VEXAG Venus Exploration Analysis Group

Program

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17th Meeting of the Venus Exploration Group (VEXAG)

November 6–8, 2019 • Boulder, Colorado

Institutional Support

Lunar and Planetary Institute

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Laboratory for Atmospheric and Space Physics

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Abstracts for this meeting are available via the meeting website at

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Guide to Sessions

17th Meeting of the Venus Exploration Group (VEXAG)
November 6–8, 2019
Boulder, Colorado

Wednesday, November 6, 2019

8:30 a.m.	W-120	Welcome, Introductions, and NASA Updates
11:00 a.m.	W-120	State of Venus Science and Technology I
1:30 p.m.	W-120	State of Venus Science and Technology II
3:30 p.m.	W-120	Lightning Talks for Poster Session I
4:45 p.m.	Poster Room	Poster Session: Interior, Surface and Atmospheric Observations and Processes
4:45 p.m.	Poster Room	Poster Session: Very Near and Very Far: Experimental, Telescopic, and Modeling Studies, Links to Exoplanets

Thursday, November 7, 2019

8:30 a.m.	W-120	Venus White Paper Presentations
10:35 a.m.	W-120	Venus White Paper Breakout Groups I
11:30 a.m.	W-120	Lunch and Field Trip
2:00 p.m.	W-120	Venus White Paper Breakout Groups II
3:00 p.m.	W-120	Lightning Talks for Poster Session II
4:15 p.m.	Poster Room	Poster Session: Technology, Instruments, Missions

Friday, November 8, 2019

8:30 a.m.	W-120	Findings Discussion
10:30 a.m.	W-120	Final Write-Ups and Additional Business

Program

Wednesday, November 6, 2019
WELCOME, INTRODUCTIONS, AND NASA UPDATES
8:30 a.m. W-120
Chairs: Darby Dyar and Noam Izenberg

Times	Authors (*Denotes Presenter)	Presentations
8:30 a.m.	Dyar M. D. Izenberg N. *	*VEXAG Introduction Welcome*
8:35 a.m.	McGouldrick K *	*Logistics for Meeting*
8:45 a.m.	NASA Representative *	*NASA SMD, program presentations*
9:45 a.m.		*Parker Solar Probe*
10:00 a.m.		Break
10:20 a.m.		*Mission Update: Akatsuki*
10:35 a.m.	Helbert J *	*Mission Update: Bepi Colombo*
10:50 a.m.		*Mission Update: ISRO*
11:05 a.m.	Prockter L. *	*PDS*

STATE OF VENUS SCIENCE AND TECHNOLOGY I
11:00 a.m. W-120
Chairs: Noam Izenberg and Darby Dyar

Times	Authors (*Denotes Presenter)	Presentations
11:15 a.m.	Trainer M. *	*Noble Gases on Venus*
11:45 a.m.	Zoltai T. Hunter G. *	*High Temperature Capabilities*
12:15 p.m.		Lunch

STATE OF VENUS SCIENCE AND TECHNOLOGY II
1:30 p.m. W-120
Chairs: Noam Izenberg and Darby Dyar

Times	Authors (*Denotes Presenter)	Presentations
1:30 p.m.	McGouldrick K. *	*Orbit to In-Situ Atmospheric Spectroscopy*
2:00 p.m.	Hensley S. *	*Venus Radar*
2:30 p.m.	Grimm R. *	*Orbit to Surface Geophysics*
3:00 p.m.		Break

LIGHTNING TALKS FOR POSTER SESSION I
3:30 p.m. W-120
Chairs: Noam Izenberg and Kevin McGouldrick

Every poster presenter will be allowed a 3-minute overview, which can include a single slide.

Times	Presentations
3:30 p.m.	*Lightning Talks for Interior, Surface and Atmospheric Observations and Processes Posters*
4:09 p.m.	*Lightning Talks for Very Near and Very Far: Experimental, Telescopic, and Modeling studies, Links to Exoplanets Posters*

Wednesday, November 6, 2019
POSTER SESSION: INTERIOR, SURFACE AND ATMOSPHERIC OBSERVATIONS AND PROCESSES
4:45 p.m. Poster Room

Authors (*Denotes Presenter)	Abstract Title and Summary
Smrekar S. E. Auerbach V. Ostberg C. O'Rourke J.	*How Thick is the Lithosphere of Venus?* **[#8035]** Numerous new estimates of elastic thickness from flexure modeling are compared to global estimates from gravity and topography. High heat flow (>95 mWm^2, similar to Earth's oceans) occurs over >40% of Venus, implying active tectonics.
Brossier J. F. Gilmore M. S. Toner K.	*Low Radar Emissivity Signatures on Venus Volcanoes and Coronae: New Insights on Relative Composition and Age* **[#8005]** We characterize how emissivity varies with altitude on Venus major volcanoes and coronae to constrain their relative composition and age. This tends to better understand the radar anomalies seen across Venus highlands.
Williams K. E. Titus T. N.	*Venus Dune Analogs: Where on Earth Do We Find Them?* **[#8007]** Our motivation is to find analogs for Venus dunes. Using COMSOL we compute shear stress over a dune for a specified flow regime. For local shear stress, the Venusian atmosphere is approximated by both the terrestrial atmosphere and sub-aqueous case.
O'Rourke J. G. Dong C.	*Detectability of Crustal Remanent Magnetism on Venus from Orbital Magnetometer Measurements* **[#8028]** Discovering any crustal remanent magnetism would vastly improve our understanding of the early evolution of Venus. Here we simulate what future orbiters could detect—and what past orbiters may have missed—using magnetohydrodynamic models.
Moruzzi S. A. Kiefer W. S.	*Thrust Faulting on Venus: Tectonic Modeling of the Vedma Dorsa Ridge Belt* **[#8021]** Quantitative modeling of thrust faulting in the Vedma Dorsa ridge belt requires fault displacements of 1–2 km, a faulted layer thickness of 10–20 km, and a fault dip of 25–30 degrees.
Bethell E. M. Ernst R. E. Samson C.	*Morphology of Wrinkle Ridges in the Alpha Regio (V-32) Quadrangle, Venus* **[#8022]** Twenty wrinkle ridges in the Alpha Regio (V-32) quadrangle, Venus, have been analyzed using stereo-derived topographic profiles. We report averages of wrinkle ridge widths, heights, and minimum associated shortening.
Williams Z. W. Byrne P. K. Balcerski J. A.	*A Global Study of Ridge Belt Morphology and Morphometry on Venus* **[#8027]** We collected detailed morphometric data for a globally distributed set of ridge belts. Low relief values imply that these surface expressions of crustal shortening may feature thrust faults that penetrate to shallow depths in the Venus lithosphere.
Byrne P. K. Ghail R. C. Gilmore M. S. Şengör A. M. C. Klimczak C. Solomon S. C. Khawja S. Ernst R. E.	*Geological Significance of Layering in Venus Tessera Units* **[#8037]** Layers in tessera/Volcanic or sediments?/We aim to find out.

Antonita T. M. Chaudhary R K. Imamua T.	*Small Scale Gravity Waves Observed from Radio Occultation Experiments of Venus* **[#8033]** Gravity waves are ubiquitous in any planetary atmospheres. Gravity waves are believed to play a major role in the dynamics of our twin sister, Venus. The characteristics of gravity waves in the Venusian atmosphere using the radio occultation data is studied.
Lee Y. J. García-Muñoz A. Yamada M. Yamazaki A. Watanabe S.	*Global Mean Microphysical Properties of Cloud Top Aerosols on Venus Retrieved from Disk-integrated Albedo at 283 and 365 nm* **[#8031]** We analyze observed disk-integrated albedo of Venus at 283 and 365 nm over the 0º-150º solar phase range using a Monte-Carlo radiative transfer model.
Gray C. L. Girazian Z. Peter K. S. Haeusler B. Paetzold M. Tellmann S. Nordheim T. Kovac S.	*Variability of the Venusian and Martian Nightside Ionosphere After Solar Storms* **[#8008]** We present observations of the Venusian nightside ionosphere after periods of solar storms as well as results of a monitoring campaign during solar minimum. These observations are compared to observations of the Martian nightside ionosphere.

POSTER SESSION: VERY NEAR AND VERY FAR: EXPERIMENTAL, TELESCOPIC, AND MODELING STUDIES, LINKS TO EXOPLANETS
4:45 p.m. Poster Room

Authors (*Denotes Presenter)	*Abstract Title and Summary*
Way M. J. Kane S. R. Lupu R. E.	*The First 100 Million Years and What It Can Tell us About Venus' History* **[#8015]** We will demonstrate that understanding the first 100 Myr of Venus' planetary evolution will make it easier to discern whether it was ever capable of hosting liquid water on its surface or not.
Aye K.-M. Young E. Bullock M. Ardavin N. Prater K.	*Setting up a new VENus IMage Analysis Package called VENIM* **[#8043]** We are creating a new community Python package for Venus image analysis. It will support pre-processing to improve SNR, image registration, and image feature flow field determination.
Dame R. H.	*Bulk Density Estimation on Venus from a Modified Nettleton Method* **[#8039]** Identifying Venus surface composition by calculating bulk density using a modified Nettleton method.
Akins A. B. Steffes P. G.	*Progress on Laboratory Studies of Sulfuric Acid Vapor Opacity with Application to Ka Band Radio Occultations of Venus* **[#8018]** Laboratory measurements of the Ka Band opacity of sulfuric acid vapor under simulated Venus conditions are ongoing at Georgia Tech. A transition between microwave and millimeter-wavelength models occurs between 30–40 GHz.
Treiman A. H. Filiberto J. Vander Kaaden K. E.	*Near-Infrared Reflectance Spectroscopy of Venus-Analog Rocks at Venus Surface Temperatures* **[#8011]** Silicic igneous rocks at Venus surface temperatures have NIR reflectances of 0.2–0.5; their emissivities are calculated to be 0.8–0.5. These values imply that such rocks should be readily recognizable with orbital NIR emissivity measurements.

Radke M. J. Hörst S. M. He C. Yant M. H.	*Optical Properties of Sulfuric Acid* **[#8032]** We have measured the optical properties of concentrated sulfuric acid from 0.2 to 25 µm in order to determine the accuracy of the frequently cited measurements of Palmer and Williams (1975), which have never been replicated at short wavelengths.
Young E. F. Tsang C. C. C. Bullock M. A. McGouldrick K. Lee Y. J. Peralta J.	*Venus Nightside Cloud Tracking and Spectral Image Cubes with IRTF/SpeX from 2001-2018* **[#8040]** We present an overview of an archive of Venus images and spectra obtained from 2001-2018 with the IRTF/SpeX instrument. The observations are available to all.
Young E. F. Bullock M. A. Skrutskie M. F. Kremic T.	*Observing Venus with NASA's High-Altitude Balloon Program* **[#8041]** NASA's balloon program could support a 100-day Venus Observing campaign from a near-space environment. Advantages include high spatial resolution of the cloud tops in UV filters and access to key UV and IR spectral bands.
Kane S. R. Arney G. Crisp D. Domagal-Goldman S. Glaze L. S. Goldblatt C. Grinspoon D. Head J. W. Lenardic A. Unterborn C. Way M. J. Zahnle K. J.	*Venus as a Laboratory for Exoplanetary Science* **[#8016]** This presentation will describe why characterization of Venus is critical for furthering studies of terrestrial exoplanets, including atmospheres, interiors, evolution, and defining the boundaries of habitability.
Ostberg C. Kane S. R.	*Identifying Potential Venus Analogs from Exoplanet Discoveries* **[#8017]** The Venus Zone will serve as a basis that we will tested using 3-D general circulation models coupled with future observations of planetary atmospheres. We hope this work promotes and illustrates the importance of future missions to Venus.

Thursday, November 7, 2019
VENUS WHITE PAPER PRESENTATIONS
8:30 a.m.   W-120
Chairs: Noam Izenberg and Darby Dyar

White paper authors will introduce their white paper and present a status update, call for assistance, co-signers solicitation, discussion, etc.

Times	Authors (*Denotes Presenter)	Presentations
8:30 a.m.	Hwang H. *	*Thermal Protection System Technologies for Enabling Future Venus Exploration*
8:34 a.m.	McGovern P. *	*Venus as a Natural Volcanological Laboratory*
8:38 a.m.	Burr D. *	*Planetary Wind Tunnel Facility*
8:44 a.m.	Komjathy A. *	*Investigating Dynamical Processes on Venus with Infrasound Observations from Balloon and Orbit*
8:50 a.m.	Limaye S. *	*Venus as an Astrobiological Target*
8:56 a.m.	Whitten J. *	*Venus Tessera*
9:02 a.m.	Helbert J. * Dyar M. D. *	*Orbital Spectroscopy of Venus*
9:08 a.m.	Smrekar S. *	*Venus Tectonics*
9:14 a.m.	Royer E. *	*Airglow as a Tracer of Venus' Upper Atmosphere Dynamics*
9:20 a.m.	McGouldrick K. *	*Venus Atmosphere/Weather*
9:26 a.m.	Brecht A. *	*3D Venus Models*
9:32 a.m.	O'Rourke J. *	*Searching for Crustal Remanent Magnetism.*
9:38 a.m.	Cutts J. *	*Aerial Platforms*
9:44 a.m.	Kremic T. *	*Surface Platforms for Venus*
9:50 a.m.	Venkatapathy R. *	*Heatshield for Extreme Entry Environment Technology (HEEET)*
9:56 a.m.	Kremic T. * Hunter G. *	*Long-Lived In-situ Solar System Explorer (LLISSE)*
10:02 a.m.	Gilmore M. *	*Venus Flagship*
10:08 a.m.	Kane S. *	*Venus as a Nearby Exoplanetary Laboratory*
10:14 a.m.	Izenberg N. *	*EMPIRE Strikes Back*
10:20 a.m.	Santos A. *	*Venus Experimental Facilities*
10:26 a.m.	Trieman A. *	*Venus Chemistry*

VENUS WHITE PAPER BREAKOUT GROUPS I
10:35 a.m.   W-120

Representatives of white papers will give short presentations and/or updates and/or calls for assistance.

LUNCH AND FIELD TRIP
11:30 a.m.   W-120
Chairs: Bob Grimm

Times	Presentations
11:30 a.m.	*Field Trip to Eldorado Canyon*

Thursday, November 7, 2019
VENUS WHITE PAPER BREAKOUT GROUPS II
2:30 p.m. W-120

Representatives of white papers will give short presentations and/or updates and/or calls for assistance.

LIGHTNING TALKS FOR POSTER SESSION II
3:30 p.m. W-120
Chairs: Noam Izenberg and Kevin McGouldrick

Every poster presenter will be allowed a 3-minute overview, which can include a single slide.

Times	Presentations
3:30 p.m.	*Missions, Instruments, Technology Posters*

POSTER SESSION: TECHNOLOGY, INSTRUMENTS, MISSIONS
4:45 p.m. Poster Room

Authors (*Denotes Presenter)	*Abstract Title and Summary*
Martynov A. B. Kosenkova A. V. Pisarenko P. D. Feofanov A. S.	*"Venera-D" Spacecraft and Maneuverable Entry* **[#8001]** Lavochkin Association is creating the Venera-D spacecraft design (development of the general design, accommodation of systems, assessment of orbit options, etc.). Launch dates between 2026 and 2031 have been evaluated.
Zasova L. Gregg T. K. P. Economou T. Eismont N. Gerasimov M. Jessup K. L. Ignatiev N. Gorinov D. Gerasimov M. Ivanov M. Khatuntsev I. Kremic T. Korablev O. Martynov A. Kosenkova A. Ocampo A. Pisarenko P.	*Venera-D: A Potential Mission to Explore Venus' Atmosphere, Surface, Interior and Plasma Environment* **[#8044]** This is a presentation of a work done by a Russian-American Joint Science Definition team on a complex mission to Venus.
Gilmore M. S. Beauchamp P. M. 32019 Venus Flagship Science Study	*A Proposed Venus Flagship Mission* **[#8019]** This proposed Venus Flagship mission could be the first mission to trace volatile inventory, phase, movement, reservoirs and loss over Venus history.
Fu H. Fu K. Hatch K. Nemanich R. Zhao Y.	*High Temperature (500 °C) GaN Based Threshold Switching Selectors for Memory Applications in Harsh Environments* **[#8004]** We demonstrated the first 500 °C GaN based threshold switching selectors via interface engineering through an etch-then-regrowth process and a PEALD-grown $Ga2O_3$ interlayer. The interlayer can dramatically improve the selector thermal performance.
Balcerski J. A. Hunter G. W. Colozza A. J. Makel D. A. Zborowski M. G.	*LEAVES – A Mission Augmentation for Global In Situ Atmospheric Exploration* **[#8026]** In cooperation with an orbital platform, LEAVES provides a route for highly distributed and cost-effective global exploration of Venus' clouds.
Sauder J. Hilgemann E. Stack K. Kawata J. Parness A. Johnson M.	*Hybrid Automaton Rover — Venus (HAR-V)* **[#8030]** The Hybrid Automaton Rover-Venus (HAR-V) is an electrical/mechanical rover powered by the wind. It is designed to enable a simple electronics package to traverse to various locations on Venus, driven by a mechanically powered system.

Gasch M. J. Hwang H. H. Ellerby D. T. Venkatapathy E.	*White Papers for the Next Decadal Survey: Thermal Protection Systems and Instrumentation for Venus Missions* [#8012] We are beginning to update and draft a new white paper that will consider TPS materials for atmospheric probes and landers with the most current information about the state-of-the-art suit-ability for TPS materials for Venus entry missions.
Rabinovitch J. Borner A. Gallis M. A. Sotin C. Baker J.	*Cupid's Arrow: Hypervelocity Sampling in the Upper Atmosphere of Venus* **[#8009]** Cupid's Arrow is a small satellite mission concept that would determine the amount of noble gases and associated isotope ratios in the Venus upper atmosphere, below the homopause.
Krishnamoorthy S. Komjathy A. Pauken M. T. Bowman D. C. Cutts J. A. Izraelevitz J. Jackson J. M. Martire L. Garcia R. F. Mimoun D.	*Progress Towards Balloon-Based Seismology on Venus* **[#8020]** We present recent progress made in our effort to measure venusquakes and other seismic activity from Venus' upper atmosphere using a balloon. Caution: This presentation includes information about very loud and large sub-surface chemical explosions.
Venkatapathy E. Ellerby D. Gage P. Gasch M. Hash D. Hwang H. Muppudi S. Stackpoole M.	*A Discussion on the Need to Sustain Mission Ready TPS and for Continued Development of Innovative Entry System Technologies* **[#8013]** To enable future Venus missions it is necessary to sustain mission ready and promising new technologies development. VEXAG support and advocacy, as well as its members to become co-authors on the white paper is requested.
Elston J. S. Bullock M. A. Stachura M. Z. Lebonnois S.	*Dynamic Soaring for Persistent Venus Upper Atmosphere Observations* **[#8023]** Although systems have been proposed for atmospheric observations of Venus, most suffer from the inability to perform targeted sampling. We propose to address this issue using a glider capable of energy harvesting through dynamic soaring.
Way M. J. Grandidier J.	*Cupids Arrows — Piercing the Heart of Venus : A Surface Instrument Concept* **[#8014]** Exploring the tectonic nature of Venus is crucial to understanding its present & past history of plate dynamics. We propose a novel concept that uses precise very long-term (years) monitoring of the surface of Venus over possibly 1000s of kilometers.
Nemanich R. J. Malakoutian M. Surdi H. Benipal M. Koeck F. A. Chowdhury S. Goodnick S. Lyons J.	*High Temperature Diamond Electronics for Actuators and Sensors* **[#8025]** This research is focused on high temperature diamond diodes for power control and conversion modules at the surface of Venus. The diamond diodes, characterized to 600C, showed blocking voltage of >50V and forward current density >3000A/cm^2.
Bugga R. V. Jones J. P. Pauken M. T. Glass D. E. Cutts J. A. Ahn C. C. Fultz B. T. Nock K. T. Bhakta D. Raub E.	*New Power Technologies for Venus Low-altitude and Surface Missions* **[#8038]** Describes two new power technologies for Venus exploration: i) A long-duration variable altitude balloon using PVs, regenerative solid oxide fuel cells and metal hydrides for H_2 storage and ii) High temperature batteries for long-duration landers.
Ghabuzyan L. G. Chhun C. C. Vega J. V. Bravo Z. B. Kuo J. K. Sauder J. S.	*A Design Methodology of Venusian Wind Turbines.* **[#8042]** The aim of this work is to develop a fast and lower cost design methodology to develop and optimize various turbine designs for the purpose of use within Venusian atmosphere.

Newkirk J. W.	_Long Life Materials for Aggressive Sulfuric Acid Environments_ **[#8036]** An alloy developed for aggressive, hot sulfuric acid environments could be enabling for longer surface operation times on Venus.
Nikolic D. Simcic J. Madzunkov S.	_Expected Performance of the QIT-MS Mass Spectrometer in Venus' Atmosphere_ **[#8024]** We present experimental and modeling results for the performance of the JPL Quadrupole Ion Trap Mass Spectrometer and its expected response in Venus' atmosphere. Emphasis is given to new development of the Advanced NanoJet Aerosol Separator Apparatus.
Lee K.-L. Tarau C.	_24-Hour Consumable Based Cooling System for Venus Landers_ **[#8045]** Extremely hostile venusian environment presents significant challenges in the designing of the thermal management system for a Venus lander. Advanced Cooling Technologies, Inc. (ACT) has developed an innovative cooling concept.
Blake D. F. Sarrazin P. Bristow T. S. Treiman A. H. Zacny K. Morrison S.	_CheMin-V: A Definitive Mineralogy Instrument for Landed Science on Venus_ **[#8029]** We describe an XRD/XRF instrument that will determine the quantitative mineralogy and elemental composition of two drilled Venus regolith samples delivered by the Honeybee Robotics Venus drill (under Venus surface conditions) in 15 minutes.
Esposito L. W. HOVER Team	_Hyperspectral Observer for Venus Reconnaissance (HOVER)_ **[#8034]** The Hyperspectral Observer for Venus Reconnaissance (HOVER) is a Venus orbiter for remote sensing of its clouds, chemistry, dynamics and surface. Its main goal is understanding the mechanics of the Venus climate.
Baines K. H. Cutts J. A. Nikolic D. Madzunkov S. M. Renard J.-B. Mousis O. Barge L. M. Limaye S.	_An Aerosol Instrument Package for Analyzing Venusian Cloud Particles_ **[#8010]** A lightweight, low-power instrument is being developed to measure, in-situ, (1) the gas abundances and (2) the microphysical properties of attendant aerosols (e.g., composition, number density. and size distributions) for use on future Venus missions.

