Venus Exploration Analysis Group

Sanjay Limaye and Sue Smrekar
VEXAG Co-Chairs

AGU Fall Meeting, 16 December 2009

http://www.lpi.usra.edu/vexag/

VEXAG

- VEXAG initiated by NASA in 2005

- past chairs: Janet Luhmann, Sushil Atreya, Ellen Stofan, Steve Mackwell
- *Current Co-chairs:* Sanjay Limaye and Sue Smrekar recently appointed
- *Executive Committee:* Mark Allen, Kevin Baines, Jim Cutts, David Grinspoon, Lori Glaze, Adrianna Ocampo, with Tibor Balint, Mark Bullock, Larry Esposito, Jim Garvin, Ronna Hurd, Natasha Johnson, David Senske, Tommy Thompson, Allan Treiman
- International participation: H. Svedhem (Venus Express) and Masato Nakamura (Venus Climate Orbiter)

The Venus Exploration Analysis Group

- The Venus Exploration Analysis Group (VEXAG) was established by NASA in July 2005 to identify scientific priorities and strategy for exploration of Venus. VEXAG is currently composed of a chair and five focus groups. The focus groups will actively solicit input from the scientific community. VEXAG will report its findings and provide input to NASA, but will not make recommendations.

VEXAG Charter

- The Venus Exploration Analysis Group is NASA's community-based forum designed to provide scientific input and technology development plans for planning and prioritizing the exploration of Venus over the next several decades, including a Venus surface sample return. VEXAG is chartered by NASA's Solar System Exploration Division and reports its findings to NASA.

  Open to all interested scientists, VEXAG regularly evaluates Venus exploration goals, scientific objectives, investigations and critical measurement requirements, including especially recommendations in the National Research Council (US) Decadal Survey and the Solar System Exploration Strategic Roadmap (NASA).

Venus Exploration Goals

Venus Exploration VEXAG Analysis Group

Table 1-1. Venus and Implications for THE Formation of Habitable Worlds

Goal	Objective	Investigation
Origin and Evolution	Understand atmospheric evolution	Characterize elemental composition and isotopic ratios of noble gases in the Venus atmosphere, especially Xe, Kr, ^{40}Ar, ^{36}Ar, Ne, ^{4}He, ^{3}He, to constrain origin and sources and sinks driving evolution of the atmosphere.
		Determine isotopic ratios of H/D, $^{15}N/^{14}N$, $^{17}O/^{16}O$, $^{18}O/^{16}O$, $^{34}S/^{32}S$ and $^{13}C/^{12}C$ in the atmosphere to constrain paleochemical disequilibria, atmospheric loss rates, the history of water, and paleobiosignatures.
	Seek evidence for past changes in interior dynamics	Characterize the structure, dynamics, and history of the interior of Venus, including possible evolution from plate tectonics to stagnant-lid tectonics.
		Characterize the nature of surface deformation over the planet's history, particularly evidence for significant horizontal surface movement.
		Characterize radiogenic ^{4}He, ^{40}Ar and Xe isotopic mixing ratios generated through radioactive decay to determine the mean rate of interior outgassing over Venus' history.
	Determine if Venus was ever habitable	At the surface, identify major and minor elemental compositions (including H), petrology, and minerals in which those elements are sited (for example, hydrous minerals to place constraints on past habitable environments).
		Characterize gases trapped in rocks for evidence of past atmospheric conditions.

Venus as a Terrestrial Planet	Understand what the chemistry and mineralogy of the crust tell us about processes that shaped the surface of Venus over time	Characterize geologic units in terms of major, minor, and selected trace elements (including those that are important for understanding bulk volatile composition, conditions of core formation, heat production, and surface emissivity variations), minerals in which those elements are sited, & isotopes.
		Characterize the chemical compositions of materials near Venus' surface as a function of depth (beyond weathering rind) to search for evidence of paleochemical disequilibria and characterize features of surface rocks that may indicate past climate or biogenic processes.
		Assess the petrography (shapes, sizes, & mineral grain relationships) & petrology (formation characteristics) of surface rocks to aid in interpretation of chemical and mineralogical characterization.
		Determine the physical properties and mineralogy of rocks located in a variety of geologic settings, including meteoritic and crater ejecta, volcanic flows, aeolian deposits, and trace metals in the high radar reflectivity highlands.
		Characterize surface exposure ages through measurements of weathering rinds.
	Assess the current structure and dynamics of the interior	Characterize the current structure and evolutionary history of the core.
		Place constraints on the mechanisms and rates of recent resurfacing and volatile release from the interior.
		Determine the structure of the crust, as it varies both spatially and with depth, through measurements of topography and gravity to high resolution.
		Measure heat flow and surface temperature to constrain the thermal structure of the interior.
		Measure the magnetic field below the ionosphere and characterize magnetic signature of rocks in multiple locations.
		Characterize subsurface layering and geologic contacts to depths up to several km.
		Determine the moment of inertia and characterize spin-axis variations over time.

