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

VENUS EXPLORATION
VEXAG
ANALYSIS GROUP

Which object?

- 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?

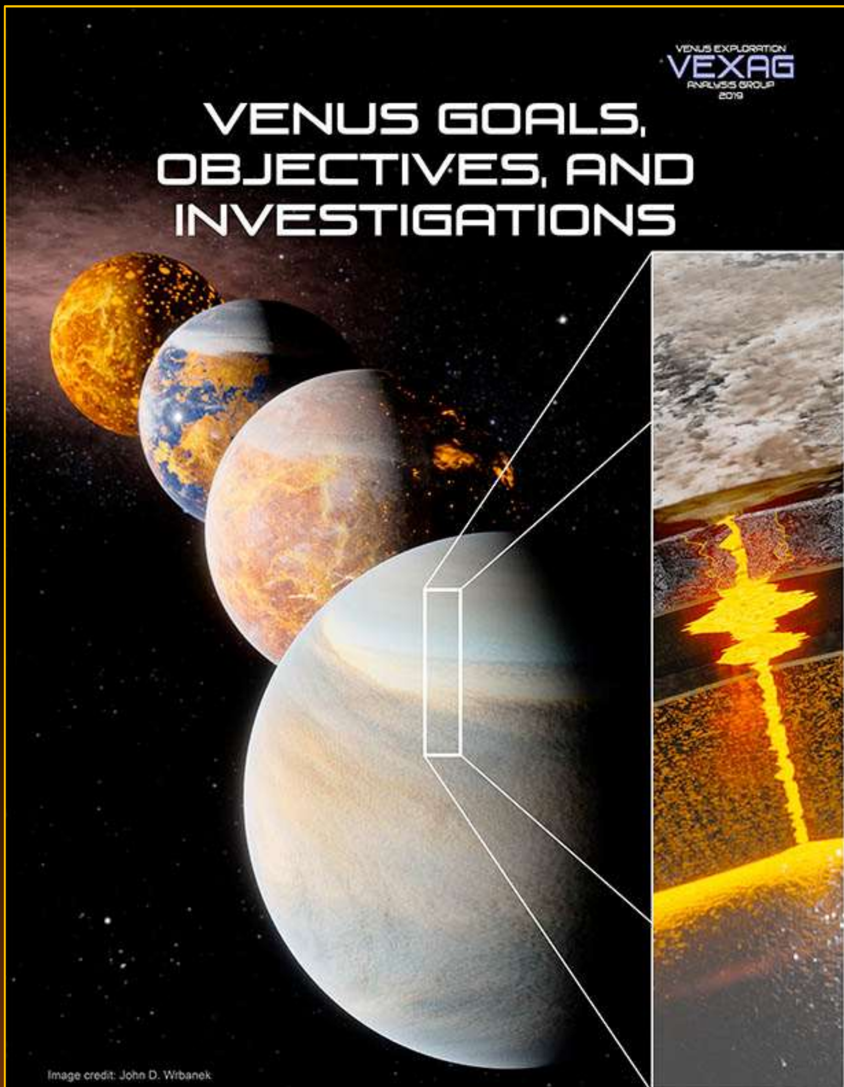
VEXAG Near-Term Goals

- 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 listserve 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

VENUS EXPLORATION
VEXAG
ANALYSIS GROUP

Preparations for Decadal Survey

- 2018 March — 3 teams formed
- April — weekly meetings, writing
- December — 1st draft versions posted
- January — Virtual Town Hall to discuss
- February — 2nd draft versions posted
- March — Pre-LPSC public meeting
- April — 3rd draft versions posted
- May — Virtual Town Hall to discuss
- June — Final drafts completed
- July — Sent out for review
- August — Formatting for consistency
- September — Revisions
- October — Final edits, proofreading
- November 2019 — DONE



Goal #1. Understand Venus' early evolution and potential habitability to constrain the evolution of Venus-sized (exo)planets

