

Executive Summary

Venus Exploration Analysis Group (VEXAG) Meeting #4
Sunday-Monday, November 4-5, 2007
Greenbelt Marriott Hotel, Greenbelt, Maryland

Some 50 members of the Venus science community met on November 4th and 5th at the Greenbelt Marriott in Greenbelt, Maryland for the 4th Venus Exploration Analysis Group (VEXAG) meeting. This is the executive summary of the meeting. Later in the week, the NASA Workshop on Planetary Atmospheres and the Outer Planets Assessment Group (OPAG) held their meetings at the same hotel.

Presentations at this meeting included:

- 2 welcome and well-received reports from NASA Headquarters
- 7 scientific presentations associated with the special session on Venus-Earth climate connections
- 5 reports from the current Venus missions (Venus Express, MESSENGER Venus Fly-by and the Japanese Venus Climate Orbiter, VCO)
- 3 open-mike presentations about future Venus exploration instrumentation

Other presentations reported on a number of parallel activities such as:

- Venus Mission Architectures and Technology Developments
- The International Planetary Probes Workshop
- The European Venus Explorer Proposal and ESA's Cosmic Vision Program
- Education and Public Outreach
- Previews of the NASA Workshop on Planetary Atmospheres and OPAG Meetings
- The Planetary Science Summer School Venus Mission Study

A major accomplishment for this meeting was the publication and distribution of the first version of the VEXAG Venus Exploration Goals, Objectives, and Investigations document (aka the White Paper). This has been in development via open discussion of these Venus Exploration Goals, Objectives, and Investigations at the previous VEXAG meetings.

NASA announced at this meeting as follow-up to a VEXAG recommendation that there will be a Venus Science and Technology Definition Team (STDT) in FY08 with Mark Bullock (SwRI, Boulder) as Chair. Other members of the STDT were selected via a NASA NSPIRES call for Letters of Intent, soon after this meeting. Also, NASA as follow-up to another VEXAG recommendation will likely be pursuing a Venus Data Analysis Program in FY08 once the MESSENGER Fly-by and Venus Express data are available to community via the PDS and ESA Data Archives. VEXAG applauds NASA for their new program of annual Mission of Opportunities and for their improvements to the Research and Analysis Program.

This meeting also marked the transition of the VEXAG Chair from Janet Luhmann and Sushil Atreya, who have served us so well since the inception of VEXAG, to Ellen Stofan (Proxemy). Also, David Grinspoon (Denver Museum of Nature & Science) agreed to be the VEXAG Focus Group Lead for Venus-Earth Climate Connections and Mark Allen (JPL) agreed to be a VEXAG Focus Group Lead for Laboratory Measurements.

The next VEXAG meeting is scheduled for Wednesday-Thursday, May 7-8, 2008 at the Greenbelt Marriott, Greenbelt Maryland. This meeting will follow a meeting Venus STDT at the same hotel.

Summary Venus-Earth Connections Special Session

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One of the key activities at this VEXAG meeting was a special session on Venus-Earth Climate Connections. This included presentations of

- Greenhouse Effect and Radiative Balance on Earth and Venus - Dave Crisp
- Climate Sensitivity and History of Venus and Earth - Mark Bullock
- Aerosols on Earth and Venus - Brian Toon
- Atmospheric Dynamics of Venus and Earth - Jerry Schubert
- Solar History Effects on Venus and Earth Climate - Janet Luhmann for David Brain
- Sulfur Isotope Ratios and Constraints on Climate - Alex Pavlov

Venus is Earth's closest planetary neighbor, and a near twin in terms of bulk properties such as mass and size. Their densities and inventories of carbon and nitrogen are similar, suggesting similar primordial inventories. Current understanding of planetary formation and volatile accretion suggest that these twin planets started out with closely comparable surface environments, geological processes and atmospheric compositions. Yet despite their close proximity and similar origins, the two planets have evolved into very different states. Rotation state, magnetic field, surface temperature and pressure, total water inventory, global tectonics, lithospheric thickness and global patterns of geological activity are among the properties that differ dramatically. An understanding of the evolutionary history and current state of the Venus climate is directly relevant for studies of the past and future climates of Earth. As an extreme example of a very different climate on an otherwise similar and nearby planet, Venus provides an opportunity to improve and validate our knowledge of planetary climate modeling. In particular, Venus can provide a test bed for extreme cases and nonlinear effects in Earth climate. This synergism goes both ways: Our understanding of Venus would benefit greatly from use of the best Earth models and the expertise of the larger community of Earth scientists. Even while representing a very different evolutionary path for an Earthlike planet, Venus remains our closest analog for many important processes and planetary mechanisms operating on Earth. This unique combination of similar initial conditions and bulk properties with radically divergent evolutionary outcomes makes Venus-Earth comparative studies a uniquely fruitful area for expanding and testing our knowledge of planetary system science and global change.

Areas of potential study include:

Climate and radiative balance.

Venus as an extreme case of global warming.

Validation of techniques and models, test for imbedded assumptions, implicit simplifications or vestigial "black box code" in current Earth climate models.

Venus middle atmosphere as a "second experiment" for Earth's middle atmosphere.

Global Circulation.

