VENERA-D: A COMPREHENSIVE MISSION TO EXPLORE VENUS' ATMOSPHERE, SURFACE, INTERIOR STRUCTURE AND PLASMA ENVIRONMENT

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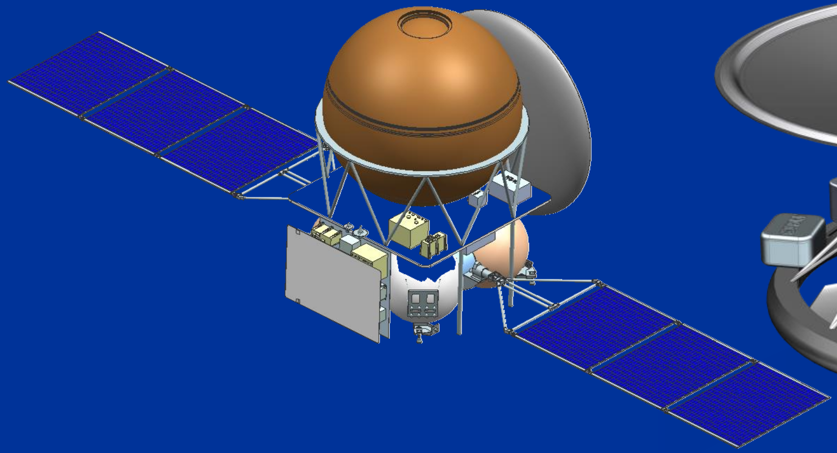
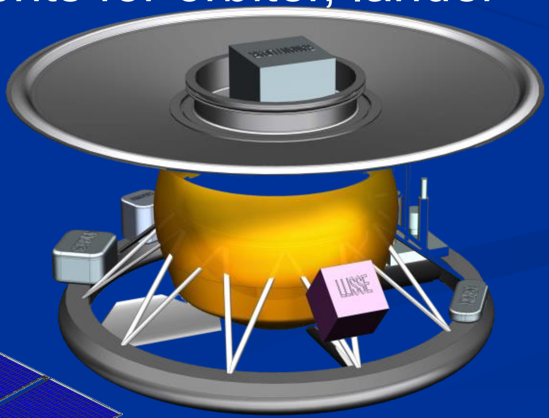
The Venera-D IKI/Roscosmos – NASA Joint Science Definition Team (JSDT) published the Phase II study report on the concept of the NASA-Roscosmos joint flagship mission to Venus

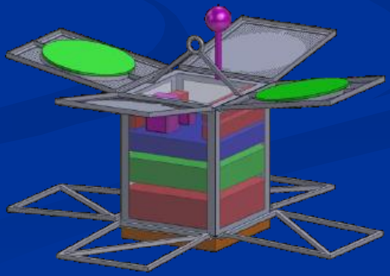
https://www.lpi.usra.edu/vexag/reports/Venera-DPhaseIIFinalReport.pdf
http://www.iki.rssi.ru/events/2019/Venera-DPhaseIIFinalReport.pdf
https://www.roscosmos.ru/26234/

Venera-D Concept: Mission Elements

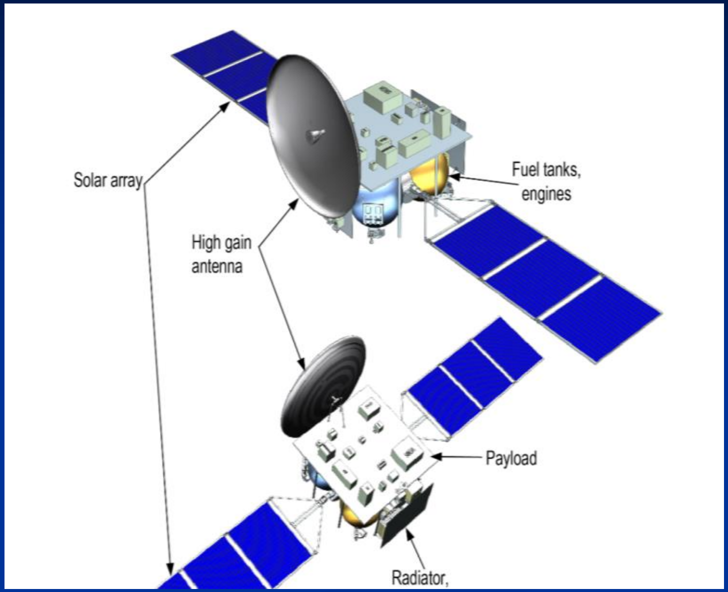
- **Baseline**:
  - Orbiter: Polar (90° ± 5°) 24-hr orbit with lifetime ≥ 3 yrs (Roscosmos)
  - Lander (VEGA-type, updated) ≥2 hrs on surface (Roscosmos)
  - LLISSE on Lander (>2 months on surface) (NASA)
- **Potential augmentations (prioritized)**:
  - SAEVes (1 or 2) (NASA)
  - Vertically maneuverable aerial platform (balloon) (NASA)
  - Subsatellite at Lagrange point L1 or L2 (Roscosmos, NASA)
  - LLISSEs (1 or 2, detached) (NASA)
- **Potential augmentations (not yet prioritized)**:
  - Additional instruments for orbiter, lander







