The State of Venus Exploration: the View from VEXAG

M. Darby Dyar, Chair
Noam Izenberg, Deputy Chair

March 20, 2019

Thank You, Bob and Marty!

VEXAG Steering Committee

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Noam Izenberg (Applied Physics Laboratory), Deputy
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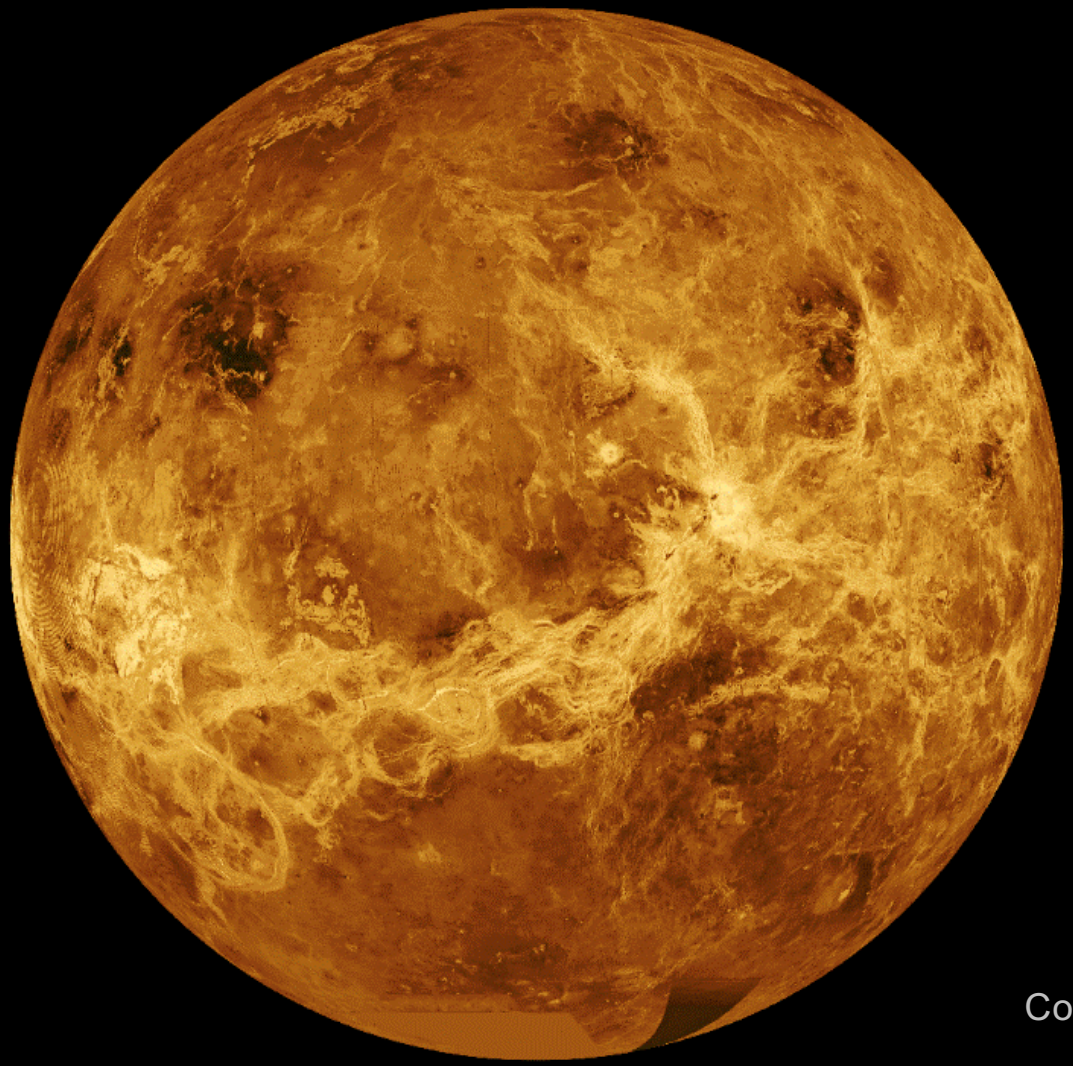


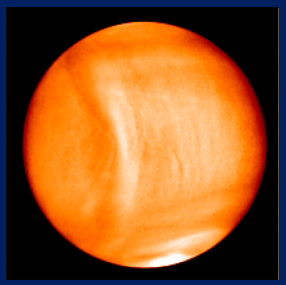
Welcome to the Decade of Venus

~500 people on Venus listserve:
Contact Darby if you want to be added!

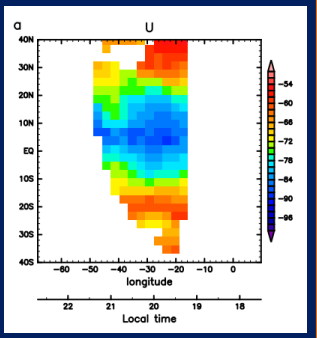
Status & Findings of Akatsuki (December 2018)

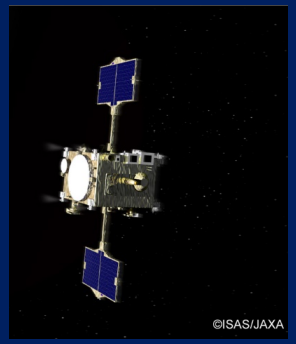
- Akatsuki celebrated "3 years in Venus orbit" on 7 December 2018. Mission extension has been approved by JAXA HQ.
- The spacecraft maintains good health with remaining fuel enough to continue mission more than 4 years (or longer).
- UVI, LIR, LAC, & RS continue scientific observations, while IR1 & IR2 are unable to operate (since December 2016).
- In 2018, two long umbra passages (150 min in July & 120 min in August) were experienced w/o problems.
- Delta-V operation of 18 December 2018 was cancelled (not necessary as Akatsuki will be able to survive long umbras).
- In 2019, longer umbra passages (up to ~5 hours including pen-umbra) are coming and preparation in progress.
- NASA DSN supports telemetry monitoring for these critical events. ISRO antenna co-operates RS observations. DLR antenna will join (tests were performed).

Discovery of topography-induced gravity wave features (LIR) changed our view about the surface-atmosphere coupling (Fukuhara et al. 2017).

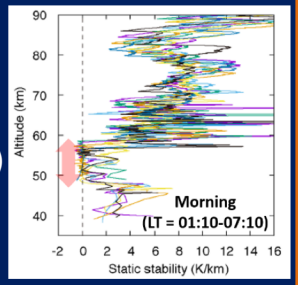


Discovery of equatorial jets in lower cloud (IR2) helps improving models to better reproducing the super-rotation (Horinouchi et al. 2017).

