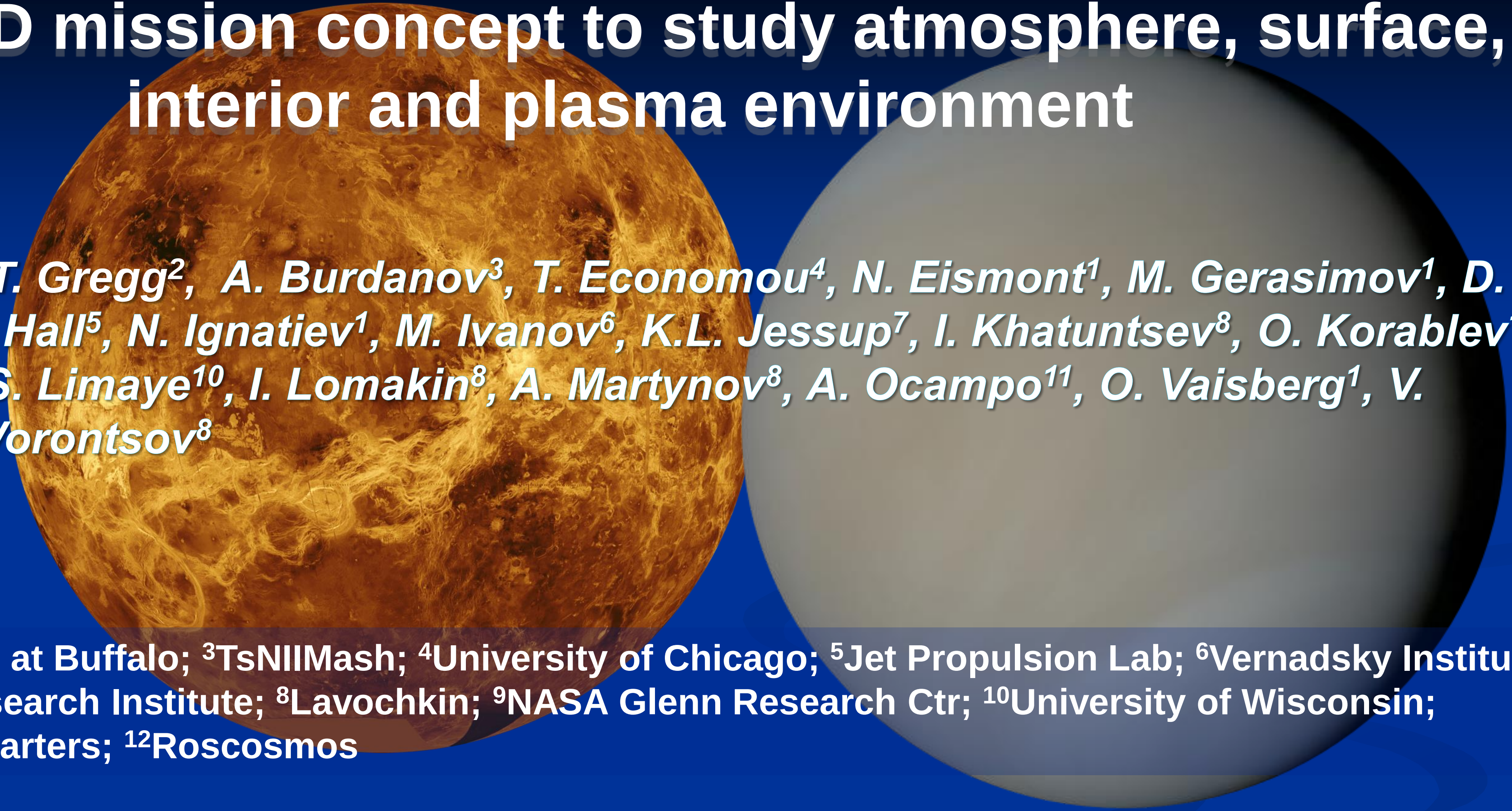
Venera-D mission concept to study atmosphere, surface, interior and plasma environment



L. Zasova[1], T. Gregg[2], A. Burdanov[3], T. Economou[4], N. Eismont[1], M. Gerasimov[1], D. Gorinov[1], J. Hall[5], N. Ignatiev[1], M. Ivanov[6], K.L. Jessup[7], I. Khatuntsev[8], O. Korablev[1], T. Kremic[9], S. Limaye[10], I. Lomakin[8], A. Martynov[8], A. Ocampo[11], O. Vaisberg[1], V. Voron[12], V. Vorontsov[8]

[1]IKI; [2]University at Buffalo; [3]TsNIIMash; [4]University of Chicago; [5]Jet Propulsion Lab; [6]Vernadsky Institute; [7]Southwest Research Institute; [8]Lavochkin; [9]NASA Glenn Research Ctr; [10]University of Wisconsin; [11]NASA Headquarters; [12]Roscosmos

