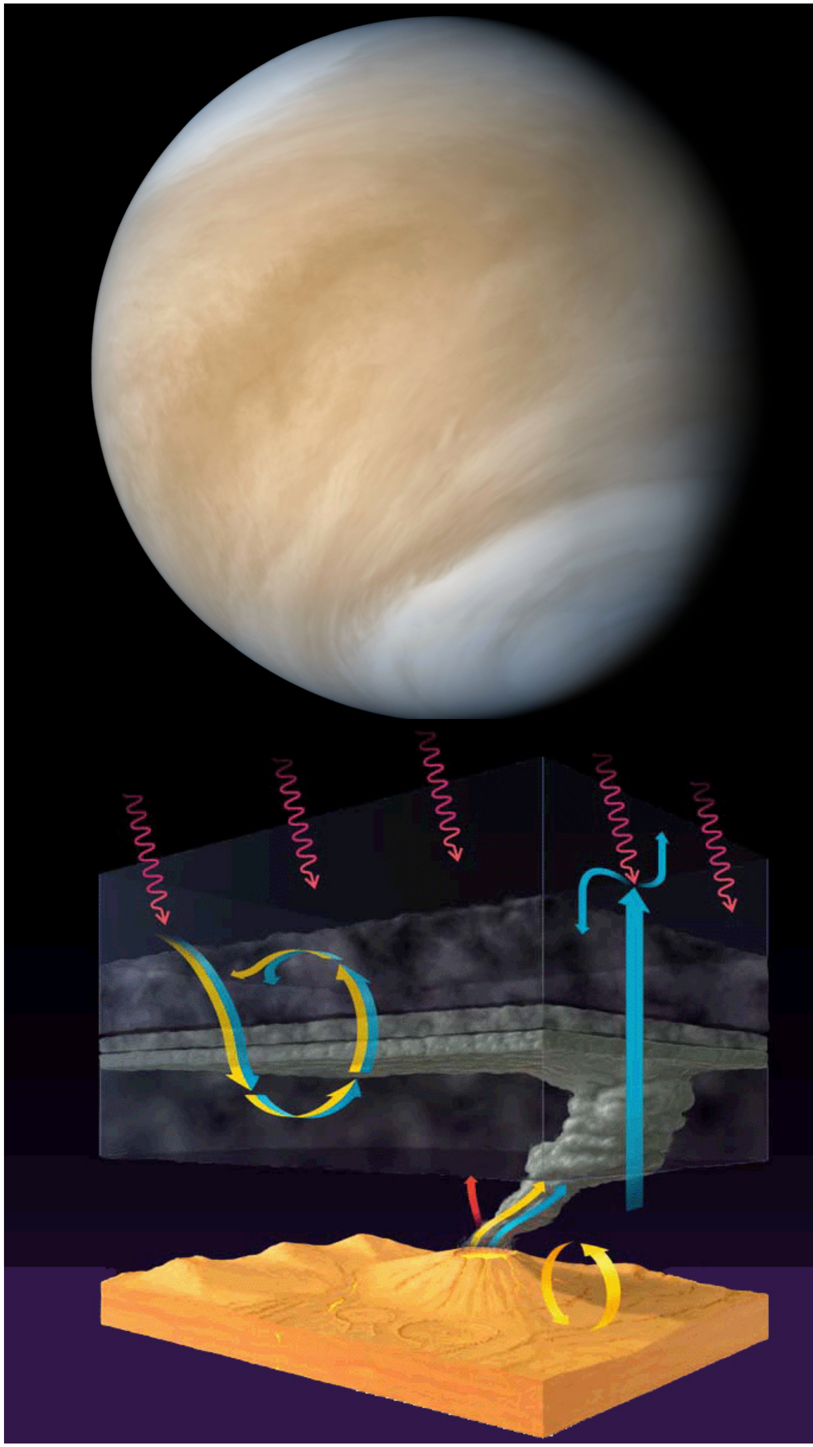
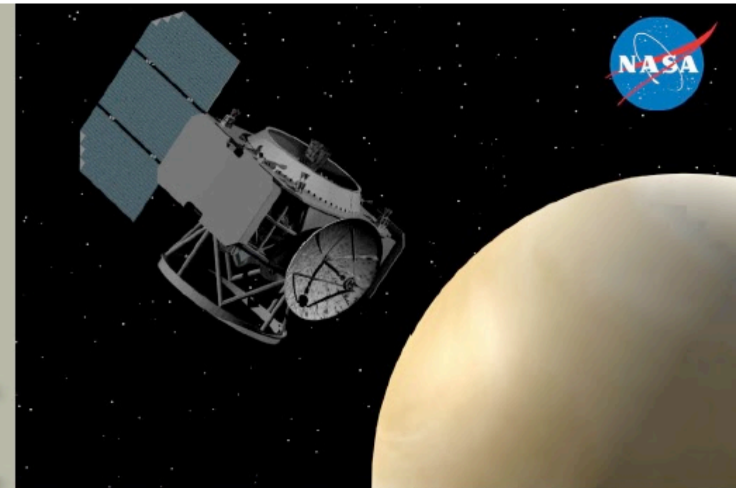


National Aeronautics and Space Administration



VCM

Mission Concept Study

Planetary Science
Decadal Survey

VENUS CLIMATE MISSION

Science Champion:
Dr. David Grinspoon
Denver Museum of
Nature and Science
David.Grinspoon@dmns.org

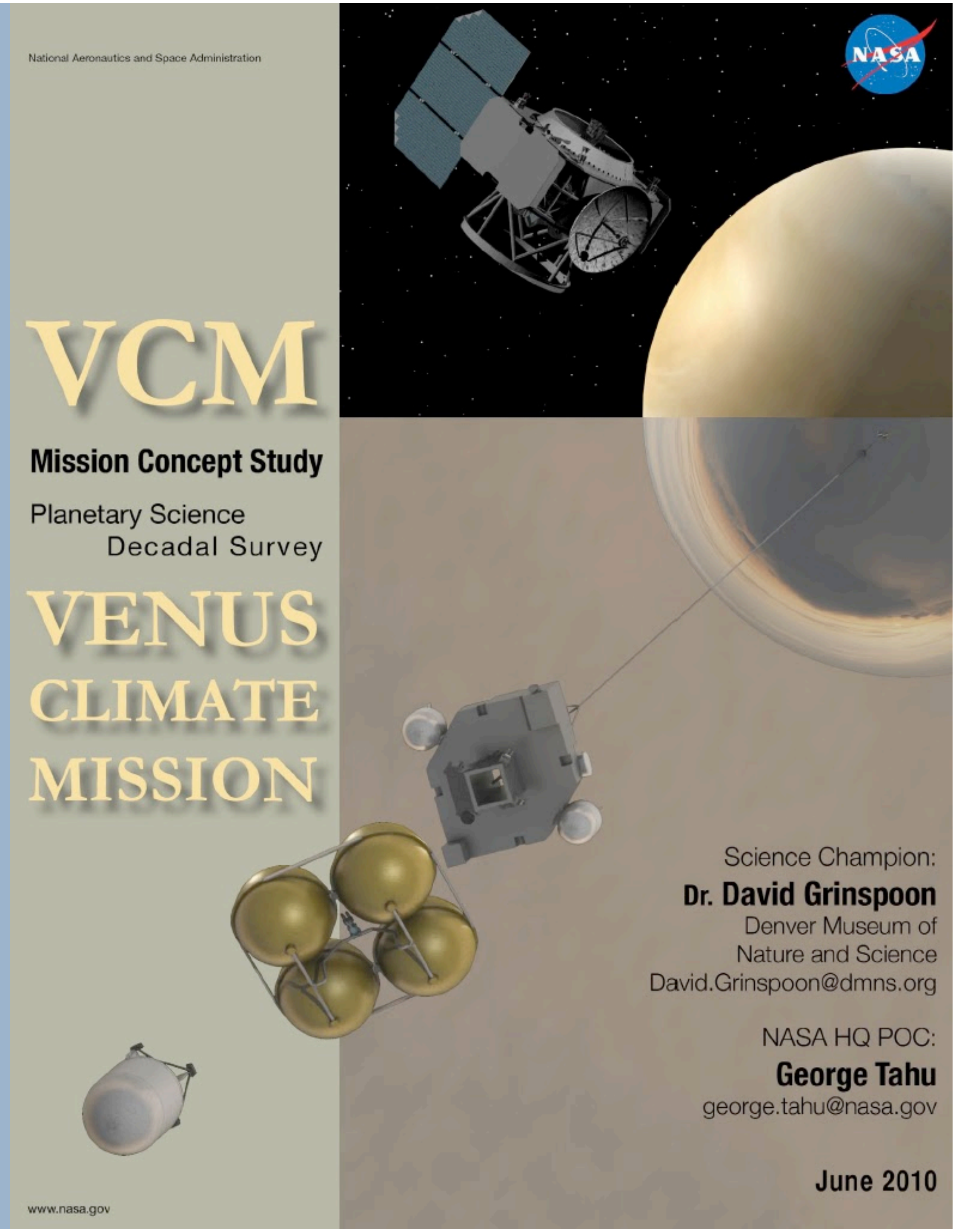
NASA HQ POC:
George Tahu
george.tahu@nasa.gov

June 2010

www.nasa.gov

Venus Climate Mission Study:

Orbiter – GSFC
Balloon – JPL
Instruments – GSFC
Sondes - GSFC and JPL
Aeroshell – Ames
Mission architecture – GSFC and JPL



David Grinspoon, VCM Science Champion
Alexander Pavlov, GSFC Science Representative

NASA/GSFC
Michael Adams, Study Lead
Michael Amato, New Business Manager
Nerses Armani, Mechanical
Charles Baker, Systems
Heather Bradshaw, Thermal
Kara Chaprnka, Costing
John Galloway, Instruments
Lori Glaze, Science
William Horne, Communications
Carol Ladd, Report Production
William Lawson, Costing
David Mangus, ACS
Greg Marr, Flight Dynamics
Robin Mauk, Systems
Richard Mills, Electrical Systems
Tom Spitzer, Power
Scott Starin, ACS
Barbara Talbott, Report Graphics
Steven Tompkins, Mission Operations and Ground System
Sanjay Verma, Costing
Carl Wales, Systems
Graham Webster, Propulsion