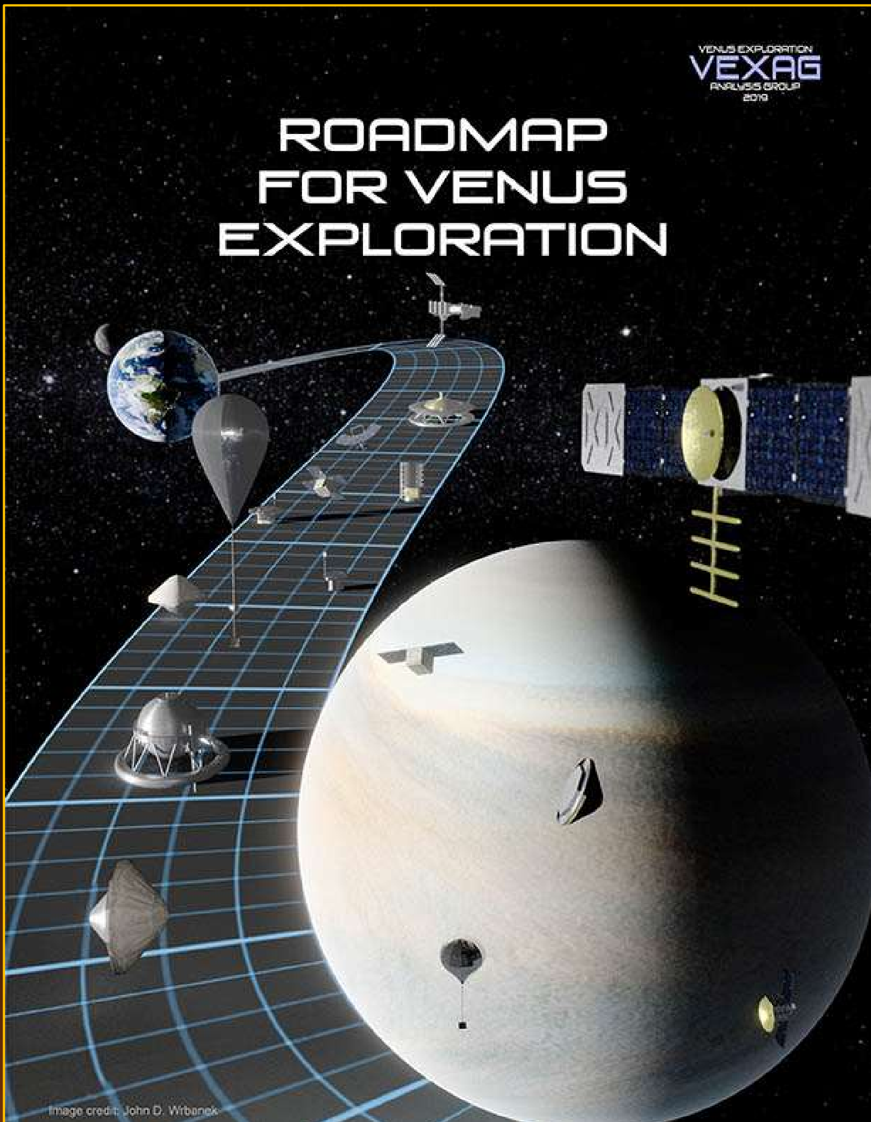
A. Did Venus have temperate surface conditions and liquid water at early times?
B. How does Venus elucidate possible pathways for planetary evolution in general?

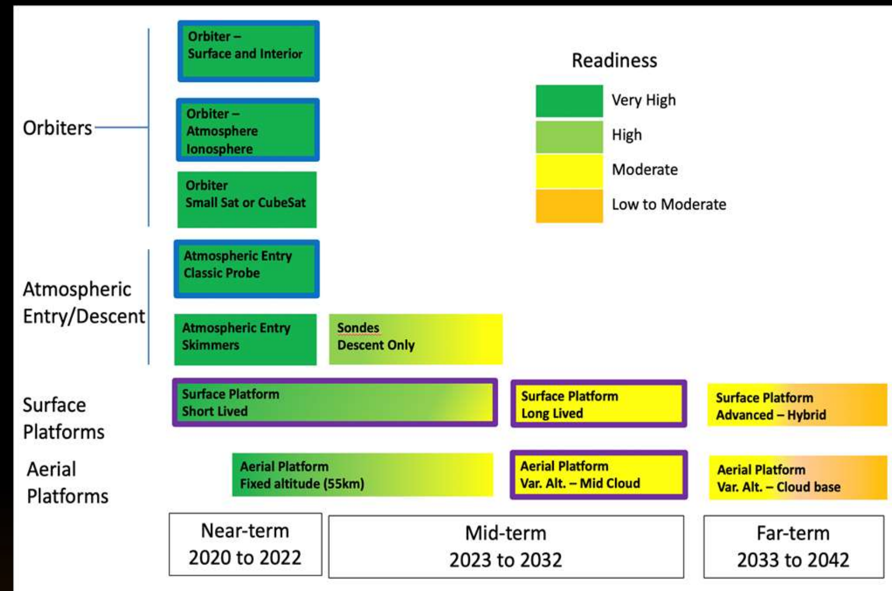
Goal #2. Understand atmospheric composition and dynamics on Venus