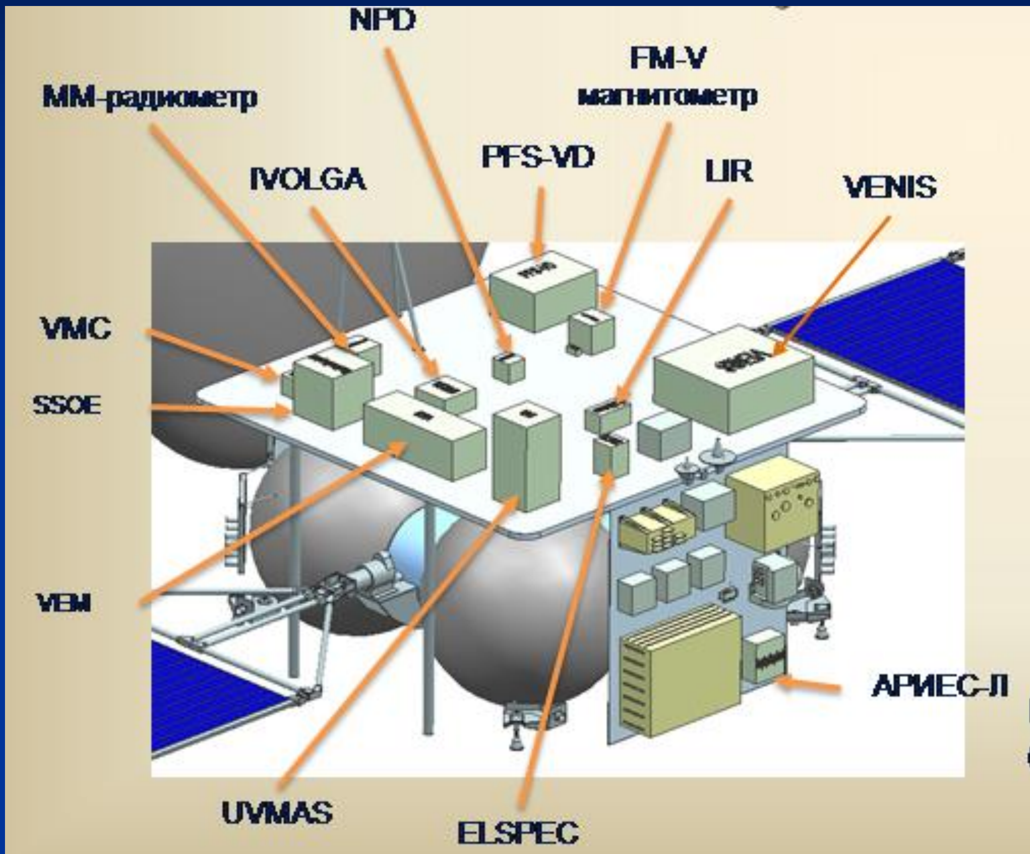
The Orbiter



Science Goals:

- Study of the dynamics and nature of superrotation, radiative balance, and nature of the greenhouse effect;
- Characterize the thermal structure of the atmosphere, winds, thermal tides, and solar locked structures
- Measure the composition of the atmosphere, study the clouds, their structure, composition, microphysics, and chemistry;
- Study the composition of the low atmosphere and low clouds, surface emissivity, and search for volcanic events on the night side;
- Investigate the upper atmosphere, ionosphere, electrical activity, magnetosphere, the atmospheric escape rate, and solar wind interaction.

Orbiter Science Payload. Preliminary accommodation



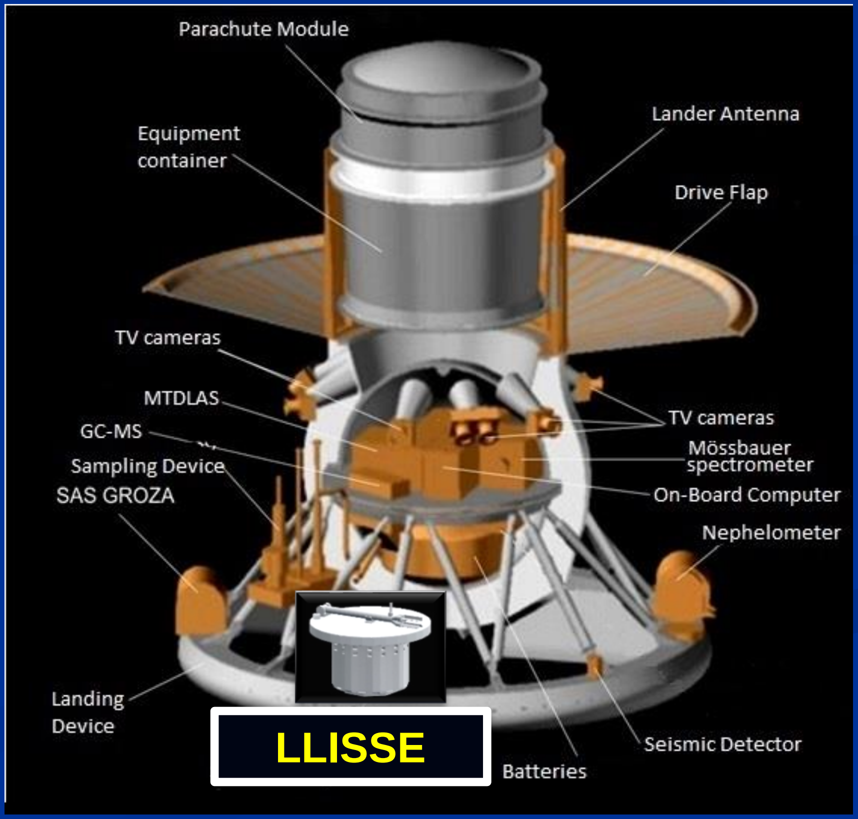
- UV mapping spectrometer
- PFS-VD Fourier transform spectrometer
- MM-radiometer
- VENIS, VIS-IR Imaging Spectrometer
- SSOE Solar and star occultation spectrometer
- VMC Monitoring camera
- VEM (Venus Emissivity Mapper)
- UVI, UV imager
- Thermal infrared camera
- IVOLGA, Infrared heterodyne spectrometer
- Radio-science two-frequency duplex occultation experiment
- Panoram energy mass-analyzer of ions
- Electron spectrometer ELSPEC
- Neutral particle detector NDP
- Energetic particle spectrometer
- FM-V Magnetometer
- GROZA-SAS2-DFM-D

Lander + LLISSE Science Goals :

- Measure elemental and mineralogical abundances of the surface materials and near subsurface (a few cm), including radiogenic elements.
- Study the interaction between the surface and atmosphere.
- Investigate the structure and chemical composition of the atmosphere down to the surface, including abundances and isotopic ratios of the trace and noble gases.
- Perform direct chemical analysis of cloud aerosols.
- Characterize the geology of local landforms at different scales.
- Study variation of near-surface wind speed and direction, temperatures, and pressure over 3 months (LLISSE).
- Measure incident and reflected solar radiation over 3 months (LLISSE).
- Measure near-surface atmospheric chemical composition over 3 months (LLISSE).
- Detect seismic activity, volcanic activity, and volcanic lightning.