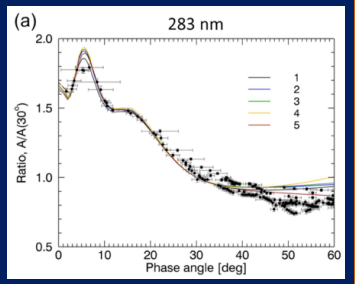




Radio occultation measurements (RS) reveal local-time dependence of unstable (convective) layer in low latitude regions (Imamura et al. 2017).



Glory features are observed with UVI and helps characterizing aerosol properties in the upper atmosphere (Lee et al. 2017).



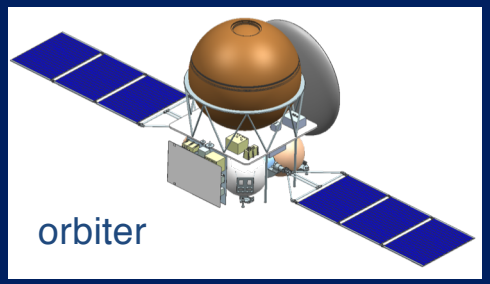
Venera-D Concept: Mission Elements

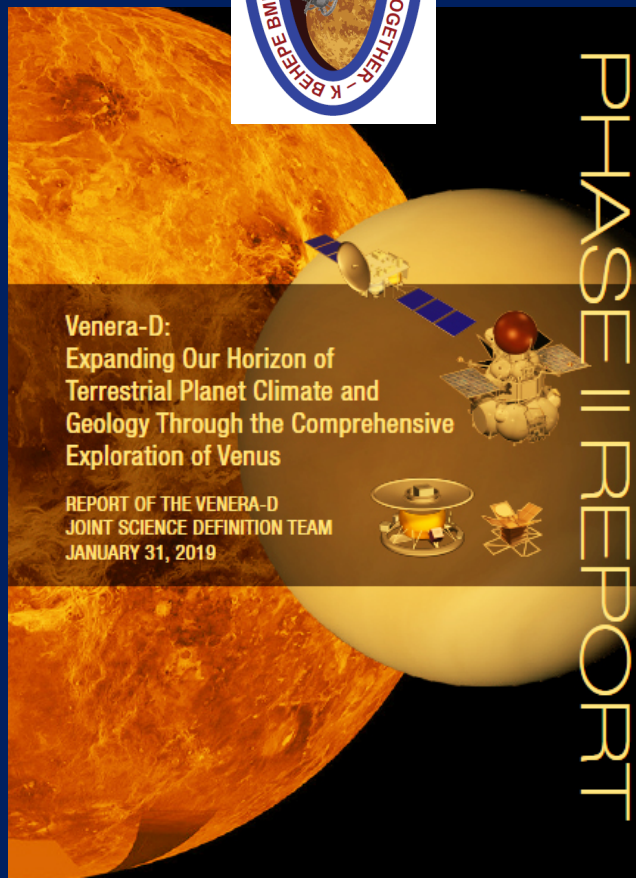
Baseline

- Orbiter: Polar (90°± 5°) 24-hr orbit with lifetime ≥ 3 yr
- Lander (VEGA-type, updated) ≥ 2 hr on surface; high-latitude
  - Sample atmosphere during descent
  - Descent imager
  - Mineral and elemental composition of surface
- Long-Lived In-Situ Solar System Explorer (LLISSE) on Lander (>2 months on surface)
  - Wind speed & direction
  - Atmosphere composition
- Flexibility to select precise landing site ~3 days before VOI

Potential augmentations:

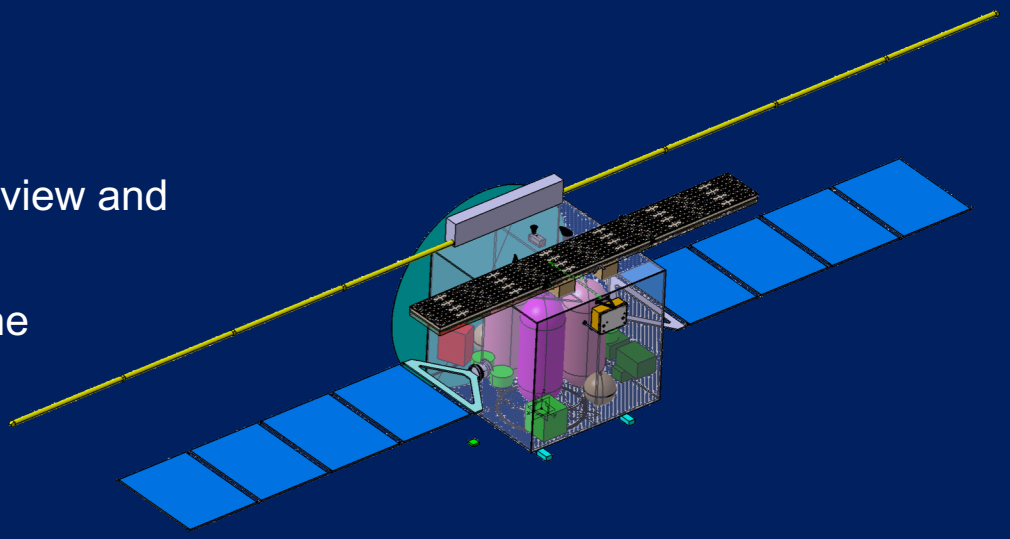
- Small stations
  - More LLISSEs
  - ≥ 2 Seismic and Atmospheric Exploration of Venus (SAEVe) stations
- Sub-satellite(s)
  - Lagrange points 1 and 2?
  - Same orbit as Orbiter?
- Aerial platform





EnVision Status

- Concurrent Design Facility baseline study successfully achieved the mission targets within the design to cost envelope
- Baseline mission is 2032 launch, chemical propulsion with aerobraking (12 to 24 months)
- Mission start in June 2035, with a 4+2 cycle science duration
- 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
- No guarantees of NASA support for US team(s)

