its atmospheric evolution.

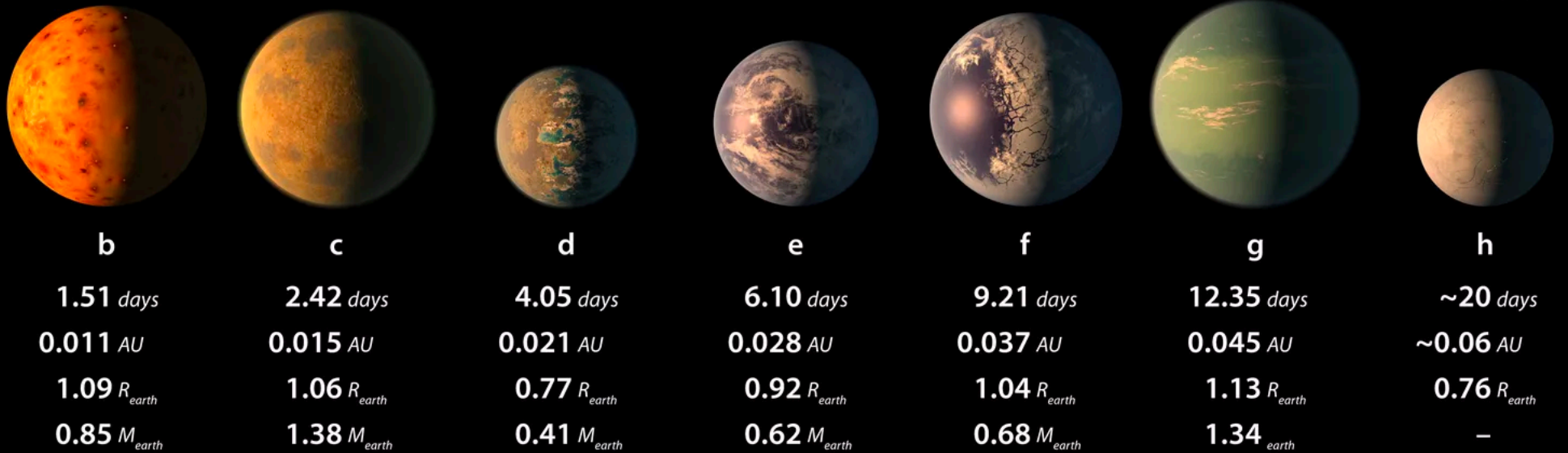
1991, Science

What we don't know about the closest Earth size planet could fill a book...or a field.



TRAPPIST-1 System

Orbital Period
days
Distance to Star
Astronomical Units (AU)
Planet Radius
relative to Earth
Planet Mass
relative to Earth



S. Kane:
“Venus is the only exoplanet we will ever touch”

Solar System Rocky Planets

Orbital Period
days
Distance to Star
Astronomical Units (AU)
Planet Radius
relative to Earth
Planet Mass
relative to Earth



Since Magellan:

Details about upper atmosphere dynamics and composition from VEx and Akatsuki, plus important observations for which these payloads were not optimized

Venus may be geologically active

Smrekar et al., 2010; Davaille et al., 2017; Marcq et al., 2012; Shalygin et al., 2015; Filiberto et al., 2020; Gülcher et al., 2020

Venus may have felsic (silica-rich) crust

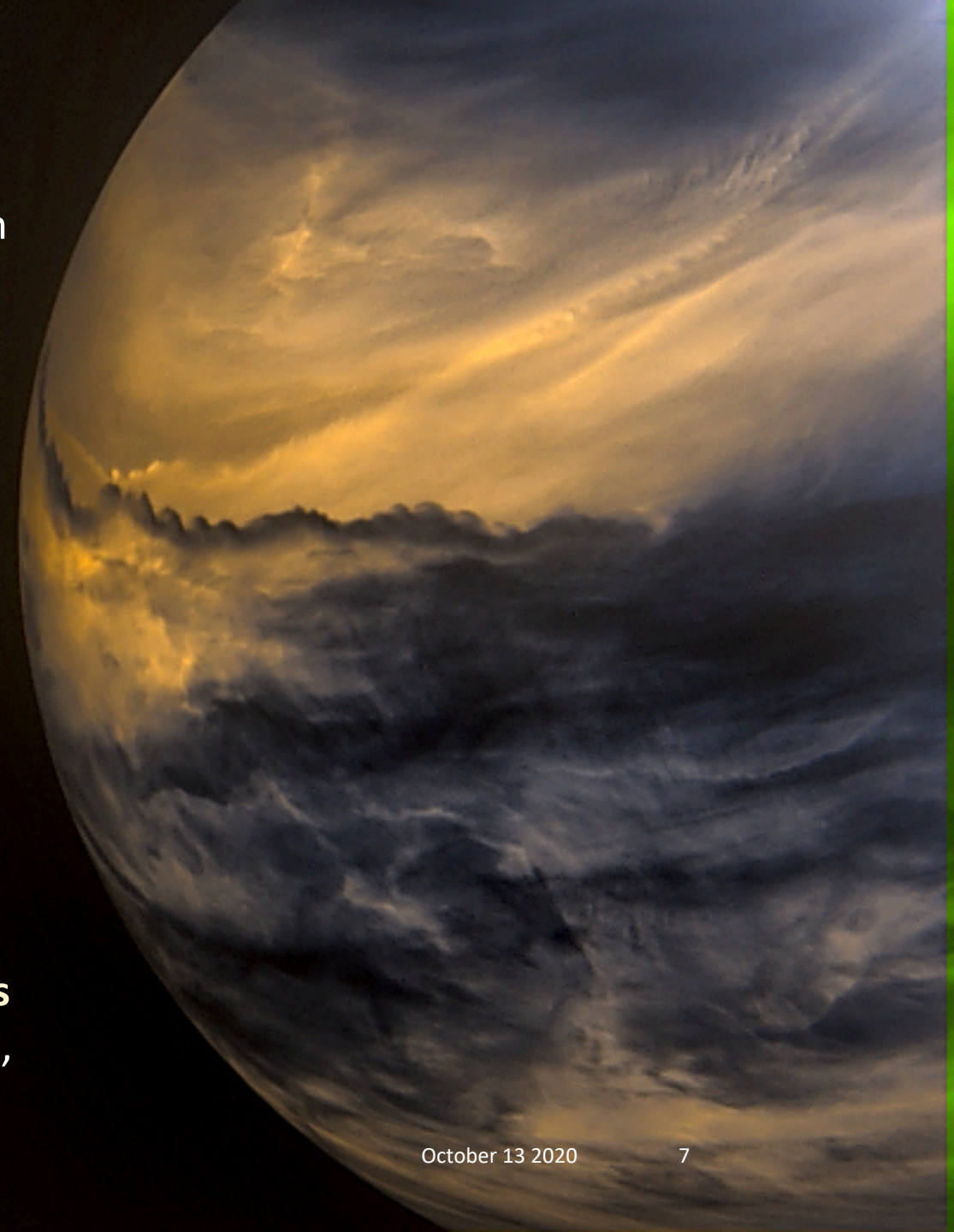
Gilmore et al., 2015; 2017

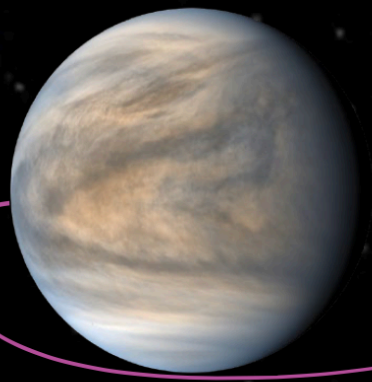
New GCM modeling showing Venus ocean may have lasted billions of years

Way et al., 2016, Way and Del Genio, 2020

Hypothesis and possible detection of life in the Venus clouds

Morowitz and Sagan, 1967; Limaye et al., 2018; Greaves et al., 2020; Seager et al., 2020





Venus Flagship Mission Study

A MISSION TO EXPLORE THE HABITABILITY OF VENUS

PI: Martha Gilmore, *Wesleyan University*; D-PI: Patricia Beauchamp, *Jet Propulsion Laboratory, California Institute of Technology* 

Science Goals	Science Objectives
Understand the history of volatiles and liquid water on Venus and determine if Venus has ever been habitable.	Determine if Venus once hosted liquid water at the surface.
	Identify and characterize the origins and reservoirs of Venus's volatiles today.
	Place constraints on whether there are habitable environments on Venus today and search for organic materials and biosignatures.
Understand the composition and climatological history of the surface of Venus and the present-day couplings between the surface and atmosphere.	Constrain the composition of the surface and chemical markers of past and present climate.
Understand the geologic history of Venus and whether Venus is active today.	Determine if Venus shows evidence of a current or past plate tectonic regime.
	Determine whether Venus is tectonically and volcanically active today.

Processes to be Studied

Altitude Ranges (approximate)

Escape to space		Exosphere 200 km
Photodissociation to H^+ , OH^- , O^+		Thermosphere 100 km
H_2O & SO_x cycles in mesosphere		Mesosphere 70 km
Volatile cycling in the clouds		Cloud Layers 50 km
Thermochemistry in troposphere		Troposphere
Weathering Active volcanism? Tectonism?		Surface 0 km Crust
Volatile cycling in Crust, Mantle and Core		Mantle, Core -50 km -6050 km



Science Objectives					
1. Did Venus once host liquid water?	2. Origins & reservoirs of volatiles today.	3. Habitability and life today.	4. Composition of surface, paleoclimate	5. Evidence of tectonic regime	6. Tectonic & volcanic activity today
Measure escape of O & H isotopes, solar wind interaction				Orbiter and Smallsats	
				Lander/Probe	
				Aerobot	
Map transport of O & H isotopes	volatiles & winds in mesosphere				Map SO ₂ & H ₂ O plumes
Noble gas isotope abundances	Profiles of gases & hazes	Environment sensors			Search for plumes
Descent imagery	Cloud & gas composition profiles	Biomolecule search			Search for volcanic gas plumes
morphology mapping SAR			Morphology mapping SAR		
surface analysis	Met. station		Composition mapping (NIR)		weathering
Crust thickness & properties (gravity)			surface analysis		Orbital Search for volcanic activity
Mantle & core properties				Crust thickness & properties (gravity)	seismicity from infrasound; remanent magnetism

		Horizontal Scale										
		1 mm	1 cm	1 m	10 m	100 m	1 km	10 km	100 km	1000 km	10000 km	
Exosphere / ionosphere	400 km	solar wind interaction, magnetosphere, escaping volatile fluxes (orbiter & smallsats)										
Thermosphere / ionosphere	200 km	trace gases, temperatures, winds (sub-mm)										
Mesosphere	100 km	Atmospheric composition profile (descent probe)										
Upper (stable) cloud	70 km											
Convective cloud layer	50 km											
Troposphere	25 km											
Troposphere	10 km	water vapour abundance (NIR)										
Planetary boundary layer	1 km	meteorology										
Surface	surface	surface imaging (descent imaging)										
		surface & sample analysis										
		composition mapping (NIR)										
		surface imaging & characterisation (SAR)										
Crust	50 km	seismicity from infrasound; remanent magnetism										
Mantle	500 km	Crust thickness & properties (gravity)										
Core	5000 km	Mantle properties										
		Core properties										
orbiter & smallsats												
descent probe / lander												
aerobot												



Key elements of Design

Launch 2031. **Synergistic measurements** between multiple assets:

- **Orbiter and 2 SmallSats** support in situ assets prior to science campaign
- **Lander** – 7 hour lifetime on tessera terrain after 1 hour of measurements on descent
- **Aerobot** – 60+ days, variable altitude between 52 and 62 km altitude
- **Long-lived lander (LLISSE)** – 60+ days
- Assumed no prior Venus missions, but flexible to accommodate them.
- The overall mission concept was derived from the three major science goals and two cost-driven requirements that were derived early in the study: **1) launch all elements on a single rocket** and **2) limit the g-load for Venus entry to $\leq 50g$** in order to maximize the use state-of-the-art instruments that had high heritage or were assessed to have high technology levels. Both of these requirements were accomplished.



Key Trades

- Definition of the elements that are needed to fulfill the science objectives.
- Evaluation of launch architectures
- Determination of how to provide communication coverage for the aerobot and the lander.
- Selection of propulsion systems for the smallsats and orbiter
- Evaluation of methods to reduce instrument g loads.
- Determination of the aeroshell shape
- Determination of the orbiter orbit.
- Determination of launch dates.

