Venera-D mission concept to study atmosphere, surface and plasma environment

Phase II Report of the Venera-D Joint Science Definition Team

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The Venera-D Science Definition Team

SDT Member	Institution	Expertise
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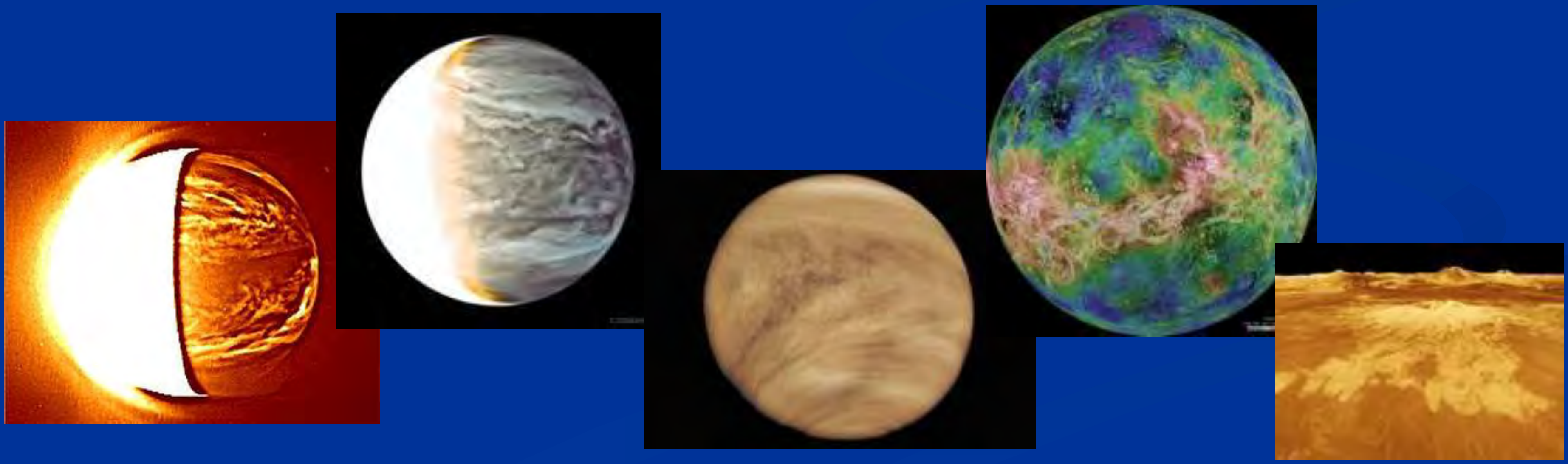
V. Voron	Roscosmos Headquarters	Roscosmos JSDT
V. Vorontsov	Lavochkin	Technology

Venera-D Mission Concept Study
Phase 2: GOALS

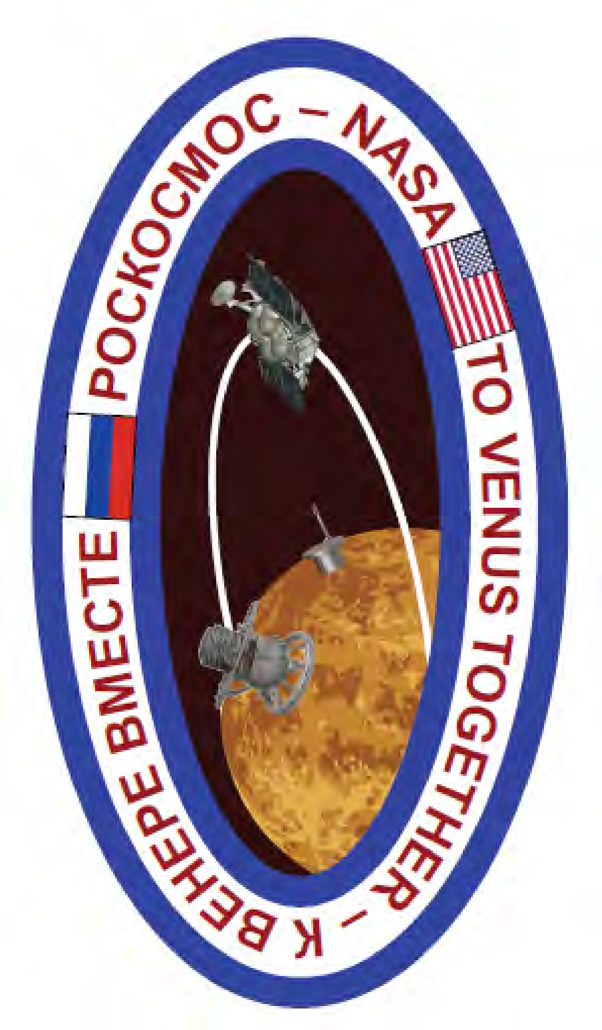
Definition of a focused Venera-D mission architecture concept based on the January 2017 JSDT report, including a prioritized list of potentially contributed elements and down-select options.



Executive Summary

- Baseline mission accomplishes breakthrough science
  - Baseline mission (orbiter in 24-hr near-polar orbit, lander + LLISSE) works for all potential launch dates & launch vehicles (Proton or Angara)
  - Baseline mission orbiter & lander instruments prioritized
- Viable landing sites achievable for all launch dates
- Lavochkin confirmed that can transfer 400Mb data volume per hour from lander
- Optional prioritized elements would contribute additional breakthrough science by filling in baseline mission gaps
- However, more work needs to be done to refine baseline and augmented mission – Phase 3 (yellow in these slides)
- We are looking forward to your directions!

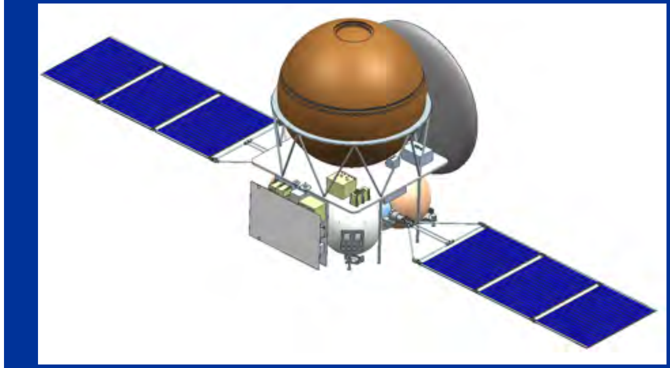
Venera-D Baseline Mission

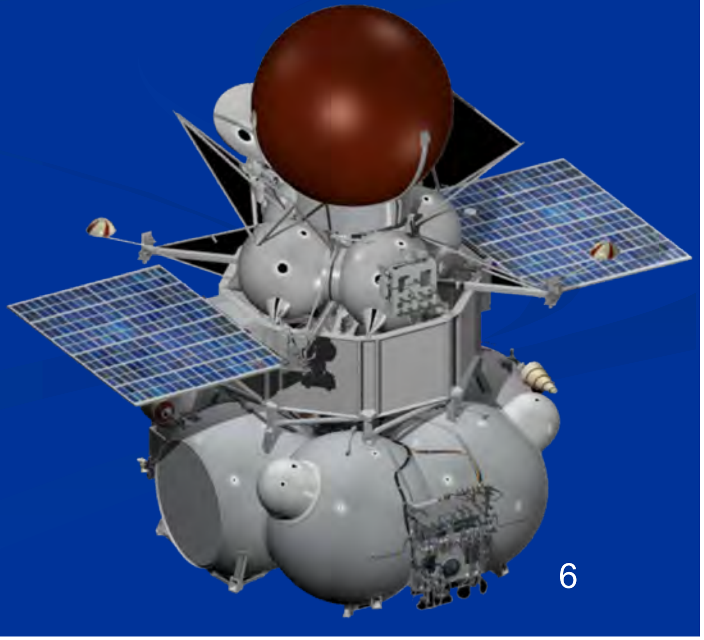


Venera-D Concept: Mission Elements

- **Baseline**:
  - Orbiter: Polar (90° ± 5°) 24-hr orbit with lifetime ≥ 3 yrs
  - Lander (VEGA-type, updated) ≥2 hrs on surface
  - LLISSE on Lander (>2 months)