International Venus Conference, 31.05-03.04.2019@
Niseko, Hokkaido, Japan

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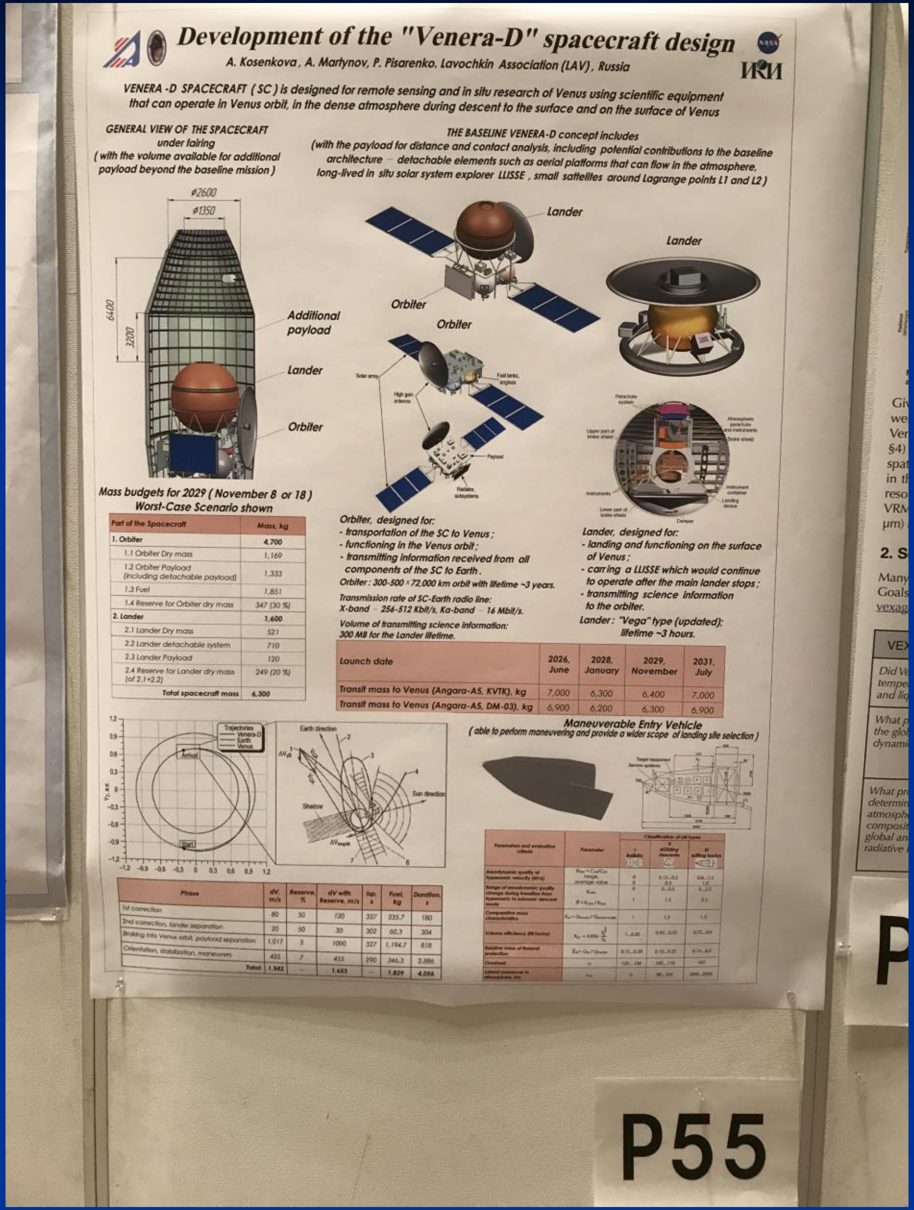


Development of the "Venera-D" spacecraft design

A. Kosenkova, A. Martynov, P. Pisarenko. Lavochkin Association (LAV), Russia

VENERA -D SPACECRAFT (SC) is designed for remote sensing and in situ research of Venus using scientific equipment that can operate in Venus orbit, in the dense atmosphere during descent to the surface and on the surface of Venus

GENERAL VIEW OF THE SPACECRAFT
under fairing
(with the volume available for additional payload beyond the baseline mission)

THE BASELINE VENERA-D concept includes
(with the payload for distance and contact analysis, including potential contributions to the baseline architecture – detachable elements such as aerial platforms that can flow in the atmosphere, long-lived in situ solar system explorer LLISSE , small sattelites around Lagrange points L1 and L2)

Mass budgets for 2029 (November 8 or 18)
Worst-Case Scenario shown

Part of the Spacecraft	Mass, kg
1. Orbiter	4,700
1.1 Orbiter Dry mass	1,169
1.2 Orbiter Payload (including detachable payload)	1,333
1.3 Fuel	1,851
1.4 Reserve for Orbiter dry mass	347 (30 %)
2. Lander	1,600
2.1 Lander Dry mass	521
2.2 Lander detachable system	710
2.3 Lander Payload	120
2.4 Reserve for Lander dry mass (of 2.1+2.2)	249 (20 %)
Total spacecraft mass	6,300

Orbiter, designed for:
- transportation of the SC to Venus ;
- functioning in the Venus orbit ;
- transmitting information received from all components of the SC to Earth .

Orbiter : 300-500 × 72,000 km orbit with lifetime ~3 years.

Transmission rate of SC-Earth radio line:
X-band – 256-512 Kbit/s, Ka-band – 16 Mbit/s.

Volume of transmitting science information:
300 MB for the Lander lifetime.

Lander, designed for:
- landing and functioning on the surface of Venus ;
- carring a LLISSE which would continue to operate after the main lander stops ;
- transmitting science information to the orbiter.

Lander : "Vega" type (updated):
lifetime ~3 hours.

Launch date	2026, June	2028, January	2029, November	2031, July
Transit mass to Venus (Angara-A5, KVTK), kg	7,000	6,300	6,400	7,000
Transit mass to Venus (Angara-A5, DM-03), kg	6,900	6,200	6,300	6,900

Maneuverable Entry Vehicle
(able to perform maneuvering and provide a wider scope of landing site selection)

Phase	dV, m/s	Reserve, %	dV with Reserve, m/s	Isp, s	Fuel, kg	Duration, s
1st correction	80	50	120	327	235.7	180
2nd correction, lander separation	20	50	30	302	60.3	304
Braking into Venus orbit, payload separation	1,017	3	1090	327	1,194.7	818
Orientation, stabilization, maneuvers	425	7	455	290	346.3	2,886
Total:	1,542	–	1,653	–	1,839	4,056

Venera-D Poster at this meeting:

Anastasia Kosenkova, Alexey Martynov and Pawel Pisarenko,

Lavochkin Association

The Venera-D IKI/Roscosmos – NASA Joint Science Definition Team (JSDT)

Phase II report on the concept of mission to Venus submitted – 04/2019

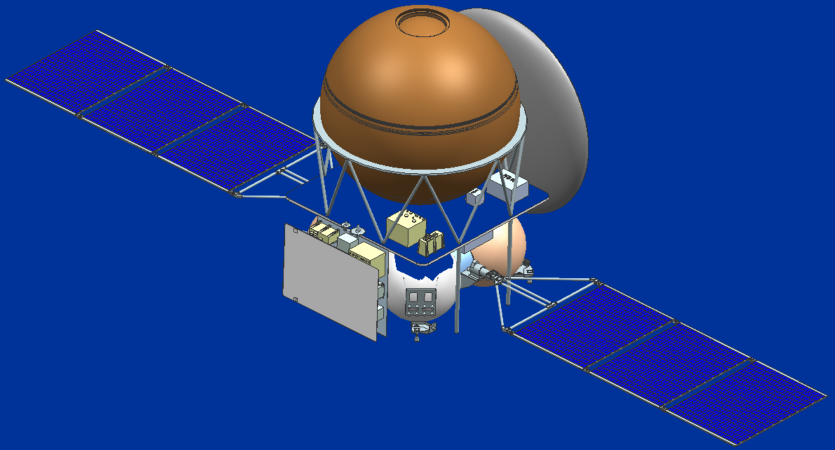
Venera-D:
Expanding Our Horizon of
Terrestrial Planet Climate and
Geology Through the Comprehensive
Exploration of Venus

