

Program



15th Meeting of the Venus Exploration and Analysis Group (VEXAG)

November 14–16, 2017 • Laurel, Maryland

Sponsors

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Universities Space Research Association
Venus Exploration Analysis Group

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Program

Tuesday, November 14, 2017
NASA AND MISSION STUDY REPORTS
8:00 a.m.

- 8:00 a.m. *Registration*
- 8:15 a.m. Grimm R. *
Welcome and Objectives of 15th VEXAG Meeting
- 8:30 a.m. Green J. *
NASA Planetary Science Division and Responses to Previous VEXAG Findings
- 9:30 a.m. Nguyen Q. V. * Hunter G. W.
NASA High Operating Temperature Technology Program Overview [#8046]
NASA's Planetary Science Division has begun the High Operating Temperature Technology (HOTTech) program to address Venus surface technology challenges by investing in new technology development. This presentation reviews this HOTTech program.
- 9:45 a.m. Gaier J. *
NASA PICASSO and MatISSE Instrument-Development Programs
- 10:00 a.m. *Coffee Break*
- 10:30 a.m. Mercer C. *
NASA Planetary Science Deep Space Smallsats
- 10:45 a.m. Senske D. * Zasova L. Economou T. Eismont N. Gerasimov M. Gorinov D. Hall J. Ignatiev N. Ivanov M. Lea Jessup K. Khatuntsev I. Korablev O. Kremic T. Limaye S. Lomakin I. Martynov A. Ocampo A. Vaisberg O. Burdanov A. Teselkin S. Vorontsov V.
The Venera-D Mission Concept, Report on the Activities of the Joint Science Definition Team [#8014]
This report will summarize the activities of the Venera-D Joint Science Definition Team. The focus will be on the mission architecture and the outcome of a Venus modeling workshop held in Moscow.
- 11:15 a.m. Satoh T. * Nakamura M. Ishii N. Imamura T.
Akatsuki: Mission Status and Major Scientific Results [#8043]
This talk is to report the current mission status of Akatsuki as well as major scientific results.
- 11:45 a.m. *Lunch*

Tuesday, November 14, 2017
VENUS MISSION AND INSTRUMENT STUDIES
1:00 p.m.

- 1:00 p.m. Fukuhara T. * Taguchi M. Imamura T. Kouyama T. Nakamura M. Sato T. M. Suzuki M. Iwagami N.
Current Status of Observation by the Longwave Infrared Camera (LIR) on Board Akatsuki Spacecraft [#8045]
Current status of observation by the Longwave Infrared Camera (LIR) on board Akatsuki spacecraft is reported. We advance the study by using the abundant LIR images, and various large stationary gravity waves have been identified in LIR images.
- 1:15 p.m. Smrekar S. E. * Dyar M. D. Hensley S. Helbert J. Sotin C. Mazarico E. VOX Team
Venus Origins Explorer (VOX), a Proposed New Frontier Mission [#8031]
VOX's new methods provide global mineralogy, high-resolution topography and radar imaging plus surface deformation. VOX exceeds New Frontiers science objectives from orbit, with essential surface reconnaissance and *in-situ* noble gas measurements.
- 1:30 p.m. Hensley S. * Smrekar S. Dyar M. D. Perkovic D. Campbell B. Younis M.
Venus Interferometric Synthetic Aperture Radar (VISAR) for the Venus Origins Explorer [#8020]
One of the three primary science instruments for the proposed Venus Origins Explorer (VOX) mission to the NASA New Frontiers Program is an X-band radar interferometer described in this talk.
- 1:45 p.m. Kremic T. * Hunter G. Rock J.
LLISSE: A Long Duration Venus Surface Probe [#8035]
The Long Lived *In-situ* Solar System Explorer (LLISSE) project is developing prototypes of small Venus landers that are designed to transmit important science data from the Venus surface for > 60 days. The briefing provides a summary of the project .
- 2:00 p.m. Sauder J. * Hilgemman E. Stack K. Kawata J. Parness A. Johnson M.
An Automaton Rover for Extreme Environments: Rethinking an Approach to Surface Mobility [#8028]
An Automaton Rover for Extreme Environments (AREE) enables long duration *in-situ* mobility on the surface of Venus through a simplified design and robust mechanisms. The goal is to design a rover capable of operating for months on the surface of Venus.
- 2:15 p.m. Cutts J. A. *
Venus Aerial Platform Study [#8015]
A Venus Aerial Platform Study, which was underway in early 2017, is assessing the science and technologies for exploring Venus with aerial vehicles in order to develop a Venus Aerial Platform Roadmap for the future exploration of the planet.
- 2:30 p.m. *Coffee Break*
- 3:00 p.m. Open Microphone and Poster Preview Presentations

Tuesday, November 14, 2017
VEXAG POSTER SESSION
4:45 p.m.

Mazarico E. Iess L. de Marchi F. Andrews-Hanna J. C. Smrekar S. E.

Advancing Venus Geophysics with the NF4 Venus Origins Explorer (VOX) Gravity Investigation [#8003]

The proposed Venus Origins Explorer NF4 mission will obtain a high-resolution field to address Venus crust evolution, in particular the structure and origin of tesserae. We present comprehensive simulation results validating science requirements.

Venkatapathy E. Stackpoole M. Violette S.

Sustaining Phenolic Impregnated Carbon Ablator (PICA) for Future NASA Robotic Science Missions Including NF-4 and Discovery [#8011]

Sustainability of PICA for the upcoming NF-4 and future Discovery to Flag missions required us to evaluate new source of domestic rayon as the current rayon supplier has discontinued manufacturing. This poster presents results from our investigation.

Grimm R. E.

Stratospheric Balloon Test of Aerial Electromagnetic Probing of the Lithosphere of Venus [#8013]

Electromagnetic sounding that resolves the outer 10s of km of Venus can be achieved from the nominal 55-km balloon float altitude. A terrestrial demonstration program from 30 km altitude is underway.

Laine P. E.

Earth and Venus: Planetary Evolution and Habitability [#8016]

What caused Earth and Venus to evolve very differently? Could Venus have evolved to more Earth-like state? Could Earth end up to similar state that Venus is today? This is a review of these questions in the light of astrobiology and Earth's future.

Antoine A. F. Bianco S. J. Jakuszeit C. A. Sievers B. T. Tiffin D. J. Kremic T.

Balcerski J. A. Hunter G. W.

Lander Concept: Surface Analysis of Venus' Atmosphere and Geophysical Events (SAVAGE) [#8019]

This lander/orbiter concept builds on LLISSE and was designed to demonstrate the capabilities of high temperature sensors and electronics while obtaining the first long term *in situ* data on the climate and geophysical activity of Venus.

Widemann T. Marcq E. Tsang C. Mueller N. Kappel D. Helbert J. Dyar M. D. Smrekar S.

The Venus Emissivity Mapper — Investigating the Atmospheric Structure and Dynamics of Venus' Polar Region [#8023]

VEM will map cloud particle modes and their temporal variations, and track cloud-level wind field in the polar vortices. VOX circular polar orbit geometry will provide an unprecedented simultaneous study of both polar regions.

Warwick S. Ross F. Sokol D.

Venus Atmospheric Maneuverable Platform (VAMP) — Future Work and Scaling for a Mission [#8029]

The Venus Atmospheric Maneuverable Platform (VAMP) offers a unique opportunity to explore the atmosphere of Venus. This poster details the mission scaling and near term work required to mature the concept.

Peltz L. Jones W. M. Frampton R. V. Keith A. R. Scherer A.

Field Emission Vacuum (FEV) Electronic Devices for Operation Above 500 Degrees Celsius [#8032]

Boeing is teamed with Caltech to develop FEV (Field-Emission Vacuum) electronics. Our Boeing-Caltech team has recently begun work, under NASA ROSES C.24 HOTTech program, to demonstrate robust FEV operating at 500C, towards Venus surface missions.

Goossens S. Lemoine F. G. Rosenblatt P. Lebonnois S. Mazarico E.
Analysis of Magellan and Venus Express Tracking Data for Venus Gravity Field Determination [#8036]
We use tracking data from Magellan and Venus Express to determine a high-resolution gravity field model for Venus.

Sauder J. Wilcox B. Cutts J.
An Airborne Turbine for Power Generation on Venus [#8037]
A stationary airborne turbine in the Venus atmosphere has the potential to generate sustained power to operate a lander. It would fly dozens of meters off the ground, to obtain higher wind power than what a surface lander could access.

Rehnmark F. Bailey J. Cloninger E. Zacny K. Hall J. Sherrill K. Melko J.
Kriechbaum K. Wilcox B.
Performance Characterization of HT Actuator for Venus [#8038]
A high temperature (HT) actuator capable of operating in the harsh environment found on the surface of Venus has been built and tested in rock drilling trials at JPL's Venus Materials Test Facility.

Mandt K. E. Luspay-Kuti A. Mousis O. Fuselier S. A.
Can Rosetta Noble Gas and Isotopic Measurements Contribute to Understanding the Origin and Evolution of Venus' Atmosphere? [#8039]
New observations of noble gas abundances and stable isotope ratios from comets provide important information on potential sources of volatiles for Venus. They can help refine current atmospheric evolution models and plan for future missions.

Jessup K.-L. Carlson R. W. Perez-Hoyos S. Lee Y.-J. Mills F. P. Limaye S. Ignatiev N. Zasova L.
Motivations for a Detailed In-Situ Investigation of Venus' UV Absorber [#8040]
Motivations for an *in-situ* investigation of Venus unknown UV absorber. This presentation will provide details of the critical measurements and the critical observational parameters that are required to define the nature of Venus' UV absorber.

Ndao S. Elzouka M.
The Way to Thermal Computers Utilizing Near-Field Thermal Radiation [#8048]
Limited performance and reliability of electronic devices in harsh environments requires alternative computing technologies development. Our research group proposed and experimentally demonstrated the first high temperature thermal logic devices.

Wednesday, November 15, 2017
VENUS SURFACE AND ATMOSPHERIC SCIENCE
8:00 a.m.

- 8:00 a.m. *Registration*
- 8:15 a.m. O'Rourke J. G. * Gillmann C. Tackley P.
Prospects for an Ancient Dynamo and Modern Crustal Remnant Magnetism on Venus [#8008]
Venus is the only major planet with no known evidence for an internally generated magnetic field now or in the past. We use numerical simulations to investigate possible explanations and to predict whether remnant magnetism awaits discovery.
- 8:30 a.m. McGovern P. J. *
How Volcano-Tectonically Active is Venus Anyway? [#8041]
The findings for magmatic flux dV/dt and seismic activity presented here suggest the obituaries for Venus that commonly appear in the literature are premature.
- 8:45 a.m. Byrne P. K. * Ghail R. C. Şengör A. M. C. Klimczak C. Solomon S. C.
Block Tectonics on Venus [#8022]
Hey! You know continental China? We think it's an analog to a bunch of places on Venus where the lithosphere is broken into chunks that have jostled into each other. You should come check out this presentation, it'll be great!
- 9:00 a.m. Martinez S. N. Treiman A. H. * Kiefer W. S.
Venus' Radar-Dark Streaks: Bakisat Crater and Impact-Related Origins [#8034]
Many small craters on Venus are associated with SAR-dark streaks. We studied the geology of one such streak, on Nissaba Corona, and consider several mechanisms for their origins.
- 9:15 a.m. Lorenz R. D. *
Venera 13 and 14 Discharge Current Measurements — Evidence for Charged Aerosols in the Venus Lower Atmosphere? [#8001]
Corona discharge! / Electrified particles? / Or large ambient field?
- 9:30 a.m. *Coffee Break*
- 10:00 a.m. Navarro T. * Schubert G. Lebonnois S.
Large Stationary Gravity Waves: A Game Changer for Venus' Science [#8018]
In 2015, the discovery by the Akatsuki spacecraft of an astonishing, unexpected, 10,000 km long meridional structure at the cloud top, stationary with respect to the surface, calls into question our very basic understanding of Venus.
- 10:15 a.m. Bellan J. *
Modeling of High-Pressure Turbulent Multi-Species Mixing Applicable to the Venus Atmosphere [#8005]
A comprehensive theory of high-pressure multi-species mixing is presented and salient results pertinent to the Venus atmosphere are discussed. The influence of the insights obtained from these results on Venus exploration are addressed.
- 10:30 a.m. Collinson G. A. * Grebowsky J. Frahm R. Glocer A. Barabash S. Futaana Y.
The Quest for Venus' Lost Water [#8026]
We discuss the measurements needed to obtain closure on the scientific mystery of what happened to Venus' water, and how we may use Venus as a natural laboratory for understanding planetary habitability of Earth-like planets around distant suns.

10:45 a.m. Limaye S. S. * Mogul R. Yamagishi A. Ansari A. Smith D. J. Slowik G. Vaishampayan P. Lee Y. J.

Possibility of Microorganisms Being the Missing Absorbers of Solar Radiation in the Clouds of Venus and Their Detection [#8025]

The cause of ultraviolet contrasts and their evolution as well as the nature of absorbers of incident sunlight (between 330–600 nm) in the clouds of Venus have been a mystery for a long time, and microorganisms could be responsible.

11:00 a.m. McGouldrick K. *

A Paradigm Shift in Planetary Exploration? [#8047]

I argue that the coming era of exoplanetary science via transit analysis will require a new way of thinking about and executing the tasks of planetary exploration.

11:15 a.m. *Lunch*

Wednesday, November 15, 2017
NASA REPORTS, MISSION AND TECHNOLOGY STUDIES
1:00 p.m.

- 1:00 p.m. Zurbuchen T. *
NASA Science Mission Directorate
- 1:30 p.m. Grimm R. *
Venus Bridge Concept Overview
- 1:45 p.m. Cutts J. A. *
VEXAG's Venus Bridge Focus Group [#8017]
VEXAG's Venus Bridge Focus Group is investigating whether viable Venus missions can be conducted within a \$200M cost-cap. Progress reports on mission concept studies of combined *in situ* and orbiter missions will be presented.
- 2:00 p.m. Hunter G. *
Venus Bridge Focus Group Studies at GRC
- 2:15 p.m. Discussion
- 2:30 p.m. Kremic T. * Gilmore M. Kiefer W. Limaye S. Hunter G. Tolbert C. Pauken M.
SAEVe: A Long Duration Small Sat Class Venus Lander [#8024]
SAEVe is a small Venus lander concept selected for further study by the PSDS3 call. SAEVe is an innovative approach to achieving Venus surface science by exploiting recent developments in high temperature electronics and unique operations scheme.
- 2:45 p.m. Cottini V. * Aslam S. Gorius N. Hewagama T. Glaze L. Ignatiev N.
Piccioni G. D'Aversa E.
CUVE — Cubesat UV Experiment: Unveil Venus' UV Absorber with Cubesat UV Mapping Spectrometer [#8044]
The Cubesat UV Experiment (CUVE) will investigate Venus' atmosphere at its absorbers at the cloud tops in the UV, with two on-board science payloads (i) a high spectral resolution UV spectrometer and (ii) a multispectral UV imager.
- 3:00 p.m. *Coffee Break*
- 3:15 p.m. Gero J. * Limaye S. Fry P. Lee Y. J. Petty G. Taylor J. Warwick S.
An Airborne Spectrophotometer for Investigating Solar Absorption on Venus [#8030]
We propose to develop a compact airborne spectrophotometer for Venus, to measure short wavelength (330–600 nm) spectra of downwelling sunlight, which will facilitate the identification of presently unknown UV absorbers in its atmosphere.
- 3:30 p.m. Dyar M. D. * Helbert J. Boucher T. Wendler D. Walter I. Widemann T. Marcq E. Maturilli A.
Ferrari S. D'Amore M. Müller N. Smrekar S.
Mapping Venus Mineralogy and Chemistry In Situ from Orbit with Six-Window VNIR Spectroscopy [#8004]
Emissivity data from ca. 1 micron lab measurements at DLR demonstrate the ability to distinguish among key rock types on Venus, and measure their redox state and transition metal contents from *in situ* orbit around Venus.

- 3:45 p.m. Helbert J. * Maturilli A. Dyar M. D. Ferrari S. Mueller N. Smrekar S.
The Spectroscopy of the Surface of Venus [#8006]
After several years of development and extensive testing, PSL at DLR has a setup in routine operation for Venus analog emissivity measurements from 0.7 to 1.5 μm over the whole Venus surface temperature range. The facility is open to the community.
- 4:00 p.m. Venkatapathy E. * Ellerby D. Gage P.
Progress Towards Providing Heat-Shield for Extreme Entry Environment Technology (HEEET) for Venus and Other New Frontiers Missions [#8009]
HEEET, in development since 2014 with the goal of enabling missions to Venus, Saturn and other high-speed sample return missions, is incentivized by SMD-PSD and will be delivered at TRL 6 by FY'18. This presentation will cover the current status.
- 4:15 p.m. Lu Y. * Athul P. G. Saikia S. J. Cutts J. A.
Aerocapture Feasibility Assessment for Missions to Venus [#8027]
Feasibility of aerocapture at Venus is assessed with a comprehensive approach considering a range of vehicle L/D, ballistic coefficient, and arrival V-infinity.
- 4:30 p.m. Krishnamoorthy S. * Komjathy A. Cutts J. A. Pauken M. T. Garcia R. F. Mimoun D. Jackson J. M. Kedar S. Smrekar S. E. Hall J. L.
Development of Venus Balloon Seismology Missions Through Earth Analog Experiments [#8007]
The study of a planet's seismic activity is central to the understanding of its internal structure. We discuss advances made through Earth analog testing for performing remote seismology on Venus using balloons floated in the mid-atmosphere.

Thursday, November 16, 2017
WORKSHOPS, DATASETS, AND TOOLS
8:00 a.m.

- 8:00 a.m. *Registration*
- 8:15 a.m. Titus T. N. * Rubin D. Bryant G.
Planetary Dune Workshop Expands to Include Subaqueous Processes as Possible Venus Analogs [#8002]
The 2017 International Planetary Dune Workshop at Dixie State University, the fifth in a series focusing on planetary dunes, brought together 65 terrestrial, marine, and planetary researchers. Highlights pertaining to Venus will be presented.
- 8:30 a.m. Wilson C. *
Report on Venus III
- 8:40 a.m. Radebaugh J. * Archinal B. Thomson B. J. Beyer R. DellaGiustina D. Fasset C. Gaddis L. Hagerty J. Hare T. Laura J. Lawrence S. Mazarico E. Nass A. Patthoff A. Skinner J. Sutton S. Williams D. A.
MAPSIT and the Importance of Planetary Spatial Data Infrastructure for Venus [#8010]
A Planetary Spatial Data Infrastructure, and associated Roadmap for attaining this, would be of great value for Venus exploration and mission success. MAPSIT exists to support creation of this PSDI.
- 8:55 a.m. Laura J. R. Hagerty J. J. Titus T. N. * Hare T. M.
Toward a Venus Spatial Data Infrastructure (VSDI) [#8012]
We present Planetary Spatial Data Infrastructure (PSDI), identify the five components of an SDI, and propose a Venus Spatial Data Infrastructure (VSDI).
- 9:10 a.m. Herrick R. R. * Wren P.
JMARS: Collecting and Ingesting Data to Create a Useful Scientific Analysis Tool [#8021]
Overview of ongoing efforts to get a variety of data sets, many not available in the PDS, into JMARS for Venus. Input from the Venus research community is desired.
- 9:25 a.m. Balcerski J. * Steffes P. Arney G. Ghent R. Thompson T.
Venus Modeling Workshop Summary [#8042]
We present an overview and summary results of the Venus Modeling Workshop, held in May 2017 in Cleveland, OH.
- 9:40 a.m. Nakley L. Vento D. Balcerski J. Kremic T. *
Glenn Extreme Environments Rig Status and Recent Testing History [#8033]
The NASA Glenn Extreme Environment Rig (GEER) is a unique asset for the Venus science community. It simulates Venus conditions for laboratory experiments, technology development, and system testing. This presentation summarizes status and activities.
- 9:55 a.m. Grimm R. *
Findings and Resolutions/VEXAG Plans for 2018
- 10:25 a.m. *Adjourn*
- 10:45 a.m. VEXAG Steering Committee Meeting

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Surface Analysis of Venus' Atmosphere and Geophysical Events (SAVAGE) A. F. Antoine¹, S. J. Bianco², C. A. Jakuszeit³, B. T. Sievers⁴, D. J. Tiffin⁵, T. Kremic⁶, J. A. Balcerski⁶, G. W. Hunter⁶

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Introduction: Recent advances in high temperature electronics open the opportunity for significantly smaller and cheaper extended lifetime Venus landers. This paper describes a “Pathfinder Class” (i.e., a mission implemented mainly as a technology proof of concept, similar to Mars Pathfinder) lander/orbiter concept designed to obtain the first ever long term scientific data on the surface of Venus. The concept would demonstrate the capabilities of high temperature sensors and electronics and their ability to return the first *in situ* temporal data on the climate and geophysical activity of Venus.¹ This study builds on the Long-Life In-situ Solar System Explorer (LLISSE) concept.² Major modifications to LLISSE were investigated; additional scientific instruments were added as appropriate in order to maximize valuable science data return and a CubeSat orbital communication system was specified.

Methods: The COMPASS concurrent engineering facility at the NASA Glenn Research Center was utilized to perform a feasibility analysis of power and communication systems using technology likely to be mission ready by 2025. A mass analysis was also done to prove the feasibility of such technology for inclusion in “Pathfinder Class” missions as well as to assess the scalability of such a concept. The general idea of using simple, low cost devices in all aspects of the mission was at the core of the analysis. Many ride-along flight possibilities as well as deployment options were weighed. Landing locations, data acquisition sequences, and orbit paths were compared to allow for maximum data delivery time and therefore a maximum science return for the duration of the mission.

Results: This innovative mission concept consists of a maximum of 5 probes and 2 orbiters (dependent upon delivery mode). The probes will have the ability to obtain *in situ* measurements of the seismic, magnetic, radiometric, chemical, and thermal characteristics of Venus’s atmosphere, surface, and interior as well as pressure, temperature, and wind velocity measurements. Ovda Regio was chosen as the landing site for optimal communication and

scientific return. Two CubeSat orbiters are utilized to relay *in situ* measurements from the probes back to the Deep Space Network. CubeSats are chosen over SmallSats because they are less massive by a factor of ten. Two CubeSats out of phase could also be used to achieve 100% contact time with the probes, yielding the maximum possible science return. Preliminary analysis revealed that using green propellant AF-M315E for insertion into a 10 day orbit is most feasible of the options considered, but still poses a major challenge to such a mission. The drawback is a higher communication power requirement due to the higher apoapsis. A ride-along secondary payload package consisting of an orbiter-probe vehicle housed in a 27U CubeSat P-POD was suggested. Ongoing analyses of its feasibility need to be undertaken.

Conclusion: A method of executing small, inexpensive missions to Venus was proposed. This comprehensive mission concept details a packaging, delivery, deployment approach; with operation of a surface probe / orbital relay combination. An expanded instrument suite, data acquisition sequences, and a preliminary CubeSat communications system were designed. The result is a greatly enhanced ability to address high priority science questions. Based on the power analysis, data acquisition can be achieved with low power requirements while yielding more scientific measurements than previous studies. Improvements in high temperature memory and batteries with higher energy densities and or recharging capabilities would greatly increase science return. Further analyses into the delivery methods as well as instrument development are needed.

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VENUS MODELING WORKSHOP SUMMARY. J. Balcerski¹, P. Steffes², G. Arney³, R. Ghent⁴, T. Thompson⁵

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Background: The Venus Modeling Workshop, held at the Ohio Aerospace Institute in May of 2017, was organized as part of an ongoing series of meetings supporting the Venus Exploration Analysis Group (VEXAG). Previous workshop topics have included exploration targets, instruments, technologies, and upper atmosphere science. Modeling approaches to Venus science continue to produce new results from Magellan-era data and provide new insights into a complex and dynamic planet through incorporation of recent observations from orbital spacecraft and remote observations. Moreover, modeling tools and approaches used for Venus investigations are highly relevant and often directly applicable to other planetary bodies, including many recently detected exoplanets.

