VEXAG Venus Exploration Analysis Group

Program

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16th Meeting of the Venus Exploration and Analysis Group (VEXAG)

November 6–8, 2018
Applied Physics Laboratory, Johns Hopkins University
Laurel, Maryland

Sponsors
Lunar and Planetary Institute
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GUIDE TO SESSIONS

16th Meeting of the Venus Exploration and Analysis Group (VEXAG)

November 6–8, 2018
Applied Physics Laboratory, Johns Hopkins University
Laurel, Maryland

Tuesday, November 6, 2018

8:30 a.m.	Bldg. 200, Room 100	VEXAG Overview and International Venus Exploration
1:30 p.m.	Bldg. 200, Room 100	Guidance Document Revisions, Mission Studies, Planning for Decadal Survey

Wednesday, November 7, 2018

8:30 a.m.	Bldg. 200, Room 100	Venus Surface and Interior Science
10:45 a.m.	Bldg. 200, Room 100	Venus Astrobiology and Exoplanets
1:30 p.m.	Bldg. 200, Room 100	Venus Atmosphere Science
4:00 p.m.	Bldg. 200, Room 100	Poster Session: Venus Surface and Atmosphere Science
4:00 p.m.	Bldg. 200, Room 100	Poster Session: Venus Technology and Instrument Studies

Thursday, November 8, 2018

8:30 a.m.	Bldg. 200, Room 100	Venus Technology and Instrument Studies

PROGRAM

Tuesday, November 6, 2018
VEXAG OVERVIEW AND INTERNATIONAL VENUS EXPLORATION
8:30 a.m. Bldg. 200, Room 100
Chairs: Robert Grimm and Martha Gilmore

Times	**Authors** (** Denotes Speaker*)	**Abstract Title and Summary**
8:30 a.m.	Grimm R. E. *	*Welcome, Review of VEXAG Activities and Meeting*
9:00 a.m.	Ocampo A. *	*NASA Status, Responses to Prior VEXAG Findings*
9:45 a.m.	C. Mercer *	*High Operating Temperature Technology (HOTTech) Program Overview*
10:00 a.m.	Simons R. *	*PICASSO/MatISSE Instrument Development Programs*
10:15 a.m.	*Break*	
10:30 a.m.	Satoh T. *	*Akatsuki at Venus: Extended Mission*
10:45 a.m.	Gregg T. K. P. * Zasova L. Economou T. Eismont N. Gerasimov M. Gorinov D. Ignatiev N. Ivanov M. Khatuntsev I. Korablev O. Kremic T. Jessup K. Limaye S. Lomakin I. Martynov A. Ocampo A.	*Venera-D: A Potential Mission to Explore Venus' Surface, Atmosphere and Plasma Environment* **[#8045]** This presentation will summarize the current accomplishments of the Venera-D Joint Science Definition Team as we work to define a mission to explore Venus in the post-2025 timeframe.
11:00 a.m.	Ghail R. C. * EnVision Team	*EnVision: Phase 0 Developments* **[#8028]** EnVision was selected for Phase 0/A study in the ESA M5 round of medium-class missions. We will report on its conclusions as far as possible and detail opportunities for community involvement and collaboration.
11:15 a.m.	Harikrishnan G. *	*Indian Space Research Organisation's Plans for Venus Exploration*
11:30 a.m.	*Lunch*	

Tuesday, November 6, 2018
GUIDANCE DOCUMENT REVISIONS, MISSION STUDIES, PLANNING FOR DECADAL SURVEY
1:30 p.m. Bldg. 200, Room 100
Chairs: Robert Grimm and Martha Gilmore

Times	Authors (** Denotes Speaker*)	Abstract Title and Summary
1:30 p.m.	Grimm R. E. *	*Intro to Current Studies*
1:40 p.m.	Treiman A. H. *	*VEXAG GOI Document*
1:55 p.m.	Hunter G. W. *	*VEXAG Technology Document*
2:10 p.m.	Cutts J. A. *	*VEXAG Roadmap Document*
2:25 p.m.	Gilmore M. S. *	*Venus Flagship Study*
2:40 p.m.	Jessup K. L. * Gilmore M. S. Grinspoon D. Limaye S. Luhmann J.	*Venus' Unique Role in Solar System History: The Five Big Questions* **[#8050]** Many questions remain regarding Venus' atmospheric, interior and habitability evolution. It is imperative that the critical investigation goals in each of these areas is adequately communicated to the public, and in the upcoming Decadal Survey.
2:55 p.m.	Gilmore M. S. *	*Decadal Survey Discussion*
3:15 p.m.	*Break*	
3:30 p.m.	Grimm R. E. *	*Venus Bridge Introduction*
3:35 p.m.	Hunter G. W. *	*Venus Bridge Study at Glenn Research Center*
3:50 p.m.	Cutts J. A. *	*Venus Bridge Study at Jet Proplusion Laboratory*
4:05 p.m.	Grimm R. E. *	*Venus Bridge Summary*
4:15 p.m.	Cutts J. A. * Matthies L. H. Hall J. L. Thompson T. W. Venus Aerial Platform Study Team	*Venus Aerial Platform Study* **[#8009]** The Venus Aerial Platform Study assessed the science that can be accomplished for exploring Venus with aerial vehicles and the required technologies.
4:30 p.m.	Izenberg N. R. *	*Venus Surface Platforms*

Wednesday, November 7, 2018
VENUS SURFACE AND INTERIOR SCIENCE
8:30 a.m. Bldg. 200, Room 100
Chairs: Jennifer Whitten and Richard Ghail

Times	Authors (** Denotes Speaker*)	Abstract Title and Summary
8:30 a.m.	Treiman A. H. * Wroblewski F. B. Bhiravarasu S.	*Ovda Fluctus, the Festoon Lava Flow on Ovda Regio, Venus: Most Likely Basalt* [#8014] We have mapped the lava flow Ovda Fluctus, on Ovda Regio, in detail. Ovda Fluctus has been interpreted as a silicic (rhyolite) lava flow. However, the preponderance of data suggests that it is composed of basaltic, not silicic, lava.
8:45 a.m.	Whitten J. L. * Campbell B. A.	*Radar Backscatter Variations in Tessera Across Venus* **[#8018]** Tessera radar brightness values vary across Venus. Some of these variations are spatially correlated with crater ejecta. Other brightness variations may be due to other fine grained materials and inherent differences in the tesserae source materials.
9:00 a.m.	Campbell B. A. * Whitten J. L.	*New Insights on Maxwell Montes Surface Properties from Multi-Year Earth-Based Observations* **[#8030]** We present initial results of Venus surface studies using Earth-based radar observations collected in 1988, 2012, 2015, and 2017. The new maps reveal unexpected variations in surface properties across Maxwell Montes.
9:15 a.m.	Dyar M. D. * Helbert J. Boucher T. Maturilli A. Walter I. Widemann T. Marcq E. Ferrari S. D'Amore M. Muller N. Smrekar S.	*Venus Surface Oxidation and Weatehring as Viewed from Orbit with Six-Window VNIR Spectroscopy* **[#8015]** Iron oxidation and changes in mineralogy due to surface/atmosphere interactions can be detected from orbit using a six-window orbital spectrometer.
9:30 a.m.	Knicely J. J. * Herrick R. R.	*Atmospheric Windows to Image the Surface from Beneath the Cloud Deck on the Night Side of Venus* **[#8019]** We explore possible atmospheric windows beneath the cloud deck to study the surface of the night side Venus. Numerous possible windows were found with the potential to elucidate questions about the composition and redox state of the surface of Venus.
9:45 a.m.	Ghail R. C. * Byrne P. K. Mason P. J.	*Towards a New Understanding of Venus* **[#8013]** In recent years there has been a convergence of ideas and observations that show Venus to be both more complex and active than previously thought. Here we review how a range of different processes contribute to the present-day appearance of Venus.

10:00 a.m.	Byrne P. K. * Ghail R. C. Sengör A. M. C. James P. B. Klimczak C. Solomon S. C.	*A Globally Fragmented and Mobile Lithosphere on Venus* **[#8008]** We report observations in support of a continuum of lithospheric mobility, with Earth's "mobile lid" tectonics at one end, the "stagnant lid" tectonics of Mercury, Mars, and the Moon at the other, and Venus somewhere in between.
10:15 a.m.	Goossens S. * Mazarico E. Rosenblatt P. Lebonnois S. Lemoine F.	*Venus Gravity Field Determination Using Magellan and Venus Express Tracking Data* **[#8029]** We present an updated gravity field model for Venus from Magellan and Venus Express data. We focus on extending the temporal baseline to determine Venus' Love number and rotational parameters, and the effects of the atmosphere on these parameters.
10:30 a.m.	*Break*	

Wednesday, November 7, 2018
VENUS ASTROBIOLOGY AND EXOPLANETS
10:45 a.m. Bldg. 200, Room 100
Chair: Giada Arney

Times	Authors (* *Denotes Speaker*)	Abstract Title and Summary
10:45 a.m.	Limaye S. S. * Mogul R. Jessup K. L. Gregg T. Pertzborn R. Ocampo A. Lee Y. J. Bullock M. A. Grinspoon D.	*An Astrobiology Aspect for Exploring Venus Clouds* [#8051] Possibility of life in the habitable zone in the cloud layer on Venus cannot be excluded from available measurements. It has been suggested that microorganisms may contribute to contrasts and albedo of Venus, making this an exploration objective.
11:00 a.m.	Arney G. N. *	*Venus: The Exoplanet Laboratory Next Door* **[#8005]** We review what present and past Venus teaches us context of comparative planetology and processes that shape habitability and biosignature "false positives" in exoplanet atmospheres. Venus plays a vital role in helping us understand exoplanets.
11:15 a.m.	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.	*Venus: The Nearby Exoplanetary Laboratory* **[#8047]** In this talk I will present the current state of detecting potential Venus analogs, expected yield from current exoplanet missions, and summarize the primary exoplanet science questions that would be addressed by a return surface mission to Venus.
11:30 a.m.	Smrekar S. E. * Davaille A.	*Venus Geodynamics, Habitability, and Initiation of Subduction* **[#8036]** Earth's plate tectonics drives volcanism, tectonism, outgassing and recycling of volatiles, surface weathering, and potentially a core dynamo, all of which strongly influence long term habitability. Can Venus show us how plate tectonics begins?
11:45 a.m.	Sasaki S. * Yoshimura Y. Miyakawa A. Fujita K. Usui T. Ohno S. Yamagishi A. Limaye S. S.	*Life Detection Microscope for Venus Cloud Particle Investigation* **[#8011]** Sulfuric acid is not sufficient to explain the observed cloud contrasts and albedo of Venus. Life Detection Microscope is well-suited to detect possible microorganisms in the clouds, contributing to the spectroscopic characteristics.
12:00 p.m.	*Lunch*	

Wednesday, November 7, 2018
VENUS ATMOSPHERE SCIENCE
1:30 p.m. Bldg. 200, Room 100
Chair: Kevin McGouldrick

Times	**Authors** (** Denotes Speaker*)	**Abstract Title and Summary**
1:30 p.m.	Justh H. L. * Dwyer Cianciolo A. M.	*Planned Improvements to the Venus Global Reference Atmospheric Model* [#8034] Venus-GRAM is an engineering-level atmospheric model applicable for engineering design analyses, mission planning, and operational decision making. This presentation is an overview of Venus-GRAM and the GRAM upgrade objectives, tasks, and milestones.
1:45 p.m.	Morellina S. Bellan J. *	*Characteristics of the Venus Lower Atmosphere: Property Computations, Modeling and Simulations* **[#8001]** Modeling and simulations are necessary to interpret the Glenn Extreme Environment Rig data, and determine lander interaction with the Venus Planetary Boundary Layer (PBL). This study is initializing computations, modeling and simulations of the PBL.
2:00 p.m.	McGouldrick K. * Peralta J. Tsang C. C. Barstow J. Satoh T.	*Capricious Cytherean Clouds: The Long and the Short of It* **[#8055]** Seeking parallels / Between the clouds of VIRTIS / And Akatsuki.
2:15 p.m.	Ledvina S. A. * Brecht S. H.	*Simulations of Ion Flow and Momentum Transfer in the Venus Environment* **[#8040]** In this presentation the hypothesis of Lundin et al., that the orbital motion of Venus transverse to the solar wind flow drives the ion tail vortex and potentially the super-rotation up the upper atmosphere is tested.
2:30 p.m.	*Break*	
2:45 p.m.	Kollmann P. * Brandt P. C. Collinson G. Rong Z. J. Futaana Y. Zhang T. L.	*Planetward Ion Flows in Venus' Magnetotail* **[#8020]** Measurements in Venus magnetotail reveal plasma returning back to Venus, a behavior that is normal at magnetized planets but surprising at Venus. These flows are studied in order to understand both fundamental physics and atmospheric evolution.
3:00 p.m.	Bills B. G. * Navarro T. Schubert G. Ermakov A. Gorski K. M.	*Gravitational Signatures of Atmospheric Mass Transport by Thermal Tides on Venus* **[#8007]** Gravitational signatures of atmospheric mass transport by thermal tides on Venus have not yet been observed, but will surely be diagnostic of atmospheric dynamics. We examine the measurement accuracy necessary to recover these signals.

3:15 p.m.	Akins A. B. * Steffes P. G.	*Millimeter-Wavelength Remote Sensing of the Tropospheric Structure of Venus: Exploratory Simulations* **[#8017]** A microwave radiative transfer model of Venus is used to study the effects of varying the abundance of key atmospheric constituents on the observed brightness temperature. Changes in SO_2 and cloud aerosol density likely explain prior observations.
3:30 p.m.	Lebonnois S. * Schubert G. Forget F. Garate-Lopez I. LeSaux A. Navarro T. Spiga A.	*Investigations Below the Clouds of Venus with the IPSL Venus GCM* **[#8024]** In this work, we review the studies conducted with the IPSL Venus GCM on the atmosphere of Venus below the cloud base. This includes wave activity and its role on the angular momentum budget, as well as properties of the Planetary Boundary Layer.

Wednesday, November 7, 2018
POSTER SESSION: VENUS SURFACE AND ATMOSPHERE SCIENCE
4:00 p.m. Bldg. 200, Room 100

Authors	Abstract Title and Summary
Williams K. E. Geissler P. E.	*Do Venusian Antidunes Exist?* [#8004] In this work we proceed under the working hypothesis that aeolian antidunes may exist on Venus, and we use characteristics of transverse dunes from the Al-Uzza Undae region of Venus to constrain the formative flow properties of putative antidunes.
Izenberg N. R. Kelly J. A.	*Reinvestigation of Venusian Splotches with Magellan and Arecibo Radar Data* **[#8027]** The scars of bolides / Exploded above Venus / Have yet more to tell.
Hensley S. Martin J. Oveisgharan S. Duan X. Campbell B.	*Radar Performance Modeling for Venus Missions* **[#8035]** This paper describes a radar performance model for imaging, stereo and interferometric modes operating from a Venus orbit.
Toner K. Gilmore M. S.	*The Radiophysical Properties of Some Large Volcanoes on Venus* **[#8041]** We observe that large volcanoes volcano have unique profiles of emissivity with elevation that may indicate differences in the type, abundance and/or age of ferroelectric minerals.
Gilmore M. S. Santos A. R. Greenwood J. P. Izenberg N. Hunter G. Treiman A. Abe K. Makel D.	*Thirty Days on Venus: Chemical Changes Minerals Exposed to the Glenn Extreme Environment Rig (GEER)* **[#8039]** Compositional changes including sulfurization of calcite, apatite, plagioclase and basalt glass (with oxida-tion) occurred over a 30-day exposure under Venus conditions in GEER.
Jindal A. S. Hayes A. G.	*Unveiling the Interior of Venus: Using Tectonic Deformations Along Canali to Constrain Lithospheric Structure and Mantle Convection* **[#8037]** Canali on Venus show uphill trends due to post-depositional tectonic deformations. We are studying the dominant length scales associated with the nearly periodic relief along canali profiles to infer the lithospheric structure and mantle convection.
McCabe R. M. Sayanagi K. M. Blalock J. J. Gunnarson J. L. Peralta J. Gray C. L. McGouldrick K. Imamura T. Watanabe S.	*Observational Analysis of Venusian Atmospheric Equatorial Waves and Superrotation* **[#8042]** We study the upper atmospheric winds of Venus through tracking cloud movement in UV images from Venus Express orbiter from 2006–2013. We also conduct ground-based observations in coordination with the JAXA Akatsuki spacecraft currently in orbit.
Lebonnois S. Schubert G. Bellan J. Kremic T. Nakley L. Phillips K. Navarro T.	*An Experiment to Investigate Venus's Deep Atmosphere* **[#8025]** We have investigated the mixing behavior of N_2 and CO_2 in 100-bar pressure conditions with the GEER facility at NASA Glenn Research Center. This experiment was designed to study a hypothetical separation of the two gases in Venus's deep atmosphere.
Wroblewski F. B. Treiman A. H. Bhiravarasu S.	*Anomalous Radar Properties of Maxwell Montes: Results from Refined Stereo Altimetery* **[#8021]** Magellan radar properties of Maxwell Montes vary both with elevation and location. Particuarly, north flanks of central Maxwell Montes have different properties than the south flanks.

Rastegar S. Jurdy D. M.	*Venus' Ishtar Terra: Topographic Analysis of Maxwell, Freyja, Akna and Danu Montes* **[#8046]** Analysis of Magellan topographic data for quantitative comparison using principal component analysis of Venus' 4 mountain chains allows for an independent and objective mode of comparison of the venusian mountains with terrestrial counterparts.
Balcerski J. A. Byrne P. K.	*Fault Analysis of Venus Ridge Belts Using Stereo-Derived Topography* **[#8012]** We use the stereo-derived topographic model to re-examine the structure of Venus' ridge belts. Numerical and comparative analyses suggest that some of these ridge systems can be modeled as fault propagation folds with shallow detachment depths.
Hensley S. Nunes D. Mitchell K. Cotton K.	*Magellan Intra-Cycle Venus Stereo Topography* **[#8026]** We describe the use of intra-cycle stereo between adjacent orbit pairs as a source of topographic data and show that the spatial resolution and elevation accuracy are suitable for use in scientific investigations.
Bullock M. A. Grinspoon D. H. Limay S. S.	*Follow the Sulfur* **[#8054]** In situ investigations of Venus' clouds are necessary to identify the agent that absorbs most of the sunlight entering Venus' atmosphere. Studying the chemistry of Venus cloud aerosols is important for terrestrial studies and in the search for life.

Wednesday, November 7, 2018
POSTER SESSION: VENUS TECHNOLOGY AND INSTRUMENT STUDIES
4:00 p.m. Bldg. 200, Room 100

Authors	Abstract Title and Summary
Rabinovitch J. Sotin C. Borner A. Gallis M. A. Avice G. Darrach M. Madzunkov S. Marty B. Baker J. Mansour N. N.	*Feasibility of Hypervelocity Sampling of Noble Gases in the Upper Atmosphere of Venus* [#8022] Cupid's Arrow is a mission concept that would determine the amount of noble gases and associated isotope ratios in the Venus atmosphere. This work investigates whether the gas sampled at ~10 km/s is representative of the true Venus atmosphere.
Vergados P. Ao C. O. Komjathy A. Preston R. Navarro T. Schubert G. Atkinson D. Cutts J. Asmar S. Lazio J.	*Investigating Waves in the Venus Atmosphere via Radio Occultations Between Orbiting SmallSats* **[#8032]** The objective of this study is to investigate the spatial-temporal coverage obtained by a constellation of small satellites via occultation soundings. We analyze different orbiting scenarios including, small satellites flying in tandem configuration.
Runyon K. D. Izenberg N. R. McNutt R. L. Bradburne C. E. Shelhamer M.	*Crewed Venus Flyby: Precursor to Mars* **[#8033]** A human flyby of Venus is a compelling exploration/science and Mars precursor mission. More attention to such an achievable mission is merited.
Shibata E.	*Propulsive Aerocapture Feasibility at Venus* **[#8052]** Aeropropcapture (APC) is the use of propulsion during an aerocapture maneuver to control the vehicle. APC allows for non-lifting vehicles to achieve a large enough corridor width to successfully complete the maneuver.
O'Rourke J. G.	*Detecting Crustal Remanent Magnetism on the Surface of Venus: Required Instrument Performance and Mission Design* **[#8053]** Future missions should search for crustal remanent magnetism on the surface of Venus (and I'll tell you why and how).

Thursday, November 8, 2018
VENUS TECHNOLOGY AND INSTRUMENT STUDIES
8:30 a.m. Bldg. 200, Room 100
Chairs: Jonathan Sauder and Ethiraj Venkatapathy

Times	**Authors** (** Denotes Speaker*)	**Abstract Title and Summary**
8:30 a.m.	Venkatapathy E. * Allergy D. Gage P.	*Enabling Future Venus In-Situ Missions — Heat-Shield for Extreme Entry Environment Technology (HEEET) Progress Towards TRL 6* [#8002] Heat-shield for Extreme Entry Environment Technolo-gy (HEEET) is nearing completion and results from recent full scale engineering test unit, arc jet testing and shock testing will be highlighted and plans for completion by March of 2019 will be outlined.
8:45 a.m.	Kremic T. * Ghail R. Gilmore M. Kiefer W. Limaye S. Hunter G. Tolbert C. Pauken M. Wilson C.	*SAEVe: Study Results for a Long Duration Venus Lander* **[#8010]** This briefing will describe the final results of the Seismic and Atmospheric Exploration of Venus (SAEVe) mission concept study. The SAEVe concept is a long duration Venus lander based on high temperature electronics and instruments.
9:00 a.m.	Helbert J. * Dyar D. Walter I. Wendler D. Widemann T. Marcq E. Guignan G. Maturilli A. Ferrari S. Mueller N. Kappel D. D'Amore M. Boerner A. Tsang C. Arnold G. Smrekar S. Ghail R.	*The Venus Emissivity Mapper (VEM) — Obtaining Global Mineralogy of Venus from Orbit* **[#8023]** The Venus Emissivity Mapper has a mature design with an existing laboratory prototype verifying an achievable instrument SNR of well above 1000 as well as a predicted error in the retrieval of relative emissivity of better than 1%.
9:15 a.m.	Baines K. H. * Cutts J. A. Nikolic D. Madzunkov S. M. Delitsky M. L. Limaye S. S. McGouldrick K.	*The Venus Aerosol Mass Spectrometer Concept* **[#8031]** A progress report on JPL's lightweight, low-power in-situ instrument to measure the composition of venusian aerosols, including the UV haze, for use on aerial missions, including long-duration balloon missions and short-duration probe missions.
9:30 a.m.	Hwang H. H. *	*A Common Probe Design for Multiple Planetary Destinations* **[#8038]** Results from the Common Probe study funded by PSD/SMD NASA, investigating feasibility of using a common aeroshell design for Venus, Jupiter, Saturn, Uranus, and Neptune.
9:45 a.m.	Sauder J. F. * Hilgemann E. Stack K. Kawata J. Parness A. Johnson M.	*Automaton Rover for Extreme Environments: Enabling Long Duration Venus Surface Mobility* **[#8043]** The Automaton Rover is a mechanical rover powered by the wind which could survive on Venus for weeks and provide mobility. The concept could obtain samples from multiple geologic units or collect surface samples for return.

10:00 a.m.	*Break*	
10:15 a.m.	Grimm R. E. *	*High-Altitude Electromagnetic Sounding of the Interior of Venus: Stratospheric Balloon Test* **[#8048]** Lightning-caused electromagnetic energy penetrates deeply into dry Venus, allowing temperature structure to be probed from high altitude. Two stratospheric balloon flights tested the method on Earth.
10:30 a.m.	Grandidier J. * Kirk A. P. Osowski M. L. Gogna P. K. Fan S. Lee M. L. Stevens M. A. Jahelka P. Tagliabue G. Atwater H. A. Cutts J. A.	*Solar Spectrum and Intensity Analysis Under Venus Atmosphere Conditions for Photovoltaics Operation* **[#8003]** Solar spectrum and intensity at Venus is significantly different and weaker from Earth. We analyze solar spectrum and intensity under Venus atmosphere conditions for photovoltaics operation.
10:45 a.m.	Pradeepkumar Girija A. * Lu Y. Saikia S. J.	*Feasibility and Mass-Benefit of Aerocapture for SmallSat Missions to Venus* **[#8044]** Aerocapture is an attractive orbit insertion technique for SmallSats to Venus. Comprehensive feasibility and mass-benefit of various control methods — lift modulation, drag modulation and hybrid propulsive-aerocapture technique will be presented.
11:00 a.m.	Vaughn L. A. *	*An Atmospheric Platform for ISRU and Long-Term Investigation of Venus* **[#8049]** A discussion of an atmosphere-centric approach to planetary-scale exploration of Venus, with multiple investigation targets on the ground and in the atmosphere.
11:15 a.m.	Krishnamoorthy S. * Bowman D. C. Martire L. Komjathy A. Cutts J. A. Pauken M. T. Garcia R. F. Mimoun D. Lai V. Jackson J. M.	*The Road to Venus Seismology via Oklahoma* **[#8016]** We are developing techniques to detect quakes from balloons to circumvent the problem of landing and surviving on Venus' hostile surface for long enough periods to perform seismology. We will discuss how the state of Oklahoma can help us do this.
11:30 a.m.	*Adjourn*	

CONTENTS

Millimeter-Wavelength Remote Sensing of the Tropospheric Structure of Venus: Exploratory Simulations A. B. Akins[1] and P. G. Steffes[1], [1]Georgia Institute of Technology School of Electrical and Computer Engineering, 777 Atlantic Drive NW, Atlanta, GA, 30313. Corresponding author e-mail: aakins6@gatech.edu

Introduction: Microwave and millimeter-wavelength continuum remote sensing observations of Venus can be used to retrieve atmospheric temperature and constituent abundance profiles for microwave absorbing gases and aerosols from the surface to the lower cloud deck. Millimeter-wavelength observations from 2-4 mm are sensitive to emission from 40 to 55 km. Venus disk images derived from 2-4 mm observations show longitudinal spatial variations in brightness temperature on the order of 30-80 Kelvins. These variations appear only on the nightside and appear to be uncorrelated to topographical features. The features seen in these images can be interpreted through inversion of a microwave radiative transfer model of the Venus atmosphere

Model Inputs: While the dominant source of millimeter-wavelength opacity at Venus is collisional absorption from the CO_2/N_2 atmosphere, trace gases such as SO_2 and H_2SO_4 vapor provide additional sources of opacity, as do H_2SO_4 cloud aerosols. Models for SO_2 and liquid H_2SO_4 absorption are given by Fahd and Steffes [1,2]. Recent laboratory measurements of H_2SO_4 vapor opacity at millimeter wavelengths suggest an absorption model based on the JPL Spectral Line Catalog [3]. Additional lineshape opacity models are included for H_2O, OCS, and CO. The abundance profiles for all non-H_2SO_4 constituents are sourced from chemical models [4]. H_2SO_4 vapor abundance profiles are sourced from radio occultation results, and cloud bulk density profiles are sourced from the Pioneer Venus LCPS experiment [5,6]. Temperature and pressure profiles are also sourced from Pioneer Venus entry probe results.

Simulation Methods: Possible causes of the observed millimeter-wavelength brightness temperature variations are explored by varying the abundances of SO_2, H_2SO_4 vapor, and the cloud aerosol by up to ten times nominal values and calculating the resulting brightness temperature through the forward model. The H_2SO_4 vapor abundance and cloud bulk density is modified by scaling the abundance and shifting the location of maximum abundance between 40 and 58 km. Variations in the vertical structure of SO_2 are explored by scaling features observed in UV retrievals of SO_2 abundance from ISAV-1 and ISAV-2 data [7]. Since the abundance and thermal profiles are uncoupled in the model, these results of these simulations are not completely realistic. Local variations in thermal structure were also not explored.