- **Potential augmentations**:
  - Small stations (2nd – 4th LLISSE, SAEVe)
  - Sub-satellite(s)
  - Aerial platform
  - Additional instruments





Venera-D Baseline: Science Goals from VEXAG GOIs and Decadal Study

***Orbiter*:**

- Study and characterize:
    - super-rotation
    - Radiative balance
    - Greenhouse effect,
    - Thermal structure of the atmosphere, winds, thermal tides and solar locked structures;
    - Upper atmosphere, ionosphere, electrical activity, magnetosphere, escape rate
    - Clouds (structure, composition, chemistry)
- Search for volcanic activity
- Measure surface night-side emissivity

***Lander + LLISSE*:**

- Study:
    - elemental and mineralogical composition of surface, including radiogenic elements
    - interaction between surface and the atmosphere;
    - structure and chemical composition of atmosphere to surface, including abundances of trace and noble gases and isotopic ratios of elements;
- Perform direct chemical analysis of the cloud aerosols;
- Characterize:
    - geology of local landforms at different scales;
    - radiative balance, vertical profiles and atmospheric dynamics near surface;
- Search for lightning and seismic activity (Phase 3)

Launch vehicle

- Proton-M
- Angora-A5

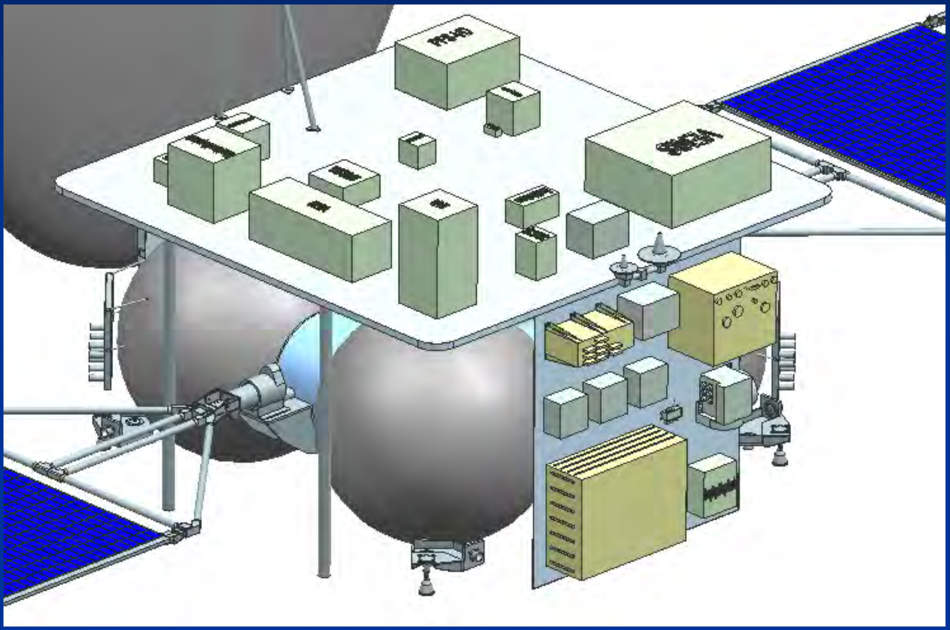

SC «Venera-D»

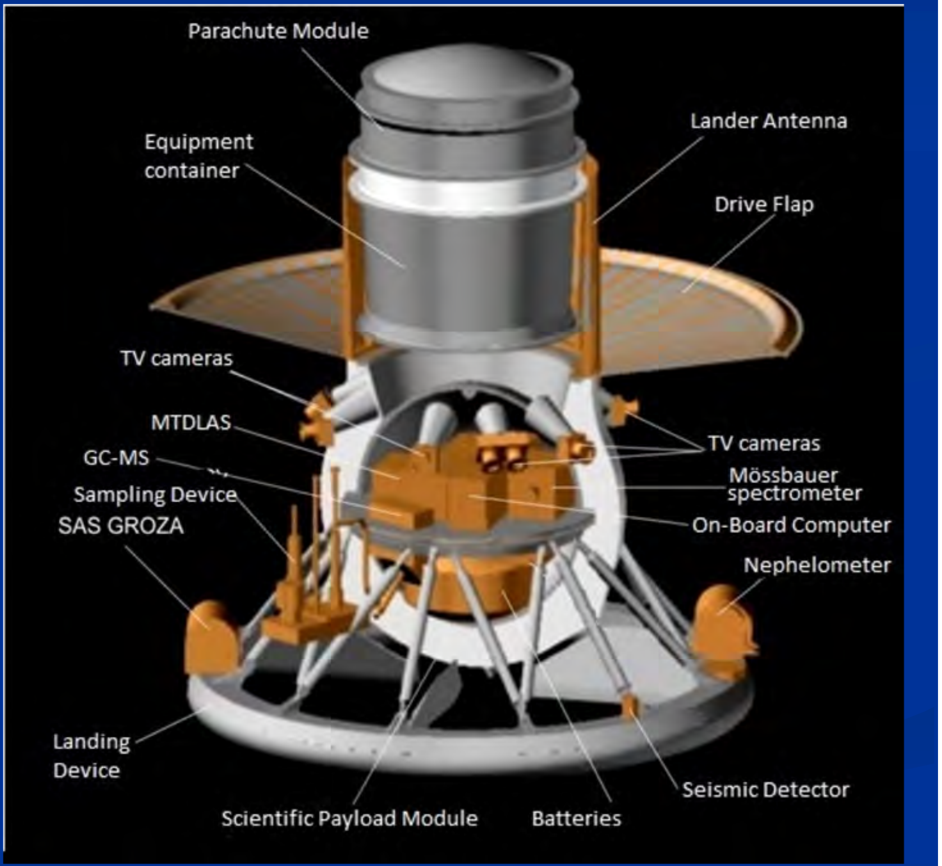
Lander

Orbiter

Start date	**2026, June**	**2028, January**	**2029, November**	**2031, June**
Mass of output spacecraft (KVTK), kg	7000	6300	6400	7000
Mass of output spacecraft (DM-03), kg	6900	6200	6300	6900