Goal	Objective	Investigation
Venus as a Terrestrial Planet	Characterize the current rates and styles of volcanism and tectonism, and how have they varied over time	Characterize active-volcanic processes such as ground deformation, flow emplacement, or thermal signatures to constrain sources and sinks of gases affecting atmospheric evolution.
		Characterize active-tectonic processes through seismic, ground motion, or detailed image analysis.
		Characterize the materials emitted from volcanoes, including lava and gases, in terms of chemical compositions, chemical species, and mass flux over time.
		Characterize stratigraphy of surface units through detailed topography and images.
		Assess geomorphological, geochemical, and geophysical evidence of evolution in volcanic styles.
	Characterize current processes in the atmosphere	Characterize the sulfur cycle through measurements of abundances within the Venus clouds of relevant gaseous and liquid/solid aerosol components such as SO_2, H_2O, OCS, CO, and sulfuric acid aerosols (H_2SO_4).
		Determine the mechanisms behind atmospheric loss to space, the current rate, and its variability with solar activity.
		Characterize local vertical winds and turbulence associated with convection and cloud-formation processes in the middle cloud region, at multiple locations.
		Characterize superrotation through measurements of global-horizontal winds over several Venus days at multiple-vertical levels (day and night) from surface to thermosphere.
		Investigate the chemical mechanisms for stability of the atmosphere against photochemical destruction of CO_2.
		Characterize local and planetary-scale waves, especially gravity waves generated by underlying topography.
		Measure the frequencies and strengths of lightning and determine role of lightning in generating chemically-active species (e.g., NO_x).
		Search for and characterize biogenic elements, especially in the clouds.

Climate Change and the Future of Earth	Characterize the Venus Greenhouse	Determine radiative balance as a function of altitude, latitude, and longitude.
		Measure deposition of solar energy in the atmosphere globally.
		Determine the size, distribution, shapes, composition, and UV, visible, and IR spectra, of aerosols through vertical profiles at several locations.
		Determine vertical-atmospheric temperature profiles and characterize variability.
	Determine if there was ever liquid water on the surface of Venus	Determine isotopic ratios of H/D, $^{15}N/^{14}N$, $^{17}O/^{16}O$, $^{18}O/^{16}O$, $^{34}S/^{32}S$ $^{13}C/^{12}C$ in solid samples to place constraints on past habitable environments (including oceans).
		Identify and characterize any areas that reflect formation in a geological or climatological environment significantly different from present day.
	Characterize how the interior, surface, and atmosphere interact	Determine abundances and height profiles of reactive atmospheric species (OCS, H_2S, SO_2, SO_3, H_2SO_4, S_n, HCl, HF, SO_3, ClO_2 and Cl_2), greenhouse gases, H_2O, and other condensibles, in order to characterize sources of chemical disequilibrium in the atmosphere.
		Determine rates of gas exchange between the interior, surface and atmosphere.

Why Venus? Why Now?
Venus as a case study of a terrestrial planet

- Venus challenges our ideas of how a terrestrial planet should behave and the factors that shape planetary evolution.
  - The study of the early evolution of Venus can help elucidate the role of deterministic vs. stochastic effects of early impact and volatile inventory
  - Venus may well have had an ocean, and thus have been habitable, up until ~ 1 by, much longer than water was abundant on Mars.
  - Venus is also an excellent place to study the interaction between the interior, outgassing, and climate
  - Venus atmospheric dynamics should be simple: Venus has no significant season, no land-ocean contrast, nearly uniform cloud cover and slow rotation, yet we do not have a good understanding of its workings.
  - Nature and properties of the Venus ultraviolet absorber remains unknown, as well as why it is so highly variable in space and time
  - The superrotation of the bulk of the atmosphere remains a puzzle for lack of salient measurements of key atmospheric processes

As we explore other solar systems, we can begin to assess whether Venus, Earth or both planets are anomalous.