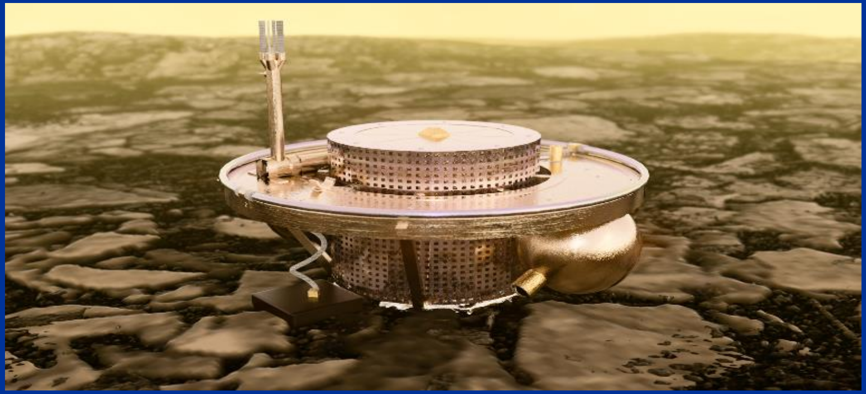
Lander scientific payload

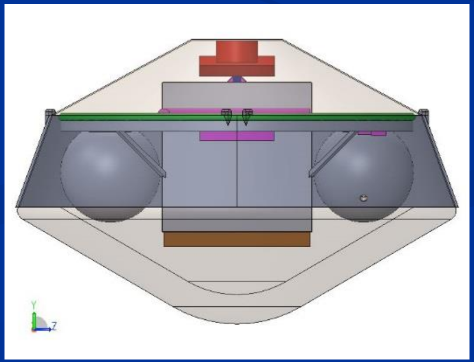
- Active Gamma and Neutron Spectrometer
- Chemical analyses package (CAP, Gas Chromatograph, Mass Spectrometer, LIMS)
- X-Ray Diffraction and Fluorescence spectrometer (XRD/XRF)
- Raman-LIDAR
- Mossbauer + Alpha Particle X-ray Spectrometer mode
- Camera System (descent, panorama, microscopic)
- Multi-channel diode laser (MDLS) spectrometer
- Meteo Package (T, P, wind)
- Net flux radiometer
- UV-Vis spectrometer
- Long-living in situ solar system
- explorer (LLISSE)
- Radio package [Phase 3]
- Wave package [Phase 3]
- Seismometer [Phase 3]
- Sample acquisition & delivery system[Phase 3]



SAEVe (Seismic and Atmospheric Exploration of Venus)

- Lander concept based on LLISSE
- Includes ≥ landers 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





The Instrument Suite

Core science centers around *long term* measurements to obtain meteorological and seismic data over 1 Venus solar day (120 Earth days)

Instrument set includes:

A 3-axis micro-machined Micro-Electro-Mechanical Systems (MEMS) seismometer

Meteorological sensor suite (temperature, pressure, wind speed & direction, solar radiance, atmospheric chemical species abundances), and solar position sensors

Two COTS Cubesat cameras

Heat Flux instrument

Contribution Candidate: Aerial Platform

- **Aerial platform could significantly contribute to mission science return by making direct *in situ* measurements > 45-50 km.**
- **Adequate science return requires instrument payloads ~10-30 kg (more than VEGA)**
- **Recent NASA-sponsored Venus Aerial Platforms study assessed a variety of candidate vehicles**
- **Study concluded that:**
    - **all potential platforms required technological development**
    - **<u>variable altitude balloon</u> = most science return compared to cost**
    - **VAMP = better science return but needs more development**

VEGA-style balloon
Courtesy of Geoffrey Landis

7 Types of Aerial Platforms Were Considered

(Mostly Terrestrial Examples Shown Below)

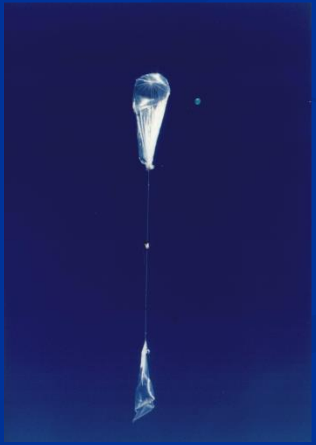
Balloons/Aerobots

Superpressure Balloon
(JPL Venus prototype)

Mechanical Compression
Balloon
(Thin Red Line Aerospace)

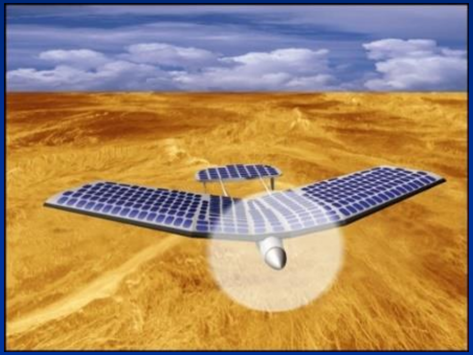
Pumped Helium
Balloon (Paul Voss
CMET)

Air Ballast Balloon (Google Loon)

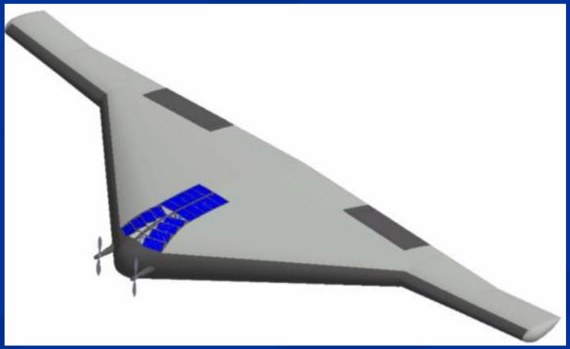


Phase Change Fluid
Balloon (JPL)