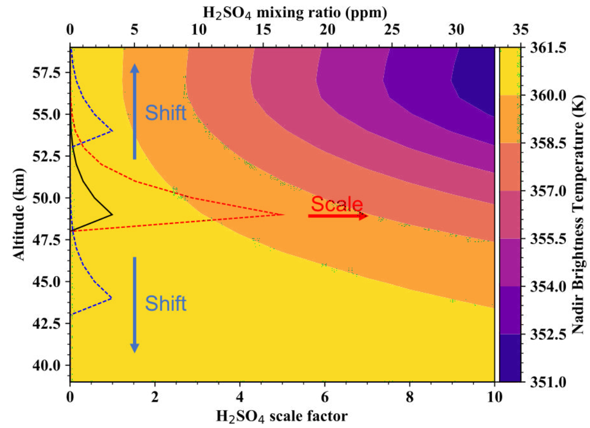

Fig. 1 Change in observed brightness from shifting and scaling the H_2SO_4 vapor abundance profile

Simulation Results: Significant variation in observed emission is likely not caused directly by spatial variation in the H_2SO_4 vapor profile, as shown in Fig. 1. However, longitudinal variations of SO_2 vertical structure on the same order of magnitude as the ISAV retrievals could explain the images. Orders of magnitude changes in the cloud bulk density have a similar effect.

Conclusions and Future Work: While it is clear that H_2SO_4 vapor abundance changes would not be visible in millimeter-wavelength images, variations in SO_2 or cloud bulk density on the nightside could explain such observations. Furthermore, opacity due to cloud bulk density is less frequency-dependent than that of SO_2. Homogeneous features in multi-wavelength observations would imply substantial cloud bulk density variation, while heterogeneity would suggest SO_2 as the source. These significant variations in SO_2 abundance could be due to enhanced nightside convection [8]. This analysis also excluded the possibility of cloud aerosols > 300 microns in diameter. Scattering from these particles could be visible in the millimeter-wavelength continuum.

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VENUS: THE EXOPLANET LABORATORY NEXT DOOR. G. N. Arney[1,2,3] [1]NASA Goddard Space Flight Center (giada.n.arney@nasa.gov), [2]The Virtual Planetary Laboratory, [3]The Sellers Exoplanets Environments Collaboration

Introduction: Venus is the most Earth-like planet in the solar system in terms of its size, mass, and bulk composition, yet the surface conditions of these two worlds could not be more different. Venus has the hottest terrestrial surface in the solar system. Despite this, Venus may once have hosted clement conditions in its deep past, possibly even with an ocean. Here, we will review what present and past Venus teaches us context of comparative planetology and processes that shape habitability and biosignature "false positives" in exoplanet atmospheres.

Important for future observations of exoplanets, Venus-analogs represent one of the most readily observable types of terrestrial planets for the transit transmission observations [1] that will become possible in the near future with the James Webb Space Telescope. Indeed, many terrestrial exoplanets already discovered, and undoubtedly many that will be uncovered by TESS, are likely to be more Venus-like than Earth-like. However, understanding the processes that affect Venus-like exoplanets will be particularly challenging in the context of characterizing these distant and data-limited worlds. Models used to understand exoVenus analogs must be validated on the Venusian environment. Yet there are still many unknowns about Venus' present and past states, so better understanding exoVenus planets demands a better understanding of Venus in the solar system.

Early Venus may have had oceans [2]. However, its early putative habitability is a provocative question. Recent 3-D modeling efforts have suggested that a slowly-rotating planet like Venus can generate a thick subsolar cloud deck that would substantially cool the planet, producing surface temperatures that could allow for liquid water for potentially billions of years [3]. These same processes have also been applied to tidally-locked, slowly-rotating planets orbiting M dwarfs, including planets interior to the inner edge of their stars' traditional habitable zones [4]. If hot, slowly-rotating exoplanets are observed to be habitable, this may shed light on processes that operated on Venus in the past.

In addition, photochemical and atmospheric loss processes that occur on Venus may also help us to understand the plausibility of mechanisms that could generate abiotic oxygen in exoplanet atmospheres [5], which has important implications for our understanding of oxygen as a robust biosignature for exoplanets.

For instance, massive water loss such as past Venus may have experienced has been invoked as a possible "false positive" mechanism to generate large quantities of abiotic O_2 in exoplanet atmospheres [6]. The strong "electric wind" recently observed at Venus [7] can strip O+ to space. Planets orbiting closely to active M dwarfs may experience even stronger electric winds. Abiotic oxygen is generated even on Venus today through CO_2 photolysis. Recombination of excited O_2 produced by this process generates nightside airglow at 1.27 μm, but ground-state O_2 has not been detected on Venus, suggesting rapid removal from the atmosphere, possibly due to catalytic chlorine chemistry [8]. Better understanding the processes involving Venusian O_2 are vitally important for understanding the viability of multiple proposed oxygen false positive mechanisms for exoplanets.

In summary, we argue that Venus is a key player in shaping our understanding of planetary habitability as a dynamic process that evolves over time. As a world of extremes in temperature and pressure, Venus is particularly useful for model validation across a range of conditions. Venus may even shape our understanding of O_2 as a biosignature. And because exoVenus planets may be ubiquitous, it is particularly important to better understand the world next door so that we may be able to better interpret future observations of analog worlds.

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THE JPL VENUS AEROSOL MASS SPECTROMETER CONCEPT. Kevin H. Baines[1], James A. Cutts[2], Dragan Nikolic[3], Stojan M. Madzunkov[4], M. L. Delitsky[5], Sanjay S. Limaye[6], and Kevin McGouldrick[7], [1]Jet Propulsion Laboratory/Caltech (M/S 183-601, 4800 Oak Grove Dr., Pasadena, CA, kevin.baines @jpl.nasa. gov), [2]Jet Propulsion Laboratory/Caltech (M/S 321-360, 4800 Oak Grove Dr., Pasadena, CA, 91109, james.a.cutts@jpl. nasa.gov), [3]Jet Propulsion Laboratory/Caltech (M/S 306-392, 4800 Oak Grove Dr., Pasadena, CA, 91109, Dragan.Nikolic@jpl.nasa.gov), [4]Jet Propulsion Laboratory/Caltech (M/S 306-392, 4800 Oak Grove Dr., Pasadena, CA, 91109, stojan.m.madzunkov@jpl.nasa.gov), [5]California Specialty Engineering, Flintridge, CA, [6]Space Science and Engineering Center, University of Wisconsin-Madison, Madison, WI 53706, [7]Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, 3665 Discovery Dr., Boulder, CO 80303

Introduction: We are developing a lightweight, low-power in-situ instrument to measure the composition of Venusian aerosols, for use on future aerial missions, including on long-duration (multi-week) balloon missions and on short-duration (several hour) probe missions. In particular, the instrument is being designed to determine the composition of the enigmatic UV-absorbing haze. Current design 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; [1]) and potential biotic species [2] 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 [3] is to measure HCl/H_2SO_4 with a concentration 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 [4,5] 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; [3, 6, 7]). Other potential species to be measured resident on or dissolved within H_2SO_4 particles include elemental sulfur polymers comprised principally of S_8 together with small admixtures of the metastable allotropes S_4 and S_3 [8], and [9]). Elemental sulfur particles may also be measured as standalone particles, unattached to H_2SO_4.

The heart of the Venus Aerosol Mass Spectrometer instrument is the Quadrupole Ion-Trapped Mass Spectrometer (QITMS, [10]) a version of which has flown on the International Space Station [11] where it has reliably monitored toxic CO against a large background of N_2. The preliminary concept involves an inlet aerodynamic lens [12,13] 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). Measurements of the entire mass spectrum are made every 0.05 seconds, and can be co-added to achieve superior precisions. Species with concentrations of 100 ppm can be determined to 10% precision in under 1.5 seconds; 1 ppm in 15 seconds; and 1 ppb in < 3 minutes.

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FAULT ANALYSIS OF VENUS RIDGE BELTS USING STEREO-DERIVED TOPOGRAPHY. J. A. Balcerski[1], P. K. Byrne[2], [1]NASA Glenn Research Center, Cleveland, OH. (jeffrey.balcerski@nasa.gov), [2]North Carolina State University, Raleigh, NC.

Introduction: Ridge belts on Venus are relatively narrow, elevated features generally tens of km wide, up to thousands of km in length, and with vertical expressions of hundreds of meters [e.g. 1–3]. These belts often border and delineate expansive lower-lying and relatively featureless plains and are often found in, or grade into, tesserae and dorsae. The relative timing of formation of ridge belts does not appear to be confined to a specific chronologic period, nor is there a clear universal relationship between belt formation, local radar-bright lineaments, surrounding terranes, and other regional structures [2]. Mechanisms of formation are difficult to determine from Magellan GTDR data, but the recent availability of stereo-derived topography for ~20% of the planet at an optimal resolution of 1–2 km/px [4] provides an opportunity to differentiate between symmetric and asymmetric ridges, and to develop a better understanding of the relationship between radar-bright lineations and the ridge (and surrounding) topography.

Location: We selected a relatively undeformed region bounded by ridge belts that were well-resolved in both the Magellan GTDR and Herrick et al. [4] topographic products, as well as the 75 m Magellan FMAP mosaics. This feature, situated at -19.4°N, 68.0°E, is bounded by Dylacha Dorsa on the western edge and Wala Dorsa on the eastern side. Xi Wang-Mu and Manatum Tesserae form the southern and northern margins, respectively. This location has not been specifically described in prior analyses, but the dorsae bear characteristics similar to the “broad arch” categorization of Frank and Head [2], with an average width around 50 km and length of about 1500 km.

Process: We constructed several topographic profiles oriented as close to perpendicular to the belt strike as the topo data permitted. These data have resolutions that are highly variable, so we selected profiles from those locations with the highest resolution (in this case, ~1.5 km/px). The resulting profiles were compared with those over the same sections using GTDR data. With the increased resolution provided by the stereo data, we were able to compare locations of the radar-bright parallel/subparallel lineations within the belt structure with the topographic expression of the belt. These profiles were then inspected for any apparent (a)symmetries; where possible, ridge slopes were then measured.

Topographic analysis*:* Although data from the GTDR are insufficient to distinguish between symmetric and asymmetric character of the ridge, the stereo data clearly show that the ridges are composed of asymmetric flanks with multiple peaks and valleys. Given the strikingly similarity to lunar and Martian wrinkle ridges [2, 5–8], we use a similar numeric elastic continuum model as previous studies [e.g., 9] to place estimates on the subsurface geometry of the underlying fault(s).

Results: The asymmetry of radar-bright lineations, present only on the southeast side of the ridge axis and decreasing in density with distance away from the ridge, suggests that these lineations are small-scale ridges whose surface brightness was enhanced by fracturing during compression. This fabric, and the associated production of intraridge peaks and valleys, may represent imbricate fans and thus suggests crustal shortening along a décollement. Given the canonically inferred low water content of Venusian crustal materials [e.g., 10], and as the planet’s surface is equivalent to a low metamorphic grade environment, it is unlikely that this detachment surface exists because of volatile pore pressure or poorly consolidated strata. We presume that this surface more likely represents Venus’ relatively shallow brittle–ductile transition [e.g., 11]. The results of our use of the to numerically model plausible fault geometry with the COULOMB software toolkit to numerically model plausible fault geometry largely support this interpretation: our best-fit models suggest that these ridges are fault-propagation folds atop an extended horizontal fault at around 6 km below the surface, which terminates about 1 km below the ridge. Further modeling will indicate whether this depth is specific to this locale, or characteristic of Venus’ ridge belts in general.

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Gravitational signatures of atmospheric mass transport by thermal tides on Venus

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Introduction: Sufficiently accurate measurements of time variable gravity at Venus will provide new constraints on key parameters of the atmospheric dynamics. In particular, we examine the feasibility and utility of measuring the gravitational signature of atmospheric mass transport on Venus, via the thermal tide.

Tidal context: The Sun raises two types of tides on Venus. One is a gravitational tide, mainly involving the solid body, the other is a thermal tide in the atmosphere. The gravitational tide has larger amplitude, and has already been detected. Accurate measurements of the smaller amplitude thermal tide will require improved gravitational measurement configurations to be deployed in orbit around Venus.

Key questions: We are interested in answering two questions concerning the gravitational signature of thermal tides on Venus. First is the measurement accuracy required to discern the pattern, and second concerns which aspects of the atmospheric structure and dynamics can best be constrained by those measurements.

Measurement accuracy: To address the first question, we present simulations of the spatio-temporal variations in atmospheric pressure on the solid surface of Venus, as driven by the thermal tide, using the high accuracy *Institut Pierre-Simon Laplace* (IPSL) general circulation model. We use this pressure pattern to estimate changes in the external gravitational potential.

Based upon these simulations, we now have an assessment of the gravitational measurement accuracy required to characterize the thermal tide. As expected, the thermal tide gravitational signature is too small to have been detected by past missions (PVO and Magellan). However, gravity measurement by future missions, using improved accuracy Doppler data, should easily suffice.

Inverse problem: We are just beginning to answer the second question, by repeating the simulations with Venus atmospheric simulations, with diagnostic changes in key parameters. It appears that the height distribution of radiative absorptions within the atmosphere will emerge as a key parameter.

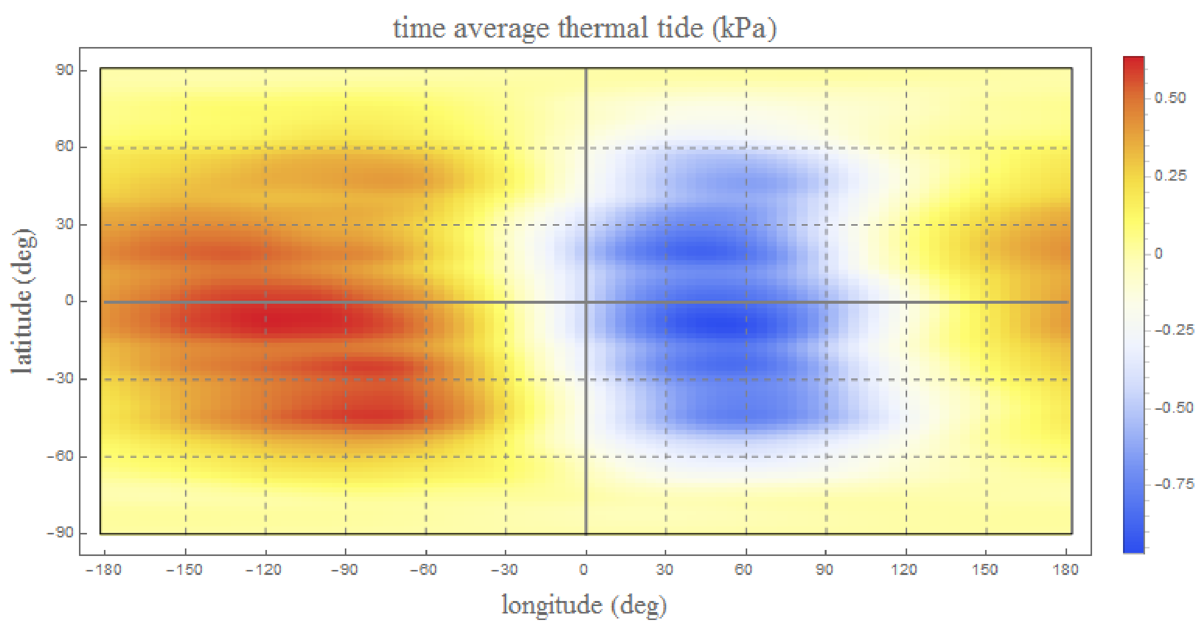

Figure 1. Spatial pattern of surface pressure variations which track the sub-solar point. Pattern is shown in a Sun-fixed frame, with sub-solar point on equator and prime meridian.

Follow the Sulfur. M. A. Bullock[1], D. H. Grinsoon[2], and S. S. Limaye[3], [1]Science and Technology Corp., bullock@stcnet.com , [2]Planetary Science Institute, david@funkyscience.net., [3]University of Wisconsin.

Introduction: The clouds of Venus are *terra incognita*, in spite of *in situ* measurements by probes and balloons in the 1970s and 1980s. The primary absorber of sunlight in the clouds is unknown. The chemistry of trace species and elemental sulfur with Venus' aerosols is completely unmeasured. Interpretations of the Pioneer Venus nephelometer data and more recent high phase angle albedo measurements both suggest that some Venus aerosols may be more than liquid sulfuric acid/water droplets.

Investigations: For these reasons, a planetary payload to do in situ investigations of the clouds of Venus should characterize the size distribution, composition, and chemistry of Venus cloud aerosols. The chemical cycles of sulfur are of primary importance to understanding what is happening in the clouds. Microscopy and Raman spectroscopy can characterize morphology and detect organic compounds. More sophisticated methods would be necessary for determining whether any organic compounds are biotic [1]

Life in Venus' Clouds?: The available data on Venus' clouds do not preclude extant life. Indeed, several species of terrestrial Archea species would be at home in Venus' highly acidic cloud aerosols [2]. The absorption and scattering of light within the clouds is poorly enough characterized to admit the possibility of a microbial community living within Venus' clouds. The chemistry and microphysics of trace species in Venus' cloud aerosol is so poorly constrained that microbial metabolism could be operating within the aerosols, heretofore undetected.

This is one reason why Venus is a target of astrobiological significance. Present data and known physical conditions do not preclude life; therefore, the clouds of Venus may be a habitable environment. We are therefore compelled to explore this potential extraterrestrial habitat (Venus' cloud aerosols) as an important scientific priority. As with Mars, the approach should be to characterize the environment with increasingly sophisticated experiments, learning valuable science on the way, while also looking out for life. Furthermore, Venus is close, *in situ* experiments in Venus' clouds are entirely technologically possible, and the results from a properly designed life experiment would be almost definitive, a rarity in planetary exploration.

Comparative Planetology: Venus aerosols have much in common with particles from large Earth volcanic eruptions, so understanding their size, distribution, constituents, and their role in heterogeneous chemistry provides valuable perspective for Earth atmospheric studies.

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A GLOBALLY FRAGMENTED AND MOBILE LITHOSPHERE ON VENUS. Paul K. Byrne[1], Richard C. Ghail[2], A. M. Celâl Şengör[3], Peter B. James[4], Christian Klimczak[5], and Sean C. Solomon[6], [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 Civil and Environmental Engineering, Imperial College London, London, SW72AZ, UK; [3]Department of Geology, Faculty of Mines and the Eurasia Institute of Earth Sciences, Istanbul Technical University, 34469 Maslak, İstanbul, Turkey; [4]Department of Geosciences, Baylor University, Waco, TX 76798, USA; [5]Department of Geology, University of Georgia, Athens, GA 30602, USA; [6]Lamont-Doherty Earth Observatory, Columbia University, Palisades, NY 10964, USA.

Introduction. Tectonic deformation on Venus is often concentrated into narrow curvilinear zones of extensional or shortening structures ("groove belts" and "ridge belts," respectively) [e.g., 1]. These belts commonly delimit low-lying areas that are infilled with smooth plains. Some belt-bound lowlands—which we term campi (singular *campus*)—extend laterally up to 2000 km, whereas others are much smaller. The interior plains are themselves deformed by sets of wrinkle ridges (i.e., folds) but are always much less distorted than the intensely deformed perimeter belts. Strain-compatible structures from the surrounding highly strained margins regularly deform and thus presumably post-date the emplacement of the plains infill.

Block Tectonic Pattern. Groove and ridge belts frequently intersect to form a distinctive cellular pattern. One such example area is Lavinia Planitia [1], where multiple belts demarcate a set of campi. Evidence of transpression and transtension (i.e., the simultaneous accommodation of lateral shear in addition to extension and shortening) within these intersecting belts is the rule [e.g., 2]. The strains recorded in the belts here imply both horizontal block translations and rotations, with lateral motions of several tens of kilometers in places [3].

These observations signify that the network of campi within Lavinia Planitia corresponds to a set of mechanically coherent but discrete blocks that have moved relative to one another in a manner similar to jostling pack ice, with that motion resulting in the highly strained belts that demarcate campus margins. The superposition of tectonic structures emerging from ridge and groove belts and deforming the campus interiors points to at least some block motion since the time of emplacement of the local plains materials.

This cellular pattern of intersecting tectonic belts is widespread across Venus. In addition to the example in Lavinia Planitia, networks of campi characterize much of the lowlands of Helen, Nsomeka, and Nuptadi Planitiae in the high southern latitudes, most of Akhtamar, Bereghinya, and Guinevere Planitiae at low northern latitudes, and a vast region that encompasses Atalanta, Ganiki, Vellamo, and Vinmara Planitiae that extends almost to the north pole.

Mantle-Driven Deformation. This tectonic style resembles that within continental interiors on Earth, including the Tarim and Sichuan basins in China, the Amadeus basin in central Australia, the Moesia block in Bulgaria and Romania, the Bohemian Massif that underlies much of the Czech Republic, and the Black Sea and South Caspian basins [e.g., 4,5]. Such deformation is facilitated by a weak lower crust, a scenario that likely applies to Venus because of the high surface temperature [6,7]. It may be, then, that a weak, ductile zone within the Venus lithosphere permits the transmission of subcrustal stresses [e.g., 8] to the near surface.

Indeed, in calculating the stresses associated with gravitationally inferred mantle flow [9], we find that peak stresses for a nominal lithospheric thickness of 100 km readily exceed 100 MPa, much greater than the expected yield strength of the lower crust at Venus for crustal thickness values ≤20 km [7], a thickness limit that likely characterizes much of the planet's low-lying terrain [9]. The combination of mantle flow and a weak lower crust therefore provides a basis by which some interior motion has been transferred to the surface.

Outlook. Our results provide an observational basis for the concept of a continuum of lithospheric mobility, with Earth's "mobile lid" tectonics at one end, the "stagnant lid" tectonics of Mercury, Mars, and the Moon at the other, and Venus somewhere in between. The planet's style of tectonics might characterize Earth-mass exoplanets in the "Venus zone" [10], and could even provide new insight into some tectonic processes away from subduction zones in the early history of our own planet during the "permobile" regime [11], before the onset of full-scale plate tectonics [12].

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New Insights on Maxwell Montes Surface Properties from Multi-Year Earth-Based Observations, Bruce A. Campbell, Jennifer L. Whitten; Smithsonian Institution, Center for Earth and Planetary Studies, MRC 315, PO Box 37012, Washington, DC 20013-7012, campbellb@si.edu

Introduction: We present initial results of Venus surface studies using Earth-based radar observations collected in 1988, 2012, 2015, and 2017. Combining a much larger number of independent radar looks improves the signal-to-noise ratio of the echoes, and allows for higher-resolution mapping of the circular polarization ratio (CPR). The new maps reveal unexpected variations in surface properties across Maxwell Montes.

Radar Data: Earth-based observations of Venus at 12.6-cm wavelength can be carried out during inferior conjunctions when the planet's declination is within the view of the Arecibo telescope. The best spatial resolution is about 1.5 km, and calibrated measurements of both reflected senses of circular polarization (OCP and SCP) allow for determination of the circular polarization ratio (CPR) [1].

The first of these high-resolution observations was carried out in 1988, and we report here on data from conjunctions in 2012, 2015, and 2017. Improvements in the Arecibo transmitter mean that the later runs have considerably higher SNR, and the accumulation of independent radar looks diminishes the effects of speckle noise (in turn improving the spatial resolution of the highly averaged CPR and Stokes vector maps). Because the sub-radar latitude changes over time, maps collected over many years provide greater coverage of the far northern and southern latitudes.

Preliminary Results: Maxwell Montes comprise the highest elevations on Venus, and thus cross both critical altitudes noted for high-dielectric constant precipitates in other locales [2]. The Earth-based data provide a crucial view of the surface in the same-sense circular polarization related to small-scale roughness [3], and both channels view Maxwell at much larger incidence angles than used by Magellan. Earlier studies showed anomalous scattering law behaviors for this region [2, 4], and the SC map is different in brightness patterns from the Magellan image (Figs. 1-2). Particularly interesting is the relatively weak correlation between elevation and SC brightness across the region.

We are using both the brightness and CPR data to better understand the roles of surface roughness, dielectric constant, and possible volcanic- or impact-generated, fine-grained mantling materials across the massif. One intriguing possibility is that the low SC echoes from so much of Maxwell are related to ejecta from Cleopatra crater, in the manner observed for numerous tesserae elsewhere on Venus [3].

Future Work: Our maps from the multi-year observations continue to improve as the radar data processing and image mosaicking methods are refined. The extended latitude coverage is allowing geologic studies from SC data of other areas mapped by Magellan at low incidence angles, such as Lada Terra. We are also using images over the 29-year interval to constrain the Venus sidereal length of day with greater accuracy than possible from earlier data. All observations to date are archived (as single look complex images) with the Planetary Data System.

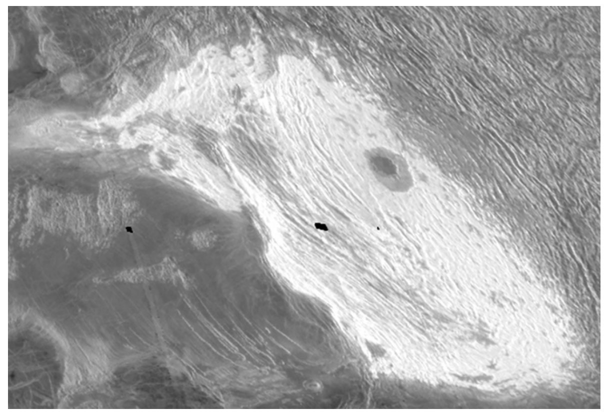

Fig. 1. Magellan view of Maxwell Montes using HH polarization at incidence angles <35 deg.

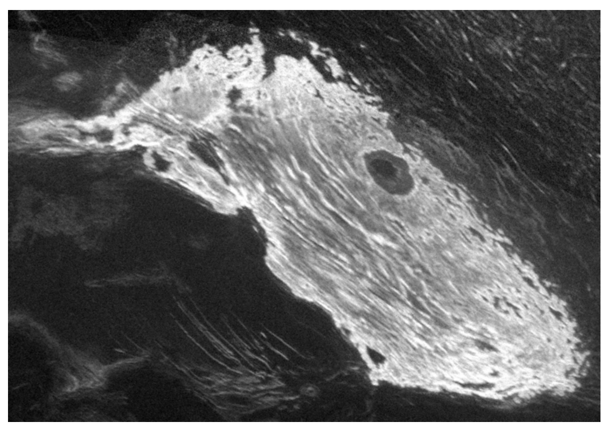

Fig. 2. Earth-based view of Maxwell Montes at high incidence (>60 deg) and same-sense circular (SC) polarization.

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VENUS AERIAL PLATFORMS STUDY: J. A. Cutts[1] and Venus Aerial Platform Study Team, [1]Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive Pasadena, CA 91109, James.A.Cutts@jpl.nasa.gov.

Introduction: The Venus Aerial Platform Study has been assessing the technologies for exploring Venus with aerial vehicles in order to develop a Venus Aerial Platform Roadmap for the future exploration of the planet. Two Study Team meetings were conducted in May and December of 2017. The first Study Team meeting in May addressed the scientific opportunities offered by aerial platforms at Venus, their operating environments, and a technical review of possible aerial platforms. The second meeting in December addressed the technologies needed for operating in the severe Venus environment. Here we focused on the technologies needed to fully exploit the potential of aerial platforms capable of operating in the altitude range 45 km to 65 km.

Key Aerial Platform Technologies: Beyond the technologies of achieving mobility in a planetary atmosphere, other key capabilities are localization of the platform, communications of data, and instrumentation.

Localization: Determining the position of the vehicle is critical to operation of the mission and to acquisitions of certain types of scientific information such as the magnitude and time variation of zonal and meridional winds. When the platform is on the Earth-facing side of Venus, extremely accurate measurements of position and velocity can be made with the Very Long Baseline measurements. A constellation of CubeSats in orbit at Venus can provide comparable information for the side of Venus facing away from the Earth and can reduce the use of ground assets through the mission.

