

**VEXAG#14 Meeting Summary**  
**Tuesday-Thursday, November 29 – December 1, 2016**  
**James Webb Auditorium, NASA Headquarters**

Eighty members of the Venus community participated in VEXAG Meeting #14, held at NASA Headquarters, Washington, DC on November 29 – December 1, 2016. Bob Grimm, VEXAG Chair, welcomed the attendees and noted that he was enthusiastic about the opportunities for Venus exploration via the two Venus Discovery Phase-A studies, the upcoming New Frontiers Announcement, the opportunities provided by SmallSats and CubeSats, our international collaborations with Akatsuki, Europe's M5 Mission call, and the Russian Venera-D missions as well as the upcoming focus on high-temperature electronics via the HOTTech call. Bob also noted that VEXAG's new slogan "Unveil Venus: Why is Earth's sister planet so different?" is now out there on social media.

At this point in the proceeding, NASA distributed Certificates of Appreciation to:

- Ellen Stofan in recognition of her extraordinary support to the VEXAG Science Community and VEXAG,
- Lori Glaze for her steadfast dedication to the exploration of Venus via her outstanding leadership as VEXAG Chair – 2011 – 2015, and
- Tommy Thompson for his steadfast support of Venus science and exploration as VEXAG Executive Secretary.

VEXAG distributed Certificates of Appreciation to:

- Robert Herrick for his outstanding leadership of the VEXAG Goals and Exploration Sites Focus Group, 2013–2016,
- Sanjay Limaye for his outstanding leadership of the VEXAG International Venus Exploration Working Group, 2012–2016, and
- Lynnae Quick for her outstanding leadership of the VEXAG's Early Career Scholars Outreach Focus Group.



Group Photo VEXAG Meeting #14 – Thursday, December 1, 2016

Ellen Stofan, who is completing her three-year term as SMD Chief Scientist, provided a report on her perspectives on Venus Exploration. She noted that NASA's Planetary Science is very strong. The new Associate Administrator for SMD is Thomas Zurbuchen, whom Ellen characterized as one of the few people at NASA Headquarters, who like herself has to write competitive proposals. Ellen noted that Venusian tectonics, volcanology, and volatiles are key to Competitive Planetology and that the fundamental questions are:

- Did Venus have a climate favorable for habitability ?,
- Did Venus have an ocean?, and
- What are the surface rocks on Venus ?,

and that there is a need to acquire new data to answer these questions.

In the Question and Answer session it was noted that:

- We need to keep in mind that Venus can be thought of as an ocean world as well as an Exoplanet, and
- Venus might harbor a habitable world in its atmosphere.

### NASA Reports

**Jim Green (NASA Headquarters)** noted that as usual, it's a pleasure to be at our VEXAG Meeting. He provided a well-received status report on activities associated with **NASA's Planetary Science Division (PSD)**, by discussing recent and near-term NASA missions, the Discovery Program, the recently completed 2016 Senior Review, the National Academy of Sciences studies and schedules, international Venus efforts, the Planetary Science Vision 2050 Workshop, as well as the NASA PSD Response to the 2015 VEXAG findings. For recent and near-term NASA missions, Jim noted: "2016 has been a fantastic year with successful orbit insertions of Juno at Jupiter and of ESA's Trace Case Orbiter (TGO) at Mars, the successful launch of OSIRIS-REx to asteroid Bennu, and the ESA's Rosetta comet mission success. This is the golden age for Planetary Science".

For the Discovery Missions, Jim noted "This is one of the lynch pins of Planetary Science" with the 11 successful missions to date and two near-term items: ESA/Mercury Surface: Strofio instrument in 2017 and the Mars InSight mission in 2018. For the Discovery Mission selections 2014, there are five Phase-A mission studies, with the Venus missions being:

- DAVINCI: Deep Atmosphere Venus Investigations of Noble gases, Chemistry, and Imaging with PI Lori Glaze, GSFC, and
- VERITAS: Venus Emissivity, Radio Science, InSAR, Topography, And Spectroscopy with PI Suzanne Smrekar, JPL.

A selection is expected in December 2016 and an announcement in January 2017.

For the 2016 Planetary Mission Senior Review (PMSR), Jim noted "The Panel unanimously believes that all missions should be approved for extension". As a result, all nine current planetary missions have been directed to continue operations through FY18 (New Horizons through 2021), subject to availability of appropriated funds and to the outcome of the annual budget process.

For National Academy Sciences studies and schedules, Jim noted:

- The 1<sup>st</sup> Planetary Decadal Survey was conducted in 2002-2012,
- The 2<sup>nd</sup> Planetary Decadal Survey was conducted in 2013-2022,
- A CubeSat Review was completed in June 2016,
- An Extended Missions Review was completed Sept 2016,
- A R&A Restructuring Review was initiated in August 2015 with its Report due to NASA December 2016,
- A large Strategic NASA Science Missions Study was tasked in December 2015 with a Report due to NASA August 2017,
- The Mid-term evaluation of the Planetary Decadal Survey, which is required by law, was initiated in August 2016 with a Report expected in December 2017,
- A new Study on Sample Analysis Future Investment Strategy was initiated in September 2016, and
- The 3<sup>rd</sup> Planetary Decadal Survey for 2023-2032 will be tasked before October 2019 with a report to NASA in 2022.

As a significant number of extraterrestrial samples are expected in the next decade, the new Study on Sample Analysis Future Investment Strategy will be a multi-national effort involving United Kingdom, France, Germany, and Japan. This study will emphasize needed facilities and instrumentation by assessing:

- What laboratory analytical capabilities are required to support analysis and curation of existing and future extraterrestrial samples?,
- International Venus efforts,
- Whether the current sample laboratories and NASA's investment strategy meet the analytical requirements of current and future decadal planetary missions?, and
- Can NASA ensure that the science community stays abreast of evolving techniques in order to be at the forefront of extraterrestrial sample analysis?

For International Venus Efforts, Jim noted that the JAXA/Akatsuki Participating Science Program has been a success. Also, a Bilateral Meeting of NASA's and Russian Space Agency's representatives in Moscow last October had a comprehensive Venera-D SDT presentation on possible mission scenarios. A report is expected by end of January 2017. This Joint SDT will be extended for another two years with a new charge for a more focused approach. Key to these Venera-D efforts will be the upcoming Venus Science Priorities for Modeling and Experiments Conference at the Glenn Research Center in May 2017 where international participation is encouraged. Conference results will be discussed with Russian Space Agency later in 2017.

Jim provided an introduction to the Planetary Science Vision 2050 Workshop that will be held at NASA Headquarters on Monday – Wednesday, February 27 – March 1, 2017. The Workshop's goal is to develop a compelling, 35-year science vision for the 2020's, 2030's, and 2040's using the notional technologies and missions of the Planetary Science Decadal Survey as the starting point.

Participation in this workshop will be space-limited and requires submission of an abstract. All of the abstracts, which will be posted on the workshop website, and then used in the development of the workshop report. Oral sessions will be live-streamed so that members of the community unable to attend the workshop can participate. The workshop program will include five half-day sessions with no parallel sessions, as well as two poster sessions on Monday and Tuesday evening. PDFs of poster presentations will be posted on the workshop website. The half-day sessions will have an invited plenary talk, followed by a series of invited and contributed oral presentations, and a panel discussion. Afternoon sessions will have brief one-slide introductions to the evening posters.

Jim provided a status update to VeGASO (Venus Gravity Assist Science Opportunities) noting that a VeGASO Flyby Venus Science Working Group, was jointly set up by NASA SMD's Heliophysics and Planetary Divisions in 2015 in order to investigate Venus fly-by science opportunities using the Solar Probe Plus, Solar Orbiter and BepiColombo missions. These missions provide an opportunity to make important observations about the ionosphere and induced magnetosphere as well as the atmosphere, surface, and interior science. A briefing to the new Heliophysics Division director will initiate discussions on next steps.

Jim discussed the Planetary Science Deep Space SmallSat Studies, noting that there were 102 Step-2 submissions, with expectation of 6-15 awards for up to \$100M mission concepts. Jim "was really delighted with the number of submissions". Two immediate events are that the 2016 Discovery selections to be announced soon, and that the New Frontiers-4 AO will be released in early 2017.

**Curt Niebur** gave a detailed report on **New Frontiers Program** by reviewing the status of Homesteader call and selections, the New Horizons (NF-2) and Juno (NF-3) missions, and New Frontiers-4 AO Call. For Homesteader call, NASA's Planetary Science Division issued the Homesteader NRA in order to pursue possible technologies that could be included as part of future New Frontiers missions. Eight out of 84 proposals were selected for near-term technology development. One of selected proposals is a Venus Entry Probe Prototype, led by Lori Glaze, Goddard Space Flight Center. In parallel, a New Frontiers Data Analysis Program was initiated via a ROSES 2016 call. Although currently focused on New Horizons this year, it will be expanded to cover other New Frontiers missions as their data are archived in the PDS.

