18th Meeting of the Venus Exploration Analysis Group (VEXAG)

Program and Abstracts
LPI Contribution No. 2356
18th Meeting of the Venus Exploration Analysis Group
November 16–17, 2020

Institutional Support
Lunar and Planetary Institute
Universities Space Research Association

Convener
Noam Izenberg
Johns Hopkins Applied Physics Laboratory
Darby Dyar
Mount Holyoke College

Science Organizing Committee
Darby Dyar
Planetary Science Institute, Mount Holyoke College
Noam Izenberg
JHU Applied Physics Laboratory
Megan Andsell
NASA Headquarters
Natasha Johnson
NASA Goddard
Jennifer Jackson
California Institute of Technology
Jim Cutts
Jet Propulsion Laboratory
Tommy Thompson
Jet Propulsion Laboratory
Abstracts for this meeting are available via the meeting website at
https://www.hou.usra.edu/meetings/vexag2020/

Abstracts can be cited as

All Times Listed are Eastern Standard Time (UTC -5) Time

**Monday, November 16, 2020**
9:00 a.m. Session 1: Current Status of Active Venus Exploration: NASA, and Mission Updates
1:00 p.m. Session 2: Mission Proposals and Concepts, Technology Updates and Current Studies and Poster Lightning Talks

**Tuesday, November 17, 2020**
9:00 a.m. Session 3: Venus Science Talks and VEXAG Findings

**Print Only**
### SESSION 1: CURRENT STATUS OF ACTIVE VENUS EXPLORATION: NASA, AND MISSION UPDATES

**Monday, November 16, 2020**

**9:00 a.m.**

Updates from NASA HQ and active mission around or flying by Venus in upcoming months/years. Discussion of the pre-decadal Flagship study.

**Chairs:** Darby Dyar and Noam Izenberg

<table>
<thead>
<tr>
<th>Times</th>
<th>Authors (*Denotes Presenter)</th>
<th>Abstract Title and Summary</th>
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<tbody>
<tr>
<td>9:00 a.m.</td>
<td>Izenberg N. *</td>
<td><strong>Welcome, Introduction, Rules of the Road</strong></td>
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<tr>
<td>9:05 a.m.</td>
<td>Dyar D. *</td>
<td><strong>VEXAG Presentation</strong></td>
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<td>9:40 a.m.</td>
<td>Glaze L. *</td>
<td><strong>HQ Presentation</strong></td>
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<td>10:15 a.m.</td>
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<td><strong>BREAK</strong></td>
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<tr>
<td>10:25 a.m.</td>
<td>Satoh T. *</td>
<td><strong>Akatsuki Update</strong></td>
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<tr>
<td>10:35 a.m.</td>
<td>Curry S. M. *</td>
<td><strong>Parker Solar Probe Venus Flyby Campaign: Latest Results [#8017]</strong></td>
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<tr>
<td></td>
<td>Parker Solar Probe Team</td>
<td>We will present the latest Parker Solar Probe gravity assists at Venus. We will compare our observations to those to VEX and PVO over similar parts of the solar cycle and discuss collaborations with BepiColombo and Solar Orbiter Venus gravity assists.</td>
</tr>
<tr>
<td>10:45 a.m.</td>
<td>Zouganelis Y. *</td>
<td><strong>Solar Orbiter Update</strong></td>
</tr>
<tr>
<td>10:55 a.m.</td>
<td>Witasse O. *</td>
<td><strong>JUICE Update</strong></td>
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<tr>
<td>11:05 a.m.</td>
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<td><strong>BREAK</strong></td>
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<tr>
<td>11:15 a.m.</td>
<td>Gilmore M. *</td>
<td><strong>Venus Flagship Mission Planetary Mission Concept Study</strong></td>
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<td>11:45 a.m.</td>
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<td><strong>DISCUSSION</strong></td>
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### SESSION 2: MISSION PROPOSALS AND CONCEPTS, TECHNOLOGY UPDATES AND CURRENT STUDIES AND POSTER LIGHTNING TALKS

**Monday, November 16, 2020**

**1:00 p.m. Virtual Meeting Room**

Upcoming US and international Venus mission concepts, proposals and plans. Venus technology studies and program updates. Poster lightning talk round.

**Chairs:** Darby Dyar and Noam Izenberg

<table>
<thead>
<tr>
<th>Times</th>
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<tbody>
<tr>
<td>1:00 p.m.</td>
<td>Dyar D. *</td>
<td><strong>Introduction</strong></td>
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<tr>
<td>1:05 p.m.</td>
<td>Niebur C. *</td>
<td><strong>New Frontier 5</strong></td>
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<tr>
<td>1:15 p.m.</td>
<td>Zasova L. *</td>
<td><strong>Venera-D</strong></td>
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<tr>
<td>1:25 p.m.</td>
<td>Smrekar S. *</td>
<td><strong>VERITAS</strong></td>
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<td>1:39 p.m.</td>
<td>Garvin J. *</td>
<td><strong>DAVINCI+</strong></td>
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<td>2:07 p.m.</td>
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<td>BREAK</td>
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<tr>
<td>2:17 p.m.</td>
<td>Noe E. *</td>
<td>Heat Exchange-Driven Aircraft for Low Altitude and Surface Exploration of Venus - NIAC</td>
</tr>
<tr>
<td>2:27 p.m.</td>
<td>Nguyen Q-V. * Mercer C. *</td>
<td>HOTTECH and PESTO program updates</td>
</tr>
<tr>
<td>2:42 p.m.</td>
<td>Kremic T. *</td>
<td>Venus Surface Platform Study</td>
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<td>2:57 p.m.</td>
<td></td>
<td>BREAK</td>
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<tr>
<td>3:04 p.m.</td>
<td>Izenberg N. *</td>
<td>Poster lightning talks intro</td>
</tr>
<tr>
<td>3:06 p.m.</td>
<td>Zhou G. Z. * Zirnov S. Z. Mardon A. M.</td>
<td>Utilization of Resources on the Moon [#8020] Structures on the lunar surface will challenge contemporary thoughts of auxiliary examination by basic and structural architects, just as originators, constructors and coordination organizers. Uncovered home units will confront numerous issues.</td>
</tr>
<tr>
<td>3:08 p.m.</td>
<td>Zacny K. * Hall J.</td>
<td>Venus Drill and Sample Delivery System [#8022] We present development and testing of Venus drill and sample delivery system.</td>
</tr>
<tr>
<td>3:10 p.m.</td>
<td>Western A. D. * Hassanalian M.</td>
<td>Bioinspired Walking, Rolling, and Jumping Robot for Venus Exploration [#8009] The proposed robot is inspired from different organisms, like long-nosed leopard lizard, golden wheel spider, and octopus to walk, roll, and jump for the exploration of a wider variety of terrain on Venus, such as mountains, with increased speeds.</td>
</tr>
<tr>
<td>3:12 p.m.</td>
<td>Sherman M. R. * Hassanalian M.</td>
<td>Microrobots Inspired by Oceanic and Bacteria Organisms for Observations of Venus’ Upper Atmosphere [#8014] This work discusses a new concept involving a hybrid aerial system inspired by a bacteria-based organism – Flagellates – that utilize the strong winds in the upper atmosphere of Venus to power their onboard equipment.</td>
</tr>
<tr>
<td>3:14 p.m.</td>
<td>Santana Gonzalez O. * Lu Y.</td>
<td>Ballistic Aerocapture at Venus: A Case Study for an Atmospheric Sampling Probe [#8039] The study examines the if ballistic aerocapture is possible at Venus.</td>
</tr>
<tr>
<td>3:16 p.m.</td>
<td>Morris I. M. * Hassanalian M.</td>
<td>Active Seismic Survey on Venus by Multi-Agent Robotic Systems [#8018] We propose collecting an active seismic survey using a multi-agent system of jumping robots deployed as part of a lander, which will reveal the structure and density of the upper crust and help answer questions about the planet’s seismic activity.</td>
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<td>3:22 p.m.</td>
<td>Knicely J. J. * Lynch R. J. Mason P. A. Ahmad N. Matthis L. H. Gramling C. J. Restrepo C. I. Gilmore M. S. Herrick R. R.</td>
<td>Strategies for Safely Landing on Venus Tesserae [8016] We explored the requirements to safely place a lander in venusian tessera terrain. The lander must autonomously detect hazards through the highly scattering atmosphere against which it must push to avoid hazards, similar to a descending bathysphere.</td>
</tr>
<tr>
<td>3:24 p.m.</td>
<td>King S. D. * Euen G. T.</td>
<td>Surprisingly Stationary Plumes and the Distribution of Active Coronae on Venus [8038] Contrary to expectations of how a vigorously convecting body should behave, we find plumes can maintain a stable spatial pattern for a Gyr, or even longer. We explore some possible implications of plume stability for Venus.</td>
</tr>
<tr>
<td>3:26 p.m.</td>
<td>Johnson P. A. * Johnson J. C. Mardon A. A.</td>
<td>Non-Independence of Variables in the Venus Life Equation [8023] In light of the hypothesis that Venus was habitable in its evolution, the Venus Life Equation has been used to model key environmental factors that were required for the sustenance of life. Here, we suggest non-independence of equation variables.</td>
</tr>
<tr>
<td>3:28 p.m.</td>
<td>Jitarwal S. * Pabari J. P. Kumar D. Dhone G. Nambiar S. Singh R. Upadhyaya T. Acharyya K. Sheel V. Bhardwaj A.</td>
<td>Time-Frequency Localization of Electrostatic Discharge for Lightning Study [8010] This study presents a comparison of several time-frequency localization techniques for a natural lightning signal, captured during a monsoon season. The Hilbert-Huang transformation is found a better technique for understanding the lightning signal.</td>
</tr>
<tr>
<td>3:30 p.m.</td>
<td>Herkenhoff B. K. * Fisher J. M. Hassanalian M.</td>
<td>Performance Analysis of Solar Fixed-Wing Drones on Venus [8007] We proposed a concept for the operational range of a solar fixed-wing drone that would operate at an altitude near 55km for an extended period. In this range, the solar efficiency is at its peak, near 7.2 %, with a potential output power of 79W/m^2.</td>
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<td>3:32 p.m.</td>
<td>Horzempa P. A. *</td>
<td>Calypso Venus Scout [8045] The Calypso Venus Scout is a mobile, low-altitude survey and mapping mission. A payload module (Bathysphere) is lowered to altitudes as low as 10 km by means of a tether deployment gondola. That gondola is attached to an “anchor” balloon that remains above 50 km.</td>
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<td>3:34 p.m.</td>
<td>Herrick R. R. * Tian Y. West M. E. Kremic T.</td>
<td>Development and Initial Testing of a Venus-Analog Seismic Events Catalog [#8051]</td>
</tr>
<tr>
<td>3:36 p.m.</td>
<td>Glass D. * Jones J.-P. Shevade A. Cutts J. Raub E. Bhakta D. Bugga R.</td>
<td>High Temperature Batteries for Venus Surface Missions [#8052]</td>
</tr>
<tr>
<td>3:38 p.m.</td>
<td>Gammill M. E. * Hassananian M.</td>
<td>Manta Ray Inspired Drone for Venus Exploration: Biological-Solution for Extreme Conditions [#8021]</td>
</tr>
<tr>
<td>3:44 p.m.</td>
<td>Bullock M. A. * Elston J. S. Stachura M. Z. Lebonnois S.</td>
<td>Long Duration In Situ Science in Venus’ Clouds Enabled by Dynamic Soaring [#8048]</td>
</tr>
<tr>
<td>3:46 p.m.</td>
<td>Bugga R. * Jones J.-P. Pauken M. Billings K. Ahn C. Fultz B. Nock K. Cutts J.</td>
<td>New Power Architecture for Venus Aerial Missions [#8053]</td>
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<td>3:50 p.m.</td>
<td>Bhattacharya A. * Izenberg N. R. Mahaffy P. R.</td>
<td>Understanding the Supercritical State on Venus and DAVINCI+ Opportunity [#8003] The work identifies the current research problems related to supercritical state of Venus near surface atmosphere and highlights DAVINCI+ mission opportunity for the Venus science community to obtain new measurements for first time in many decades.</td>
</tr>
<tr>
<td>3:52 p.m.</td>
<td>Bhagwat R. S. * Alva B. H. Hartwell B. D. Bernard E. O. Rajesh V. V.</td>
<td>Vibrissae Inspired Mechanical Obstacle Avoidance Sensor for the Venus Exploration Rover AREE [#8034] An obstacle avoidance sensor (OAS) was developed for the AREE with an array of mechanical sensors akin to mammalian vibrissae and associated electromagnetic actuators to enable terrain traversal and navigation in the extreme environment of Venus.</td>
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<td>3:56 p.m.</td>
<td>Alvarado Mejia A. F. Acevedo Mena J. D. * Aldana Hernandez M. Rincón Martinez S. Casadiego Molina J. F. Duque Baron P. A.</td>
<td>Cytherean Sep Mission: Venus Exploration [#8041] This document is a research concept to explore the upper atmosphere of Venus, which will have an orbiter, a main navigation ship and drones in order to discover new scientific data of this planet.</td>
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<tr>
<td>3:58 p.m.</td>
<td>Alvarado Mejia A. F. Acevedo Mena J. D. Casadiego Molina J. F. Rincón Martinez S. * Aldana Hernandez M. Duque Baron P. A.</td>
<td>Prototype of Unmanned Aircraft to Explore the Skies of Venus Exploration and Astrobiological Research [#8040] A planetary exploration concept was designed using an aircraft in order to explore the lower atmosphere of Venus between 50 and 60 km, analyzing atmospheric compounds, and having the opportunity to generate astrobiological studies.</td>
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<td>9:00 a.m.</td>
<td>Greaves J. *</td>
<td>Invited Phosphine talk</td>
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<td>9:06 a.m.</td>
<td>Johnson J. C. *</td>
<td>Prospecting Microbial Biosignatures from Venusian Clouds [8024]</td>
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<td></td>
<td>Johnson P. A.</td>
<td>The search for extant life has taken on several chemically-driven approaches to measure chemical signs of life. The lower cloud layer of Venus represents a potential habitat for microbial life. Here, we consider some questions for probe sampling.</td>
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<td>Mardon A. A.</td>
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<td>9:11 a.m.</td>
<td>Slowik G. P. *</td>
<td>The Lower Layer of Venus’ Clouds as a Giant Bioaccumulator [8011]</td>
</tr>
<tr>
<td></td>
<td>Dabrowski P.</td>
<td>The lower layer of the Venus’ clouds (47.5–50.5 km above its surface), due to physicochemical conditions, may constitute a habitat for electric bacteria whose potentially analogues maybe found on Earth using electricity as the only source of energy.</td>
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<td>9:16 a.m.</td>
<td>Mogul R. *</td>
<td>Venus’ Mass Spectra Show Signs of Disequilibria in the Middle Clouds</td>
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<td>We present a re-examination of published mass spectral data obtained from the Pioneer Venus Large Probe Neutral Mass Spectrometer (51.3 km).</td>
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<td>9:21 a.m.</td>
<td>Seager S. *</td>
<td>Paned Discussion / Q&amp;A 1st 4 talks</td>
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<tr>
<td>9:30 a.m.</td>
<td>Seager S. *</td>
<td>Invited talk on Venus life chemistry</td>
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<td>9:35 a.m.</td>
<td>Dong C. *</td>
<td>Atmospheric Escape from TOI-700 d: Venus Versus Earth Analogs [8001]</td>
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<td>Jin M.</td>
<td>We found that TOI-700 d with a 1 bar Earth-like atmosphere could be stripped away rather quickly (&lt;1 gigayear), while TOI-700 d with a 1 bar CO2-dominated atmosphere could persist for many billions of years.</td>
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<td>Lingam M.</td>
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<td>9:40 a.m.</td>
<td>Kane S. R. *</td>
<td>Could the Migration of Jupiter have Accelerated the Atmospheric Evolution of Venus? [8036]</td>
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<tr>
<td></td>
<td>Vervoort P.</td>
<td>This work addresses three primary questions: (1) How has the orbital eccentricity of Venus evolved? (2) What are the possible mechanisms behind such evolution? (3) What are the implications for the atmospheric and surface evolution?</td>
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<td>Horner J.</td>
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<td>Pozuelos F. J.</td>
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<td>9:45 a.m.</td>
<td>Ostberg C. M. *</td>
<td>Differentiating Exo-Earth and Exo-Venus with Transmission Spectroscopy [8047]</td>
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<td></td>
<td>Dalba P. A.</td>
<td>Earth and Venus have been shown to have remarkably similar transmission spectra. Here we conduct a feature-by-feature comparison of CO2 absorption features between 1–5 microns in Earth and Venus transit spectra.</td>
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<td>Kane S. R.</td>
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<td>9:50 a.m.</td>
<td></td>
<td>Panel Discussion / Q&amp;A 2nd 4 talks</td>
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<td>10:01 a.m.</td>
<td>Hahn R. M. * Byrne P. K.</td>
<td><em>A New Assessment of Volcano Morphology and Distribution on Venus [#8019]</em>&lt;br&gt;We created a new global survey of shield volcanoes across Venus that documents edifices on a finer spatial scale than previously created databases. We report preliminary volcano morphological measurements and spatial distributions.</td>
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<td>10:06 a.m.</td>
<td>Ganesh I. * McGuire L. Carter L. M.</td>
<td><em>Modeling Deposition from Dense Pyroclastic Density Currents on Venus [#8043]</em>&lt;br&gt;Radar bright features / If these are pyroclastics / What could have made them?</td>
</tr>
<tr>
<td>10:11 a.m.</td>
<td>Brossier J. * Gilmore M. S. Toner K. Stein A. J.</td>
<td><em>Distinct Mineralogy Associated with Individual Lava Flows in Atla Regio, Venus [#8012]</em>&lt;br&gt;Maat and Ozza montes (Atla Regio) exhibit several declines in radar emissivity at different altitudes. These emissivity excursions correlate with individual lava flow events that imply distinct mineralogy and age.</td>
</tr>
<tr>
<td>10:16 a.m.</td>
<td>Whitten J. L. * Campbell B. A.</td>
<td><em>Local Variations in Venus Tesserae Identified by Backscatter Variations [#8049]</em>&lt;br&gt;Tesserae represent the oldest rock record on the surface and may preserve evidence of different earlier climate conditions. Characterization of backscatter coefficient varies across 21 tesserae and shows some correlation with geologic features.</td>
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<td>10:21 a.m.</td>
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<td><em>Panel Discussion / Q&amp;A 1st 4 talks</em></td>
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<td>10:31 a.m.</td>
<td>Byrne P. K. * Krishnamoorthy S.</td>
<td><em>Estimates on the Frequency of Volcanic Eruptions on Venus [#8037]</em>&lt;br&gt;On Venus, how oft’ / do mountains roar? The answer / may be here on Earth.</td>
</tr>
<tr>
<td>10:36 a.m.</td>
<td>Borrelli M. E. * O’Rourke J. G.</td>
<td><em>A Global Survey of Lithospheric Flexure and Elastic Thickness at Steep-Sided Domes on Venus [#8042]</em>&lt;br&gt;We use signs of lithospheric flexure at steep-sided dome volcanoes to determine the elastic thickness and surface heat flow. We confirm the hypothesis that steep-sided domes are likely to form where the elastic thickness is between 10 and 40 km.</td>
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<td>10:41 a.m.</td>
<td>Williams Z. W. * Byrne P. K. Balcerski J. A.</td>
<td><em>Insights into Structure and Elastic Thickness of Ridge Belts on Venus [#8044]</em>&lt;br&gt;Structural analysis of ridge belts show that they are complex systems of thrust fault duplexes. Lithospheric flexure models imply an elastic thickness of 10–24 km around ridge belts which do not exceed 1 km in relief, indicating a thin lithosphere.</td>
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<td>10:46 a.m.</td>
<td>O’Rourke J. G. *</td>
<td><em>A Basal Magma Ocean in Venus: Implications for Gravity, Heat Flow, Magnetism, and Noble Gases [#8046]</em>&lt;br&gt;The lowermost ~100–400 km of the mantle of Venus may remain molten today, just like Earth’s mantle was a few billion years ago. It’s where the argon-40 hides?</td>
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<td>10:51 a.m.</td>
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<td><em>Panel Discussion / Q&amp;A 2nd 4 talks</em></td>
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<td>11:01 a.m.</td>
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<td>11:11 a.m.</td>
<td>Group C: Atmospheres</td>
<td><strong>Evolution of Nightside Features from Deconvolved Akatsuki Image Sequences at 1.74, 2.26 and 2.32 μm [8050]</strong>&lt;br&gt;Present a close look at an 18-hr sequence of high-resolution Akatsuki images of clouds on Venus’s nightside.</td>
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<tr>
<td>11:12 a.m.</td>
<td>Young E. F. * Ali-Zade S. Aye K. M. Bullock M. A. Cantrall C. Satoh T. Vierrling S. Vun C. W.</td>
<td><strong>Flows Instabilities in Venus Clouds Explored by Akatsuki Radio Science Experiment [8008]</strong>&lt;br&gt;The work will explore the flow instabilities in the clouds of Venus due to interaction between zonal wind and convective activity using data from Akatsuki Radio Science Experiment. We also highlight their role in various atmospheric processes.</td>
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<tr>
<td>11:17 a.m.</td>
<td>Bhattacharya A. * Sheel V. Pabari J. P. Imamura T. McGouldrick K.</td>
<td><strong>Variations in the Peak Electron Density of the Venus Ionosphere: Some New Insights Using Akatsuki Radio Science Measurements [8013]</strong>&lt;br&gt;Akatsuki have unique opportunity to probe equatorial region of Venus atmosphere with radio signals. Paper is exploring the variation of peak electron density (nmV2) and explaining the result by using in house developed photochemical model.</td>
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<tr>
<td>11:22 a.m.</td>
<td>Tripathi K. R. * Ambili K. M. Choudhary R. K. Imamura T. Ando H.</td>
<td><strong>A Study on the Characteristic Features of the V1 Layer of the Venus Ionosphere Using Akatsuki Measurements [8025]</strong>&lt;br&gt;The study is about the characteristics of V1 layer studied using Akatsuki measurements and one dimensional photochemical model. Akatsuki measurements provided a opportunity to study the V1 layer of the equatorial, mid and high latitude ionosphere.</td>
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<tr>
<td>11:27 a.m.</td>
<td>Ambili K. M. * Tripathi K. R. Choudhary R. K. Imamura T. Ando H.</td>
<td><strong>Is GCR Induced Ionization the Prime Driving Force for Venus Lightning? [8004]</strong>&lt;br&gt;In this work, we present calculations that shows that GCR induced ionization cannot produce fields greater than breakdown fields even at high altitudes where breakdown field is much lower.</td>
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<td>11:32 a.m.</td>
<td>Kumar V. R. D. * Pabari J. P. Acharyya K.</td>
<td><strong>Simulation Experiments on Electrochemical Effects of Venus Lightning [8032]</strong>&lt;br&gt;A laboratory simulation experiment about the effect of lightning on Venus, which is excepted to have some indications to second UV absorber happening in Venus cloud.</td>
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<td>11:42 a.m.</td>
<td>Royer E. M. * Young E. F. Bullock M. A.</td>
<td><strong>Distribution of the O2 Nightglow at Venus from the NASA Infrared Telescope Facility (IRTF) SpeX Instrument [8029]</strong>&lt;br&gt;We present a new technique to retrieve the O2 nightglow signal at Venus using data from the IRTF SpeX Instrument.</td>
</tr>
</tbody>
</table>
### 11:57 a.m.

**Fowler C. M. * Agapitov O. V. Artemyev A.**

<table>
<thead>
<tr>
<th><strong>Abstract Title and Summary</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><em>PVO Observations of Low Frequency, Large Amplitude Magnetosonic Waves Interacting with the Upper Venusian Ionosphere: Implications for Ionospheric Structure, Heating and Escape [#8015]</em></td>
</tr>
<tr>
<td>Wave-particle interactions may play an important role in topside ionospheric heating at Venus, similar to Mars. We present PVO observations of one such case study, demonstrating that plasma conditions are likely able to support such wave heating.</td>
</tr>
</tbody>
</table>

### 12:02 p.m.

**Panel Discussion / Q&A 2nd 4 talks**

### 12:12 p.m.

**BREAK**

### 12:17 p.m.

**Treiman A. ***

<table>
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<tr>
<td><em>Brines Across the Solar System: October 25-28, 2021</em></td>
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</table>

### 12:20 p.m.

**Draft Findings Discussion, Additional VEXAG Business**

### PRINT ONLY

<table>
<thead>
<tr>
<th><strong>Authors (<em>Denotes Presenter)</em></strong></th>
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</thead>
<tbody>
<tr>
<td>Helbert J. Maturilli A. D’Amore M. Haus R. Lee Y.-J. Garcia Munoz A. Arnold G. Hiesinger H.</td>
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### Venus as Seen by the MERCURY Radiometer and Thermal infrared Imaging Spectrometer (MERTIS) During the First Flyby of the ESA-JAXA Bepicolombo Spacecraft [#8027]

We will report here on the MERTIS observations obtained during the first Venus flyby of BepiColombo.

### Way M. J.

**Abstract Title and Summary**

*Solar Luminosity Through Time: Does it Determine Venus’ Climate History? [#8030]*

Assuming that ancient Venus was once a watery temperate world, we demonstrate that Venus’ climate history is not determined by increasing solar luminosity through time, contrary to popular conjecture.

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“CYTHEREAN SEP MISSION: VENUS EXPLORATION”
A Novel Concept for High Altitude Planetary Atmospheric Exploration.

Introduction: Cytherean Sep, aims to provide new science data, complementing the studies carried out on prior exploration missions, highlighting a research approach on astrobiological field and enhancing the understanding of evolution led to a hostile environment. Applying, the proposed exploration platforms to complete in-situ research of physicochemical processes in Venus’ upper atmosphere, which could catalyze the organic compound formation processes. Landing for a long duration mission and descent safely on the region require a significant advance in engineering development and it’s estimated that this kind technology will be ready for the next decade or beyond. On the other hand, the panorama for aerial platform is more promising in the medium term according with “Venus technology plan December 2018” [1].

According to recent studies by a team of Russian and American-scientists [2], including Limaye, who is a member of the Venera-D scientific team; it was detected in the ultraviolet spectrum certain spots in the clouds of the high atmosphere of Venus, which by the way, has pressure and temperature conditions similar to the Earth at a height between 50 to 60 km, and possibly it is a formation of organic compounds that despite the presence of carbon dioxide, sulfuric acid among other compounds, could develop and survive, considering the existence of complex organic compounds that develop and exist in extreme environments in the Planet Earth.

Although, the planetary research scientific community has sufficient information to understand the origin and composition of dark traces detected in the ultraviolet spectrum. It is not understood why it has not been mixed with the other particles present in the atmosphere and why it is absorbing ultraviolet light.

The instrument for meteorological and cartographic analysis:

- V28: The V28 camera uses a 24mm lens; that allows ultraviolet photographs.
- IF40: Using 24mm lens infrared photographs, provide a way to penetrate the cloudy part of Venus.
- IF41: Like the IF40, the IF41 features a 24mm lens; but they use a different frequency variation that would provide density and temperature information for cloud formations.
- EV30: For a similar perspective to human vision, visible spectrum (focal strait) photographs with a 1000mm lens are used.
- EV31: Allows visible spectrum photography with an 8mm wide-angle lens for larger amplitude shots.
- OS132: The display of the infrared solar concealment camera allows possessing accurate information about the ambient radiation and temperature of the planet, its design has a lens of 24mm that favors the taking of spectra.

The configurations of scientific cameras give a great contribution to the research, since we can work with the information obtained from the Venusian atmosphere around climate changes (drastic), temperature gradients, topography and images in various color scales with great detail of possible discoveries for the scientific world.

- Gas analysis chamber (RAG): The explorer will be equipped with a gas analysis system, composed of a chromatograph, allowing deep molecular analysis of the various gas particles and aerosols found in the Venus clouds. The gas will be drawn in by a turbine where it will enter a ream with corrosion protection (critical deterioration), the gate has a "diaphragm" mechanism type door that allows he closure and opening efficiently, quickly and airtightly.
- After the entire gas analysis process using the chromatograph, the data will be sent to the analysis facilities attached to Nasa.
● Navigation cameras: The unmanned vehicle has 4 cameras for dynamic navigation in the Venus atmosphere since in the field of research Venus has drastic climate changes which constitute dangers to the vehicle. In its field of view, it has an angle of 60° with the type of wide-angle lens, so you can see a greater area than linking it to an artificial vision system, the camera will allow evading the possible risks to the vehicle.

● Cloud mapping and weather radar: The aerial explorer will have weather radar which will allow the mapping of cloud formations; allowing the safe movement of the vehicle; and it will also show us the behavior of the atmosphere for further studies and analysis.

● Radioactivity Meter: The aerial explorer will have the measurement instrument on the highest and lowest peaks in radioactivity, since the planet has critical indices, this radiation is presented even on the planetary surface and thus, with the data provided by this team, may allow to hypotheses or knowledge in the area of radioactivity in the field of Venus.

**(SOCSV) Venusian space communication system:** In a space exploration mission, communication has a fundamental role for the success of the same; in this case, it is proposed to use three types of ships (Orbiter, AFISV, and AVEV), each one of them with its communication instruments to ensure a data findings and real-time monitoring for the study of Venus. The ships will have dual-band systems. These have an X band transmission and receiver, allowing to send and receive 8 GHz signals, and will also have another S band system that handles 2 GHz frequencies. On the other hand, a redundant system will be implemented for the mothership and the orbiter, so that it works omnidirectionally and links the ships in case of phenomena or problems during the mission. The orbiter will be the link between the mothership and the (DSN) Deep Space Network. It will perform a triangulation with trajectory, calculated between three points from earth, the orbiter which rotates with Venus, taking advantage of its slow cycle of rotation, and finally the naves on the surface of Venus.

**Solar cells for AFISV, assumptions/goals for the air explorer vehicle:**

<table>
<thead>
<tr>
<th>Power</th>
<th>10 kW/h SOP 7.628 kW/h SOP, assuming 33% worst-case degradation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deployed area (4 wings section)</td>
<td>48 m², assuming 7.628 kW/h SOP</td>
</tr>
<tr>
<td>Deployed stiffness</td>
<td>&gt; 0.05 Hz</td>
</tr>
<tr>
<td>Deployed strength</td>
<td>&gt; 0.1 g</td>
</tr>
<tr>
<td>Specific power</td>
<td>&gt; 120 W/kg SOP</td>
</tr>
<tr>
<td>Stowed volume</td>
<td>&gt; 40 kW/m³</td>
</tr>
<tr>
<td>Voltage</td>
<td>100 - 160 V</td>
</tr>
<tr>
<td>Blanket</td>
<td>Flexible substrate, assuming &lt; 1</td>
</tr>
</tbody>
</table>

**Deployment reliability**

| Goal: "100%" - Deployment is highest perceived project risk |

Table 1.

**Solar cells for orbiter and protective thermal shield, assumptions/goals for the orbiting vehicle:**

<table>
<thead>
<tr>
<th>Power</th>
<th>5 kW/h BOL 3.8 kW/h EOL, assuming 33% worst-case degradation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deployed area (4 wings section)</td>
<td>24 m², assuming 3.8 kW/h BOL</td>
</tr>
<tr>
<td>Deployed stiffness</td>
<td>&gt; 0.05 Hz</td>
</tr>
<tr>
<td>Deployed strength</td>
<td>&gt; 0.1 g</td>
</tr>
<tr>
<td>Specific power</td>
<td>&gt; 120 W/kg BOL</td>
</tr>
<tr>
<td>Stowed volume</td>
<td>&gt; 40 kW/m³</td>
</tr>
<tr>
<td>Voltage</td>
<td>100 - 160 V</td>
</tr>
<tr>
<td>Blanket</td>
<td>Flexible substrate, assuming &lt; 1 kg/m² areal density, 0.03&quot; thick</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Planar vs concentrator</th>
<th>Assuming planar arrays will be used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deployment reliability</td>
<td>Goal: &quot;100%&quot; - Deployment is highest perceived project risk</td>
</tr>
</tbody>
</table>

Table 2.