Atmospheric angular momentum

Venus superrotation,

Earth stratospheric Quasi-Biennial Oscillation,

ENSO-connected variations of Earth's rotation period

Vorticity and storm morphology.
Volcano-climate interactions.
Climate feedbacks in complex global systems
Photochemistry (Cl, O, S)
The role of water in
 climate,
 geology (rheology and composition)
 plate tectonics
 interior dynamics and structure.

Studies of Venus meteorites
 Where are they? (impact ejection, orbital dynamics)
 How to identify them on the Earth or the Moon?
 Should an effort be made to find and study them before sample return?

Interior structure and dynamics, seismicity, heat flow, lithospheric thickness and surface manifestations (geological expression).
Volcanic compositions and morphologies
Isotopes and Atmospheric Evolution
 Rare Gases
 Stable isotopes (D/H, S, N, O)
Clouds and radiative balance (connections between microphysics, cloud morphology/dynamics/coverage and radiative balance)
Atmospheric escape
 Present day escape and fractionations
 Early solar system (enhanced XUV and solar wind)

Magnetic Fields
 Dynamo models
 Venus as an analog for Earth during future and past magnetic field reversals.
Venus, Earth and long term solar evolution (faint young sun, bright aging sun)
Solar climate forcing
Solar cycle response
 Climate
 Escape fluxes
Space weather and upper atmospheres
The future of Earth
 Climate
 Tectonics
Venus-Earth comparisons and extrasolar planet modeling.
Laboratory Studies relevant for Venus and Earth science.

Venus Exploration Analysis Group (VEXAG) Meeting #4
Sunday-Monday – November 4-5, 2007
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Sunday – November 4, 2007 - Afternoon

12:30 PM - Sign-In / Coffee and Pastries

1:00 PM - VEXAG Meeting #4 Overview and Objectives - Sushil Atreya and Janet Luhmann

1:15 PM - VEXAG Goals and Objectives Document – Janet Luhmann

1:30 PM - Venus Mission Architectures and Technology Developments - Jim Cutts/Tibor Balint

2:00 PM – Recap of International Planetary Probes Workshop – Jim Cutts

2:15 PM - European Venus Explorer Proposal and ESA's Cosmic Vision Program
– Eric Chassefiere

2:30 PM - Coffee Break

2:45 PM - Education and Public Outreach – Sanjay Limaye for Rosalyn Pertzborn

3:00 PM - Preview of OPAG Meeting – Sushil Atreya for Fran Bagenal

3:15 PM - Special Science Briefing – Venus Express VIRTIS Science Results
- Pierre Drossart / Giuseppe Piccioni

3:45 PM - Open Mike Presentations (1-2 slides, up to 10 minutes)
- Provide your presentation to the projectionist during the coffee break

4:30 PM - Planetary Science Summer School Venus Mission Study
- Britney Schmidt and Giovanni Minelli

4:50 PM – Preview of Monday's Activities – Sushil Atreya and Janet Luhmann

5:00 PM –SMD Update to VEXAG - Andy Cheng

5:20 PM – ADJOURN

Venus Exploration Analysis Group (VEXAG) Meeting #4
Monday – November 5, 2007
Salons A and B, Greenbelt Marriott Hotel, Greenbelt, Maryland

8:30 AM - Sign-In / Pick-up Handouts / Coffee and Pastries

9:00 AM - NASA Headquarters Perspective on Venus Exploration - Jim Green

9:30 AM - Status Report: ESA's Venus Express - Hakan Svedhem

9:50 AM - JAXA's Venus Climate Orbiter - Masato Nakamura and Takeshi Imamura

10:10 AM - MESSENGER Flyby – Sean Solomon, Hakan Svedhem

10:40 AM – Coffee Break

11:00 AM – Evidence for Past Oceans on Venus – Mark Bullock

11:30 AM – Preview of NASA Workshop on Planetary Atmospheres - Phil Crane

11:45 – LUNCH

1:00 PM - Venus-Earth Climate Connections (25-minutes each)

- o Greenhouse Effect and Radiative Balance on Earth and Venus - Dave Crisp
- o Climate Sensitivity and History of Venus and Earth - Mark Bullock
- o Aerosols on Earth and Venus - Brian Toon

2:15 PM - Coffee Break (15 Minutes)

- o Atmospheric Dynamics of Venus and Earth - Jerry Schubert
- o Solar History Effects on Venus and Earth Climate
– Janet Luhmann for David Brain
- o Sulfur Isotope Ratios and Constraints on Climate - Alex Pavlov

4:00 PM General Discussion - Venus-Earth Climate Connections – Larry Esposito, lead

4:30 PM – White Paper Discussion

5:00 PM - Wrap-up - Next Meeting - Recommendations - Action Items
- Sushil Atreya and Janet Luhmann

5:15 PM – ADJOURN

Narrative Minutes

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Some 50 members of the Venus science community met November 4th and 5th at the Greenbelt Marriott in Greenbelt, Maryland for the 4th Venus Exploration Analysis Group (VEXAG) meeting. This is a narrative summary of the proceedings. Most of the presentations made at this meeting have been posted to the VEXAG website.

Sushil Atreya (VEXAG Co-Chair, Univ. of Michigan) opened the meeting promptly at 1:00 PM and welcomed the attendees. Sushil noted that this is to be an 'expression' meeting, with the goal of gathering information on where we should be going, and that the agenda includes both input from the European community and from the science community. Sushil noted that the Venus Exploration Goals, Objectives, Investigations, and Priorities document (aka the VEXAG White Paper) is now posted to the web site, and also has been delivered to NASA Headquarters where it's being reviewed.

