Venus Exploration

VEIL

In-Situ Lander
Team PSSS-2 2007
New Frontiers

Mission Phases
- Development
- Cruise
- Operations
- Extended

New Frontiers - Pluto Kuiper Belt Explorer
Juno - Jupiter Polar Orbiter
Saturn Flyby w/ Shallow Probes
Comet Surface Sample Return
Venus In Situ Explorer (VISE)
South Pole-Aitken Basin SR

New Frontiers missions: Development ~5 years
Decision Points: by science & technology (completed)
Unanswered Questions

- **Key issues that remain unresolved:**
  - Chemical composition of the lower atmosphere
    - Only have 12 measurements of 5 species below 22 km
    - Some of these measurements conflict
      - At an altitude of 22km, Pioneer Venus reported $[\text{SO}_2] = 185 +/-$ 43 ppm, while Vega 1 reported $[\text{SO}_2] = 38 \text{ ppm}$
  - Mineral composition of the surface
    - Only elemental composition has been studied thus far
    - Not sensitive to elements less massive than $Z < 12$ (Mg)
Unanswered Questions

• Why are these measurements important?
  – To determine if the surface interacts with the atmosphere, and how
    • (ex.) If CO is at equilibrium with CO$_2$ near the surface, specific iron oxide species are expected. Measuring surface minerals places a constraint on the CO-CO$_2$ system.
  – To understand the history of the venusian crust
    • (ex.) Measurements of felsic minerals would place constraints on the formation of the venusian crust.
  – To understand the current rate of volcanism
    • (ex.) Measurements of atmospheric sulfur gases and surface minerals will tell us if active volcanism is required to maintain the sulfur cycle on Venus.
Science Motivation

• Main Science Goal:
  – Investigate Venus to understand its current state and the conditions that gave rise to its extreme environment
Solar System Roadmap

- SSE Roadmap themes addressed:
  - Understanding solar system diversity
  - Understanding habitable regions around other stars
  - Understanding the future of Earth
Science Objectives

Surface-Atmosphere Interactions

- Noble gas abundances
- Compositions below 22 km
- Mineralogy
- Oxidation state
- Morphology
- Wind speed
- Age
- PT profile
Science Objectives

Science Floor
A. Characterize the nature of weathering and surface-atmosphere exchange on Venus
B. Characterize the lower Venusian atmosphere
C. Determine the present surface conditions on Venus

Baseline Mission
D. Look for evidence of volcanism on Venus
E. Investigate the dynamics of the upper atmosphere

Enhanced Science
F. Search for lightning signatures
G. Investigate the space environment around Venus
Science Themes

VEIL’s science links to three main themes:

<table>
<thead>
<tr>
<th>Theme</th>
<th>NRC Decadal Survey</th>
<th>2006 Solar System Exploration Roadmap</th>
</tr>
</thead>
<tbody>
<tr>
<td>Origins</td>
<td>• Learn how the Sun's family of planets originated and</td>
<td>• How did the Sun’s family of planets and minor bodies originate?</td>
</tr>
<tr>
<td></td>
<td>evolved.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Discover how the basic laws of physics and chemistry,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>acting over eons, can lead to the diverse phenomena</td>
<td></td>
</tr>
<tr>
<td></td>
<td>observed in complex systems, such as planets.</td>
<td></td>
</tr>
<tr>
<td>Processes</td>
<td>• How did the solar system evolve to its current</td>
<td>• Understand the processes that determine the fate of the</td>
</tr>
<tr>
<td></td>
<td>• How did the solar system evolve to its current</td>
<td>solar system and life within it.</td>
</tr>
</tbody>
</table>
## Science Traceability: Science Floor