Notable objectives of this workshop were to communicate the status of existing models, share recent science obtained via modeling approaches, and identify common needs of the modeling community. Another objective was to explore the ways in which modeling results and needs may inform future mission planning and development (e.g. helping define instrument measurement targets and requirements.) Attendees were encouraged to consider and discuss how modeling may guide reference mission definition, such as that being undertaken by the international Venera-D Joint Science Definition Team (JSDT), or for upcoming National Academies of Science Decadal Surveys.

Organization and Events: A primary goal for this workshop was to foster cross-disciplinary interaction. In order to support this goal, each of the 3 days began with a morning plenary and ended with a collective group assembly to summarize the day's presentations and allow for a guided, open-floor discussion. Following the organization of other similar workshops, the afternoon sessions were separated by discipline (orbital+atmosphere and surface+interior) to allow participants to explore these themes in detail.

Summary and findings: Throughout the event, discussion revolved around several major themes. Based upon the organizers' observations and notes from student reporters and attendees' notes, these broad themes are noted below:

1. The greatest need for advancing Venus modeling is more in situ data. Remote measurements of the full depth of the atmosphere, surface, and interior are challenging and limited by practical constraints. It was noted that the Venus Global Reference

Atmospheric Model (GRAM) will soon be updated with recent mission results. Direct sampling of both the atmosphere and surface are highly desired. Additionally, attendees expressed a strong desire to conduct modeling that enables future Venus missions.

2. Venus is a natural laboratory for comparative planetology. Because of the strong coupling between interior, surface, and atmosphere, efforts are needed to model Venus as a system of interacting phenomena rather than as a set of isolated parts.

3. In exoplanet study, Venus may be more representative of terrestrial planets than Earth or Mars. Models developed for Venus will have wide applicability in gaining insight into exoplanets, and vice versa.

4. Laboratory work is still required to advance understanding of chemical kinetics, spectral properties, and surface-atmosphere interactions. This is critical both for obtaining maximum benefit from existing new data and for preparing for the next generation of high-resolution instruments.

6. The longevity of liquid water on the surface of Venus, the mechanisms by which that water was lost, and the potential for evolutionary pathways for extinct and/or extant microbial life were topics of great interest for attendees and the public.

5. Reference models, lists of updated software, available data sources, and an archive of modeling approaches and resources is desired and in the process of being implemented. This information will be captured online in a wiki format and is in the process of being generated by volunteers from the workshop organizing committee and participants.

Further information: Meeting information and abstracts can be found at: www.hou.usra.edu/meetings/venusmodeling2017

When complete, a workshop report will be available at the address above. The Venus Modeling Wiki will be made publicly viewable and linked from both the VEXAG website and the one above.

Acknowledgements: The organizing committee recognizes and thanks the following organizations and individuals for their generous contributions and hard work in making this event a success: USRA/LPI for event logistics; NASA Planetary Science Division for event resources; Ohio Aerospace Institute and NASA GRC support staff; Southwest Research Institute for supporting student travel; and Dr. Jim Head of Brown University for an engaging keynote and public presentation.

MODELING OF HIGH-PRESSURE TURBULENT MULTI-SPECIES MIXING APPLICABLE TO THE VENUS ATMOSPHERE. J. Bellan, Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, MS. 125/109, Pasadena CA 91109 and Mechanical and Civil Engineering Department, California Institute of Technology, Pasadena, CA 91125, Josette.Bellan@jpl.nasa.gov

Introduction: The thermodynamic conditions in the Venus atmosphere, nominally at a pressure of 92 atm, a temperature of 750 K and having a global nominal composition of 96.5% CO₂ and 3.5% N₂ imply that heat and mass exchange processes in the atmosphere occur under supercritical conditions. In contrast to well-known heat and mass exchange processes at 1 bar, 298 K and Earth atmosphere composition, those on Venus must be described using real-gas thermodynamics, generalized species-mass and heat fluxes based on the formulation of dissipation-fluctuation theory [1] and consistent high-pressure transport properties utilizing high-pressure valid mixing rules [2]. The presence of minor (i.e. tracer) species in the Venus atmosphere – 150 ppm SO₂, 70 ppm Ar, 20 ppm H₂O and 17 ppm CO --- may though introduce some aspects, such as metastable states, that have not been considered so far.

A comprehensive theory of high-pressure multi-species mixing [3] is presented and salient results pertinent to the Venus atmosphere are discussed. Further, using this theory, simulations of CO₂ and N₂ mixing at high pressure and temperature are discussed and analyzed [4]. The influence of the insights obtained from these results on Venus exploration and planned future studies are addressed.

Turbulent mixing of CO₂ and N₂:

To evaluate the model, spatial, rather than temporal simulations were performed of a N₂ jet at 750 K injected into a chamber pressurized to 60 atm and containing CO₂ at 450 K. This configuration represented an experimental configuration used at the University of Southern California (USC). While the experimental data is still forthcoming, the DNS computations revealed that the high density gradients observed in the five-species mixing are still present and are of order 10⁴ kg/m⁴ as shown in Fig. 1 where the mass fraction of N₂ is also plotted showing the mixing with CO₂ further downstream and furthermore depicted is the second invariant of the rate of deformation tensor which is indicative of vortical structures in the flow displaying the vortex rings near the inlet and the breakdown of the flow into small turbulent features downstream. Time-averaged results (not shown) reveal a potential core near the inlet downstream of which the density increases due to the mixing of N₂ with the heavier CO₂.

Summary and conclusions: The studies described above show the intricacies of multi-species mixing under high-pressure high-temperature turbulent conditions. The model can be used to study the time evolution of a three-dimensional vertical slice of the Venus PBL with a domain having non-reflecting boundary conditions (i.e. domain size influence minimized). Since the near-ground Venus atmosphere composition is not known with certainty, additional to CO₂/N₂, other compositions, i.e. including minor species, can be simulated to determine whether the Venus atmosphere could be in a metastable state in which micro-drops are suspended into a fluid; then the interpretation of signals from probes moving vertically through the Venus atmosphere would require special interpretation, i.e. accounting from scattering from the micro-drops. The near-ground unstable temperature gradient may also be explained by such findings.

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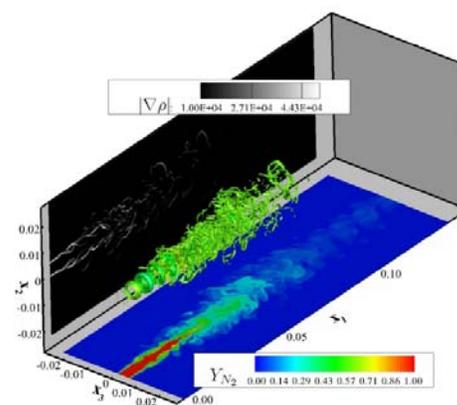


Figure 1 N₂ jet (at 750 K) injection into a CO₂-filled chamber at 60 atm (and 450 K). Instantaneous snapshot of the vortical jet features, the density gradient magnitude in kg/m⁴ and the mass fraction of N₂.

BLOCK TECTONICS ON VENUS. Paul K. Byrne¹, Richard C. Ghail², A. M. Celâl Şengör³, Christian Klimczak⁴, and Sean C. Solomon⁵, ¹Planetary Research Group, Department of Marine, Earth, and Atmospheric Sciences, North Carolina State University, Raleigh, NC 27695, USA (paul.byrne@ncsu.edu); ²Department of Civil and Environmental Engineering, Imperial College London, London, SW72AZ, UK; ³Department of Geology, Faculty of Mines and the Eurasia Institute of Earth Sciences, Istanbul Technical University, 34469 Maslak, İstanbul, Turkey; ⁴Department of Geology, University of Georgia, Athens, GA 30602, USA; ⁵Lamont-Doherty Earth Observatory, Columbia University, Palisades, NY 10964, USA.

Introduction: Considerable lithospheric extension and shortening has occurred on Venus. In places, tectonic deformation has been broadly distributed spatially, for example, at tesserae. In other areas, strain has been concentrated into narrow curvilinear zones [1].

Bands of shortening structures that accommodate crustal thickening correspond to orogenic belts and are typically manifest as broad, linear rises a few hundred meters tall, tens of kilometers in width, and many hundreds of kilometers long [2]. The extensional counterparts to the orogenic belts are long rift zones [2], which host normal faults that form graben and half graben that show sub-parallel and anastomosing surface ruptures as well as evidence for fault linkage.

Belt-bound Crustal Blocks: In many instances, orogenic and rift belts delimit low-lying areas that are infilled with lava flows. These flows are themselves deformed by sets of wrinkle ridges, but the interiors of the lows do not otherwise appear tectonically deformed. Distributed across Venus, some belt-bound lowlands extend laterally as much as 1200 km, whereas others are but a few hundred kilometers across. Intersecting belts also define multiple low-lying areas across a region, such as at Lavinia Planitia, where numerous orogenic belts form the polygonal boundaries of irregularly shaped lows. Other sets of belt-delineated lowlands occur near Artemis Corona, at Vedma Dorsa in the eastern hemisphere, and at about 40° S, 260° E.

Evidence for Lateral Shear: Many of these orogenic and rift belts have accommodated lateral shear in addition to crustal extension or shortening. For example, some orogenic belts boast secondary sigmoidal ridges arranged in en echelon patterns. Further, rift belts are frequently associated with smaller fractures that curve into the main system, appearing to have been dragged into parallelism with the belt, as well as lozenge-shape graben that are similar to pull-apart basins at releasing bends in strike-slip settings.

Terran Analogues: Geometrically similar low-lying regions in continental interiors on Earth may offer insight into how these Venusian lowlands formed. The Sichuan Basin in southeastern China is delineated by the Sichuan fold belts to the south and the Longmenshan Mountains to the northwest; the basin interior is relatively undeformed and of generally uniform crustal thickness [3]. The Tarim Basin, in northwestern China, is demarcated by the Tian Shan range to the northwest and the Altin Tagh range to the southeast. The basin

interior is largely intact and has behaved as a single coherent block akin to a rigid piece of oceanic crust [e.g., 4]. The Altin Tagh mountains are underlain by the Altyn Tagh fault, a major left-lateral strike-slip system [5], and the Beichuan fault beneath the Longmenshan has a right-lateral strike-slip component [6].

Lateral Motion on Venus: The common occurrence of restraining and releasing bends within orogenic and rift belts on Venus implies that these narrow zones of deformation are often transpressive or transtensive. Under this interpretation, many of the low-lying regions that the belts enclose have behaved as rigid blocks that experienced considerable lateral motion. This behavior is similar to that inferred for the rigid crustal blocks that constitute, for example, the lithosphere of continental China [4]. Of note, strike-slip faulting has been reported elsewhere on Venus, including within Lavinia Planitia [1], at Ovda and Thetis Regiones [e.g., 7], at Lakshmi Planum [8], and at Artemis Chasma [9].

The horizontal movement of crustal blocks on Venus may have been driven by mantle convection [e.g., 10], mantle overturn [8], or rejuvenation of the mantle portion of the planet's stagnant lithospheric lid through thinning and recycling [11]. Whatever the driving force, lateral motion on Venus has likely been facilitated by a relatively shallow brittle-ductile transition (BDT) [e.g., 11], a result of the planet's high surface temperature.

The shallow BDT on Venus and the density contrast between crust and mantle preclude these blocks from subducting, and so their fate is to shorten, lengthen, or retain their geometry at the expense of adjacent blocks. This behavior, then, may be analogous to plate-tectonic-driven deformation of at least some continental interiors on Earth.

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THE QUEST FOR VENUS' LOST WATER. G. A. Collinson¹, J. Grebowsky¹, R. Frahm², A. Glocer¹, S. Barabash³, Y. Futaana³,

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Introduction: Discovering what processes govern the evolution of atmospheres, and specifically the loss of planetary water and oxygen are key to determining what makes planets habitable, and is a driving science objective behind recent missions including the NASA Mars Atmosphere and Volatile Evolution (MAVEN) mission, the ESA Mars Express, and the ESA Venus Express. Of all other planets, Venus is in many respects the most Earth-like. Its atmosphere however is incredibly dry, with four to five orders of magnitude less water than Earth (De Bergh, et al., 1991). The high deuterium-to-hydrogen ratio (McElroy, et al., 1969; Donahue, et al., 1982; De Bergh, et al., 1991) is indicative this was not always the case, and that Venus once had a substantial quantity of water (Donahue, et al., 1992; Hartle, et al., 1996; Donahue, 1999), possibly even forming Earth-like oceans (Svedhem, et al., 2007). Although it is thought that Venus lost much of its water early in its history (Kulikov, et al., 2006), one of the major early discoveries of the ESA Venus Express (Svedhem, et al., 2009) mission was that the primary ion species escaping down the comet-like plasma tail were H⁺ and O⁺ ions in a water-like stoichiometric ratio of 2:1. Thus, regardless of the original water inventory, atmospheric escape mechanisms at Venus today appear to be far more effective at driving water and oxygen loss than at nearby Earth, with a comparable size and gravity.

Orbiter-based in-situ particle and fields measurements are a crucial tool for the exploration and understanding of Venus. Unlike landers and aerial platforms, orbiters offer long duration observations covering the entire planet, and particle and fields instrument packages thus flew on Mariner, Venera, Pioneer Venus Orbiter, and most recently Venus Express. However, despite large existing datasets, many mysteries remain that are crucial to understanding the evolution of the atmosphere and water on Venus that can only be solved with particle and fields instruments, but cannot be answered due to limitations in past sensors on these missions. We outline some of these key questions, and discuss the measurements needed to obtain closure on the scientific mystery of what happened to Venus' water, and how we may use Venus as a natural labora-

tory for understanding planetary habitability of Earth-like planets around distant suns.

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CUVE - Cubesat UV Experiment: Unveil Venus' UV Absorber with Cubesat UV Mapping Spectrometer. V. Cottini^{1,2}, S. Aslam², E. D'Aversa², L. Glaze², N. Goriuss^{4,2}, T. Hewagama^{1,2}, N. Ignatiev⁵, G. Piccioni³. ¹University of Maryland, College Park, USA (valeria.cottini@nasa.gov), ²NASA Goddard Space Flight Center, Greenbelt, USA, ³INAF-IAPS, Italy, ⁴Catholic University of America, USA, ⁵IKI RAN, Russia

Abstract: Our Venus mission concept Cubesat UV Experiment (CUVE) is one of the proposals selected for funding by the NASA Planetary Science Deep Space SmallSat Studies (PSDS3) program. CUVE concept is to insert a CubeSat spacecraft into a Venusian orbit and perform remote sensing (Fig. 1) of the UV spectral region using a high spectral resolution point spectrometer to resolve UV absorbers bands, observe nightglow, and also characterize the still unidentified main absorber present in the UV region. The UV spectrometer is complemented by an imaging UV camera with multiple bands in the UV absorber main band range for contextual imaging. CUVE would complement past, current and future Venus missions with conventional spacecraft, and address critical science questions cost effectively.

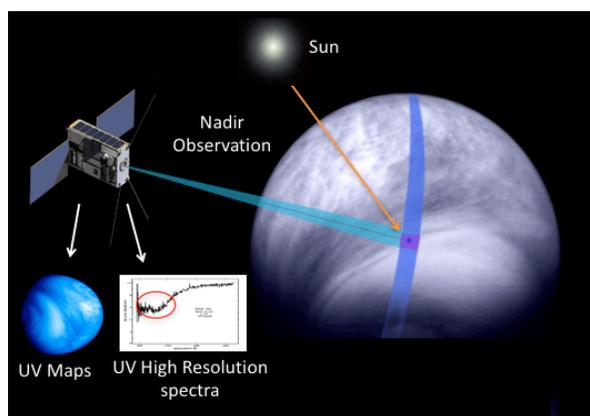


Figure 1: CUVE – Cubesat UV Experiment – in orbit around Venus will observe dayside and night side.

Introduction: The maximum absorption of solar energy by Venus occurs in the UV where we observe spectral contrast features that originate from the non-uniform distribution of unknown absorbers within its clouds. This opacity source affects the energy balance in the Venusian atmosphere. The efficient absorbing power of the unknown UV absorbers in the clouds controls Venus' atmospheric engine. Determining the nature, concentration and distribution of these absorbers will increase the understanding of the overall radiative and thermal balance of the planet, in particular the atmospheric dynamics and the chemistry of the upper clouds. Sulfur dioxide SO_2 and the later discovered sulfur monoxide SO are strong UV absorbers present in Venus' spectrum between 200 and 340 nm; however, these species do not explain the strong absorption at longer wavelengths, around 365 nm which signifies a different substance (in gas or aerosol form) distributed

non-uniformly in the cloud top and absorbing in the UV (for overview see [1]). Some candidate species have been proposed to explain the spectral contrast features in the UV. Spectroscopic measurements that reveal spatial and temporal variability will constrain contributions from these species. Previous missions and studies did not successfully detect the origin of the absorber. Venus Express instruments didn't have sufficient resolution, spectral range and UV sensitivity to study the relation between the unknown absorber and sulphur bearing species. VMC on Venus Express and Akatsuki are UV cameras with filters and not spectrometers. Pioneer Venus resolution was 1.3 nm and spectra were very noisy (e.g., [2]). It is hard to investigate the UV absorber from Earth's surface due to strong UV absorption in Earth's atmosphere. Venus was observed by Hubble Space Telescope ([3]), but future observations are unlikely due to Sun-avoidance requirements.

Concept: CUVE is a targeted mission, with a dedicated science payload and a compact spacecraft bus capable of interplanetary flight independently or as a ride-share with another mission to Venus or to a different target. CUVE Science Objectives are: 1) Nature of the "Unknown" UV-absorber; 2) Abundances and distributions of SO_2 and SO at and above Venus's cloud tops and their correlation with the UV absorber; 3) Atmospheric dynamics at the cloud tops, structure of upper clouds and wind measurements from cloud-tracking; 4) Nightglow emissions: NO , CO , O_2 . CUVE has a high spectral resolution spectrometer capable of resolving SO and SO_2 lines. The payload measures a broad spectral range spanning all relevant UV absorbers, and also includes a UV imager.

Summary and Conclusions: CUVE will produce high spectral resolution UV spectra of Venus and broad spectral range imaging maps. These maps will characterize the nature of the components in its atmosphere that absorb in the UV. This mission will be an excellent platform to study Venus' cloud top atmospheric properties where the UV absorption drives the planet's energy balance.

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VENUS AERIAL PLATFORMS STUDY. J.A. Cutts¹ and the Venus Aerial Platform Study Team,
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Background and Goals: The Venus Aerial Platform Study, which was underway in early 2017, is assessing the technologies for exploring Venus with aerial vehicles in order to develop a Venus Aerial Platform Roadmap for the future exploration of the planet. Much of this will be accomplished via two Study Team meetings in May and December of 2017. The first Study Team meeting in late May 2017 focused on the scientific opportunities offered by aerial platforms at Venus, their operating environments, and a technical review of possible aerial platforms. The second meeting in early December 2017 will emphasize establishing the feasibility of the technologies needed for operating in the severe Venus environment.

The product of this study will be a report for NASA's Planetary Science Division in early 2018. This report will guide future scientific and technical developments for NASA's Venus exploration efforts; specifically as: (1) an input for possible NASA/U.S. auxiliary payloads for the Russian Venera-D mission, (2) a Venus Flagship Mission Concept Study for the next *Planetary Science Decadal Survey*, and (3) technology investment plans for a Venus Surface Sample Return mission concept.

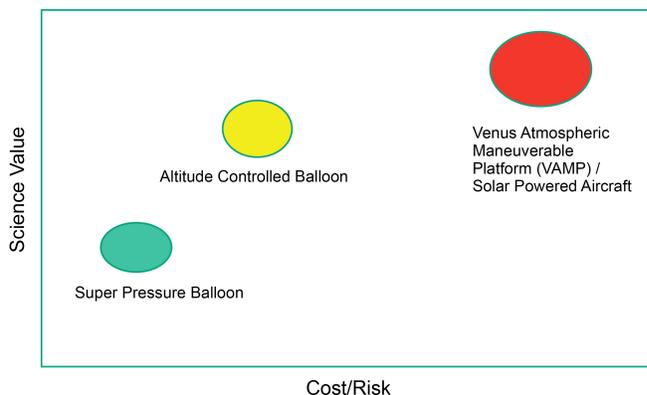
Summary of First Meeting in May At this first Study Team meeting in May, the Aerial Platforms Study Team analyzed which of the VEXAG's *Goals, Objectives, and Investigations for Venus Exploration* [1] could be addressed by the aerial platforms described in VEXAG's *Roadmap for Venus Exploration* [2]. In particular, the Roadmap's "sustained aerial platforms" were separated into the following categories:

Probes and sondes – One-time descent vehicles that would provide a single vertical profile through the deep atmosphere with little-to-no horizontal or temporal sampling.

Constant altitude, uncontrolled – "Classical" superpressure balloon at moderate (50–55 km) altitudes.

Variable altitude, uncontrolled – Vertically controlled, horizontally uncontrolled balloons that could vary in buoyancy to move up and down in the atmosphere to access different temperature/pressure regimes.

3D control – Powered lighter-than-atmosphere vehicles such as the Venus Atmospheric Maneuverable vehicle (VAMP) or heavier-than-atmosphere solar airplanes.



Study participants at the first meeting also developed a preliminary assessment of the Science Value of the concepts as a function of Cost and Risk. Altitude Controlled Balloons, which offer a significant gain in science capability for modest increase in cost and risk, appear to be a "sweet spot" in the overall trade space. Further analyses will be needed, incorporating other dimensions of performance, to verify and complete this assessment.

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- [1] *Goals, Objectives, and Investigations for Venus Exploration*, VEXAG, August 2016. <http://www.lpi.usra.edu/vexag/reports/GOI-Space-Physics-Update-0816.pdf>
- [2] *Roadmap for Venus Exploration*, VEXAG, May 2014. <http://www.lpi.usra.edu/vexag/reports/Roadmap-140617.pdf>

Acknowledgement: Work described here was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration and by a number of other organizations with funding from the National Aeronautics and Space Administration and other sources.

VEXAG's VENUS BRIDGE FOCUS GROUP. J.A. Cutts¹ and the VEXAG Venus Bridge Focus Group, ¹(james.a.cutts@jpl.nasa.gov) Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Mail Stop 321-B60, Pasadena, CA 91109

The Venus Exploration Analysis Group (VEXAG) established a Venus Bridge Focus Group in the spring of 2017 in response to an inquiry made by NASA's Science Mission Directorate as to whether viable Venus missions could be conducted within a \$200M cost-cap. This Focus Group objectives are to evaluate: (1) if useful Venus exploration can be performed within a \$200M cost-cap, and (2) if there are viable and cost-effective options for continuity between NASA's most recent mission to Venus (Magellan 1990-1994) and any future medium-to-large class U.S.-led mission to the planet Venus in the late 2020s. This effort also recognizes the need to address technology advancements that would further the success of large-scale missions to Venus launched subsequent to 2025. Thus, the Venus Bridge Focus Group is considering science, architectures, and technologies that could be pursued via small spacecraft (SmallSats or CubeSats) carrying payloads with masses of 30 kg to 120 kg, that could perform significant science investigations as defined in VEXAG's *Goals, Objectives, and Investigations for Venus Exploration* [1] with launch dates in the early-to-mid 2020s.

Mission concept architectures that are being addressed include stand-alone missions (including launch vehicle), ride-alongs on other planetary missions, or missions that fly by Venus for gravity assists. Thus, low-cost mission architectures could be implemented via fly-bys, orbiters, probes, or landers. As the study of new technologies is an important target for the Venus Bridge missions, the Focus Group is addressing the most recent advances in propulsion, communications, atmospheric-probes, aerial-platforms, and lander technologies.

A dozen mission concepts were collected in response to a community call. These concepts are being collated into basic architectures with the emphasis on linkages between mission elements. These linked mission elements could enable cost-effective feasibility-advancing Venus missions that might not otherwise arise. Noting that a successful probe or lander mission would likely require a telecom relay via an orbiter already on-station, the Focus Group is

addressing mission architecture studies linking orbiters and in-situ elements.

Two complementary mission concept feasibility studies will be completed this year. The first study linking a Surface Element (lander) and Orbiter Relay will be performed by the COMPASS Team at NASA Glenn Research Center. The second study linking an Orbiter and Atmospheric Element (Probe or Aerial Platform) will be performed by JPL's Team-X. Based on these studies, the Venus Bridge Focus Group will establish feasible combinations of mission architectures that agree with the *Roadmap for Venus Exploration* [2]. A Final Report will be delivered to NASA in early 2018.