Aircraft and Hybrid

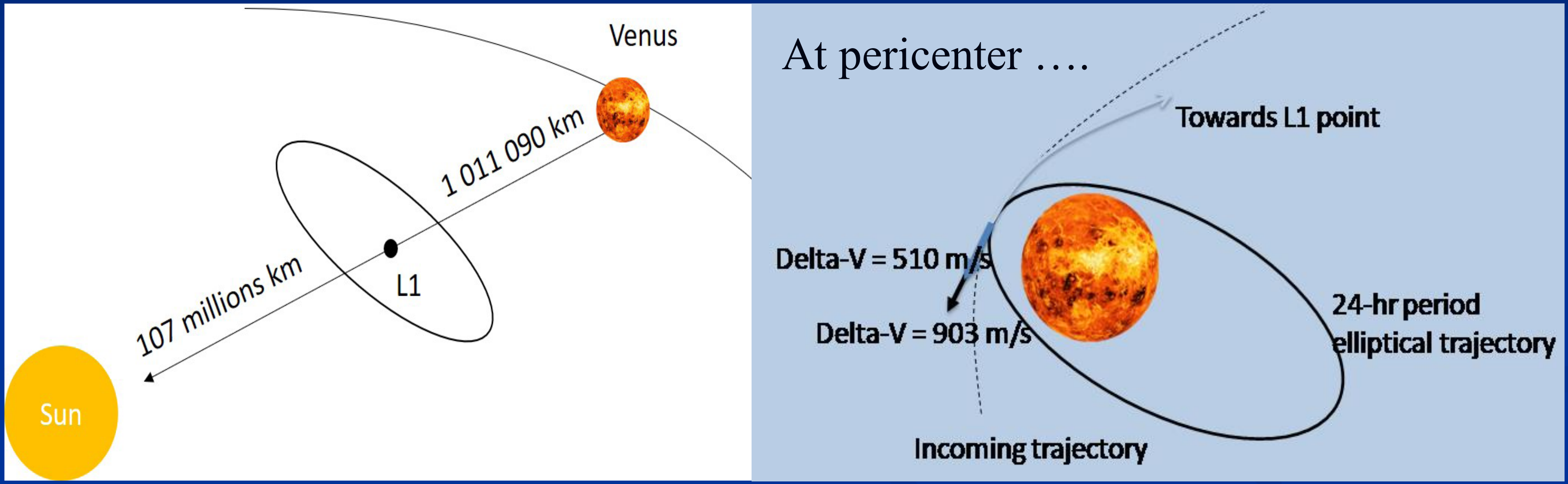


Solar Aircraft
(GRC)



Hybrid Airship
(Northrup Grumman VAMP)

Contribution Candidate: Subsatellites L1/L2



Science payload includes: plasma package and cameras for cloud and surface emissivity (night side) monitoring.

Occultations between main orbiter and L1:

- Duration: 30 minutes or less
- Frequency: every day

Breakthrough Science:

Case 1: Subsatellite near L1

- Dependence of atmospheric ion escape on solar EUV and solar wind
- Permanent measurement of space weather near Venus
- Continuous dayside global albedo monitoring
- Tracing UV absorber (energy balance, cyclical behavior, solar cycle)
- Regular occultations without local time bias

Case 2: Subsatellite near L2

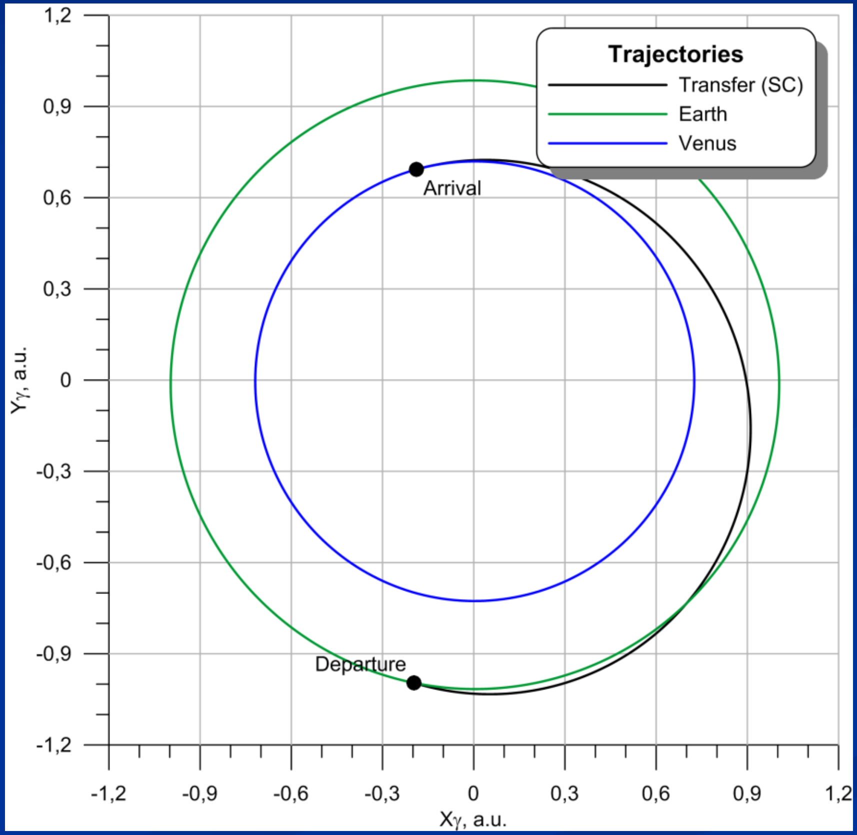
- Dynamics of ionospheric and atmospheric ion escape
- The role of different channels in global ion escape
- Energy balance through escaping radiation
- Dynamics through airglows. Cloud structure, surface emissivity.

Case 3: Subsatellite in same orbit as main orbiter

- Separate temporal and spatial variations
- Detailed study of different atmospheric loss channels

Траектории перелета и параметры орбиты КА Венера-Д: Базовый вариант

- Наклонение орбиты 90º ± 5º
- Период 24ч
- Перицентр над южным полушарием
- Апоцентр над северным полушарием



Траектория перелета для 2026

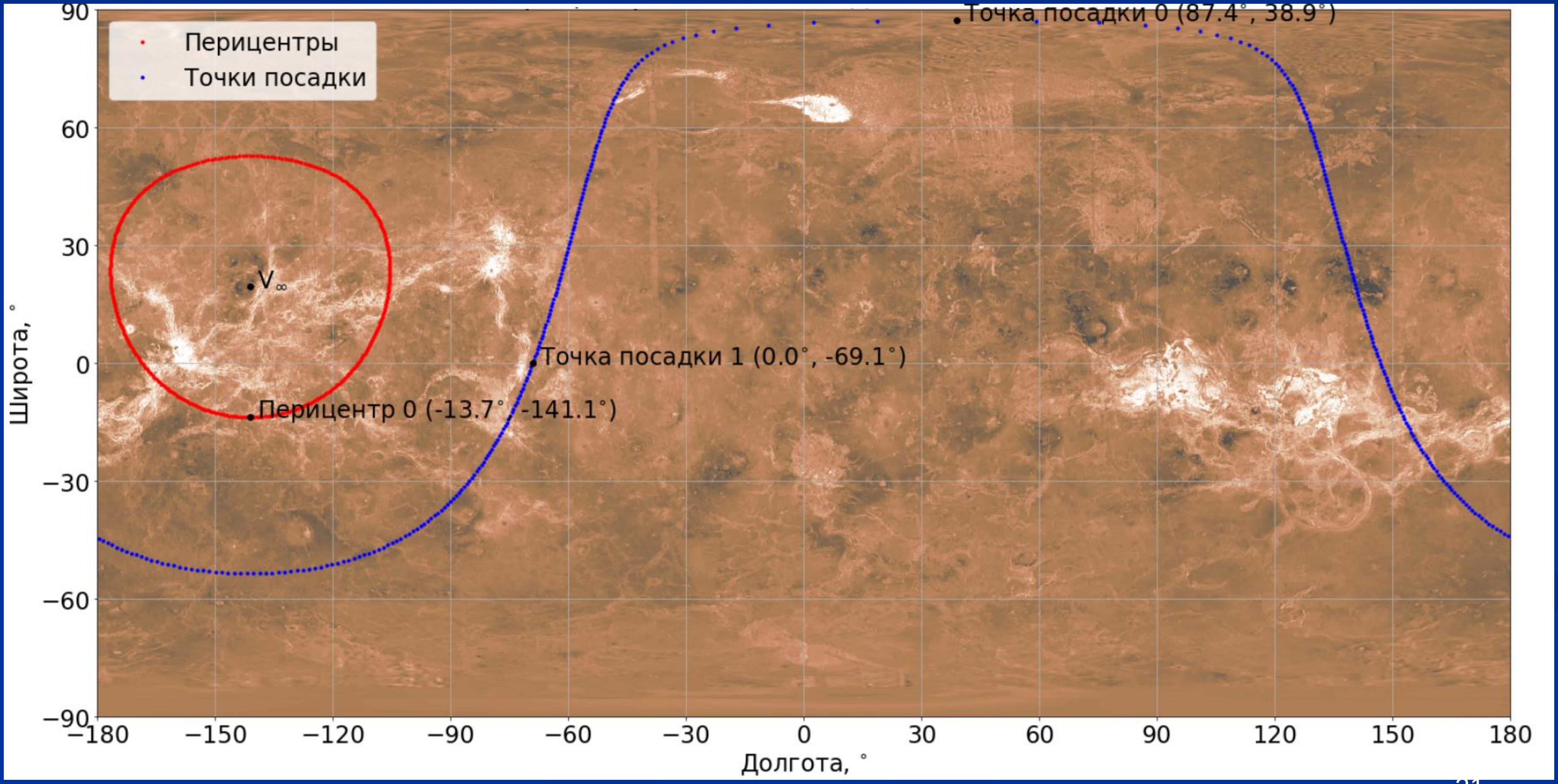
Основные характеристики для стартового окна 30.05.26. – 20.06.26 и окна прибытия 05.12.2026 – 17.12.26