Friday, November 8, 2019
FINDINGS DISCUSSION
8:30 a.m.   W-120

Times	Presentations
8:30 a.m.	*Findings Discussion*
10:00 a.m.	Break

Friday, November 8, 2019
FINAL WRITE-UPS AND ADDITIONAL BUSINESS
10:30 a.m.   W-120

Presentations
Final Business
EDI Working Group Activity
New Working Group Formation, if any
Other Preparations for Decadal
Next Meetings
Exoplanets in Our Backyard
Next VEXAG
Other Business

CONTENTS

Progress on laboratory studies of sulfuric acid vapor opacity with application to Ka Band radio occultations of Venus.

A. B. Akins and P. G. Steffes, Georgia Institute of Technology, School of Electrical and Computer Engineering, 777 Atlantic Drive, Atlanta, GA, 30313. (aakins6@gatech.edu)

Introduction: Future missions to Venus will include radio occultation experiments operating in the Ka Band. Compared with prior radio occultation experiments operating at S and X Band, the use of Ka Band will enable finer vertical resolution for the retrieval of Venus atmospheric structure and composition. As with prior radio occultations, accurate retrievals of H_2SO_4 vapor abundance profiles from the attenuation of the radio signal will rely on models of the H_2SO_4 vapor opacity based on laboratory measurements under Venus conditions. Such measurements are currently underway at Georgia Tech.

Experimental Method: Fabry Perot-type microwave open resonators have been constructed using corrosion resistant materials to measure the pressure-broadened absorptivity and refractivity of H_2SO_4 vapor mixtures from 26-42 GHz. A gold-plated flat mirror and a curved mirror with a 40 cm radius of curvature (ROC) are oriented in 'semi-confocal' and 'parallel-plate' configurations. In the semi-confocal configuration, the mirrors are separated by close to half of the ROC, resulting in resonances with quality factors up to 12,000 at the upper end of the Ka Band. In the parallel plate configuration, the mirrors are separated by a shorter distance (~5 cm), resulting in resonances with a high signal to noise ratio evenly spaced in 4-5 GHz intervals across the entire band. Both configurations are housed in a borosilicate glass pressure vessel.

During a measurement cycle, the pressure vessel and an isolated flask containing a known volume of 98% sulfuric acid solution are placed in an oven and brought to a temperature of 565 K. When the resonator system achieves thermal stability, the valve connecting the flask and the pressure vessel is opened, introducing H_2SO_4 vapor into the resonator path. Measurements of the opacity of H_2SO_4 evaporates (H_2SO_4, SO_3, and H_2O) are made as well as mixtures with up to 3 bar of CO_2. The pressure-broadened opacity of the H_2SO_4 evaporates is isolated from that of the CO_2 by matching gas-induced shifts in resonant frequency using pure CO_2. Following the completion of a measurement, the system is allowed to cool to room temperature, and the remaining volume of H_2SO_4 solution is measured.

Prior Models: Prior radio occultation experiments have made use of the S and X Band H_2SO_4 vapor opacity models derived from the laboratory measurements of Kolodner and Steffes [1]. Akins and Steffes have also made measurements of the 2-4 millimeter absorption spectrum of H_2SO_4 vapor and developed a model based on the JPL millimeter line catalog [2]. Extrapolation of these models to Ka Band frequencies give conflicting interpretations of the attenuation that would result during a Venus radio occultation experiment. Measurements of the H_2SO_4 vapor opacity near 42 GHz are in relative agreement with the model of Akins and Steffes, and lower frequency measurements suggest that the transition region between models occurs between 30 and 40 GHz. In the JPL catalog (shown in Fig. 1), this range of frequencies represents a transition between the dominance of spectral features associated with elastic and inelastic collisions. Further measurements are underway to confirm the nature of the transition region and to determine if modifications to the lower frequency portion of the JPL catalog for H_2SO_4 can be used to model the opacity.

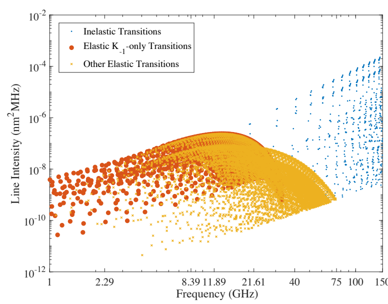

Fig 1. Line intensities for H_2SO_4 in the JPL Catalog

Implications for Dual Band Radio Occultations: In addition to measurement of the vertical profile of H_2SO_4 vapor at Venus, dual band X and Ka Band radio occultations are potentially capable of retrieving vertical profiles of other atmospheric constituents. Since the opacities of both the cloud and SO_2 increase with frequency, their effects on the downlink signal become more apparent at Ka Band. Subtraction of the H_2SO_4 vapor contribution (determined from X Band attenuation) from the Ka Band signal attenuation will result in residual attenuation, which can be interpreted as cloud or SO_2 opacity, depending on the height of the features. Accurate Ka Band opacity models for the cloud aerosols and SO_2 exist under Venus conditions [3,4].

References: [1] Kolodner, M. A. and Steffes, P. G. (1998) Icarus, 132, 151-169. [2] Akins, A. B and Steffes, P. G. (2019) Icarus, 326, 18-28. [3] Fahd, A. K. and Steffes, P. G. (1991) *JGR: Planets 96,* 17471–17476. [4] Fahd, A. K. and Steffes, P. G. (1992) *Icarus,* 97, pp. 200-210.

Small scale gravity waves observed from Radio Occultation experiments of Venus . T. Maria Antonita, R. K. Chaudhary[2] and T. Imamura[3]
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Introduction: Gravity waves are ubiquitous in any planetary atmospheres. Planetary exploration over decades provided clue to the presence of gravity waves in the inner planets like Venus[1],[2],[3] as well as Outer Giant planets like Jupiter [4] apart from the Earth's atmosphere [5]. The sources of the gravity waves in the terrestrial atmosphere are proven to be orography, jet streams and convection[5]. These waves are mainly generated in the tropospheric regions of Earth's atmosphere and propagate to the upper atmosphere thus carrying energy and momentum from source to sink regions. By depositing of energy and momentum fluxes they play paramount role in influencing the dynamics and chemistry of Earth's mesospheric lower thermospheric regions.

Gravity waves are believed to play a major role in the dynamics of our twin sister, Venus. Though the super rotation of the Venusian atmosphere are believed to be caused by the Tidal oscillations, the contribution from gravity waves to this phenomena still remains a puzzle. Radio occultation experiments of the various missions to Venus provide unique opportunity to study the gravity waves in the Venus atmosphere globally. The present study aims to delineate the characteristics features of gravity waves such as its vertical wavelength, energy and momentum fluxes in the Venusian middle atmosphere using the radio occultation data from Venus missions like Akatsuki and Venus express. The results will be discussed in detail.

Data used : Radio Occultation data from Akatsuki Radio Science experiment using UDSC and IDSN for the years 2016-2018 are used in the present study. The RO over the equatorial region are taken from Akatsuki mission. RO data used from Akatsuki are X- band (~8.4 GHz) in open loop mode[6]. More 50 occultation events from Akatsuki has been chosen to study the gravity wave characteristics. In addition to Akatsuki RO data, VEX Radio Science Experiment (VeRa) data are also used in the present study. VEX uses two coherently generated S-Band (2.3 GHz) and X-band (8.4 GHz) in the closed loop mode [7]. Combination of these two mission provides a opportunity to elucidate the variations in the gravity waves characteristics in both temporal and spatial domains.

Advantage : This work provides background to the Radio Occultation experiments proposed in the ISRO Venus mission. The RO proposal with International collaborators will definitely compliment the Radio Science Experiment of the ISRO'S Venus mission and bring out new perspective to the mysteries pertaining to the Venusian atmospheric dynamics and unique science results along with other suite of experiments.

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SETTING UP A NEW VENUS IMAGE ANALYSIS PACKAGE CALLED VENIM.

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Introduction: VENIM (Venus Imaging package) is a Python package that focuses on investigations of Venus images, particularly cloud tracking on Venus's dayside and nightside. There is a legacy of feature-tracking work on Venus [1, 2, 3, 4]. The main drivers for VENIM are to improve two key aspects of cloud tracking studies: registration of Venus's disk (errors in the sub-pixel registration of Venus's disk are often the largest source of cloud velocity errors) and image preprocessing to enhance detection of feature motion, especially in small, low contrast sub-regions. In addition, VENIM includes some convenience functions that perform standard tasks like flat-field and bias correction, image stacking, robust rejection of bad pixels, cosmic rays and detector artifacts, and translation from detector (x,y) coordinates to (lat,lon) coordinates on Venus. VENIM's initial targets will be Akatsuki, IRTF and Venus Express data sets.

Registration: VENIM treats the problem of disk registration as one of limb identification. For nightside images (typically obtained in the 1.74 or 2.3 micron windows), locating the limb can be a challenge: flux counts may be low and variable. VENIM has two methods for limb identification: a radial gradient method and an iterative limb modeling search method.

Cloud Tracking Tracking clouds on Venus faces the dual challenges of low-contrast fields and features that are often elongated in the E-W direction. As a result, cross-correlation techniques often have spurious peaks that indicate incorrect motions and poor feature-tracking resolution along the elongated axes. Some image preprocessing has been shown to improve cross-correlation feature tracking, including high-pass filtering of images and comparing the gradients of image pairs instead of the images themselves. VENIM includes routines to cross-correlate the gradients of image pairs, see for example Fig.1.

Routines We expect that some of VENIM's routines will be specific to individual instruments (e.g., removing scattered light in Akatsuki IR2 images or masking a diagonal flaw in the IRTF/SpeX GuidDog array).

Dissemination VENIM is intended to be an open repository to which the entire Venus community can contribute. We will disseminate the package via a GitHub repository, including documentation and example Jupyter notebooks. The package will also have automatically run tests to ensure software quality.

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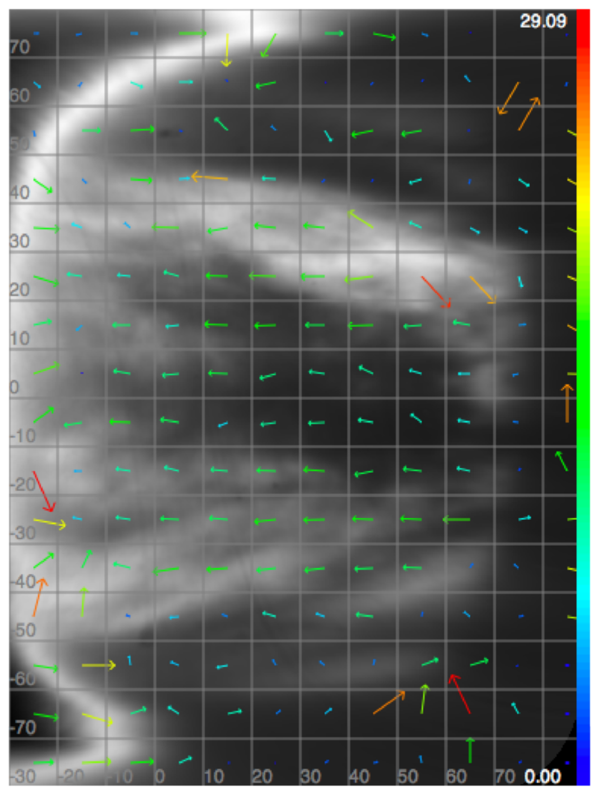

Figure 1: Example flow field for 4-JUL-2004 (left), calculated from pairs of projected images.

AN AEROSOL INSTRUMENT PACKAGE FOR ANALYZING VENUSIAN CLOUD PARTICLES.

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Introduction: Beyond a significant component of H_2SO_4, the composition of the hazes and clouds within Venus's thick atmosphere is poorly understood. Sulfuric acid clouds and hazes in the ~ 40-70 km altitude range result from photochemical processes involving SO_2 and H_2O. An admixture of constituents is evident by the surprisingly strong UV absorption observed within this cloud environment, providing evidence of poorly-understood chemical - and possibly biotic [1-3] - processes within the clouds.

To understand the cloud chemical and possibly biotic processes, we are developing a lightweight,low-power instrument package to measure, in-situ, both (1) the local gaseous environment and (2) the microphysical properties of attendant Venusian aerosols, including their composition and their number density and size distributions. This device would be used on future aerial missions, including on long-duration (multi-week) balloon missions and on short-duration (several hour) probes to explore the clouds and hazes of Venus, as well as potentially on missions to other cloudy worlds such as Titan, the Ice Giants, and Saturn.

Current requirements include the ability to measure mass ranges from 2 to 300 AMU at <0.02 AMU resolution to, for example, measure the component of iron chloride ($FeCl_3$ - 158 AMU; [4]) and potential biotic species embedded within sulfur acid aerosols. Another requirement, based on the expected saturated equilibrium concentration of HCl in H_2SO_4 aerosols near the 55-km-altitude level [5] is to measure HCl/H_2SO_4 with a mixing ratio of 2×10^{-9} to better than 10% in less than 300 secs. Solution chemistry of H_2SO_4 with HCl and with its sister hydrogen halides HF and HBr [6,7] may produce significant amounts of associated sulfonic acids (e.g., $ClSO_3H$, FSO_3H, $BrSO_3H$) and their daughter products (e.g., $SOCl_2$ and SO_2Cl_2, SOF_2, SO_2F_2 [4, 8]). Other potential species to be measured resident on or dissolved within H_2SO_4 particles include elemental sulfur polymers comprised largely of S_8 together with small admixtures of the metastable allotropes S_4 and S_3 [9,10].

The heart of the aerosol mass spectrometer component of the instrument package is the Quadrupole Ion-Trap Mass Spectrometer (QITMS, [11,12]).The preliminary concept involves an inlet aerodynamic lens [13,14] together with an adjustable piezo-electric aperture that allows only aerosols of a selectable size range within an overall range of 0.3 to 3.0 μm radius into the QITMS. Upon entering the QITMS, aerosols are vaporized by its hot electrode surfaces (~320° C). Notably, the elimination of CO_2 and other gas species provided by the aerodynamic lens increases the trace aerosol species concentration by about 4 orders of magnitude. As a result, to a precision of 10%, trace aerosol species with concentrations relative to the expected dominant H_2SO_4 material of 100 ppb and 2 ppb (corresponding to about 0.01 ppb and 0.2 ppt relative to the ambient atmospheric CO_2) can be measured to 10% precision in <6 secs and <5 minutes, respectively.

As a front end to the aerodynamic lens, we are considering adding a lightweight, compact nephelometer/particle-counter device being developed at LP2CE-CNRS [15]. Evolved from designs regularly flown on balloons in recent years [16,17], this component will enable the particle number density and size distributions to be determined as well, perhaps indicating, for example, that aerosols involving unexpected molecular species have a distinctly different size and number density than typical particles.

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LEAVES – A MISSION AUGMENTATION FOR GLOBAL IN SITU ATMOSPHERIC EXPLORATION. J. A. Balcerski[1], G. W. Hunter[2], Anthony Colozza[3], Maciej Zborowoski[3], Darby Makel[4]. Ohio Aerospace Institute, Cleveland, OH (jeffreybalcerski@oai.org), [2]NASA Glenn Research Center, Cleveland, OH, [3]Vantage Partners, LLC, Cleveland, OH, [4]Makel Engineering, Inc, Chico, CA.

Introduction: The LEAVES (Lofted Environmental and Atmospheric VEnus Sensors) concept mission and technology design exercise, supported by the NASA Innovative Advanced Concepts (NIAC) program, is a "swarm" approach to obtaining key Venus atmospheric data for exceptionally low cost and risk. This is made possible by an ultra-lightweight, passively-lofted, inexpensive atmospheric sensor package that can be deployed directly from orbit without an aeroshell, is robust enough for the harsh Venus environment, cheap enough to deploy by the dozens, and is sensitive enough to yield valuable new, transformative information on planetary atmospheres. LEAVES uniquely enables atmospheric sensing through combining miniaturized sensors, electronics, and communications on a lightweight physical "kite" that acts as a passive, drifting body when in the presence of a substantial planetary atmosphere, like the cloud-bearing upper and middle atmosphere of Venus. The benefits of this architecture include scalability, straightforward integration as a secondary payload, and reduced cost of obtaining high-priority science data. LEAVES utilizes components appropriate for Venus such as harsh environment chemical species sensors which are now commercially available or have been matured to TRL 5-6 by other applications and programs (i.e. NASA SBIR and HOTTeCH).

LEAVES fills an exploration platform gap between dropsondes and aerostat/aerobot balloons. In the former case, isolated vertical profiles of the atmosphere are obtained in a very short amount of time. In the latter case, isolated horizontal (with some limited vertical) atmospheric profiles are obtained over an extended period of time. However, a comprehensive global picture of atmospheric conditions remains elusive due to sparse lateral *and/or* vertical coverage. Leveraging a "swarm" of inexpensive, independent atmospheric sensors with high atmospheric residence times, LEAVES provides a way of obtaining comparatively dense coverage in both lateral and vertical extents with a temporal resolution between that of dropsondes and balloons.

Probe Design: Each lightweight atmospheric probe is made of a ~100 g, high-drag structure and a 20 g science payload. A spring-hinge expands the 3-sided, inverted shuttlecock structure upon deployment, which then self-stabilizes due atmospheric resistance and a low center of gravity. The remarkably low areal density of ~ 0.1 g/m^2 allows for both a direct orbital deployment (i.e. without aeroshell) and a period of extended science operations in Venus' middle atmosphere.

Each probe in the swarm is equipped with at least two highly-sensitive, chemical species sensors (e.g. SO_2 and CO at better than 1 ppm resolution), temperature and pressure sensors, 6-axis inertial measurement unit, a microprocessor, 400 MHz transmit-only radio, and coin cell battery power supply. Sensor data is recorded every 30 seconds, at 8-bit resolution, and cached by the microprocessor for upload to an orbiting relay.

Unprecedented Atmospheric Data: *LEAVES provides in situ, high priority, targeted science that substantially augments and enhances the value of a primary, orbiting asset.* During a host spacecraft's aerobraking or orbit circularizing campaign, cohorts of a dozen or more probes are released from their compact, flat-packed storage unit at an altitude of ~150 km. If the carrier spacecraft is in a polar orbit, the deployment sequence can be timed to space out the probes over 10-20 degrees of latitude. Over the next several days, the LEAVES' orbits decay until they reach their target operational altitude of 100 km. For the next 9-10 hours, they each collect around 1 MB of data, comprised of >1000 repeated sensor measurements. These data span 60 km of altitude (including the clouds) and 1500 km of lateral travel (roughly 30 degrees of longitude, assuming ascending and descending deployment).

Summary: Enabled by a new generation of miniaturized electronics and sensors, and a failure-resilient swarm approach, LEAVES is capable of obtaining high priority, high resolution data of the atmosphere of Venus for exceptionally small cost and mass. This makes it ideal as a secondary payload for a Venus orbiter. Ongoing work will rapidly mature this concept through prototype construction, enhanced payload capability, Venus environmental testing, and terrestrial flight tests.

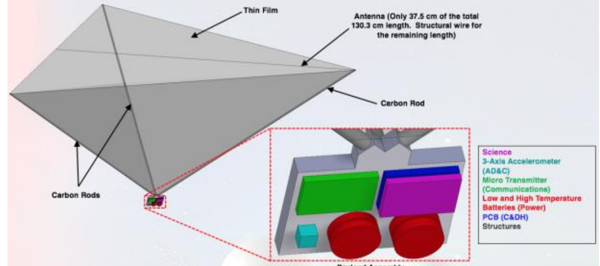

Figure 1. Schematic of a single LEAVES unit.

Acknowledgements: This work was completed through support of the NASA NIAC program. We also gratefully acknowledge the support of the NASA Postdoctoral Program during early concept development.

https://www.nasa.gov/directorates/spacetech/niac/2018_Phase_I_Phase_II/Lofted_Environmental_and_Atmospheric_Venus_Sensors/

MORPHOLOGY OF WRINKE RIDGES IN THE ALPHA REGIO (V-32) QUADRANGLE, VENUS. E. M. Bethell[1], R. E. Ernst[1,2], and C. Samson[1,3]. [1]Department of Earth Sciences, Carleton University, 1125 Colonel By Dr, Ottawa, ON, Canada, K1S 5B6; erinbethell@cmail.carleton.ca, [2]Faculty of Geology and Geography, Tomsk State University, Lenin Ave, 36, Tomsk, Tomskaya Oblast', Russia, 634050 [3]Department of Construction Engineering, École de Technologie Supérieure, 1100 Notre-Dame St W, Montréal, QC, Canada, H3C 1K3.

Introduction: Wrinkle ridges are common surface features on the terrestrial bodies of our solar system. They are typically sinuous along strike, have positive topography, and are inferred to be contractional in origin [1]. A thrust fault and anticline origin for wrinkle ridges has commonly been proposed [e.g. 2, 3, 4].

The morphology of wrinkle ridges on Venus is not well understood. This is largely a result of the low resolution of the altimetry data provided by the Magellan mission. The altimetry data have footprint sizes of approximately 10-20 km, which is relatively large compared to the size of individual wrinkle ridges. Improved resolution has been provided by a recently developed stereo-derived topography dataset that has a horizontal resolution of ~1-2 km and a vertical resolution of ~50-100 m [5].

A 1:2.5 million scale geological map of the Alpha Regio (V-32) quadrangle has recently been completed [6]. Among the mapped structural features, a regional system of ENE-WSW trending wrinkle ridges was identified. We present preliminary observations on the morphology of these wrinkle ridges, obtained from analysis of 225 stereo-derived topography profiles across 20 wrinkle ridges.

Methods: The structural mapping of wrinkle ridges produced by [6] was used to inform the construction of topographic profiles; profiles were only constructed along mapped wrinkle ridges. Multiple profiles were created for each wrinkle ridge, with an approximate spacing of 5 km between each profile line. Profile lines were constructed perpendicular to the local strike of the wrinkle ridge.

Results: We report average measurements on the morphology of individual wrinkle ridges and of the whole population.

Width. Average widths for each wrinkle ridge range from 7.0 ± 1.2 km to 13.5 ± 1.9 km. The average width of all wrinkle ridges is 8.9 ± 1.9 km.