For the current New Frontiers Missions, Curt noted that:

- New Horizons – downlink of data for 2014 fly-by was completed in October,
- Juno is now in Jupiter orbit, and
- OSIRIS-REx was successfully launched on Sept. 8, 2016 with arrival at the asteroid Bennu in 2018, and sample return to Earth in 2023

For the New Frontiers-4 AO Call, Curt noted that:

- These will be PI managed missions with a cost cap of \$850M for Phases A-D,
- The Draft AO was released in August 2016, with 46 replies from the community,
- A 4<sup>th</sup> Community Announcement with some information requested in the Draft AO replies was released earlier in November,

- The Final AO was released in a week after this VEXAG meeting with a due date of April 28, 2017. Technology incentives will be \$10M for NEXT (ion propulsion) and \$20M for HEEET (heat shield). There will be increased scrutiny of the traceability of proposed science objectives to the Decadal Survey. Specifically there is a need for a discussion of how proposed measurements will trace to a specific science objective or test a particular hypothesis, and
- Selection of competitive Phase-A Studies (at \$4M each) is currently scheduled for November 2017 with Phase-A Study Reports due in October 2018, and an announcement of mission selection in May 2019.

In the Question and Answer closeout of this report, Curt noted that he expects the New Frontiers cadence to continue at 5-year intervals.

**Jonathan Rall** provided a status report on **Planetary Science R&A**. Overall selection rate is 21% with funding provided in 60 to 90 days. Jonathan described a Keyword Analysis of the R&A program based on Type of Task, Object(s) of Study, and Science Discipline. This analysis includes R&A awards, Data Analysis Programs, as well as Participating Scientist and Guest Investigator Programs. Excluded from this analysis were support activities and facilities such as the RPIFs, AVGR, GEER, PAL, RELAB, etc).

**Max Bernstein** supplemented this discussion of Planetary Science R&A with a discussion of **ROSES Selection Data**. Planetary proposal selection rate has been between 21-23% since 2010, while the number of proposals submitted has gone up and down from 1250 to 1600 in the same timeframe. The downward trend in planetary proposal selection has leveled off.

**Jonathan Rall** also provided a report on **Chartering of SMD Division Committees** by noting that NASA is proposing to Congress that the four (Earth Sciences, Planetary Sciences, Astrophysics and Heliophysics) subcommittees of the NAC Science Committee associated with SMD divisions become stand-alone Federal Advisory Committee Act (FACA) committees. These new FACA Committees will provide their respective Division Director within SMD with the advice that will be acted upon at the right organizational level. Many community-based studies, such as Senior Reviews, Science and Technology Definition Teams will, in turn, have a chartered Federal Advisory Committee to report to. These new FACA Committees will have Charters (rather than Terms of Reference) and Membership Balance plans. As of September 1st, Charters and Membership Balance Plans were in review by the General Services Administration (GSA). Remaining steps are:

- A Federal Register 15-day Publication announcing the planned establishment of these new FACA Advisory Committees,
- Charters and Membership Balance Plans signed off by the NASA Administrator, and
- Filing with Congress.

**Carolyn Mercer** filling in for **Mike Seabлом** gave a presentation on **Planetary CubeSats** and then followed with her own presentation on the **Planetary SmallSat ROSES call**. Carolyn noted that 12 assigned CubeSat science missions are one element of a balanced approach to achieving SMD Science. Recent SMD/STMD Studies have focused on accomplishing Planetary Decadal Science Goals and Objectives with spacecraft that range from CubeSats and SmallSats up to the Flagship missions.

There are a number of challenges, such as platform and instrument technology gaps, which are being addressed. These were addressed by a SMD-led NRC study on Achieving Science Goals Through CubeSats, and a NASA internal SMD Small Earth and Heliophysics Satellite Study.

A Joint SMD/STMD Study of New Opportunities for Low-Cost Science Instruments, Platforms, and Mission Architectures was initiated in February 2015 with goals of:

- Investigating current paradigm shifts in the miniaturization of science instruments and small satellite platform disruptive technologies,
- Determining the potential for novel approaches that could break the cycle of “larger but fewer” expensive missions,
- Identifying key SMD science measurement requirements that could be satisfied through such paradigms, and
- Identifying technology gaps that could be addressed through solicitations such that barriers to alternative paths are removed.

Specifically, SMD is now requesting input from the NASA Assessment Groups (AGs) to help define the notional requirements for small spacecraft via a survey that addresses NASA relevance, nature of the investigation, targets, instruments, the possible novel and unique contributions, and challenges.

Carolyn described a new ROSES Solicitation for Planetary Science Deep Space SmallSat Studies, where funding will be provided for formal mission concept studies. Approximately \$3M will be available for six to fifteen 6-month studies. The SMD goals are to acquire detailed concept studies for deep space Planetary Science missions that can be accomplished with small spacecraft, and to stimulate creativity in the community for science enabled by small, low-cost( \$10M - \$100M) deep space missions. Proposals should be for state-of-the-art implementations that address NASA's Planetary Science Division goals. Some 120 proposals were received in mid-November, just before this VEXAG meeting. Mission destinations for these proposed studies were the Moon, Mars, Venus, asteroids, comets, and the outer planets. Up to 16 of these proposals are expected to be selected.

**Adriana Ocampo** provided an update on the **Hot Operating Technologies (HOTTech) Program**. This program supports advanced development of technologies for robotic exploration in high-temperature regimes, such as the Venusian surface, Mercury and the Gas Giants. This was a ROSES solicitation in August. 29 proposals were received. Selections were to be announced in December, about a month after this VEXAG Meeting.

### **New Frontier and Flagship Mission Forums**

**Martha Gilmore** chaired a **New Frontiers (NF) Forum**. She set the stage by noting that the NF Program was established at recommendation of 2002 Decadal to help address 12 fundamental scientific questions with a recommended cadence of every 2-3 years.

For various reasons, the actual NF cadence was 2 years, 6 years, 8 years. Based on 2012 Decadal Survey, the NF missions being solicited in the 2017 call are:

- A Saturn probe,
- A Lunar South Pole Aitken Basin Sample Return,
- A Venus lander,
- A Trojan Asteroid Tour and Rendezvous Probe, as well as
- Oceans World, which was inserted after 2012 Decadal Survey.

Venus NF goals are supported by the 2014 VEXAG reports - the Goals Objectives and Investigations, the Roadmap for Venus Exploration, and the Venus Technology Plan. The Venus Technology Plan identifies critical technologies needed for a Venus NF mission.

**Larry Esposito** augmented this NF discussion by describing **VISAGE: Venus In Situ Atmospheric and Geochemical Explorer**. Larry noted that this mission would address a subset of objectives from the Decadal survey that can be accomplished within the cost cap. This would be implemented via a carrier and a lander. Key questions that will be addressed by VISAGE are:

- What is the nature (chemical and mineral composition) of the Venusian surface and how did it get that way?
- What do noble gases in atmosphere tell us about its history?
- Is there evidence of past hydrological cycles?
- Are there any indications of life or habitability?
- How do rocks/minerals on the plains constrain Venus interior, surface and surface-atmosphere interactions?

**Bob Grimm** chaired a **Venus Flagship Forum**. He set the stage by noting that the 2009 Venus Flagship Mission Study was an important resource as:

- Its goals agree with the 2014 VEXAG Goals, Objectives, Investigations 2014,
- It had an InSAR Orbiter
- It had a two entry systems, a lander and a VEGA-style balloon.

Its goals were to address the following questions:

- What does the Venus greenhouse teach us about climate change?,
- How active is Venus?, and
- When and where did the water go?, and

It had a cost of \$2.7-3.8B, FY'09.

During the run-up to the 2012 Decadal Survey, a Venus Climate Mission 2010 was designed to address the goals of:

- Characterizing CO<sub>2</sub> greenhouse,
- Characterizing dynamics and variability of super-rotation,
- Measuring surface/lower atmosphere exchange, and
- Searching for evidence of climate change on Venus

It had a cost of \$1.1-1.6B, FY12.

The 2013 Decadal Survey recommendations were either Enceladus or Venus flagship mission in the lowest priority of all of the recommended Flagship Missions. The key question is whether VEXAG in the next decade continues to advocate for a Flagship Mission or shift the emphasis to smaller missions and/or international collaboration?

Comments in the Q&A were:

- We need to start a conversation now,
- We need to focus on Flagship missions after New Frontiers-4,
- The Venus Climate Mission (VCM) although it was conceived in a short time with heritage instruments, to be cost-effective, was a good start at a pared down version of the Venus Reference Mission ,
- Could a radar added to VCM?,
- We need to explore Venus as an Earth-like planet and as Earth's nearest exoplanet,
- The Discovery and New Frontiers selections, as well as Venera-D and Envision will bear upon what we do, and
- The next Decadal Survey will be "a new ball game", and we need to keep Venus "on the front burner".

### Mission Reports

**Masato Nakamura** provided a status report on **Japan's Akatsuki (Planet C) mission**.

Venus orbit insertion was successfully accomplished on December 7, 2015 and first-light images were obtained on December 7-11, 2015. Recent notable dates since then are:

- Orbital period reduction to 10.5 days with an apocenter altitude of 0.36 million km on December 20, 2015,
- Start of regular observations on April 1, 2016,
- Orbit adjustment to a period of 10.8 days with apocenter altitude: 0.37 million km on April 4, 2016,
- Superior conjunction with solar corona observations centered on June 7, 2016, and
- One Venus year in orbit completed on July 19, 2016.

Masato showed a number of interesting recent Akatsuki science results including:

- The first-light images in orbit from the the ultraviolet imager (UVI),
- Surface images through clouds with the 1  $\mu\text{m}$  IR camera (IR1),
- Dayside images for altimetry with the 2  $\mu\text{m}$  IR camera (IR2),
- Cloud tracking "Day vs. night" comparisons,
- Fine-resolution limb images with the 2  $\mu\text{m}$  IR camera (IR2),
- Bow-shaped stationary thermal features with the long-wave infrared camera (LIR),
- Vertical scans of atmosphere from Radio Science occultations, and
- Preliminary lightning observations with the Lightning and Airglow Camera (LAC).