Communications: Transmitting data from the aerial platform to Earth is also critical. Transmission directly to Earth is only practical when the aerial platform is on the Earth-facing side of the planet. Even then, this is not an efficient approach in terms the power consumed on the platform as well as the DSN antenna time that must be dedicated to data transfer. Orbital relay is an alternative, and a SmallSat in a near circular orbit can provide a substantial enhancement in data return. Trade studies indicating dependence of data return on orbital parameters were examined. This indicated that aerial platforms inserted in the equatorial regions will remain near the equator indefinitely. A complementary vehicle in a high-inclination orbit would support communication with aerial vehicles, if they drift to high latitudes. However, solar-powered aerial platforms will have limited lifetimes at latitudes more than 70° from the equator.

Instrumentation: The limited payload mass of aerial platforms of 10 to 20 kg means that instruments that are or can be miniaturized define the science that can be performed. For investigating the physics and chemistry of the atmosphere, a range of mass spectrometers, tunable diode spectrometers and nephelometers will make it possible to characterize both the active gases and the haze and cloud particles that constitute the atmosphere. For investigating the crusts and interior, a range of infrasound and electromagnetic techniques are also feasible. The capabilities of these different instrument capabilities for meeting VEXAG's Venus exploration science goals was examined.

Venus Aerial Platform Implementations – Implementations concepts range from Fixed Altitude Balloons, Variable Altitude Balloons, Solar Aircraft, and Hybrid Airships. The Fixed Altitude Balloon like the Russian VeGa balloons, operating at 55 km would be the lowest risk option. More science would be accomplished by Variable Altitude Balloons implemented via bellows or phase-change techniques. The Solar Airplane and the Hybrid Airship would provide 3-D control, but with significant increases in coat and complexity. Variable Altitude Balloons occupy a "sweet spot" with enhanced science return at a modest increase in cost and risk.

Next Steps: NASA and VEXAG have commissioned a parallel Venus Lander Platform Study that addresses current science objectives and the state of the technology for exploring Venus' surface with lander and probes and how additional technical capabilities could enable new science objectives. Both studies will enable a development of the updated VEXAG Roadmap and Technology Plan and for the future exploration of the Venus that will be addressed in a Venus Flagship Mission Study as well as white papers for the next Planetary Decadal Survey.

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

VENUS SURFACE OXIDATION AND WEATHERING AS VIEWED FROM ORBIT WITH SIX-WINDOW VNIR SPECTROSCOPY. M. D. Dyar[1], J. Helbert[2], T. Boucher[3], A. Maturilli[2], I. Walter[4], T. Widemann[5], E. Marcq[6], S. Ferrari[7,1], M. D'Amore[2], N. Müller[8], and S. Smrekar[8], [1]Planet. Sci. Inst., 1700 East Fort Lowell, Tucson, AZ 85719 USA (mdyar@mtholyoke.edu); [2]Inst. Planet. Res., DLR, Rutherfordstrasse 2, 12489 Berlin, Germany; [3]Col. of Inform. and Computer Sci., Univ. of Massachusetts Amherst, Amherst, MA, 01003, USA; [4]Inst. Optical Sensorsystems, DLR, Rutherfordstrasse 2, 12489 Berlin, Germany, [5]LESIA. [6]LATMOS. [7]Center of Studies and Activities for Space G. Colombo, University of Padova, Via Venezia 15, 35131 Padova, Italy. [8]Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Dr., Pasadena CA, 91109.

Introduction: Knowledge of Venus mineralogy is key to constraining surface/atmospheric interactions as they contribute to our understanding of weathering reactions [1] and identify sites of recent volcanism [2]. As basalt weathers, first reacting with SO_2 and CO_2 and then oxidizing, its emissivity should transition from high to low, culminating in formation of new mineral alteration products. These reactions are likely defined by progressive oxidation of iron from Fe^{2+} to Fe^{3+} surface minerals as first suggested in 1964 [3]. This project uses laboratory data to assess whether iron oxidation and changes in mineralogy due to surface/atmosphere interactions can be detected from orbit using a six-window orbital spectrometer [4,5].

Samples and Methods: Rocks and minerals examined include six rocks: two basalts, basaltic andesite, granite, rhyolite, and rhyolitic glass; and four minerals: pyrite, pyrrhotite, magnetite, and hematite. Compositions were determined by x-ray fluorescence (XRF) at the University of Massachusetts [6] or by electron microprobe at Brown University. Fe^{3+}/Fe^{2+} ratios were measured using Mössbauer spectroscopy. Visible near-infrared (VNIR) data were collected in the Planetary Spectroscopy Laboratory (PSL) at the German Aerospace Center (DLR) in Berlin [7].

Oxidation State Results: Figure 1 (top) shows the relationship between the internsity of the 1.18 μm band and iron oxidation state. Samples that are dominated by Fe^{2+} have the highest emissivities, while those containing Fe^{3+}, like magnetite ($Fe^{3+}_2Fe^{2+}O_4$) and hematite ($Fe^{3+}_2O_3$), have the lowest. Inspection of the entire spectral range shows that magnetite has the largest negative slope of any sample measured between 0.86 to 0.91 μm. All the felsic rocks also have negative slopes in that region, while Fe^{2+}-rich basalts are distinguished on the basis of their positive slopes. Results show that metrics can easily be developed to assess oxidation state of Venus surface rocks.

Surface-atmosphere chemical reactions also result in changes in mineralogy that cause both gradual and sudden changes to radar backscatter at higher elevations. No one mineral satisfies all the current observations that could account for these changes [8]. Compounds such as pyrite, pyrrhotite, magnetite, hematite,

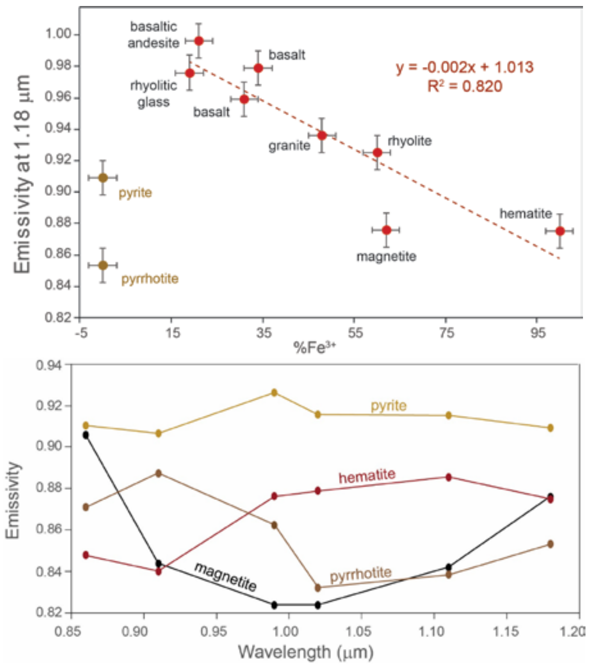

Figure 1. (top) Relationship between the magnitude of emissivity at 1.18 μm versus total iron contents, expressed as the percentage of the total iron that is Fe^{3+}. Pyrite and pyrrhotite are not expected to lie on this trend line because their spectra are so affected by the dominantly covalent bonding in their structures. (bottom) Diagnostic emissivity spectra of possible alteration products from surface-atmosphere interactions at the six observable wavelengths.

chlorapatite and others [8,9] have been proposed by various workers to cause these changes (Figure 1 bottom). Our data show that at least four of these minerals have distinctive spectral signatures that should be sufficient to distingui them on Venus highlands. Acquisition of additional spectra data is underway to further constrain this observation.

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EnVision: Phase 0 Developments. R. C. Ghail[1] and the EnVision team, [1]Imperial College London, London, SW7 2AZ.

Introduction: EnVision [1] was selected for Phase 0/A study in the ESA M5 round of Medium-class missions. A key factor in this decision was the allocation of NASA funds to ensure affordability. Preparations for ESA's baseline (CDF) study are nearly complete and that study will be reporting its conclusions immediately after the 16th VEXAG meeting, on 9 November 2018. We will report on its conclusions as far as possible and detail any opportunities for community involvement and collaboration.

Fortuitously, NovaSAR-1 [2], the UK's S-band radar satellite that is the direct precursor for VenSAR [3], was successfully launched on 16 September 2018 and we anticipate being able to show the first directly comparable terrestrial imagery from NovaSAR at the meeting.

Baseline Issues: The primary issues arising from the Phase 0 baseline study relate to orbit selection and delivery. Aerobraking modelling and experience indicate that the 'minimum fuel' approach in the proposal will requires an unacceptable 12-18 months; potentially more than two Venus cycles. Since the new Ariane 6 launcher provides far greater lift capability than Soyuz, options are being explored for conventional orbit insertion. Orbital altitude is constrained quite tightly to ~260 km by the competing requirements of gravity field resolution and SAR swath coverage. Hence orbital insertion and maintenance remain a significant challenge.

EnVision's unprecedented data storage and return volume, particularly when Venus is farthest from Earth, is technically challenging. Our proposed approach is to reduce data collection as distance increases, to just the essential InSAR swaths, sounder and IR emission mapping. Because only six orbits are then required for science operations in every 24-hour period, the remaining nine orbits are available for communications, of which only three are used in the proposal, requiring significant storage. Downlinking data during all nine available orbits effectively triples the data return volume and reduces storage requirement to below 10 Tbits.

Community Involvement: Our proposed approach is to select mapping areas representative of the variety of Venus terrains, obtaining a complete suite of data and 'drilling down' to higher resolutions (up to 1 m) to aid in a full understanding of their origin, history and current activity. There may be cases where InSAR and StereoPolSAR coverage need not overlap (which is essential for stereo views), e.g. at extended crater parabolas, thereby potentially extending surface area coverage. In addition, should specific targets or representative areas (as proposed) be preferred? Are there optimal locations for 'drilling down' to the highest resolution 1 m spotlight images?

Trades: Within the constraints of capability and contiguity, early community involvement at this stage is encouraged to identify features of interest, to assist in the inevitable trades and compromises, e.g. Artemis vs Thetis, or Ishtar vs Alpha and Lada, and to ensure broad community support through the next stages. What should be the balance between InSAR coverage, which drives data rate and storage requirements, and polarimetric and high resolution data, which require higher data rates but without the repeat pass constraints? How much total surface coverage is sufficient to meet the science goals of surface change detection and geological history?

Future Developments: The Phase 0/A study is based on the as-proposed mission, but there may be a possibility for contributed experiments; currently a USO is under consideration. As noted in the proposal, in principle such a contribution might include a separate smallsat probe that could undertake complementary science. Assuming final selection, EnVision is likely to spark a similar level of public and scientific interest in Venus as currently enjoyed by Mars. What complementary or follow-on missions might be proposed to explore Venus in a similarly systematic way?

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Towards a New Understanding of Venus. R. C. Ghail[1], P. K. Byrne[2] and P. J. Mason[1], [1]Imperial College London, London, SW7 2AZ, [2] Planetary Research Group, Department of Marine, Earth, and Atmospheric Sciences, North Carolina State University, Raleigh, NC 27695, USA.

Introduction: In recent years there has been a convergence of ideas and observations that show Venus to be both more complex and active than previously thought. The strong dependence of rheology on geothermal gradient leads to a wide variety of tectonic and magmatic styles, and hence landforms, across Venus, leading to conflicting views about its geological history. Subcrustal rejuvenation, the mechanism by which Venus loses most of its internal heat [1], broadly explains the locations of many landforms, such as wrinkle ridges in the lowlands, but much heterogeneity remains. Clearly, local geological history—contingency—is important, and very likely compositional variability is too, particularly in highland tesserae [2]. Despite the apparently pristine surface, mass wasting and weathering are also significant factors in morphological change. Here we review how these different processes contribute to the present-day appearance of Venus.

Subcrustal Rejuvenation: Analogous to plate tectonics below the crust, Venus loses most of its internal heat through the recycling of subcrustal lithosphere, but like terrestrial plates, there is considerable variability in 'spreading' rates and magmatic activity, e.g. the 'slow' Dali–Diana Chasma system consists of a series of tectonic deformation belts but the 'fast' Parga and Hecate systems are characterized by magmatism—particularly coronae—over a wide sector, and are the primary reason for the high concentration of volcanoes in the Beta–Atla–Themis (BAT) zone.

Away from these subcrustal 'spreading ridges', the geothermal gradient is lower, magmatism less important, and traction stresses are transmitted through the subcrustal boundary. Characteristic networks of narrow tectonic bands surrounding less deformed plains—campi (*sing*. campus)—are formed as crustal blocks jostle together. Their large area-to-thickness ratio (~1000 km across but only 10–15 km thick) means these blocks readily fragment, buckle and shear, generating an appearance similar to continuous pack-ice [3].

Farthest from the chasmata, in geoid lows where geothermal gradients are below 20 mK m^{-1}, are the low-lying wrinkle-ridged plains. Inferred to overlie cold, downwelling subcrustal lid, the wrinkle ridges are probably inversion structures.

Magmatism: Subcrustal rejuvenation explains much of the variability in magmatic style across Venus. Upwelling regions are characterized by extensive flows from coronae and large volcanoes. The largest volcanic clusters most likely overly core-mantle boundary plumes; several of these are associated with subcrustal ridge junctions, indicating perhaps a genetic relationship. As noted, the 'faster' ridges are associated with disproportionately greater volcanism and coronae.

Heterogeneity is most apparent in the network of campi, which may be dominated by intermediate volcanoes, or coronae, and some appear to evolve into true whole-crust subduction-bounded structures. This variety may reflect both crustal heterogeneity and differences in styles of mantle convection and plumes [4].

Many of the low-lying wrinkle-ridged plains are relatively featureless but where volcanism is observed, it often takes the form of shield fields and pancake domes (farra). Their associated thin flows may be the materials deformed by inversion, but recent reappraisals of Venera lander images and Magellan data point to another possibility: sedimentary rocks.

Sedimentary Processes: Analysis of Magellan SAR [5] and altimeter [6] data combined with Venera lander panoramas [7–9] indicate that sedimentary processes have a more important role in surface change than previously recognized, particularly in the lowland plains. Terrain above ~2 km elevation appears to be eroding material that is then deposited across the lowlands. Relatively rapid lithification of this material—a function of the high surface temperature, and consistent with Venera landing site morphology—may be the reason that sedimentary deposits have previously lacked recognition.

Anomalies: What is most obvious is that Venus defies simple global models, and instead displays a highly heterogeneous nature. In modelling terms, it is characterized by anomalies, features that don't fit global paradigms. It is in understanding those anomalies that we will learn most about the complex nature of Venus, and Earth-like planets throughout the galaxy.

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THIRTY DAYS ON VENUS: CHEMICAL CHANGES MINERALS EXPOSED TO THE GLENN EXTREME ENVIRONMENT RIG (GEER).

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Introduction. The NASA Glenn Extreme Environment Rig (GEER) is a pressure vessel that can simulate Venus conditions of pressure, temperature and atmospheric composition. We placed nine natural mineral samples in GEER at: T = 733 K, P = 93 bars, 96.5% CO_2, 3.5% N_2, 180 ppm SO_2, 51 ppm OCS, 30 ppm H_2O, 12 ppm CO, 2 ppm H_2S, 0.5 ppm HCl and 2.5 ppb HF. The run lasted 30 days. Minerals were selected to address two sets of questions:

Venus Apatites. Several of the mountaintops of Venus display anomalous radar emissivity has been explained as a consequence of the presence of ferroelectric minerals created or precipitated in rocks over time by chemical reaction(s) with the ambient atmosphere [1,2]. We seek to test the hypothesis of [2] that exposed grains of fluorapatite ($Ca_5(PO_4)_3F$), the more common apatite mineral in igneous rocks on Earth [2-4], will convert to chlorapatite ($Ca_5(PO_4)_3Cl$), which is ferroelectric, under Venus surface conditions.

Venus Surface Mineralogy In-Situ Instrument System (V-Lab). V-Lab is a proposed *in situ* reaction chemistry experiment where known geological materials whose properties may change over time upon exposure to the Venus atmosphere will be placed on a microsensor platform. Changes in this geological material are monitored through electrical measurements constraining redox solid-gas reaction(s) in the Venus environment. We sought to determine if detectable compositional changes occurred in GEER over the 30-day run. The reactants include: hematite (α-Fe_2O_3), magnetite (Fe_3O_4), anhydrite ($CaSO_4$), pyrite (FeS_2), a mid-ocean ridge tholeiitic basalt (Juan de Fuca) and calcite ($CaCO_3$).

Results. Mineral surfaces were analyzed visually and using the Hitachi FEG-SEM at Wesleyan Univ.

Decomposition of calcite – Significant portions (~70% by area) of the calcite sample converted to anhydrite. This is consistent with the predicted reaction [e.g., 5,6]: $CaCO_3 + 1.5\ SO_2 = CaSO_4 + CO_2 + 0.25\ S_2$ The speed and magnitude of this reaction supports the theoretical prediction that calcite will be unstable at the surface of Venus [5,7] and is consistent with prior exposure of calcite to Venus conditions [8,9].

Changes in Basalt – Reddening of the MORB sample suggests hematite may have formed during this experiment presumably by the oxidation of Fe in minerals and/or glass. The near surface atmosphere of Venus is thought to be at the magnetite/hematite buffer potentially controlled by this reaction favoring oxidation of ferrous phases in basalts [e.g., 7]: $2\ Fe_3O_4 + CO_2 = 3Fe_2O_3 + CO$ That the magnetite sample is not visibly oxidized in this experiment suggests that the oxidation progresses more quickly in the more reactive volcanic glass that comprises the bulk of the MORB sample. Both the plagioclase and glass matrix in the MORB sample acquired S during the run, which has been predicted in the literature [e.g., 6,10] and observed under Venus conditions [11]. Plagioclase may decompose by this reaction: $CaAl_2Si_2O_8 + SO_2 \rightarrow CaSO_4 + Al_2SiO_5 + SiO_2$ [7]. The correspondence of Ca with S in the sample after exposure suggests that anhydrite has formed on the sample.

Changes in Apatite – Apatite acquired S during the experiment demonstrating the reactivity of apatite to Venus conditions in this time frame. None of the apatites acquired measurable Cl during this run, suggesting this reaction, if it occurs, is slow.

Conclusions. Compositional changes including sulfurization of calcite, apatite, plagioclase and basalt glass (with oxidation) occurred over a 30-day exposure under Venus conditions in GEER. Based on the speed of these reactions, the primary mechanism for sulfurization is likely the migration of cations to the surface, their reaction with SO_2 and redeposition as a surface coating of sulfate [7,8,11]. We confirm experimentally that calcite is very unstable under Venus surface conditions. The fast reactions seen here open the possibility of measuring the kinetics of Venus-relevant reactions in the lab and measuring surface-atmosphere interactions directly on Venus using long-lived platforms.

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VENUS GRAVITY FIELD DETERMINATION USING MAGELLAN AND VENUS EXPRESS TRACKING DATA.
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Introduction: The gravitational field of a planet depends on its internal density distribution and is thus of interest to constrain models of the planet's interior structure. Tracking data from the Pioneer Venus Orbiter mission (1978-1980) and from the Magellan mission (1990-1994) have been used to determine models of the Venusian gravity field. The most recent gravity field model is an expansion in spherical harmonics up to degree and order 180 (corresponding to a resolution of 1˚ by 1˚ at the surface), called MGNP180U [1]. Due to computational constraints at the time when the model was derived (1999), the coefficients were estimated in successive batches, resulting in artificial discontinuities in the solution and its error estimates (see also Figure 1). This hampers the quality of geophysical analysis. We present an updated model of the Venus gravity field from a re-analysis of the Magellan tracking data, and we augment this data set with tracking data from the recent European Space Agency's Venus Express mission (VEX, 2006-2014) [2].

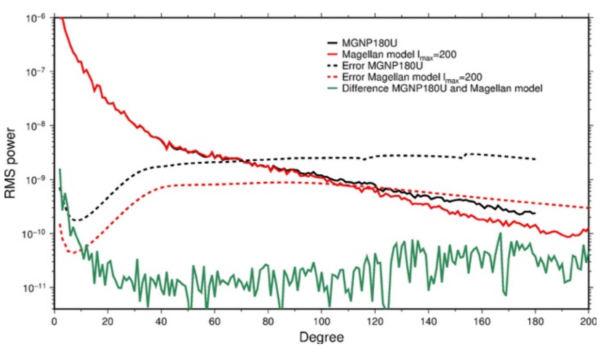

Figure 1: Power spectrum for our solution based on Magellan data (up to degree and order 200).

Methods: We process the Magellan and VEX data using a dynamical approach [3]. We use a batch least-squares method to estimate parameters related to the spacecraft motion (such as the state vector at the initial epoch, drag and solar radiation pressure coefficients) and to estimate geophysical parameters related to Venus and its gravity field (coefficients of a spherical harmonic expansion of the gravitational field up to degree and order 200, the gravitational parameter *GM*, the potential degree 2 Love number k_2, and Venus' rotational state). We use our NASA Goddard Space Flight Center (GSFC) GEODYN II Orbit Determination and Geodetic Parameter Estimation package [4] to process the Venus tracking data. We show the data fit for the entire span of VEX data in Figure 2. Data affected by solar plasma (low Sun-Earth-Probe angles close to superior conjunction) will not be included. We will also pay close attention to the effects of the atmosphere on the estimated low-degree gravity field coefficients, by forward modeling pressure fields from a General Circulation Model [5], following a technique developed for Earth [6] that has also been applied at Mars [7].

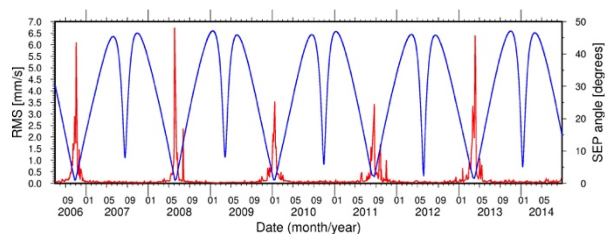

Figure 2: RMS of VEX X-band Doppler data fit, including the Sun-Earth-Probe (SEP) angle.

Results: A preliminary result used only Magellan data (Figure 1). The resulting error spectrum does not show breaks, because our solution consists of a one-step inversion. Our value for k_2 is 0.292 ± 0.008, close to an earlier result [8]. We will present a new gravity model that includes the VEX data. With these data, resolution can be increased in areas where VEX collected gravity passes. In addition, we use VEX data to extend the temporal baseline for the estimation of time-varying gravity effects such as those described by potential degree 2 Love numbers, and the spin-rate secular variations. The effects of atmosphere modeling on these parameters will also be investigated.

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SOLAR SPECTRUM AND INTENSITY ANALYSIS UNDER VENUS ATMOSPHERE CONDITIONS FOR PHOTOVOLTAICS OPERATION.

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Solar spectrum and intensity at Venus is significantly different from Earth. Due to its thick sulfuric acid clouds, solar illumination at Venus is very weak, altitude dependent and diffused. This analysis uses measured solar spectrum from Venera 11 [1] and Venera 13 [2] missions (Figure 1). Venera 11 entered the Venus atmosphere at -14 degrees latitude at 11:10 AM local solar time (solar zenith angle 37°) and descended to the surface of Venus. Venera 13 entered the Venus atmosphere at -7.5 degrees latitude at 9:27 AM local solar time (solar zenith angle 38°) and descended to the surface of Venus [3]. Current solar cells do not function

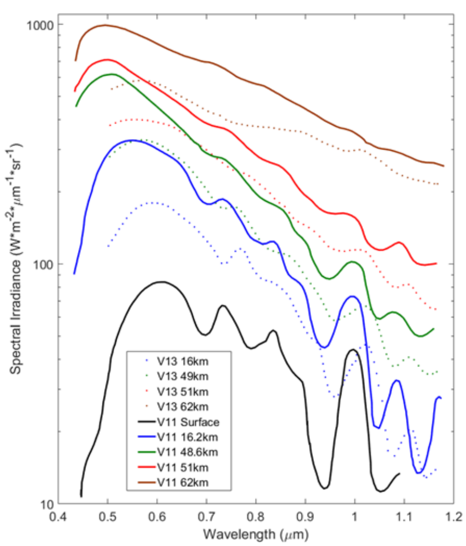

Fig. 1. Solar spectra of the downward scattered solar radiation measured by the Venera 11 and Venera 13 descent probes.

effectively in Venus aerial and surface environments, and are not suitable for long-duration Venus aerial missions. This work is focused on the development of solar power system technologies required for mid/low altitude Venus exploration mission concepts. Venus variable altitude (mid- to surface level) missions would require solar power systems that can operate at high temperature (200-350°C) for long duration, survive at 465°C Venus surface environment for short duration and generate power under 100-300 W/m^2 solar irradi-

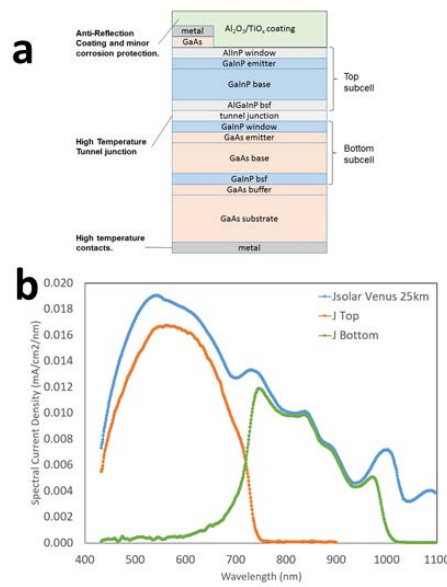

Fig. 2. (a) Simplified cross-section schematic of a GaInP/GaAs 2J solar cell designed for Venus solar and high temperature operation. (b) Calculated current density in the GaInP (3.90 mA/cm2) and GaAs (2.42 mA/cm2) subcells for the 300°C EQE data using the Venus solar spectrum at 25 km altitude where temperature is 300°C.

ance conditions. Based on Venera 11 descent probe measurement, we propose to develop solar cells as depicted in Figure 2a that can generate power for Venus aerial missions [4]. Although current III-V multi-junction solar cells are typically designed to operate under AM1.5 or AM0 solar spectrum, the objective here is to design a solar cell structure that is optimized for Venus red-shifted solar spectrum. High temperature Current-Voltage (IV) and external quantum efficiency (EQE) measurements under Venus conditions will be presented (Figure 2b).

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VENERA-D: A POTENTIAL MISSION TO EXPLORE VENUS' SURFACE, ATMOSPHERE AND PLASMA ENVIRONMENT. T.K.P. Gregg[1], L. Zasova[2], T. Economou[3], N. Eismont[2], M. Gerasimov[2], D. Gorinov[2], N. Ignatiev[2], M. Ivanov[4], I. Khatuntsev[2], O. Korablev[2], T. Kremic[5], K. Jessup[6], S. Limaye[7], I. Lomakin[8], A. Martynov[8], and A. Ocampo[9]; [1]Affiliation Dept. of Geology, University at Buffalo, Buffalo NY 14260 (tgregg@buffalo.edu), [2]Space Research Institute RAS, Moscow, Russia, [3]Enrico Fermi Institute, Chicago, USA, [4]Vernadsky Institute RAS, Moscow, Russia, [5]Glenn Research Center, Cleveland, USA, [6]Southwest Research Institute, Boulder, USA, [7]University of Wisconsin-Madison, Madison, USA, [8]Lavochkin Association, Moscow, Russia, [9]NASA Headquarters, Washington DC, USA.

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, recent investigations [1] present evidence for microbial life 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) [2], a baseline Venera-D mission would include an orbiter, a VEGA-style lander, and a Long-lived In-Situ Solar System Explorer (LLISSE) [3] on the surface. In addition, the Joint Science Definition Team (VDJSDT) is working to identify additional science objectives (relying on the NASA Planetary Decadal Survey [4] and VEXAG [5]) that could be addressed by incorporating additional potential elements (e.g., an aerial platform or subsatellites).

