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# VADER: Venus Atmosphere, Descent and Environmental Researcher, a NASA Planetary Science Summer School mission concept

**P. Sharma[1], D. Nuding[2], P. Ozhogin[3], I. Bell[4], K. Bennett[5], T. Broiles[6], P. Byrne[7], M. Chojnacki[8], E. Frank[9], J. Hanley[10], J. Kay[11], E. Larson[12], M. Pendleton[13], S. Schwartz[14], G. Vixie[15], C.J. Budney[16], L.L. Lowes[16] and K. Mitchell[16]**

[1]Division of Geological and Planetary Sciences, California Institute of Technology, [2]Cooperative Institute for Research in Environmental Sciences, Department of Atmospheric and Oceanic Sciences, University of Colorado at Boulder, [3]Center for Atmospheric Research, University of Massachusetts Lowell, [4]University of Michigan, [5]School of Earth and Space Exploration, Arizona State University, [6]University of Texas-San Antonio/Southwest Research Institute, [7]Department of Terrestrial Magnetism, Carnegie Institution of Washington, [8]Department of Earth and Planetary Science, University of Tennessee, [9]Department of Geological Sciences, University of Colorado at Boulder, [10]Arkansas Center for Space and Planetary Sciences, University of Arkansas, [11]Department of Earth and Environmental Science, University of Illinois at Chicago, [12]Department of Atmospheric and Oceanic Sciences, University of Colorado at Boulder, [13]Department of Geological Sciences, University of Idaho, [14]University of Maryland/Observatoire de la Côte d'Azur, Nice, France, [15]Department of Physics, University of Idaho, [16]Jet Propulsion Laboratory

psharma@caltech.edu

## INTRODUCTION

- In 2011, the Planetary Science Decadal Survey [1] identified a Venus In-Situ Explorer as one of the top candidates for a New Frontiers class mission for the decade 2013-2022.
- In response to this survey and the New Frontiers Announcement of Opportunity (2009) [2], we propose a mission concept, Venus Atmosphere, Descent and Environmental Researcher (VADER), to explore the lower atmosphere and surface of Venus.
- Following the requirements of the 2009 AO, our proposed lander-probe hybrid would examine the physics and chemistry of the atmosphere and surface, Venus's atmospheric dynamics, and the surface-atmosphere interactions in terms of weathering and hydrology.
- VADER would be launched onboard an Atlas 411 launch vehicle on July 8th, 2020 with a launch mass of 1354 kg.
- The proposed mission described here resulted from an intensive one-week mission design exercise, conducted as part of the 2012 NASA Planetary Science Summer School at the Jet Propulsion Laboratory (JPL) (https://pscischool.jpl.nasa.gov/index.cfm).

**Fig. 1. Proposed mission's logo**

## SCIENCE GOALS

Investigating Venus's atmosphere and surface would not only answer questions about its origin, evolution, and the dominant processes shaping the planet [3], it would also provide insights into the fate of Earth's environment under a scenario of increasing greenhouse gas emissions and sustained climate change.

The science goals for this mission are to understand:

- The physics and chemistry of the atmosphere of Venus;
- The interactions between atmosphere and surface to understand radiative balance, climate dynamics and chemical cycles,
- The physics and chemistry of the crust of Venus;
- The properties of Venus's atmosphere down to the surface, and to improve our understanding of Venus's zonal cloud-level winds;
- The weathering environment of the crust of Venus; and
- To search for planetary-scale evidence of past hydrologic cycles, oceans, and life.

Figure 2 shows a schematic view of measurements that would be taken by instruments onboard the spacecraft to achieve these scientific objectives.