Masato concluded by noting that Akatsuki was successfully inserted in Venus orbit, and on-board science instruments are acquiring high-quality Venus data since then. Although the orbit is more elongated than originally envisioned, the benefit is being in the equatorial plane to study cloud dynamics. The science team expects to achieve all success criteria at the end of March 2018, when the nominal mission period ends.

**Ludmila Zasova** provided a status report of the **Joint Russian-U.S. Venera-D Science Definition Team (SDT)** aka "Together to Venus". This effort has been in place for several years with a first report expected in early 2017. Goals of the Venera-D SDT are to:

- Identify, prioritize and develop science goals, investigations, and measurements consistent with the current Venera-D concept,
- Assess the Venera-D mission architecture including possible modular options (e.g., subsystems) for collaboration opportunities and required instrumentation capabilities. Assess technology readiness level to implement the mission concept and identify areas for which development is required,
- Identify mission components (mission elements/subsystems/instruments) that best lend themselves to potential international collaboration,
- Outline a maturation schedule needed to support the Venera-D mission for launches in the post-2025 timeframe,
- Assess the precursor observations and instrumentation validation experiments needed to enable or enhance the Venera-D mission (e.g., instrument testing in a chamber that emulates the chemistry, pressures and temperatures found in the atmosphere or at the surface of Venus), and
- Evaluate how Venera-D would advance the scientific understanding of Venus and feed forward to future missions with the ultimate goal of sample return.

The baseline mission concept consists of an Orbiter with a polar 24-hour orbit and a lifetime greater than 3 years and an updated VEGA-type Lander with a life time of 2+ hours on the surface. Other components discussed as potential augmentations include a free-flying aerial platform, balloons, a sub-satellite, and small long-lived surface stations.

Science priorities for the Orbiter are:

- Studying of the dynamics and nature of super-rotation, radiative balance and nature of the greenhouse effect,
- Characterizing the thermal structure of the atmosphere, winds, thermal tides and solar locked structures,
- Measuring the composition of the atmosphere, study the clouds, their structure, composition, microphysics, UV-absorber and chemistry, and
- Investigating the upper atmosphere, ionosphere, electrical activity, magnetosphere, and the escape rate.

Science priorities for the Lander are:

- Performing chemical analysis of the surface material and studying the elemental composition, including radiogenic elements,
- Studying of interaction between the surface and atmosphere,
- Studying the structure and chemical composition of the atmosphere down to the surface, including abundances and isotopic ratios of the trace and noble gases,
- Performing direct chemical analysis of the cloud aerosols,
- Characterizing the geology of local landforms at different scales,
- Searching for volcanic and seismic activity, and
- Searching for lightning.

The current mission scenario is:

- A mission launch in 2026, 2027 using the Angara-A5 rocket with a KVTK or Briz upper stage with a spacecraft mass on a trajectory to Venus of 6500 kg,
- A scientific payload mass, including subsystems and structural elements of 1650 kg, plus 100 kg on the Lander, and
- An Orbiter-Earth communication Orbiter.

An aerial platform could be implemented if its folded size is 3x6 m, although it would require further development of the rocket, its upper stage and the fairing.

**Colin Wilson** described a **Venus Long-Life Surface Platform**, a concept developed in response to a 2016 ESA Call for New Scientific Ideas for future >400M€ missions. This would address the question of whether Venus is geologically active by:

- Establishing the level and style of seismic activity,
- Constraining interior structure,
- Determining Venus' spin rate and axis variations,
- Searching for seismic signs of volcanism and tectonics, and
- Measuring interior heat fluxes and changes in volcanic gases.

This Surface Platform is designed for a lifetime of over 100 Earth days and would be equipped with a core payload of a seismometer, as well as  $p$ ,  $T$ ,  $w$  sensors to quantify atmospheric influence on the seismometer and on Radio Science. These core measurements could be supplemented with a heat flux sensor, an image sensor, SiC gas sensors, and electric field sensors (to measure conductivity and DC electric fields). Preliminary work will focus on core payload to keep design reference mission simple. Power would be 1 or 2 units, either battery or (preferably) an RTG. The CPU would be implemented in SiC with only a few kbytes of onboard memory, assuming ADC of all sensor channels with live transmissions to space. Options for mission scenarios are either a stand-alone entry probe, or delivery to surface by an entry probe. Delivery by an entry probe would provide descent measurements including chemical profiles, and landing site imagery. A proposal for this Venus Long-Life Surface Platform was submitted to ESA in September, with a decision expected soon.

**Richard Ghail** provided a status report on the **EnVision Mission concept**, an ESA M5 Proposal. Richard noted that the science case for EnVision was updated to make it more pertinent to where we are today. These new goals are to:

- Determine the level and nature of current geological activity,
- Determine the geological events that generated the wide range of observed Venus' surface features,
- Assess whether Venus once had oceans or was hospitable for life, and
- Understand the organizing geodynamic framework that controls the release of internal heat over the history of the planet.

Key challenges and design drivers are that Venus is shrouded in permanent clouds, with a 90 bar surface pressure. The 750° K Venus atmosphere is prohibitive for surface rovers and the atmosphere is opaque to radio wavelengths shorter than about 3.5 cm. However, other aspects of the atmosphere are benign as the total electron count is less than 1 TeV, the IR

brightness temperature is about 50 K cooler than Earth, and orbits are drag-free above 220 km altitude. One key to implementing EnVision is adapting the United Kingdom's small NovaSAR, a low-cost SAR earth-orbiting satellite, to Venus. An auxiliary Subsurface Radar Sounder would acquire information on the shallow subsurface with the goals of:

- Characterizing the different stratigraphic and structural patterns of the subsurface,
- Studying the volcanism phenomena and their impact on the geological evolution of the Venusian topography,
- Detecting of subsurface structures not directly linked with surface,
- Analysing the materials in the surface and subsurface and their metamorphism linked to the burial process,
- Conducting synergistic analysis to study the evolution of the planet using the data provided by SAR and radar sounder sensors, and
- Measuring the total electron content of the ionosphere.

These 2 radars would be complemented with three auxiliary IR spectrometers:

- A VEM-H spectrometer for probing near IR night-side windows with high spectral resolution,
- A VEM-UV spectrometer that will map mesospheric SO<sub>2</sub> on the dayside, and
- A VEM-M global IR mapper.

In addition, tracking and radio science would enable one to distinguish between different models of internal structure.

The current EnVision design is a 2-m cubic platform with a dry mass of 950 kg, planned for launch by Ariane 6.2 rocket in October 2029. After orbit insertion, 200 days of aerobraking would achieve circular polar orbit at 259 km altitude. Operating modes during each 24-hour period would be:

- Communications mode: 5½ hour HGA Earth-pointed, solar array oriented towards the Sun,
- VenSAR mode: Less than 15 minutes, nadir face pointed towards Venus, rolled by up to ±35° around the spacecraft velocity vector (x-axis), and
- Nightside science mode: 45-minute nadir face pointed towards Venus.

Telemetry would be supported by a fixed 3-m, 65 W RF, Ka-band high-gain antenna for a minimum link rate of 4 Mbps.

**Håkan Svedhem** provided a report on the **Venus Express Data Archive**. The Venus Express Data Archive is an element of ESA's Planetary Science Archive (PSA), which provides the services to the science community in PDS-compliant formats of:

- A FTP repository with all eight of the ESA planetary mission datasets,
- Search interfaces (via metadata and maps),
- Documentations and ancillary datasets,
- Workshops and training, and
- Support in the creation of archive-compliant datasets.

Venus Express data volumes in the ESA's Planetary Science Archive are:

- 1.8 Tbit total for ASPERA-4 (Ion and Electrons),
- 0.5 Tbit total for MAG (Magnetometer),
- 0.5 Tbit total for SPICAV (imaging Spectrometer),
- 0.05 Tbit total for SPICAV-SOIR (IR Solar Occultations),
- 0.002 Tbit total for VeRA (Radio Science),

- 5.1 Tbit total for VIRTIS (Imaging Spectrometer), and
- 2.9 Tbit total for VMC (Venus Mapping Camera).

Total data for Venus Express is 11 Tbit, about ¼ of PSA total of 42 Tbit.

### Open Microphone Presentations

**Jörn Helbert** in his open microphone presentation on **High Temperature NIR Emissivity Measurements of Venus Analogs** noted that his high temperature rig in Germany that he described during VEXAG 13 meeting is now up and running. The emissivities of several Venus analogs such as hematite, oxidized and fresh basalts have now been measured for wavelengths of 0.8 to 1.2  $\mu$ . Oxidized basalts have flat spectra while fresh and Low Si basalts have spectra that show an increase of emissivity with wavelength.

**Colin Wilson** in his open microphone presentation on a **Proposed Venus UHF Data Relay Standard** noted that the Venus community should consider forming an International Working Group for Venus Data Relay. At Mars, there is already an agreed UHF protocol for data relay from landers/rovers. Establishing this at Venus would be beneficial for all in situ missions, in particular long-lived ones. This would reduce need to carry one's own data relay orbiter, increase data return from in situ missions and from CubeSats/SmallSats, and help in measuring the position and velocity of in situ assets. Requirements for a Venus data relay standard would support of 1- and 2-way communication, at frequencies where the atmosphere is largely transparent (e.g. UHF or S-band). As a bonus, a passive listening mode could be implemented to detect radio frequency emissions from lightning.