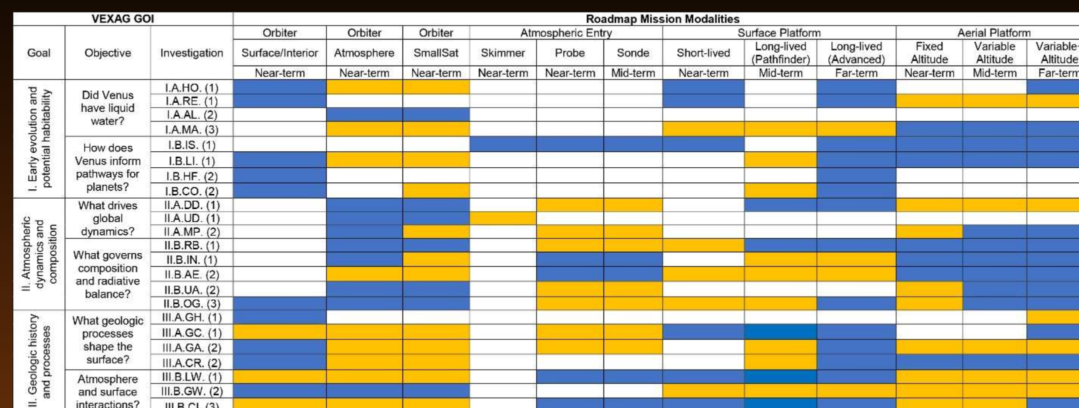
A. What processes drive the global atmospheric dynamics of Venus?
B. What processes determine the baseline and variations in Venus atmospheric composition and global and local radiative balance?

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?







Color Code	Meaning
Blue	**Vital:** Mission modality enables measurements that are vital (either alone or in combination) to completing the investigation.
Yellow	**Supporting:** Mission modality enables measurements that substantially contribute to completing the investigation.

Table 1. Major Needs Arising from This Study	
Area	**Needs**
Entry Technology	Funding to ensure the entry technology capability does not atrophy
Subsystems	Development of high temperature electronics, sensors, and high-density power sources for the Venus environment with increasing capability
Aerial Platforms	A competitive program to determine which Variable Altitude balloons approach is most viable
In situ Instruments	Adaptation of flight-demonstrated technology and development of new instrument systems uniquely designed for the Venus environment
Communications and Infrastructure	Study of the feasibility of and methods for establishing a Venus communications and navigation infrastructure
Advanced Cooling	Investments in highly efficient mechanical thermal conversion and cooling devices
Descent and Landing	New concepts for adapting precision descent and landing hazard avoidance technologies to operate in Venus' dense atmosphere
Autonomy	Transitioning of automation and autonomous technologies to Venus-specific applications
Small Platforms	Development of small platform concepts in addition to larger missions, as well as a new mission typedesigned around small platforms
Facilities and Infrastructure	Support of laboratory facilitiies and capabilities for instrument and flight systems, including critical technologies to avoid atrophy of capabilities
Modeling and Simulations	Establishment of a system science approach to Venus modeling
Unique Venus Technology	Continued and expanded support for programs such as HOTTech, and other technology development

VEXAG White Papers

Drafts due Nov. 6, 2019

Round robin discussions at VEXAG

1. 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…
9. Kevin McGouldrick: Venus atmosphere/weather
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
18. Helen Hwang: Thermal Protection System Technologies for Enabling Future Venus Exploration
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?