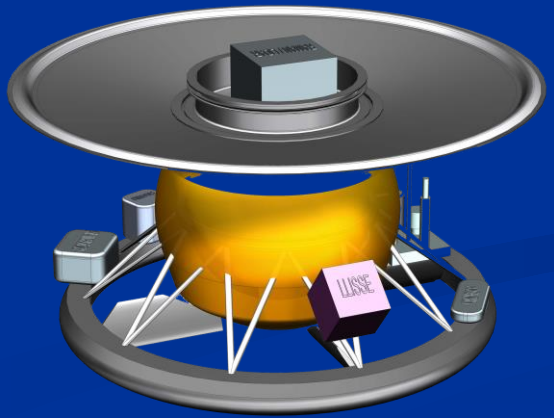
REPORT OF THE VENERA-D
JOINT SCIENCE DEFINITION TEAM
JANUARY 31, 2019

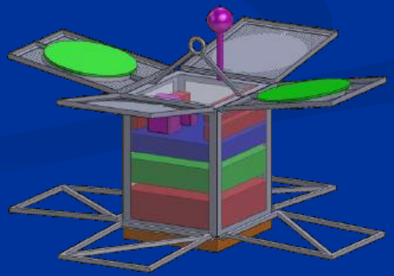
https://www.lpi.usra.edu/vexag/reports/Venera-DPhaseIIFinalReport.pdf
http://www.iki.rssi.ru/events/2019/Venera-DPhaseIIFinalReport.pdf
https://www.roscosmos.ru/26234/

Venera-D Concept: Mission Elements

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



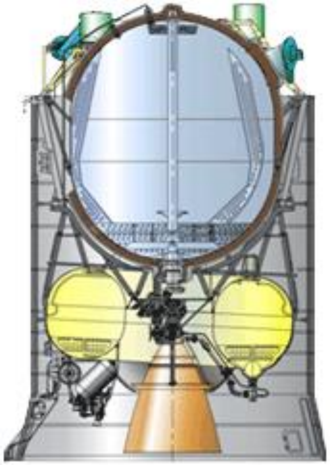




Launch vehicle: Angara – A5

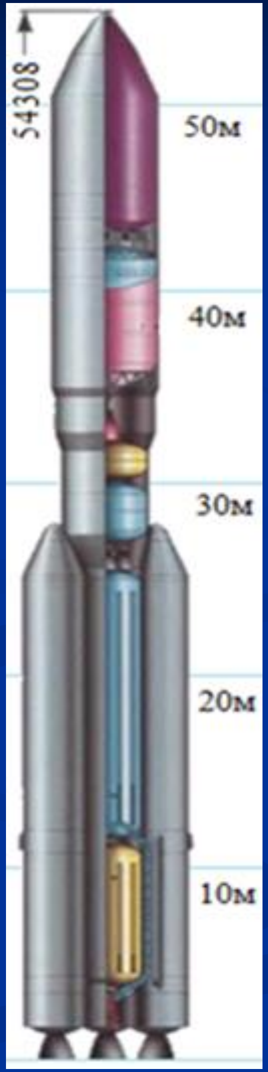
Launch date	Upper Stage	2028, январь	2029, ноябрь	2031, июнь
Maximum launch mass of spacecraft (kg)	**KVTK**	6300	6400	7000
Maximum launch mass of spacecraft (kg)	**DM-03**	6200	6300	6900

DM-03



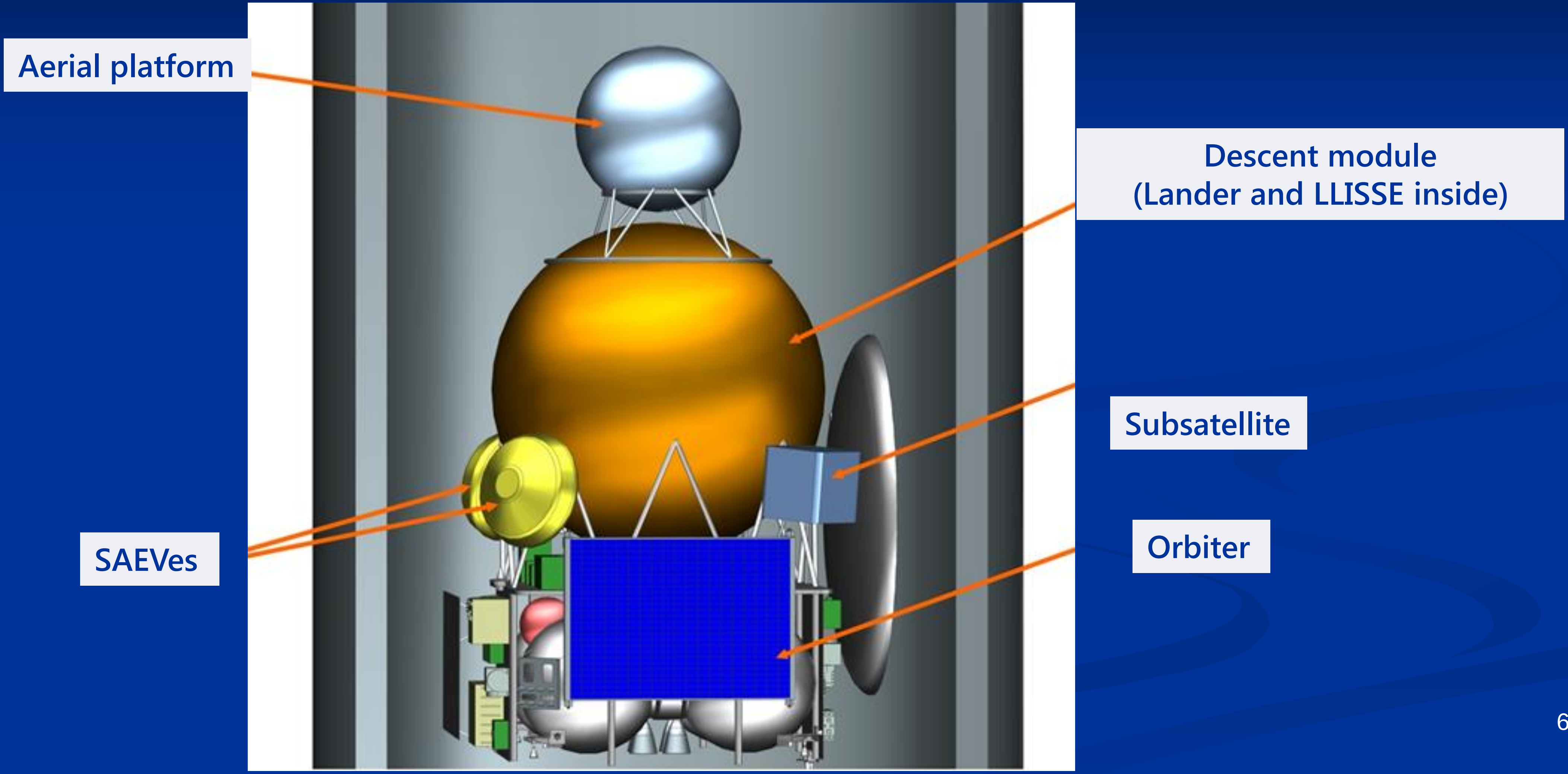
KVTK

«Ангара-А5»