**References:**

1. Venus technology plan, December 2018

2. K. Cooper, «Astrobiology at Nasa LIFE IN THE UNIVERSE, » astrobio.net, 1 February 2017. [En línea].
“PROTOTYPE OF UNMANNED AIRCRAFT TO EXPLORE THE SKIES OF VENUS: EXPLORATION & ASTROBIOLOGICAL RESEARCH”

A Novel Concept for High Altitude Atmospheric Exploration.


Introduction: We developed a design concept derived from the previous CYTHEREAN SEP research, in this case will focus on the development of a complementary design of unmanned aircraft (UAVs) capable of withstanding the adverse conditions of the planet Venus flying over a height between 50 km and 60 km (kilometers), all in order to collect important scientific data that can accurately reveal the composition of isotopes and particles in the atmosphere of Venus, in addition to clarifying the recent discovery about strange spots detected in the ultraviolet spectrum, which do not dissipate or dilute with other components, and at the same time seems to absorb ultraviolet light. Relevant engineering studies will be submitted to ensure the feasibility and operational safety of the proposed aircraft, such as materials, mechanical properties of these engineering estimates and the design of the UAV adapted to research needs.

Figure 1: Aerial platform. own source.

The aircraft named (AFISV) Venus Atmospheric Flying Research Station, Figure 1, is a large platform which is formed of fibers of solar panels in its wings which will have a hinge-like deployment mechanism and also a low-power turbine, is designed to fly over at least 90 earthly days. It will have high-tech instruments to observe and take scientific samples, in addition its aerodynamic design will allow to withstand the high air currents that are presented on this planet.

The objective of the designs is to carry out aerospace studies with mathematical aeronautical models, which validate the operation, service life, aerodynamic behavior and other variables that allow prototyping and developing the ship.

Figure 2: drones. own source.

Figure three shows the design of a drone which detaches from the main ship and will fly over at specific points to take scientific samples, multispectral images, images in the ultraviolet range among others. The drone could be used as a sacrificial platform because it will be located in hard-to-reach locations, predicting new flight paths so that AFISV avoids passing through these locations and ensuring the safety of the main ship. The mission calls for the use of three drones to cover more areas of research, drones have a mechanism for vertical and horizontal flights, in addition to equipment that would provide data to the AFISV spacecraft for processing interpreted and transmitted to the ground.

Figure 3: Glider. own source.

The design of Figure 3 consists of a deployable wing glider which takes advantage of the strong air currents experienced on the planet Venus to fly at different heights of the surface; it would also reduce its energy consumption to a high percentage and prolong more mission time. The following illustrates the design of the folding design so that it can be stored and coupled in the tapered control module for atmospheric ingress protection:
Figure 4: coupling in heat shield. Own source

The manufacturing materials that make up the ship are a very important complement within this research, this allows to evaluate variables such as weight, thermal resistance, mechanical resistance, corrosion and other factors that analyze the future behavior of the ship to evaluate possible events that help predict a high success rate. Some material proposals will then be presented in the following tables:

<table>
<thead>
<tr>
<th>PRINCIPAL MATERIALS</th>
<th>SPECIFIC GRAVITY (g/cm³)</th>
<th>RANGE OF THERMAL CONDUCTIVITY (W/mK)</th>
<th>RANGE OF PRESSURE RESISTANCE (MPa)</th>
<th>RANGE OF ELASTIC MODULE (GPa)</th>
<th>RANGE OF CORROSION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon Nanotubes theoretical</td>
<td>1.4</td>
<td>6000</td>
<td>68</td>
<td>1000</td>
<td>Corrosion rate (mm/year) = 0.00327 (σ/icorr/n)</td>
</tr>
<tr>
<td>Carbon Nanotubes (measured)</td>
<td>1.4</td>
<td>150</td>
<td>1.8</td>
<td>80</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 5:** Own source. Correlation of atmospheric variables

In the graph above, the optimal operational area is delimited in the orange table, between a balance of atmospheric variables, in which pressure and temperature are inversely proportional to the height, and the wind speed is proportional to the height, so an equilibrium point must be found that meets the best flight conditions for the unmanned aircraft, with an optimal operating height between 50 to 60km of the surface.

One of the materials to be considered in the tables above is carbon Fiber Reinforced Polymers (CFRP). This compound allows to compensate for strength and weight; its application in the aerospace world is getting stronger due to the mechanical properties that are better than metal alloys.

---

**Range of Corrosion:** Where $a$ is atomic weight, $icorr$ is corrosion current density, $n$ is the number of equivalents exchanged, and $D$ is density

---

A study on the characteristic features of the V1 layer of the Venus ionosphere using Akatsuki measurements.

K.M Ambili1, K.R. Tripathi1, R.K. Choudhary1, T. Imamura2, and H. Ando3. 1Space Physics Laboratory (SPL), VSSC, Thumba, Trivandrum (tripathikr95@gmail.com, ambilisadasivan@gmail.com, rajukumar.choudhary@gmail.com), 2The University of Tokyo, Japan (t_imamura@edu.k.u-tokyo.ac.jp). 3Kyoto Sangyo University, Japan (hando@cc.kyoto-su.ac.jp).

Abstract: The source of V1 layer of the Venus ionosphere is as enigmatic as its very existence itself. Discovered, for the first time by the radio occultation experiment (VeRA) onboard Venus Express, it is known to exist at about 125 km altitude and has been surmised to be caused by soft X-ray emissions [1]. A characteristic feature of this ionospheric layer as well as consensus on its source, however, is yet to emerge mostly because of the lack of observation opportunities. In this context, radio occultation measurements of the Venus ionosphere using Akatsuki measurements assume significance as these not only add to the data base but also give measurements from the low latitude regions which have remained less explored during previous missions due to satellite trajectory [2].

In this paper, we study the characteristics of V1 layer using some thirty radio occultation measurements done since 2016 both at UDSC in Japan, and IDSN in India [2]. Only those measurements were considered where the ionosphere was in the sunlit side and solar zenith angle was less than 85 degree. In all we got sixteen profiles satisfying these conditions. We get several profiles from the low latitude regions of the Venus ionosphere giving some interesting features of the V1 layer. Interestingly, distinct V1 layers were not visible in many cases. While in some profiles it appeared as a ledge, there were few examples too when a very distinct peak was also visible. The origin for such features has been explored using an in-house developed one dimensional photochemical model for the Venustian ionosphere (1DPCM) [3]. Though both the peak V1 layer height and density get neatly reproduced in the model, in most of the cases we note the model V1 layer appears only as a shoulder. A detailed comparison of the model and Akatsuki derived altitude profiles of the Venus ionosphere under varying solar conditions would be provided and reasons for the occurrence of V1 layers of varying characteristics would be discussed.

Acknowledgments: Sincere thanks to Shri Umang Parikh, manager, IDSN, and his team to conduct the experiments and provide valuable data set. We also acknowledge, JAXA, Akatsuki team for providing data set recorded at UDSC https://www.darts.isas.jaxa.jp/planet/project/akatsuki/r

References:
NEW-FRONTIERS CLASS VENUS IN-SITU EXPLORATION: THE VENUS CLIMATE AND GEOPHYSICS MISSION (VCGM) CONCEPT. 

K. H. Baines1, J. A. Cutts1, L. Dorsky1, J. Hall1, A. Akins1, A. Davis1, A. Komjathy1, S. Krishnamoorthy1, D. Nikolić1, P. Vergados1, A. Akins1, S. Atreya2, M. Bullock3, G. Hunter4, S. Lebonnois5, P. Lognonné6, O. Mousis7, J. O’Rourke8, J.-B. Renard9, C. Wilson10, 1 Jet Propulsion Laboratory, California Institute of Technology (4800 Oak Grove Dr., Pasadena, CA, 91109, USA) [kevin.baines@jpl.nasa.gov], 2 University of Michigan, Ann Arbor, MI, 3Science and Technology Corp, Boulder CO, 4NASA Glenn Research Center, Cleveland, OH, 5LMD/IPSL, Sorbonne University, Paris, France, 6Institute de Physique du Globe de Paris, Paris, France, 7Aix Marseille Universite., CNRS, CNES, LAM, Marseille, France, 8Arizona State University, Tempe, AZ, 9LPC2E-CNRS, Université d’Orléans (3A Avenue de la Recherche Scientifique, 45071 Orléans, France), 10Oxford University, Oxford, UK

Introduction: We present a class of Venus New Frontiers mission concepts that effectively and affordably address the majority of priority science objectives dealing with Venus’ formation, evolution, interior, surface, and atmosphere promulgated by the Venus Exploration Analysis Group (VEXAG) [1]. Collectively called Venus Climate and Geophysics Missions (VCGMs), this mission class incorporates both in-situ and orbital elements to obtain an optimum science return within the New Frontiers ~$1B cost constraint. We do not specify a single mission concept, but instead describe a suite of possibilities that could be fit within the New Frontiers envelope. A detailed study could be carried out under the auspices of the Planetary Science Decadal Survey to guide the Survey on the potential of such a New Frontiers mission.

Mission Goals: The overarching goal of VCGM is to combine measurements of the atmosphere and near-surface to understand Venus as a planetary system and why its atmospheric circulation/dynamics, evolution and geophysical properties are unique in general and different from Earth in particular. Taking our initial direction from the most recent VEXAG Roadmap [1] supplemented by two Venus community workshops on the science return, complexities, and risks of a variety of aerial platforms [2], we center our mission around a key element: a long-lived, altitude-varying balloon-borne instrumented science platform (hereafter, "aerobot"). Utilizing the large (~60 m s⁻¹) zonal winds found at all latitudes equatorward of ~60°, the aerobot would circle the planet more than a dozen times over a notional 90-Earth-day science phase. Global Circulation Model simulations [3] indicate that the aerobot would sample a wide range of latitudes between the equator and 50°.

Approach: Onboard instrumentation would sample the environment over all times of day including (1) the winds in all three dimensions, (2) the pressure/temperature structure, and (3) the composition of the air and aerosols [4], including (A) UV-absorbing material which possibly may be linked to astrobiology [5,6], (B) the reactive sulfur-cycle gases that create the aerosols, and (C) the noble gases, their isotopes and the isotopes of light gases. - key to understanding the formation of the planet and the evolution of its atmosphere (e.g., [7]). The aerobot, capable of multiple altitude traverses of up to 10 km centered near an altitude of 55-500 km (~0.5 bar, 25°C), will enable three-dimensional maps of up to 10 km centered near an altitude of 55-60 km in altitude. Geophysical investigations of these environmental characteristics, as well as the dynamically and chemically influenced size distribution of aerosol particles via a nephelometer (e.g., [8]) and/or particle counter [9]. These traverses also reveal the vertically-varying characteristics of atmospheric stability, gravity and planetary waves, and Hadley cells, all important for understanding the mechanisms that power and sustain the planet’s strong super-rotation. As well, these altitude excursions enable measurements of the radiative balance and solar energy deposition via a Net Flux Radiometer [10], another key to understanding super-rotation.

As it circumnavigates Venus every 5 days, the aerobot monitors the terrain that it passes over from 50-60 km in altitude. Geophysical investigations of the interior of the planet take advantage of (1) the proximity to the surface relative to an orbiter and (2) the contact with the atmosphere which enables infrasound to be observed in situ. Electromagnetic measurements of the thickness of the lithosphere using excitation by the Schumann resonance [11], surveys of remanent magnetism [12,13] evidence of an early Venusian magnetic field, and an infrasound survey of seismic activity [14] are envisioned.

A supporting near-equatorial orbiter will 1) relay data from the aerobot to greatly increase data return and 2) locate and track the aerobot, particularly on the farside of Venus when out of view of Earth-based radio telescopes [15]. Imagers/spectrometers for both atmospheric and surface science provide synergistic support of aerobot measurements. Near-infrared
imaging spectrometers/imagers (e.g., [16, 17]) would spectrally image (1) clouds and trace gases at depth [18], and (2) most of the surface. Seismic investigations of the interior can also be conducted complementary to those provided by the aerobot through the airglow generated by the interaction of infrasound emanating from Venus quakes. [14,19]. Other spectral imagers would map the UV-absorbing atmosphere [24], and (2) 2-3 location support and enhanced radio occultation may include (1) up to two Cubesats for balloon measurements via aerobot and orbiter instrumentation working in concert cover 7 (30%).

In addition to the two primary platforms, the VCGM may include (1) up to two Cubesats for balloon location support and enhanced radio occultation coverage of the atmosphere [24], and (2) 2-3 dropsondes to provide atmospheric P/T and trace gas profiles, and to image the surface at high resolution. [25]. Another possibility would be to measure the vertical variability of N₂ (via a speed-of-sound/attenuation sensor [26]) throughout the atmosphere down to the surface including within the ~7 km-thick surface boundary layer, a critical measurement for understanding the stability and dynamics of the lower atmosphere [27].

Out of the 23 VEXAG investigations [1], VCGM effectively addresses 20 (87%) of them. Superior measurements via aerobot and orbiter instrumentation working in concert cover 7 (30%).

Acknowledgments: Part of this research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

VIBRISSA INSPIRED MECHANICAL OBSTACLE AVOIDANCE SENSOR FOR THE VENUS EXPLORATION ROVER AREE. R. S. Bhagwat1*, B. H. Alva2, B. D. Hartwell3, E. O. Bernard4, V. V. Rajesh5

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Introduction: The Automaton Rover for Extreme Environments (AREE) is a NASA Innovative Advanced Concepts project to design a rover that can operate for six-months on the surface of Venus. To enable terrain traversal and navigation, AREE must be equipped with a robust obstacle avoidance sensor (OAS), however modern electronics cannot operate in the extreme surface temperature and pressure [1]. Therefore, as part of the NASA "Exploring Hell: Avoiding Obstacles on a Clockwork Rover" challenge, an OAS was developed with an array of mechanical sensors akin to mammalian vibrissae and associated electromagnetic actuators, shown in Figure 1 and 2. The obstacle detection method of the OAS can be described as a mechanical and electrical relay system.

Vibrissae Mechanism: The first component of this relay is the vibrissae mechanism, an assembly of three mechanical vibrissa that extend from the front of the rover to the Venusian surface to detect obstacles. The outer two vibrissa are directly in front of the rover wheels, while the third is positioned in between the two. The ends of these vibrissae, which make direct contact with the Venusian surface, are characterized as vibrissa heads. The vibrissae are connected by rigid arches that allow motion hindering obstacles between the vibrissae heads to be detected, while allowing shorter obstacles to pass undetected. Rotary motion of these arches is possible through universal joints that connect the arches to the vibrissa heads. The impact of an obstacle on an arch or vibrissa head causes the entire vibrissa to translate backwards. Each individual vibrissa head is also capable of translating vertically by allowing the entire vibrissa to act as a lever which pivots about a fulcrum at the vibrissae base. Because the vibrissa arms are rigid and this fulcrum is fixed, the entire outer vibrissa will also have to yaw backwards via a bearing connection during this vertical translation of the vibrissa heads. To enable the outer vibrissa heads to be continuously stationed directly in front of the rover wheels, the arches are fixed to slider assemblies on the vibrissa heads, and non-extendible ceramic fiber loop bands are used to connect the outer vibrissa heads to eyebolts that are located on the underside of a rectangular plate atop the top-section of the OAS hull. During vertical extension of the vibrissa head, all sliders translate from their initial position towards the opposing ends of the vibrissa head as a result of centripetal force that acts towards the middle vibrissa and is induced by the rigid arch. However, any inward motion of the vibrissa head is prevented, because the aforementioned centripetal force is negated by the reaction force between the non-extendible ceramic-fiber loop band and the vibrissa head. The sliders are associated with self-retracting cord reels, which provide a spring force that allows all sliders to return to their initial position when backing away from obstacles upon detection.

Trigeminal Mechanism: The second set of components are the trigeminal mechanisms, which function via flexural-based mechanics to convert...
vibrissa displacement into an electrical signal, shown in Figure 3. The trigeminal mechanism, of which there are three included within the OAS, translates the two-dimensional movement of each vibrissa, which act as type one levers, into compressions or extensions of three sets of linkages and accompanying spring shafts.

![Figure 3: Trigeminal mechanism components with a section of the mechanism cage removed for improved interior visualization.](https://flexpivots.com/flexural-pivot-products/double-ended-pivot-bearing/)

Much of the trigeminal mechanism is composed of Ti-6Al-4V, apart from the springs, foil, and screws. The linkages are constantly held in a resting state that resists displacement of the vibrissa head from level surface, where rover inclination acts as the reference, but are displaced by the slightest movements of the vibrissa. The restoring force is provided by nine Ti-6Al-4V double-ended pivot bearings, three per linkage, and the spring shafts that hold four springs that function to provide either a tension or compression force given the circumstance. The pivot bearings are a flexural-based device that employs three crossed internal flexure beam springs enclosed in a three-part cylindrical housing sleeve [2]. The system of nine differentiated double-ended pivot bearings provides precise rotation with low hysteresis that allow the trigeminal mechanism to resist inappreciable vibrissa movement, sustain a resting state, and allow angular displacement to specified degrees that define the pin actuating configurations. In addition, there is a shaft adjustment system that holds the circular shaft acting as the fulcrum for the vibrissae in place with two springs, which compress when against an obstacle of significant inclination, allowing for the aft linkage and spring shaft to fully compress.

**Inclination Sensor:** There are many obstacles that can be detected by the vibrissae and trigeminal mechanism. However, when inclination increases or decreases gradually, such as a slope on a hill or mountain, these systems will not detect this change since they are limited to sensing obstacles in reference to the plane tangent to the bottom of the rover wheels (i.e. rover inclination). Therefore, rover inclination in reference to the gravity of Venus must be monitored by the OAS and be able to detect when inclination maximums are exceeded to prevent the rover from losing surface traction or becoming overturned on a steep slope. To mitigate the risk that gradual inclines pose, a mechanical-based inclination sensor was designed for use in the OAS to detect gradual declines and inclines in any directions by referencing the orientation of gravity.

**Electromagnetic Actuation System:** The electromagnetic actuation system is the final component, containing four highly compact solenoids [3] Using two wires for power and ground connections, an electric circuit which is completed with sufficient compression of a trigeminal mechanism linkage and shaft was designed to pass current through the solenoids. Using a cylindrical, ferritic slug placed within the solenoid, the magnetic field generated by the energized coils exerts an axial force which actuates a pin via translation of the parallel slug to relay obstacle detection. This system allows the detection of a multitude of obstacles but can also differentiate them into four distinct signals, which include holes and negative 30-degree inclines, positive 30-degree inclines, 90-degree or near 90-degree inclines, and gradual inclination that accumulate to 30-degree in any direction. These signals trigger the rover to reverse and seek a different path forward upon obstacle contact.

**Conclusion:** The function of the various mechanisms, along with an extensive material trade study to determine the appropriate composition of OAS components, and failure modes with mitigation strategies, ensure that all problematical obstacles outlined by NASA are detected. The present OAS ensures that AREE is capable of operating in the extreme surface conditions of Venus for an extended period of time and was officially recognized by NASA as one of the top design solutions.

**Acknowledgements:** The authors would like to thank the NASA Jet Propulsion Laboratory, NASA Tournament Lab, and HeroX for organizing the NASA "Exploring Hell: Avoiding Obstacles on a Clockwork Rover" challenge, NASA Jet Propulsion Laboratory and NIAC for their extensive prior work on the AREE Rover, and NASA Ames Research Center for promoting the challenge.

UNDERSTANDING THE SUPERCRITICAL STATE ON VENUS AND DAVINCI+ OPPORTUNITY. A. Bhattacharya¹, N. R. Izenberg², and P.R. Mahaffy³, ¹Sardar Vallabhbhai National Institute of Technology Surat, India, ananyo0806@gmail.com, ²Johns Hopkins University Applied Physics Laboratory, Laurel, MD, US, ³NASA Goddard Space Flight Center, Greenbelt, MD US

Introduction: Thermal properties of the lower atmosphere of Venus has been studied from atmospheric probes and lander missions. In-situ measurements have provided valuable information about the atmospheric composition [1]. However, little reliable information or reproducible results are available for the near surface environment. It is known to be composed of supercritical mixture of major constituents i.e. carbon dioxide and nitrogen.

VeGa-2 probe descent measurements of atmospheric temperature, which are the only reliable sources of temperature measurements below 12.5 Km altitude [2], due to high uncertainties in temperature measurements by other missions. There is an indication of gradient in the concentration of major constituent species with altitude in the average molecular mass derived [2], with no known evidence for sinks of nitrogen [3].

Table 1: \(N_2\) concentration measurements by some instruments onboard previous missions [1]. MS = mass spectrometer, GC = gas chromatograph.

<table>
<thead>
<tr>
<th>Missions and instruments</th>
<th>(N_2) conc. (%</th>
<th>error (%)</th>
<th>Altitude/region measured</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pioneer Venus MS; Venera 11/12 GC combined</td>
<td>3.5</td>
<td>0.8</td>
<td>&lt; 100 km</td>
</tr>
<tr>
<td>Venera 12 GC</td>
<td>2.5</td>
<td>0.5</td>
<td>&lt; 42 km</td>
</tr>
<tr>
<td>Venera 13/14 MS</td>
<td>4</td>
<td>-</td>
<td>26 km to the surface</td>
</tr>
<tr>
<td>Venera 11/12 MS</td>
<td>4</td>
<td>0.3</td>
<td>23-1 km</td>
</tr>
</tbody>
</table>

Table 1 shows that the in-situ measurements do not vary much with altitude, but have significant error bars.

The Deep Atmosphere Venus Investigation of Noble gases, Chemistry, and Imaging Plus (DAVINCI+) mission now in Phase A led by Principal Investigator Dr. James B. Garvin and NASA Goddard Space Flight Center is the first opportunity in 35 years to study the deep atmosphere of Venus, and will measure physical properties as well as chemical constituents of the near surface environment.

Supercriticality on Venus: Studies based on experiments [4] and computational chemistry [5] have investigated the supercritical mixture of major atmospheric constituents at pressure and temperature conditions approximating those near the surface of Venus.

![Figure 1. Pressure vs. Temperature for N2, CO2 and measurements of Venus atmosphere by VeGa 2 from [5].](8003.pdf)

Figure 1 shows that a supercritical state is expected approximately below 3 km altitude. The CO2 and N2 lines in red and black show the vapor-liquid equilibrium lines. The Widom lines zone refers to the region consisting of regimes that separate liquid like behaviour and gas like behaviour in fluids around the critical point. Exact information about these regimes would predict the characteristics of fluid mixtures in the phase diagram. However, much of the studies done on supercritical fluids in Venus are yet to be supported by in-situ measurements, and the current knowledge gap highlights some important questions about Venus:
(i) At what altitude is the transition to a supercritical state expected? What are the possible mechanisms for such a transition?

(ii) Is the concentration gradient in nitrogen observed by VeGa 2 real, and is it a local or global phenomenon?

(iii) What are the potential impacts of volcanic activity or other degassing processes on the physical state of the atmosphere?

(iv) What are the possible heat, momentum, and mass transport characteristics in the supercritical environment?

DAVINCI+: The mission proposed to the NASA Discovery Program is designed to study the atmospheric composition of different chemical species and to gather more knowledge about the atmospheric evolution [6]. As a part of the mission, the deep atmospheric chemistry probe armed with instruments for in-situ measurements would explore the lower atmosphere of Venus and study potential non-equilibrium processes and surface atmosphere interactions.

DAVINCI+ science goals are to study the origin of Venus atmosphere and its evolution, rate of volcanic activity and history of surface processes [6]. Thus, it can be seen that the science objectives are directly in line with questions (i), (ii) and (iii) in relation to the supercritical state.

The mission’s one-hour atmospheric descent will be an opportunity to explore the questions related to the physical state of Venus’ atmosphere. The Venus Mass Spectrometer (VMS), a quadrupole mass spectrometer and the Venus Tunable Laser Spectrometer (VTLS) provide the isotopic composition and concentration of major constituents [7]. Further, the Venus Atmospheric Structure Investigation (VASI) suite of instruments provides temperature and absolute pressure measurements. The knowledge of chemical composition and thermal properties would constrain the physical state of the expected supercritical environment. The combined measurements would then be analyzed to get temperature and chemical concentrations of nitrogen and carbon dioxide. These measurements will be used in mathematical models to understand properties of the physical state. Co-incident measurement of the final descent would help in identifying the factors influencing the supercritical state.

DAVINCI+, combined with future atmospheric probes and lander opportunities with the ability to explore the near surface environment are also needed to answer supercriticality question (iii) completely and constrain question (iv).

References:
FLOW INSTABILITIES IN VENUS CLOUDS EXPLORED BY AKATSUKI RADIO SCIENCE EXPERIMENT.  A. Bhattacharya1, V. Sheel2, J. P. Pabari2, T. Imamura3 and K. McGouldrick4, 1SVNIT Surat, India, ananyo0806@gmail.com, 2PRL Ahmedabad, India, 3Graduate Institute of Frontier Sciences, University of Tokyo, Japan and 4LASP, CU Boulder, US.

Introduction: Planetary atmosphere of Venus undergoes strong zonal circulation consisting of high speed winds around the cloud region i.e. 48-70 Km. The atmospheric circulation patterns in the middle cloud region i.e. 50-56 Km shows strong convective activity. Thus, the interaction between the mean zonal circulation and vertical motion due to convective activity can give rise to shear flow instabilities leading to formation of Kelvin-Helmholtz billows in the cloud region.

Measurements from radio occultation experiments from various Venus orbiters have been utilized to study the thermal structure of the atmosphere. Akatsuki radio science experiment derived temperature profiles and in-situ measurement of zonal wind speeds from Pioneer Venus probes are utilized to study the possibility of shear flow instability. Computation of Richardson’s number yields low magnitudes in the cloud region indicating multiple instances of occurrence of shear flow instabilities due to interaction flow interactions.

Radio occultation: In this method, the orbiter transmits radio wave signals to a Earth based tracking station and in the process, it passes through the atmosphere of the planet. The propagation of radio waves through the atmosphere is then processed to retrieve the properties of ionosphere and neutral atmosphere. Radio occultation experiments onboard Venus orbiters have studied thermal structure, composition, small scale disturbances and characteristics of internal gravity waves and saturation characteristics.

Method: JAXA Data ARchive and Transmission System (DARTS) has data from 34 radio occultation experiments performed by Akatsuki. Level 4 data from Akatsuki radio science experiment [1] is used to compute static stability and Brunt-Vaisala (BV) frequency equation (1) by incorporating adiabatic lapse rate values from Venus International Reference Atmosphere (VIRA) [2]. The wind speeds are calculated using an analytic formula [3] from the in-situ measurements of Pioneer Venus probes. Further, the wind speed inputs are then corrected for latitudinal variation [4].

The necessary condition for occurrence of KH instability is expressed in terms of Richardson’s number, Ri using equation (2). KH instability occurs if the magnitude of Ri is less than or equal to 0.25. However, it is to be noted that it is a necessary but not a sufficient criterion. We have only considered the non-negative values of Ri, as negative values indicate presence of static instability. Ri has been previously utilized in radiative-dynamical models for Venus clouds [5] to study mixing processes in unstable and turbulent atmosphere. Our computations for Ri yield values varying by large order of magnitude from one another, therefore to incorporate the range of absolute values we define a term Z as expressed in equation (3) such that KH instability occurs when Z is less than zero.

\[ N^2 = \frac{g}{T} S \]  

\[ Ri = \frac{g}{T} \left( \frac{S}{dh} \right)^2 \]  

\[ Z = \log_{10} \left( \frac{Ri}{0.25} \right) \]

Where \( N^2 \) is square of BV frequency, \( g \) is acceleration due to gravity, \( S \) is static stability, \( T \) is the temperature, \( u \) is the zonal speed, \( h \) is length along vertical direction and \( Ri \) is Richardson's number.

Results: Figure 1 depicts the combined magnitude of \( N^2 \) vs. altitude for all the 34 radio occultation experiments. It can be seen that the atmosphere has a quasi-neutral stability in the 50-55 km region, due to the static stability earlier reported [6] and a comparison with previous radio occultation measurements. The relatively larger magnitudes of \( N^2 \) could be attributed to intense convective activity and noise in the measurement. Negative values of \( N^2 \) in figure 1 indicate static instability in the clouds.
The interaction of zonal wind with convective activity in the cloud region is of great interest in order to study the dynamical process of Venusian atmosphere. Breaking of the KH billows can be expected to be a source of generation of turbulent flow in the cloud leading and thus, playing a role in atmospheric transport of momentum and energy. Furthermore, KH instability is one of the saturation mechanisms for internal gravity waves.

Lastly, the phenomenon of the atmospheric lightning process is yet to be fully understood. Convection has been the driving force for charge separation mechanisms on Earth. The role of zonal circulation and convective activity into possible charge separation mechanisms has not been explored in case of Venus. Charge separation due to transport of large sized ice particles has been discussed earlier [7]. Further work will explore the characteristics of flow instability and their role in various atmospheric processes on Venus.

### References:


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**Discussion:** From equations (1) and (2), it can be seen that computations of Richardson’s number are sensitive to static stability, temperature and wind speed measurements. Thus, input data from peer-reviewed works are used for the computation.
IN-SITU MINERALOGICAL ANALYSIS OF THE VENUS SURFACE USING X-RAY DIFFRACTION.

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Introduction: The history of a planet is written in its rocks and the minerals they contain. Because minerals are stable under known ranges of temperature, pressure and composition, a rock comprised of specific minerals can be used to identify the conditions under which it formed and subsequent environmental changes, based on individual mineral stability ranges and the presence or absence of equilibrium between them. More than optical, elemental or isotopic analysis, definitive mineralogical analysis with X-ray Diffraction (XRD) provides information about habitability: T, P conditions of formation, present/past climate, water activity, the activity of biologically significant elements and the like. Such determinations are not possible if qualitative mineralogical data are obtained or if the complete mineral assemblage is not characterized.

The CheMinV Instrument Intended for Landed Venus Science: Like MSL-CheMin [1], CheMinV [2] is a powder X-ray Diffractometer. For more than a century XRD has been the preferred method for mineralogical analysis of unknowns in terrestrial laboratories. CheMinV will utilize a Silicon Drift Detector (SDD) integral to the instrument to determine the chemical composition of the exact sample used for diffraction analysis. It is important to note that the major element chemistry of every mineral present in the sample at >5 wt. % concentration is determined using XRD data alone. XRF is only required to quantify minor or trace elements which are not reflected in the lattice parameter measurements.

CheMinV is the product of a decade of post-CheMin technology development, yielding a >10X increase in data acquisition speed, a 50% reduction in instrument mass and volume and improved pattern resolution. X-ray Diffraction analyses of drilled and powdered samples on Venus by CheMinV will yield:

- Identification of all minerals present >1 wt. %.
- Quantification of all minerals present >3 wt. %, including their structure states and cation occupancies.
- Abundance of all major elements present in each mineral (H and above) from their refined lattice parameters, for minerals present at >5 wt.%.
- Valence state of all major elements, including speciation of multi-valent species such as Fe for minerals present at >3 wt% from their empirical formulas.

There are no spacecraft instruments currently in NASA’s planetary science inventory that can claim even one of these capabilities.

Fig. 1 shows the proposed geometry of the CheMinV instrument. Further details and examples of its mineralogical capabilities are presented in [2].

Fig. 1: 3D model of CheMinV. Dimensions: 290 X 190 X 162 mm. Samples are delivered through a funnel (not shown) positioned over the cell to be analyzed.

CheMinV meets the requirements of five investigations described in the recent Venus GOI document [3], including I. A. HO(1): Evidence for silicic rocks and/or ancient sedimentary rocks; I. A. RE(1): Evidence of crustal recycling; III. A. GC(1): Determine elemental chemistry, mineralogy and rock types representative of global geologic units; III. B. LW(1): Evaluate mineralogy, oxidation states, etc. of weathered rock exteriors; and III. B. GW(2): Determine the causes and extent of global weathering.

A Global Survey of Lithospheric Flexure and Elastic Thickness at Steep-Sided Domes on Venus. M. E. Borrelli*, J. G. O’Rourke1, S. E. Smrekar2, C. M. Ostberg1. 1School of Earth and Space Exploration, Arizona State University, Tempe, AZ. 2Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA. 3Department of Earth and Planetary Sciences, University of California, Riverside, CA. *meborrel@asu.edu.