<table>
<thead>
<tr>
<th>Science Objective</th>
<th>Science Investigation</th>
<th>Measurement Objectives</th>
<th>Instruments</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A Characterize the nature of weathering and surface-atmosphere exchange on Venus</strong></td>
<td>A1. Determine the composition of the lower 22 km of the atmosphere.</td>
<td>A1a. Direct measurement of reduced (COS, H2S, S1-8) and oxidized (SO2) sulfur gases below 22 km.</td>
<td>GCMS</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A1b. Direct measurement of CO concentration below 13 km.</td>
<td>GCMS</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A1c. Direct measurement of H2O concentration below 22 km</td>
<td>GCMS</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A1d. Direct measurement of Hydrogen isotopes in the lower atmosphere.</td>
<td>GCMS</td>
</tr>
<tr>
<td></td>
<td>A2. Determine the oxidation state of the Venusian crust</td>
<td>A2a. Determine oxidized species on surface.</td>
<td>Raman/IR spectrometer</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A2b. Direct measurement of CO concentration below 13 km</td>
<td>GCMS</td>
</tr>
<tr>
<td></td>
<td>A3. Determine wind speeds, thermal and pressure profiles throughout the atmosphere.</td>
<td>A3a. Measure wind speeds upon descent from entrance to the surface.</td>
<td>Doppler tracking</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A3b. Measure temperatures through descent.</td>
<td>Thermometer</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A3c. Measure pressures through descent.</td>
<td>Barometer</td>
</tr>
<tr>
<td></td>
<td>A4. Determine heat flux from the surface.</td>
<td>A4a. Measure the temperature gradient from the base of the cloud deck to the surface.</td>
<td>Thermometer</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A4b. Measure the temperature at the landing site.</td>
<td>Thermometer</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A5b. Assess the size, shape and weathering of rocks near the landing site.</td>
<td>Visible Imager</td>
</tr>
</tbody>
</table>
## Science Traceability:
### Science Floor

<table>
<thead>
<tr>
<th><strong>B</strong> Determine the present surface conditions on Venus</th>
<th><strong>B1.</strong> Determine the mineralogy of the surface of Venus.</th>
<th><strong>B1a.</strong> Measure mineral composition on the surface, especially carbonates and basaltic minerals.</th>
<th>Raman/IR spectrometer</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td><strong>B1b.</strong> Measure mineral composition below the weathered layer</td>
<td>Raman/IR spectrometer/Surface Preparation Tool</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>B1c.</strong> Measure iron oxide (hematite, magnetite) abundances on surface.</td>
<td>Raman/IR spectrometer</td>
</tr>
<tr>
<td></td>
<td><strong>B2.</strong> Determine the oxidation state of the Venusian crust.</td>
<td><strong>B2a.</strong> Determine oxidized species on surface.</td>
<td>Raman/IR spectrometer/GCMS</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>B2b.</strong> Direct measurement of CO concentration below 13 km</td>
<td>GCMS</td>
</tr>
<tr>
<td></td>
<td><strong>B3.</strong> Investigate surface for aeolian features and evidence of wind erosion.</td>
<td><strong>B3a.</strong> High-resolution imaging of surface features.</td>
<td>Visible Imager</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>B3b.</strong> Assess the size, shape and weathering of rocks near the landing site.</td>
<td>Visible Imager</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>B3c.</strong> Identify regions of varying regolith properties.</td>
<td>Visible Imager</td>
</tr>
<tr>
<td></td>
<td><strong>B4.</strong> Assess relative surface ages.</td>
<td><strong>B4a.</strong> Look for evidence of cratering.</td>
<td>Visible Imager</td>
</tr>
<tr>
<td></td>
<td><strong>B5.</strong> Characterize surface morphology</td>
<td><strong>B5a.</strong> Image the surface of Venus on descent</td>
<td>Visible Imager</td>
</tr>
<tr>
<td></td>
<td><strong>B6.</strong> Assess surface strength</td>
<td><strong>B6a.</strong> Measure hardness of rocks on the surface.</td>
<td>Surface Preparation Tool</td>
</tr>
</tbody>
</table>

### C Characterize the lower Venusian atmosphere

| **C1.** Determine the composition of the lower 22 km of the atmosphere. | **C1a.** Direct measurement of reduced (COS, H2S, S1-8) and oxidized (SO2) sulfur gases below 22 km. | GCMS |
|  | **C1b.** Direct measurement of CO concentration below 13 km. | GCMS |
|  | **C1c.** Direct measurement of H2O concentration below 22 km. | GCMS |
|  | **C1d.** Direct measurement of Hydrogen isotopes in the lower atmosphere. | GCMS |
|  | **C1e.** Direct measurement of trace species (e.g. Chloride, Floride). | GCMS |
| **C2.** Determine noble gas abundances. | **C2a.** Measure noble gas abundances as a function of distance from the surface. | GCMS |
| **C3** Determine wind speeds, thermal and pressure profiles throughout the atmosphere. | **C3a.** Measure wind speeds upon descent from entrance to the surface. | Doppler tracking |
|  | **C3b.** Measure temperatures through descent. | Thermometer |
|  | **C3c.** Measure pressures through descent. | Barometer |
|  | **C3d.** Measure density through descent. | Accelerometer |
## Instrumentation