Baseline Mission





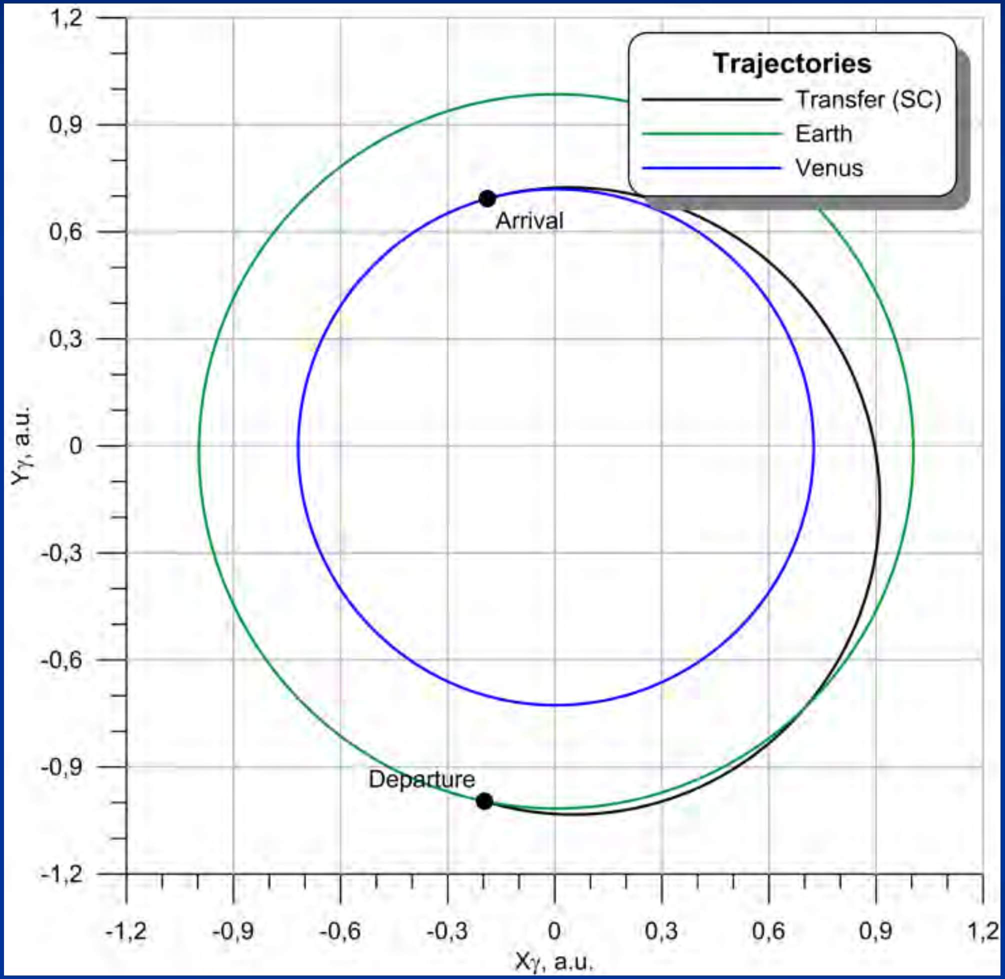
From 2011

Baseline mission architecture: Key points

- All launch dates deliver nominal mission goals
- Angara or Proton launch vehicles can accommodate baseline mission architecture for any launch window
- Landing sites are planned in the Northern Hemisphere, high latitudes
- Flexibility to select precise landing site ~3 days before VOI
- Main Lander will be in view of orbiter for first 3 hours
- Orbiter can have long-term (>60-day) visibility of LLISSE

VENERA-D TRANSFER AND ARRIVAL ORBITS: Baseline Mission

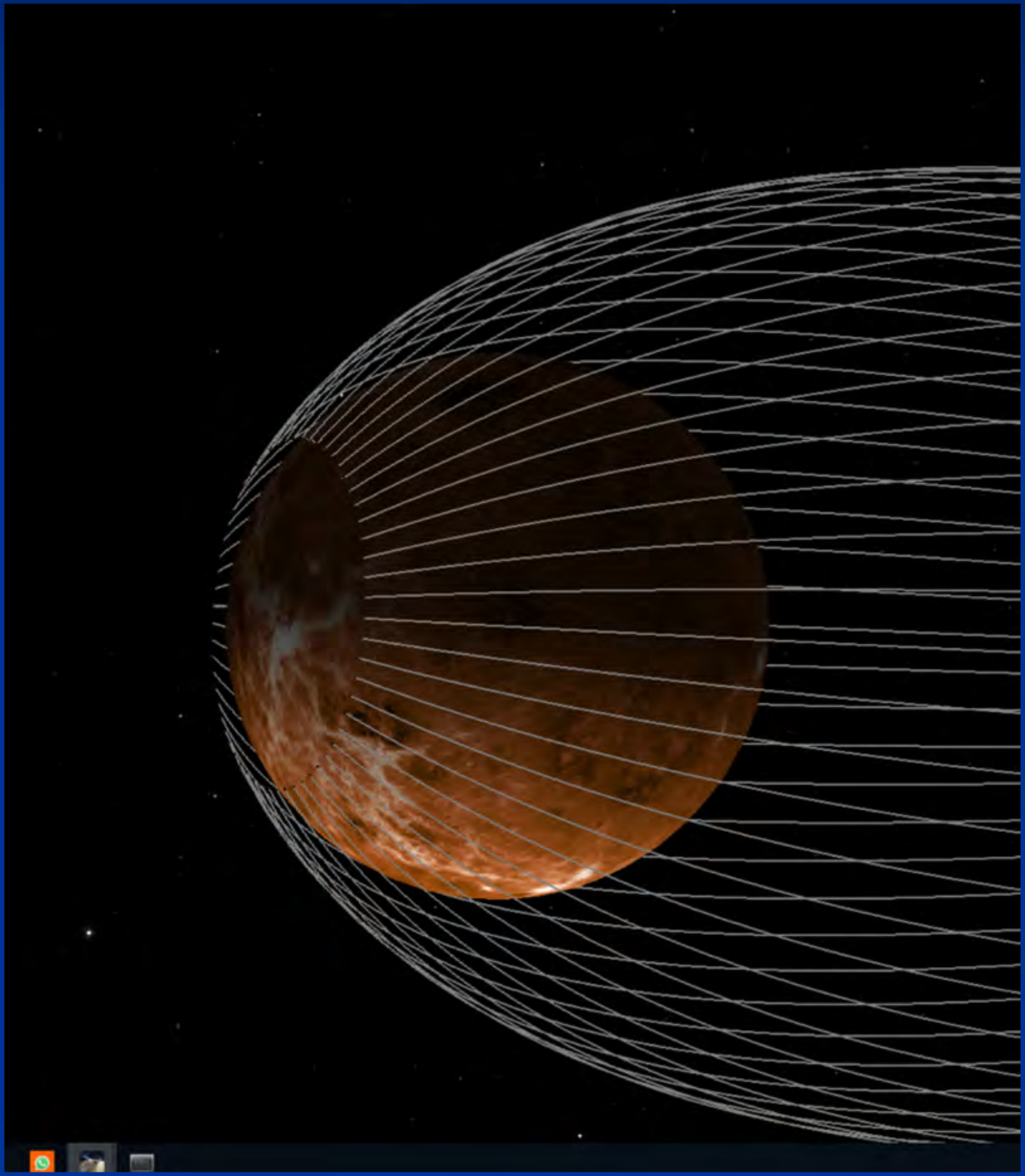
- 90º ± 5º orbit
- 24-hour period
- Periapsis = southern hemisphere
- Apoapsis =northern hemisphere