Introduction: Volcano morphology seen on the surface can be used to learn about the interior of a planet. Signs of lithospheric flexure around these volcanoes can help us interpret the lithospheric thickness and heat flow at certain locations. McGovern et al (2013) [1] hypothesized that, in general, steep-sided domes on Venus should form where the elastic thickness is between ~15 and 40 km, while volcanic features resembling some coronae are expected to form where the elastic thickness is less than ~10–15 km. Large conical volcanoes may form where the lithosphere is thickest, over ~40 km.

We focused our study on steep-sided domes rather than coronae or large conical volcanoes. We were unable to conduct an analysis of large conical edifices because the flexural moats around these features are not visible. McGovern et al. (1997) [2] suspect that these moats were filled in by flows from the volcano. Previous studies have calculated low elastic thicknesses at the locations of coronae. O’Rourke and Smrekar (2018) [3] used newly available stereo topography to study flexural signatures around coronae. They used plate bending models to estimate elastic thickness, finding elastic thicknesses of ~5–15 km at most coronae. Smrekar et al. (2019) also calculated plate thickness at >70 features including coronae using an elastic plate bending model along with topographic profiles. Their derived elastic thicknesses ranged from ~3–30 km. They also determined the heat flow at these locations by converting elastic to mechanical thickness using an assumed rheology for the lithosphere. They found heat flows ranging from ~21–350 mW/m². Their study confirmed that coronae often form where the lithosphere is thin. Crucially, local estimates of low elastic thicknesses from flexure generally agree with regional inferences derived from admittance (gravity and topography) [4].

We searched for flexural signatures around steep-sided dome volcanoes on Venus to determine the elastic thickness and heat flow at the surface. Our study confirmed the initial hypothesis: Our derived value for elastic thickness averaged ~22 km at domes that are not near coronae, while the thickness at domes near coronae averaged ~7 km. These estimates, like those obtained from coronae, agree with admittance values.

Methods: We conducted the first global survey of flexural signatures around steep-sided domes on Venus. We drew topographic profiles around 75 steep-sided domes on Venus using JMARS. Eight profiles were drawn around each dome at increments of 45°. The profiles began at the edge of each dome and extended ~800 km into the surrounding topography. We avoided interfering features such as craters whenever possible. Where it was available, we used the stereo-derived topography which covers ~20% of the surface. The profiles were trimmed to start at the lowest-elevation point in the topographic moat. The elevations were normalized to a minimum of zero in each profile.

We analyzed the profiles in MATLAB to determine which domes showed signs of flexure. Flexural signatures present as a moat around the volcano, followed by a topographic rise culminating in a forebulge before flattening out. There were convincing signs of flexure in 29 profiles around 14 different domes. We used both Cartesian and axisymmetric models of flexure with a curve-fitting algorithm to determine the elastic plate thicknesses. The axisymmetric model assumes a disc-shaped load imposed on a continuous plate, which is most realistic.

We collected the flexural parameter and the maximum plate curvature near the forebulge for each profile. A yield stress envelope for (nominally) dry olivine then converted the elastic thicknesses to mechanical thicknesses and calculated the surface heat flows.

Results: We used a Monte Carlo method to take averages and calculate uncertainties for each profile. We averaged all the profiles around domes for which multiple profiles showed signs of flexure. When considering all profiles, we found the average elastic thickness for a continuous plate using the Cartesian model was ~16 km, and the elastic thickness using axisymmetric geometry was ~15 km.

Our results were significantly different based on whether or not the domes were located near coronae. The average elastic thickness for profiles near coronae was ~7 km using both Cartesian and axisymmetric geometry. The average elastic thickness for profiles not near coronae was ~25 and 22 km using Cartesian and axisymmetric geometry, respectively. In general, the mechanical thicknesses were approximately 20% larger than the elastic thicknesses.

We also recreated results from Russell and Johnson (2019) [5] for Narina Tholi. This steep-sided dome is on the margin of Aramaiti Corona, which is consistent with the thin elastic thickness. We found an elastic thickness of ~4 ± 0.2 km at this location, which is similar to the previous estimate of ~2–3 km [5].
We then determined the agreement between our derived elastic thicknesses and those derived from gravity data [4]. Specifically, we analyzed the pixels on the map of admittance-derived values and counted the percentage that were the same as those we calculated within the spatial resolution of the gravity data. Our derived thicknesses agreed with at least some percent of the gravity-derived values at 12 out of 14 domes. Of these, 7 domes showed excellent agreement (>50%), while 5 domes showed good agreement (0 to 50%). The remaining 2 domes did not show any agreement with the admittance-derived values. For this analysis, we ignored regions where results from gravity data were missing.

Finally, differences in elastic thickness translate into differences in heat flow based on proximity to coronae. We found an average surface heat flow for profiles near coronae of ~220 mW/m², while the average value for profiles not near coronae was ~60 mW/m².

**Conclusion:** Our results strongly support the hypothesis that steep-sided domes are likely to be found where the elastic thickness is between ~15 and 40 km. We assert that the presence of steep-sided domes can be used to make inferences about the lithospheric thickness. Ultimately, volcano morphology is a probe of lithospheric thickness, and lithospheric thickness is a window into the dynamics of planetary interiors.

New spacecraft missions would vastly improve our understanding of the Venusian lithosphere, global heat flow, and interior dynamics. For example, stereo-derived topography was an important resource for this analysis. This data only covers about 20% of Venus’s surface, but over 40% of the domes showing flexural signatures were revealed using stereo data. Better data would reveal new features and permit more precise analyses. Higher-resolution imagery, topography, and gravity data with global coverage would be invaluable.


**Figure 1.** Derived elastic thicknesses (a) and surface heat flows (b) at steep-sided domes on Venus. Domes near coronae have “coronae-like” values. Nearly all other domes have elastic thicknesses ~15–40 km.
DISTINCT MINERALOGY ASSOCIATED WITH INDIVIDUAL LAVA FLOWS IN ATLA REGIO, VENUS. J. Brossier, M.S. Gilmore, K. Toner, and A.J. Stein. Dept. of Earth and Environmental Sciences, Wesleyan University, Planetary Science Group, 265 Church St., Middletown CT 06459, USA (jbrossier@wesleyan.edu).

Introduction. A decline in radar emissivity at many Venus mountaintops [1,2] is thought to be the result of atmosphere-surface interactions in the highlands, where temperatures are lower [3–5]. These reactions are a function of rock composition, atmospheric composition, and degree of weathering. Recent analysis of NASA’s Magellan radar data [6,7] reveal that some large volcanoes on Venus exhibit multiple, often sharp declines in radar emissivity values over a range of altitudes. This phenomenon was also reported in earlier studies [8]. Here we perform detailed mapping of these volcanoes and examine any correlations between their location and stratigraphic position and emissivity signature; this may yield insight into the evolution of the volcanic system. Here we focus on Sapas, Maat and Ozza montes, located in Atla Regio.

Data & Methods. We mapped the lava flow units of the volcanoes with the Magellan Synthetic Aperture Radar (SAR) images at 75 m per pixel. Mapping of the flow units is primarily based on morphology, radar backscatter, and stratigraphic relationships, e.g., [9]. Magellan elevation and emissivity data are extracted to produce scatterplots of the variation of emissivity with altitude [1,6]. Both datasets are oversampled to 4.6 km per pixel. The elevation data are given in planetary radius with a mean value of 6051.8 km [10]. We retrieved temperatures by correlation to the Vega 2 lander entry profile [11]. We derived permittivity from emissivity after [12], as described in [13].

Geologic Mapping and Emissivity Excursions. Emissivity excursions are defined as a reduction of radar emissivity below a value of 0.7 on an elevation vs. emissivity plot. The shape and elevation of these excursions can be seen in Fig. 1, plotted as permittivity, which is considered as the inverse of emissivity.

We identified 6 lava flow units on Sapas (S1-6 units). Most flow units participate in the same emissivity excursion (e1) and reach their minimum values at around 6054 km. The radiating bright flows (S5 unit) display a more gradual decline above this altitude until 6054.6 km with an emissivity low of ~0.4, before returning to slightly higher emissivity values at the summit features (S6 unit). The summit region comprises the two scalloped-margins domes and dark materials exposed on their flanks [9].

Then, we identified 5 lava flow units on Maat (M1-5 units). The southwest bright flows (M2 unit) are the main source of the emissivity excursions at 6056.2 km (e1), 6055.4 km (e2) and 6053.9 km (e3). The northwestern flows (M1 unit) are the main source for the excursion at 6052.7 km (e4). The SAR dark materials identified in the north flank (M3 unit) and in

![Figure 1 - Derived permittivity vs elevation plots with modeled excursions for each volcano.](8012.pdf)

8012.pdf
the summit region (M4 unit) of Maat have mostly high emissivity values. The eastern flows (M5 unit) extending from the summit also have high emissivity for the entire elevation range of the volcano.

Finally, we identified 8 lava flow units on Ozza (O1-8 units, see Fig. 2), however stratigraphic relations among them remain ambiguous. The tectonized caldera (O3 unit) is the main source of the emissivity excursions at 6056.7 km (e1) and 6055.7 km (e2), before returning to higher values at elevations above 6057 km (i.e. SAR dark plateau). Another set of flows (O4 unit) is stratigraphically above the caldera and may contribute in the previous excursions (e1–2). The field of shield volcanoes found near the dark plateau (O5 unit) has an average emissivity of 0.55. The hummocky flow field (O2 unit) surrounding the summit is the main source for the excursion at 6052.5 km (e3) and participates in the high elevated excursions (e1–2). We also include two large flow fields (O7–8 units) identified near Atla Regio and Parga Chasma that are possibly associated to Ozza’s activity. They both participate in the low elevated excursion at 6052.5 km (e3).

**Ferroelectric Model.** The shape of the emissivity variations seen in these volcanoes are consistent with the presence of ferroelectric minerals in the rocks undergoing a phase change at a specific temperature (Curie temperature, Tc) [14] (see also Ovda Regio [15]). If we assume that the elevation of the major excursions represent their Curie point temperature, we can estimate the volume of the ferroelectric assuming a constant mineral shape (see Fig. 1).

**Discussion & Conclusion.** Emissivity excursions in the studied volcanoes are spatially correlated to specific flows, ensuring that they are related to rock composition rather than atmospheric conditions (composition, temperature). The low elevated excursions are consistent with ferroelectric minerals at higher Curie temperature than for the excursions previously considered on Venus.

There are multiple excursions in one volcanic system, suggesting there are multiple minerals in that system. Flow events with similar excursions in emissivity with altitude are not always contiguous or sequential. Sapas flows are consistent in dielectric composition through its history, unlike Maat and Ozza. Only the two oldest flows of Maat have undergone the weathering, while all of the flows of Ozza have had enough time, implying much of Maat is younger than Ozza. This is supported by the volumes of ferroelectrics in Ozza modeled to be greater than in Maat, indicating more time to produce them.

The temperature and altitude of the emissivity excursion are functions of composition, while the magnitude of the excursion is a function of volume of the ferroelectric [4]. The existence of emissivity excursions at the same altitude across several flow events provides an opportunity to study the evolution of the reactions creating these excursions. Some excursion elevations are shared between volcanoes, implying that similar common minerals are turning on within these volcanoes, particularly Maat and Ozza montes, while Sapas has its own distinct mineralogy.

In-situ exploration of Venus is challenging due to its severe environment, which is benign (~25°C) at an altitude of 55 km, but rapidly becomes more hostile at lower altitudes. The temperature increases at ~7°C/km to ~465°C, with the pressure reaching 90 bars at the surface.1 These challenging conditions have limited in-situ exploration missions to high altitude balloons at 55 km (above the clouds) that lasted for 48 h, or even shorter duration surface missions that survived for two hours.2,3 The high-altitude (55-65km) balloon missions are stymied by the opaqueness of the Venusian clouds, which underlines the need for long-duration and deep atmosphere missions for a better understanding of the Venus atmosphere across the cloud layers and below, as recommended by the Venus science community, Venus Exploration Analysis Group (VEXAG).4 Long-duration variable-altitude balloons (VABs) extending below the clouds have gained particular interest. Durable VABs would allow i) long-term measurements across Venus clouds, ii) determination of chemical species and isotopes underneath the clouds, iii) transport to different longitudes on the planet and measure atmospheric flow patterns, especially with the altitude control, iv) probing the interior structure through close-range imaging, and v) investigation of the seismic activity from acoustic measurements at various altitudes.

For these missions, conventional power technologies are not adequate, e.g., the performance of photovoltaics (PV) is hampered by the decreasing solar flux deeper in the clouds, the selective loss of short wavelength radiation, and the performance loss from the high temperatures.5 An energy storage system tolerant to high temperatures is needed to compensate for the reduced power generation of PVs at low altitudes, and to support nighttime operations. In this paper, we will describe a novel power architecture we have developed for Venus VABs under NASA Innovations and Advanced Concepts (NIAC) program. The probe concept utilizes: i) PV to provide power at high altitudes, ii) Solid oxide fuel cell (SOFC)6 operating at 800 °C to provide power at low altitudes, iii) H2 storage bed for on-demand storage or release of H2,7 using chemical (metal) hydrides and iv) a balloon filled with hydrogen and with hydrogen buoyancy-based altitude control system. Both H2 and O2 would be regenerated through electrolysis of the water produced in the fuel cell (a closed–system) at high altitudes. Because of the innate thermal and chemical stability of the components, the VAB will operate for multiple altitude excursions on Venus and facilitate long-term exploration of the Venus atmosphere from 55 km to 20 km.

Acknowledgments: This work was carried out at the Jet Propulsion Laboratory, Caltech under a contract with National Aeronautics and Space Administration and supported NASA-NIAC.

LONG DURATION IN SITU SCIENCE IN VENUS’ CLOUDS ENABLED BY DYNAMIC SOARING. M. A. Bullock1, J.S Elston2, M. Z. Stachura2 and S Lebonnois3, 1Science and Technology Corp., 2Black Swift Technologies, 2840 Wilderness Pl Ste D, Boulder, CO 80301, elstonj@bst.aero, stachura@bst.aero, 10015 Old Columbia Road E-250, Columbia, MD 21046, bullock@stcnet.com, 3Laboratoire de Météorologie Dynamique, 24 rue Lhomond 75005 Paris, sebastien.lebonnois@lmd.jussieu.fr

Introduction: In regions with high vertical shear, it is proposed that gliders in Venus’ atmosphere can soar for as long as conditions persist. This will allow for in situ sampling and analysis of the atmosphere and aerosols at several important levels in Venus’ clouds. At the equator, the top of an unstable atmospheric layer at about 55 km above the surface marks the top of the middle cloud. This unstable layer is deeper at higher latitudes, but persists through day and night. Above this, a persistent layer of vertical shear at 55 km produces ideal conditions for energy harvesting flight. Dynamic soaring above the large convection cells of Venus’ middle cloud gains access to this vital region. The condensation and evaporation of cloud particles happen here, and reactions with photochemical products from above drive the atmospheric and cloud chemistry. Typical flight paths would enable periodic measurements and sampling of Venus’ middle and upper cloud atmosphere as the aircraft circles the planet. Practical payloads and sampling schemes have the potential to achieve most of the VEXAG Objectives on the chemistry, dynamics, and cloud processes of Venus’ atmosphere.

Science: The VEGA balloons in Venus’ atmosphere were tracked by a global network of radio receivers, including in the US, in 1986. The resulting tracks of the VEGA balloons as they floated in Venus’ clouds are by far the most detailed dynamical information we have of the middle cloud environment. Each balloon’s 4 Watt transmitter was tracked from Earth for the entire 48 hours of duration of operation, until their batteries died. The VEGA 1 and 2 balloons entered on the night side of Venus, at 7°N and 7°S, respectively. They both continued to operate and return data as they drifted onto the day side, traversing about 30% around the planet.

Numerous authors have pointed out that the dynamics of Venus’ atmosphere can’t be understood without direct measurements of its winds. While VEGA acquired 48 valuable hours of dynamical data in the clouds, much longer and more widely dispersed measurements are needed. Fixed wing aircraft using autonomous dynamic soaring with no propulsion can linger for weeks or months in the stable layer above the middle cloud at about 55 km above the surface. The average temperature here is 8°C and the atmospheric pressure is 500 mbar. If an aircraft with a single 4W transmitter could be tracked from Earth for 30 days, it will have circled Venus 5 times.

At low latitudes, an additional unstable region at 63 km develops at night, and disappears in the morning. Horizontal winds increase rapidly above 63 km, providing ideal conditions for dynamic soaring. At higher latitudes, this unstable region with vertical shear above may persist for most of the day. This region in the upper cloud is where the sulfuric acid particles are made, among other photochemical products. Flying in this region offers the opportunity to sample and analyze upper cloud constituents and products of photochemistry. At 63 km, the average temperature is -32°C and the ambient pressure is 150 mbar.

To harvest energy from the atmosphere, the aircraft flies a corkscrew path into and out of a vertical shear layer. Vertical travel along a typical path may be about 1 km, providing a sampling grid of measurements 1 km wide over 55-56 km, all the way around the planet with the prevailing winds.

Instruments: Aside from a low power transmitter for tracking from Earth, some very simple and inexpensive instruments can be deployed for in situ measurements judged as high priority science by VEXAG. Temperature, pressure, accelerometry and relative wind speed would provide fundamental thermodynamic quantities for 5 circuits around the planet. A solid state inertial navigation system would be necessary for autonomous navigation and reconstructing the flight path between transmissions. Miniature atmospheric structure instrument suites are available that weigh 200 g. A single chip IMU may also be 200 g.

Atmospheric composition measurements of specific gases can be performed by MEMS sensors to the parts per billion level. The substantial questions about the atmospheric sulfur cycle can be answered by the monitoring of S, Cl, and C gases in the cloud during flight around the planet. The sensors are about 10 g each, so a suite of 12 would have a mass of 120 g.

Simple optical instruments that measure the light field from UV to near-IR in several directions as the aircraft flies through the clouds would enable a much better understanding of Venus’ atmospheric energy balance and the role of scattering. The optics and detector for each direction may weigh 150 g. At least 3 directions (up, down, forward) will be required, or 450 g.

Another optical device that could be carried on each aircraft is a nephelometer - a hoop through which cloud particles flow, lined with lasers and detectors to measure their sizes, number densities, indices of refraction, phase functions, and polarimetric measurements. The characterization of cloud particles as the aircraft flies through the middle cloud will test long-standing uncertainties about the composition of some of the size modes, and the existence of trace species such as FeCl₃ and elemental sulfur. With 12 scattering angles and hence 12 solid state lasers and 12 detectors, such an instrument might weigh 4 kg.
The next step up in instrument mass would be an aerosol collection system for microscopic imaging, polarimetry, and fluorescence. Insoluble cores, if they exist, and coatings on the aerosols (such as Sn) would be visible, and measurable. The collection system maybe 2 kg, and the microscope with filters and light sources may be 1 kg, for a total of 3 kg. All these sensors and instruments come to 7.97 kg.

Truly revolutionary science could be done with a state-of-the-art miniaturized gas chromatograph, particularly if it was able to separate out the aerosols and analyze them separately. Such an instrument would provide a continuous inventory of the gases and aerosols of the middle cloud, as the aircraft speeds through the 6 day day and night cycle, circling the planet.
Volcanic Venus: The NASA Magellan mission [1] showed Venus to be a world with discernable lava flows, thousands of shield volcanoes, shield fields and domes [2], and a range of volcanotectonic landforms [3]. The planet also boasts a dearth of impact craters below 25 km in diameter and none <3 km across [4]. Crater statistics derived from global Magellan data give an average model age for the surface of 700–800 Myr [5], with global-scale volcanic resurfacing likely the dominant reason for such apparent youth [6].

Ongoing Volcanism: But is Venus volcanically active today? Circumstantial evidence comes in the form of anomalously high thermal emissivity values of stratigraphically young flows recorded by the ESA Venus Express (VEx) Visible and Infrared Thermal Imaging Spectrometer. These values were interpreted as a lack of weathering arising from those flows having been emplaced perhaps within the last 250,000 years [7]. The VEx Venus Monitoring Camera also observed, over successive orbits, localized increases and decreases in surface temperature on a timescale of days to months, consistent with short-lived effusive activity [8].

The planet’s atmosphere may record the effects of ongoing volcanism, with the global H2SO4 cloud layer [9] itself likely maintained by the release of sulfur and water from the interior within the last several tens of millions of years [10]. And a dramatic reduction in the cloud top abundance of SO2 observed during the Pioneer Venus mission is consistent with the injection into the atmosphere of that volatile by volcanism of a scale comparable to the 1833 eruption of Krakatau [11].

Extrapolating Eruption Data From Earth: We collated volcanic eruption data from the Smithsonian Institution’s Global Volcanism Program (GVP) database [12], extrapolating those findings to Venus to estimate the frequency of eruptive events there. The GVP database catalogs the number and duration of terrestrial and submarine volcanic eruptions extending beyond the last 2,000 years. To minimize inconsistent reporting of historical eruptions, we only considered eruptions between 1 January 1900 through 24 July 2020 (assigning any ongoing eruptions that end date).

We identified 3,780 individual eruptions from 441 unique volcanoes in the GVP database between 1 January 1900 and 24 July 2020. We removed 316 eruptions associated with 65 submarine volcanoes, leaving 3,464 subaerial eruptions, of which approximately 100 were active as of 24 July 2020. Of those, 2,897 were recorded with both a specific start and end date, to which we limited our analysis.

Eruptive Frequencies: Most eruptions on Earth are relatively short-lived, with 12.7% ending within a day and 53% within 100 days; only 20% of eruptions persist beyond 1,000 days. With the GVP dataset, we generated bootstrapped estimates of the expected number of new or ongoing eruptions within a random 30-day period on Earth. We find that an average of 2.34 new eruptions (σ = 1.79) of any duration are expected on Earth in any 30-day period. When considering both new and ongoing eruptions that endure ≤100 days, 1.93 (σ = 1.56) events are expected within 30 days. That frequency increases to 7.74 (σ = 5.22) eruptions lasting ≤1,000 days.

We extrapolate our findings to Venus by assuming that eruptive frequency can be directly scaled first by surface area (344%, from land surface on Earth to planetary surface on Venus), and then by some planetary parameter, e.g., planetary mass, volume, silicate portion, or surface area. Of these parameters, planetary mass offers the lowest ratio: 0.816. Thus, by this reasoning, we calculate ~six new eruptions on Venus of any duration on Venus within any 30-day window. Similarly, we might expect ~five new and ongoing Venusian eruptions ≤100 days in length, but as many as ~22 by considering new and continuing eruptions lasting ≤1,000 days, in a given 30-day span.

Outlook: This scaling approach is simplistic—but serves to illustrate that, should Venus’ volcanic activity resemble that of Earth, a nominal 30-day [13] aerial platform mission in the Venus atmosphere might reasonably expect to detect volcanic eruptions (via infrasound through direct atmospheric coupling or pre- and co-eruptive seismicity [14], say). Moreover, an orbiter equipped to detect changes in surface thermal emissivity [15] could, over a nominal four-year mission, be present for more than 1,000 discrete eruptive events.

FUTURE SPACE PHYSICS AT VENUS. G. A. Collinson¹, C. Fowler², R. Ramstad³, S. Curry², M. Chaffin³, S. Xu⁴, S. Boucher⁴, G. DiBraccio¹, C. Dong⁵, Y. Futaana⁶, M. Fillingin¹, R. Jarvinen⁷, S. Ledvina², J. Luhmann², Joe O’Rourke⁸, Chris Russell⁹, Moa Persson⁶, Michael Way¹⁰,

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We summarize white papers recently submitted to the Planetary Science and Astrobiology Decadal Survey 2023-2032.

EXPLORING ATMOSPHERIC DYNAMICS, ESCAPE, AND EVOLUTION

Our understanding of ancient Venus and its evolution to the present day could be substantially advanced through future Space Physics investigations from orbit. We outline three high-priority strawman investigations, each possible for relative thrift with existing (or near-future) technology. 1.) To understand the physical processes that facilitate Venusian atmospheric escape to space, so that we may extrapolate backwards through time; 2.) To explore ancient Venus through the measurement of the escape rates of key species such as Deuterium, Noble elements, and Nitrogen; 3.) To understand and quantify how energy and momentum is transferred from the solar wind, through the ionosphere, and into the atmosphere, so that we may reveal its impact to the dynamics of the atmosphere.

Unravelling the drivers of Venusian ionospheric structure, energy balance and evolution, through in-situ plasma measurements at Venus

We recommend a multi-spacecraft dedicated plasma mission at Venus, capable of sampling the entire induced magnetosphere, while simultaneously measuring the upstream solar extreme ultraviolet (EUV) flux and solar wind. Such observations, obtained over a range of solar activity levels, would revolutionize our understanding of how the Venus time-dependent induced magnetosphere and ionosphere respond to solar EUV flux and solar wind variability, and would address several high priority VEXAG and planetary science goals.

The lack of a dipole magnetic field at Venus means that the solar wind interacts directly with the gravitationally bound conducting ionosphere, producing an induced magnetosphere that acts to slow down and deflect the solar wind around Venus. This interaction leads to a highly structured and dynamic plasma environment that responds strongly to changes in the solar EUV flux and the upstream solar wind conditions.

Previous in-situ observations of the Venus plasma environment have provided information on the basic physical processes that dictate this interaction, however, limitations in instrument capabilities, solar cycle phase, and orbit coverage have left a plethora of questions unanswered. In particular, comprehensive (high time cadence and full distribution) plasma, neutral, magnetic and electric field measurements, as well as simultaneous upstream solar wind monitors, are needed to fully characterize the state of Venus’ magnetosphere, ionosphere and atmosphere, and the real-time response of these to variations in upstream solar wind conditions.
PARKER SOLAR PROBE VENUS FLYBY CAMPAIGN: LATEST RESULTS.

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Introduction: In order for the NASA’s Flagship Parker Solar Probe (PSP) mission, to study the solar corona, it will fly closer to the sun than any spacecraft ever has by performing seven gravity assists at Venus [Figure 1]. These gravity assists provide a rare opportunity to study the induced magnetosphere and solar-wind interaction at Venus using the instrumentation aboard PSP. These gravity assists provide a rare opportunity to study the current induced magnetosphere and solar-wind interaction at Venus using the instrumentation aboard PSP. Venus's upper atmosphere hosts several atomic species such as hydrogen, helium, oxygen, carbon, and argon, some of which are energized in the upper atmosphere to escape energies or ionized and carried away from the planet. What is special about Venus, as opposed to Mars, is that virtually all significant present-day atmospheric escape of heavy constituents is in the form of ions.

Results: Using the Fields experiment (FIELDS) and Solar Wind Electrons Alphas and Protons Investigation (SWEAP), we will present recent observations from the first 3 PSP Venus gravity assists, including the first high resolution in-situ electric field observations to ever have been measured at Venus. We will use the observed solar wind moments as upstream boundary inputs into a magnetohydrodynamic (MHD) model and present a global picture of the induced Venusian magnetosphere and the subsequent ion acceleration, as well as the magnetic topology throughout the first three flybys. For the third flyby, the Wide-field Imager for Parker Solar PRobe (WISPR) instrument observed the Venusian cloud deck, which we will discuss in context with Akatsuki as well as the ground campaign at Apache Point and Keck Observatories. We will also compare the PSP Venus flyby during the deep minimum of solar cycle 24 to previous observations downtail with VEX and PVO. Finally, we will also discuss the ongoing collaborations with BepiColombo and Solar Orbiter with respect to their Venus gravity assists.

Figure 1: An equatorial view of the Parker solar Probe Venus gravity assists. Top: Venus encountering the solar wind proton velocity; bottom: Venus encountering the interplanetary magnetic field (IMF). [Curry et al. 2020]
References:

Acknowledgments: A special thanks to the PSP team as well as Candace Gray and Sarah Kovac for their collaboration on the group campaign at APO and Keck/Lick.
VENUS CORONA AND TESSERA EXPLORE (VeCaTEx) MISSION CONCEPT: INVESTIGATING THE SURFACE OF VENUS FROM BENEATH THE CLOUDS. James A. Cutts, Kevin Baines1, Patricia Beauchamp1, Chad Bower2, Anthony Davis1, Len Dorsky1, Darby Dyar3,4, Lorraine Fesq1, Anthony Freeman1, Richard Ghail5, Martha Gilmore6, Robert Grimm7, Anna Gülcher8, James Head9, Joern Helbert10, Jennifer Jackson11, Maxim De Jong,12 Jeffery L. Hall1, Jacob Izraelevitz9, Siddharth Krishnamoorthy9, Larry Matthies1, Laurent Montesi13, Michael T. Pauken1, David Senske1, Christophe Sotin1, Brian Sutin1, Colin Wilson14, Jet Propulsion Laboratory, California Institute of Technology, 1Paragon Space Development Corporation, 2Planetary Science Institute, 4Mount Holyoke University, 6Royal Holloway, University of London, 7Wesleyan University, 9South West Research Institute, ETH Zurich, Brown University, 10German Aerospace Center (DLR), 11Division of Geological and Planetary Science, California Institute of Technology, 12Thin Red Line Aerospace, 13University of Maryland, 14Dept. of Physics, University of Oxford

The goal of the Venus Corona and Tessera Explorer (VeCaTEx) mission concept is to study the two feature categories that are believed to record the earliest geological events on the planet and the most recent volcanic and tectonic activity. VeCaTEx would acquire near infrared images of the surface of Venus with a special focus on coronae and tesserae with the object of learning more about the most ancient rocks on Venus exposed in the tessera and the most recent volcanic events taking place within the coronae. VeCaTEx accomplishes this by acquiring these images from an aerobot operating beneath the base of the Venus clouds thereby avoiding the degradation in spatial resolution of infrared signatures viewed from orbit. The spectral information would characterize the iron contents and infer rock types of the surface of Venus at high spatial resolution. In addition to surface images, VeCaTEx could also image gas plumes resulting from outgassing in regions of recent volcanic activity.

The concept of remotely mapping the composition of the surface of Venus by observing thermal emission on the nightside of Venus, in a set of visible and near infrared spectral windows, emerged from Venus flyby observations by the Galileo and Cassini spacecraft [1], [2], [3], [4]. When improved data from ESA’s Venus Express mission became available, areas of enhanced near infrared emissivity were identified and correlated with volcanic features identified in radar images [5]. Emissivity differences have also been associated with the Venus tessera [6]. VeCaTEx looks beyond the limitations of orbital platforms to provide a method of acquiring emissivity maps with spatial resolution in the near infra red (NIR) comparable to that of existing radar data or better. Orbital near infrared imaging suffers from an inherent limitation that scattering in the deep cloud layer limits spatial resolution to 100km. VeCaTEx incorporates a Type 3 aerobot [7] capable of penetrating below the cloud base from where it images the Venus surface. Beneath the clouds, particulate and aerosol scattering is largely absent but a deep Raleigh scattering atmosphere still impedes imaging at visual and near infrared wavelengths and gaseous absorption features limit surface imaging to narrow spectral windows. Because of the inverse fourth power dependence of the Rayleigh scattering cross section on wavelength, the optical depth varies dramatically from 3.7 at 0.82 µm to 0.7 at 1.18 µm. At 1.18 µm, almost 63% of the emitted radiation is not scattered by the atmosphere and can be focused on a pixel with a projected size of 10 m on the Venus surface. Imaging at shorter wavelengths will involve much larger contributions from scattered photons but is still feasible.
Table 1 VEXAG Goals Objectives and Investigations (GOI) addressed by the VEXATEX Mission Concept

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
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<tr>
<td>LAVH</td>
<td>Hydrous Origins: Determine whether Venus shows evidence for abundant silicic igneous rocks and/or ancient sedimentary rocks</td>
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<tr>
<td>LARE</td>
<td>Recycling: Search for structural, geomorphic and chemical evidence for crustal recycling on Venus</td>
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<tr>
<td>ILAR</td>
<td>Outgassing: Determine the products of volcanic outgassing on Venus and their effect on atmospheric composition</td>
</tr>
<tr>
<td>ILAGH</td>
<td>Geologic History: Develop a geologic history for Venus by characterizing the stratigraphy, modification state and relative ages of surface units.</td>
</tr>
<tr>
<td>ILAGA</td>
<td>Geologic Activity: Characterize current volcanic tectonics, and sedimentary activity that modifies geologic units, impact craters and ejecta.</td>
</tr>
<tr>
<td>ILBKW</td>
<td>Global Weathering: Determine the causes and spatial extent of global weathering regimes on Venus.</td>
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The VeCaTex aerobot would make repeated descents to 48 km on Venus during which it would acquire stereoscopic images at 1.18 um and several shorter wavelengths. These data would enable investigations of the surface itself and the presence of plumes of water vapor at an unprecedented spatial resolution of 10m/sec. This will enable six of the high priority objectives established by VEXAG [8] to be addressed (see Table 1).