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

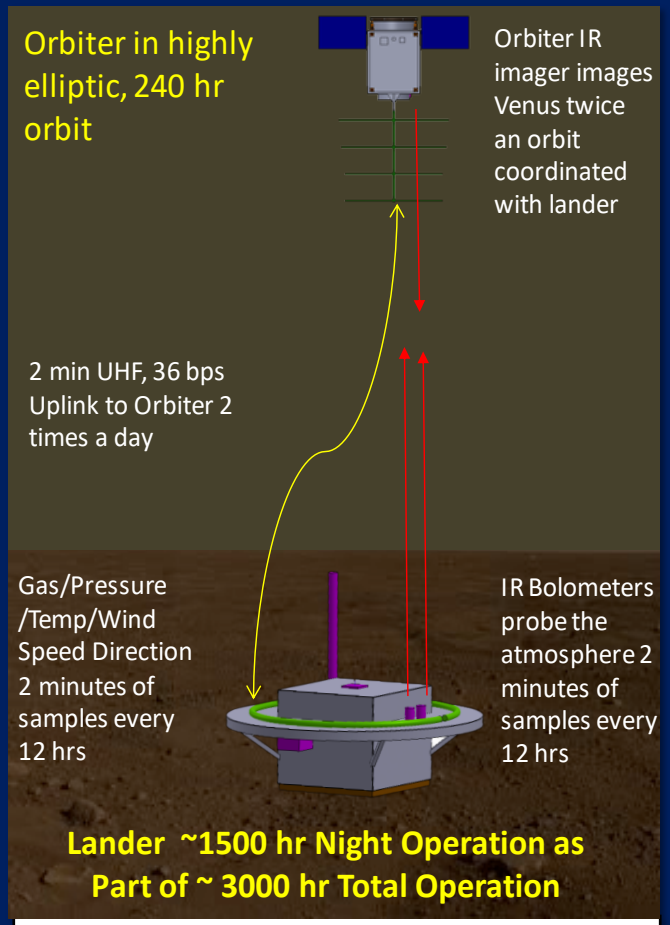
https://www.dos.gov.in/update/06-nov-2018/announcement-of-opportunity-ao-to-international-science-community-space-based

Venus Technology Development

1. Venus Bridge
2. HOTTech
3. LLISSE
4. HEEET
5. PICASSO
6. MATISSE
7. EPSCoR
8. Laboratory Facilities: GEER, LANL
9. Venus Aerial Platforms
10. Venus Surface Platforms
11. Venus Autonomy

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.



GRC Venus Bridge Orbiter and Surface Study (V-BOSS) Concept

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

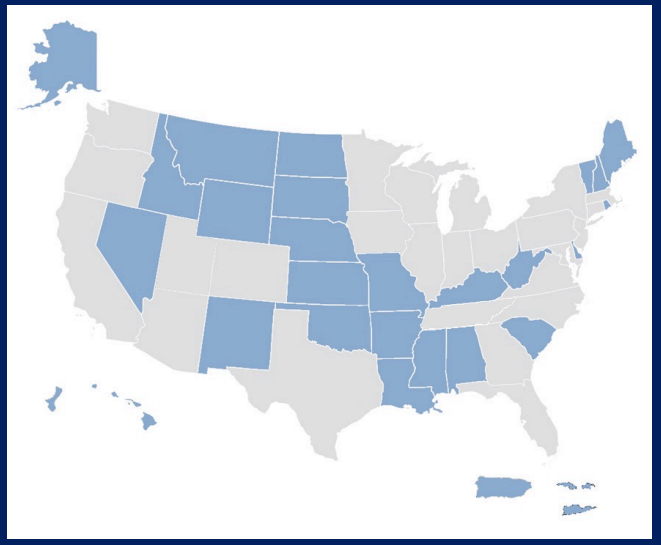
Heat Shield for Extreme Entry Environment Technology (HEEET) – NASA Ames

- 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

Established Program to Stimulate Competitive Research (EPSCoR)

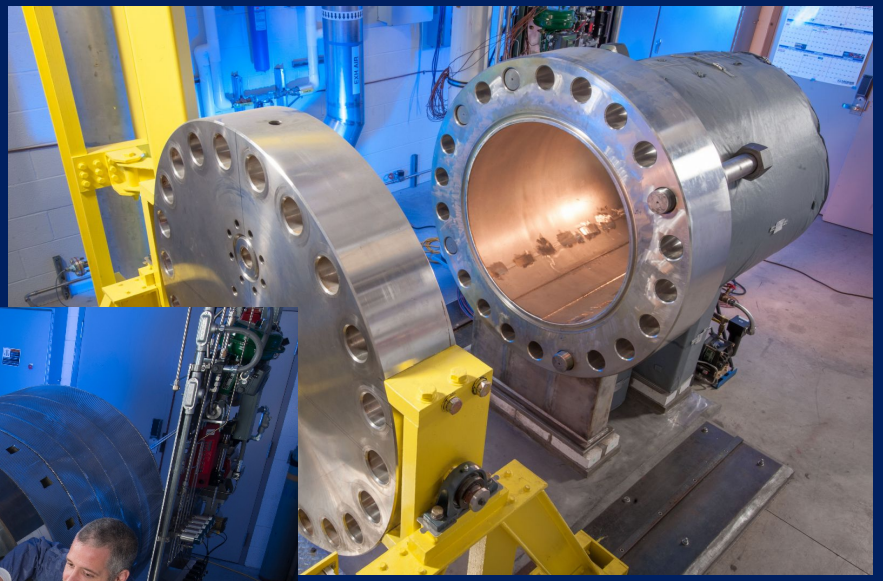
- Rapid response opportunities: 1 year, $100K
- Planetary exploration topics include:
  - High-Temperature Subsystems and Components for Long-Duration (months) Surface Operations
  - Aerial Platforms for Missions to Measure Atmospheric Chemical and Physical Properties
- EPSCoR selected 5 previous Extreme Environment (EE) proposals that complement the HOTTech current awards.
- A 2019 workshop is being planned for HOTTech and EE EPSCoR awardees to share findings.