HOTTech Project Technology Areas from NASA Technology Office

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

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

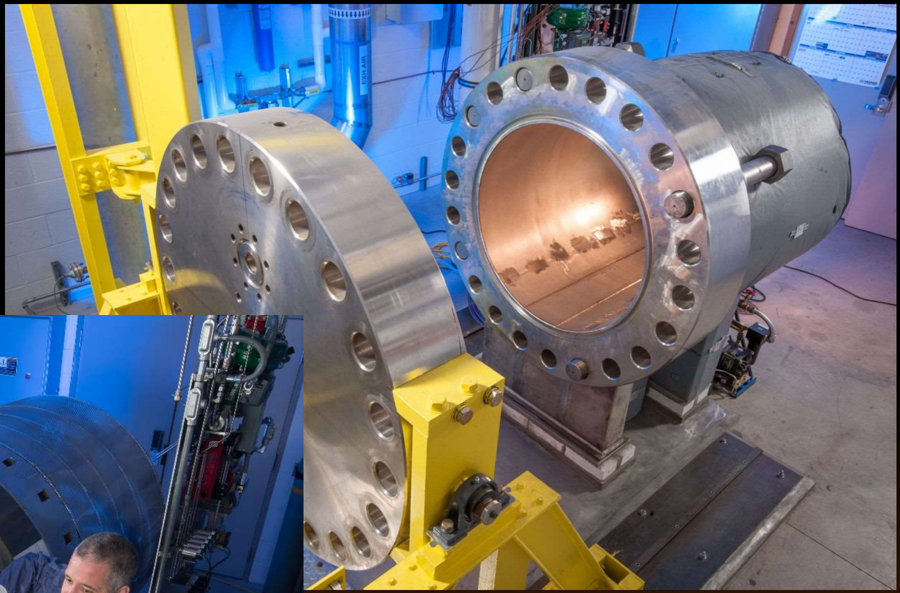
Heat Shield for Extreme Entry Environment Technology (HEEET) – NASA Ames

- 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



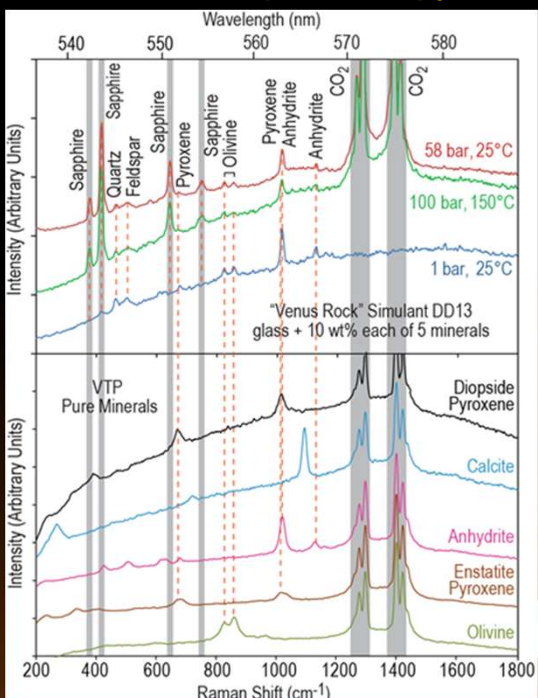
https://www.spaceflightinsider.com/wp-content/uploads/2017/02/GRC-2013-C-04417compressed.jpg

https://www.nasa.gov/sites/default/files/thumbnails/image/geer-samples.jpg

https://images-assets.nasa.gov/image/GRC-2017-C-00519/GRC-2017-C-00519~orig.jpg

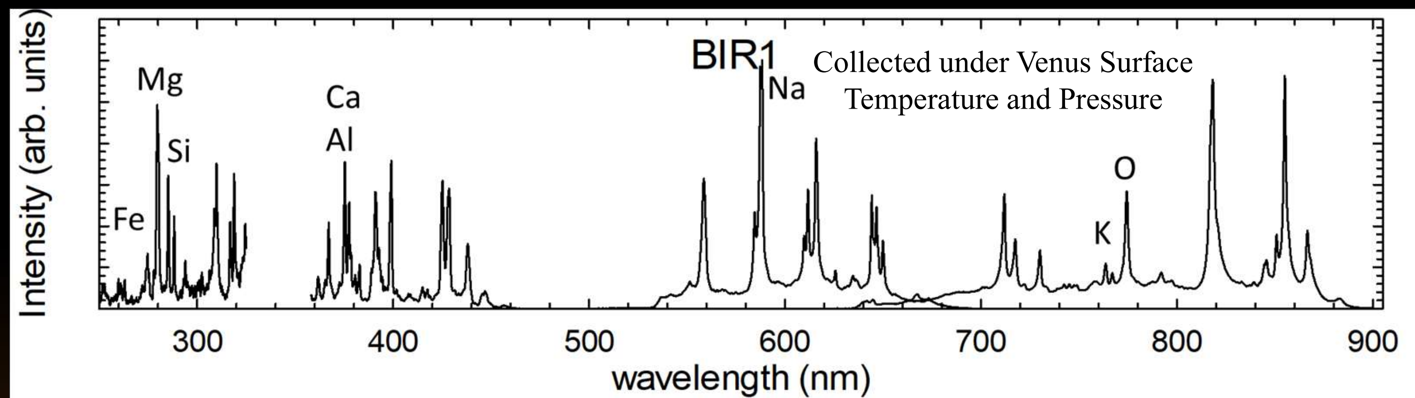
Venus Elemental and Mineralogical Camera (VEMCam)