In summary, VeCaTEx can transform knowledge of the origin and evolution of Venus as expressed in the youthful coronae and ancient tesserae. It exploits advanced aerobot technologies that can be matured during the next decade according to VEXAG’s Venus Strategic plan. VeCaTEx would naturally follow the next Venus surface-directed orbital mission and a mid-cloud aerobot mission with a launch early in the decade 2033-2042.

References
Atmospheric Escape From TOI-700 d: Venus versus Earth Analogs. C. Dong¹, M. Jin², M. Lingam³, ¹Princeton University (dcfy@princeton.edu), ²Lockheed Martin Solar and Astrophysics Lab, ³FIT/Harvard-Cfa

Introduction: The recent discovery of an Earth-sized planet (TOI-700 d) in the habitable zone of an early-type M-dwarf by the Transiting Exoplanet Survey Satellite constitutes an important advance. Here we assess the feasibility of this planet to retain an atmosphere – one of the chief ingredients for surface habitability – over long timescales by employing state-of-the-art magnetohydrodynamic models to simulate the stellar wind and the associated rates of atmospheric escape. We take two major factors into consideration, namely, the planetary atmospheric composition and magnetic field. In all cases, we determine that the atmospheric ion escape rates are potentially a few orders of magnitude higher than the inner solar system planets, but TOI-700 d is nevertheless capable of retaining a 1 bar atmosphere over gigayear timescales for certain regions of the parameter space. The simulations show that the unmagnetized TOI-700 d with a 1 bar Earth-like atmosphere could be stripped away rather quickly (<1 gigayear), while the unmagnetized TOI-700 d with a 1 bar CO₂-dominated atmosphere could persist for many billions of years; we find that the magnetized Earth-like case falls in between these two scenarios.

Results: The steady-state stellar wind solution is shown in Figure 1. The stellar wind speeds at the orbits of TOI-700 planets are comparable to the solar wind speed at 1 AU (~200 – 600 km s⁻¹). However, because of the much closer distances to the star, the stellar wind density and dynamic pressure are higher, as seen from panels (b) and (c) of Figure 1. The critical surface, defined as the region where stellar wind speed is equal to the fast magnetosonic speed, is also computed and shown in Figure 1. As with our solar system, all the planets in the TOI-700 system are outside this critical surface, i.e., the stellar wind environment of the planets is always "superfast."

Figure 1. Steady-state stellar wind characteristics of TOI-700. (a) The 3D stellar wind configuration comprising select magnetic field lines. Contours in the background illustrate stellar wind speed at the equatorial plane (z = 0). The blue isosurface signifies the critical surface beyond which the stellar wind becomes supermagnetosonic (or "superfast"). Black solid lines indicate the orbits of three planets, namely, TOI-700 b, TOI-700 c, and TOI-700 d. (b) Stellar wind dynamic pressure in the equatorial plane normalized by the solar wind dynamic pressure at 1 AU. (c) Stellar wind density in the equatorial plane normalized by the solar wind density at 1 AU. In panels (b) and (c), the dashed line represents the critical surface location.

Figure 2: The logarithmic scale contour plots of the O⁺ ion density (units of cm⁻³) with magnetic field lines (in white) in the meridional plane based on the stellar wind conditions at P_min (first row) and P_max (second row), which respectively correspond to the minimum and maximum total stellar wind pressure (P_tot) over one orbital period of TOI-700 d. The first column shows the unmagnetized Venus-like cases, whereas the second and third columns depict the unmagnetized and magnetized Earth-like cases.

The salient results concerning atmospheric escape are depicted in Figure 2, which shows the calculated oxygen ion density with the associated magnetic field lines in the meridional plane for all six cases. This figure yields some general conclusions. Table 1 summarizes the six cases along with the associated atmospheric ion escape rates.

Table 1: Stellar wind input parameters and the associated atmospheric ion escape rates at TOI-700 d for P_min and P_max.
We select two locations in the orbit, namely, $P_{\text{min}}$ and $P_{\text{max}}$, because they ought to yield the minimum and maximum ion escape rates, thus providing the range of values associated with this system. To begin with, as seen from Table 1, we note that $\text{O}^+$ constitutes the dominant ion species undergoing escape for all configurations considered here. The atmospheric oxygen escape rates vary from $O(10^{26})$ s$^{-1}$ to $O(10^{28})$ s$^{-1}$, indicating that they are higher by a few orders of magnitude than the typical escape rates of $O(10^{25})$ s$^{-1}$ for the terrestrial planets in our Solar system.

Let us first compare the unmagnetized cases, namely, the first and second columns in Figure 2. We find that the Earth-like case exhibits a stronger and broader flux of escaping $\text{O}^+$ compared to the Venus-like case; this result is also consistent with the atmospheric ion escape rates shown in Table 1. The reason chiefly stems from the fact that the upper atmosphere of a Venus analog is cooler than its Earth-like counterpart due to the efficient $\text{CO}_2$ cooling caused by 15 µm emission. In consequence, the exobase of a Venus-like planet is situated lower than that of an Earth-analog, thereby making the former more tightly confined. In other words, the extent of the atmospheric reservoir that is susceptible to erosion by stellar wind is smaller for the Venus analog as compared to an Earth-like atmosphere.

Now, let us hold the atmospheric composition fixed and vary the magnetic field, i.e., we compare the second column (unmagnetized Earth-analog) with the third column (magnetized Earth-analog) in Figure 2. Despite the fact that the magnetized cases exhibit a larger interaction cross-section with the stellar wind, the planetary magnetic field exerts a net shielding effect for the configurations studied herein for TOI-700 d. The presence of the global magnetic field reduces the atmospheric loss rate by roughly one order of magnitude relative to the unmagnetized case (see Table 1). Hence, of the three different scenarios considered in this work, unmagnetized Earth-like worlds are characterized by the highest atmospheric ion escape rates.

References:
PVO observations of low frequency, large amplitude magnetosonic waves interacting with the upper Venusian ionosphere: implications for ionospheric structure, heating and escape

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Introduction: Venus does not possess a significant global dipole magnetic field and subsequently the solar wind interacts with the electrically conducting gravitationally bound ionosphere to produce an induced magnetosphere that acts to slow down and deflect the solar wind flow about the planetary obstacle. The structure and relatively small scale size of the resulting induced magnetosphere (compared to magnetized planets such as Earth) mean that waves produced in the foreshock (a region magnetically connected to and just upstream of the bow shock) [1,2,3] are able to propagate planetward through the shock and sheath regions [4,5,6] to reach the upper Venusian ionosphere. Such waves may then facilitate the deposition of solar wind energy into the upper ionosphere via wave-particle interactions – a process that has long been cited as a possible mechanism to explain observed elevated electron temperatures in the Venusian ionosphere [8, 9, 10]. Understanding the mechanisms and conditions under which these large amplitude waves form, and their effectiveness at depositing energy into the upper ionosphere, is crucial for understanding ionospheric structure, dynamics and loss to space at Venus. These topics ultimately inform us about long term evolution of the Venusian atmosphere.

We report here Pioneer Venus Orbiter (PVO) observations of low frequency, large amplitude magnetosonic waves (MS) generated upstream of the shock, which are observed to propagate planetward into the upper ionosphere. The corresponding upper ionospheric density structure is highly disturbed during this event, as compared to “quiet time” conditions when ionopause-like structures are present. These observations suggest that the MS waves interact with the planetary ions, and comparison to similar events observed at Mars by the Mars Atmosphere and Volatile EvolutioN (MAVEN) mission [11] suggest that ion heating also occurs. Such events may drive substantial ion escape to space, however, the lack of full ion distribution observations from PVO mean that these effects cannot be conclusively determined.

Additionally, we show that ionospheric plasma conditions during the PVO event may be suitable to facilitate the heating of planetary electrons via the “magnetic pumping” mechanism. The low frequency MS waves are expected to produce anisotropic suprathermal electron distributions as the waves propagate into the upper ionosphere, via conservation of the first magnetic moment. Such distributions can become unstable to the generation of whistler mode waves, which are observed in the 100 Hz channel of the PVO electric field detector (OEFD). Under certain conditions, which we demonstrate likely exist here, these whistler waves can act back on the anisotropic suprathermal electron population via efficient pitch angle scattering. Such scattering breaks the reversibility of the low frequency MS waves, leading to heating of the suprathermal electron population over several MS wave periods [12, 13]. Such a process would provide a possible mechanism to explain coincident observations of whistler waves and elevated electron temperatures at Venus [8, 9, 10].

This electron heating mechanism has recently been observed active in the upper Martian ionosphere [14] by MAVEN, however, the lack of full electron distribution function measurements (not) made by PVO prevent a conclusive identification of this process at Venus.

If active at Venus, the heating of ionospheric electrons via low frequency magnetosonic waves and the magnetic pumping process may be common to unmagnetized bodies exposed to the supersonic solar wind flow in general.

Acknowledgments: PVO data were obtained from the Planetary Data System (PDS).

Manta Ray Inspired Drone for Venus Exploration: Biological-Solution for Extreme Conditions. M. E. Gammill¹, and M. Hassanalian², ¹Graduate student, Department of Mechanical Engineering, New Mexico Tech, Socorro, NM 87801, USA, ²Assistant Professor, Department of Mechanical Engineering, New Mexico Tech, Socorro, NM 87801, USA.

Introduction: Venus is the second planet from the sun and possesses characteristics similar to Earth. It is approximately the same size as Earth and has a similar chemical composition and density. However, Venus is also very different from Earth. The lack of a magnetic field and a runaway greenhouse effect cause Venus to be swelteringly hot. Venus’s atmosphere is made up of mostly carbon dioxide and the clouds that exist there are composed of sulfuric acid. The pressure on Venus’s surface is around 90 atmospheres, which is similar to the pressure on Earth 1 km below the surface of the ocean. While the temperature on Venus can be over 740 K, which would boil any trace of liquid water away, the atmospheric chemistry of Venus suggests that oceans may have once existed on its surface. Further exploration of Venus is necessary to determine the reasoning why this planet has a similar makeup to Earth but a very different outcome.[¹] Past spacecraft have not survived on Venus’s surface for more than an hour. This is due to the acidic clouds, intense heat, and crushing pressures present there. In order to explore this planet further, a spacecraft will need to be designed that is able to withstand these extreme conditions. Due to the high density of Venus’s atmosphere and the lowered gravity, drone exploration is a viable solution to this problem. A drone would be able to soar from higher to lower elevations to escape the high pressures and extreme temperatures present on Venus.[²]

Manta ray-inspired concept: Manta rays are extremely graceful and efficient swimmers. Their pectoral fins are large and attached to their head, which forms a broad, flat disc that can be manipulated into a variety of shapes. Primarily, manta rays use oscillatory motion similar to that of a bird flapping its wings, but an undulatory component of motion is also present. When mantas use a flapping wing, they can generate a great deal of power. Because of the large surface area of their pectoral fins, mantas can swim at incredible speeds. A manta can weigh over 1580 kg and has a high aspect ratio of 3.5 with a wingspan of over 9 m.[³] Manta rays offer a good solution to UAVs in that their body is rigid and they are efficient swimmers. The stiffness of their body would allow for easy integration of electronics for the design of a bioinspired manta ray UAV. Manta rays have a small turning radius of 0.27 of its body length, which also allows them to maneuver easily. While manta rays are fast and efficient, they are also able to withstand high pressures while hunting, diving over 1 km below the ocean’s surface.[⁴] Many bioinspired manta ray robots have been designed to swim and fly on Earth but none have been proposed for use in space exploration.[⁵] This study analyzes a bioinspired manta ray wing shape for use on an exploratory UAV on Venus. Presented is the analysis for a flapping-wing and fixed-wing drone in Venus’s atmosphere. Shown in Fig. 1 is the wing shape used for this analysis alongside the wing shape of a manta ray.

![Inspired wing shape](image1.jpg) ![Manta-ray](image2.jpg)

Figure 1: Manta ray bio-inspired wing shape.

Flapping-wing Manta ray inspired drone: The flapping-wing and fixed-wing drone proposed in this paper are analyzed for the flight on Venus at an altitude between 30 and 70 km above Venus’s surface. The density of the Venus atmosphere in altitude around 50 km is similar to Earth. The drone would soar to the surface of Venus, take measurements for a period of time, and fly back to a safer altitude. The flapping wing drone was designed in FlapSim with a wingspan of 2 m, an elevation amplitude of 75 degrees, a pronation amplitude of 20 degrees, a stroke plane of -10 degrees, and a velocity of 10 m/s. Using these parameters, the lift, drag and mechanical power for a flapping-wing drone of the defined wing shape are calculated. These can be seen in Figs. 2 to 4. From these figures, it can be seen that the lift force, drag force, and mechanical power are all maximized closer to the surface of Venus. This is due to the increased density closer to Venus’s surface. Also, to be seen from Fig. 4 is the large amount of mechanical power that is generated by the large surface area of the manta ray wing shape. These values can be investigated to find the altitude that would allow the drone to be safe from the extreme conditions on Venus’s surface, but would allow for maximum power savings. Some tabulated average values for these aerodynamic properties are shown in Table 1. The visualization of the drone’s phase is shown in Fig. 5.

![Figure 2](image3.jpg)

Figure 2: Lift force of flapping-wing drone on Venus from 30 km to 70 km.
The analysis for a fixed-wing drone was done in XFLR5 using the same wing shape and wingspan mentioned above. NACA 0012, 0015, and 0020 airfoils were used to create a wing shape that tapers, similar to that of a manta ray. This model is shown in Fig. 6. Using the described model, the lift and drag for a fixed-wing drone on Venus are calculated at an altitude between 30 km and 70 km. This is shown in Figs. 6 and 7. Similar to the flapping-wing drone, the lift and drag are maximized closer to Venus’s surface. Additionally, a higher angle of attack generates a higher lift and drag force.

Figure 3: Drag force of flapping-wing drone on Venus from 30 km to 70 km.

Figure 4: Mechanical power of flapping-wing drone on Venus from 30 km to 70 km.

Table 1: Average lift force, drag force, and mechanical power for a drone on Venus from 35 km to 70 km.

<table>
<thead>
<tr>
<th>Altitude (km)</th>
<th>30</th>
<th>35</th>
<th>40</th>
<th>45</th>
<th>50</th>
<th>55</th>
<th>60</th>
<th>65</th>
<th>70</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal force (N)</td>
<td>659</td>
<td>422</td>
<td>264</td>
<td>164</td>
<td>97</td>
<td>58</td>
<td>25</td>
<td>11</td>
<td>4</td>
</tr>
<tr>
<td>Axial force (N)</td>
<td>516</td>
<td>376</td>
<td>235</td>
<td>146</td>
<td>86</td>
<td>51</td>
<td>23</td>
<td>10</td>
<td>4</td>
</tr>
<tr>
<td>Mechanical power (W)</td>
<td>28122</td>
<td>18027</td>
<td>11260</td>
<td>6995</td>
<td>4151</td>
<td>2408</td>
<td>1083</td>
<td>458</td>
<td>188</td>
</tr>
</tbody>
</table>

Figure 5: Visualization of one cycle of flapping-wing drone's flight progression.

Figure 6: Model of the manta ray-inspired fixed-wing drone in XFLR5.

Figure 7: Lift force of fixed-wing drone on Venus vs. angle of attack from 30 km to 70 km.

Figure 8: Drag force of fixed-wing drone on Venus vs. angle of attack from 30 km to 70 km.

References:
MODELING DEPOSITION FROM DENSE PYROCLASTIC DENSITY CURRENTS ON VENUS. I. Ganesh¹ (indujaa@email.arizona.edu), L. McGuire² and L. M. Carter¹, ¹Lunar and Planetary Laboratory, University of Arizona, Tucson AZ 85721, ²Department of Geosciences, University of Arizona, Tucson AZ 85721.

Introduction: Radar-bright summit features associated with some volcanic centers on Venus have been proposed to be deposited from pyroclastic density currents (PDCs) [1,2]. These deposits have diffuse margins that expose underlying lava flows, high radar backscatter in Magellan SAR, and lack flow structures in the deposit interior, all of which are consistent with a rough-textured mantling layer of clastic debris [1]. The extent of continuous bright material from the summit to the deposit terminus ranges from 40 – 120 km. While such long runout PDC eruptions are not observed in the present day, older (>1800 yr. BP) PDC deposits extending for more than 100 km from the source are found at many places on Earth [3-7]. In this study, we model PDC propagation under Venus conditions to constrain the physical properties of PDCs required to emplace long runout deposits.

Study sites: We initially focus on the deposits at two different sites in Eistla Regio – Irnini Mons (Fig. 1A) and Pavlova Corona (Fig. 1B) Irnini Mons (14.3°N, 15.65°E) is a volcano-tectonic construct with two radar-bright, diffuse deposits marked I1 and I2 at the northern summit (Fig. 1A). These deposits appear to originate at the corona margins and extend down slopes of ~1.2° up to distances of ~70 km. Similar diffuse deposits have been noted in the western and southwestern flanks of Pavlova Corona (14.5°N, 40°E) and Didilia Corona (18°N, 37.3°E) (Fig. 1B). These deposits extend up to ~100 km from the corona margins down shallower slopes (~0.3°). Due to model run time and stereo-DEM coverage constraints, we have so far limited our focus to one proposed PDC deposit at each of these sites, I2 and P1, for the present study. Runout distances for P1 range from 40 – 60 km while I2 has a longer extent with a maximum runout of ~110 km.

Pyroclastic flow model: The pyroclastic current is treated as a two-component granular flow with ~30% volume fraction of solids (ash, pumice and lithics) supported by excess pore fluid pressure in a laminar Newtonian fluid [9].

Fig. 1: Magellan SAR image of (A) Irnini Mons and (B) Pavlova Corona. Radar-bright diffuse deposits have been mapped in yellow based on [1].

Model limitations. This simplified 2D model assumes initial conditions arising from the instantaneous collapse of constant volume columns. This has implications for modeling both the flow thickness and the velocity. The flow dynamics immediately following instantaneous collapse is not captured effectively by the shallow water equations. However, the model is well suited for describing the flow as it evolves away from the initial conditions towards flow depths that are much smaller compared to the flow’s areal extent. Instantaneous column collapse imparts high initial velocity that might drive the flow to turbulent regimes. But once past this initial phase, the flow slows down to velocities required for non-turbulent propagation captured by the model. Additionally, the granular flow model approach only simulates dense flows in which the effects due to entrainment of the Venusian atmosphere are negligible.

Initial conditions. We use a bulk flow viscosity of 10⁻¹ Pas, and a bulk flow density corresponding to a
dielectric permittivity $\epsilon' = 3$. Starting velocity of 100 ms$^{-1}$ and initial interstitial fluid pressure to basal stress ratio of 0.98 are used. Table 1 shows the initial parameter values used for both deposits. We chose 10 locations with good stereo topography along the corona margins to represent multiple eruption centers that were the likely source of PDCs (solid white circles in Fig. 2). Results from the simulations for parameters specified in Table 1 are discussed below.

<table>
<thead>
<tr>
<th>Deposit name</th>
<th>I2</th>
<th>P1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total volume (km$^3$)</td>
<td>125</td>
<td>38</td>
</tr>
<tr>
<td>Initial velocity (ms$^{-1}$)</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Initial pore fluid pressure</td>
<td>0.98</td>
<td>0.98</td>
</tr>
</tbody>
</table>

Table 1: Parameter values used in the simulation

Most of the predicted runouts are 0.4 – 0.65 times measured runout lengths. Longer runouts can be generated by the model using larger deposit volumes, higher initial velocities, and higher ratio of pore fluid pressure to basal stress in the model parameters. The pore fluid pressure to basal stress ratio used here is already quite high (0.98). Ideally, it is possible for PDCs to have a maximum velocity equal to the speed of sound (~400 ms$^{-1}$ on Venus). However, higher velocity flows begin to develop turbulence which limits the distances to which larger clasts can be transported. Large volume flows will be thicker, thereby making the diffusion of the interstitial fluid pressure slower. The sustained high pore fluid pressure helps in mobilizing flows for longer distances. But it is important to note that large flow thicknesses also induce turbulence. It has been proposed that semi-fluidized PDCs more than a few meters thick moving faster than 15-60 ms$^{-1}$ will develop turbulence [13]. If the Venus deposits have a PDC-origin, it is likely that they were deposited from a steady current generated from sustained fountaining or boiling-over which would ensure continued supply of volume at low velocities resulting from shorter collapse heights.

**Future work:** The next step is to explore the parameter space more thoroughly for the PDCs shown in Fig. 1 and extend the model simulations for other proposed PDCs [1]. We also intend to explore turbulence driven PDC transport that has been suggested to the mechanism of emplacement for large ignimbrite sheets such as Taupo ignimbrites [14].

**Acknowledgments:** This study was supported by a FINESST award to I. Ganesh and partly by an SSW grant to L. M. Carter. Magellan SAR images were processed using USGS Astogeology Science Center’s Map-A-Planet 2 (MAP2).

High Temperature Batteries for Venus Surface Missions
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The hostile conditions of Venus surface, i.e., high temperature of ~465°C and high CO₂ pressure of ~90 bars¹ have limited the previous surface missions to less than two hours. For example, the Russian Venera series and Vega-2 Landers,² barely survived for two hours after deployment with lithium-primary batteries, despite the use of considerable insulation, phase-change materials, and similar heat sinks to isolate batteries and avionics from high surface temperatures. There is a need for long-duration Venus surface missions for a better understanding of its surface. The recent decadal survey, ‘Vision and Voyages for Planetary Science in the Decade as well as the more recent VEXAG study³ have recommended long-duration landers, probes and seismometers to gather basic information on the crust, mantle, core, atmosphere/exosphere, and bulk composition of Venus, to understand it evolutionary paths in relation to Earth.

In order to enable extended surface missions on Venus and Mercury, NASA has initiated the development of high temperature electronics and power technologies, under its ‘Hot Operating Temperature Technology’ (HOTTech) program. Under this program, we have been developing advanced primary batteries that are resilient to the hostile surface conditions of Venus and operate for several days with high specific energy. Here, we will describe the development of high temperature batteries based on lithium alloy (e.g., Li-Al) anodes, molten salt electrolytes containing binary/ternary mixtures of alkali metal halides, cathodes consisting of transition metal sulfides, and designs similar to the aerospace thermal batteries.⁴ With FeS cathode and changes to the electrolyte composition, binder and active material ratios, we have shown improved operational life to ~20 days at 475°C in the laboratory cells. Incorporation of these design features into ~1.5 Ah prototype cells led to even longer operational life of 30 days. Furthermore, these cells have shown good rechargeability by operating continuously over 150 days at 475°C.

To further improve the operational life of the batteries in the primary mode, new surface coatings have been developed on the cathode which would minimize its dissolution in the electrolyte, which include Al₂O₃, AlPO₄ and AIBO₃. Preliminary results with the coated cathode are encouraging, with about 50% improvement in the operational life in the laboratory cells.⁵ Implementation of the AIBO₃-coated cathode in prototype cells to demonstrate similar performance enhancement is underway.

Acknowledgements

The work described here was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration (NASA) and supported by the NASA’s HOTTech project. The information in this document is pre-decisional and is provided for planning and discussion only.
References

A NEW ASSESSMENT OF VOLCANO MORPHOLOGY AND DISTRIBUTION ON VENUS. Rebecca M. Hahn¹ and Paul K. Byrne¹, ¹Planetary Research Group, Department of Marine, Earth, and Atmospheric Sciences, North Carolina State University, Raleigh, NC 27695 (rhahn@ncsu.edu).

Introduction: NASA’s Magellan spacecraft was the first to map nearly the entire Venustian surface with synthetic aperture radar (SAR) as well as nadir-directed altimetry [1–3]. The SAR data collected during this mission enabled the detection and classification of volcanic features and structures across Venus far beyond the extent of earlier missions [4,5]. These data revealed a planetary surface covered in volcanic edifices of a range of sizes, as well as a number of volcanic landforms unique to Venus including coronae (ring- to oval-shaped features with concentric ridges and variable topography), arachnoids (concentric features with radial fractures along their periphery), and novae (sets of focused, radial fractures) [4,6]. The radar image data also revealed a surprising absence of impact craters [7,8], which may indicate large-scale volcanic resurfacing [5,6].

Data and Methods: Previous studies documented volcanic structures across Venus [e.g.,9]. To build upon this earlier work, we have developed a new global catalog of Venustian volcanic edifices with the Magellan SAR FMAP (full-resolution radar map) left- and right look global mosaics at ~100 meter-per-pixel (m/px) resolution. The Magellan Volcano Catalog [9] was used to confirm the locations of existing volcanoes, but our dataset was built independently and documents volcanoes on a finer spatial scale than before.

All mapping was completed in the ESRI ArcGIS environment. The “Fishnet” tool in ArcMap was used to divide the planet into 5° × 5° bins, and each bin was thoroughly examined at a view scale of 1:400,000. For the equatorial region between 40° N and 40° S, mapping was completed in an equirectangular projection. To preserve volcano geometry, datasets were projected as North– or South Pole stereographic when mapping edifices at latitudes above 40° N and below 40° S, respectively. We recorded the latitude, longitude, and footprint (i.e., areal extent) of well-defined volcanic edifices across Venus by mapping features into polygon or point vector shapefiles. We identified a “well-defined volcanic edifice” following earlier studies for Venus [e.g., 2,4,6,10], i.e., a landform that is quasi-circular and approximately conical, with one side more radar-bright than the opposite side (consistent with being illuminated from a single radar-look direction). Additionally, the Magellan global altimetric topography (with a resolution of ~10 km per pixel (km/px)) [11] and stereo-derived digital elevation models (DEMs) generated from Magellan radar image data [12–14] were used to establish that a given landform is a local high, providing further support that the feature is a volcano. Edifices <5 km in diameter were denoted as a point feature and their coordinates recorded. For edifices ≥5 km in diameter, a polygon outlining the edifice was constructed and the coordinates, area, and perimeter of the feature was recorded. The “Minimum Bounding Geometry” tool in ArcMap was used to calculate the aspect ratio using the length and width values from the tool output.

Lastly, we calculated quantitative statistics for each polygon dataset, including the mean, median, mode, and variance and standard deviation for the aggregate dataset in the MATLAB environment. MATLAB was also used to evaluate the spatial relationships between volcanoes across the planet by nearest-neighbor analysis to better understand the spatial dispersion of volcanoes of varying sizes.

Results: Our preliminary mapping results include 32,435 volcanic edifices <5 km in diameter, 1,329 edifices 5–100 km in diameter, 126 edifices >100 km in diameter, and 81 edifices (of all diameters) that show evidence for gravitational deformation, e.g., flank collapse (Figure 1). Furthermore, we included an additional 51,634 edifices <5 km in diameter for which only geographic coordinates were recorded, given locally poor radar image quality (termed “uncertain” in Figure 1). We find that edifices >100 km in diameter have an average diameter of ~440 km, and an average area of ~150,000 km². Volcanoes 5–100 km in diameter have an average diameter of 16 km and an average area of ~220 km². In general, most of the edifices <5 km in diameter are situated in topographically low lying regions, with an average elevation of 654 m (relative to the planetary reference datum of 6,052 km). Additionally, we note a distinct decrease of in spatial density of edifices <5 km in diameter in the lowlands near the south pole, particularly in the southwestern quadrant.

Overall, we find that Venus hosts far more volcanoes than previously recognized—almost nineteen times more than previously catalogued [9]—and that the geographic extent of this type of landform spans virtually the entire planet. Our catalog enables follow-on analyses, including assessing the spatial distributions of volcanoes of various sizes, their stratigraphic relations to dominant plains units on the planet, and the temporal and spatial relations between gravitationally deformed volcanoes and neighboring geological features.


Figure 1: Completed global survey of volcanic edifices on Venus. This survey includes 32,435 volcanic edifices ≤5 km in diameter (aqua triangles), 51,634 edifices ≤5 km in diameter for which only geographic coordinates were recorded due to locally poor radar image quality (yellow triangles), 1,329 edifices 5–100 km in diameter (dark blue circles), 126 edifices >100 km in diameter (pink circles), and 81 edifices (of all diameters) that show evidence for gravitational deformation (orange circles). Outlines of major Venusian landforms are shown in black for geographic context.
Venus as seen by the MErcury Radiometer and Thermal infrared Imaging Spectrometer (MERTIS) during the first flyby of the ESA-JAXA Bepicolombo spacecraft

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Introduction: BepiColombo [1] is a dual spacecraft mission to Mercury to be launched in October 2018 and carried out jointly between the European Space Agency (ESA) and the Japanese Aerospace Exploration Agency (JAXA). BepiColombo uses a solar electric propulsion system. The trajectory is a combination of low-thrust arcs and flybys at Earth (1), Venus (2), and Mercury (5) and will be used to reach Mercury with low relative velocity. Before arriving at Mercury, BepiColombo will perform Venus flybys in 2019 and 2020.

The MERTIS instrument [2, 3, 4] will obtain observations of Venus in the spectral range from 7-14µm. This range is highly sensitive for studies of Venusian atmosphere. This includes analyses of the 15-µm CO2 band short wavelength flank as well as analyses of aerosol properties below 10 µm. These measurements will be the first spectrally resolved observations in this spectral range since the Venera 15 mission in 1983. The Venera 15 dataset has recently been archived at DLR and will allow a direct comparison to the MERTIS observations.

In addition, MERTIS will acquire data of “Venus as an Exoplant”, observing the planet from the distance with sub-pixel resolution. MERTIS will obtain time series of spectra that will be analyzed to test retrieval algorithms commonly used for determining the (cloud) rotation period as well as information about the cloud structure.

Observational constraints: BepiColombo was launched by an Ariane 5 from the ESA launch facility in Kourou (French Guyana) in October 2018. The ESA Mercury Planetary Orbiter (MPO) and the JAXA Mercury Magnetospheric orbiter were launched in a composite with a propulsion element - the Mercury Transfer Module (MTM) and a sunshade cone (MOSIF) to protect the MMO (see Figure 1).

In this configuration the nadir (z-axis) of the spacecraft points towards the MTM. Therefore, most instruments cannot operate during cruise. However, the MERTIS instrument has a viewport through the radiator which in nominal operations is used for deep space calibration. During the Venus flyby this port will be used for the observations. It has already been used successfully to perform observations of the Moon on April 9, 2020.

The MERTIS instrument: MERTIS (Figure 2) combines a push-broom IR grating spectrometer (TIS) with a radiometer (TIR). TIS operates between 7 and 14 µm and will record the day-side emissivity spectra from Mercury, whereas TIR is going to measure the surface temperature at day- and night side in spectral range from 7-40 µm corresponding to temperatures from 80-700 K. TIR is implemented by an in-plane separation arrangement. TIS is an imaging spectrometer with an uncooled micro-bolometer array. The optical design of
MERTIS combines a three mirror anastigmat (TMA) with a modified Offner grating spectrometer. A pointing device allows viewing the planet (planet-baffle), deep space (space-baffle), and two black bodies at 300 K and 700 K temperature, respectively. During the Venus flybys we will use the deep space view for Venus observations and obtain deep space observations before the flybys.

**Flyby operations for MERTIS:** The spacecraft approaches the planet from the solar direction, over the dayside. The closest approach (CA) occurs above the evening terminator of the planet (Fig. 3), and then the spacecraft moves away from the planet to the anti-solar direction, over the night side. MERTIS will observe the planet from about 48h out until about 20h out. In this time the apparent size of Venus will increase from slightly larger than on MERTIS TIS pixel (0.7 mrad) to more than 1 degree. From about 8 h out up to ~50 min before CA, MERTIS performs close-up dayside observations from late morning to late afternoon via noon time on Venus at low latitudes of the southern hemisphere. Due to the 100% cloud cover on the planet, most of thermal emissions are corresponding to temperatures at the upper cloud level atmosphere (60-70 km) [5]. The shorter wavelength edge of the 15-µm CO₂ band covered by TIS/MERTIS will be useful to retrieve temperature profiles from the cloud tops to slightly above using the inversion methods of radiative transfer. Simultaneous cloud top structures and SO₂ gas abundances above the clouds can be estimated from the observed spectra over the 7-14 µm range of TIS/MERTIS. This spectral range observation from space is the first time after Venera missions in 1980s [6,7,8].