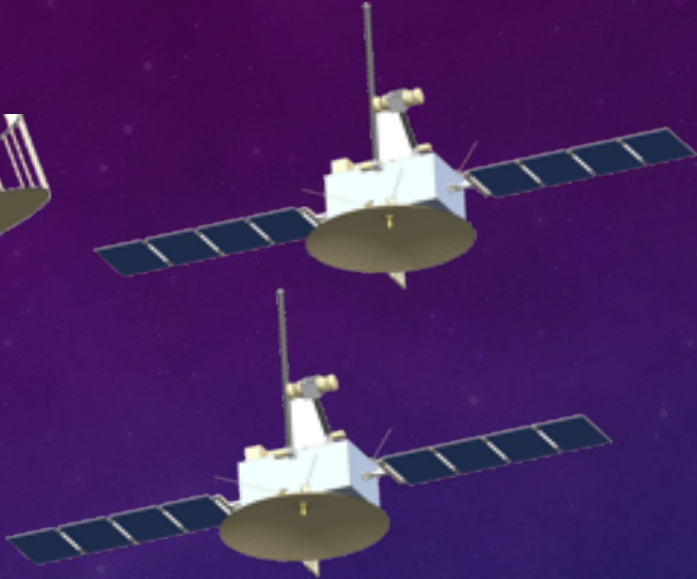
VFM PLATFORMS



Falcon 9 Heavy Expendable w/ 5 m Fairing



Orbiter and carrier spacecraft



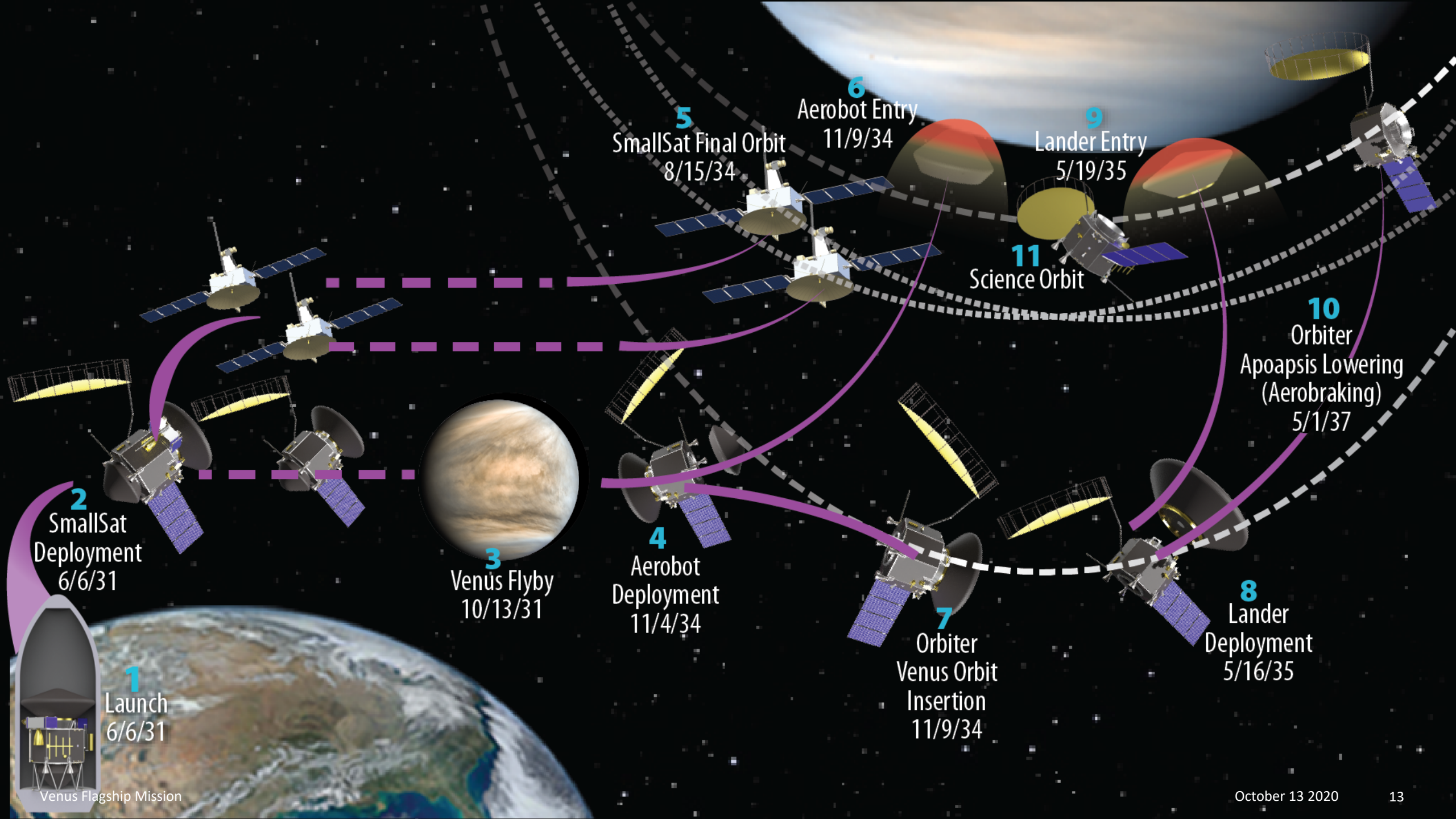
Two SmallSat orbiters



Lander/Descent Probe and LLISSE



Aerobot



Lander

Neutral Mass Spectrometer (NMS)
Tunable Laser Spectrometer (TLS)
Atmospheric Structure Suite [P, T, Radiometer] (AS)
Descent NIR Imager (DI)
Nephelometer (Neph)
Neutron Generator/Gamma Ray Spectrometer (GRS)
X-Ray Diffractometer (XRD)
Raman-LIBS Instrument (R-LIBS)
Panoramic Camera (PC)
X-ray Fluorescence Spectrometer (XFS)
Long-Lived In-Situ Solar System

Aerobot

Aerosol Mass Spectrometer with Nephelometer (AMS-N)
Fluorimetric Microscope (FM)
Meteorological suite (P, T, Radiometer, 3-d Wind Sensor Dosimeter) (MET)
Visible Imager (student experiment) (VI)
Magnetometer (Mag)

Instrument Key

 Atmospheric
 Mineralogy and Geology
 Magnetic Fields
 Particles
 Aerosols

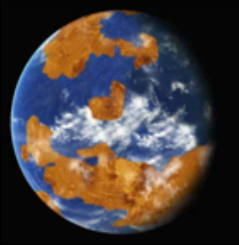
Orbiter

Synthetic Aperture Radar (SAR)
Near IR Imager (NIR-I)
Sub-mm Spectrometer (S-mm)
Magnetometer (Mag)
Ion Electrostatic Analyzer (ESA-i)
Electron Electrostatic Analyzer (ESA-e)
2 each Neutral Mass Spectrometer (NMS)

SmallSats

Magnetometer (Mag)
Electron electrostatic analyzer (ESA-e)
Ion electrostatic analyzer (ESA-i)
Langmuir Probe (LP)
Electric Fields Detector (E-FD)
Solar Energetic Particle Detector (SEPD)
EUV Sensor (EUV)

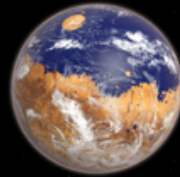
Our neighborhood 4 billion years ago 3 habitable planets?