General view of the launch configuration

Venera-D under the fairing of Angara-A5



Aerial platform

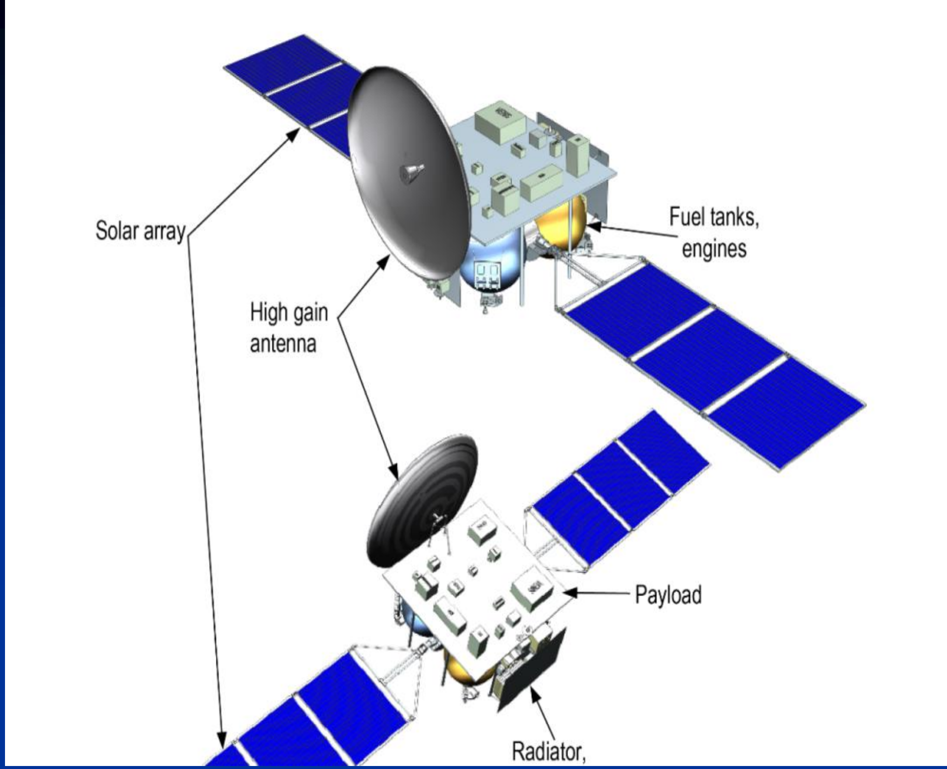
Descent module
(Lander and LLISSE inside)

Subsatellite

SAEVes

Orbiter

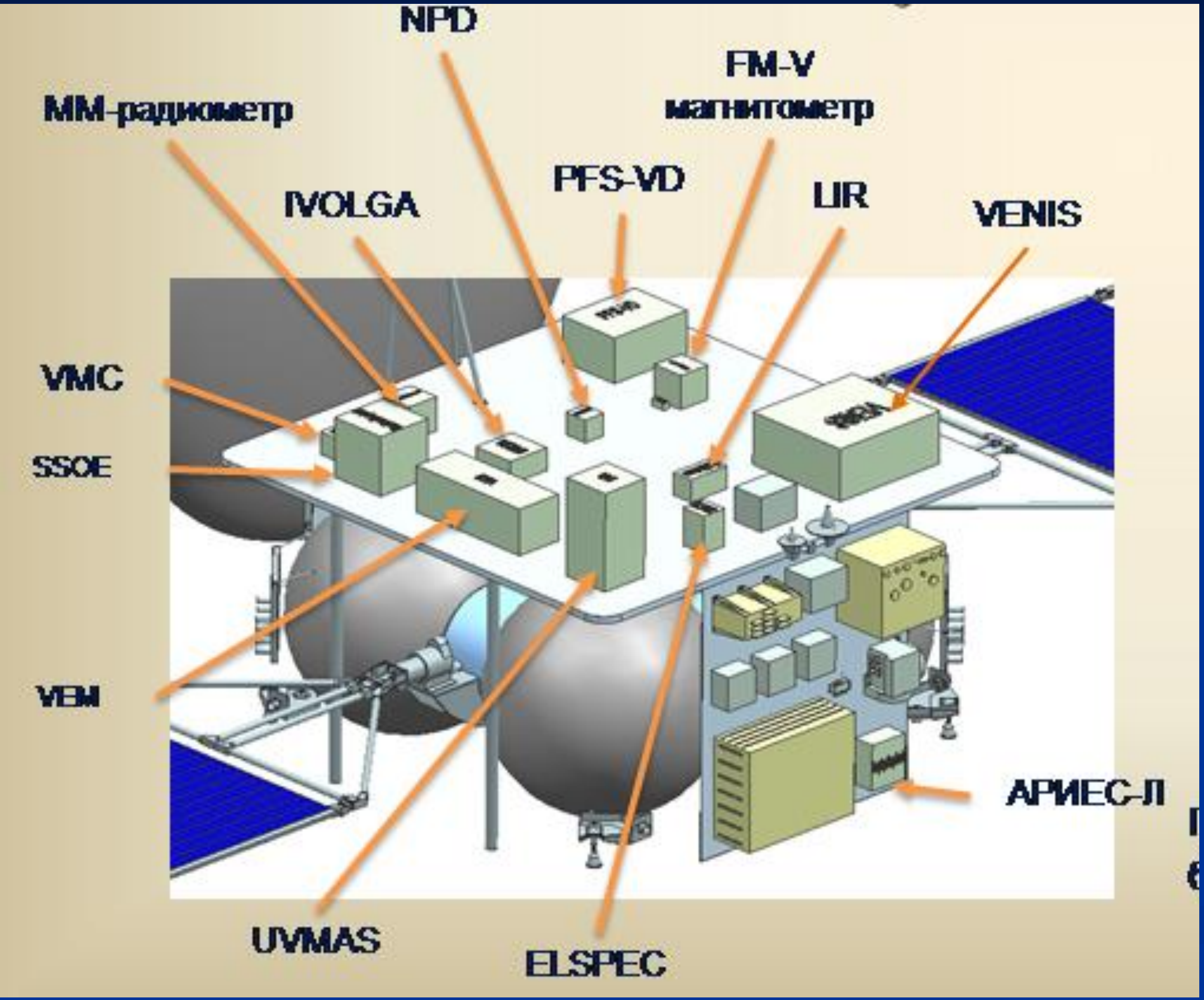
ORBITER



Science Goals:

- Study 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 solarlocked 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



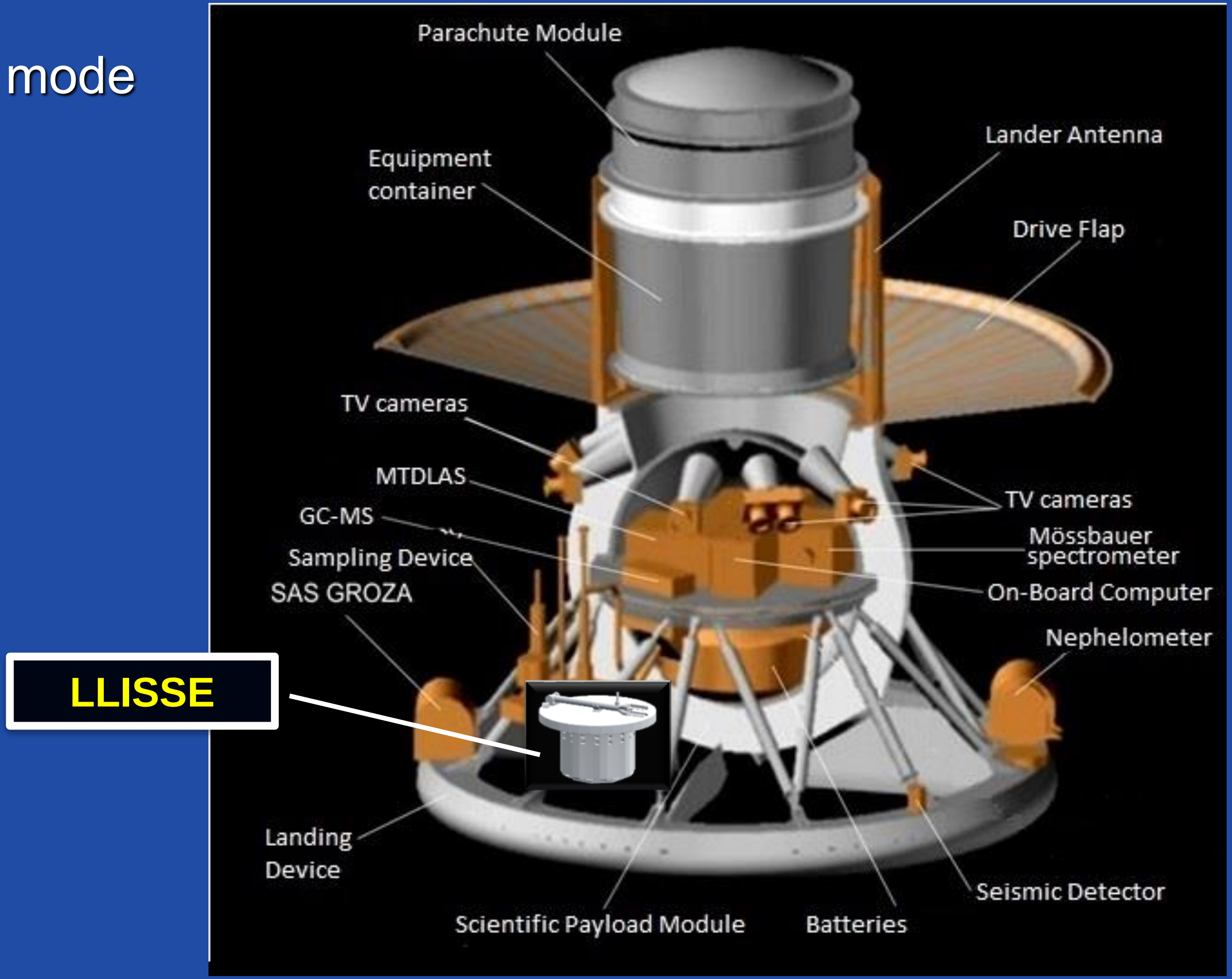
- UV mapping spectrometer
- PFS-VD Fourier transform spectrometer
- MM-radiometer
- VENIS, *UV-IR Imaging Spectrometer*
- SSOE *Solar and stellar occultation spectrometer*
- VMC *Venus Monitoring camera*
- VEM *(Venus Emissivity Mapper)*
- UVI *(UV imager)*
- Thermal infrared camera
- IVOLGA, Infrared heterodyne spectrometer
- Radio-science two-frequency duplex occultation experiment
- Panoramic 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 station (LLISSE)
- Radio package [Phase 3]
- Wave package [Phase 3]
- Seismometer [Phase 3]
- Sample acquisition & delivery system [Phase 3]