In summary, Venus Bridge is a unique opportunity to examine low-cost mission concept architectures with linked mission elements that would enable the acquisition of new Venus science in the early 2020s, ahead of the next generation of medium-to-large NASA/U.S. Venus missions.



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- [1] *Goals, Objectives, and Investigations for Venus Exploration*, VEXAG, August 2016. <http://www.lpi.usra.edu/vexag/reports/GOI-Space-Physics-Update-0816.pdf>
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Acknowledgement: Work described here was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration and by a number of other organizations with funding from the National Aeronautics and Space Administration and other sources.

MAPPING VENUS MINERALOGY AND CHEMISTRY *IN SITU* FROM ORBIT WITH SIX-WINDOW VNIR SPECTROSCOPY. M. D. Dyar¹, J. Helbert², T. Boucher³, D. Wendler², I. Walter⁴, T. Widemann⁵, E. Marcq⁶, A. Maturilli², S. Ferrari^{7,1}, M. D'Amore², N. Müller⁸, and S. Smrekar⁸, ¹Planet. Sci. Inst., 1700 East Fort Lowell, Tucson, AZ 85719 USA (mdyar@mtholyoke.edu); ²Inst. Planet. Res., DLR, Rutherfordstrasse 2, 12489 Berlin, Germany; ³Col. of Inform. and Computer Sci., Univ. of Massachusetts Amherst, Amherst, MA, 01003, USA; ⁴Inst. Optical Sensorsystems, DLR, Rutherfordstrasse 2, 12489 Berlin, Germany, ⁵LESIA; ⁶LATMOS; ⁷Center of Studies and Activities for Space G. Colombo, University of Padova, Via Venezia 15, 35131 Padova, Italy ; ⁸Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Dr., Pasadena CA, 91109.

Introduction: How can Venus' surface mineralogy and geochemistry best be studied? Technological advances in surface techniques since prior Venus landed missions such as LIBS, Raman [1], and XRF [2] make in-situ instrumentation attractive. However they are limited to short analysis times, autonomous sample collection, and provide local versus global information.

Although not designed to image the Venusian surface, both the Galileo spacecraft and VIRTIS on Venus Express were able to image the surface through transparent windows in the CO₂ spectrum near 1 μm [3-7]. To leverage this capability, the Venus Emissivity Mapper (VEM) was developed specifically to study the surface of Venus through six different windows at 0.86, 0.91, 0.99, 1.02, 1.11, and 1.18 μm. This project explores what can be learned about Venus surface geochemistry and mineralogy using those six windows from an orbiter *in situ* at Venus, with two focuses:

- 1) the ability of VEM-window data to distinguish among key rock types on Venus, and
- 2) their capability to evaluate redox state and transition metal contents of Venus surface rocks.

Data: VNIR data were collected at Venus temperatures in the Planetary Spectroscopy Laboratory at DLR [8-10]. Fe³⁺/Fe²⁺ ratios were measured using Mössbauer spectroscopy [11] and standard methods. Samples studied were reported in [12].

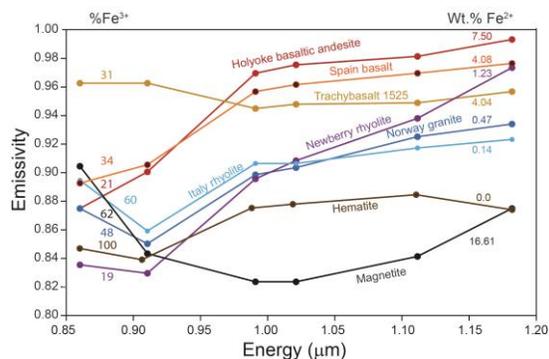


Figure 1. Laboratory emissivity data with %Fe³⁺ (left) and wt.% Fe²⁺ (right, indicated as determined by combining Mössbauer, x-ray fluorescence, and EMPA).

Rock Type Distinctions: As seen in **Figure 1**, samples containing Fe oxides (rhyolite, granites, and the oxides themselves) have negative slopes between the two lowest wavelength bands. The wavelength region ~0.99 and 1.02 μm allows felsic rocks to be distinguished from mafic ones. In this region, Fe (and other transition metals) in silicate minerals causes elevated emissivity, causing felsic rocks to group separately, and oxides to have low emissivities. Binary classifiers [1] demonstrate that at current best estimate errors, basalt spectra can be confidently discriminated from basaltic andesites, andesites, and rhyolite/granite.

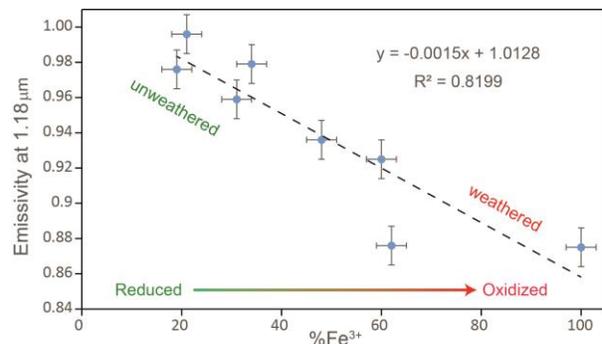


Figure 2. Assessment of weathering based on emissivity at 1.18 μm; other bands can also be used to support this trend.

Redox state: Surface weathering based on oxidation state can be inferred from the 1.18 μm and other bands (**Figure 2**). This distinction can also be made using the 0.99 and 1.02 μm bands, where hematite is easily distinguished from magnetite.

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Current status of observation by the Longwave Infrared Camera (LIR) on board Akatsuki spacecraft

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Introduction: Akatsuki has started observation of the Venus atmosphere since 2015 [1]. Immediately after the orbit insertion of the spacecraft, LIR discovered a large stationary gravity wave which appeared above the highland of Aphrodite Terra toward evening [2]. We advance the study by using the abundant LIR images, and various large stationary gravity waves have been identified in LIR images. On the other hand, brightness temperature derived from LIR images contained an unexpected bias that related not to natural phenomena but to a thermal condition of the instrument. Causes of the bias have been investigated and corrected by using calibration data derived from deep space images.

Large stationary waves: 8 stationary waves also have been identified in the LIR observations since the first discovery of the wave above Aphrodite Terra. The apparent wave fronts are roughly aligned in the north-south direction and the meridional span exceeds 2000 km in all cases. The peak-to-peak amplitudes of the brightness associated with the waves are larger than 1 K. All of the center positions of the stationary waves correspond to four specific highlands in the low latitudes but not in the high latitude. They periodically appeared when these regions were toward evening, while the wave amplitudes attenuated after the wave locations passed beyond the evening terminator.

We consider three outstanding issues of the stationary gravity waves. (1) Why is the local time of the waves appearing limited toward evening? Does a source of the wave near the surface appear only in the specified local time? Does the specified altitude such as cloud layer where the static stability is relatively low and generates convection disturb wave propagation to upward? (2) How is the wave source near the surface generated at the highland areas? Does a weak wind or a temperature anomaly near the surface generate atmospheric disturbance? (3) Why is the stationary gravity waves not observed at the high latitude? The Maxwell Mountain located at latitude of 65.2°N is the highest mountain on Venus. However, no wave has been detected there. Does the equatorial orbit of Akatsuki not meet observations of the high latitude area? Does the feature become obscure in the prominent feature such as a polar dipole? Does the wave not be generated at the highland in the high latitude area?

Numerical studies would be a potential tool to clarify the issues.

Correction of a systematic bias: LIR provides horizontal distributions of the brightness temperature on the Venus disk in both dayside and nightside by detecting emissions at wavelengths from 8 to 12 μm [3]. Simulation of radiative transfer with a typical cloud height distribution in the Venus atmosphere indicates that the thermal infrared radiation emitted from an altitude of ~ 65 km mostly contributes to the thermal contrast in the LIR images [4]. The brightness temperature at that altitude is generally ~ 230 K according to the vertical temperature distribution of the Venus atmosphere derived from previous observations [e.g., [5]]. However, it became clear that images include background-offset more than 20 K unrelated to cloud features. LIR has two suspicious noise factors on orbit; one is power-supply management and the other is variation of solar incident angle accompanying temperature deviation of instrument. The power supply unit turned on the instrument before every observation, which obviously affected thermal balance. Hence, we have improved operation procedure of LIR observation; power status of the instrument has been changed to normally turn-on. Consequently, thermal potential of the instrument have been stable with background offset decreasing. The offset still remaining has well correlated with temperature of baffle which prevents sunlight input to the detector. The baffle is configured outside of spacecraft and temperature drastically changes with solar incident angle. It probably affects thermal potential of the germanium lens which would be major cause of the offset. Deep space observation with solar incident angle gradually changed has been carried out. Reference table for correction of background offset has been derived from the observation, and it has been confirmed that the offset can be well corrected by the reference table.

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AN AIRBORNE SPECTROPHOTOMETER FOR INVESTIGATING SOLAR ABSORPTION ON VENUS.

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Introduction: It has been known for decades that the chemical species detected to date from in-situ and remote observations of Venus clouds cannot explain the absorption of incident solar radiation at wavelengths below about 600 nm, to at least 330 nm [1,2]. Sulfuric acid, the primary constituent of Venus clouds, does not absorb visible wavelengths; sulfur dioxide absorbs only below 330 nm. Furthermore, Venus cloud cover shows a peculiar dependence of contrast on wavelength and it has been shown that other absorbers must be present in Venus clouds [3,4,5]. A variety of substances from elemental sulfur to FeCl₃ crystals have been proposed [1,2,6-8], but the possibility of organic substances or micro-organisms cannot be excluded [9-12].

Mission: In order to understand the nature and identity of the absorbers of solar radiation in the clouds of Venus, measurements from a long lived aerial platform capable of sampling different altitudes and carrying a suite of instruments to sample cloud properties is needed. Venus Atmospheric Mobile Platform (VAMP), [13,14] is one such vehicle which has been recommended as the highest priority contributed to Russia's Venera-D mission [15], and will also be likely considered for a future Venus flagship mission. Measurements of solar radiation from such a platform would provide the ability to relate the spatial and temporal variations in differential UV absorption (365-410 nm), which characterize the contrast features seen in spacecraft images of Venus cloud cover, to environmental and cloud properties.

Instrument: We have proposed to develop a spectrophotometer with integrated meteorological sensors that can provide the required data for these science goals. Our effort will include modeling the solar radiation levels at various altitudes in the Venus atmosphere, and the design of an appropriate sampling and optical system for the observations. The spectrophotometer will be prototyped in the laboratory, including the electronics and the data system, and performance will be tested for requirements for noise, resolution, radiometric accuracy. Algorithms will be developed to identify various UV absorption regimes that can be used to trigger observations by complementary instruments in the payload. The instrument will be designed to integrate into a mobile airborne platform and ad-

dress constraints imposed on mass, power, observing geometry, and communication with other instruments in the payload.

Summary: We present an overview of this instrument proposal and mission. This work directly addresses the VEXAG goals and objectives [16] to determine the chemical makeup and variability of the Venus clouds, their roles in the atmospheric dynamical and radiative energy balance, and their impact on the Venus climate. Furthermore, it provides a test of whether the habitable zone in the Venus clouds harbors life.

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ANALYSIS OF MAGELLAN AND VENUS EXPRESS TRACKING DATA FOR VENUS GRAVITY FIELD DETERMINATION. Sander Goossens^{1,2}, Frank G. Lemoine², Pascal Rosenblatt³, Sébastien Lebonnois⁴, Erwan Mazarico². ¹Center for Research and Exploration in Space Science and Technology, University of Maryland Baltimore County, 1000 Hilltop Circle, Baltimore MD 21250 U.S.A. (email: sander.j.goossens@nasa.gov), ²NASA GSFC, 8800 Greenbelt Road, Greenbelt MD 20771 U.S.A., ³Royal Observatory of Belgium, Av. Circulaire 3, B-1180 Uccle, Belgium, ⁴Laboratoire de Météorologie Dynamique, CNRS/UPMC, Place Jussieu, Box 99, 75252 Paris Cedex 05, France.

Introduction: The gravitational field of a planet depends on its internal density distribution, and in combination with topography it can provide a powerful method to probe the interior structure of a planet [1]. Models of planetary gravity fields are determined from satellite tracking data. For Venus, data from the Pioneer Venus Orbiter (1978-1980) and Magellan (1990-1994) spacecraft have been used, and the most recent gravity field model is an expansion in spherical harmonics of degree and order 180, called MGNP180U [2]. Due to computational constraints, the potential coefficients of this model were estimated in successive batches, resulting in artificial discontinuities in the solutions and their error estimates. This hampers the application in geophysical analysis of the models over their whole range, but especially at higher resolutions. We present results of a reanalysis of the Magellan tracking data. We augment this data set with tracking data from the European Space Agency's Venus Express mission (VEX) [3].

Methods: We use our NASA Goddard Space Flight Center (GSFC) GEODYN II Orbit Determination and Geodetic Parameter Estimation package [4] to process the Venus tracking data. We use tracking data from cycles 4, 5 and 6 from Magellan since those were dedicated to radio tracking for the gravity experiment [2]. We also add VEX data. We process the tracking data in continuous spans of data called arcs. We account for the effects of angular momentum desaturation (AMD) events by estimating a constant acceleration in three directions (in the radial, along, and cross-track component). We pay specific attention to the mismodeling of atmospheric effects by employing an atmosphere model [5] in our modeling of the drag force on the satellite, and by estimating scale coefficients on this drag force, once every orbit with time-correlation, in a similar fashion as we estimated empirical accelerations on the Gravity Recovery and Interior Laboratory (GRAIL) data [6]. We also pay close attention to the effects of the atmosphere on the estimated low-degree gravity field coefficients, by forward modeling pressure fields from a General Circulation Model [7], following a technique developed for Earth [8] that has also been applied at Mars [9].

Results: Preliminary efforts have focused on the processing of the Magellan data. We use data with a 2

second count interval with the goal to extract high-resolution information from the data. Our efforts will focus on the determination of a gravity model of degree and order 220 at maximum. Despite indications that the remaining dependence of data noise on altitude is related to ionospheric influences rather than unmodeled gravity [2], we aim for a larger expansion because of our use of 2 s data. We will also leverage the computational tools that we developed for the analysis of the GRAIL gravity data [e.g.,6]. Data from VEX will mostly be used to increase resolution in certain areas where VEX collected gravity passes [3], and to extend our temporal baseline for the estimation of time-varying gravity effects such as those described by potential degree 2 Love numbers and the spin-rate secular variations. Effects of atmosphere modeling on these parameters will also be investigated.

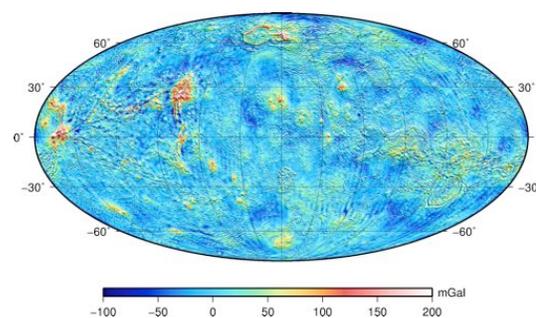


Figure 1 Preliminary gravity field model from Magellan data, shown up to degree and order 140, shaded by topography.

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STRATOSPHERIC BALLOON TEST OF AERIAL ELECTROMAGNETIC PROBING OF THE LITHOSPHERE OF VENUS. R.E. Grimm, Southwest Research Institute, 1050 Walnut St. #300, Boulder, CO 80302 (grimm@boulder.swri.edu).

Introduction. Electromagnetic (EM) sounding uses induction from natural sources to build profiles of electrical conductivity of planetary interiors, which in turn can be translated to temperature and composition. Recently developed theory indicates that measurements of transverse electromagnetic (TEM) waves—in particular, lightning-caused global Schumann resonances—at any altitude in the ground-ionosphere waveguide contain information on the resistivity structure of the boundaries [1]. In other words, aerial measurements in this bandwidth can be used to probe the subsurface. This technique can measure geothermal gradient and hence lithospheric thickness (Fig. 1) from a nominal 55-km balloon float altitude, and thus make a fundamental contribution to understanding the geodynamics and interior structure of Venus without ever touching the surface. I will report on a demonstration from a stratospheric balloon.

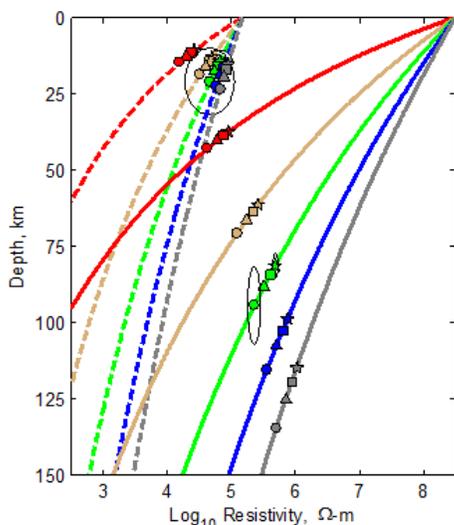


Fig. 1. Discrimination of different geothermal gradients on Venus (colored lines) using Schumann resonances (symbols) for “dry” (solid) vs “wet” (dashed) interiors [1].

Balloon Transverse Electromagnetic Measurement (BTEM). A demonstration payload (Figs. 2, 3) measuring AC electric and magnetic fields is scheduled to fly at 30 km altitude over the Idaho's Salmon River Mountains in October, 2017. This location was chosen for extensive resistive crystalline rocks that are the best terrestrial analog to Venus: although resistivities are expected to be much lower than Venus, and penetration depths much less, the experiment can still achieve the following objectives (1) demonstrate that Schumann resonances can be characterized in the

stratosphere. (2) demonstrate that electric fields follow lossy waveguide theory. (3) determine simultaneously the frequency dependent electrical conductivities of the ground and ionosphere. (4) determine the requirements to advance to TRL 6 for Venus flight.



Fig. 2. BTEM outdoor ground test near Boulder. Electric fields are measured between boom-tip electrodes; magnetometers are inside booms.



Fig. 3. BTEM (above cones) rigging test beneath balloon avionics package (near ceiling) at World View high bay. Separation mitigates potential interference from continuously operating radio systems.

References: Grimm R.E. et al. (2014) *Icarus*, 217, 462.

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The Spectroscopy of the surface of Venus. J. Helbert¹, A. Maturilli¹, M. D. Dyar^{2,3}, S. Ferrari^{4,1}, N. Müller⁵, S. Smrekar⁵, ¹Institute for Planetary Research, DLR, Rutherfordstrasse 2, 12489 Berlin, Germany (joern.helbert@dlr.de), ² Planetary Science Institute, 1700 East Fort Lowell, Tucson, AZ 85719, ³ Dept. of Astronomy, Mount Holyoke College, South Hadley, MA 01075, ⁴ Center of Studies and Activities for Space (CISAS) G. Colombo, University of Padova, Via Venezia 15, 35131 Padova, Italy, ⁵Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Dr., Pasadena CA, 91109.

Introduction: Many efforts have been made since the landing of Venera 9 and 10 [1] to obtain optical spectra of Venus analog materials at relevant temperatures. Pieters *et al.* [2] provided a first set of reflectance measurements of basaltic materials in the spectral range from 0.4 to 0.8 μm . Since then, all efforts to extend these measurements to longer wavelengths have stalled.

It was commonly accepted that compositional data could only be obtained by landed missions because Venus' permanent cloud cover prohibits observation of the surface with traditional imaging techniques over most of the visible spectral range. Fortunately, Venus' CO₂ atmosphere is actually transparent in small spectral windows near 1 μm . Ground observers have used these windows to obtain limited spectra of Venus' surface during a flyby of the Galileo mission at Jupiter, and from the VMC and VIRTIS instruments on the ESA VenusExpress spacecraft. In particular, the latter observations have revealed compositional variations correlated with geological features [3-8].

These new observations challenged the present notion that landed missions are needed to obtain mineralogical information. However any interpretation in terms of mineralogy of VNIR spectroscopy data from orbiters requires spectral libraries acquired under conditions matching those on the surfaces being studied.

Venus facility at PSL: The Planetary Spectroscopy Laboratory (PSL) at DLR took up this challenge, building on nearly a decade of experience in high temperature emission spectroscopy in the mid-infrared [9-11]. After several years of development and extensive testing, PSL now has a setup in routine operation for Venus analog emissivity measurements from 0.7 to 1.5 μm over the whole Venus surface temperature range.

PSL has started a database of Venus analog spectra including measurements of rock and mineral samples covering a range from felsic to mafic rock and mineral samples [12]. This first set already shows the potential for mapping of Venus mineralogy and chemistry *in situ* from orbit with six-window VNIR spectroscopy [13,14,15].

As of summer 2017 the Venus facility at PSL is open to the community through the Europlanet Research Infrastructure (<http://www.europlanet-2020-ri.eu/>).

Laboratory challenges: Measuring emissivity at 1 μm at Venus analog temperatures is very challenging for a variety of reasons. Even at Venus' surface tempera-

ture, emission at 1 μm is relatively low. At the same time, many natural materials have high transparency at 1 μm , requiring development of new protocols and equipment for these measurements. The setup at PSL was from inception focused on obtaining high signal-to-noise measurements. Recent upgrades to the spectrometer electronics and a switch to an InGaAs detector provided further increases in sensitivity in 1 μm range. New measurement equipment including ceramic sample holders have helped suppress background radiation.

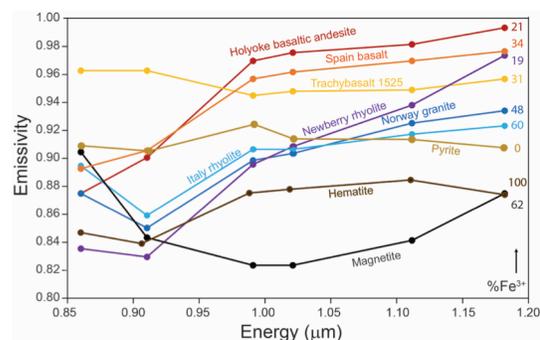


Figure 1. Spectra of Venus analog sample at all known atmospheric surface windows of Venus. Samples represent a suite of crustal differentiation and thus different Fe and Si concentrations. Additional spectral analysis techniques allow for robust identification of subtle spectral differences [13,14,15].

Conclusion: After extensive testing, the new setup at PSL for Venus analog measurements obtains precise spectra for a wide range of samples. It is stable and produces reproducibility results. Therefore, we froze the design at the end of 2016 as our standard set-up for emissivity measurements of Venus-analogue samples in the visible spectral range.

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Venus Interferometric Synthetic Aperture Radar (VISAR) for the Venus Origins Explorer. S. Hensley¹, S. Smrekar¹, M. D. Dyar^{2,3}, D. Perkovic¹, B. Campbell⁴, Marwan Younis⁵, and the VOX team, ¹Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Dr., Pasadena CA, 91109 (shensley@jpl.nasa.gov), ²Planetary Science Institute, 1700 East Fort Lowell, Tucson, AZ 85719, ³Dept. of Astronomy, Mount Holyoke College, South Hadley, MA 01075, ⁴Smithsonian Institution, Center for Earth and Planetary Studies, MRC 315 PO Box 37012, Washington, DC 20013, ⁵German Aerospace Center (DLR), Münchener Straße 20, 82234 Weßling, Ger.

Introduction: One of the three primary science instruments for the proposed Venus Origins Explorer (VOX) mission [1] to the NASA New Frontiers Program is an X-band radar interferometer. This radar is designed to provide 1-2 order of magnitude improvements in both imaging and topographic resolution as well as make repeat pass observations of selected targets to look for deformation signatures from active geological processes.

Radar Overview: The Venus Interferometric Synthetic Aperture Radar (VISAR) instrument is an X-band single pass interferometer designed to generate high-resolution imagery and topography of the surface of Venus. High-resolution topography is integral to many of the proposed VOX science investigations and single pass radar interferometry is the optimal means of obtaining these measurements at Venus [2, 3]. X-band at 7.9 GHz optimizes performance within the launch vehicle and Venus atmospheric attenuation constraints.