Venus



Earth

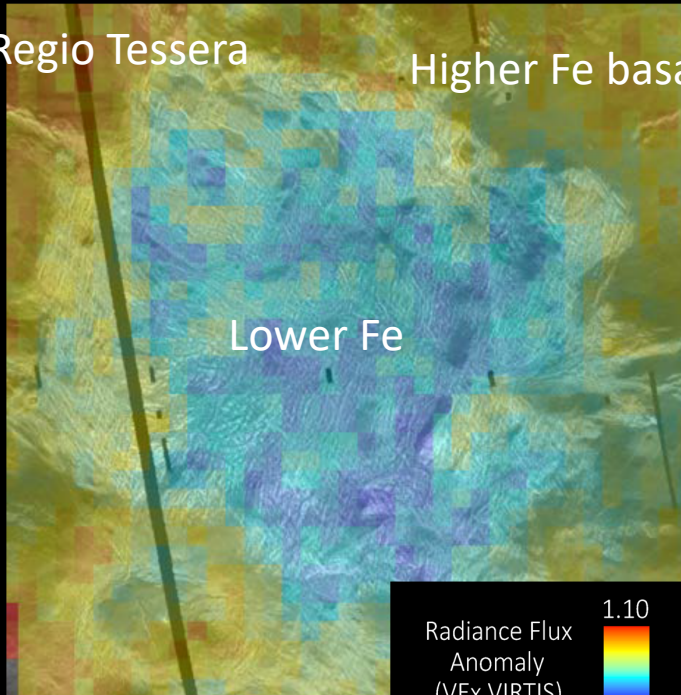


Mars

Alpha Regio Tessera

Higher Fe basalts

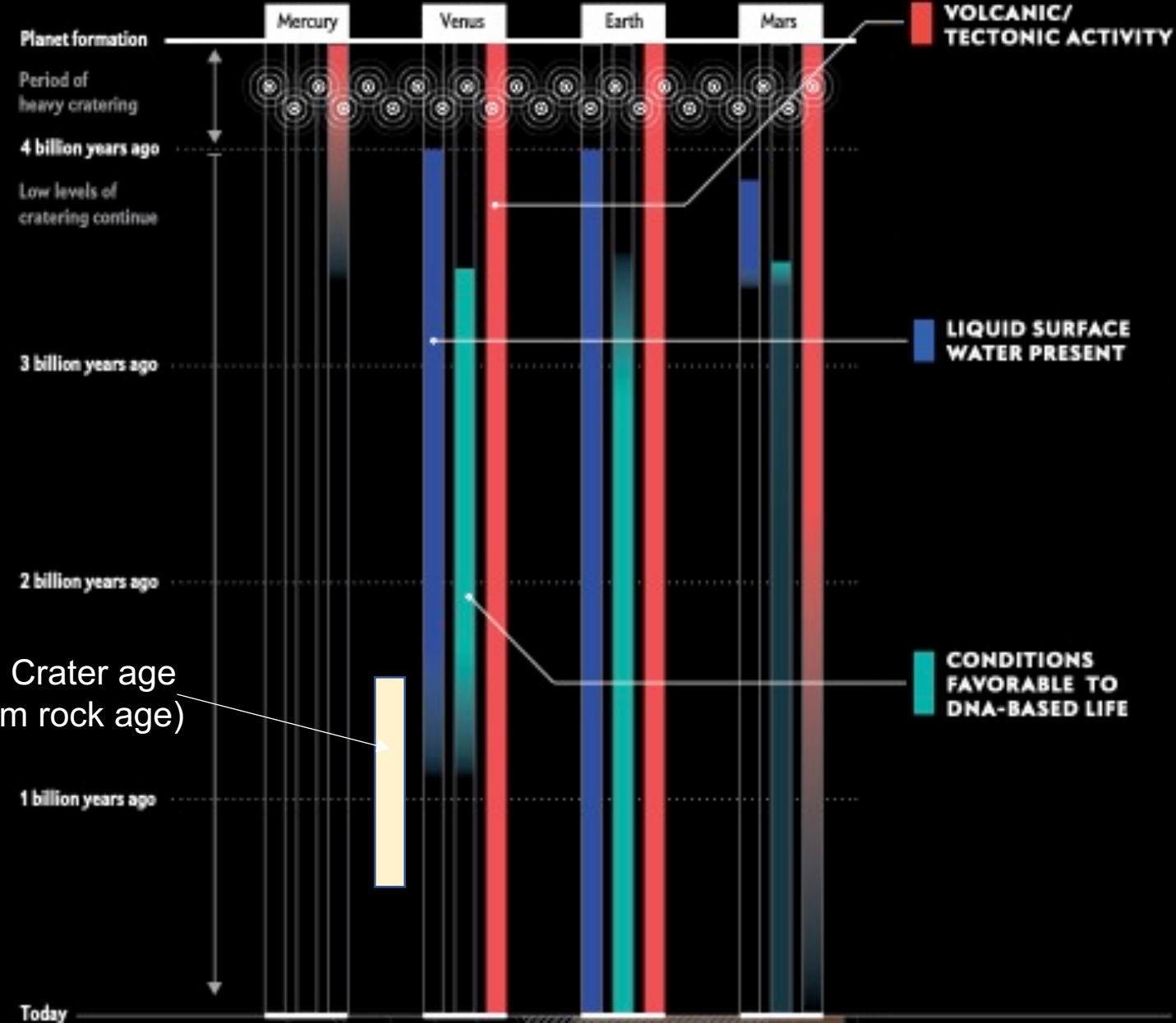
Lower Fe



Radiance Flux
Anomaly
(VEx VIRTIS)
1.10
0.79

Gilmore et al., 2015

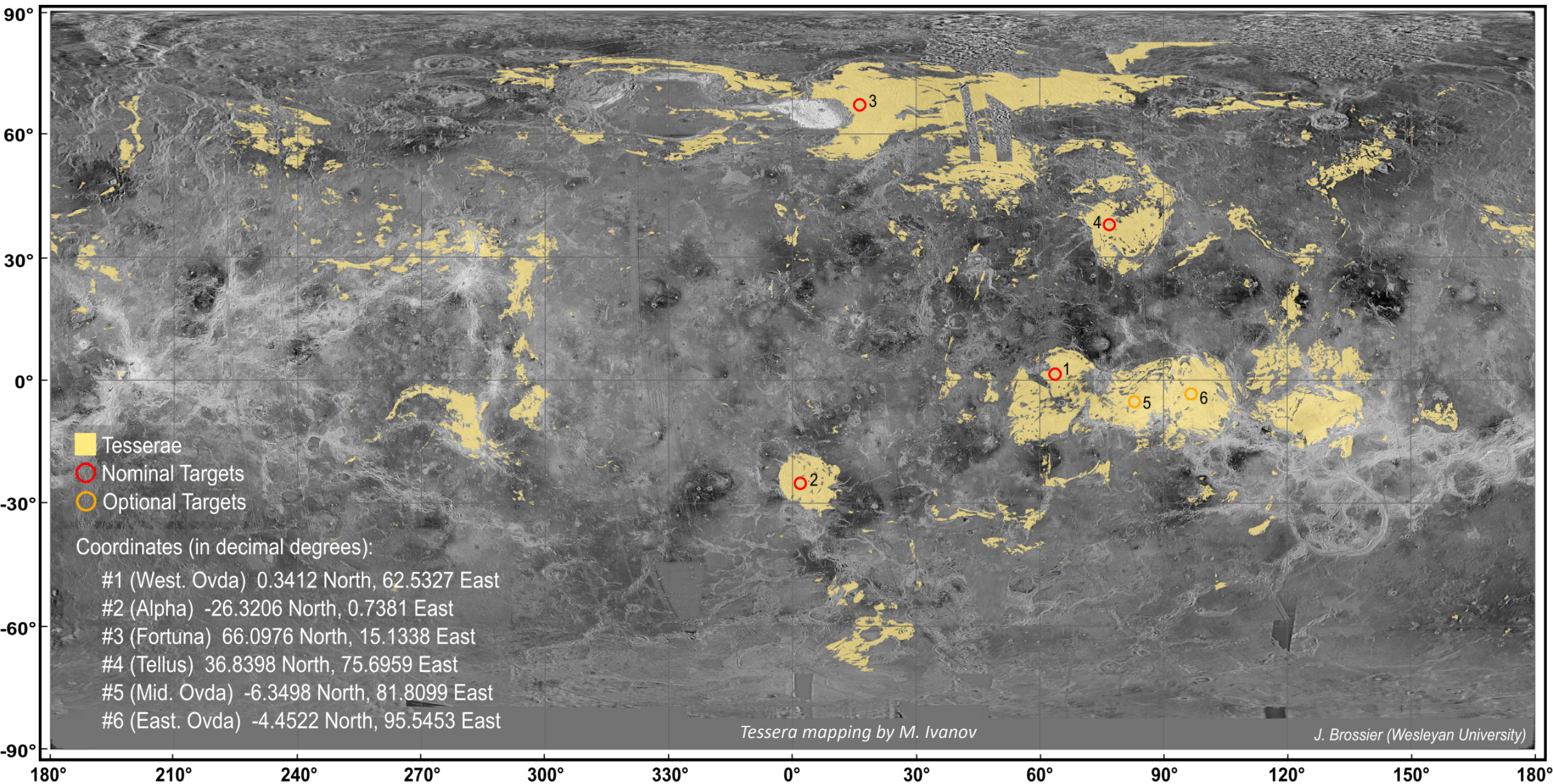
Venus Flagship Mission



Graphic by Tiffany Farrant-Gonzalez, Dyar et al. Sci. Am. Feb 2019

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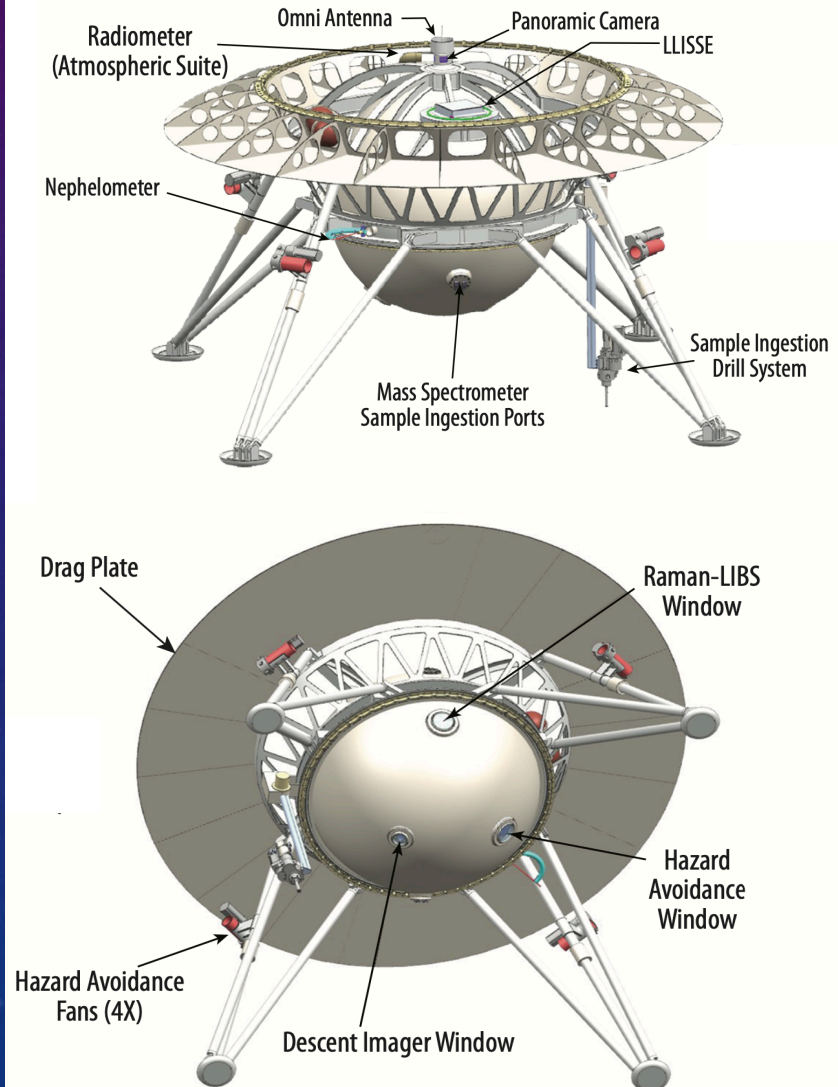
LANDER

Science: Mineralogy, geochemistry and morphology of Venus tessera terrain, constrain surface-atmosphere interactions, long-duration near surface atmosphere characterization

- **Ingestion** of samples into the lander for elemental chemistry and mineralogy
- AND
- **“Mobility”** achieved with Raman/LIBS by analyzing many targets for chemistry and mineralogy
 - Gamma-ray spectrometer to get integrated measurement
 - **LLISSE – Long-Lived In Situ Solar System Explorer**, T. Kremic, GRC – atmospheric measurements over 60 days

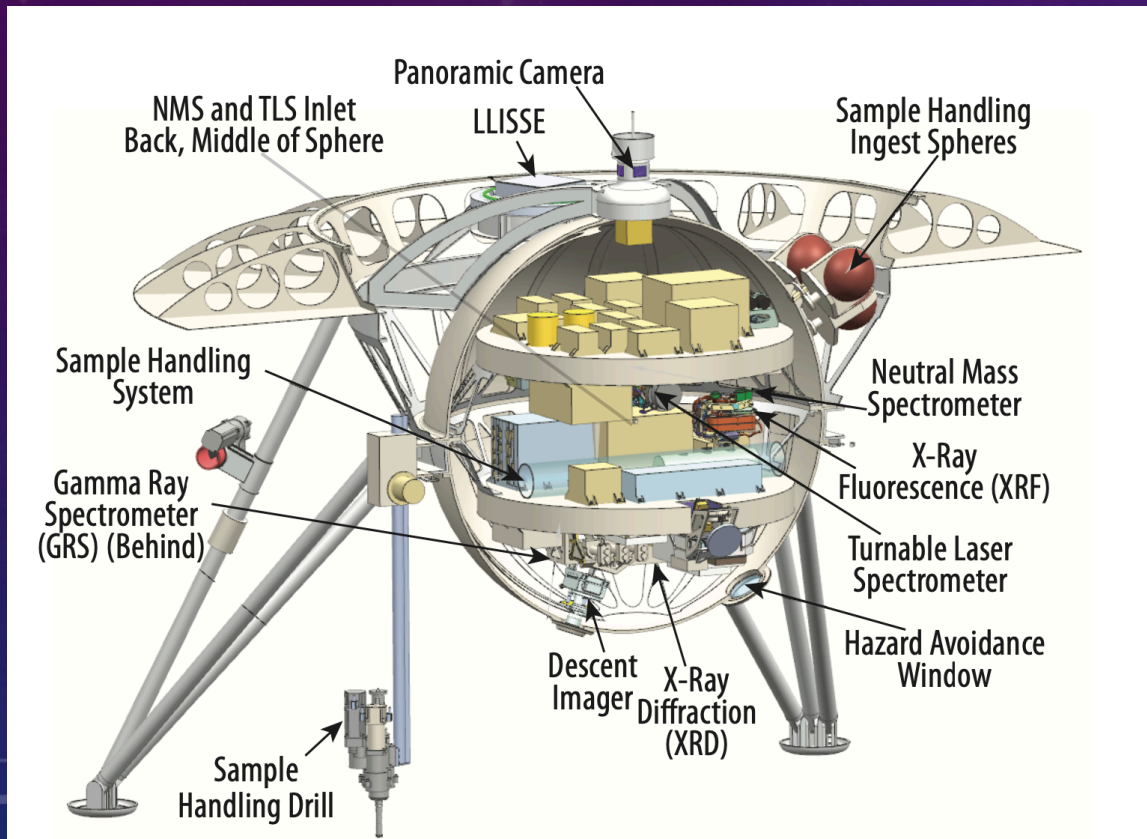
Addresses VFM Objectives

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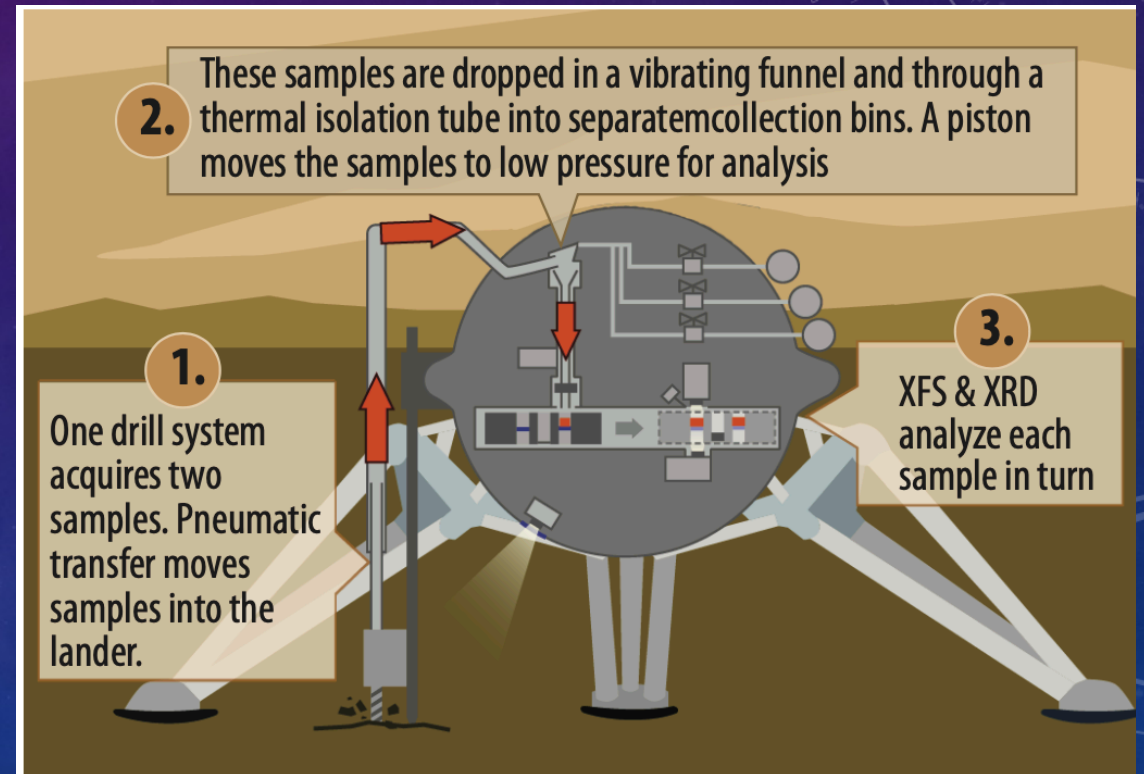


SAMPLE HANDLING

- 3 individual samples collected by drill Ingested and analyzed by X-ray Florescence, then dropped into X-Ray Diffractometer



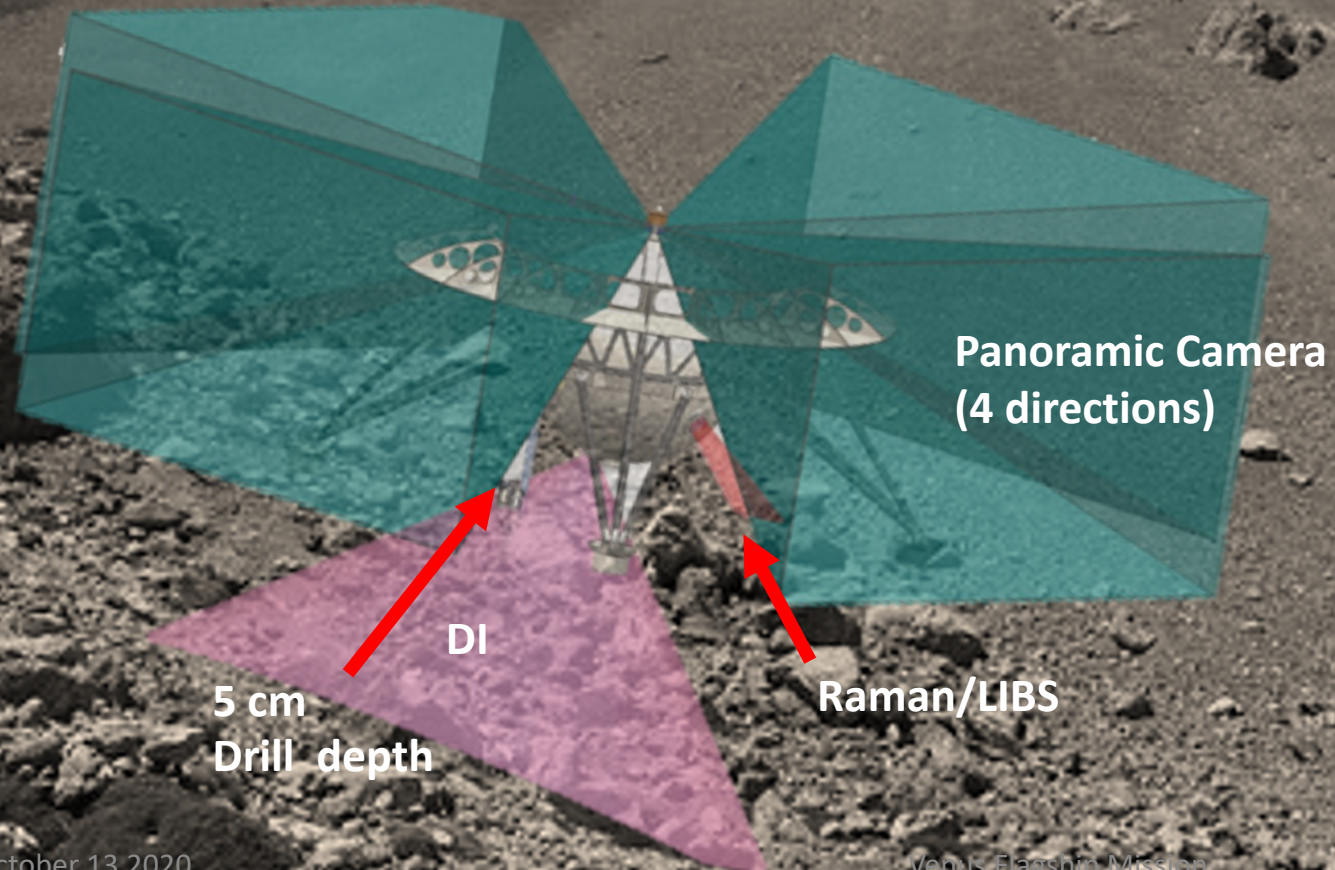
Venus Flagship Mission



VN147

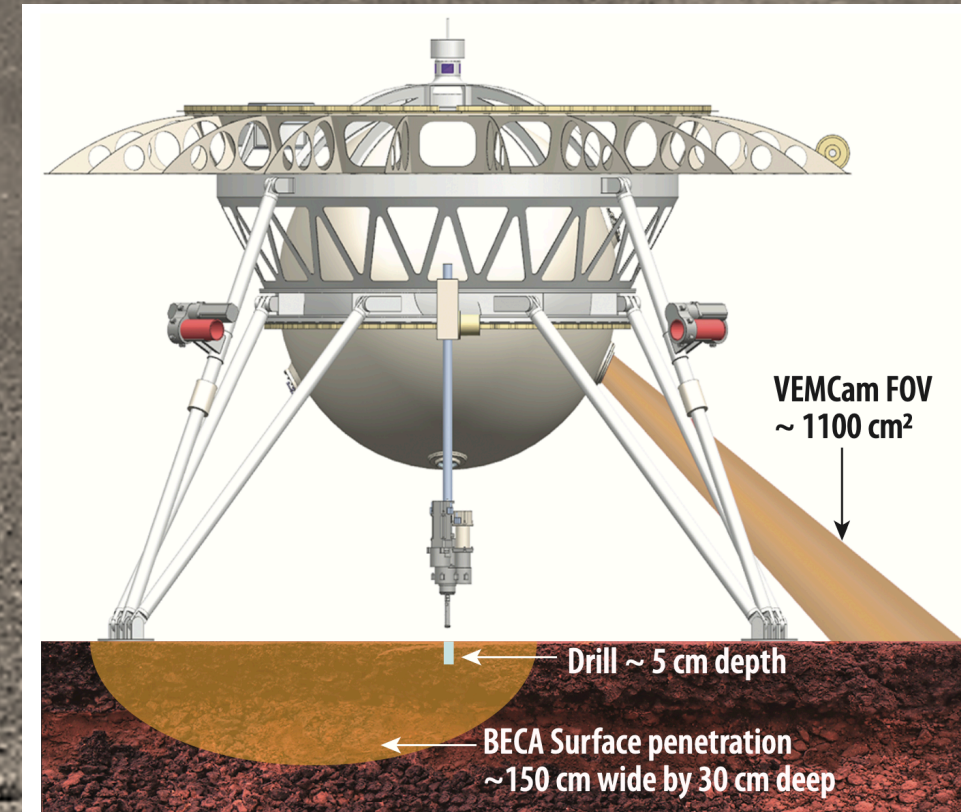
Figure B-84. Schematic of drill and sample transfer system modified from JPL graphic