Table 1. – Key trajectory parameters for 2026 date of

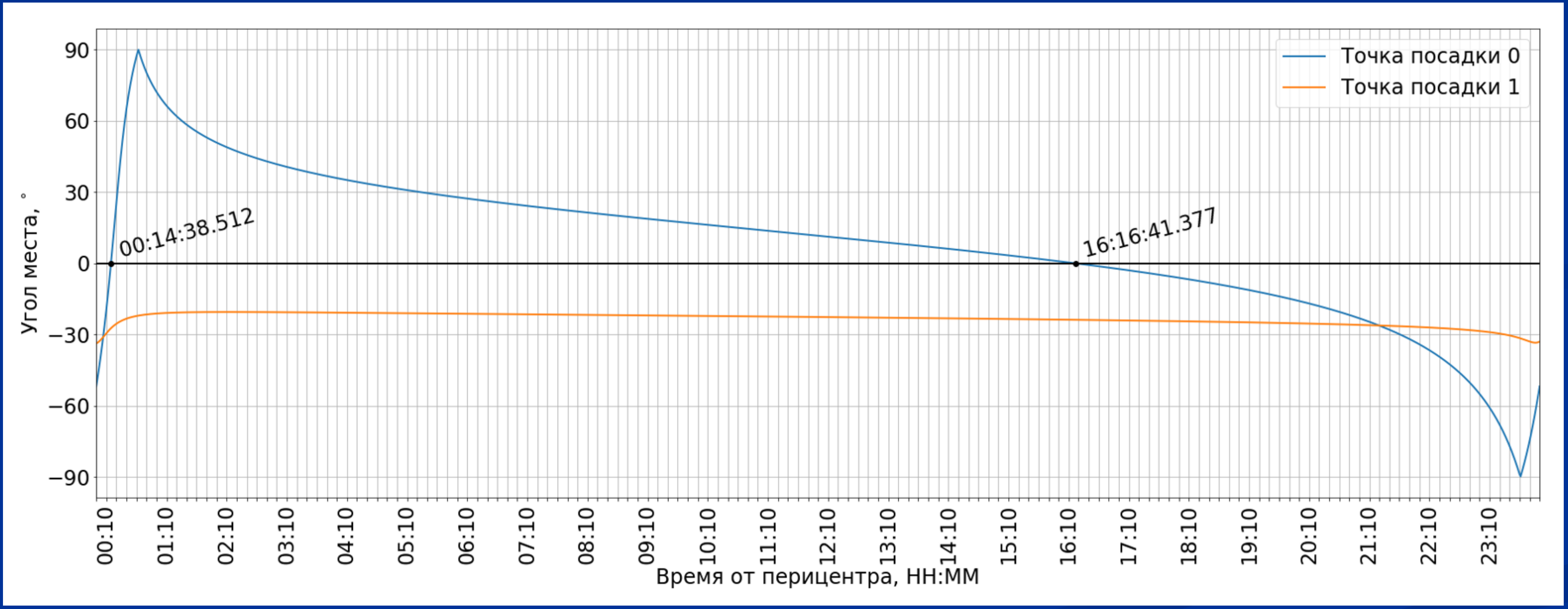
Параметр	First date for launch period	Middle date for launch period	Last date for launch period
Date of launch	30.05.2026	09.06.2026	20.06.2026
ΔV_1, km/s	3.905	3.881	3.896
V_1^∞ (C_{31}), km/s	3.930 (15.4)	3.858	3.904
δ_1^∞, ° - J2000 - ecliptic	 -28.44 -17.64	 -38.33 -26.50	 -46.17 -33.46
α_1^∞, °	202.50	203.15	203.65
Duration of transfer trajectory days	189	182	180
Angular distance of transfer, degrees	210.04	206.57	209.05
Date of arrival	05.12.2026	09.12.2026	17.12.2026
ΔV_2, km/s	0.899	0.859	0.899
V_2^∞ (C_{32}), m/s	3.117 (9.7)	2.982	3.118
δ_2^∞, ° - J2000 - ecliptic - Venus equator	 -12.71 -9.00 -10.17	 -0.12 6.66 5.46	 13.14 20.76 19.56
α_2^∞, °	186.73	197.25	202.11

Initial mass of spacecraft after separation from upper stage (Hydrogen block «КВТК»): 6500 кг.
Mass of the orbital module after putting it onto Venus satellite orbit with 24 hours period and 500 km pericenter altitude: 3100 кг.