EPSCoR seeks to avoid undue concentration of research and education at all levels throughout the US

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



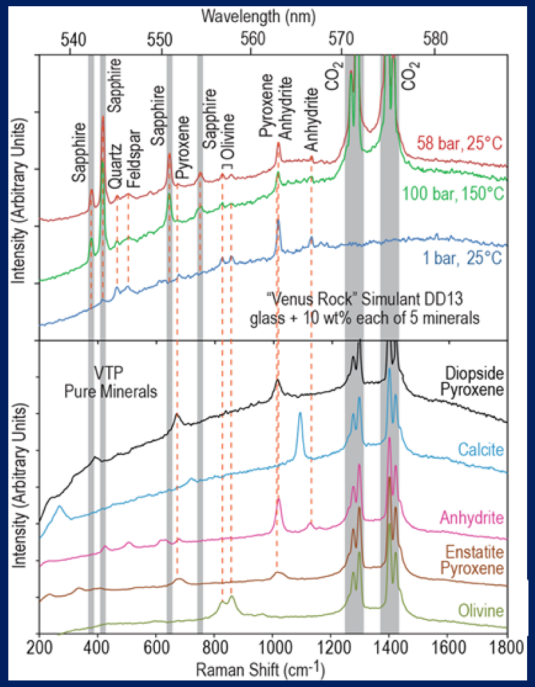
https://www.spaceflightinsider.com/wp-content/uploads/2017/02/GRC-2013-C-04417compressed.jpg

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

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

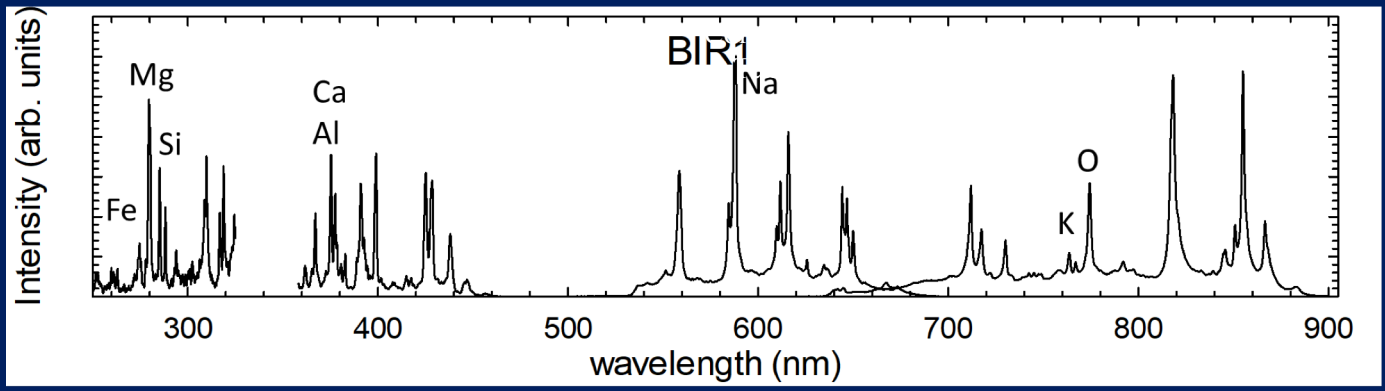
Venus Elemental and Mineralogical Camera (VEMCam)

Mineralogy/
Raman Spectroscopy



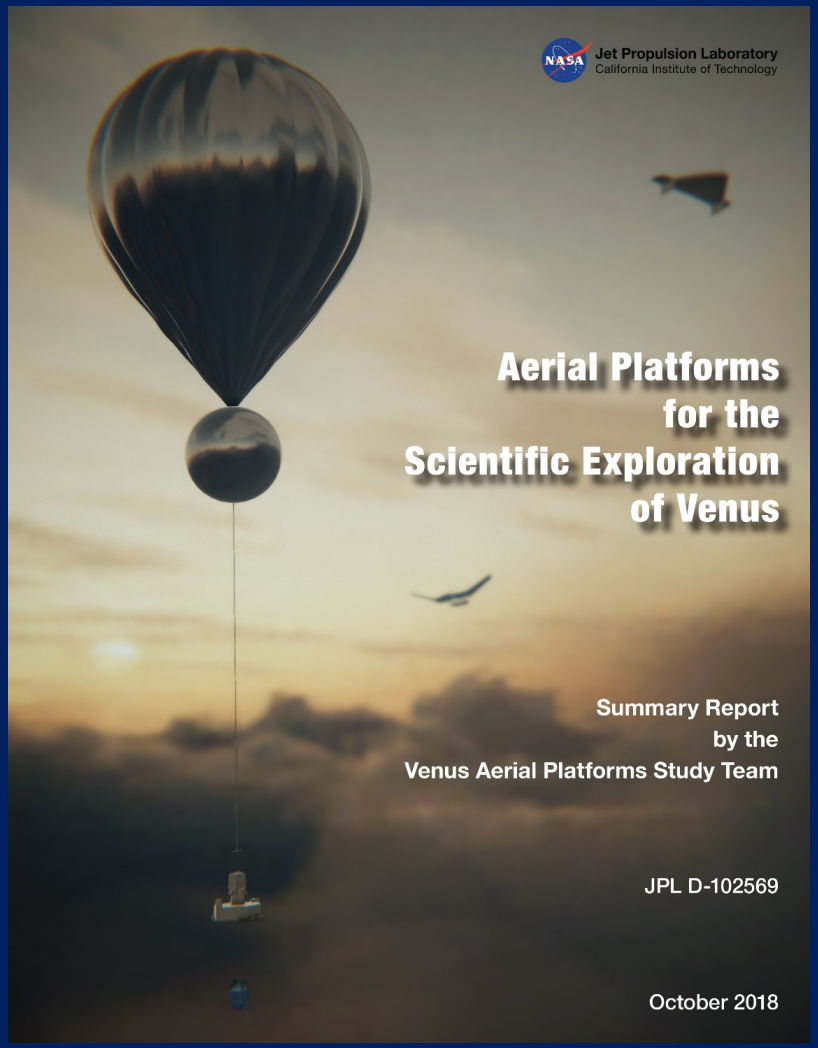
Clegg et al. (2014) Applied Spectroscopy, 68, 925

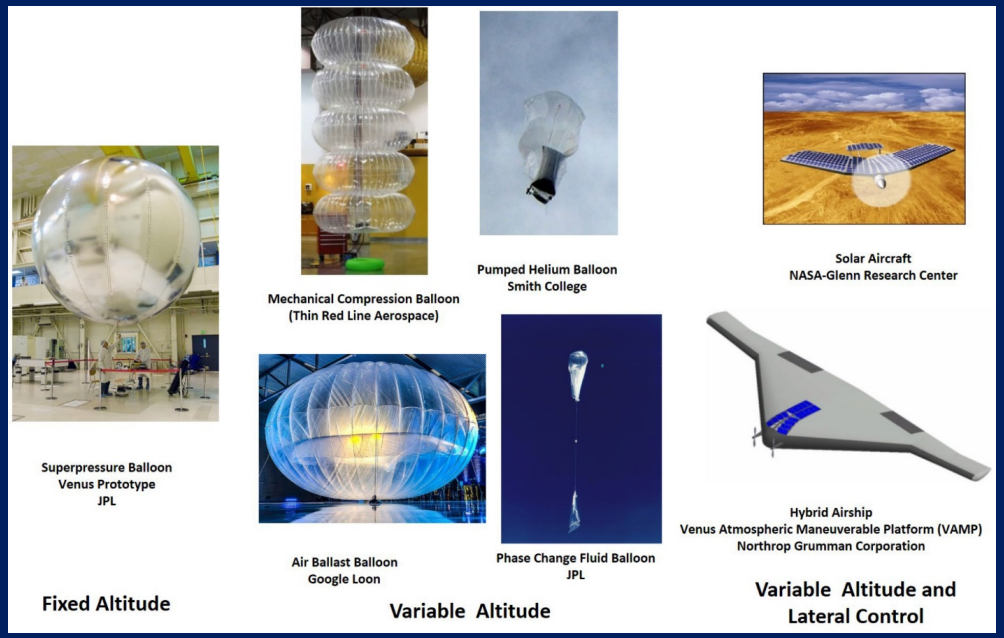
Chemistry
Laser-Induced Breakdown Spectroscopy