Mineralogy/
Raman Spectroscopy



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

Chemistry
Laser-Induced Breakdown Spectroscopy



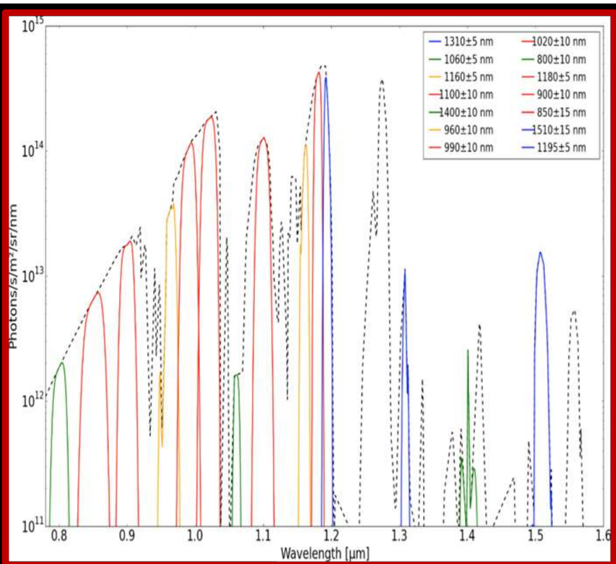
LANL Venus Chamber
Currently 2 m long,
110 mm diameter
4 m capability by February 2019