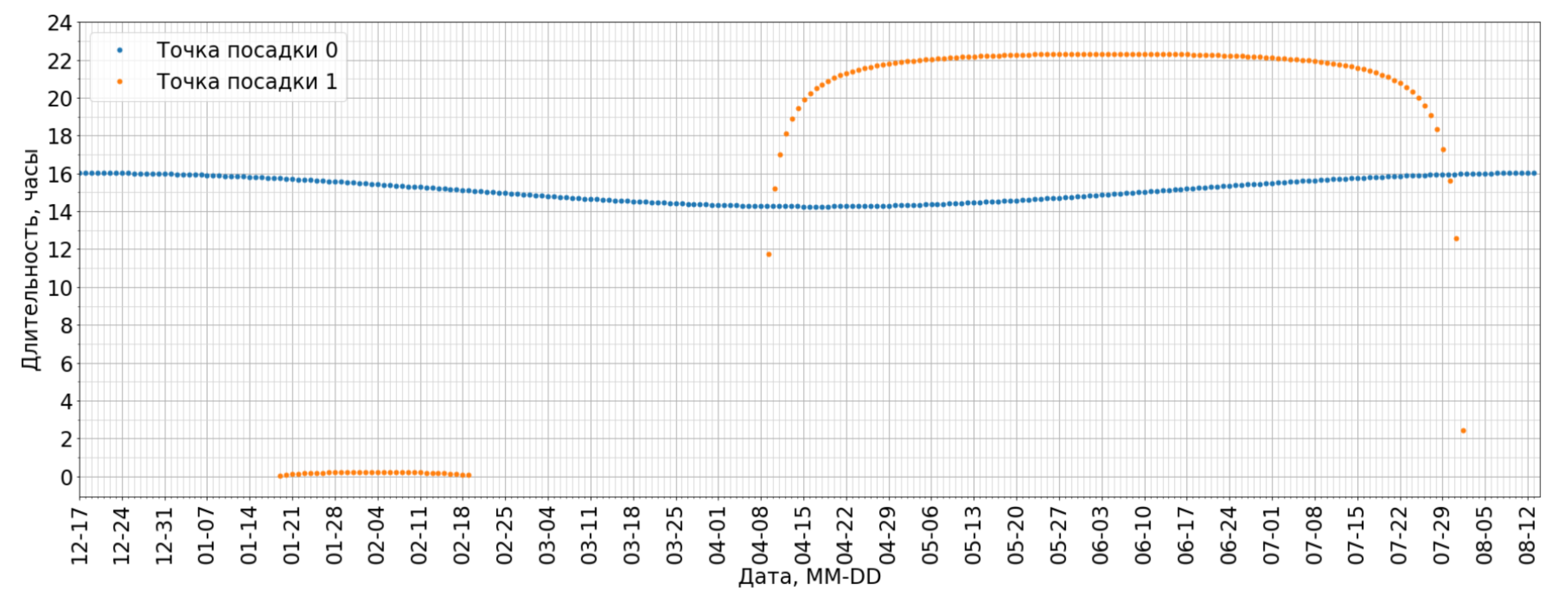
Достижимые места посадки для даты 17.12.2026, выбранные для анализа точка 1 на экваторе и точка 0 в северном полушарии, соответсвующие положения перицентра, выбранное положение перицентра 0. V∞ - вектор относительной гиперболической скорости.



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



Duration (hours) of Orbiter/LLISSE visibility per each 24 hours starting from 17.12.26 vs Date for northern landing point (blue) and equatorial landing point (orange) for the southern position of the pericenter