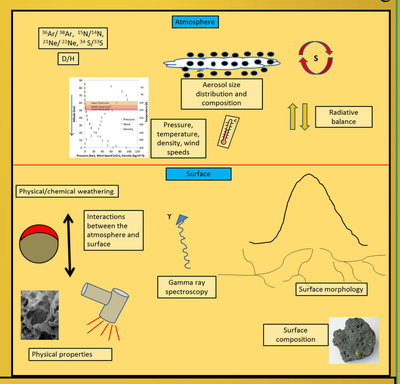


**Fig. 2. Proposed measurements from atmosphere and surface of Venus**

As the mission timeline in Fig. 3 shows, VADER would conduct scientific investigations for 60 minutes during descent through Venus's atmosphere and upon landing for 75 minutes at a location inside our selected landing ellipse (75 km × 150 km, centered at 8°S, 289°E on the flanks of Phoebe Regio, shown in Fig. 4)

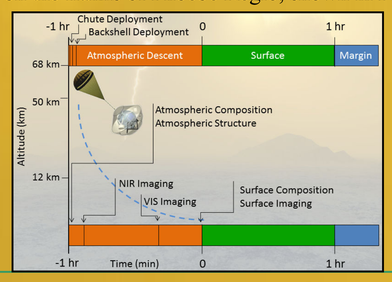


**Fig. 3. Mission Timeline**

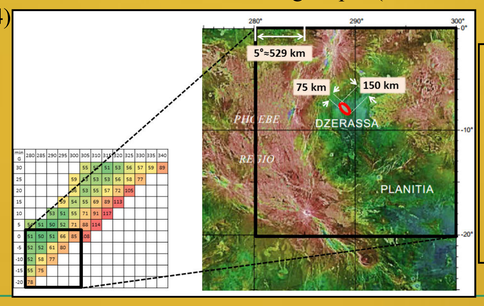


**Fig. 4. Selected landing ellipse on the flanks of Phoebe Regio. The basemap shows Magellan radar altimetry data at a scale of 1: 10 million**

## INSTRUMENTS

VADER would carry four suites of instruments to address its science goals: 1) *Atmospheric Composition Suite*, 2) *Imaging Suite*, 3) *Surface Composition Suite*, and 4) *Atmospheric Dynamics Suite*. Figure 5 and Table 1 show the different instruments that would be included within each of these four suites and the scientific measurements they would take.

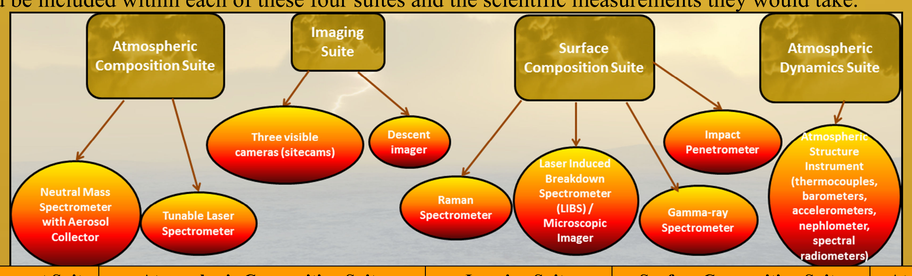


**Fig. 5. Proposed instruments onboard VADER**

| Instrument Suite | Atmospheric Composition Suite | Imaging Suite | Surface Composition Suite | Atmospheric Dynamics Suite |
|---|---|---|---|---|
| Scientific Measurements | 1) Identify chemical make-up of aerosol particles<br>2) Measure sulfur ($SO_2$, OCS/COS, $H_2S$)<br>3) Isotopic ratios of allotropic Sulfur ($S_{34}$, $S_{33}$)<br>4) Isotope ratios of $Xe_{134}$ through $Xe_{136}$, $Ar_{36}$ /$Ar_{38}$, $Ne_{21}$ and $Ne_{22}$, $N_{15}/N_{14}$, $He_3/He_4$<br>5) D/H ratio and escape fluxes; atmospheric water vapor abundance | 1) Small scale surface morphology: e.g. joints, cracks, ventifacts, ripples<br>2) Large scale surface morphology: e.g. yardangs, sinuous ridges, channels, dunes | 1) Remote elemental composition<br>2) Mineralogical composition<br>3) Petrography (shapes, sizes and mineral grain relationships)<br>4) Measure major elements, especially U, Th, and K<br>5) Mechanical hardness/ compressive strength | 1) I/F at different wavelengths from IR-VIS-UV<br>2) Temperature, Pressure, Density, Wind speed<br>3) Backscattered light from aerosols |

