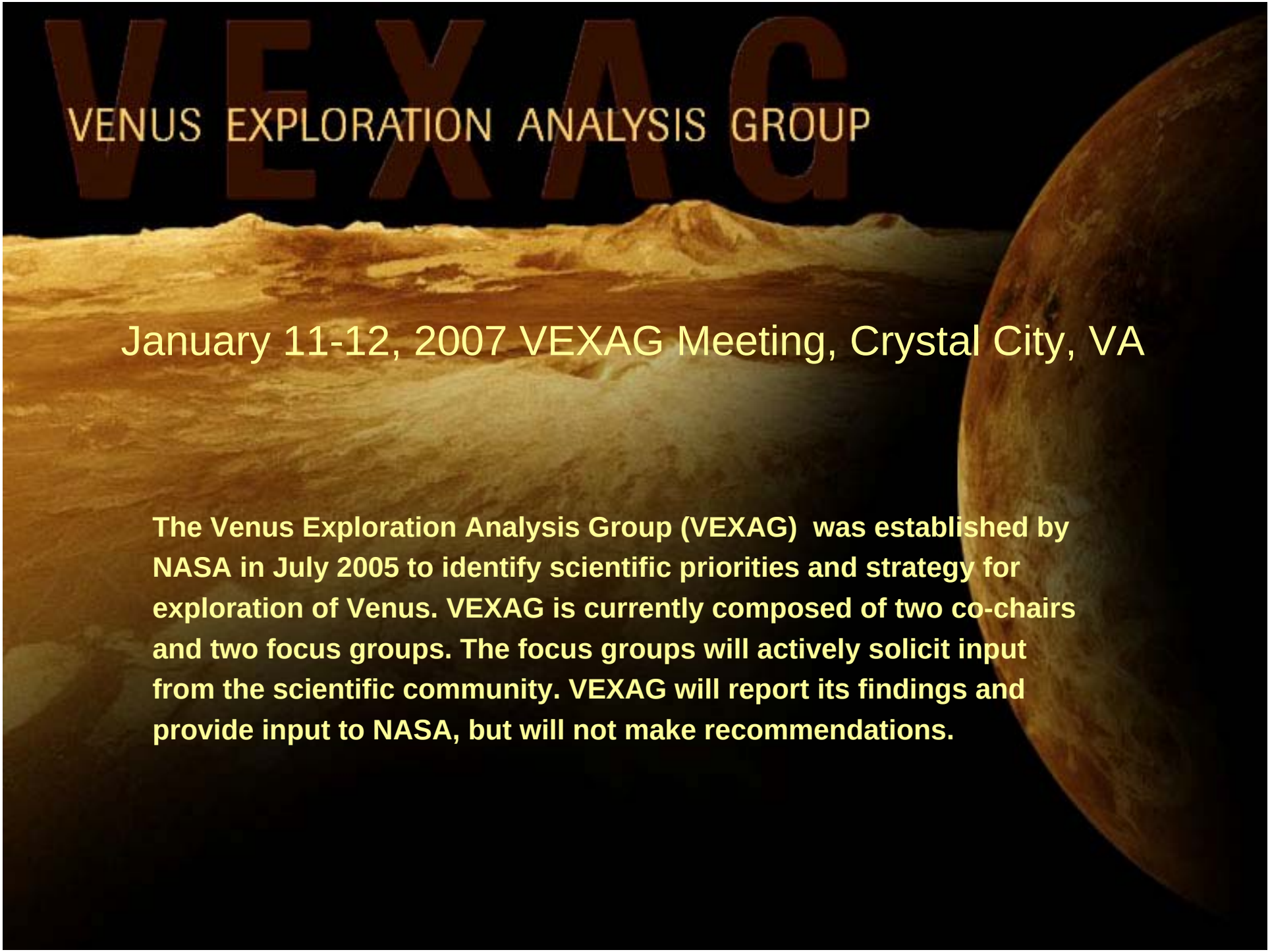