Radar Design and Parameters: The basic requirements driving the radar design are: 1) generate imagery with 20 m resolution for targeted regions; 2) obtain global imagery with 30 m resolution; 3) obtain global topography with 300 m resolution and 10 m height accuracy; and 4) make repeat pass radar interferometric (RPI) deformation measurements. These requirements represent an order of magnitude improvement to Magellan SAR imagery resolution (120 m) and 2 orders of magnitude to the topography resolution (~20 km) with the elevation accuracy improved from 80 m (at best) to 5 m.

To meet these requirements VISAR is configured as a single pass radar interferometer with a 3.1 m cross-track baseline and two 4 m × 0.6 m antennas at each end of the baseline. VISAR has an operating bandwidth of 20 MHz (slant range resolution of 7.5 m) that enables 15 m cross-track resolution at an incidence angle of 31°. The 3.9 m along-track antenna length provides 2 m along-track resolution. Operating from an orbit of roughly 240 km VISAR has a 14.4 km swath to allow contiguous overlapping swaths covering the 10 km of equatorial planetary rotation between orbits.

Viable repeat pass radar interferometric measurements impose several constraints on the imaging geometry. Primary among these is that the perpendicular baseline (length of the projection of the vector between the two observing vantages perpendicular to the line-of-sight) be less than the critical baseline length that is 400

m for VISAR [3]. To accomplish this the spacecraft will perform an orbital adjustment maneuver to place the spacecraft within a 160 m diameter tube ensuring the perpendicular baseline is < 80 m for 92% of the time.

Onboard processing is required to reduce the onboard data rate by about a 1000 fold enabling global coverage within downlink constraints. Onboard processing consists of range compression, motion compensation, azimuth compression, interferogram formation and multi-looking prior to downlink. Raw radar signal data is downlinked for selected repeat pass targets.

After the data are downlinked the remainder of the interferometric processing including phase unwrapping, height reconstruction (that includes atmospheric compensation) and mosaicking is performed. Tie pointing between tracks is used to improve spacecraft ephemeris and provide cartographically accurate mapping.

Radar Capability and Products: VISAR will generate the following data products, comfortably exceeding science requirements:

1. Radar imagery with 15 m resolution for 40% of the surface.
2. Radar imagery at 30 m and 250 m resolutions globally.
3. Topography with 250 m posting and 5 m elevation accuracy globally.
4. Repeat pass interferograms and correlation maps with 30 m resolution for targeted 200×200 km regions on the surface (between 12 and 24 locations depending on resources) with 2 cm line-of-sight deformation precision.

Conclusion: The proposed VISAR instrument on VOX will provide global high resolution imagery and topography of Venus and as well make the first systematic radar deformation observations using RPI on another planet. Onboard processing enables VISAR to reduce the onboard data rate by about 1000× enabling global high-resolution measurements to be made with planned DNS data downlink capability.

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JMARS FOR VENUS: COLLECTING AND INGESTING DATA TO CREATE A USEFUL SCIENTIFIC ANALYSIS TOOL. R. R. Herrick¹, and P. Wren², ¹Geophysical Institute, University of Alaska Fairbanks, Fairbanks, AK 99775-7320 (rrherrick@alaska.edu), ²Mars Space Flight Facility, Arizona State University, AZ 85287-1404 (pwren@mars.asu.edu)

Introduction: JMARS, Java Mission-planning and Analysis for Remote Sensing [1], has become a valuable research tool for analysis of multiple solar system bodies. While the analysis tools are limited compared to comprehensive GIS programs such as ArcGIS, JMARS excels at data visualization because it can overlay multiple data sets and the display can be rapidly reprojected into a local cylindrical projection that shows both shape and distances accurately. Because it is Java-driven, JMARS works on all major computer operating systems. Relatively recently, Venus has been added as one of the planetary bodies available in JMARS. The lead author has begun collaborating with the second author, a scientific programmer for JMARS, to ingest scientifically valuable data sets into JMARS. Many of these data sets are neither in PDS format nor easy to find for the general public. This abstract details the current plans for JMARS for Venus and solicits input from the community of Venus researchers.

Existing data sets:

As of 9/1/2017 the data sets available in JMARS are the following:

- The FMIDR data sets: The three different cycles of Magellan SAR data at their processed resolution of 75 m.
- The GxDR mg_3002 data sets: Magellan altimetry, emissivity, slope (roughness), and reflectivity at their processed resolution of 4.64 km/pixel. The altimetry is available as either planetary radii or elevation relative to 6051.0 km radius.
- A shaded relief map of the topography, generated with ISIS using the GTDR data.
- A colorized shaded relief map (rainbow, blues low elevations, reds high) of the topography, generated with ISIS using the GTDR data.
- A colorized (JPL burnt-orange, Hot!) version of the C3-MIDR mosaic processed to a resolution of 4.64 km/pixel.
- Planetary nomenclature from the USGS.

Some of the redundant data (e.g., the colorized mosaic) will likely be removed from JMARS in future releases.

Proposed future data sets:

Additional data sets that the lead author has proposed adding to JMARS, in roughly decreasing priority order, are the following:

- Databases of impact craters from Herrick et al. [2] and Schaber et al. [3]. These are in testing and should be in the next JMARS release.
- The volcano database of Crumpler et al. [4].
- A corona database, although we are not aware of a publicly available version.
- The revised versions of the gridded emissivity and topography that Peter Ford generated that was never put in the PDS (ftp://voir.mit.edu/pub/mg_3003/).
- Stereo-derived topography processed to 900 m/pixel resolution from Herrick et al. [5].
- Landing sites with error ellipses for previous probes and landers.
- Some version of the spherical harmonic gravity. Current thoughts are that the most useful maps might be the geoid, the free-air anomaly, and the two-layer inversion of James et al. [6].
- Topography-corrected IR emissivity from Venus Express and other derived near-IR maps.
- South-pole mosaic from Senske and Ford [7].
- Thermal IR maps from Galileo NIMS data.
- Other SAR data sets for Venus, especially Venera 15/16 and Arecibo mosaics. Arecibo mosaics from different years might be particularly useful.
- Other databases that can be located, such as dune fields, wind streaks, landslides.
- Global photogeologic unit maps, such as those generated by Price et al. [8].

The prioritization of these data sets represents a combination of their importance and the ease of obtaining and importing the data.

Solicitation for input:

This is an incipient (and largely unfunded) activity and the authors are interested in opinions and data contributions from the Venus community. Please contact the lead author if you have input.

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MOTIVATIONS FOR A DETAILED IN-SITU INVESTIGATION OF VENUS' UV ABSORBER.

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Photos of Venus' distinctive near-UV contrasting cloud features provided the first evidence of Venus' infamous UV absorber [1]. Barker et al. [2] was the first to show the spectral signature of the absorber and assert that broad its absorption at 0.33-0.39 μm occurs ubiquitously at the cloud tops in UV bright and dark regions. Detailed studies of radiative properties of the atmosphere indicate that the UV absorber is responsible for 50% of the solar energy deposited in Venus' atmosphere [3]. Consequently, the UV absorber plays a key role in planetary energy budget and is expected to be a key factor in the dynamics of the atmosphere including the superrotation of the clouds. For this reason, studying the nature of the UV absorber has been assigned a high priority science target for both in-situ and remote sensing Venus observing programs proposed and executed throughout the decades.

Currently, a unique identification of the absorbing species has yet to be accomplished; and on-going research on the topic continues to reveal the complexity of the absorber. For example, long-term image monitoring of the cloud tops at NUV ($\sim 0.34\text{-}0.39 \mu\text{m}$) wavelengths completed by multiple missions to Venus indicates that the morphology of the NUV markings is highly variable. Analysis of Venus Express data indicates that the NUV contrast boundaries are linked to important changes/boundaries in the cloud top altitude and temperature [4]. This result implies a link to dynamics and may in fact motivate a link to microphysical [5] if not chemical changes at the cloud tops—i.e., the composition and/or nature of the absorber itself may be highly variant. Additionally, the first spectrally resolved NUV spectrum of the cloud tops revealed absorption that onset at $\sim 0.5 \mu\text{m}$, increased in strength at shorter wavelengths following a positive gentle gradient between 0.5 and 0.39 μm and then ended in a broad (nearly flat) absorption band between 0.33 and 0.39 μm [2]; however, these initial spectra were disk-integrated. Spatially resolved spectral observations obtained with VIRTIS [6], HST [7] and MESSENGER [8] during the Venus Express era indicate that while the spectral signatures of Venus' NUV bright, dark and minimal contrast regions all have significant absorption between 0.33 and 0.39 μm , the shape of their absorption spectra from 0.3 to 0.6 μm is variant. Only the relatively NUV bright regions have an 0.3-0.7 μm absorption structure that can be well replicated by the species fit to the disk-integrated Barker et al. data. Additionally, contrary to the earliest spectral measurements of the UV absorber, the VIRTIS data implies that the onset of the UV absorption commonly occurs at wavelengths longward of 0.5 μm . Preliminary analysis of these data implies that the variance in NUV brightness may correspond to an actual change in the nature (rather than the abundance) of the absorber; these changes may correspond to variances in the particle size, age and/or composition of the primary absorber. Additionally, the observed range of NUV brightness levels may be an indication that a variety of absorbers with different lifetimes (or responses to UV exposure) contribute to the observed spectral signatures—perhaps even some of organic origin [9].

Thus, we assert that the high variability of the spectral signature of the absorber strongly motivates a need to consistently map the spectrum of the absorber over multiple altitudes at all possible local times for the full duration of a cloud rotation cycle if not a full Venus day (i.e., 117, 24hr periods of time). The 60-70 km altitude range is most critical because it is directly below the cloud top altitude where the NUV absorber has been repeatedly detected—and it has never before been successfully sampled by an in-situ mission element. Additionally, to identify how the changes in the observable cloud contrasts relates to changes in the nature of the UV absorber, the size of the aerosol particles, the atmospheric thermal emission, and both the horizontal and vertical wind shears at the altitudes where the absorber is observed must be simultaneously obtained. In summary, with the proper payload, an airborne in-situ investigation that is able to access an altitude of 60 km or higher would provide the first opportunity in over 20 years to obtain the required observational data without any temporal disparity using state of the art instrumentation in UV spectroscopy, nephelometry, microimaging, and anemometry. It could also provide the first opportunity to definitively confirm or refute the organic or inorganic nature of the absorber in Venus' atmosphere.

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SAEVe: A long duration small sat class Venus lander, Tibor Kremic¹ (Tibor.Kremic@nasa.gov), Richard Ghail², Martha Gilmore³, Walter Kiefer⁴, Sanjay Limaye⁵, Gary Hunter¹, Carol Tolbert¹, Michael Pauken⁶, Colin Wilson⁷ 1, NASA Glenn Research Center, Cleveland, OH 2, Imperial College of London, London, UK, 3, Wesleyan University, Middletown, CO 4, Lunar and Planetary Institute, Houston, TX 5, University of Wisconsin, Madison, WI 6, Jet Propulsion Laboratory, Pasadena, CA 7, University of Oxford, UK

NASA's science mission directorate has put increasing emphasis on innovative, smaller, and lower cost missions to achieve their science objectives. One example of this was the recent call by the Planetary Science Division for cube and small satellite concepts expected to cost \$100M or less, not including launch and weighing less than 180kg. Over 100 proposals were submitted suggesting that indeed this is a size of mission worthy of being considered in future planning. Nineteen missions were selected for study, one being a long-lived Venus mission called SAEVe, for **Seismic and Atmospheric Exploration of Venus**.

The science objectives and relevance of SAEVe include: Is Venus seismically active? What can we learn about its crust (thickness and composition) and its interior (lithosphere, mantle, and core)? What can be learned about its evolutionary history or about the planet / atmosphere interactions? SAEVe begins to address these science questions with simple, but capable, instrumented probes that can survive on the surface of Venus and take temporal measurements over months—something never attempted before. The data returned will further our understanding of the solar system and Earth, and aid in meeting the NASA Science Plan goal to “**ascertain the content, origin, and evolution of the solar system...**” and “**the chemical and physical processes in our solar system...**” [1]

SAEVe is delivered to Venus as a ride-along on another mission to Venus. Its two small probes are placed into the Venus atmosphere via a single Stardust-like entry capsule, are ejected at different times, free fall, and decelerate in the thickening atmosphere to touchdown under 8 m/s² or less. The probes will begin taking measurements and transmitting important parameters at or near the surface and will focus on measurements like seismic activity, heat flux, wind speed and direction, basic chemical abundances, temperature, and pressure. At preset intervals, the probes acquire the science measurements and beam the data to the orbiting host spacecraft. SAEVe will serve as a highly capable precursor and pave the way for larger and more complex lander missions to explore Venus. The objectives of the study include:

- Refine science objectives, trade instrument options
- Flow driving science requirements down to probe systems / instruments
- Trade communication approaches—considering science, cost, and risk
- Identify key technology development needs and assess mission readiness
- Develop parametric costs for implementing the mission concept



Science Objectives	Anticipated Instruments/ Measurement	Team	
Determine if Venus is seismically active	Seismometer and chemical composition	Principal Investigator (PI)	Dr. Tibor Kremic, NASA Glenn Research Center (GRC)
Determine the thickness and composition of the crust and lithosphere	Seismometer and heat flux	Co-Investigator (Co-I)	Dr. Walter Kiefer, Lunar and Planetary Institute, Science Team
Determine current rate of energy loss from the interior	Heat flux	Co-I	Dr. Richard Ghail, Imperial College of London
Estimate the momentum exchange between the planet and its atmosphere	Wind speed and direction, temperature, and pressure	Co-I	Dr. Gary Hunter, GRC
Acquire acquire meteorological measurements to update global circulation models	Winds, temperature, pressure, and chemical composition	Co-I	Dr. Sanjay Limaye, U. Wisconsin
Estimate sources of atmospheric chemistry variability	Chemical composition, temperature, pressure, and winds	Co-I	Dr. Colin Wilson, U. Oxford
Potential: Examine rock and soil distribution and morphology	Potential: Camera package	Co-I	Dr. Martha Gilmore, Wesleyan U.
		Mission Study Concept Team	GRC COMPASS team

The SAEVe study will be completed and be presented around the LPSC conference in March of 2018.

References:

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LLISSE: A long duration Venus surface probe, Tibor Kremic¹ (Tibor.Kremic@nasa.gov), Gary Hunter¹, Jennifer Rock¹, ¹, NASA Glenn Research Center, Cleveland, OH

Exploration to better understand the deep Venus atmosphere and surface have been long standing objectives by the Venus science community as stated in Venus Exploration Analysis Group (VEXAG) documents [1] and the Planetary Decadal Survey Report [2]. The extreme environmental conditions at the surface of Venus, coupled with the thick clouds and dense atmosphere, have made achieving the science objectives very challenging. So challenging in fact that many have believed that our ability to survive on the surface of Venus and do in-situ science is limited to timeframes of hours, as seen with the former Soviet Venera and VEGA landers. Further, it was not clear that this situation will improve much in the foreseeable future. Recent technology advances in high-temperature electronics [3] and the addition of new capabilities to simulate Venus conditions, such as provided by the Glenn Extreme Environment Rig (GEER) [4], are changing this paradigm. One project in particular, known as the Long-Lived In-situ Solar System Explorer (LLISSE), is challenging these perceptions [5]. LLISSE has a goal of developing and demonstrating proof of concept probes that will function in Venus surface conditions and do so for long time periods (weeks to months) (Figure 1). These probes will be designed, fabricated, and demonstrated by test to operate in Venus conditions. To accomplish these goals, LLISSE leverages NASA Glenn Research Center (GRC) high-temp electronics, sensors, power, and communications in an innovative operations model to collect and transmit science data for 60 Earth days or longer in Venus conditions.

The key science questions targeted by LLISSE include: better knowledge of super-rotation of the atmosphere (Goal 1, Objective B), the climate and its evolution (Goal 1, Objective B), and surface – atmosphere interaction/weathering (Goal 3, Objective B). A significant contribution toward these questions will be the ability to take periodic measurements over a long-duration – Venus daylight period and a transition(s) at the end- or approximately 60 Earth days minimum. Science objectives include: estimating the momentum exchange between the planet and its atmosphere, acquiring temporal weather data to update global circulation models and quantify near surface atmospheric chemistry variability. Anticipated instruments include: Wind speed/direction sensors, temperature sensors, pressure sensors, chemical multi-sensor array.

Given its small volume and expected low mass (10 kg), LLISSE could be delivered to the Venus and its surface as a ride along with an orbiter and then descend with a lander or probe or be dropped from an aerial platform, or a set of probes put in a dedicated capsule for entry and deployment. Once the probe is deployed into the Venus atmosphere, it decelerates in the thickening atmosphere with its drag plates to touchdown on the surface at under 8 m/s² or less. The probe then begins taking measurements and transmitting important parameters at or near the surface. At preset intervals, the probes acquire the science measurements and beams the data to the orbiting host spacecraft. LLISSE will not only acquire important science measurements but also pave the way for larger and more complex lander missions to explore Venus in the future.



Figure 1. LLISSE probe concept

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DEVELOPMENT OF VENUS BALLOON SEISMOLOGY MISSIONS THROUGH EARTH ANALOG**EXPERIMENTS.** S. Krishnamoorthy¹, A. Komjathy¹, J. A. Cutts¹, M. T. Pauken¹, R. F. Garcia², D. Mimoun², J. M. Jackson³, S. Kedar¹, S. E. Smrekar¹ and J. L. Hall¹¹ Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA² Institut Supérieur de l'Aéronautique et de l'Espace (ISAE), Toulouse, France³ Seismological Laboratory, California Institute of Technology, Pasadena, CA

Introduction: The study of a planet's seismic activity is central to the understanding of its internal structure. Seismological studies of the Earth led to the discovery of the layered structure of its interior, which in turn has led to great advances in the understanding of catastrophic events such as earthquakes and volcanic eruptions. Earth's planetary twin, Venus, has shown strong evidence of recent geological activity. Seismological studies can help us understand the evolution of these geological events and aid our quest to determine why Venus is so similar to Earth in certain aspects yet so different. However, extremely high temperature and pressure conditions on the surface of Venus present a significant technological challenge to performing long-duration seismic experiments. Therefore, despite visits from many spacecraft since Mariner 2 in 1962, the internal structure of Venus still remains a mystery.

Seismic experiments conducted from aerial platforms offer a unique opportunity to explore the internal structure of Venus without needing to land and survive on its surface for long durations. In particular, the dense atmosphere of Venus allows for balloons to be flown in the mid and upper atmospheric regions. These balloons may be used as vehicles for seismic experiments that can collect infrasound data as indication of seismic waves while floating in the prevailing winds. One possible way to detect and characterize quakes from a floating platform is to study the infrasonic signature produced by them in the atmosphere. Infrasonic waves are generated when seismic energy from ground motions are coupled into the atmosphere. The intensity of the infrasound depends heavily on the relative density of the atmosphere and the planet's crust. On Venus, where the atmospheric impedance is approximately 60 times that of Earth, the coupling of seismic energy into the atmosphere is expected to be commensurately greater.

However, the performance of seismic experiments from balloons comes with its own set of challenges – sulfuric acid in the Venusian atmosphere can degrade balloon material and the remote deployment of balloons on another planet is also a technological challenge. There also exist scientific challenges – the process of infrasound generation and propagation is complex, depending on many factors such as quake location,

intensity, and prevailing atmospheric conditions, to name only a few. Therefore, sophisticated simulations and experiments are needed to develop a scientific mission that can inform us of the internal structure of Venus.

In order to achieve the aim of performing geophysical experiments from an atmospheric platform, JPL and its partners (ISAE-SUPAERO and California Institute of Technology) are in the process of developing technologies for detection of infrasonic waves generated by earthquakes from a balloon. The coupling of seismic energy into the atmosphere critically depends on the density differential between the surface of the planet and the atmosphere. Therefore, the successful demonstration of this technique on Earth would provide ample reason to expect success on Venus, where the atmospheric impedance is approximately 60 times that of Earth.

Presentation Content: In this presentation, we will share results from the first set of Earth-based balloon experiments performed in Pahrump, Nevada in June 2017. These tests involved the generation of artificial sources of known intensity using a seismic hammer and their detection using a complex network of sensors, including highly sensitive micro-barometers suspended from balloons, GPS receivers, geophones, microphones, and seismometers. This experiment was the first of its kind and was successful in detecting infrasonic waves from the earthquakes generated by the seismic hammer. We will present the first comprehensive analysis of the data obtained from these sensors and use these data to characterize the infrasound signal created by earthquakes. These data will also inform the design of future experiments, which will involve tropospheric and stratospheric flights above naturally occurring areas with high seismicity.

EARTH AND VENUS: PLANETARY EVOLUTION AND HABITABILITY. P. E. Laine¹, ¹Departments of Physics and Computer Science and Information Systems, P.O. Box 35, FI-40014 University of Jyväskylä, Finland, pauli.e.laine@jyu.fi.

In our Solar System Earth and Venus are very similar at planetary level. Venus has sometimes even named Earth's twin because they both have similar size, density, surface composition and have cloudy atmosphere. There are also some differences between these planets. Venus is about 30% closer the Sun than Earth. Venus has retrograde rotation (opposite to Earth's) of 243 days, longer than its's orbital period, 225 days. The most striking difference is the atmosphere, 90 times more dense than Earth, and it contains 96.5% CO₂, compared to 0.04% on Earth. These planets' orbits are within the habitable zone (for the existence of liquid water). What caused these two planets to evolve very differently? Could Venus have evolvel to more Earth-like state? Could Earth end up to similar state that Venus is today? This presentation will review these important questions in the light of astrobiology and Earth's future.

TOWARD A VENUS SPATIAL DATA INFRASTRUCTURE (VSDI). J. R. Laura, J. J. Hagerty, T. N. Titus, and T. M. Hare, USGS Astrogeology Science Center, Flagstaff, AZ, 86001, email: jlaura@usgs.gov.

Introduction. The efficient collection and utilization of remotely sensed planetary data is a primary driver for efficient and effective active flight mission operations and nearly all scientific research projects. The value and complexity of collected data increases when the data are accurately spatialized. Colloquially, the act of “pushing the pixel” to the body increases the amount of information included in the collected data, adds the ability to perform cross data set studies, and increases the complexity of data storage, search, and use. The terrestrial community has broadly developed Spatial Data Infrastructures (SDIs) to address the aforementioned complexities and more recently, the planetary science community has begun development of a Planetary Spatial Data Infrastructure (PSDI) framework [1]. Herein, we describe what a PSDI is and who may benefit from the development and adoption of a Venus SDI (VSDI).

Planetary Spatial Data Infrastructure (PSDI) A PSDI is the collection of users, policies, standards, data access mechanisms, and the data themselves [2,3]. These components are grouped into two themes: human- data interaction (data and people), and facilitating technologies (policy, access, and standards). We briefly describe each component of a PSDI in turn.

Users: A PSDI seeks to remove the burden of data processing from the end user, and improve data access, discovery, and use in order to allow for increased focus on the science that uses the data. **Policies:** A PSDI succeeds or fails at the adoption phase and policies to support the collection and sharing of data in standards compliant ways, and to ensure longevity of infrastructural services are critical to that success. **Standards:** The development, codification, and adoption of standards to support data interoperability and use in widely available tools are critical for usability. **Data Access:** Improved discoverability and ease of spatial data use would not be impactful without data access mechanisms to reduce the burden of discovery for end users. Access mechanisms are transient and dependent upon infrastructural data providers. **Data:** Data can be divided into two broad categories: foundational and framework. The former include geodetic control, topography, and orthorectified images [1] and are essential as baseline data products across a range of scientific and decision-making processes. For example, NASA’s Magellan mission provided the initial seeds for a VSDI once derived products like the synthetic aperture radar (SAR) F-MAP mosaics [4] and global topography [5] were generated. Framework data products are those of critical importance to a smaller subset of the research community.

Benefits of a PSDI Simplistically, “spatial data

should just work” and PSDIs exist to support complex decision-making and knowledge synthesis by the user community. The collection, preparation for use, and dissemination of spatial data requires significant expertise and the planetary science community currently pushes that burden across the entire research community. We argue that, as the volume and complexity of collected spatial data increases this model is not sustainable. A PSDI seeks to address this issue by pushing the requirement away from the planetary research scientist and towards the spatial expert. Additionally, PSDIs seek to: (1) improve channels of communication between data providers, maintainers, and users, (2) improve data reusability and data fusion potential, (3) improve data access and discovery mechanisms, (4) reduce duplication of infrastructural data storage and dissemination solutions to support increased development of end- user access portals, and (5) identify gaps in knowledge.