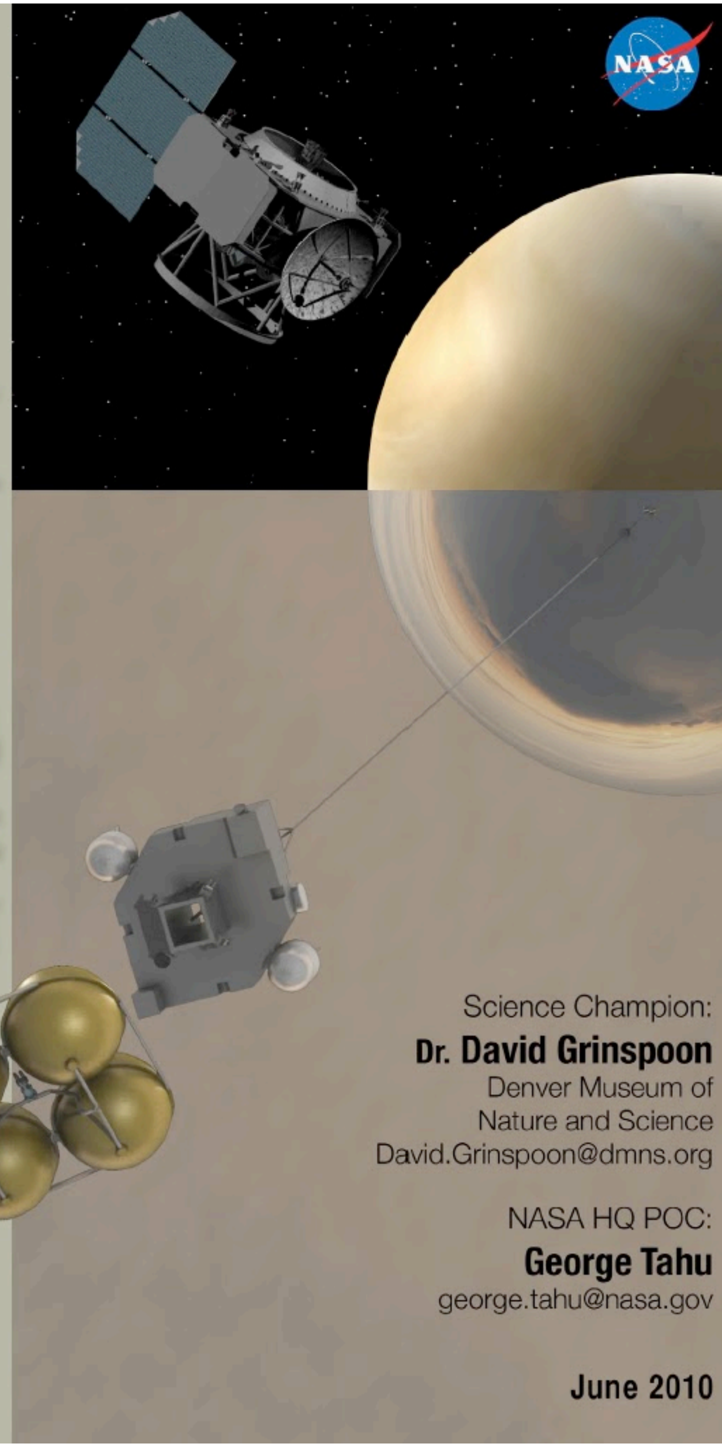
JPL

Tibor Balint, Study Lead
Harry Balian, Software
Deberati Chattopadhyay, Risk
Loucas Christodoulou, Propulsion/Inflation Douglas Equils, Ground Systems
Dwight Geer, CDS
Jeff Hall, Balloon Design and Sizing Support
Casey Heeg, Systems
Jennifer Herman, Power
Scott Howe, Configuration
Viktor Kerzhanovich, Balloon Design and Sizing Support
Ryan Lim, ACS
Michael Mercury, Deputy Systems
Robert Miyake, Thermal
Jeffrey Parker, Mission Design
Jamie Piacentine, Configuration
Michael Pugh, Telecom
Leigh Rosenberg, Costing
Brian Schratz, Telecom
Partha Shakkottai, Thermal
Evgeniy Sklyanskiy , EDI/Probe Descent
William Smythe, Science Operations
Matthew Spaulding, Mechanical
Paul Stella, Power
Marc Walch, Instruments
Keith Warfield, Facilitator

NASA/ARC

Ethiraj Venkatapathy, Aeroshell Chief Technologist
Gary Allen, Systems Analyst
Ken Hamm, Structural Analyst
Todd White, Aeroshell Engineer

National Aeronautics and Space Administration

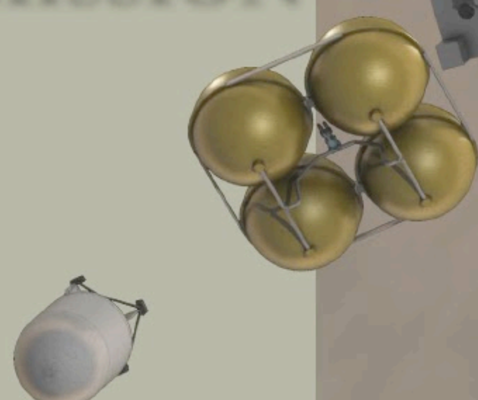


VCM

Mission Concept Study

Planetary Science
Decadal Survey

VENUS CLIMATE MISSION



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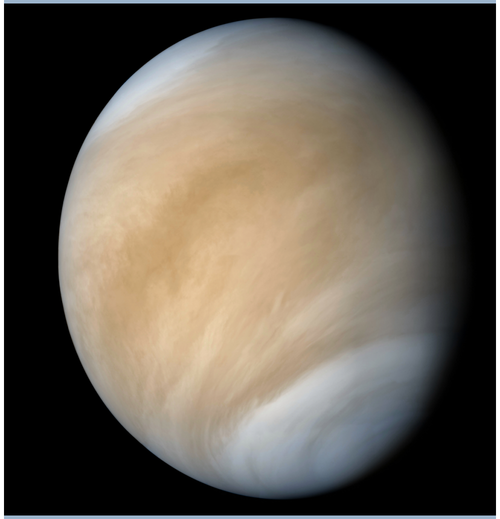
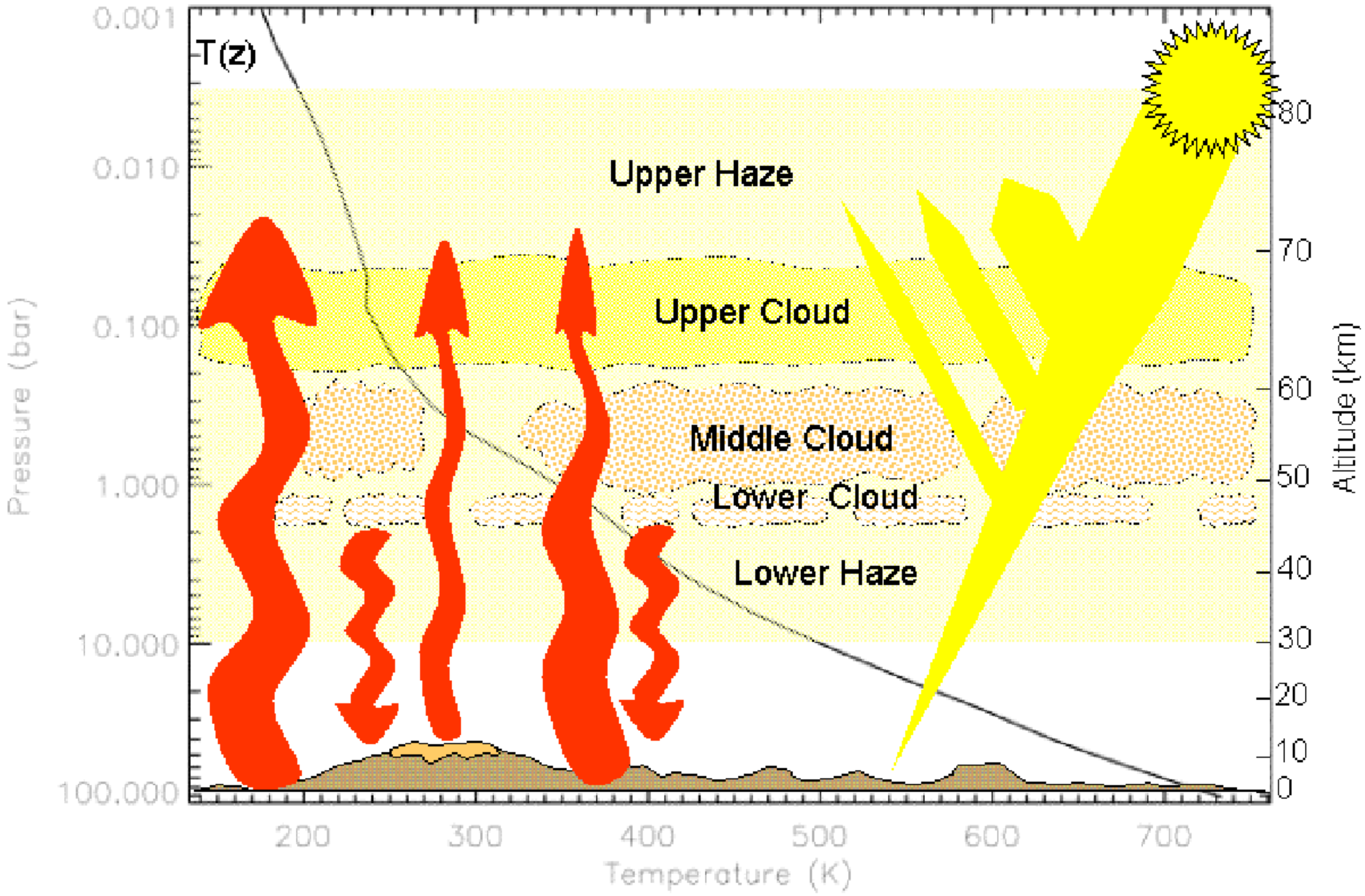
Venus Climate Mission Science Objectives

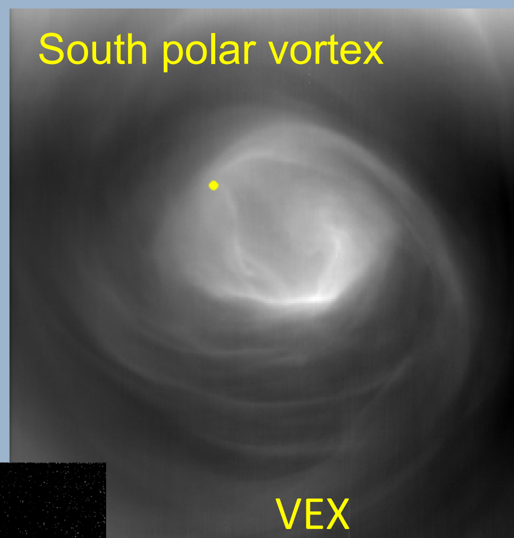
- Characterize the strong CO_2 greenhouse atmosphere of Venus, including variability.