**Table 1**

## SPACECRAFT STRUCTURE

- VADER's spherical shape provides the optimum design to survive the harsh Venusian environment while accommodating the requirements of the scientific payload. Figure 6 shows the placement of all the instruments on and within the spacecraft bus. Table 2 shows the mass, power, and data volume requirements for each of the instrument suites.

| Atmospheric Composition Suite | Neutral Mass Spectrometer (NMS) and Aerosol Collector | Tunable Laser Spectrometer (TLS) |
|---|---|---|
| Mass (kg) | 3 | 4.5 |
| Power (W) | 5 | 25 |
| Data Volume (Mb) | 0.435 | 0.289 |

| Atmospheric Dynamics Suite | ASI | Nephelometer | Radiometer |
|---|---|---|---|
| Mass (kg) | 1 | 0.5 | 0.4 |
| Power (W) | 3 | 1.2 | 2.5 |
| Measurement Freq. | 0.3/0.03 Hz | 4 bands/s | 20 bands/s |
| Data Volume (Mb) | 17.7 | 0.384 | 0.192 |

| Descent Imaging System | Visible Camera | Near-IR Camera |
|---|---|---|
| Mass (kg) | 1 | 2 |
| Power (W) | 3 | 2.5 |
| Image Resolution | 8 m at 10 km<br><1 m at 100 m | 48 m at 60 km<br>7 m at 5 km |
| Band(s) (μm) | 0.55, 0.7, 0.8 | 2.3 |
| Data Volume (Mb) | 454 | 338 |

**Table 2**

| Surface Composition Suite | |
|---|---|
| Mass (kg) | 16.8 |
| Power (W) | 66 |
| Data Volume (Mb) | 790 |

| SiteCam | |
|---|---|
| Mass (kg) | 0.735 |
| Power (W) | 6.45 |
| Sensor Size (pixels) | 1024 x 1024 |
| Band(s) (μm) | 0.55, 0.7, 0.8 |
| Data Volume (Mb) | 92 |

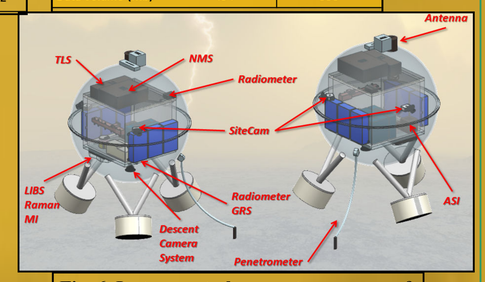


**Fig. 6. Instrument placement on spacecraft**

- Phase-change material ($H_2O$ and $LiNO_3.3H_2O$) would fill the walls and the voids between instruments to protect the hardware from the extreme thermal environment.
- The landing system would consist of three legs, ending with pads of crushable material to help absorb the landing shock. The bottom of the shell would be 0.25 m above the surface to meet the AO rock-hazard avoidance requirement. Its low center of gravity would stabilize the lander and satisfy the 0–10° slope stability requirement of the AO.
- A 30% margin is incorporated for mass, power, and propellant, based on JPL proposal phase models. This mission would return the largest in-situ dataset of measurements from Venus to date (~1.7 GB).

## MISSION ARCHITECTURE

- The proposed launch date for VADER is July 8th, 2020 with a 20-day launch window. The spacecraft would take 108 days from launch to Venus atmosphere entry interface (Fig. 7).