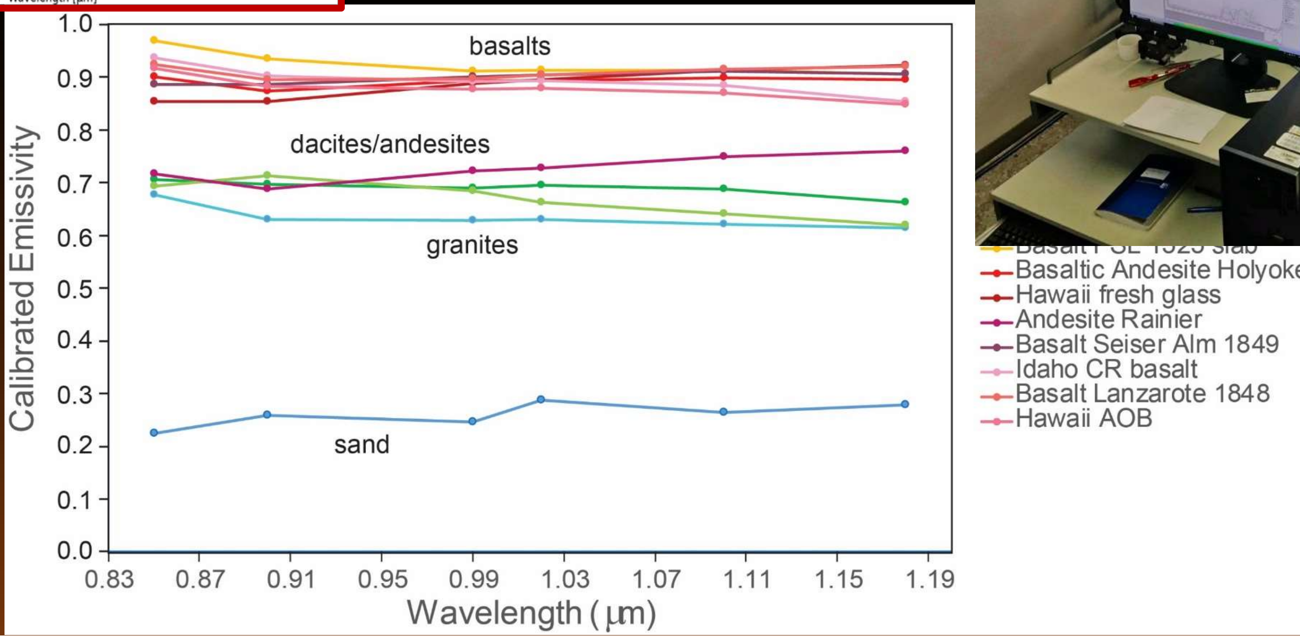
Funded by New Frontiers Program

Venus Spectroscopy

Windows in Venus' CO_2 atmosphere allow emission spectra to be acquired

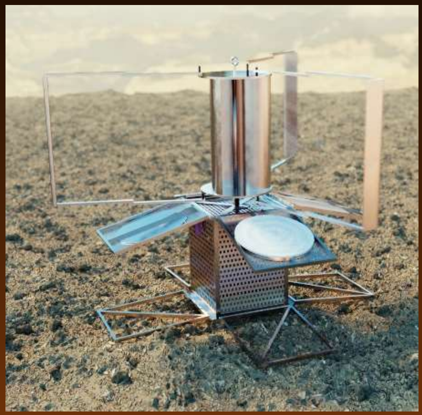
Emission 1 to 100 µm
35°-700°C
Vacuum/nitrogen/air





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

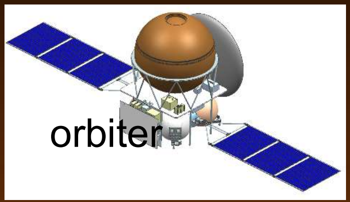


Venera-D Concept: Mission Elements

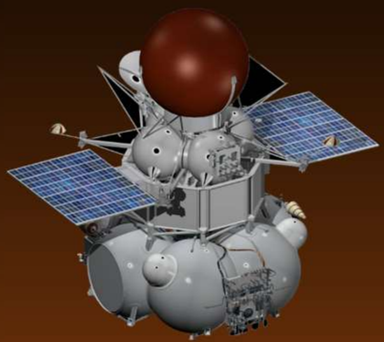
Baseline:

- 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

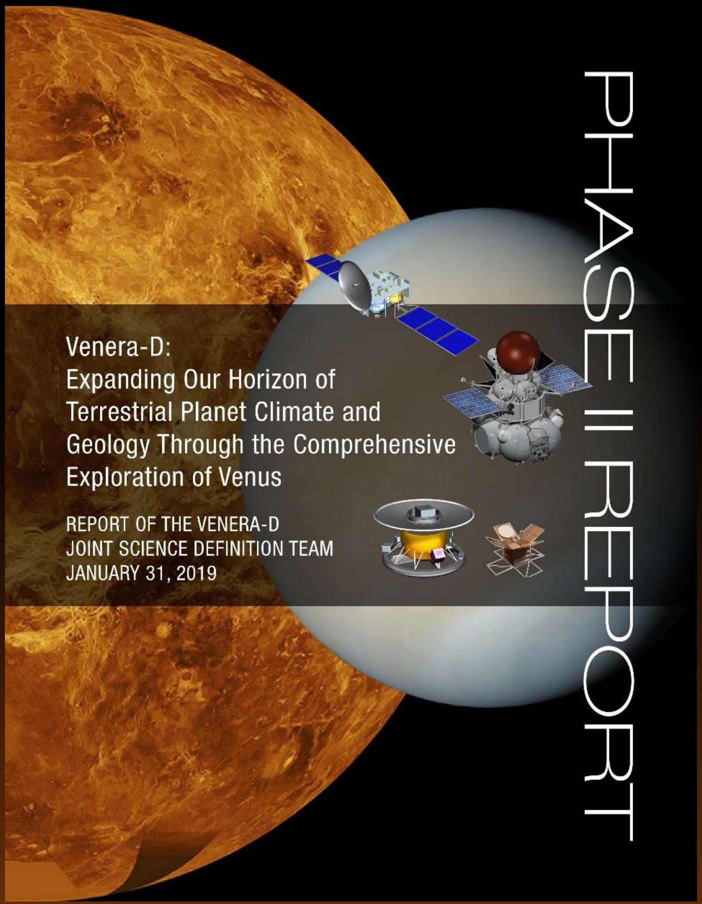
- **Potential augmentations**:
  - Small stations (2nd – 4th LLISSE, SAEVe)
  - Sub-satellite(s)
  - Aerial platform



LLISSE



lander



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.