FIELDS OF VIEW



October 13 2020

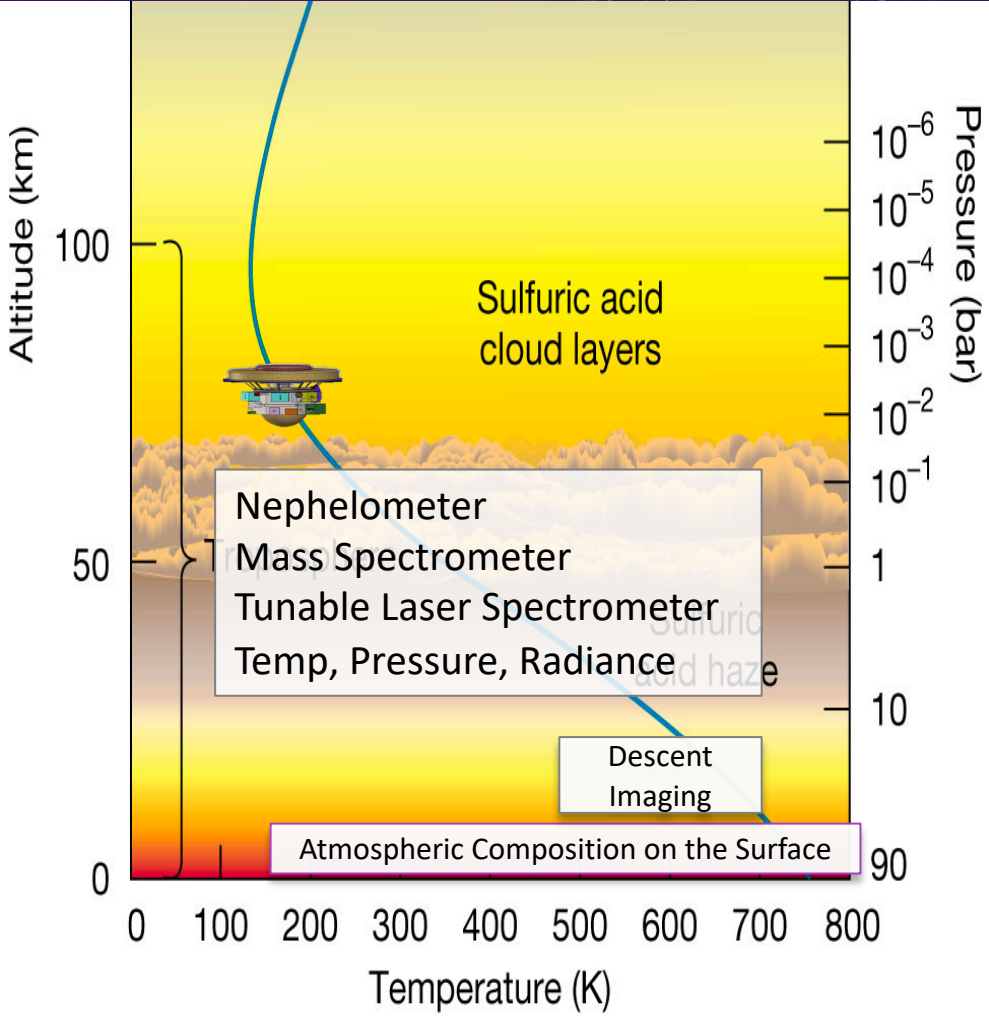
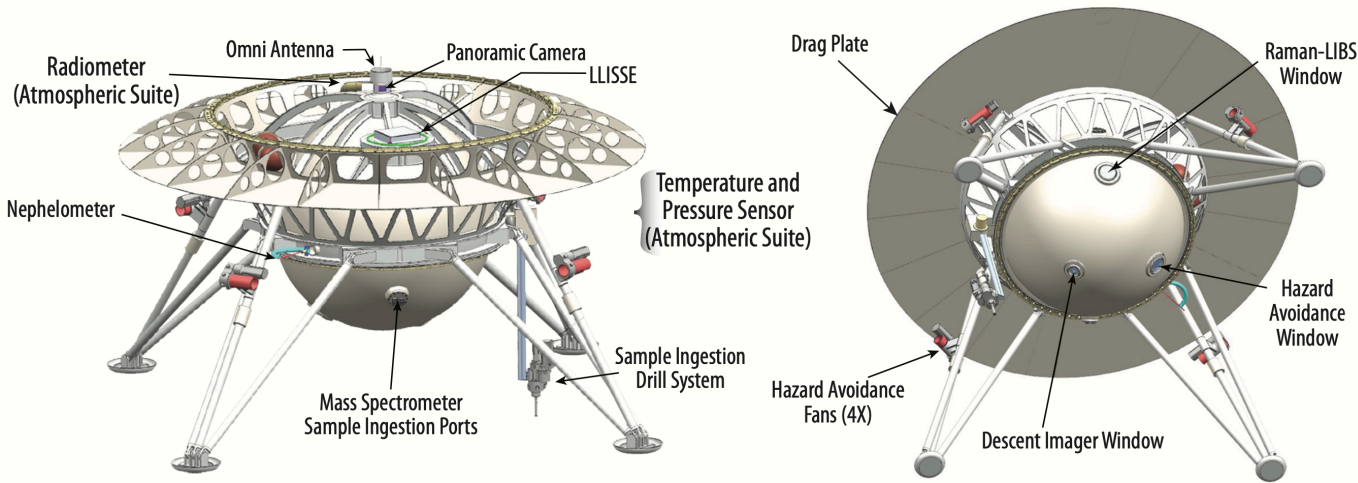
Venus Flagship Mission



LANDER DESCENT SCIENCE

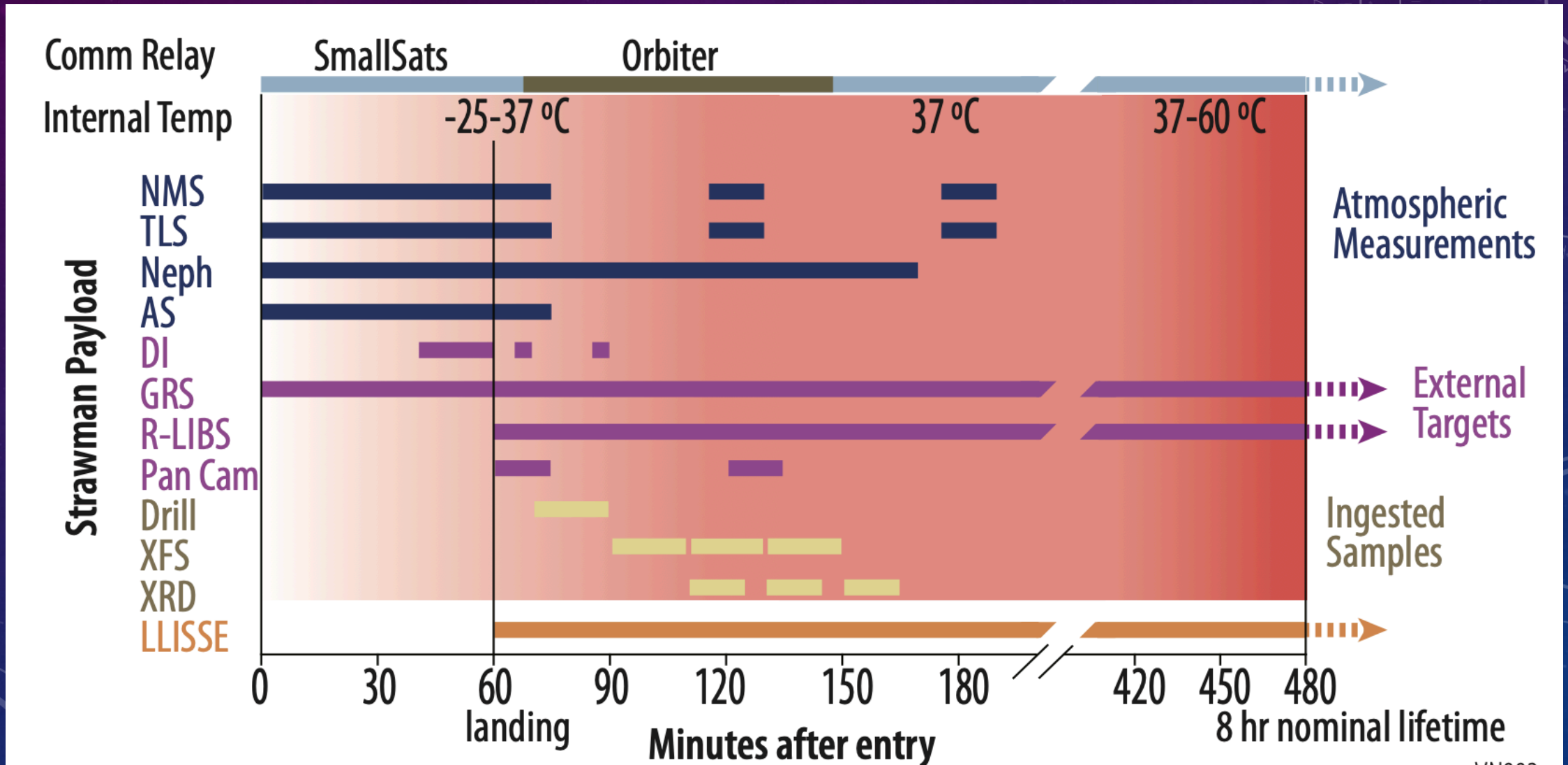
Composition, dynamics, imaging of the atmosphere to and on the surface.

Instrument	Measurement
Mass Spectrometer	Noble gases and their isotopes
Tunable Laser Spectrometer	Major and trace gases and their isotopes
Nephelometer	Cloud particles
Descent Camera	NIR
MET Suite	P, T, winds, radiance



Addresses VFM Objectives					
1	2	3	4	5	6

LANDER OPERATIONS



SAFE LANDING IN TESSERA TERRAIN

Goal

Land in tessera and acquire and ingest 3 surface samples
Sample ingestion depends on gravity for sample delivery

Challenges

Potentially uneven surface
Surface materials could be rocks, regolith or sediment

Solutions

Landing site analyses

Slope map analyses
Maps of mantling materials

Hazard Detection and Avoidance

Real time processing of descent images and LiDAR
Use of fans to redirect the lander to avoid steep slopes

Mechanisms

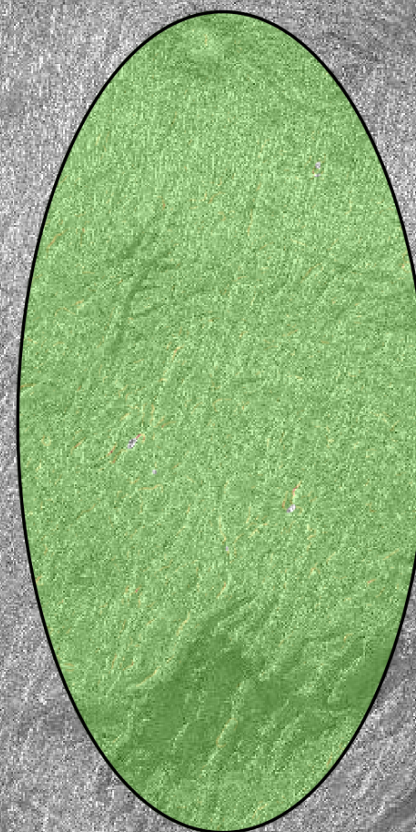
Landers Design to tolerate 30° slopes

Operations

Drill has flexibility to access unknown surface
Antenna points close to zenith

Redundant instrumentation for rock chem/mineralogy

Manatum Tessera
Western Ovda



Coodinates

lon: 67.5497
lat: 2.7013

Size

a: 300 km (S-N)
b: 150 km (W-E)

Slopes (degrees)

below 15°
15° - 25°
25° - 30°
30° - 35°
above 35°

Entry Interface, $t=0$
175 km at 10.076 km/s
Entry Angle -8.4659
Alt rate -1,480.7 m/s
Peak 50 g



Chute Deploy, $t=125.3$
Alt 75.3 km
Mach 1.4
Alt rate -178.5 m/s
Chute size 10 m
Lander Mass 1,200.8 kg