Height. Average heights for individual wrinkle ridges give minimum values of 68.4 ± 33.8 m and maximum values of 178.4 ± 62.6 m, with an average height for all wrinkle ridges of 116.3 ± 29.1 m.

Estimates of Shortening and Strain. Estimates of shortening due to folding represent the difference between the initial length of the profile (i.e. the surface length) and the length of the profile in its deformed state (i.e. the straight-line length), after [3]. Shortening estimates have been converted into percentages of strain using a ratio of shortening to initial length. Average shortening estimates for each wrinkle ridge range between 1.45 ± 1.40 m or 0.02 ± 0.02%, to 12.26 ± 10.91 m or 0.18 ± 0.18%. The average shortening for all wrinkle ridges is 4.86 ± 2.9 m or 0.06 ± 0.04%.

Discussion and Conclusions: Analysis of topographic profiles across wrinkle ridges has yielded an average ridge width of 8.9 km and an average ridge height of 116 m. Calculations of shortening due to folding indicate that the average wrinkle ridge has accommodated 4.9 m of shortening, representing a strain of 0.06%. The wrinkle ridges studied here have an average aspect ratio of 60:1, representing broad, low-amplitude features.

The shortening values calculated here are much smaller than previous estimates for Venusian wrinkle ridges (1-5%; obtained from structural models and analysis of radar imagery) [7] and for wrinkle ridges on other bodies [e.g. 3,8]. It should be noted that the estimates of shortening presented here represent only the component of shortening resulting from folding at the surface. Following the methodology of [3], a component of shortening is also produced by faulting at depth and can be calculated using the elevation offset across the ridge. We have not yet been able to quantify elevation offsets across wrinkle ridges, and therefore the shortening due to faulting, due to complex regional topographic gradients in this region. Notwithstanding, the low values obtained for shortening due to folding suggest that thrust faulting may play a more significant role in the formation of these wrinkle ridges. Future work will focus on the analysis of potential regional trends in wrinkle ridge dimensions, spacing, and shortening. We will also attempt to use a variety of more complex structural models to evaluate the total shortening associated with wrinkle ridges.

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CHEMIN-V: A DEFINITIVE MINERALOGY INSTRUMENT FOR LANDED SCIENCE ON VENUS. D. F. Blake[1], P. Sarrazin[2], T. S. Bristow[1], A. H. Treiman[3], K. Zacny[4], and S. Morrison[5]. [1]NASA Ames Research Center, Moffett Field, CA USA 94035-1000 (david.blake@nasa.gov), [2]SETI Institute, 189 N. Bernardo Ave. suite 200, Mountain View, CA USA, 94043, [3]Lunar and Planetary Institute, 3600 Bay Area Blvd., Houston, TX, USA 77058-1113, [4]Honeybee Robotics, 398 W. Washington Blvd., suite 200, Pasadena, CA USA 91103. [5]Carnegie Institution of Washington, Washington, DC., 1530 P St. NW, Wash, DC 20005 (smorrison@carnegiescience.edu).

Introduction: Science objectives of a Venus Lander [1] include: 1). Determine the elemental composition of surface rocks, and 2). Identify mineral phases to address atmosphere and surface evolution along with surface mineralogy. These objectives must be met within 1-2 hours.

Mineralogical Analysis using X-ray Diffraction and X-ray Fluorescence: X-ray Diffraction (XRD) is the only *in-situ* technique able to definitively identify, quantify and determine the elemental composition of minerals present in planetary regolith. XRD provides a comprehensive analysis of regolith mineralogy that can only be improved upon by sample return.

X-ray diffraction was employed in robotic planetary exploration for the first time on the Mars Science Laboratory (MSL) *Curiosity* rover [1-4]. Descriptions of the samples analyzed by CheMin as well as publications related to the analyses can be downloaded from the CheMin database: https://odr.io/Chemin.

The Terra XRD/XRF Instrument, a Prototype for CheMin-V: The Terra instrument shares its diffraction geometry with CheMin, but delivers 30X more X-ray flux to the sample, yielding much improved diffraction intensity as well as slightly improved 2θ resolution. A block of Saddleback basalt was drilled by the Honeybee Robotics (HBR) Venus drill under Venus surface conditions. The as-received sample was analyzed in a Terra instrument for 15 minutes, then reanalyzed for 8 hours in a Rigaku laboratory Diffractometer. Table 1 shows the resulting Rietveld refinement and quantitative analyses from Terra, compared to that of the Rigaku instrument.

The CheMin-V instrument. Fig. 1 shows a 3D model of the proposed CheMin-V XRD/XRF geometry. A single X-ray source emits a cone of CoKα radiation intercepted by two pinhole collimators. The two collimators produce ~70 μm diameter parallel beams of X-rays directed at the centers of two sample cells. The direct beams from the source/collimators strike opposite ends of a 256X1024 pixel CCD, and the diffracted beams from each sample are detected by the CCD along its long dimension. The CCD is split into two halves, yielding two separate 128X1024 pixel detectors, each recording an XRD pattern. Silicon Drift Diode detectors (SDD) are placed on the X-ray entrance side of each sample cell, recording an XRF spectrum of each sample.

Powdered samples delivered to the sample cells are vibrated, producing a random motion of the grains in the X-ray beam (as in the CheMin and Terra instruments). CheMin-V can return quantitative mineralogical results from two separate samples in ~15 minutes, leaving margin for sample delivery and data transmission. Parameters of the instrument are 27 X 18 X 15 cm, mass 5 kg. CheMin-V exceeds all mineralogical requirements for landed science on Venus.

Table 1: Rietveld refinement of Saddleback Basalt drilled under Venus surface conditions with the HBR Venus drill. 15 minute analysis with Terra vs. 8 hours in Rigaku laboratory XRD.

Phase	Formula	Terra 15 minutes (Wt %)	Rigaku 8 hours (Wt %)
Andesine	$Ca_{0.24}Na_{0.26}(Al_{0.735}Si_{3.265})O_8$	72	69
Augite	$Mg_{0.82}Fe_{0.52}Ca_{0.66}Si_2O_6$	14	14
Pigeonite	$(Mg_{0.78}Fe_{1.04}Ca_{0.18})Si_2O_6$	5	6
Olivine	$(MgFe)SiO_4$	8	8
Hematite	Fe_2O_3	2	2
Total		101	99

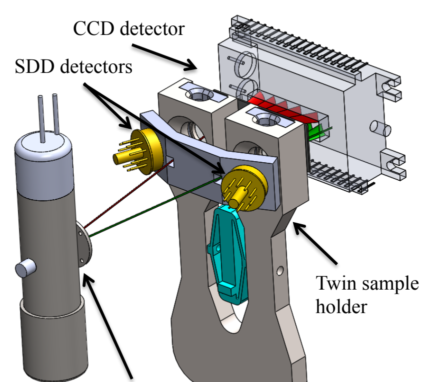

Fig. 1: Geometry of the CheMin-V diffraction experiment. Two samples are analyzed at the same time on a single CCD detector.

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LOW RADAR EMISSIVITY SIGNATURES ON VENUS VOLCANOES AND CORONAE: NEW INSIGHTS ON RELATIVE COMPOSITION AND AGE.

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Introduction: Following NASA's Magellan mission, several studies [1,2] revealed that most of Venus highlands exhibit unusual declines in radar emissivity. This is thought to be the result of atmosphere-surface interactions in the highlands, where temperatures are lower [3-5]. These reactions are a function of rock composition, atmospheric composition, and degree of weathering. The detailed variations in radar emissivity with altitude may yield insight into these characteristics. Here we focus our study on a selection of volcanoes and coronae at different locations and elevations on the planet. Investigating radiophysical behaviors of these volcanic edifices may help to retrieve, or at least constrain, their composition and relative age [6].

Data & Methods: We mapped 35 large volcanoes (isolated or located in topographic rises) and 15 coronae (isolated or in clusters) with the Magellan Synthetic Aperture Radar (SAR) images at 75 m per pixel. Elevation and emissivity data are extracted to produce scatterplots of the variation of emissivity with altitude [1]. Both datasets are oversampled to 4.6 km per pixel. The elevation data are given in term of planetary radius with a mean value taken as 6051.8 km [7]. We retrieved temperatures with the Vega 2 lander data [8].

Results & Discussion: Radar emissivity of many regions decreases from a global mean value (~0.8) from low to higher elevations [1,2]. We define an emissivity excursion as the region on an emissivity – elevation plot where emissivity values decline and become distinct from values seen in the lowlands. Almost all our regions show such excursions with altitudes and magnitudes varying from a region to another. The complex relationships between emissivity and elevation allows us to group the regions sharing similar patterns. This classification is based on whether there is an emissivity excursion and its magnitude (strong, weak or none), and it also depends on the elevation range where the volcano or corona stands. Each volcanic edifice is therefore affiliated to a group referring to a unique pattern [9]. The detailed description of these pattern permits to determine whether the rocks are compatible with known substances.

We correlate the emissivity excursions with the geological landforms by putting together emissivity and SAR images. For most volcanoes, the low emissivity values are located at the summits, except for the tallest volcanoes. Their emissivity decreases smoothly with elevation to a maximum of ~6056 km, and then increases abruptly to their summits at ~6057 km and above. This transition is followed by a "darkening" of their summits, except for Maat Mons. This particular behavior is consistent with the presence of ferroelectric minerals in the rocks undergoing a phase change at ~6056 km, and thus corresponding to a Curie temperature of ~700 K, as seen for Ovda Regio [10]. The other volcanoes could consist of rocks with ferroelectrics, but, they are too short to reach their Curie temperatures. The lack of low emissivity on Maat Mons, except for the stratigraphically older lava field on the southern flank, is assigned to young, unweathered lava flows extending on its flanks and summit region [11].

In addition to Maat Mons, Idunn and Otafuku montes also have high emissivity at their peaks despite their high elevation (above 6055 km). This suggests that they have relatively young surface, where the fresh rocks have not had time to react with the deep atmosphere to produce high dielectric minerals.

As for the coronae, the emissivity excursions are confined at their highest locations, either topographic ridges, extensive flows, or interior edifices, such as radially fractured domes (novae). Interestingly, Pavlova and Didilia coronae (east Eistla Regio) host novae in their interiors that are more elevated than their highest rims. These novae could be made of young and unweathered rocks considering their high emissivity despite their height. Also, the stratigraphic and topographic relationships of the novae and coronae indicate that novae are younger than the coronae [12].

Conclusion: Here, we point out that different classes of dielectric minerals (ferroelectrics and semiconductors) can account for the radar anomalies seen across Venus. This contrasting mineralogy could be related to distinct mantle source regions. We also find that some edifices could be made of fresh and unweathered rocks indicating recent or possibly current volcanism on the Earth's evil twin.

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New Power Technologies for Venus Low-altitude and Surface Missions: Ratnakumar Bugga,* John-Paul Jones, Michael Pauken, Dean Glass, and James Cutts (Jet Propulsion Laboratory, Caltech, Pasadena, Ca 91109), Channing Ahn, Brent Fultz (California Institute of Technology, Pasadena, CA 91125, Kerry Nock (Global Aerospace Corporation, Irwindale, CA 91706) and Dharmesh Bhakta, Eric Raub (Eagle Picher Technologies, Joplin, MO 64802) *ratnakumar.v.bugga@jpl.nasa.gov.

Introduction: The *in-situ* exploration of Venus is seriously hampered by its hostile environment,[1] limiting the in-situ exploration missions to high altitude balloons at 55 km (above the clouds) that lasted for 48 h, or even shorter duration surface missions that survived for two hours.[2,3] The high-altitude (55-65km) balloon missions, though successful, are stymied by the opaqueness of the Venusian clouds, which underlines the need for more long-duration in-situ missions for a better understanding of the Venus atmosphere across the cloud layers and even to the surface, as recommended by Venus Exploration Analysis Group (VEXAG).[4] Two types of mission concepts, i.e., i) long-duration variable-altitude balloons with extended range below the clouds, and ii) landers with lifetimes of more than a few hours, have gained particular interest: i) Durable Variable Altitude Balloons (VABs) and ii) Long-durations landers.

Need for New Power Technologies: For either of these mission types, conventional power technologies are inadequate. For example, the performance of photovoltaics (PV) is hampered by the decreasing solar flux deeper in the clouds, the selective loss of short wavelength radiation, and the performance loss from the high temperatures.[5] Advanced high temperature-tolerant technologies, are therefore being developed under NASA's Hot Operating Temperature Technology (HOTTech) program. An energy storage system (rechargeable batteries or fuel cells) tolerant to high temperatures is needed to compensate for the reduced power generation of PVs at low altitudes, and to support nighttime operations for the VABs. Likewise, a high-temperature primary battery systems, survivable and operational at 465°C, would be required to support long-duration Venus landers, e.g., NAS/GRC's Long-life In-situ Solar systems Explorer (LLISSE).

New Power Technology for Long-duration VAB: We have been developing a novel Venus Interior Probe using in-situ Power and Propulsion (VIP-INSPR) under NASA-NIAC (Novel Innovative and Advanced Concepts) program. The probe concept utilizes: i) PV as a power source to the probe at high altitudes, and to electrolyze water carried from ground using regenerative solid oxide fuel/ electrolysis cell (SOEC), ii) Solid oxide fuel cell (SOFC)[6] to provide power at low altitudes, iii) H_2 storage bed for on-demand storage or release of H_2,[7] iv) and a balloon filled with H_2 and with H_2 buoyancy-based altitude control system. Both H_2 and O_2 would be regenerated through electrolysis of the H_2O produced in SOFC (a closed–system) at high altitudes. This novel architecture enables generation of fuel from in-situ resources at high altitudes, power at low altitudes, and uses H2 for buoyancy and altitude control. In contrast to earlier Venus balloons, this probe will survive the hostile environments over 60-15 km, without the need for any thermal management. Our analysis show that the balloon is both mass and volume efficient and allows 3X payload than in the previous missions.

High Temperature Batteries for Landers: In addition to this VAB, we have been developing high-temperature primary batteries for Venus surface mission concepts under NASA's HOTTech program. These batteries are based on lithium alloys anodes (Li-Al), molten salt electrolytes based on binary/ternary mixtures of alkali metal halides, cathodes consisting of transition metal sulfides and designs similar to the aerospace thermal batteries.[8] We will present our preliminary results with different cathode materials in laboratory test cells and also the performance in the prototype cells, which suggest the batteries can survive and operate on the Venus surface for 26 days. Furthermore, these batteries are rechargeable, proving > 60 days of operation through three cycles thus far.

Acknowledgments: This work presented here was carried out at the Jet Propulsion Laboratory, California Institute of Technology under a contract with National Aeronautics and Space Administration and supported NASA-NIAC and NASA-HOTTech projects.

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GEOLOGICAL SIGNIFICANCE OF LAYERING IN VENUS TESSERA UNITS. Paul K. Byrne[1], Richard C. Ghail[2], Martha S. Gilmore[3], A. M. Celâl Şengör[4], Christian Klimczak[5], Sean C. Solomon[6], Sara Khawja[7], and Richard E. Ernst[7,8], [1]Planetary Research Group, Department of Marine, Earth, and Atmospheric Sciences, North Carolina State University, Raleigh, NC 27695, USA (paul.byrne@ncsu.edu); [2]Department of Earth Sciences, Royal Holloway, University of London, Egham, TW20 0EX, UK; [3]Department of Earth and Environmental Sciences, Wesleyan University, Middletown, CT 06459, USA; [4]Department of Geology, Faculty of Mines and the Eurasia Institute of Earth Sciences, Istanbul Technical University, 34469 Ayazaga, İstanbul, Turkey; [5]Department of Geology, University of Georgia, Athens, GA 30602, USA; [6]Lamont-Doherty Earth Observatory, Columbia University, Palisades, NY 10964, USA; [7]Department of Earth Sciences, Carleton University, Ottawa, ON K1S 5B6, Canada; [8]Faculty of Geology and Geography, Tomsk State University, Tomsk, 634050, Russia.

Introduction. Tessera units occupy ~7% of the surface of Venus [1] and are characterized by pervasive tectonic deformation. Numerous sets of lineaments, interpreted as mixes of extensional and shortening structures, record complex strain histories for individual tessera exposures [e.g., 2–4]. On the basis of gravity anomaly, morphology, and inferred composition, it has been proposed that tesserae are the Venus counterparts to continents on Earth [5–7]; indeed, surface emissivity data from the ESA Venus Express mission provide supporting evidence that the Alpha Regio tessera is more felsic than adjacent basaltic plains [8]. A better understanding of Venus' tessera units is therefore key to determining if, for example, these units formed in the presence of abundant volumes of water [9].

Interior Layering. In Alpha Regio, in addition to the recognized extensional and shortening structures, a set of (often highly) curved, parallel lineaments is present. These structures strongly resemble tilted strata in layered sequences on Earth that have an arcuate or sinuous outcrop pattern because of erosion. The irregular curvilinear patterns of these lineaments in tesserae may thus be indicative of layers that follow undulating topography with ~10-km length scales (**Figure 1**, as well as examples at e.g., 24°S, 5°E, and 22°S, 6°E). These candidate strata are ~50–200 m thick, although fainter lineaments that parallel the more prominent examples suggest some thinner layers, perhaps <10 m thick, as well.

Interpretation. The nature of these strata is unclear, although by analogy with Earth they could be stacked lava flows (i.e., trap terrain) or sedimentary units. The map patterns in Alpha Regio are consistent with gently dipping layers; however, even for conformal strata with a dip angle of 1°, their presence across the breadth of this region (~1,900 km) indicates a stratigraphic sequence as much as 33 km thick, with commensurately substantial erosion. Alternatively, these strata may represent periclinal folds with dip angles of 20° or greater, similar to those that comprise the Zagros fold-and-thrust belt on Earth [e.g., 10]. Dipping fold limbs do not require such a great stratigraphic thickness or extent of erosion. Yet whether these lineaments are folded or gently dipping, planar layers, their curved outcrop patterns implies some erosion throughout Alpha Regio; the radar-dark materials filling local lows may be deposits of that eroded material. This outcrop pattern is also seen in Tellus Tessera (39°N, 80°E) [11,12] and Manatum Tessera (8°S, 67°E), as well as in Ovda (3°S, 86°E) and Thetis (11°S, 130°E) regiones.

Outlook. Given the widespread occurrence of apparent layering in these units, the preservation of interior strata may characterize Venus tesserae in general. If so, the presence of such layering challenges inferences that this enigmatic unit represents uneroded, fractured crystalline rocks, and requires instead a more complex history of volcanic and/or sedimentary deposition, deformation, and exhumation.

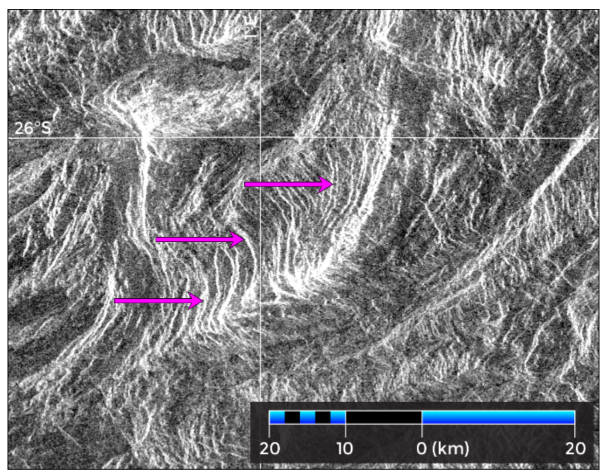

Figure 1. *Examples of arcuate structures in Alpha Regio tessera (marked by pink arrows). Radar image in azimuthal equidistant projection, centered at 26°S, 1°E; look direction is from the left.*

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BULK DENSITY ESTIMATION ON VENUS FROM A MODIFIED NETTLETON METHOD. R. H. Dame[1] and P. B. James[1], [1]Baylor University Department of Geosciences, (Rudger_Dame1@baylor.edu).

Introduction: One of the three main science goals identified in the 2019 VEXAG “Goals, Objectives, and Investigations for Venus Exploration” document is to “Understand the geologic history preserved on the surface of Venus…”. One objective pertaining to this goal is answering the question of “what geological processes have shaped the surface of Venus?”. Determining the composition of the surface will hint at geological processes that has shaped Venus.

One promising way to identify the composition of the surface is through calculating bulk density. Higher bulk densities could imply a more mafic surface while a lower bulk density could imply a more felsic surface. If the tesserae were shown to be more felsic in composition than the plains because of a lower density, this might hint at an ancient hydrosphere and plate recycling mechanism [1]. Bulk density of localized regions could be calculated using a modified Nettleton Method.

Venus geophysical data: The degree and order 180 *MGNP180U* data product was based on Magellan data and augmented with observations from Pioneer Venus Orbiter [2]. The gravity degree strength l_s is the spherical harmonic degree at which the power of the gravity uncertainty surpasses the signal power (this can be thought of as the maximum data resolution). The power spectrum of the error in the MGNP180U gravity surpasses the power of the coefficients above degree 70 (spatial block size 270 km), so this is the nominal degree strength of the data set. The actual degree strength varies considerably, with a resolution as high as degree 100 near the equator and as low as degree 40 elsewhere on the planet (Fig. 1).

Nettleton’s method: It has been known for 80 years that the bulk density of a terrain may be estimated using gravity measurements [3]. While the initial implementation of Nettleton’s method was flawed in the presence of large terrain variations, recent advancements in mathematical techniques enable us to precisely estimate the gravitational attraction of finite-amplitude terrains on other planets [4]. As a result, we can estimate the bulk density of Venus’ crust in various locations through a simple least-squares regression between the observed gravity and the gravity expected from a crust with a density of 1 kg/m^3.

Expected gravity: The gravity from Venus’s topography can be estimated for a density of 1 kg/m^3 using the calculation described in [4]. The crust–mantle boundary also contributes to the observed gravity field, and this contribution may be estimated either by using an existing crustal thickness model (e.g., [5]) or by assuming a state of Airy isostasy. The bulk density may be estimated with and without relief on the crust–mantle boundary, and the difference between those two densities provides a plausible estimate of the uncertainty.

Ideal spectral filtering: Unlike spatio-spectral estimates of Venus’ crustal density [6], our new method is capable of inferring density on relatively short scales. The downside of Nettleton’s method is that it is influenced by gravity anomalies at all wavelengths. The gravity data at low spherical harmonic degrees are sensitive to the presence of crustal roots and the deeper mantle, which can sometimes artificially decrease the interpreted density. Therefore, we apply a filter to the observed and predicted gravity data: we suppress the lowest spherical harmonic degrees and also suppress the spherical harmonic degrees higher than the local degree strength (Fig. 1).