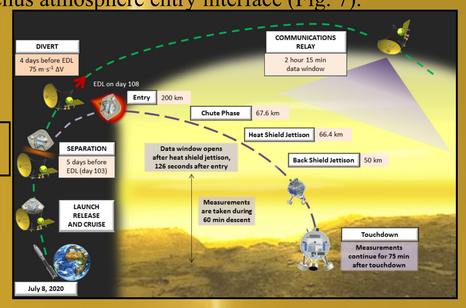


**Fig. 7. Mission architecture**

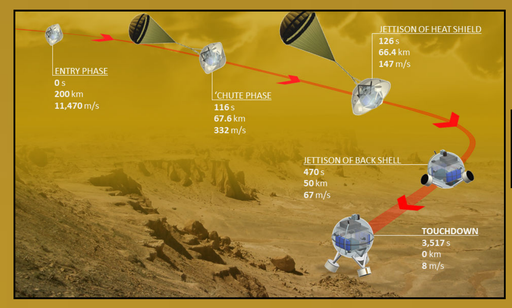


**Fig. 8. Entry, Descent and Landing**

- Four days before Entry, Descent, and Landing (EDL) (as shown in Fig. 8), a divert maneuver would increase periapsis and position the VADER carrier spacecraft so it is within communication range of the probe for 135 minutes once descent has commenced. Measurements would be taken for 60 minutes during descent and for 75 minutes on the ground.

## SYSTEMS ENGINEERING ASSESSMENT

| Constraint | Driving requirement | Fulfillment |
|---|---|---|
| Extreme temperature | Short surface duration, instruments inside shell | Cooling, remote sensing through windows |
| Extreme pressure | High pressure probe | Remote sensing through windows |
| Landing site | Constrained to narrow region due to orbital dynamics, <10° slopes and <25 cm-sized rocks | Compromise between science goals and risks |
| Short mission lifetime | High data volume | 100 W transmitting antenna |

**Table 3.**

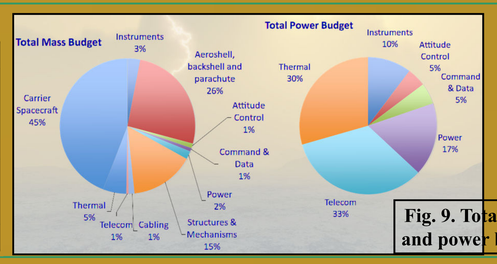


**Fig. 9. Total mass and power budget**

## SCHEDULE AND COST

- Figure 10 shows the proposed schedule for VADER. This schedule describes the mission life cycle.
- At $1.042B, our proposed mission is below the AO-specified cost cap of $1.069B. This estimate includes a 50% reserve as recommended by the Decadal Survey. This amount was estimated using Team-X/JPL institutional cost models (Fig. 11).

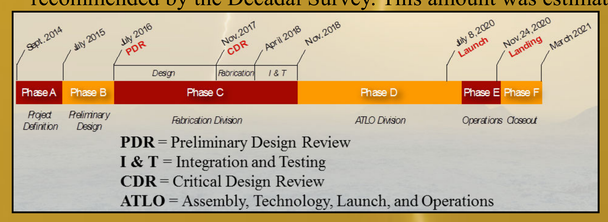


**Fig. 10. Proposed mission life cycle for VADER**

| COST SUMMARY (FY2015 $M) | Team X Estimate CBE | Res. | PBE |
|---|---|---|---|
| Project Cost | $696.4 M | 50% | $1042.3 M |
| Launch Vehicle | $0.0 M | | $0.0 M |
| Project Cost (w/o LV) | $696.4 M | 50% | $1042.3 M |
| | | | |
| Development Cost | $672.8 M | 50% | $1008.0 M |
| Phase A | $6.7 M | 50% | $10.1 M |
| Phase B | $60.6 M | 50% | $90.7 M |
| Phase C/D | $605.5 M | 50% | $907.2 M |
| Operations Cost | $23.6 M | 45% | $34.3 M |

**Fig. 11. Cost summary**

## REFERENCES

*[1] National Research Council. (2011) Visions and Voyages for Planetary Science in the Decade 2013-2022, National Academies Press. [2] NASA (2009) Announcement of Opportunity: New Frontiers. [3] Taylor, F. (2006) Plan. & Spa. Sci., 54, 1249–1262.*