**Colin Wilson** in his open microphone presentation on the European **Venus 360 Visual Reality Film** noted that EuroVenusOutreach films are now posted on the web at [www.eurovenus.eu6x](http://www.eurovenus.eu6x), where there are several 10-minute episodes that discuss winds, temperature, volcanoes (SO<sub>2</sub> emissions), Venus transits across the solar disk, and the future of Venus exploration. The full documentary, which runs for about 52 minutes, has several Venus Express legacy session videos. A 360° virtual reality film is a hit with school children. All of this is being produced by White Fox Pictures (Lyon) with EU-funding.

### Poster Presentations

The poster presentations on Tuesday afternoon were:

- High Temperature Diamond Electronics for Actuator and Sensor Applications, Brianna Eller, et al.,
- How well do we know Venus' Gravity Field ? A Retrospective, Peter James,
- Ultraviolet Absorbers on Venus – Bacteria?, Sanjay Limaye,
- Constraints on Lithospheric Rheology and Volatile Content from Observations of Coronae on Venus – Joseph O'Rourke,
- Automaton Rover for Extreme Environments (AREE) - Jonathan Sauder, et al., and
- Venus Heat Flow Instrument – Sue Smrekar.

**Brianna Eller** in her poster on **High Temperature Diamond Electronics for Actuator and Sensor Applications**, noted that:

- Diamond is an ideal semiconductor for high temperature applications and requires no cooling at Venus's temperature,
- Her team at Arizona State University is already part of an ongoing ARPA-E Project and has developed diamond high-voltage and high-current diodes with a forward current density >500 A/cm<sup>2</sup> at 4 V, moderate reverse leakage current density of 10 mA/cm<sup>2</sup> at 150 V, and a high breakdown at >500V. This team is now fabricating BJTs.
- In addition, the diodes demonstrate low resistance contacts on both p- and n-type diamond using Ti/Pt/Au metallization in contact with diamond layers doped p- or n-type to a concentration >1020 cm<sup>-3</sup>. Ultra nanocrystalline diamond reduces interface resistance at temperatures up to 600° C.
- The goal is to develop these devices into low-noise amplifiers to enable the exploration of Venusian surface.

**Peter James** in his poster on **How well do we know Venus' Gravity Field ? A Retrospective** described his studies on lithosphere and mantle thicknesses based on the Magellan's 180 – degree gravity field from Alex Konopliv.

**Sanjay Limaye** in his poster **Ultraviolet Absorbers on Venus – Bacteria?** addressed a number of questions:

- Why are Venusian clouds are different from those on Earth ?,
- Why isn't the UV absorber well mixed?,
- What are clouds on Venus made of ?,
- Could life have evolved on the Venusian surface ? and most importantly,
- When Venus was warming and losing its water, could bacteria have migrated to the clouds ?.

**Jonathan Sauder** in his poster on **Automaton Rover for Extreme Environments (AREE)** reported on a JPL's effort that has developed a feasible design for a capable Venus surface rover via the NASA Innovation and Advanced Concepts.

**Sue Smrekar** in her poster on **Venus Heat Flow Instrument** described a conceptual design that is being pursued via NASA's PICASSO Program.

### General Topics

**Colin Wilson** provided an update on the **Venus-III Book**, noting that this will be published as a Special Issue of *Space Science Reviews* (Springer) with each chapter accessible as a *Space Science Reviews* paper. 9 of 11 chapters have been received in draft form. The first chapter is now ready for submission. 5 of 11 chapters have been reviewed by the editorial board for omissions and overlap with others chapters, with feedback sent to authors. A *Space Science Reviews* submissions page has been opened for submission for all of the chapters.

**Noam Izenberg** provided a provocative presentation on **Leveraging Human Spaceflight for Venus Planetary Science** by noting that a human Earth-Mars-Venus-Earth flyby mission was envisioned in the 1950's. This led to a number of NASA's EMPIRE studies by

various aerospace companies in the 1960's and 1970's. After a hiatus in the 1980's and the 1990's, Mars, Moon, asteroids and Venus can now be envisioned as human spaceflight targets. In particular, fly-bys of Venus can optimize human spaceflight to Mars by reducing the launch energies and shortening the flight times. Noam concluded by noting that there are multiple arguments for human spaceflight to include Venus as flyby destination alone and/or on way to Mars enabling significant opportunities for Venus planetary community (science) and satisfying NASA communities, such as HEOMD and SMD).

**Tim Titus** provided an overview of **United States Geological Survey (USGS) Capabilities to Support Venus Missions** by noting that the overall goals are to:

- Get the Venus community thinking about USGS contributions for future missions,
- Get the USGS thinking about how best to support Venus,
- Provide links to USGS products/services, and
- Prepare and educate the next generation.

Key USGS capabilities to support this are:

- Data user workshops,
- MRCTR GIS Lab,
- Image processing,
- Cartography,
- Nomenclature,
- Data archiving,
- Science expertise,
- Data fusion, and
- Change detection.

USGS conducts comparative planetology of tectonics, volcanism, aeolian features, and volatiles using optical spectral windows and radar imaging. A key supporting USGS software suite is the Integrated Software for Imagers and Spectrometers Version 3 (ISIS3) that currently supports over 20 past and current missions. The USGS also supports the science community via the PDS Imaging Node, a Regional Planetary Imaging Facility (RPIF), Nomenclature, and Data Workshops. Tim concluded by noting that engaging USGS has the advantages of cradle-to-the-grave data management via:

- Use of ISIS3 (which has free tools for image processing that enable data-fusion and change detection),
- Assisting with Planetary Data System (PDS) data deliveries,
- Providing expertise in GIS Mapping, as well as
- Providing expertise in tectonic, volcanic and aeolian processes.

**Kevin Baines** reported on the **Study on the Value of Participating Scientist (PS)**

**Programs to NASA.** This was originated at an OPAG meeting where there was a concern about possible inconsistencies in how Participating Scientist (PS) programs are offered and implemented, and their value to the science community. This led to an OPAG finding:

*"We encourage NASA to consider broader use of participating scientist programs and early career mission support. At NASA's request OPAG (working with other AGs) will lead a White Paper providing more detailed information to NASA about the importance and effectiveness of such programs."* Other Analysis Groups also supported this finding and asked to be involved in the White Paper. The goal of this White Paper is to evaluate PS programs by assessing their value to NASA missions, to understand similarities and differences, to gather lessons learned, and to investigate how to maximize the usefulness of these programs.

A survey was conducted by questioning the former and current Participating Scientists and anyone else who has an interest in (or had an opinion about) these programs. There were about 200 responses to this survey, of which about 120 were from current or former Participating Scientists or Guest Investigators. Respondents noted several benefits to NASA, including intellectual diversity, expertise throughout the mission timeline, increased science return, and workforce development. They also commented on the personal value of the programs, including collaboration, data access, unique experience of involvement in mission teams, personal career development, and the development of skills for future mission leadership. A second survey is now being conducted by questioning former and current Principal Investigators and Project Scientists.

Preliminary recommendations are:

- PS programs bring significant value to NASA and to the scientific community, and should be included on every planetary mission, whether competed or directed,
- Expectations for timing and funding of Participating Scientists should be clearly communicated to (and agreed with) mission leadership and the planetary community early on,
- PS requirements should be included in the AO for competed missions,
- PSs should be brought onto a mission as early as feasible, bearing in mind the trade between cost and integration issues,
- PSs who are selected later in a mission (e.g., missions with a long cruise phase) should be given assistance with team integration and training, and
- If a PS program is not included on a mission, this decision should be discussed with the planetary community, e.g., via the Planetary Science Subcommittee (PSS).

Results from the second survey for Principal Investigators and Project Scientists are still coming in, with just a few responses outstanding. The timeline for completing this is:

- Draft of the White Paper, including recommendations, completed by the end of December 2016, and
- A final White Paper will be submitted to AGs and made available to entire community (e.g., via newsletters, LPI webpage, AG webpages, etc.) by end of January.

Given the strong support received for this study from the AG Chairs and PSS, it is expected that the PSS will deliver a formal finding about PS programs to NASA during their February 2017 meeting. Hopefully, these recommendations will be incorporated into future New Frontiers and Discovery Step 2 studies.

### Invited Student/Young Career Presentations

**Erin M. Bethell** (a graduate student at Carleton University, Ottawa, Canada) in her presentation on **Detailed Mapping in the Alpha Regio and Model for Coronae** noted that some coronae appear to have multiple generations of circumferential and radiating systems, which are commonly associated with volcanic features, such as volcanic flows, volcanoes, steep-sided domes, and canali/sinuous rilles. Many of these Venusian coronal systems are likely underlain by dyke swarms that are similar in size and geometry to recently discovered radiating mafic dyke swarms on Earth.

**Candace Gray** (a support Astronomer at Apache Point Observatory) in her presentation on **Ground-based Observations of Venus from Apache Point Observatory** described the Venus oxygen green line observations from unique aurora on Venus. This line is most intense after large CMEs and not seen after solar flares. Electron-excited oxygen atoms are the likely source of these green line emissions. Venus Express radio occultations show increases in the night-side ionospheric layers from night-side electron precipitation flux and energy during these CMEs, indicating that CMEs deposit more electrons deep in the atmosphere at altitudes of 100 to 200 km.