**Venus observing campaign:** International collaboration on Venus observations are under way during the flybys of BepiColombo (ESA-JAXA), on its way to Mercury. The collaborative observations have been planned between BepiColombo and the operating Venus orbiter, Akatsuki (JAXA), during the cruise and the 2 times of Venus flybys on 2020 October 15 and 2021 August 10. This represents unique Venus observation opportunities, perhaps in coming decades, to be coordinated with two spacecraft. More details can be found at [http://bit.ly/BepiVenus](http://bit.ly/BepiVenus).

**Conclusions:** We will report here on the MERTIS observations obtained during the first Venus flyby of BepiColombo. MERTIS will obtain valuable data both with the spectrometer channel, covering the range from 7-14 µm in 80 spectral channels, as well as with the radiometer channel providing highly accurate temperature readings. The MERTIS observations will complement the data acquired by Venera 15 and Pioneer Venus with a much higher sensitivity.


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**Figure 3** Venus as seen from BepiColombo (left), Akatsuki (center), and Earth (right). The size of Venus is not scaled in the figures, but the apparent sizes in degree and arcsec are written in the bottom. Solar phase angle (α, degree) and the distance to the center of Venus also indicated. The background Venus is actual images of LIR with mountain induced waves.
**Performance Analysis of Solar Fixed-wing Drones on Venus.** B. K. Herkenhoff, J. M. Fisher, and M. Hassanalian

**Introduction:** Unmanned Aerial Vehicles (UAVs) have been developed and implemented for a range of potential applications due to their ease of use, low cost, and form factor. Unfortunately, as it stands, traditional drone technology is extremely limited by flight endurance. Drones typically rely on battery power as it is an inexpensive, highly efficient alternative to systems, such as a combustion engine, although this comes at the cost of a lower energy density. For this reason, the implementation of passive and active energy harvesting systems becomes an important element in modern drone design with the aim of greatly increasing potential mission duration.

With this in mind, the application of a fixed-wing drone design becomes necessary as it has greatly improved flight efficiency over what may be considered a more traditional drone style, such as a multirotor drone. In addition to this, methods intended to recharge the power supply of a drone are crucial in the application of extended flight duration. Solar energy harvesting is one such method and is very commonly applied in a variety of applications.

The concept of solar-powered flight is not new to the world of aviation, but one that has not been extensively explored or commonly implemented. In the early 1970s, the first fully solar-powered flight was achieved with a flight time near 20 minutes. Since then, substantial advancements in solar harvesting technologies have been made, providing a platform for extreme endurance drones given the correct environment [1]. This concept could be applied in a multitude of applications, including the exploration of Venus (see Fig. 1). Venus’ atmosphere contains a section approximately 5 km in height that contains an operable temperature range [2-4]. This range also conveniently has a similar density and irradiance to that of Earth’s atmosphere providing a convenient zone of operation for a continuously flying fixed-wing drone platform. The deployment of such a system would provide means for long term data collection and monitoring of Venus’ atmospheric conditions through a suite of onboard sensors.

![Fig.1. Views of fixed-wing concept for Venus exploration.](image)

**Operational Altitude:** Venus’ atmosphere is home to some of the harshest operational conditions within our solar system. The surface temperatures are swelteringly high, in the range of 700 K, and the winds can blow up to 150 m/s [3, 5]. On top of this, there are layers of sulfuric acid over a substantial range of the planet’s atmosphere. All of this amounts to an extremely hazardous operational environment and provides multiple challenges in designing platforms for extended operation on or above the planet.

![Fig.2. Views of average temperature and irradiance changes versus altitude on Venus.](image)

Within this harsh environment, there is a layer with Earth-like elements. Looking at the region between 50 and 60 km above the planet’s surface there is a temperate zone in which standard electronics could operate. This is significantly important in regards to battery operated electronics as most rechargeable battery systems have an operation range of 278 K to 328 K [2-6]. The operation of a drone within this altitude range would allow for the implementation of relatively standard electronic components, including any necessary sensors and the batteries required to power the drone.

Although this altitude range provides ideal temperatures for electronics operation, it has several other harsh environmental factors to take into consideration. The winds in this range have the potential to reach upwards of 125 m/s, which could prove to be a significant hurdle for autonomous drone flight, especially in a lightweight platform [5]. This does, however, provide for an interesting opportunity to harvest a substantial amount of energy in the form of increased lift. It should also be noted that special care will need to be taken in the selection of the drone materials as this region of the atmosphere also houses clouds of sulfuric acid [7].
Solar-Powered Drones: There are several important factors that must be considered when designing a solar-powered drone, especially the maximum potential efficiency of the panels, as this determines the maximum power produced. Following this, the maximum voltage is another factor that must be considered, and this is directly related to the efficiency and maximum current. Finally, the efficiency degradation of the panels must be considered as this characteristic is determined by the operational temperature of the solar cells.

Even while operating at peak efficiency, there are a multitude of external elements that have a significant impact on the potential power absorption and, thus, output, the most crucial of which is known as solar irradiance. The energy from the sun can be referred to as radiant energy and can be measured and referred to as solar irradiance. Irradiance is the power measured per unit area (W/m²) and varies with respect to a combination of the altitude, latitude, and longitude.

The weight and structure of the solar panels are also important criteria to consider in the application of a solar-powered drone. Traditional solar panels are typically a rigid construction, and thus can be rather costly from an aerodynamic perspective. With this in mind, the implementation of a flexible solar panel becomes a point of interest as it would improve aerodynamic efficiency. Thin-Film Solar Cells (TFSC) can meet these criteria and easily be implemented on the top surfaces of fixed-wing drone designs without greatly reducing the aerodynamic efficiency. There is an increasing selection of solar companies that produce thin, flexible, lightweight, and efficient solar modules that can be applied to different types of drones. Currently, there are two types of TFSCs, mono-crystalline, and multi-crystalline, and in recent years the efficiency of both cell types has become very similar, meaning the choice of TFSC comes down to the color of the panels as this has a significant impact of the panels emissivity coefficient.

To assess the performance of a solar panel, the above factors must be calculated. The current, voltage, and efficiency of a solar panel can be expressed as seen below [1, 4]:

\[ I_{pv} = I_{ph} - \frac{V_{oc} + I_{ph}R_s}{R_{ph}} - I_0 [\exp \left( \frac{q(V_{oc} + I_{ph}R_s)}{m R_{ph}} \right) - 1] \]  
\[ V_{dc} = V_{oc,STC} + \frac{m R_{ph}}{q} \ln(G_s) + \mu V_{oc}(T_P - T_R) \]  
\[ \eta = \eta_{TR}[1 - \beta R(T_P - T_R) + \gamma \log G_0(T_R)] \]

where \( I_{ph} \), \( I_0 \), \( R_s \), \( R_{ph} \), \( V_{oc} \), \( m \), \( k \), \( q \), \( T_P \), \( T_R \), \( V_{oc,STC} \), \( \mu V_{oc} \), \( G_s \), \( \beta R \), and \( \gamma \) are the photovoltaic current (A), light generated current (A), reverse saturation current (A), module series resistance (\( \Omega \)), module parallel resistance (shunt resistance) (\( \Omega \)), module output voltage (V), the ideality factor (diode factor), Boltzmann's constant (J/K), the charge of an electron (coulomb), and module temperature (K), reference temperature of cells (K), open-circuit voltage at standard test conditions (V), thermal coefficient of the open-circuit voltage (V/°C), solar irradiance (W/m²), photovoltaic module’s electrical efficiency in the reference temperature and standard test condition solar radiation, temperature coefficient, and solar radiation coefficient, respectively.

Solar Performance: Several important metrics for how the solar panels are anticipated to perform on Venus are depicted within the ideal operating range. The target elevation at which the drone should be flying will be from 50 km to 60 km above the surface of the planet. This is where the batteries are limited to functioning given the harsher and much more drastic atmospheric conditions of Venus discussed previously. The current, power, voltage, and irradiance of the solar panels provide valuable insight into how effective such methods would be. A Flisom eFlex Wp 30 was used for the following analysis.

![Fig. 3. Power vs. voltage vs. altitude for PV on Venus.](8007.pdf)

<table>
<thead>
<tr>
<th>Altitude (km)</th>
<th>Temp. (K)</th>
<th>Irrad. (W/m²)</th>
<th>Efficiency (%)</th>
<th>Power (W/m²)</th>
</tr>
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<tr>
<td>0</td>
<td>729</td>
<td>20</td>
<td>0</td>
<td>12.2</td>
</tr>
<tr>
<td>5</td>
<td>694</td>
<td>107</td>
<td>0</td>
<td>14.4</td>
</tr>
<tr>
<td>10</td>
<td>659</td>
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<td>0.22</td>
<td>17.0</td>
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<td>612</td>
<td>233</td>
<td>0.80</td>
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<td>363</td>
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<td>448</td>
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<td>4.47</td>
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<td>422</td>
<td>800</td>
<td>5.16</td>
<td>51.8</td>
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<td>60</td>
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<td>2640</td>
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References:
INTRODUCTION: A network of seismometers on Venus could characterize the planet’s internal structure and provide knowledge of the nature and level of current geologic activity, but the desired observation period of at least weeks far exceeds the ~1-hour lifetimes of previous landers in the harsh Venusian surface conditions. NASA Glenn Research Center (GRC) has been engaged in development of high-temperature electronics with the goal of enabling deployment of long-lived instruments on the Venus surface. They are working through various aspects of instrument design and testing for a seismometer [1]. The instrument will likely have a variety of limitations and restrictions. In particular, the instrument will likely be battery powered with little or no memory capability, and both data transmission and continuous operation will rapidly expend the battery. Part of the design process is testing approaches to solve these problems against anticipated seismicity.

PROJECT OVERVIEW: With funding from NASA EPScor’s Rapid Response Research and Research Infrastructure Development grant programs, we have developed a partnership with GRC and the Alaska Earthquake Center (AEC) to conduct a one-year research project to do the following:

1. Evaluate the expected level and nature of seismic activity on Venus. Initial estimates of the total level of Venus seismicity exist [2,3] that are simple scalings from terrestrial activity. We will expand on this effort and incorporate current knowledge of elastic plate thickness, lithosphere/upper-mantle properties, tectonic style, geodynamic/resurfacing scenarios, and other Venus-Earth differences to generate endmember estimates of the level and nature of expected seismicity.

2. Construct catalog of terrestrial analog events. AEC has access to its own database of ~700,000 published (named, described) events and other world-wide databases. Based on the results of Task 1, we will create a catalog of events that spans expected event types, a range of magnitudes, and different detector properties. The environment and tectonics of Alaska provide a rich set of seismic signals: there are recordings from a variety of plate-boundary and intraplate events, volcanic eruptions, landslides and other mass-wasting signals. Chemical explosions from mining activities (AEC also has the larger explosions of North Korea’s nuclear tests) provide a set of impulsive signals ideal for benchmarking trigger algorithms and serving as proxies for Venusian meteoroid airbursts.

3. Assess how potential design restrictions affect interpretability. We will apply restrictions such as the following to records in the catalog developed: convolve the record with potential Venus sensor design response functions and noise levels; apply current seismometer designs for an amplitude “trigger” that turns on data collection; and apply data collection limitations imposed by battery life and data transmission capabilities. We will then evaluate the effects on desired outcomes from future Venus seismometers, including: obtaining the overall seismicity level for Venus; describing the source and energy of individual seismic events; and assessing the distances and locations of events.

INITIAL WORK: Work on the project began in August, and by the VEXAG meeting we expect to have results from Task 1 nearly completed. Our plan of work on this task is as follows:

- Summarize the current state of knowledge.
- Break out Earth seismicity in a variety of ways, including: plate boundary versus intraplate seismicity; different plate boundary types; continental collisions versus ocean-continent; by depth; volcanic seismicity, and by volcano type (especially felsic versus mafic). Certain regions, such as the African plate, may be good analog locations.
- Detail how Venus differs from Earth and how that might affect the level, location, and nature of seismicity. Examples of relevant issues include: effect of higher surface temperature on the brittle-ductile transition; implications of the lack of an atmosphere; the apparent lack of organized plate tectonics; and implications of various geodynamic scenarios for surface-interior history. We will also consider the implications of better surface-atmosphere coupling.
- Apply scaling factors to Earth’s divided up seismicity (above) to develop overall picture of Venus seismicity.
- Determine the expected role, if any, that meteoroid airbursts, which should be more common on Venus than Earth, have in Venus seismicity.
- Incorporate “lessons learned” from predictions versus reality for the InSight mission to Mars.

CALYPSO VENUS SCOUT. Horzempa, Philip, LeMoyne College (Syracuse, New York; horzempa45@gmail.com).

Introduction: The Calypso Venus Scout is a mobile, low-altitude survey and mapping mission. A unique design allows the science payload to view a significant amount of the surface of Venus from an altitude of 10-25 km. The harsh environment of the planet makes a surface rover or a low-altitude balloon untenable. Venus presents 4X the continental surface area of the Earth. This is a vast territory which would take centuries to explore by landers.

Venus is not an easy place to explore. The key to the viability of this design is the separation of hardware elements. They operate in environments that do not require leaps in technology. The anchor balloon stays at high altitude, obviating the need for metallic bellows that can survive at a temperature of 350C (700F). The whole purpose of Calypso is to allow cameras to venture below the clouds and haze layers of Venus, and get a clear view of the surface.

Mission Overview: The Descent Module (“Bathysphere”) will descend on a tether, “skimming” over the terrain below. The deployment gondola is suspended a few meters below the balloon, and reels out the tether to a length of 20-40 kilometers. Solar panels are located along the upper rim of the gondola. At the flotation altitude of 50-55 km, sunshine will provide ample power.

The anchor balloon will be traveling with the winds of Venus. The science module will also be carried along at that velocity, allowing it to conduct a transect of the ground below. The temperature at an altitude of 10 kilometers is 380 C (720F).

The Bathysphere will be well insulated, but the duration of its “dive” is limited by the time required for its interior to reach 150C, the limit of state-of-the-art electronics. Calypso aims to limit technology development and will use available avionics. Allowance needs to be made to guard against the effects of droplets of sulfuric acid. This, however, is a well understood technology challenge.

After being reeled in to the anchor balloon, the science module will cool to 50 C, followed by another deep dive. Calypso will demonstrate control of the module during deployment, aerodynamic stability at various altitudes, and the ability to collect meaningful science data.

Payload: Calypso will carry a High-Resolution Imager and a wide-angle Context Camera. Both are crucial to conducting aerial Field Trips. Below the haze layers, the atmosphere is clear. However, Rayleigh scattering will be a factor. As the Bathysphere reaches greater depths, the visible-light cameras will get a clearer view of the terrain below. The Context Camera will provide an overview of a location, with 1-meter resolution. The narrow-angle Hi-Res camera will produce images with a resolution of 1-10 cm.

Further insight will be provided by the near-IR imager. It will allow first-order estimates to be made of the mineralogy, and by inference, lithology. The power of Calypso is that these measurements will not be confined to one or two landing sites. Rather, a large number of targets will be surveyed, allowing access to most of Venus’ major geological provinces.

The Gondola will include an engineering camera to monitor the operation of the tether winch. This camera will provide, as a bonus, views of flight within the haze layer. The Gondola could also carry instruments to sample, and analyze, the atmosphere. That bonus science will depend on the funding level.

Future Missions: Block II Calypso vehicles will be able to actively steer, or hover, above a site of interest. Block III vehicles will have the ability to set the Descent Module on the surface for several minutes. This “touch-and-go” operation will allow the collection of samples that can be analyzed at high altitude. During this brief visit, rapid analyses of rocks at the site can be conducted with a Laser-Induced Breakdown Spectrometer (LIBS). Tests have demonstrated that a Venus-specific LIBS instrument will function on the surface. This design also provides a pathway for a plausible Venus Sample Return mission. Soil and rocks can be taken to a waiting Earth-return rocket attached to the high-altitude balloon. There is no need to launch the vehicle from the surface.
TIME-FREQUENCY LOCALIZATION OF ELECTROSTATIC DISCHARGE FOR LIGHTNING STUDY
S. Jitarwal1*, J. P. Pabari1, D. Kumar2, G. Dhote3, S. Nambiar3, Rashmi2, T. Upadhyaya4, K. Acharyya1, V. Sheel1 and Anil Bhardwaj1,1Physical Research Laboratory, Ahmedabad, INDIA, (sonam@prl.res.in), 2BITS Pilani, Hyderabad, 3IEHE, Bhopal, 4Charusat, Changa.

Introduction: Lightning is a large electrical discharge of very short duration of the order of few tens of microseconds that occurs in a planetary atmosphere. Though the lightning on Earth is well studied, it is not yet fully understood in the case of Venus. In case of Earth, water clouds are responsible for the lightning to occur; while in case of Venus, Sulphuric acid is an important constituent of the atmospheric cloud, at heights from ~47 to 65 km [1]. On Earth, lightning flash is mostly detected as cloud-to-ground discharge and ~20% of the events are cloud-to-cloud discharge type [2]. However, the cloud-to-cloud lightning is more likely to occur on Venus [3]. To understand the lightning on Venus in detail, a Lightning Instrument for VEnus (LIVE) is proposed for future Venus mission [4].

The captured signal by the instrument is processed further to obtain more information of the detected lightning event. An efficient way of representation of the lightning signal is frequency-time localization [5, 6], which can be implemented using several transformation techniques like Short Time Fourier transformation (STFT), Hilbert-Huang transformation (HHT), Wigner-Ville distribution (WVD) and continuous Wavelet transformation (CWT) [7]. In the present work, various transformations are applied on a natural lightning pulse. We have captured this lightning pulse using LIVE at PRL during the past Monsoon season. We discuss which transformation provides better time-frequency localization for the captured lightning event based on their representation.

Time-Frequency Localization: A natural lightning discharge was captured earlier by the instrument, whose time domain signal is shown in Figure 1. Different transformations are applied on the time domain pulse to understand the representation.

\[ S(t, f) = \int_{-\infty}^{\infty} x(t) h(\tau - t) e^{-j2\pi ft} d\tau \] (1)

where, \( h(t) \) is time window centered in \( t = 0 \) which is used to extract the time segments. The length of window \( h(t) \) determines the time frequency representation of the signal.

\[ W(t, f) = \int_{-\infty}^{\infty} x(t + \tau/2)x^*(t - \tau/2) e^{-j2\pi ft} d\tau \] (2)

However, the WVD is nonlinear and it is responsible for introduction of the interference terms. These interference terms can make the time-frequency representation challenging to interpret. In such case, Pseudo Wigner Ville Distribution (PWVD) is used, which includes a windowing function for removal of these interference terms.

\[ Z(t) = x(t) + jH[x(t)] \] (3)

Where, \( H[\cdot] \) denotes the Hilbert Huang Transform. The instantaneous amplitude and frequency can be extracted from the analytical signal as follows.
\[ a(t) = |z(t)| \]  
\[ f(t) = \frac{1}{2\pi} \int \frac{d}{dt} (\arg[z(t)]) \]  

where, \(|\cdot|\) and \(\arg[\cdot]\) operations denote the modulus and the argument of complex number respectively. The time-frequency representation is obtained by displaying the \(a(t)\) and \(f(t)\) of each intrinsic mode function in the time-frequency plane.

**(D) Continuous Wavelet Transform:** The CWT is another tool for time-frequency analysis. It is obtained by breaking up the signal into the shifted and scaled versions of a mother wavelet. Mathematically, the CWT is defined as [3]

\[ C(t, a) = \frac{1}{\sqrt{a}} \int_{-\infty}^{\infty} f(\tau) \psi^*(\frac{\tau-t}{a}) d\tau \]  

where \(a\) is the scale and \(\psi(t)\) is the mother wavelet. CWT provides the signal time evolution at different scales. The frequency of mother wavelet \(\psi(t)\) having a central frequency \(f_c\) and scale \(a\) is given as \(f = f_c/a\).

**Simulation Results:** In this section, we compare several time-frequency representations for a lightning discharge pulse, i.e., as depicted in Figure 1. The time domain signal has been analyzed using a Kaiser window and STFT, CWT, PWVD and HHT. All representations are given on the basis of the parameters like the window sample length (L), the shaping parameter (β), the overlap between adjoining sections (no) and the number of discrete points (n) with their values as 256, 5, 220 and 512, respectively. All transformations have been implemented using the MATLAB software, whose results are shown in Fig. 2 to Fig. 5, respectively. One can observe that by keeping all the parameters same for all the transformations, the STFT provides better resolution for the background with moderate resolution for the discharge event, the CWT and PWVD give poor resolution for the signal while the HHT provides best resolution for the discharge event with moderate resolution for the background.

**Conclusion:** This study has presented a comparison of several time-frequency localization techniques for a natural lightning signal, captured during the past monsoon season in Ahmedabad. Our results show that each technique is capable of providing time-frequency localization, however HHT gives easiness of interpretation or better resolution as compared to other transformations. Also, the realization complexity of the HHT is not very high. Thus, HHT provides higher resolution with lesser implementation complexity.

**References:**
The search for extant life has taken on several chemically-driven approaches to measure chemical signs of life. The lower cloud layer of Venus (47.5-50.5 km) represents a prospective habitat for microbial life, with chemical conditions and optimal temperatures and pressures (\(\sim 60^\circ\text{C}\) and 1 atm). Earth-based photographs of Venus' cloud layer revealed ultraviolet spectral contrast. [1] Would it be possible to detect byproducts of microbial metabolism with probes? Can atmospheric composition of the lower cloud regions reveal anything that is indicative of microbial life? Are there organic compounds in this region of the Venusian clouds?

References:
Early Venus may have been similar to Earth with respect to the development of life, consisting of bodies of water, landforms, and perhaps similar chemical molecules and energy synthesis and utilization pathways. If life ever developed on Venus, it might have existed for up to 1-2 billion years and also propagated the very barren, uninhabitable environment we observe today. The Venus Life Equation has previously been proposed as both a theory- and evidence-based approach to calculate the probability of extant life on Venus, \( L \), using: (i) origination, (ii) robustness, (iii) continuity, and (iv) adaptation. In particular, Izenberg et al. have suggested the Venus Life Equation identifies poorly understood factors that can be addressed by direct observations with future exploration missions. Here, we propose the further refinement of this equation. This is because various factors, such as continuity and adaptation, are variables that may not be completely independent of one another. For example, the sustainability of niches in the Proterozoic Earth would ultimately determine the habitability of the surface and the level of adaptation, which can be achieved by a lifeform.

References:

Could the Migration of Jupiter have Accelerated the Atmospheric Evolution of Venus?

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Abstract: In the study of planetary habitability and terrestrial atmospheric evolution, the divergence of surface conditions for Venus and Earth remains an area of active research. Among the intrinsic and external influences on the Venusian climate history are orbital changes due to giant planet migration that have both variable incident flux and tidal heating consequences. Here, we present the results of a study that explores the effect of Jupiter’s location on the orbital parameters of Venus and subsequent potential water loss scenarios. Our dynamical simulations show that various scenarios of Jovian migration could have resulted in orbital eccentricities for Venus as high as 0.31. We quantify the implications of the increased eccentricity, including tidal energy, surface energy flux, and the variable insolation flux expected from the faint young Sun. The tidal circularization timescale calculations demonstrate that a relatively high tidal dissipation factor is required to reduce the eccentricity of Venus to the present value, which implies a high initial water inventory. We further estimate the consequences of high orbital eccentricity on water loss, and estimate that the water loss rate may have increased by at least ~5% compared with the circular orbit case as a result of orbital forcing. We argue that these eccentricity variations for the young Venus may have accelerated the atmospheric evolution of Venus toward the inevitable collapse of the atmosphere into a runaway greenhouse state. The presence of giant planets in exoplanetary systems may likewise increase the expected rate of Venus analogs in those systems.

Introduction: The current state of the Venusian atmosphere and the pathway through which it arrived there is an exceptionally complicated topic. Numerous studies have provided insights into the climate evolution of Venus and discussed primary influences on the atmospheric dynamics (Bullock & Grinspoon 1996; Taylor & Grinspoon 2009; Taylor et al. 2018). The evolutionary history of the atmosphere of Venus, and its potential divergence from a temperate “Earth-like” climate, depends heavily upon assumptions regarding the initial conditions. For example, Hamano et al. (2013) proposed that Venus may have never had surface liquid water oceans due to an extended magma surface phase. Alternatively, some models suggest that Venus may have had temperate surface conditions that allowed the persistence of surface liquid water until as recently as ~0.7 Ga (Way et al. 2016), depending upon assumptions regarding rotation rates and convection schemes (e.g., Leconte et al. 2013; Ramirez 2018). Such potential for past Venusian surface habitability has been the basis for defining the empirically derived inner edge of the “Habitable Zone” (Kasting et al. 1993; Kopparapu et al. 2014; Kane et al. 2016). The connection to planetary habitability has further fueled the relevance of Venus to refining models of exoplanets (Kane et al. 2019), both in terms of studying atmospheric chemistry (Schaefer & Fegley 2011; Ehrenreich et al. 2012) and detection prospects for potential Venus analogs (Kane et al. 2014; Ostberg & Kane 2019).

In the consideration of climate evolution, the orbital parameters of a planet can play a key role in the energy budget distribution over the surface of the planet (Kane & Torres 2017). In particular, it has been demonstrated that the orbital eccentricity can have significant consequences for the climate evolution of terrestrial planets (Way & Georgakarakos 2017; Palubski et al. 2020). Overall planetary system architectures can also play a role, such as the effect of Jupiter on impact rates (Horner & Jones 2008) and refractory elemental abundance (Desch et al. 2018) in the early inner solar system. Correia et al. (2012) showed that the eccentricity of planetary orbits can be increased by the excitation effects of outer planets that exceed the dampening effects of tidal heating. For those planets where the eccentricity contributes to significant tidal heating, the additional surface energy flux can trigger a runaway greenhouse for an otherwise temperate terrestrial planet (Barnes et al. 2013). Furthermore, the current rotation rate of Venus appears to be impacted by eccentricity and resulting solar tidal torques (Ingersoll & Dobrovolskis 1978; Green et al. 2019), in addition to interactions between the atmosphere and topography (Fukuhara et al. 2017; Navarro et al. 2018).

Results: Using the results of our extensive suite of dynamical simulations, we extracted the minimum and maximum orbital eccentricities attained by Venus for the full range of Jupiter semi-major axis values. Our eccentricity data show that the most powerful perturbations to the Venusian orbit occur when Jupiter is located in the vicinity of 4.3 AU. The maximum Venusian eccentricity of 0.31 occurs at a Jupiter semi-major axis of 4.31 AU. If Venus once had an orbital
eccentricity as high as 0.31, then the question remains as to how the orbit circularized to its current state. One of the most efficient mechanisms to circularize a planetary orbit is through tidal interactions between the planet and its host star. Our tidal dissipation calculations suggest that the effects of tides may have played a key role in circularizing and stabilizing Venus’s orbit. We found that the current value of Venus’s tidal dissipation is not enough to achieve this, suggesting that Venus was not as dry in the past as it is today. To circularize its orbit over the timescale of the age of the solar system (~4000 Myr, post gas phase and migrations), the dissipation factor needed is 1.5 current Earth values. This suggests that Venus might have had a water-rich past, possibly in the form of surface or sub-surface oceans.

![Figure 1: Maximum insolation (perihelion passage) and minimum insolation (aphelion passage) at Venus as a function of time.](image)

To simulate the expected insolation flux of Venus during a possible early era with a high eccentricity, we adopt a solar luminosity that is 75% of the current value. At the semi-major axis of Venus, this results in an insolation flux of $S/S_0 = 1.43$, where $S_0$ is the present-day solar flux received at Earth. The evolution of the maximum flux (perihelion) and minimum flux (aphelion) received by Venus is represented in Figure 1. Venus starts in a circular orbit, then the rise in eccentricity results in a maximum insolation flux that rapidly starts to oscillate high above its present value, indicated by the horizontal dashed line.

**Conclusions:** The study presented here specifically investigates the effect of possible orbital dynamical scenarios on the evolution of an early Venus. Our simulations and subsequent analyses demonstrate that (1) the eccentricity of the Venusian orbit is dramatically increased for particular locations of Jupiter and (2) the consequences of the increased eccentricity would have included a significantly increased rate of surface liquid water loss. Our investigations of tidal dissipation and circularization timescales show that damping the eccentricity perturbations of Venus to their current value requires a larger initial water inventory than that for the current Earth, lending credence to the notion of substantial water delivery to an early Venus.

These results have been published in the Planetary Science Journal and are available on arXiv (arXiv:2008.04927).

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Introduction: In vigorously convecting planetary interiors, including Earth and Venus, plumes are expected to migrate unless they are anchored to fixed structures. Within the Earth both LLSVPs (Large Low Shear Velocity Provinces) and core-mantle boundary topography have been proposed as the anchors of mantle plumes, fixing the location of hotspots [1-2]. It is unclear whether LLSVPs or core-mantle boundary topography might be present on Venus. The relative stability of active coronae, which are thought to be related to mantle plumes, as indicated by the absence of apparent hotspot tracks on Venus, have not be satisfactorily explained.

Model Results: Here we present high-Rayleigh-number, stagnant-lid, spherical-shell convection calculations where the pattern of convection is seeded by the structure of the initial condition. Surprisingly, we find that the pattern of the initial condition persist in a stable convective planform for more than 2.5 Gyr (Fig. 1). This is unexpected because it is expected that vigorously convecting systems retain no memory of the initial conditions [3].

If there is long-wavelength symmetry in the initial plume distribution, this long-wavelength symmetry can prevent the lithosphere from becoming unstable and overturning, leading to a significantly over-thickened lithosphere relative to predictions based on scaling laws. This is confirmed by considering an identical calculation where the long-wavelength symmetry in the plume distribution is broken (Fig. 2). In the calculations considered, long-wavelength means a significant component of degree-1 or degree-3 spherical harmonic perturbation to the initial condition. Odd spherical harmonic initial conditions higher than degree 8 do not lead to models with lithospheric overturns and these short-wavelength initial condition models revert to a stable pattern similar to Fig. 1.

Method. The equations for the conservation of mass, momentum, and energy in a spherical shell geometry assuming an incompressible fluid are solved using CitcomS (version 3.3.1) with a 64 x 64 x 64 element mesh for each of the 12-cubes within the spherical shell [4]. The Rayleigh number, defined by the radius of the
planet and not the thickness of the mantle, is fixed at 3.18x10s. Free-slip boundary conditions are applied to both the surface and the core-mantle boundary. The surface temperature is held constant at 460 °C, and the initial core-mantle boundary temperature is 3980 °C (the core-mantle boundary temperature includes a 0.3 °C/km adiabatic gradient added to the temperature in the calculation of core thermodynamics and the rheology). The calculations use an initial mantle potential temperature of 2282 °C (potential temperature is the temperature at zero pressure, i.e., without the adiabatic gradient. A single temperature perturbation of 20 °C is added at the middle depth of the spherical shell. The calculations use a temperature-dependent, yield stress rheology [5] with core boundary condition based on analytical models of core cooling similar to the formulation described in Nakagawa and Tackley [6] and Zhang and O’Neill [7].

Application to Venus: The geoid of Venus differs significantly from Earth in that the spectral power is not dominated by the longest wavelengths [c.f., 8] and there is a strong correlation between geoid and topography on Venus up to degrees 40 [e.g., 9]. The small offset between the center of mass and center of figure of Venus cannot be reconciled with the significant dense ‘pile’ of cold material deep in the Venusian mantle that is expected from a catastrophic’ resurfacing event [10].

Comparison with coronae. A recent paper suggested that some coronae on Venus are the surface expressions of mantle plumes [11]. In the absence of plate tectonics or catastrophic resurfacing, volcanism associated with mantle plumes could be the dominant processes for active resurfacing on Venus [12]. We compare locations of coronae identified as potentially active using a von Mises-Fisher distribution to represent the plumes and evaluate the active coronae distribution with the (8,4) spherical harmonic pattern that gives rise to the stable plumes in the convection models. We then compare the correlation of the observed distribution with randomly generated points to test the significance of the correlation.