Towards a Venus Spatial Data Infrastructure Rajabifard [3], identifies a process based view of SDI development that can act as a road map for the implementation and adoption of SDIs within a research community. In this abstract we seek to fulfill the first goal in creating an SDI, the communication of the existence of PSDI and engagement with the community. A knowledge inventory is the second step in developing a body specific PSDI. A knowledge inventory seeks to answer questions such as “What data products are available and at what accuracies?”, “Are data products available in a standards compliant form?”, “What data are missing and how might they be collected or derived?”, “Who can provide infrastructural data management?”. In proposing future data acquisition missions, it is essential to focus on strategies that seek to maximize the science return *and* support collection and generation of high quality, low-error, spatial data products.

Conclusion. The development of a VSDI supports current research efforts and demonstrates a comprehensive plan for the management and dissemination of newly collected data to the broader planetary science community in a highly usable form should new missions be proposed.

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Possibility of Microorganisms being the Missing Absorbers of Solar Radiation in the Clouds of Venus and their Detection

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Since the inference [1] and subsequent confirmation that the Venus cloud particles are composed primarily of concentrated sulfuric acid [2], the causes of the absorption of solar radiation in the clouds has been a puzzle [3, 4]. Many substances have been proposed [5] but none can be confirmed due to observational difficulties as well as due to lack of detection of any processes that can create them. FeCl₃ is favored as the most likely absorber [6, 7], but its lifetime is limited by the presence of sulfuric acid and requires a constant re-supply from somewhere, either from within the clouds or from surface. In light of the suggestion that Venus may have been the first habitable planet and could have harbored liquid water on the surface for as long as two billions years and the realization that some terrestrial microorganisms exhibit spectral absorption characteristics similar to those of Venus clouds [8, 9], the possibility of their existence in the clouds of Venus in the habitable zone cannot be ignored. Recent discovery that life has been detected in the extremely hot conditions (on Earth surface) in concentrated acid found in the Danakil depression in Eritrea bolsters the need to undertake efforts to detect the possible existence of micro-organisms in the clouds of Venus with a life detection imaging microscope and/or Raman LIDAR in case life evolved in its early history and migrated to the clouds. Microorganisms are common in Earth clouds even at altitudes as high as 41 km.

A long lived aerial platform capable of sampling different altitudes in the Venus clouds is needed to sample the cloud particles, trace species, solar spectrum and the ambient meteorological conditions towards identifying the absorbers, whether particulate, gaseous or organic.

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Venera 13 & 14 Discharge Current Measurements – Evidence for Charged Aerosols in the Venus Lower Atmosphere? R. D. Lorenz¹, ¹Johns Hopkins Applied Physics Laboratory, Laurel, MD 20723, USA (ralph.lorenz@jhuapl.edu)

Introduction: Measurements of discharge currents on the Venera 13 and 14 landers during their descent in the lowest 35km of the Venus atmosphere are interpreted as driven either by an ambient electric field, or by deposition of charge from aerosols. The latter hypothesis is favored, and would entail a modest lower atmosphere aerosol opacity, with particles with charge density within a factor of a few of that observed in Saharan dust transported over long distances on Earth. This would imply the lower atmosphere is not as 'clear' as is often assumed.

Measurements: Following the discovery of low frequency (LF, 10-80 kHz) electromagnetic emissions within the Venus atmosphere during the descents of the Venera 11 and 12 landers in 1979 using the Groza ("thunderstorm") instrument (Ksanfomality et al., 1979; 1983), follow-up measurements were made with a slightly augmented instrument ("Groza-2") on Venera 13 and 14. In addition to a loop antenna to detect LF distant emissions from electrostatic discharges such as lightning, Groza carried a microphone to detect thunder, while Groza-2 instead carried a seismometer. In addition, in order to be certain that the LF emissions measured were not due to some kind of local activity generated by the descent of the vehicle itself, a corona discharge electrode was included on Venera 13 and 14 and the discharge current was monitored.

The measurements were made only in the post-parachute phase of descent, when the vehicles were falling at a terminal velocity controlled by the disk-like drag brake at the top. This velocity varied smoothly, as the inverse square root of atmospheric density, declining from about 40 m/s at 40km, to about 8 m/s near the surface. The current measurements were reported with little comment in graphical form by Ksanfomality et al. (1982) and are reproduced in figure 1, but have received essentially no discussion in the literature since.

In [1] I provide quantitative interpretation of two possible mechanisms for these currents.

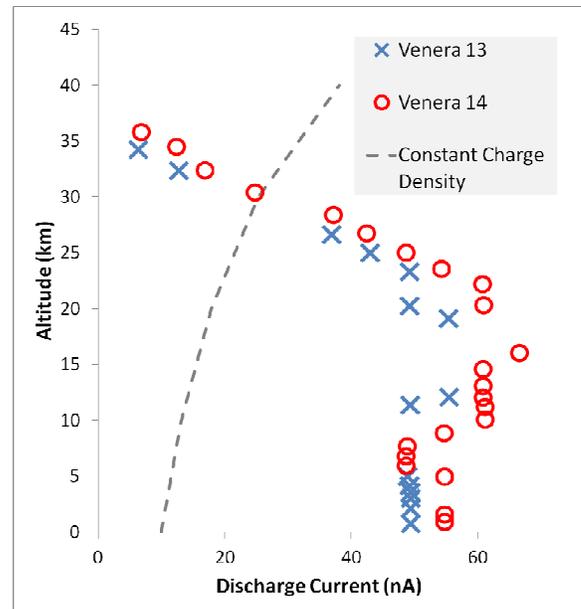


Figure 1. Measurements (Ksanfomality et al., 1982) obtained during the descent of the Venera 13 and 14 landers (crosses and circles respectively). Currents above 35km, and on the surface, were too low to be measurable. The vehicle descent speed in m/s is shown with the dashed line.

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AEROCAPTURE FEASIBILITY ASSESSMENT FOR MISSIONS TO VENUS. Y. Lu^{1†}, P. G. Athul^{2†}, and S. J. Saikia^{3†} and J. A. Cutts^{4‡}, ¹yelu@purdue.edu, ²apradee@purdue.edu, ³ssaikia@purdue.edu, [†]School of Aeronautics and Astronautics, Purdue University, 701 W. Stadium Ave., West Lafayette, IN, 47907, [‡]james.a.cutts@jpl.nasa.gov, NASA-Caltech Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, CA, 91109.

Venus Exploration: Venus has been visited by spacecraft from US, Russia, and Japan over the last few decades; however, the last US mission to Venus—Magellan, was over 20 years ago. As instrument capability increases, another mission to Venus could significantly improve our understanding. Exploring Venus will help in understanding how our planet has formed. three goals were identified in VEXAG Goals, Objectives & Investigations study [1]:

- understanding the atmosphere’s origins and its evolution, as well as the climate history,
- determining how the surface and interior evolved,
- understanding the interior-surface- atmosphere interactions over time, as well as if liquid water was ever on Venus.

There have been missions proposed to perform atmospheric and/or surface sample returns, where an Earth return orbiter is required [2]. Recently, Venus Bridge—a SmallSat program is studies at NASA, aiming to link the past and future US exploration by one or more small missions launching in the early-to-mid 2020s [3].

Venus Bridge Study: Venus Bridge study considered low-cost candidate concepts including CubeSats, SmallSats, in-situ/lander, and balloon, all of which have delivered payload less than 200 kg. For a low-cost mission, ride-along options with spacecraft that are using Venus for gravity assist either for exploring the heliosphere or the outer planets, are particularly attractive. However, the ΔV requirements for achieving orbit and particularly a tight orbit using chemical propulsion can be prohibitive. Aerocapture is a promising alternative for mass-efficient Venus Bridge orbital missions but approaches to aerocapture that avoid complex navigation and control capabilities will be essential if aerocapture is to be affordable.

Aerocapture Assessment: Aerocapture has been shown to enhance mission capabilities to Venus by an increase in delivered payload of 79% for circular orbit (and 43% for elliptic orbit) [4]. Aerocapture assessments were completed by NASA in 2006 for missions to Neptune, Titan, and Venus [5]. While the study results on Neptune and Titan are detailed, Venus aerocapture study report lacked in detail and provided a reference point design. Parametric study of Venus aerocapture was also conducted in [6]; they considered an Apollo style entry vehicle with L/D of 0.2 and 0.35, and entry velocities from 10-15 km/s. There is a need

to perform a feasibility study on Venus aerocapture and conduct more comprehensive parametric studies. Previous study on Aerocapture assessment for ice giants conducted at Purdue University has provided more insights on the applicability of aerocapture—key parameters in aerocapture system design being vehicle L/D , required corridor width, peak g-load, peak heat rate, and total heat load [7].

In this study, feasibility of aerocapture at Venus is analyzed with a comprehensive approach considering a range of vehicle L/D , ballistic coefficient, and arrival V_∞ . Deceleration load limited is considered, and peak heating rate and total heat load are also evaluated using empirical relations. A parametric study of the target apoapsis and post-capture required ΔV will also be conducted. Detailed applicability and feasibility space will be presented. Results and conclusions will be drawn in the perspective of vehicle design consideration and interplanetary arrival conditions.

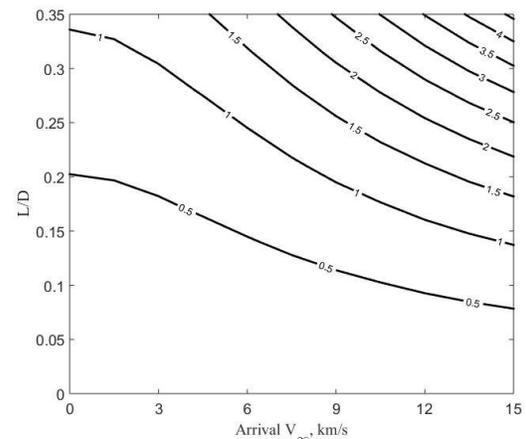


Fig 1: Theoretical corridor width for aerocapture missions to Venus.

Interplanetary Trajectory Consideration. In addition, trajectory search will be performed for a ballistic transfer for Venus orbiting mission, thus obtaining for more details on the arrival declination and time of flight to Venus.

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CAN ROSETTA NOBLE GAS AND ISOTOPIC MEASUREMENTS CONTRIBUTE TO UNDERSTANDING THE ORIGIN AND EVOLUTION OF VENUS' ATMOSPHERE? K. E. Mandt¹, A. Luspay-Kuti², O. Mousis³, S. Fuselier^{2,4}. ¹Johns Hopkins University Applied Physics Laboratory, Laurel, MD, ²Southwest Research Institute, Space Science & Engineering, San Antonio, TX 78228, ⁴Department of Physics and Astronomy, University of Texas at San Antonio, San Antonio, TX.

Introduction: Comparative planetology of the atmospheric evolution of the terrestrial planets is essential for understanding how life formed and continues to thrive on Earth, but not on present-day Venus or Mars. Extensive studies have been conducted for Earth [e.g. 1] and an entire mission has been devoted to evaluating the history of the Martian atmosphere [2]. This leaves the evolution of Venus as the least understood [3].

Studying the atmospheric history of Venus can determine: (1) the origin of volatiles on Venus compared to Earth and Mars; (2) the total initial abundance of volatiles, in particular of water; and (3) the outgassing history of Venus. The VEXAG goals include the above objectives and outline the need for measurements of stable isotope ratios, D/H, ¹²C/¹³C, ¹⁴N/¹⁵N, ¹⁶O/¹⁷O, ¹⁶O/¹⁸O and ³⁴S/³²S, as well as the relative abundances and isotope ratios of the noble gases.

Sources of volatiles: Atmospheric evolution studies require some information about contributing sources of initial isotopic abundances. Solar values, representative of the bulk abundance of the protosolar nebula (PSN), have been investigated in depth [4]. However, meteoritic studies show that the isotopic abundances of the PSN were not homogenous [4]. Furthermore, observations of D/H in comets remain puzzling [5]. This suggests that the isotopic and noble gas abundances of the terrestrial planets is likely to result from a complex mix of gas absorbed directly from the PSN and volatiles contributed by impact of planetesimals and comets formed at varying distances from the Sun.

Comet measurements remain limited. Ground-based observations have provided D/H in water and HCN, ¹²C/¹³C in C₂, CN and HCN, ¹⁴N/¹⁵N in HCN and NH₃ and ¹⁶O/¹⁸O in water for several comets [see 6 and refs. therein]. No noble gas measurements in comets were available prior to the Rosetta mission. Since arrival at the comet 67P/Churyumov-Gerasimenko (67P), a Jupiter family comet, the Rosetta mission has reported precise measurements of D/H ¹⁶O/¹⁷O and ¹⁶O/¹⁸O in water [5], ¹²C/¹³C and ¹⁶O/¹⁸O in CO₂ [7], ¹²C/¹³C in C₂H₄, C₂H₅ and CO [8], ²⁹Si/²⁸Si [8] and ³⁰Si/²⁸Si the relative abundance of the Argon [9] and Xenon isotopologues [10]. Further analysis of the Rosetta data continues, and more stable isotope ratios and noble gas abundances are expected in the coming years.

Relevance to Venus: New observations of noble gas abundances and stable isotope ratios from comets provide important information on potential sources of volatiles for Venus. They can first be used to refine models of atmospheric evolution based on the limited measurements available for the atmosphere of Venus [e.g. 11]. However, given the limitation of these measurements, they can also contribute to models that could be used to project measurements for future missions, as we did for *New Horizons* prior to the arrival at Pluto [11].

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VENUS' RADAR-DARK STREAKS: BAKISAT CRATER AND IMPACT-RELATED ORIGINS. S. N. Martinez^{1,2,3}, A. H. Treiman², and W. S. Kiefer², ¹University of Houston, Department of Earth and Atmospheric Sciences. ²Lunar and Planetary Institute, 3600 Bay Area Blvd, Houston, TX 77058 <treiman@lpi.usra.edu>; ³Department of Earth and Environmental Sciences, Tulane University, 6823 St. Charles Avenue, New Orleans, LA 70118 <smartinez1@tulane.edu>.

Introduction: Many large impact craters on Venus are associated with SAR-dark parabolic deposits [1,2], which are inferred to form as plumes of ejecta penetrate up through Venus's atmosphere, spread ballistically, fall back down, and are dispersed by zonal winds. Many smaller craters are associated with SAR-dark deposits which are not typical parabolas. We investigated the SAR-dark streak on Nissaba Corona, confirm its association with the impact crater Bakisat, and speculate on mechanisms for the formation of it and similar SAR-dark streaks [3].

Nissaba Dark Streak: Nissaba Corona, on the north flanks of Sif and Gula Montes, shows a long narrow SAR-dark streak oriented ~E-W with its E end near the Bakisat impact crater, Fig. 1 [3-5]. Bakisat is a double impact crater, 7.2 km across. The streak is clear in Magellan SAR for at least 330 km, and is as wide as 40 km. The streak passes over an elliptical depression on Nissaba and is slightly mis-aligned with Bakisat.

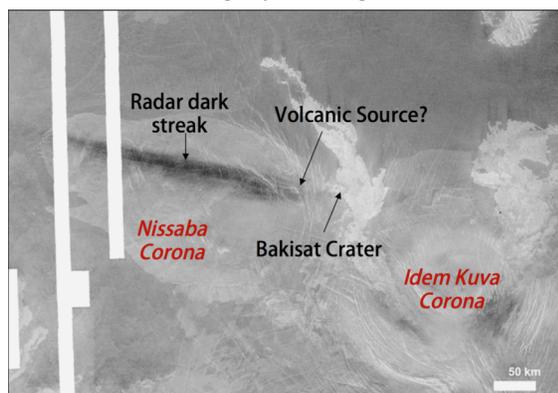


Figure 1: Magellan SAR image of Nissaba Corona and Bakisat radar dark streak. Bakisat Crater post-dates the radar-bright lava flow from Idem-Kuva, which overlies the flanks of Nissaba Corona.

The Nissaba streak has lower RMS slope than its surroundings (Fig. 2), and lower radar emissivity. These data are consistent with the geological mapping (from Magellan SAR) that the Nissaba streak is best interpreted as an airfall deposit of relatively smooth and porous material.

Streak Formation: The idea that the Nissaba streak is volcanic in origin [4] does not withstand scrutiny; it appears that the dark material post-dates the potential caldera source, the elliptical depression. The Nissaba streak is clearly not a parabolic impact deposits [1,2], nor is it like eroded remnants of a parabola's deposits [6,7].

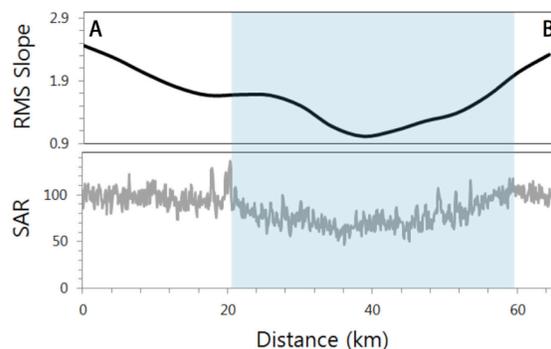


Figure 2. N-S profiles of Magellan RMS slope (degrees) and SAR brightness (DN) taken across the Nissaba dark streak. The blue region denotes the streak.

Other Impact Processes. Accepting that the Nissaba streak is genetically related to the Bakisat Crater, several mechanisms for streak formation can be proposed. 1) A streak could represent ejecta from a post-impact plume, similar to those which produce parabolas [8], but which was not buoyant enough to penetrate through Venus' atmosphere. 2) A streak could represent a low-angle jet of ejecta from impact (e.g., Ferber crater). 3) A streak could represent dust created in an airburst as the crater-forming meteoroid descended through the atmosphere [9]. 4) A streak could represent dust shed by a bolide travelling at low angle through the atmosphere (e.g., at -19.5° , 358.5°) [10].

It is not yet clear how to distinguish among Venusian dark-streak deposits that might have formed by these mechanisms. At least 12 narrow, linear streaks exist at Venus craters, including Bakisat. Nine of the 12 craters are less than 23 km diameter. The absence of parabolic deposits at these craters indicates a lack of ballistic spreading, consistent with ejecta plumes that remained confined within the Venus atmosphere. The association with small craters is consistent with a buoyancy mechanism such as mechanism 1 above but does not rule out contributions from other processes.

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ADVANCING VENUS GEOPHYSICS WITH THE NF4 VENUS ORIGINS EXPLORER (VOX) GRAVITY INVESTIGATION. E. Mazarico¹, L. Iess², F. de Marchi², J. C. Andrews-Hanna³, and S. E. Smrekar⁴, ¹NASA Goddard Space Flight Center, Greenbelt MD, 20771, USA (erwan.m.mazarico@nasa.gov); ²Sapienza University of Rome, Rome, Italy; ³Lunar and Planetary Laboratory, University of Arizona, Tucson AZ, 85721, USA; ⁴Jet Propulsion Laboratory, California Institute of Technology, Pasadena CA, 91109, USA.

Introduction: The Venus Origins Explorer (VOX) is a JPL-led New Frontiers 4 mission [1] to answer critical questions about the origin and evolution of Venus. Venus stands out among other planets as Earth's twin planet, and is a natural target to better understand our own planet's place, in our own Solar System but also among the ever-increasing number of exoplanetary systems. Here, we focus on the VOX radio science investigation, which will make use of the Ka-band telecom unit provided by the Italian Space Agency (ASI) to map the global gravity field of Venus to much finer resolution and accuracy than current knowledge based on the NASA Magellan mission [2].

Science Goals: An improved gravity field of Venus is necessary to address essential questions, particularly the root causes of the divergent evolutionary paths of Earth, with its recycling of the crust through plate tectonics, and of Venus, with its diverse tectonics and potentially active regions. The tesserae features, uniquely found on Venus, are hypothesized to be continent-like remnants, but studies based on Magellan data have not been conclusive. The determination of gravity over global scales with sufficient accuracy to reveal differences in elastic and crustal thickness over the tesserae terrain will constrain thermal evolution of Venus' crust. This will inform their origin and composition and determine the relative importance of tectonism and subduction.

Additional science investigations will of course be enabled by an accurate global gravity field. In particular, gravity gradiometry techniques applied to the Magellan field over very limited areas have shown hints of interesting structures [3], such as folding in Ovda Regio, a major tesserae plateau, and active rifting in Hecate Chasma. Just detectable at degree 80 with gravity gradiometry techniques [3], they are not visible at degree 60, which characterizes the existing resolution over much of the planet.

Science Requirements: Although the Magellan gravity field was calculated to degree and order 180 [2] to avoid aliasing of high-frequency power, its actual resolution is much lower (~70 on average). The Magellan field was also hampered by the non-uniform coverage. Numerous areas of high interest have poor Magellan coverage and elude quantitative gravity interpretation: Artemis Chama ($l \sim 55$, a possible subduction zone); Parga Chasmata ($l \sim 60-75$); high VIRTIS emissivity areas such Imdr, Themis, and Dione Regio

($l=45-70$); tesserae plateaus such as Alpha Regio and Lakshmi Planum and low-elevation planitia that could host buried structures ($l=40-70$).

The minimum gravity resolution requirement for VOX ($l=95$) was chosen to be near the highest Magellan degree strength ($l \sim 100$), which was only realized over a very small fraction of the planet in that dataset [2]. It follows that what has been learned from Magellan in the very limited areas of good gravity coverage can be extended to the entire planet. The VOX resolution requirement is the minimum needed to perform robust analysis and to answer geophysical questions that could only be partially studied by even the best Magellan data [4]. However, the actual VOX performance will exceed this requirement, and will very likely enable unanticipated advances and discoveries.

Comprehensive simulation: We performed comprehensive simulations of gravity field recovery with VOX data, with the NASA GSFC orbit determination and geodetic parameter estimation software GEODYN, using a realistic mission scenario, tracking schedule, and high-fidelity Doppler tracking noise model.

GEODYN is the orbit determination and geodetic parameter estimation software developed and maintained at NASA GSFC [5]. It relies on a number of models to integrate the spacecraft trajectory (force models) and to determine a computed observation to be compared with the actual observable (measurement models). GEODYN incorporates state-of-the-art models to enable high-accuracy geodetic studies such as that of VOX.

We assess the quality of the recovered gravity solution by comparing the estimated spatially-resolved uncertainties to the actual errors (differences with the truth). These uncertainties and a resolution map, derived through a clone-mapping method [6], demonstrate the VOX requirements to conduct the science investigations are met.

Conclusions: The capable Ka-band telecom onboard VOX enables a robust, highly-accurate gravity science investigation that will answer profound questions related to Venus' evolution.

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A Paradigm Shift in Planetary Exploration? K. McGouldrick¹, ¹University of Colorado Boulder (key-in.mcgouldrick@lasp.colorado.edu).

Over 3000 extrasolar planets have now been discovered, and the vast majority of these via the transit method. Looking forward, we will soon be seeing a tremendous volume of exoplanetary data derived from observations of transiting exoplanets. For the most part, due to the realities of transit observations of exoplanets, this information will be atmospheric in nature. Making sense of this coming dataset requires a more thorough understanding of the terrestrial planetary atmospheres in our own solar system. Here, I argue that as a result of the growing field of exoplanetology we are at the cusp of a major shift in the methods used to understand planetary processes, and that responding to this shift will require a new way of thinking about and executing the tasks of planetary exploration.

HOW VOLCANO-TECTONICALLY ACTIVE IS VENUS ANYWAY? P. J. McGovern, Lunar and Planetary Institute, USRA, 3600 Bay Area Blvd., Houston, TX 77058 (mcgovern@lpi.usra.edu).

Introduction.

Data collected during the initial reconnaissance of the inner solar system (through the mid-1990s) indicated ages for terrestrial planet surfaces (other than the plate tectonics-endowed Earth) of order 10^9 years, suggesting dead or at best dormant planets. For Venus in particular, a consensus emerged, based largely on the impact cratering record, that a somewhat rapid and quite vigorous era of volcano-tectonic (V-T) resurfacing was followed by an era of relatively low V-T activity of substantial duration. Under such a scenario, cratering-derived mean surface ages of as much as 750 Myr [1] pointed towards rather small present day V-T rates. However, data obtained during the last two decades, combined with careful re-analysis of previous datasets, point to substantial present-day activity at Venus. For example, Venus Express instruments have uncovered signatures of geologically recent [2] and even possibly active [3] volcanism on that planet. A re-examination of Magellan SAR images of dark-floored craters [4] suggested a mean surface age for Venus of around 150 Ma. This result was followed up by a recalibration of the Venus impactor distribution curve giving a comparably young surface age [5].