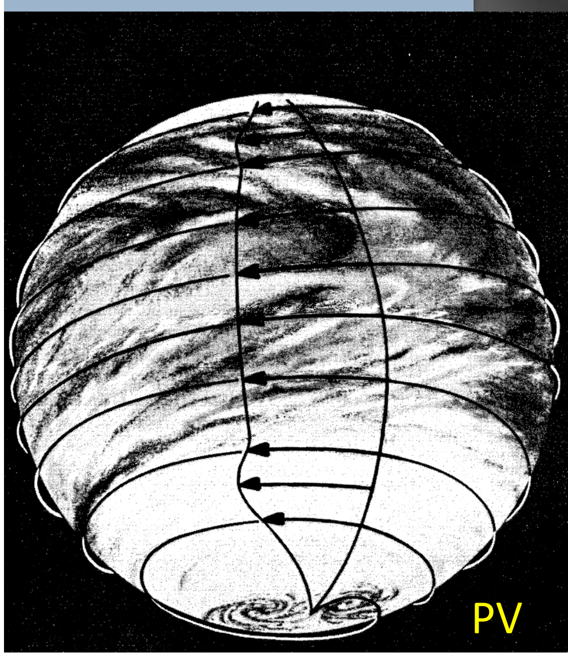




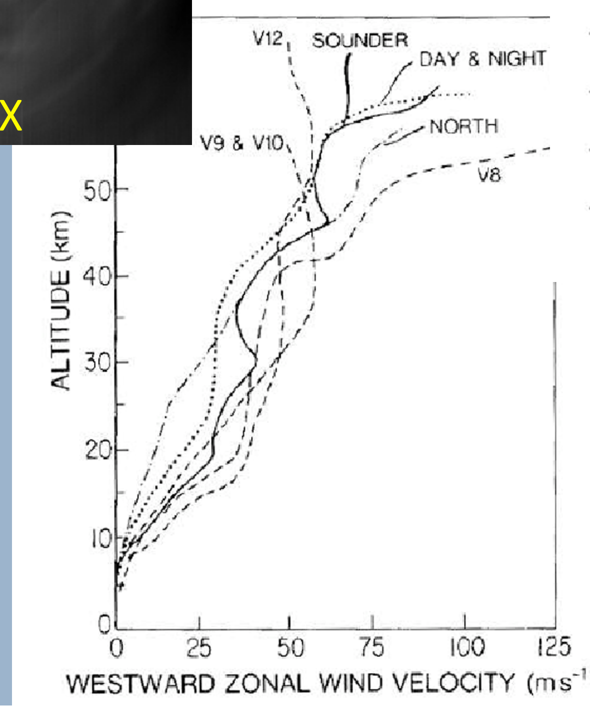
Venus Climate Mission Science Objectives

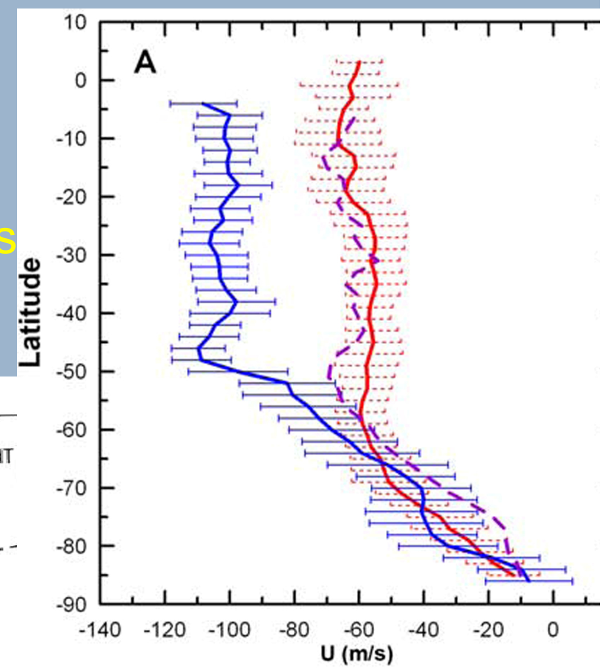
- Characterize the nature and variability of Venus ' superrotating atmosphere.