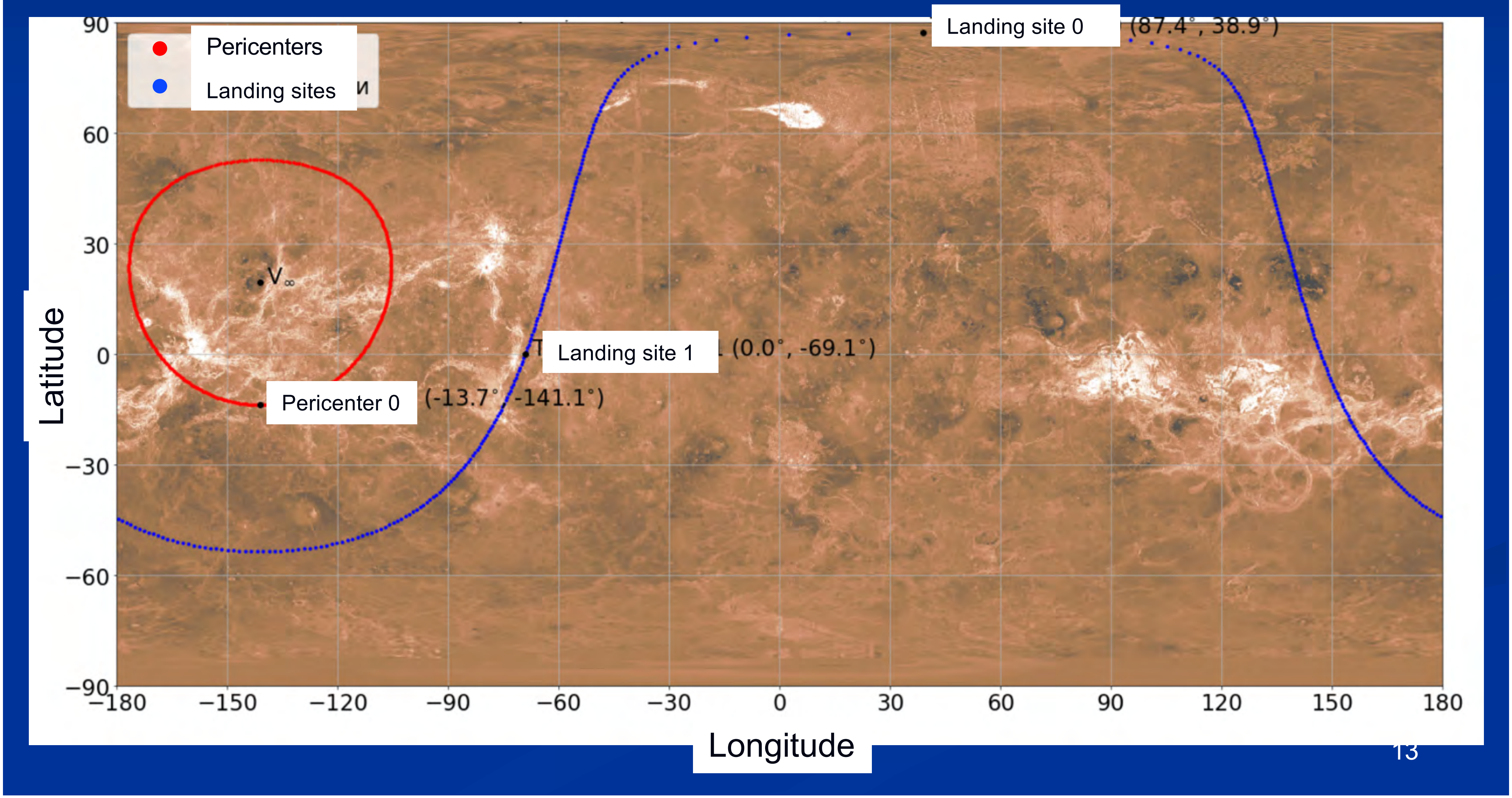
2026 LRD Trajectory

Family of close approaching relative to Venus trajectories with common Earth-to-Venus transfer orbit

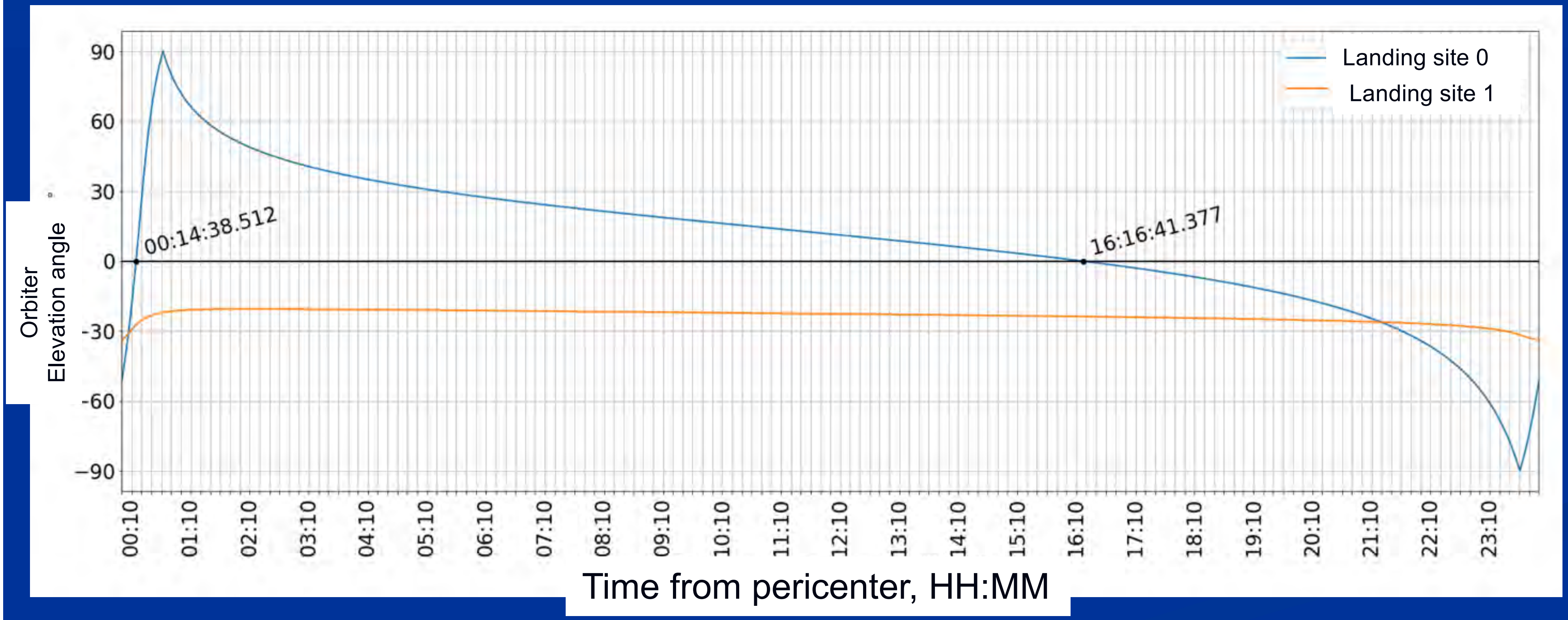
Orbital simulations developed by IKI for all considered launch dates



Positions of accessible landing points for 17.12.2026 landing, selected for analysis equatorial point 1 and on the northern point 0 corresponding positions of possible pericenters (red) with the selected one marked as zero. V∞ is vector of relative hyperbolic velocity.