Orbiter Science Goals: A major unknown in our understanding of the Venusian atmosphere comes from the observation of atmospheric superrotation [6], which depends on the atmospheric radiative balance. Although recent investigations based on data collected by JAXA's Akatsuki craft have revealed a possible equatorial jet that may play a role in superrotation [7], questions remain. 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, 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 and sampling of the region thought to contain the "unknown absorber(s)' [1]. 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 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 a subsatellite placed at the Lagrange point L1 to examine the interaction of the Venusian upper atmosphere with the solar wind; an aerial platform; additional LLISSEs or a long-lived seismic instrument such as the Seismic and Atmospheric Exploration of Venus (SAEVe) package [8].

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HIGH-ALTITUDE ELECTROMAGNETIC SOUNDING OF THE INTERIOR OF VENUS: STRATOSPHERIC BALLOON TEST R.E. Grimm, Southwest Research Institute, 1050 Walnut St. #300, Boulder, CO 80302 (grimm@boulder.swri.edu).

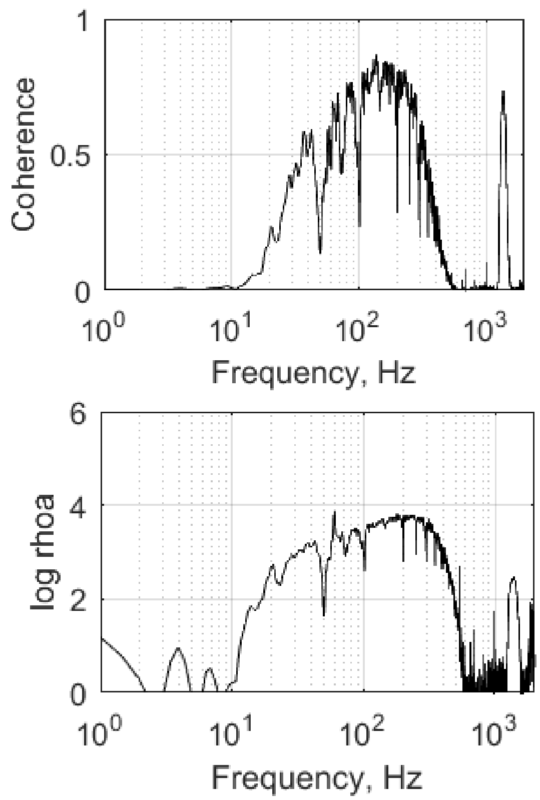
Introduction. Electromagnetic (EM) sounding uses induction from natural sources to build profiles of electrical conductivity (or resistivity) of planetary interiors, which in turn can be translated to temperature and composition. Theory indicates that measurements of transverse electromagnetic (TEM) waves—in particular, lightning-caused global Schumann resonances—at any altitude in the ground-ionosphere waveguide contain information on the resistivity structure of the boundaries (Grimm et al., Icarus, 217, 462, 2014). In other words, aerial measurements can be used to probe the subsurface. This technique can measure geothermal gradient and hence lithospheric thickness of Venus from a nominal 55-km balloon float altitude, and thus make a fundamental contribution to understanding the geodynamics and interior structure of Venus without ever touching the surface.

Balloon Transverse Electromagntic Measurement (BTEM). An experiment measuring AC electric and magnetic fields flew over the Idaho's Salmon River Mountains in October, 2017 (Fig. 1). The objectives were to (1) demonstrate that the TEM band can characterized in the stratosphere, (2) demonstrate that electric fields follow lossy waveguide theory, (3) determine the frequency dependent electrical conductivity of the ground, constrained by independent information on the ionosphere, (4) determine the requirements to advance to TRL 6 for Venus flight. Results of the initial flight confirmed that the ground and ionosphere were sensed with correct order-of-magnitude resistivities (Fig. 2). A follow-up night flight in Sept 2018 will test different environmental conditions.

Acknowledgements: Payload and science analysis were funded by NASA PICASSO (NNX-16AL73G); balloon and flight operations were funded by NASA Flight Opportunities Program (FO166-B). I thank World View Enterprises, Earth Science Systems, and Quasar Federal Systems for their contributions.

Fig. 1. BTEM in flight near Butte, MT, USA. Electric fields are measured between boom-tip electrodes (4-m separation); magnetometers are inside booms. Payload is spatially and electrically isolated from balloon avionics (teal cable in foreground is fiber-optic connector).

Figure 2: Analysis of 1 minute of data at float altitude 33 km. Coherence (top) was reduced in the Schumann band <50 Hz due to vibration but 100-300 Hz TEM signals recovered apparent resistivity (bottom) expected at altitude. Features > 1 kHz are electronic artifacts.



The Venus Emissivity Mapper (VEM) – Obtaining Global Mineralogy of Venus from Orbit. J. Helbert[1], D. Dyar[2], I. Walter[1], D. Wendler[1], T. Widemann[3], E. Marcq[4], G. Guignan[4], A. Maturilli[1], S. Ferrari[5], N. Mueller[1], D. Kappel[1], M. D'Amore[1], A. Boerner[1], C. Tsang[6], G. E. Arnold[1], S. Smrekar[7], R. Ghail[8]; [1]DLR (Germany); [2]Mount Holyoke College (USA); [3]LESIA (France); [4]LATMOS (France); [5]Univ. degli Studi di Pavia (Italy); [6]Southwest Research Institute (USA); [7]Jet Propulsion Laboratory (USA); [8]Imperial College (UK)

Introduction: The Venus Emissivity Mapper is the first flight instrument designed to focus on mapping the surface of Venus using atmospheric windows around 1 µm. After several years of development, VEM has a mature design with an existing laboratory prototype verifying an achievable instrument SNR of well above 1000, as well as predicted error in retrieval of relative emissivity of better than 1%, assuming the availability of an improved Venus topography.

It will provide a global map of rock type, iron contents and redox state of the surface by observing the surface with six narrow band filters, ranging from 0.86 to 1.18 µm. Three additional windows allow corrections for cloud composition and variability, two measure water abundance, and three compensate for stray light. Continuous observation of Venus' thermal emission will also place tighter constraints on current day volcanic activity. Eight of the channels provide measurements of atmospheric water vapor abundance as well as cloud microphysics and dynamics and permit accurate correction of atmospheric interference on the surface data. Combining VEM with a high-resolution radar mapper, such as on the ESA EnVision or NASA VERITAS mission proposals, will provide key insights into the divergent evolution of Venus and Earth.

VEM Design: The VEM system design, discussed in detailed in [1, 2], is a pushbroom multispectral imaging system. It leverages a proven measurement technique pioneered by VIRTIS on Venus Express (VEX) [3-10], but it incorporates lessons learned from VIRTIS to achieve greatly improved sensitivity and spectral and spatial coverage:

- a filter array (rather than a grating) provides wavelength stability (band-center and width-scatter) ~5× more stable and maximizes signal to the focal-plane array (FPA), and
- first coverage of the spectral windows below 1µm,
- a two-stage baffle decreases scattered light and improves sensitivity,
- use of an InGaAs detector with an integrated thermal electric cooler (TEC) eliminates the need for cryogenic cooling.

VEM's design draws strongly on DLR's BepiColombo MERTIS instrument (launching in 2018). This design maturity, combined with a standard camera optical design, leads to low development risk.

A first performance evaluation of the VEM prototype used two Venus analog samples heated to Venus surface temperatures [2]. The retrieved emissivities match the laboratory values, and the uncertainty for a single unbinned exposure is <0.35%. VEM uses onboard software developed for MERTIS to bin, co-add, and losslessly compress data upon uplink command. During the science orbits, VEM oversamples at 10 km spatial resolution (33×33 pixel binning). To further enhance SNR, VEM uses digitial TDI to provide 189× gain over single-pixel SNR. Using current performance of the laboratory prototype for a single unbinned exposure and SNR enhancement due to onboard processing, we expect a system SNR of well beyond 1000.

VEM atmospheric correction: Methodology for retrieving surface emissivity is complex but well understood and demonstrated. To distinguish between surface and atmospheric contributions, VEM uses an updated version of the extensively tested pipeline developed to process VIRTIS data [5], combined with a radiative transfer model (RTM) [11-14]. Surface emissivity retrieval techniques were developed based on Galileo NIMS observations at 1700, 1800 and 2300 nm [15]. VEM cloud bands occur at 1195, 1310, and 1510 nm [16], the first on the flank of the 1180-nm surface windows [17]. VEM's cloud bands are close to surface bands, providing near-optimal correction.

Conclusion: VEM builds on recent advances in the laboratory analog spectroscopy at PSL at DLR [1, 18]. It is the first flight instrument specially designed to focus on mapping the surface of Venus using the atmospheric windows around 1 µm. VEM has a mature design with an existing laboratory prototype verifying an achievable instrument SNR of well above 1000 as well as a predicted error in the retrieval of relative emissivity of better than 1%.

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Radar Performance Modeling for Venus Missions. Scott Hensley[1], Jan Martin[1], Shadi Oveisgsharan[1], Xueyang Duan[1] and Bruce Campbell[2], [1]Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Dr., Pasadena, CA, 91109, scott.hensley@jpl.nasa.gov, [2]Smithsonian Institution, Air and Space Museum, Center for Earth and Planetary Studies, MRC 315, PO Box 37012, Washington, DC, 20013.

Introduction: The next generation of radar missions to Venus will employ more sophisticated radar instruments and operate in modes not previously used at Venus. We have developed a family of performance models for assessing how radar imaging, interferometry and stereo modes will perform at Venus.

The performance model is comprised of several elements that capture the instrument configuration, atmospheric propagation, and Venus backscatter. An overview of the performance model is described here.

Orbit Model: Ephemeris data can be supplied either using a simple Keplerian two-body orbit or from a more exact orbital dynamic model.

Instrument Model: The instrument model computes radar performance metrics like noise equivalent σ^o based on instrument parameters including radar frequency, bandwidth, noise temperature, antenna dimensions, gain pattern, range and instrument losses.

Atmosphere Model: The Venus atmosphere affects radar measurements in two ways: 1) it attenuates the signal with losses proportional to the frequency squared in dB 2) it slows and bends radar waves resulting in range measurements being increased relative to the geometric range. We use a detailed electromagnetic atmospheric permittivity model to account for these effects [1]. This is particularly important for characterizing interferometric radar performance [2].

Backscatter Model: To assess global performance it is desired to have a global backscatter model of Venus. Magellan S-band imagery and a physical scattering model are employed to convert S-band backscatter measurements to the desired frequency. We use the nearest imaged incidence angle to the desired incidence angle to derive backscatter measurements of a radar operating in the frequency range of X-L bands (2-10 GHz) [3].

Radar Stereo: Radar stereo uses data collected from two different vantages to measure topography. Points at elevations different from the reference surface will appear shifted in the radar imagery, termed radar parallax or disparity. Disparity measurements can be made manually or via automated image matching algorithms. Matching and ephemeris errors are the major sources of elevation error and can be modeled from a rigorous sensor model via [4]

$$\begin{aligned}\Delta\vec{T} &= \Delta\vec{P}_1 + \langle\hat{v},\hat{\ell}\rangle\Delta\rho_1\hat{v} + \frac{\rho_1}{\langle\hat{b},\hat{\ell}\times\hat{v}\rangle}\left[\frac{\Delta\rho_1}{\rho_1}\left(1-\langle\hat{v},\hat{\ell}\rangle^2\right)\hat{v}\times\hat{b}\right.\\ &+ \frac{1}{b\rho_1}\left(\rho_1\Delta\rho_1 - \rho_2\Delta\rho_2 - \rho_1\langle\Delta\vec{b},\hat{\ell}\rangle + b(\langle\Delta\vec{b},\hat{b}\rangle - \langle\hat{b},\hat{v}\rangle\langle\hat{\ell},\hat{v}\rangle)\Delta\rho_1\right)\hat{\ell}\times\hat{v}\\ &+ \left.\left(\frac{1}{v}\langle\hat{\ell},\Delta\vec{v}\rangle\left(1-\frac{\langle\Delta\vec{v},\hat{v}\rangle}{v}\right) - \left(\frac{\Delta\lambda}{\lambda}+\frac{\Delta f_1}{f_1}\right)\langle\hat{v},\hat{\ell}\rangle\right)\hat{\ell}\times\hat{b}\right] \qquad (1)\end{aligned}$$

An empirical model of the matching error based on Magellan stereo data and general radar theory is used to characterize matching performance.

Radar Interferometry: Radar interferometry can be used to measure topography or millimeter level surface deformation. Single pass interferometry is used for topographic measurement and repeat pass interferometry can be used for topography and surface deformation measurement [5].

Single Pass Interferometry: Radar interferometric topographic errors are primarily a function of baseline and phase errors given by [4]

$$\begin{aligned}\Delta\vec{T} &= \Delta\vec{P} + \Delta\rho\hat{\ell} + \frac{\rho}{\langle\hat{b},\hat{\ell}\times\hat{v}\rangle}\left[\left(-\frac{1}{b}\langle\hat{\ell},\Delta\vec{b}\rangle - \frac{\lambda\Delta\phi}{2\pi pb}\right)\hat{\ell}\times\hat{v}\right.\\ &+ \left.\frac{1}{v}\langle\hat{\ell},\Delta\vec{v}\rangle\hat{\ell}\times\hat{b} - \frac{\Delta\lambda}{\lambda}\left(\hat{v}\times\hat{b} - \langle\hat{v}\times\hat{b},\hat{\ell}\rangle\hat{\ell}\right)\right] \qquad (2)\end{aligned}$$

Phase errors are a function of SNR and the amount of pixel averaging used to reduce noise. Interferometry, unlike radar stereo, does not rely on scene contrast to make elevation measurements.

Repeat Pass Interferometry: Repeat pass interferometry can be used to measure topography, however atmospheric changes between observations can cause large errors and hence single pass systems are preferred. Equation 2 can used to assess the topographic measurement performance.

Surface deformation, e.g., from motion along faults or volcanoes, can be measured using two observations separated in time. Major error sources are ephemeris errors, temporal decorrelation or changes in the surface between observations, and atmosphere changes between observations. SO_2 variability is the major atmospheric error source we have modeled [2]. Surface decorrelation is informed by terrestrial earth analogs and the one repeat pass interferometric measurement made at Venus with the Magellan radar [6].

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Acknowledgement: This research was partially conducted at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

Magellan Intra-Cycle Venus Stereo Topography. Scott Hensley, Daniel Nunes, Karl Mitchell and Kevin Cotton, Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Dr., Pasadena, CA, 91109, scott.hensley@jpl.nasa.gov.

Introduction: Topographic data are a key piece of information for identifying and quantifying geological processes that have and continue to modify the surface of Venus and aid the establishment of the chronology of these processes. Venus topography knowledge comes primarily from either Magellan radar altimetry with a spatial resolution of 15-20 km and a elevation accuracy of no better than 100 m or derived from radar stereo data collected by Magellan during Cycles I and III with spatial resolution on the order of half a kilometer and elevation accuracy of 20-50 m that only covered roughly 20% of the surface. We present a previously unexploited source of Venus topography with intermediate spatial resolution and elevation accuracy to the aforementioned sources thereby extending the available Venus topographic data. We describe the use of intra-Cycle stereo between adjacent orbit pairs as a source of topographic data and show that the spatial resolution and elevation accuracy are suitable for use in scientific investigations.

This Intra-Cycle stereo work is funded by an effort that is utilizing all available F-BIDR imagery to produce the best achievable topographic solution for all surface regions of Venus covered by Magellan SAR imaging. Although Cycle I-III stereo topography has been notably produced by colleagues in the community [e.g., [1], [2]], their efforts have used different combinations of F-MAPs mosaics of the surface, older Magellan ephemeris, or significant manual input. Each of those aspects represents a compromise of either stereo quality or spatial coverage. Our approach of using individual F-BIDR noodles and updated ephemeris [3] for fully automated stereo matching and elevation calculations should yield the best results and global coverage, with the added benefit of producing formal elevation uncertainties.

Radar Stereo: Radar stereo used data collected from two vantages with different incidence to derive topography measurements. Cross-track image offsets that can be measured either manually or by automated matching algorithms are related to height by a factor which is a function of the incidence angles given by

$$h = \frac{\Delta p}{\cot\theta_2 - \cot\theta_1} \tag{1}$$

where h is the elevation above the reference surface, Δp is the parallax measurement and θ_1 and θ_2 are the incidence angles. From Equation 1 it follows that the sensitivity to topography increases as the incidence angle difference increases, however the ability to accurately match decreases due to the image distortion resulting from the different incidence angles. Radar stereo pairs are usually designed to have incidence angle differences between 5°-15° to balance these considerations. The Magellan Cycle III incidence angle profile was specifically designed to enable good radar stereo measurements.

Intra-Cycle Measurements: By utilizing the F-BIDR data which was designed to have overlap between adjacent orbit pairs, we have an additional source of radar stereo data albeit with less than optimal relative incidence angle geometry. However, because the imaging geometry is more nearly identical than the Cycle I-III, pairs the automated matching accuracy would be expected to be much better. In fact measurements indicate the matching accuracy is better by about a factor of 3-4. We have conducted a global assessment of the expected intra-Cycle stereo elevation accuracy for all three Cycles taking into account imaging geometry and expected matching accuracy and found that useful elevation measurements are possible with intra-Cycle data. For latitudes away from the poles it is possible to make elevation measurements with greater spatial resolution and accuracy than Magellan radar altimeter data.

Summary: This talk will present an outline of our stereo processing methodology using radar sensor model that allows us to include improved ephemeris, include improved atmosphere compensation and produce a height precision map to accompany the elevation data. Based on the radar geometry and expected matching accuracy, we will present our global assessment of the expected intra-Cycle stereo elevation measurement accuracy and compare it with Cycle I-III stereo data. We will then show an example of Cycle I-III stereo and intra-Cycle stereo data for the Artemis region and compare the elevation accuracies in the region. These data illustrate the utility of augmenting the standard topographic measurements in both quality and coverage for scientific analysis.

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Acknowledgement: This research was conducted at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

A Common Probe Design for Multiple Planetary Destinations

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Introduction: Atmospheric probes have been successfully flown to planets and moons in the solar system to conduct *in situ* measurements. They include the Pioneer Venus multi-probes, the Galileo Jupiter probe, and Huygens probe. Probe mission concepts to five destinations, including Venus, Jupiter, Saturn, Uranus, and Neptune, have all utilized similar-shaped aeroshells and concept of operations, namely a 45° sphere cone shape with high density heatshield material and parachute system for extracting the descent vehicle from the aeroshell. The current paradigm is to design a probe to meet specific mission requirements and to optimize mass, volume, and cost for a single mission. However, this methodology means repeated efforts to design an aeroshell for different destinations with minor differences. A new paradigm has been explored that has a "common probe" design that could be flown at these different destinations and could be assembled in advance with multiple copies, properly stored, and made available for future NASA missions. Not having to re-design and rebuild an aeroshell could potentially result in cost and schedule savings and reduce the risk of losing technologies and skills difficult to sustain over decades.

The NASA Planetary Science Division has funded a study in 2018 to determine feasibility of a common probe design that meet most, if not all, mission needs to the five planetary destinations with extreme entry environments. The Common Probe study involved four NASA Centers (Ames Research Center, Goddard Space Flight Center, Jet Propulsion Laboratory, and Langley Research Center) and addressed these issues. Also investigated were, design constraints and inefficiencies that occur in specifying a common design versus designing for specific mission and target destination.

Study methodology: First, a notional payload of instruments for each destination was defined based on priority measurements from the Planetary Science Decadal Survey. Steep and shallow entry flight path angles (EFPA) were defined for each planet based on qualification and operational *g*-load limits for current, state-of-the-art instruments. Interplanetary trajectories were then identified for a bounding range of EFPA.

Next, 3-DoF simulations for entry trajectories were run using the entry state vectors from the interplanetary trajectories. Aeroheating correlations were used to generate stagnation point convective and radiative heat flux profiles for several aeroshell shapes and entry masses. High fidelity thermal response models for various TPS materials were used to size stagnation point thicknesses, with margins based on previous studies. Backshell TPS masses were assumed based on scaled heat fluxes from the heatshield and also from previous mission concepts. The resulting notional probe design is shown in Figure 1.

Presentation: An overview of the study scope, highlights of the trade studies and design driver analyses, and the final recommendations of a common probe design and assembly will be presented. The limitations that the common probe design may have for the different destinations will also be discussed, as well as the considerations for implementing missions.

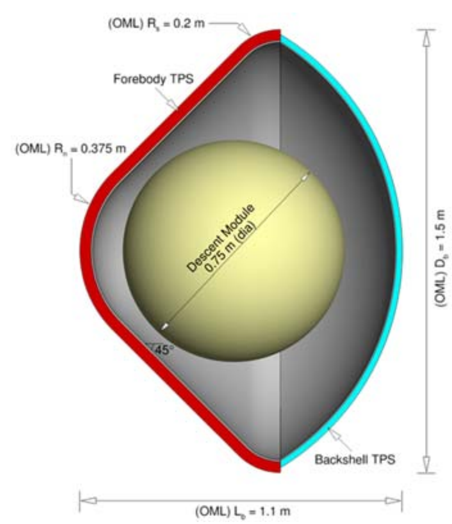

Figure 1. Common aeroshell design studied for multiple planetary destinations.

REINVISTIGATION OF VENUSIAN SPLOTCHES WITH MAGELLAN AND ARECIBO RADAR DATA. N. R. Izenberg[1] and J. A. Kelly[1,2]. [1]Johns Hopkins University Applied Physics Laboratory, Laurel, MD, USA (noam.izenberg@jhuapl.edu), [2]Liberty High School, Eldersburg, MD, USA.

Splotches, or airblast features are diffuse irregularly circular areas of radar contrast on the surface of Venus, likely caused by atmospheric pressure waves created by the disintegration and incineration of meteorites or comets too small to survive transit through the thick atmosphere the surface [1]. A total population of 401 was characterized by [2] using Magellan synthetic aperture radar (SAR) maps. Of the total, 138 splotches are also visible from earth via the Arecibo Observatory radar system [3]. The Arecibo data, although at lower spatial resolution (1 km/pixel at best, vs. 75 m/pixel at best of Magellan), was fully polarimetric, as opposed to the horizontal transmit-receive polarization of Magellan.

Splotch features are usually dark in SAR images, indicating a smooth, forward scattering, surface on the scale of 12-cm S-band radar [4]. This has been interpreted as shock waves and fine-grained ejecta like material, possibly the remains of the pulverized meteorite, covering the surface to some depth. Some splotches interact with topography such as ridges or rifts or tesserae, and some can have bright centers or concentric halos around the dark material (Fig. 1), possibly indicative of surface disruption or scouring effects [4].

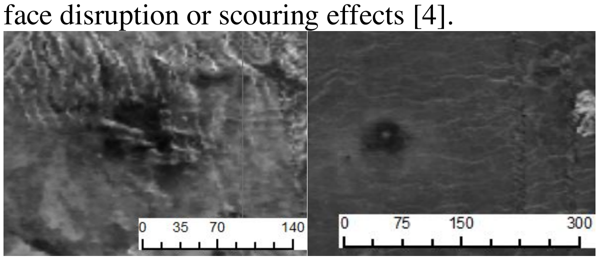

Fig. 1. Example splotches from Magellan global SAR images. Scales in km. Left: splotch #348 (-34.1, 359.5E) just south of Eve Corona. Right: Splotch #83 (36.1, 351.9E) in southeast Sedna Planitia.

In [5] we used profiling in SAR, direct comparison of Magellan and Arecibo radar backscatter, and Arecibo Same sense/opposite sense circular polarization (SC/OC) ratios to investigate the properties of a small pilot set of splotches in the Arecibo incidence angle vs. resolution 'sweet spot', and found examples where contrasts muted or reversed between the two data sets. Some differences are due to resolution, but in some cases, comparing Magellan/Arecibo backscatter of splotches Arecibo SC/OC ratios implied that the depths, compositions, or relationships of the splotch materials with the background varied.

We have begun a systematic evaluation of the splotches in the Magellan, Arecibo overlap, beginning with the ~59 in the Arecibo sweet spot region using both 2015 Arecibo data [6] and derived degree of linear polarization (DLP) and circular polarization ratio (CPR) data from Arecibo campaigns from 1999-2004 [3] and [7]. The derivation process results in the DLP and CPR maps having lower spatial resolution (12-16 km/pixel), which may be too coarse for small features like the center of Splotch #321 (Fig. 1) but is certainly sufficient for general comparison of large splotch features with surroundings. Early results show DLP values of some splotches indistinguishable from surrounding materials, and some with DLP slightly elevated from surroundings (Fig 2).

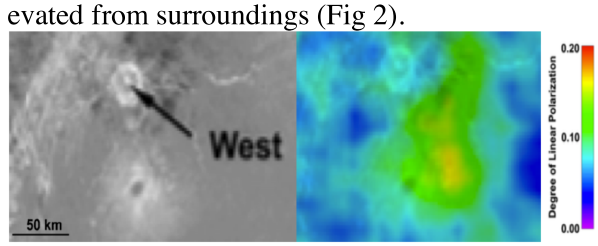

Fig. 2. Splotch #125 (25.1, 303.3E) south of crater West in Magellan SAR (left) and DLP (right) from [3]. The splotch DLP is elevated from the surroundings, though its relationship with West needs to be determined.

A deep (on the scale of several radar wavelengths) mantling of fine ejecta like material over more competent subsurface (e.g. lava flows) should show elevated DLP, so the lack of such a sign may be indicative of shallow deposits, or other material differences in some locations. We also are evaluating splotches in derived emissivity and roughness, and elevation data from Magellan altimetry and SAR stereo.

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VENUS' UNIQUE ROLE IN SOLAR SYSTEM HISTORY: THE FIVE BIG QUESTIONS.

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Introduction: Development of the next Planetary Decadal Survey will commence in February 2019. Now is the time to clearly articulate the outstanding mysteries regarding Venus' evolution as a planet, its unique and influential role in Solar System Research and the investigations needed to probe her decades' old secrets. This motivates our community to consider: a) what links may exist between Venus' list of unsolved riddles, and b) do the unanswered questions regarding Venus' atmospheric evolution, interior structure, surface evolution and habitability suggest that a single event or series of catalytic events are responsible for the state of Venus as we know it?

The Questions: Both the similarities and dissimilarities between the Earth and Venus raise challenging questions. Similarities include the solid body density and radius, the existence of mountains. ridges and plateaus -- possibly made of granite [1], and surface properties that suggest the surface is young and volcanically active [2-3]

The potential for granite compositions suggests an ocean period; yet, Venus' current dry state raises questions about the timeline of Venus' oceanic period and loss [4-5]. Venus' apparently random pattern of (arguably) unmodified craters, along with the un-Earth like lack of plate tectonics raises questions about the mechanisms and time scales that drive Venus' volcanic and tectonic activity.

Additional un-Earthlike Venus traits include: (1) the absence of a magnetic field (allowing continuous ionization and stripping of the upper atmosphere -- contributing to the dry condition of the atmosphere); (2) its retrograde rotation; (3) a slow solid body rotation rate, and the accompanying 4-5 Earth day, cloud super-rotation; (4) The 460°C surface temperature and and 90 bar surface pressure; and (5) an absence of advanced life forms. Indeed the only region of the planet that may host extant microbial life similar to that of the Earth is located 48-70 km above the planet surface in the dense H_2SO_4 clouds [6-7].

As VEXAG considers how to communicate "why Venus?" in a succinct way, it is important to consider how Venus' distinctly un-Earthlike characteristics may be linked. Over the decades theories suggested for Venus current spin state include surface-atmosphere interactions, the disruption of a once present Venus moon, or catastrophic impact [8-12]. Similarly, multiple hypothesis exists for the origin of Venus' lost ocean including comet impact [12]; yet, the true mechanism and timeline for Venus' water evolution is also an open question [5]. If catastrophic impact was a part of Venus' history could it have been the catalyst for the shift in Venus' climate and the proliferation of the greenhouse effect. Could it have been the mechanism to drive any microbial life that may have been developing and/or thriving during Venus' early temperate period to the cloud top regions [7,13]?