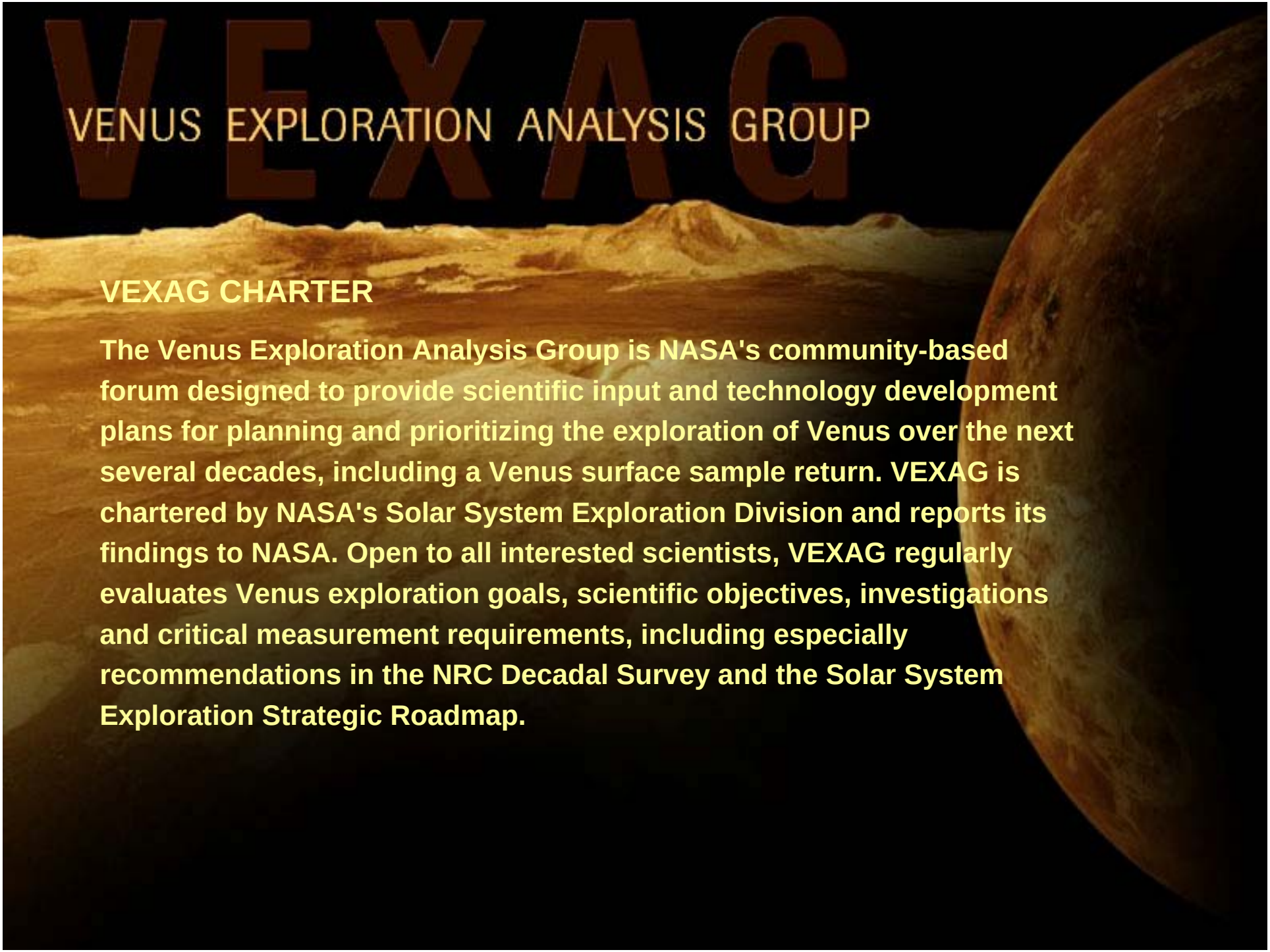