Telemetry windows: Orbiter angle of elevation in landing point vs. time (hours, minutes) since pericenter (~400 km) during 24 hours for the equatorial (orange) and the ***northern (blue) landing point*** for the southern position of pericenter

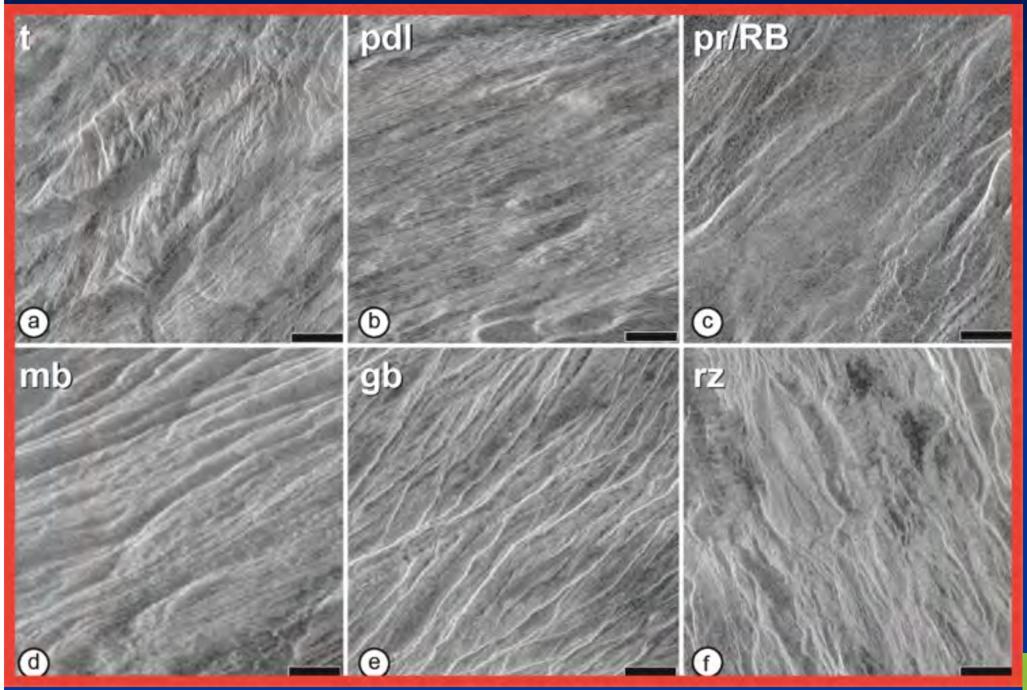


Landing site selection criteria

- Safety of the lander.
- Typical (representative) of Venus surface.
- Geochemical uniformity of the target materials.
- Orbital restrictions.

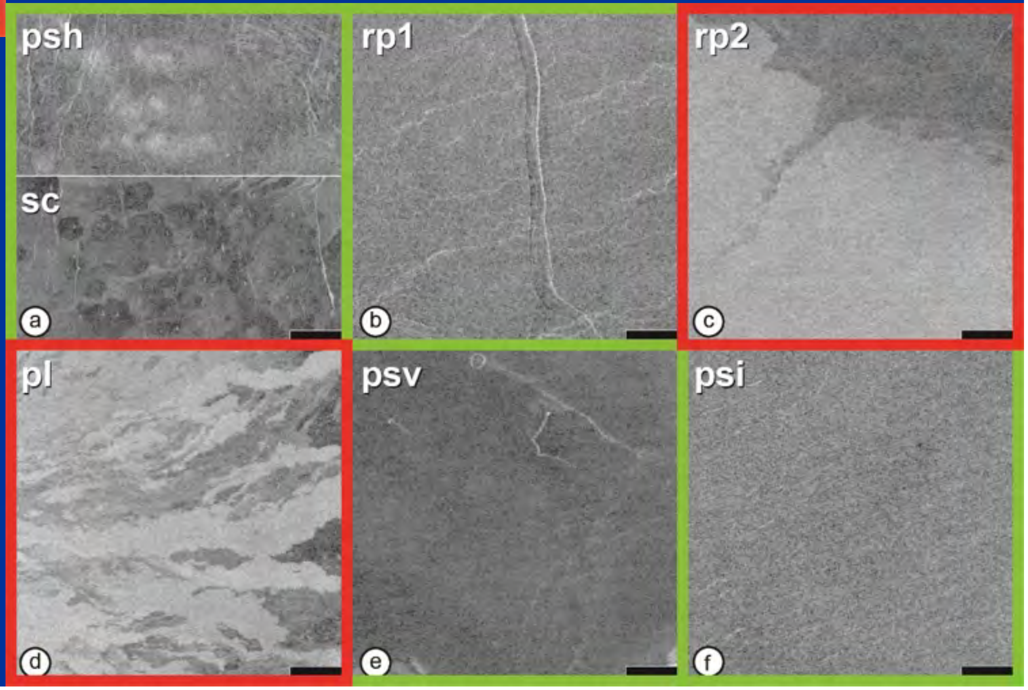
Using these criteria, we can select many potential sites that provide safe landing on a surface with high scientific priority.

Criterion #1: Landing Site Safety

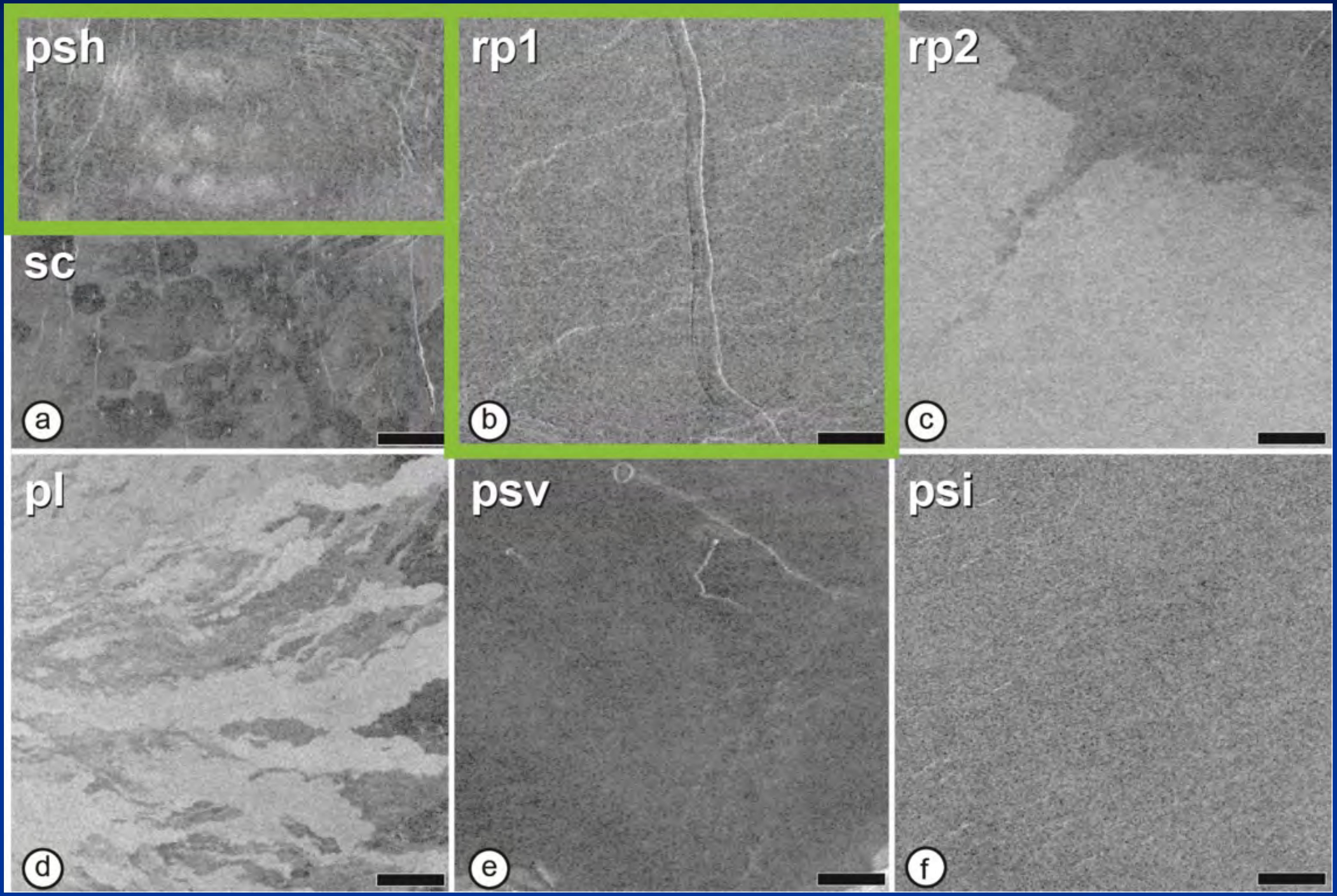


<u>Tectonized units = unsafe!</u> All tectonized units must be excluded on the basis of their unsafety.