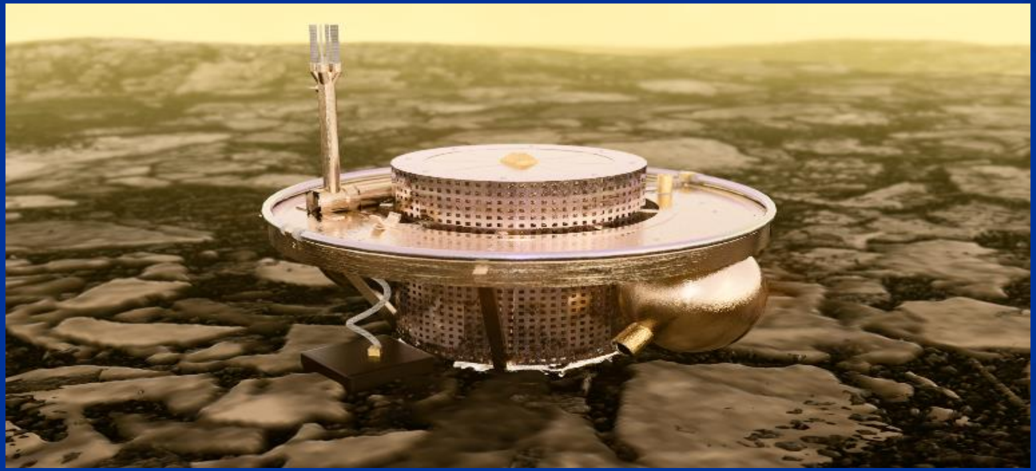
Potential augmentations

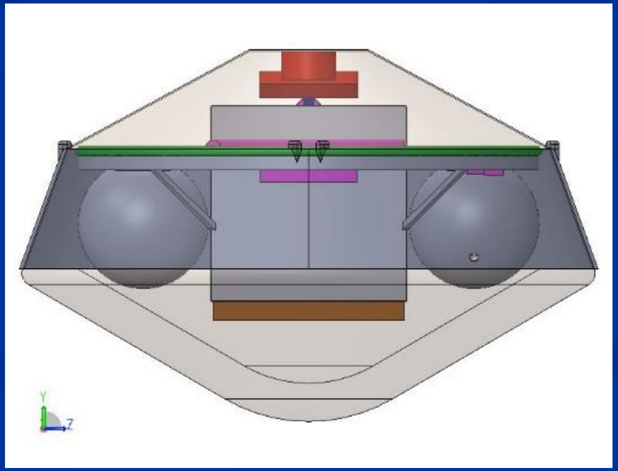
- SAEVes (1 or 2)
- Vertically maneuverable aerial platform (balloon)
- Subsatellite at Lagrange point 1 (2)
- LISSEs (1 or 2, detached)

Element	Mass (kg)
SAEVe 1	50
SAEVe 2	50
Aerial platform	600 (with 20kg of science payload)
Subsatellite L1	55
Subsatellite L2	55
LLISSE attached	10
LLISSE detached	15

SAEVe (Seismic and Atmospheric Exploration of Venus

- Long life 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





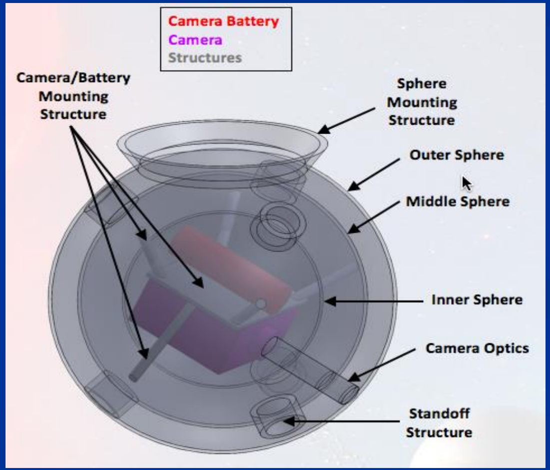
SAEVe Instrument Suite

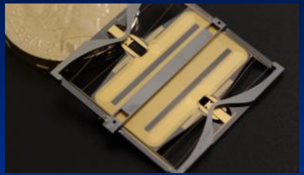
Core science centers around ***long term*** measurements to obtain meteorological and seismic data over 1 Venus solar day (120 Earth days)

Instrument set includes:

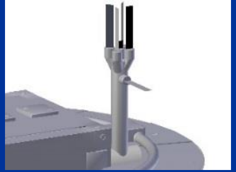
- A 3-axis micro-machined Micro-Electro-Mechanical Systems (MEMS) seismometer (0.3 kg)
- Meteorological sensor suite (temperature, pressure, wind speed & direction, solar radiance, atmospheric chemical species abundances), and solar position sensors (0.7 kg)
- Two COTS Cubesat cameras

  (0.1 kg each)
- Heat Flux instrument (0.3 kg)



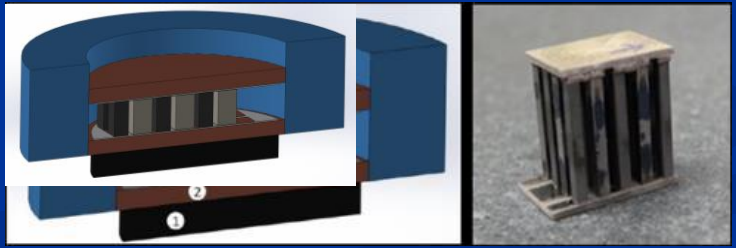


MEMS seismic event sensor
Courtesy: Tom Pike



Courtesy of D. Makel, Makel Engineering, Inc.

Sensors images – Courtesy: NASA GRC



Heat Flux sensor - Courtesy: Mike Pauken

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)

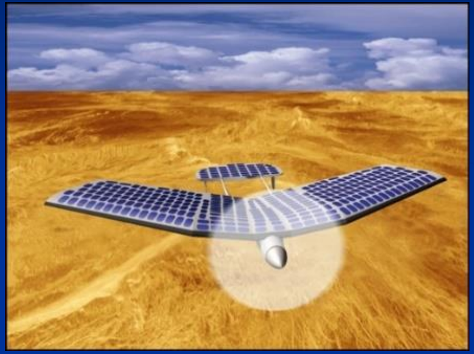
Mechanical Compression
Balloon
(Thin Red Line Aerospace)

Air Ballast Balloon (Google Loon)

Pumped Helium
Balloon (Paul Voss
CMET)

Phase Change Fluid
Balloon (JPL)

Aircraft and Hybrid



Solar Aircraft
(GRC)

Hybrid Airship
(Northrup Grumman VAMP)

Using information from the NASA Aerial Platform Study, the JSDT estimated the science instrument payload mass that could be carried by the different platform options in the worst case 2029 opportunity:

Platform	Altitude Range (km)	Venera-D Mass Availability (kg)	Aerial Vehicle Science Instrument Mass (kg)
Superpressure balloon	54	900	30
Pumped helium balloon	50-60	900	27
Mechanical compression balloon	50-60	900	27
Air ballast balloon	50-60	900	27
Phase change fluid balloon	50-60	900	27
Solar airplane	66-75	900	25
VAMP (aerobraked)	50-60	750	10

- *Altitudes above 60 km for the buoyant vehicle options are possible but the attendant reduction in science instrument mass has not been computed.*

