VEXAG Steering Committee

Darby Dyar (PSI, Mount Holyoke College), Chair
Noam Izenberg (Applied Physics Laboratory), Deputy
Giada Arney (NASA GSFC)
Lynn Carter (University of Arizona)
James Cutts (JPL), Roadmap Focus Group
Candace Gray (NM State University) Early-Career Representative
Robert Grimm (Southwest Research Institute)
Gary Hunter (NASA GRC), Technology Focus Group Lead
Kevin McGouldrick (University of Colorado)
Pat McGovern (Lunar & Planetary Institute)
Joseph O'Rourke (ASU), Early-Career Representative
Emilie Royer (University of Colorado)
Allan Treiman (Lunar & Planetary Institute), Goals, Objectives, and Investigations Lead
Colin Wilson (University of Oxford)
Tommy Thompson (JPL), Scribe

Adriana Ocampo (NASA HQ) ex officio
• Had liquid water for as long as 3 billion years?
• Directly analogous to large numbers of exoplanet discoveries?
• Surface geology and rock type nearly unknown?
• Holds the key to understanding solar system formation through isotopic data?
• Has lower resolution topography data than Pluto?
• Has signs of nascent plate tectonics?
• Not visited by U.S. in 25 years?

Which object?
VEXAG Near-Term Goals

• Provide support for the Decadal Survey
  • 3 documents nearly in press, paper in *Space Science Reviews*

• Build a **Venus program**!
  • Engage the community to come together with a common vision
  • Improve communication within Venus community and among the general public: new listserv has >500 members, media outreach
  • Open meetings and public forums
  • Expand **visibility of Venus science** at conferences and at NASA: 67 Venus papers at DPS/EPSC, AGU session and Town Hall
### Preparations for Decadal Survey

<table>
<thead>
<tr>
<th>3 teams formed</th>
<th>weekly meetings, writing</th>
<th>1st draft versions posted</th>
<th>Virtual Town Hall to discuss</th>
<th>2nd draft versions posted</th>
<th>Pre-LPSC public meeting</th>
<th>3rd draft versions posted</th>
<th>Virtual Town Hall to discuss</th>
<th>Final drafts completed</th>
<th>Sent out for review</th>
<th>Formatting for consistency</th>
<th>Revisions</th>
<th>Final edits, proofreading</th>
<th>DONE</th>
</tr>
</thead>
<tbody>
<tr>
<td>March</td>
<td>April</td>
<td>December</td>
<td>January</td>
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<td>May</td>
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<td>July</td>
<td>August</td>
<td>September</td>
<td>October</td>
<td>November 2019</td>
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</table>
Goal #1. Understand Venus’ early evolution and potential habitability to constrain the evolution of Venus-sized (exo)planets
   A. Did Venus have temperate surface conditions and liquid water at early times?
   B. How does Venus elucidate possible pathways for planetary evolution in general?

Goal #2. Understand atmospheric composition and dynamics on Venus
   A. What processes drive the global atmospheric dynamics of Venus?
   B. What processes determine the baseline and variations in Venus atmospheric composition and global and local radiative balance?

Goal #3. Understand the geologic history preserved on the surface of Venus and the present-day couplings between the surface and atmosphere.
   A. What geologic processes have shaped the surface of Venus?
   B. How do the atmosphere and surface of Venus interact?
Table 1. Major Needs Arising from This Study