**Sayali Mulay** (an undergraduate biotechnology student at Fergusson College, Pune, India) in her presentation on **Plausible Organic Chemistry in Venusian Clouds**, addressed the question of "Could There Be Life on Venus?" by noting that the middle and upper cloud layers on Venus have environments similar to that on Earth. These cloud layers at altitudes of 50 km to 70 km are composed of reactive gases at favorable temperatures of about 10°C to 76°C with atmospheric pressures of about 1 atm. They would be favorable environments for organics as demonstrated by the 1950's Miller-Urey experiment.

**Sara Port** (a graduate student at University of Arkansas) in her presentation on **Metal Frossts on Venus** discussed bismuth tellurides, sulfides mixtures, and their relation to metal frossts on Venus. This addresses the observation that radar data show highly reflective surfaces concentrated in the Venusian highlands at altitudes of 2.5 to 4.75 km. Bismuth tellurides and sulfides mixtures are good candidates, as bismuth, tellurium, and sulfur occur around volcanic vents, are present in volcanic gases, and could condense in the cooler Venusian highlands.

**David Tovar** (a graduate Student at University of Minnesota) in his presentation on **Insights about Formation Mechanisms of Fracture Zones from Detailed Geological and Structural Map of Aphrodite Terra** noted that rift zones on Venus are much different than those on Earth. A detailed structural analysis was pursued in order to understand their evolution and to gain insights into possible heat transfer mechanisms on Venus. His models for fractures formation suggest that excavation from beneath plays a major role in forming these fracture zones.

### Technology Reports

**Prof. Carl-Mikael Zetterling** provided a report on **Silicon Carbide (SiC) Electronics** noting that he has had success in fabricating SiC semiconductors and microcircuits in his laboratory/clean room at the Swedish Royal Institute of Technology in Stockholm. Wafers are being tested at temperatures of 620°C. A Swedish High-Temperature Electronic Venus Project with a goal of uncooled operation at 460°C is underway with the development and testing of Seismic, UV Image, Gas Sensors, Amplifiers, Analog to Digital Converters, Power Supplies, Microcontrollers and Memories. Future work will emphasize the development of a 4-bit Microcontroller and Memory with 5000+ transistors using integrated SRAM, CMOS, and TTL technologies.

**Jim Cutts** provided a report on a feasibility study of **Venus SmallSat and CubeSat**

**Missions.** Study objectives were to:

- Examine the feasibility of Venus science missions using CubeSats or SmallSats,
- Determine the primary technical challenges, and
- Describe the science that could be accomplished via a Venus SmallSat.

The key challenges are launch vehicles, communications as well as lifetime and reliability.

There are rideshare options for getting to Venus that include Venus, Mars, high earth orbit and lunar missions. Each of these rideshare options has its own frequency, candidate Venus missions, trip times, and accessible Venus orbits. Venus mission rideshares could support CubeSat or SmallSat missions, while missions to Mars, high earth orbit, or the Moon would have to be the larger and heavier SmallSats.

Jim concluded by noting that affordable solutions exist for getting both CubeSats and SmallSats to Venus and that SmallSats in the high circular orbit could also provide a communications relays for long duration in situ missions such as balloons and surface seismic measurements.

**Brian Drouin** supplemented this discussion of CubeSats and SmallSats by providing a report on **VAST, the Venus Terahertz Atmospheric Sounder, a Submillimeter-Wave Spectrometer for Small Satellites.** This is outgrowth of VESPER, a Venus mission concept study managed by Goddard that included a JPL submillimeter Limb Sounder (SLS) to provide upper atmospheric science. THz limb sounding at Venus would yield atmospheric dynamics, physics and chemistry, including:

- $^{12}\text{CO}/^{13}\text{CO}$  winds with 10 m/s accuracy for altitudes 75 to 90 km, and 5 m/s accuracy for altitudes of 90 to 120 km,
- Vertical profiles of atmospheric temperature, and
- Mixing ratios of trace species, such as  $\text{H}_2\text{O}$ ,  $\text{HDO}$ ,  $\text{H}_2^{18}\text{O}$  (isotope ratios),  $\text{H}_2\text{O}_2$ ,  $\text{O}_2$ ,  $\text{ClO}$  (catalytic agent),  $\text{O}_3$  (catalytic agent),  $\text{SO}_2$ ,  $\text{OCS}$ ,  $\text{H}_2\text{S}$ ,  $\text{NO}$  (diagnostic of lightning)

Brian noted that significant number of components have already been miniaturized including a Reference Oscillator, a 100 GHz Synthesizer, a 85 GHz Amplifier, a 600 GHz Receiver, a 600 GHz Calibration Switch, Waveguide Calibration Loads, and the IF Amplifier Chain. Continuing objectives include:

- Developing a flat antenna that can be mounted directly on a small satellite,
- Replacing the current Quasi-optical Flip Mirror Calibration with a compact Waveguide Calibrator,
- Integrating CMOS Synthesizer and Spectrometer to reduce power consumption, and
- Expanding the bandwidth of receiver to capture important molecular species in Venusian atmosphere.

**Raj Venkatapathy** provided a report on **HEEET AEDC - Successful Seam and Acreage Testing**, addressing heatshield material for extreme entry environments. The goal is to develop this material in time to support New Frontiers-4 missions, such as Venus Lander or Saturn Probes. The new seam design of gap filler with adhesive performs the primary function of providing relief of structural loads with an aerothermally robust joint. As no current ground test facility is capable of combined thermo-structural testing at extreme entry conditions, arc-jet testing on patches was successfully performed.

**Tibor Kremic** provided a report on **Long-Lived In-Situ Solar System Explorer, LLISSE**, a small (about 10 kg) probe being developed to acquire and transmit simple but important science measurements for extended periods from the surface of Venus. The three key support elements are:

- Recent developments in high-temperature electronics,
- Emphasis on low data volume measurement, and
- Novel operating schemes.

Science goals are to:

- Estimate moment exchange between planet and atmosphere,
- Quantify near-surface atmospheric chemistry variability, and
- Acquire temporal weather data to update global circulation models.

This is being pursued as a Technology Demonstration for more capable future landers.

Specific scientific measurements measured over long time scales could be:

- Surface wind speed and direction,
- Surface temperature and pressure,
- Near-surface atmospheric chemical compositions, and possibly
- Incident radiance,

Operational goals are to operate for a minimum of one Venus “daylight period” and day/night transition (~60 Earth days), and to take and transmit measurements periodically timed for science need and to maximize transfer to orbiter/data relay.

Two versions (one powered by a battery and one powered by the wind) are being pursued. Both have common features of being deployable from a balloon, a lander, or via its own entry shell. The battery version would send data for 2 minutes every 8 hours. The wind version has indefinite life, with variable data transmission frequencies. Current project objectives are to develop half- and full-scale prototype probes (one battery powered and one wind powered) and then demonstrate their performance in Venus conditions using the Glenn Extreme Environment Rig (GEER) by taking scientific measurements and transmitting the data. The wind version would be tested with simulated winds in GEER. Long-range goals are to complete performance tests of full-scale prototype models running with a 10 MHz communication system within 3 years. Turbine tests on a wind powered half-scale model would be completed 2 years later.

**Tibor Kremic** continued with a status update on the **Glenn Extreme Environment Rig (GEER)** noting that its current capabilities are to simulate Venus atmospheres with ambient temperatures to 500°C, pressures of 0.001 to 100 bar with virtually any chemistry for indefinite durations. This supports science, technology and/or mission applications for:

- Venus (environment and chemistry from the surface to above clouds),
- Saturn, Jupiter, Uranus, and their moons (chemistry and temperature/pressure),
- Exoplanets (chemistry for science and model inputs).

Major GEER subsystems include pressure vessel, gas containment, gas mixing, programmable control systems, pumping station, temperature control, analytics, and operation stations – all housed in a specially designed facility. GEER is coming back online after its first year of operations and a required maintenance period. Improvements during of this recent annual maintenance shutdown include:

- Installing high performance insulation replacing the old blankets,
- Polishing of the interior surfaces,

- Improving a gas handling system for even higher accuracy chemistry via a precision high pressure dosing pump, and
- Adding an on-site Quadrupole Mass Spectrometer and a Micro Gas Chromatograph.

GEER has recently completed several specific successful experiments involving tests at Venus surface temperatures and pressures with appropriate materials. Tests have been conducted for over 95 days at Venus surface conditions in full chemistry as well as 25 days with a CO<sub>2</sub>/N<sub>2</sub> atmosphere. These tests and experiments support science experiments as well as technology development and maturation.

More access and users' capabilities are being provided by:

- Establishing Science Advisory Committee,
- Providing feed-throughs for power and other signals,
- Accommodating remote users,
- Incorporating small Parr pressure vessels into small and quick operations,
- Enhancing the analytics, and
- Providing an optical port.

Tibor concluded by noting that GEER is available for users via a ROSES proposal. The GEER website is <https://geer.nasa.gov>.

**Natasha Johnson** provided a status update on the **Goddard Venus Pressure Test Chamber, VICI, the Venus in situ Chamber Investigations**. This chamber was built for testing high-temperature components by Dr. William Byrd at Iowa State University and subsequently transferred to Goddard in mid-summer 2009. It consists of a stainless steel pressure vessel that operates at maximum pressure of 95.6 bar (1,387 psi), and rated to rupture at 1500 psi. The cylindrical volume with a diameter of 12.7 cm (5 inches) and depth of 30.5 cm (12 inches) is about 4 liters. Tests are computer-monitored via NI LabView, which records pressures and temperatures in real time.