Heat Shield Sep, $t=358.6$
60 km
Mach 0.7
Alt Rate -36.3 m/s



Backshell Sep, $t=388.6$
59.1 km
-27.9 m/s



Hazard Avoidance Initiated, $t=2,634$
Altitude 5 km



Hazard Avoidance Maneuver,
Altitude 2 km

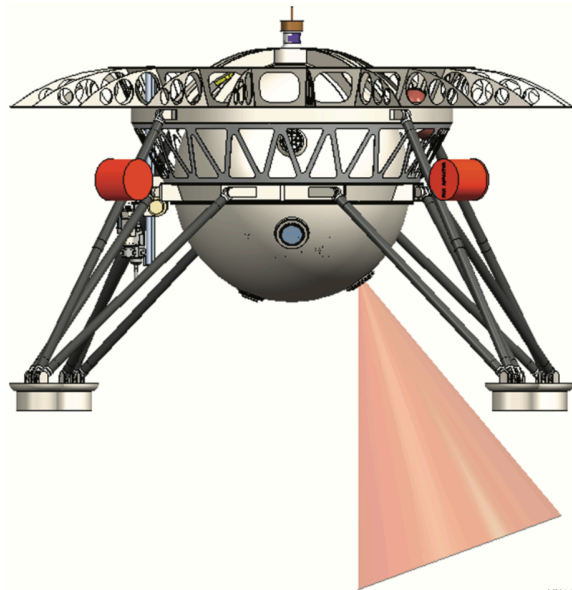


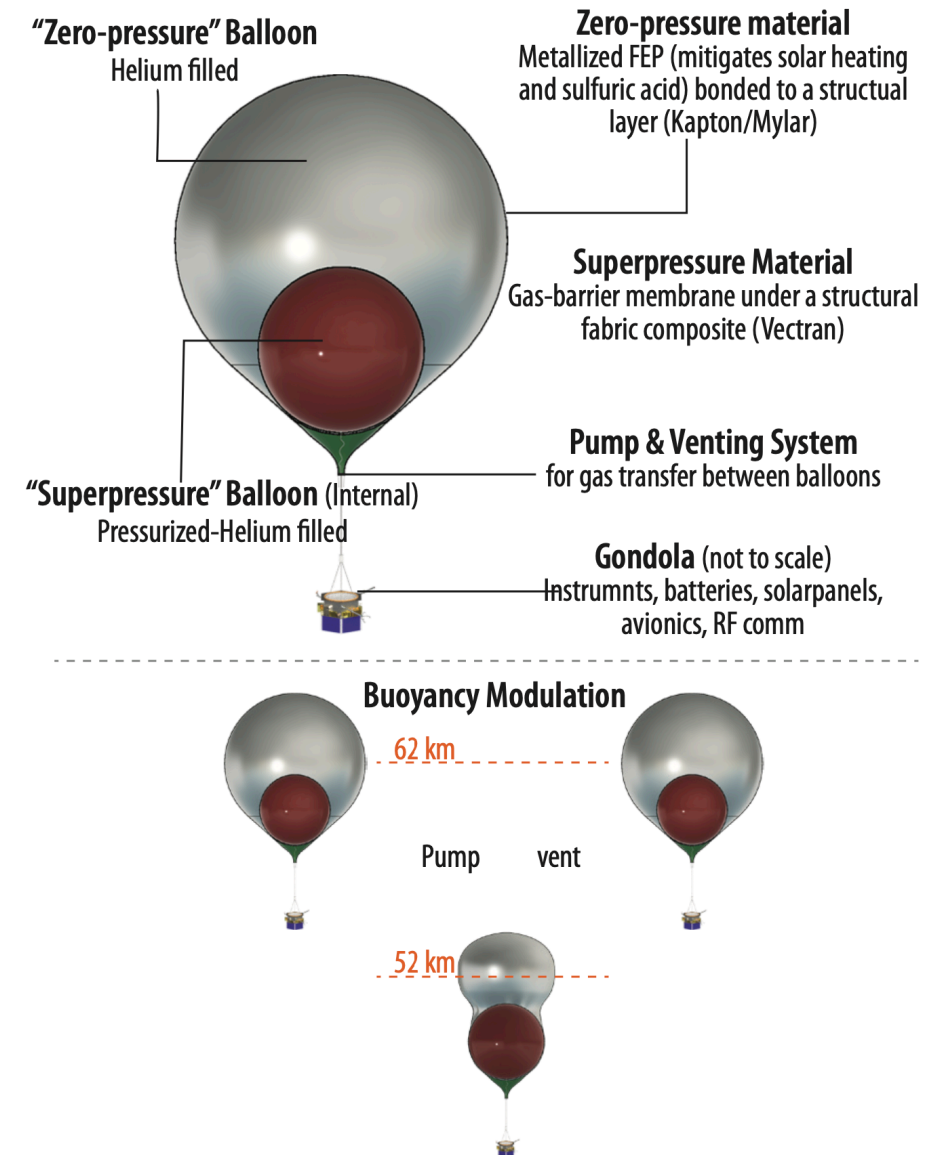
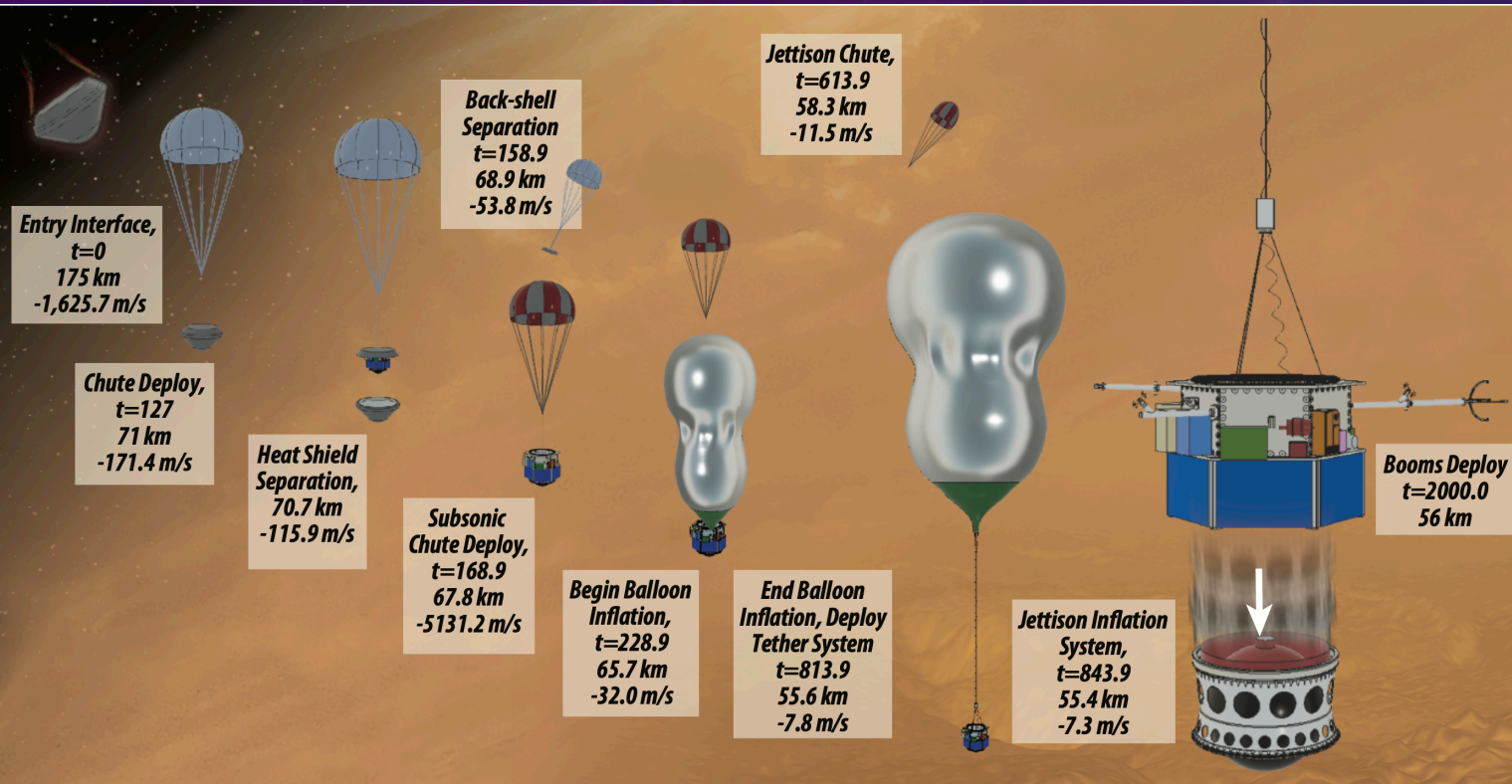
Figure B-82. LIDAR, laser range finders, and the engineering camera FOV

VN089

Touchdown, $t=3,697.5$
0 km
Alt Rate -7.8 m/s



ENTRY, DESCENT AND FLOAT



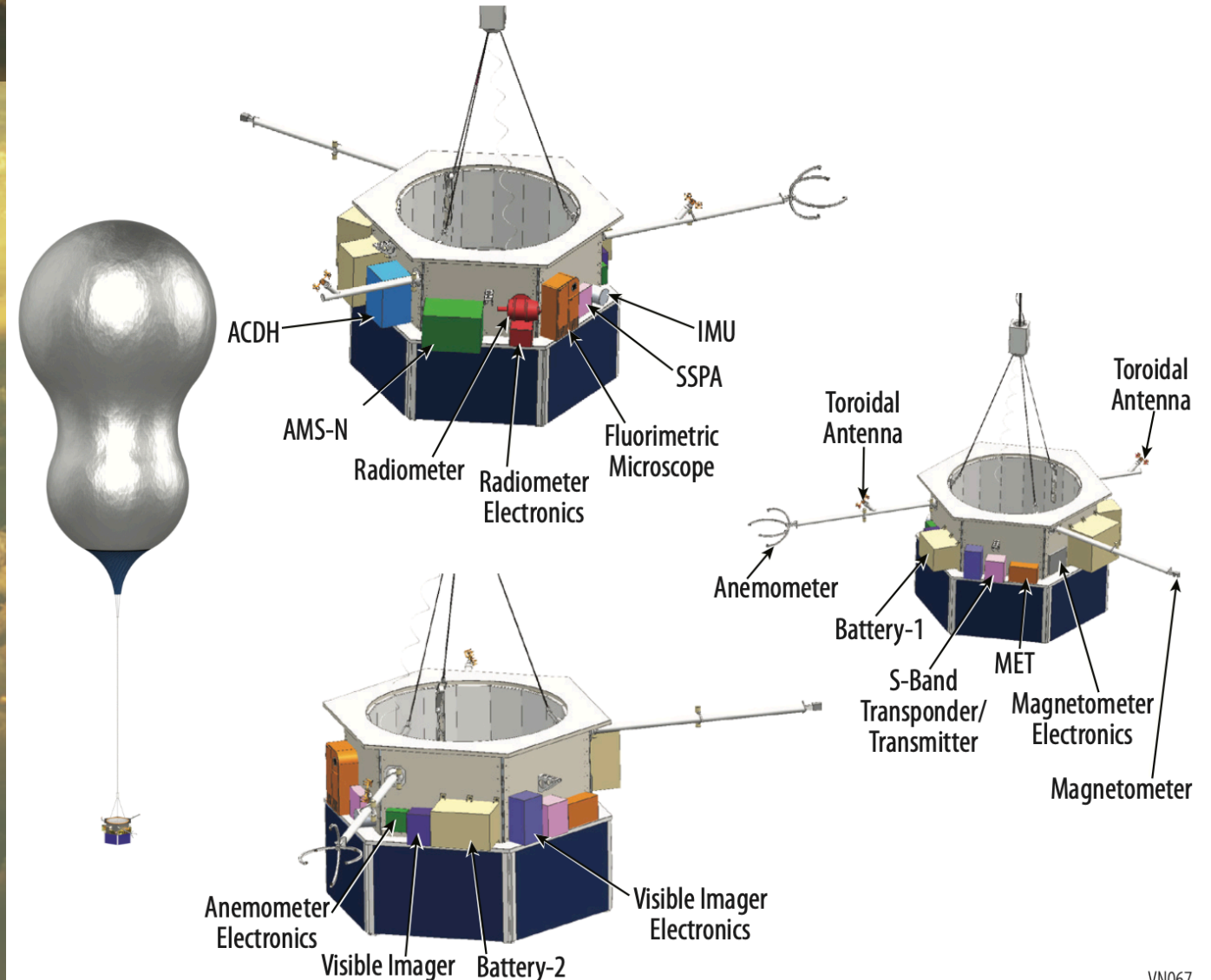
AEROBOT PAYLOAD

Science goals:

- **Chemistry:** Measure composition and microphysics of cloud particles, including search for biomolecules.
- **Meteorology:** Measure cloud-level dynamics & radiances & role in volatile transport.
- **Surface science:** Measure seismicity by infrasound; search for remanent magnetism.

Addresses VFM Objectives

1	2	3	4	5	6

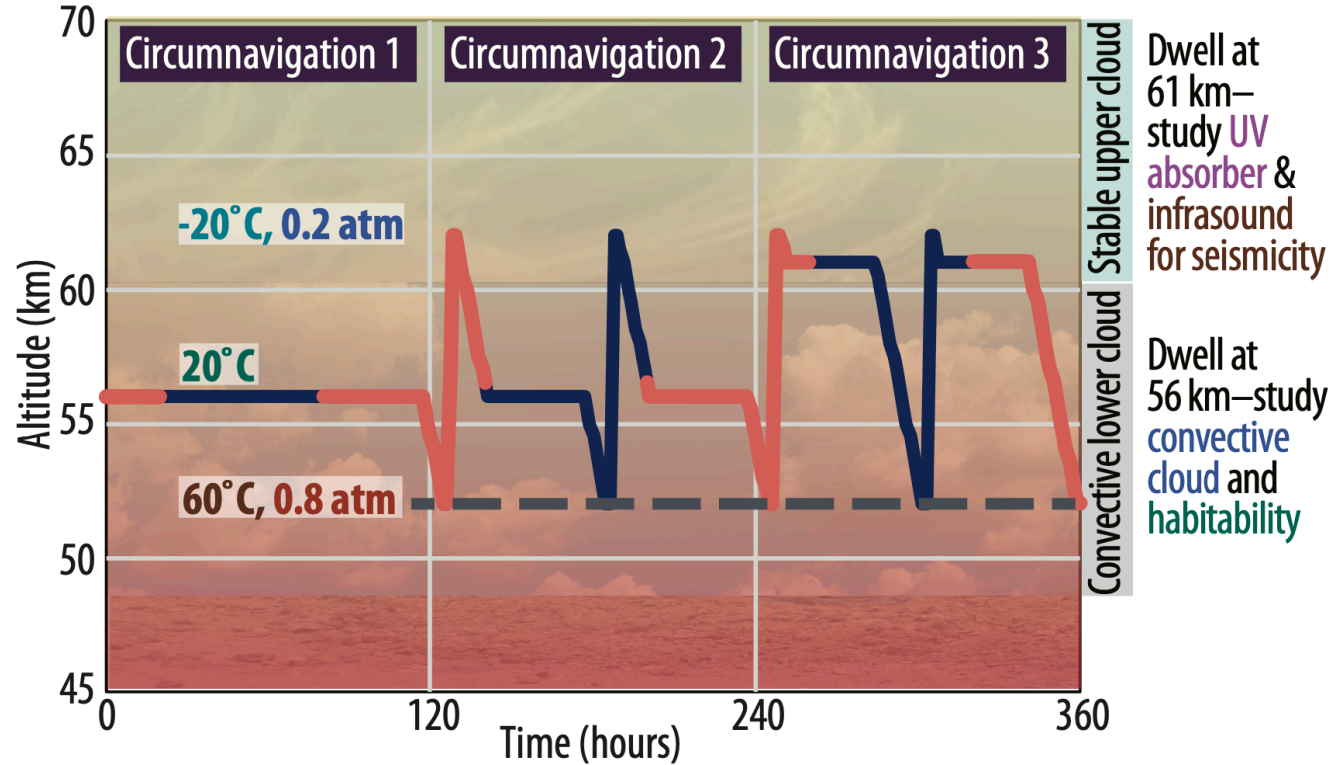


VFM SCIENCE OBJECTIVE 1.3

PLACE CONSTRAINTS ON WHETHER THERE ARE HABITABLE ENVIRONMENTS ON VENUS TODAY AND SEARCH FOR ORGANIC MATERIALS AND BIOSIGNATURES.