In the end, the web of questions raised by the similarities and dissimilarities between Earth and Venus can be categorized into 5 big Questions/Histories that need to be resolved/defined:

- What is Venus' water history: where did it come from, how did it evolve with time?
- How has the habitability of Venus evolved over time for microbial life?
- What are the characteristics of Venus' interior and how did it come to its current state?
- What is Venus' crust and weathering story***?***
- How have the spin states of the solid planet and the atmosphere evolved and interacted over time?

The Message: Lessons learned regarding Venus' atmospheric, interior and habitability evolution directly influence our understanding of the evolution of the Solar System. Likewise, these same lessons help us to refine what observables may be used as diagnostics in the investigation and interpretation of the evolution of extra solar planets. As the Venus Exploration community considers how to communicate "why Venus?" to the public and our policy makers, connections to these critical questions must be made in a way that is accessible and memorable.

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UNVEILING THE INTERIOR OF VENUS: USING TECTONIC DEFORMATIONS ALONG CANALI TO CONSTRAIN LITHOSPHERIC STRUCTURE & MANTLE CONVECTION. A. S. Jindal[1] and A. G. Hayes[2], [1]Department of Astronomy, Cornell University (asj59@cornell.edu), [2]Department of Astronomy, Cornell University (hayes@astro.cornell.edu).

Introduction: Venus is Earth's "sister planet", they both have nearly identical sizes and densities. However, analysis of its surface and atmosphere reveals that it took a very diverse evolutionary path from Earth. Studying the interior of Venus can help us understand when the evolutionary paths of Earth & Venus diverged and what caused this divergence. With the massive interest in the search for life beyond Earth, understanding the evolution of Venus could also significantly contribute towards answering the timely and provocative question of what makes a planet habitable.

Deformational features of various varieties and styles are ubiquitous on the surface of Venus, and many of these display characteristic scales (widths or spacings) of deformation that fall into distinct size classes. We will study the mantle convection and lithospheric structure of Venus by analyzing tectonic deformation features along canali. Canali-type channels are long lava channels with almost constant widths found in the Venusian plains. Stratigraphic evidence points towards the canali being old features on the plains that formed with the last phases of extensive plains volcanism possibly induced by the hypothesized global resurfacing event 300 Myr ago [1,2]. When these channels were emplaced, they must have had downhill gradients, but post-depositional tectonic deformations in the Venusian lithosphere have caused them to be interspersed with nearly periodic topographic relief [3]. The dominant length scales associated with these nearly periodic deformation features can inform us on the lithospheric structure and mantle convection of Venus.

We will map all major (longer than 300 km) canali on Venus, and generate their topographic profiles. Since the canali are sinuous and may not always flow perpendicular to the deformation features, the characteristic length scales of tectonic deformations we obtain by studying the canali undulation profiles may have a path dependent error in them. We will apply statistical modeling methods to eliminate this sinuosity-induced error and attempt to accurately determine the deformation length scales. Once we successfully obtain the deformation length scales, we will build on crustal-thickness models [4] and plume models [5], to link the observed length scales to the lithospheric structure and mantle convection of Venus.

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PLANNED IMPROVEMENTS TO THE VENUS GLOBAL REFERENCE ATMOSPHERIC MODEL. H. L. Justh[1] and A. M. Dwyer Cianciolo[2], [1]NASA Marshall Space Flight Center, EV44, Huntsville, AL 35812 hilary.l.justh@nasa.gov, [2]NASA Langley Research Center, MS 489, Hampton VA 23681 alicia.m.dwyercianciolo@nasa.gov.

Introduction: The Venus Global Reference Atmospheric Model (Venus-GRAM) is an engineering-level atmospheric model applicable for engineering design analyses, mission planning, and operational decision making. Missions to Venus have generated a wealth of atmospheric data, however, Venus-GRAM has not been updated since its development and release in 2005. GRAM upgrades and maintenance have depended on inconsistent and waning project-specific support. The NASA Science Mission Directorate (SMD) has agreed to provide funding support in Fiscal Year 2018 and 2019 to upgrade the GRAMs. This presentation will provide an overview of Venus-GRAM and the objectives, tasks, and milestones related to the GRAM upgrades.

Venus-GRAM: Venus-GRAM provides density, temperature, pressure, and wind components from 0 to 1000 km. It also allows simulation of random perturbations about the mean. Venus-GRAM has been widely used by the engineering community because of its ability to create realistic dispersions; GRAMs can be integrated into high fidelity flight dynamic simulations of launch, entry, descent and landing (EDL), aerobraking and aerocapture.

The lower atmosphere model in Venus-GRAM (up to 250 km) is based on the Venus International Reference Atmosphere (VIRA) [1]. The Venus-GRAM thermosphere (250 to 1000 km) is based on a MSFC-developed model [2] which assumes an isothermal temperature profile initialized using VIRA conditions at 250 km [3]. The VIRA version included in Venus-GRAM includes Pioneer Venus Orbiter and Probe data as well as Venera probe data, but it does not include a solid planet model or a high resolution gravity model [4].

GRAM Upgrade Objectives, Tasks, and Milestones:

Objectives. The GRAM upgrade effort focuses on three primary objectives: upgrade atmosphere models within the GRAMs, modernize the GRAM code, and socialize plans and status to improve communication between GRAM users, modelers and GRAM developers.

Model Upgrade Task. The focus of this task is to update the atmosphere models in the existing GRAMs and to establish a foundation for developing GRAMs for additional destinations. For Venus, the Venus General Circulation Model (VGCM), Venus Thermospheric General Circulation Model (VTGCM), Venus analytic wind models [5], updated VIRA model and development of the Venus Global Ionosphere-Thermosphere Model (V-GITM) will be of interest. Earth observation data of Venus, Akatsuki and Venus Express data will be used as the basis for Venus-GRAM verification and validation. Adding the highest resolution topography available/reasonable to Venus-GRAM will also be addressed.

Code Upgrade Task. Another key element is modernizing the GRAM code. A new common GRAM framework is being developed in C++.

Model Socialization Task. Socializing the status of the GRAM upgrades and advocating and promoting its continued use in proposals and projects is being conducted by the GRAM upgrade team.

Milestones. Project milestones for fiscal year 2018/2019 and beyond include: meeting with key modeling groups, identifying, obtaining and implementing atmosphere model upgrades for GRAMs, acquiring observational and mission data sets for GRAM comparisons, upgrading the GRAM code framework, and releasing updated and new GRAMs that include programming and user guides.

Conclusions: Venus-GRAM is a critical tool set that influences mission selection and decisions. The funding provided by the NASA SMD is vital to address current limitations and accomplish Venus-GRAM developmental goals.

Acknowledgments: The authors gratefully acknowledge support from the NASA SMD.

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Venus: The Nearby Exoplanetary Laboratory. Stephen R. Kane[1], Giada Arney[2], David Crisp[3], Shawn Domagal-Goldman[2], Lori S. Glaze[2], Colin Goldblatt[4], David Grinspoon[5], James W. Head[6], Adrian Lenardic[7], Cayman Unterborn[8], Michael J. Way[9]
[1]University of California, Riverside, CA, 92521, [2]NASA GSFC, [3]JPL, Pasadena, CA, [4]University of Victoria, Canada, [5]Planetary Science Institute, Tucson, AZ, [6]Brown University, Providence, RI, [7]Rice University, [8]Arizona State University, [9]NASA GISS

Abstract: A fundamental aspect of understanding the limits of habitable environments and detectable signatures is the study of where the boundaries of such environments can occur, and the conditions under which a planet is rendered into a hostile environment. 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. Whilst ever we struggle to understand the fundamental properties of the Earth-sized planet directly next door, the task of characterizing the surface environments of Earth-sized planets around other stars will remain proportionally inaccessible.

In this talk I will describe the gaps in our knowledge regarding Venus within the context of how these gaps are impacting our ability to model exoplanet atmospheres and interiors. I will outline the premise behind the "Venus Zone" and how testing the conditions of runaway greenhouse is an essential component of understanding the development of habitable conditions. I will present several detected potential Venus analogs including detailed climate simulations that constrain their surface environments. I will further present the expected yield of Venus analogs from the Transiting Exoplanet Survey Satellite (TESS) and the potential for atmospheric characterization with the James Webb Space Telescope (JWST). Finally, I will summarize the primary exoplanet science questions that would be addressed by a return surface mission to Venus.

ATMOSPHERIC WINDOWS TO IMAGE THE SURFACE FROM BENEATH THE CLOUD DECK ON THE NIGHT SIDE OF VENUS. J. J. Knicely and R. R. Herrick, Geophysical Institute, University of Alaska Fairbanks, Fairbanks, AK 99775-7320 (jknicely@alaska.edu).

Introduction: The study of the Venusian surface is an arduous task. Surface probes are short-lived due to the harsh surface conditions (~735 K and 92 bars) [e.g., 1, 2] and sulfuric acid [3], requiring other means for long-term or comprehensive study of the surface. Generally, that involves the use of orbiting satellites or ground-based telescopes. With Venus, we have the option of using balloons which can float beneath the cloud deck where conditions are similar to Earth surface conditions [4]. It is well understood which parts of the surface emissivity spectrum can be viewed from space on the Venus night side through atmospheric windows. Here, we evaluate whether more of the spectrum can be observed by placing the sensor below the cloud deck. Moroz [4] examined possible windows at 0.65, 0.85, and 1.02 microns through which emission from the surface on the night side of Venus could reach a sensor. This work expanded on [4] by modeling the surface emission of bands from 0.7 to 250 microns using a total extinction coefficient data set from [5]. The emission from the surface, its scattering and absorption, and the emission from the atmosphere were calculated from the surface to various heights beneath the cloud deck. We explored the effects of different sensor heights and surface emissivities, variation in surface elevation, and variations in the temperature profile on the possible atmospheric windows.

Methods: We defined a surface viewing atmospheric window as any wavelength at which 50% or more of the detected signal comes from the surface. We calculated the observed signal using the radiative transfer equation. Under Venus conditions, we generally expect mafic rocks (e.g., basalt) to have emissivities greater than 0.9, and more felsic rocks (e.g., granite) to be less than 0.9 [6, 7, 8]. Sensor height was varied in 10 km intervals from 10 to 100 km. Surface elevations were 0 and 11 km, with surface temperatures of 735 and 650 K, respectively. The temperature profile of [1] was used with 20 K added, and then with 20 K subtracted from both the surface and temperature at all altitudes to simulate changes in the temperature profile that may occur at different latitudes [9].

Discussion: The prospective windows are largely expanded versions of previously identified windows that have been exploited by satellites and ground-based observatories. Figure 1 illustrates the results for our nominal case, in which emissivity was unity, sensor altitude was 40 km, surface elevation was 0 km, surface temperature was 735 K, and the temperature profile was that from [1]. Under these conditions, surface viewing atmospheric windows occur at 0.758-0.867, 0.876-0.926, 0.940-0.942, 0.952, 0.958-1.033, 1.082-1.109, 1.136-1.142, and 1.171 microns. Sensor altitude and regional temperature variations had little effect on identified windows. If the assumed emissivity is reduced from 1.0 to 0.7, then the total bandwidth for which radiance from the surface exceeds the atmospheric radiance drops by 32.3%. Simulating a surface at 11 km elevation results in a 96.3% increase in total bandwidth and new windows centered at 1.27, 1.34, and 1.72 microns as compared to the nominal conditions. Any lander or balloon mission should make use of 1.0, 1.1, 1.14-1.19, and 1.27 micron windows as these provide a comprehensive ability to extract information about the surface from the night side. These windows have the potential to elucidate questions about the composition and redox state of the surface of Venus [8, 10], which have important implications for the evolution of the planet.

References: [1] Seiff et al. (1985) *Adv. Space Res*. Vol 5. [2] Crisp & Titov. (1997) *Venus II*. [3] Bezard & de Bergh. (2007) *Jrnl. Geop. Res*. Vol 112. [4] Moroz. (2002) *Planet. & Space Sci*. Vol 50. [5] Lebonnois et al. (2015) *Jrnl. Geop. Res.: Planets*. Vol 120. [6] Jensen. (2007) *Remote Sensing of the Environment*. [7] Lillesand et al. (2015) *Remote Sensing and Image Interpretation*. [8] Helbert et al. (2018) *LPSC XLIX* Abstract #1219. [9] Haus & Arnold. (2010) *Planet. & Space Sci*. Vol 58. [10] Dyar et al. (2017) *VEXAG XV* Abstract #8004.

Acknowledgments: Supported in part by the Alaska Space Grant Program. Comments from F. Meyer, L. Glaze, and G. Arney improved this work.

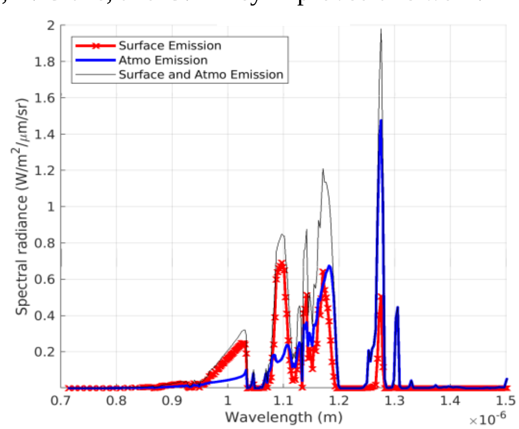

Figure 1. Surface vs Atmospheric emission for our nominal conditions. There is approximately 0.27 microns of total bandwidth.

PLANETWARD ION FLOWS IN VENUS' MAGNETOTAIL.

Peter Kollmann[1*], *Pontus C. Brandt[1], Glyn Collinson[2], Zhao Jin Rong[3], Yoshifumi Futaana[4], and Tielong L. Zhang[5], [1]The Johns Hopkins University Applied Physics Laboratory (JHU/APL), Laurel, USA, Peter.Kollmann@jhuapl.edu; [2] NASA Goddard Spaceflight Center (GSFC), Greenbelt, USA; [3] Swedish Institute of Space Physics (IRF), Kiruna, Sweden; [4] Chinese Academy of Sciences, Beijing, China; [5] Space Research Institute (IWF), Graz, Austria*

Introduction: Venus is continuously losing parts of its atmosphere into space. A large fraction of this escape occurs in the form of ions flowing down along Venus' magnetotail. Countless studies followed these ions in order to constrain the atmospheric escape. Interestingly, there are also ions in the magnetotail that return to Venus. These flows, their properties, and possibilities for the underlying physics have been barely studied in the past.

Results: Data from the ASPERA-4 instrument on board of Venus Express is used in our study. We find that the planetward flow rate decreases with EUV irradiance. This irradiance changes over the 11-year solar cycle and over the age of our Sun. Since we also find that the planetward return rate is comparable to the escape rate, the relation between EUV and return flows also affects the net atmospheric escape. It turns out that the relation between net escape and EUV irradiance scales opposite to Mars, even though Mars is an unmagnetized planet as Venus (see Figure 1.)

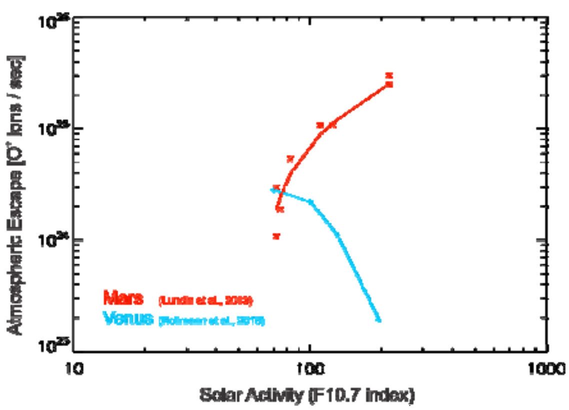

Figure 1: Net atmospheric ion escape rates of Venus (blue) and Mars (red) as a function of solar activity.

Planetary flows are often associated with magnetic reconnection. However, we find that the bulk of these flows do not correlate with proximity to the magnetotail current sheet, as it would be expected from magnetic reconnection. Instead, we find that the flows we observe are consistent with flows that naturally emerge from pickup ions moving in the magnetic environment of Venus.

SAEVE: STUDY RESULTS FOR A LONG DURATION VENUS LANDER. Tibor Kremic[1] (Tibor.Kremic@nasa.gov), Richard Ghail[2], Martha Gilmore[3], Walter Kiefer[4], Sanjay Limaye[5], Gary Hunter[1], Carol Tolbert[1], Michael Pauken[6], Colin Wilson[7], [1]NASA Glenn Research Center, Cleveland, OH, [2]Imperial College of London, London, UK, [3]Wesleyan University, Middletown, CT, [4]Lunar and Planetary Institute, Houston, TX, [5]University of Wisconsin, Madison, WI, [6]Jet Propulsion Laboratory, Pasadena, CA, and [7]University of Oxford, UK

Many crucial geophysical and atmospheric science investigations at Venus require operations on the surface for an entire solar day. Until recently this was not achievable, but new developments in high temperature electronics have now made months long operations on the Venus surface possible even with smallsat class missions. Here we describe a study of a long-lived Venus lander called SAEVe, for **S**eismic and **A**tmospheric **E**xploration of **Ve**nus—this was one of the concepts selected in 2017 under NASA's Planetary Science Deep Space SmallSat Studies (PSDS3) call.

SAEVe is delivered to Venus as a ride-along on an arbitrary orbiter mission. Its two small probes (~45 kg each) are placed into the Venus atmosphere via their own entry capsules, ejected at different times and free fall, decelerating in the thickening atmosphere to touchdown with a velocity of 5 m/s or less. They take meteorology and seismic measurements for 120 Earth days (1 Venus solar day) or longer, which is over three orders magnitude longer than anything previously achieved. In addition, the landers are equipped with a short-lived (hours) imaging system to collect data on the surface and during descent. The long operating life of SAEVe is enabled by three key elements, 1) high temperature electronics and systems that operate without cooling at Venus surface conditions, 2) use of simple instrumentation and supporting avionics with emphasis on low data volume instruments and sensors, and 3) minimizing energy utilization through a novel operations approach. The orbiter mission is used to relay data back to Earth. Integrating these elements into an innovative mission concept allows SAEVe not only to conduct unprecedented seismic and climatological observations on our nearest planet but also to serve as a technology pathfinder for larger and more capable Venus surface missions in the future.

This briefing will summarize final results of the study and address ongoing related activity. The final report for this mission concept is available at https://www.lpi.usra.edu/vexag/reports/SAEVe-6-25-2018.pdf .

Table 1 lists the science objectives and measurements planned and Figure 1 is a rough concept model showing basic physical characteristics. The baseline payload referenced in Table 2 does not include the cameras and heat flux instruments.

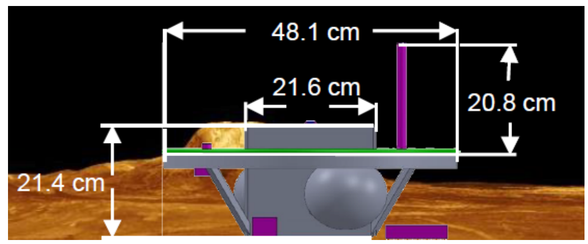

Figure 1. SAEVe concept model

Table 1. Science Summary

Science Objectives	Anticipated Instruments/ Measurement
Determine if Venus is seismically active and the rate and style of activity	Seismometer and wind sensors
Determine the thickness and composition of the crust and lithosphere	Seismometer and wind sensors, two stations for interior science
Acquire temporal meteorological data	Measurement of p, T, u, v and light
Estimate momentum exchange between the surface and the atmosphere	Measurement of p, T, u, v and light
Determine the key atmospheric species at the surface over time	Measure the abundance of gases
Determine the current rate of energy loss at the Venus surface	Heat Flux
Determine the morphology of the local landing site(s)	Camera package

References: [1] National Aeronautics and Space Administration Science Plan (2014). https://cor.gsfc.nasa.gov/docs/2014_Science_Plan.pdf.

Table 2. Cost Estimates for Various Configurations [Numbers based on both COMPASS and independent estimates]

Estimates	Full Payload, 2 Landers (point)	Full Payload, 2 Landers (with 25% reserves)	Full Payload - Single Lander (point)	Full Payload - Single Lander (reserves)	Baseline Payload - Single Lander (point)	Baseline Payload - Single Lander (reserves)
Combined	$106M	$131M	$87M	$109M	$71M	$89M

THE ROAD TO VENUS SEISMOLOGY VIA OKLAHOMA. S. Krishnamoorthy[1], D. C. Bowman[2], L. Martire[3], A. Komjathy[1], J. A. Cutts[1], M. T. Pauken[1], R. F. Garcia[2], D. Mimoun[2], V. Lai[4], J. M. Jackson[4]

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Introduction: The passage of elastic waves through planetary interiors reveals fundamental characteristics of the subsurface that are difficult to resolve through other methods. The generation of these waves also describes the ongoing geologic activity on planetary bodies. Seismic studies have revealed key structures such as the Earth's inner core and partial melt at the base of the lunar mantle; the upcoming InSight mission to Mars is expected to provide similar information about the Red Planet. In contrast, the interior structure and present activity of Venus is unknown. However, surface conditions on Venus make it impossible to deploy seismic sensors for more than a few hours.

Seismic experiments conducted from aerial platforms offer a unique opportunity to explore the internal structure of Venus without needing to land and survive on its surface for long durations. In particular, the dense atmosphere of Venus allows for balloons to be flown in the mid and upper atmospheric regions. These balloons may be used as vehicles for seismic experiments that can collect infrasound data as indication of seismic waves while floating in the prevailing winds. One possible way to detect and characterize quakes from a floating platform is to study the infrasound (pressure waves with frequency < 20 Hz) signature produced by them in the atmosphere. Infrasonic waves are generated when seismic energy from ground motions are coupled into the atmosphere. The intensity of the infrasound depends heavily on the relative density of the atmosphere and the planet's crust. On Venus, where the surface pressure is 90 atmospheres, the energy from the surface is coupled into the atmosphere 60 times more efficiently than the Earth.

The Use of Earth as a Venus Analog: JPL and its partners (ISAE-SUPAERO, the Seismological Division at the California Institute of Technology, and Sandia National Laboratories) are in the process of developing technologies for detection of infrasonic waves generated by earthquakes from a balloon platform using the Earth as a Venus analog. In the last year, the team has conducted multiple experiments and demonstrated the detection and geolocation of artificially generated seismic events from a balloon platform and the long-range detection of infrasound from rocket launches. Further, our sensors flew on-board a NASA balloon at 38 km altitude as a secondary payload to study the noise characteristics of the stratospheric infrasound background. In November 2018, our sensors will be deployed on balloons to overfly sub-surface chemical explosions in the Nevada desert as part of the Department of Energy's Source Physics Experiment. A brief update from our activities in the last year will be shared in this presentation. The next step in our program is to detect naturally occurring earthquakes from the stratosphere – this will be the primary focus of our presentation.

Presentation Content: The State of Oklahoma has the largest concentration of earthquakes in the continental United States. In 2017 alone, there were 1095 earthquakes of magnitude 2.0 and above, concentrated primarily over a region in North-Central Oklahoma. In addition, Oklahoma's large distance from the ocean compared to seismically active zones on the West Coast and its flat relief make it a particularly viable candidate for developing balloon-based seismic infrasound sensing using the Earth as a Venus analog.

In this presentation, we will illustrate the design of a campaign to detect and characterize naturally occurring earthquakes from balloon-borne barometers in the stratosphere. We aim to conduct a prolonged balloon-based measurement campaign in central Oklahoma, where we will deploy two balloons a day for up to 6 weeks. Each balloon will reach a floating altitude of approximately 20 km, overfly the central band of earthquakes and be terminated a few hours later. Ground truth for earthquake timing and location will be provided by the Oklahoma Geological Survey's ground network of seismometers. Using detailed statistical analysis and trajectory simulations, we will show that our campaign guarantees the successful detection of infrasound from an earthquake from a balloon, the first of its kind. Several earthquake detections are expected, data from which will be utilized to develop algorithms that can discriminate seismic infrasound from other sources. Data will also be combined with seismo-acoustic simulations to learn the dependence of acoustic signal strength on the intensity of the earthquake.

The success of this campaign will demonstrate that quakes can be detected and characterized by barometers suspended from high-altitude balloons. Since Venus is able to couple seismic energy into the atmosphere much better than the Earth, success on Earth will provide a compelling argument for performing aerial seismology on Venus.

AN EXPERIMENT TO INVESTIGATE VENUS'S DEEP ATMOSPHERE. S. Lebonnois[1], G. Schubert[2], J. Bellan[3], T. Kremic[4], L. Nakley[4], K. Phillips[5], T. Navarro[2], [1] LMD/IPSL, Sorbonne Université, Campus P&M Curie, CNRS, Paris, France (sebastien.lebonnois@lmd.jussieu.fr), [2] Department of Earth, Planet. and Space Sci., UCLA, Los Angeles, CA, USA, [3] Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA, [4] NASA Glenn Research Center, Cleveland, OH, USA, [5] HX5 Sierra, LLC, NASA GRC, Cleveland, OH, USA.

Introduction: The characteristics of the Venus atmosphere closest to the ground are still unknown to a large degree. The only reliable temperature profile measured below 12 km altitude was obtained in 1985 by the VeGa-2 lander [1]. This profile, obtained during the ~1h descent, is highly unstable in the lowest 7 km, meaning that the near-constant vertical gradient is steeper than the adiabat, a characteristic that may be explained by a variation of the abundance of nitrogen from 3.5% at 7 km altitude to 0 at the surface, as proposed by Lebonnois & Schubert (2017) [2]. The physics of the composition gradient is difficult to understand in the absence of more information. However, considering the observations in a recent experiment [3] (designed by H13 below), it was conjectured that this gradient could result from gravity effects inducing a density-driven separation of nitrogen and carbon dioxide.

Experiment with GEER: To investigate the behavior of the CO_2-N_2 mixture under conditions ranging from the H13 experiment to the near-surface atmosphere of Venus, we have designed an experiment that was conducted at the “Glenn Extreme Environments Rig” (GEER) [4], at NASA Glenn Research Center in Cleveland in August 2018. The CO_2-N_2 gas mixture experienced experimental conditions of 100 bar at various temperatures in a 66 cm vertical steel pressure vessel with an internal diameter of 8.7 cm. The composition of the gas mixture was measured using gas chromatography at the top, middle and bottom of the vessel, to investigate the vertical composition gradient. To increase the accuracy of the measured abundance of nitrogen, mass spectrometry was also used in some cases. The first step in our experiment was to use the H13 experimental conditions, with a mixture of 50% CO_2 / 50% N_2 at 296K and 100 bar, to inquire whether the strong vertical gradient observed (i.e. 70% N_2 at the top, 10% N_2 at the bottom) in the H13 18-cm tall experimental vessel [3] was reproducible. Then, fixing the temperature at 310K and the pressure at 100 bar, we varied the abundance of nitrogen from 50% to 3%, to reach a proportion resembling the Venus atmosphere. In a second phase, maintaining the pressure at 100 bar and the nitrogen abundance at 3%, the temperature was step-wise increased up to 735K, so as to reach Venus's near-surface conditions. At every step, the vertical gradient of nitrogen in the 66-cm high vessel was measured.

Preliminary results: For each test condition, the CO_2-N_2 mixture was delivered to the vessel by two different methods. First, CO_2 and N_2 were premixed in a separate tank and then transfered to the the vessel as a single, well-mixed fluid. Gas chromatography was used to verify the mixture before transferring to the vessel. Secondly, after evacuating the test vessel, a layered mixture was inserted by first injecting CO_2, then N_2 – the same type of technique performed in the H13 experiment. A full analysis of our experiment results has not been completed. An initial inspection of the data appears to indicate that:

(1) For the well-mixed batch of gas, the composition was measured at all three ports during roughly 15 hours in each configuration. The results appeared to be the same: the composition is identical at all three ports, and stable. No density-driven separation is observed.