Stability comes from the lithosphere. It is the topography on the base of the stagnant lithosphere (i.e., the lithosphere-asthenosphere boundary) that is responsible for the spatial stability of the plumes in these calculations. In an otherwise identical calculation with a constant-thickness, high-viscosity lithosphere the initial (8,4) spherical harmonic pattern is maintained for ~1 Gyr, a significantly shorter time than was the case for the temperature-dependent stagnant lithosphere case although this is still longer than the current surface age of Venus. The stronger the lithosphere, the more long-lived and stable the plume pattern becomes.

Large impacts and anti-symmetric initial conditions. We note that impacts will impart an anti-symmetric thermal perturbation to the mantle and our calculations shown that this leads to large-scale lithosphere instability and convective. However, anti-symmetric thermal perturbations also lead to a large center of mass/center of figure offset within the body and this is inconsistent with the present state of Venus [10]. We are working to quantify the minimum size of impact necessary to initiate an episodic overturn for Venus.

STRATEGIES FOR SAFELY LANDING ON VENUS TESSERAE. J. J. Knicely, R. J. Lynch, P. A. Mason, N. Ahmad, L. H. Matthies, C. J. Gramling, C. I. Restrepo, M. S. Gilmore, and R. R. Herrick. 1University of Alaska Fairbanks, 2156 Koyukuk Drive, Fairbanks, AK 99775 (jknicely@alaska.edu), 2NASA Goddard Space Flight Center, 3NASA Jet Propulsion Laboratory, 4Wesleyan University.

Introduction: We characterized tessera landing sites and analyzed current hazard detection and avoidance (HD&A) methods in support of the Venus Flagship Mission (VFM) concept study for the Planetary Decadal Survey. The successful and safe placement of a lander in tessera terrain is required to address many of the open questions regarding the evolution of Venus and is essential to the question of habitability. The VFM design requires the lander to avoid slopes >30°, boulders >0.5 m in diameter, and any sites with a mantling of extraneous material >5 cm in order for our drill assembly to access true tessera material.

Landing Site Characterization: Our highest resolution data for characterizing tessera terrains comes from a combination of Magellan and Arecibo data. Magellan-derived information, including stereo topography, imagery, and altimeter products (roughness, RMS slope) suggest generally low slopes and sufficiently smooth surfaces. Cursory analysis of stereo-derived topography indicates that >90% of tessera terrains have slopes <20°, with a median of ~5°; Figure 1 shows an example landing ellipse and slopes in Western Ovda Regio. Magellan data has previously been used to identify areas of thick mantling deposits, but these have been limited by the polarization of the Magellan SAR system; work by [1] combined the Magellan data with Arecibo data to find crater mantling layers as thin as 5 cm on tessera terrains near crater impacts. Problematically, these data represent properties over kms of scale. The stereo-derived topography and mantling maps have a horizontal footprint of ~1-2 km [1, 2]. These large footprints allow only broad-scale characterization. Although the imagery has a much higher resolution of 75-200 m, this is still far too coarse to resolve potentially hazardous regions [3]. In order to avoid excessive slopes and large boulders, the lander system must then identify and avoid meter-scale hazards autonomously.

HD&A: We identified 5 primary issues with which the lander’s HD&A system must contend: a monochromatic surface, near-isotropic lighting, atmospheric scattering, atmospheric turbulence, and the need for autonomy. Several of these issues have already been partially addressed (e.g., Chang’e-3 successful landing on the monochromatic surface of the Moon’s far side). The VFM lander design includes a NIR descent imager that is used at relatively high altitudes (~15 km) for broad scale hazards and a LIDAR system used at relatively low altitudes (~2 km) for small scale hazards. Early work on the problem of the near-isotropic lighting suggests that texture analysis may solve problems with reliable feature tracking [4]. If these issues can be addressed, autonomous neural networks capable of dealing with uncertainty are the best option to allow efficient prioritization and guidance to a low hazard, high science value location, as well as address unknown wind conditions in the lower atmosphere that may unexpectedly redirect the lander’s descent. Identification of meter-scale hazards is only possible in the last few km of descent with avoidance maneuvers in the final 2.5 km, providing ~3-6 minutes to divert the spacecraft. Goddard LIDAR experts are working on increasing the effective range up to 9 km, which would provide ~11-20 minutes to divert the spacecraft. We considered different options for horizontally maneuvering the spacecraft in the dense atmosphere and identified using fans as the most SWaP-efficient method. A fan system with 20 cm propellers and ~17 W can divert the lander up to 50 m if activated by 2 km altitude, with larger propellers and a higher activation height resulting in larger maximum divert distances.


Figure 1. Slope analysis over VFM landing ellipse using radargrammetric data from [2].
PROGRESS TOWARDS BALLOON-BASED SEISMOLOGY ON VENUS IN 2019-2020. S. Krishnamoorthy\textsuperscript{1}, A. Komjathy\textsuperscript{1}, M. T. Pauken\textsuperscript{1}, J. A. Cutts\textsuperscript{1}, D. C. Bowman\textsuperscript{2}, Q. Brissaud\textsuperscript{3,4}, J. M. Jackson\textsuperscript{1}, L. Martire\textsuperscript{5}, Y. Chaigneau\textsuperscript{5}, R. F. Garcia\textsuperscript{5}, D. Mimoun\textsuperscript{5}, and J. Izraelevitz\textsuperscript{1}

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Introduction: Adverse conditions on the surface of Venus have thus far prevented long-duration seismic studies. While Mars has hosted a fleet of rovers on the surface and the InSight lander has studied the interior of Mars for nearly two years, a similar experiment on Venus is decades away. In this presentation, we will explore the possibility of performing planetary science on Venus using infrasound (pressure waves with frequencies less than 20 Hz) as a remote sensing tool and discuss the progress our group has made in the last year.

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

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

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

In this presentation, we will share a progress report using results from multiple flight tests and simulation studies in the past year, which include the deployment of tethered balloons near buried chemical explosions in Glanes, France, solar balloon overflights of the aftershocks in the Ridgecrest, CA area in the aftermath of the July 2019 earthquakes, and the development of an integrated infrasound sensor for future Venus balloon application. Further, we will discuss our preparation for our summer 2021 flight campaign in Oklahoma for the detection of infrasound from natural seismic activity from the stratosphere. The success of this remote sensing technique can greatly accelerate the study of Venus’ interior by circumventing the need to use high-temperature electronics.
Is GCR induced ionization the prime driving force for Venus Lightning? V. R. Dinesh Kumar\textsuperscript{1}, Jayesh Pabari\textsuperscript{2} and Kinsuk Acharyya\textsuperscript{3}, \textsuperscript{1}Birla Institute of Technology and Science, Pilani (f20140771h@alumni.bits-pilani.ac.in), \textsuperscript{2}Physical Research Laboratory, Ahmedabad.

Introduction: The lack of global magnetic fields on Venus has resulted in the formation of weak induced magnetic fields which give unrestricted access to Galactic Cosmic Rays (GCR) \cite{1,2}. The ionization of lower atmosphere as a result of GCR has been a subject of many of the earlier studies and it has been considered as the primary source for cloud electrification on Venus \cite{3,4}. In this work, we provide calculations that if GCR was indeed the prime driving mechanism for cloud electrification, then the intracloud discharges would be extremely long and results from earlier missions are not consistent with such discharges. We also show that even if we consider high altitude lightning initiation, where breakdown field is much lower, GCR induced charging still falls short and does not produce fields greater than breakdown field.

Methods: In terrestrial thunderstorms, the charged regions in the clouds have been approximated as a cylinder of radius \(R\), thickness \(t\) and charge density \(\rho\) \cite{5,6}. The proposed geometry is as shown in Figure 1. It can be easily shown that the electric field due to this configuration at any point on the central axis is given by

\[
E = \frac{-\rho R}{2\varepsilon_0} \left[ b_1 - \sqrt{1 + b_1^2 - a_1} + \sqrt{1 + a_1^2} \right]
\]

where \(a_1 = \frac{|z_0 - z_1|}{R}\) and \(b_1 = \frac{|z_0 - z_2|}{R}\). Central axis if of interest because at any given altitude level, the maximum field produced by the cylinder will be at the point on the central axis. The maximum electric field produced by this unipolar charged cylinder as shown in Figure 1 is at altitude levels \(z_1\) and \(z_2\) on the central axis (i.e.) at cylindrical boundaries. The fields at these maxima points are equal and opposite and field is zero at the center of the cylinder. The effective electric field due to multiple charged regions, (i.e.) dipolar charged regions in atmosphere and their image charges due to Venus surface, is simply the vector sum of the fields due to each individual charge regions. Breakdown field is the field at which free electrons in the atmosphere gain sufficient kinetic energy to ionize a neutral molecule. Thus, lightning will initiate only when total field due to charged cylinders is greater than the breakdown field (i.e.) \(|E_{Tot}| \geq E_{br}\). The breakdown field of Venus atmosphere can be determined using the relation

\[
E_{br}(z) = E_{br,0} \frac{n(z)}{n_0}
\]

where \(E_{br,0} = 6.95 \times 10^4\) kV/m, \(n(z)\) and \(n_0\) are the atmospheric number density at an altitude \(z\) and at the surface, respectively \cite{7}.

The Venustian middle clouds have high concentration of all modes of cloud particles \cite{8}. It is shown in the work of Michael et al. \cite{4} that the cloud particles in the regions of 48 – 55 km acquire negative charge as a result of electron attachment and charge transfer from ions. However, the typical charge density observed is in the order of pC/m\(^3\) or lower in these regions. Beyond 55 km, appreciable amount of charge is not acquired by the cloud particles because of reduction in concentration of the cloud particles. At each altitude level, the remainder of positive ions and negative ions after the cascade of chemical processes are nearly equal. However, the concentration of free electron steadily increases from \(10^6\) m\(^3\) at 45 km altitude level and attains a maximum concentration of \(4 \times 10^7\) m\(^3\) at about 60 km. Beyond that, it steadily continues to fall. We assume that the convective cells in the middle cloud \cite{9,10} and gravitational segregation enable the formation of two distinct charge regions. Since breakdown field required for lightning initiation reduces with altitude \cite{7}, the breakdown field at upper cylinder is lower than that of the breakdown field at lower cylinder. Using the analytical expression and lower breakdown field at higher altitudes, we estimate the radius of the charged cylinders required to produce fields greater than breakdown fields. We also study the possibility of lightning initiation in higher altitudes due to the increased concentration of free electrons produced in higher altitudes as a result of GCR induced ionization.

Results: Free electrons produced by GCR induced ionization are not constrained to initiate lightning within convective cells and can initiate lightning at any higher altitude level. From a theoretical perspective, even a unipolar cloud charge region can produce fields greater than breakdown fields. Assuming a charged cylinder exists with its top face at 70 km (the boundary of upper clouds) and the charge density of this cylinder is 6.4 pC/m\(^3\) (corresponding to maximum electron concentration), the resultant electric field at 70 km altitude due to various combinations of thickness and radius of cylinder is shown in Figure 2. Breakdown field at 70 km is 43 kV/m and even when assuming maximum possible thickness of 20 km (height of cloud layers) and extremely large radii, the maximum field produced is only 7.3 kV/m. Even under best possible condition, GCR
produced free electrons are not capable of producing fields greater than critical fields.

We assumed that with the aid of convective cells and gravitational segregation, two distinct charge cells are formed with a thickness of few kms and have charge density in the order of pC/m³. To cross breakdown fields, the radius of the charged cylindrical regions of these charge cells within middle clouds is required to be in the order of 1500 km and more. In the fractal modelling works of intracloud discharges, lightning usually initiates in the region between the charged cylinders and continues to grow in both directions till it reaches close to periphery of the charged cylinders [5,6]. The typical duration of one stroke of these extremely long discharges is in the order of 150 – 1500 ms (assuming propagation speeds of 10⁷ and 10⁶ m/s, respectively). For ‘k’ number of strokes, the length of the bursts recorded will be much longer. This results in whistler bursts in the order of few seconds. Statistical study of Venus Express Magnetometer datasets has shown that whistler bursts detected on Venus were typically 100 ms [11]. Such long discharges and time scales of these discharges are not consistent with spacecraft observations. Based on these results, we conclude that GCR induced ionization cannot be the prime driving mechanism for Venus Lightning.

Mass spectrometric study of planetary atmospheres in future missions: a case study, Venus Neutral and Ion Mass Analyzer (VENIMA). R. R. Mahajan¹, S. K. Goyal¹, N. Upadhyay¹, A. Auknoor¹, P. Sharma¹, J. Kaur¹, Varun Sheel¹, A. Bhardwaj¹, J. Ramí² and SAC team. ¹Physical Research Laboratory, Ahmedabad, 380009, India, ²Space Application Centre, Ahmedabad, 380015, India. *Email: ramakant@prl.res.in

Introduction: The exploration of Venus continues to be of utmost priority for planetary scientists to quench their thirst for comparative assessment of terrestrial planets. The Pioneer Orbiter missions by NASA [1] and the Venera orbiter/lander missions [2] by Lavochkin (Soviet Union) flew about 30 years ago. In the last couple of decades, Venus has only been studied through flyby missions and orbiters such as Venus Express and Akatsuki. Venus is categorized as an arid planet through the data from early missions. The majority of its atmosphere is largely unknown. The greenhouse effects cater to the formation of a 25 km thick cloud layer composed of sulphuric acid derivatives. The search for similarities between Earth, Mars and Venus is still on. Understanding Venus will help us answer the question of how Earth, with a habitable environment, may evolve to become a desiccated planet like Venus in the future [3, 4, 5, 6]. Determination of atmospheric composition through in-situ measurements is required for understanding the role of chemistry in various processes that took place to shape present day structure.

Discussion: The VENus Neutral and Ion Mass Analyser (VENIMA) is based on the concept of quadrupole mass spectrometer (Mass range: 2 – 200 amu and mass resolution [M/ΔM] >10). The incoming sample of gaseous species is filtered based on the ratio of their mass to their charge (m/q). VENIMA can be programmed to either sweep across a range of (m/q) ratios or allow only a species of interest to pass, by tuning the instrument to a fixed (m/q). It can be optimized for an orbiter mission as well as an atmospheric flight (atmospheric entry on board a nano-sat or balloon). The instrument shall employ a faraday-cup and a channeltron-electron multiplier as detectors. VENIMA shall function in two different modes viz. a) The Neutral Mode, which is used to measure neutral species by passing them through an ionizer, and b) The Ion mode, which is used to measure the positively-charged ambient ions. VENIMA will effectively characterize the neutral gases and ambient ions by measuring the isotopic and molecular compositions of the Venus’ upper atmosphere and ionosphere. These compositional measurements are required to understand the effect of interplanetary plasma and electromagnetic fields on the Venusian atmosphere.

Measurement of chemical compositions of the upper and middle atmospheric regions to verify against the models of primordial accretion, measurement of vertical and sectoral variations in the chemical composition of the Venusian atmosphere, estimation of atmospheric loss and measurement of isotopes to determine the early evolution of Venus are some of the objectives that we hope to achieve through our investigations with VENIMA instrument.

ACTIVE SEISMIC SURVEY ON VENUS BY MULTI-AGENT ROBOTIC SYSTEMS.  I. Morris1, M. Hassanalian1, Assistant Professor, Department of Civil and Environmental Engineering, New Mexico Tech, Socorro, NM 87801, USA, 2Assistant Professor, Department of Mechanical Engineering, New Mexico Tech, Socorro, NM 87801, USA.

Introduction: There has been an interest in studying our neighboring planets for specific research purposes, like Venus, because it is less resource-intensive than other small solar system bodies. Venus is a challenging planet to explore: the first Soviet space probe Venera 3 crash landed on the planet in 1966, the 1967 Venera 4 probe successfully returned some measurements on Venus’ atmosphere, the 1975 Venera 9 became the first artificial satellite on Venus, and a lander vehicle from this probe made its descent on the surface of Venus and made temperature and pressure measurements and transmitted photos. The problem with all Venus landers is that they hold communication for a short time. In 1982, the Venera 13 probe maintained communication for 127 minutes, which remains the current record [1, 2]. Some promising high temperature electronics are being developed, such as those included in the SAEVe mission [3]. Current technology allows for a wide variety of accurate measurements to be made, but gathering and transferring those data continues only as long as the instruments can withstand the intense heat.

One of the primary questions remaining to answer about Venus is the planet’s level of geologic or seismic activity. The geological structure of the planet is unknown, which includes core and mantle dynamics, the interaction between the geological structure and the surface heat flux, and the level of volcanism and seismic activity. Because virtually nothing is known about the structure or composition of the geological crust, active seismic surveys of any suitable landing site could illuminate the planet’s geological structure and offer clues about its seismic and volcanic activity.

Active seismic surveys differ from passive seismic or seismometer data in that they deploy both a source and a receiver; the source replaces the natural seismic and volcanic activity by applying smaller-scale physical impulses. This allows the geological structure to be investigated without depending on natural seismicity, which may or may not be present at the landing site or during the mission. These surveys are the primary mechanism of offshore resource exploration and, in the best conditions, are able to resolve the geometry and physical properties of the geological subsurface features in the surveyed area [4].

A hybrid lander that includes an atmospheric sensing unit (flying drone) that oscillates between high and low elections, and an on-ground network of robots performing the active seismic survey is proposed (see Fig. 1). This hybrid system is to be deployed by an orbiter, which will receive the data transmitted from the lander instruments, as in [3]. The payload of this system is to be limited and defined by the capacity of the orbiter; this proposal focuses on the hybrid system for active seismic survey.

Multi-agent Robotic Systems: Venus provides a good representation of the harsh space environments that must be considered when designing for extraterrestrial exploration. Three large problems to consider and overcome, particularly for data collection and transmission, when designing for Venus exploration are the high pressure (92 bar at the surface), high and variable temperature (average surface temperature or 735 K), and corrosiveness found in its atmosphere, which is mainly carbon dioxide but has small amounts of nitrogen, hydrogen, oxygen, and sulfur. The structural integrity of exploration vehicles is also at risk in this type of environment and design must consider some of the strongest materials with high thermal masses. The electrical components are possibly the most important consideration, as these are most likely to fail, and the structural and scientific components must be able to endure surface conditions on Venus for longer than 127 minutes [1,2].

One way of exploring Venus for the above-mentioned application is by using multi-agent systems equipped with sensors that can gather data of interest. This system is composed of a fixed-wing Unmanned Air Vehicle (UAV) that would be able to fly in the atmosphere of Venus and carry different types of
ground-based robots. The environment at higher altitudes may be easier to endure. Venus has varying wind speeds, faster (186 m/s) around 60 km from the surface, that affect the aerodynamic properties of a drone. The flying drone must optimize energy consumption and weight to fly on Venus. A fixed-wing drone that oscillates between high and low altitudes could provide a more resilient solution to the challenging near-surface environment [1].

To collect the active seismic data, the drone can fly at lower altitudes and release the bioinspired jumping robots onto the surface of Venus. These robots will be able to communicate with each other and also with the flying drone (see Fig. 1). Once the drone reaches a certain temperature limit, it will go back to higher altitudes where there is a less extreme environment. At this higher altitude, the drone will be able to cool before returning to the planet surface, possibly with an included cooling system.

**Design of jumping robots for active seismic survey:** Each jumping robot performing the seismic survey (minimum 2) is equipped with a 3C geophone system in the body for recording ground motions, a positioning system based on Kalman filtering of accelerometer and gyroscope sensors [e.g., 5], and small springs located in the legs of the jumping robot that can record the impact forces at each leg. These systems provide either the characteristic of the impact source (in jumping mode) or the resulting time series of ground motions (in receiving mode). The electrical systems that record and perform these operations must be adapted and proven to perform under Venus’ surface conditions (particularly very high temperature and pressure). Appropriate electronics systems are being developed using MEMS and tested at Venus-like conditions by LLISSE and NASA Greer systems, as proposed for the SAEVe mission [3].

An active seismic survey on land is carried out by placing an array of geophones to record ground motions. At selected geophones, a source is triggered (i.e., landing of jumping robot) and the rest of the array records the ground motions induced by that source. As the process is repeated for different source and receiver locations, the recorded waveform can describe the physical structure of the subsurface. The proposed system would deploy an array or pair of jumping robots which would survey the landing site.

There are two survey methods available to this system: In the first, the jumping drone remains in one location; for each jump (or source wave), the receiving drones record the motion and then moves to the next recording position. In the second option, the receiving drones remain in one position while the jumping robot acts as the moving source. The second option optimizes the locomotion of the jumping robots, which are more efficient and can create a larger force when jumping from one location to another. The data collected via the second option could be higher resolution but would comprise larger data volumes.

A 3C (3 components of motion) geophone located in the body of the jumping robots can provide useful data in both the source and receiver modes. In source mode, it can characterize the force generated by the robot. In receiving mode, the geophones will record the local ground motions experienced by the robot, like a traditional seismometer. If appropriate data volumes are available for transmission and recording on the orbiter, 3C seismic data could be recorded, which allows the geophones to identify the kind of wave (i.e., P-wave, S-wave) and the direction in which the wave is travelling. Processing these data can identify the subsurface geometry and density.

There are a number of advantages to carrying out an active seismic survey on Venus. In addition to providing novel scientific data about the structure and density composition of the crustal geology, the active survey aspect allows for direct exploration of the subsurface. Individual or paired seismometers deployed on Venus’ surface are reliant upon concurrent natural seismic activity, so they would be deployed and useful if they can record data that captures seismic events. Therefore, an active seismic survey could actually be conducted in a shorter period of time that captures actual seismic events. Due to planetary conditions, collecting data in a reduced time frame is an advantage. The primary drawbacks to the active seismic system are that the data volume is relatively large (compared with 3C seismometer recordings at discrete and triggered seismic events [3]), the relative locations and motions of each jumping robot are required to process the data, and the unknown structure of the crust may prove to be a poor setting to perform a seismic survey. However, even if the geolocations of each recording cannot be determined, the geophone data would still provide valuable insight into the seismic activity of Venus.

**References:**

Introduction: Magma oceans were ubiquitous during the formation of rocky planets. Crystallization of the mantle of Earth and Venus may have proceeded from the middle outwards. Liquid silicates are gravitationally stable near both the surface and core/mantle boundary (CMB) [1,2]. The surficial magma ocean of Venus solidified within ~100 Myr via rapid cooling to space [3]. However, a basal magma ocean (BMO) could survive for billions of years—and, perhaps, still exist as global layer within Venus today.

Earth’s putative BMO has been invoked to solve various geochemical puzzles [1]. In particular, the BMO is a “hidden reservoir” for incompatible elements including heat-producing isotopes. Seismology hints that iron-rich melt and compositional anomalies at the base of the mantle are the last residua of a BMO.

Why would Earth but not Venus have a BMO? These planets are assumed to have similar compositions because their bulk densities are nearly identical. Assuming that Venus and Earth accreted under similarly energetic conditions, a BMO on Earth would be mirrored by one with a comparable initial size on Venus.

Many models predict that the interior of Venus cools slowly relative to Earth. A popular story is that the proximity of Venus to the Sun led to desiccation of the surface and atmosphere [3]. Mantle dynamics on Venus may have transitioned between different regimes over time [4]. However, any period of mobile-lid convection (i.e., plate tectonics) was likely short-lived. Other modes of mantle dynamics such as stagnant- or episodic-lid convection are relatively less efficient at cooling the mantle. Roughly speaking, the total heat flow from the solid mantle of Venus to the surface has been estimated at ~20 TW versus ~44 TW for Earth.

This study [5] argues that the lifetime of a BMO in Venus plausibly stretches until today. In other words, Venus has an internal structure resembling that of Earth ~2 Gyr ago. However, the internal dynamics of Earth and Venus are different because middle-aged Earth cooled faster than modern Venus.

Methods: Parameterized models of Earth [1,2] were adapted to track the thermal evolution of the BMO and core inside Venus. These models are one-dimensional (radial). Relative to Earth, structural parameters for the core and mantle of Venus were adjusted to reflect lower internal pressures (i.e., ~125 vs. 130 GPa at the CMB) [6]. The initial condition for the model is the starting thickness of the BMO. Temperatures within the BMO and core are determined self-consistently from the thickness of the BMO based on the assumed liquidus. In contrast to the situation with a fully solid mantle, temperature cannot change dramatically across the CMB while the basal mantle is a low-viscosity fluid.

The heat flow into the base of the solid mantle \(Q_{BMO}\) in Fig. 1) controls the thermochemical evolution of the BMO and core. By definition, the total heat flow \(Q_{BMO}\) is the sum of energy terms related to specific and radiogenic heat in both the BMO and core, along with latent heat and gravitational energy associated with the freezing of the BMO from above and of the inner core.

Scaling laws determine when and where a dynamo could exist. The BMO and/or core are assumed to create a strong magnetic field if they are vigorously convecting. Critically, recent studies show that liquid silicates are electrically conductive under extreme pressures and temperatures. “Slow” rotation of Venus relative to Earth does not preclude dynamo activity because it is “fast” in the context of dynamo physics.

Results: Benchmark models for Earth were initialized with the thickness of the BMO equal to 750 km [1,2,5]. The thickness of the BMO shrinks to <10 km over 4.5 Gyr if \(Q_{BMO}\) linearly decreases from 55 to 15 TW over geologic time. This result agrees with the seismic constraint that there is no thick, global layer of liquid silicates at the base of Earth’s mantle today.

Nominal model for Venus. As a crude approximation of the differences between mantle dynamics on Venus and Earth, \(Q_{BMO}\) for Venus was reduced by half at all times relative to \(Q_{BMO}\) for Earth. In other words, \(Q_{BMO}\) decreased linearly from 27.5 to 7.5 TW over 4.5 Gyr. Figure 2 illustrates the thermal evolution of the deep interior. The BMO cools by only ~233 K over 4.5 Gyr because radiogenic and latent heat dominate its energy budget. That is, there is not enough total heat flow to rapidly change the specific heat of the BMO. The thickness of the BMO remains ~230 km today—clearly thick enough to constitute a global, detectable layer. Temperatures at the liquid-solid interface atop the BMO were estimated by averaging the

Figure 1. Internal structure of Venus today? Illustration by JoAnna Wendel [5].
solidus and liquidus of peridotite. A thermal boundary layer should exist at the base of the solid mantle. Otherwise, the mantle would likely have an extremely high potential temperature and produce unrealistic amounts of volcanism.

This model is consistent with available constraints on the magnetic history of Venus. Neither the BMO nor the core are cooling fast enough at present day to drive a dynamo. The BMO acts to suppress a dynamo in the core. However, a dynamo may have existed until recently in the BMO. Its lifetime is highly sensitive to the scaling law chosen for convective velocities in the BMO. The favored (CIA) scaling predicts that a dynamo lasted until ~1 Gyr ago (i.e., within the age of surface units) and had Earth-like strengths (i.e., ~10–30 µT).

Sensitivity analyses for Venus. The chemistry of the BMO influences how fast it cools. This study uses a simple, linear phase diagram [1]. Varying the density contrast between the BMO and the solid mantle can change the present-day size of the BMO by a factor of ~2. Future work should include a better phase diagram with partition coefficients [2] and track compositional layering in the BMO and solid mantle [7].

Implications: Gravity. A BMO is potentially detectable via future measurements of the tidal Love number ($k_2$) and the tidal phase lag. Measuring a high $k_2$ (>0.27 versus 0.295 ± 0.066 from Magellan) would indicate that the deep interior remains liquid, although the detection limit for a BMO needs definition [8].

Heat flow. The present-day thickness of a BMO is an integrated signal of the cooling history of Venus. Future missions may provide better constraints on the modern cooling rate of the mantle via analyses of high-resolution gravity, imagery, and topography. Such data are essential to verifying the assumption that Venus has cooled slowly relative to Earth over time.

Magnetism. Crustal remanent magnetism is a potentially observable consequence of an early dynamo in either the core or BMO [9]. In the absence of a BMO, the core could power a dynamo for billions of years [6]. High thermal conductivity for the core (>100 W/m/K) was previously invoked because simulations using lower conductivities over-predicted the dynamo’s lifetime. With a BMO, the prospects for a dynamo in Venus are less sensitive to assumed properties of the core. A dynamo is predicted to exist for similar timescales—but it would be located in the BMO, not in the core. The BMO gives, and the BMO has taken away.

Alternatively, Venus could have accreted under low-energy conditions where any BMO solidified quickly and chemical stratification blocked convection in the core forever [10]. Any detection of crustal remanent magnetism would disprove this alternate story.

Noble gases. Incompatible elements from the lowermost ~650–1250 km of the primitive mantle (e.g., ~11–25% of the mantle’s total volume), especially potassium, could remain hidden in a reservoir unsampled by volcanism and degassing. Future work should investigate whether the BMO could explain why Venus has less atmospheric argon-40 than Earth [8].

Ultimately, the prospect that a major feature such as a BMO could lurk undetected within Venus is one of many indications that new missions are needed.


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**Figure 2. Nominal model for Venus [5].**
Differentiating Exo-Venus and Exo-Earth Using Transmission Spectroscopy

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Abstract: The Transiting Exoplanet Survey Satellite (TESS) is expected to discover a multitude of multi-planetary systems. Of particular interest for comparative planetology are systems with a terrestrial planet in both the Venus Zone and the Habitable Zone. Studying the atmospheres of these planets through transmission spectroscopy will offer a unique opportunity to directly compare the evolutionary differences of two terrestrial planets in the same system. The transmission spectra of Earth and Venus have been shown to be remarkably similar however, which can cause ambiguities when inferring the differences between exo-Earth and exo-Venus climates. In this work, we present a new method of comparing Earth and Venus transmission spectra by conducting a feature-by-feature comparison of four major CO2 absorption bands between 1 and 5 microns. In comparing the transmission spectra, we find that the CO2 feature at 4.3 microns is comparable in absorption size for both exo-Venus and exo-Earth transit spectra, while the smaller CO2 features at 1.7 and 2.0 microns are the best indicators of a CO2-rich atmosphere. We conclude that the CO2 feature at 2.7 microns should be used as a basis for comparison of the amounts of CO2 in exo-Venus and exo-Earth atmospheres, since it most consistently portrays exo-Venus with the more CO2-rich atmosphere.

Introduction: The discovery of multiplanetary systems with planets in both the Venus Zone (VZ; Kane et al. 2014) and the Habitable Zone (HZ; Kopparapu et al. 2013) will allow for the opportunity to directly compare the evolutionary differences of Earth and Venus to another system. This will not be a straightforward endeavor however since identifying whether a planet is Earth-like or Venus-like from its transmission spectrum can be quite ambiguous. Barstow et al. (2016) conducted an extensive study which illustrated how retrieval methods can struggle to determine whether a Venus spectrum was best fit by an Earth or Venus model. A major result from their work showed that their retrieval method found that an Earth model was the best fit for a cloudy Venus transmission spectrum when using a reduced cloud prior. This illustrates that the lack of unique features in Venus’ transmission spectrum will make it very difficult to clearly identify that a planet is Venus-like. Although the Earth spectrum can be distinguished from a Venus spectrum by its H2O and O3 absorption features, it would require significantly high S/N, which would take over 20 transit observations to achieve (Morley et al. 2017). Additionally, the presence of clouds will vastly increase the amount of time needed to detect an Earth-like atmosphere, and the H2O features could be completely removed (Komacek et al. 2020). Therefore, we choose to focus on CO2 bands when comparing the spectra of Earth and Venus, as they are the largest absorption features and would require far less time to detect in comparison to H2O and O3 (Lustig-yaeger et al. 2019, Morley et al. 2017). Specifically, we are analyzing the features located between 1 and 5 microns, as there are several CO2 features present, and JWST can most efficiently detect absorption features in that wavelength range (Lustig-Yaeger et al. 2019).

To conduct the comparison, we first created spectra for Earth and Venus using Exo-Transmit (Kempton et al. 2017). We first produced spectra for a baseline Earth and Venus with cloud decks that extend to their present-day elevations, and then created additional spectra which have cloud decks that are at elevations both higher and lower than present-day Earth and Venus. Creating this matrix of spectra allows the comparison to be applicable to exo-Earths and exo-Venuses that have a variety of different cloud scenarios. To quantify the differences of a feature’s absorption depth in each planet’s transit spectra, we calculated the integrated absorption depth of the same feature for both planets and compared their values. This allows us to determine which planet has the larger absorption feature, and by what amount. The goal of this comparison is to determine which of the 4 features can best be used as a proxy for determining whether a planet has a CO2 dense atmosphere like Venus.