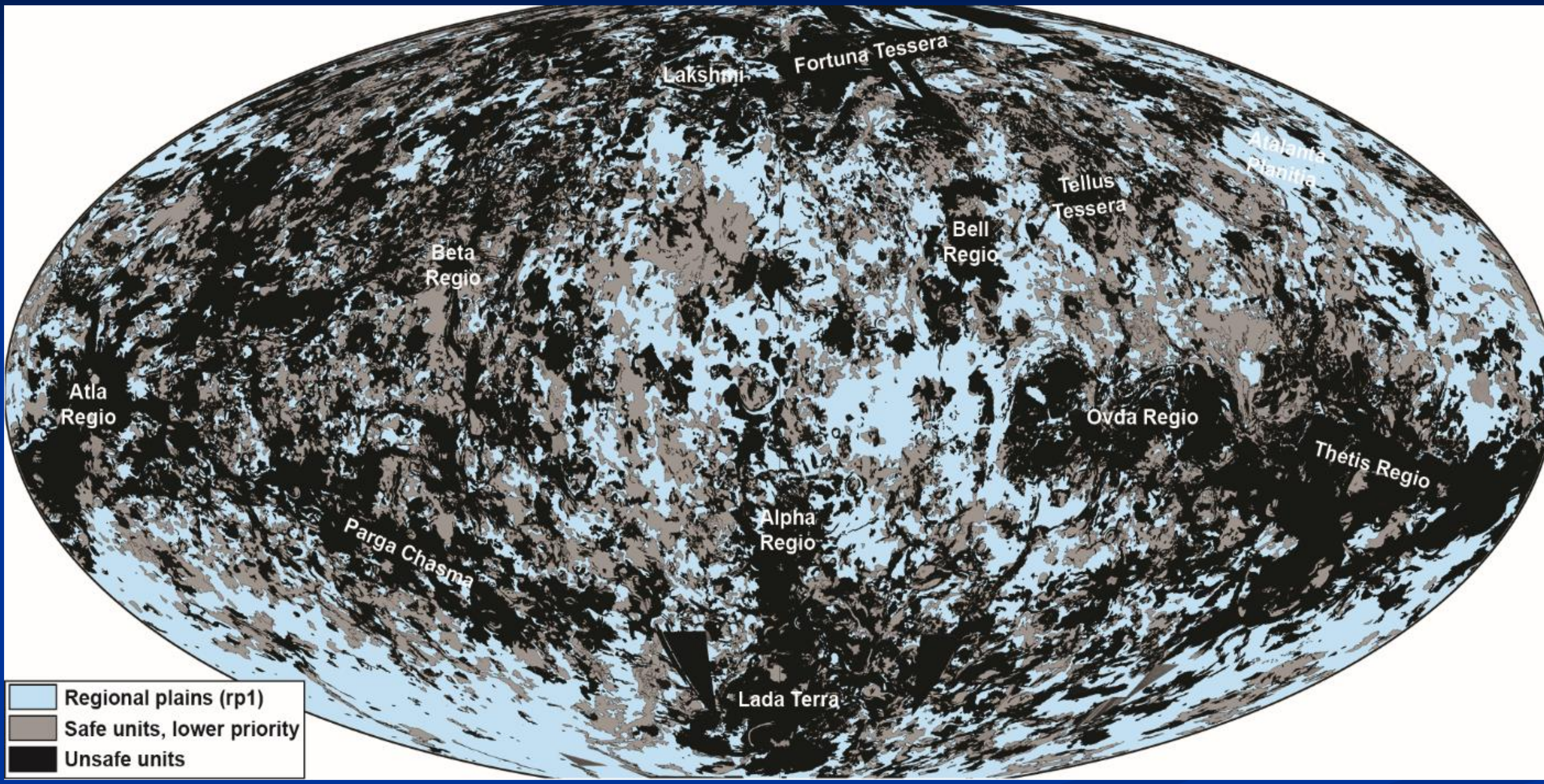


Selection of the Venera-D landing sites
Landing site selection criteria

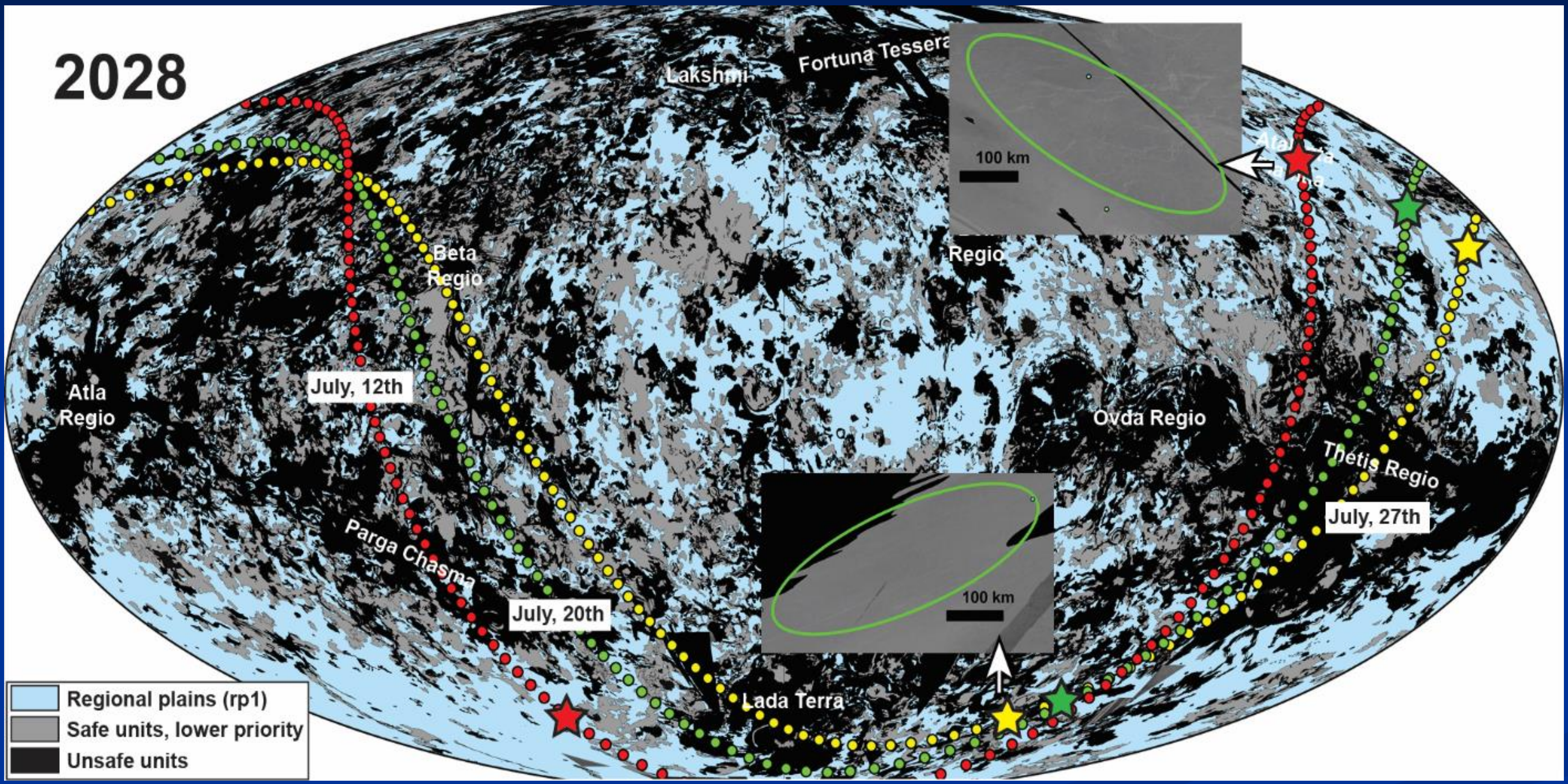
- Safety of the lander.
- Typical (representative) of Venus surface.
- Geochemical uniformity of the target materials.
- Orbital restrictions (near-polar latitudes of the northern hemisphere

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

Selection of the Venera-D landing sites



Geological map of Venus. Unsafe units are shown in black, low-priority units are in gray.

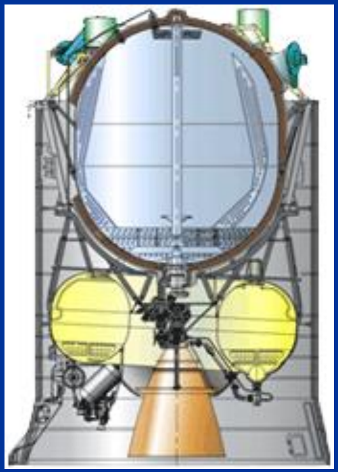


Position of the attainability arcs for year of 2028. Insets show examples of the uncertainty ellipses for two selected landing sites. Stars indicate the other sites.