Probes: Winds decrease with altitude

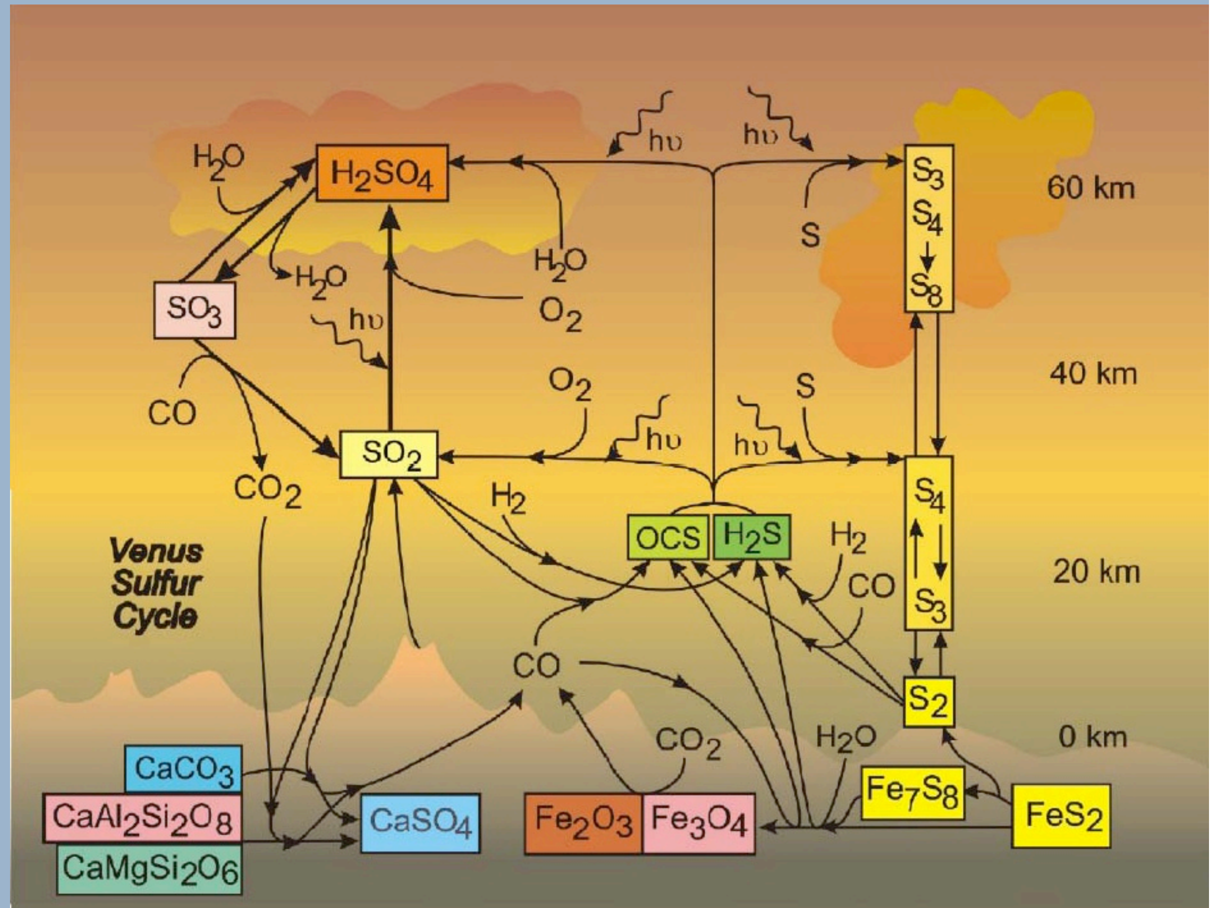




VEX East-west winds, decreasing at the poles

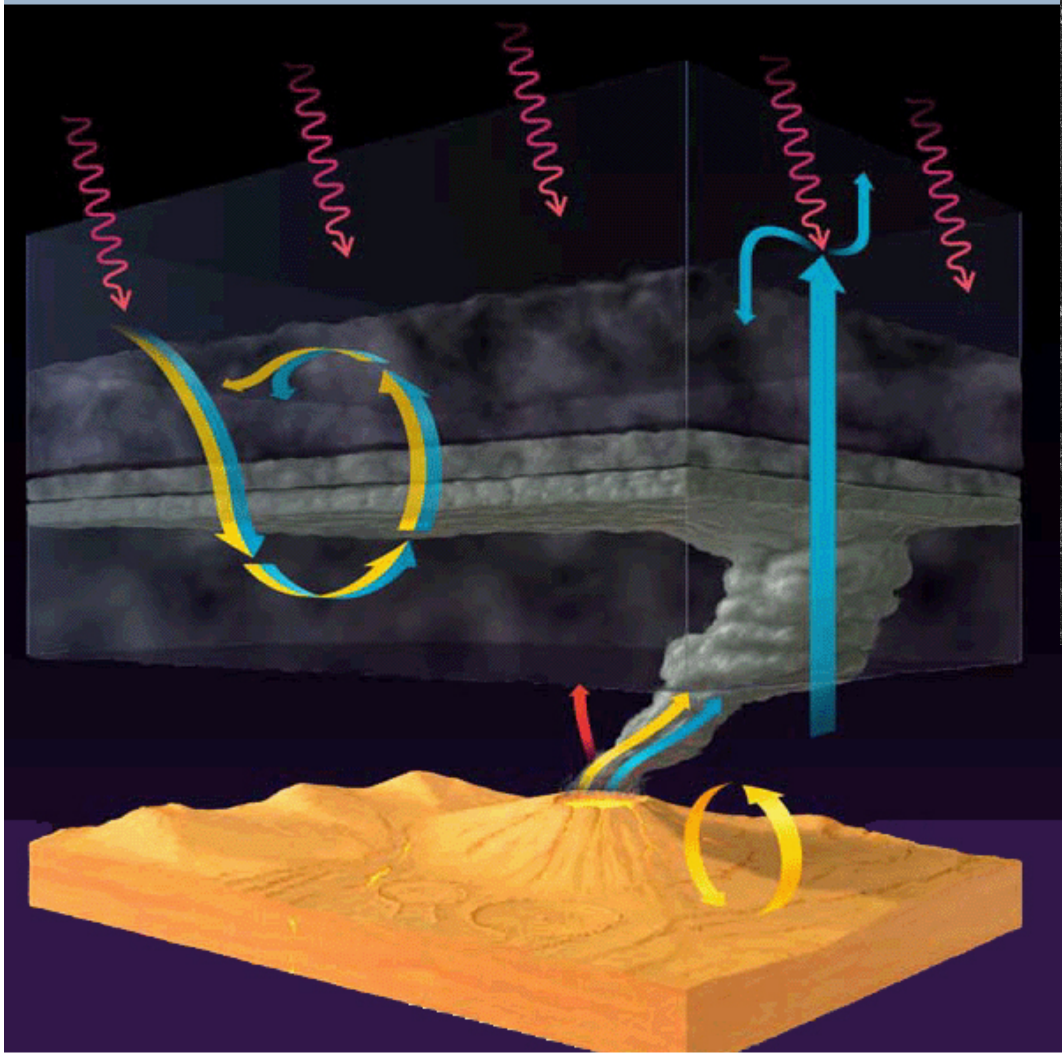
Venus Climate Mission Science Objectives

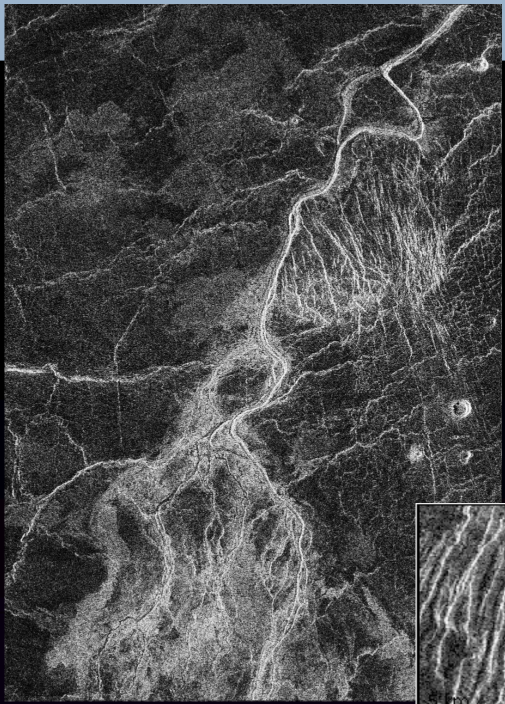
- Characterize surface/ atmosphere chemical exchange in the lower atmosphere.

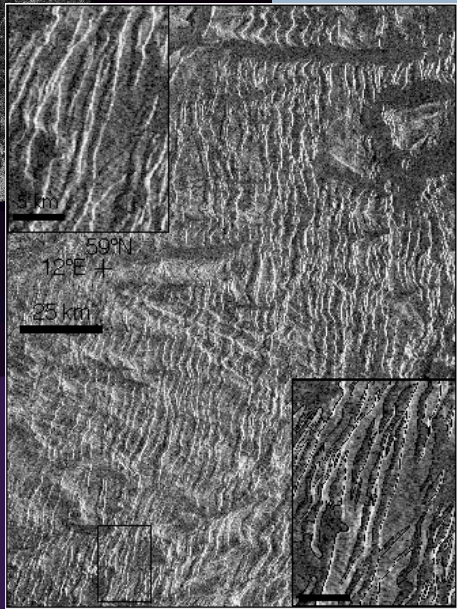


Venus Climate Mission Science Objectives

- Search for atmospheric evidence of climate change on Venus
- Determine the origin of Venus' atmosphere and the sources and sinks driving evolution of the atmosphere.

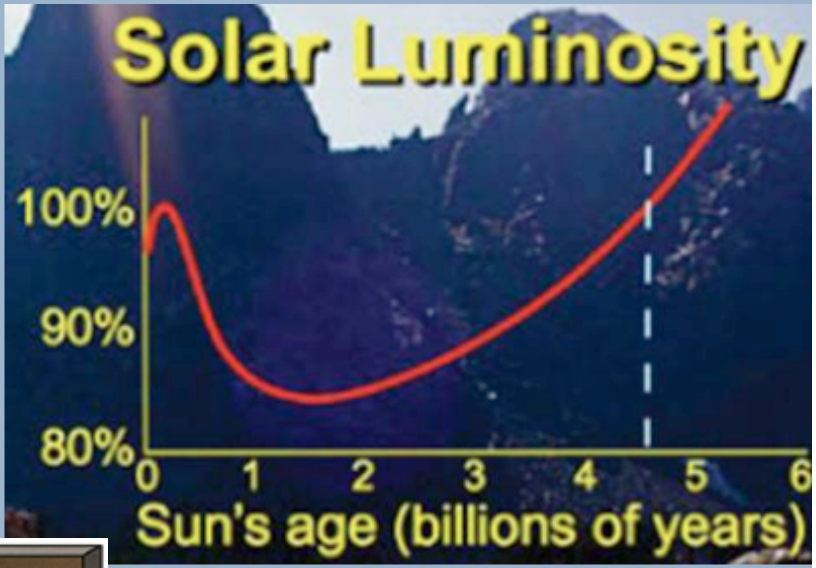


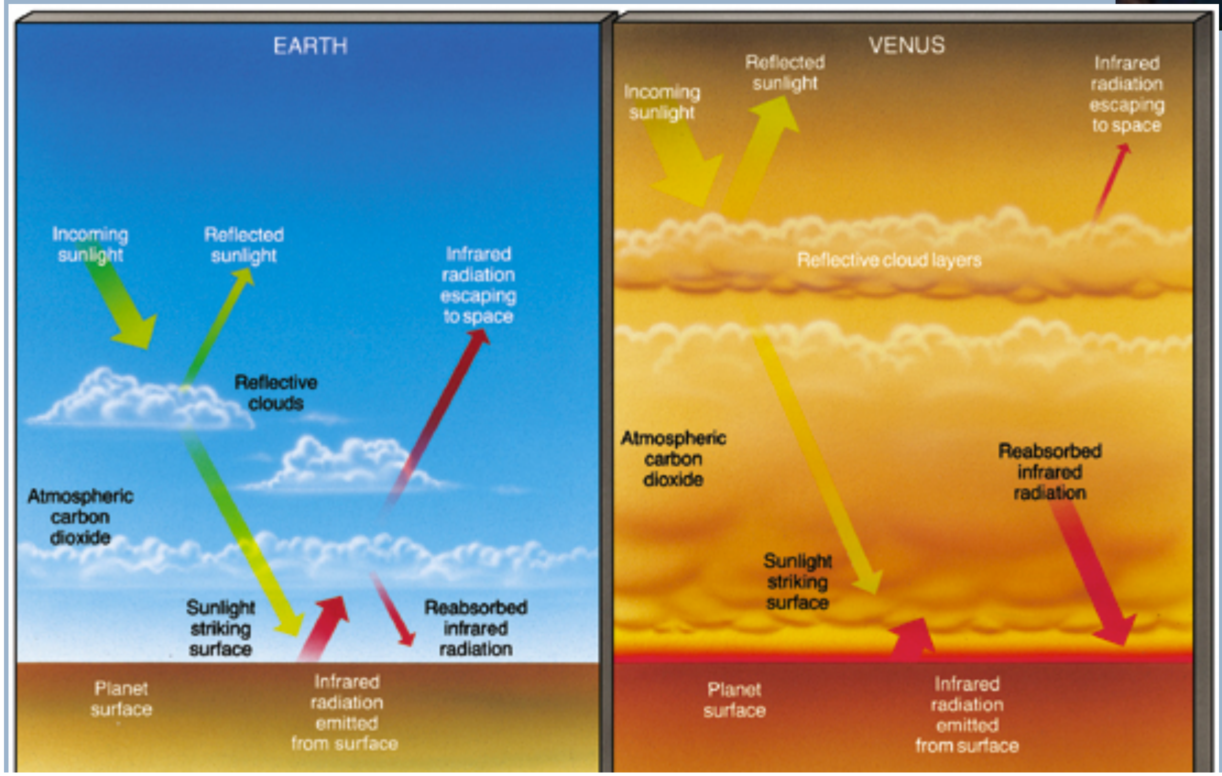




Venus Climate Mission Science Objectives

- Understand implications of Venus' climate evolution for the long-term fate of Earth.





Payload

Balloon:

- Tracking of balloon motions to measure winds, thermal tides and super-rotation.
- Atmospheric Structure Instrument will measure P and T over local time and latitude.
- Accelerometer will measure vertical winds and turbulence.
- Nephelometer to measure cloud particle size and composition.
- Net Flux Radiometer will measure upwelling and downwelling solar and IR flux.
- Tunable Laser Spectrometer will measure ~~cloud and~~ atmospheric composition.
- Neutral Mass Spectrometer will measure composition including noble gases and isotopes.

Payload

Drop Sondes (2):

- Atmospheric Structure Instrument will measure P, T, winds and stability on descent at 3 locations with differing local solar times.
- Net Flux Radiometer will measure radiation balance and composition over 3 vertical traces from the cloud base to the surface.