<u>Volcanic/impact units</u>: radar-bright units (rp2, pl)-- some are excluded (too rough, unsafe surfaces).

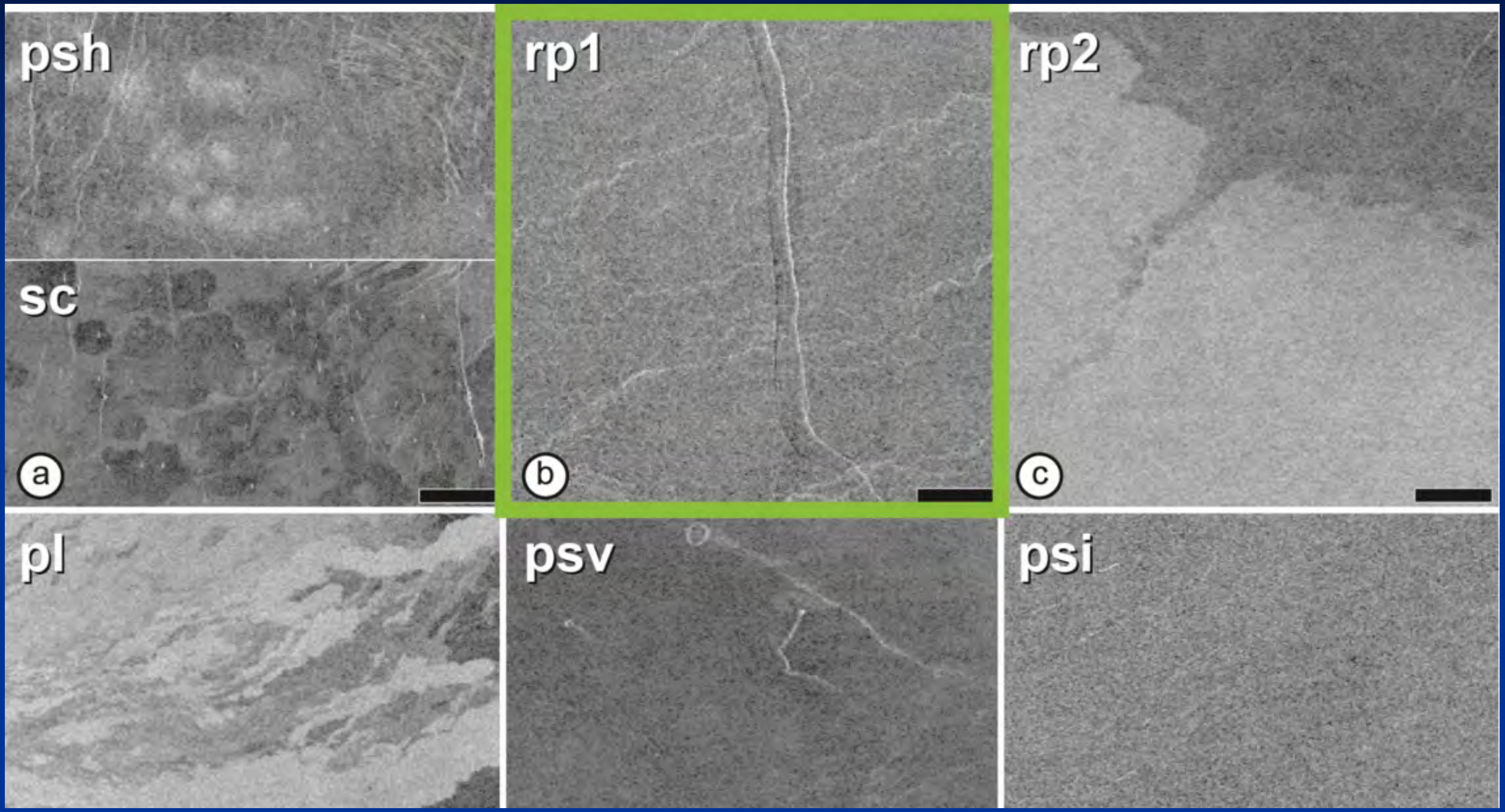


Criterion 2: Representative of Venus terrains



<u>Volcanic/impact units</u>: only two units, shield plains (psh, ~19% of the surface of Venus) and regional plains (rp1, ~30% of the surface) provide representative targets.