<table>
<thead>
<tr>
<th>Area</th>
<th>Needs</th>
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</thead>
<tbody>
<tr>
<td>Entry Technology</td>
<td>Funding to ensure the entry technology capability does not atrophy</td>
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<tr>
<td>Subsystems</td>
<td>Development of high temperature electronics, sensors, and high-density power sources for the Venus environment with increasing capability</td>
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<tr>
<td>Aerial Platforms</td>
<td>A competitive program to determine which Variable Altitude balloons approach is most viable</td>
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<tr>
<td>In situ Instruments</td>
<td>Adaptation of flight-demonstrated technology and development of new instrument systems uniquely designed for the Venus environment</td>
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<tr>
<td>Communications and Infrastructure</td>
<td>Study of the feasibility of and methods for establishing a Venus communications and navigation infrastructure</td>
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<tr>
<td>Advanced Cooling</td>
<td>Investments in highly efficient mechanical thermal conversion and cooling devices</td>
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<tr>
<td>Descent and Landing</td>
<td>New concepts for adapting precision descent and landing hazard avoidance technologies to operate in Venus’ dense atmosphere</td>
</tr>
<tr>
<td>Autonomy</td>
<td>Transitioning of automation and autonomous technologies to Venus-specific applications</td>
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<tr>
<td>Small Platforms</td>
<td>Development of small platform concepts in addition to larger missions, as well as a new mission typedesigned around small platforms</td>
</tr>
<tr>
<td>Facilities and Infrastructure</td>
<td>Support of laboratory facilities and capabilities for instrument and flight systems, including critical technologies to avoid atrophy of capabilities</td>
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<tr>
<td>Modeling and Simulations</td>
<td>Establishment of a system science approach to Venus modeling</td>
</tr>
<tr>
<td>Unique Venus Technology</td>
<td>Continued and expanded support for programs such as HOTTech, and other technology development</td>
</tr>
</tbody>
</table>
Noam Izenberg: EMPIRE Strikes Back: Venus Exploration in the New Human Spaceflight Age
2. Stephen Kane: Venus as a Nearby Exoplanetary Laboratory
3. Marty Gilmore: Venus Flagship report (only if not funded)
4. Tibor Kremic/Gary Hunter: LISSEe, VBOS, etc. small platforms for long-lived surface missions
5. Gary Hunter: High temperature electronics, recent advancements
6. Raj Venkatapathy: HEEET
7. Jim Cutts: Aerial platform update to prior report, with ore emphasis on exploring the habitable zone
8. Joe O’Rourke: Searching for crustal remanent magnetism…
10. Emilie Royer: Airglow as a tracer of Venus’ upper atmosphere dynamics
11. Sue Smrekar: Venus tectonics and geodynamics
12. Joern Helbert: Orbital spectroscopy of Venus
13. Amanda Brecht: Coupling of 3D Venus models and innovative observations
14. Jenny Whitten: Venus tessera as a unique record of extinct conditions
15. Sanjay Limaye: Venus as an astrobiological target
16. Attila Komjathy: Investigating dynamical processes on Venus with infrasound observations from balloon and orbit
17. Pat McGovern: Venus as a natural volcanological laboratory
19. Alison: Venus facilities and applications for them for technology development and science investigations
20. Allan Treiman/Molly McCanta: Experimental work for understanding Venus
21. Frank Mills: Carbon, oxygen, and sulfur cycles in Venus’ atmospheric chemistry
22. Eliot Young: Ground-based observations of Venus in support of future missions
23. Glyn Collinson: Space plasma science questions and technologies
24. Colin/Sanjay: Coordination and strategy for international partners and collaborations for Venus: future fly-bys and international missions?

Drafts due Nov. 6, 2019
Round robin discussions at VEXAG
<table>
<thead>
<tr>
<th>Technology Area</th>
<th>Description</th>
<th>PI</th>
<th>Organization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Packaging</td>
<td>500°C Capable, Weather-Resistant Electronics Packaging for Extreme Environment Exploration</td>
<td>Simon Ang</td>
<td>University of Arkansas</td>
</tr>
<tr>
<td>Clocks &amp; Oscillators</td>
<td>Passively Compensated Low-Power Chip-Scale Clocks for Wireless Communication in Harsh Environments</td>
<td>Debbie Senesky</td>
<td>Stanford University</td>
</tr>
<tr>
<td>GaN Electronics</td>
<td>High Temperature GaN Microprocessor for Space Applications</td>
<td>Yuji Zhao</td>
<td>Arizona State University</td>
</tr>
<tr>
<td>Computer Memory</td>
<td>High Temperature Memory Electronics for Long-Lived Venus Missions</td>
<td>Phil Neudeck</td>
<td>NASA GRC</td>
</tr>
<tr>
<td>Diamond Electronics</td>
<td>High Temperature Diamond Electronics for Actuators and Sensors</td>
<td>Bob Nemanich</td>
<td>Arizona State University</td>
</tr>
<tr>
<td>Vacuum Electronics</td>
<td>Field Emission Vacuum Electronic Devices for Operation above 500°C</td>
<td>Leora Peltz</td>
<td>Boeing Corp.</td>
</tr>
<tr>
<td>ASICs &amp; Sensors</td>
<td>SiC Electronics To Enable Long-Lived Chemical Sensor Measurements at the Venus Surface</td>
<td>Darby Makel</td>
<td>Makel Engineering, Inc.</td>
</tr>
<tr>
<td>Primary Batteries</td>
<td>High Temperature-resilient And Long-Life Primary Batteries for Venus and Mercury Surface Missions</td>
<td>Ratnakumar Bugga</td>
<td>NASA JPL</td>
</tr>
<tr>
<td>Rechargeable Batteries</td>
<td>High Energy, Long Cycle Life, and Extreme Temperature Lithium-Sulfur Battery for Venus Missions</td>
<td>Jitendra Kumar</td>
<td>University of Dayton</td>
</tr>
<tr>
<td>Power Generation</td>
<td>Hot Operating Temperature Lithium combustion IN situ Energy and Power System (HOTLINE Power System)</td>
<td>Michael Paul</td>
<td>JHU/APL</td>
</tr>
</tbody>
</table>
Long-Lived In Situ Solar System Explorer (LLISSE)
NASA Glenn Space Center