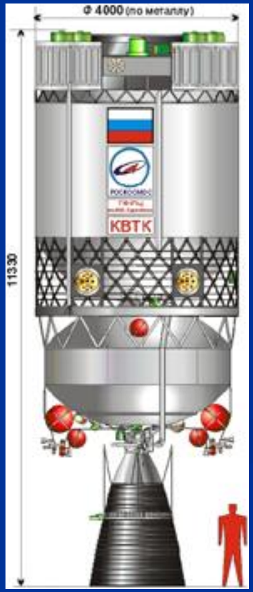
Launch vehicle: Angara – A5

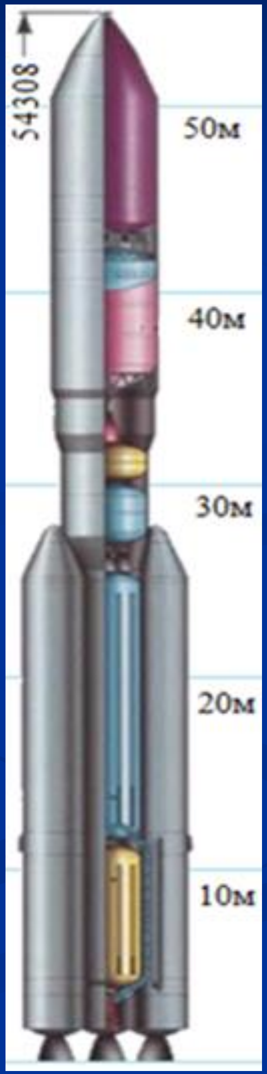
Start date	2028, Jan	2029, Nov	2031, Jun
Mass of output spacecraft (KVTK), kg	6300	6400	7000
Mass of output spacecraft (DM-03), kg	6200	6300	6900

DM-03



KVTK





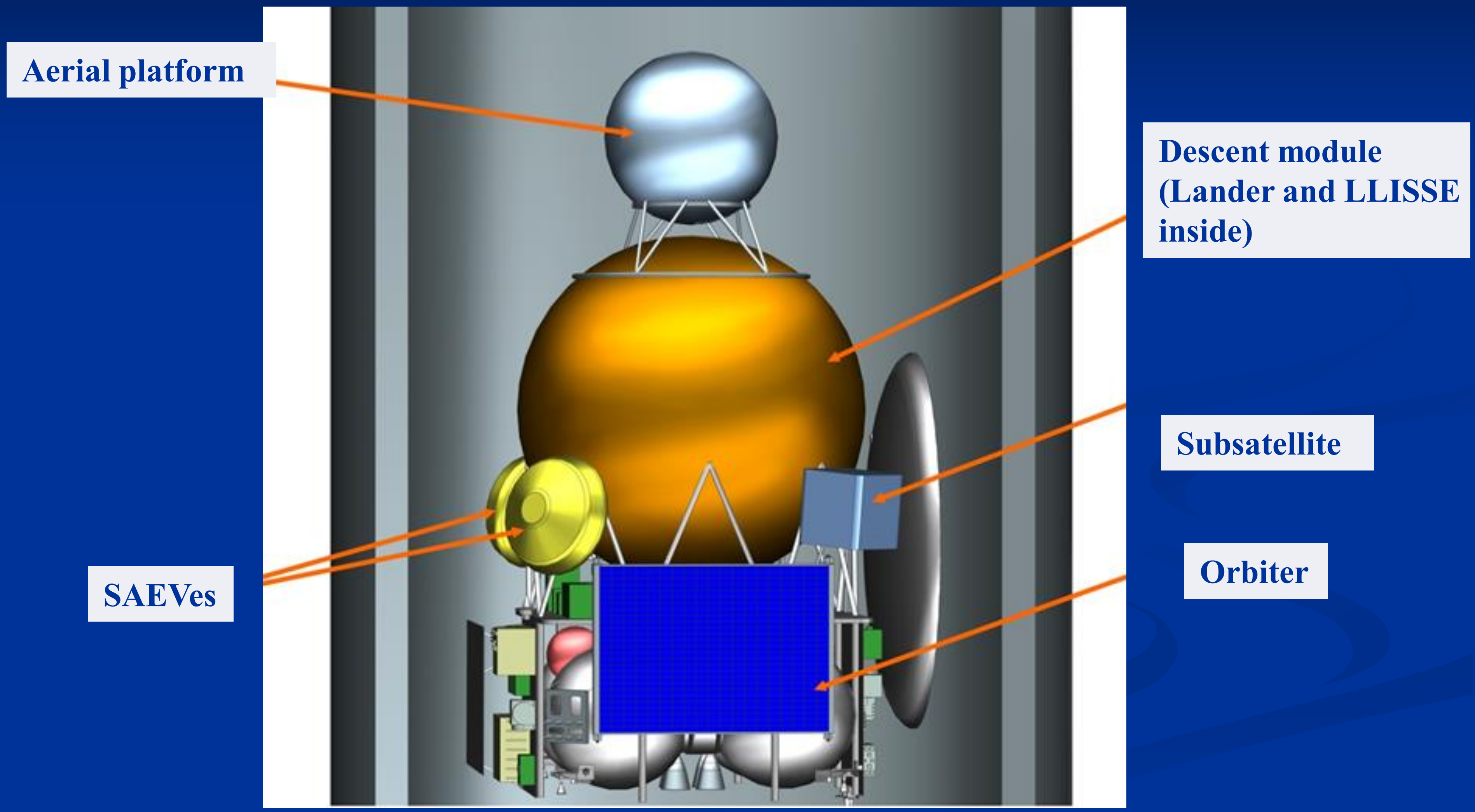
Potential augmentations :

- SAEVes (1 or 2)
- Vertically maneuverable aerial platform (balloon)
- Subsatellite at Lagrange point L1 (L2)
- LISSEs (1 or 2, detached)

Element	Mass (kg)
SAEVe 1	55
SAEVe 2	55
Aerial platform	600 (with 20kg of science payload)
Subsatellite L1	55
Subsatellite L2	55
LLISSE attached	10
LLISSE detached	15

Geneal view of the spacecraft

Venera-D under the fairing of Angara-A5



Summary of Key Mission Stages

1) Launch from Earth using Angara-A5 rocket and Vostochny launch facility in 2028 – 2031 start windows
2) Transition to the Earth-Venus flight trajectory using hydrogen KVTK upper stage vehicle.
3) Flight along the Earth-Venus trajectory with necessary corrections.
4) Separation of the aerial planform and SAEVes several days before VOI
5) Separation of the descent module 3 days before VOI
6) Maneuver to transfer the orbiter to the nominal approaching orbit.
7) Entry into the atmosphere: lander+LLISSE inside the descent module. Aerial platform and SAEVes enter separately.
8) Transfer of the orbital module onto high elliptical orbit by use of the rocket engine.
9) Separation of the sub-satellites.
10) Nominal scientific operations assuming data transmission from the Venus surface (Lander and small long-lived stations). Aerial platform, SAEVes and sub-satellite also to the Earth through the orbiter.

Venera-D mission architecture: Key points

- All launch dates in 2028 – 2031 launch windows deliver Venera-D mission goals
- Angara - A5 launch vehicle can accommodate mission composed from baseline and potentially contributed elements for any launch window
- Landing sites are planned in the Northern Hemisphere, high latitudes
- Flexibility to select precise landing site for the main lander ~3 days before VOI
- Main Lander will be in view of the orbiter for the first 3 hours
- Orbiter can have long-term (>60-day) visibility of LLISSE

Together to Venus!