Janet Luhmann (VEXAG Co-Chair, UC Berkeley) provided an overview of the White Paper by discussing its contents: goals, objectives, outstanding questions in Venus exploration, and VEXAG's findings and proposals. Janet's take-home messages were:

- There is a lot of exciting and important science to do above and on Venus, our closest neighbor in the solar system.
- Venus' proximity to earth makes it a highly accessible target.
- Important science can be accomplished with existing technologies including missions under the New Frontiers program.
- However, investments in new technologies are required for next major steps forward in exploration, following the scientific exploration pathway established for Mars.
- Technology demonstrations in early missions will retire risk for later missions and should be considered as a desirable and acceptable part of a New Frontiers mission to Venus.

Janet invited the meeting attendees to make suggestions as to how the White Paper can be improved in the future. Mark Allen noted that the White Paper had been completed without the entire community involved in the process, and that White Paper needed to address 'laboratory science'. The VEXAG Executive Committee pointed out that the VEXAG Focus Groups via extensive discussion in the previous VEXAG meetings had developed the Venus Exploration Goals, Objectives, Investigations, and Priorities as they appear in the White Paper. The final document, which is just a few months old, has been posted to the VEXAG web site at the Lunar and Planetary Institute. There was some discussion about how the process to produce the next iteration of the White Paper might be improved. Further discussion of this occurred at the end of this meeting.

Tibor Balint (JPL) reviewed the results of a recently completed JPL internal study of potential Venus Flagship Mission Architectures and Technology Developments. He acknowledged the several contributors to the study that culminated in a workshop held in July. The study goals were to:

- Recommend one or more suitable flagship class mission architecture(s) for a NASA-sponsored flagship class Venus mission concept study by identifying mission architecture elements; science instruments, and technologies.

- Assess potential mission cost for the various architectures using a suitable methodology; e.g., from the NASA SRM-3 Study in support of the SSE Roadmap.
- Assure that science and architectures are in line with VEXAG goals.
- Report the findings to NASA Headquarters and the VEXAG community.

Tibor reviewed the several options for typical/generic Venus mission architectures and then presented the three sets of mission architectures that were selected by the workshop for future Flagship studies. They were:

- Venus Static Lander Architectures
- Venus Mobile Explorer Architectures
- Venus Geophysical Network Architectures

The lower bound of these would be a short-lived lander plus a single fly-by and the upper bound being sample return plus an orbiter. Technology development areas to support these options were identified as:

- Visibility/measurements/instruments
- Long-lived power and thermal control systems
- Mobility-related issues
- Sample acquisition

Jim Cutts (JPL) provided an overview of the 5th International Planetary Probe Workshop (IPPW-5) that was held in conjunction with a short course on Controlled Entry and Descent into Planetary Atmospheres in Bordeaux in June 2007. Presentations at IPPW-5 of interest to Venus community were on missions, technology, and packaging for extreme environments. Jim noted that the next International Planetary Probe Workshop (IPPW-6) will be held in conjunction with a Short Course on Extreme Environment Probe Technologies in Atlanta, Georgia, in June 2008. Georgia Tech will have a permanent website for IPPW. One goal of the next few IPPW's will be to expand student participation in these workshops. Later in the meeting, **Jim Cutts** introduced **Elizabeth Kolawa**, editor of the publication, *Technology of Extreme Environments*. Copies of this publication were available at this meeting for interested attendees.

Eric Chassefiere (Service Aéronomie, France) presented the European Venus Explorer (EVE), a proposed mission for ESA's Cosmic Vision 2015-2025. Eric discussed the arguments for a Venus mission (EVE) a mission that combines an orbiter, a balloon and a descent probe. The expected baseline science return from EVE would be:

- In situ measurement from the balloon of noble gas abundances and stable isotope ratios to study the record of the evolution of Venus.
- In situ balloon-borne measurements of cloud particle and gas composition, and their spatial variation, to understand the complex cloud-level chemistry.
- In situ measurements of environmental parameters and winds (from tracking of the balloon) for one rotation around the planet (7 days), to understand atmospheric dynamics and radiative balance in this crucial region.

EVE was proposed to be a cooperative mission with 170 Co-Investigators from 70 laboratories in 18 countries, including Russia, Japan, USA, and Canada. ESA's SSWG did not select EVE, even though it was highly ranked scientifically. The next AO for a second slice of Cosmic Vision will be issued in, or about 2010.

Sanjay Limaye (University of Wisconsin, Madison - filling in for Rosalyn Pertzborn) provided an update on Venus Express Education and Public Outreach. This is a coordinated effort with ESA, which is proving to be a useful. Sanjay described current Informal Education and Formal Education efforts, gave examples of curriculum activities developed under this program, as well as evaluations of the curricula by teachers. A list of public outreach accomplishments to date and

planned future efforts were presented. Contact for NASA sponsored Venus Education and Public Outreach is Rosalyn Pertzborn, rosep@ssec.wisc.edu.

Sushil Atreya (on behalf of Fran Bagenal, OPAG Chair, University of Colorado, Boulder) gave a preview of the Outer Planets Assessment Group (OPAG) meeting planned for this same venue on Thursday and Friday, November 8 and 9. Sushil noted that the highlights of the meeting are would be the status of the four Flagship Mission studies to Enceladus, Titan, Europa and the Jupiter System, as well as the two ESA Cosmic Vision proposals for two comet missions and their Titan Airplane study.