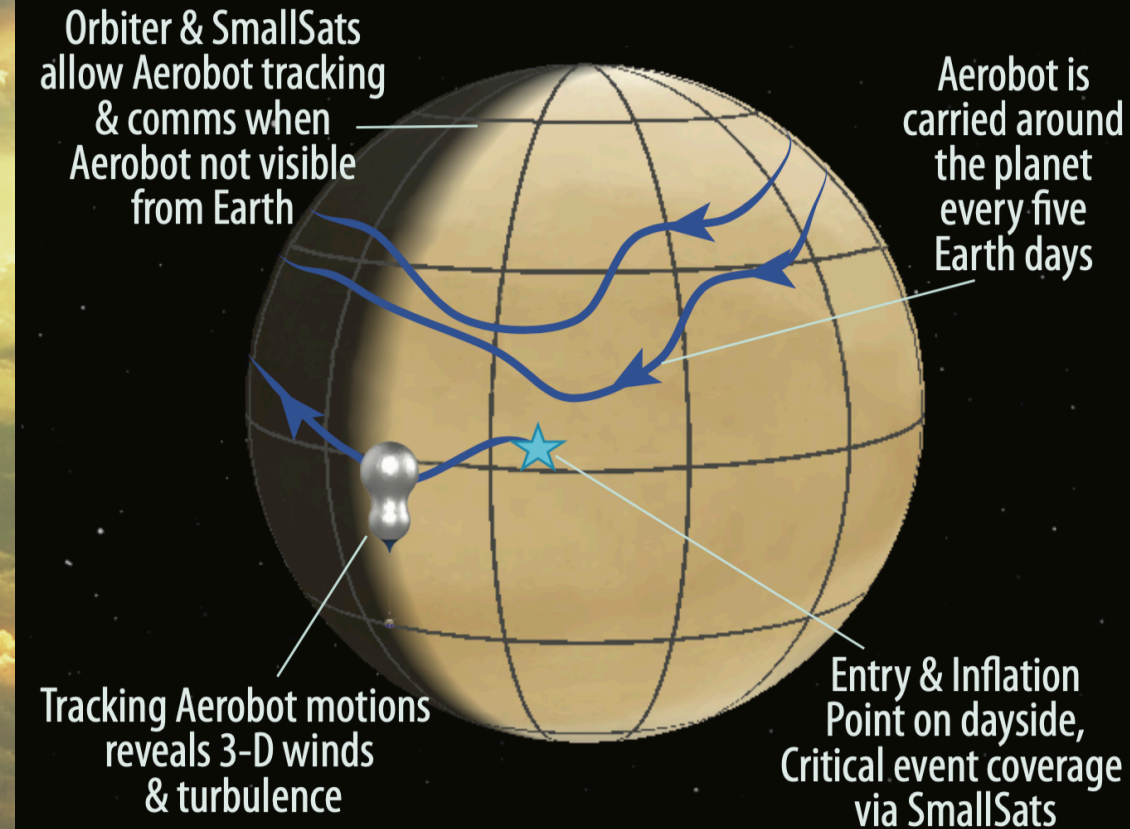
Science Goals	Science Objectives	Science Investigations	Measurement Approach	Measurement Requirement	Performance Requirement	Strawman Instruments	Functional Requirements
I. Understand the history of volatiles and liquid water on Venus and determine if Venus has ever been habitable.	3. Place constraints on whether there are habitable environments on Venus today and search for organic materials and biosignatures.	A. Assess the present-day habitability of the Venus cloud environment	Measure environmental parameters which determine habitability	Environmental sensors: P, T, UV, radiation	Measure temperature, pressure, turbulence. Measure UVA, UVB, UVC up- and downwelling light. Measure ionizing radiation levels. Measure H ₂ SO ₄ vapor & droplet abundances	MET Suite, Radiometer, EUV Detector, Radio Occultation	Aerobot, SmallSat constellation
			Measure composition relevant to habitability	Measure composition of cloud particles; characterize availability of biologically important elements including C, H, N, O, P, S in gaseous, liquid and/or solid form	Measure effective size of particles to a resolution of 0.1 µm Measure refractive index to a resolution of < 0.02 Identify non-spherical (non-liquid) particulates Mass spectrometer with dedicated aerosol sampling inlet. Measure CHNOPS species to a sensitivity of 1 ppm, to determine chemical environment of cloud droplets	Nephelometer and Aerosol Mass Spectrometer (AMS-N)	Aerobot
		B. Determine if there are any extant or recently dead organisms or fragments present in the clouds	Collect and fluorescently characterize any biomolecules or larger fluorescing organic objects in the altitude range of 52-62 km	Identify fluorescent biomolecules, e.g. chlorophyll or other photosynthetic pigments that could allow for photosynthetic activity	Collect 7 samples over 60 days, at variable altitudes, using images (fluorescence and dark-field) of cloud droplets on 10, 1.0 and 0.2 µm pore-size filters with <0.5 µm spatial resolution at 265, 370, 470, and 530 µm to determine the difference between bio-content on day and night-sides during the course of each circumnavigation	Fluorimetric Microscope (FM)	Aerobot

AEROBOT FLIGHT PLAN

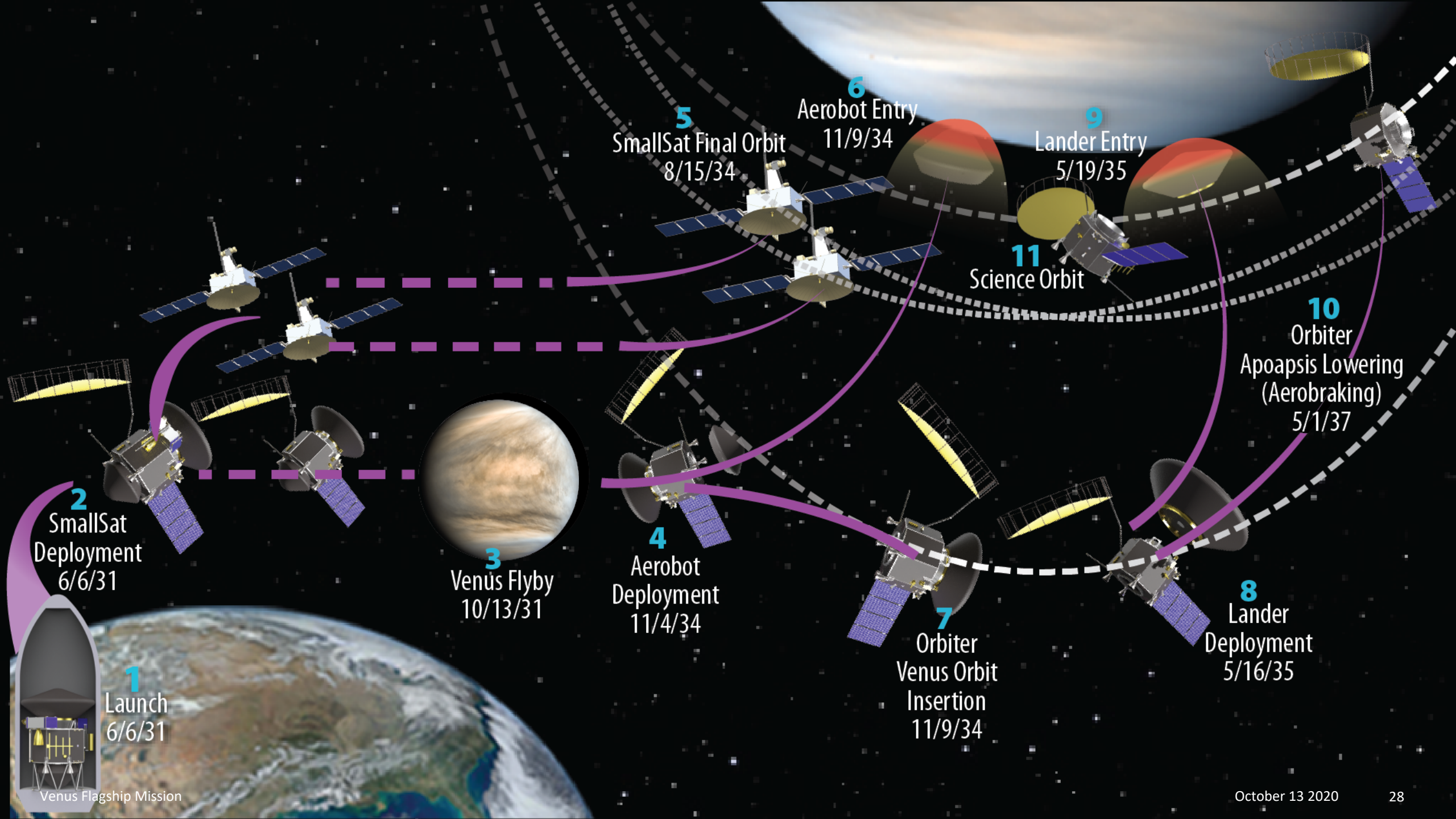


Later circumnavigations: obtain **vertical profiles** at all times of day and **night**. Choose dwell altitude to study different cloud layers.

First circumnavigation: dwell at $\sim 20^{\circ}\text{C}$ to complete initial chemical characterization including noble gases.



12 navigations over 60 day lifetime



VFM ORBITER

Addresses VFM Objectives

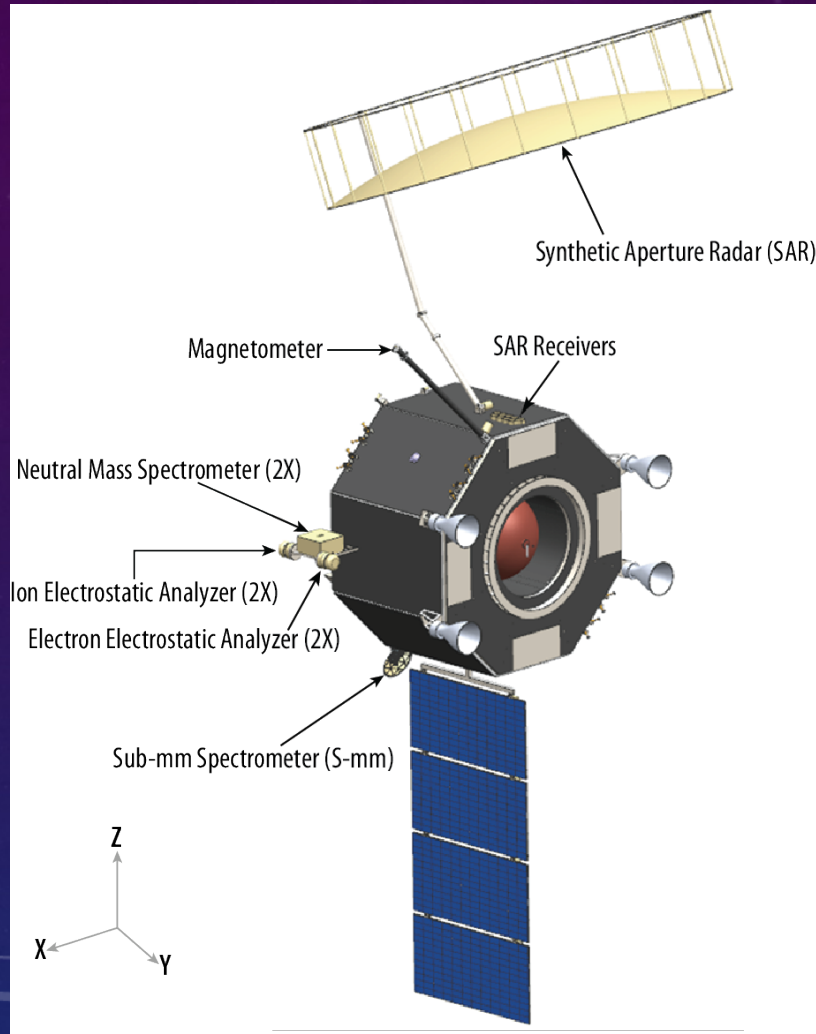
1	2	3	4	5	6
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Science: Morphology and composition of Venus surface, gravity field, particles and fields, upper atmosphere composition.

After lander release aerobreak to circular mapping orbit.

Provides critical comm for aerobot and lander

Targeted SAR images of ~5% of the surface to accomplish science objectives. Specifics of mapping campaign will consider status of Venus missions currently in consideration in Discovery and by ESA.



ORBITER PHASES

Orbit Parameters (Venus Inertial Frame)	Orbiter Elliptical	Orbiter Circular
Apoapsis (km)	116,108.4	300
Periapsis (km)	300	300
Eccentricity	0.945	0
Inclination (°)	90	90
Orbital Period	5 days	1.55 hours
RAAN (°)	334.4	334.4
Argument of Periapsis (°)	188.6	188.6

Table B-18. Orbiter Data Generation by Orbit

Instrument	Circular Orbit		Elliptical Orbit				Mission Total
	Gbit/Orbit	Total	Pre-Aerobraking Orbit		Aerobraking Orbit		Gbit
			Gbit/Orbit	Total	Gbit/Orbit*	Total	
NIR Imager (NIR-I)	0.1	2658	0.1	4.2	0.1	44	2707
Flux Gate Magnetometer (Mag)	0.01	252	0.9	31.5	0.3	126	410
SAR	2.4	53611	103	3707	0.0	0	57318
Sub MM	0.4	10092	35	1261.4	13.4	5046	16399
Mass Spectrometer	0.161	3650.0	12.7	456.3	4.8	1825	5931
Ion Electrostatic Analyzer (ESA-i)	0.19	4365	15.2	545.7	5.8	2183	7094
Electron Electrostatic Analyzer (ESA-e)	0.02	555	2	69.4	0.7	277	902
	3.3	75183	169	6075	25.2	9501	90760

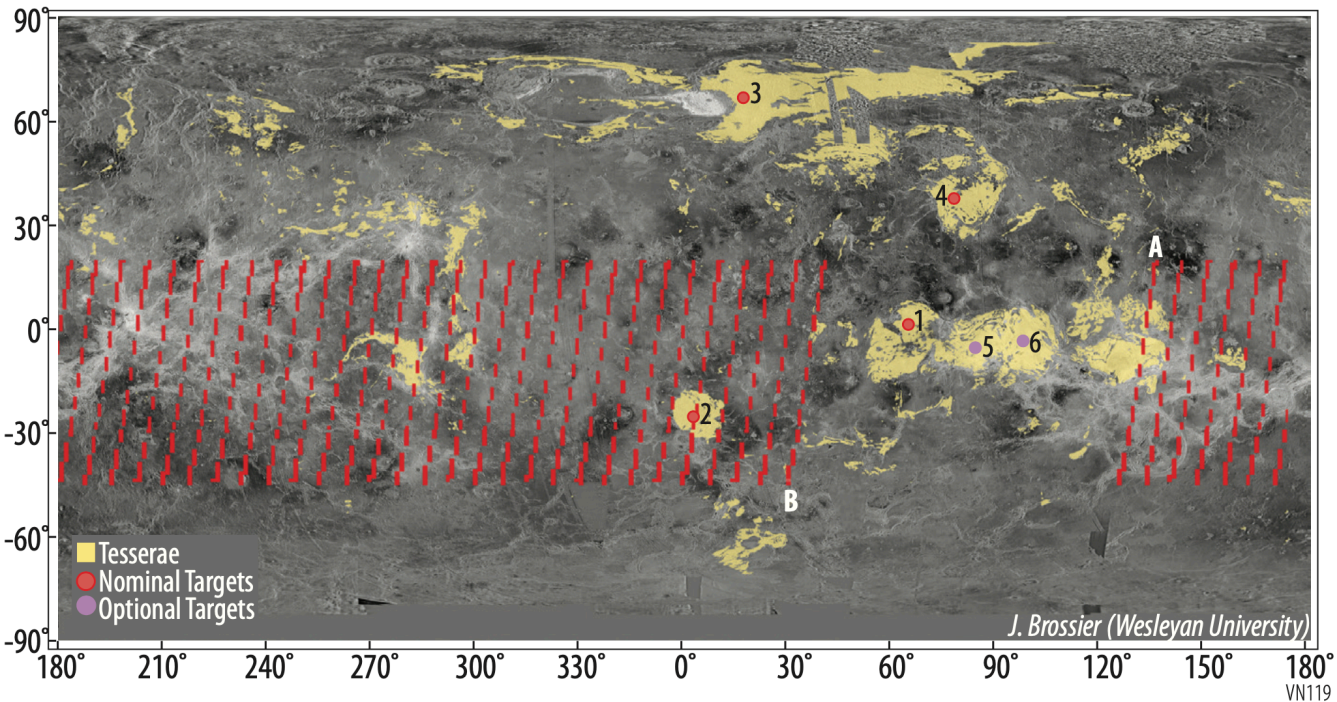


Figure B-39. SAR Ground Coverage during the Elliptical Polar Orbit. For the baseline missions, coverage starts at 120° longitude (point A) and moves eastward to point B. Coverage can be increased by extending the length time the Orbiter is in the initial elliptical orbit.