• LLISSE is a small and completely independent probe for Venus surface applications
• Measures surface wind speed, orientation, T and P, near-surface atmospheric composition
• Planned to operate for 60 Earth days
• Could travel on Venera-D
Heat Shield for Extreme Entry Environment Technology (HEEET) – NASA Ames

• Utilizes a novel material based on 3D weaving
• Target missions include Venus Lander and Saturn Probes
• Capable of withstanding extreme entry environments, such as peak heat-fluxes >5000 W/cm\(^2\) and peak pressures >5 atm
• Scalable system from small probes (~1m scale) to large probes (~3m scale)
• Developing an integrated system, including seams
  • Culminates in testing 1m Engineering Test Unit (ETU)
  • Integrated system on flight relevant carrier structure
  • Proves out manufacturing and integration approaches
  • Used to validate structural models

Images and text from Don Ellerby presentation 6/12/18 posted at https://www.colorado.edu/event/ippw2018/sites/default/files/attached-files/aeroentrytech_7_ellerby_presid594_presslides_docid1160.pdf
Glenn Extreme Environments Rig (GEER)

- 28 cubic ft. (800 L) chamber
- Simulates the extreme T <500° C (932° F) and P (near vacuum to 1400 PSI)
- Gas mixing capabilities to reproduce unique planetary environments, such as caustic sulfuric acid found in Venus’ atmosphere
Venus Elemental and Mineralogical Camera (VEMCam)

Mineralogy/Raman Spectroscopy

Clegg et al. (2014) Applied Spectroscopy, 68, 925

Chemistry Laser-Induced Breakdown Spectroscopy

LANL Venus Chamber

Currently 2 m long, 110 mm diameter
4 m capability by February 2019

Collected under Venus Surface Temperature and Pressure

Funded by New Frontiers Program
Venus Spectroscopy

Windows in Venus’ CO$_2$ atmosphere allow emission spectra to be acquired.
Venus Surface Platform Study Group

- Assess current science objectives and the state of the technology for exploring Venus’ surface with lander and probes
- Look at how additional technical capability could impact new science achievable.
- Lay out a roadmap for the future exploration of the planet by this means given certain technologies be made available
Venera-D Concept: Mission Elements

**Baseline:**
- Orbiter: Polar (90°± 5°) 24-hr orbit with lifetime ≥ 3 yrs
- Lander (VEGA-type, updated) ≥2 hrs on surface; high-latitude LLISSE on Lander (>2 months)
- Sufficient lift mass for either Proton or Angora launch vehicle
- Flexibility to select precise landing site ~3 days before VOI
- Lander visible to orbiter for first 3 hrs
- Orbiter can see lander (LLISSE) for >60 days

**Potential augmentations:**
- Small stations (2nd – 4th LLISSE, SAEVe)
- Sub-satellite(s)
- Aerial platform
Exoplanets in our Backyard
February 5-7, Houston TX
Joint meeting convened by VEXAG, OPAG, and ExoPAG

- Examine and discuss **exoplanet-solar system synergies** on planetary properties, formation, evolution, and habitability.

- **Topics to be covered** include comparative planetology on worlds near and far; solar system studies as a baseline to inform studies of extrasolar planetary properties and evolution; and lessons learned on planetary statistics, demographics, and system architectures from extrasolar planetary systems.

- Aims to **foster and build new collaborations** among scientists in the solar system and exoplanet communities and to help guide the direction of future exploration and observations of worlds in the solar system and beyond.
• Both *Dragonfly* and *Europa Clipper* baseline launch scenarios include Venus gravity assist/flybys.

• Pending final confirmation of launch vehicle and trajectories:
  • Both missions' launches represent perfect opportunities to deliver payloads of opportunity to Venus.
  • Multiple, high science return, low cost cubesat to smallsat Venus missions have been studied and deemed feasible via PSDS3, Venus Bridge*, and other efforts. (*Venus Bridge study targeted a higher cost point, but resulted in multiple elements within SIMPLEx or SALMON range*).
  • Small Venus missions would ride along on launch and separate as early as initial boost to Venus trajectory.