Venus small-mission opportunities from Dragonfly and Europa Clipper

- 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.


Scientific American
February 2019
PLANETARY SCIENCE
THE EXOPLANET NEXT DOOR
What Venus can teach us about planets far beyond our own solar system
By M. Darby Dyar, Suzanne E. Smrekar and Stephen R. Kane
MENU
nature
International journal of science
NEWS FEATURE · 05 JUNE 2019
Venus is Earth's evil twin — and space agencies can no longer resist its pull
Once a water-rich Eden, the hellish planet could reveal how to find habitable worlds around distant stars.
VOL. 100 • NO. 9 • SEP 2019
EOS
Earth & Space Science News
100 YEARS
What Are the Earth Blobs?
The DDT Legacy
Forams Forever
VENUS IS ALIVE
Let's go back to this "criminally underexplored" world
AGU 100
ADVANCING EARTH AND SPACE SCIENCE
PHYSICS TODAY
DOI:10.1063/PT.6.3.20180323a
23 Mar 2018 in Commentary & Reviews
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
PREV
NEXT
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.
SPACE.com
9/23/19
News
Tech
Spaceflight
Science & Astronomy
Search For Life
Venus May Have Supported Life Billions of Years Ago
By Samantha Mathewson 2 hours ago Science & Astronomy
Drastic climate shifts 700 million years ago made the planet's atmosphere incredibly dense and hot.
VENUS EXPLORATION
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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

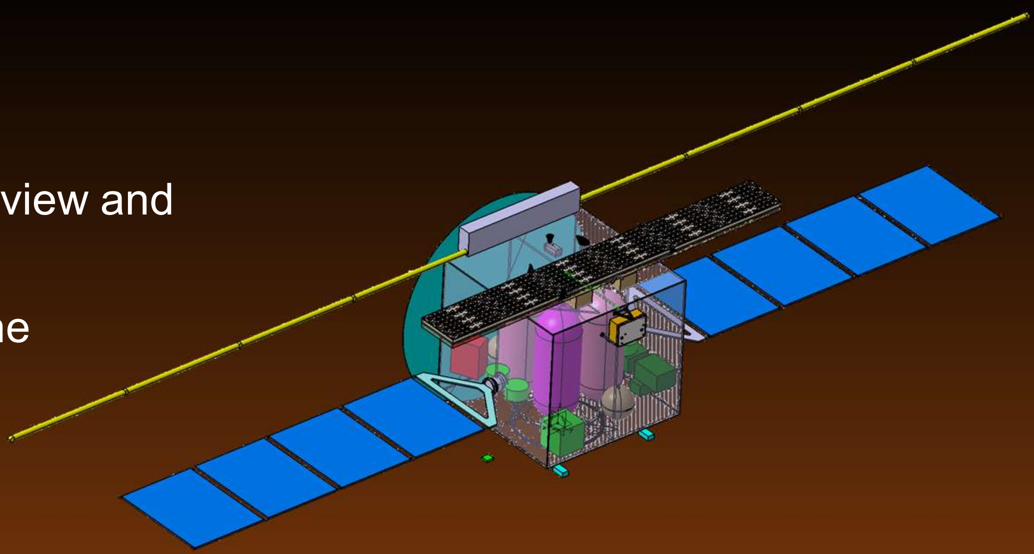
- Clarity in ride-along mission decision process, advocacy for Venus.
- Support programmatic balance among bodies, areas of science. Better define a "program"? Does a program have a start and end date? Exactly how are programs initiated? How do they end?
- Underscore importance of U.S. leadership on 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