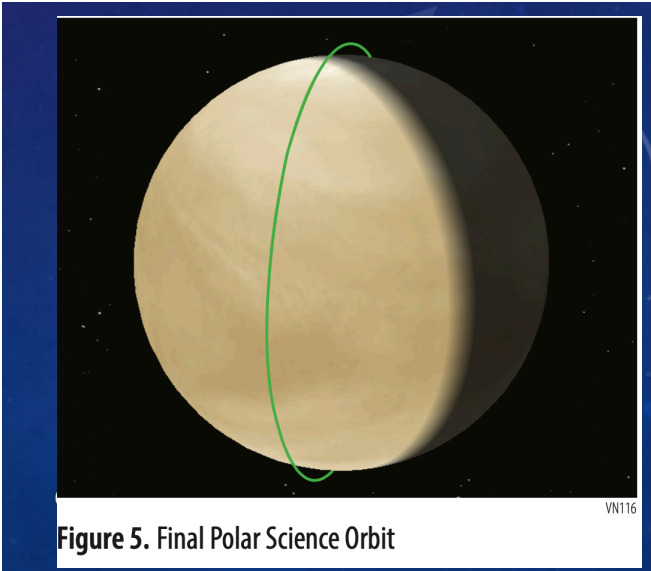


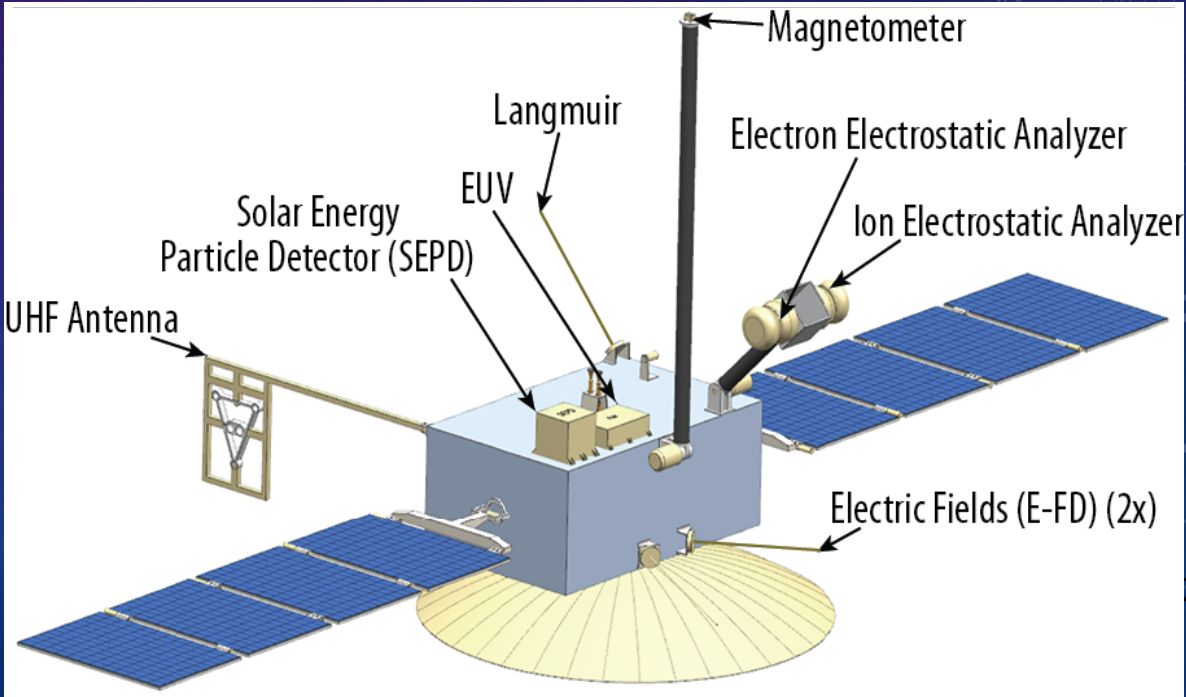
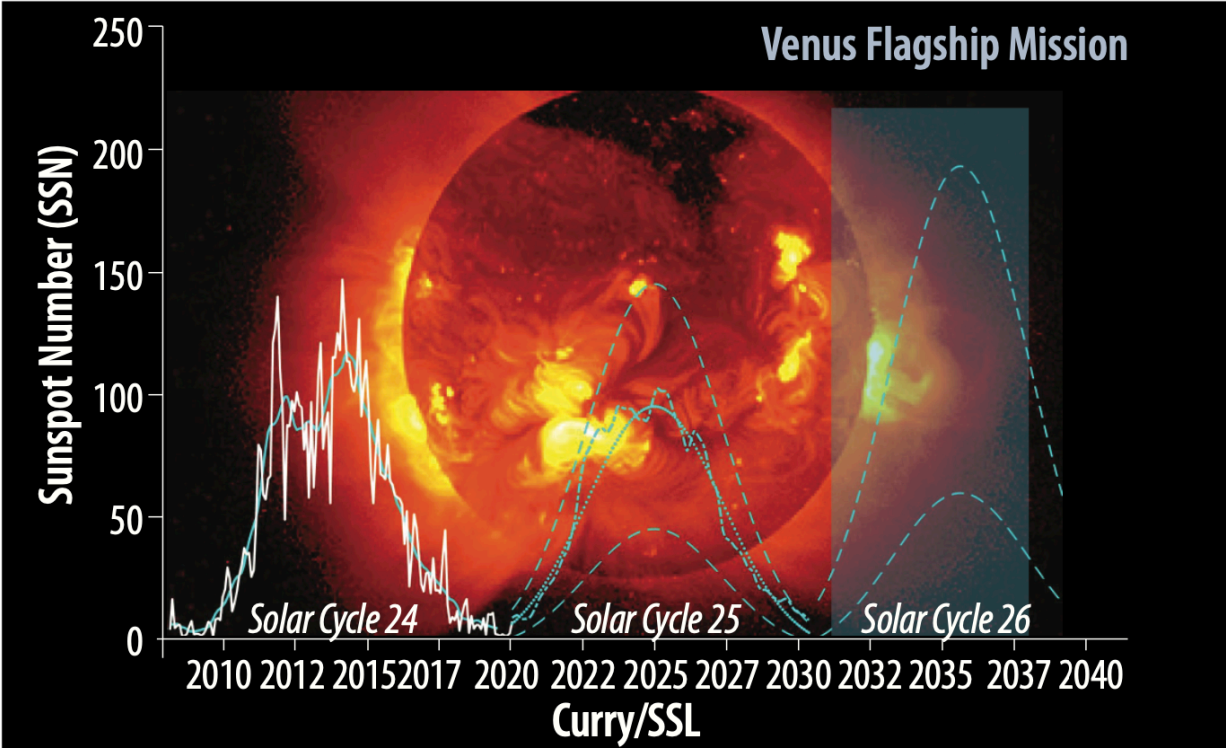
Figure 5. Final Polar Science Orbit

TWO SMALLSATS

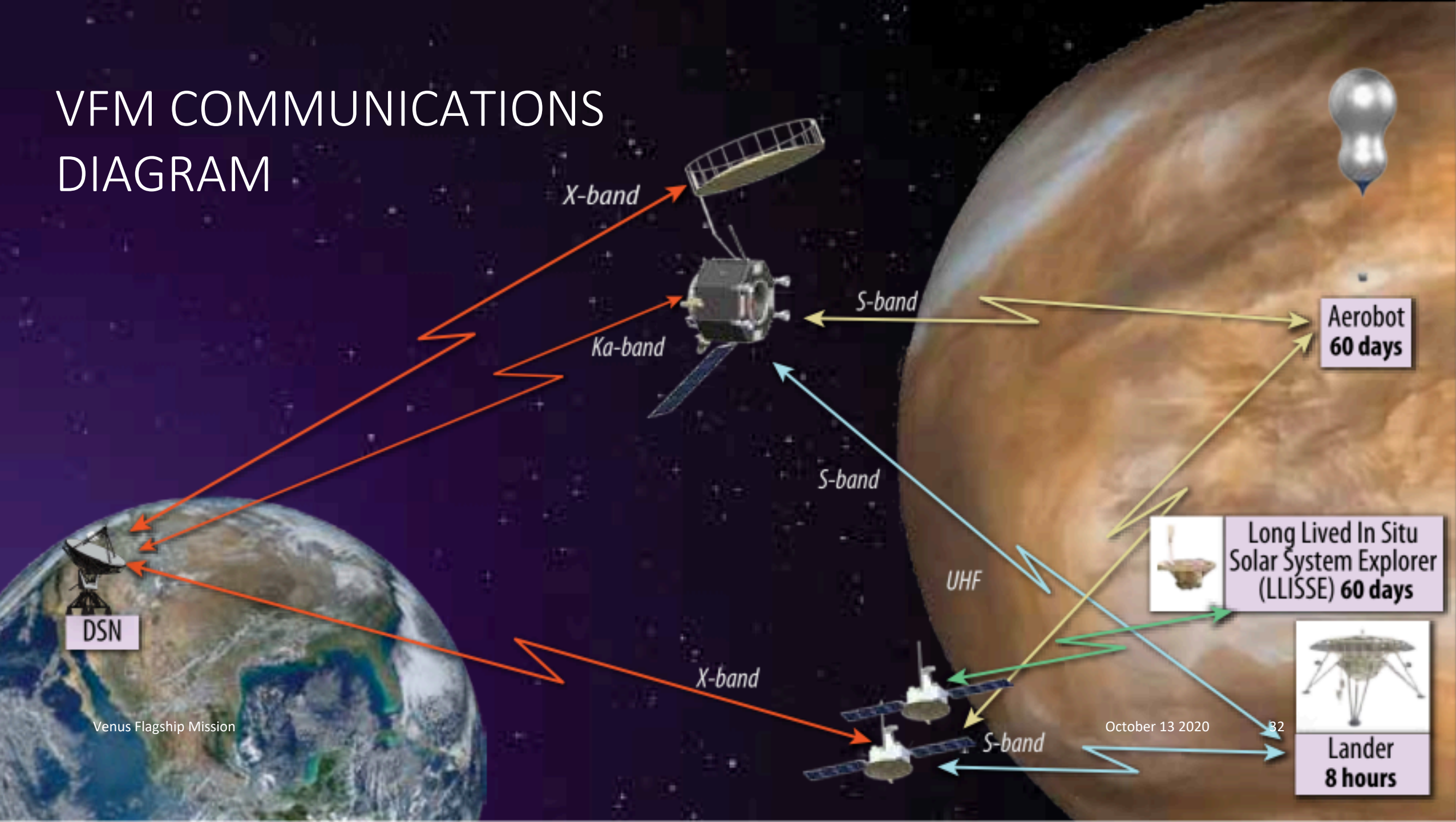
Science: Understand evolution of Venus atmosphere and magnetosphere via measurements of the interaction the with solar wind.

- Elliptical orbits with periapses in both Northern and Southern hemispheres during solar cycle 26
- *Critically* aid in tracking, comm and data return of in situ elements

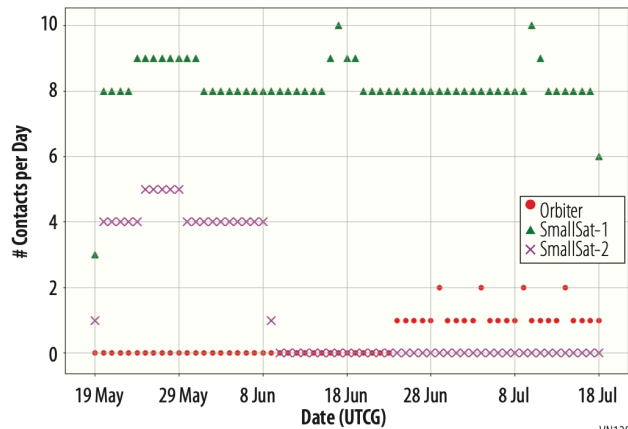
Addresses VFM Objectives					
1	2	3	4	5	6
SmallSat 1		SmallSat 2			
18,661		18,661			
500		500			
0.578		0.578			
22.5		65			
6 hours		6 hours			
251.0		339.9			
86.7		359.5			



VFM COMMUNICATIONS DIAGRAM

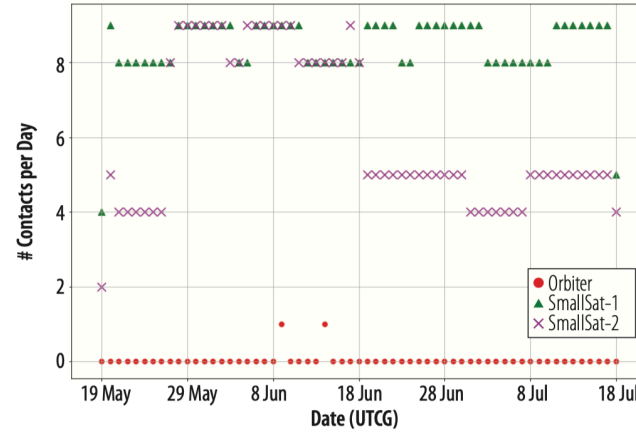


EXAMPLE AEROBOT COMMUNICATIONS



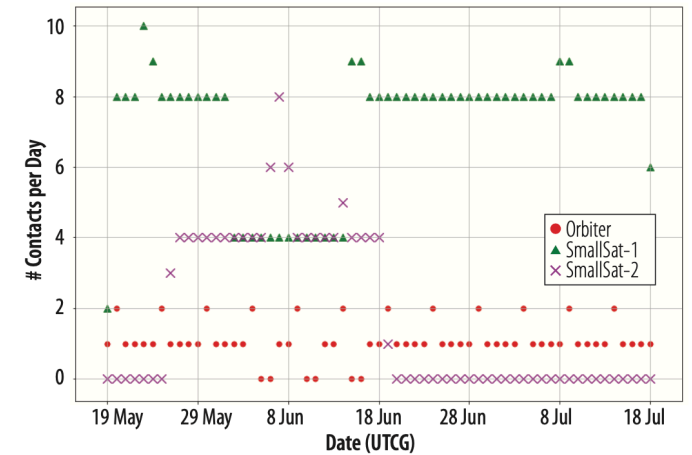
VN138

Number of contacts per day to Aerobot (0°, 0°) during the 60-day period



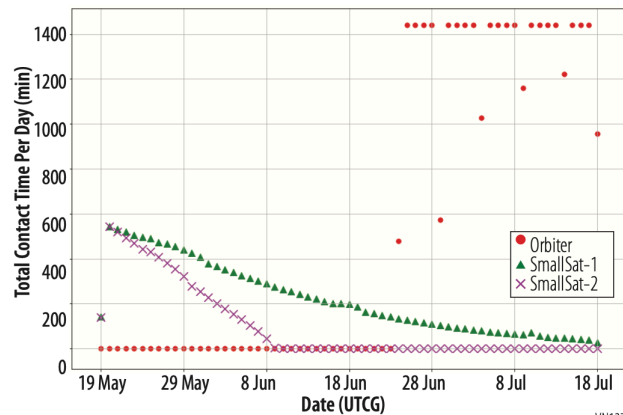
VN135

Number of contacts per day to Aerobot (0°, 90°) during the 60-day period.