Mini-Probe:

Above plus:

- Neutral Mass Spectrometer will measure vertical profiles of key trace gases in the lower atmosphere.

Carrier Spacecraft:

- VIS-IR camera to provide hemispheric context for in situ science, measure cloud motions, and characterize winds.

Science Instrument and Data

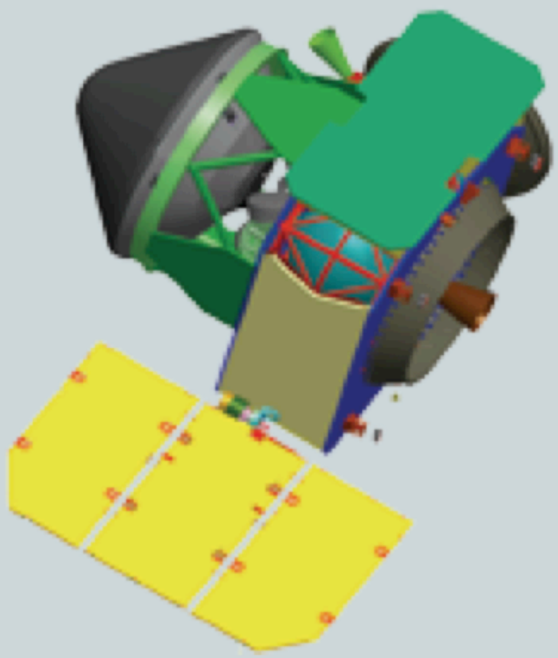
Gondola	Mini Probe	Drop Sonde (each)	Orbiter
Neutral Mass Spectrometer (NMS)	NMS	NFR	IR Imager
Tunable Laser Spectrometer (TLS)	NFR	ASI	
Nephelometer	ASI		
Net Flux Radiometer (NFR)			
Atmospheric Structure Instrument (ASI)			
(Doppler ranging through telecom system)			

Total science data return from in situ ~135 Mbits

Balloon: 128 Mbits
Mini probe: 5 Mbits
Drop sondes: 1 Mbits each

Venus Climate Mission Science Traceability Matrix

Science Objective	Measurement	Instrument	Functional Requirement
Characterize the strong CO2 greenhouse atmosphere of Venus, including variability.	Upward and Downward visible and IR fluxes, atmospheric composition, aerosol composition and size distribution.	ASI, Nephelometer, Radiometer, TLS, NMS	Three decent traces at varied longitude and solar zenith angles. Four complete gondola/balloon system circumnavigations of Venus.
Characterize the dynamics and variability of Venus' superrotating atmosphere	Cloud motions, global and local wind speeds at multiple altitudes, P, T, stability, radiation balance, thermal tides & turbulence.	VIS-IR Camera, Gondola/Balloon system tracking, ASI, Descent Spectrometer, Accelerometer, Radiometer.	Three descent traces at vaied longitude and solar zenith angles. Four complete gondola/balloon system circumnavigations of Venus
Constrain surface/atmosphere chemical exchange in the lower atmosphere.	Measure stable isotopes and trace reactive gases and with altitude.	NMS, TLS	One descent trace.
Search for atmospheric evidence of climate change on Venus.	Stable isotopes and atmospheric composition.	NMS, TLS	In situ sampling of atmospheric gases and aerosols, descent trace.
Determine the origin of Venus' atmosphere and the sources and sinks driving evolution of the atmosphere.	Noble gases and isotopes. Stable isotopes.	NMS, TLS	In situ sampling.
Understand implications of Venus' climate evolution for the long-term fate of Earth.	Stable isotopes (D/H,S,O,N) rare gases and isotopes,	NMS, TLS	In situ sampling of atmosphere and cloud aerosols.



Carrier Spacecraft

Function: Deliver and deploy Entry Flight System; orbit Venus as communication relay for Gondola/Balloon system

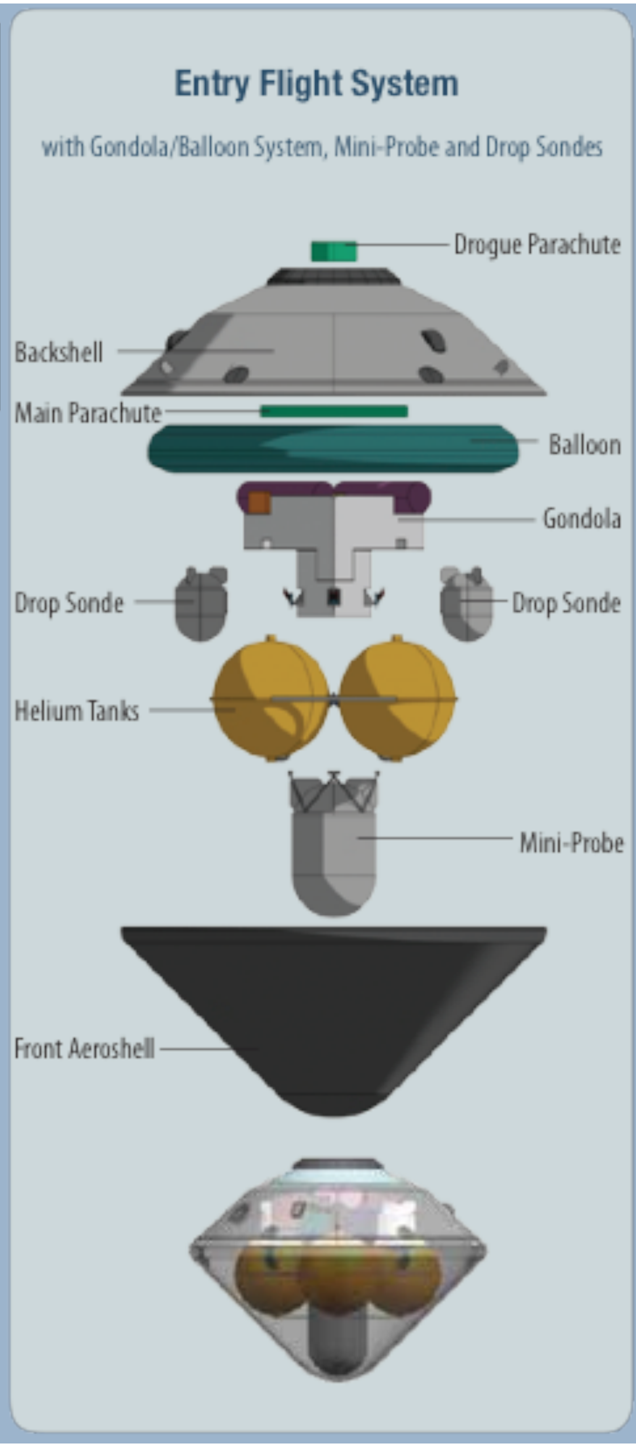
Power: 5 m^2 solar panels

Attitude Control: 3-axis stabilized (Spin up for release of the EFS)

Telecom: 1.7m dia. HGA; two-way S-band comm. with gondola; two-way Ka-band comm. with Earth

Science Data Return: 14 Gb from Carrier Spacecraft Camera plus 142 Mb from Gondola/Balloon System; Mini-Probe and Drop Sondes

Entry Flight System
Function: Deliver in situ elements through the atmosphere; carries the Gondola/Balloon System, Inflation System, Mini-Probe and two Drop Sondes
Power: Lithium-thionyl chloride (Li-$SOCl_2$) primary battery
Design: Carbon-Phenolic front shell, Phenolic Impregnated Carbon Ablator back shell, 45 deg cone angle (Pioneer-Venus heritage), 2 m diameter



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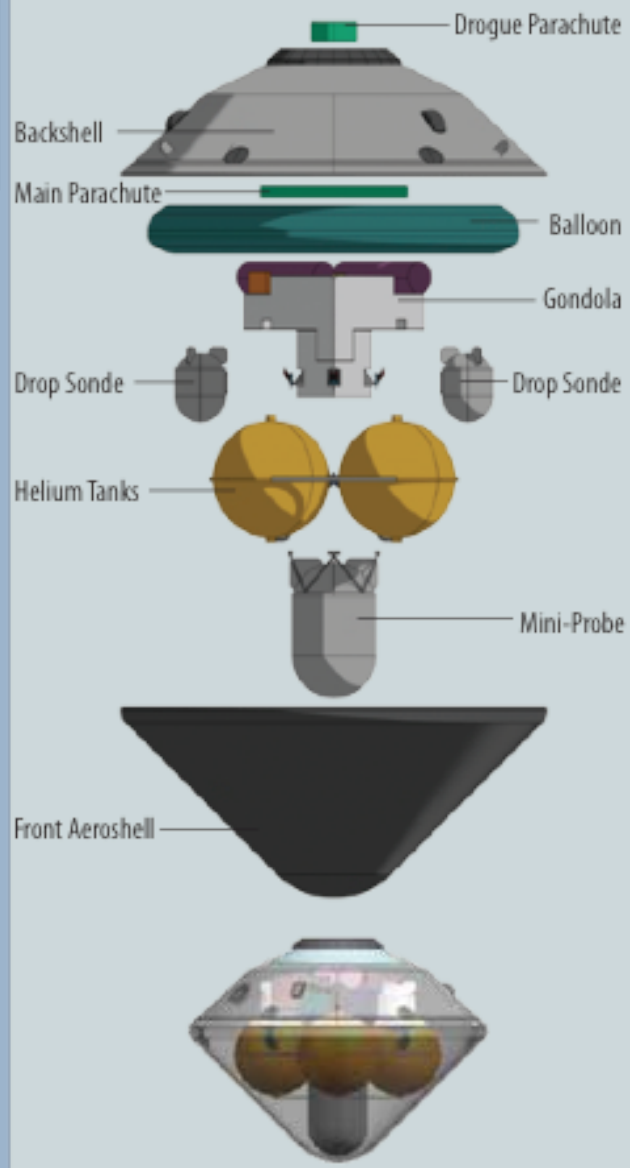
Entry Flight System

with Gondola/Balloon System, Mini-Probe and Drop Sondes



Gondola/Balloon System

Function: 21 day science campaign at 55.5 km float altitude
Power: Lithium-thionyl chloride (Li-$SOCl_2$) primary battery
Telecom: Two way S-band (plus Doppler) to Carrier Spacecraft; one way S-band from Mini-Probe and Drop Sondes
Science Data Return: 135 Mb from Gondola science + 7 Mb from Probe & Sondes science
Balloon Design: 8.1 m diameter helium filled balloon; teflon coated for sulfuric acid resistance; Vectran fabric plus Mylar film construction; metalized for low solar heating
Inflation System Design: 4 x 0.5 m dia. titanium tanks; pipes; valves