January 11-12, 2007 VEXAG Meeting, Crystal City, VA

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 two co-chairs and two 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 NRC Decadal Survey and the Solar System Exploration Strategic Roadmap.

VEXAG

VENUS EXPLORATION ANALYSIS GROUP

Co-Chairs:

Sushil Atreya, University of Michigan, Ann Arbor (atreya@umich.edu)

Janet Luhmann, University of California, Berkeley (jgluhmann@ssl.berkeley.edu)

Focus Groups:

1. Planetary Formation and Evolution: Surface and Interior, Volcanism, Geodynamics, etc.

Goal – Prioritize science objectives pertaining to the evolution and nature of Venus' surface and interior

Focus Group Lead: Steve Mackwell, LPI (mackwell@lpi.usra.edu)

2. Atmospheric Evolution: Dynamics/Meteorology, Chemistry, Solar Wind Interaction, Escape, etc.

Goal – Prioritize science objectives pertaining to the evolution and nature of Venus' atmosphere

Focus Group Lead: Kevin Baines, JPL (kbaines@pop.jpl.nasa.gov),

3. Technology Needs for Venus In-Situ Exploration

Goal – Establish the technology needs for future long-lived lander and mobile surface platforms

Focus Group Lead: Jim Cutts, JPL (James.A.Cutts@jpl.naa.gov)

Other VEXAG contacts:

Adriana Ocampo, Steve Saunders, NASA Headquarters (adriana.c.ocampo@nasa.gov, stephen.saunders@nasa.gov)

Steve Mackwell, LPI ((mackwell@lpi.usra.edu)

Tommy Thompson, JPL (twthomposn@jpl.nasa.gov)

VEXAG Web-Site - http://www.lpi.usra.edu/vexag
(Search on VEXAG and LPI) - Log in and fill out the Expression of Interest Form

VENUS EXPLORATION ANALYSIS GROUP

Past meeting action items

-months timescale: take on technology advisory role for VISE- Venus In-Situ Explorer New Frontiers candidate mission (Jim Cutts)

--~year timescale: Create a VEXAG Venus science goals/investigations/priorities document

- support Venus science and mission planning activities (Chapman Conferences, VEX and VEP workshops, etc.)

VEXAG

VENUS EXPLORATION ANALYSIS GROUP

VEXAG Meeting #1 - Pasadena, California - November 2005

Focus Group Formation and Kickoff

- Focus Groups (1) and (2) reviewed the current understanding of the current and past history of the atmosphere, surface and interior of Venus
- Focus Groups (1) and (2) identified critical technology areas in need of further investigation via future robotic missions.

Note: While several potential missions would involve remote sensing from orbit, many important measurements require surface or near surface components that must survive temperatures in the range of 350 to 470^{o}C, transient exposure to corrosive environments in the atmosphere during entry, and static pressures up to around 90 bars for periods of ~1 day to as much as a year. VEXAG provided S. Saunders with a white paper on Venus mission technical needs.

Some Venus Chapman Conference Conclusions of Relevance to VEXAG

- Deepest part of atmosphere still unexplored
- Super-rotation of atmosphere unexplained
- Surface mineralogy unknown
- Beta-Atla-Themis region is younger
- Early magnetic field could leave signatures
- Climate history has more sensitivities: Venus ocean could have persisted 2 b.y.
- Venus may have been habitable for much of its history

VENUS EXPLORATION ANALYSIS GROUP

VEXAG High-Priority Technology Development Requirements

Venus Exploration Analysis Group Meeting, Pasadena, CA

November 4, 2005

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

Recommendations/Disclaimers re. VEXAG Technology Development Paper

- Priority should given for the development of the following technologies for exploration of Venus.
- This list is not in priority order and is not meant to provide any prioritization for mission planning.
- There are a number of potential missions to study Venus that do not require significant technological development but utilize existing capability.

Short-duration missions (hours to days)

- **Passive cooling systems** to enable survival of communications systems and instruments at external temperatures of 470ºC and pressures of 90 bars for periods of at least 1 Earth day.
- **High-temperature electronics** for instruments and communication systems that must survive temperatures of up to 470ºC for both short- and long-duration missions.
- **Balloons** with mobility in both the vertical and horizontal directions, able to survive in corrosive environments at (variable) warm to hot temperatures.
- **Precision Landing** Capability
- **Autonomous Hazard avoidance** systems
- **Communications systems** for large data volumes, multiple platforms
- **High temperature extraction** and handling capability

Long-duration missions (months to years)

- **Active cooling systems** to enable survival of scientific instruments and communication systems at external temperatures of 470^{o}C and pressures of 90 bars for periods of at least 1 Earth year.
- **High-temperature power systems** capable of providing power for instruments and communications systems
- **Long-lived balloons** capable of operating within the cloud layer and below the cloud deck, tolerant to high temperatures and potentially corrosive environments.
- **Seismometers** able to operate on and communicate from the surface
- **Heat flow measurement** capability for near surface, including sample extraction

Synergies

Enabling technologies have applications to the exploration of other solar system bodies:

- Technology challenges of the operation in and communication from the extreme high-temperature and high-pressure environments at or near the surface of Venus are similar to those for deep entry probes at the outer gas-giant planets.
- Communications microsatellites are equally useful for multiple planetary missions.
- *In-situ* instrumentation (such as chemical analysis tools, and seismometers) may also be useful for other terrestrial planets or icy satellites.