These VICI capabilities support tests with pressure range of 1 to 95.6 bars at temperatures of 298 to 740°K. Gases can be CO<sub>2</sub> or N<sub>2</sub> at pressure, a Venus atmosphere mixture of CO<sub>2</sub> and N<sub>2</sub>, or a mixture of CO<sub>2</sub> and SO<sub>2</sub> at 150ppm. This chamber is available to the community via a ROSES proposal. Please feel free to call or email Natasha at: [natasha.m.johnson@nasa.gov](mailto:natasha.m.johnson@nasa.gov) / 301-286-3919.

### Venus Conferences

**Colin Wilson** provided a recap of the **Venus 2016 Conference**, held at Oxford University, last April. There were 140 participants from 16 countries with 21 "early career" scientists (PhD students and 1<sup>st</sup> year postdocs) supported with accommodation costs and registration fees. The conference covered all aspects of Venus science from its interior and surface to its atmosphere and magnetosphere, spanning a wide range of missions from the VeGa balloons, through Venus Express, onwards to Akatsuki and future missions. Conference highlights included first results from Akatsuki and a Venus Express legacy session. Colin also noted that he is looking forward to a Venus 2018 Conference (possibly in Japan) that would cover topics such as Akatsuki results, a BepiColombo Venus flyby, DAVINCI and/or VERITAS, EnVision, VAMP, and an EMPIRE manned flyby.

**Paul Steffes** provided a preview of the **Venus Science Priorities for Modeling and Experiments Workshop** aka **Venus Modeling Workshop** that will be held at the Ohio Aerospace Institute, Cleveland, OH, on May 9-11, 2017. This will be the third in a series, following the Venus Exploration Targets Workshop in May 2014, and the Venus Science Priorities for Laboratory Measurements and Instrument Definition Workshop in April 2015. The May 2017 workshop is intended to be highly interactive and will consist of a combination of cross-disciplinary plenary sessions and discipline-specific topical breakout sessions. Invited talks will be solicited for the purpose of providing a focus for community discussion. The plenary briefings will provide short overviews and summary information and will lay a foundation for the breakout sections. There will be a Focus Session on Venera-D, as well as Plenary Sessions with four breakouts on the Interior, Thermal and Chemical Interaction with the Surface, the Neutral Atmosphere, and the Upper Atmosphere and Ionosphere.

**Dmitri Titov** provided a preview of the **ESLAB Symposium on Comparative Aeronomy of Terrestrial Planets** that will be held May 2018, at ESTEC, Noordwijk, Netherlands. This conference will emphasize:

- Processes in the upper atmospheres and plasma envelopes of terrestrial planets, Titan and Moon,
- Escape and evolution of the atmospheres,
- Results from space missions, and
- Numerical modeling and theoretical investigations.

This will be a follow-on to a Mars Aeronomy Conference, Boulder CO, on May 15-19, 2017.

**Giada Arney filing in for Shawn Domagal-Goldman** provided a preview of **Comparative Climatology of Terrestrial Planets III Conference (CCTP3)**. This will be the third CCTP meeting with the first was held in Boulder, CO in 2012, and the second was held at Moffett Field, CA (NASA Ames) in 2015. This will be a cross-divisional workshop including Earth, planetary, astrophysics, and heliophysics disciplines with the goal of addressing issues across planetary targets including the Earth and exoplanets with an overarching theme of "Systems Interactions Near and Far".

A key question for this Conference is "How best to foster cross-disciplinary interactions that have an impact beyond the meeting? Current thoughts about the venue are summer 2018 in an East Coast city such as Washington/Baltimore, Atlanta, or Boston. Expected attendance is about 100 participants, similar to the CCTP I and CCTP II Conferences.

**Tim Titus** provided a preview of **5<sup>th</sup> International Planetary Dunes Workshop**. This workshop will address dune fields across the Solar System:

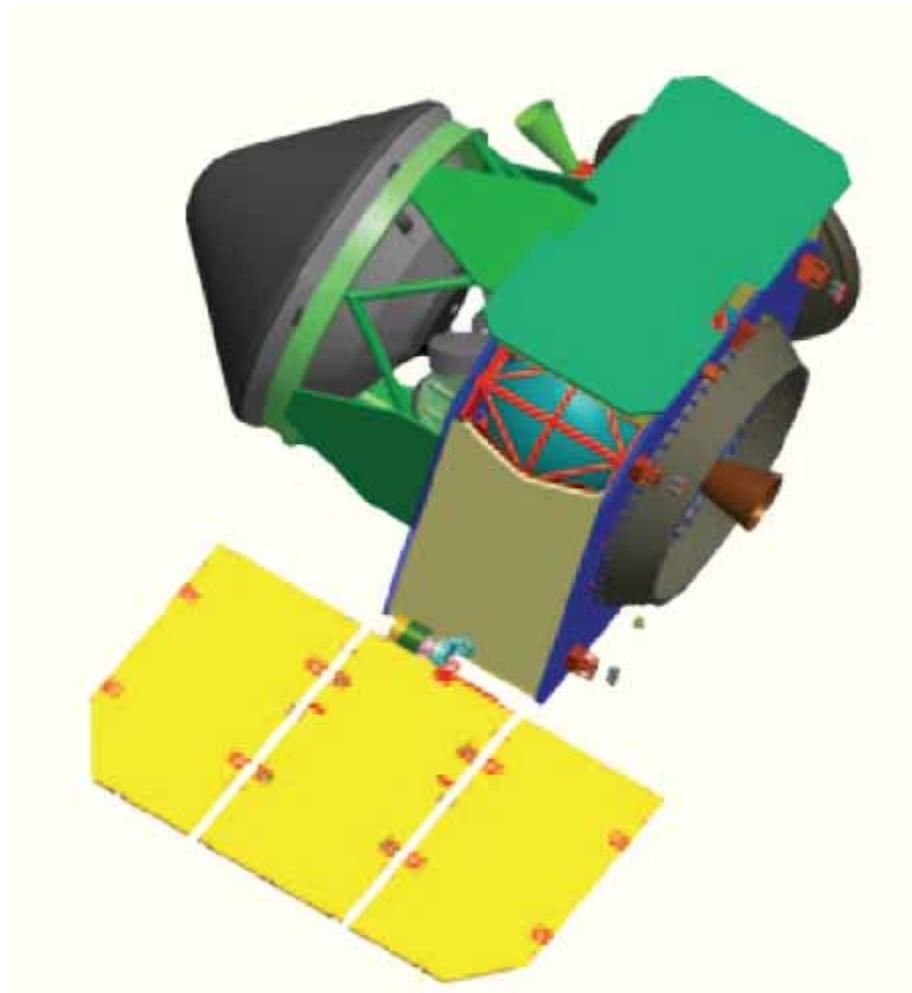
- Terrestrial Planets - Venus, Mars and Earth (land/deserts and oceans/rivers),
- Outer planet satellites, such as Titan, and
- Airless bodies – comets and volatile rich impacts.

The objectives of the this workshop are to:

- Increase the collaborations between terrestrial aeolian scientists and planetary aeolian scientists across multiple disciplines,
- Facilitate the fusion of remote sensing, analog research, laboratory experiments, including wind tunnels, computer modeling and simulations,
- Prepare the next generation of scientists, and in particular
- Expand aeolian studies to terrestrial subaqueous bedforms, which may provide analogs for aeolian processes on planets such as Venus.

Specific questions for Venus dunes are: "Why do we only observe two large dune fields?" and "Are there micro dune fields?". Those two large Venusian dune fields are Al-Uzza Undae with a diameter of 150 km and Menat Undae with a diameter of 100km. The apparent lack of dunes on Venus could be due to low surface wind speeds, a lack of sediment, or possibly the lack of high spatial resolution data needed to resolve smaller dune fields.

The next Interplanetary Dunes Workshop, which includes a field trip to Pink Coral Sand Dunes, will be held at Dixie State University, St. George, Utah on May 16-19, 2017. Abstract deadline is March 7, 2017. Registration will be about \$225. Focus will be on dunes in thick atmospheres, such as Venus with terrestrial oceans and rivers as analogs. Meeting website is <http://www.hou.usra.edu/meetings/dunes2017/>. Workshop output, as it has been for past workshops, is expected to be an EOS Meeting Report, an Aeolian Research Report, as well as a special issue of an appropriate scientific journal.



Artist Concept of the Venus Climate Mission (VCM) Flagship Mission Spacecraft

Findings and Resolutions from VEXAG Meeting #14  
November 29 - December 1, 2016 meeting

Findings

Finding #1

**VEXAG again requests a reassessment of the Venus flagship described in the 2011 Planetary Science Decadal Survey (PSDS), before the next Decadal Survey convenes in 2020.** The Venus Climate Mission (VCM) was ranked below the Ice Giants flagship, whose detailed study is nearing completion. VCM was ranked equally with Enceladus, which is now a key target in the new Ocean Worlds program. Therefore a Venus flagship mission concept will now also benefit from more detailed study in order to provide a framework to the 2020 deliberations. Driving factors include (1) advancements in instrument maturity that would decrease mass and cost, (2) new concepts in aerial platforms that could enable greater vertical mobility or directed flight, (3) innovation in geophysical techniques and technology that could expand the scope of orbital, aerial, or landed science, (4) the impact of the imminent Discovery selections and upcoming New Frontiers as well as international competitions, and (5) new observations of extrasolar planets that frame Venus in the context of the question: "Does Earth-sized mean Earth-like?"