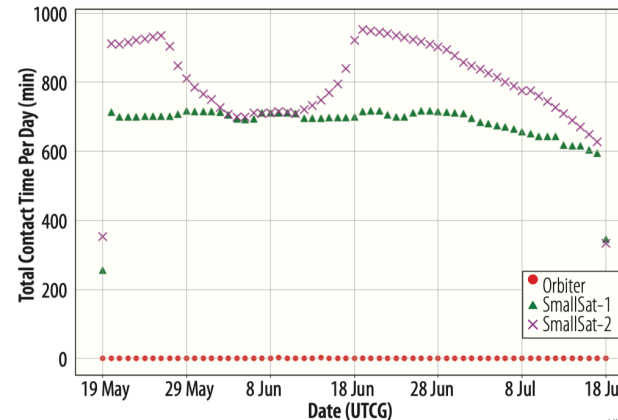
VN129

Number of contacts per day to Aerobot (0°, 270°) during the 60-day period



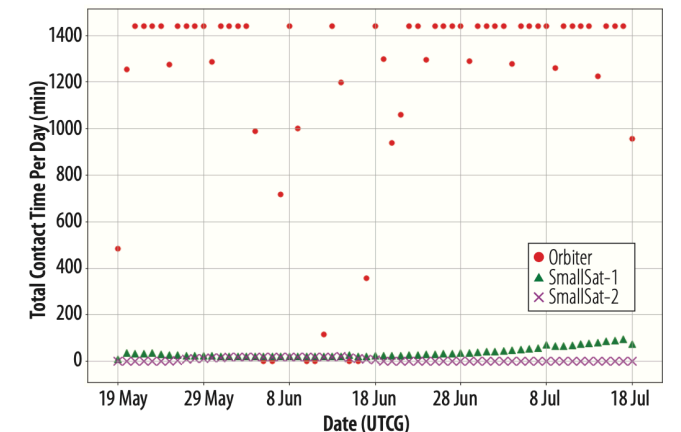
VN137

Total contact time per day to Aerobot (0°, 0°) during the 60-day period.



VN134

Total contact time per day to Aerobot (0°, 90°) during the 60-day period.



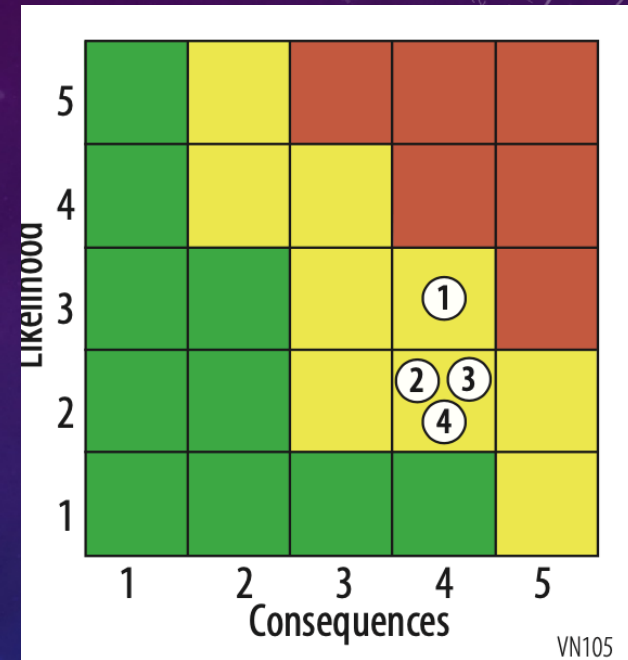
VN128

Total contact time per day to Aerobot (0°, 270°) during the 60-day period

RISK AND TRL

1. Landing
2. Landing Terrain Relative Navigation and Hazard Avoidance Subsystem
3. Lander Pressure Vessel complexity
4. Mission Complexity

- Development needed for Lander Integrated Terrain Navigation and Landing Hazard Avoidance
- Continued Investment in:
 - Variable Altitude balloon
 - Instruments and Sample Acquisition Handling
- See VFM Study Technology Development Plan



COST AND SCHEDULE

	Mass (MEV Dry, kg)	Cost (\$M, with 50% reserve)
Orbiter	1930	\$761
SmallSats (2), Wet Mass	600	\$280
Aerobot	1443	\$771
Lander	2002	\$1,238
Total Dry Mass	5965	-
Orbiter Propellant	3548	-
Launch Vehicle Adapter	71	-
Science/Management		\$662
Total	9584	\$3712

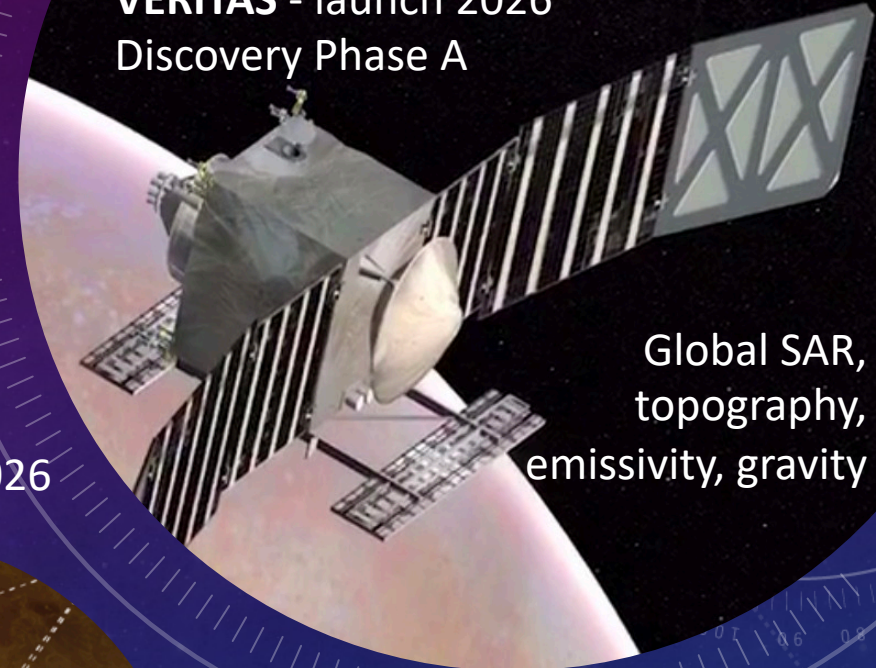
Parameter	Orbiter Elliptical	Orbiter Circular	SmallSat 1	SmallSat 2
Orbit Parameters (apogee, perigee, inclination, etc.)				
Apoapsis (km)	116,108.4	300	18,661	18,661
Periapsis (km)	300	300	500	500
Eccentricity	0.95	0	0.578	0.578
Inclination (deg)	90	90	22.5	65
Orbital Period	5 days	1.6 hours	6 hours	6 hours
RAAN (deg)	334.4	334.4	251.0	339.9
Argument of Periapsis (deg)	188.6	188.6	86.7	359.5
Mission Lifetime	10 years		6 years	
Maximum Eclipse Period (minutes)	22.2	22.3	87.7	90.0
Launch Site	Cape Canaveral, FL			
Total Mass with contingency (includes instruments)	1,930.2		300.0	300.0
Propellant Mass without contingency	3,193.2		112.5	112.5
Propellant contingency	354.8		12.5	12.5
Propellant Mass with contingency	3,548.0		125	125
Launch Adapter Mass with contingency	71			
Total Launch Mass	9,584.6			
Launch Vehicle	Falcon 9 Heavy Expendable 5 m fairing			
Launch Vehicle Lift Capability	11,694.0			
Launch Vehicle Mass Margin	2,109.4			
Launch Vehicle Mass Margin (%)	22.0			

VFM Study	Beginning	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	///	2042	2043
	TRL	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
		PrePhA - 12m										◆ Launch						
ATP 1/22		ATP		PhA - 16 m														
IPDR 2/25, MPDR 6/25					PhB - 25 m													
ICDR 8/26, MCDR 12/26						PhC - 31 m						Transit to V						
IRR 12/28, LRR 5/31						IPDR	MPDR		IRR	Phase D - 42 m								
10 years							ICDR	MCDR				LRR	Phase E - 120 m					
																		Phase F
Key Mission Milestones												Small-Sats Deploy Orbiter Venus Flyby	Small-Sats Orbit Venus Aerobot Deploy & Entry	Lander Deploy & Entry	Orbiter Science Orbit 05/37			

A FLAGSHIP COMPLEMENTS OTHER VENUS MISSIONS

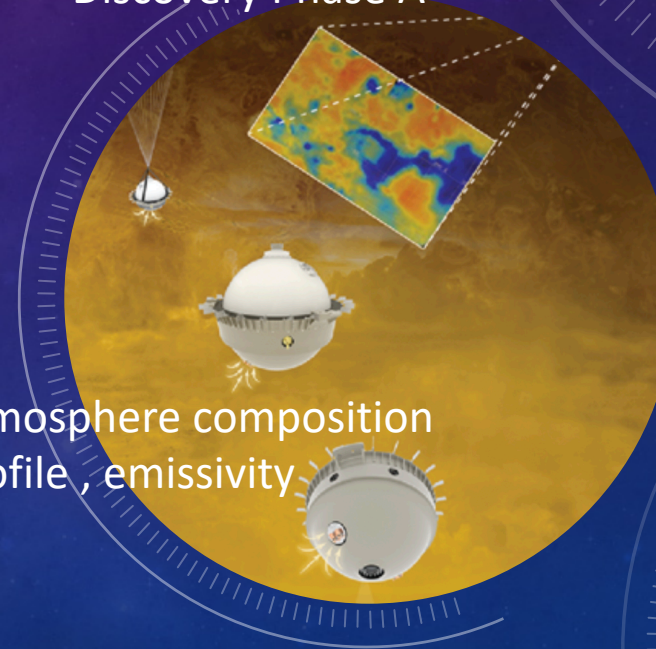
- **VERITAS** would be pathfinder for VFM lander site selection and hi-res SAR targets. *Possible VFM descope: NIR emissivity/gravity.*
- **DAVINCI+** would inform VFM descent profile at another location. VFM does unique surface atmospheric science. *Possible VFM descope: None*
- **EnVision** at Venus concurrently with VFM could provide the SAR and NIR emissivity to support VFM objectives.
- **VENERA-D** lander will visit the plains

VERITAS - launch 2026
Discovery Phase A



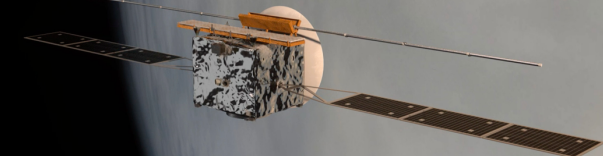
Global SAR,
topography,
emissivity, gravity

DAVINCI+ - launch 2026
Discovery Phase A



Atmosphere composition
profile, emissivity

EnVision - launch 2032
ESA M5 candidate



SAR, topography,
emissivity, gravity

FLAGSHIP FIRSTS

The Venus Flagship mission will provide major, unprecedented advancements in our understanding of the formation, evolution and habitability of terrestrial planets and would be the first mission to trace volatile inventory, phase, movement, reservoirs and loss over Venus history.

- first landing in tesserae thought to represent the oldest rocks on Venus
- first measurement the mineralogy and precise geochemistry of tessera terrain; the first inventory of all major atmospheric noble gases and their isotopes
- first measurement of global surface composition from orbit; first co-located mapping of winds and composition in the mesosphere and thermosphere
- first measurements of lower atmosphere composition with modern, high-accuracy, high-resolution instruments
- first simultaneous multipoint measurements in Venus exosphere and ionosphere
- first measurement of seismicity and remanent magnetism of Venus first deployment of uncooled ambient temperature electronics to enable long-life operation at the Venus surface.
- Complementary & descopable with respect to proposed smaller Venus missions.

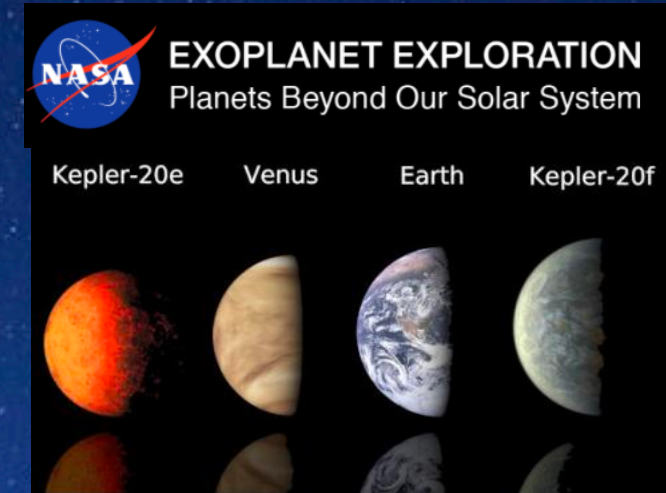
VENUS TOUCHES US ALL



How do Earth, the planets, and the heliosphere interact?



How did life begin and evolve on Earth?
How did the solar system evolve?
How did the sun's family originate?
What are the characteristics of the Solar System?



How do we find habitable planets?

Venus is the closest planet to Earth in size and heliocentric distance. Yet it stands in striking contrast to our home planet in terms of its habitability. Still largely untapped for its scientific value, Venus is the key to understanding what leads to conditions hospitable to life on terrestrial planets. We therefore recommend that NASA institute a funded, coherent Venus Program of missions, scientific research and technology developments, culminating in a Venus Flagship mission.

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