These results justify a re-examination of tectonic and volcanic activity on Venus. Suggestions of substantial ongoing volcano-tectonic activity on a “one-plate planet” [6] provide strong motivation to return to Venus with modern remote sensing and in-situ monitoring technology, in order to listen for the vital signs of a planet heretofore left for dead.

Volcano-tectonic seismicity: Hawaii Baseline.

Large basaltic volcanic edifices formed at intraplate volcanic settings (“hotspots”) on Earth are the best analogs for large volcanoes on Mars and Venus. At Hawaii, extensive instrumentation provides detailed records of seismic activity. A catalog of 7022 earthquakes spanning 45 years, with moment magnitudes M_0 ranging from 3.2. to 6.6 [7], can be used to derive the Gutenberg-Richter (G-R) frequency-magnitude relation for the Island of Hawaii, expressed as $\log(N) = a - bM_0$, where N is the number of earthquakes with magnitudes greater than or equal to M_0 , and a and b are constants [8]. By this analysis, (Fig. 1), one earthquake with M_0 4.9 or greater can be expected every year. Under the assumption that the mechanisms of seismicity for edifice building are similar across the planets, we use the same b for all planets [9] and scale a according to estimates of magmatic volume flux rates dV/dt at the various planets. Over the 80 Myr history of the Hawai-

ian-Emperor volcanic chain, dV/dt is around 1.7×10^{-2} km^3/yr [11].

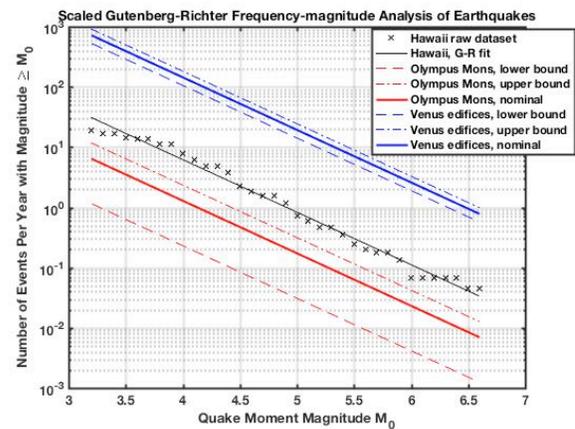


Figure 1. Frequency of seismic events with moment $\geq M_0$ as a function of M_0 . Black ‘x’s show raw data for Hawaii [7], and the black line shows the best-fit G-R relation ($a = 5.93$ and $b = 0.872$), scaled to the duration of the seismic catalog to give rates. Red lines show nominal and bounding G-R relations for quakes at Olympus Mons, Mars; blue lines show them for volcanic edifices on Venus.

Extrapolation to Venus.

Findings of a young(er) Venus surface age [4,5] greatly enhance predicted rates of volcanism. Estimates of dV/dt associated with 145 large volcanoes on Venus [10], under the assumption of a surface age of 150 Ma [4,5], yields nominal $dV/dt = 3.95 \times 10^{-1}$ km^3/yr , more than an order of magnitude greater than the Hawaiian-Emperor flux and comparable to Earth’s total intraplate volcanic flux [11]. Scaling the Hawaiian G-R relation to Venus edifices (alone) yields a prediction of at least one quake with $M_0 \geq 6.5$ per year.

Activity Levels: Not Dead Yet?

The findings for magmatic flux dV/dt and seismic activity suggest the obituaries for Venus that commonly appear in the literature are premature.

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Glenn Extreme Environments Rig Status and Recent Testing History. L. Nakley, D. Vento, J. Balcerski, T. Kremic: *NASA John H. Glenn Research Center at Lewis Field, 21000 Brookpark Road, Cleveland, OH 44135*

History: The Glenn Extreme Environments Rig (GEER) first became operational in the early part of 2015. Since that time GEER has completed a number of scientific tests and has undergone improvements in the chemical delivery system and analytics following a year of operations experience.

Recent Updates: In June 2016, the GEER process system was rebuilt to provide a more robust system, higher accuracy and new capabilities. New insulation was installed on the exterior of the pressure vessel and gas lines. The newly revamped GEER plumbing system can provide extremely precise custom gas mixtures using any gas desired by the investigator in any combination. GEER can heat the resulting mixture up to 500 deg C and 1500 psia.

The 304 stainless steel vessel walls were polished to reduce corrosion rate and reduce unwanted chemical reactions. The process lines were replaced with high purity Sulfinert coated tubing. The GEER team added the ability to individually boost specialty gases to GEER thus allowing operators to make very precise changes to the gas chemistry inside of GEER during a test while at high temperature and pressure. High accuracy mass flow meters were added to further improve gas mixing accuracy and precision. An in-line, integrated Inficon MicroGC Fusion was added for real time gas analysis along with a high purity gas sampling system, providing fully automated, real time analysis of the gas chemistry inside of GEER in minutes. This complements a co-located mass spectrometer and both are used for regular monitoring of the vessel chemistry. All internal vessel components were replaced with polished 304SS equivalents. Hot vent down capability was increased. Finally, an automated liquid injection system was added and is rated for max vessel operating conditions of (1500 psia, 500 C).

Recent Results and Publications: In May 2016, GEER completed a test that exposed high temperature electronics to Venus surface conditions for 21.5 days. *This demonstrated the potential for operating robotic spacecraft in the Venus environment without the need for thermal or environmental protection.* Results from this test were published in December 2016 and received national media attention [1].

In April 2017 GEER implemented an 80 day test at Venus surface conditions to simulate chemical weathering of expected Venus minerals. This test supported a ROSES award to a team led by Prof. Ralph Harvey of Case Western Reserve University. The test

concluded in July 2017 and nearly doubled previous operation record of 42 days at Venus surface conditions. Preliminary results of these and previous experiments were presented at the recent Venus Modeling Workshop[2].

In June 2017, NASA TM2017-219437 “Chemical and Microstructural Changes in Metallic and Ceramic Materials Exposed to Venusian Surface Conditions” was published. This report provides an extensive and valuable resource detailing the behavior of a variety of engineering materials at Venus surface conditions[3].

Community Involvement: An external science advisory panel has been formed. This panel receives updates on GEER operations and plans, and provides guidance to ensure that the facility continues to meet the needs of the science community. Recent recommendations that are actively being incorporated into the GEER development plan include: expanded capability to service multiple customers simultaneously utilizing additional pressure vessels, enabling solid sample in situ optical analysis to observe real-time material changes during atmospheric exposure, and providing increased clarity and guidance for prospective users and researchers.

Expected Work in the Near Future: A number of future tests are scheduled. Activities will support technology development efforts such as HOTTECH awards, support for the Long Lived In-Situ Solar System Explorer (LLISSE) project[4], and potential science experiments proposed to ROSES.

References:

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- [2] Costa, G., et al. (2017) Chemical and Microstructural Changes in Metallic and Ceramic Materials Exposed to Venusian Surface Conditions. *NTRS 20170006025*.
- [4] Kremic, T., et al. (2016) Long-Lived In-Situ Solar System Explorer. *VEXAG presentation located at: http://www.lpi.usra.edu/vexag/meetings/archive/vexag_14/presentations/27-Kremic-Long-Lived%20Venus%20Station.pdf*

LARGE STATIONARY GRAVITY WAVES: A GAME CHANGER FOR VENUS' SCIENCE. T. Navarro¹, G. Schubert and S. Lebonnois², ¹Dept of Earth, Planetary, and Space Sciences, UCLA, USA (tnavarro@epss.ucla.edu), ²Laboratoire de Météorologie Dynamique (LMD/IPSL), Sorbonne Universités, UPMC Univ Paris 06, CNRS/INSU France.

Introduction: Illustrated in figure 1, the recent discovery of a stationary planetary-scale structure in the atmosphere of Venus by the spacecraft Akatsuki [1] leaves many unanswered questions: What is the nature of this wave? What is its origin? What is its role in the superrotation of the atmosphere? Etc ... In this work, we tackle these issues with the use of a Global Climate Model (GCM). It appears that the implications of this study are of substantial importance for science priorities and future measurements.

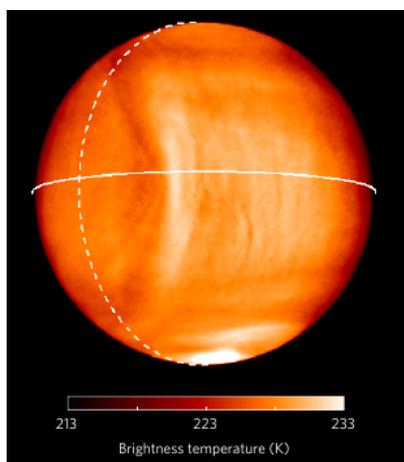


Figure 1: Brightness temperature of the Venus disk acquired by Akatsuki's Long Infrared camera on December 7th, 2015. From [1].

Model: The model used in this study is the Institut Pierre-Simon Laplace (IPSL) Venus GCM [2]. It includes a dynamical core on a longitude-latitude grid and a full parameterization of the physics with, among other things, a predicted vertical stability profile, a complete radiative transfer and a latitude-dependent cloud layer. In order to address the origin of the gravity wave seen by Akatsuki, we implement a parameterization of the effects of subgrid topographic slopes on the flow, a classic implementation for Earth GCMs [3].

Results: As seen in Figure 2, the GCM is able to reproduce well the observations, above Aphrodite Terra (Figure 1), by turning on the slope parameterization. The results show a direct link of the topography on the whole Venusian atmosphere, with preferred locations above topographic heights, suggesting that the nature of this wave is a mountain wave.

Implications: Before the Akatsuki-era, such a big structure dominating the atmosphere was unthinkable. The ability to reproduce it with a model opens the possibility to better understand and study it. In the face of

this discovery, there are several considerable, previously not recognized, implications for science on Venus that we will elaborate on at the meeting. We hope to see these issues tackled by the Venus Exploration Analysis Group in the future.

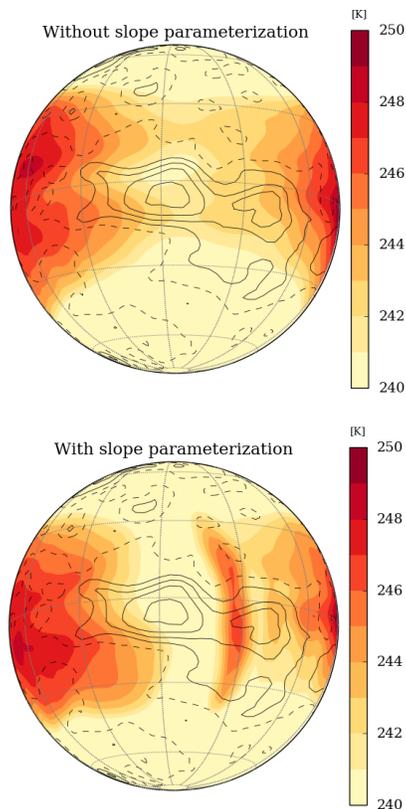


Figure 2: Temperature at 70 km simulated by the IPSL GCM, with and without slope parameterization of sub-grid topography. Topography at the GCM grid scale is shown in black contours.

References:

- [1] Fukuhara, T. et al. (2017) Nature Geoscience, 10(2), pp. 85-88 [2] Lebonnois, S. et al. (2010) JGR, 115(6) [3] Lott F., and Miller M.J. (1997) QJRM, 123, pp. 101-127

The Way to Thermal Computers Utilizing Near-field Thermal Radiation. Mahmoud Elzouka¹ and Sidy Ndao,
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Abstract: Electronics can't perform in extreme temperatures and extensive radiation environments, which prevent us from exploring deep in our Earth or our own solar system (e.g., Venus). This mandates developing alternative computing technologies, which can be classified under one of two main categories: material research (e.g., alternative wide bandgap semiconductor materials such as silicon carbide) and NanoElectroMechanical memory and switches, both of which still dependent on semiconductor properties and/or electricity.

Our research group has introduced the concept of near-field NanoThermoMechanical memory [1] and rectification [2], which can lead eventually to a computer that can run on heat, and its data are stored in hot or cold logic states (instead of zero and ones in electronics). We have achieved thermal rectification and memory functions through nonlinear heat transfer between two terminals; by coupling the near-field radiative heat transfer [3] between two terminals with the expansion in the microstructures that support the terminals, which in turn manipulate the size of the micro vacuum gap between the terminals.

We have demonstrated the thermal memory function numerically [1], and thermal rectification experimentally [2] at temperatures as high as 600 K, with a maximum rectification of 10.9%. We have proven numerically that we can boost the rectification to 2500% by including meshed photonic crystal structures [4] to our NanoThermoMechanical rectifier. With this high thermal rectification value, we can claim our thermal rectifier to be a thermal diode.

Here in this presentation, we are demonstrating the ability of our NanoThermoMechanical rectifiers to be able to work together and perform logic operations. We simulate a simple logic circuit that is composed of our NanoThermoMechanical rectifiers with meshed photonic crystals (i.e., thermal diodes). Our goal is to show that our logic circuit can achieve logic operation with enough contrast in output logic states to be identifiable, and with enough tolerance to input logic state.

References:

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 [4] Meshed doped silicon photonic crystals for manipulating near-field thermal radiation, *J. Quant. Spectrosc. Radiat. Transf.* 204 (2018) 56–62. doi:10.1016/J.QSRT.2017.09.002.

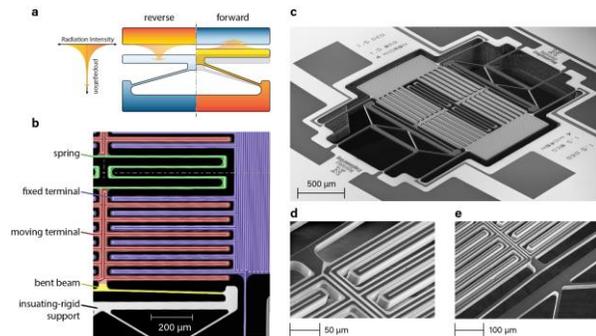


Figure 1: NanoThermoMechanical Rectifier [2]

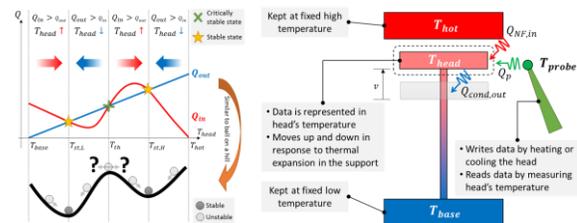


Figure 2: NanoThermoMechanical Memory [1]

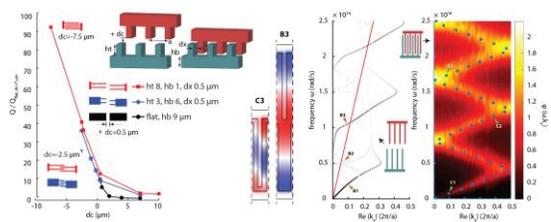


Figure 3: Meshed Photonic Crystals for Enhanced Rectification [4]

NASA High Operating Temperature Technology Program Overview, Quang-Viet Nguyen¹, Gary W. Hunter²,

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Mission concepts that require operation on the Venus surface for more than a couple hours have proven challenging. Recent progress in high temperature electronics [1] and other system elements are making possible realistic concepts for small landers with relatively simple instruments. LLISSE [2] is one such prototype development project that takes advantage of these new capabilities with new mission approaches. These innovative ideas however cannot address all the science desired and technology development of high temperature/pressure systems will be required. For example, generation of long duration power, in sufficient capacity to cool a pressure vessel and then also power science instruments that are inoperable in Venus ambient conditions, will be required for some instruments such as imagers. Eventually science will demand mobility, which again will likely require significant power capability. These and other challenges have been noted in the Venus Exploration Analysis Group documents such as the Technology Plan [3], the Planetary Decadal Survey Report, and other documents.

NASA's Planetary Science Division (PSD) has begun a structured approach to addressing Venus surface technology challenges by beginning to invest in new technology development efforts. The program initiated is called **High Operating Temperature Technology (HOTTech)**. The HOTTech program supports the advanced development of technologies for the robotic exploration of high-temperature environments such as the Venus surface, Mercury, or the deep atmosphere of Gas Giants. The goal of the program is to develop and mature technologies that will enable, significantly enhance, or reduce technical risk for in situ missions to high-temperature environments with temperatures approaching 500 degrees Celsius or higher. It is a priority for NASA to invest in technology developments that mitigate the risks of mission concepts proposed in response to upcoming Announcements of Opportunity (AO) and expand the range of science that might be achieved with future missions. HOTTech does not soliciting hardware for a flight opportunity and is limited to high temperature electrical and electronic systems that could be needed for potentially extended in situ missions to such environments.

Ultimately NASA funded 12 awards in the recent call. Selected 1-3year development projects include technology topics ranging from high temperature batteries, solar cells and power generation technologies, various electronics (processors, memory, different approaches to electronic devices, and a high temperature motor. Table 1 lists the selected projects including the

Principle Investigator (PI) and home institution. As one reviews the list of selected projects, one can envision these components as potential complementary elements of a future high temperature "system".

NASA is taking the development investment one step further. In order to increase the maturation potential of the individual investments, maximize the potential for infusion, and to begin to address integration level challenges, NASA has initiated a new approach that will explore the potential path to integration of these individual developments into a "system". PI's of the HOTTech awards have an opportunity, if desired, to plug into a system level development and test effort. The details of this system level development/test are still in development, but it is expected that this new approach will produce a number of advantages.

This briefing will describe the HOTTech program, summarize the development efforts and describe, to the degree known, the integration/system level opportunity that is being made available to the PI's.

P.I.	Title
Simon Ang. / Univ. of Arkansas	500°C Capable, Weather-Resistant Electronics Packaging for Extreme Environment Exploration
Kris Zacny / Honeybee Robotics Corp.	Development of a TRL6 Electric Motor and Position Sensor for Venus
Debbie Senesky / Stanford Univ.	Passively Compensated Low-Power Chip-Scale Clocks for Wireless Communication in Harsh Environments
Jonathan Grandier / JPL	Low Intensity High Temperature (LIHT) Solar Cells for Venus Exploration Mission
Michael Paul / JHUAPL	Hot Operating Temperature Lithium combustion IN situ Energy and Power System (HOTLINE Power System)
Robert Nemanich / Arizona State Univ.	High Temperature Diamond Electronics for Actuators and Sensors
Leora Peltz / Boeing Corp.	Field Emission Vacuum Electronic Devices for Operation above 500 degrees Celsius
Darby Makel / Makel Engr. Inc.	SiC Electronics To Enable Long-Lived Chemical Sensor Measurements at the Venus Surface
Ratnakumar Bugga / JPL	High Temperature-resilient and Long Life (HiTALL) Primary Batteries for Venus and Mercury Surface Missions
Phil Neudeck / NASA GRC	High Temperature Memory Electronics for Long-Lived Venus Missions
Jitendra Kumar / Univ. of Dayton	Higher Energy, Long Cycle Life, and Extreme Temperature Lithium Sulfur Battery for Venus Missions
Yuji Zhao / Univ. of Arizona	High Temperature GaN Microprocessor for Space Applications

Table 1. Selected HOTTech projects and Principle Investigators

References:

- [1] P. G. Neudeck, R. D. Meredith, L. Chen, D. J. Spry, L. M. Nakley, and G. W. Hunter, *AIP Advances* **6**, 125119 (2016). [2] T. Kremic, G. W. Hunter, P. G. Neudeck, D. J. Spry, G. E. Ponchak, G. M. Beheim, R. Okojie, M. C. Scardelletti, J. D. Wrbanek, D. M. Vento, L. M. Nakley, and J. Balcerski, "Long-Lived In-Situ Solar System Explorer (LLISSE) Probe Concept And Enabling High Temperature Electronics", 48th Lunar and Planetary Science Conference, The Woodlands, Texas, March 20–24, 2017. [3] <http://www.lpi.usra.edu/vexag/reports/Venus-Technology-Plan-140617.pdf>.

PROSPECTS FOR AN ANCIENT DYNAMO AND MODERN CRUSTAL REMNANT MAGNETISM ON VENUS. J. G. O'Rourke¹, C. Gillmann², and P. Tackley³, ¹School of Earth and Space Exploration, Arizona State University, Tempe, AZ (jgorourk@asu.edu), ²Royal Observatory of Belgium, Brussels, Belgium, ³Department of Earth Sciences, ETH Zurich, Institute of Geophysics, Zurich, Switzerland.

Introduction: Venus has no internally generated magnetic field today, and whether one existed in the past is unknown. In contrast, every other major planet besides Mars currently hosts a dynamo. Spacecraft and meteorites have also revealed ancient remnant magnetism produced on Mercury, Mars, Earth's Moon, and myriad asteroids [1]. Numerical models indicate that Venus rotates fast enough—albeit much slower than Earth—to produce a dynamo in convecting, liquid metal alloy like Earth's core. Three broad explanations have been proposed for the lack of a dynamo on Venus: First, recent work suggests that a solid core is compatible with the tidal Love number measured by the Magellan mission [2]. Second, earlier modeling argued that cooling and thus convection in even a liquid core would halt after catastrophic resurfacing until the present [3]. Third, perhaps most intriguingly, a lack of giant impacts during the accretion of Venus may result in a stratified core that never convects [4].

We evaluate these possibilities using numerical simulations built on a previous investigation of coupled atmospheric and mantle dynamics on Venus [5].

Numerical Methods: Surface temperature changes over time according to a one-dimensional, gray radiative-convective atmosphere model with time-varying H₂O and CO₂ atmospheric abundances. The StagYY code, in 2-D, spherical annulus geometry, tracks melting and compositional changes in a convecting mantle.

Core Model: We used a one-dimensional model for the core based on a fourth-order parameterization of the radial density profile [6]. This includes conventional energy sources like secular cooling, radioactivity, and exclusion of light elements from an inner core. We also consider heat loss from the inner core and, most importantly, precipitation of light elements like MgO [e.g., 7] and/or SiO₂ [8] over geologic time. Initially, there is no thermal or chemical stratification.

Sensitivity Tests: Recycled basalt or primordial material may provide a dense layer at the bottom of the mantle that inhibits core cooling [e.g., 9]. The initial temperature and the rates of radiogenic heating and precipitation are also important to thermal histories. The thermal conductivity of iron-rich alloys under

core conditions is critical and poorly constrained. Fortunately, testing all plausible values requires no additional simulations since it only affects entropy production—and not the global heat budget.

Preliminary Results: Given available constraints, all three proposed scenarios remain plausible. If future measurements of the spin state of Venus confirm a liquid core *and* the lowest estimates for thermal conductivity are correct, then absence of a dynamo is strong evidence for a compositionally stratified core. However, relatively slow cooling on Venus means that dynamo action in an “Earth-like” core is suppressed at higher values of thermal conductivity. Complete solidification of the core likely requires low initial temperatures and the absence of both precipitation and radiogenic heating. Magnetic fields comparable to Earth's are predicted for ~2–3 Gyr after accretion. Interestingly, many simulations imply that the dynamo only perished within the past ~0.5–1.5 Gyr. The mean surface temperature (~740 K) lies below the Curie point of magnetite (~858 K). So, crustal remnant magnetism may await detection today [10], which would support similar accretion processes for Venus and Earth.

References: [1] Stevenson (2003) *EPSL*, 208, 1–11. [2] Dumoulin et al. (2017) *JGR*, 122, 1338–1352. [3] Nimmo (2002) *Geology*, 30, 987–990. [4] Jacobson et al. (2017) *EPSL*, 474, 375–386. [5] Gillmann & Tackley (2014) *JGR*, 119, 1189–1217. [6] Labrosse (2015) *PEPI*, 247, 36–55. [7] O'Rourke & Stevenson (2016) *Nature*, 529, 387–389. [8] Hirose et al. (2017) *Nature*, 543, 99–102. [9] Nakagawa & Tackley (2014) *GGG*, 15, 619–633. [10] Rong et al. (2016) *AGU Fall Meeting Abstracts*, GP13A-01.