We need new or better measurements of key Venus surface and atmospheric processes or properties

Why Venus? Why Now?
Venus, Earth and Climate Change

- Venus represents an extreme case of global warming
  - Provides an active example of runway greenhouse warming and demonstrates the role of cloud-climate feedback
- Venus provides our closest (and only) planetary analog for many important terrestrial climate processes
  - Ozone loss on the Earth was discovered due to the study of Venus upper atmospheric Chemistry
- Simulating the extreme climate of Venus can:
  - Help to validate terrestrial general circulation models and increase understanding of non-linear climate models.
  - Expose limitations of current climate models
- Many scientific problems of common interest to both Venus and Earth climate studies:
  - Aerosol microphysics and radiative properties, cloud morphologies and climate forcings, mesoscale and vortex dynamics, atmospheric responses to short and long term solar forcing
  - Volcano-climate interactions
  - Atmospheric angular momentum, and exchange with the sold planet
  - Venus dynamical phenomenon compared to Earth stratospheric oscillations

Recent VEXAG Activities

Completed:

- **12 White papers** on Venus were submitted to the **National Academy Planetary Science Decadal Survey** in September 2009 (www.lpi.usra.edu/vexag)
- 8th Low Cost Planetary Missions Conference (IAA)
  - Presentations on VCO, EVE and **VALOR**
  - Posters on NASA's **Flagship Mission to Venus** and VEXAG
- **VEXAG Open House** Meeting held on 4 October 2009 at the **DPS Meeting** in Fajardo, Puerto Rico
- **VEXAG Co-Chairs** provided some input to the **Decadal Survey Inner Planets Panel** Open Meeting in Irvine, California on October 26, 2009
- **7th VEXAG** Meeting held in Irvine, California (28-29 October 2009) immediately after the Decadal Survey Inner Planets Panel meeting
- Telecon with the Inner Planets Panel of the Decadal Survey (2 December 2009)
  - Venus Climate Mission (Flagship "Lite")
  - Recommendation for building communications assets at Venus for future missions

Upcoming:

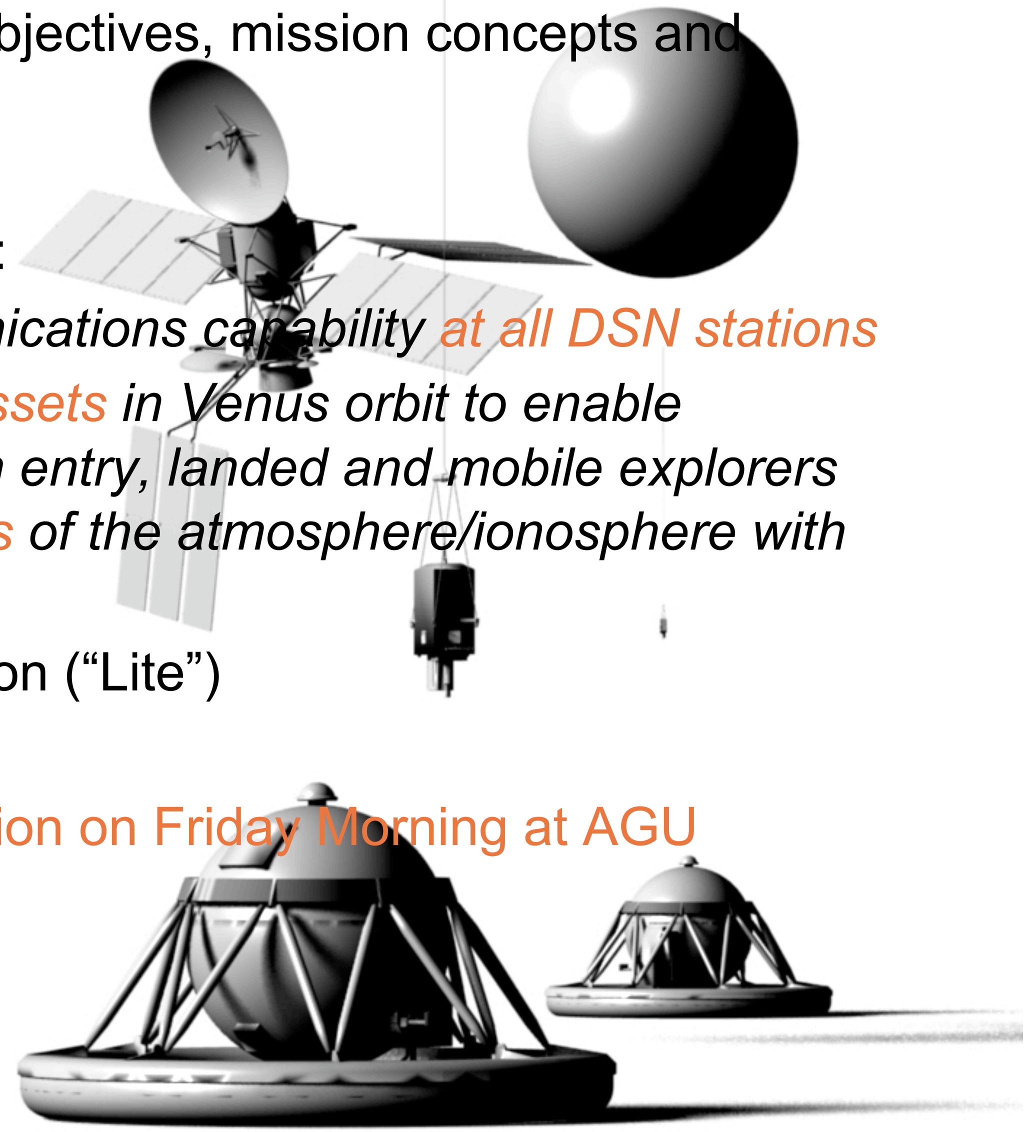
- Will hold a **VEXAG** Open House during **2010 LPSC** (1 – 5 March 2010)
- **8th VEXAG** Meeting and "Venus Atmosphere: Surface to Thermosphere" conference in Madison, Wisconsin 30 August – 2 September 2010.

Input to the Decadal Survey Inner Planets Panel

Venus Exploration Analysis Group

- 12 White papers on science objectives, mission concepts and technology development
- Specific recommendations for:
  - *Retaining S-band communications capability at all DSN stations*
  - *Building communication assets in Venus orbit to enable enhanced data return from entry, landed and mobile explorers and for mutual occultations of the atmosphere/ionosphere with other orbiters*
- Venus Climate Flagship Mission ("Lite")