Results: We compared the CO2 absorption features located at 1.7, 2.0, 2.7, and 4.3 microns for a Venus and Earth transit spectrum. To determine which feature would best be suited for future comparison of Earth and Venus transit spectra, we considered the
size of the feature, the amount of scenarios where the feature is larger on Venus than on Earth, and how the size of the feature is affected by clouds. Our results show that the largest feature at 4.3 microns would be the best feature used to identify CO2 in the atmosphere of either planet. However this feature is frequently larger in the Earth spectrum than the Venus spectrum, and by a large margin. Both the features at 1.7 and 2.0 microns are excellent for identifying a CO2 dense planet, however they also are much smaller than the features at 2.7, and 4.3, which would result in the need for far more observation time with JWST. Additionally, there are H2O features in the Earth transit spectra which overlap with these CO2 features, which could make it difficult to determine whether the feature was created by CO2 or H2O in JWST observations. The feature at 2.7 microns is consistently larger in the Venus transit spectrum, and would be the second easiest feature to detect with transmission spectroscopy given its size.

**Conclusions:** We have determined that the smaller CO2 features at 1.7 and 2.0 microns are the best indicators of a CO2 dense atmosphere, since their absorption cross sections require large amounts of CO2 for the feature to be significant in a transit spectrum. However those features are also quite small, and unless large amounts of JWST time was allotted, they would be very difficult to resolve. We conclude that when comparing the transmission spectrum of an exo-Earth and exo-Venus, the CO2 feature at 2.7 microns would give the best opportunity of identifying which planet truly has the larger amount of CO2, and therefore is more likely to be Venus-like.

**References:**


**Figure 1:** Transmission spectra for Earth and Venus with 4 different cloud scenarios generated using Exo-Transmit. The four CO2 features are labeled with dotted lines as ‘F1-F4’.
SIMULATION EXPERIMENTS ON ELECTROCHEMICAL EFFECTS OF VENUS LIGHTNING.

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**Introduction:** As one of the three terrestrial planets with an atmosphere (Venus, Earth, Mars) in our solar system, Venus owns the densest atmosphere (with a pressure of ~95 bars at surface) in which two main gases CO₂ and N₂ account for 96.5% and 3.5%, respectively. Chemically reactive trace gases, e.g., H₂O/HDO, SO₂, SO, COS, CO, HCl, and HF, exist with trace concentrations (on the level of ppm or ppb) at different altitudes [1, 2].

From previous Venus mission observations, we have accumulated knowledge about Venus, and developed an understanding that sulfur species play important roles in venusian geochemical cycles. Two commonly accepted processes affecting sulfur chemistry are photochemistry and thermochemistry [1].

Owing to the limited information obtained by past missions to Venus, many theoretical models [2-3] and laboratory experiments [4-5] have been developed to help with the interpretations of mission observations, and to provide further constraints on the implications of the data. For example, models of sulfur cycles on Venus have been proposed [6]. Nevertheless, it is still difficult to match in detail the proposed Venus sulfur cycle with the mission observations. For example, SO₃ was not detected by any missions to Venus but should exist based on theoretical modeling. One of the mysteries is the origin of a second UV absorber in cloud layers of the venusian atmosphere.

On the other hand, lightning on Venus was first reported from mission observations in the 1970s [7]. Recently, more mission observations (optical and electric) have been regarded as evidence of lightning on Venus, as listed in table 2 of [8]. If Venus lightning does occur, a variety of electrochemical reactions, driven by electrostatic discharge (ESD) during lightning, could exist on Venus, which might explain some of the differences between models and mission observations.

In the venusian atmosphere, aerosols, ice particles, and dust particles can be electrified by friction or impacts induced by atmospheric convection, which seems to be a universal process on the other planets with an atmosphere (Earth and Mars), and even on the gas giants. Frictional electrification (triboelectric charges) is generally thought to make smaller particles (or droplets) have negative charge and larger ones with similar composition have positive charge [9-10].

The separation of charges induced by atmospheric processes will generate an active electric field. As the accumulated local electric field exceeds the breakdown electric field threshold (BEFT), electrostatic discharge (ESD) is expected to happen. The BEFT is strongly dependent on atmospheric pressure. For example, Mars has a BEFT around ~25-34 kv/m, [11-12], which is about 1% of Earth’s BEFT (~ 3 Mv/m [13]). This difference in threshold can be explained by the fact that the martian atmospheric pressure is < 1% that of Earth. For the same reason, the BEFT on Venus’s surface should be much higher, > 3x10⁶ Mv/m.

ESD events could generate large quantities of high-speed electrons (electron avalanches) that could impact and ionize the gas molecules in Venus’s atmosphere, CO₂, N₂, SO₂, H₂O, etc., and generate further positively and negatively charged ions, plus neutral molecules of new species [14]. Electrochemical reactions would be driven by these charged particles in the atmosphere and / or at the surface of Venus.

Here, we report progress (since the 2020 LPSC, [17]) in experimental development to simulate electrostatic discharge (ESD) under Venus atmospheric conditions.

**Experimental Setup:** The newly developed experimental setup is shown in Figure 1. Our Venus-ESD-Chamber (VEC) contains three subsystems with different functions:

1. A cylindrical Venus chamber (made of ceramics) with P, T, and C monitoring and control, whose highest temperature can reach up to 1300°C, higher than the temperature of Venus’s surface, 462°C (Fig. 2 shows its T profile). Gaseous mixtures can be made using two gas...
flowmeters, with gas pressure fine-tuned via vacuum pump, pressure gauge, and a set of valves.

(2) ESD apparatuses are inserted into an end-flange of the cylindrical VEC. The two electrodes (stainless steel, 1.2±0.02 mm diameter) were armored by two ceramic tubes (Fig. 1) that can sustain high temperature (up to 1450 °C) and maintain electrical insulation. The distance of the two electrodes in the VEC is kept at 4.89±0.03 mm. The electric power supply and the devices for voltage, current, and frequency measurements were pre-tested during an early experiment in the PEACH, where ESD at 1 bar CO₂ was successfully generated [17].

(3) Three optical sensors were installed outside of the VEC, looking through an SiO₂ window on the second end-flange of the VEC, in order to catch the images, the plasma, and the Raman spectra of generated ESD and ESD products in the VEC.

Results: We successfully generated ESD in the VEC using the new experimental setup, with air pressure up to 1010 mbar. We noticed that BEFT increases steeply with pressure, and higher driving voltage (Vₐ) is needed to start ESD at higher pressure (Fig. 4a).

Figure 3 shows the ESD current I (mA) and Vₑₘₛ (kV) as functions of Vₑ (kV), at 10, 350, 700, and 1010 mbar air pressure. Apparently, the ESD current (blue curve) monotonically increases with increasing Vₑ, while the ESD voltage Vₑₘₛ (orange curve) varies differently. The Vₑₘₛ curves tend to have similar variations at 10 and 350 mbar, i.e., a small decrease at Vₑ < 10 kV, and then monotonic increase. At 700 and 1010 mbar, Vₑₘₛ experienced a sharp drop near ~20 kV (Vₑ), then continued a slow decrease following the increase of Vₑ. These data suggest a sudden and then continuous increase of electrical conductivity in air, which could be caused by increased ionization of air molecules at higher air pressure.

The changes in ESD Vₑₘₛ & I vs Vₑ are also reflected in the color and the brightness of ESD images in the VEC (Fig. 4, c, d, e, f). ImageJ-Fiji was used to quantify the luminescence of ESD photon emissions at different air pressures. From Figure 4(b), we can conclude that luminescence increases with the increase of Vₑ, indicating the radiation of more light by ESD processes at high P and high Vₑ. The changes of color of these images correspond also to the changes in ESD emission spectra. Additional details will be reported at the VEXAG meeting.

Future work: A second and third set of ESD experiments will be conducted in pure CO₂, in SO₂, and in gaseous mixtures. Our goal is to develop an improved understanding of the observed ESD process and its products.

Acknowledgments: This work was supported by the CSC scholarship (NO. 201906220244) for HKQ; by NASA SSW-80NSSC17K0776 to AW. We thank Prof. Fegley for providing the systems of high-T furnace and gas-mixing.

**Introduction:** We present a new technique to retrieve the O$_2$ nightglow signal at Venus using the IRTF SpeX Instrument. Airglow emissions occurring in Venus’ upper atmosphere are ideal tracers of the atmospheric dynamics at high altitudes between 90 and 120 km. In particular, the 1.27 μm O$_2$ airglow, peaking around 95 km of altitude, is at the convergence of two circulation regimes: a retrograde superrotating zonal flow below ~100 km and a sub-solar/anti-solar circulation (SSAS) above 100 km altitude. The O$_2$ airglow arises from the three-body recombination reaction of oxygen atoms that were produced during daytime from the photo-dissociation of CO$_2$, CO, O$_3$, and O$_2$. Its counterpart, the nitric oxide (NO) nightglow, peaks at about 110 km of altitude and arises from the night side radiative recombination of oxygen and nitrogen atoms produced similarly on the dayside.

From 2006 to 2014, the European Space Agency (ESA) Venus Express (VEX) mission provided us with extended observations of both the NO and O$_2$ nightglow at Venus and demonstrated the complexity of the dynamical pattern in Venus’ thermosphere. According to models of the sub-solar/anti-solar circulation, both the NO and O$_2$ nightglow are expected to peak at equatorial latitudes at midnight solar local time. This behavior was generally observed for the O$_2$ nightglow. However, the NO nightglow, whose peak is only about 15 km above the O$_2$ peak, is shifted toward southern latitudes and 2AM local time. To date, models are not able to reproduce such discrepancies in the behavior of the two nightglows, illustrating our need of additional datasets for a better understanding of Venus’ upper atmosphere dynamics and transport mechanisms.

By using IRTF SpeX ground-based observations taken before, during and after the VEX mission, our objective is to complete the spatial and temporal coverage and improve our knowledge of the characteristics of the O$_2$ airglow at Venus. In particular, data from the Visible and Infrared Thermal Imaging Spectrometer (VIRTIS) instrument onboard Venus Express have shown a second localized maximum near 50°N and 30°N, which is not currently reproduced in models and can be investigated using the IRTF-SpeX data.

**Method:** The SpeX instrument acquired Venus observations from 2001 to 2020, through a program dedicated to the investigation of the Venustian clouds. However, signal from the 1.27 μm O$_2$ airglow (an average of 2 images at 1.27 μm per night) was also acquired during observations. The new technique presented here allows for the retrieval of the O$_2$ airglow intensity and distribution from this dataset, as shown in Figure 1. Corrections for stray light, thermal emission from the lower atmosphere of Venus, sky background, telluric absorption and correction of Venus O$_2$ airglow emission that is scattered to the Earth by the underlying clouds were applied to extract the O$_2$ nightglow brightness. Scanning the SpeX slit across Venus’ disk provide the necessary spatial coverage to image nightglow patches at the limb and on the disk.

![Figure 1: Construction of an O$_2$ IRTF SpeX Image.](image-url)

Geometrical correction is then applied to retrieve the latitude and longitude of each pixel on the disk and to reconstruct a geometrically accurate image of the Venus disk as seen at 1.27 μm. Slight variations in the telescope’s tracking and timing of spectrum exposures during a scan sometimes result in Venus not appearing as a circular disk. Since each spectrum is accompanied by simultaneous imaging by the SpeX guide camera, we can determine the location of the slit on Venus’ disk with a 1-σ error of about 60 - 100 km in all directions.

This unique dataset provides a novel vantage point on the O$_2$ 1.27 μm at Venus, allowing for the analysis of short-term nightglow morphology changes on nights...
when the SpeX instrument acquired multiples images. Additionally, the 19 years of available data also provide the necessary information for long-term analysis of the airglow behavior, complementary to existing mission datasets.
BALLISTIC AEROCAPTURE AT VENUS – A CASE STUDY FOR AN ATMOSPHERIC SAMPLING PROBE. Oswaldo Santana¹ and Ye Lu², ¹osantana@kent.edu, ²ylu16@kent.edu, College of Aeronautics and Engineering, Kent State University, Kent, OH, 44240.

Introduction: Aerocapture has been studied to be feasible for getting a probe to a capture orbit while allowing for significant mass savings [1]. Special consideration must be taken to ensure that given the mission requirement, there is enough margin for uncertainties and errors for a successful aerocapture [2]. A ballistic aerocapture can only vary the entry flight path angle as a means of trajectory control and no guidance or control will be available during the maneuver. It is therefore important to select the entry parameters that can ensure that the probe will not crash or burn in the atmosphere.

An important requirement for ballistic aerocapture is that the probe has a heatshield. An example Venus atmospheric sampler probe is used in the study to determine the benefit and feasibility of ballistic aerocapture. Generally, ballistic aerocapture can be incorporated to help increase mass margins in smaller probes which tend to be more mass constrained. The effectiveness and reliability of using aerocapture is dependent on each mission requirement, but it is a beneficial option that is available for applicable cases.

Results and Analysis: In order to investigate the possibility of using ballistic aerocapture, selected cases were studied using various entry velocities, vehicle ballistic coefficients, and different target orbits. It was first determined if it was possible to use aerocapture with only entry flight path angle as a control. An entry flight path angle for all cases studied was found that allowed for orbit capture of the probe. Limiting cases for ballistic aerocapture were identified from the initial analysis of finding entry flight path angles.

In some cases, we observed that aerocapture is not possible due mainly to the excessive high heat rates which are consistent with previous studies [2]. A high limiting survivable heat rate would have the probe experiencing heat rates of a few 100 W/cm² for ballistic coefficients of the same magnitude. Heat rates increase with increasing ballistic coefficients and entry velocity. Heat rate limitations provide a high limiting entry velocity of around 12 km/s. Probes with a higher entry velocity were seen to experience heat rates of a few kW/cm². In the ballistic coefficient range of interest heat rates allow for ballistic aerocapture below the high limiting entry velocity. Adding thermal protection systems to protect against the extremely high heat rates at higher than 12 km/s entry velocity would diminish from the benefit of using ballistic aerocapture for reducing mass.

The sensitivity of successfully executing ballistic aerocapture to each of the variables is also investigated in the study [3]. Small deviations from entry velocity and ballistic coefficient were used to determine the proper entry flight path angles for a target capture success rate (99% is used, as shown in Figure 1). It is important to note that 100% may also be achieved. Using the nominal entry flight path angles found for each case, an overall capture rate when targeting a low apoapsis radius was near 60% and near 90% for apoapsis radii that are tens of thousands of kilometers in altitude. The results show that a 99% capture rate is possible for all cases by having the probe enter at a shallow angle that may result in an escape orbit. The change in entry flight path angle increases post-capture ∆V needed to enter the target orbit, but it is significantly reduced compared to a fully propulsive capture.

Figure 1 shows the result for a case studied with ballistic coefficient of 200 kg/m², entry velocity of 12 km/s (i.e., equivalent V∞ of 7.5 km/s), target orbital period of 8.3 h, and a target apoapsis of 50,000 km. Using a Monte-Carlo analysis by varying ballistic coefficient and entry velocity, we observe a maximum value of near 4 km/s for the required ∆V post-aerocapture. In a fully propulsive maneuver, 5 km/s of ∆V is needed to reach the target orbit. Figure 1 shows the distribution of ∆V post aerocapture of the analysis. The difference in ∆V between ballistic aerocapture and fully propulsive option shows that there is a possible significant reduction in ∆V, leading to mass savings.

Microrobots Inspired by Oceanic and Bacteria Organisms for Observations of Venus’ Upper Atmosphere, M. R. Sherman¹ and M. Hassanalian², ¹Graduate student, Department of Electrical Engineering and Mathematics, New Mexico Tech, Socorro, NM 87801, USA, ²Assistant Professor, Department of Mechanical Engineering, New Mexico Tech, Socorro, NM 87801, USA.

Introduction: Since the 1960's, several countries such as the United States, Russia, Japan, and Europe have planned and executed missions to observe atmospheric, climate, and structural characteristics of Venus. The last dedicated mission to Venus was in 1989 with NASA’s Magellan spacecraft that used a Synthetic Aperture Radar to map its surface. The spacecraft that had the longest duration of survival on the surface of Venus was the USSR’s Venera 13 probe, which lasted for 127 minutes. The lander touched down on March 1, 1982 and took panoramic images of the Venusian surface, transmitting the first colored pictures. The lander also carried out scientific studies related to Venus’ atmosphere and soil composition.

Due to its similar size, complex atmosphere, and surface composition, Venus is commonly known as Earth’s twin. However, Venus is not as welcoming with overwhelming temperatures (over 800°F), thick atmosphere, corrosive, and high-pressure environments. Fig. 3(a) shows the average temperature profile as a function of altitude for Venus. At the surface, temperatures of almost 900°F are recorded, which is hot enough for conventional electronic systems to overheat.

Many projects issued by NASA and other space agencies have investigated the feasibility of a purely mechanical based rover to perform scientific analyses on the hot planet’s surface. One example is the Automation Rover for Extreme Environments (AREE, see Fig. 1), which uses gears, springs, and other mechanical components to provide rover mobility, power generation, and functionality without having the worry of electronic overheating. Other projects, such as aerial platforms, have also been explored to investigate the Venus environment and avoid the harsh conditions of the surface looking at the atmosphere circulation and chemical nature.

![Flagella/Squid Shaped Structure](Image)

**Figure 1.** Wind-powered rover concept for potential Venus mission [1].

There is an interest in the aerospace and scientific community for developing new concepts and methodologies with energy harvesting techniques that can broaden the scope and range of Venussian scientific discoveries. This work discusses a new concept involving a hybrid aerial system inspired by a bacteria-based organism – Flagellates – that utilize the strong winds in the upper atmosphere of Venus to power their onboard equipment (see Fig. 2). These Flagellate systems are equipped with various sensors needed for climate monitoring, topographical mapping, chemical composition and much more. This concept can provide answers to VEXAG’s goals and objectives for Venus Exploration, such as Venus’ atmospheric development, evolution, and climate history.

![Onboard Sensors](Image)

**Figure 2.** Flagella Micro-Robot Concept for Venus Upper Atmosphere Exploration.

The Climate of Venus: Venus has a similar mass, density, chemical composition, and gravity compared to Earth’s. However, as discusses, it also has un-friendly qualities like hot temperature extremes, acidic-like atmosphere, and crushing pressures (about 92 times that of Earth’s). Its atmosphere is almost entirely composed of Carbon Dioxide and is much denser than Earth, composed of opaque clouds of sulfuric acid. The upper atmosphere of Venus exhibits a super-rotation effect where the atmosphere circles the planet in just 4 Earth days. High wind speeds in higher elevations support this super-rotation phenomenon.

Due to these harsh conditions, information about the planet’s topography has been made through radar imaging. Venus’ characteristics make it extremely challenging in designing surface and atmospheric exploration systems intended to have long-duration missions. However, at around a range between 50 to 65 km above the surface of the planet, the atmospheric pressure and temperature are comparatively the same as that of Earth’s. In fact, Venus’ upper atmosphere is marked as the most Earth-like atmosphere in the Solar System and is the designated location for exploration and colonization.
Average temperature, pressure, and wind speed profiles for Venus are shown in Fig. 3. Observe that within the 50 to 65 km range, wind speeds are at a maximum, reaching up to about 96 m/s. That is a significant amount of energy that can be stored and harvested from a low-power, lightweight system that will have months to year-long mission durations. In addition, within this altitude range, standard electronics would be able to operate. Commercial/standard electronics have an operational range between 32°F to 158°F. Thus, the operation of a small system within this range, can be equipped with various sensors and equipment needed to conduct various scientific experiments.

Wind-Energy Harvesting on Venus: The upper atmosphere of Venus rotates at an incredible velocity, forcing winds to accumulate to up to about 345 kilometers per hour. Conversely, at the surface, there is almost little to no wind or just a gentle breeze. In February 2020, NASA ran a public challenge to develop an obstacle avoidance sensor for a potential Venus rover, the AREE. While previous landers lasted from minutes to a couple hours, AREE would be powered for long-duration surface missions utilizing a wind-turbine mechanism that harnesses the available Venustian winds to provide power for scientific instruments and mobility.

Wind energy harvesting can be achieved by considering wind power principles from fluid mechanics. In the case of a wind turbine, power generation can be highly effective during high-velocity winds. NASA has performed tests of wind turbines in Antarctica stations where there are extreme temperatures. According to Betz’ Law, the theoretical maximum power produced from a wind turbine is about 60%. The amount of power (P) than can be extracted from a turbine depends on the turbine efficiency (\(\eta\)), atmospheric density (\(\rho\) [kg/m^3]), swept area of the turbine (\(A\) [m^2]), and the wind speed (\(v\) [m/s]), modeled by Eq. 1 [4].

\[
P = \frac{1}{2} \rho v^3 A \eta \text{ [Eq. 1]}
\]

The scope of this work focuses on the development of a singular device that harnesses the available atmospheric winds, which can provide reliable, year-round power on Venus.

Flagellates/Squid-Like Hybrid System: Bacteria Flagellum is a thin, hair-like structure that acts like an actuator in the cells of organisms. There are many types of flagella, but both prokaryotic and eukaryotic flagella are primarily used for “swimming” locomotion, providing a whip-like, propulsive movement. This mobility is similar to that found in the flying squid. The flying squid uses a jet propulsion by taking water into its siphon muscle from one side and pushing it out the other side. They have been observed to reach distances up to 30m above the ocean surface.

Studies have tried to replicate this method of locomotion from both organisms to produce aquatic-aerial vehicles [5]. Considering Venus’s’ dense atmosphere, it would be a scientific breakthrough to develop an aerial system that harnesses this propulsion power while simultaneously using the available winds for power. This concept enables a whole new perspective of aerospace missions and provides a great leap in capabilities for NASA and VEXAG. These bacteria-like structures can “swim” through the upper atmosphere of Venus, undertaking future aerospace missions, expanding the region covered by traditional rovers, landers, and orbiters, recording a variety of sensory measurements such as air temperature, ground-penetrating radar, pressure, climate conditions, etc.

THE LOWER LAYER OF VENUS’ CLOUDS AS A GIANT BIOACCUMULATOR. G. P. Slowik¹ and P. Dabrowski²,¹Department of Anatomy and Histology, Collegium Medicum, University of Zielona Gora, Poland (grzegslowik@o2.pl), ²Division of Normal Anatomy, Department of Human Morphology and Embryology, Wroclaw Medical University, Poland (pawel.dabrowski@umed.wroc.pl).

Introduction: On the basis of 3-D climate simulations, it is known that the Venusian climate could have been habitable until at least 715 million years ago [1]. There is a hypothesis that the conditions (temperature, pressure, biomass, availability of appropriate substrates for metabolism) prevailing in the lower cloud layer of this planet (47.5-50.5 km above its surface), may favor the existence of microbiological life in them [2]. Just like on Earth, and at a similar time on it, life could have arisen and developed on Venus. Extremely interesting is the climate change on Earth, which took place 750-550 million years ago, described in literature as “the Snowball Earth” [3], after which the life of multicellular organisms flourished, culminating in the now recognized fossils from the “Ediacara Garden” (Australia) [4]. Around this time, life regressed on twin-like Venus, and if it has survived to this day, then in a completely different form, perhaps in the form of specialized single-celled organisms, resistant to the planet’s climatic extremes. The mystery is the factor or a series of factors that, at that convergent moment in time, triggered different, yet apocalyptic, changes in ecosystems. As a result of the changing climate of Venus and the deepening greenhouse effect, this life could completely change its existing habitat, i.e. leave the surface of this planet to adapt to life in its clouds [2], where it may continue to this day. Proposed terrestrial analogues of potentially cloud-living microorganisms of Venus are acidophilic bacteria Acidithiobacillus ferrooxidans [2]. These organisms are able to survive in extremely acidic environments [5], and these are the conditions in the lower part of Venus’ clouds.

Model assumptions: There are microorganisms known on Earth that can generate electricity [6,7]. Bacteria are also able to conduct electricity (cable bacteria) at distances up to the order of centimeters [8,9]. Electric bacteria can form individual cultures as well as occur in mixed communities [10]. The dependence presenting the value of the average charge per cloud particle at various altitudes using monodisperse distribution of particles shows that at an altitude of about 50 km there is a very significant decrease in the value of the electric charge from the value recorded at an altitude of about 46 km and a return to this value of electric charge at an altitude of about 55 km above the surface of Venus [11]. Such rapid oscillations of the electric charge can be explained (biologically) by the absorption of negative ions (electrons) directly from the atmosphere by anaerobic bacteria potentially living in the lower layer of Venus' clouds. Electron transmission could be used by these microorganisms in metabolic processes or in other mechanisms causing the recombination of negative ions in the environment, to create electrically neutral molecules. Metabolic energy processes (redox reactions) of these microorganisms potentially existing in Venus' clouds must be related, like their possible terrestrial analogues, to the flow of electric charges (electron transfer metabolism) [12]. The best example of recognized bioelectric processes of this type are the oxidation of iron and sulfur at low pH with the use of oxygen as the final electron acceptor [13]. They are characteristic e.g. for Acidithiobacillus ferrooxidans, an acidophilic, autotrophic bacterium that can act as a biocatalyst not only in the anode but also in the cathode. It has been shown that Acidithiobacillus ferrooxidans cells are able to grow on a graphite electrode, using electricity as the only source of energy [13].

Aims: The paper presents a model of bioelectric adaptation processes, presumably exaptation, of microorganisms potentially inhabiting the lower layer of Venus clouds, based on the example of their extremophilic, terrestrial analogues (such as Acidithiobacillus ferrooxidans bacteria). The presented model may contribute to the development of new concepts when searching for extraterrestrial life and its biomarkers.

Summary: The physicochemical parameters of bacterial metabolism based on electrical phenomena, potentially present in Venus clouds, could be better understood under laboratory conditions by studies with a reconstituted atmosphere that corresponds to the environment of Venus' lower clouds. Such works are currently in the logistical preparation phase.

Variations in the peak electron density of the Venus ionosphere: some new insights using Akatsuki Radio Science measurements. K.R. Tripathi1, K.M Ambili1, R.K. Choudhary1, T. Imamura2, and H. Ando3, 1Space Physics Laboratory (SPL), VSSC, Thumba, Trivandrum (tripathikr95@gmail.com, ambilisadasivvan@gmail.com, rajku-mar.choudhary@gmail.com, respectively), 2The University of Tokyo, Japan (t_imamura@edu.k.u-tokyo.ac.jp), 3Kyoto Sangyo University, Japan (hando@cc.kyoto-su.ac.jp).

Abstract: Radio occultation is simple yet an unique technique using which the altitude profiles of temperature, pressure, and electron density of a planetary medium are derived unambiguously. It relies on the principle that the phase of a radio signal, propagating from a satellite to the ground station, gets perturbed when it crosses through the planetary atmosphere or ionosphere [1]. This perturbation leads to changes in the frequency of radio signal which is known as atmospheric residual (atmospheric Doppler). By calculating Newtonian Doppler and subtracting from total Doppler we obtain atmospheric residual. Assuming that there is no abrupt changes in earth ionosphere in preceding a few minutes before occultation, basic parameters (temperature, pressure, neutral number density and electron density of ionosphere etc.) of planetary atmosphere are retrieved using standard procedures [2].

Since 2016, Radio Science (RS or radio occultation, RO) experiments are being carried out using Akatsuki satellite to study Venus atmosphere, and ionosphere [3]. As per MOU between ISRO, and JAXA, the RO measurements are being conducted at IDSN, Bangalore as well. Orbital geometry of this spacecraft provides rare opportunities to probe Venusian ionosphere in equatorial region with single X-band (8410-9320 Hz) radio signal. We used geometrical optics (GO) method to retrieve electron density profile of Ionosphere from raw data collected at IDSN, India and UDSC, Japan [2], Fresnel zone for X-band signal in ionosphere limited the vertical resolution of electron density between 400-700 meter [3]. Retrieved electron density profiles show direct correlation with the solar zenith angle (SZA). As the SZA increases, the peak electron density of V2 layer (nmV2) decreases while the peak height of V2 layer (hmV2) increases. The peak electron density of V2 layer varies from 5*105/cc to 1*104/cc for corresponding changes in SZA from 0 to 90 degree (SZA 00 stand for Sun on overhead). For higher SZA (>1200), the ionosphere becomes too thin to get any discernible profile. The highlight of Akatsuki measurements are the electron density profiles from the low latitude ionospheric regions. There are about 18 profile for which the solar zenith angle is less than 850. All the profile was simulated using an in-house developed one-dimensional photo chemical model (1DPCM) [4]. We note that though the model is able to reproduce the height of the V2 layer in most of the cases, there are a few cases when model overestimates the peak density of V2 layer. We will discuss about reasons for such overestimates and also describe characteristic features of V2 layer of Venus ionosphere as observed by the Akatsuki Orbiter.

Acknowledgments: Sincere thanks to Shri Umang Parikh, manager, IDSN, and his team to conduct the experiments and provide valuable data set. We also acknowledge, JAXA, Akatsuki team for providing data set recorded at UDSC https://www.darts.isas.jaxa.jp/planet/project/akatsuki/rs.html.ja.

References:
**Solar Luminosity through time: Does it determine Venus' climate history?**

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**Introduction:** In the popular mind the idea of Venus' water past with abundant surface oceans is a compelling concept. In the scientific mind it is equally compelling, if rightly accompanied by deep skepticism. In both minds there is a penchant to believe that Venus reached its current hot greenhouse state because of the gradually increasing luminosity of the sun through time [1]. Yet even 4.2Ga Venus received nearly 40% more luminosity than Earth receives today. It has been shown in a number of 1-D and 3-D modeling studies [2,3,4,5] that the mechanism to maintain habitable conditions on Venus 4.2Ga is via wide area high albedo clouds at the substellar point. In the 1-D case [2] the dense cloud mechanism went unexplained until the work of [3,4,5] showed that slowly rotating worlds have extensive Hadley cells that generate large contiguous cloud decks at the substellar point that reflect much of the incident solar radiation back to space.

Unfortunately what has been overlooked by many is the effectiveness of the cloud mechanism through time. In two different 3-D GCMs [3,5] it was explicitly demonstrated that even today when Venus receives nearly twice as much incident solar radiation as Earth the cloud albedo feedback mechanism would be intact and temperate surface conditions would be still be possible.

We explicitly demonstrate the fact that if the cloud mechanism of [3,4,5] is correct that the increase in solar luminosity through time could not be the primary determining factor in the evolution of Venus' climate history. In other words the evolution from a temperate Earth-like state to the present hot-house state cannot be motivated by increasing solar luminosity through time. We have proposed an alternative mechanism [5] that could have been responsible for Venus' climate catastrophe: large area volcanism similar to the large igneous provinces (LIPs) on Earth. Such LIPs have been tied to multiple mass extinction events through geologic time on Earth. However, the evolutionary scenario we propose is more complicated (planets are complex!) than this. The present day young surface of Venus may be the result of a post-LIP epoch when Venus became a stagnant lid world. This evolutionary hypothesis may be completely incorrect, or it may be fully correct, but either way it may contain important lessons for planetary evolution that we should consider as we look to Venus and Earth-like worlds around other stars.

**Acknowledgments:** This work was supported by the National Aeronautics and Space Administration (NASA) Astrobiology Program through collaborations arising from our participation in the Nexus for Exoplanet System Science (NExSS) and the NASA Habitable Worlds Program. Resources supporting this work were provided by the NASA High-End Computing (HEC) Program through the NASA Center for Climate Simulation (NCCS) at Goddard Space Flight Center. M. J. W. acknowledges the support from the GSFC Sellers Exoplanet Environments Collaboration (SEEC), which is funded by the NASA Planetary Science Division's Internal Scientist Funding Model.

**References:**


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**Not shown in the document:**

- The presence of a title, author, and affiliations.
- The introduction to the paper.
- The details of the modeling studies and their implications for Venus' climate history.
- The acknowledgment of support from NASA programs and collaborations.
- The references to key studies that support the proposed alternative mechanism for Venus' climate.
- The conclusion that explores the implications of the proposed evolutionary scenario for understanding planetary evolution.