Finding #2

**VEXAG reaffirms its endorsement of the Venus Gravity Assists Science Opportunity (VeGASO).** We appreciate that the BepiColombo (BC) mission has already agreed to operate its science instruments during the Venus flybys, and we encourage continued science dialogue about the forthcoming Venus gravity-assist opportunities provided by Solar Probe Plus, Solar Orbiter, Europa Multiple-Flyby Mission, and other future missions. VEXAG suggests that a simple two-step sequence is the most efficient path to VeGASO implementation. Beginning with BC, the flight project first issues a Proposal Information Package (PIP) that would describe (in greater detail than the VeGASO report), the spacecraft trajectory and operating parameters and capabilities of the instruments. Next, NASA and ESA would issue concurrent Participating Scientist (PS) calls that would propose science consistent with the PIP, and selections would be coordinated between NASA and ESA. VEXAG recommends this path to ensure that the best possible detailed science justification for potential investigations rests directly with the proposers. VEXAG will encourage participation by interested US scientists at a VeGASO splinter meeting during the BepiColombo Science Working Team in May 2017.

Finding #3

**VEXAG appreciates recent support from the Planetary Science Division for international science participation and strongly encourages the continued support of these opportunities for collaboration.** The VEXAG community is excited by the science results from the Akatsuki mission to Venus and the involvement of NASA's Participating Scientists in this mission. VEXAG continues to support NASA participation in future international partnerships including mission collaboration and participating scientist programs such as the upcoming European Space Agency's M5 opportunity. Continued

NASA support of the COSPAR International Venus Exploration Working Group will facilitate the needed dialogue among other international partners including ESA, JAXA, IKI, and ISRO.

#### Finding #4

**VEXAG encourages NASA to support efforts that engage a broader cross- section of the US science community in the Russian Venera-D mission.** We are encouraged by the imminent release of the first report of the Venera-D Joint Science Definition Team and we anticipate continued advancement on this effort. We appreciate NASA's support of VEXAG's May 2017 Workshop on Venus Science Priorities for Modeling and Experiments, which will include a program component for Venera-D.

#### Finding #5

**VEXAG encourages NASA to continue its investment in facilities, instruments, and technology maturation that critically enable Venus missions, and we further encourage identification of novel opportunities to deliver these assets to Venus.** VEXAG appreciates NASA's significant investment in facilities like GEER and VICI and the Homesteader, MatISSE, PICASSO, and especially HOTTech programs. VEXAG strongly endorses SmallSat and CubeSat development and the goal of their regular integration into future launches. In particular, VEXAG encourages NASA to consider development of a standardized infrastructure for Venus communications relay (such as the UHF protocols for Mars) that could be sized for such spacecraft. Such a relay could facilitate long-lived surface operations or secondary payload drop-off at Venus.

#### Finding #6

**VEXAG encourages NASA to form a cross-divisional research program for Comparative Climatology of the Terrestrial Planets (CCTP).** It is essential to understand Venus, Earth, and other solar system worlds in the context of exoplanets, and to leverage our detailed knowledge of Earth and our solar system to understand new data on exoplanets. Understanding Venus and other worlds in the context of solar/stellar forcings is, by its very nature, an interdisciplinary endeavor. Collaborations with the Earth climate research community have already provided important expertise and tools to understanding Venus and other worlds. These synergies have been evidenced at prior CCTP meetings. CCTP meetings have been a model of cross-divisional support and other cross-divisional programs (NAI, NLSI/SSERVI, NeXSS) have been successful. It was our understanding that a relevant new program element was forthcoming and we urge NASA to implement this important opportunity.

## Finding #7

**VEXAG encourages coordination between SMD and HEOMD to study the synergies presented by the human Path to Mars.** Venus flyby trajectories offer unique elements of the delta-V vs mission-duration trade space for heavy lift to Mars of piloted missions and human-infrastructure elements. This enables unique opportunities for Venus science – akin to VeGASO described above – for deployed payloads and human-in-the-loop flyby investigations. Further, Earth-Venus-Earth flyby missions can also provide these science benefits while testing <1-yr interplanetary flights on the human spaceflight on the Path to Mars.

## Finding #8

**VEXAG encourages PSD support for upcoming opportunities and initiatives, including travel support to international conferences specifically for young career scientists in the following Venus-relevant meetings supported by VEXAG:**

- a. Workshop on Venus Science Priorities for Modeling and Experiments, May 2017, Cleveland, Ohio.
- b. 5<sup>th</sup> International Dunes Workshop, May 2017, St George, Utah.
- c. 15th VEXAG meeting, October or November 2017, Location TBD.
- d. CCTP3 Conference, Summer 2018, Atlanta, Washington/Baltimore, or Boston
- e. Potential Targets Workshop 2018 or later.

## Resolutions

VEXAG will encourage Venus science community participation in the following meetings:

- Interplanetary Probes Workshop 14, The Hague, June 2017
- European Planetary Science Congress (EPSC), Riga, Latvia, September 2017.
- ESLAB Comparative Aeronomy Conference ESTEC, Noordwijk, Netherlands, May 2018
- COSPAR, Pasadena, California, July 2018
- International Venus Conference, Japan, Sept 12-15 2018.

VEXAG recognizes the upcoming mid-term review of the 2011 Planetary Science Decadal Survey and resolves to develop appropriate input from Executive Committee deliberations and community input via the VEXAG website, Venus Town Hall at 2017 LPSC, and Workshop on Venus Science Priorities for Modeling and Experiments.

Because of the accessibility of Venus and the potential value to science and infrastructure there, VEXAG resolves to provide input to the NASA SmallSat and CubeSat requests for information through web forms advertised to the community.

VEXAG recognizes the importance of long-range planning and resolves to contribute one general abstract and solicit specialized abstracts for the Planetary Science Vision 2050 Workshop to be held at NASA HQ early in 2017.

Attendees – VEXAG Meeting #14 – November 29 – December 1, 2016

<b>First Name</b>	<b>Last Name</b>	<b>Affiliation</b>
Michael	Amato	NASA Goddard Space Flight Center
Giada	Arney	NASA Goddard Space Flight Center
David	Atkinson	Jet Propulsion Laboratory
Sushil	Atreya	University of Michigan
Kevin	Baines	University of Wisconsin-Madison
Jeffrey	Balcerski	NASA Glenn Research Center
Patricia	Beauchamp	JPL-Caltech
Max	Bernstein	NASA Headquarters
Erin	Bethell	Carleton University
Kerry	Burns	Raytheon/Jacobs/MSFC Environments
Josh	Cahill	Apiled Physics Laboratory,
Bruce	Campbell	National Air and Space Museum
Stephen	Clark	Spaceflight Now magazine
Valeria	Cottini	NASA Goddard Space Flight Center
James	Cutts	Jet Propulsion Laboratory
Dwayne	Day	National Research Council
Shawn	Donagal-Goldman	NASA Goddard Space Flight Center
Brian	Drouin	Jet Propulsion Laboratory
Brainna	Eller	Arizona State University
Larry	Esposito	University of Colorado
Jeff	Foust	Space News
Martha	Gilmore	Wesleyan University
Zach	Girazian	NASA Goddard Space Flight Center
Lori	Glaze	NASA Goddard Space Flight Center
Richard	Ghail	Imperial College
Nicolas	Gorius	NASA Goddard Space Flight Center
Candace	Gray	New Mexico State University
Jim	Green	NASA Headquarters
Robert	Grimm	Southwest Research Institute
David	Grinspoon	Planetary Science Institute
Jeff	Grossman	Massachusetts Institute of Technology
Scott	Guzewich	NASA Goddard Space Flight Center

<b>First Name</b>	<b>Last Name</b>	<b>Affiliation</b>
Jorn	Helbert	German Air and Space Agency (DLR)
Robert	Herrick	University of Alaska, Fairbanks
Gary	Hunter	NASA Glenn Research Center
Noam	Izenberg	Applied Physics Laboratory
Peter	James	Lunar and Planetary Institute
Natasha	Johnson	NASA Goddard Space Flight Center
Hilary	Justh	NASA Marshall Space Flight Center
Walter	Kiefer	Lunar and Planetary Institute
Erika	Kohler	NASA Goddard Space Flight Center
David	Kraemer	Johns Hopkins University
Tibor	Kremic	NASA Glenn Research Center
Sanjay	Limaye	University of Wisconsin
Iván	López Ruiz	Universidad Rey Juan Carlos, Spain
Ralph	Labradoras	
	Lorenz	JHU Applied Physics Lab
Alex	Macdonald	NASA Headquarters
Paul	Mahaffy	NASA Goddard Space Flight Center
Erwan	Mazarico	NASA Goddard Space Flight Center
Alfred	McEwen	University of Arizona
Patrick	McGovern	Lunar and Planetary Institute
Carolyn	Mercer	NASA Headquarters
Michael	Mischna	Jet Propulsion Laboratory
Sayali	Mulay	Fergusson College, Pune, India
Masato	Nakamura	Japan Aerospace Exploration Agency (JAXA)
Curt	Niebur	NASA Headquarters
Sarah	Noble	NASA Headquarters
Adriana	Ocampo	NASA Headquarters
Joseph	O'Rourke	California Institute of Technology