<table>
<thead>
<tr>
<th>Instruments</th>
<th>Mass</th>
<th>Power</th>
<th>Descoped</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visible Imager</td>
<td>1kg</td>
<td>4W</td>
<td></td>
</tr>
<tr>
<td>Meteorological Package</td>
<td>2.4kg</td>
<td>5W</td>
<td></td>
</tr>
<tr>
<td>Gas Chromatograph Mass Spectrometer (GCMS)</td>
<td>17.2kg</td>
<td>10W</td>
<td></td>
</tr>
<tr>
<td>Thermal Infrared Imaging Spectrometer (TIRIS)</td>
<td>4.8kg</td>
<td>5W</td>
<td></td>
</tr>
<tr>
<td>Raman/Laser-Induced Breakdown Spectrometer (LIBS)</td>
<td>12kg</td>
<td>15W</td>
<td></td>
</tr>
<tr>
<td>Surface Preparation Tool</td>
<td>0.2Kg</td>
<td>4W</td>
<td>X</td>
</tr>
<tr>
<td>Lightning Detector (VLF and Photodiode) Probe &amp; Carrier S/C</td>
<td>2kg</td>
<td>1W</td>
<td>X</td>
</tr>
<tr>
<td>Magnetometer on Carrier S/C</td>
<td>8.1kg</td>
<td>14W</td>
<td>X</td>
</tr>
<tr>
<td>Visible Imager on Carrier S/C</td>
<td>1kg</td>
<td>4W</td>
<td>X</td>
</tr>
<tr>
<td>Space Env. Monitor on Carrier S/C</td>
<td>19.5kg</td>
<td>10W</td>
<td>X</td>
</tr>
</tbody>
</table>
Landing Sites

L1: Alpha Regio
Lat/Lon: 0.5W, 28S
Elevation: ~ 2 km

L2: Lavinia Planitia
Lat/Lon: 5.5W, 35.5S
Elevation: ~ -0.5 km
Landing Sites

L1
L2
Alpha Regio

Magellan (NASA)
## Data Acquisition Profile

<table>
<thead>
<tr>
<th>Distance</th>
<th>Equipment</th>
<th>Bandwidth</th>
</tr>
</thead>
<tbody>
<tr>
<td>80 km</td>
<td>MET package, Imager, and Doppler radio tracking</td>
<td>16 Mb</td>
</tr>
<tr>
<td>22 km</td>
<td>GCMS, TIRIS, MET package, Imager, and Doppler radio tracking</td>
<td>183 Mb</td>
</tr>
<tr>
<td>Ground</td>
<td>MET package (15 min.), Imager, TIRIS, and Raman/LIBS</td>
<td>100 Mb</td>
</tr>
</tbody>
</table>

- Imaging rate at 5 images/sec between 80-1 km; 2 images/sec between 1 km and ground.
MISSION DESIGN
Trajectory

30 day ticks

Launch Period

<table>
<thead>
<tr>
<th></th>
<th>Launch</th>
<th>Arrive</th>
<th>C3</th>
<th>DLA</th>
<th>EntVel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open</td>
<td>5/10/15</td>
<td>11/8/15</td>
<td>8.89</td>
<td>-7.2</td>
<td>11.2</td>
</tr>
<tr>
<td>Mid</td>
<td>5/20/15</td>
<td>11/8/15</td>
<td>7.93</td>
<td>-9.2</td>
<td>11.1</td>
</tr>
<tr>
<td>Close</td>
<td>5/30/15</td>
<td>11/8/15</td>
<td>8.08</td>
<td>-11.6</td>
<td>11.0</td>
</tr>
</tbody>
</table>

7 month mission
172 day cruise

Launch Vehicle:
Atlas V (401)
2900 kg max payload

Delta-V Budget: 135 m/s
TCMs: 60 m/s
Lander 2 Retargeting: 5 m/s
Carrier Divert: 70 m/s
Sun to Venus View

30 minute ticks on Carrier trajectory
Orange lines are communication links
Blocked from Sun: 53.5 minutes
Approaching Venus

Probes stacked on carrier
Carrier is 3-axis stabilized

T – 5 days to entry
11/3/15
- Spin S/C
- Release Probe
- Stabilize S/C

12 hrs after first probe release
- Pointing maneuver
- Spin S/C
- Release Probe
- Stabilize
- Maneuver/ Point Antennas
- Listen for probe

Entry 11/8/15
Scientific data transmitted to Earth
Entry, Descent, and Landing

Assumes uniform atmospheric profile

Descent to 32 km:
- 15 minutes
- 25 m/s terminal velocity

Descent to surface:
- 45 minutes

Velocity will need to be reduced to 11.85 m/s

Increase drag or reduce ballistic coefficient by a factor of 4.45
Probe Descent Profile