Inner Planets Panel presentation on Friday Morning at AGU



Future Venus Exploration Efforts

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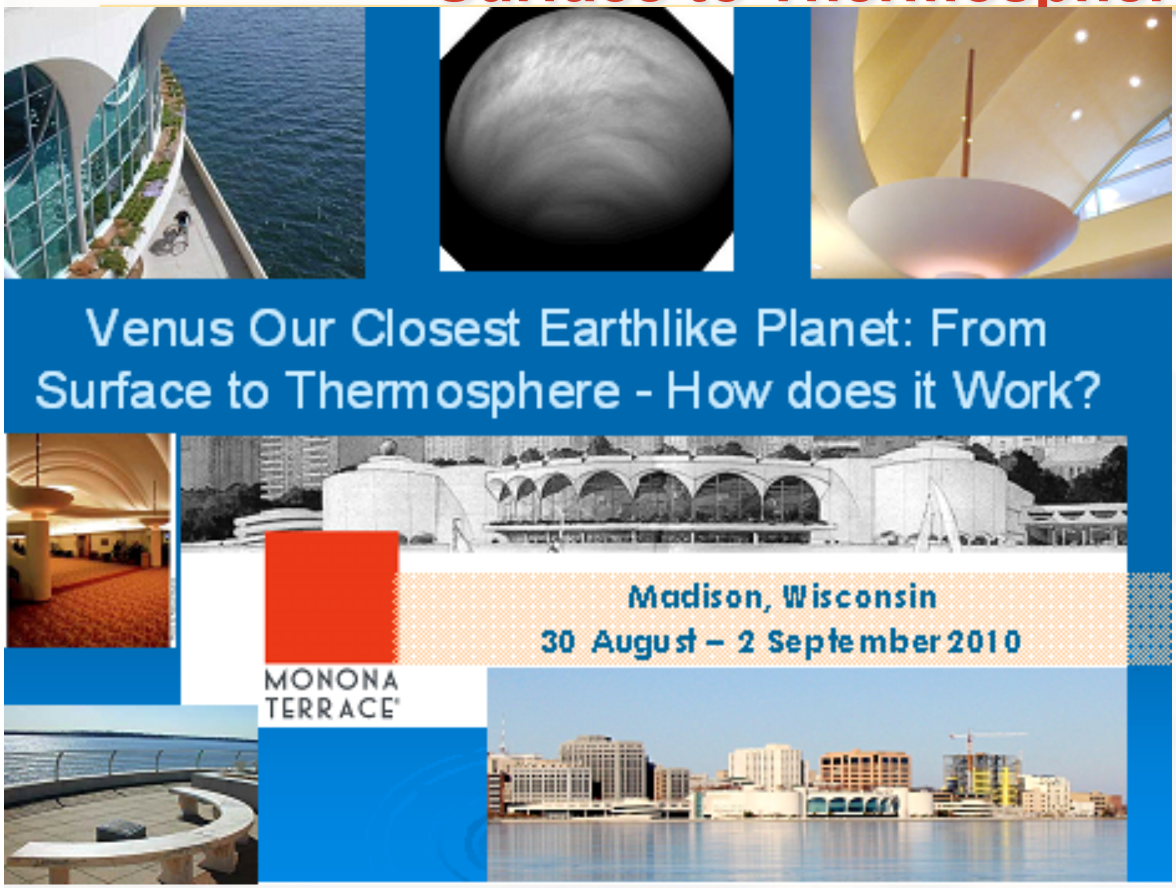
VEXAG provides opportunities for information exchange and effort coordination and collaborations

- **Venus Climate Orbiter (VCO)** to be launched by **JAXA** in May 2010. Arrival at Venus in December 2010
- **European Venus Explorer** (EVE) being developed for proposal to **ESA**'s Cosmic Vision Program
  - EVE will be re-proposed in 2010
- **Venera-D** being developed by **Russia (2016?)**
- **Venus Flagship Mission** Study Completed for NASA (2009) and a "Lite" version presented to IPP (December 2009)
- **Proposals submitted to NASA's New Frontiers** AO (July 2009)
- Anticipate several **Venus** proposals for **NASA's Discovery** Program (Draft AO is out for comments, Final AO ??)

Conference/Workshop on Venus Atmosphere: From Surface to Thermosphere

Venus Exploration VEXAG Analysis Group



A meeting to discuss current state of knowledge of the Venus atmosphere, challenges, observational, modeling and analsysis needs is being considered to be held. All interested scientists interested in Venus atmosphere and its interaction with the surface and comparative planetary meteorology are invited to participate.

Your ideas and suggestions for the conference format and program are solicited.

Contact: Sushil Atreya (atreya@umich.edu)
Sanjay Limaye Sanjay.Limaye@ssec.wisc.edu)

Venus, Closest Earth-like Planet: from Surface to Thermosphere - How does it Work?

- Major questions remain unanswered in dynamics, chemistry, surface-atmosphere interactions, radiative balance, climatology, and evolution of the Venus atmosphere. Here is a sampling of suggested topics for the conference:

- Nature, process, and consequence of surface-atmosphere interaction?
- Timing and cause of loss of water from Venus' surface, and its impact on atmospheric evolution
- Venus' runaway greenhouse effect and implications for Earth's climate evolution?
- Nature, period, an atmospheric impact of the global cataclysm that resurfaced Venus?
- Atmospheric dynamics, including origin of the superrotation of the Venus atmosphere, possible coupling between Hadley circulation and the hemispheric vortex circulation?

- It is anticipated that the conference will have a number of comprehensive presentations that will assimilate available spacecraft and ground-based observations as constraints to answering some of the major questions about the atmosphere of Venus. Extensive, lively, and appealing poster sessions are being envisioned also. Ample time will be reserved for discussions, with a focus on addressing key unresolved questions with models and future observations including those from approved (JAXA's Akatsuki), in development (Russian Venera-D, etc.) and yet to be proposed missions to Venus.