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

POC: Sam Clegg, Los Alamos National Laboratory





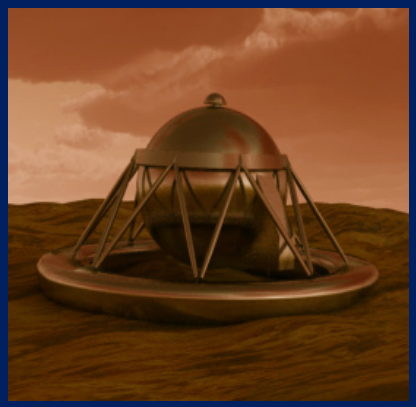
Venus Aerial Platform Concepts considered in this study are subdivided into three categories:

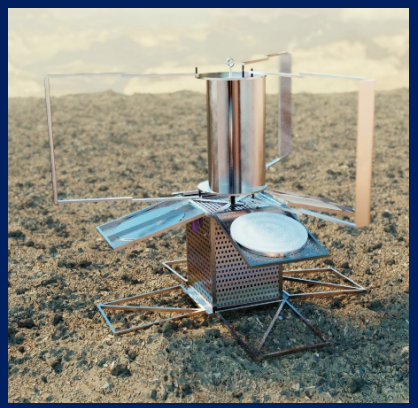
1. Fixed Altitude platforms
2. Variable Altitude platforms
3. Platforms with both Variable Altitude and Lateral Control

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

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





VENUS Team

Pat Beauchamp
JPL/ Team Lead

Darby Dyar
PSI/Mt Holyoke/Science

Gary Hunter
GRC/VEXAG Tech Plan lead

Jim Cutts
JPL/VEXAG Roadmap Lead

Ian Gravseth
Ball Aerospace

Lorraine Fesq
JPL/System Eng

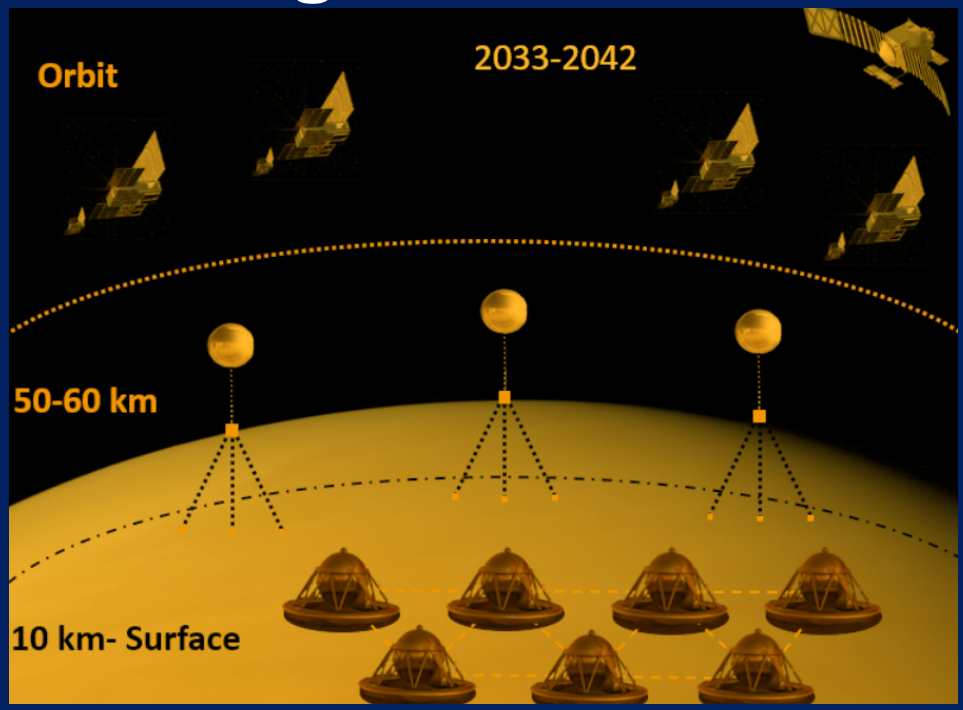
Rebecca Foust
UIUC and Caltech

Michelle Chen
Applied Physics Lab - JHU

2018 Workshop on Autonomy for Future NASA Science Missions

October 10-11, 2018

Venus Design Reference Mission



Findings, 2018: VEXAG requests that:

1. NASA clarify its position on and timeline for a directed program for Venus.
2. NASA take steps to ensure that the mission balance, cadence and schedule as proposed in the original Decadal report are maintained.
3. NASA conduct a pre-decadal study of a Venus Flagship mission
4. NASA support for a workshop on astrobiology and habitability at Venus.
5. NASA provide funding for relevant Venus and comparative planetology studies as part of exoplanet programs.
6. NASA renew HOTTech and provide additional funding to increase the selection rates for MATISSE and PICASSO
7. NASA take steps to ensure that high-energy entry capabilities be fostered and maintained over time
8. NASA initiate a technology program that is accessible to researchers in non-EBSCOR states.
9. NASA continue to engage in international missions as part of an integrated Venus exploration program, maintaining complementarity with US efforts.
10. NASA form a cross-divisional research program for Comparative Climatology of Terrestrial Planets.

Pre-Decadal Documents in Preparation

- Goals, Objectives, and Investigations
- Technology and Laboratory Instrumentation
- Venus Exploration Roadmap
- Revised New Frontiers Goals
- ROSES-18 Amendment 64: New Opportunity in C.30 Planetary Mission Concept Studies

Watch the VEXAG website for further developments, updated versions!