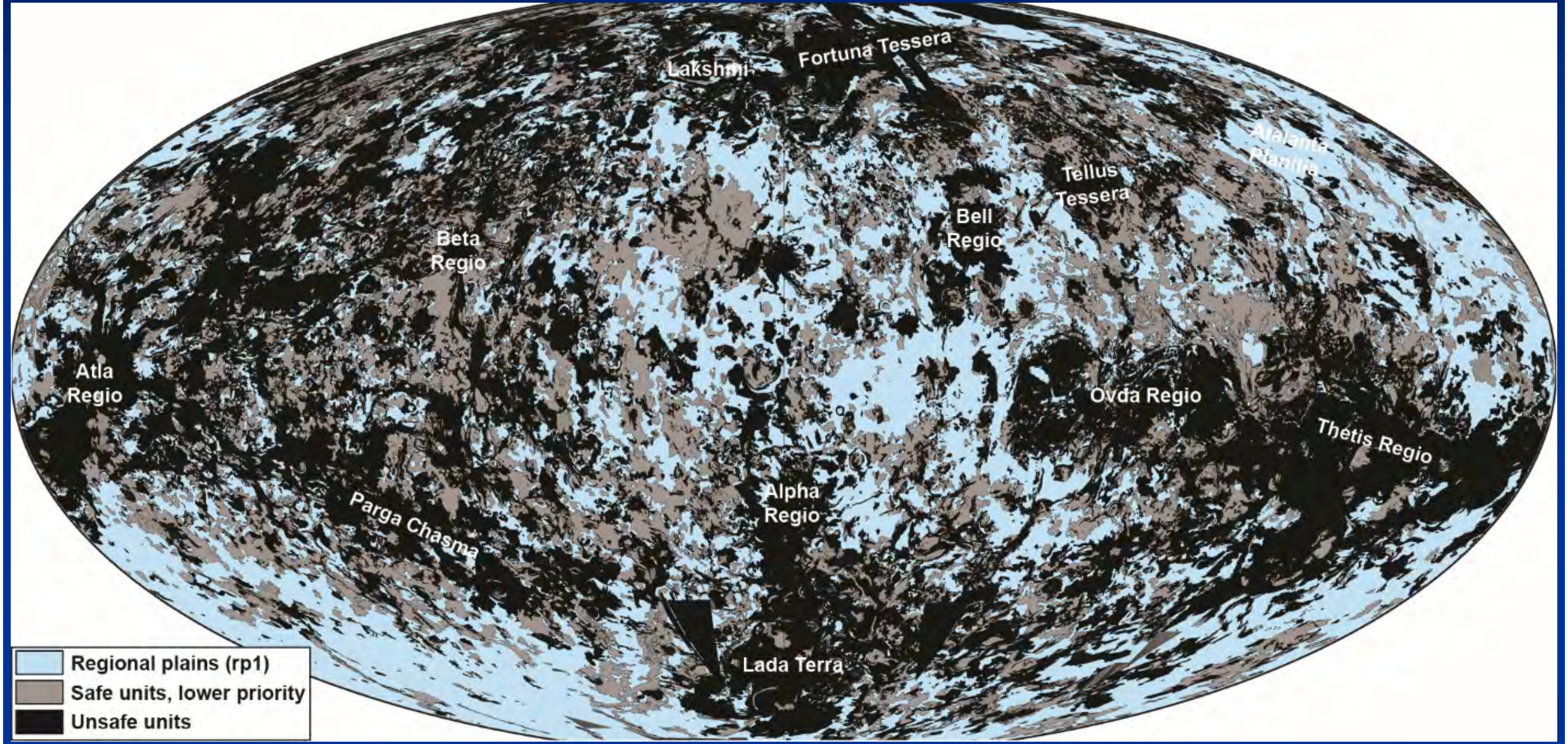
Criterion 3: Geochemical uniformity



Shield plains (psh): geochemistry may be too complex and sampling of their material may give largely equivocal results.
Regional plains (rp1): seem to be dominated by a single process and their materials may be much more geochemically uniform.

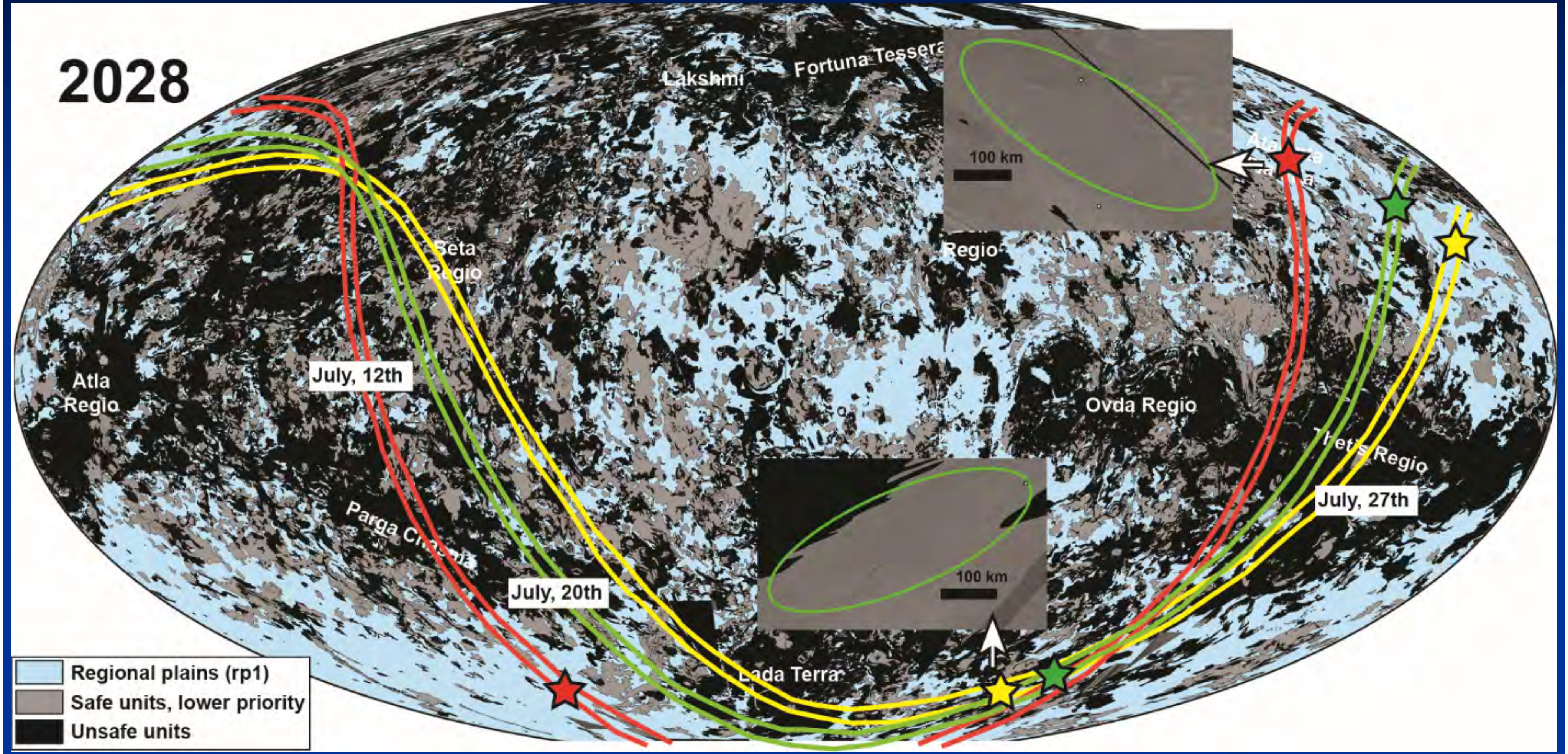
Regional plains likely represent materials derived directly from the upper mantle of Venus.

Regional Plains = Priority #1



Geological map of Venus. Unsafe units are shown in black, low-priority (non-representative, geochemically complex) units are in gray.

Orbital restrictions



Position of the attainability arcs for year of 2028. Insets show examples of the uncertainty ellipses for two selected landing sites. Stars indicate the other sites.

Descent and Surface Science*: Traceability to VEXAG & Decadal Survey

Prioritized Science Goal	Prioritized Payload Instrument
Rock Analysis and Characterization **1. Mineralogy**	X-Ray Diffraction (XRD) spectrometer Mossbauer Spectrometer
2. Elemental Abundance **3. Geomorphology**	X-Ray Fluorescence (XRF) Spectrometer Chemical Anal. Package (Laser Induced Mass Spec. mode) Mossbauer (Alpha Particle X-ray Spec. mode) Gamma and Neutron Spectrometer Camera System
Atmospheric Studies **4. Gas Composition, Aerosols**	Chemical analyses package (CAP) (Gas Chromatograph Mass Spec mode; including isotopes and noble gases) Multi-channel diode laser (MDLS) spec. (including isotopes) UV-Vis Spectrometer Raman-LIDAR
5. Physical Characterization (T, P, NetFlux, wind behaviors)	Meteo Package (T, P, wind) Radiometric Tracking Net flux radiometer
6. Radioscience (Phase 3)	Radio Package
7. Lightning and Seismology (Phase 3)	Wave Package Microphones (Infrasonic and Acoustic)

Preliminary Lander Instrument Accommodation

- Instruments + infrastructure = 120 kg
- Sample acquisition & delivery system = 35 kg
- Phase 3: detailed lander instrument accommodation

LLISSE

Baseline LLISSE Science

- LLISSE will begin to tackle the science questions (mostly atmospheric) that require *long-duration* surface operations

- Science Objectives
  1) Acquire temporal data to update global circulation models
     - Temp, Pressure, Wind speed and direction, Radiance
  2) Begin to quantify near surface energy balance
     - Incident and reflected solar radiation
  3) Estimate moment exchange between planet and atmosphere
     - Wind speed and direction
  4) Quantify near surface atmospheric chemistry variability
     - Measure key chemical species abundance over time
  5) Technology Objective
     - Technology demonstration for more capable future lander missions

- *Operations Goals:*
  - *Operate for a minimum of ½ Venus solar day (~60 Earth days)*
  - Assuming 2 minutes data transmission every 8 hours

Approved for public release

Baseline Lander Future Work (Phase 3)

1. Development and optimization of lander operations
    a) Modification of entry profile to have higher-altitude detachment of lander heat shield for better sampling of UV-absorber
    b) Slower descent through cloud layer to enhance measurements
    c) Sample acquisition, distribution and instrument operations
2. Lander payload accommodation – some instruments require agreement
3. Using LLISSE to transmit signals from Lander sensors (meteo, seismo, etc.) – requires agreement
4. How to know Lander orientation after landing (rotation sensors, radio science, …?)