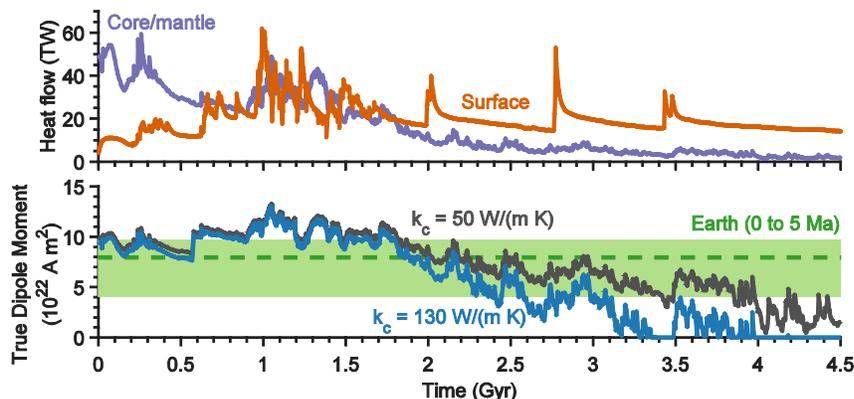


Figure 1 | Representative results. Heat fluxes and estimated magnetic field strengths for high and low thermal conductivity (k_c) in the core.

Field Emission Vacuum (FEV) Electronic Devices for Operation above 500 degrees Celsius.Leora Peltz^{1,a}, William M. Jones², Robert V. Frampton³, Alan R. Keith¹, Axel Scherer²¹ Boeing Research & Technology, Huntington Beach, CA² California Institute of Technology, Pasadena, CA³ retired, formerly at Boeing Phantom Works, Huntington Beach, CA^a email: leora.peltz@boeing.com

Abstract: The SSED (Solid State Electronics Development) group in Boeing Research & Technology is teamed with the Nanofabrication Group at California Institute of Technology to develop robust electronics for the Venus applications. Our Boeing-Caltech team has recently begun work under NASA R&A Award in the ROSES C24, Hot Operating Temperature Technology (HOTTech) Program. The main focus of our effort is to: (1) demonstrate Field Emission Vacuum (FEV) Electronics devices capable of operation at 500°C; (2) apply FEV devices to design and prototype an oscillator for frequencies corresponding to S-band (2-4 GHz). This small integrated circuit will allow us to demonstrate the utility and the performance of FEV technology, and its relevance to avionics functions for Venus surface missions. In addition, our team will develop infrastructure required for future, larger-scale design of FEV circuits for mission applications, namely: design flow; simulation software and PDK (process design kit); test procedures for long-duration tests; test and data acquisition software.

We aim to establish the FEV devices as a robust yet low-cost technology for analog and digital circuits for operation at 500°C. The classic well-established technology of microwave vacuum tubes is dominant for 500°C, yet its large dimensions limit severely the complexity of circuits. Multiple development efforts in the past sought a technology which brings the simplicity of vacuum tubes at micrometer scale. During 2015-2016, the Nanofabrication Group at Caltech, under Boeing funding and collaboration, has pioneered a fabrication approach that obtains Fowler-Nordheim emission at low voltages, well below the ablation/damage threshold. This concept, which was prototyped and evaluated in detail, is the basis for the FEV devices for our C.24 HOTTech work for NASA ROSES. These robust devices are fabricated using a simple lithography process that yields stable, reproducible sub-50nm gaps between emitter, collector and gate. Heating the device to 500°C in vacuum is compatible with the device operation, since they are not susceptible to traditional semiconductor limitations of carrier leakage, temperature dependence, and crystal imperfections.

Our paper will outline the construction and properties of the FEV devices, as contrasted with prior micro-

vacuum-tube technologies. We will outline the applicability of FEV circuits to NASA's Planetary Science Research Program, along the guidelines of the Venus Technology Plan (May 2014) published by NASA Venus Exploration Analysis Group (VEXAG): "Development of high-temperature electronics, sensors and the thermo-electric power sources designed for operating in the Venus ambient would be enabling for future missions."

MAPSIT AND THE IMPORTANCE OF PLANETARY DATA SPATIAL INFRASTRUCTURE FOR VENUS. J. Radebaugh¹, B. Archinal², B. J. Thomson³, R. Beyer⁴, D. DellaGiustina⁵, C. Fassett⁶, L. Gaddis², J. Hagerty², T. Hare², J. Laura², S. Lawrence⁷, E. Mazarico⁸, A. Nab⁹, A. Patthoff¹⁰, J. Skinner², S. Sutton⁵, D. Williams¹¹; ¹Brigham Young Univ., Provo, UT, USA (janirad@byu.edu), ²USGS, Flagstaff, AZ, USA, ³Univ. of Tennessee, Knoxville, TN, USA, ⁴SETI/NASA/Ames, Mountain View, CA, USA, ⁵Univ. of Arizona, Tucson, AZ, USA, ⁶NASA/MSFC, Huntsville, AL, USA, ⁷NASA/JSC, Houston, TX, USA, ⁸NASA/GSFC, Greenbelt, MD, USA, ⁹DLR, Berlin, Germany, ¹⁰PSI, Tucson, AZ, USA, ¹¹Arizona State Univ., Tempe, AZ, USA.

Introduction: Planetary spatial data continue to rapidly increase in volume and complexity. Maintaining these data using accessible formats and standards for all scientists is essential for the success of past, present, and future planetary missions. We describe here the efforts in these areas by the Mapping and Planetary Spatial Infrastructure Team (MAPSIT). MAPSIT is a planetary community group tasked by the Planetary Science Subcommittee and NASA Headquarters to identify and prioritize the infrastructural spatial data needs for research and analysis for NASA's past, current, and future planetary science and exploration missions.

Planetary Spatial Data and MAPSIT: Data from planetary missions are the currency of these projects and should be accessible and easily useable by the whole community. The extraction of scientific knowledge from planetary mission data relies on several steps of refinement of the raw data from instruments. Creating scientifically useful information is often a major research and development effort in itself. To complete this process, goals need to be identified, missions need to be properly designed, and instruments need to be appropriately developed and calibrated. The models, software tools and content distribution platforms required for scientists to obtain, process, and analyze planetary mission data need continuing development and maintenance. For these reasons, community coordination and strategic planning for the use of planetary spatial data are essential for the success of planetary research and exploration.

MAPSIT has been established with a mission to ensure that planetary spatial data are readily available for any scientific investigations, now or in the future. Some its functions include: Provide community findings, in the form of a Planetary Geospatial Infrastructure Roadmap, which will address the scientific rationale, objectives, technology, and long-range strategic priorities for accessing and using planetary spatial data, and engaging in software development (e.g., [2]) and mapping [1]. MAPSIT also encourages the development of standards for present and future planetary missions and research activities. We help define community needs for critical research and planetary mission infrastructure [e.g., 3]. We provide findings on the accuracy and precision required for spatial technolo-

gies and products, and finally MAPSIT coordinates and promotes the registration of data sets from international missions and US missions to optimize their combined utility.

MAPSIT exists to help enable the broad spectrum of planetary spatial data and programmatic capabilities required to effectively achieve robotic exploration of the Solar System. These include (but are not limited to) the analysis of planetary surfaces and atmospheres, the identification of ideal landing sites, the down-selection of sample acquisition and analysis locations, and hazard assessment [4, 5, 6]. It will help meet VEXAG goals for exploration and technology development.

Planetary Geospatial Strategic Plan: To build a Planetary Spatial Data Infrastructure (PSDI) Roadmap, MAPSIT will solicit broad stakeholder input, with a goal to recommend and prioritize the needed data products and infrastructural developments. The roadmap seeks for progress towards a Planetary Spatial Data Infrastructure (PSDI) [7], or several PSDIs, which will outline and define aspects of planetary spatial data and lay out the needs, capabilities and tasks of the community. This builds on a similar document for US Earth Sciences, the National SDI [8]. It is envisioned that the roadmap will be a living document that evolves as milestones are met and the state of the art advances.

For Venus in particular, the roadmap will consider Venus Mission Planning Documents and other resources, to see where key recommendations regarding PSDI can best advance Venus science. This will include recommendations for mission planning, standards, identifying current foundational data products, and what data and products are needed in the future.

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Performance Characterization of HT Actuator for Venus. F. Rehnmark¹, J. Bailey¹, E. Cloninger¹, K. Zacny¹, J. Hall², K. Sherrill², J. Melko², K. Kriechbaum², B. Wilcox², ¹Honeybee Robotics (398 West Washington Blvd, Ste 200, Pasadena, CA 91103, rehnmark@honeybeerobotics.com), ²JPL (4800 Oak Grove Dr, Pasadena, CA 91109, jeffery.l.hall@jpl.nasa.gov).

Introduction: A high temperature (HT) actuator capable of operating in the harsh environment found on the surface of Venus has been built and tested at JPL's Venus Materials Test Facility (VMTF) [1,2]. The actuator has been used to power a rotary-percussive rock sampling drill operating in carbon dioxide gas at full Venus temperature and pressure (see **Figure 1**). The technology can be scaled to power other mechanisms for planetary exploration in harsh environments, such as deployment devices, manipulators and mobility platforms.

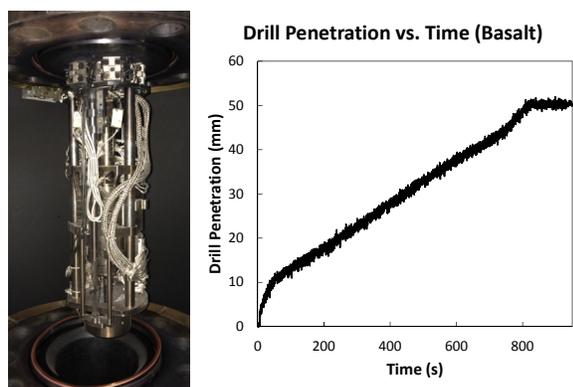


Figure 1. Venus rock sampling drill with results of drilling trial performed at Venus temperature and pressure (VTP).

Actuator sizing for the high temperature environment must account not only for variability in the driven load but also for reduced torque and efficiency available from the motor. Analysis and testing is underway to investigate these effects. Life testing is also planned with the goal of demonstrating margin against proposed mission sampling timelines.

Motor Torque and Efficiency at High Temperature: The drop in motor torque and efficiency at elevated temperature is due to two important temperature dependencies which must be accounted for when designing for operation across a wide temperature range. The first is the increase in electrical resistance of the motor coils at elevated temperature, which both increases i^2R losses in the motor and decreases the theoretical stall current (and therefore stall torque) of the motor for a given supply voltage. The second is the reduction in magnetic flux linkage density between the rotor and stator. This decreases the motor torque constant K_t , which, in turn, reduces the stall torque of the

motor. The motor speed constant K_e is decreased by the same amount, thereby increasing the no-load speed. The overall effect is a reduction in both maximum efficiency and maximum power output which, incidentally, occur at different operating points [3].

Motor Performance Testing: The continuous output torque of the drill motors is limited by their ability to dissipate waste heat generated in the coils. Constant torque load dynamometer tests were performed at room temperature and 482°C under Earth atmospheric pressure to determine the steady-state temperature rise under each condition. As expected, the increased resistance of the motor coils at high temperature limits the motor's continuous output torque capability. However, the thermal endurance of the motors improved significantly in drilling trials in the simulated Venus atmosphere, likely due to the combined benefits of good thermal conduction to a massive heat sink (i.e., the drill) and enhanced convection in the high pressure carbon dioxide atmosphere.

Modeling and Simulation: Like ordinary brushless DC motors, custom HT actuators can be designed to meet mission requirements using conventional modeling and simulation tools. If the temperature dependency of winding resistance and magnetic flux density are known, motor performance at any temperature can readily be simulated.

Summary: HT actuator technology is available to meet the needs of planetary exploration missions to harsh environment destinations such as Venus. Conventional methods can be used to size these actuators and account for losses at high temperature.

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Current Status of Akatsuki and Mojar Scientific Results

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Since the successful orbit insertion (VOI-R) in December 2015 [1], Akatsuki has been in Venus' orbit for over 650 earth days. The current orbit is highly elongated with the apocenter ~ 0.39 M km from the planet and the orbital period is ~ 10.8 earth days. This orbit will be kept until near the end of 2018 at the time when a slight adjustment will be made to avoid extremely long umbra passages predicted for later years.

The onboard scientific instruments are healthy except IR1 and IR2 as the control electronics (IR-AE) is not working now. Two cameras, UVI and LIR, regularly observe the atmospheric dynamics and temperatures at the cloud-top levels. Another camera, LAC, attempts to detect lightning flashes on night-side disk at all available umbra passages. RS measures the atmospheric profiles (temperature and sulfuric acid vapor) with ground antennas in Japan and in India.

This talk is to report the current mission status and near-future plans (as briefly described in the above), as well as the major scientific results. As the stationary gravity wave features, most prominent in LIR's thermal channel [2], will be presented by Fukuhara et al., other scientific results such as the equatorial jet in the middle to lower atmosphere [3] will be presented in this talk.

[1] Nakamura, M., et al., Earth, Planets and Space 68:75, doi:10.1186/s40623-016-0457-6, 2016.

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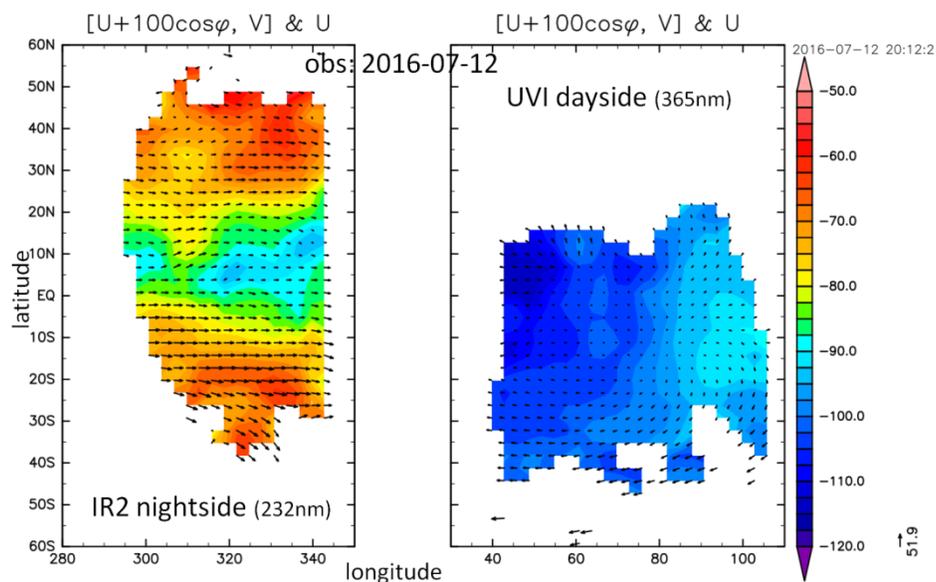


Figure: Wind velocity maps of night-side (left) and day-side (right). The night-side map exhibits strong equatorial jet (reaching 90 m/s westward) while such feature is absent in the day-side.

AN AUTOMATON ROVER FOR EXTREME ENVIRONMENTS: RETHINKING AN APPROACH TO SURFACE MOBILITY

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Introduction: Venus is one of the most challenging in-situ environments to explore. Most in-situ mission concepts to Venus are short-lived probes or landers with lifetimes between 2 to 24 hours, which limits the types of data that can be collected. However, the concept presented here, a mechanical automaton rover powered by the wind, could not only survive for long durations of time, but would also provide mobility. This opens up a myriad of uses for a Venus in-situ explorer, with one of the most compelling being obtaining samples from multiple geologic units across the surface of Venus. However to create such a rover requires rethinking current interplanetary rover designs.

Background on Venus Rovers: Ideas for a long duration Venus rover began in the 1980s with the Russian DzhVS and the wind powered Venerokhod rovers [1]. More recently radioisotope powered Stirling engines have been proposed to enable long duration landers [2] and rovers [3]. However, the concept still requires large amounts of R&D investment. A second approach would be to build a mission around gallium nitride or silicon carbide circuits, which have been demonstrated at Venus temperatures. Several long duration lander concepts use near-current technology [4]–[6]. However, current levels of integration are in the range of just a few hundred to thousand transistors, which fall far short of the requirements for standard rovers. While there are a couple papers which discuss rover concepts utilizing high-temperature electronics, they rely heavily on future developments [7], [8].

The Automaton Rover: Automaton Rover for Extreme Environments (AREE) is an exciting concept, which enables long duration in-situ mobility on the surface of Venus through robust mechanisms, designed to operate for months in Venus’s hostile environment.

An automaton is a mechanical device capable of performing a series of complex actions to achieve a specific result, or a mechanical robot. The automaton rover is designed to reduce requirements on electronics and require minimal human interaction by utilizing concepts from robotics including behavior based control and emergent systems in a similar manner to the subsumption architecture which yields complex robotic behavior from simple rules. [9].

System Overview: Wind power would be collected and stored mechanical in a spring. This energy is then routed to the rest of the rover to run the mobility system, distributed computing and obstacle avoidance, signaling system, and instruments. While initially a purely mechanical rover was considered, it was realized high temperature electronic instruments would be required to do science.

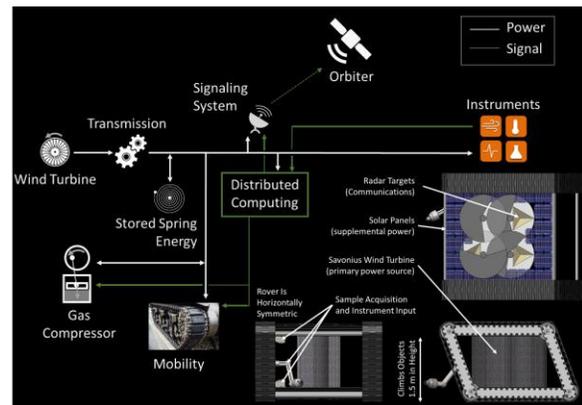


Figure 1: Automaton Rover System

Another key concept illustrated in Figure 1 is the rover geometry. It has tracked mobility with a parallelogram shape, much like WWI tanks, to enable to climb as large of obstacles as possible. The rover is also symmetric, which means it can flip upside down and continue operation as normal.

Conclusion: AREE is a radical departure from traditional planetary rover models in terms of terrain accessed and cost, due to heavy use of distributed, reactive controls and the implementation of novel mechanical solutions. The authors hope this concept contributes to shifting the conversation about a long-duration Venus rover mission, to something that could occur in the near future, as previous concepts have relied on yet-to-be developed technologies.

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AN AIRBORNE TURBINE FOR POWER GENERATION ON VENUS J. SAUDER, B. WILCOX, J. CUTTS¹

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Introduction: While there are a number of questions about Venus that can be answered by orbiters and high altitude balloons, many science questions (such as geology) require surface access. All prior Venus surface missions and most current surface mission proposals have a lifetime of 2 to 24 hours. However, this stands to change with the advent of silicon carbide and gallium nitride electronics, which have been demonstrated to operate for thousands of cycles above 460C. As the projected life of lander concepts extend from hours to months [1]–[3], providing power to the lander becomes a challenge.

Power Challenges: Standard approaches to power planetary landers would utilize a radioisotope thermoelectric generator (RTG) or solar panels. Although RTG's have parts which operate the hot side of the thermocouples at high temperatures, no RTG has yet been designed for and tested in the Venus environment and development would require significant investment. Also, unlike recent RTG systems that have a multi-mission focus, an RTG for Venus presents a much more limited use case. While an RTG would provide an elegant power solution, a full development and qualification of one for the Venus environment is uncertain.

A second option would be to utilize solar panels on Venus, which is appealing since it should be possible to make them survive the Venus surface environment.[4]. However, there are several key problems with this approach. First, because of the dense cloud layer, the solar flux measurements on the surface of Venus averages 33 W/m²[5], compared to the ~ 1360 W/m² a spacecraft in orbit around the earth can access. Further, because of the extreme heat, solar panel efficiency is reduced from approximately 30% to a 7-10% [4]. Finally, the Venus day is approximately 60 days, which means there is a 60 day night period during with the solar panels would not function. Some of these problems can be mitigated by buoyant vehicles that are designed to operate only during the Venus day and cycle between the surface where they perform science and the 30 km level in the atmosphere where they generate power but a long duration surface power source is clearly of great interest.

An Airborne Turbine: Placing a stationary airborne turbine in the Venus atmosphere has to the potential to generate sustained power to operate a lander. The turbine would fly between ten to several hundred meters off the ground, where there is an opportunity to obtain higher wind power than what a surface lander could access. At such an altitude, a 3-meter diameter turbine with an assumed efficiency of 42% could pro-

duce 12 watts of power at 0.5 m/s and almost 100 watts at 1.0 m/s. The basic concept would be to have the turbine tethered to a heavy lander. The turbine would be initially launched via a metal bellows filled with helium or water vapor, but then would support itself in the air with an aerodynamic surface much like a kite. This would prevent it from being dependent on maintaining buoyancy despite eventual loss of the lifting gas at Venus temperatures, and thus extend its life.

Design Considerations: The specific wind speed on the surface of Venus remains a significant question, and means the design has to make considerations for wind speeds from approximately 0.3 m/s to 2.8 m/s [6]. The key driving factors are those of power, force of the wind speed, and lift. While power scales with velocity cubed, force and lift scales with velocity squared, and all are a multiple of density and area. This has a significant implication in comparison Earth based airborne turbines. While the amount of power is less than what could be generated on Earth because of Venus's much lower wind speeds (even when accounting for the increase in density), a wind turbine would have to be designed to take forces similar to those on Earth.

Science Applications: In addition to generating power, the airborne turbine would also be able to measure wind speed at an altitude in the Venus atmosphere. The force on the tether and/or total power generated can measure wind speed. Better wind speed information would not only help us to better understand Venus weather data, but would also provide critical data required to estimate the moment of inertia of the planet, which in turn could help us understand more about Venus's core.

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THE VENERA-D MISSION CONCEPT, REPORT ON THE ACTIVITIES OF THE JOINT SCIENCE DEFINITION TEAM. D. Senske¹, L. Zasova², T. Economou³, N. Eismont², M. Gerasimov², D. Gorinov², J. Hall¹, N. Ignatiev², M. Ivanov⁴, K. Lea Jessup⁵, I. Khatuntsev², O. Korablev², T. Kremic⁶, S. Limaye⁷, I. Lomakin⁸, A. Martynov⁸, A. Ocampo⁹, O. Vaisberg², A. Burdanov¹⁰, S. Teselkin⁸, V. Vorontsov⁸, ¹Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, ²Space Research Institute RAS, Profsoyuznaya 84/32, Moscow 117997, Russia, ³Enrico Fermi Institute, University of Chicago 933 East 56th Street, Chicago, IL 60637, ⁴Vernadsky Inst. RAS, Kosygin St., 19 Moscow, Russia, ⁵Southwest Research Institute 1050 Walnut, Suite 300 Boulder CO 80302, ⁶Glenn Research Center, 21000 Brookpark Rd, Cleveland, OH 44135, ⁷Univ. of Wisconsin, 1225 W Dayton St Madison, WI 53706, ⁸Lavochkin Assoc. 24, Leningradskaya Str. 141400 Khimki, Russia, ⁹NASA Headquarters, Washington, DC., ¹⁰TSNIIMASH, Korolev, Russia

Background: The Venera-D mission concept is devoted to the detailed study of the atmosphere, surface, and plasma environment of Venus [1]. Envisioned as launching in the post-2025 timeframe and consisting of an orbiter and lander with advanced, modern instrumentation with potential contributions consisting of an aerial platform/balloon, small long-lived surface stations or a sub-satellite. This mission would build upon the Venera, VEGA, Pioneer Venus, and Magellan missions carried out in the 1970's and 1990's [2,3,4] along with the more recent Venus Express [5]. In January of 2017, the NASA and IKI/Roscosmos Joint Science Definition Team (JSDT) provided its first report.

Venera-D science goals: Specific areas of scientific investigation for Venera-D would focus 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, the chemical processes related to the interaction of the surface and atmosphere, solar wind interaction and atmospheric losses.