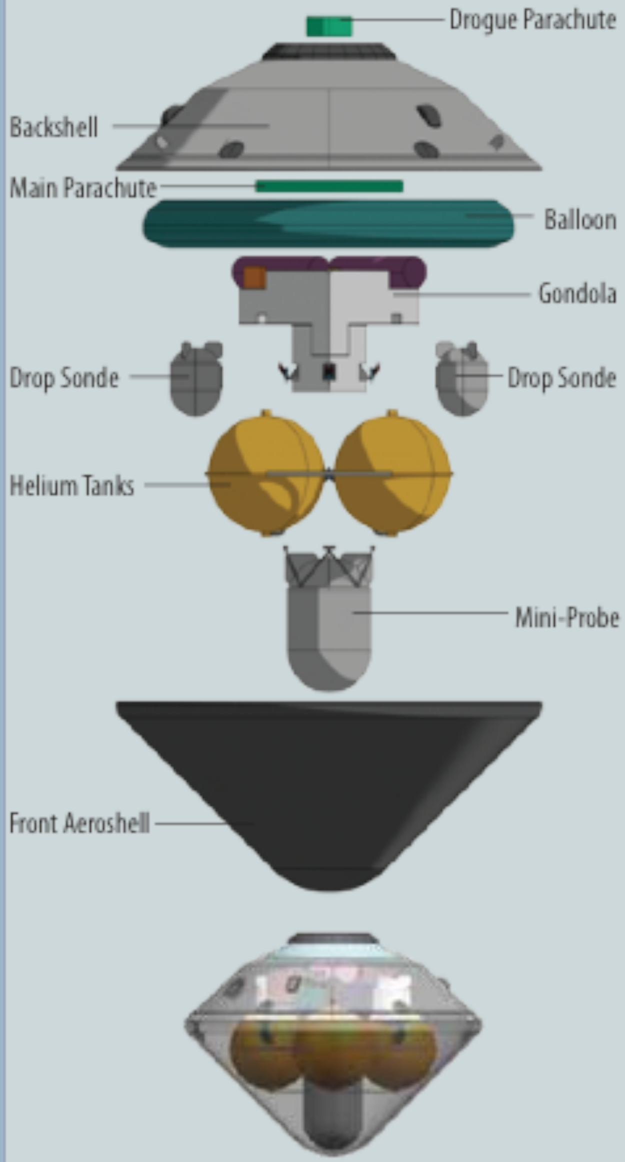
Entry Flight System
Function: Deliver in situ elements through the atmosphere; carries the Gondola/Balloon System, Inflation System, Mini-Probe and two Drop Sondes
Power: Lithium-thionyl chloride (Li-$SOCl_2$) primary battery
Design: Carbon-Phenolic front shell, Phenolic Impregnated Carbon Ablator back shell, 45 deg cone angle (Pioneer-Venus heritage), 2 m diameter

Mini-Probe
Function: 45 minute descent from 55.5 km to surface
Power: Distributed rechargeable Polymer Lithium-ion batteries
Telecom: 1 way S-band to gondola
Science Data Return: 5 Mb
Design: 44 cm dia., 66 cm tall titanium pressure vessel, passive thermal control

Drop Sondes (2)
Function: 45 minute descent from 55.5 km to surface
Power: Distributed rechargeable Polymer Lithium-ion batteries
Telecom: One-way S-band to gondola
Science Data Return: 1 Mb (each probe)
Design: 29 cm dia., 35 cm tall titanium pressure vessel, passive thermal control

Entry Flight System

with Gondola/Balloon System, Mini-Probe and Drop Sondes



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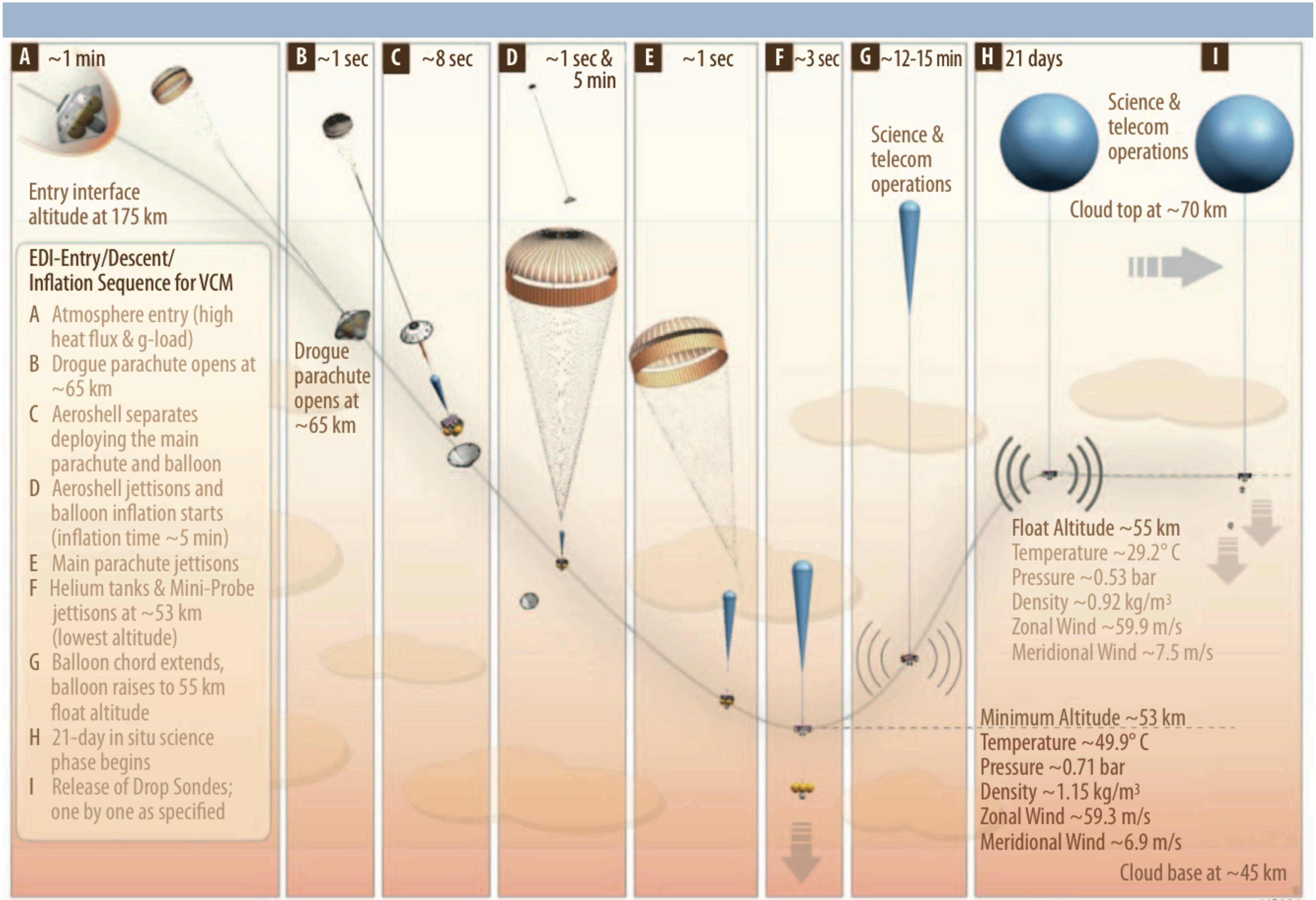


