VENERA-D, A MISSION CONCEPT FOR THE COMPREHENSIVE SCIENTIFIC EXPLORATION OF VENUS. D. Senske[1], L. Zasova[2], T. Economou[3], N. Eismont[2], L. Esposito[4], M. Gerasimov[2], N. Ignatiev[2], M. Ivanov[5], K. Lea Jessup[6], I. Khatuntsev[2], O. Korablev[2], T. Kremic[7], S. Limaye[8], I. Lomakin[9], M. Martynov[9], A. Ocampo[10], [1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, [2]Space Research Institute RAS, Profsoyuznaya 84/32, Moscow 117997, Russia, [3]Enrico Fermi Institute, University of Chicago 933 East 56th Street, Chicago, IL 60637, [4]University of Colorado 1234 Innovation Drive Boulder, Colorado 80303, [5]Vernadsky Inst. RAS, Kosygin St., 19 Moscow, Russia, [6]Southwest Research Institute 1050 Walnut, Suite 300 Boulder CO 80302, [7]Glenn Research Center, 21000 Brookpark Rd, Cleveland, OH 44135, [8]Univ. of Wisconsin, 1225 W Dayton St Madison, WI 53706, [9]Lavochkin Assoc. 24, Leningradskaya Str. 141400 Khimki, Russia, [10]NASA Headquarters, Washington, DC.

Background: Formed in the inner solar system out of the same protoplanetary material as the Earth, Venus is considered Earth's twin. Although these siblings have nearly the same size, mass, and density, unlike the Earth, Venus' climate is fueled by a massive CO_2 atmosphere producing an enormous greenhouse effect with a surface pressure of 90 atm. and a near-surface temperature of 470°C. Shrouded in clouds of sulfuric acid, the surface lacks water and has been sculpted by volcanism and deformed by folding and faulting resulting in belts of mountains and rifts. The lack of an intrinsic magnetic field suggests the planet's interior structure may also be different than that of the Earth.

Why did Venus take an evolutionary path so different from that of the Earth? Currently, the Earth stands as our only example of a planet hosting life. We are therefore compelled to understand when the evolutionary paths of these twin planets diverged, as well as understand how and why the divergence occurred. Answers to these questions can help us determine if conditions ever existed on Venus that could have fostered the origin of life and in turn help us understand what makes a planet habitable.

Venera-D baseline concept: To address the overarching scientific questions regarding the evolution of earth's nearest neighbor the baseline Venera-D (Venera-Dolgozhivuschaya (long-lasting)) concept has been developed. Envisioned as launching in the post-2025 timeframe and consisting of an orbiter and lander with advanced, modern, instrumentation this mission would build upon the Venera, VEGA, Pioneer Venus, and Magellan missions carried out in the 1970's and 1990's [1,2,3] along with the more recent Venus Express mission [4].

Venus science goals: To establish the science goals and priorities, mission architecture, and technology needs of the Venera-D concept, NASA and IKI/Roscosmos established in 2015 a Joint Science Definition Team (JSDT). A key task of the JSDT was to codify the synergy between the goals of Venera-D with those of NASA. To this end, the group established traceability to the NASA Planetary Decadal Survey [5] and the VEXAG goals, objectives, and investigations [6]. Specific areas of investigation would address questions focused on the dynamics of the atmosphere with emphasis on atmospheric superrotation, the origin and evolution of the atmosphere, and the geological processes that have formed and modified the surface with emphasis on the mineralogical and elemental composition of surface materials, and the chemical processes related to the interaction of the surface and the atmosphere. For each Venera-D baseline mission component, the following goals would be addressed:

***Orbiter Goals*:**

- Study of the dynamics and nature of super-rotation, radiative balance and nature of the greenhouse effect;
- Characterize the thermal structure of the atmosphere, winds, thermal tides and solar locked structures;
- Measure composition of the atmosphere; study the clouds, their structure, composition, microphysics, and chemistry;
- Investigate the upper atmosphere, ionosphere, electrical activity, magnetosphere, and the escape rate

***Lander Goals*:**

- Perform chemical analysis of the surface material and study the elemental composition of the surface, including radiogenic elements;
- Study the interaction between the surface and the 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 the cloud aerosols;
- Characterize the geology of local landforms at different scales

As part of this analysis, the JSDT identified areas where important VEXAG science may not be addressed by the baseline concept and generated a list of "contributed" options, ranging (in order of interest) from specific instruments such as a Raman Spectrometer and an Alpha-Proton X-Ray Spectrometer (APXS) to possible flight elements such as a maneuverable aerial platform, small long-lived surface stations, a balloon, a small subsatellite (Roscosmos contribution), or a small aerial platform to fill these "science gaps."