The conference will also present an opportunity for fostering coordination between various international missions to Venus to maximize the science return.

Flagship "Lite" Mission Concept

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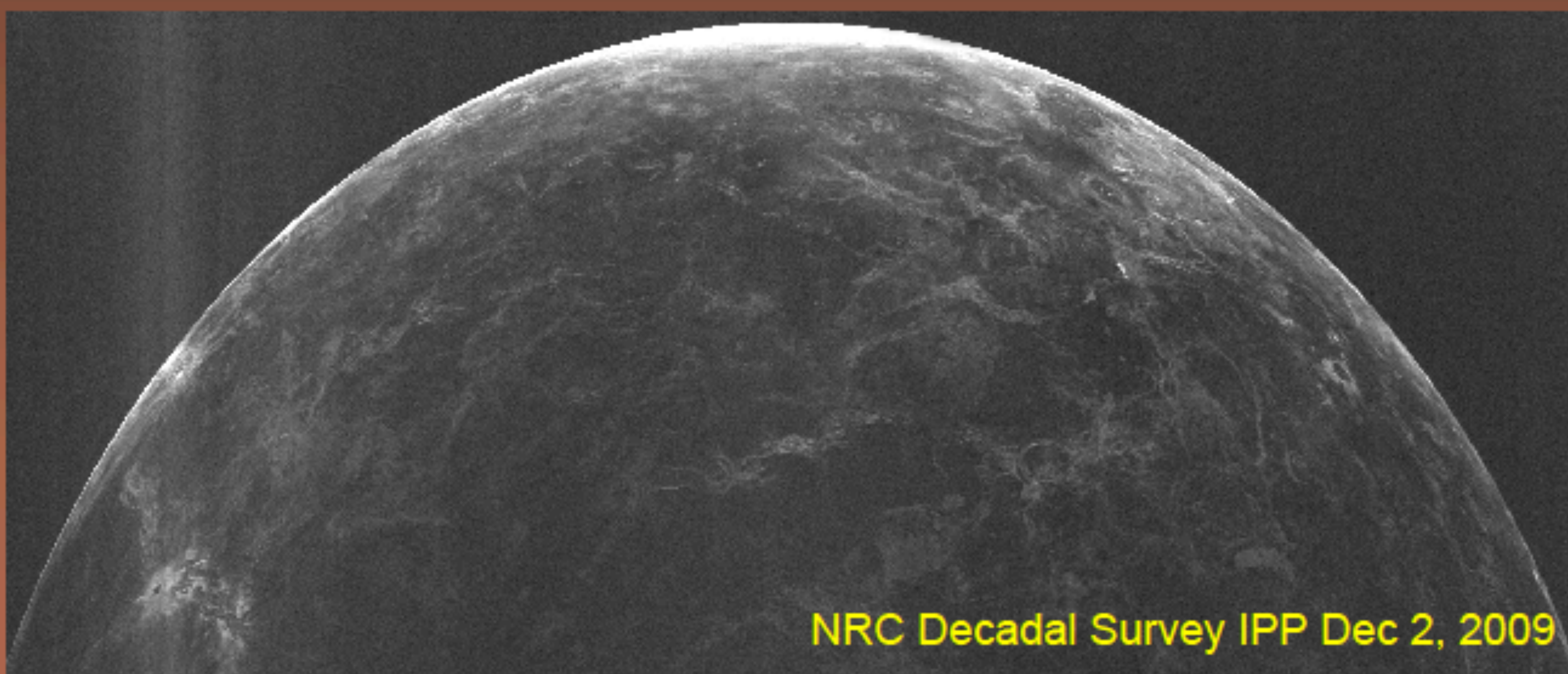
Venus Climate Flagship

Mark A. Bullock, Tibor S. Balint, Larry W. Esposito, Suzanne E. Smrekar, Sanjay S. Limaye, Kevin H. Baines, Lori S. Glaze, David H. Grinspoon, Mark Allen, Allan H. Treiman, Dave A. Senske, James B. Garvin, Tommy Thompson, Natasha M. Johnson, Sushil Atreya,