<b>First Name</b>	<b>Last Name</b>	<b>Affiliation</b>
Sara	Port	University of Arkansas
Louise	Prockter	Lunar and Planetary Institute
Jonathan	Rall	NASA Headquarters
Christina	Richey	NASA Headquarters
Jonathan	Sauder	Jet Propulsion Laboratory
David	Senske	Jet Propulsion Laboratory
Marcia	Smith	SpaceTech
Suzanne	Smrekar	Jet Propulsion Laboratory
Paul	Steffes	Georgia Tech University
Ellen	Stofan	NASA Headquarters
Hakan	Svedhem	European Space Agency
Timothy	Titus	U.S. Geological Survey
Tommy	Thompson	Jet Propulsion Laboratory
Dmitry	Titov	European Space Agency
David	Tovar	University of Minnesota
Melissa	Trainer	NASA Goddard Space Flight Center
Allan	Treiman	Lunar and Planetary Instutite
Constantine	Tsang	Southwest Research Institute
Ethiraj	Venkatapathy	NASA Ames Research Center
Paul	Voosen	Science magazine
Jennifer	Whitten	National Air and Space Museum
Thomas	Widemann	Paris Observatory
Colin	Wilson	University College London
Ludmila	Zasova	Space Research Institute (IKI), Moscow
Carl-Mikael	Zetterling	Royal Institute of Technology (KTH), Stockholm
First Name	Last Name	Affiliation

## Agenda - VEXAG Meeting #14

Tuesday-Thursday, November 29 – December 1, 2016  
James Webb Auditorium, NASA Headquarters (Ground Floor, West Entrance)  
300 E St. SW, Washington DC 20546

Meeting Theme - Unveil Venus: Why is Earth's sister planet so different?"

### **Tuesday, November 29, 2015 - 8:00 AM – 7:00 PM – NASA and Mission Reports**

- 8:00 Sign-In, Pick up Handouts, Coffee
- 8:15 Welcome and Objectives of 14<sup>th</sup> VEXAG meeting – Bob Grimm  
- Venus Exploration Slogan & VEXAG Web-Site Updates
- 8:30 NASA Reports**
- 8:30 Perspectives on Venus Exploration – Ellen Stofan
- 8:45 Update on NASA Planetary Science Division - Jim Green  
- Response to VEXAG Meeting #13 Deliberations  
- Mid-Term Decadal Survey Preview and VeGASO Update
- 10:00 COFFEE BREAK
- 10:30 New Frontiers Program – Curt Niebur
- 10:50 NASA R&A – Jonathan Rall / Max Bernstein
- 11:10 NASA Headquarters Q & A
- 12:00 Student/Young Career Meet and Greet / Luncheon
- 12:00 LUNCH
- 1:00 Mission Reports**
- 1:00 Akatsuki Report – Masato Nakamura
- 1:30 Venera-D Joint Science Definition Team – Ludmila Zasova, Dave Senske,
- 1:45 Planetary Cubesats – Michael Seabloom, NASA Headquarters
- 2:00 Planetary Smallsat ROSES Study Call – Carolyn Mercer, NASA Headquarters
- 2:00 COFFEE BREAK
- 2:30 – New Frontiers Venus Flagship Missions Forums**
- 2:30 Venus New Frontiers Forum – Martha Gilmore, Lead
- 3:15 Venus Flagship (Mid-Term Decadal) Mission Forum – Bob Grimm, Lead
- 4:30 Open Microphone and Poster Preview Presentations**
- 4:30 Open Microphone Presentations (5 minutes/2 view-graphs each)
- 5:00 Poster Presentations Previews (2-3 minutes/1 view-graph each)
- 5:15 Summary of Tuesday's Key Items / Wednesday Agenda Items – Bob Grimm
- 5:30 POSTER PRESENTATIONS
- 7:00 ADJOURN

**Wednesday, November 30, 2016 - 8:00 AM – 5:00 PM**

- 8:00 Sign-In, Pick up Handouts, Coffee  
8:30 SiC electronics – Carl-Mikael Zetterling (Web-Ex)  
8:45 An Uncooled Long-Life Venus Seismometry Station - Colin Wilson (Web-Ex)  
9:00 Venus III Book - Colin Wilson (Web-Ex)  
9:15 2016 International Venus Conference Recap - Colin Wilson (Web-Ex)  
9:30 Envision Mission Overview- Richard Ghail (Web-Ex)  
9:45 VERITAS (Sue Smrekar, PI), an orbiting mission to produce high-resolution topography and imaging as well as global surface composition; and  
10:00 DAVINCI (Lori Glaze, PI), an atmospheric probe mission to study the origin, evolution, and chemical processes of the atmosphere.  
10:15 Thoughts for Human Exploration of Venus – Noam Izenberg  
10:30 COFFEE BREAK  
**11:00 Student/Young Scholar Invited Talks**  
11:00 Detailed Mapping in the Alpha Regio and Model for Coronae  
- Erin M. Bethell, Carleton University, Ottawa, Canada  
11:10 Ground-based Observations of Venus from Apache Point Observatory  
- Candace Gray, Apache Point Observatory,  
11:20 Plausible Organic Chemistry in Venusian Clouds, Sayali Mulay,  
Fergusson College, Pune, India  
11:30 Metal Frost on Venus, Sara Port, University of Arkansas  
11:40 New Insights about Formation Mechanisms of Fracture Zones from Detailed Geological and Structural Map of Aphrodite Terra (15S-20S / 110E-124E), David Tovar, University of Minnesota  
11:50 LUNCH BREAK

**Wednesday, November 30, 2016 – 1:30 – 5:00 PM – Science and Technology**

- 1:30 Venus Smallsat and Cubesat Missions – Jim Cutts,  
1:45 Submillimeter-Wave Spectrometer for Small Satellites  
- Brian Drouin, Theodore Reck  
2:00 USGS Capabilities to support Venus Missions- Tim Titus  
2:15 Venus Express Data Archives – Hakan Svedhem  
2:30 COFFEE BREAK  
3:00 Hot Tech Program Overview – Adriana Ocampo  
3:15 Long-Lived Station for Venus - Tibor Kremic, Ludmila Zasova, Sanjay Limaye,  
and Gary Hunter  
3:30 HEEET AEDC - Successful Seam and Acreage Testing – Raj Venkatapathy  
3:45 Venus Entry Probe Prototype (Homesteader Program) Lori Glaze  
4:00 Glenn Extreme Environment Rig (GEER) - Tibor Kremic, Gary Hunter  
4:15 Venus In situ Chamber Investigations (VICI) – Natasha Johnson  
4:30 Summary of Wednesday's Key Items / Thursday Agenda Topics – Bob Grimm  
4:45 ADJOURN

**Thursday, December 1, 2016 - 8:00 AM – 12:00 PM – VEXAG Activities**

- 8:00 Sign-In, Pick up Handouts, Coffee  
8:30 Welcome – Bob Grimm  
8:40 Venus Goals, Objectives and Investigations Update– Bob Grimm  
9:00 PSS Participating Scientist Survey – Kevin Baines  
9:15 Workshop on Venus Science Priorities for Modeling and Experiments  
- Tibor Kremic, Paul Steffes  
9:30 ESLAB Symposium on Comparative Aeronomy of Terrestrial Planets,  
- May 2018, ESTEC – Dmitri Titov (Web-Ex)  
9:40 Comparative Climatology of Terrestrial Planets III Conference Preview  
- Shawn Domagal-Goldman  
9:50 International Dunes Workshops – Tim Titus  
10:00 Japan's International Venus Conference, September 2018 - Masato Nakamura  
10:10 COFFEE BREAK  
10:40 Proposed Findings and Resolutions / VEXAG Goals & Plans for 2017  
- Bob Grimm  
11:45 Group Photo  
12:00 ADJOURN  
  
1:30 VEXAG Executive Committee Meeting

**Open Microphone @ Poster Presentations – Tuesday, November 29, 2016**

High Temperature Diamond Electronics for Actuator and Sensor Applications - Brianna Eller, Robert Nemanich, James Lyons, Stephen Goodnick, and Srabanti Chowdhury

Venus in a box – High Temperature NIR Emissivity Measurements of Venus Analogs  
- Jörn Helbert, Alessandro Maturilli, Darby Dyar, Sabrina Ferrari, Dennis Wendler, Marty Gilmore, Thomas Widemann, Mario D'Amore, Sue Smrekar

How well do we know Venus's gravity field? A retrospective - Peter James

Ultraviolet Absorber(s) on Venus – Bacteria? Physical, Chemical and Spectral Properties similar to some Micro-organisms? - Sanjay S. Limaye, Rakesh Mogul, Parag Vaishampayan, Arif Ansari, and Grzegorz Słowik

Constraints on Lithospheric Rheology and Volatile Content from Observations of Coronae – Joseph G. O'Rouke, Sue Smrekar, and L-N Moresi

Automaton Rover for Extreme Environments (AREE) - Jonathan Sauder, Evan Hilgemann, Michael Johnson, Bernard Bienstock, Aaron Parness

ADEPT SR-1 Flight Experiment Overview - Paul Wercinski, Alan Cassell, Brandon Smith, Bryan Yount, Shakib Ghassemieh, Ethiraj Venkatapathy, and Som Dutta

Venus UHF Data Relay Standard - Colin Wilson

EuroVenus Outreach Films – Colin Wilson