Pierre Drossart (Principal Investigator for the Visible and Infrared Thermal Imaging Spectrometer –VIRTIS; Observatoire de Paris) provided an overview of Venus atmosphere science results obtained with Venus Express. Pierre discussed instrument characteristics and current status. Recent VIRTIS papers have appeared in *Nature* and *Geophysical Research Letters*, and are in preparation for the Venus Express special issue of *Journal of Geophysical Research*. Recent data from day and night side observations were described. Pierre opined that the polar vortex is not just a cloud-top feature, but extends to considerable depth into the atmosphere. As of orbit 422 (about a year and 2 months into the mission), VIRTIS has collected 110 Gigabytes of data, that their first level analysis (measurements of physical quantities) is now routinely achieved. The VIRTIS team is beginning to address their their second level objectives (general circulation, radiative balance, survey of potential surface variability, and systematic survey of emissions by CO₂ and O₂ and modeling).

Open Microphone Presentations - At this point in the meeting, the microphone was opened for brief presentations by meeting participants.

Shiv Sharma (University of Hawaii), discussed work by the University of Hawaii and NASA Langley on the possibility of exploring the surface mineralogy and atmosphere of Venus with a combined remote Raman spectroscopy and elastic lidar system. Shiv suggested that if there has been water on Venus, amphiboles may exist and these and similar minerals are easily detected by Raman spectrometers. Spectra of terrestrial amphiboles and other hydrous minerals and their alteration products detected by a combined Raman spectroscopy and elastic lidar system were discussed. Spectra of controlled atmospheres and the aerosol scattering coefficient derived from lidar data around southeast Oahu were also described.

Jerri Ji (Honeybee Robotics) discussed two types of high temperature motors and drive trains developed by Honeybee for Venus exploration. A switched reluctance motor (SRM), which is currently in a SBIR development phase and was awarded Phase II in October 2007, has been operated for over 20 hours at 460 degrees C. Future development of these types of motors will enable Venus sample acquisition systems, robot arms, and even mobility systems. A comparison of the SRM with the flight standard Maxon motor, indicates that the SRM has two advantages over the brushless DC motor, with its higher initial torque and built-in redundancy.

Gary Hunter (NASA Glenn) described a number of recent developments with implementing semiconductors at extreme temperatures. The first transistor to surpass 3000 hours of stable operation at 500 degrees C has been demonstrated. It had less than 7% degradation in performance was observed, and most of that was in the first 100 hours. Also, the first analog semiconductor IC to surpass 3000 hours of electrical operation at 500 degrees C has been demonstrated. This provides an ability to interconnect transistors and other components in a small area on a single SiC chip to form useful IC's that are durable at 500 degrees. The first digital semiconductor IC to surpass 1000 hours of operation at 500 degree C has been

demonstrated. These recent accomplishments result from of continuous incremental improvements in the processing of the components over the last few years and not the result of any single breakthrough.

Britney Schmidt (UCLA) and **Giovanni Minelli** (Santa Clara University) presented the results of this year's Planetary Summer School at JPL, which developed a design for a Venus Exploration In-Situ Lander, VEIL. The summer school design team commenced by identifying the unresolved questions about Venus' atmosphere and mineral composition. This, combined with objectives directly traceable to the NASA Exploration Roadmap (**Check**) and Next Decadal Study, established a set of science objectives starting with their main science goal, to *Investigate Venus to understand its current state and the conditions that gave rise to its extreme environment*. Based on these objectives, their VEIL mission was characterized by:

Science Floor

- A. Characterize the nature of weathering and surface-atmosphere exchange on Venus
- B. Characterize the lower Venusian atmosphere (the lower 22 km)
- C. Determine the present surface conditions on Venus

Baseline Mission

- A. Search for evidence of volcanism on Venus
- B. Investigate the dynamics of the upper atmosphere

Enhanced Science

- A. Search for lightning signatures
- B. Investigate the space environment around Venus

The summer school design team established a suite of descent lander instruments to address these items and then determined their mass, power requirements, expected cost, as well as their placement on the descent lander. Landing sites were selected and subsequent data acquisition profiles were characterized. A proposed mission including trajectory, approach, entry descent and landing, and their probe descent profile was established. Major hardware components were defined including a novel pop-out descent braking plate. Two probes for cost effectiveness and redundancy were defined. Operations during each lander's one-hour descent and one hour lifetime on the surface were studied. The total cost of this mission was \$776M. An enhanced mission that included a surface preparation tool and lander "rocker" to better access the samples was costed at \$906M. Overall conclusions of this summer school study were:

- Venus presents challenging new scientific opportunities
- Surface and atmospheric science are feasible with New Frontiers budget (various architecture includes options that would increase science returns and there are options for international collaboration
- VEIL type mission could pave the way for future exploration of Venus (it establishes a heritage for landed Venus missions and provides a precursor mission to a Flagship rover)

Andy Cheng (NASA Headquarters SMD Deputy Chief Scientist) completed Sunday's presentations with an update on NASA's Science Mission Division (SMD) activities. The current SMD organization chart has Alan Stern as Associate Administrator and Jim Green, as Director of the Planetary Science Division. Alan Stern's four core objectives are to:

- Get more science done with our budget
- Ensure "The Vision" succeeds
- Promote US leadership across all of SMD science disciplines
- Create a better workplace

A new Lunar Science Institute for lunar science with a Central Node at NASA Ames has been established. Node proposals will be due early in 2008. Alan Stern has taken actions to repair what he sees as a 'broken' Research and Analysis (R&A) process by putting Yvonne Pendleton in

the front office with the job (Senior Advisor of Research and Analysis) of making science work better. Email her at sara@nasa.gov if you have issues, suggestions, or need help. Additional R&A changes, with more to come, are to give more money to each individual grant and make grants for longer periods (four years versus three). As these grants “come from the same bucket”, there will be fewer overall grants. Alan Stern is standing firm that over-budget missions will not get well by taking moneys from the Research and Analysis program.