Figure 3: Entry, Descent and Inflation Sequence

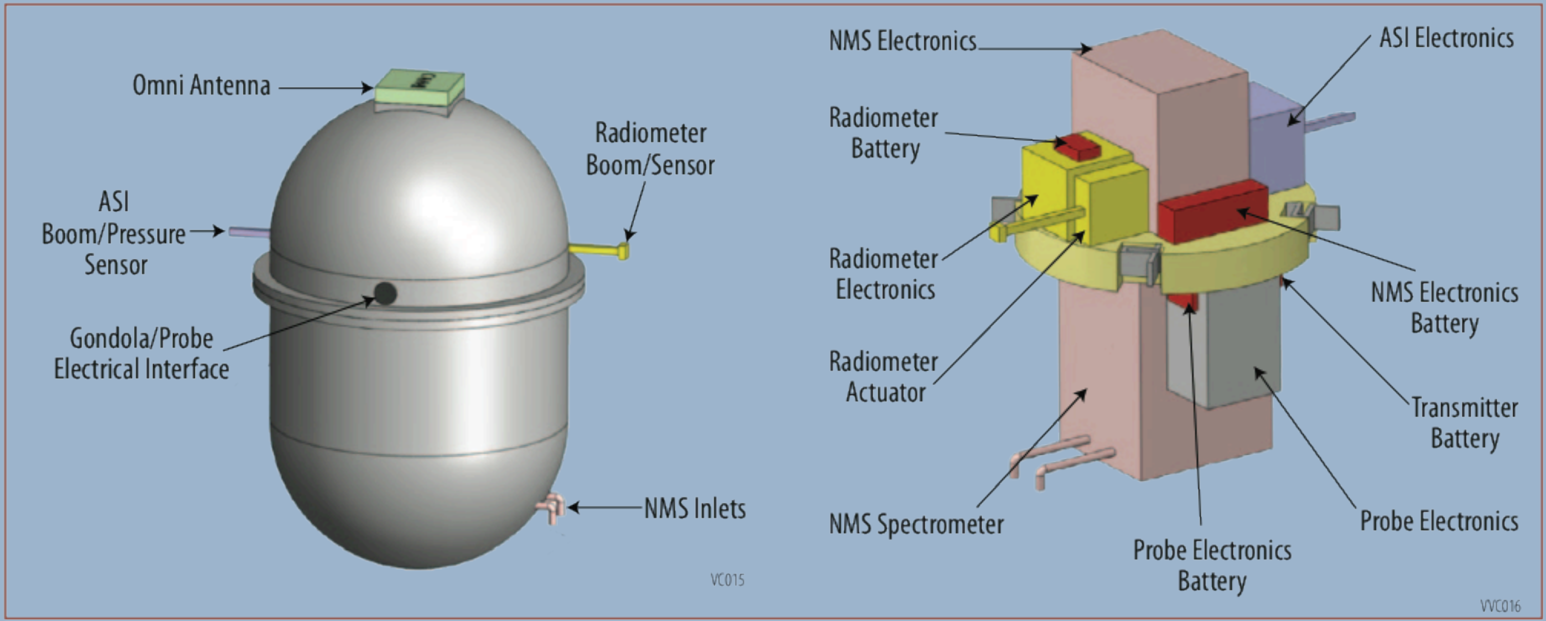


Figure 20: Mini-Probe with internal components

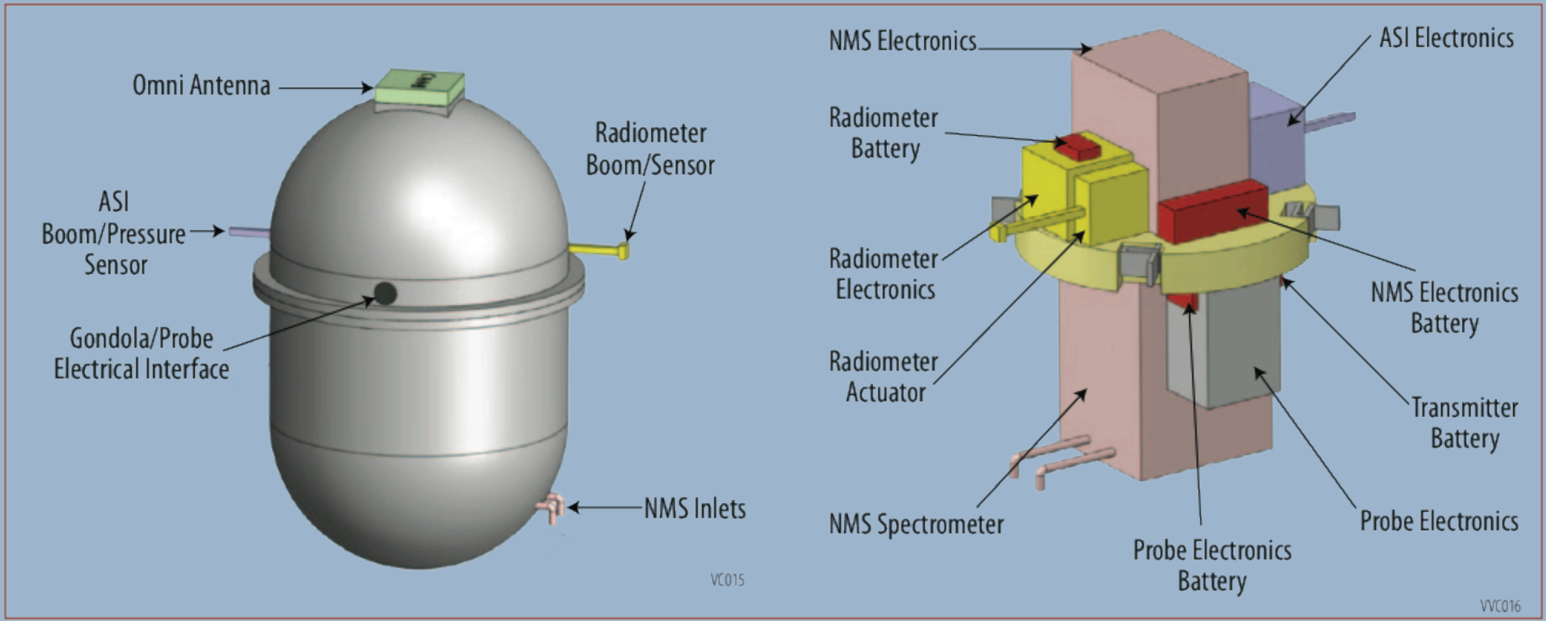


Figure 20: Mini-Probe with internal components

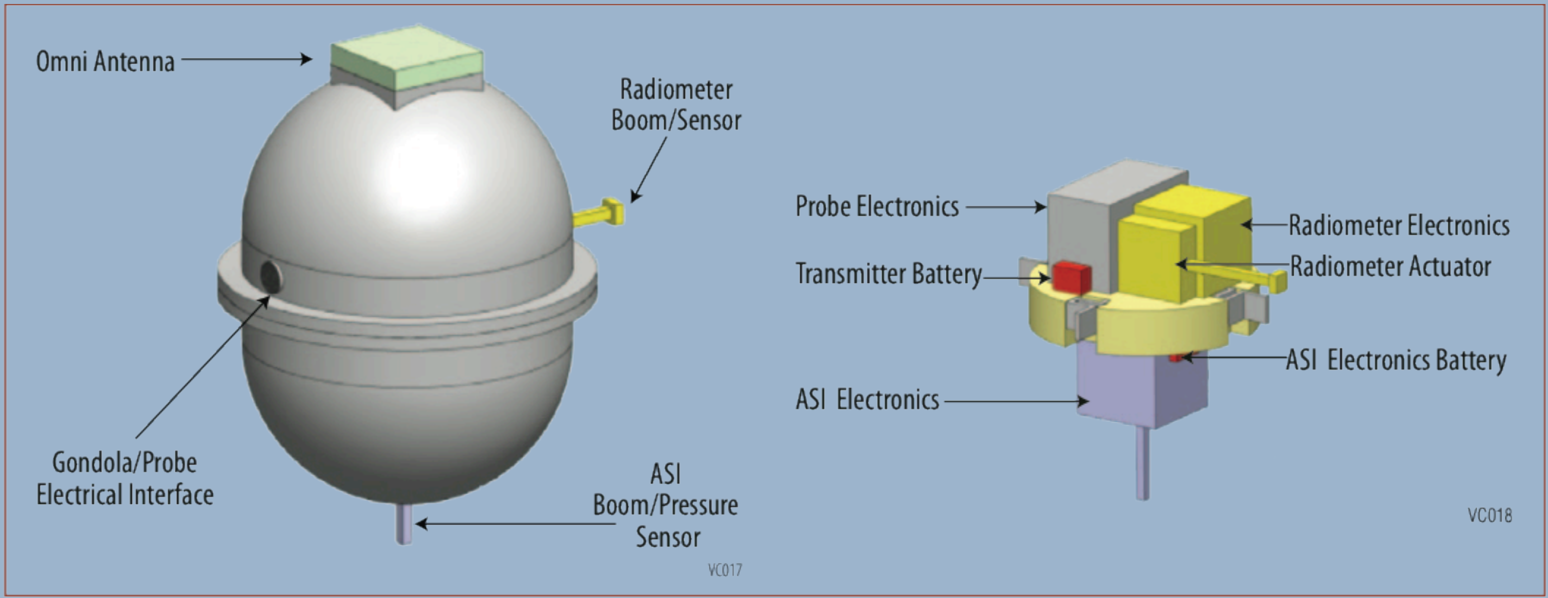


Figure 21: Drop Sonde with internal components

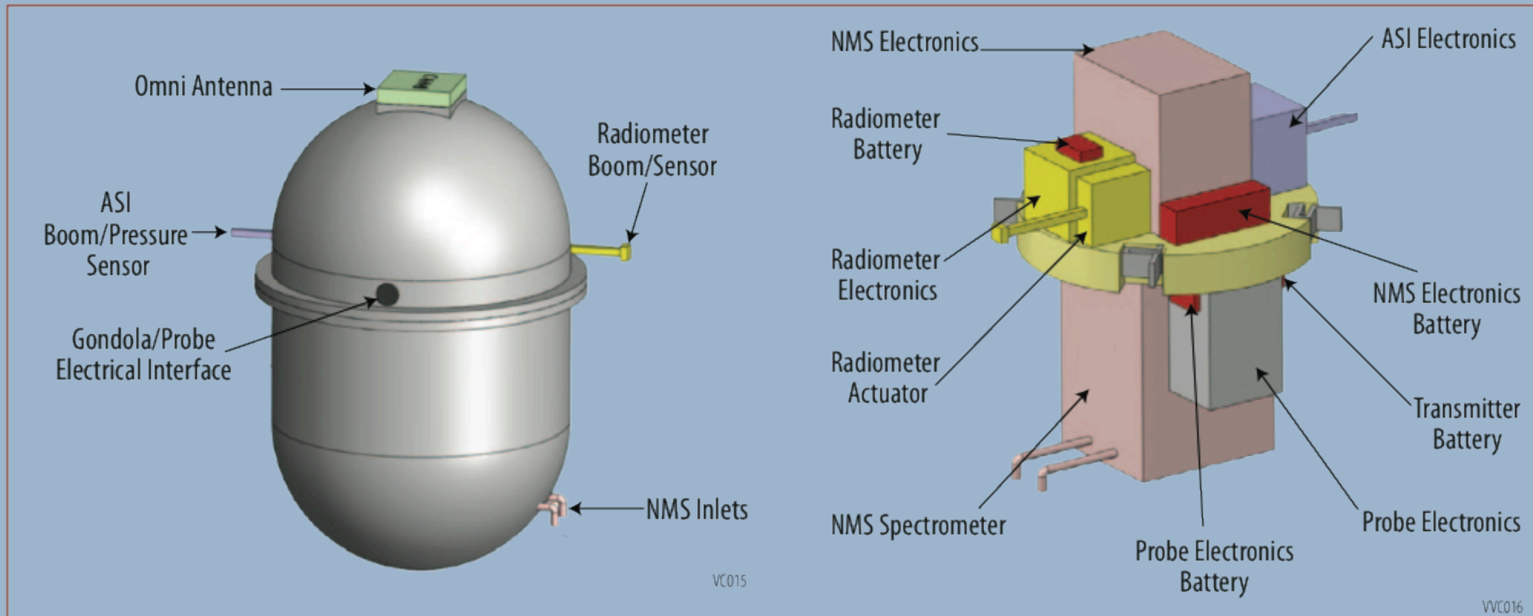
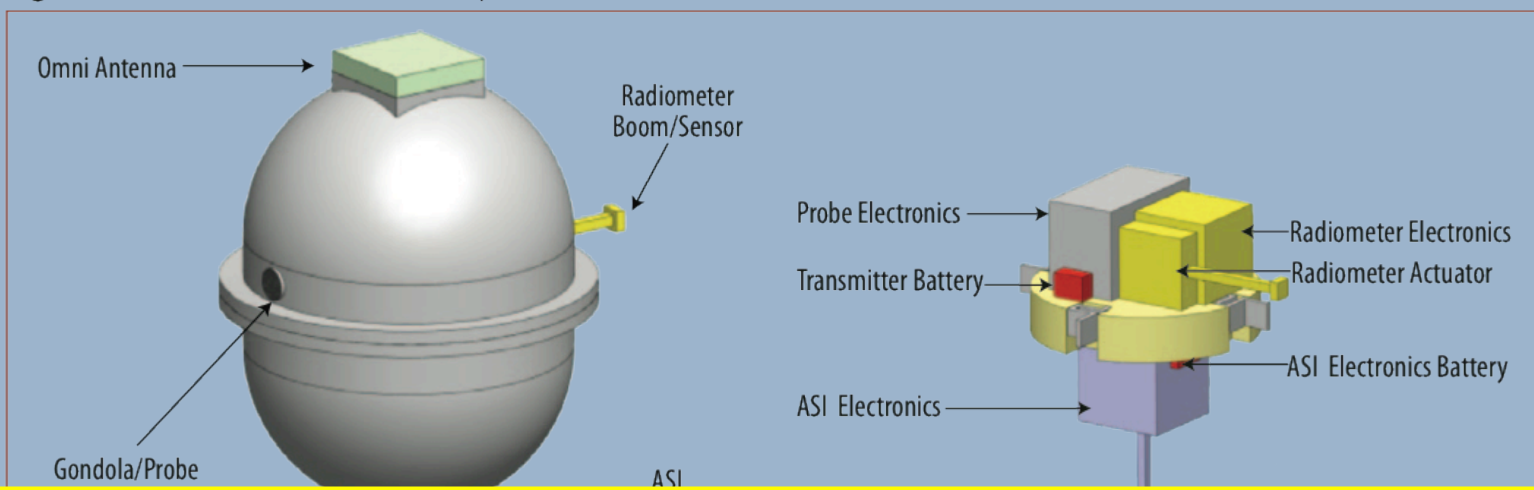


Figure 20: Mini-Probe with internal components



For this study, the Mini- Probe and Drop Sondes have not been optimized for mass or volume.

Further design efforts will reduce the size and mass of these units, resulting in a more efficient Gondola/Balloon System design.

Mission Design: Concept of Operations

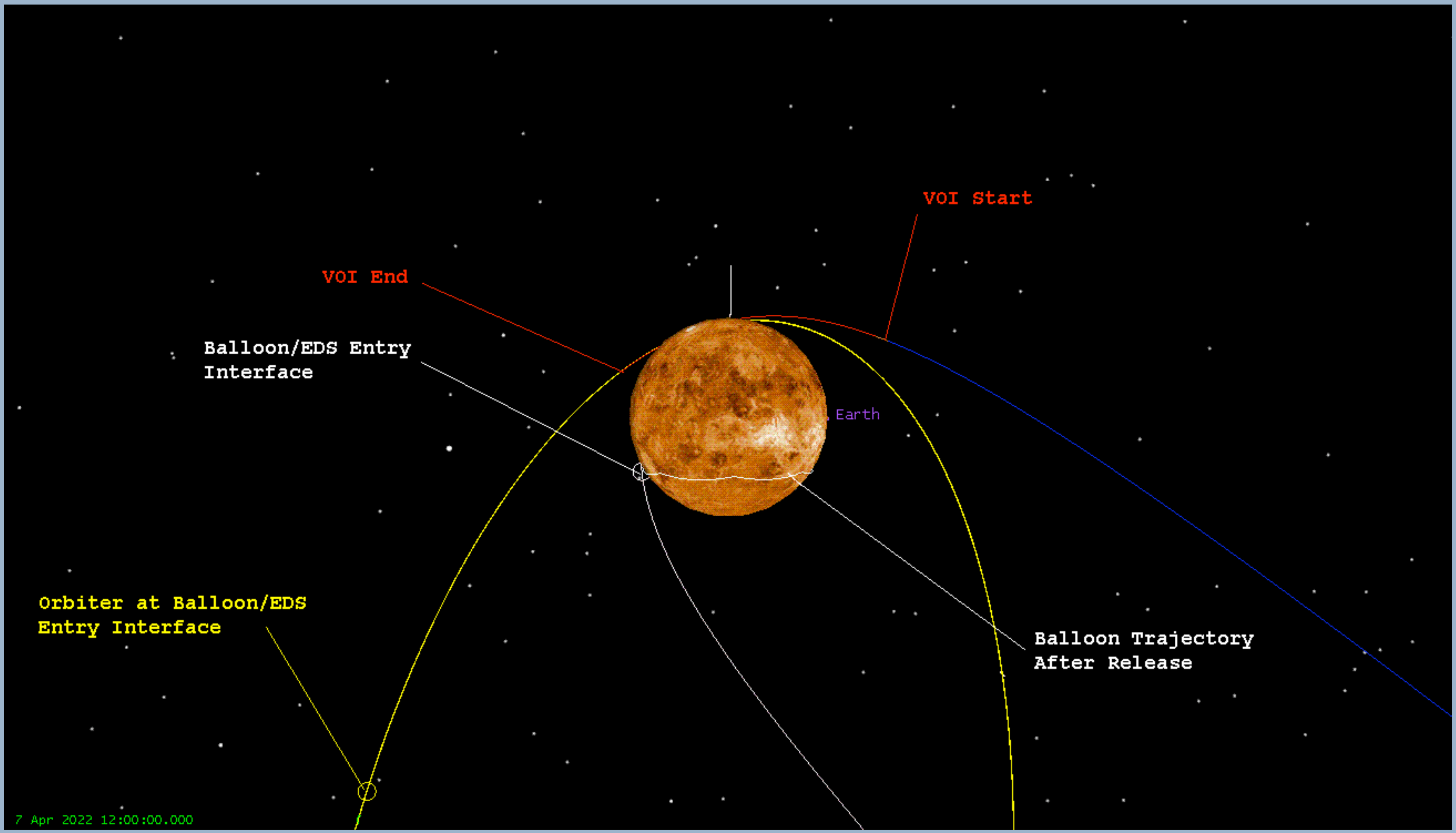
- **Launch:**
  - November 2, 2021
  - On an Atlas V-551 Launch Vehicle

- **Entry System (Aeroshell) release** from Carrier:
  - March 29, 2022