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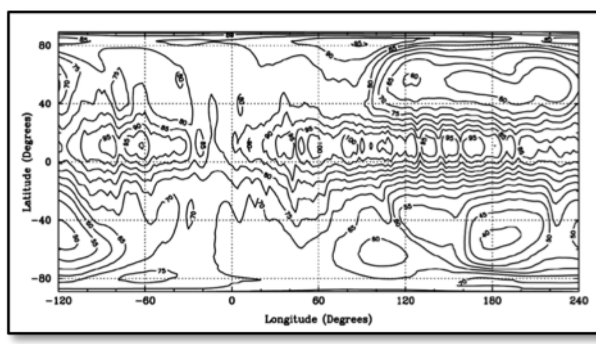

Figure 1. Map of the “degree strength” l_s of Venus’s gravity field (from [1]). The degree strength indicates the spherical harmonic degree at which the power of data noise surpasses that of the signal.

DYNAMIC SOARING FOR PERSISTENT VENUS UPPER ATMOSPHERE OBSERVATIONS. J. S. Elston[1], M. A. Bullock[2], M. Z. Stachura[1] and S Lebonnois[4], [1]Black Swift Technologies, 3200 Valmont Rd Ste 7, Boulder, CO 80301, elstonj@bst.aero, stachura@bst.aero, [2]Science and Technology Corp., 10015 Old Columbia Road E-250, Columbia, MD 21046, bullock@stcnet.com. [4]Laboratoire de Météorologie Dynamique, 24 rue Lhomond 75005 Paris, sebastien.lebonnois@lmd.jussieu.fr

Introduction: Although a majority of the proposed systems for upper atmospheric observations of Venus have consisted of dirigibles [1] or solar-powered heavier than air vehicles [2,3], both suffer from their own particular drawbacks and neither deal effectively with the high wind speeds. We propose a solution based on dynamic soaring, a proven method to extract energy from atmospheric shear that has propelled the fastest small-scale aircraft in the world, and provided for long-endurance low-level flights of birds across oceans [4]. An aircraft system will be designed to not only survive in the harsh wind environment of Venus, but also simultaneously perform targeted sampling while continuously extracting energy, even on the night side of the planet. The design will be based on proven dynamic soaring platforms, but will be constructed to allow deployment from a standard aeroshell.

Models and direct observation of the atmosphere of Venus have shown that the environment above the cloud layer is incredibly dynamic. Given that the upper cloud level of the atmosphere circles the planet roughly every 90 hours, any vehicle designed to operate in the proposed 50 to 60 km region will have a major power management challenge. An aircraft will either need to have sufficient battery capacity to continue functioning while traveling around the dark side of the planet, expend a large amount of energy to maintain position on the sunlit side, or make use of alternative methods to provide propulsive power to the system. Fortunately, the rapid movement of the atmosphere also creates locations conducive to energy harvesting. These ideal environments for the use of soaring techniques provide not only energy to maintain altitude, but sufficient wind-relative velocity to navigate to desired global locations. Large areas of the atmosphere on Venus contain characteristically high wind shear, particularly at the cloud interface[5,6] and above high elevation ground structures[7].

GCM Integration with Flight Path Modeling: Sophisticated Venus GCMs now exist that can produce predictions of the winds, thermodynamics, and chemistry at all altitudes, latitudes, longitudes, and local times of day. This presentation details the development of a simulation environment that makes use of the GCM output to test various complexities of atmospheric flight, including dynamic soaring algorithms. It has been designed to accommodate the inclusion of various vehicles, small scale atmospheric, and sensor models, as well as tie in directly to the output from the GCM for information about the thermodynamics of the local environment. It is envisioned that such a simulation could be extended to cover development of atmospheric vehicles for other locations including Mars or Titan.

VEXAG Goals: A long-lived aerial vehicle would be capable of performing all of the scientific investigations listed in the pursuit of VEXAG Goal II, except one (upper dynamics II.A.2) [8]. A long-lived vehicle would provide precise wind speeds in Venus' upper clouds over all times of day and at most latitudes. In situ sampling and analyses of the atmosphere and its aerosols over this large a geographic range will be far superior and more comprehensive than the snapshots that we have obtained so far with entry probes.

A mass spectrometer or tunable diode lasers could perform accurate noble gas and light element isotopes measurements (I.B.1) at many locations in the atmosphere. If fitted with a magnetometer and electric field sensor, the thermal state and possibly water content of the lithosphere (I.B.2) could be probed over a large fraction of the planet [9].

Carrying a near infrared camera, a Venus airplane that lingers in the clouds for weeks or months could also address most of the investigations suggested for achieving Goal III. Constant imaging of the surface from within the clouds at several wavelengths would provide higher resolution images than have been obtained by Venus Express or Akatsuki from orbit. An aerial vehicle could therefore map a large fraction of the surface at multiple near-IR wavelengths, enabling investigations III.A.1 (geologic history), III.A.2 (geochemistry), III.A.3 (geologic activity), and III.A.4 (crustal structure).

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Hyperspectral Observer for Venus Reconnaissance (HOVER).

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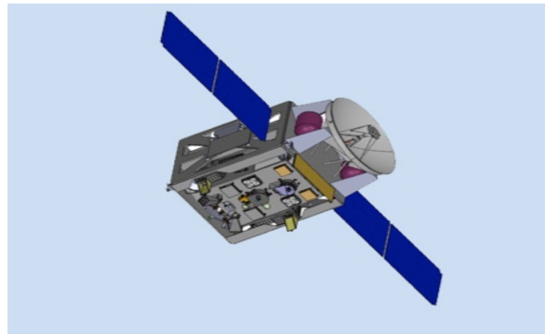
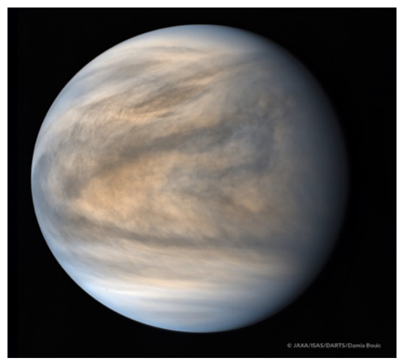
Abstract





The Hyperspectral Observer for Venus Reconnaissance (HOVER) is a Venus orbiter for remote sensing of its clouds, chemistry, dynamics and surface. Its main goal is understanding the mechanics of the Venus climate. HOVER has the following science objectives: Dynamic meteorology of the cloud layer; Determine distribution of key absorbers and parent gases of the clouds; Characterize super-rotation and solar to anti-solar circulation and compare to observations; Regional rock mineralogy to infer the distribution of continental crust; Monitor for volcanic eruptions. The HOVER mission will address the following key questions:

1. How do convection and chemistry produce the global clouds?
2. Where and how is solar energy deposited?
3. How is energy transported by large-scale circulation?
4. What does Venus surface tell us about past climates?
5. How is Venus current climate impacted by current volcanism?

LASP provides the Project Management, Project Systems Engineering, Mission Management, Orbiter, Payload Integration, Mission Ops, instruments; Science Leadership and Science Data Center. **SwRI** provides the Project Scientist; **Uni-Köln** provides the Radio Occultation investigation.

This proposed mission would address the Decadal Survey priority questions for aqueous environments and life; current habitable environments; understanding climate change on Earth; and Solar System processes.

HIGH TEMPERATURE (500 °C) GAN BASED THRESHOLD SWITCHING SELECTORS FOR MEMORY APPLICATIONS IN HARSH ENVIRONMENTS

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Introduction: Resistive random access memory (RRAM) has garnered considerable interests in non-volatile memory, neuromorphic computing and artificial intelligence (AI), etc. [1] Crossbar RRAM arrays exhibit small cell area, high integration density, and good scalability. But the sneak current path of unselected cells pose a significant challenge. To reduce the sneak path, threshold switching selectors with strong I-V nonlinearities are desired to be added in series with RRAM cells. [1] However, there are very few materials suitable for selectors, and no reports on devices working above 200 °C, which limit their potential for harsh environment applications such as space explorations.

In this work, we demonstrated the first GaN based threshold switching selectors based on an etch-then-regrowth process and Ga_2O_3 insertion layer. The devices showed stable high-temperature performance up to 500 °C, the record high value ever reported.

Device Fabrication: The devices were homoepitaxially grown by metalorganic chemical vapor deposition on *n*-GaN substrates. An 4 µm unintentionally doped (UID) GaN was first grown. Then 500 nm GaN was etched away to form etched surface by inductively coupled plasma (ICP) etching, followed by 50 nm UID-GaN as an insertion layer and 1 µm *p*-GaN successively regrown on the etched surface. Top and bottom electrodes were deposited by electron-beam evaporation using Pd/Ni/Au and Ti/Al/Ni/Au, respectively.

Results and Discussions: The etch-then-regrowth process resulted in a large amount of Si and O impurities according to SIMS analysis. TEM shows an interfacial layer was formed after the etch-then-regrowth process. These results indicate that interface states can form at the regrowth interface due to the etching damages, defects and accumulated impurities.

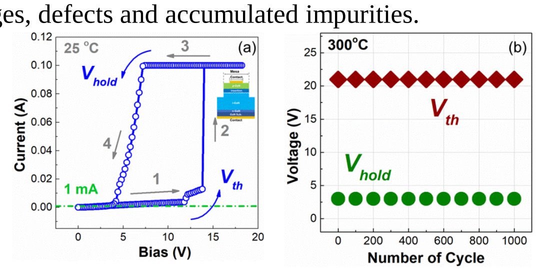

Fig. 1. (a) I-V characteristics of the GaN based threshold switching selectors. The inset shows device structure. (b) High temperature tests of the device.

The devices showed threshold switching behaviors as shown in Fig. 1(a) after the soft breakdown as a forming process. The threshold voltage (V_{th}) and the hold voltage (V_{hold}) had a large voltage margin of over 10 V, which is beneficial for selectors. The selector devices also exhibited excellent thermal stability up to 300 C in multi-cycle measurements (Fig. 1(b)). We proposed the electron/hole traps in the interfacial layer to explain the observed threshold switching behaviors. These traps can trap/detrap electrons/holes to form/rupture the conductive path.

Interface Engineering: The etch-then-regrowth process resulted in a maximum operation temperature of 300 ºC. To future improve the thermal performance for some high temperature environments (e.g., Venus), interface engineering was utilized where an interlayer was intentionally inserted to make the interface more controllable and stable.

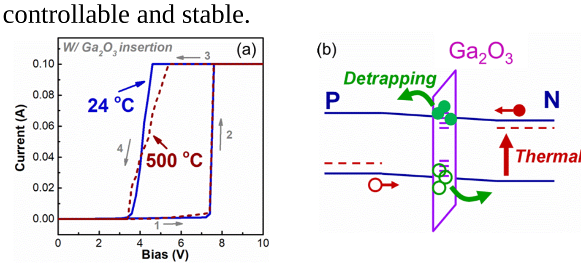

Fig. 2. (a) I-V characteristics of the GaN selectors with the Ga_2O_3 interlayer. (b) Trapping/detrapping process.

As the native oxide of GaN, Ga_2O_3 is a very promising candidate. The two materials also have very small lattice mismatch (< 5%). 1 nm Ga_2O_3 as the interlayer was deposited by PEALD prior to the regrowth. All the other processes remained the same. The device with the Ga_2O_3 interlayer showed stable performance up to 500 ºC (Fig. 2(a)). The trapping and detrapping process (Fig. 2(b)) can also be used to explain the threshold switching behaviors.

Conclusion: We demonstrated 500 °C GaN threshold switching selectors. This is realized via interface engineering through an etch-then-regrowth process in combination with a PEALD-grown Ga_2O_3 interlayer. The traps in the interfacial layer can form/rupture a conductive path by trapping/detrapping electrons/holes, responsible for the threshold switching behavior. It's revealed that the addition of Ga_2O_3 interlayer can remarkably improve the selector thermal performance.

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WHITE PAPERS FOR THE NEXT DECADAL SURVEY: THERMAL PROTECTION SYSTEMS AND INSTRUMENTATION.

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Introduction: NASA is anticipated to commission the next Planetary Science Decadal Survey (PSDS) with preparation expected in early calendar year 2020. The new PSDS will outline the priorities of science missions for the decade spanning 2023-2032. For the previous PSDS [1], the science and technology communities have been invited to submit white papers to the PSDS sub-panels as background information to guide the PSDS recommendations. The National Research Council has previously stated that white papers that represent the opinion of many authors from different institutions carried more significance and weight, and the recommendations from the previous PSDS attempted to reflect more of a consensus opinion.

In 2009, a total of 4 white papers were submitted to the PSDS panels regarding thermal protection system (TPS) readiness for missions [2] – [5], as well as one on TPS instrumentation [6]. The TPS readiness papers were co-authored by 90 individuals from many institutions. These white papers surveyed the TPS materials for both forebody and afterbody of a probe and analyzed the suitability of materials for missions to each destination. In addition, each paper outlined the ground testing required and ongoing technology development. Recommendations were provided for further technology development and ground test capability in order to fulfill future missions.

Planning for Venus and the next PSDS: Many changes have occurred in the past 10 years with regard to TPS materials and instrumentation in support of Venus missions. After a long period of absence of US Venus missions, fully dense Carbon-Phenolic materials were allowed to atrophy. Qualified raw materials are no longer available and fabrication skills have not been maintained, thus heritage Carbon-Phenolic for a blunt body aeroshell is no longer available.

However, new materials and systems have been developed and tested, such as the high density material Heatshield for Extreme Entry Environment Technology (HEEET), and new capabilities for ground testing for high heating and high pressures have been added. The 3-inch nozzle at the Ames arc jet can now test at heat fluxes and pressures for most proposed Venus trajectories which will enable entry system certification. NASA has also flown several TPS instrumentation suites, such as MEDLI and EFT-1.

In order to provide the PSDS sub-panels with the most current information about the state-of-the-art suitability for TPS materials for Venus entry missions, we are beginning to update and draft a new white paper that will consider TPS materials for both atmospheric probes and large aeroshells for landers. We will present the outline for material to be covered in the white papers, and we invite all VEXAG attendees to particiate in co-authoring these papers.

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A DESIGN METHODOLOGY FOR VENUSIAN WIND TURBINES. L. Ghabuzyan[1], C. Chhun[2], J. Vega[2], Z. Bravo[2], J. Kuo[2], and J. Sauder[3], [1]lghabuz@calstatela.edu, California State University, Los Angeles, Los Angeles, CA; [2]California State University, Los Angeles, Los Angeles, CA; [3]Jet Propulsion Laboratory, Pasadena, CA.

Introduction: Venus is known as Earth's sister planet, due to their similar size and proximity. Yet, Venus remains relatively unexplored compare to Earth's more distant neighbors. This is because, unlike Earth, the Venusian atmosphere is made up of 96% carbon dioxide, a greenhouse gas. As a result of greenhouse effect, its atmospheric temperature has been recorded to be as high as 464°C. In addition, the pressure at the planet's surface is approximately 90 atm. This harsh environment makes it difficult for conventional rovers with electrical components to survive for long duration. Therefore, any future rover missions on Venus will need to rely on mechanical means to power the rover, e.g. wind turbine. Wind turbines have been extensively studied under Earth conditions [1], which existing design tools and principles can be applied to design a wind turbine to operate on Venus. The aim of this work is to develop a fast and lower cost design methodology to develop and optimize various turbine designs.

Proposed Design Methodology: The proposed design methodology utilizes Blade Element Momentum (BEM) theorem [2], a well-established accurate and low cost approach to predict the performance of a turbine. In this work, a BEM model was implemented in conjunction with computational fluid dynamics (CFD) simulations and wind tunnel experiments, and they are used to study and optimize performance of wind turbines.

The geometry of the blade will tremendously influence the turbine's coefficient of power. To reduce cost and improve design speed, a design process was established, shown in Figure 1. Once an initial blade shape (such as optimum blade [3]) has been developed, and its performance can be predicted using the BEM model. If the performance of the blade meets the design requirements, CFD simulations are performed to validate BEM results. Then, a scaled wind turbine model is manufactured and tested in the wind tunnel for validation. From simulation and experimental results, any necessary modifications can be made to the blade design and the process is repeated until the turbine performance is optimized. An overview of the design methodology, highlights of simulation and experimental results, as well as lessons learned will be presented.

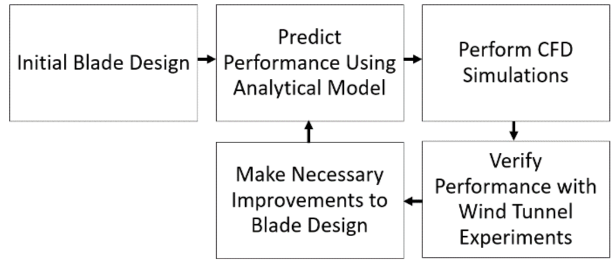

Figure 1: Turbine Design Methodology

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A PROPOSED VENUS FLAGSHIP MISSION.

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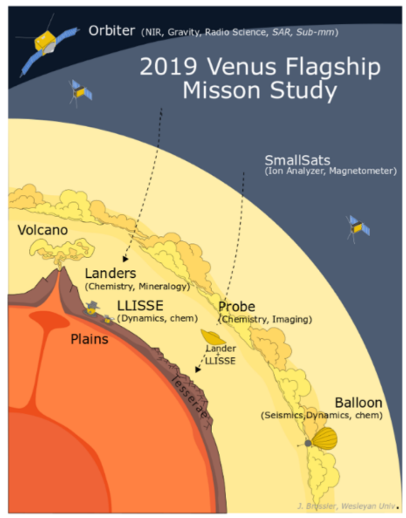
Introduction: More than any other known planet, Venus is essential to our understanding of the evolution and habitability of Earth-sized planets in the solar system and throughout the galaxy. Volatile elements have strong influence on the evolutionary paths of rocky bodies and are critical to understanding planetary evolution. It is clear that Venus experienced a very different volatile element history than the Earth, resulting in a different evolutionary path. The science objectives of the Venus Flagship Mission (VFM) focus on understanding volatiles on Venus. The mission concept's science goals, similar to those for other solar system bodies that were shaped by volatiles such as Mars and Europa, are: to 1) assess the volatile reservoirs, inventory, and cycles over Venus history, and 2) use the understanding of the environments created by and availability of these volatiles to constrain the habitability of Venus. The VFM aims to address two critical questions for planetary science: How, if at all, did Venus evolve through a habitable phase? What circumstances affect how volatiles shape habitable worlds?

Objectives and Overview. The VFM concept study seeks to design a flagship class that mission enables us to understand the: 1) History of volatiles and liquid water on Venus and determine if Venus was habitable, 2) composition and climatological history of the surface of Venus and the present-day couplings between the surface and atmosphere and 3) geologic history of Venus and whether Venus is active today.

The proposed VFM concept comprises an Orbiter with several instruments (near infrared spectrometer, radar, gravity measurements), two (or more) SmallSats that carry magnetometers and ion analyzers, and two Landers/Probes capable of measuring atmospheric chemical composition, isotopic ratios, pressure, temperature, as well as obtaining 1-µm descent images below ~5 km altitude. Once landed, a panoramic camera would sweep the horizon, and instruments, such as the Planetary Instrument for X-ray Lithochemistry or Raman/Laser Induced Breakdown Spectroscopy, would be used to measure the rock chemistry and mineralogy at nominally two sites. The landers would target the basaltic plains that comprise the bulk of the surface, and tessera terrain, which provide the only access to rocks from the first 80% of the history of the planet. One lander would carry a longer-lasting technology demonstration, the Long-Lived In- Situ Solar System Explorer, which measures surface temperature, pressure, wind and atmospheric chemistry as a function of time. The proposed study will also examine the possibility of detecting ground motions via a landed seismometer or by an infrasound technique from aerial platforms.



A Venus Flagship mission, similar to prior flagship missions such as Galileo and Cassini, would accomplish scientific discoveries greater than the sum of what is possible with the individual instruments, employing synergistic observations that work together to answer the 'big questions' relating to Venus' evolutionary path. Our proposed mission could be the first mission to trace volatile inventory, phase, movement, reservoirs and loss over Venus history. Specifically, it will provide the first measurements of the isotopes and inventory of all major atmospheric noble gases, the first measurement of the isotopes and volatile content of rocks, and the first measurement of the chemistry of the oldest rocks on Venus, the first measurement of global sur-face composition from orbit, the first measurement of interior structure and remanent magnetism, the first modern, multiple measurements of lower atmosphere in situ and over time via orbital spectroscopy, the first deployment of SmallSats at Venus and simultaneous measurements of the exosphere. Although we will be specifying a point-design, we will provide a range of mission implementation strategies at a number of cost points that can address significant science goals. This study will also evaluate and make recommendations for future technology investments and maturation schedules.

Variability of the Venusian and Martian nightside ionosphere after solar storms

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1. Introduction

Interactions between planetary atmospheres and the solar wind can be observed via atmospheric emission and ion/electron density profiles. The interaction of the solar wind with Venus and Mars is unique given that both planets lack an intrinsic magnetic field (or, in the case of Mars, only posesses a weak crustal field) and have similar atmospheric composition (95% CO_2).

The Venusian and Martian nightside ionospheres have two distinct electron density peaks: the V1 and V2 peaks for Venus (located near 125 and 150 km), and the M1 and M2 peaks for Mars, (located near 100 and 150 km). These peaks are known to be be highly variable for both planets but the chemical pathways and processes, particularly for the V1 and M1 layers, are not well understood.

Both the V1 and M1 layers exhibit increases in density after intense solar storms, such as coronal mass ejections (CMEs) and solar flares [1, 2]. These increases in density are observed almost immediately and are present on the deep nightside and are coincident with auroral emission [3]. While ions are transported from the dayside to the nightside of the planet, the time for this process to occur is much longer then the response seen in the electron density profiles and auroral emission. Thus, proton and/or electron precipitation must play a key role in the variability of these ionospheres. Here, we study the variability of the Venusian and Martian nightside ionosphere and its connection to the solar wind, particularly after solar storms but also during quiet times of solar minimum.