VEXAG Goals, Objectives & Investigations

Rework 2016 GOI, harmonize with Roadmap and Technology Plans

Goal I: Understand Venus' early evolution and potential habitability to constrain the evolution of Venus-sized (exo)planets

Goal II: Understand atmospheric dynamics and composition on Venus

Goal III: Understand the geologic history preserved on the surface of Venus

Draft document on VEXAG website

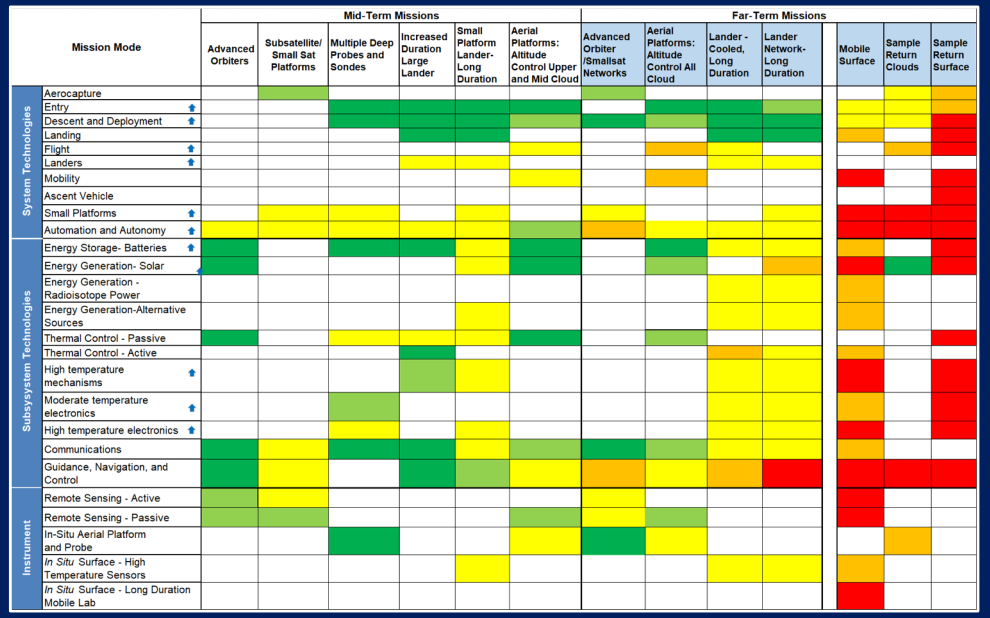
Feedback to Joe O'Rourke (jgorourk@asu.edu)

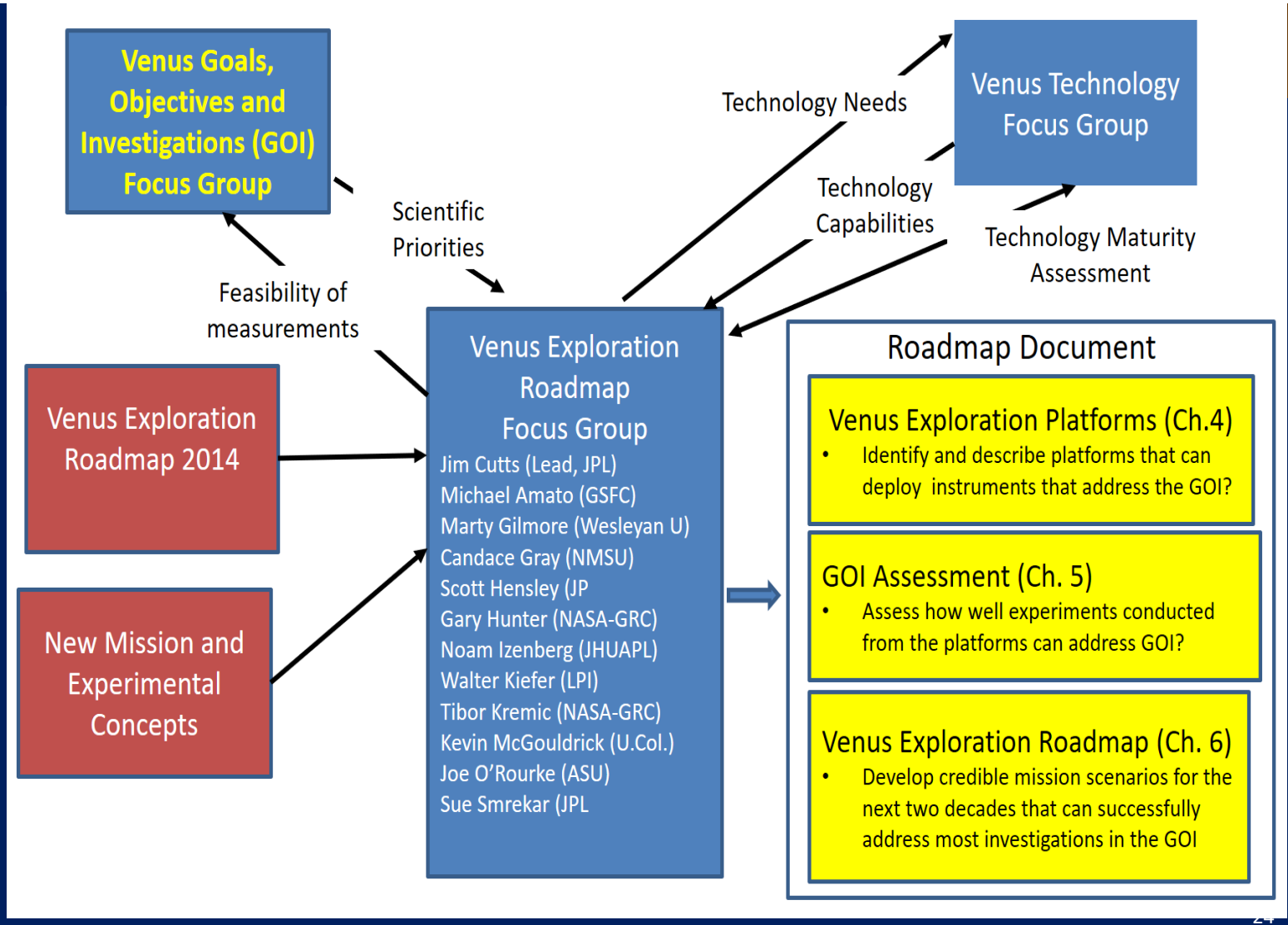
VEXAG GOI Focus Group: Joseph O'Rourke and Allan Treiman (Co-Chairs), Giada N. Arney, Paul Byrne, Lynn Carter, Darby Dyar, James Head III, Candace Gray, Stephen Kane, Walter Kiefer, Kevin McGouldrick, Laurent Montesi, Chris Russell, and Suzanne Smrekar