Venus Climate Flagship Mission

Venus Exploration Analysis Group

VCF Science Objectives

- Distinguish between theories of Venus' atmospheric origins and how it evolved differently from Earth's
- Reveal the tectonic and volcanic evolution of Venus and its link to climate
- Determine the interplay between photochemistry, clouds, atmospheric circulation and the greenhouse effect
- Investigate processes that have been suggested as critical in driving Venus' atmosphere superrotation
- Examine surface/atmosphere chemical cycles that influence climate
- Explore the geology & geochemistry at one location, obtaining ground truth for understanding geologic history

Venus Climate Flagship Mission

VCF Mission Architecture

- Orbiter with radar imaging, altimetry, near-IR spectroscopic imaging
- Balloon with atmospheric structure, tracking, and GCMS
- Lander with LIBS/Raman, imaging, gamma ray spectroscopy.
- Landing on plains or gentle slope of a volcano
- Orbiter, balloon, lander stacked for delivery by one Atlas V launch vehicle

Venus Climate Flagship Mission

VCF Straw Man Payload

Platform	Instrument	Investigation	Measurement
Orbiter	SAR/Radar altimetry VIS-IR imaging spectrometer VIS-IR camera	regional imaging & global topography composition, clouds, surface emissivity clouds & winds	10X Magellan horiz & vertical Optimized atm & surface Optimized for wind speeds
Lander	Descent camera Neutral Mass Spectrometer Atmospheric Structure Spectrometer Panoramic camera LIBS/Raman spectrometer Gamma ray spectrometer Microscope	nested images, compare to SAR noble gases, isotopes, composition P, T, winds, stability radiation balance & composition geologic history & mineralogy elements and mineralogy bulk element composition mineral texture	100 m to 10 cm/pixel Precision noble & light elements Rapid P,T, accel. on descent Up & down solar & IR flux High res multi-color panorama Several locations near lander Average of 1 m^3 under lander Mineral formation & alteration
Balloon	Tracking Atmospheric Structure Accelerometer Nephelometer Radiometer GCMS	winds, thermal tides, and super-rotation P, T vertical winds & turbulence cloud particle size & composition atmospheric energy balance cloud & atmosphere composition	4 circumnavigations Over local time and latitude Convective instabilities Composition with height Up & down solar & IR flux Cloud & photochemistry

Venus Climate Flagship Mission

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VCF Science Performance

MAJOR OPEN SCIENTIFIC QUESTIONS ABOUT VENUS	VENUS FLAGSHIP MISSION			VENUS CLIMATE FLAGSHIP		
	Orbiter	Landers	Balloons	Orbiter	Lander	Balloon
VENUS ATMOSPHERE						
How did Venus evolve to become so different from Earth?						
Was Venus ever habitable, and for how long?						
Did Venus lose a primary atmosphere due to impacts or loss to space?						
What drives Venus' atmospheric superrotation?						
How do geologic activity and chemical cycles affect the clouds and climate?						
How are atmospheric gases lost to space?						
VENUS GEOLOGY						
What is the volcanic and tectonic resurfacing history of Venus?						
How were the heavily deformed highlands made?						
How active is Venus geologically?						
Did Venus ever have plate tectonics and if so, when did it cease?						
How are geology and climate connected on Venus?						
What has been the role of water and other volatiles in Venus geology?						
VENUS INTERIOR STRUCTURE						
Does Venus have Earth-like continents?						
What are the chemical, physical, and thermal conditions of the interior?						
How does mantle convection work on Venus?						
What is the size and physical state of the core?						
What is the structure of the Venus lithosphere?						
How have water and other volatiles affected Venus' interior evolution?						
VENUS GEOCHEMISTRY						
Was there ever an ocean on Venus, and if so, when and how did it disappear?						
What caused the resufacing of Venus over the past billion years?						
What is the nature of chemical interactions between surface and atmosphere?						
What are the tectonic forces behind Venus' volcanism?						
How were the rocks and soils of Venus formed?						
What do chemical differences of terrains say about the evolution of Venus?						

Venus Climate Flagship Mission

Venus Exploration VEXAG Analysis Group

VCF Summary

- Highest priority VEXAG science goals can be met with a mission that focuses on climate.
- A mission that simultaneously deploys an orbiter, lander and balloon is the most cost-effective means for studying the climate system – atmosphere, clouds, surface.
- Such a mission, Venus Climate Flagship, could be flown for $1.7B

VEXAG

- Get involved! VEXAG represents you!
- Participate in the VEXAG meetings

Thank you