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**Additional notes:**

- The document appears to be a scientific paper discussing the role of solar luminosity in determining Venus' climate history, with a focus on alternative mechanisms such as large area volcanism.
- The references cited are key studies that support the discussed theories and models.
- The acknowledgments recognize the support of NASA programs and collaborations, highlighting the interdisciplinary nature of the research.

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**Incorporated insights:**

- The importance of considering alternative mechanisms to explain Venus' climate history beyond the traditional solar luminosity explanation.
- The role of extended cloud cover and Hadley cells in maintaining habitable conditions on slowly rotating planets like Venus.
- The potential significance of large area volcanism similar to Earth's LIPs in shaping Venus' geological and climate evolution.

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**Request for elaboration:**

- For a deeper understanding of Venus' climate history, it is crucial to consider not only the gradual increase in solar luminosity but also other factors like volcanic activity and cloud dynamics.
- The paper's references to 1-D and 3-D modeling studies provide insights into how Venus' climate could have been maintained in the past with relatively high solar luminosity.
- The acknowledgment of support from NASA programs highlights the collaborative nature of modern planetary science research.

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**Conclusion:**

- The paper challenges the conventional view that Venus' current hot greenhouse state is solely due to increasing solar luminosity through time.
- It proposes an alternative mechanism involving large area volcanism, similar to Earth's LIPs, as a possible driver for Venus' climate evolution.
- The implications of this evolutionary scenario offer new directions for understanding the complex processes that shape the climates of Earth-like worlds in our solar system and beyond.
Bioinspired Walking, Rolling, and Jumping Robot for Venus Exploration. A. Western1, M. Hassanalian2, 1Graduate student, Department of Mechanical Engineering, New Mexico Tech, Socorro, NM 87801, USA, 2Assistant Professor, Department of Mechanical Engineering, New Mexico Tech, Socorro, NM 87801, USA.

Introduction: The environmental conditions on Venus are extremely harsh and have led to the quick destruction of many landers. The atmosphere temperature on the surface can reach over 700 K, and is composed of 96.5 % carbon dioxide and 3.5% nitrogen with clouds of sulfuric acid. Temperatures that high can melt metals with lower melting points after only a few hours of being on the planet’s surface. The atmospheric pressure on Venus is 93 bar, over 90 times that of Earth’s, which can lead to unforeseen consequences if not carefully planned for. The surface of Venus is covered in volcanoes, rocky plains, and mountain ranges, with peaks reaching 7 miles in height. Research suggests that Venus is volcanically active and has had several large eruptions over the past few decades.

Venera 13 lasted the longest out of all landers that have reached the surface of Venus. It transmitted data for over 2 hours before failing. Pictures transmitted showed a relatively flat surface covered in sediment and slabs of rock. Ground samples determined the surface material corresponded to volcanic rock. Developing a small robotic system for the exploration of Venus that is capable of walking, running, rolling, and jumping would allow for quick and efficient movement across Venus’ rocky surface [1].

Inspiration from Organic Creatures: Earth’s organisms have evolved to be efficient and resourceful in a wide variety of environments. They have adapted and developed unique skills to give them an advantage over other creatures. Nature is full of inspiration for designs, and mimicking natural characteristics can provide for a more successful design. The pressure on Venus is comparable to the pressure roughly 950 m below the ocean’s surface. The ocean’s Bathypelagic zone starts at 1,000 m below the surface and extends to 3,900 m below the surface. The zone below the Bathypelagic zone is the Abyssopelagic zone, which extends down to around 6000 m below the surface. Deep-sea creatures that live in the Abyssopelagic zone survive in pressures reaching 760 bars. Empty cavities in their bodies have evolved to be minimized in volume to protect against collapsing. In Fig. 1, some examples of these creatures are shown.

Fig. 1. Views of natural creatures underwater.

Proposed Bioinspired Robot: The proposed robot in this study will draw inspiration from three different animals, including the Long-nosed Leopard lizard, Golden wheel spider, and Octopus. The Long-nosed Leopard lizard lives in flat, wide-open deserts with sparse vegetation, such as the Mojave desert. The wide-open spaces allow for prolonged running and basking. The lizard’s coloration changes seasonally between darker and lighter shades of brown. The longer limbs allow the lizard to hold itself higher above the surface, which results in less absorption of radiating surface heat. When running quickly, it runs on its hind legs while holding its front limbs up in the air. Toes with small spiny scales allow for the lizard to run across the sand without sinking. In Fig. 2(a), a view of this spider is shown.

The Golden wheel spider moves in a very unique way (see Fig. 2(b)). In order to conserve energy, the spider spreads its legs out around it’s body in a circle and rolls down a sloped surface. The longer the spider is able to roll, the more momentum it gains. This effortless motion allows the spider to move quickly to escape predators without expending its energy.

Octopus can move across the ocean floor by walking on their tentacles (see Fig. 2(c)). They have no skeletons, but their bodies are very muscular and supported by fluids. They have two tentacles that are especially muscular and can support their bodies as they walk underwater. Octopuses are also capable of crawling onto land and moving out of the water for extended periods. The suckers on the undersides of their tentacles allow for climbing up vertical surfaces. They have also been sighted rolling across the ocean floor, sometimes inside of objects, such as coconut shells, pushing themselves with their tentacles. Rolling inside of a shell allows the octopuses to move quicker, as well as protection from any predator.

Fig. 2. Views of (a) walking Long-nosed Leopard lizard, (b) rolling Golden wheel spider, and (c) rolling Octopus.

The proposed robot would mimic aspects of all three animals to move across the sediment covered surface of Venus rapidly. The robot’s body will be spherical with multiple legs that can change configuration around the body. Like the Long-nosed Leopard lizard, these legs will have wide, flat feet to increase surface area and allow for traction on the sediment. Longer legs will be
able to help slightly protect the robot from surface radiation. The robot will be able to walk/run when the legs are positioned on one side. The robot will roll by placing the legs in a ring configuration around the body, similar to the Golden wheel spider. Rolling will be useful when going down slopes to save energy and will allow for quick movement. Rolling on flat surfaces still allows for efficient movement due to the momentum gained. Like the octopus, the robot will be able to boost its rolling on level surfaces with quick, small movements from the feet. The robot will be able to bend the legs and jump while rolling. The robot will be made of flexible composite capable of withstanding the high temperatures on Venus’ surface. The electronics will be housed inside of the spherical body. Equal distribution of weight inside of and around the robot will help to balance it while rolling.

Modeling of the Bionsoired Robot: In Fig. 5, $W$ is the weight of bioinspired robot, $R$ is the radius of the sphere, $M_c$ is the moment about the center of the sphere, $M$ is the mass of rover, $g$ is the gravity on Venus (8.87 m/s$^2$), $N$ is the normal force, $F_f$ is the force of friction, $\mu$ is the coefficient of friction, $F_D$ is the drag force, $C_D$ is the drag coefficient, $A$ is the reference area, $\rho$ is the density of the atmosphere on Venus surface, and $V$ is the velocity of the robot [3].

$$F_D = \frac{1}{2} \rho V^2 A C_D$$

Fig. 5. Schematic of forces acting on Venus robot.

As shown in Fig. 6, the robot is modeled as two rigid body systems.

Applying Lagrange equations, we have:

$$\frac{d}{dt} \left( \frac{\partial L}{\partial \dot{\theta}_1} \right) - \frac{\partial L}{\partial \theta_1} = -T$$

(1)

$$\frac{d}{dt} \left( \frac{\partial L}{\partial \dot{\theta}_2} \right) - \frac{\partial L}{\partial \theta_2} = T$$

(2)

where $T$ and $t$ are the torque between the sphere and the pendulum and time, respectively.

References:

**LOCAL VARIATIONS IN VENUS TESSERAE IDENTIFIED BY BACKSCATTER VARIATIONS.** J. L. Whitten\textsuperscript{1} and B. A. Campbell\textsuperscript{2}, \textsuperscript{1}Dept. Earth and Environmental Sciences, Tulane University (6823 St. Charles Ave., New Orleans, LA 70118; jwhitten1@tulane.edu), \textsuperscript{2}Smithsonian Institution, National Air and Space Museum, Center for Earth and Planetary Studies, Washington DC, 200013.

**Introduction:** Tesserae only cover 7% of the surface of Venus \cite{1}, but these materials represent the oldest \cite{2} rock record on the surface and may preserve evidence of different earlier climate conditions on Venus. Generally, tesserae are regions of high standing topography. Tesserae are identified by their complex morphology, which involves at least two sets of intersecting tectonic structures (e.g., graben, ridges, fractures) \cite{3}. Their high degree of deformation, which created areas of increased surface roughness, leads to a radar-bright appearance of tesserae in the Magellan SAR data and often enhanced Fresnel reflectivity.

Despite the importance of the tesserae for understanding Venus prior to \~500 Ma, its surface properties are not well constrained. The range in radar brightness, or backscatter coefficient, across the tesserae has not been quantified in detail, 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 analyze the Magellan synthetic aperture radar (SAR) and Earth-based radar datasets to more specifically constrain the radar properties of tesserae. The range in radar brightness 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. This is a first and fundamental step to addressing the much larger questions about tesserae, including their composition and formation mechanism(s).

**Methodology:** We quantify radar brightness variations across tesserae by calculating the backscatter coefficient \cite{4} of backslopes (slopes that are facing away from the Magellan spacecraft) using Magellan SAR orbital datasets. Magellan SAR data (12.6-cm) have a linear HH polarization and are sensitive to slopes on the order of tens to hundreds of meters. The pattern of backscatter coefficient variations in each tessera deposit is compared with the presence of various geologic landforms, such as impact craters and volcanic structures. Fine-grained particles in distal impact crater ejecta or erupted during volcanic activity can modify surface roughness [e.g., 5, 6]. For example, these particles can smooth the surface by infilling small-scale topographic lows and cracks. Identifying where impact craters or volcanic eruptions have modified the radar surface properties of tessera will enable

![Figure 1](8049.pdf) Distribution of tesserae backscatter coefficient values (colorful dots) across Venus. Note variations between and within different tesserae (e.g., Sudenitsa, Alpha, Cocomama, Tellus). Base map: Magellan SAR left and right look data.
identification of more “pristine” regions to determine natural variations in tessera material properties.

**Results and Discussion:** The backscatter coefficient varies across the 21 tesserae measured, with values from -28 dB to almost 13 dB. There are substantial backscatter coefficient variations both within and between tesserae (Fig. 1). Correlations between backscatter coefficient and the expected location of crater ejecta exist [7], where ejecta regions have lower backscatter coefficient values. For example, the fine-grained ejecta from Stuart crater smooths the surface of eastern Alpha Regio [5]. Our analysis indicates that crater ejecta is preserved in the rougher tessera longer than on adjacent low-lying plains (>35±15 Ma). Lower backscatter coefficient values occur in Tellus Tessera, but not in the adjacent plains [6].

While no correlations between backscatter and volcanic constructs have been identified, there is evidence from northern Nedoyla Tesserae that differences in tesserae morphology and/or local elevation differences are associated with variations in backscatter coefficient. These backscatter coefficient variations may be related to the inherent tesserae properties, rather than to the properties of materials emplaced as airfall from another geologic process.

Magellan data show that the tesserae vary substantially in their radar properties, both within an individual tessera and also between tesserae. Some, but not all, of these variations can be attributed to local geologic landforms and their associated processes, such as impact craters. These remaining backscatter coefficient variations suggest that the original tesserae materials varied in some way (composition, grain size, formation process, local geologic processes) to cause such different expressions of radar properties.

The results of this study provide tantalizing information about the geologic history of Venus preserved in the tesserae. To fully constrain tesserae composition additional datasets are needed from future missions.


**Introduction:** EnVision [1,2] is a Venus orbiter mission proposal that will determine the nature and current state of geological activity on Venus, and its relationship with the atmosphere, to understand how and why Venus and Earth evolved so differently. EnVision is one of three competing ESA M5 mission concepts currently in their study phase (A1-A2) with a final down-selection expected in 2021. The EnVision mission is studied in collaboration with NASA, with the potential sharing of responsibilities currently under science, technical and programmatic assessment.

If selected, the proposed international mission will launch in 2032 on Ariane 62. Following orbit insertion and periapsis walk-down, orbit circularisation will be achieved by aerobraking over a period of several months, followed by a nominal science phase lasting at least 6 Venus days (4 Earth years).

EnVision will use a number of different techniques to search for active geological processes, constrain style and occurrence rate of current-day volcanism on Venus, by searching for thermal, morphological and volatile signatures in repeated observations of the surface and of the atmosphere. It will characterise regional and local geological features, determine crustal support mechanisms and constrain mantle and core properties.

The Synthetic Aperture Radar, VenSAR, will address the key science objectives of the EnVision mission. It will:
- Obtain images at a range of spatial resolutions from regional coverage to images of targeted localities;
- Search for changes in surficial radar imagery;
- Measure surface topography regionally by means of stereo radar imaging; and globally by means of nadir altimetry;
- Characterise surface polarimetric reflection and emission properties using both SAR and radiometer measurements.

The Subsurface Sounder, SRS, will be the first instrument to investigate the subsurface structure of Venus and acquire fundamental information on subsurface geology; it will:
- Characterize the vertical structure and stratigraphy of geological units including volcanic flows; and
- Determine the depths of weathering and aeolian deposits.

The Venus Spectrometer suite, VenSpec, will:
- Obtain global maps of surface emissivity in five wavelength bands in the near-infrared to constrain surface composition and inform evolution scenarios [3]; and
- Measure variations of SO₂, SO and chemically-related gaseous species in the mesosphere and nightside troposphere, in order to link these variations to atmospheric dynamics, chemistry and volcanism.

The Radio Science experiment will:
- Constrain crustal & lithospheric structure at finer spatial scale than Magellan;
- Measure spin rate and spin axis variations to constrain interior structure; and
- Measure spatial and temporal variations of H₂SO₄ liquid and vapor at 55-35 km.

EnVision will produce a huge dataset of geophysical data of a quality similar to that available for Earth and Mars, and will permit investigation across a large range of disciplines. Lab-based and modelling work will also be required to interpret results from the mission. We therefore invite scientists from across planetary, exoplanetary and Earth science disciplines to participate in the analysis of the data.

**References:**


Insights into Structure and Elastic Thickness of Ridge Belts on Venus. Zachary W. Williams\(^1\), Paul K. Byrne\(^1\), and Jeffrey A. Balcerski\(^2\).\(^3\)Planetary Research Group, Department of Marine, Earth, and Atmospheric Sciences, North Carolina State University, Raleigh, NC 27695 (zwillia@ncsu.edu), \(^2\)Ohio Aerospace Institute, Cleveland, OH 44142.

**Introduction:** Despite Venus showing no evidence of a global system of tectonic deformation, a variety of tectonic landforms across Venus suggests a complex and active geologic history that is not fully understood. Widely distributed within Venus’ low-lying plains are linear to arcuate, positive-relief systems of shortening structures, termed ridge belts in the literature[1–7]. Although these landforms have been recognized for some time, the relatively recent availability of regional topographic data at resolutions greater than the Magellan altimetry dataset \(^3\) allows the morphology and structure of ridge belts to be studied in finer detail.

Here, our aim was to acquire detailed morphometric data for a globally distributed set of ridge belts. Once such data were acquired, we mapped observable tectonic structures—faults and folds—within a subset of those selected ridge belts. We then used topographic profiles and relief values from the collected morphometric data to acquire local estimates for the effective elastic thickness of the lithosphere, evidenced by flexural signatures in topography proximal to these ridge belts.

**Data and Methods:** We utilized global Magellan synthetic aperture radar (SAR) full-resolution radar map (FMAP) 75-meter-per-pixel (m/px) left- and right-looking mosaics for the initial identification of candidate ridge belts. For topographic measurements, we used stereo-derived digital elevation models (DEMs) produced by Herrick et al. \(^8\), which offer ~20% global coverage at 1–3 km/px resolution.

Morphological analysis: We conducted a global survey with ArcGIS to identify ridge belts on the basis of morphological descriptions from existing studies [e.g., 1, 4–7, 9]. Our survey yielded 24 candidates for further analysis that have a well-preserved morphology and are not obviously kinematically associated with neighboring systems. Of these 24 structures, 12 are within the Herrick DEM coverage \(^8\). We recorded the strike of each landform and width measurements (representing the distance across strike to opposing boundaries of the landform) at regular intervals along the structure. For those ridges covered by the Herrick DEMs, we extracted 20 cross-sectional profiles at the point of width measurements. Relief values were extracted from topography data using the area of the ridge belt as a mask to extract pixel values from the DEM.

Fault Mapping: Identification and mapping of faults was conducted using the left- and right-looking SAR survey global mosaics at 1:200,000 view scale for six ridge belts (with an example shown in Fig 1a). These six were selected on the basis of their orientation relative to the look directions of the Magellan radar, and coverage by both left- and right-looking SAR data. Assuming a similar surface mineralogy across the ridge belts, the variation in backscatter (the value gathered by SAR) is a function of surface roughness and incidence angle [10]. Radar bright lineations are thus interpreted as alterations in surface angle due to faulting. On the basis of comparison with tectonic structures on Earth and other rocky bodies, we interpreted arcuate fault traces as denoting shortening structures (likely folds atop thrust faults) \([11]\). Linear fault traces, commonly offset in an en echelon manner, were taken to correspond to normal faults. The orientation of the six ridge belts orthogonal to the Magellan radar look-directions means that the survey in which a lineation is prominently displayed denotes the direction of the steeper fore-limb and therefore up-dip direction. This method was statistically supported by calculating the vector mean of each fault population and using the resultant length to quantify distribution of orientation.

Lithospheric Flexure: Cross-sectional profiles were reviewed for topographic signals associated with the flexure of the elastic lithosphere in response to the mass of the ridge belt, representing a line load, akin to a seamount chain \([12]\). Four of the selected ridge belts displayed evidence of lithospheric flexure as resolved by the Herrick DEM data \([8]\) (Fig 2). The solution to the topographic response to a line load (represented as a point load on a 1-dimensional profile), \(w\), is given by the dampened sinusoidal function \([12]\):

\[
w = w_0 e^{-z^2 (\cos \left(\frac{x}{a}\right) + \sin \left(\frac{x}{a}\right))},
\]

where \(w_0\) is the maximum amplitude of flexure along the breadth of the profile, \(x\), with respect to the flexural parameter, \(a\), given by the relation:

\[
a = \frac{4D}{(\rho_m - \rho_i)g}
\]

where \(D\) is the flexural rigidity, \(\rho_m - \rho_i\) is the difference between mantle and atmospheric density, and \(g\) is the acceleration due to gravity. Flexural rigidity is given by

\[
D = \frac{E}{12(1-v^2)}h^3,
\]

where \(E\) is Young’s modulus, \(v\) is Poisson’s ratio, and \(h\) is the depth of the elastic lithosphere. Values for Young’s modulus and Poisson’s ratio for anhydrous basalt, and density contrast across the lithosphere, were taken from previous studies of lithospheric flexure on Venus \([13, 14]\). The depth of the elastic lithosphere was determined using a least-squares optimization of a cost function for the set of equations using a simplex method, with \(w\) and \(w_0\) as two of the free parameters.

**Results and Discussion:** The average width of the 24 ridge belts we selected is 81 km (with a maximum width value of 207 km, a minimum width of 9 km). The standard deviation of width measurements within each ridge belt ranged from 59 to 4 km, with an average value of 19 km. For the 12 ridges within the DEM coverage, we found an average relief value of 597 m and a median value of 551 m (with maximum and minimum values of 938 m and 232 m, respectively). The uniform low relief values, not exceeding 1 km despite width values of
9 to 207 km, are thus the most consistent morphological parameter. Cross-sectional profiles of the ridge belts commonly display an observable fore- and back-limb morphology consistent with thrust-fault-related landforms.

Fault Analysis: Mapping and morphological assessment indicate that tectonic structures within ridge belts are predominately thrust faults and their related folds (Fig 1b), the majority of which strike roughly parallel with the long axis of the host ridge belt (Fig 1c). The cumulative lengths of fault populations, discretized by dip-direction, were compared within a given ridge belt to determine if a dominant fault dip direction is present within that belt. This analysis yielded a direction of tectonic transport that agrees with that suggested by the fore- and back-limb morphology seen in cross-sectional profiles for ridge belts that displayed this asymmetry. Thrusts within the ridge belts commonly form antithetic thrust pairs and imbricated anticlines (Fig 1b), the distance between which may offer information regarding homogeneity in slip and fault dip angle along major underlying fault planes [15]. The spacing distribution of surface anticlines varies among the ridge belts we included (Fig 1d). We interpret this spatial variation to reflect heterogeneities in the properties of the major faults comprising these ridge belts. Our interpretation leads to the view that ridge belts are complex systems of thrust fault duplexes, in contrast to shortening structures on other worlds that are often morphologically more simple.

Lithospheric Flexure: Results for depth of the elastic lithosphere supporting each ridge return values of 10–24 km (Fig 2), largely consistent with previous studies for the planet’s lowlands [e.g., 16-18]. The optimization function was run with an unbounded number of iterations, and solutions represent a best fit of modelled solutions to the observed curvature of the foreland basin flanking the ridge belts (Fig 2). The range of values given by these model results, along with the low-relief values we measured, support the hypothesis that the elastic lithosphere surrounding these ridge belts is relatively thin, compared to the breadth and length values of these landforms and to the crusts of other terrestrial planets. Furthermore, this result agrees with predictions of yield strength envelopes that suggest a thin elastic lithosphere as a function of Venus’ high surface temperature [19]. This inference can be further tested with forward modeling of ridge belt morphology [20].

Introduction: The IR2 camera on the Akatsuki spacecraft obtained images of Venus throughout most of 2016 with three filters (1.74, 2.26 and 2.32 µm) designed to image clouds on Venus's nightside. We present a set of images obtained on 25-AUG-2016 that is remarkable for two reasons. First, it consists of sequences of 19 images in each filter, spanning an 18-hr period with a 1-hr cadence. Second, each image has been deconvolved with a modeled PSF to remove scattered daylight near the terminator and improve the spatial resolution.

We present cloud-tracking results based on careful registration of the limb in each image. The high spatial resolution lets us recover cloud motions with velocity errors less than 1 m/s.

This particular day of observations show some unusual clouds that appear to boil into existence during the image sequence. We present cloud tracking data for these features that suggests a different altitude than other cloud features in the immediate vicinity.

Disk Registration: Although disk registration may seem like a trivial task, it is, in fact, the major source of error in estimating cloud motion velocities. We show results from a robust limb gradient fitting technique that locates Venus's limb at the 5 km level (rms).

Cloud Tracking: We use a cloud-tracking method based on the cross-correlations of the gradients of IR2 images [1]. In addition, we adapt the Advection Correction method of [2] to fit cloud motions with functional forms over periods of several hours. The resulting velocity fields are accurate enough to show meridional motions and local vorticities.
**VENUS DRILL AND SAMPLE DELIVERY SYSTEM.** K. Zacny\(^1\), J. Hall\(^2\), and VISAGE Team, \(^3\)Honeybee Robotics (kazacny@honeybeerobotics.com), \(^2\)NASA JPL.

**Introduction:** For over a decade, Honeybee Robotics and NASA JPL have been developing Venus technologies to enable surface missions and operations. Critical subsystem of these technologies include drilling and sample delivery. Venera 13, 14 and Vega 2 successfully demonstrated drilling and sample delivery to an XRF instrument from up to 3 cm depth. Drilling was performed using a 90 Watt rotary drill and sample delivery was done using a series of pyrotechnic actuators and pneumatic transfer. This heritage is non-existent though – blue prints are not available and engineers that design the systems have retired by now.

As part of the technology development that will enable analysis of Venus surface and subsurface, Honeybee Robotics and JPL developed high temperature actuators, drills, deployment systems, and sample delivery systems.

**Venus drill:** We developed a rotary-percussive rock sampling drill and high temperature (HT) electromagnetic actuator for a proposed mission to Venus known as VISAGE (Venus In Situ Atmospheric and Geochemical Explorer). The drill is powered by two brushless DC motors that have been characterized in dynamometer tests run at both room temperature and Venus surface temperature of ~462°C (Figure 1). Dynamometer test results are compared with performance estimates obtained using ANSYS Maxwell analysis software, demonstrating that losses at high temperature can be predicted with reasonable accuracy.

![Figure 1. Venus actuator.](image1)

The Venus drill with its major subsystems is depicted in Figure 2 (the Deployment and Feed stages are not shown). The design includes a hollow drill stem extension through the bit and hammer drive assemblies up to the top of the drill body, where it will interface with the pneumatic sample transfer system. The sample will flow directly from the bit, through the hollow transfer tube into the rest of the sample transfer plumbing (not shown).

![Figure 2. Schematics of Venus drill.](image2)

Drilling trials conducted in JPL’s Venus Material Test Facility (VMTF) shown in Figure 3 have demonstrated the feasibility of sampling threshold strength Venus analog material within a time window compatible with the proposed VISAGE mission concept of operations.

The tests showed that the rate of penetration in 120 MPa Saddleback Basalt at Venus temperature and pressure was slower (3.8 mm per minute) than at Room Temperature (5.1 mm per minute). This has been attributed to the lower stiffness of the percussive spring (and, therefore, the percussive energy per blow) as well as increased electrical (i^2R) losses at high temperature because of the higher resistance of the motor coils.

Additional tests have been conducted to demonstrate combined drilling with pneumatic sample delivery under Venus conditions. These tests used the Large Venus Test Chamber (LVTC) at JPL plus additional external hardware for the pneumatic transfer and airlock systems that would be located inside the Venus lander (Figure 4). These end-to-end tests successfully demonstrated all major steps in the complete sampling process: deployment of the drill to the surface, drilling, pneumatic transfer of the drill
cuttings to an airlock and movement inside the airlock of samples to a low pressure, low temperature location for scientific analysis.

![Diagram of Venus drill components]

**Figure 3.** Venus drill prior to Venus chamber tests.

**Figure 4.** JPL Large Venus Test Chamber and associated pneumatic sample transfer equipment.

**Conclusions:** This work demonstrated that drilling and sample delivery under Venus conditions is feasible. Further development is required to improve the reliability and efficiency of the system prior to flight.

Utilization of Resources on the Moon. Gordon Zhou¹, Svetozar Zirnov², Austin Mardon³, ¹The Antarctic Institute of Canada, (#103, 11919- 82 Street NW, Edmonton, Alberta, Canada, aamardon@yahoo.ca).

Introduction: Structures on the lunar surface will challenge contemporary thoughts of auxiliary examination by basic and structural architects, just as originators, constructors and coordination organizers. Uncovered home units will confront numerous issues with response to the extraordinary lunar temperature cycles and impacts of high vacuum. Uncovered material and basic exhaustion because of extraordinary lunar temperature cycles and temperature affect-ability differential on ceaseless auxiliary parts must be tended to night time lows of -110°C (-170°F) would mean originators must take a gander at the potential fragile cracks and stress focuses inside the potential material. A potential fractional arrangement is inside to pressurize supporting individuals, for example, those for claspings, hardening and propping to meet well being and unwavering quality prerequisite. The flighty idea of the lunar condition requires minimization of hazard to a worthy level. Stacking must consider the 1/6 gravity of the moon. This implies a structure will have multiple times the weight-bearing limit (dead weight) on the moon as on the Earth. Notwithstanding, it cannot be expected that the structure can bolster more load because of this reality. This would possibly be valid if the material is straightly versatile. In any case, most materials have a non-direct. Current building thinking and configuration depends on the point of confinement state conditions. Chuaetal (1992) propose a nonlinear hyperbolic pressure strain model to all the more likely reflect how structure-regolith recreations should be possible utilizing the limited component approach. This is actually the reason clarifying the usage utilizing kg-power (estimations without gravity segment). Basic parts must display a degree of repetition as in statically vague structures. This infers burdens are redistributed to a balance state when individuals are to fall flat. A degree of worthy hazard and well being elements should be inferred. Since, the condition’s on the moon’s surface are very harsh, safety measures must also be taken into account. One way of making sure that an astronaut is safe while on a mission to the moon is through the use of the lunar lava tubes. One of the ways by which lava tubes may be used for future moon expeditions is by providing astronauts a shelter from the rough conditions on the moon’s surface, which include falling micrometeorites, exposure to extreme temperatures, as well as fatal levels of radiation. Micrometeorites are small pieces of space debris which may have various impacts on the astronauts in the expedition, depending on the size and speed of the micrometeorites falling. Even though most of the falling micrometeorites do not reach earth’s surface because they vaporize by the large amounts of heat that are generated by the friction of passing through earth’s atmosphere, in space there is no atmospheric cover that would protect a spacecraft or a spacewalker in a case of falling micrometeorites. Also, as previously mentioned Another issue that must be taken into account is the issue of exposure to fast-changing extreme temperatures, for on the moon there is no atmosphere like on the earth and temperatures greatly vary between the day time highs and night time lows. Exposure to such extreme temperatures that are quickly-changing can cause various kinds of harm to the human body. Another major issue that should be taken into account is the exposure of astronauts to fatal levels of radiation while on the moon’s surface, which may come in various ways such as: solar flares which are constituted similarly to the solar wind, but the individual particles hold higher energies, and also galactic cosmic rays which are composed of very high energy particles, mostly protons and electrons. Thus, just as astronauts face those various issues, while on missions to the moon, humanity will have to face similar issues when it will be inhabiting it, in the near future.

Research: Inflatable have for quite some time been proposed as a plausible and a financial strategy for a lasting lunar base. The inflatable pressurized tractable structure of fiber composites offers radiation protecting under local regolith and little temperature varieties. Erectable tetrahedral, hexahedral, octahedral structures have likewise been proposed and offers huge numbers of indistinguishable advantages from inflatables. The different geometrically arranged space outline components can be effectively expandable and rushes to build and introduce. As individuals from these structures are not locally discovered, it must be pre-manufactured and brought to the moon. At present it isn’t financially achievable. It must be truly considered and taken into account that the utilization of lunar resources is essential to protect the health and well being of astronauts on a mission in space, as well as to ensure their safety at all times while on the mission. Lunar lava tubes can also act as a storage for various things, including medical supplies, food water, and even space equipment, thus keeping it in good condition, without damage. As the article in the argoverse
website states: [4] "One other idea that has been proposed for the case of the Moon is that the sheltered environment and consistently cold temperatures in lava tubes may serve as a kind of trap for water ice and other volatiles (Billings, 1991, p. 256) ". Thus, helping astronauts survive during emergency situations. Thus, being a confined space it may also meet other astronaut's necessities, such as water, and dehydration. Since, confined spaces are cooler in temperature and are able to generate ice at times, the ice could be used either as water directly, or may be heated up using a piece of technology and turn into water that will be able to help the astronaut's in the mission, in case of a lack of water, and likewise help them to avoid dehydration. At times it may even save an astronaut's life, since water is the largest component of our bodies. This may also be used by the future human inhabitants as a source of water in a situation where water resources may become scarce. Thus, lunar lava tubes must be taken into account as a way of protecting astronauts and other humans in an emergency situation, or even as large storage facilities for storing food, medicine, or various kinds of equipment.

Conclusion: This paper shows a synopsis of squeezing issues encompassing the planning, engineering and development of lunar home units. Auxiliary honesty relies upon different flighty factors present on the moon. Temperature and regolith varieties must be considered into the plan standard of the structure. Essential, Material and Structural mechanics and conduct are reliant on these factors. Because of various factors inside the extent of planning of lunar structures, a strategy model for the thought of disappointment modes that vary from earthly structures must be made. The test during the structure stage is the powerlessness to test plan models under lunar condition. A sensible testing situation can be not practically tried. This thus does not enable architects and fashioners to successfully and precisely assess the total basic life cycle. The separation far from Earth related to surprising expenses related with vehicle of material to the lunar surface recommends the requirement for the utilization of local material. This is otherwise called In-situ Re-source Utilization (ISRU). This will be critical however future achievability investigation into this theme must be inquired about. Humanity's inhabiting of the moon is an important step in its history, that must be clearly planned and executed carefully. Since, astronauts are being effected by various kinds of issues such as, rapid temperature changes, exposure to high levels of radiation, as well as falling micrometeorites, humanity must be ready to face such issues. Lunar lava tubes may be used both by astro-


Research Support: This research is supported by the Antarctic Institute of Canada and the Government of Canada CSJ Grant.