Progress Report on preparation of **VEXAG Goals and Objectives** Document

Venus Exploration Analysis Group Meeting

Pasadena, CA

May 1-2, 2006

VEXAG Science Goals

I. Origin and Early Evolution of Venus: How did Venus originate and evolve, including the lifetime and conditions of a habitable environment? *(maps to Solar System Roadmap Objectives 1,2,5)*

II. Venus as a terrestrial planet: What are the processes that have and still shape the planet? *(maps to Solar System Roadmap Objectives 1,2,4)*

III. What does Venus tell us about the fate of Earth's environment? *(maps to Solar System Roadmap Objective 4)*

VEXAG Science Goals

…IN SIMPLE TERMS…

I. Origin and Early Evolution of Venus: How did Venus originate and evolve, including the lifetime and conditions of a habitable environment? *(maps to Solar System Roadmap Objectives 1,2,5)…VENUS OCEAN PROOF AND TIMING*

II. Venus as a terrestrial planet: What are the processes that have and still shape the planet? *(maps to Solar System Roadmap Objectives 1,2,4)…SURFACE OBLITERATION EXTENT AND CAUSE*

III. What does Venus tell us about the fate of Earth's environment? *(maps to Solar System Roadmap Objective 4) …IMPLICATIONS FOR EARTH*

Compare SRM 3: The Solar System Exploration Strategic Roadmap*

1. How did the Sun's family of planets and minor bodies originate?
2. How did the solar system evolve to its current diverse state?
3. What are the characteristics of the Solar System that led to the origin of life?
4. How did life begin and evolve on Earth and has it eveolved elsewhere in the Solar System?
5. Identify environmental hazards and resources enabling human presence in space

- *Roadmap Recommended Venus Missions: VISE, VME*

VENUS EXPLORATION ANALYSIS GROUP

Venus In-Situ Explorer (VISE) concept

Scientific Objectives:

•.Composition and isotopic measurements of surface and atmosphere

• Near IR descent images

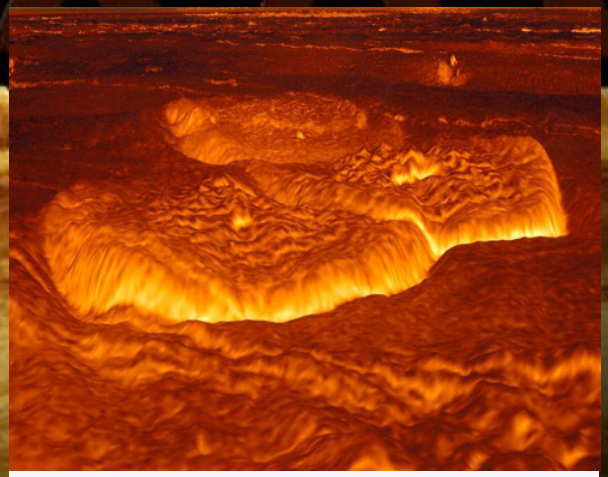
• Acquire and characterize a core sample.

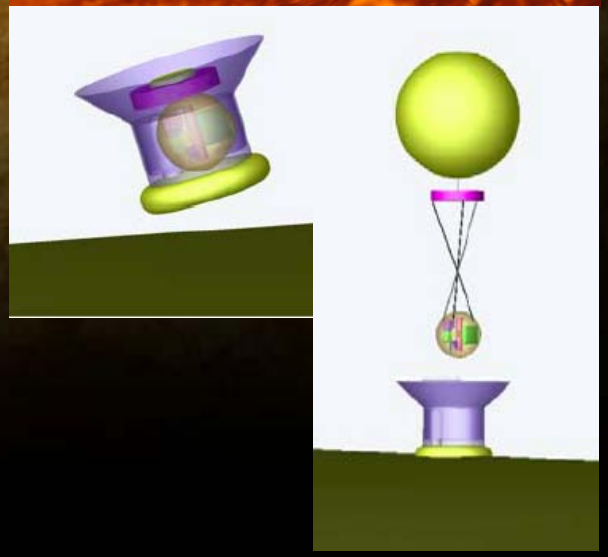
• **Demonstrate key technologies for VSSR**