2. Observations

Using the Venus Radio Science Experiment (VeRa) instrument on Venus Express (VEX), Mars Radio Science Experiment (MaRS) on Mars Express (MEX), and Langmuir Probe and Waves (LPW) instrument on the Mars Atmosphere Volatile and EvolutioN (MAVEN) spacecraft, we compare electron density profiles of the Venusian and Martian nightside before and after solar storms. In order to constrain possible chemical pathways that lead observed ionospheric density increases, we compare nightside ion density profiles observed by Neutral Gas and Ion Mass Spectrometer (NGIMS) onboard MAVEN. Lastly, we present results from a monitoring campaign of the Venusian aurora using high resolution echelle observations conducted from Apache Point Observatory in order to constrain solar wind conditions needed to produce Venusian aurora.

3. Discussion

The MAVEN spacecraft is able to observe low ionsphere composition directly. [4] and [5] Giazian et al. 2017 shows that NO^+ is the dominate ion at the M1 level on the Martian nightside. NO^+ was predicted to be the source of the nightside V1 layer on Venus as well as a possible chemical pathway to the observed auroral emission of OI 5577.7 “oxygen green line” [5]. We propose that the the V1 and M1 layers are dominated by NO^+ and that production is sensitive to electron precipitation on Venus.

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Venus as a Laboratory for Exoplanetary Science

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Abstract: The prime focus of astrobiology research is the search for life elsewhere in the universe, and this proceeds with the pragmatic methodology of looking for water and Earth-like conditions. In our solar system, Venus is the most Earth-like planet, yet at some point in planetary history there was a bifurcation between the two: Earth has been continually habitable since the end-Hadean, whereas Venus became uninhabitable. Indeed, Venus is the type-planet for a world that has transitioned from habitable and Earth-like conditions through the inner edge of the Habitable Zone (HZ); thus it provides a natural laboratory to study the evolution of habitability (Way et al. 2016). At the present time, exoplanet detection methods are increasingly sensitive to terrestrial planets, resulting in a much needed collaboration between the exoplanetary science and planetary science communities to leverage the terrestrial body data within the solar system. In fact, the dependence of exoplanetary science on solar system studies runs deep, and influences all aspects of exoplanetary data, from orbits and formation, to atmospheres and interiors. A critical aspect of exoplanetary science to keep in mind is that, unlike the solar system, we will never obtain in situ data for exoplanet surface environments and thus exoplanet environments may only be inferred indirectly from other measurables, such as planetary mass, radius, orbital information, and atmospheric composition. The inference of those environments in turn are derived from detailed models constructed using the direct measurables obtained from observations of and missions to solar system bodies (Fuji et al. 2014; Madden & Kaltenegger 2018). Thus, whilst ever we struggle to understand the fundamental properties of terrestrial objects within the solar system, the task of characterizing the surface environments of Earth-sized planets around other stars will remain proportionally inaccessible. If we seek to understand habitability, proper understanding of the boundaries of the HZ are necessary, exploring both habitable and uninhabitable environments. Furthermore, current and near-future exoplanet detection missions are biased towards close-in planets, so the most suitable targets for the James Webb Space Telescope (JWST) are more likely to be Venus-like planets than Earth-like planets (Kane et al. 2014). The further study and understanding of the evolution of Venus' atmosphere and its present state provides a unique opportunity to complement the interpretation of these exoplanet observations (Kane et al. 2018).

Here we describe how the current limitations in our knowledge of Venus are impacting present and future exoplanetary science, including remote sensing techniques that are being or will be employed in the search for and characterization of exoplanets. We discuss Venus in the context of defining the boundaries of habitability, and how candidates from the *Kepler* and *TESS* exoplanet missions will enable testing of potential runaway greenhouse regimes where Venus analogs may reside. We discuss specific outstanding questions regarding the Venus environment and the relevance of those issues to understanding the atmospheres and interior structure of exoplanets (Kane et al. 2019).

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PROGRESS TOWARDS BALLOON-BASED SEISMOLOGY ON VENUS. S. Krishnamoorthy[1], A. Komjathy[1], M. T. Pauken[1], D. C. Bowman[2], J. A. Cutts[1], J. Izraelevitz[1], J. M. Jackson[3], L. Martire[4], R. F. Garcia[4], D. Mimoun[4]
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Introduction: Over five decades have passed since the Mariner spacecraft visited Venus in 1962, but its interior structure remains unexplored. This is in large part due to the technological challenges in exploring Venus posed by its extremely high surface temperature and pressure conditions. These adverse conditions have thus far rendered long-duration experiments on or near the surface impossible. Therefore, while Mars has hosted a fleet of rovers on the surface and the InSight lander has commenced seismology experiments, a similar experiment on Venus is decades away. In this presentation, we will explore the possibility of performing planetary science on Venus using infrasound (pressure waves with frequencies less than 20 Hz) as a remote sensing tool and discuss the progress our group has made in the last year.

Infrasound and Atmospheric Remote Sensing: Infrasound has been recorded from a variety of events on Earth. Of particular interest to planetary science are infrasound signals from quakes, volcanic eruptions, thunderstorms, and meteors. While infrasound generation from quakes relies on the coupling between the solid planet and the atmosphere, in the case of volcanic eruptions, thunderstorms, and meteors, energy is directly deposited into the atmosphere. Venus offers a unique opportunity for the use of infrasound as an investigative tool – due to its dense atmosphere, energy from seismic activity couples with the Venusian atmosphere up to 60 times more efficiently than Earth. As a result, infrasound waves from Venusquakes are expected to be an almost exact replica of ground motion. Infrasound is also known to propagate long distances from generating events with relatively little attenuation, thereby making it an effective alternative to placing sensors on the surface of Venus. Lastly, acoustic sensors used to capture infrasound may also be used to investigate low-frequency, large-scale planetary atmospheric features such as planetary-scale gravity waves, which have recently been observed by JAXA's Akatsuki mission.

Balloon-based Infrasound Detections on Venus: The main advantage of performing balloon-based infrasound science on Venus is the extension of mission lifetimes by virtue of being in a more benign environment. Compared to 460 C temperature and 90 atmospheres pressure on the surface, atmospheric conditions are more Earth-like at 55-60 km altitude on Venus. Further, acoustic sensors greatly benefit from being on a platform that floats with the wind, leading to higher coverage and lower wind noise. Krishnamoorthy et al. recently showed that acoustic waves from artificially generated seismic signals can be detected from balloons, show the same spectral character as epicentral ground motion, and can be utilized to geolocate seismic activity by using an array of airborne barometers.
From a scientific perspective, there are also several challenges with performing such an experiment. Signals are often weak compared to the noisy background. Multi-channel correlation is difficult, since balloon platforms have payload restrictions and cannot feasibly support a large number of instruments. In the presence of a variety of infrasound-generating events, source discrimination and localization also represent challenges that need to be overcome.

Recent Progress: Our team has been involved in a campaign to use the Earth's atmosphere as an analog testbed for Venus to demonstrate the feasibility of balloon-based infrasound science on Venus and address the challenges associated with it.

In this presentation, we will share a progress report using results from multiple flight tests and simulation studies in the past year, which include overflight of buried chemical explosions that produce seismic activity, and solar balloon overflights of the aftershocks in the Ridgecrest, CA area in the aftermath of the July 2019 earthquakes. Further, we will present our plans for the future, which include balloon flights over naturally occurring quakes in the State of Oklahoma to demonstrate the detection of natural seismic activity from the stratosphere. The success of this remote sensing technique can greatly accelerate the study of Venus' interior by circumventing the need to use high-temperature electronics.

24-HOUR CONSUMABLE BASED COOLING SYSTEM FOR VENUS LANDERS. Kuan-Lin Lee[1] and Calin Tarau[2], [1] Advanced Cooling Technologies, Inc. 1046 New Holland Ave. Lancaster PA 17601 kuan-lin.lee@1-act.com, [2]Advanced Cooling Technologies, Inc. 1046 New Holland Ave. Lancaster PA 17601 calin.tarau@1-act.com

Introduction: Venus in-situ exploration has been ranked as one of the highest priorities for future inner solar system studies [1]. However, the extremely hostile Venusian environment presents significant challenges in designing of the thermal management system for a Venus lander. The Venus surface temperature can be as high as 460°C and the atmospheric pressure can be around 92 bar (1334 psi), making it extremely difficult to reject the waste heat generated by the electronics inside a lander. To date, the longest survival duration on Venus surface was achieved by the Russian Venera lander 13 (127 minutes), which uses Phase Change Material (PCM) to absorb the payload waste heat, and multi-layer insulation (MLI) to mitigate the incoming heat leaks from the environment [2] [3]. Another attractive concept for Venus lander cooling is by venting two-phase coolant (ammonia) into Venus ambient. However, the limitation is that the ammonia vapor pressure at the payload set point (70°C) is not enough to overcome the high pressure on Venus environment. Therefore, the evaporative cooling of ammonia venting is only applicable to reject the incoming environmental heat leaks, maintaining the lander shell temperature at 121°C. In order to address this thermal design challenge, Advanced Cooling Technologies, Inc. (ACT) developed an innovative cooling concept that is based on venting of consumable fluids into an environment with higher pressure than the vapor pressure that corresponds to the temperature of payload.

The consumable-based cooling system consists of two pressurized vessels: the primary vessel and the secondary vessel. The primary vessel will contain two-phase working fluid where the vapor will be mixed with a secondary species (i.e. compressed gas such as argon or helium) that serves as pressurizer. The secondary vessel will contain only the compressed gas, initially at a much higher pressure (~ 400 bar). The role of the secondary vessel is to pressurize the primary vessel, so that the total pressure consisting of working fluid vapor pressure at saturation and gas partial pressure is higher than the environmental pressure. Internal heat load of payload will be transferred to the primary vessel through thermal links (heat pipes or other…) to vaporize the working fluid within the vessel. Two valves will be used to control system pressure and temperature. A venting valve will be mounted on the top of the primary vessel to control venting of the consumable fluid mixture. Another valve will be installed between the two pressure vessels to control recharging of the primary vessel with compressed gas.

The system has a bonus heat guarding effect: the consumable fluid mixture (working fluid vapor + compressed gas) leaving the primary vessel will be at payload set point (~70°C). Before being ultimately vented into Venus ambient at 460°C, there is a significant amount of sensible heat capacity which can be used to absorb incoming environmental heat leaks and then vented away. The flow paths (tubing) embedded within the lander structure that will allow the consumable fluid to collect incoming environmental heat leaks and ultimately rejected into the ambient is referred as the "heat guarding system". In Phase I, a thermodynamic-based model for consumable-based cooling was developed and validated by a pilot-scale experimental system with three different pairs of working fluid/compressed gas. After validation, the mathematical model was employed to predict the required fluid mass to achieve 24 hours survival of Venus lander in relevant operating conditions.

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GLOBAL MEAN MICROPHYSICAL PROPERTIES OF CLOUD TOP AEROSOLS ON VENUS RETRIEVED FROM DISK-INTEGRATED ALBEDO AT 283 AND 365 NM.

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The clouds of Venus are composed of sulfuric acid-water aerosols. Their single scattering albedo is 1.0 at ultraviolet (UV) wavelengths [1], meaning that almost no absorption occurs. However, UV observations of Venus at 283 and 365 nm show clear dark features across the dayside [2-4]. This absorption is caused by UV absorbers, such as mesospheric SO_2 gas above the clouds [2,3] and an unidentified absorber in the clouds [4]. Therefore understanding the scattering properties of aerosols in the UV range is a baseline to retrieve the absorption amounts caused by the UV absorbers.

In this study, we use UV images at 283 and 365 nm taken by the UV imager (UVI) onboard Akatsuki [5]. UVI has been observing Venus since December 2015 from its elliptical equatorial orbit [6]. The distance of the spacecraft to the planet varies from 7,000-18,000 km at pericenter to ~37,000 km at apocenter [4]. Global monitoring becomes suitable at off-pericenter, and we used these global images, ~6,000 images at each channel, to calculate the disk-integrated albedo over a broad solar phase angle (α) from 0º to 150º.

The data present clear glory features at small solar phase angle (α<10º). Also the disk-integrated albedo decreases with increasing solar phase angles as the illumination ratio of the disk reduces from 100% (α=0º) to ~6% (α=150º). We notice that the slope of the disk-integrated albedo versus solar phase angle at 283 nm is steeper than that at 365 nm, and sharper peak of glory features appear at 283 nm than 365 nm [4]. We also compare morning and afternoon sides at the two channels using the images taken near 90º solar phase angle, when half of the illuminated disk is visible, either morning or afternoon side. We are progressing numerical model calculations to retrieve microphysical properties of cloud top aerosols, such as effective radius and effective variance of particles, and a required absorption to fit the observed phase curves, using a Monte-Carlo radiative transfer model that takes into account the spherical geometry [7,8].

The same analysis technique will be used to analyze disk-integrated UV albedo data at the 240-365 nm range that will be acquired in 2020-2021 during the Venus flybys of BepiColombo (ESA-JAXA) [9, 10] using its UV spectrometer (PHEBUS) [11], and the coordinated UVI's simultaneous observations [9].

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"Venera-D" Spacecraft and Maneuverable Entry. A.B. Martynov [1], A.V. Kosenkova [1], P.D. Pisarenko [1], A.S. Feofanov [1]. [1] Lavochkin Association (Russia, Khimki, Leningradskaya 24, 141402, alexey.martynov@laspace.ru)

Introduction:

Building on the results of the highly successful Soviet Venera and VEGA missions [1], along with the Pioneer, Magellan [2, 3], and more recent Venus Express and Akatsuki missions [4, 5], a joint NASA Roscosmos/IKI Science Definition Team (JSDT) was established in 2015. Within the overarching goal of understanding why Venus and the Earth took divergent evolutionary paths, the JSDT has the task of defining the science and architecture of a comprehensive Venera-D (Venera-Dolgozhivuschaya (long lasting)) mission. The baseline Venera-D concept includes two elements, Orbiter and a Lander, with payload for distance and contact analysis, including detachable elements such as aerial platforms that can flow in the atmosphere, small long-lived surface stations, small satellite(s). In January of 2017, the JSDT completed the first phase and generated a report to NASA - Roscosmos/IKI of its findings [6]. The second phase was completed in January of 2019 with a focus on refining the science investigations, undertaking a compressive development of the core Orbiter and Lander mission architecture, a detailed examination of contributed elements and aerial platforms that could address key Venus science [7, 8, 9]. The current activities are focused on more precise definition of the payload, landing sites, orbits and landing, including variations of a maneuverable landers.

Lavochkin Association is creating the spacecraft design. This work includes:

(1) development of the general design and configuration for the spacecraft;

(2) accommodation of systems and standalone devices within the spacecraft;

(3) assessment of orbit options along with the strategy for descent and landing and long term observation long-lived stations;

(4) forming the radio communications between Earth, spacecraft, surface stations, satellites.

Launch dates between 2026 and 2031 have been evaluated.

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THRUST FAULTING ON VENUS: TECTONIC MODELING OF THE VEDMA DORSA RIDGE BELT

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Introduction: Radar images from the Magellan mission revealed networks of ridge belts in several low-lying plains on Venus, including Atalanta Planitia, Vinmara Planitia, Lavinia Planitia, and Rusalka Planitia [1-3]. The ridges in these low lying plains have been interpreted to form over cold, downwelling mantle, which causes crustal shortening and convergence by a combination of thrust faulting and folding.

We focus here on Vedma Dorsa, a ~1800 km long, N-S trending ridge belt in Llorona and Vellamo Planitiae. In this study region, ridges are 30-70 km wide and 0.5-1 km high and are commonly asymmetric in topographic cross-section. We modeled thrust faulting in order to constrain fault parameters such as fault displacement, faulted layer thickness, and fault dip. Our results support the interpretation that the ridge belts are formed by thrusting faulting and provide an improved understanding of the lithospheric properties and conditions under which these ridges formed.

Method: We modeled thrust faulting as elastic dislocations using Coulomb 3.3 [4]. We assumed Young's modulus of 80 GPa and Poisson's ratio of 0.25, appropriate for a basaltic crust. Our results are not sensitive to the specific value of coefficient of friction along the fault in the range 0.4-0.8. In order to avoid unphysical discontinuities in the stress at the edges of the fault zone, we applied a linear taper to the imposed displacement. The model grid has a resolution of 0.1 km. We compare the predicted fault topography with topography from a stereo digital elevation model [5].

Results: We have modeled three regions along Vedma Dorsa. Representative results for 28.4° N, 159.3° E are shown in Figure 1. We varied faulted layer thickness while holding displacement along the fault and dip angle of the fault plane constant (Figure 1a). Faulted layer thickness of ~10-20 km allows for the best fit to the observed topography. Faulted layer thickness >30 km proves unacceptable for the fit. We also varied the displacement along the fault while holding the dip of the fault plane and faulted layer thickness constant (Figure 1b). An offset of 1.4-1.5 km gives the best fit to the observed topography. The best fitting fault dip is 25-30°. A blind thrust fault, whose upper tip is 3-6 km below the surface, improves the fit in the foreslope region (20-50 km along profile) and increases required fault displacement from 1.4 to 2 km. Allowing the fault to be listric (dip decreases with depth) improves the fit in the backslope region (60-80 km). Best results are obtained when the fault displacement increases on the deeper segment of the fault, as also observed for lobate scarps on Mars [6]. Because the ridge consists of fault-weakened material, downhill mass wasting could also contribute to the observed topography in both the foreslope and backslope. In other portions of Vedma, we also find evidence for secondary thrusting in the backslope, which is also seen on Mars [7].

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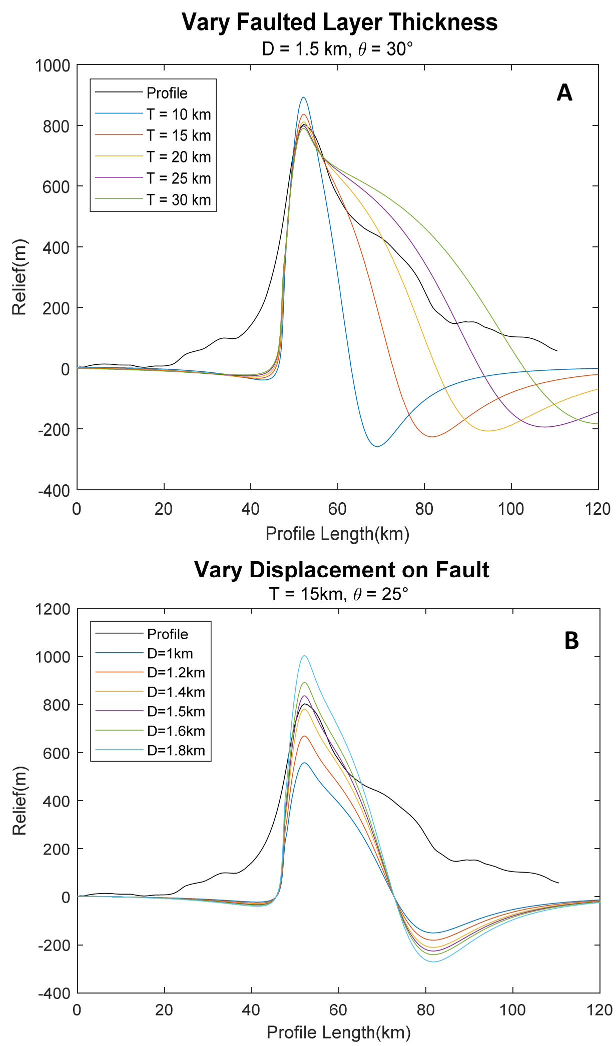

Figure 1: Comparison of observed topography with planar fault models. A) Variation in faulted layer thickness. B) Variation in fault displacement.

HIGH TEMPERATURE DIAMOND ELECTRONICS FOR ACTUATORS AND SENSORS

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Introduction: The wide bandgap, thermal conductivity and stability, and high electron and hole mobilities indicate diamond as an ideal high temperature semiconductor.[1] This research is focused on demonstrating the properties of diamond diodes for operation in power control and conversion modules for exploration of the surface and atmosphere of Venus where the 480°C surface requires high temperature operation.

Diamond electronics are enabled by high quality epitaxial layer growth of doped and undoped diamond layers on single crystal substrates. Epitaxial growth is achieved using microwave plasma chemical vapor deposition (MPCVD) with the substrate at ~800°C. Doping with boron is employed for p-type layers, and doping with phosphorus is employed for n-type layers.

In this project, an undoped intrinsic layer was grown on heavily B-doped substrates. A P-doped n-type layer completed the N-I-P structure. Circular diodes were fabricated using standard lithography. Metal contacts were fabricated using Ti/Pt/Au layers with Au as the outer layer. The individual diodes were isolated using a partial mesa etch to avoid surface leakage.

Diodes were characterized to 600°C in air. The initial target specifications were a blocking voltage of 50V and a forward current density of > 100A/cm^2.

Results: Electrical characterization of diamond pin diodes were evaluated from RT to 600°C and typical results are shown in Fig. 1. Diodes with an intrinsic layer thickness of greater than 500 nm showed blocking voltage greater than the 50 V target. The diodes showed forward current densities often surpassing 1000 A/cm^2 at a forward voltage of less than 10 V.

Diodes were tested for times of 60 min at high temperature and operating at significant forward voltage, and they showed minimal degradation. Longer testing is planned as is testing in the GEER facility.

Discussion: The diamond diodes met the performance targets at temperature of 600°C in air. The following characteristics differentiated diamond devices from other high temperature semiconductors.

The diamond diodes employed an undoped intrinsic layer. Consequently the transport involved carrier injection and drift. The mode of transport has been described as space charge limited current that is modelled by the Mott-Gurney expression. Interestingly, the current increases proportional to the voltage squared, and the forward I-V characteristics showed a clear parabolic dependence confirming this transport mechanism.

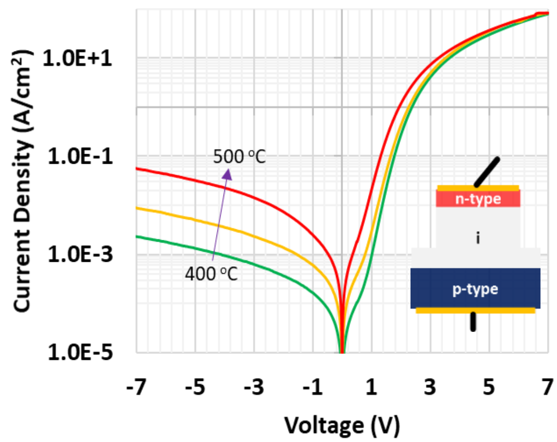

Fig. 1. Cross-section of a diamond Schottky PIN diode and current density vs voltage up to 500°C showing good rectification and consistent forward current.