• **SIMPLEx or SALMON calls for these planetary missions should be dedicated to Venus opportunities.**

• PSDS3, HOTTech, Venus Bridge concepts: CUVE, Cupid’s Arrow, VAMOS, LLISSE, SAEVe, V-BOSS, VB-IRO, -SMO, -RSOC, -UVO, -PFO, -Skim, -Probe, -Balloon.
The case for Venus

Ignored by NASA for nearly 25 years, Venus offers valuable insights into the formation and evolution of terrestrial planets like our own.

M. Darby Dyar
Suzanne E. Smrekar
Lori S. Glaze

The search for life elsewhere in our universe is exploding. Discoveries of new exoplanets are now a weekly occurrence. Our curiosity about exoplanets is motivated by the tantalizing possibility that we might discover another world where life as we know it could thrive.
VEXAG Findings

1. Treat Venus more seriously as a target of astrobiological interest
2. Continue to support HOTTech; foster and maintain high-temperature technologies
3. Support programmatic balance among mission selections
4. New Frontiers call should remain on schedule for a draft AO in 2021
5. Support of international missions to Venus is not the same as US-led mission(s)
6. Importance of ride-along opportunities
7. Consider a new class of mission (smallsats) in which Venus Bridge would be a type example (Sub $100m components)
8. Investment in telecommunications infrastructure
9. Form a cross-divisional research program for Comparative Climatology of the Terrestrial Planets
10. Address workforce issues
VEXAG Requests for PAC Advocacy

• Clarity in ride-along mission decision process, advocacy for Venus.

• Support programmatic balance among bodies, areas of science. Better define a “program”? Does a program have a start and end date? Exactly how are programs initiated? How do they end?

• Underscore importance of U.S. leadership on Venus missions. Careful consideration of U.S. funding commitments to international vs. domestic-led missions.

• Consider workforce issues on NASA committees and review panels. Teaching faculty and soft money personnel increasingly unable to participate due to lack of funding. Disproportionate representation from NASA centers. Diversity continues to be needed.

• Funding of fundamental science to understand not only “what” but also “why”
Decade of Venus
Backup slides
EnVision (ESA) Status

• Concurrent Design Facility baseline study successfully achieved the mission targets within the design to cost envelope
• Baseline mission is 2032 launch
• Mission start in June 2035
• 278 Tbit data return in 4-cycle, with >60% IR and sounder coverage, >15% InSAR and polarimetry coverage (30 m resolution), and 2% high resolution (~2 m resolution) NASA contributions include the Ka TT&C and either
  • VenSAR front end with UK back end, or
  • Whole SAR instrument
• EnVision passed the Mission Development Review and will start Phase A study
• Two parallel industrial studies will run from June 2019 to March 2021 ahead of final down-selection in June 2021
Announcement of Opportunity from Indian Space Research Organisation for Space-Based Experiments to Study Venus

- Soliciting important science experiments that strengthen / complement overall science from the suite of pre-selected proposals
- Payload capacity ~100 kg with ~500W of power
- Highly inclined orbit proposed
- Must work collaboratively with teams from India on design and development of instrument hardware
- Deadline extended to January 31, 2019

PRE-SELECTED PROPOSALS FROM INDIA:
1. S-Band Synthetic Aperture Radar (SAR)
2. Advanced Radar for Topside Ionosphere and subsurface sounding
3. Ultraviolet (UV) imaging spectroscopy telescope
4. Thermal camera
5. Cloud monitoring camera
6. Atmospheric spectropolarimeter
7. Airglow photometer
8. Radio occultation experiment
9. Ionospheric electron temperature analyzer
10. Retarding potential analyzer
11. Mass spectrometer
12. Plasma wave detector

Venus Bridge

- In January of 2017, NASA SMD AA asked VEXAG to assess viable mission concepts that could fit within a $200M cost cap.
- Study group treated smallsats that could launch as secondary payloads in early-mid 2020s.
  - Focused on *linked* orbital and in situ (probe, lander, aerial elements) – not missions with dedicated launch vehicles.
  - GRC developed a point design with strong linkages between orbiter and lander: **V-BOSS**.
- JPL studied 8 *mission architectures* that could be combined if desired.
- Feasible within cost cap, with significant risk
  - Class D = zero to minimal redundancy.
  - Development costs to TRL 6 untreated.
- Small, low-cost missions could answer *some* important questions for Venus and galvanize support for larger follow-ons.
Venus Aerial Platform Concepts considered in this study are subdivided into three categories:
1. Fixed Altitude platforms
2. Variable Altitude platforms
3. Platforms with both Variable Altitude and Lateral Control

https://solarsystem.nasa.gov/resources/2197/aerial-platforms-for-the-scientific-exploration-of-venus/