Baseline Mission Prioritized Science Goals	Baseline Mission Prioritized Instruments
Vertical Structure of Atmosphere (Temperature profiles, Trace species abundances, Unknown absorber, Thermal tides)	MM-radiometer Thermal IR Spectrometer Visible to Mid IR Spectrometers UV mapping spectrometer Solar and star occultation spectrometer Infrared heterodyne spectrometer Radio-science two-frequency duplex occultation **Thermospheric Wind Instrument (Phase 3)**
Atmospheric Dynamics and Cloud Motions	UV - NIR Imaging (Dayside: 65-75 km; Nightside: 40-60 km; Nightglow:90-110 km) IR Imaging Camera (Cloud top level and Slant τ=1 level at limb Thermal IR Camera
Solar Wind Interactions	Panoramic energy mass-analyzer of ions Electron spectrometer Langmuir Probe Neutral particle spectrometer Energetic particle spectrometer Magnetometer **Aurora Imager (Phase 3)**
Atmospheric Conductivity	**Lightning and plasma waves detector (Phase 3)**

JSDT Future Work: Baseline Mission Phase 3

Short-term

- Data downlink and data transfer options
- High-temp, high-pressure lab work
- Refining landing site selection for different launch dates
- Continued assessment of instruments, including data sheets

Long-term

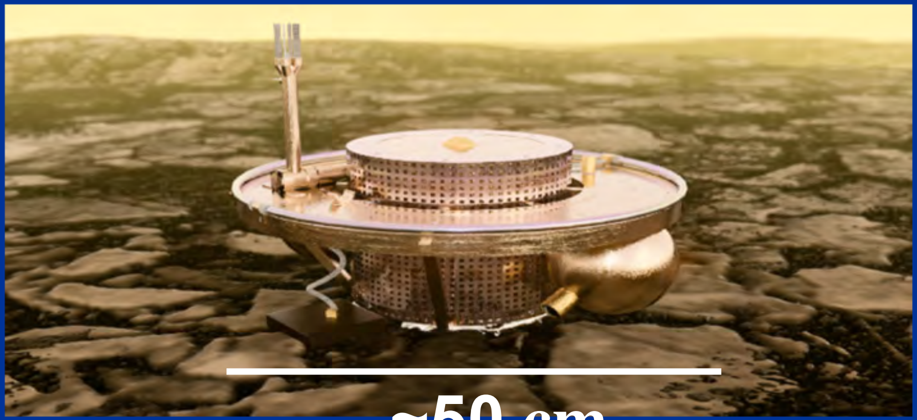
- LLISSE integration with Lander sensors
- Precise landing site selection
- Pre-project team providing technological / scientific input
- Consistent Lavochkin support
- Lander & orbiter instrument accommodation

Potential Augmentations

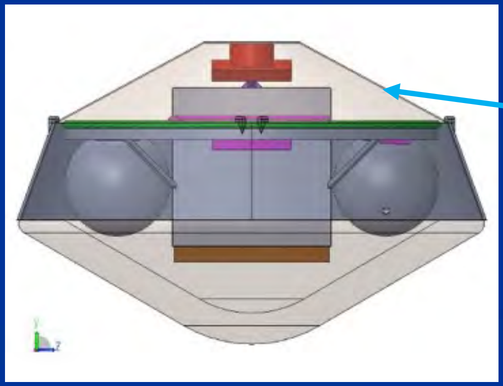
- Augmentation means not baseline
- Small stations (2nd – 4th LLISSE, SAEVe)
- Sub-satellite(s)
- Aerial platform
- Additional Instruments

SAEVe Basics

- SAEVe is a compact lander concept based on LLISSE developments and capability
- Includes >1 SAEVes that are placed 300 - 800 km apart
- Each SAEVe has own entry shell, and is carried and released by the orbiter
- SAEVe stations would operate for 120 days, > 1 Venus solar day
  - Adds important new science capability in addition to longer life
- LLISSE approach is used, only transmits periodically – except when seismic event detected



~50 cm



60 cm

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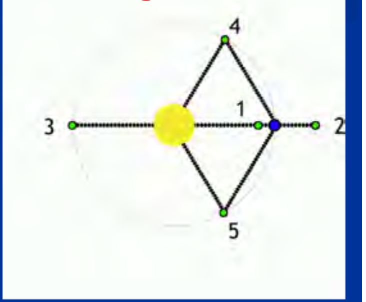
Breakthrough Science Achieved with subsatellite(s)

- Escaping planetary ions: composition and flux
- Processes and channels: upper atmosphere and ionosphere pick-up, ionosphere scavenging, detached clouds
- Influence of driving factors: solar parameters, catastrophic events, solar UV flux
- Energy and momentum transfer to ionosphere
- Solar wind ion precipitation and accumulation in atmosphere
- Temporal evolution of dayside albedo through continuous monitoring


LaGrange Points

Contribution Candidate: Aerial Platform

- JSDT identified two distinct aerial vehicle measurement phases:
  - During initial descent to 90 to 65 km.
  - During normal flight / float operations at 45 to 65 km.
- Based on the results of the NASA Aerial Platforms study:
  - Between 90 - 65 km is likely only accessible with VAMP.
  - Between 45 - 50 km may require development of high-temperature avionics and instruments to tolerate > 75 °C temperatures.
- Candidate instrument lists have been generated and the desired measurements specified.

Decadal Survey Goals	Aerial Platform Science Objectives	Measurements	Instrument Requirements
A) Understand the processes that control climate on Earth-like planets.	1) Determine atmospheric physical properties over a range of altitudes	Temperature, pressure, vertical and horizontal winds	Temperature sensor Pressure sensor Anemometer Accelerometer Radiometer
B) Understand chemistry of the middle, upper and lower atmosphere	2) Acquire atmospheric compositional data over a range of altitudes	Measure the abundance of gases: CH_4, H_2O, SO_2, SOx, CO, HF, HCl, HCN, OCS, NO, N_2, CO_2, O_2 Measure abundance and distribution of aerosols	Aerosol composition sensor Aerosol particle size sensor UV-VIS-IR spectrometer Trace species sensor
C) Understand how the evolution of terrestrial planets enables and limits the origin and evolution of life	5) Search for biological components in the atmosphere	Composition of atmosphere	Life Detection Sensors Microscopic imager Tunable spectrometer Net flux radiometer

Variable Altitude Balloons

- Variable altitude balloons were recommended in the NASA study.
- There are 4 different kinds of variable altitude balloons (aerobots):
  - Pumped helium balloons
  - Air ballast balloons
  - Mechanical compression balloons
  - Phase change fluid balloons
- All have been flown on Earth to prove basic feasibility.
- Significant technological development is required to adapt terrestrial versions for Venus.
  - Venus-compatible materials
  - sizing
  - atmospheric conditions over altitude range and lifetime
- One or more of these options may provide superior performance and/or less risk, but the work has to be done.

Together to Venus!