Andy provided updates on on-going missions by noting that:

- Both EPOXI and NExT as well as 2013 ExoMars instruments Discovery/New Frontiers Missions of Opportunity had been selected
- The Outer Planet Flagship Mission studies are in and are being evaluated. Down-select is due in December 2007.
- SMD is moving to a yearly Mission of Opportunity call; e.g., there will be moneys set aside to support partnering with a foreign partner on a foreign mission.

Andy also noted that SMD's new Chief Scientist and two Deputy Chief Scientists are members of the science community, who represent the science community to the Associate Administrator (Alan Stern) by providing him with independent science and technical advice. Andy concluded by noting that he can be contacted at andrew.f.cheng@nasa.gov.

Jim Green (Director, NASA Headquarters Planetary Science Division, PSD) opened Monday's proceeding by presenting an update on Venus exploration activities within the PSD. Jim reported that:

- A New Discovery Program Scientist has been selected – Dr. Mike Kelly of Southern Georgia University.
- A new NASA Post-Doc has accepted to come to PSD – Dr. Sarah Noble
- NASA Headquarters has recently sponsored two successful workshops - Discovery at 15 (that was less about the science and more about how the program works and how to make it more successful) and Satellites of the Outer Solar System, - and a Planetary Atmospheres Workshop would be conducted on November 6 and 7, 2007.

Jim noted that Phoenix and Dawn are launched and on their way, that EPOXI and NExT have been selected as Missions of Opportunity, that the down-selection from the three finalists for Discovery Phase-A funding (GRAIL, OSIRIS, and Vesper) would be in December, and that the Mars Scout down-selection can be expected in January of '08. Jim noted here that the problem with making these selections is that NASA is currently under a continuing resolution. Because of this, NASA is operating at 2006 budget funding levels. Jim also noted that he had received the VEXAG White Paper and thanked and congratulated the writers on their product. It is NASA PSD's intention to implement as many of the VEXAG White Paper recommendations as possible and as soon as possible. In addition, the White Paper will play an important role in the next PSD roadmap.

Specifically, in response to the Findings in the White Paper:

- # 1:** In order to fully exploit the results from both the Venus Express and MESSENGER at Venus, made available via the Planetary Data System, funds should be identified to amend the NASA Research Announcement to include a Venus Data Analysis Program open to all.
- Action:** A new program in ROSES 2008 will be announced as the Planetary Data Analysis Program (PDAP) replacing DDAP. This is support studies of Venus data in the Planetary Data System. Up to 4 years may be proposed

2: NASA should initiate a study of a Flagship mission to Venus at the earliest opportunity.
Action: A Venus STDT will be formed for a FY08 study effort. This will be lead by JPL with Mark Bullock, SwRI, as chair. The STDT should also identify technologies needed for future Venus missions.

#3: The Venus In-Situ Explorer should be included in the New Frontiers AO for 2008 and the general scientific goals for this mission should remain unchanged.

Action: A National Academy committee (NOSSE) has been asked to provide guiding principles for the determination of the mission set in the next New Frontiers call and their report is expected in the January-March time frame. In addition, NASA is working on a PI qualifications list, which will be implemented via a web-accessible checking system by January

#4: NASA should initiate a program to develop technologies for operation in Venus extreme environment

Action: Agree in principle that Venus missions will require development of new technologies. Actual implementation is TDB

#5: A research program, encouraging conferences and/or workshops, should be initiated that brings together Earth scientists and Venus scientists for a focused study of the evolutionary aspects (past and future) of these terrestrial-planet twins.

Action: Agree with supporting forums in this area as acceptable plans can materialize as this is exciting. Suggest that heliophysicists be included along with earth scientists because the sun is a dominating influence on the system.

Regarding the Science and Technology Definition Team (Finding #2, above), the STDT will have the following goals:

- **Identify the key scientific questions** to be addressed by a long duration *in situ* exploration missions to Venus;
- **Conduct a pre-Phase A study** of a concept for a Flagship class mission, addressing those scientific questions, and that would be ready for launch in the 2020 to 2025 timeframe;
- **Identify the technology needs** and formulate a technology development plan for enabling this Flagship class mission;
- **Assess the precursor observations and technology validation experiments** needed to enable the Flagship class mission, which could be implemented as part of a prior New Frontiers class Venus mission;
- Evaluate how both **New Frontiers and Flagship** class missions would **contribute towards** the ultimate goal of **Venus Surface Sample Return** mission (the "Holy Grail")

The Team will have 12 members - there will be a call for participation via NSPIRES. The 1st meeting of the Team will be in January 2008, a mid-term report will be expected in June 2008, and the study conclusion and presentation to NASA Headquarters will be in September of 2008.