Venus Focus Group on Technology and Laboratory Instrumentation

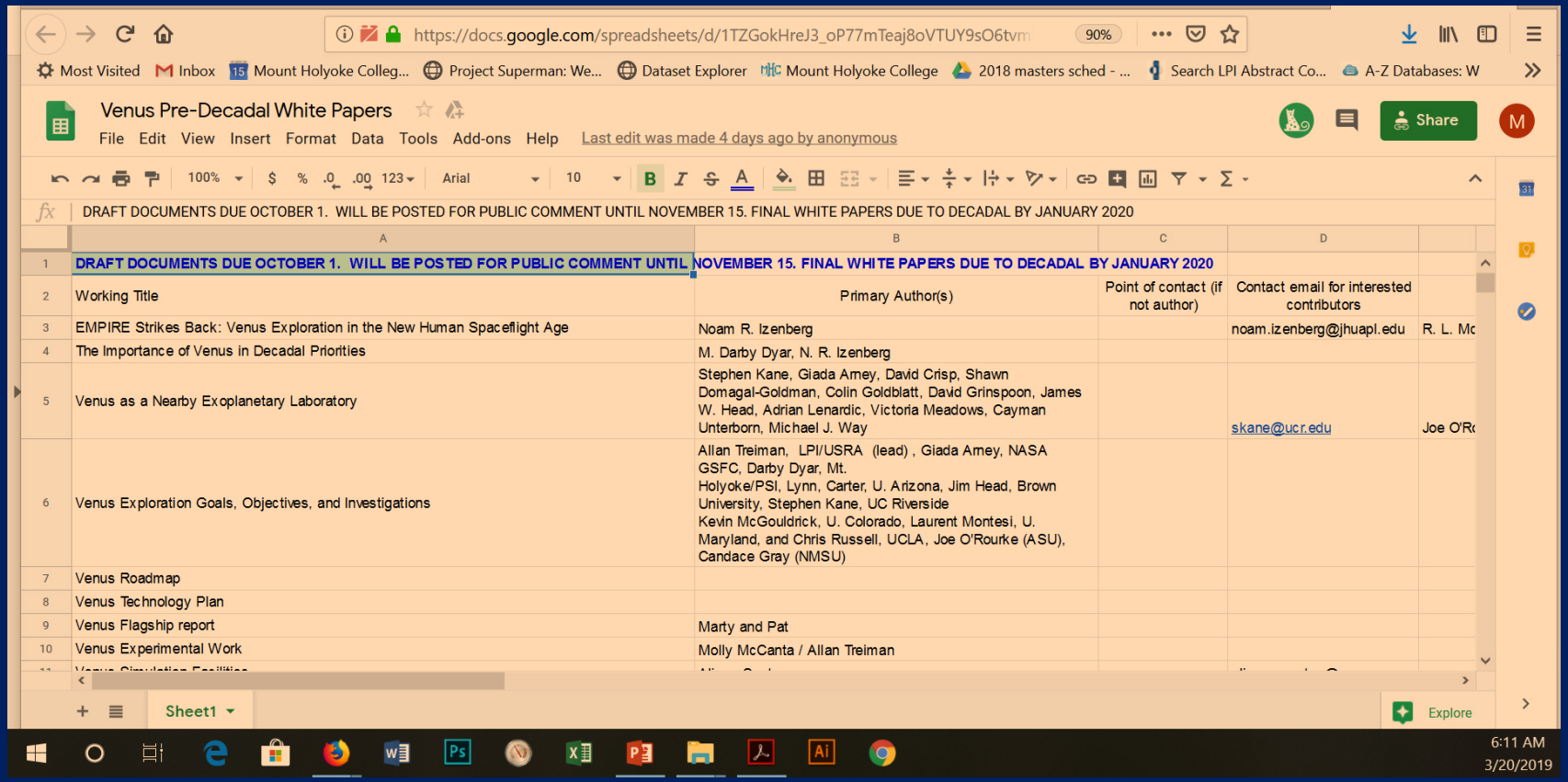
- The approach was to use the 2014 Venus Technology Plan as a baseline and modify as appropriate, but keep the basic structure of the report
  - Update the core technology sections
  - Add new sections as appropriate
  - Update Findings and Mission Modes/Technology Maps
- Notable Changes in Multiple Sections of the Document Based on Technology Advances since 2014
  - New Capabilities and Notable Advancements Highlighted in a Number of Areas
    - New Mission Modes, Platforms, and Capabilities
    - Technology Advances in e.g., Entry Technology, Aerial Platforms, Long- Lived Landers, Communications, Instruments
- Three Timeframes Examined
  - Near-Term, 2018 to 2022: We Can Do A Lot Now
  - Mid-Term, 2023 to 2032: New Missions and Science in Next Decadal
  - Far-Term, 2033 to 2042: Venus Exploration More Like Other Planets, but Major Technical Challenges
- Progress Made in Enabling Venus Exploration, But Need To Keep Up What We Have and There Much More to Do

Gary Hunter (Chair)
Samuel Clegg
Candace Gray
Natasha Johnson
Lawrence Matthies
Ethiraj Venkatapathy
Jeffery Balcerski
James Cutts
Noam Izenberg
Tibor Kremic
Joseph O'Rourke





White papers: *in work* starting July 1, finish by January 1



Venus Pre-Decadal White Papers

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DRAFT DOCUMENTS DUE OCTOBER 1. WILL BE POSTED FOR PUBLIC COMMENT UNTIL NOVEMBER 15. FINAL WHITE PAPERS DUE TO DECADAL BY JANUARY 2020