(2) To understand the H13 experiment, the same protocol was used: introducing CO_2 first, then N_2. To reproduce a similar mixture of gas, the masses used for each gas were roughly the same. In these cases, the first samples indicated nearly 100% CO_2 at the bottom port and nearly 100% N_2 at the top port. The composition evolved very slowly over time at each port, with time scales of the order of days. The composition was measured over at least 24 hours, over 3 days for the first and last tests.

As stated above, the results of these tests are still preliminary and a determination on our original hypothesis cannot be made until all the data are fully analyzed.

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Acknowledgements: The team acknowledges support from NASA Solar System Workings Program.

INVESTIGATIONS BELOW THE CLOUDS OF VENUS WITH THE IPSL VENUS GCM. S. Lebonnois[1], G. Schubert[2], F. Forget[1], I. Garate-Lopez[1,3], A. LeSaux[1], T. Navarro[2], A. Spiga[1], [1] LMD/IPSL, Sorbonne Université, Campus P&M Curie, CNRS, Paris, France (sebastien.lebonnois@lmd.jussieu.fr), [2] Department of Earth, Planet. and Space Sci., UCLA, Los Angeles, CA, USA, [3] Universidad del País Vasco/Euskal Herriko Unibertsitatea (UPV/EHU), Bilbao, Spain.

Introduction: Thanks to the various space missions that investigated Venus's atmosphere since the 70's, and in particular the recent Venus-Express (Europe, 2006-2014) and Akatsuki (Japan, 2015-) missions, the atmosphere of Venus above roughly 45 km altitude including the clouds (~48-70 km) has been thoroughly investigated. This vast amount of data helps to understand how this complex atmospheric system works, in particular with the help of advanced Global Climate Models (GCMs). However, data from below the clouds are sparse, despite the importance of the deep atmosphere in the global behavior of Venus's atmospheric system: peak of angular momentum content, interactions between surface and atmosphere (including angular momentum exchange, volcanism, weathering). A better knowledge of the region is also needed for specific mission planning purposes, such as aerial platforms or landers.

Investigations with the IPSL Venus GCM: To investigate this region while planning new missions, GCMs are valuable tools and we review here all the studies conducted on this region with the IPSL Venus GCM developed in Paris [1,2].

Radiative transfer improvements. To model the temperature profile in the deep atmosphere, it is crucial to investigate the radiative transfer and the opacity sources below the clouds. [3] studied how the solar energy absorbed below the cloud may be balanced with infrared energy heating the base of the cloud, convecting up to the middle cloud to escape finally to space mostly in the 20-30 micron region. Using recent solar flux calculations [4] and up-to-date datasets for IR gaseous opacities and collision-induced absorptions, the temperature profile in our GCM is tuned through assumptions on the haze below the cloud to fit the observed temperature profile between the cloud base and the surface.

Wave activity near and below the cloud-base. Though we obtain realistic superrotation in the upper cloud, the vertical profile of zonal wind observed below 60 km is not fully understood. Around the cloud base (40-60 km), wave activity obtained in our most recent simulations contributes to angular momentum convergence in the equatorial region [2]. In previous simulations [1], large-scale gravity waves were transporting angular momentum equatorward and downward, improving the distribution of zonal wind below 40 km. As both wave activities are not obtained in the same simulations, we are investigating the conditions for the development of each of these wave groups.

Planetary Boundary Layer. Near the surface, the IPSL Venus GCM was also used to investigate the behavior of the Planetary Boundary Layer (PBL), in particular diurnal convective activity [5]. The deepest 10 km above the surface are neutrally stable in our simulations, a peculiar environment for the diurnal cycle of the PBL. A nocturnal stable layer is obtained due to cooling of the surface during nighttime. In daylight hours, convection develops in mid- to low-latitude regions, with a maximum around noon and a convective layer mostly limited to just over 1 km thickness. Strong slope winds are obtained in the simulations, with a diurnal cycle: downslope katabatic winds at night, upslope anabatic winds during daytime. The convergence of anabatic winds at noon over the western slopes of topographic features induces a large increase in the vertical extension of the convective activity, reaching higher than 5 km thickness in some of these regions.

Topographic waves. The interactions between the near-surface flow and the topography are also explored with the IPSL Venus GCM [6]. A parameterisation of the drag due to orographic gravity waves generated by topographic features is now implemented and can help interpret the stationary bow-shape waves observed at cloud-top by the Akatsuki spacecraft [7].

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Acknowledgements: This work is supported by the INSU/Programme National de Planétologie. Most of the simulations of the IPSL Venus GCM are done at the HPC facility of CINES, supported by the GENCI project number 11167.

Simulations of ion flow and momentum transfer in the Venus environment. S. A. Ledvina[1] and S. H. Brecht[2], [1]Space Sciences Lab, University of California, Berkeley, CA 94720, Ledvina@berkeley.edu, [2]Bay Area Research Corp. Orinda CA 94563, sbrecht@pacbell.net.

Introduction: The solar wind interaction with Venus produces a particularly unique feature. *Lundin et al.,* [2011] using observations from Venus Express (VEX) found the existence of a large-scale vortex-like ion flow pattern in the Venus plasma tail. The flow pattern is characterized by a dominating anti-sunward flow, also a lateral flow component of solar wind (H^+) and ionospheric (O^+) ions. The lateral flow component is directed opposite to the Venus orbital motion. The combined anti-sunward and lateral H^+ and O^+ flow wraps over the planetary atmosphere, from the terminator into the nightside. The net lateral flow near Venus is in the direction of the Venus atmospheric super-rotation. Further down in the Venus plasma tail the flow display a circular motion around the central tail axis. This large-scale vortex ion flow pattern has not been observed at other planets or in any simulation of Venus interacting with the solar wind. *Lundin et al.,* [2011] speculated that the observed vortex features are driven by the orbital motion of Venus transverse to the solar wind.

Furthermore *Lundin et al.,* [2011] postulated that the general agreement in direction between the nightside ion flow over the Northern hemisphere, and the retrograde motion of the Venus atmosphere, implies a cause-effect relation between the ionospheric O^+ flow and the atmospheric neutral flow. Thus leading them to the question: Is the super-rotating upper atmosphere at Venus a consequence of solar wind forcing? Is the ion flow capable of accelerating, and maintaining, a super-rotating upper atmosphere at Venus?

In this presentation the hypothesis of *Lundin et al.,* that the orbital motion of Venus transverse to the solar wind flow drives the ion tail vortex and potentially the super-rotation up the upper atmosphere is tested. We perform hybrid (kinetic ion, fluid electron) simulations of the Venus solar wind interaction using the HALFSHEL code. The simulations include models for the ionospheric chemistry, ion-neutral collisions, Hall and Pederson conductivities. The model atmosphere (densities and dynamics) used in the simulations are taken from the VTGCM code. The orbital motion of the planet is included in the simulations by moving the planet each time step. The Venusian ion tail is examined to check for the ion vortex. Furthermore, we examine the magnitude and location of the energy and momentum deposited into the neutral atmosphere by the solar wind and pickup ions to examine the postulate that ion flow is capable of accelerating and maintaining the super-rotation in the upper atmosphere of Venus.

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AN ASTROBIOLOGY ASPECT FOR EXPLORING VENUS CLOUDS.
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Introduction: Venus' clouds are responsible for nearly half of the energy absorbed from the sun by the planet at wavelengths < 600 nm [1], yet the many identities of the absorbers responsible across the solar spectrum are still unknown. While more than a dozen possible absorbers have been proposed, no individual candidate satisfactorily explains the contrasts and temporal evolution of the cloud features.

Recently, the potential for bioorganic contributions to Venus' contrasts has been discussed [2]. The possibility of life was explored earlier by Morowitz and Sagan [3] and investigated further by Cockell [4] and discussed by Grinspoon [5], Grinspoon and Bullock [6] and others [7-9] Life could have evolved on Venus independently when it had liquid water on its surface with the same life sustaining biochemistry present in Earth's early atmosphere [10, 11].

In the lower cloud layer (47.5-50.5 km), the estimated pH of the aerosols is ~0, the atmospheric pressure is ~ 1 atm, and temperature is ~60 ˚C, which together are compatible with many forms of terrestrial microbial life. The aerosols in the lower clouds also account for ~70% of the total columnar mass, with particles of 2-8 μm in diameter (mode 2' and 3) comprising ~94% of the mass within the lower clouds. For these particles, the physiochemical comparisons show similarities between the (i) size regime for the Venus aerosols and the aerosols from Earth containing cultivable bacteria, (ii) estimates of theoretical Venus biomass and cell densities with measured values from Earth, and (iii) estimates of Venus mass extinction coefficients with those obtained from ground-based spectroscopic studies.

Together, these similarities suggest that Venus' aerosols contain sufficient mass to harbor microorganisms, water, and bulk solutes, and sufficient mass optical extinction coefficients to be amenable to spectral studies for habitability or life. Further, when considering Venus' atmospheric constituents and terrestrial microbial analogs (for life in low pH, high temperature, and sulfur-rich environments), a plausible geochemical cycle, inclusive of the phototrophic reduction of CO2 and a coupled Fe/S metabolism can be constructed.

Venus once had an ocean of liquid water [12]. Volcanism has been a dominant geologic process on Venus, and recent observations by Venus Express suggest that Venus may still be volcanically active [13]. As Venus lost its surface water over time, it is possible that thermophilic and sulfur-metabolizing bacteria may have been transported into the atmosphere, ultimately finding a habitable niche in the clouds. Hence, Venus' cloud contrasts may currently include contributions from sulfur compounds, other chemicals, and microorganisms. The spectral similarity between Venus' cloud contrasts and terrestrial biomolecules support this premise [2]. Further, the persistent nature of the contrasts suggest the presence of solar cycles, and contributions from gravity waves and convection, and possibly explain at least some of the observed long-term variations of Venus' UV albedo [14] which may be due to the effects of EUV radiation on the microorganisms at the cloud tops.

Previous studies on Venus' clouds could not distinguish between abiotic and biological aerosols. We need laboratory measurements of the physical, chemical, spectral, and biological properties of terrestrial candidate microorganisms capable of thriving in Venus' clouds. The biological explanation of absorption and cloud contrasts can be tested by examining the nature and identity of the absorbers from aerial platform missions with Raman and UV-Visible spectrometers, imaging microscopes, and other life detection instruments [15, 16]. Cloud layer acidity level (pH) measurements will be crucial because microorganisms can modify the environmental pH.

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OBSERVATIONAL ANALYSIS OF VENUSIAN ATMOSPHERIC EQUATORIAL WAVES AND SUPERROTATION. R. M. McCabe[1], K. M. Sayanagi[1], J. J. Blalock[1], J. L. Gunnarson[1], J. Peralta[2], C. L. Gray[3], K. McGouldrick[4], T. Imamura[2], and S. Watanabe[5], [1]Atmospheric and Planetary Sciences, Hampton University, 23 E Tyler Street, Hampton, VA 23661 (rymccabe999@aol.com), [2]Institude of Space and Aeronautical Sciences, JAXA, [3]Apache Point Observatory, Sunspot, NM, [4]Laboratory for Atmospheric and Space Physics, University of Colorado Boulder, [5]Earth and Planetary Science Department, Hokkaido University.

Introduction: We investigate the dynamics of Venus's atmosphere in an attempt to link variability of atmospheric superrotation to the existence and occurrences of the Y-feature seen at ~365 nm, representing an altitude of ~65 km. The atmospheric superrotation, in which the equatorial atmosphere rotates with a period of approximately 4-5 days (~60 times faster than the solid planet), has forcing and maintenance mechanisms that remain to be explained. Temporal evolution of the zonal wind could reveal energy and momentum transport in or out of the equatorial region and shed light on mechanisms that maintain the superrotation. We postulate that the Y-feature is a manifestation of equatorial waves (Kelvin, Rossby, or a combination of the two) [2,5,6] that may play a role in such energy transport that could affect superrotation. To understand the connection between the Y-feature and the superrotation, we must determine the frequency of Y-feature existence, the variability of the atmospheric wind field, and analyze the connection between the two to determine to what extent the Y-feature plays a role in Venus's superrotation.

Results: We characterize the total and annual zonal mean wind fields of Venus between 2006 and 2013 in ultraviolet images captured by the Venus Monitoring Camera on board the ESA Venus Express (VEX) spacecraft which observed Venus's southern hemisphere. Our measurements show that, between 2006 and 2013, the westward wind speed at mid- to equatorial latitudes exhibit an increase of ~20 m/s, similar to that of previous measurements [4]. We additionally examine wind speed dependencies on both longitude and local time. There is a longitudinal variation at mid- to equatorial latitudes of about 15-20 m/s and a local time variation in similar latitude ranges of about ~20-25 m/s, similar to past measurements [1,3]. We also conduct ground-based observations, concurrent to observations by the Japanese spacecraft Akatsuki, with the 3.5 m ARC telescope at the Apache Point Observatory (APO) in Sunspot, NM to extend our temporal coverage to present. Images captured at APO to date demonstrate that it is possible to see large features that could be used to confirm the Y-feature existence to later be compared to future wind analyses of Akatsuki images. The viability of tracking the existence of the Y-feature during VEX and Akatsuki is discussed and the analysis of such occurrences and wind field variability is ongoing.

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CAPRICIOUS CYTHEREAN CLOUDS: THE LONG AND THE SHORT OF IT. K. McGouldrick[1], J. Peralta[2], C. C. Tsang[3], J. Barstow[4], and T. Satoh[2,5], [1]University of Colorado Boulder, [2]Japan Aerospace Exploration Agency, [3]Southwest Research Institute, [4]University College London, [5]Sokendai University.

Introduction: Variations in the condensational clouds of Venus at altitudes between roughly 45 km and 60 km altitude were first revealed by Allen and Crawford [1]. Understanding these variations was a primary goal of the VIRTIS instrument on Venus Express [2]. And these variations are also being leveraged by Akatsuki in a continuing effort to understand the super-rotation of the Venus atmosphere [3].

Background: We previously characterized the evolution of individual features by using data from VIRTIS-M-IR on Venus Express to quantify the variability of those features [4]. That work found that individual features evolved on time scales typically of about one day (24 hours), though smaller features were seen to form and/or dissipate on much shorter time scales (as short as the 30 minute cadence of the analyzed data). That work also found that the mesoscale dynamics in the vicinity of the features was consistent with the circulation that would develop in response to convergence and divergence on an Earth-sized planet having a seven-Earth-day rotation period. More recent work found a roughly 150-Earth-day periodicity in the 1.74μm radiance, indicating long-term, periodic, variations in the cloud cover are also present [5]. These long-term variations were most pronounced at mid-latitudes (30°−60°), but could not be ruled out at equatorial latitudes (0°−30°), due to the observation geometry of VIRTIS. No long-term polar (60°−90°) trends were noted.

Present Work: In the present work, we build on those previous efforts in two ways. First, we demonstrate a baseline whereby results from VIRTIS (a medium-resolution imaging spectrometer) can be quantifiably compared with images through the several filters of the IR2 camera on Akatsuki. Next, we quantify the physical changes in the clouds that are observed at different times of high or low overall cloud opacity, and attempt to leverage this information to produce a reasonable picture of both long- and short-term cloud evolution in the constantly changing, capricious, clouds of Venus.

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CHARACTERISTICS OF THE VENUS LOWER ATMOSPHERE: PROPERTY COMPUTATIONS, MODELING AND SIMULATIONS. S. Morellina[1] and J. Bellan[1,2], [1]Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, MS. 125/109, Pasadena CA 91109; [2]Mechanical and Civil Engineering Department, California Institute of Technology, Pasadena, CA 91125, Josette.Bellan@jpl.nasa.gov

Introduction: During the early Venus history, the Venus Planetary Boundary Layer (PBL) was instrumental in the establishment of the planet super-rotation. Also, the PBL is one of the governing aspects in determining the characteristics of the planet's upper troposphere and tropopause. Moreover, understanding the Venus PBL is crucial in Venus exploration because landers must interact with this turbulent high-pressure high-temperature environment. The NASA Glenn GEER facility is currently experimentally studying this environment, and modeling and simulations are necessary to physically interpret that data. The present study is initializing computations, modeling and simulations of the Venus PBL, considering that this knowledge continuously changes interpretation [1].

A rigorous computation of the fluid viscosity and density for the Venus lower atmosphere conditions will be presented that permits, to our knowledge for the first time, the quantititative estimate of the Reynolds number of the flow in the lower Venus atmosphere. The thus computed Reynolds number is very large, in the fully turbulent regime. Further, using thermodynamic concepts verified with experimental data [2] the spinodal loci of CO_2, CO_2/N_2, five, seven and eleven Venus-species mixtures are computed and visualized, permitting to determine the thermodynamic stability regime. To obtain physical insights [3], Direct Numerical Simulations are ongoing to address a Venus three-dimensional vertical slice of 1.1 km in height that is located 1-2 km off the ground. Once analyzed, these results will provide much needed information, particularly the effective Prandtl number spatial distribution which would impact Venus lander design.

Thermodynamic regime: To compute the spinodal, several sets of species are considered as shown in Table 1. The results of Figure 1a show that as long as the thermodynamic calculation includes more than one species of the lower Venus atmosphere, the spinodals coincide. This is attributed to the much larger mole fraction of N_2 than of all other trace species. The end result as far as the phase diagram is independent of this fact: the lower Venus atmosphere is in the single-phase regime, as shown in Figure 1b. This fact does not prevent though the possibility of uphill diffusion, a phenomenon occurring when minor species are present and is due to their fluxes being coupled to those of major species [4].

	1 species	2 species	5 species	7 species	11 species
χ_{CO_2}	1	0.96499	0.96482	0.964816395	0.964693
χ_{N_2}	-	0.03501	0.03500	0.03500	0.03500
χ_{SO_2}	-	-	0.00015	0.00015	0.00015
χ_{H_2O}	-	-	$3\text{x}10^{-5}$	$3\text{x}10^{-5}$	$3\text{x}10^{-5}$
χ_{H_2S}	-	-	$3\text{x}10^{-6}$	$3\text{x}10^{-6}$	$3\text{x}10^{-6}$
χ_{HCl}	-	-	-	$6\text{x}10^{-7}$	$6\text{x}10^{-7}$
χ_{HF}	-	-	-	$5\text{x}10^{-9}$	-
χ_{Ar}	-	-	-	-	$7\text{x}10^{-5}$
χ_{CO}	-	-	-	-	$3\text{x}10^{-5}$
χ_{He}	-	-	-	-	$1.2\text{x}10^{-5}$
χ_{Ne}	-	-	-	-	$7\text{x}10^{-6}$
χ_{OCS}	-	-	-	-	$4.4\text{x}10^{-6}$

Table1: Mole fractions, X_i, of Venus lower atmosphere where the species are designated by *i*.

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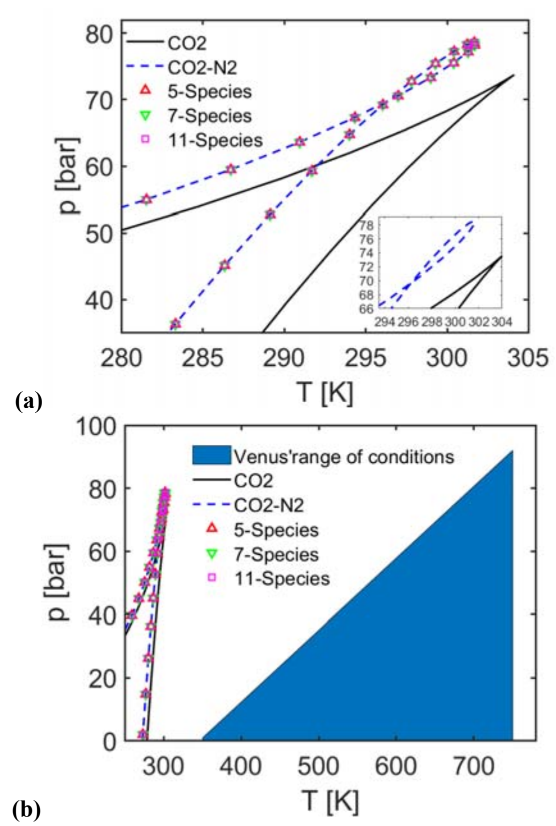

Figure 1 (a) Comparison in the (p,T) plane between spinodal loci for different mixtures. (b) The Venus lower atmosphere regime is highlighted on the thermodynamic phase diagram, where spinodal loci of Venus-like lower atmosphere mixtures are shown.

DETECTING CRUSTAL REMANENT MAGNETISM ON THE SURFACE OF VENUS: REQUIRED INSTRUMENT PERFORMANCE AND MISSION DESIGN. J. G. O'Rourke, SESE Exploration Postdoctoral Fellow, School of Earth and Space Exploration, Arizona State University, Tempe, AZ, USA (jgorourk@asu.edu).

Introduction: Venus is the only major planet with no known evidence for an internally generated magnetic field either today or in the past. Pioneer Venus Orbiter constrained the intrinsic dipole moment of Venus to less than 10^{-5} times that of Earth [1]. Crustal remanent magnetism—as already observed on Mercury, Mars, Earth, and Moon [2]—may still await detection because the surface temperature is currently below the Curie points of common magnetic carriers such as magnetite and hematite [3]. However, no magnetometer measurements have been made below the ionosphere—let alone a global search for magnetic signatures. Detecting crustal remanent magnetism would provide strong evidence that Venus and Earth both suffered energetic impacts during accretion, which formed metallic cores that were initially liquid and chemically homogenous. A non-detection would indicate formation under cold conditions, and thus that Venus and Earth always evolved along different paths.

Motivational Modeling: Previous presentations described numerical simulations that assessed the prospects for a dynamo in Venus over time [3]. Atmosphere/interior coupling was implemented to account for feedbacks between atmospheric evolution and mantle convection, including atmospheric escape and changes in mantle convective regime with surface temperature [4,5]. Core/mantle heat flow governs the thermal and chemical evolution of the core.

The key result with implications for Venus exploration is that dynamo activity within the surface age (~1 Gyr) is predicted even in simulations with no dynamo at present day, assuming that Venus has an "Earth-like" (chemically homogenous and at least partially liquid) core. An alternative scenario—chemical stratification in the core (Si & O abundances increasing with radius) that persists after accretion [6]—predicts no dynamo activity at any time. Completely solidifying the core of Venus [7] requires initial temperatures so low that stratification would also exist.

Searching for Crustal Remanence: Designing a magnetic survey requires estimating the magnitude of potentially observable fields and defining the associated requirements on instrument performance and mission design. Previous simulations yield estimates for the cumulative volume of magnetized crust—obtained by counting the volume of extrusive volcanism during periods of dynamo activity. Terrestrial basalt is an analogous carrier for thermoremanent magnetism. Crust that is buried below the depth where temperature equals the Curie point will have demagnetized. The lateral extent of individual lava flows and temporal pace of resurfacing remain critical unknowns [8].

Aerial platforms are ideal for a magnetic survey because of the possibility of covering long distances. Low altitudes are ideal because magnetic fields decay sharply with distance. Magnetometer performance requirements are defined assuming that the mission is focused on a search for remanent magnetism (unlikely) and also assuming that the platform primarily resides at altitudes convenient for achieving other science goals like EM sounding [9] and atmospheric studies.

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Science Goal	**Science Objective**	**Physical Parameter**	**Observable**	**Instrument Performance Requirements**	**Mission Requirements**
Understand potentially habitable environments on Venus over time for comparison to Earth and exoplanets	What processes and conditions defined the divergent evolutions of Venus and Earth?	Remanent magnetic field	Magnetic flux density	Magnetometer: - Sensitivity - Accuracy - Precision - Range	Measurements below the ionosphere of Venus: - Altitude - Distance covered Observing geometry: - Multiple sensors separated by ~1 m Estimated data volume

FEASIBILITY AND MASS-BENEFIT OF AEROCAPTURE FOR SMALLSAT MISSIONS TO VENUS. A. Pradeepkumar Girija[1], Y. Lu[2], and S. J. Saikia[3], [1]apradee@purdue.edu, [2]yelu@purdue.edu, [3]ssaikia@purdue.edu, School of Aeronautics and Astronautics, Purdue University, 701 W. Stadium Ave., West Lafayette, IN, 47907.

Earth's Unidentical Twin Planet: Venus and Earth are considered planetary twins due to their identical size, bulk densities, and similar surface conditions during the beginning of the solar system. Despite the similarities, Venus is often referred to as Earth's unidentical twin—a hot hellish world with no oceans and a thick corrosive atmosphere. Understanding Venus is also important in assessing whether newly discovered Earth-size exoplanets may be habitable worlds [1].

Figure 1: Left: Venus cloud structure in the ultraviolet (UV) band from Pioneer Venus Orbiter, 1979; Right: Radar image of Venus from Magellan, 1994.

Need for Venus Missions: Venus has been studied using orbiters, entry probes, landers, and balloons providing critical measurements in advancing our understanding of the planet [2]. Though past missions have provided a wealth of information, major questions remain regarding the formation about the origin and formation of the planet and its climate [3].

Lack of Missions to Venus: After more than four decades of vigorous exploration beginning in the 1960s, the number of Venus missions has been relatively low in the past two decades. There have been no US missions to Venus since Magellan (1989). Two of the five finalists of Phase A in NASA's Discovery program in 2016 were Venus missions, but neither was selected for flight. Three Venus missions were proposed to New Frontiers AO in 2017, but none were selected [4]. NASA has turned attention to SmallSats for low-cost Venus missions as a gap filler between Magellan and a future Discovery or New Frontiers class mission [4].

Aerocapture for SmallSat Missions: Aerocapture uses atmospheric drag to decelerate and capture a spacecraft into a closed orbit, eliminating the need for carrying significant propellant. To compensate for uncertainties in entry flight path angle, atmospheric density profiles, and vehicle aerodynamics, and still achieve the desired atmospheric exit state, the aerocapture vehicle needs control authority. Drag modulation is a simple control technique which is attractive to SmallSats [5]. Control authority is deemed adequate if the technique offers a theoretical entry corridor width sufficient to accommodate the uncertainties.

Aerocapture Feasibility Chart: Detailed feasibility charts will be presented for three aerocapture control methods—lift modulation, drag modulation, and a hybrid propulsive-aerocapture technique. Key design variables for drag modulation aerocapture are ballistic coefficient ratio before and after drag skirt separation (β_2/β_1) and hyperbolic arrival speed V_∞.

Figure 2 graphically presents the constraints imposed by theoretical corridor width, deceleration load, peak heat rate, and heat load for single-event drag modulation aerocapture at Venus. The boundaries of the shaded feasible region show that the corridor width and peak heat rate are dominant constraints for aerocapture with drag modulation at Venus.

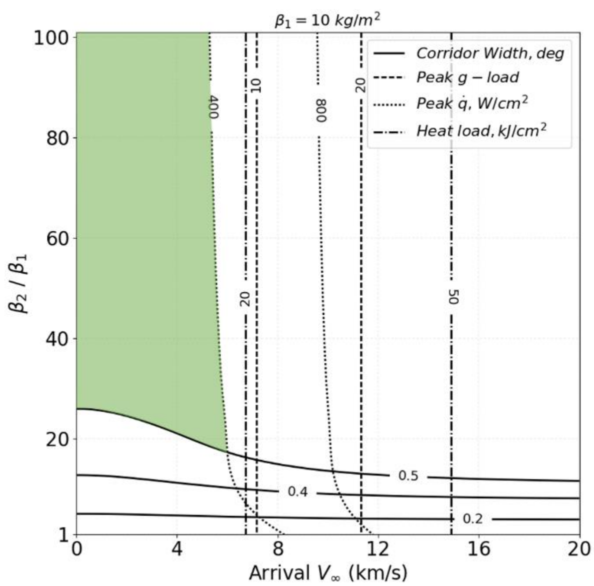

Figure 2: Venus aerocapture feasibility chart for single-event drag modulation. To obtain at least 0.5 deg. of theoretical corridor width and limit peak heat rate to 400 W/cm², a β_2/β_1 ratio of 17 or greater is required. Nose radius R_N =0.1 m is used to estimate the stagnation point heating rate.