Jim continued by describing R&A improvements that are being pursued and the new approach of annual Planetary Missions of Opportunity (MoO). The first MoO call will be in the Spring of 2008. Jim concluded by noting that there is a New Mission Concepts Study call for 6-month studies on how Discovery and Mars Scout missions can use Stirling Radioisotope Power Systems. Future Discovery and Mars Scout missions can use Stirling RPS units, and the Stirling RPS units would be GFE.

Jim Green presented plaques to **Sushil Atreya** and **Janet Luhmann** to express NASA and Venus science community's appreciation for their serving as the first Co-Chairs of VEXAG. They were also given photo posters that all the attendees were invited to sign. **Ellen Stofan (Proxemy, Inc.)** was announced as the next Chair of VEXAG.

Haken Svedhem (ESTEC) presented the status and latest results from Venus Express (VEX). Hakan described the VEX instruments and then noted that the spacecraft and the operational troubles experienced by the sister spacecraft, Mars Express, have been successfully mitigated and the ground system is working flawlessly. The mission is very robust with regards to margins for power, fuel and thermal control. Venus Express has been running in its prime mission since June 2006, and well over one terabyte of science data have been received. Hakan described the polar vortex observed at both UV (VMC) and thermal IR (VIRTIS) wavelengths by showing a short movie representing 8 hours of real-time approach toward Venus in the UV. Analysis of these types of images enables characterization of zonal winds versus latitude. In addition, Venus Express data was also shown for the thermal structure of the atmosphere, structure of the ionosphere, and whistler radio waves caused by lightning. The Venus Express mission has been extended until May 2009 and they are preparing a proposal to ESA for an additional extension to bridge the gap until the Japanese VCO arrives in 2010 and for a period that will allow parallel operations. More information and images are available at [http://www.esa.int/SPECIALS/Venus Express](http://www.esa.int/SPECIALS/Venus_Express)

Masato Nakamura (JAXA) provided a report on recent major activities related to Japan's VCO/PLANET-C, a Venus orbiter with five instruments on board that is scheduled to launch in 2010. VCO's instruments include a lightning and airglow camera, a long-wave IR camera, an ultraviolet imager, and two shorter-wave IR cameras. Masato discussed the project schedule and noted that the current status is that the Proto-flight model has been integrated, all five cameras plus the control electronics were connected to the data handling unit, and these were tested as though they were on board the spacecraft. A nominal observing sequence was performed and bugs were fixed. Further tests are scheduled for December. In addition, a mechanical test model of the spacecraft was tested to characterize its response to vibrations of various modes and the numerical model was verified. Currently, tests of a thermal test model are in preparation, and data analysis tools are being developed. In the meantime, ground-based observations of Venus are being carried out -- wind profiles at the Nobeyama Millimeter Array and temperature mapping using radio and IR measurements. The VCO/PLANET-C project has an active EPO program that includes many public demonstrations and talks.

Sean Solomon (Carnegie Institution of Washington) presented early results from MESSENGER Venus Fly-by in June. Of six planetary fly-bys of MESSENGER's trip to Mercury, two are of Venus. The first was last year, while the second fly-by had cameras pointed at Venus and the antenna pointed toward the Earth. The MESSENGER data from the June fly-by will get to the PDS in December, within six months of acquisition. The observation objectives for each of the MESSENGER instruments during the fly-by were:

- MDIS:** images of the nightside surface in near-IR bands; color and high-resolution monochrome mosaics of both the approaching and departing hemispheres.
- MASCS:** profiles of atmospheric species on the dayside and nightside, UV observations of the exospheric tail, visible-near-IR observations of the clouds and surface near closest approach
- MLA:** passive radiometry at 1064 nm and ranging to the cloud decks
- EPPS:** charged particle acceleration at the Venus bow shock and elsewhere
- MAG:** interplanetary magnetic field (IMF) and its penetration into the Venus ionosphere, primary plasma boundaries, and near-tail region.

NS: observations of neutrons produced by the interaction of galactic cosmic rays with the atmosphere.

XRS: Venus X-ray spectrum (cf. Chandra)

For the Venus fly-by:

- MDIS obtained high-resolution color images of Venus clouds.
- Combined MDIS and VIRTIS observations at 1020 nm yielded surface images of most of southern Aphrodite Terra.
- MASCS observed absorption and emission features consistent with earlier observations.
- MAG observed three foreshocks upstream of the Venus bow shock.
- MLA laser ranging signals were strongly scattered by upper atmosphere; analysis of returns is ongoing.
- GRNS observed gamma-rays and neutrons from the Venus atmosphere.

This Venus fly-by served as a practice dry run for arrival at Mercury as well as an opportunity for coordinated observation of Venus with Venus Express, including:

- Complementary viewing geometry of atmosphere and cloud properties
- Coordinated observations by MDIS, MASCS, and VIRTIS
- Complementary measurements of IMF penetration into ionosphere, plasma boundaries, and tail

There will be a special session at the Fall AGU in December where both MESSENGER and Venus Express data and analyses will be presented.