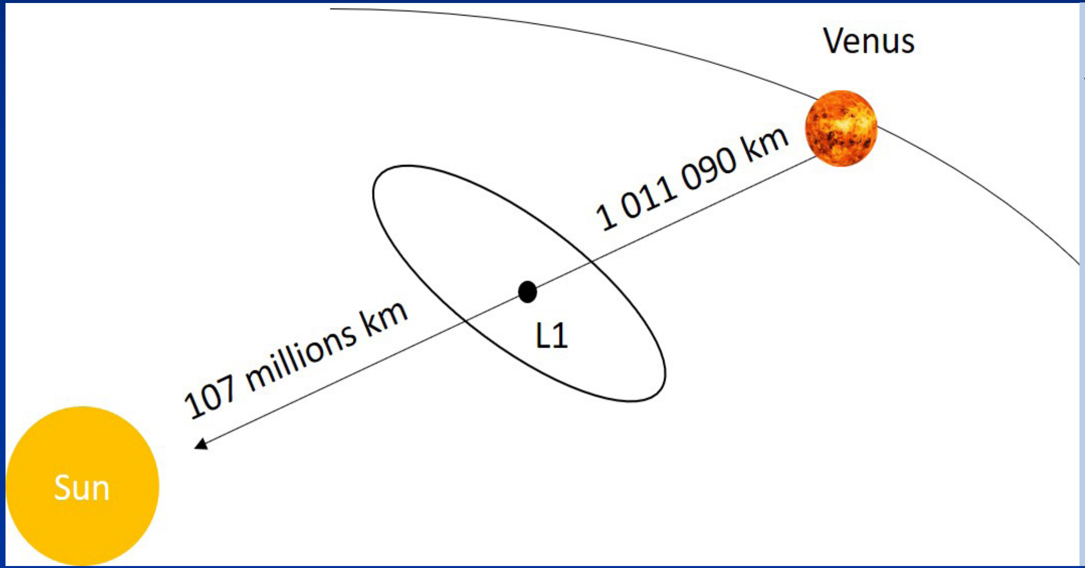
Variable Altitude Balloons

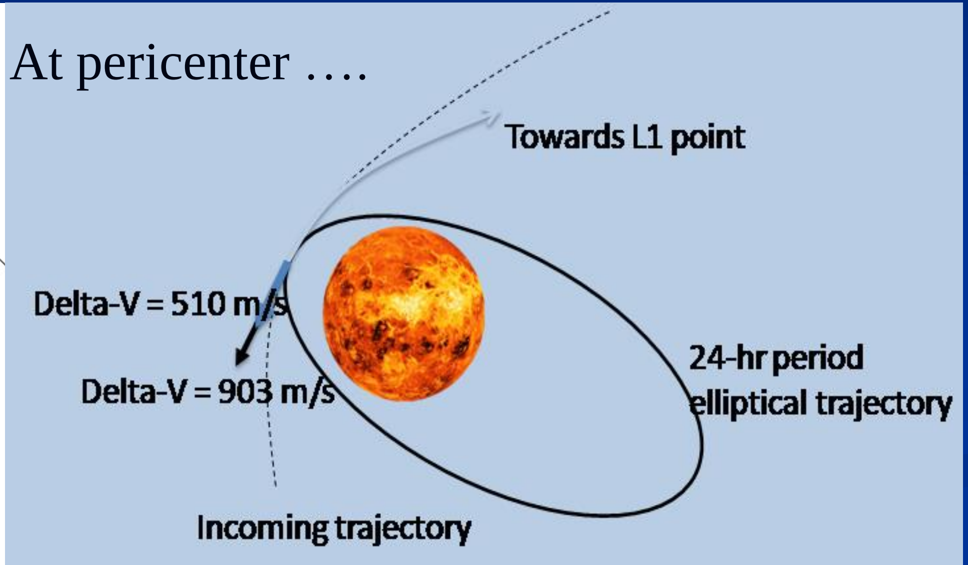
- Variable altitude balloons were recommended in the NASA study.
- There are 4 different kinds of variable altitude balloons (aerobots):
  - Pumped helium balloons move helium between a main balloon and a pressurized reservoir to modulate the total buoyancy and hence move the aerobot upwards or downwards
  - Air ballast balloons move atmospheric gas into a pressurized chamber to modulate the total weight and hence move the aerobot upwards or downwards
  - Mechanical compression balloons use an internal cable to compress or expand a stack of pressurized compartments to modulate the buoyancy
  - Phase change fluid balloons use a buoyancy fluid that evaporates or condenses depending on altitude (temperature) to create a vertical oscillatory motion without pumping

All have been flown on Earth to prove basic feasibility.

- All can (in principle) be used on Venera-D, but significant technological development is required to adapt terrestrial versions for Venus
- Venus-compatible construction materials (e.g., sulfuric acid resistance), sizing for Venus payloads and atmospheric conditions across the desired altitude range, etc.
- It may emerge during development that one or more of these options provides superior performance and/or less risk, but more work has to be done.

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

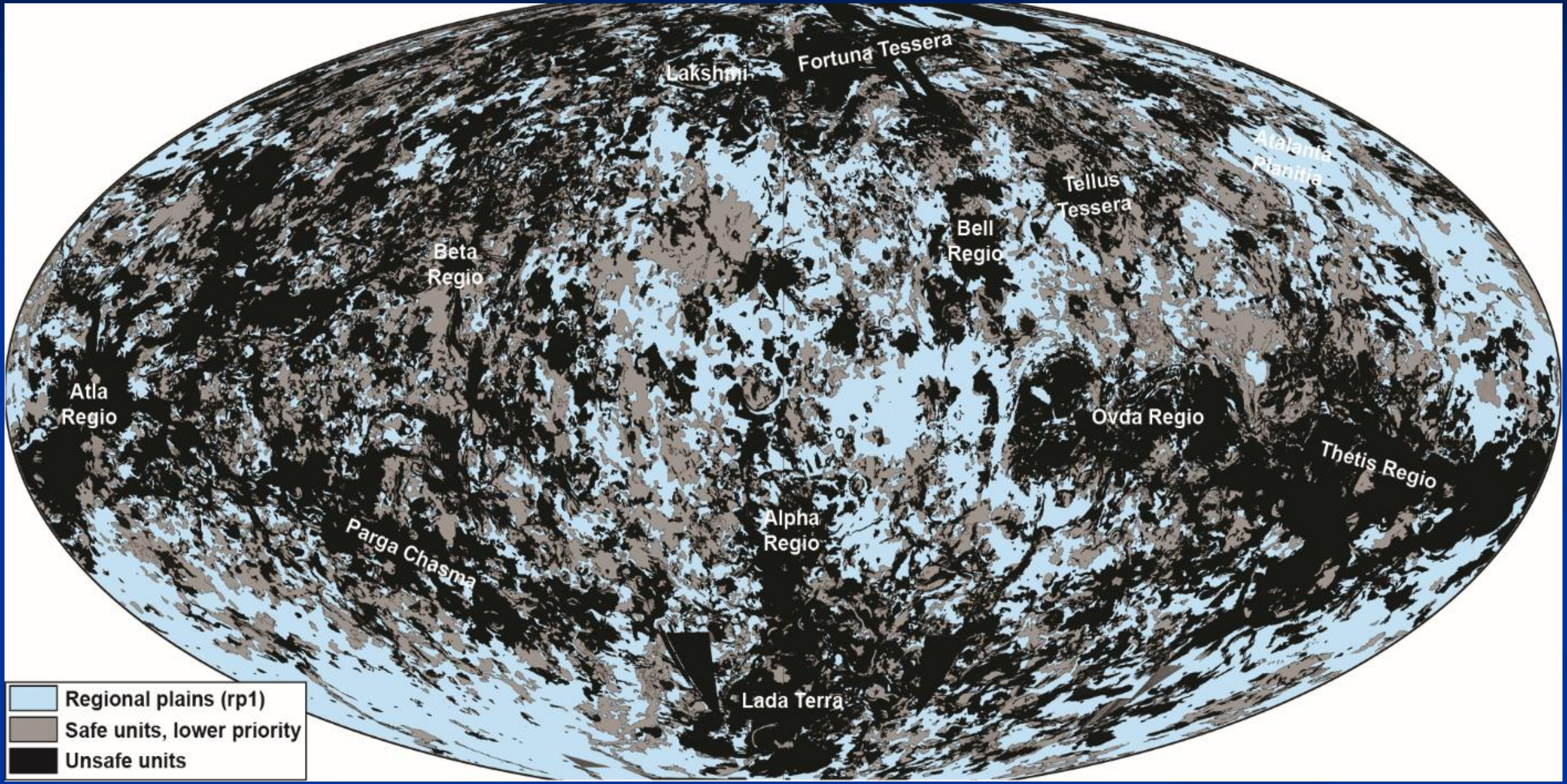
Selection of the Venera-D landing sites
Landing site selection criteria