Mass-Benefit Analysis: Delivered mass for SmallSats using three aerocapture control methods will be presented and compared to propulsive orbit insertion to quantify the mass-benefit of aerocapture at Venus.

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FEASIBILITY OF HYPERVELOCITY SAMPLING OF NOBLE GASES IN THE UPPER ATMOSPHERE OF VENUS.
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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 atmosphere. Noble gases act as tracers of the evolutionary process of planets, as their concentration ratios are correlated to processes such as the original supply of volatiles from the solar nebula, delivery of volatiles by asteroids and comets, escape rate of planetary atmospheres, and degassing of the interior and its timing in a planet's history. Performing high-fidelity noble gas measurements in the Venus atmosphere would 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: The Cupid's Arrow mission concept is a small spacecraft skimmer that would sample the Venus atmosphere below the homopause where the different atmospheric compounds are well mixed [1]. Four samples of Venus atmosphere would be acquired at periapsis, and then noble gas concentrations for each sample would be determined with a miniaturized Quadrupole Ion Trap Mass Spectrometer (QITMS) [2,3]. Velocity at periapsis, where sampling is to occur, is expected to be ~10.5 km/s, and the altitude is expected to be ~110 km. One potential issue with this mission architecture relates to whether or not a sample that is collected by the spacecraft is representative (compositionally) of Venus' atmosphere. Due to the high velocity of the spacecraft and associated high enthalpy of the flow, complicated thermodynamic and fluid mechanical processes occur around the spacecraft and associated sampling system. Therefore, it should be demonstrated that elemental and/or isotopic fractionation processes do not significantly alter the relative concentrations of the gas to be measured by QITMS. In order to address this topic, both experimental and modeling work is being performed, though this work will focus on numerical modeling progress.

Numerical Simulations: The Direct Simulation Monte Carlo (DSMC) code SPARTA, an open source software package developed by SANDIA National Laboratories [4], is used in this work. SPARTA, based on Bird's DSMC method [5], 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 Results: Preliminary simulations have been run for simplified spacecraft and sampling system geometries in both 2D axisymmetric and full 3D configurations. Preliminary results show that while there is no significant isotopic fraction for Xe or Ar isotopes, the total ratio of Ar to Xe does change throughout the domain. Additional simulations are being performed in order to investigate the sensitivity of the numerical results to a wide range of parameters that include, but are not limited to: 1) thermo/chemical models, 2) surface models, 3) sampling geometry (valves, orifices, tanks, etc.), 4) initial gas compositions, 5) vehicle velocity and attitude, 6) 2D vs 3D simulation frameworks, and 7) freestream flow properties. Numerical simulation results will help inform the overall spacecraft and sampling system design.

Conclusion: Through a combination of numerical and experimental work, 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 allow an optimized Cupid's Arrow spacecraft to be designed, and also demonstrate whether or not elemental and/or isotopic fractionation is expected to contaminate scientific measurements performed by QITMS on gas samples acquired in the upper atmosphere of Venus.

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Acknowledgements: Parts of this work have been performed at the Jet Propulsion Laboratory, California Institute of Technology, under contract to NASA. Sandia National Laboratories is a multi-mission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525. The information in this paper is pre-decisional and is presented for planning and discussion purposes only.

Venus' Ishtar Terra: Topographic Analysis of Maxwell, Freyja, Akna and Danu Montes. Sara Rastegar[1] and Donna M. Jurdy[2], [1]City Colleges of Chicago, Harold Washington College, 30 E. Lake Street, Chicago, IL 60601, sara.rastegar@gmail.com, [2]Department of Earth and Planetary Sciences, Northwestern University, 2145 Sheridan Rd, Evanston, IL 60208, donna@earth.northwestern.edu

Introduction: Venus' mountain chains (Figure 1) surround Lakshmi Planum, a 3-4 km highland, making up Ishtar Terra. No other mountain belts exist on Venus. Circling Ishtar Terra, Maxwell Montes, ascends to over 11 km, ranking as the location of highest elevation on the planet. Freyja Montes rises to over 7 km, higher than Akna Montes at about an elevation of 6 km. Danu Montes, ~1.5 km over Lakshmi Planum, alone displays a distinctly arcuate form.

Tectonic Enigma: The existence of the four venusian mountain chains has been attributed to localized downwelling - analogous to terrestrial subduction - in response to the proposed upwelling beneath Lakshmi Planum [1,2]. If so, why the asymmetry in the location of the mountain chains, the differences in their elevation and structural topography? Regional E-W shortening (compression), surrounding the planum may have subsequently modified Maxwell and Freyja Montes, as evidenced by the folds and faults [3].

Analysis: We attempt to address these questions with analysis of Magellan topographic data for quantitative comparison of Venus' four mountain chains: Maxwell, Freyja, Akna and Danu. Patterns in topography may provide clues to the dynamics forming these Venusian orogenic belts. From topographic profiles across the ec mountain chain, we then determine an average profile for each mountain belt. Next, we correlate these averages to establish a measure of similarity between the chains and terrestrial analogs. These correlations allow construction of a covariance matrix, which can be diagonalized for eigenvalues, for Principal Component Analysis (PCA) [4].

Summary: PCA allows an independent and objective mode of comparison of the venusian mountains with terrestrial counterparts with known tectonic origins. Comparison can be made with other topographic features on Venus, such as the chasmata.

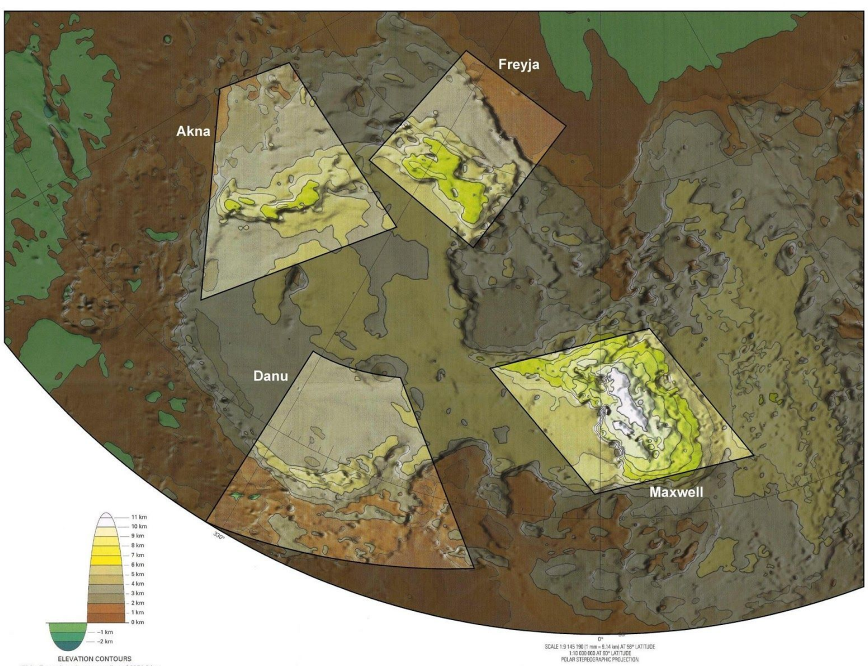

Figure 1; Topographic Map of the Ishtar Terra Region of Venus, USGS, V 1OM 9O/O RTK, 1998

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CREWED VENUS FLYBY: PRECURSOR TO MARS. K. D. Runyon[1], N. R. Izenberg[1], R. L. McNutt[1], C. E. Bradburne[1], M. Shelhamer[2]. [1]Johns Hopkins University Applied Physics Laboratory, Laurel, MD, USA (kirby.runyon@jhuapl.edu), [2]Johns Hopkins University Institutes of Medicine, Baltimore, MD, USA.

Introduction: Humans' first planetary foray out of the Earth-Moon system may well be on a flyby exploration mission of Venus. Not only would such a mission provide exploration and science opportunities at and on Venus, but would also serve as needed deep space practice for the first humans-to-Mars mission. This is a separate consideration from Venus flybys on the way to Mars in the same mission.

Communications Latency: On or orbiting Mars, astronauts will experience telecommunications latency with Earth due to the finite speed of light. The round-trip light travel time between Earth and Mars ranges from 6.4 minutes to 44 minutes, making real-time conversations impossible. For Venus, the same metric ranges from 4.6 minutes to 28 minutes (calculated via data from Wolfram|Alpha): comparable to the Mars case. A human Venus mission will give practice for dealing with this communications latency while providing a compelling exploration destination other than empty space such as a Lagrange point. In analog simulations, EVA crew have found that the equivalent of text messaging seems the best way to communicate with such a latency (Abercromby et al., 2013).

Crew Health: Information is currently lacking on the physiological and cognitive effects of long duration spaceflight outside Earth's magnetosphere on mission scenarios lacking a quick Earth-return capability. While a human Venus flyby mission would be shorter than even a human Mars flyby mission, it would not afford the opportunity to return to Earth at any time, unlike LEO and lunar missions. With the telecommunications latency, such a mission would provide emotional stressors and the opportunity to characterize and mitigate them for longer Mars missions.

Accessibility and Radiation: Venus, on average, is much closer to Earth (1.12 AU) than Mars (1.69 AU), allows for shorter overall mission durations (thus simplifying crew logistics and time in space) and has more frequent planetary alignments than Mars of every 19 versus 26 months. A human Venus flyby mission would take less than a year—shorter than some missions to the International Space Station—and yet still emulate a deep space transit with radiation levels and isolation challenges comparable to Mars transit.

Crewed Venus flyby missions enable multiple mission scenarios. All of these scenarios "kill two birds with one stone:" accomplishing human exploration and planetary science objectives for their own sake but also serving as test beds for more distant and longer-term human Mars missions. Specifically having a crew present en route, during, and after Venus flyby enables several mission architectures, including, but not necessarily limited to:

- Large, potentially modular probes or constellations launched in pieces and assembled by crew en route to Venus. Mission concepts includes cubesat – or larger – constellations [Majid et al., 2013], or probes launched in pieces in multiple SLS launches with final assembly en route to Venus,
- Real-Time Telemetry and human-in-the-loop probes actively guided in the Venus environment by human crew during the days or weeks around closest approach, where light-speed communication delays are minimal. These mission concepts include guide-able aerial platforms [Lee et al., Ashish et al] to surface rovers [Landis et al., 2003],
- Fast sample return from the Venus atmosphere, rendezvousing with the departing spacecraft instead of transiting to Earth. [Sweetser et al., 2014].

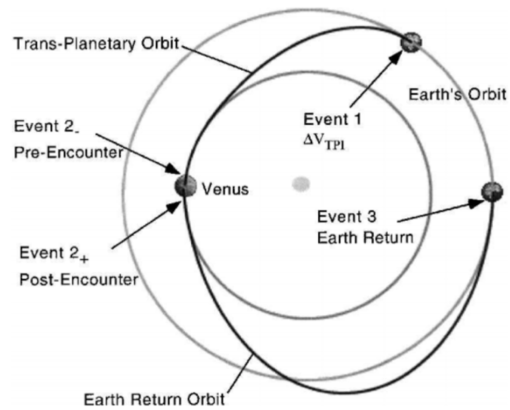

Fig. 2 Mission profile illustration (EVE).

Figure: Earth-Venus-Earth (EVE) mission (Crain et al., 2000)

Conclusion: A human Venus flyby simultaneously addresses human exploration and planetary science goals in addition to serving as an intermediate step to the longer range goals of a human Mars mission.

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LIFE DETECTION MICROSCOPE FOR VENUS CLOUD PARTICLE INVESTIGATION. S. Sasaki[1], Y. Yoshimura[2], A. Miyakawa[3], K. Fujita[4], T. Usui[4], S. Ohno[5] , A. Yamagishi[3] and S.S. Limaye[6], [1]Tokyo University of Technology, 5-23-22 Nishikamata, Ohta-ku, Tokyo 144-8535 JAPAN, [2]Tamagawa University, 6-6-1 Tamagawa Gakuen, Machida, 194-8610 Japan, [3]Tokyo University of Pharmacy and Life Sciences, 1432-1 Horinouchi, Hachioji, 192-0392 Japan, [4]JAXA, 3-1-1 Yoshinodai, Chuo-ku, Sagamihara, 252-5210 Japan, [5]Chiba Institute of Technology, 2-17-1 Tsudanuma, Narashino 275-0016 Japan, [6]University of Wisconsin, 1225 W. Dayton St, Madison, WI 53706, USA.

Venus clouds consist of droplets of 75-85% sulfuric acidic-water. However, sulfuric acid is not sufficient to explain the observed cloud contrasts and albedo of the planet [1], requiring other chemical species involved in absorption [2]. Active volcanos are expected on current Venus [3]. Based on the possible existence of the past liquid water, evolution and emergence of sulfur-metabolizing or thermophilic bacteria have been postulated [4]. Though surface of current Venus may be hostile to organic compound and living organism, there is area with moderate temperature and pressure several tens kms above surface on Venus. Limaye et al [4] have postulated the presence of microorganisms in the clouds, contributing to the spectroscopic characteristics. To distinguish biological aerosols from abiotic ones, missions with aerial platforms equipped with life detection instruments would be effective [4].

Life Detection Microscope (LDM) is well-suited for this purpose. LDM is designed to search for possible "cells" in the samples. LDM will be able to get high-resolution visible images of particles with 1 μm/pixel resolution. To distinguish biotic organic compounds from abiotic, LDM is equipped with an originally designed pigment system. Observation of biotic organic compounds surrounded by membrane is also feasible by the system [5]. The LDM detects life as particles carrying organic compounds characteristics of terrestrial life. Life on Earth utilizes organic compounds to sustain itself. The compounds are separated by an envelope, so-called membrane, from their environment so that variations in the external conditions would least affect their function. In definition, organic compounds surrounded by membrane ("cells") are the fundamental framework for terrestrial life. Organic compounds in a cell thus possess the catalytic activities to generate free energy to survive. Although no one knows yet what life on Venus clouds look like, as our biology stands on the dogma that all the terrestrial life has cells as the building block, it would be reasonable to apply the similar recognition for Venus life. With such assumption of life, LDM is capable of detecting and characterizing organic compounds by using a combination of fluorescent dyes, which is widely used in the field of biology.

Combination of fluorescent dyes will enable the detection of various compounds; i.e., those of abiotic origin such as polycyclic aromatic hydrocarbon (PAH), biotic organic compound seen inside cells such as DNA, RNA and proteins, or biotic organic compound surrounded by membrane. In addition, the product of catalytic activity will also be detected. Our microscope is, therefore, capable of identifying what we think to be the most fundamental features that a cell should have to maintain life, organic compounds surrounded by membrane having catalytic activity. In case of Mars LDM, in specific, fluorescence dyes named SYPRO Red, SYTO 24, propidium iodide and CFDA-AM will be used for these purposes, respectively. SYPRO Red can stain both PAH and protenoid. SYTO 24 can stain organic molecules inside cells irrespective of their state, dead or alive. Propidium iodide, on the other hand, stains only the dead cells. When cells are alive, membranes are functioning and are not permeable to hydrophilic molecules such as propidium iodide. This is why only organic molecules inside dead cells can be stained by propidium iodide. By combining SYTO 24 and propidium iodide, it is possible to distinguish living cells from dead cells. CFDA-AM will yield fluorescent compound upon the reaction catalyzed by esterase, which is the most common reaction found in terrestrial biological organisms [6]. Aerosol corrected on the aerial platforms such as Venus Atmospheric Mobile Platform can be analyzed by LDM [7].

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AUTOMATON ROVER FOR EXTREME ENVIRONMENTS: ENABLING LONG DURATION VENUS SURFACE MOBILITY

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

Background on Venus Rovers: Ideas for a long duration Venus rover began in the 1980s with the Russian DzhVS and the wind-powered Venerokhod rovers [1]. More recently radioisotope powered Stirling engines have been proposed to enable long duration landers [2] and rovers [3]. However, the concept still requires large amounts of R&D investment. A second approach would be to build a mission around gallium nitride or silicon carbide circuits, which have been demonstrated at Venus temperatures. Several long duration lander concepts use near-current technology [4]–[6]. However, current levels of integration are in the range of just a few hundred to thousand transistors, which results in extreme mission constraints when compared to the 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 Automaton Rover for Extreme Environments (AREE) is an exciting 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 high-temperature alloys, the automaton rover reduces requirements on electronics and requires minimal human interaction by utilizing concepts from robotics including behavior-based control and emergent systems. Similar to subsumption architecture, this yields complex robotic behavior from simple mechanical rules [9].

Instead of being reliant on image processing and onboard navigation, which cannot be done with available high-temperature electronics, 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, AREE 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, so it performs an obstacle avoidance maneuver.

While early concepts explored keeping the entire system mechanical it was determined a hybrid system would be most effective, combining high temperature electronics with mechanical systems. Mobility and obstacle avoidance are mechanical, whereas data storage and instruments are electrical. Communication could be mechanical or electrical, depending on technology readiness.

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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PROPULSIVE AEROCAPTURE FEASIBILITY AT VENUS. E. Shibata[1], [1]AirSat Engineering (eijishibata@airsatengr.com).

Introduction: For any orbiter mission to other planets, the spacecraft must be able to slow down from hyperbolic speeds to elliptical speeds. Traditionally, chemical propulsion has been used to provide that change in energy, expending large amounts of fuel for this single maneuver.

Aerocapture is an alternative to chemical propulsion, where an atmospheric pass is used to provide that change in energy. However, aerocapture has only been applicable to missions with higher entry velocities, as the available corridor width that a lift-to-drag ratio (L/D) can provide increases with entry velocity. Aeropropcapture (APC) is the use of propulsion, rather than lift, in an aerocapture maneuver[1]. Since propulsion does not depend on the dynamic pressure, APC can provide a larger available corridor width than lifting aerocapture at lower entry velocities. In APC, the engine(s) is located on the backshell of the vehicle at an angle ν from the velocity vector, which may not necessarily be at 90° (Figure 1). The thrust vector can be modulated both in magnitude and direction using throttle and roll control, respectively.

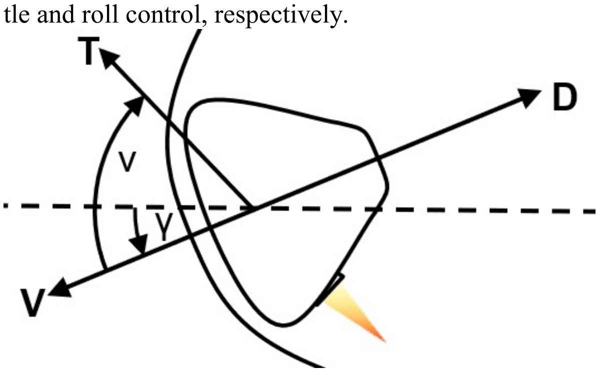

Figure 1: View of relevant vectors and angles for APC.

Aeropropcapture: In APC, propulsion is used as the source of control rather than lift. In Figure 2, the L/D is compared to the thrust-to-drag ratio (T/D) for a variety of thrust-to-weight ratios (T/W) on Venus, at a velocity of 11 km/s and ballistic coefficient (BC) of 200 kg/m^2. At lower velocities (and higher altitudes), the T/D is much larger than L/D, which in turn gives the vehicle a greater amount of control.

The shallowest and steepest entry flight angles allowed are found by varying the throttle and bank angle, and the different between the two is the theoretical corridor width (TCW). For Venus, the required corridor width considered is 1°[2]. Then, the BC, T/W, entry velocity, and desired final orbit sizes are varied to see the effects of those on the TCW. The required propellant mass fraction (PMF) of the resultant trajectories are also compared for different vehicle and entry conditions.

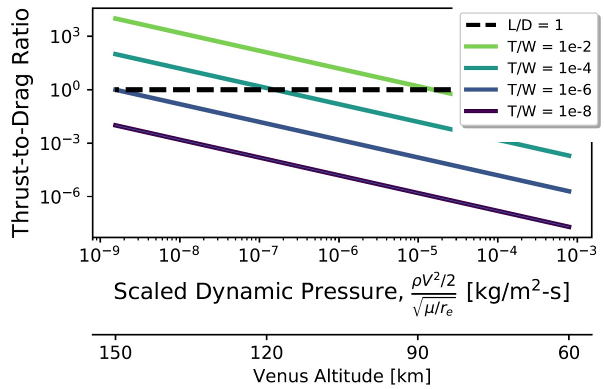

Figure 2: Comparison of T/W to L/D for a range of altitudes. Velocity is 10 km/s and BC is 200 kg/m^2.

Dual-Mode Aerocapture: An extension of APC is to combine both the lifting and propulsive forces to have a larger amount of control. The propulsion would enable lower L/D vehicles to reach the required corridor width at lower entry velocities. Here, the L/D and T/W would be constant, and controls are throttle and bank angle. Using both propulsion and lift increases the available corridor width relative to using just one, and allows the use of lower L/D and T/W vehicle designs.

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Venus Geodynamics, Habitability, and Initiation of Subduction, S. Smrekar[1] and A. Davaille[2], [1]Jet Propulsion Laboratory (USA), ssmrekar@jpl.nasa.gov, [2]CNRS/FAST, Univ. Paris Sud (France), anne.davaille@u-psud.fr.

Introduction: In addition to the push to find past or present life beyond our home planet, a key astrobiological objective is to understand what it takes to create a habitable world [1]. Currently we have one example of such a world: Earth. Understanding the divergent evolution of Venus from a geodynamic viewpoint is essential to understanding how Earth successfully developed and sustained life.

Plate tecontics and habitability: Plate tectonics may play a key role in supporting life on Earth. Since both life and plate tectonics began billions of years ago, their definitive origins are murky. However plate tectonics clearly drives the release of volatiles from the interior that forms the bulk of Earth's atmosphere and hydrosphere and the recycling of volatiles into the interior via subuction, thus strongly regulating long term climate [1]. Plate tectonics is responsible for cooling the mantle and driving the core dynamo that shields Earth from radiation. Erosion of continents introduces nutrients into the oceans. Subduction of carbon may have lead to the great oxidation event that promoted the flourishing of life [2]. An increase in continental area, due to creation of continents via plate tectonic processes, increased nutrient concentrations in the oceans via enhanced weathering.

Just as plate tectonics is a key process for Earth's habitability, Venus' geodynamic evolution is essential to understanding how it arrived at its current uninhabitale state. Given its similarities to Earth, a fundamental question for Venus is why does it lack plate tectonics? For a long time, the prevailing hypothesis was that Venus is too dry. A dry interior can make the lithosphere very strong, and may prohibit a low viscosity zone, both of which inhibit plate tectonics. However, numerous lines of evidence point to the fact that planets start with the bulk of their volatiles, which are outgassed via volcanism. Venus' Ar isotope data strongly suggests that Venus retains more interior volatiles than Earth, possibly due to the absence of plate tectonics. [3,4].

Plate tectonics and the initiation of subduction: A key question for plate tectonics on Earth is how did it transistion from a single plate to multiple plates? The initiation of subduction appears to be the necessary (but insufficient) first step as it allows for the lithosphere to fully break and initiates slab pull forces. One hypothesis is that mantle plumes are responsible for initiating subduction on Earth [5].

Venus may be undergoing present-day initiation of subduction, and providing a blueprint for how Earth may have transitioned to plate tectonics. Both Artemis and Quetzelpetlal Coronae appear to be locations of plume-induced subduction [5]. Artemis is by far the largest corona (2600 km diam.) and Quetzelpetlatl is the 3rd largest (800 km diam.). Several other smaller coronae, mostly located along major extensional belts, have also been proposed to be subduction zones. How common is plume-induced subduction on Venus and what are the conditions required for initiation?

Analytic [6] and numerical [7] models examine this question for Earth. The lithosphere must be weak enough to allow it break, yet strong enough to remain intact as it bends and sinks into the mantle. Lithospheric strength is dominated by temperature and composition. Venus' lithosphere is hotter than Earth's currently, but similar that of early Earth. For plume induced subduction, the lithosphere breaks due to extension driven by plume buoyancy. For a given mantle temperature, these requirements constrain the lithospheric thickness range favorable for plume-induced subduction (figure 1) [5].

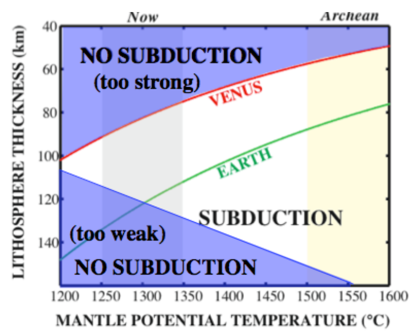

Fig. 1. Venus' high surface T predicts subduction over a wide range of thermal lithospheric thickness (beneath red line) but is limited on Earth (beneath green line).

New estimates of elastic thickness at numerous coronae with and without the characteristic surface features of plume induced subduction [8,9] support this prediction. Most coronae occur on lithosphere that is too weak to support intiation of subduction.

Conclusion: The quest to identify habitable exoplanets relies on habitility models. Venus' similarities to and differences from Earth make it the ideal control case for understanding how interior dynamics, surface volcanism, tectonism, outgassing and weathering produce habitable planets -or not [e.g. 10, 11]. In particular, Venus may constrain the initaiton of plate tectonics.

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Acknowledgement: This research was partially conducted at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

THE RADIOPHYSICAL PROPERTIES OF SOME LARGE VOLCANOES ON VENUS. K. Toner and M. S. Gilmore, Dept. of Earth and Environmental Sciences, Wesleyan University, 265 Church St., Middletown CT, 06459 USA mgilmore@wesleyan.edu.

Introduction. Reductions in radar emissivity at high altitudes (>2.5km above MPR) on volcanoes are currently best explained by chemical reactions between the surface and the atmosphere [e.g., 1-3] The presence of ferroelectric materials or production of semiconductor materials are possible chemical explanations for the low emissivity. The elevation and temperature of these transitions can constrain the possible minerals present on these volcanoes. This study attempts to understand the variability of the magnitude and elevation of the low emissivity excursions found on volcanoes by surveying 16 large volcanoes, mapped using Magellan synthetic aperture radar (SAR) and emissivity data.

Methods: In ArcMap, 16 large volcanoes were mapped using Magellan SAR FMAP global mosaic, with a resolution of 75km/pixel. The volcano maps were classified by whether or not they were covered by crater ejecta. These parabolic crater ejecta deposits are derived from recent plains craters mapped by [4] and older plains craters (modeled by [5]). Elevation, radar emissivity and effective permittivity were derived for each volcano from global maps processed by [5]. RStudio was used for plotting and statistics. Finally, to test whether different ferroelectric minerals could be responsible for the low emissivity excursions happening at different elevations, this study used the equations used by [2] to model the change in permittivity with changes in elevation (temperature), the permittivity and concentration of the ferroelectrics.

Results. Most volcanoes taller than 2.5 km exhibit a sharp change to low emissivity that is consistent with the presence of ferroelectric minerals. Many volcanoes also undergo changes below the 2.5 km height. Additionally, Nyx Mons does not reach 2.5 km, but still undergoes a low emissivity change.

The elevation of the emissivity excursions is variable from one volcano to another, even in the same local region (e.g., Sapas, Ozza and Maat or Nyx and Tepev). This strongly supports that the changes in emissivity in these volcanoes is due to differences in the type and abundance of high dielectric minerals in the rocks as opposed to differences in the composition of the atmosphere.

Young volcanoes? Unlike many of the other volcanoes, Maat Mons and Ongwuti Mons lack a prominent low emissivity change around 2.5 km. This supports the idea that these volcanoes are young enough that their minerals have not yet completely reacted to the atmosphere [e.g., 1], consistent with their stratigraphic positions.

Idunn Mons lacks low emissivity excursions like many other volcanoes, which could mean that either the ferroelectric minerals responsible for those low excursions on other volcanoes are not present on Idunn, or that Idunn's flows are too young to have changed consistent with a young age for this volcano suggested by [6].

Multiple emissivity excursions. Low emissivity transitions occur at common elevations among volcanoes, supporting the idea that some ferroelectric minerals are found on multiple volcanoes; however, each volcano has a unique set of critical elevations and excursion magnitudes.