	A	B	C	D	
1	DRAFT DOCUMENTS DUE OCTOBER 1. WILL BE POSTED FOR PUBLIC COMMENT UNTIL	NOVEMBER 15. FINAL WHITE PAPERS DUE TO DECADAL BY JANUARY 2020			
2	Working Title	Primary Author(s)	Point of contact (if not author)	Contact email for interested contributors	
3	EMPIRE Strikes Back: Venus Exploration in the New Human Spaceflight Age	Noam R. Izenberg		noam.izenberg@jhuapl.edu	R. L. Mc
4	The Importance of Venus in Decadal Priorities	M. Darby Dyar, N. R. Izenberg			
5	Venus as a Nearby Exoplanetary Laboratory	Stephen Kane, Giada Arney, David Crisp, Shawn Domagal-Goldman, Colin Goldblatt, David Grinspoon, James W. Head, Adrian Lenardic, Victoria Meadows, Cayman Unterborn, Michael J. Way		skane@ucr.edu	Joe O'R
6	Venus Exploration Goals, Objectives, and Investigations	Allan Treiman, LPI/USRA (lead) , Giada Arney, NASA GSFC, Darby Dyar, Mt. Holyoke/PSI, Lynn, Carter, U. Arizona, Jim Head, Brown University, Stephen Kane, UC Riverside Kevin McGouldrick, U. Colorado, Laurent Montesi, U. Maryland, and Chris Russell, UCLA, Joe O'Rourke (ASU), Candace Gray (NMSU)			
7	Venus Roadmap				
8	Venus Technology Plan				
9	Venus Flagship report	Marty and Pat			
10	Venus Experimental Work	Molly McCanta / Allan Treiman			

Sheet1

Explore

6:11 AM 3/20/2019

https://docs.google.com/spreadsheets/d/1TZGokHreJ3_oP77mTeaj8oVTUY9sO6tvmKqCc537nEc/edit?u#gid=0

Upcoming Venus Events

International Planetary Probe Workshop 2019
8-12 July 2019, Oxford University, Oxford, Oxford, UK

Joint DPS-ESPC Conference: special Venus session
Week of September 15-20, 2019, Centre International de Conferences de Geneve (CICG), Geneva, Switzerland, Abstract deadline: May 8, 2019, 13:00 CEST.

Fall AGU Special Session and Possible Venus Town Hall Meeting
Special Session: What's New at Venus. This will encourage technology talks in addition to the traditional science presentations. / Venus Town Hall Meeting is tentative.

VENERA D Landing Site, Cloud Habitability and Astrobiology Workshop
October 3-5, right before the 10th Solar System Symposium, which is https://ms2019.cosmos.ru.
Space Research Institute of the Russian Academy (IKI) Moscow, Russia
NASA will fund ~6-8 early- and mid-career people from US. Announcement is under review now, released by May or earlier. Abstracts due summer 2019.

VEXAG 2019

Boulder, Colorado

November 6-8, 2019

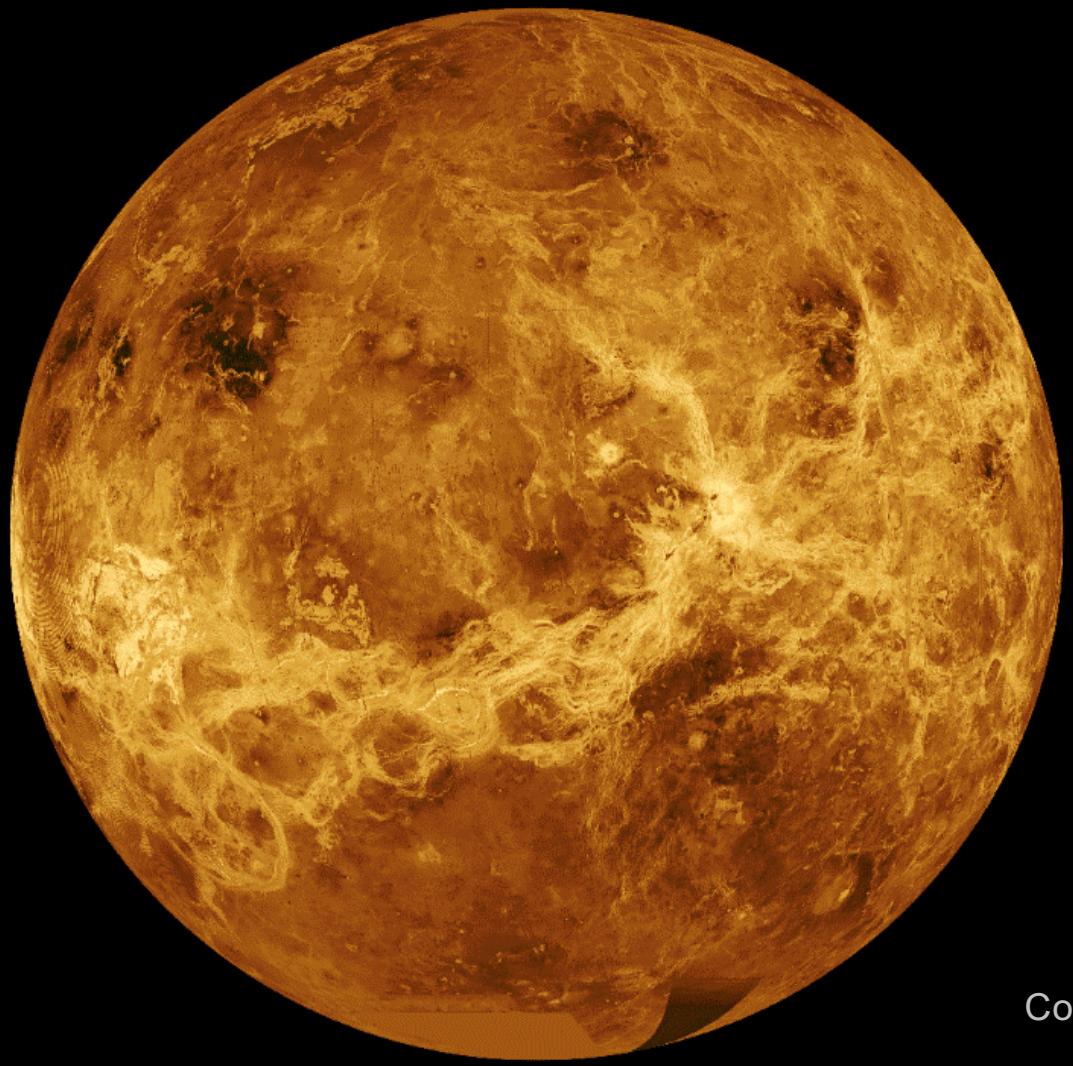
Questions or comments? Contact Darby Dyar (mdyar@mtholyoke.edu) or Noam Izenberg (noam.izenberg@jhuapl.edu)

Coming in February 2020:

Exoplanets in our Backyard: Solar System and Exoplanet Synergies on Planetary Formation, Evolution, and Habitability

Joint VEXAG, OPAG, and ExoPAG Conference

Organizing Committee: Stephen Kane, Giada Arney, Noam Izenberg, Lynnae Quick, Kathy Mandt, Abby Rymer, Darby Dyar, Vikki Meadows



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