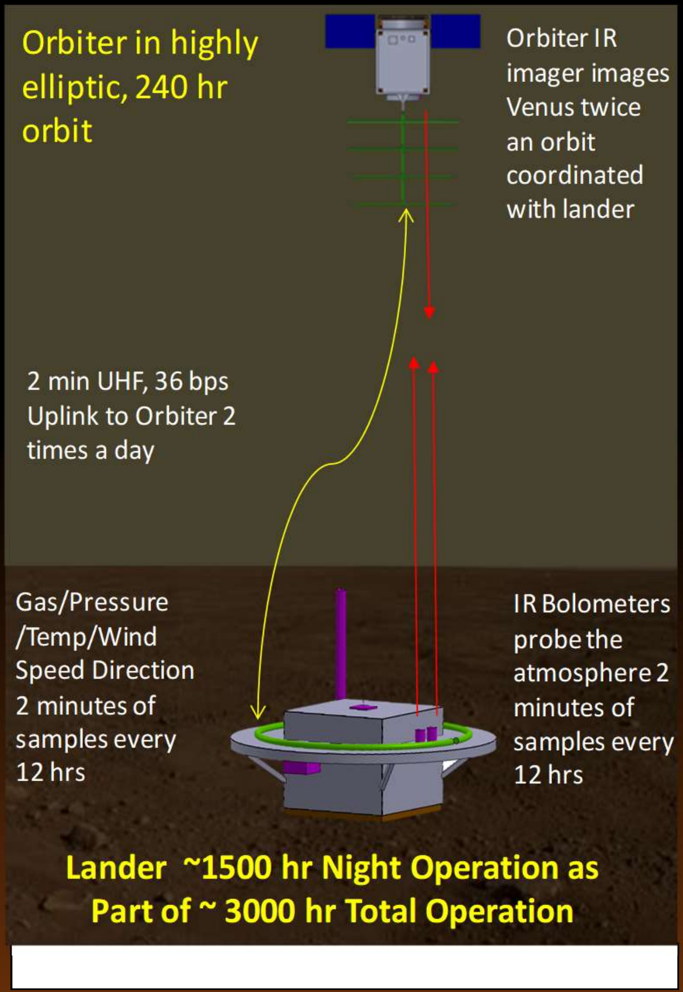
PRE-SELECTED PROPOSALS FROM INDIA:

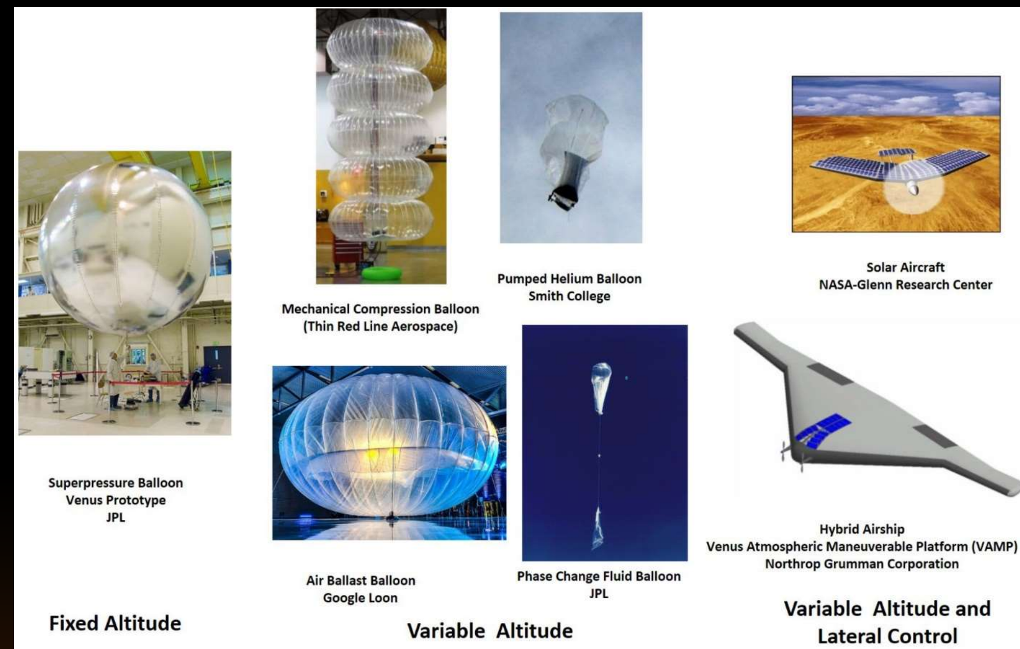
1. S-Band Synthetic Aperture Radar (SAR)
2. Advanced Radar for Topside Ionosphere and subsurface sounding
3. Ultraviolet (UV) imaging spectroscopy telescope
4. Thermal camera
5. Cloud monitoring camera
6. Atmospheric spectropolarimeter
7. Airglow photometer
8. Radio occultation experiment
9. Ionospheric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

https://www.dos.gov.in/update/06-nov-2018/announcement-of-opportunity-ao-to-international-science-community-space-based

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 <u>*some*</u> 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/