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

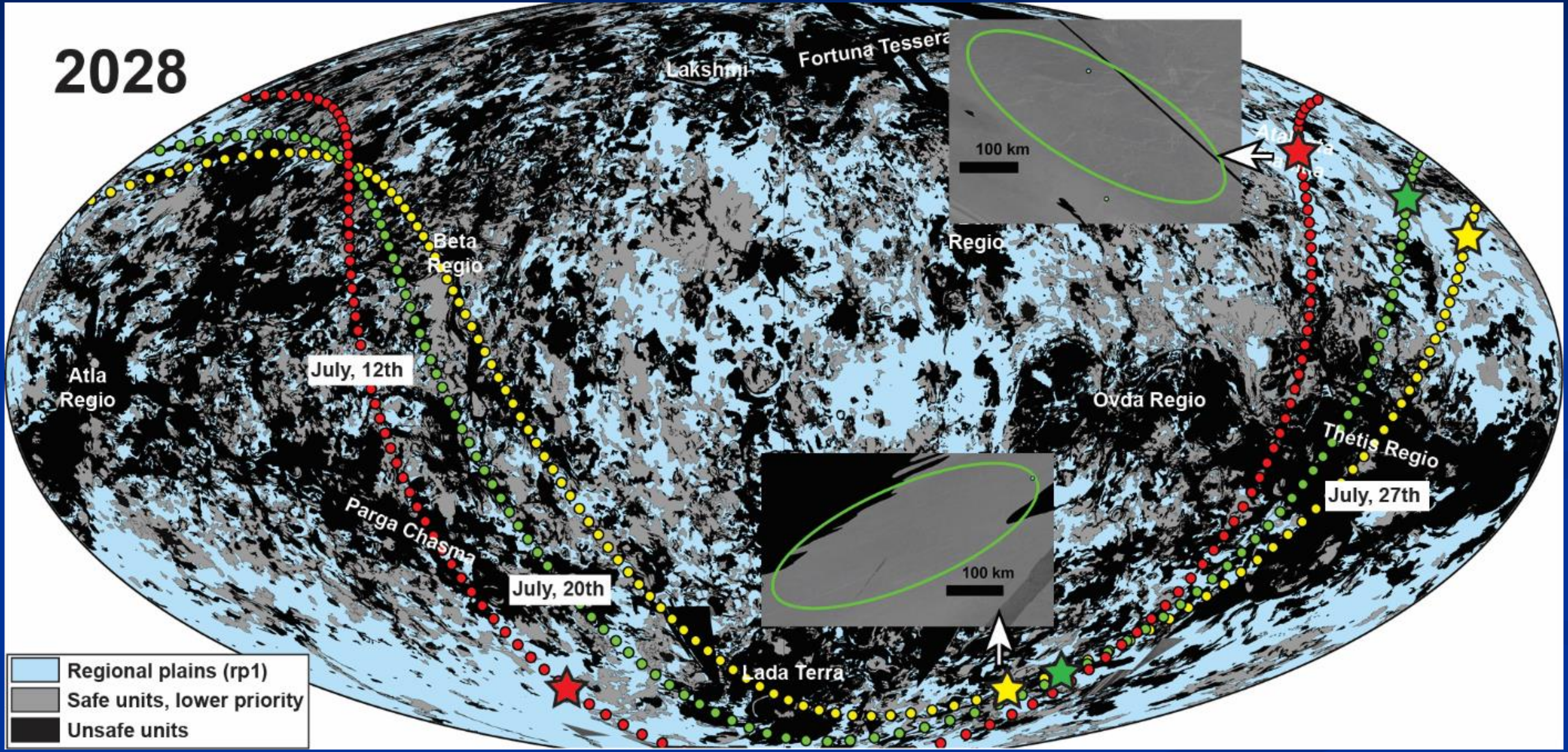
Using these criteria, we can select many potential sites that provide safe landing on a surface with high scientific priority.


Data : Brown U. / Vernadsky Institute. Image O. de Goursac

Selection of the Venera-D landing sites

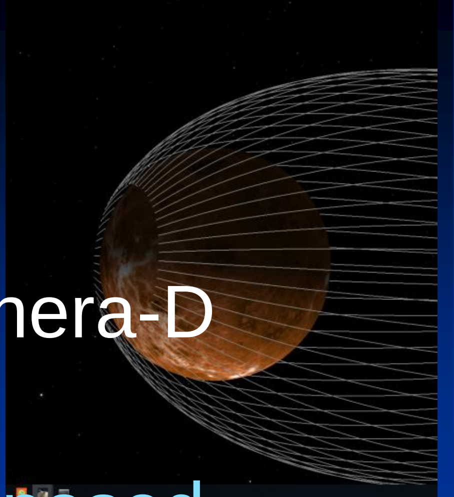


Geological map of Venus. Unsafe units are shown in black, low-priority units are in gray.



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.

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 orbiter for first 3 hours
- Orbiter can have long-term (>60-day) visibility of LLISSE

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 - to the Earth through the orbiter.

JSDT Future Work

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
- Downselect instruments
- Landing site / habitability workshop (October 2019)

Long-term (with MOU)

- Testing facilities for entire lander
- LLISSE integration with Lander sensors
- Precise landing site selection
- Pre-project team providing technological / scientific input
- Significant Lavochkin support (engineers, instrument PIs)
- Lander & orbiter instrument accommodation

Together to Venus!