The JSDT concluded that, *in situ* measurements, both at the surface and aloft made over an extended period of time (many hours to months) would be enabling, especially for understanding the processes that drive the atmosphere. Mobility within the atmosphere was also deemed to be of high priority in terms of understanding the location of the UV absorber and identifying its composition. High priority augmentations to the baseline concept could include (1) an aerial platform (balloon) to address science focused on atmospheric superrotation (UV–absorber), chemistry, and trace species in the middle cloud layer and (2) a small long-lived station for studying superrotation, meteorology and chemistry in the near surface layer.

Technology assessment: The extremes of temperature and pressure make the operation of a spacecraft in the Venus environment a unique challenge. Key areas where technology maturation is required are: (1) the lander sample acquisition and handling/processing system, (2) the need for facilities to test and qualify a full-scale lander, and (3) maturation, testing, and validation of instruments that would need to operate under Venus conditions.

To ensure scientific success of the Venus science goals, laboratory experiments will be fundamental to validating scientific results. Among the high priority analyses needed to be performed include studies of (1) spectral line profiles under high pressures and temperatures (orbiter), (2) optical properties of the lower Venus atmosphere in the visible to near infrared (lander), (3) evaluation of the compositional change of the trace gas components due to temperature and pressure drop during atmospheric sampling (lander); (4) trace and noble gas enrichment procedures (lander); (5) atmosphere (pressure/temperature) effects on remote sensing instruments (lander); (6) supercritical properties of Venus-like atmospheres (lander); (7) UV absorption experiments to aid in constraining the identity of the unknown UV absorber and identify insolation energy deposition (aerial platform).

JSDT findings and recommendations: The JSDT identified priorities for the science goals and objectives for the comprehensive scientific exploration of Venus. Based on these priorities, a baseline mission would consist of a single highly capable orbiter and a single highly capable lander. Each would address science questions regarding the composition and dynamics of the atmosphere. In regard to surface and surface-atmosphere interactions, the lander would be the primary mission element to address these objectives while the orbiter, making surface observations in the near-infrared would provide global-scale data to address questions related to recent volcanic activity and compositional variability of terrains. In addition to the baseline mission, the JSDT identified potential “contributed” augmentations that would enhance the science return.

In formulating a strategy for the development of Venera-D, the JSDT identified areas where investments would need to be made to bring the mission concept to fruition. For an anticipated launch in the post-2025 time frame, activities of the following nature would be needed to ensure mission success:

- The types of instruments, including lander sample collection and handling to achieve the science require various levels of validation and maturation to ensure robust and successful operation in the Venus environment (470° C and 90 atm.)
- Laboratory work to characterize the chemistry of the Venus atmosphere at high temperatures and pressures
- Development of capable facilities to test mission enabling instruments and the spacecraft at the component and system level in a simulated Venus environment
- Continued development regarding aerial platforms and long-lived surface stations

Framework for future work: The next phase of development of the Venera-D concept would focus on a deeper examination of the science measurements and potential instrumentation along with the definition of spacecraft requirements. Within this context, specific areas that deserve attention include the following:

(1) Definition of a focused mission concept
(2) Definition of the concept of operations for the lander including a timeline of science observations, strategy for sample acquisition, handling and analysis, data flow and downlink
(3) Refinement of instrument capabilities relative to the ability to achieve the science goals
(4) Refinement of the envelope (mass, power, volume) for a potentially aerial vehicle or long-lived surface station(s)
(5) Maturation of the small station concept; instrumentation and concept for targeting and deployment
(6) Aerial platform accommodation and deployment optimization along with science priorities and instrumentation

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