Hakan Svedhem provided the Venus Express perspective of the coordinated Messenger /VEX experiment. Coordinated observations included:

- Observation of the same region before and after the flyby
- Complementary viewing of cloud geometries
- Atmospheric dynamics
- Airglow measurements
- Plasma investigations

Data gathered and cloud top and air-glow images were presented. Hakan noted that the MESSENGER fly-by occurred just at Venus' maximum elongation from the sun. At this time, a European ground-based and space-based observation campaign was running. A workshop addressing the ground-based observations will be held in ESTEC on December 17-19, in conjunction with a Venus Express Science Working Team meeting.

Mark Bullock (Southwest Research Institute, Boulder) as a precursor to the special session on Venus-Earth Climate Connections later in the meeting, presented work by himself and David Grinspoon on possible approaches to searching for evidence of past oceans on Venus. They considered six possibilities:

- Atmospheric isotopes, specifically the D/H ratio. He noted that it will be difficult to tell what the D/H ratios tell us until we refine the hydrogen escape flux and fractionation factor
- Atmospheric escape rates
- Better constrained models
- Surface mineralogies
- Evidence for sediments
- Zircons

Presently, the problem is underdetermined and improved measurements of D/H are needed in order to constrain escape flux. A proposed timeline for Venus history over was presented as:

- ≈ 2 G.Y. Loss of surface water. Subduction of hydrated sediments ceases.
- ≈ 700 M.Y. Episode of global subduction, global resurfacing
- 700 M.Y. to present: localized volcanism and tectonism, conductive heat release, and production population of craters.

To proceed further with this, Mark suggested that the following goals should be pursued:

- Push at the chronology of water loss from both ends:
 - Arrive at a consistent, better-constrained evolution of Venus.
 - Expand from Venus to a generalized model of terrestrial planet evolution.
- Improve the definition of habitable zones.
- Make useful predictions for extrasolar terrestrial planets.

Phil Crane (NASA Headquarters) provided a preview of the two-day NASA Planetary Atmospheres Workshop that followed this meeting. The Purpose, Goals, and Themes of the workshop are:

Purpose:

To highlight the planetary atmospheres research enabled primarily by the NASA Planetary Atmospheres program. The overarching goal of the workshop is to facilitate communication between researchers and to provide the opportunity for cross-disciplinary interaction.

Goals:

To enhance communication between planetary atmospheres researchers. Stimulate theoretical, laboratory, and observational activities in planetary atmospheric research in the next decade. Identify particular fields of critical interest, if any.

Themes

Atmospheres Around Solid Surfaces

Giant Planets

Other topics: Extra-solar Planets, Comets

Speakers and topics for each of the themes were presented.

Dave Crisp (JPL) opened the special session on Venus-Earth Climate Connections by addressing the Greenhouse Effect and Radiative Balance on Earth and Venus. Dave noted that while the surface of the Venusian cloud cover receives about 170 W/m^2 , only 17 W/m^2 reaches the surface. Then at the surface, trace gases CO_2 , SO_2 , OCS , and H_2S make the atmosphere nearly opaque. Further understanding of the Venus greenhouse effect would require the measurements such as:

- Vertical temperature profiles
- Trace gas distributions below the clouds
- Clouds distribution and optical properties
- Spectrally-dependent radiation field measurements (Solar/Thermal)

Dave noted that there are common greenhouse processes on Venus and Earth, where the greenhouse processes that contribute to the Earth's climate are easier to study in the atmosphere of Venus.

Mark Bullock (Southwest Research Institute, Boulder) discussed the climate sensitivities of Venus and Earth by comparing the responses of their atmospheres to greenhouse gases. The recent Intergovernmental Panel on Climate Change (IPCC) report indicates that 250 years of industrial activity on the Earth has resulted in an increase equivalent to 1.25 watts/meter-squared in the lower atmosphere. The net effect of forcing, response and feedback of doubling of carbon dioxide on the Earth creates a temperature difference of 2.9 K. On Venus, the net effect of forcing, response and feedback of water vapor and sulfur dioxide creates temperature differences of -2.9 K and -8.0 K respectively.

Brian Toon (LASP, University of Colorado) described the Aerosols and Clouds on Earth and Venus, noting that there are still many unexploited science problems on Venus. Among them are a basic understanding of the clouds, parallels between the Earth and Venus, learning about dynamics by using clouds as tracers, as well as the role clouds play in Venus climate and climate

change. On Venus, the photo-chemically produced sulfuric acid upper clouds are significant contributors to the greenhouse effect. In contrast, the Earth's sulfur budget is only approximately 0.02% of that of Venus. In addition, the middle and lower cloud decks on Venus are condensational, similar to terrestrial marine stratocumulus. This middle cloud deck, between about 50 and 57 km is neutrally stable, and the lower cloud deck may produce a radiative-dynamical feedback. Brian discussed a cloud dynamical analysis that compared closely with VIRTIS imagery. Current work is modeling of the holes in the condensational cloud deck using a microphysical cloud model with a radiative-dynamical feedback. Brian concluded by noting that on-going studies of Venus clouds will provide:

- Information about convection, waves, and large scale motions in the 45-60 km region from interpretations of near infrared markings. These motions may be drivers of the circulation.
- A better understanding of the sulfur cycle, and possibly climate change.
- Identification of the UV absorber with possible parallels to the anoxic early Earth.
- Insights into SO₂ reaction rates from the SO₂ vertical profile, and its changes

Gerry Schubert (UCLA) presented the current understanding of the Atmospheric Dynamics of Venus and the Earth from a dynamics point of view. Gerry noted that "the VEXAG Steering Committee had been discussing the connections between Earth and Venus studies and would like to highlight current understanding and possible opportunities for joint research in climate change." This could be addressed via three questions:

- What do the dynamical regimes of Venus and Earth have in common?
- What accounts for the differences in the atmospheric dynamics of these planets?
- Why study Venus' atmospheric dynamics to understand the dynamics of Earth's atmosphere?