Orbiter Goals consist of the following: study of the dynamics and nature of superrotation, radiative balance and greenhouse effect; investigation of the thermal structure of the atmosphere, winds, thermal tides and solar locked structures; measurement of the composition of the atmosphere; study of the clouds, their structure, composition, and chemistry; evaluation of the nature of the 'unknown' UV-absorber; and investigation of the upper atmosphere, ionosphere, electrical activity, magnetosphere, and the escape rate.

Lander Goals focus on the study of the elemental and mineralogical composition of the surface, including radiogenic elements; characterization of the geology of local landforms at different scales; study of the interaction between the surface and the atmosphere; investigation of the structure and chemical composition of the atmosphere down to the surface, including abundances and isotopic ratios of the trace and noble gases; and performing direct chemical analysis of the cloud aerosols.

The JSDT identified areas where important science may not be addressed by the baseline concept and generated a list of potential "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, and a small subsatellite to fill these "science gaps."

In situ measurements, both in the atmosphere and on the surface, have not been carried out for more than 30 years. Long-duration measurements in the atmosphere (from several weeks to several months) would aid in understanding the processes that drive the atmosphere. A well instrumented mobile platform or balloon that could maneuver to different altitudes in the clouds could help understand the 'puzzles' of the UV-absorber, its nature, composition, vertical and horizontal distribution as well as providing a platform to measure key trace and noble gases and their isotopes, meteorology and cloud properties, composition, etc., depending on the scientific payload. Another high priority augmentation considered would be a small long-lived surface station (possibly 1-5 stations with an operation life time from 60 days to up to one year) and a subsatellite.

Ongoing JSDT activities: The development of the Venera-D concept is now focusing on a detailed study of the mission architecture with additional examination of the science measurements and potential instrumentation. The JSDT will incorporate into its deliberations information from a set of science community modeling workshops (in May 2017 at Glenn Research Center, Cleveland OH, USA and in October 2017 at IKI in Moscow) to identify additional key measurements (and corresponding instruments) that could be achieved by the planned Venera-D mission.

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Venus Origins Explorer (VOX), a Proposed New Frontier Mission. S. Smrekar¹, M. D. Dyar^{2,3}, S. Hensley¹, J. Helbert⁴, C. Sotin¹, E. Mazarico⁵ and the VOX team, ¹Jet Propulsion Laboratory, Caltech, 4800 Oak Grove Dr., Pasadena CA, 91109 (ssmrekar@jpl.nasa.gov), ² Planetary Science Institute, 1700 East Fort Lowell, Tucson, AZ 85719, ³ Dept. of Astronomy, Mount Holyoke College, South Hadley, MA 01075, ⁴Institute for Planetary Research, DLR, Rutherfordstrasse 2, 12489 Berlin, Germany, ⁵NASA Goddard Space Flight Center, Greenbelt MD, 20771.

Introduction: Of all known bodies in the galaxy, Venus remains the most Earth-like in terms of size, composition, surface age, and distance from the host star. Although not currently habitable, Venus lies within the ‘Goldilocks zone’, and may have been habitable before Earth [1]. As we search for habitable planets around other stars, we do not yet understand why Venus is currently not a habitable planet. What caused Venus to follow a divergent path towards its present hostile environment, devoid of oceans, magnetic field, and plate tectonics that enable Earth’s long-term habitability? How do we know if an exoplanet is an Earth 2.0 or rather a Venus 2.0?

Venus Origins Explorer (VOX) determines how these twin planets diverged, and enables breakthroughs in our understanding of terrestrial planet evolution and habitability in our own solar system — and others.

Overview: At the time of the 2011 Decadal Survey, the full capabilities of near-IR instruments to map global mineralogy from orbit and present-day radar techniques to detect active deformation could not be fully assessed because their development was still ongoing. VOX leverages these new methods to answer essential questions, many of which can only be addressed with high resolution, global data. VOX meets and exceeds the New Frontiers science objectives using orbital, global reconnaissance, and in-situ noble gas measurements:

1. Atmospheric physics/chemistry: noble gases, their isotopes, and light stable isotopes to constrain atmospheric sources, escape processes, and volcanic outgassing; additional, multi-year global search for volcanically outgassed water.
2. Past hydrological cycles: global tesserae composition to determine the role of volatiles in crustal formation, determines if global, ‘catastrophic’ resurfacing occurred, and assess initial volatile sources and outgassing history.
3. Crustal physics/chemistry: determine global variations in crustal mineralogy/chemistry, tectonic framework and heat flow, whether catastrophic resurfacing occurred, what types of geologic processes are currently active and possible crustal recycling.
4. Crustal weathering: global mineralogy distinguishes between surface-atmosphere weathering reactions by quantifying the redox state and the chemical equilibrium of the near-surface atmosphere.
5. Atmospheric properties/winds: map cloud particle modes and their temporal variations, and track cloud-

level winds in the polar vortices.

6. Surface-atmosphere interactions: mineralogy maps distinguish between models for surface-atmosphere chemical interactions; search for new and/or recent volcanism and outgassed water.

VOX consists of: 1) an Atmosphere Sampling Vehicle (ASV), and 2) an Orbiter that performs global reconnaissance using two instruments and a gravity science investigation. The ASV dips into the well-mixed atmosphere to deliver an atmospheric sample to the Venus Original Constituents Experiment (VOCE [2]). Measurement of noble gases reveals the source and evolution of volatiles in the inner solar system.

From orbit, Venus Emissivity Mapper (VEM [3-5]) provides global surface mineralogy and thus a test of whether tesserae formed in the presence of water [5], unprecedented frequency of observations of clouds (and thus winds) in the polar vortices [6], and searches for active and/or recent volcanism. Venus Interferometric Synthetic Aperture Radar (VISAR [7]) generates long-awaited high-resolution imaging and digital elevation models, and surveys possible active deformation locations with repeat-pass interferometry to reveal geologic evolution. Ka-band tracking provides the gravity field resolution needed to estimate global elastic thickness [8]. Requirements are specified in references.

Conclusion: VOX is the logical next mission to Venus because it delivers: 1) top priority atmosphere, surface, and interior science objectives; 2) key global data for comparative planetology; 3) the first high-resolution global topography, composition, and imaging to optimize future landed missions; 4) opportunities for revolutionary discoveries including active geologic processes, with a 3-year long orbital mission and proven implementation; and 5) 44 Tb of data to fuel the next generation of planetary, Earth, and exo-planet scientists.

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PLANETARY DUNE WORKSHOP EXPANDS TO INCLUDE SUBAQUEOUS PROCESSES AS POSSIBLE VENUS ANALOGS. T. N. Titus¹, D. Rubin² and G. Bryant³, ¹USGS (2255 N. Gemini Dr., Flagstaff, AZ 86001, ttitus@usgs.gov), ²Department of Earth & Planetary Sciences, UC Santa Cruz, Santa Cruz, CA (drubin@ucsc.edu), ³Physical Sciences Department, Dixie State University, St. George, UT (gbryant@dixie.edu).

Introduction: Dune-like structures appear in the depths of Earth's oceans, across its landscapes, and in the extremities of the Solar System and beyond. These structures rise up within the thick dense atmosphere of Venus and have also been found on a comet, with perhaps the most ephemeral atmosphere imaginable. Understanding how similar bedforms originate under such a wide range of environmental conditions is key to our comprehension of surface dynamics throughout the Solar System.

The 2017 International Planetary Dune Workshop at Dixie State University, the fifth in a series focusing on planetary dunes, brought together 65 terrestrial, marine, and planetary researchers, including students, from diverse backgrounds. The goal of fostering collaborative interdisciplinary research was accomplished through small-group interactions, both in formal meetings and through associated field trips. The 2017 workshop was unique due to the involvement of members of the terrestrial subaqueous research community; this involvement was key to the workshop's success.

It Flows, Not Blows: The first session of the workshop focused on subaqueous analogs, experiments and models. Dave Rubin [1], one of two keynote speakers, provided a comparison of morphology, dynamics, and stratification of eolian and subaqueous dunes. Jacob Nienhuis [2], another keynote speaker, reported on recent developments towards a firm mechanistic understanding of subaqueous ripple spacing that is essential for accurate ripple-derived (paleo) flow reconstructions of distant environments. Neakrase [3] discussed the comparison of terrestrial subaqueous seafloor dunes morphology to Venusian dunes. He examined similarities in flow environments and how they relate to morphological similarities observed between the two environments. Sutton [4] presented a classification of aeolian fluid ejections and transport based on observations from high atmospheric density wind tunnel experiments in the Titan Wind Tunnel. Implications for transport on Venus and Titan were discussed. Wang [5] discussed large-eddy simulation and experimental measurements that were used on four different stages of two proximal deformed barchan dunes in high Reynolds number. Special fluid structure and sediment migration had been found in the flow channel area. Sakimoto [6] used a Computational Fluid Dynamics (CFD) approach with commercial software to model particle trajectories within Venusian and sub-aqueous environments as a func-

tion of particle size, density, flow field velocity, and ambient conditions.

Dune Morphology Records the Winds: In addition to the Venus session, participants also discussed the effect of prevailing wind directions and strengths in determining dune morphology. In general, barchans result from unidirectional transport winds while longitudinal dunes are formed by seasonally reversing transport winds. Variations of these morphological endmembers result from other combinations of multidirectional winds [7]. However, research presented at the workshop suggests that not only is the number of transport wind directions important, but also the dispersion of those wind modes [7]. Participants agreed that a more complete understanding of these dynamics would enable us to interpret wind directions and dispersions from remote sensing images of planetary dune morphologies. Since there are no meteorological stations on Venus, dune morphology may be the best way to determine the direction (and perhaps magnitude) of prevailing winds.

Planetary Dunes Goals Document: One recommendation from the workshop was the development of a planetary dunes goals document – similar to the goals documents for each of the NASA Assessment Groups (e.g. [VEXAG Goals, Objectives and Investigations for Venus Exploration](#)). The focus of this document will be to address science questions and identify needed investigations to answer those questions for the wide range of surfaces where Aeolian processes are observed. Venus exploration will have a prominent role within this document, including an emphasis on the need for studies of sub-aqueous dunes as analogs for Venus.

The Next Workshop: The 6th International Planetary Dunes Workshop is tentatively scheduled for mid-May 2019, somewhere along the U.S. West Coast. The workshop will continue to emphasize the need for more input from the Venus and subaqueous research communities.

Acknowledgments: We would like to acknowledge NASA's MPO and SSW program for providing travel support to several students and invited speakers.

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Progress Towards providing Heat-shield for Extreme Entry Environment Technology (HEEET) for Venus and other New Frontiers Missions.

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Introduction: Heat-shield for Extreme Entry Environment Technology (HEEET) has been in development since 2014 with the goal of enabling missions to Venus, Saturn and other high-speed sample return missions. It is offered as a new technology and incentivized for mission use in the New Frontiers 4 AO by NASA. The current plans are to mature the technology to TRL 6 by FY'18. The HEEET Team has been working closely with multiple NF-4 proposals to Venus, Saturn and has been supporting recent Ice-Giants mission studies. This presentation will provide progress made to date and the plans for development in FY'18.

Background: HEEET utilizes 3-D weaving as the basis for the highly capable TPS. An integral dual-layer ablative material system is produced by the three-dimensional weaving process. The outer, which is woven with high density carbon yarn, offers protection against the extreme external environment during entry. The inner insulating layer, made of much lower density composite yarn, is adhesively attached to underlying structure, protects the structure and the science payload from the heat that penetrates the outer layer. The dual layer system is both robust and mass efficient.

Progress and Plans: The HEEET material has been woven and tested for thermal performance at NASA Ames and DoD's AEDC arc jet facilities. These tests confirmed the two layer system to be very efficient and capable of withstanding extreme entry heating. The challenge has been in the design and development integrates the material into a heat-shield system that conforms to the entry vehicle shape, which is typically a blunt sphere-cone, as shown in Figure 1.. Flat panels are 3-D woven to produce preforms that are porous, with yarn that can move under load. The flat panels have to be formed to match the surface profile of the sphere-cone. The formed panels are resin infused and cured, which produces so as to rigid tiles that can be machined and bonded to the carrier structure. This integration requires gaps between panels to accommodate differential strains between the thermal protection material and the structure, which arise under mechanical and thermal loads. The gaps are filled with compliant seams, which need to remain intact throughout the mission to prevent heat from penetrating between acreage tiles. In addition, the seam and the acreage tiles have to have very similar performance,

both in terms of recession and thermal conduction, so that local steps are not created, because such features can cause severe heating augmentation in a local region. Hence the seam material is created by working acreage material to break up the phenolic resin matrix and thereby increase compliance without much change in thermal properties. The seam material is wrapped in tape adhesive and inserted in the gaps, with lateral clearance between gapfiller and tiles, and excess height for the gap filler. When the adhesive is cured in an autoclave at high pressure, the load at the outer surface causes the gap filler to decrease in height and expand laterally, to close the gap and load the adhesive that bonds the seam material to the acreage tiles. This process permits very thin adhesive layers to be used, and the thermal response across the joint is almost continuous..

The integration of the molded panels and seam material requires complex bonding, curing and routing operations that requires high precision. The integration is illustrated in Figure 1. The HEEET team has completed the manufacturing of all the parts needed to assemble a 1m heat-shield. The integration process that is currently in progress will be completed by February, 2018. The assembled heatshield will then undergo a series of testing at full scale.

The 1m heat-shield is designed to be capable of enduring Saturn entry conditions, so the test load levels should bound those for most future mission need. Missions to Venus, Saturn and other destinations will likely use a heat-shield design that differs in some ways from the Engineering Test Unit. The HEEET integration processes for the ETU are designed to be relevant for different structural arrangements, and for both areal and thickness scale-up.

The full presentation will report on the testing at relevant scale in relevant environments that will deliver system TRL of 6 by the end of FY'18.



Figure 1. HEEET integration with the carrier structure. Molded and resin infused tile panels are bonded and routed precisely for integration of seam between the acreage tiles.

Sustaining Phenolic Impregnated Carbon Ablator (PICA) for future NASA Robotic Science Missions including NF-4 and Discovery. E. Venkatapathy¹, M. Stackpoole² and S. Violette³, ¹Ms 229-3, NASA Ames Research Center, Moffett Field, CA 94035, ethiraj.venkatapathy-1@nasa.gov, ² NASA Ames Research Center, Moffett Field, CA 94035, ³Fiber Materials Inc., Biddeford, ME 04005.

Abstract: Phenolic Impregnated Carbon Ablator (PICA), invented in the mid 1990's^[1], is a low-density ablative thermal protection material proven capable of meeting sample return mission needs^[2] from the moon, asteroids, comets and other "unrestricted class V destinations". It's low density and efficient performance characteristics have proven effective for use in Discovery to Flag-ship class missions. It is important that NASA maintain this TPS material capability and ensure its availability for future NASA use. The rayon based carbon precursor raw material used in PICA preform manufacturing had to be replaced at least twice in the past 25 years and a third replacement is now needed. The carbon precursor replacement challenge is twofold – the first involves finding a long-term replacement for the current rayon and the second is to assess its future availability periodically to ensure it is sustainable and that a replacement could be found in a timely manner if required. This presentation reviews the current SMD-PSD funded PICA sustainability activities in ensuring a rayon replacement for the long term is identified and in establishing that the capability of the new PICA from an alternative precursor is in family with previous versions of the so called "heritage" PICA. This presentation will summarize efforts in evaluating Lyocell based PICA manufacturing and present preliminary results comparing the properties and performance of Lyocell based PICA with heritage PICA.

Results: Under contract, FMI was successful in manufacturing fiberform using Lyocell. FMI manufactured both a single piece net shape cast fiberform at the OSIRIS REx scale as well as fiberform billets. The net casting allows a single piece of PICA to be manufactured into a heatshield while the billet form yields PICA blocks similar to those used in the MSL tiled PICA heatshield. Figure 1 shows the final net shape cast fiberform manufactured using Lyocell.



Figure 1. Lyocell based net-casted fiberform (same size as OSIRIS REx).

A series of thermal and mechanical properties were completed to compare with heritage materials. Arc jet tests were also performed at three different test condi-

tions to evaluate and compare the thermal response and recession performance of Lyocell based PICA with heritage PICA. In Figure 2, in-depth thermocouple response between the two precursors are compared. The differences are minimal indicating that the Lyocell PICA performance is in family with rayon derived PICA at this high condition ($\sim 1550\text{W}/\text{cm}^2$ and 1.3 atm).

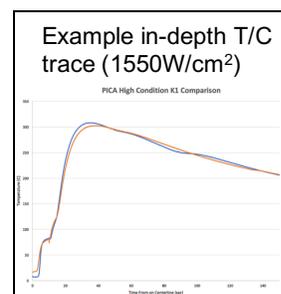


Figure 3. In-depth temperature comparison from an arc-jet test at $\sim 1550\text{ W}/\text{cm}^2$ and 1.3 atm shows the performance are comparable.

Summary: PICA manufactured from a Lyocell precursor, a domestic rayon, has presented no manufacturing issues and FMI has demonstrated manufacturing both fiberform and PICA in billet form as well as a net shape cast form. Lyocell derived PICA is within the density specification of standard (heritage) PICA. Preliminary arc-jet testing at high conditions indicates that Lyocell PICA behavior is in family with heritage material. From these preliminary results Lyocell PICA is likely to be a "drop in" replacement for future NASA mission needs. Since Lyocell is manufactured in the US in very large quantities and the need is in the commercial sector, Lyocell based PICA could be a sustainable source for the future mission needs.

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Venus Atmospheric Maneuverable Platform (VAMP) – Future Work and Scaling for a Mission

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Introduction: Northrop Grumman Aerospace Systems has been developing an innovative and versatile new class of vehicle that will serve as an atmospheric rover for exploration of planets and moons of the solar system that have atmospheres. The new class of vehicle is called Lifting Entry Atmospheric Flight (LEAF), which provides a new way to enter an atmosphere from space and transition to flight within the atmosphere. Additionally, the LEAF system is semi-buoyant and the on-board propulsion system provides the capability to adjust altitude on command and travel in specified directions. It is also robust to failures since it can safely float at full buoyancy should it lose power. The LEAF system further reduces mission risk by deploying prior to entry at a relatively slow pace and gently enters the atmosphere.

In this poster we discuss upcoming work to further mature the technologies of the VAMP platform, specifically in the areas of mission design, atmospheric entry profile, environmental exposure of the skin material, and buoyancy, inflation and control for operation at variable altitudes.

In addition we detail the Mid-Altitude vehicle that is well suited to being a companion to a Venus lander and orbiter mission such as VENERA-D. More specifically, we discuss various VAMP configurations and atmospheric science operations for this size of vehicle, and discuss potential instruments and how they can inform Venus’ atmospheric models.

A planet well-suited for exploration with a system such as LEAF is Venus. Our Venus atmospheric rover is called Venus Atmospheric Maneuverable Platform (VAMP). Over the past several years, we have been developing the VAMP concept that supports long duration instruments in the Venus atmosphere, providing empirical data to inform modeling of the atmosphere. We have identified three classes of VAMP vehicle that offer compelling missions in the Venus Atmosphere. These are sized for; a technical demonstration of concept; a mission ride along opportunity such as VENERA-D; and a Venus Flagship mission. Figure 2.

	Low Altitude (Small)	Mid Altitude (Mid-Size)	High Altitude (Large)
Float Alt	48 km	50 km	52 km
Minimum Power	100 w (day); 20 w (night)	300 w (day); 100 w (night)	8,000 w (day); 100 w (night)
Wing Span	6 m	30 m	59 m
Mass	90 kg including instruments	450 kg incl. 10 kg of instruments	880 kg incl. 50 kg of instruments
Tech	<ul style="list-style-type: none"> • Simple inflation-based deployment • TPS material for lifting entry • Sulfuric acid resistant skin material 	<ul style="list-style-type: none"> • Mechanical plus inflation-based deployment • Autonomous navigation and hazard avoidance • Enhanced night time power • Limited propulsion capability 	Next generation versions of pathfinder technologies

Figure 2. Low Risk VAMP Concepts

THE VENUS EMISSIVITY MAPPER – INVESTIGATING THE ATMOSPHERIC STRUCTURE AND DYNAMICS OF VENUS' POLAR REGION. T. Widemann^{1,2}, E. Marcq^{3,2}, C. Tsang⁴, N. Mueller⁵, D. Kappel⁶, J. Helbert⁶, M. D. Dyar^{7,8}, and S. Smrekar⁵. ¹LESIA, Paris Observatory, F-92190 Meudon, France (thomas.widemann@obspm.fr); ²University of Versailles-Saint-Quentin, Versailles, France; ³LATMOS, 11 Boulevard d'Alembert, F-78280 Guyancourt, France; ⁴SwRI, Boulder, CO; ⁵Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Dr., Pasadena, CA, 91109; ⁶German Aerospace Center (DLR), Rutherfordstrasse 2, 12489 Berlin, Germany; ⁷Planetary Science Institute, 1700 East Fort Lowell, Tucson, AZ 85719; ⁸Dept. of Astronomy, Mount Holyoke College, South Hadley, MA 01075.

Introduction: The Venus Emissivity Mapper (VEM) is the first flight instrument specially designed to map the surface of Venus using the narrow atmospheric windows around 1 μm [1]. VEM is proposed for NASA's Venus Origins Explorer (VOX) and the ESA M5/EnVision mission proposals in combination with a high-resolution radar mapper. Mapping of Venus with VEx/VIRTIS using the 1.02 μm thermal emission band can be viewed as a proof-of-concept for an orbital remote sensing approach to surface composition and weathering studies for Venus [2-7].

Thermal brightness on Venus' night side is mainly modulated by the lower clouds, imaged at 2.3 μm by the Akatsuki IR2 camera [8]. Thanks to the circular polar orbit geometry of VOX and the ESA M5/EnVision, VEM has the unique capability to (1) better constrain the microphysics of the lower cloud particles in three spectral bands at 1.195, 1.310 and 1.510 μm at a spatial resolution of ~ 10 km, and (2) investigate short-timescale cloud dynamics and thus local wind speeds by tracking cloud features in both polar regions.

Cloud parameters: Global cloud layers (~ 45 to 70 km) drive the energy balance of the atmosphere and hence climate at the Venus' surface [9]. While much progress has been made since the early suggestion that the Venus clouds are H_2O - H_2SO_4 liquid droplets [10], several cloud parameters are still poorly constrained, particularly in the lower cloud layer and optically thicker polar regions [11-13]. Observations at small horizontal scales are of great importance to microphysical models of cloud and haze systems [14]. VEM has the capability to better constrain the microphysics (vertical, horizontal, time dependence of particle size distribution, or/and composition) of the lower cloud particles in three spectral bands at 1.195, 1.310 and 1.510 μm at a spatial resolution of ~ 10 km.

Wind measurements: Venus displays the best-known case of polar vortices evolving in a fast-rotating atmosphere. Few wind measurements exist in the polar region due to unfavorable viewing geometry of currently available observations. Cloud-tracking data indicate circumpolar circulation close to solid-body rotation. E-W winds decrease to zero velocity close to the poles. N-S circulation is marginal, with extremely variable morphology and complex vorticity patterns [15-17] (Fig. 1).

Circular polar orbit geometry would provide an unprecedented study of both polar regions within the same mission. VEM's pushbroom method will allow short-timescale cloud dynamics to be assessed, as well as local wind speeds, using repeated imagery at 90 minute intervals.

Tracking lower cloud motions as proxies for wind measurements at high spatial resolutions will greatly benefit modeling of the vortices' physics. Convective modeling demonstrates that there will be cloud-level

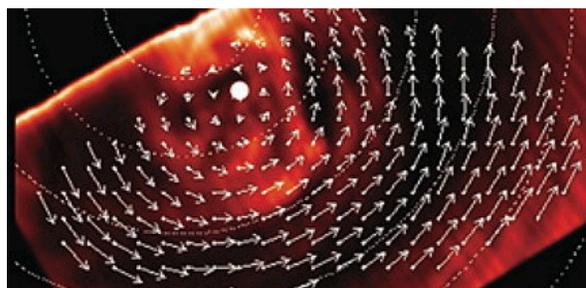


Figure 1 - Polar projection of South vortex morphology and cloud tracking zonal wind velocities near 1.74 μm [17].

convection at high latitudes, so repeated imagery at 90 minute intervals will help constrain the time evolution of cloud-level convection as well as wave-generating dynamical instabilities [17]. This will also allow a direct comparison of the N-S wind regimes and their temporal evolution at several time scales during a 4-yr mission.

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