Based on the model used by [2] it is plausible that different excursions within a single volcano are caused by different ferroelectric materials with variable dielectric constants. It is also possible that the variation in magnitude of some excursions are caused by variations in the concentration of a single ferroelectric mineral.

Effect of crater parabolas. Of the 7 volcanoes that overlap with Campbell parabolas, 5 have a lower distribution of emissivity values in uncovered regions than in covered by Campbell parabolas. This finding supports the idea that younger crater parabolas increase the emissivity of volcanoes by moving younger excavated plains basalts on top of older lava flows weathered to low emissivity.

Conclusions: We find that volcanoes on Venus contain ferroelectric minerals which react with the atmosphere to create the low emissivity changes observed by the Magellan orbiter. We observe that each volcano has a set of ferroelectric minerals that have different critical temperatures and/or concentrations. Some of these minerals are common to multiple volcanoes. Additionally, ejecta from recent plains craters correlates with higher emissivity values, suggesting that radiophysical behavior in ejecta-covered regions can't be attributed entirely to the volcano. These findings lead us closer to understanding the composition and age of Venus's large volcanoes.

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OVDA FLUCTUS, THE FESTOON LAVA FLOW ON OVDA REGIO, VENUS: MOST LIKELY BASALT.

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Introduction: A fundamental question about Venus is whether its highlands areas, its tesserae and the 'continent' of Ishtar Terra and Maxwell Montes, are made of granitic (silica-rich) igneous rock [1]. On one such Venus highland, Ovda Regio (Fig. 1), sits a lava flow, with a rumpled surface, that has been interpreted as silica-rich [2,3]. The flow, Ovda Fluctus or 'the festoon flow', has not been mapped in detail. Here we have mapped the flow using all available data, emphasizing properties that might be diagnostic of its chemical composition. The preponderance of data is consistent with Ovda Fluctus being of basaltic, not silica-rich, lava.

Data and Methods: All data are from the Magellan Venus orbiter mission, mostly downloaded from the USGS "Map-a-Planet" site. Magellan altimetry was augmented with the stereo radar DEM [4]. Images were processed and interpreted in ArcGIS. Fractal dimensions of lava flow margins were calculated using the 'ruler' method [5,6].

Results: We evaluated several properties of Ovda Fluctus that are affected by its lava's rheology.

Roughness. Silicic lava flows are very rough at the meter-scale [7], more so than a'a basalt, because of their viscosity. Ovda Fluctus is relatively smooth at this scale (Fig. 1), suggesting that it is not of silicic lava (despite the larger-scale roughness of its festoons, Fig. 2).

Fractal Dimension. The fractal dimension of a lava flow's margin depends on its effective viscosity – less viscous flows are more digitate, and have higher dimensionality [6]. Sixteen flow lobes (Fig. 2) gave dimensions of 1.15 – 1.42, average 1.26. This range is consistent with pahoehoe basalt flows, and not with silicic lavas (rhyolite or dacite).

Overall Morphology. The area and volume of Ovda Fluctus (~60,000 km^2 and ~6,000km^3 [8]) are more consistent with basalt effusions than silicic lava, at least on Earth [9,10]. The center of the Ovda Fluctus flow is lower elevation than its rim – such depression is common with basalt lava flows [11], but seemingly not observed on silicic flows. Festoon surface ridges (Fig. 2) may be present on both silicic and basaltic flows [12].

Results: The bulk of available data on Ovda Fluctus are consistent with it being basaltic, and inconsistent with a silicic composition. A test of this inference could come from near-IR emissivity data [1].

Acknowledgements: This work was performed during an LPI/ARES Summer Internship to the second author, mentored by the first and third authors. The LPI is operated by Universities Space Research Association, under a cooperative agreement with NASA.

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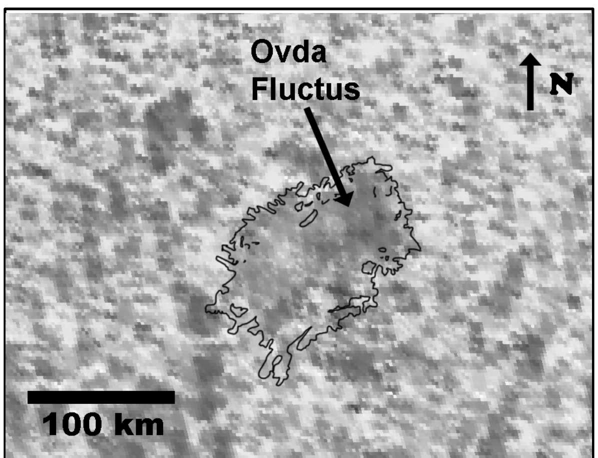

Figure 1. Outline of Ovda Fluctus lava flow, overlain on the Magellan meter-scale roughness map. Flow center at ~[95.4E, 6.0S]. The flow is significantly smoother than the surrounding tessera surfaces.

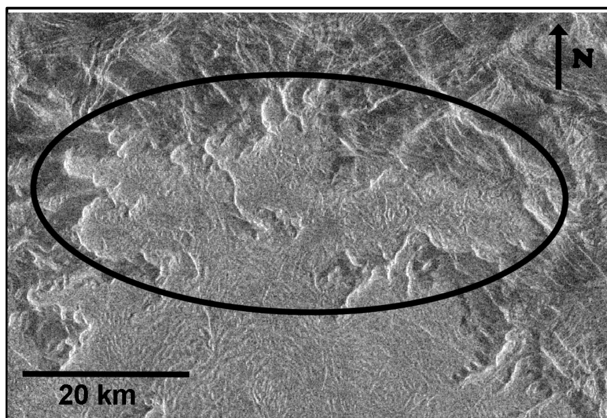

Figure 2. Detail of a flow lobe at north edge of Ovda Fluctus, ~[96.5E, 5.0S]. Note the festoon folds on the flow surface, esp. at bottom of image. The margin of the flow lobe in the ellipse has a fractal dimension of ~1.3, consistent with a pahoehoe basalt flow but not dacite or rhyolite.

An Atmospheric Platform for ISRU and Long-Term Investigation of Venus. L. A. Vaughn[1], [1]Triplanetry Exploration Systems (tony.vaughn@triplanetary.space).

Abstract: The atmosphere of Venus provides a much more hospitable environment for the kinds of technological devices that humans use for doing science than the surface of the planet. Equipment delivered to the surface can be expected to function only for a few hours, while conditions of temperature and pressure at moderate altitudes can be compared to those found normally on Earth. Venus provides a ready supply of CO_2, N_2, H_2SO_4, and H_2O, which can be processed into a wide variety of raw materials and finished products, including fuel and acid-resistant materials from which devices can be constructed that will endure exposure to conditions on the surface and at lower altitudes. A balloon supported research facility above the clouds on Venus can utilize the atmospheric constituents, combined with materials brought up from the surface and delivered from Earth, as well as solar energy to develop techniques for the production and utilization of these materials. Moreover, one or more sustainable research platforms in the clouds can serve as bases of operations for aviation-oriented investigation of both the atmosphere and geology of Venus, by sending out sorties of aircraft and landers that return to base to await future missions, rather than dying on the surface.

Enabling Future Venus In-situ Missions – Heat-shield for Extreme Entry Environment Technology (HEEET) Progress Towards TRL 6

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Introduction: Heat-shield for Extreme Entry Environment Technology (HEEET) has been in development since 2014 with the goal of enabling missions to Venus, outer planets and high-speed sample return missions. It is nearing successful completion and will be delivered by March of 2019.

Background: HEEET utilizes 3-D weaving as the basis for the highly capable TPS. An integrally woven dual-layer ablative material system is produced by the three-dimensional weaving process . The outer layer, high density carbon yarn weave, offers protection against the extreme external environment during entry. The inner insulating layer, lower density composite yarn weave, is adhesively bonded to underlying structure, protects the structure and science payload from the heat that penetrates the outer layer. The dual layer system is both robust and mass efficient. The HEEET material has been woven and tested for thermal performance at NASA Ames and DoD's AEDC arc jet facilities. These tests confirmed the two layer system to be very efficient and capable of withstanding extreme entry heating.

Component Manufacturing, Heat-shield Integration and Testing: A primary objective of the project has been to establish the manufacturing and integration processes necessary to build a heat-shield system, which is typically a blunt sphere-cone. The 3D material is woven as flat panels that have to be formed to match the surface profile of the sphere-cone. The formed panels are subsequently resin infused and cured, producing rigid tiles that are machined and bonded to the carrier structure.

The requirements for the gap filler are that: a) it must be compliant enough to accommodate the strain in the heat shield during all mission phases (acreage tiles are very stiff) and b) gap filler must have similar aerothermal performance (recession) as the acreage material, to minimize formation of local steps in the system that can lead to augmented heating during entry. The integration approach is required to end up with a very thin adhesive layer between the acreage panels and the gap filler material to prevent augmented recession of the lower density adhesive that could result in augmented heating of the structure. Development of the gap filler material and integration procedures was the most significant challenge the project encountered.

Validation of manufacturing/integration processes was demonstrated by the fabrication and testing of a 1m diameter "flight like" Engineering Test Unit (ETU). The ETU has undergone static load tests, point load tests, thermal vac tests and finally another round of point load tests. Preliminary data shows the ETU performed well and the comparisons of the data with predictions will be used to validate the structural design tools.

In addition, a series of arc jet tests were recently completed. These tests, conducted at the AEDC facility and NASA Ames' IHF were successful in establishing the heat-shield design features are capable of withstanding extreme entry environment. Testing in the IHF arc jet achieved heat fluxes of ~ 6500 W/cm2 and pressures of 5.5 atm. The test articles included acreage specimens, and seam specimens that incorporated the adhesive between acreage tile and gap filler. The model was 1" in diameter the small size is required to achieve the high test conditions. As part of the technology development, Bally Ribbon Mills has scaled up the weaving from 1" thickness and 6" width to 2" thickness at 24" width, requiring a loom that can manage tens of thousands of yarns. The heat-shield architecture and manufacturing/integration processes utilized in the 1m ETU is designed to be scalableto much larger sized vehicles. As part of the ETU build the HEEET team has successfully transferred the molding and resin infusion techniques to Fiber Materials Inc. (FMI). FMI then fabricated the piece parts for the ETU as a way to validate they can make parts necessary to assemble flight heat-shield for future missions. With the technology transfer to Industrial partners, and the successful testing and demonstration of the 1m heat-shield, HEEET team is nearing completion of achieving TRL 6.

Mission Infusion: HEEET was offered as a new technology and incentivized for mission use in the New Frontiers 4 AO by NASA. The HEEET Team worked closely with multiple NF-4 proposals to Venus, Saturn and has been supporting recent Ice-Giants mission studies and as a result, the technology delivered will be mature and ready for mission infusion

The full presentation will report on the HEEET development completed to-date and also remaining testing and documentations prior to delivery of a TRL 6 technology.

INVESTIGATING WAVES IN THE VENUS ATMOSPHERE VIA RADIO OCCULTATIONS BETWEEN ORBITING CUBESATS. P. Vergados[1], C. O. Ao[1], A. Komjathy[1], R. Preston[1], T. Navarro[2], G. Schubert[2], D. Atkinson[1], J. Cutts[1], S. Asmar[1], and J. Lazio[1]. [1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena CA, 91109, [2]Department of Earth, Planetary, and Space Sciences, UCLA, Los Angeles CA, 90095

Objective: Modeling efforts suggest that mountain waves that succeed in reaching cloud levels could explain the observed Venusian bow-shaped structures [1], and gravity and planetary waves are associated with other dynamical features including Venus's double polar vortices and its super-rotating atmosphere [2]. This emphasizes the role of waves in driving Venus's dynamics, but there is a large window of uncertainty of the vertical temperature structure and wave activity of the planet. Our goal is to study the spatial-temporal coverage a constellation of small satellites (SmallSats) could provide via occultation soundings.

Introduction: Occultation sounding is a remote sensing technique that vertically scans a planetary atmosphere to retrieve its properties in a fine vertical resolution by measuring the amount of bending of propagating signals between occulting spacecrafts over a planet's limb. Radio occultations (RO) between an orbiting spacecraft around Venus and a ground-based antenna on Earth have been used to probe the vertical thermal structure and wave activity of Venus's atmosphere, with measurements conducted by the Pioneer Venus Orbiter (PVO), Magellan, Venus Express (VEX), and Akatsuki missions. The PVO and the Magellan missions revealed temperature inversion layers at different latitude regions on Venus [3] and small-scale temperature oscillations caused by vertically propagating gravity waves [4]. The VEX mission captured a double cyclonic vortex over Venus's south pole [5], whereas the Akatsuki mission observed a 10,000 km long inter-hemispheric bow-shaped structure aloft the cloud-top at ~65 km [6]. The only operating satellite orbiting Venus today is Akatsuki, but it provides vertical temperature profiles only when it occults behind Venus's limb as seen from Earth.

Methodology: Spacecraft crosslinks have already been demonstrated in the planetary context at Mars, with RO measurements of the Martian ionosphere via the Mars Reconnaissance Orbiter – Mars Odessey crosslinks [7], and an initial study at JPL found that SmallSats with a 6U form factor would be technically capable of conducting such measurements. RO crosslinks between two or more Venus-orbiting SmallSats would enable measurements with dramatically improved spatial and temporal coverage compared to previous missions, analogous to the use of RO observations now providing detailed sensing of the Earth's atmosphere via the use of Global Navigation Satellite System (GNSS) constellations. Denser atmospheric measurements at Venus might allow deeper insight into surface-atmosphere coupling through physical processes related to large- and small-scale wave perturbations in the Venusian atmosphere, including gravity, planetary and acoustic waves, and the polar vortices.

Preliminary Results: We modify JPL's advanced occultation simulator to Venus's planetary properties to estimate the locations of RO soundings acquired by a constellation of three SmallSats. Our preliminary results show that during seven Earth days' time period, we obtain more than 1,500 occultations with dense spatial coverage that sample 75-110 degrees East and 75-110 degrees West longitude regions from the South to the North pole of Venus. These are regions of high interest, because they coincide with Venus's bow-shaped structures. At latitudes greater than 80 degrees, in both hemispheres, we obtain a good spatial coverage at almost all longitudes. Such high latitude occultation soundings could be potentially beneficial to probe the vertical thermal structure and wave activity of the polar vortices. Further, the possibility of SmallSats flying in tandem in Venus orbits at low altitudes would allow for prolonged flying time within Venus's ionosphere, perhapse providing access to the greatly amplified waves that could be produced during seismic phenomena.

Conclusions: A constellation of three SmallSats could fill in the spatial-temporal gaps and complement observations from the Akatsuki satellite, and could also provide synergistic observations from future Venus balloon-borne platforms that cannot retrieve high resolution vertical profiles. RO measurements could also help improve state-of-the-art global circulation models (GCMs) of Venus, which are key components in understanding the circulation and dynamic properties of the Venusian atmosphere.

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RADAR BACKSCATTER VARIATIONS IN TESSERA ACROSS VENUS. J. L. Whitten and B. A. Campbell, Smithsonian Institution, National Air and Space Museum, Center for Earth and Planetary Studies, Washington DC, 200013 (whittenj@si.edu).

Introduction: Tesserae are some of the oldest deposits on Venus, appearing bright in SAR images due to their high surface roughness and often an enhanced Fresnel reflectivity [e.g., 1, 2]. The surface properties of this geologic unit as a whole are not well constrained. The range in radar brightness, or backscatter coefficient, across the tesserae has not been quantified, and could provide important information about the distribution of crater ejecta or locally-derived regolith, as well as inherent differences in original tessera materials. Here we present the preliminary results of an ongoing global study of the backscatter coefficient of tesserae across the surface of Venus.

Methodology: Magellan SAR data are used to calculate the backscatter coefficient of individual slopes within tesserae [3]. The polarization of the Magellan SAR (HH) is sensitive to roughness variations at the few-cm scale and to slopes on the scale of tens to hundreds of meters. The variations in backscatter from away-facing slopes (aka backslopes) are compared with various geologic landforms, such as impact craters, to determine if there is a correlation between backscatter and a geologic process. Fine grained ejecta and/or materials erupted during volcanic events can modify the surface roughness of the underlying materials.

Results: The backscatter coefficient varies across tesserae, with values ranging from -28 dB to almost 13 dB (Fig. 1). There is a correlation between the highest elevations across Venus and the backscatter coefficient. For example, the backscatter values associated with Maxwell Montes are high, as are the backscatter values for elevated regions of Rhea Mons.

There are also correlations with the expected location of crater ejecta. The fine-grained ejecta from Stuart crater smooths the surface of the eastern half of Alpha Regio [4, 5]. Ejecta from impact craters is also detected in Tellus, Virilis, and Husbishag tesserae. There is also evidence of preserved crater ejecta in tessera without an obvious source crater [5]. Our analysis indicates that crater ejecta is preserved in the rougher tessera longer than on adjacent low-lying plains (>35±15 Ma Ma [6]). Lower backslope values are identified in Tellus Tessera, but not in the adjacent plains [5].

Discussion and Conclusion: Magellan data can be used to infer the presence of fine-grained materials in tessera, despite the variation in local incidence angles. These materials have to be >5 cm thick to be detected with the Magellan SAR dataset. Some of the backscatter coefficient variations are obviously correlated with craters. None have been unambiguously correlated with volcanic constructs. Other backscatter variations must be related to other processes or inherent differences in the original tessera materials.

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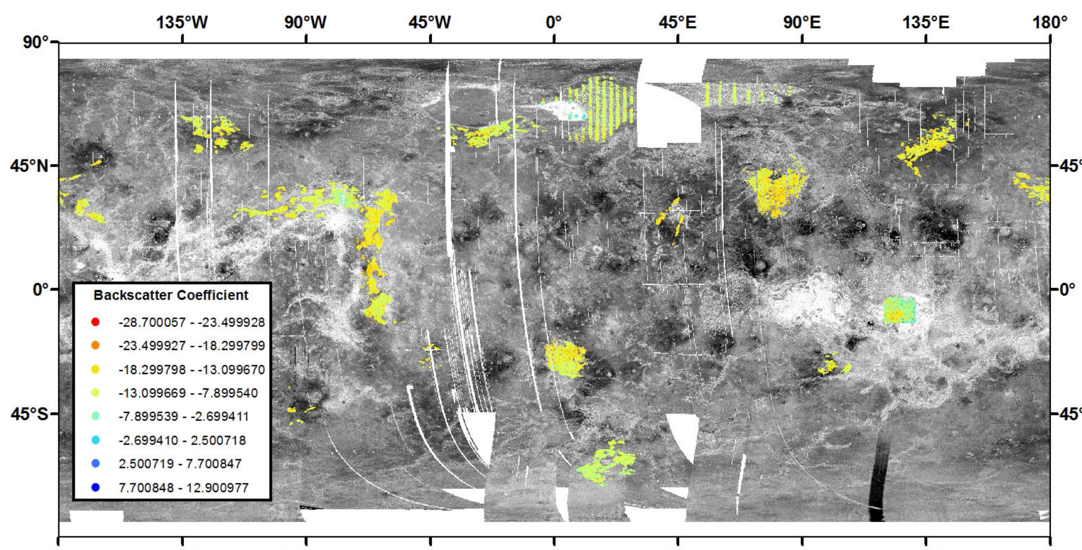

Figure 1. Distribution of tesserae backscatter values (colorful dots) across Venus. Base map: Magellan SAR left and right look data.

Do Venusian Antidunes Exist? K. E. Williams, P. E. Geissler. USGS Astrogeology Science Center, 2255 N. Gemini Dr., Flagstaff, AZ 86001 kewilliams@usgs.gov.

Introduction: The surface pressure conditions beneath the 92 bar CO_2 atmosphere of Venus are similar to subaqueous terrestrial ocean pressure environments at a depth of ~1 km. Experimental evidence exists to suggest that sediment transport in the high-pressure CO_2 atmosphere on Venus may be similar to terrestrial fluvial sediment transport [1]. This has led other researchers [2] to propose that the dunes on Venus may be comparable to subaqueous dunes on Earth that formed at low flow speeds. Another alternative is that dunes on Venus formed under much higher flow speeds as antidunes in turbidity currents. In this work we proceed under the working hypothesis that aeolian antidunes may exist on Venus, and we use characteristics of transverse dunes from the Al-Uzza Undae region of Venus to constrain the formative flow properties of putative antidunes. Additional high-resolution data are required to further constrain dune properties and provenance, hence future investigation would benefit greatly from reprocessing of existing Magellan data.

Background and Model: Antidunes are fluvial bedforms found in supercritical flows. Antidunes are notable in that they can move against the flow. Terrestrial antidunes generally form in shallow, fast-flowing aqueous environments. Antidunes have also been found to form in terrestrial turbidity currents (Fig. 1). It seems plausible that antidunes could form under the thick Venusian atmosphere in a manner analogous to terrestrial turbidity currents. Venus has at least two officially named dune fields: Al-Uzza Undae and Menat Undae.

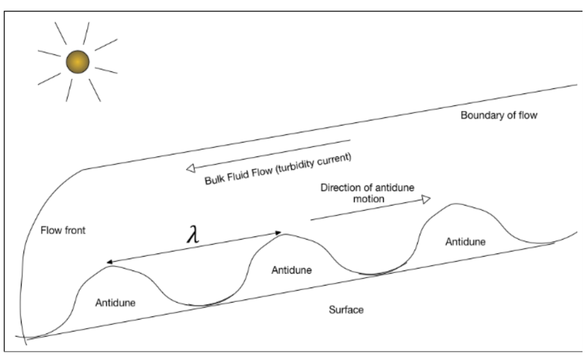

Figure 1. Diagram of antidunes and turbidity current.

Recent work by Geissler [3] has suggested that, given estimates of transverse dune spacing λ and an estimate of the operative reduced gravity term g', we may infer flow velocity v using the relation suggested by Kennedy [4] for subaqueous antidunes: $\lambda = \frac{2\pi v^2}{g'}$ where g' is defined via the gradient of the flow density and the ambient density [5] $g' = g\frac{\Delta\rho}{\rho_a}$. Here ρ_a is the ambient fluid density and g is gravity. There is a fair amount of uncertainty with this term, given that it depends on the sediment concentration of the flow.

The Froude number $Fr = \frac{v}{\sqrt{g'd}}$ is used to determine the potential for antidune formation in a given flow. $Fr \geq 1$ is required for antidune formation, though terrestrial flume work by Kennedy [4] as reported in Geissler [3] suggests that antidunes begin to form once flow velocities reach 80% of wave celerity or flow depths are less than ~14.2% of dune wavelength.

Solving for flow velocity and flow depth as functions of wavelength and reduced gravity, we find there is only a weak dependence on reduced gravity.

Radarclinometric analysis by Lorenz [6] suggests that dune wavelengths in Al-Uzza Undae are approximately 500 m, with a few slightly longer wavelengths of up to 1000 m. Given these constraints we can infer the flow depths may have been close to 80 m thick with a few thicker flows of close to 140 m. Similarly, flow velocities may be inferred to be approx. 22 m/s, with a few up to 32 m/s. We find that the suggested Venusian dune mechanisms relating wavelength and reduced gravity to wave speed and depth are more likely to exhibit weak (or zero) dependence on the reduced gravity of the flow.

Conclusion: The suggested Venusian antidune velocity and flow depth show only a weak (or zero) dependence on reduced gravity, whereas they show a significant dependence on estimated wavelength. We find, assuming the dunes in Al-Uzza Undae are analogous to those produced via terrestrial subaqueous turbidity currents, that we may infer flow depths of 80-140 m with flow velocities of 22-32 m/s. While measured surface wind speeds on Venus are generally < 1.5 m/s [7], it is worth noting that turbidity currents, being gravitationally induced flows, are potentially of much higher velocity than ordinary wind speeds. It is hoped that additional constraints on dune wavelength will be gleaned from the reprocessing of existing Magellan data in the manner suggested by Lorenz [6].

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ANOMALOUS RADAR PROPERTIES OF MAXWELL MONTES: RESULTS FROM REFINED STEREO ALTIMETERY.
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Introduction: Maxwell Montes, on the eastern side of Ishtar Terra, is the highest and steepest mountain range on Venus, and has been of great interest for both tectonic origin and material properties. Maxwell's region is characterized by a 'snow line' of radar properties – an elevation at which radar-backscatter, emissivity, etc. change abruptly [1,2]. We mapped features in detail on Maxwell's north- and south-facing flanks with refined stereo-DEMs [3], and search for trends that might be apparent at higher spatial resolution than of Magellan altimetry & emissivity [4].

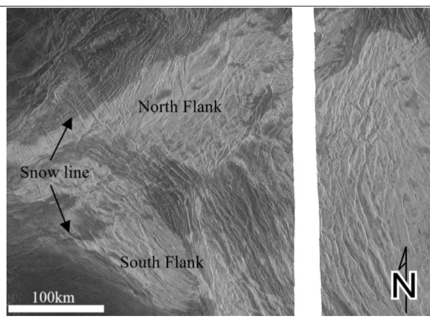

Figure 1: *Magellan SAR image of western Maxwell Montes; image center ~[359.7E, 66.6N]. The highest elevations (center) have lower backscatter than the foothills, and the south flanks of Maxwell have lower backscatter than north.*

Data and Methods: All data are from the Magellan Venus orbiter mission, mostly downloaded from USGS "Map-a-Planet" and JMARS. Magellan altimetry was augmented with the stereo radar DEM of [3]. We focused on SAR swaths of limited longitude range in western Maxwell (Fig. 1). Images were processed and interpreted in ArcGIS. Small areas of constant elevation and SAR backscatter were chosen, and those data were correlated (Fig. 2).

Maxwell Montes 'Snow': Magellan Synthetic Aperture Radar (SAR) images of Maxwell Montes show a distinct 'snowline:' elevated radar backscatter above a critical elevation of ~5 km, Fig. 1 [1,2]. The north and south flanks of Maxwell show distinctly different patterns of radar response (Figs. 1, 2). At elevations above ~ 7.5 km on the north flank, both emissivity and SAR backscatter have values intermediate between those of the lowlands and the "snow," Figs. 1 & 2. On the south flanks, however, neither emissivity nor backscatter shows clear trends with elevation (Fig. 2). Surface roughness affects SAR backscatter more than emissivity (compare north flank data, Fig. 2), but roughness alone seems insufficient to explain the differences between north and south flanks.

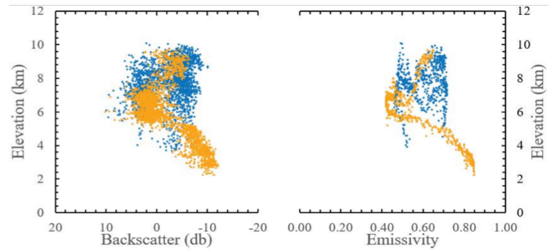

Figure 2: *Backscatter (left) and emissivity (right) vs. elevation of Maxwell Montes. Orange and blue symbols are for north and south flanks respectively.*

Discussion / Interpretation: The cause(s) of the 'snow line' on Maxwell have been controversial [2,4,5-10], and most commonly ascribed to the presence of semiconductor compounds (e.g., Te, PbS, BiTe), deposited from the atmosphere [6,7], or formed by chemical reactions between rock and the atmosphere (e.g., pyrite FeS_2, magnetite Fe_3O_4) [8,9]. These ideas do not, of themselves, explain either the change in radar properties at ~7.5 km nor the difference between Maxwell's north and south flanks.

In general, the variations in radar properties could represent different rock materials or atmospheric conditions. On one hand, it is possible that rock types across Maxwell vary enough to allow different products or proportions of rock-atmosphere chemistry. The decrease in SAR backscatter at high elevation on Maxwell could be ascribed to the presence of a ferroelectric material [1,11], although the notional substance on near-equatorial highlands (chlorapatite [1]) is not appropriate for these elevations. On the other hand, the atmosphere might be different on either flank of Maxwell, possibly as a result of equatorward meridional flow at low elevations [12]. Such a flow might experience orographic lift as it crossed Maxwell, allowing different conditions on its north and south flanks.

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