Mission & LV Class:

• Intermediate Class

• TBD





Science Payload:

• Neutral mass spectrometer with enrichment cell.

• Instruments to measure elements and mineralogy of surface materials.

• Imaging microscope

Technology & Heritage:.

• Sample acquisition and handling in Venus environment

• Passive insulation and survival at Venus

Mission Technology Studies:

• Decadal Survey 2002 of ***Surface & Atmospheric In Situ Explorer (SAIVE)***

• JPL proposal in response to New Frontier Mission solicitation.

• Technology studies in In Space Propulsion, Low temperature materials and autonomy.

Earliest Launch Opportunity: Technology Readiness: 2010 Programmatic Slot: 2013

POC: Tibot.Balint@jpl.nasa.gov

VENUS EXPLORATION ANALYSIS GROUP

Venus Mobile Explorer-VME concept

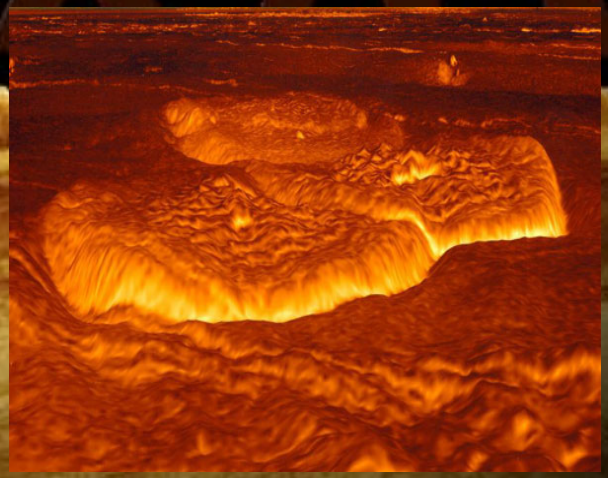
Scientific Objectives:

• Composition and isotopic measurements of surface and atmosphere

• Near IR descent images

• Acquire and characterize a core sample.

• **Demonstrate key technologies for VSSR**

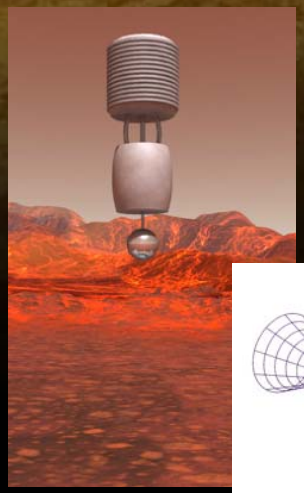


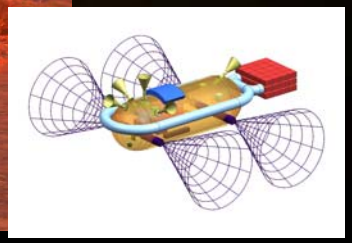
Exploration Metrics:

• Operate in Venus surface environment for 90 days

• Range across surface if rover TBD

• Range and altitude if aerial vehicle TBD





Mission & LV Class:

• Intermediate Class

• LV: TBD

Science Payload:

• Neutral mass spectrometer with enrichment cell.

• Instruments to measure elements and mineralogy of surface materials.

• Imaging microscope

Technology & Heritage:.

• Sample acquisition and handling in Venus environment

• Passive insulation and survival at Venus

Mission Technology Studies:

• Decadal Survey 2002 - none.

• Technology studies for definition of advanced RPS systems, 2005

Earliest Launch Opportunity: Technology Readiness: 2013 Programmatic Slot: 2013

POC Tibot Balint@jpl.nasa.gov

VENUS EXPLORATION ANALYSIS GROUP

NRC New Frontiers in the Solar System
An Integrated Exploration Strategy (2003)

2: Inner Solar System: Key to Habitable Worlds

Unifying themes for studies of the inner planets

The past: Where did we come from? What led to the unique character of our home planet?