The characteristics of the diodes were simulated using a customized version of ALTAS Silvaco. The simulation was used to guide the design of the diodes to maximize the diode rectification ratio at the operating temperature. The optimal design was a structure where the n-type layer was fully depleted. This design allowed engineering the diode barrier to achieve the desired high temperature operation.

The next phase of the project will involve high temperature packaging and extended testing at the GEER facility. Beyond this testing, the team is working towards a diamond vertical power junction field effect transistor (JFET) that would be combined with the diodes in a power conversion module.

Acknowledgment: This research supported through the NASA HOTTech program.

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LONG LIFE MATERIALS FOR AGGRESSIVE SULFURIC ACID ENVIRONMENTS.

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Introduction: Venus' atmosphere presents a very difficult materials problem to mitigate. While materials are available for specific concentration or temperature ranges such as found in industrial plants, Venus presents variable environments with altitude. Ranges of sulfuric acid and other corrosive agents, combined with variations in pressure and temperature requires a material which can protect itself over this entire environmental envelop, and perhaps including even some unknown hazards.

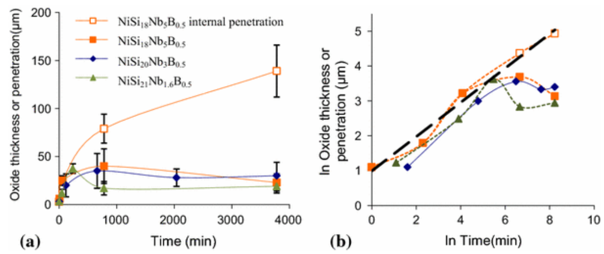
An alloy was developed specifically for the most aggressive ranges of sulfuric acid concentrations for commercial purposes [1]. This alloy was based on a ductile Ni-Si intermetallic, Ni3Si, rather than more conventional metal alloys which typically depend on chromium additions to provide protection. The alloy forms amorphous SiO2 in the presence of strong oxidizing environments, rather than Cr2O3, like traditional corrosion resistant alloys.

It is proposed that this alloy system, or a modification of it, could be used for spacecraft protection, particularly in the descent phase of the mission. The exceptional corrosion resistance of this alloy could enable much longer residence times on the surface of Venus than were previously thought possible.

Description of Developed Alloy: This new alloy contains Ni, Si, Nb, and B [2]. The Nb is able to impart extra ductility to the alloy. The high concentration of Si is exceptional for any other known alloy, and enables the production of an amorphous silica (glass) reaction layer, which has excellent adherence and physical match with the underlying alloy, producing an almost zero rate of corrosion. If the coating is damaged, the oxidizing environment will promote new formation of the glass, and repassivates the material.

The alloy was developed for a casting application, and is therefore highly castable, as well as weldable [3]. Given the fabricability of this alloy, it should be easy to 3D print it as well. A later project to develop this material for hydrogen production, as well as heat exchanger applications, resulted in a sort term project to develop a wrought analog, which could be formed into sheet or tubes. In addition, there was interest in using the alloy as a coating material, which was successfully applied by plasma spraying [4].

Alloy Performance: The alloy has been tested in a number of environments for extensive periods of time. The figure shows some test results from the development project for different compositions of the basic elements. The commercialized alloy has a composition of NiSi20Nb3B0.5, and it can be seen that it passivates and then basically stops corroding. The sulfuric acid concentration is 70% and the tests were conducted at the boiling temperature. The natural log graph shows the parabolic film formation followed by the corrosion arrest.



Additional testing has been carried out at high atmospheric pressures and temperatures and performed equally well [5]. The alloy is also capable of good strengths at elevated temperatures and is very erosion resistant. All of these attributes would be useful in a descent stage.

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EXPECTED PERFORMANCE OF THE QIT-MS MASS SPECTROMETER IN VENUS' ATMOSPHERE.

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Introduction: The chemical composition of aerosol particles is of importance to understanding the behavior of planetary atmospheres. Despite previous ground-based, orbital, and in situ probe measurements the chemical composition of particulates in the Venus' UV-absorbing layer is still unknown and is likely do to the aerosol activity. Even though laboratory scale aerosol mass spectrometers exist, there are no in situ instruments that can perform this analysis with the mass, volume and power restrictions of a planetary mission.

We report on current development of the Advanced NanoJet Aerosol Separator Apparatus (NJASA) aimed to extend the capabilities of the existing JPL mass spectrometer (QIT-MS) [1] to analyze particulates in planetary atmospheres during subsonic probe descents or as a part of aerial platforms, see Figure 1. The preliminary concept relies on the JPL piezoelectric valve [2] as an adaptive front-end pressure control that maintains the flow rate despite changes in the atmospheric pressure. Apparatus will assess acidic aerosols in the 0.3um-3um size range relevant for Venus haze layer [3].

First modeling results indicate near 100% transmission efficiencies [4] when relaxation tube is maintained at 2Torr - 10Torr pressure. This is achieved with help of the differential pumping system with miniature Creare scroll (mSP) and turbo-molecular (mTMP) pumps, see Figure 1. These results were supported by laboratory tests involving silver nanoparticles embedded in inkjet droplets. In these tests the NanoJet flow cell operated in the air for four hours without clogging or change in the operating pressure [4], a crucial requirement for long term atmospheric sampling applications.

We also present measured QIT-MS performance in determining isotopic abundances of noble gases in active [1] and passive [5] pumping regimes. These are further supported by the simulated QIT-MS responses to noble gases [6] when our instrument is deployed in the small hypervelocity atmospheric skimmer, such is the Cupid's Arrow Venus' mission concept [7].

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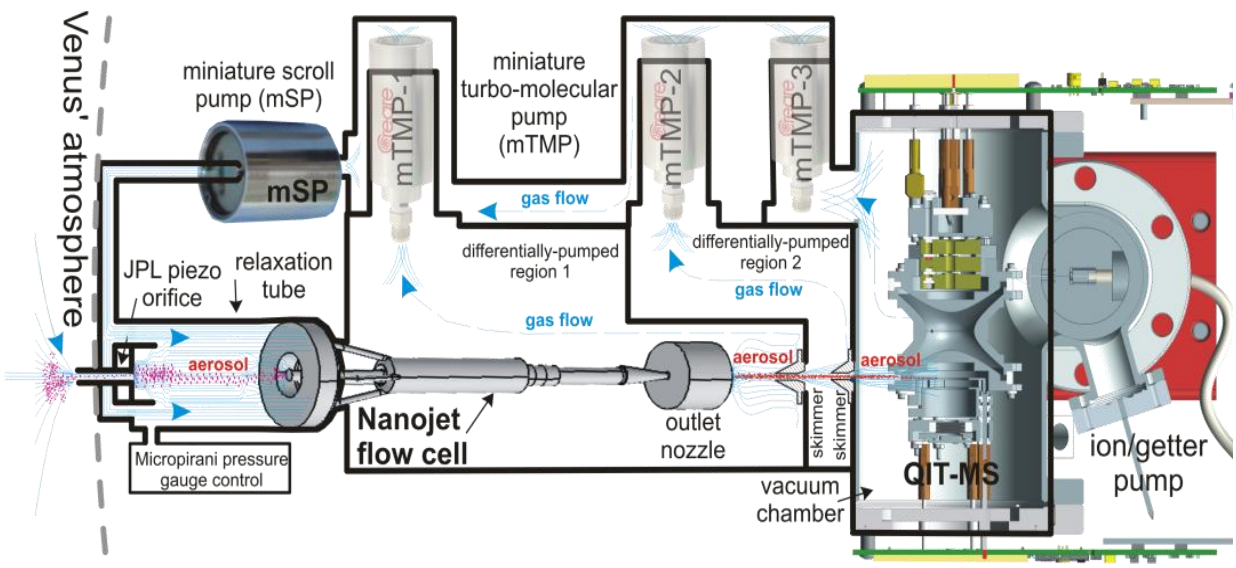

Figure 1: Advanced NanoJet Aerosol Separator Apparatus concept to sample the Venus' atmosphere through an adaptive JPL piezoelectric orifice [2]. The NanoJet flow cell is designed to aerodynamically focus aerosol particles near the flow axis and keep lighter gas molecules (96.5% CO2 & 3.5% N2) off axis [4]. The narrow beam of aerosol particles leaves the outlet nozzle

DETECTABILITY OF CRUSTAL REMANENT MAGNETISM ON VENUS FROM ORBITAL MAGNETOMETER MEASUREMENTS. J. G. O'Rourke[1] and C. Dong[2], [1]School of Earth and Space Exploration, Arizona State University, Tempe, AZ (jgorourk@asu.edu), [2]Department of Astrophysical Sciences and Princeton Plasma Physics Laboratory, Princeton University, Princeton, NJ (dcfy@princeton.edu).

Introduction: Venus lacks a strong internally generated magnetic field today. Pioneer Venus Orbiter established ~10^{-5} times the total magnetic moment of Earth as the upper limit for Venus [1], which is consistent with magnetic measurements from Mariner 2 and 10, Venera 9–12, and Venus Express [2]. One lander (Venera 4) measured magnetic fields down to 25 km altitude above Eistla Regio but failed to detect any intrinsic field or crustal remanence [3]. However, whether a strong global field existed prior to the first flyby of Venus by Mariner 2 in 1962 is unknown. Any evidence for early intrinsic magnetism would provide vital constraints on the evolution of Venus.

Broadly speaking, there are two reasons why Venus may fail to sustain a long-lived dynamo like Earth. First, accretionary processes may naturally produce chemical gradients in planetary cores that inhibit convection and thus a dynamo. The giant, Moon-forming impact may have mechanically mixed Earth's core. If Venus did not suffer late energetic impacts during accretion, then its core may retain primordial stratification and never host a dynamo [4]. Second, Venus could have an "Earth-like" core (i.e., at least partially liquid and chemically homogeneous) that is cooling too slowly at present for vigorous convection. In most models, the mantle of Venus cools slowly in the absence of plate tectonics and thermally insulates the core. Cooling rates were probably faster in the past when the core was hotter. Critically, simulations suggest that Venus may have hosted a dynamo and a strong global magnetic field until recent times within the surface age [5].

Many studies have assumed that knowing whether Venus had a dynamo in the past is practically impossible [2]. Thermoremanent magnetization in rocks is less stable at higher temperatures, and the surface of Venus is famously hot. However, its average temperature now (~737 K) is still >100–200 K below the Curie points of common magnetic carriers such as magnetite and hematite. Plausible depths to the Curie temperature of magnetite are >5–10 km and perhaps >20 km at regions with low heat flow. As long as the surface was not much hotter in the past, Venusian rocks could retain remanent magnetism for billions of years if their magnetic mineralogy is similar to terrestrial basalts [6].

Exploration Objectives: This new step in an ongoing series of investigations has two objectives: (1) Determine the distribution and intensity of crustal magnetism that could have escaped detection by Pioneer Venus Orbiter and Venus Express, which reached periapsis within ±50º latitude of the equator and ±40º latitude of the North Pole, respectively, and (2) Derive realistic measurement requirements and detection thresholds for future orbiters that may perform aerobraking over the South Pole, which is unexplored.

Computational Methods: We use the BATS-R-US Venus multi-species magnetohydrodynamic (MS-MHD) model. The model solves a separate continuity equation for each ion species, whilst also solving one momentum and one energy equation for the four ion fluids: H^+, O^+, O_2^+, and CO_2^+. In contrast to most Earth global magnetosphere models that start from 2 to 3 Earth radii, the Venus MS-MHD model contains a self-consistent ionosphere. The MS-MHD model includes many of the detailed ionospheric chemical processes such as charge exchange, photoionization and electron impact ionization. In this study, we extend the model lower boundary into the planetary interior by including an electrically conductive core and a resistive mantle; therefore, the newly developed Conducting-Core-Surface-to-Interplanetary-Space MS-MHD (CCSIS-MS-MHD) model solves the planetary interior, planetary ionosphere, and solar wind-Venus interaction in a self-consistent way [7].

Possible Magnetization Distributions: Regions of magnetized crust are implemented as circular patches with a constant magnetization intensity down to a uniform depth. Python routines in SHTools are used to transform the crustal magnetization into a spherical harmonic (SH) basis [8]. Finally, the SH coefficients of the crustal magnetization are transformed into the SH coefficients for the lithospheric magnetic field [9], which is a boundary condition for the MS-MHD model. Given the wide range observed in terrestrial rocks, magnetization intensities on Venus are a priori uncertain within a few orders of magnitude [6]. Strong crustal fields may await detection near the South Pole, and weak magnetization could still exist at most locations.

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Identifying Potential Venus Analogs from Exoplanet Discoveries C. Ostberg[1] and S.R. Kane[2],
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Introduction: With a radius of $0.95R_{Earth}$ and a mass of $0.85M_{Earth}$, Venus is the most analogous planet to Earth in the solar system. Study of Venus and Venus-like exoplanets is invaluable in understanding factors that determine a planet's habitability throughout its evolution. Fortunately, many Venus-analogs are expected to soon be discovered as the recently launched Transiting Exoplanet Survey Satellite (TESS) mission is sensitive to planets in close proximity to their host stars. TESS is predicted to discover hundreds of terrestrial planets within the inner boundary of their host star's Habitable Zone (HZ), placing them in the 'Venus Zone' (VZ), defined by Kane et al. (2014) [1]. TESS in tandem with the launch of the James Webb Space Telescope in the coming years will allow for the characterization of these planets' atmospheres, providing a better understanding of atmospheric compositions of planets inside the VZ. This will help delineate the primary factors that determine whether a planet develops sustainable temperate surface conditions, or if it would be pushed into a runaway greenhouse state, leading to a more well-defined outer boundary for the VZ. Here we provide a progress report on discoveries from the TESS mission, identification of planets in the VZ, and methods used to determine runaway greenhouse scenarios. The observed properties of these planets will be applied to Global Climate Models, such as ROCKE-3D, to better constrain the boundaries of the HZ and VZ, and study the atmospheric demographics of terrestrial planets.

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CUPID'S ARROW: HYPERVELOCITY SAMPLING IN THE UPPER ATMOSPHERE OF VENUS. J. Rabinovitch[1], A. Borner[2], M. A. Gallis[3], C. Sotin[1], J. Baker[1], [1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, United States (jason.rabinovitch@jpl.nasa.gov), [2]STC at NASA Ames Research Center, Moffett Field, CA, United States, [3]Sandia National Laboratories, Albuquerque, NM, United States.

Introduction: Cupid's Arrow is a small satellite mission concept that would determine the amount of noble gases and associated isotope ratios in the Venus upper atmosphere, below the homopause. This mission concept, and the importance of possible scientific return of the mission has been discussed in previous works [1-3], but performing high-fidelity noble gas measurements in the Venus atmosphere would help provide the required information to understand why Earth and Venus have diverged in their geological evolution; a critical piece of information required to assess whether a terrestrial exoplanet is Earth-like or Venus-like.

Mission Concept: In brief, the Cupid's Arrow mission concept is a small spacecraft (~80 cm diameter) skimmer that would sample the Venus atmosphere below the homopause where the different atmospheric compounds are well mixed [1-3]. The velocity of the spacecraft where sampling would occur is expected to be ~10.5 km/s, and the altitude is expected to be ~110 km. QITMS, a miniaturized quadrupole ion trap mass spectrometer, will be used to measure the noble gas concentrations in the acquired gas samples [4]. In order to ensure that it is possible to relate the composition of the sampled gases to the free stream atmospheric composition (and to quantify any possible isotopic fraction), numerical simulations are used to model the flow through the Cupid's Arrow sampling system.

Numerical Simulations: The Direct Simulation Monte Carlo (DSMC) code SPARTA, an open source software package developed by Sandia National Laboratories [5], is used in this work. SPARTA, based on Bird's DSMC method [6], is a molecular-level gas-kinetic technique. As SPARTA is able to model hypervelocity reacting flows in strong chemical and thermal non-equilibrium, this software package is well suited to determine relevant flow properties for the Cupid's Arrow mission concept, and to numerically investigate the possibility of elemental and/or isotopic fractionation in the sampled gases.

Preliminary 3D Simulation Results: Recent work has focused on 3D simulations that include realistic valve and tank geometries for the internal flow in the Cupid's Arrow sampling system. Preliminary simulations suggest that while there is some elemental and isotopic fraction as the flow travels through the sampling system (i.e., whether or not relative concentration ratios are the same in the sampling tanks as they are in the freestream), it can be quantified with DSMC simulations. Simulations are also used to determine how long the sampling system needs to acquire a gas sample at ~110 km altitude, in order to ensure that there are enough atoms to obtain the required accuracy with the QITMS. A sensitivity analysis is ongoing in order to quantify the uncertainty expected with the numerical predictions. Numerical results and uncertainties will be compared to the original Science Traceability Matrix, in order to ensure that all science objectives can be accomplished.

Conclusion: Through the ongoing numerical simulations, it is believed that a better understanding of the physical processes occurring during hypervelocity sampling in the upper atmosphere of Venus will be acquired. This knowledge will demonstrate whether or not elemental and/or isotopic fractionation is expected to occur in the Cupid's Arrow sampling system, and allow measured gas compositions to be related to the freestream composition and isotopic ratios. Future work will include experiments to validate specific aspects of the numerical simulations.

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OPTICAL PROPERTIES OF SULFURIC ACID. Michael J. Radke[1], S. M. Hörst[1], C. He[1], and M. H. Yant[1]
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Introduction: The complex refractive indices—sometimes called the optical properties or optical constants—of aqueous H_2SO_4 have been measured over a wide range of concentrations and temperatures [1]–[11]. Interpretations of remote sensing observations of Venus' clouds rely heavily on these laboratory data to determine properties of the cloud particles. While the *real* refractive indices of H_2SO_4 are reported over a wide wavelength range, spanning from ultraviolet to mid-infrared there is only one measurement of the *imaginary* refractive indices at wavelengths below 1.4 μm [3].

Remote sensing of the surface and lower atmosphere of Venus must account for the effects of the overlying clouds [12]. Given that most of these observations are made in visible and near-infrared wavelengths, it is important to verify the only existing data set of the optical properties of H_2SO_4 at these short wavelengths.

Previous measurements of the imaginary refractive index (k) have large discrepancies in the near-infrared (3 to 4 orders of magnitude). These discrepancies are so large that if they were to continue into the blue-ultraviolet, then sulfuric acid itself could be the unknown absorber! Measurements of the real refractive index (n) also show some differences, albeit smaller (only ~5%), in the mid-infrared. Nevertheless, this small difference in n could result in a ~20 wt% difference in the derived concentration of H_2SO_4. Furthermore, for many of the data sets, experimental uncertainties are often unrealistically small or are sometimes not even reported, leaving it unclear as to which data sets might be the most reliable under specific temperature-concentration-wavelength conditions.

Methods: We have determined the complex refractive index of aqueous H_2SO_4 (50–96 wt%) at room temperature (294 K) using a combination of transmission and reflection spectroscopy techniques. Our complex refractive indices cover a wavelength range from 0.2 to 25 μm, reproducing the experiments of [3].

Results: To date, we have only measured the optical properties of H_2SO_4 at room temperature. However, we plan on repeating these measurements at temperatures as low as 180 K, representative of temperatures in Venus' upper clouds or Earth's stratosphere. We also plan to measure the optical properties of other proposed Venus cloud species in the future such as H_3PO_4, HCl, various sulfur species, and transition metal salts.

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HYBRID AUTOMATON ROVER-VENUS J. SAUDER, E. HILGEMANN, K. STACK, J. KAWATA, A. PARNESS, M. JOHNSON[1] [1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA

Introduction: Venus is one of the most challenging in-situ environments to explore. Despite these challenges, incredible progress has been made in recent years on long lived platforms using high temperature electronics. However, these platforms have very limited capabilities. The concept presented here takes those long lived, high temperature electronics, and provides them with a method for long duration sustained mobility on Venus. This opens up a number of opportunities for a Venus in-situ explorer, with one of the most compelling being obtaining samples from multiple geologic units across the surface of Venus. Such a rover is also enabling for Venus surface sample return concepts. However, a rover which would operate on Venus needs to be completely redesigned.

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, those concepts still require 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 not even close to the processing capabilities required by current Mars rovers. While there are a couple papers which discuss rover concepts utilizing high-temperature electronics, they rely heavily on future developments [7], [8], especially in the area of visual navigation.

Mechanical Approach: The Hybrid Automaton Rover-Venus (HAR-V) is a innovative concept, which enables long duration in-situ mobility on the surface of Venus. An automaton is a mechanical device capable of performing a series of complex actions to achieve a specific result or a mechanical robot. Built of stainless steel and titanium, the automaton rover reduces requirements on electronics and requires minimal human interaction by focusing on a basic, robust capabilities.

HAR-V is not reliant on image processing and onboard navigation current Mars rovers use, as these cannot be done with available high-temperature electronics. Instead, the rover physically senses the environment around it and uses those inputs to navigate. This is a departure from traditional rover control, required by Venus.

While mobility requires a significant amount of power, which is challenging on the surface of Venus, HAR-V enables exploration of the Venus surface by directly collecting mechanical wind energy and transferring it to the mobility system. Keeping the energy in a mechanical state conserves ninety percent of the mechanical energy when compared to using a generator and electric motor. The Venus wind provides a low speed, high torque input, which is directly beneficial for mobility, which requires low speed, high torque.

System Overview: Wind power would be collected and stored in a spring. This mechanical energy is then routed via shafts to the rest of the rover to run the mobility system and obstacle avoidance. When the rover detects an obstacle, energy is rerouted in the mobility system, using a planetary reversing gearbox so it performs an obstacle avoidance maneuver.

While the mobility system is mostly mechanical, the instruments, data collection, and data transmission are done with basic high temperature electronics. There are also opportunities for electrical system to provide inputs to HAR-V, to enable humans to guide it's path.

Ongoing Work: To develop and demonstrate complex mechanical systems operating at high temperatures, a stainless steel clock operating at 500C has been developed. In parallel, a mechanical rover prototype has also been developed, and operations have been demonstrated in ambient conditions. This has revealed a mechanism to reverse the rover is critical.

Combining the lessons learned from these two prototypes a representative rover is being constructed to demonstrate a planetary reversing gearbox. The poster will specifically dicuss preperations for testing the rover in the Venus Environment.