A key goal is have a better understanding of the possible consequences of future climate changes on Earth. Although we currently depend on Global Climate Models (GCMs), it's not clear whether the current GCMs can simulate the dynamics of future atmospheres. There are some starts underway, such as the Venus atmospheric project at UCLA (which uses the NCAR CAM model) and Caltech's utilization of the NCAR WRF GCM. In addition, a proposed workshop at ISSI in Bern will bring Venus and Earth people together to understand the Venusian atmosphere. Gerry concluded by addressing, "Why study Venus (dynamics) from an Earth perspective?", by noting that it is because:

- It can tell us about future Earth atmospheric circulations.
- It can help us assess extrasolar planet habitability.

This in turn enables us to:

- Evaluate the ability of Earth GCMs to simulate atmospheric circulations under conditions different from the present.
- Learn about Venus itself.
- Enhance our understanding of atmospheric dynamics.

Janet Luhmann (filling in for David Brain - UC, Berkeley) discussed Solar History Effects on Venus and Earth Climate. Janet noted that the Sun is a factor as both radiative and non-radiative solar processes over time have affected both Venus' and Earth's climates. An important factor is that the Sun's energy input varies in time. There will be changes in the effects of fluxes of solar photons, solar wind, and solar storms on Venus' atmosphere and possibly effects of changing planetary albedo. Although there are ongoing efforts to incorporate these solar effects into atmospheric modeling, "more observation-inspired modeling experiments need to be done to simulate evolutionary scenarios that we can't directly observe." In summary:

- Solar XUV, solar wind, and solar storms provided more significant atmospheric energy inputs early in solar system history, and can vary significantly over shorter timescales at present.
- Recent modeling and observational efforts for Venus (and terrestrial planets) expand on

previous work, showing that solar photon and particle output variability should influence upper atmospheric structure, atmospheric temperatures, and particle escape

- Solar variability may drive changes in the Venus climate over short timescales, and has most certainly influenced the Venus climate and atmospheric water content over the past 4.5 Gyr. The parallel effects for Earth would need to be considered taking into account the effects of its planetary magnetic field.

Alex Pavlov (LPL, University of Arizona) concluded the presentations of the special session on Venus-Earth Climate Connections by describing the role that sulfur plays in the Venusian atmosphere. Alex noted that anomalous fractionation (MIF) in sulfur isotopes can be used to constrain the amount and state of sulfur in the Venusian atmosphere. Sulfur MIF signatures are observed in Martian meteorites, Archean rocks, and Antarctic ice cores during deposition of the volcanic sulfates from the large volcanic eruptions. The sulfur cycle on Venus has 2 branches where on one branch, the photosynthesis of sulfur dioxide in the atmosphere produces H₂SO₄ clouds. In the second branch, reactions with OCS produce various forms of pure sulfur. The implications for Venus are that there are several reservoirs of oxidized and reduced sulfur on Venus, and as a consequence sulfur MIF should exist in Venus aerosols. Thus, the magnitude of sulfur MIF would place constraints on the sulfur cycle in general as well as in the mixing between lower and upper atmosphere of Venus.

Larry Esposito (Univ. of Colorado) wrapped up the special session on Venus-Earth Climate Connections by leading a general discussion of what was learned by the presentations on Venus-Earth Climate Connections. This ended with the formation of a new VEXAG Focus Group with David Grinspoon as lead. David was asked by Ellen Stofan to provide a 1-page recommendation list for Ellen to present to NASA Headquarters. Possible recommendations were holding a workshop, writing an article for *Nature*, etc.

Janet Luhmann led a White Paper discussion as follow-up to the items raised when the White Paper was discussed at the beginning of the meeting. **Mark Allen** (JPL) requested that the VEXAG Goals, Objectives and Investigations be revisited by the VEXAG members in a near-term VEXAG meeting. **Ellen Stofan** agreed noting that VEXAG Goals, Objectives and Investigations would be a topic that should be revisited regularly (although the next VEXAG meeting would likely focus on the preliminary report from the new Venus STDT). **Janet Luhmann** said that for the next iteration of the White Paper, Mark will lead a VEXAG Focus Group on Laboratory Measurements, and David Grinspoon (as noted above) will lead a VEXAG Focus Group on Modeling Atmospheres for Venus, and the VEXAG prioritizations should be revisited after these two new Focus Groups have time to formulate their Goals, Objectives and Investigations. **Ellen Stofan** noted that the Venus STDT activity would likely impact the VEXAG priorities.

Ellen Stofan concluded the proceedings for this meeting by noting that the Venus STDT will get started in January. Their interim report is due to Jim Green in the spring. VEXAG will meet next in early May in the Eastern US, and then again possibly in November. The late early May VEXAG meeting will have a review of the preliminary findings of the Venus STDT.

Janet Luhmann thanked Monica Washington, Latessa Tuck, Andy Morrison and Tommy Thompson for their superb logistical support of this meeting.