1. Atmosphere Entry
2. Parachute Deploys
3. Aeroshell dropped; Probe attached to top shell by tether.
4. Tether holding probe released.
5. Landing struts deployed
6. Drag characteristics altered Alt. < 22 km
7. Contact w/ surface
Major Architectural Components

- Carrier Spacecraft w/ 2 probes mounted
- Two probes selected for cost effectiveness and redundancy
- Carrier S/C acts as communications relay
- TPS selection from heritage

Thermal Protection System

Probe Lander
VEIL Entry Vehicle

Pioneer/Venus Heritage

Cost Constraints
No new developments
Flight qualified
Only minor modifications

1.5m diameter entry shell
Houses 73.5cm diameter probe

Teflon radio-transparent window
Aft Cover
Fiberglass
Aluminum

Carbon Phenolic or PICA TPS
(Front and Aft Shells)

Aluminum Entry Shell
Proposed Probe Design

Folding Braking Plate

Folding Legs

Stowed

Deployed
Descent Lander

- 6 Total Penetrations
- 3 Windows
- 3 Ports

- Paraffin Embedded in Package
Atmosphere/Surface Operations

Descent

- telecom
- GCMS
- 45° imaging

Surface

- telecom
- 45° imaging

- RAMAN/LIBS
Carrier Spacecraft

Stowed

1st Probe Stowed

2nd Probe Deployed
### Mass and Power

<table>
<thead>
<tr>
<th></th>
<th>Mass (kg)</th>
<th>Contingency %</th>
<th>Total Mass (kg)</th>
<th>Power (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Probe</td>
<td>187.7</td>
<td>27</td>
<td>240.7</td>
<td>209</td>
</tr>
<tr>
<td>Carrier</td>
<td>324.8</td>
<td>27</td>
<td>413.0</td>
<td>387</td>
</tr>
</tbody>
</table>
# Total Cost

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost (M$, FY07)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carrier &amp; Misc. Total</td>
<td>578.07</td>
</tr>
<tr>
<td>Probe Total</td>
<td>197.76</td>
</tr>
<tr>
<td>TOTAL</td>
<td>775.83</td>
</tr>
</tbody>
</table>
Enhanced Configuration – SPT

- Mineralogical analysis of rock under the weathered exterior
  - Drill / Rock abrasion tool
  - Chisel
  - Ballistics
  - Diamond saw
  - Explosives
  - Articulated arm raises sample to camera
- Rocker chassis mechanism deploys tool to instrument workspace with little mechanical complexity

Mars Exploration Rover RAT surface preparation (NASA/JPL/Cornell)
Enhanced Configuration

• An alternative design for a higher cost cap

• Probes: $240.98M, 413.8kg
  – Surface Preparation Tool (SPT)
  – Lander lightning experiment

• Carrier: $538.08M, 369.6 kg
  – Magnetometer experiment
  – Space environment monitor
  – Imager

• Total: $906.06M
  – No change in launch vehicle or flight trajectory
Conclusions

• Venus presents challenging new scientific opportunities

• Surface and atmospheric science are feasible with New Frontiers budget
  – Architecture includes options that would increase science returns
  – Options for international collaboration

• VEIL type mission could pave the way for future exploration of Venus
  – Establishes “heritage” for landed Venus missions
  – Precursor mission to Flagship rover
## Acknowledgements

PSSS-2 wishes to thank:

<table>
<thead>
<tr>
<th>Tibor Balint</th>
<th>Steve Kondos</th>
<th>Coco Karpinski</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anita Sohus</td>
<td>Susan B-K</td>
<td>Daniel Sedlacko</td>
</tr>
</tbody>
</table>

**Team-X:**

<table>
<thead>
<tr>
<th>Harry Aintablian</th>
<th>Charles Baker</th>
<th>Susan Barry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Richard Cowley</td>
<td>Brian Cox</td>
<td>David Hansen</td>
</tr>
<tr>
<td>Samantha Infeld</td>
<td>Cin-Young Lee</td>
<td>Peter Meakin</td>
</tr>
<tr>
<td>Bob Miyake</td>
<td>Adam Olvero</td>
<td>Bill Smythe</td>
</tr>
<tr>
<td>Ted Sweetzer</td>
<td>Mark Wallace</td>
<td>Mark Welch</td>
</tr>
<tr>
<td></td>
<td>Julie Wertz</td>
<td></td>
</tr>
</tbody>
</table>