Conclusion: AREE is a radical departure from traditional planetary rover models but enables access to the Venus surface without advanced cooling systems or orders of magnitude increase in the capability of high temperature electronics. 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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THE ISSUES OF SELECTING BIOMARKERS OF LIFE IN LABORATORY CONDITIONS FOR THE NEEDS OF THE VENUS CLOUDS BIOTOPE ASSESSMENT

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Introduction: In research on the existence of potential environmental conditions enabling the existence of single-cell life forms in the atmosphere of Venus, the determination of chemical markers of their metabolism is a basic research problem that should be resolved in laboratory work. Therefore, the authors of this study postulate an assessment of the survival of extremophilic (terrestrial-type) microorganisms under laboratory-created conditions resembling Venus atmosphere with the possibility of controlling its composition with reference to real physicochemical parameters, such as the percentage of gases forming it [1]. The atmosphere will be reconstituted in multifunctional bioreactors (Fig. 1-2).

Fig. 1.

Fig. 2.

In the case of terrestrial life, its chemical markers, due to the nature of metabolism are: oxygen (O_2) and methane (CH_4). Oxygen consumption prevents an "oxygen disaster." In contrast, the current level of methane is on the one hand the effect of both weak on a global scale volcanism, and on the other hand the effective metabolism of anaerobic bacteria inhabiting the structure of the digestive system in higher organisms. In the case of Venus, such a marker, due to its concentration in the planet's clouds, could be considered sulfuric acid (H2SO4) - which is a product of the metabolic activity of biotopes of chemoautotrophic strains found in terrestrial conditions. Earth type chemoautotroph metabolism is based on iron (Fe) and sulfur (S) redox transformations whose compounds also exist in the atmosphere of Venus. In an exemplary oxidation reaction: $S + 4O_2 + H_2O + 1/2O_2 \rightarrow H_2S + 6O_4$, where the oxygen involved in the reaction comes from the reduction reaction $C + 4O_2^- \rightarrow C + 2O + 1/2O_2$. The product of this reaction may also be carbon monoxide, whose presence, like the presence of sulfuric acid, has been identified in a Venusian atmosphere. Carbon (C), chemoautotrophs can be taken from inorganic sources, such as carbon dioxide (CO_2) [2]. Among many terrestrial strains of chemoautotrophic bacteria, Acidithiobacillus ferrooxidans - an acidophilic bacterium, due to its adaptability to environmental factors such as: high ambient temperature, its pH (even pH < 3.0), availability of carbon, can be considered an example of a microorganism capable of atmospheric survival in the lower layer of Venus clouds (at an altitude of 47.5 to 50.5 km above its surface), where the pressure is approximately 1 atm, the temperature is about 60° C and practically anaerobic conditions [3]. Currently, laboratory tests are starting in Poland with the use of strains of extremophilic bacteria, such as Acidithiobacillus ferrooxidans, whose UV spectra [4], as it turns out, are highly correlated with the spectra recorded for the Venus atmosphere in the same wavelength range λ of electromagnetic radiation, which may constitute in turn, an important, physical indicator of the existence of microbiological life on this planet.

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HOW THICK IS THE LITHOSPHERE OF VENUS?
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Introduction: Size, density and radiogenic elements [1] all point to Venus having an Earth-like interior thermal engine to drive surface volcanism and tectonism. Earth loses most of its heat though plate tectonics. Although Venus appears to have subduction [2,3], it lacks terrestrial style plate tectonics, and has been proposed to experience a range of possible convective styles such as episodic, sluggish, and stagnant lid [e.g. 4-6]. A key constraint on convective style is the thickness of the thermal lithospheric, which includes the brittle, elastic and lower ductile portions of the lithosphere. Here we show that new estimates of local elastic thickness (Te), a proxy for heat flow and the thermal lithospheric thickness, at small coronae are in good agreement with regional estimates of Te from gravity. This suggests that heat flow is >95 mWm^{-2} over ~ 40% of the planet. This value is similar to terrestrial oceanic heat flux [7], and implies a tectonically active planet.

Background: Te is the brittle portion of the lithosphere that supports earthquakes. Based on terrestrial seismic and heat flow data, ductile flow takes over at a temperature of ~ 750°C, assuming a strain rate of 10^{-16} s^{-1} for dry olivine or diabase [8-10]. Thus Te is a valuable means of approximating heat flow.

Predictions of heat flow from geodynamic models. Thermal and geodynamic models of the convective state of Venus commonly assume either no plate tectonic processes or episodic plate tectonics. Episodic models are motived by both an interpretation of surface impact craters as indicting catastrophic resurfacing and the inferred need to lose heat more rapidly than at present. Most models predict average surface heat flow of <40 mWm^2 with spikes of 60+ mWm^2 during regions of greater activity [e.g. 2-4].

Te Estimation. One method is modeling the admittance – the transfer function between gravity and topography in the spectral domain, which provides an estimate of Te over ~2000 km, here referred to as a regional estimate. [11] used a spatio-spectral method to calculate admittance on a global grid. The poor resolution of the gravity data result in an error bar of ±10-20 km. [11] interpreted Te values <20km (~50% of planet) as either indicating isostatic compensation, which gives no constraint on Te, or as high heat flow.

New Constraints: Another Te estimation method is to model bending of the topographic surface of the lithosphere in response to a load. Bending occurs on a local (100s km) scale. Using this method, [10] estimated Te at 18 small coronae, finding Te=5-15 km, giving heat flow estimates of > 95 mW/m^2. [10] interpret the low Te values as likely due to localized high heat flow above small scale mantle plumes that are the proposed mechanism for some small coronae.

We have estimated Te for an additional 40 small coronae. Using a total of 78 local estimates, we find good agreement between local and regional values in most locations.

Interpretation and Implications: Comparison between local and regional Te estimation methodologies imply a higher confidence than the formal errors based on regional values, and significantly changes the preferred interpretation. Specifically:

1. The presence of flexural bending in many locations confirms a non-isostatic, high heat flow interpretation of low Te from regional gravity/topo.
2. The agreement between Te estimates from the regional and local estimates indicates high heat flow is likely in large regions, not just at coronae.
3. Surface heat flow appears highly variable based on gravity/topo results. Interpretation of Te in terms of heat flow requires assumptions about composition, strain rate, and volatile content [e.g. 5]. If the rheology is significantly weaker than typically assumed, the Te is larger and the heat flow smaller.
4. Overall heat flow over ~40% of Venus is much higher than thermal evolution models predict. Both the variability and high values need to be considered.

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NEAR-INFRARED REFLECTANCE SPECTROSCOPY OF VENUS-ANALOG ROCKS AT VENUS SURFACE TEMPERATURES. A. H. Treiman[1], J. Filiberto[1], K.E. Vander Kaaden[2]. [1]Lunar and Planetary Institute, 3600 Bay Area Blvd. Houston TX 77058 <treiman@lpi.usra.edu>. [2]Jacobs, NASA Johnson Space Center, Mail Code XI3, Houston, TX 77058.

Introduction: Venus' surface can be viewed in emission through the relatively opaque atmosphere via a few spectral 'windows' in the near-infrared (NIR, most near 1 µm) [1]. Venus' surface appears to show emissivities that correlate with surface geology [2-4], and these emissivity variations are interpreted as differences in surface rock type (mafic vs. silicic) and/or extent of weathering (Fe^{2+} silicates vs. Fe^{3+}-oxide-coated).

To understand and quantify the observed variations in NIR emissivity, laboratories are measuring high-T NIR emissivity directly [5,6]. For example, the measured emissivities of basalts in the wavelength range 0.85 – 1.2 µm are ~0.9. This value can be tested by measurement of reflectance, because Kirchoff's Law holds that emissivity (**e**) = 1 – reflectance (**r**). The **r** of basalt in the NIR is ~0.1 [7] so its **e** should be ~0.9.

However, high-T NIR **e**'s of silicic igneous rocks (granitic, rhyolite) are reported to be 0.8-0.9 [5,6] (but see [8]), which is inconsistent with **r** values of 0.3-0.7 of such rocks at room-T [7,9]. For both datasets to be correct, the **r** values of silicic igneous rock would have to decrease precipitously between room and Venus surface temperatures. This seems unlikely.

Samples & Methods: We measured reflectances of rough surfaces of: alkali basalt, tholeiite, and dunite (Spitsbergen, Norway); granite (San Gabriel Mts., CA); hematite-coated basalt (Vesuvius, Italy); dacite (Mt. Hood, CA), and sandstone (UT). Standards were rods of polycrystalline MgO and graphite, with estimated **r**'s of 0.95 and 0.05 respectively. **r** values at 25°C (350 – 2500 nm) were measured with a Spectral Evolution OreXpress Spectrometer using its contact reflectance probe.

Then, reflectances at ~470°C were measured on samples and standards in a box furnace, illuminated by a 950 nm LED flashlight (Figure 1). The materials were imaged through a ~900 nm long-pass filter with a pocket digital camera, that was modified to pass NIR light. Average DN were taken from JPG images; the DN were converted to **r** values by interpolating between the standards' DNs, after calculating (and un-doing) the camera's γ-correction. A γ=3 yielded a linear response between pixel DN and **r** values from a photographic gray card (950 nm flashlight at room temperature).

Conclusion: 950 nm **r** values of most common rocks at ~470°C are similar to those measured at 25°C (Table 1). Our **r** for dunite is comparable to that for olivine at high T [10,11]. The tholeiite became partially coated with hematite during heating, which accounts for its increase in **r**. So, for most substances, one can estimate their NIR **e** at Venus surface T from room-T **r**, following Kirchoff's Law. We calculate that silicic igneous rocks (e.g., granite, dacite) will have **e** values of 50-75% [8], far lower than reported recently [5,6]. These lower **e** values imply that silicic igneous rocks should be readily recognizable with orbital NIR emissivity measurements.

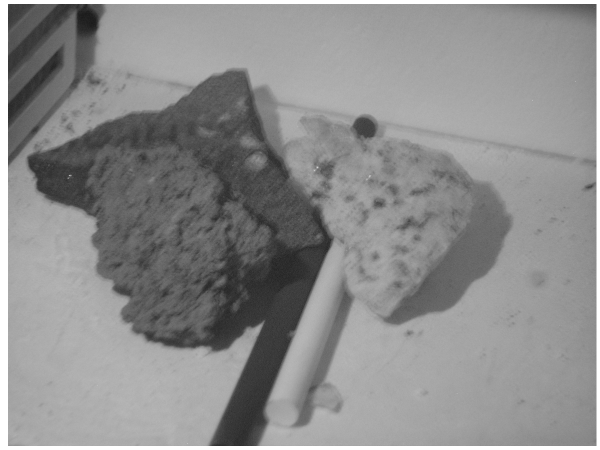

Figure 1. Rocks and standards at ~470°C, imaged in ~950 nm light. Rocks (clockwise from left) are: hematite-coated basalt, tholeiite basalt, granite. DN here used for Table 1.

Table 1. Reflectances, **r** (%) at 950 nm.

	Temperature	
Substance	25°C	~470°C
Alkali Basalt	4	5
Tholeiite	6	10
Granite	48	49
Dacite	25	22
Dunite	9	6
Hm. Basalt	18	15
Sandstone	41	38

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A Discussion on the Need to Sustain Mission Ready TPS and for Continued Development of Innovative Entry System Technologies.

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Flight proven entry system and TPS technologies are critical for the successful execution of *in situ* science missions at Venus. Emerging new technologies point to new possibilities and offer innovative approaches to delivering small satellites for orbital science. Venus entry can be very demanding and there are only a few flight proven TPS materials, some developed by Industry and others by NASA, capable of meeting the mission needs. NASA-developed TPS technology has largely been transferred to Industry under the assumption that industry would maintain the fabrication capability. However, lack of mission needs could result in obsolescence of TSP fabrication capability, or NASA's expertise could be diverted to other higher priority objectives thereby impacting the readiness of particular material systems. Atrophy of capabilities can come about in other ways as well, such as, changes to raw materials. Even small manufacturing process changes could result in requalification of materials and/or reduction in TRL. Carbon-Phenolic is a text book example.

After a long period of absence of US Venus missions, VEXG and the Science community is making the case for future missions. It is insufficient to assume the TSP technologies will be there in 5 or 10 years without active and continual planning and assessment. After Galileo, Carbon-Phenolic materials and fabrication skills were allowed to atrophy. Then when missions needed it, in early 2000, it was no longer possible to make the heritage Carbon-Phenolic.

What do we need to do? The first step is to advocate for the establishment of TPS readiness assessment. VEXAG needs to advocate for active monitoring of needed capabilities, assessment of emerging risks, development of risk mitigation strategies, and implementation plans. Such an approach reduces the threat of material obsolescence and helps maintain the availability of entry system and TPS technology capabilities, both old and new.

Venus probes, landers, balloons and other variable altitude missions, skimmer missions, such as, "Cupid's Arrow," as well as aerocapture missions to deliver small spacecraft, require qualified entry systems and ablative TPS. VEXAG advocated for HEEET in 2013/2014 and the community is well versed with the need to sustain it. However, other TPS that need to be sustained may not be apparent to VEXAG community.

The following figure summarizes the ablative TPS capabilities *vs*. Venus mission needs for both primary heatshield and backshell.

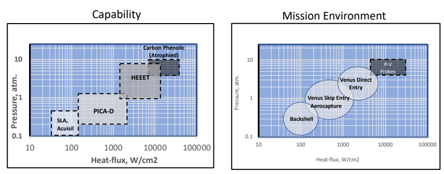

Figure 1. Mission ready TPS capability vs Venus entry conditions.

The list of ablative TPS that needs to be sustained contains just a few materials, but each material is unique, *i.e*., there is no alternate. This makes it even more important that VEXAG advocate for sustaining flight-ready TPS. The VEXAG community may not be aware that PICA has been impacted by raw material (rayon) availability. In 2016, NASA learned that the rayon supplier (foreign) was going to discontinue production and SMD-PSD was advised to invest in the establishment of a PICA based on domestic rayon. A three-year effort with FMI starting FY16, culminated in establishment of PICA-D (Domestic) as a "drop-in replacement" for the heritage PICA. Unfortunately, a few months ago, FMI's parent company decided to discontinue the production of carbon FiberForm™, which is the substrate for the PICA TPS. With missions such as Dragonfly, MSR SRL and MSR EEV needing PICA-D for missions in 2026, NASA has had to work with FMI to fund an activity to ensure FMI will reestablish PICA-D production just to meet NASA needs.

The continued advocacy for new approaches, drag modulated aerocapture with the deployable entry system technology (ADEPT), which is showing promising approaches to deliver small spacecraft (cube sats and bigger) and delivery of balloons using direct entry with ADEPT, can enable innovative missions.

The intent of the poster is to make the case for white papers on "Sustaining Mission Ready TPS and Continuing Development of Innovative Entry System Technologies."

CUPIDS ARROWS - PIERCING THE HEART OF VENUS : A SURFACE INSTRUMENT CONCEPT

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Introduction: Exploring the tectonic nature of Venus is crucial to understanding its present and past history of plate dynamics. We propose a novel concept that uses precise very long-term (years) monitoring of the surface of Venus over possibly 1000s of kilometers. These observations will unveil the current seismic activity on Venus and the movement of large areas of the surface – assuming the surface remains dynamic.

Background: Currently on Earth today there is an array of GPS transmitters scattered across the globe that measure the real-time motion of local and continental scale structures on land with respect to each other [1]. This work is reliant upon the current GPS satellites circling the Earth and clever algorithms that constantly iterate to get relative accuracies down to millimeters. It is used in combination with other observations to better understand land, ocean and airflow on Earth [2]. We propose a smaller scale concept that could be deployed in a possibly interesting area on Venus 100s to 1000s of kilometers in area

Methods: The system architecture is simple and robust. We use well documented high temperature solar cells designed for the Venusian surface [3] and battery technology [4] and transmitting antenna that will allow real-time monitoring of the surface over a period of years. High temperature solar cells and primary batteries that can survive and operate under Venus surface conditions for several weeks are currently under development within the HOTTech program [5]. Lifetime testing show that Low Intensity High Temperature solar cells survive for 1 month at 465°C without performance degradation and 7 weeks with limited degradation. Under conditions close to the surface of Venus, 465°C & 67W/m^2, the measured solar cell characteristics allow a power density P=1.6W/m^2 & power conversion efficiency η=2.45%. Modeling shows that an optimized solar cell for the Venus surface could generate ~4W/m^2. The system would be in-operational during the long Venusian night, but the solar arrays and batteries would continue to function each time the system comes into contact with the Venusian solar day. An orbiter would be required to receive data from the surface stations and it would also use triangulation techniques to determine their precise locations across the planet. The concept relies upon a very long-lived orbiter in a stable orbit that would allow years of data acquisition & algorithmic development. The basic design would consist of a plethora of “arrows” (~10s) released from an orbiter upon arrival to the planet. The arrows are extremely simple and would not need any guidance, steering capability or need any atmospheric braking. Upon arrival they will either pierce the surface directly or lie upon it (yet to be decided). The solar panels will then deploy (see Figure) which will automatically stand the object upright if it is lying on its side & a small communications antenna would deploy. If solar efficiency decreases because of dust accumulation the system would fold up & redeploy before solar efficiency drops below a given threshold.

Instrumentation: The system could contain at least three lightweight low power detectors: 1) Seismometer [6], 2) Temperature, 3) Pressure. It would also require a small antenna for communication purposes. If large power requirements are required power can be stored in the battery via solar cells and then utilized in bursts to communicate infrequently.

Conclusions: Understanding the current state of Venus’ surface is critical to understanding its long-term past & future evolution. Does Venus have active plate tectonics? Does Venus’ surface temperature and pressure fluctuate? Is there plate movement even on a one plate planet like Venus? All of these will help us to better constrain current modeling studies, which are currently mostly unconstrained! The system is purposely inexpensive and simple to operate and deploy – critical in the harsh Venusian environment.

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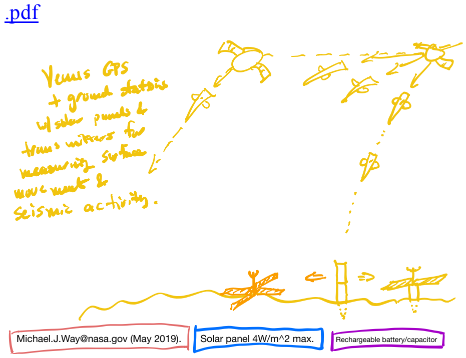

Figure: Cupids Arrows: Device can pierce surface or land on its side and deploy.

THE FIRST 100 MILLION YEARS AND WHAT IT CAN TELL US ABOUT VENUS' HISTORY

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Introduction: Understanding the first 100 Myr of Venus' planetary evolution will make it easier to discern whether it was ever capable of hosting liquid water on its surface or not. Using the methods of comparative planetology we will try to compare and contrast Venus' early evolution and that of Earth. We will discuss the shortcomings in present day early Venus evolutionary models and where improvements can be found. Finally we will discuss how exoplanetary science may contribute to better understanding Venus' early evolution and the key in-situ observables (that we are missing!) that can also help us constrain its evolution. If Venus did start out cool and wet it may be the poster child for what we call "The Optimistic Venus Zone" of exoplanet liquid water habitability.

Background: Current models of Venus' early climate evolution [1] put Venus at the boundary of starting out very dry (Type II) or allowing for an Earth type evolution (Type I). A Type II world is one that is close enough to the Sun that the initial steam/CO_2 atmosphere covering its magma ocean will last for up to 100Myr. Such an atmosphere will experience photodissociation of H_2O and hydrodynamic escape of Hydrogen (H). This is one possible source of the high Deuterium to Hydrogen ratio measured by Pioneer Venus [2]. The remaining Oxygen was likely absorbed by the magma ocean and may contribute to a highly oxidized mantle partially explaining the abundance Nitrogen in Venus' present day atmosphere [3,4]. The Type 1 world's steam and CO_2 atmosphere would last about the samelength of time as Earth's, or ~1Myr. This would allow Venus to retain much of its primordial H_2O and allow an evolutionary scenario similar to that of the Cool Early Earth hypothesis [5,6,7], see Figure 1. In the latter scenario Venus' long-term evolution could follow a number of paths.

Methods: We have recently proposed to extend the 1-D model of [8] to include species not included in the older work of [1] such as SO_2, H_2SO_4 and HCl. The high planetary albedo from clouds have been shown to be a key component to explain how the inner edge of the habitable zone is much closer to the host start for slow rotating planets [9,10]. Hence we plan to include H_2O and H_2SO_4 type clouds as well as additional SO_2 aerosol products such as SO_4 known to cool the Earth's atmosphere. We plan to use the 1-D model until we reach temperatures and pressures suitable for our 3-D GCM [11] which we plan to extend to temperatures approaching 400K and pressures up to 10-20 Bar as described in [12]. We will also include those gas species and the aerosol mentioned above. Using these simulations we will produce observables such as transmission, reflection, & emission spectra that can be used by the exoplanet community to search for Venus-like worlds around nearby young stellar systems with planets.

Conclusions: Understanding the early state of Venus' climate is necessary to understand its long-term climatic evolution. Did Venus really have an early period of liquid water habitability [13], or has it always been dry? Unless we return to the surface of Venus and make detailed in-situ measurements of the heavy noble gases [14] only exoplanetary studies will help us to inform Venus' history.

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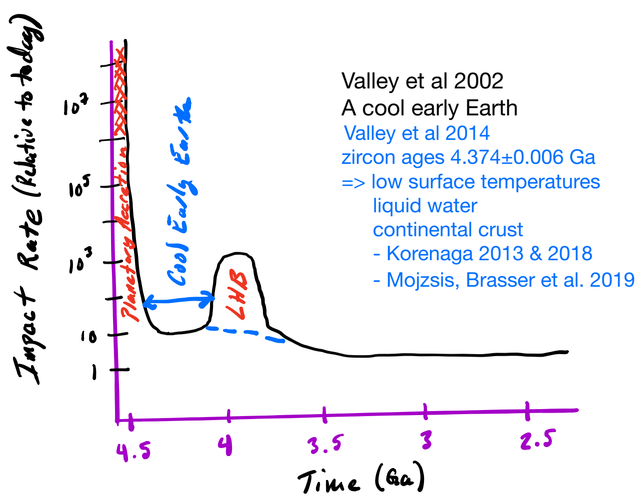

Figure 1: The Cool Early Earth, inspired by [4]. Note that the LHB (Late Heavy Bombardment) is not as certain today as it was 20+ years ago [6], hence the additional blue dashed line has been added.