The present: What is going on? What common dynamical processes shape Earth-like planets?

The future: Where are we going? What fate awaits Earth's environment and those of the other terrestrial planets?

VENUS EXPLORATION ANALYSIS GROUP

NRC New Frontiers in the Solar System An Integrated Exploration Strategy (2003) (cont.)

Crisp et al. companion report: "Divergent Evolution among Earth-like Planets: The Case for Venus Exploration", ASP Conference Series

Unifying themes for studies of Venus

-past: Origin of terrestrial planets in our Solar System

-present: What processes shape the terrestrial planets?

-future: What does Venus tell us about the fate of the Earth's environment?

VEXAG Goal I. Origin and Early Evolution of Venus: How did Venus originate and evolve, including the lifetime and conditions of a habitable environment?

- **Objective 1:** Determine atmospheric composition to seek chemical and isotopic signatures of earlier epochs of Venus' history, and clues to Venus' origin, formation and evolution through time.
- **Objective 2:** Quantify the history of volatiles in the interior, surface and atmosphere of Venus, including degassing and atmospheric escape, to understand the planet's geologic and atmospheric evolution.
- **Objective 3:** Map rock mineralogy and elemental composition on a planetary scale to search for evidence of an earlier, cooler and wetter Venus.
- **Objective 4:** Seek evidence for biologic markers in Venusian environments, including sedimentary rock structures and/or fossil evidence of biological organisms, isotopic anomalies and disequilibrium.

VEXAG Goal I. Origin and Early Evolution of Venus: How did Venus originate and evolve, including the lifetime and conditions of a habitable environment?

- **Objective 5:** Determine the ages of the various rock units on the surface of Venus, both absolute and relative.
- **Objective 6:** Understand Venus as an analogue for extra-solar planets.
- **Objective 7:** Understand the orbital dynamical history of Venus, including its movement through the solar system "habitable zone".

VEXAG Goal II. Venus as a terrestrial planet: What are the processes that have and still shape the planet?

- **Objective 1:** Constrain the coupling of thermochemical, photochemical and dynamical processes in the Venusian atmosphere to understand radiative balance, climate, dynamics and chemical cycles.
- **Objective 2:** Determine the nature of the solar wind interaction and ionosphere and its role in volatile loss.
- **Objective 3:** Characterize three-dimensional atmospheric circulation to understand the super-rotation of the atmosphere and meridional transports.
- **Objective 4:** Characterize the Venus Greenhouse effect, including the interplay of chemistry and physics of the atmosphere, especially the clouds.

VEXAG Goal II. Venus as a terrestrial planet: What are the processes that have and still shape the planet?

- **Objective 5:** What is the nature of tectonic evolution on Venus, what is the level of current activity, and what effect does it have on the atmosphere or climate?
- **Objective 6:** Constrain the resurfacing history of Venus, including the current and past rates of volcanic activity, including outgassing and interior-surface-atmosphere coupling.
- **Objective 7:** Determine the history of and current state of interior evolution of Venus, including the internal physical, chemical, thermal and magnetic structure.

VEXAG Goal III. What does Venus tell us about the fate of Earth's environment?

- **Objective 1:** Search for evidence of past global climate change on Venus.
- **Objective 2:** Search for evidence of past changes in interior dynamics and tectonics.
- **Objective 3:** Characterize the Venus Greenhouse effect, including its interaction with surface and interior, allowing a comparison to atmospheric evolution on Earth, Mars, Titan and extra-solar planets.
- **Objective 4:** Using Venus data, determine the evolution of planetary atmospheres in the absence of a shielding magnetosphere, as may have happened in the past or may occur in the future on Earth.

VEXAG Goals and Objectives
Where to from Here?

- Approval of objectives from VEXAG community (June 2006)
- Prepare text for each Objective (June 2006)
- We already have a long list of Investigations for each Objective from the May 2006 VEXAG meeting, which we will refine and send to the VEXAG community for comment/input/addition (Summer 2006)
- Next VEXAG meeting: present and refine Goals/Objectives/Investigations document, define Measurements and develop priorities