VENUS DUNE ANALOGS: WHERE ON EARTH DO WE FIND THEM? K. E. Williams[1], T. N. Titus[1]. [1] U.S. Geological Survey Astrogeology Science Center, 2255 N. Gemini Dr., Flagstaff, AZ 86004, US.

Introduction: Planetary analogs are important for basic scientific investigation, given limited access to the planetary body. Whether a particular analog is appropriate depends on the variables of interest. Our motivation here is to find Earth analogs for Venus dunes. Here we compute shear stress over an artificial dune for a specified flow regime. We find that, if our interest is confined specifically to local shear stress, the Venusian atmosphere is fairly well approximated by the terrestrial atmosphere with a wind scaling factor. The subaqueous Earth case, which is perhaps the best analog in terms of factors such as particle to fluid ratios, can be matched to the Venusian shear stresses if the current is reduced from 1.2 m/s to ~2.2 cm/s.

Background: The shear stress field for a given fluid flow is fundamental to the study of dune formation: shear velocity and particle fluxes are dependent on local shear stress. When studying particle entrainment, the ratio of particle to fluid densities is also important [1].

Model: We have used the COMSOL commercial software package to construct a $k-\varepsilon$ turbulence model in order to simulate shear stresses over the top of the lee face of the dune (the area of interest). The $k-\varepsilon$ model was chosen as it is used for high Reynolds number flows; it performs well for flow past complex geometries and has fast convergence rates. A representative velocity field is shown in Fig. 1. Local shear stresses were then modeled for the Earth atmospheric case, the Venus atmospheric case, and the Earth subaqueous case (depth 1km which approximates the Venus surface pressure).

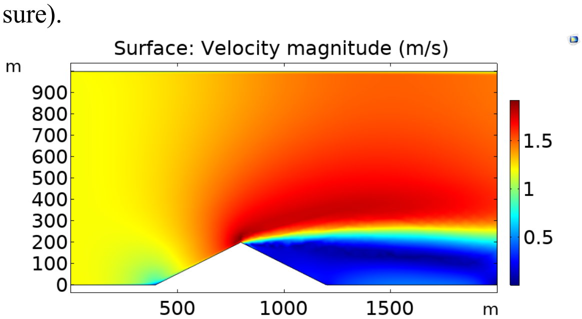

Figure 1: Velocity Field of Earth atmosphere case. Wind direction is from left to right.

Results: The local shear stress for the current Venusian atmosphere is shown in Fig. 2, where $\tau_s \approx 3 \times 10^{-6}\ Pa$. The subaqueous Earth case (Fig. 3) indicates a shear stress of 1.5×10^{-4} Pa. The atmospheric Earth case (Fig. 4) indicates maximum shear stresses near the dune apex as 1.5×10^{-6} Pa, which can then be matched to the Venus case by doubling the inlet wind speed. The subaqueous Earth case can be matched to the Venus case by reducing the current from 1.2 m/s to 0.022 m/s. Such low current speeds are reasonable in subaqueous dune fields on the continental shelf by the southeast continental margin of Africa, where currents were found to be less than 1.3 m/s [2]. Even smaller bottom currents (~14 cm/s) were found in dune fields in the southeast Indian Ocean at depths near 600 m [3].

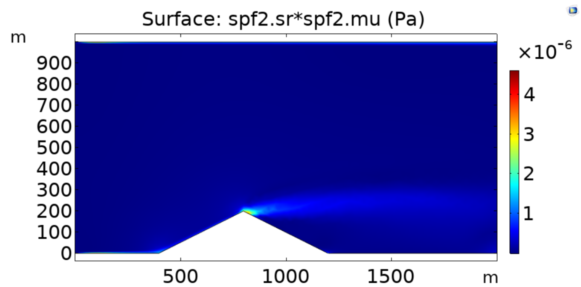

Figure 2: Shear stress for Venusian atmosphere, given an inlet velocity of 1.2 m/s.

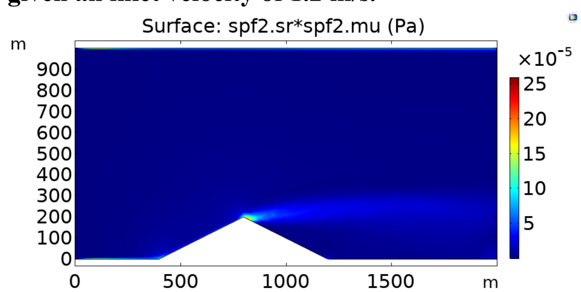

Figure 3: Shear stress plot for subaqueous Earth. Depth 920m. Inlet velocity is 1.2 m/s.

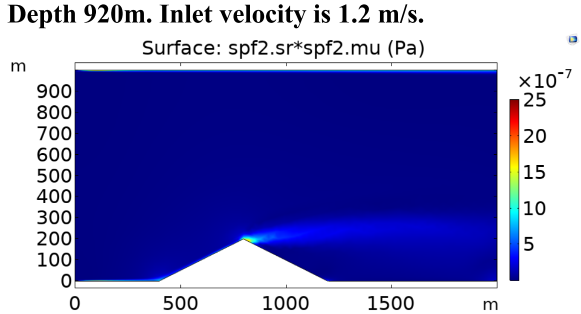

Figure 4. Shear stress plot for Earth atmosphere. Inlet velocity is 1.2 m/s.

Conclusions: Local shear stress is well approximated with Earth atmospheric conditions, given a wind scaling factor (~50% of the Venus inlet wind). The subaqueous Earth case is still the better analog, given that $\frac{\rho_p}{\rho} \approx 3$ (Venus ~50) [1] and the shear stresses can be matched to Venus if the current is reduced.

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A Global Study of Ridge Belt Morphology and Morphometry on Venus. Zachary W. Williams[1], Paul K. Byrne[1], and Jeffrey A. Balcerski. [1]Planetary Research Group, North Carolina State University, Raleigh, NC 27695 (zwwillia@ncsu.edu), [2]Ohio Aerospace Institute, Cleveland, OH 44142.

Introduction: Ridge belts are linear, positive-relief systems of shortening structures widely distributed across Venus. Previous studies concluded that ridge belts are surface expressions of spatially concentrated crustal shortening accommodated by thrust faulting and folding, akin to fold and thrust belts on Earth [1–7]. Despite assessment in previous studies [1–6], the morphological characteristics of these globally distributed systems have yet to be fully established. With the recent availability of topographic data at resolutions greater than the Magellan altimetry dataset [8], it is now possible to gain a more comprehensive understanding of the morphological properties of these shortening structures. Here, we aim to acquire detailed morphometric data for a globally distributed set of ridge belts.

Data and Methods: We utilized global Magellan synthetic aperture radar full-resolution radar map (SAR FMAP) 75-meter-per-pixel (m/px) left- and right-look mosaics. For topographic measurements, we used stereo-derived digital elevation models (DEMs) produced by Herrick et al. [7], which offer ~20% global coverage at 1–3 km/px resolution. We conducted a global survey with ArcGIS to identify ridge belts on the basis of morphological descriptions from existing studies [e.g., 1, 4–7, 9]. This survey yielded 398 discrete landforms as potential study structures. We downselected 24 candidates for further analysis that have a well-preserved morphology and are not obviously kinematically associated with neighboring systems. Of these 24 structures, 12 are within the Herrick DEM coverage. Outlines of the selected ridge belts were manually traced and recorded within ArcGIS. We developed a Python routine to automatically record the strike of each landform from the mapped outline and to take width measurements (representing the distance across strike to opposing boundaries of the landform) at regular intervals along the structure, orthogonal to the strike at the point of collection. For those ridges covered by the Herrick DEMs, we extracted cross-sectional profiles at each point where we recorded a width measurement (**Fig. 1a**).

Results and Discussion: Average relief values were determined from the range of the cross-sectional profiles for each of the subset of DEM-covered ridge belts (**Fig. 1b**). For these 12 structures, we found an average relief value of 597 m (with maximum and minimum values of 938 m and 232 m, respectively). Values for strike, width, and location for all 24 structures were extracted from the global SAR FMAP (**Fig. 1a**). The average width of the 24 ridge belts was 81 km, with a maximum width value of 207 km and minimum width value of 9 km. The standard deviation of width ranged from 59 to 4 km, with an average variance of 19 km, for all 24 structures.

Their relatively low relief indicates that these shortening systems may feature thrust faults that penetrate only to shallow depths in the Venus lithosphere. Such a scenario is consistent with yield strength envelopes that suggest a relatively thin brittle lithosphere as a function of the high surface temperature [12]. This possibility can be tested with forward modeling of ridge belt morphology [13].

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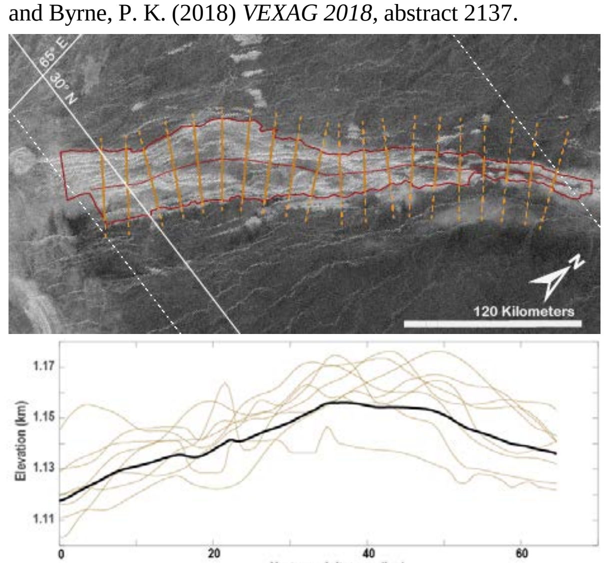

Fig. 1. ***a.*** *Example of mapping and data extraction for a ridge belt centered at 30.8° N, 66.8° E. Width measurements (solid orange lines) and cross-sectional profiles (dashed orange lines) are shown.* ***b.*** *Cross-sectional profile of the ridge. Solid black line is the average of 20 extracted profiles (light grey). Relief is 386 m with a standard deviation of 105 m.*

OBSERVING VENUS WITH NASA'S HIGH-ALTITUDE BALLOON PROGRAM. E. F. Young[1], M. A. Bullock[2], M. F. Skrutskie[3], T. Kremic[4], [1]Affiliation Southwest Research Institute, 1050 Walnut St., Boulder, CO 80302 (efy@boulder.swri.edu; con@boulder.swri.edu), [2] Science and Technology Corp., 21 Enterprise Parkway, Suite 150 Hampton, VA 23666-6413 (mbullock75@gmail.com), [3] PO Box 400325, University of Virginia, Charlottesville, VA 22904-4325 (mfs4n@virginia.edu), [4] 21000 Brookpark Rd, Cleveland, OH 44135 (tibor.kremic@nasa.gov).

Introduction: NASA's Balloon Program Office (BPO) regularly flies payloads weighing several tons at altitudes of 33 - 38 km, above 99.3% - 99.6% of the Earth's atmosphere, respectively. Balloon-borne telescopes operating in the stratosphere have three distinct advantages over ground-based telescopes with respect to tracking daytime and nighttime clouds on Venus and obtaining spectral image cubes.

- The Fried parameter, r_0, is thought to be larger than 4 meters at float altitudes, compared to 10-15 cm at good terrestrial sites. Balloon-borne telescopes should have diffraction-limited performance as a result, even at visible and UV wavelengths where ground-based adaptive optics (AO) systems typically have poor Strehl ratios. As an example, a stratospheric 1-m aperture telescope has a Point Spread Function (PSF) width of 0.10" at λ=0.4 µm.
- Balloon-borne telescopes have access to most of the UV and IR spectrum (Figs.1,2), with sky backgrounds dominated by zodiacal light and sky emission lines [1].
- NASA has developed super-pressure balloons with nominal flight durations of ~100 days [2]. These platforms provide consecutive nights to help determine wave phenomena in Venus's atmosphere.

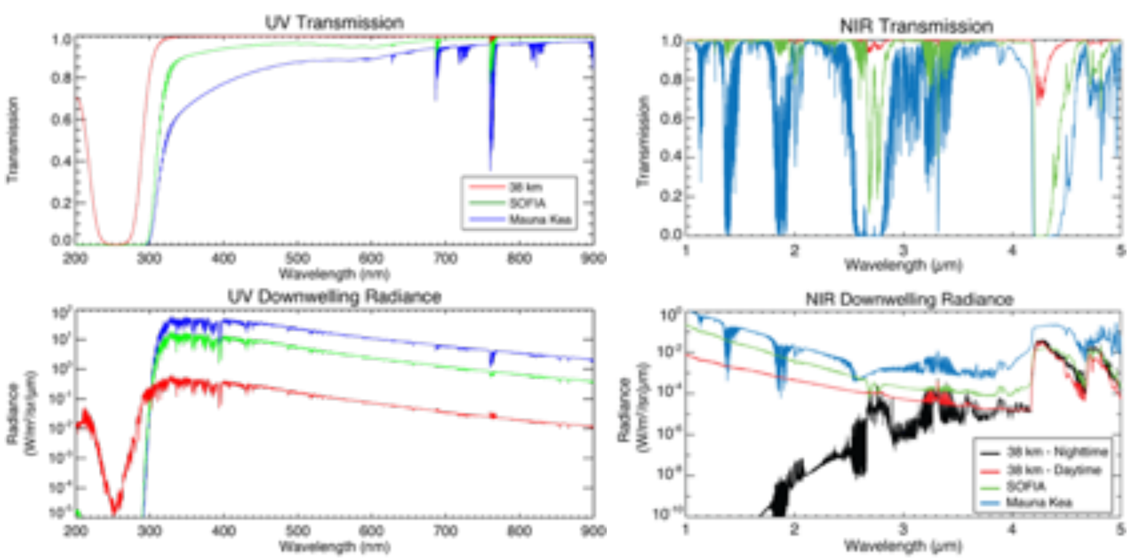

Figure 1. Stratospheric balloons have access to key parts of the UV and IR spectrum. The UV window at 200-240 nm can constrain the ratio of SO/SO_2 at the cloud tops. The IR spectrum has nearly complete access to the 1 - 5 µm range, including partial access through the terrestrial CO_2 band at 4.3 µm.

The Case for a Stratospheric Venus Observing Platform: A balloon-borne telescope dedicated to observing Venus during the 100-day period around inferior conjunction could provide an uninterrupted sequence of pole-to-pole images and spectra. Unlike previous space missions (Venus Express and Akatsuki), a balloon campaign could monitor cloud top features continuously for 2 days and middle/lower cloud deck features for 3-4 days. A one-meter aperture telescope could resolve 100-km cloud top features at 283 and 365 nm, over time spans of at least ten hours, sufficient to determine cloud motions at the 1 m/s level (rms). A stratospheric telescope has access to spectral ranges that are normally opaque to terrestrial observers. Some useful bands include 2.5 - 2.55 µm (diagnostic of cloud base altitudes, sensitive to SO_2), 200-240 nm (sensitive to SO and SO_2 features) and 4.3 µm (allows limb sounding).

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VENUS NIGHTSIDE CLOUD TRACKING AND SPECTRAL IMAGE CUBES WITH IRTF/SPEX FROM 2001–2018.
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Introduction: We present observations of Venus obtained at the IRTF with the SpeX spectrograph over a period from May 2001 through December 2018. Observations focused on Venus's nightside. Campaigns were scheduled just before or after Venus's inferior conjunctions. In total there were 11 separate observing campaigns (5/2001; 9/2002; 5/2004; 7/2004; 2/2006; 7/2007; 9/2007; 12/2010; 9/2015; 4/2017; 11/2018), ranging in length from 4 to 21 days. Each observing session consists of imaging with the SpeX guide camera through two filters, "cont-K" (2.26 µm, 1.5%) and "Brγ" (2.166 µm, 1.5%), and most sessions also included image cubes (0.8 - 2.5 µm, R = ~300) obtained with the PRISM mode spectrograph. The two most recent campaigns in 2017 and 2018 also included guide camera images at 1.74 µm (2.3%) and with the FeII filter (1.644 µm, 1.5%) and spectral image cubes at R = ~2000 in H- and K-bands. Campaigns scheduled before inferior conjunction consist of evening observations, generally less than 2 hours from the first to the last images; campaigns that followed conjunctions could last up to 4 hours of morning observations, up to about 10 AM local HST.

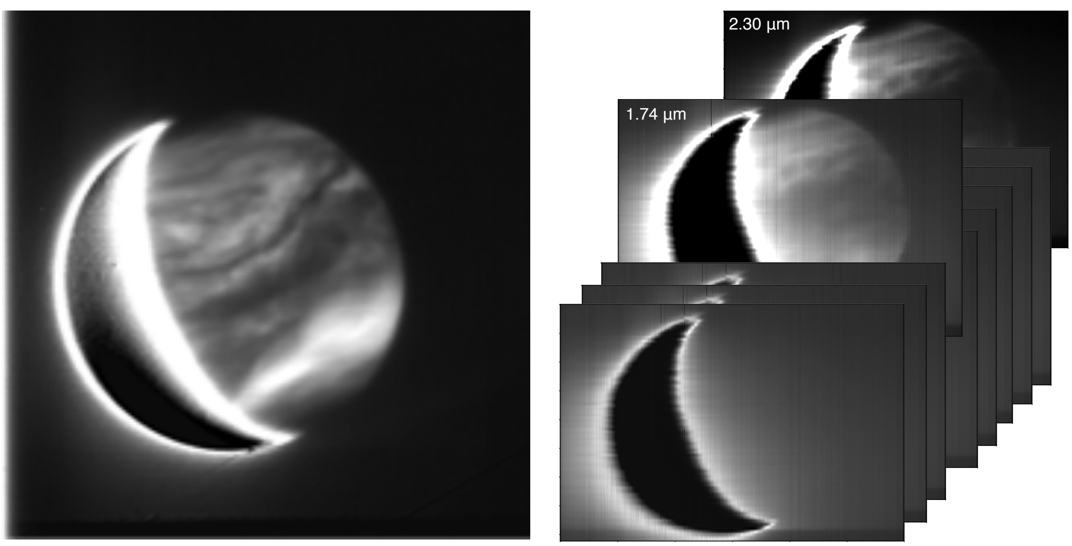

Figure 1. The right panel shows an image taken on 5-DEC-2018 with the SpeX guide camera in the cont-K filter. Spatial resolutions of 0.5" or better are routinely achieved by selecting and stacking subsets of the sharpest images. The left panel shows a PRISM-mode image cube from 27-NOV-2018 with slices highlighting the CO_2 windows at 1.74 and 2.30 µm.

Applications of the Observations: The guide camera images are useful for cloud-tracking applications. In the best cases (4-hour observing windows), cloud velocities in the middle and lower cloud decks can be obtained with rms errors of 3 m/s. The spectra constrain cloud particle sizes, cloud acidity and map the abundances of trace gases CO, H_2O and OCS.

Venera-D: A Potential Mission To Explore Venus' Atmosphere, Surface, Interior And Plasma Environment.,

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Introduction: Venus and Earth were formed approximately the same distance from the Sun, and have almost the same masses and volumes: they should be the most similar pair of planets in the Solar System. An outstanding question is how and when these planets diverged in their evolutions Significantly, did ocean and life exist in Venus early history? Recent investigations based on similarity of "unknown UV-absorber" and spectra of some bacteria suggest that microbial life may still exists in Venus' cloud deck. Venus presents us with fundamental questions about the origin and evolution of planetary bodies and life in our Solar System. Venera-D (D stands for "long-lived": dolgozhivushaya) is a potential mission that combines simultaneous observations of Venus' atmosphere, plasma environment, and surface to try to answer these essential questions.

Venera-D Baseline Architecture: Based on the initial report from the Venera-D Joint Science Definition Team (composed of scientists from both Russia and the USA) , a baseline Venera-D mission would include an orbiter, a VEGA-style lander and attached to it a Long-lived In-Situ Solar System Explorer (LLISSE) on the surface. In addition, the Joint Science Definition Team (VDJSDT) identified the additional science objectives (relying on the NASA Planetary Decadal Survey and VEXAG) that could be addressed by incorporating additional potential elements (e.g., additional long-lived stations, an aerial platform or subsatellites).

Orbiter Science Goals: Despite the fact that Venus is the planet nearest to Earth, it is a planet of mysteries, one of the most intriguing of them is the dynamics of the atmosphere. In the troposphere and mesosphere, the main circulation mode is retrograde zonal superrotation RZS), while in the thermosphere – sub-solar – anti-solar circulation (SS-AS)

Although recent investigations, based on the ESA's Venus Express and JAXA's Akatsuki spacecraft data analysis, showed the determining factors influencing the dynamics of the atmosphere, are insolation (in particular solar tides) and surface relief, possibly through the generation of gravity waves. An orbiter associated with the Venera-D mission would need to examine the thermal tides, atmospheric composition and structure, examine the atmosphere in the ultraviolet, visible, and infrared wavelengths, study the possible surface thermal activity on the night side and look at the interaction between the upper atmosphere, ionosphere, and magnetosphere with the solar wind. Ideally, the orbiter would take measurements for a minimum of 3 years.

Lander Science Goals: During descent, the lander would investigate the physical structure and chemical composition of the atmosphere down to the surface, including composition and distribution of atmospheric aerosols. Once below the cloud deck, cameras would image the surface to provide a geologic context for the landing site; on the surface, the chemical composition of the landing site would be measured, the drilling and soil sampling and study the sample inside will be performed and additional cameras would image the near- and far-field. Combining measurements of the surface and the adjacent atmosphere would allow us to constrain the chemical interactions occurring at that interface. A VEGA-style lander would likely live on the surface for 2 – 3 hours.

LLISSE Science Goals: A LLISSE would measure surface winds (velocity and direction), pressure, temperature, and chemical composition over a lifetime of 2 – 3 months on the Venusian surface. Ideally, the LLISSE would transition from the dayside to the nightside during this time.

Potential Elements: The Joint Science Definition Team is examining the science return from potential additional elements, depending on the mass and volume available, which in turn are controlled at least partly by the precise launch date.

Additional contributed augmentations being discussed include additional LLISSEs or a long-lived seismic instrument such as the Seismic and Atmospheric Exploration of Venus (SAEVe) , a variable altitude balloon, a subsatellite(s) placed at the Lagrange point L1 (L2).