  - 10 days before VOI & Probe entry

- **Venus Orbit Insertion** (VOI) & Entry System entry
  - April 7, 2022
  - VOI & Entry System entry is separated by ~2 hours
  - Entry is seen by the orbiter
  - Entry phase + initial data taking includes telecom to orbiter

- **In situ Mission Phase** for the balloon / probe / sondes:
  - April 7, 2022 to April 28, 2022
  - 21 days baseline balloon operations
  - Probe is released after atmospheric entry (45 min descent)
  - Two drop sondes are released sometime during the 3 weeks in situ operations (45 min descent)

Mission Design: Venus Orbit Insertion

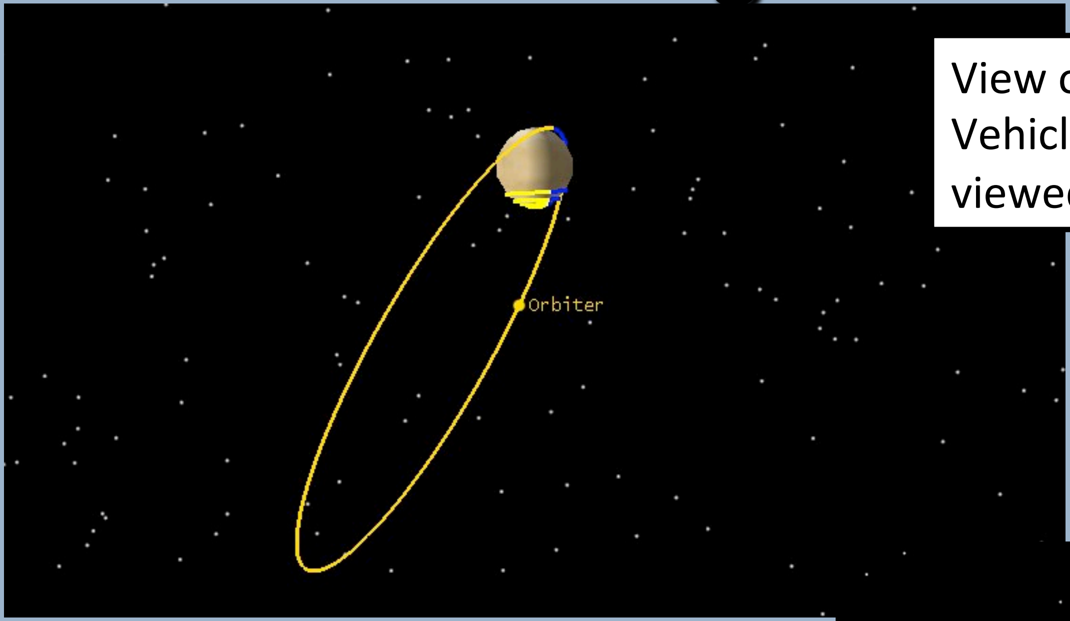


White: Aeroshell trajectory after release from spacecraft
Blue : Spacecraft trajectory prior to VOI
Yellow: Spacecraft trajectory after VOI

View from sun, Earth behind Venus

The orbiter will see the balloon from entry through the first 2 hours

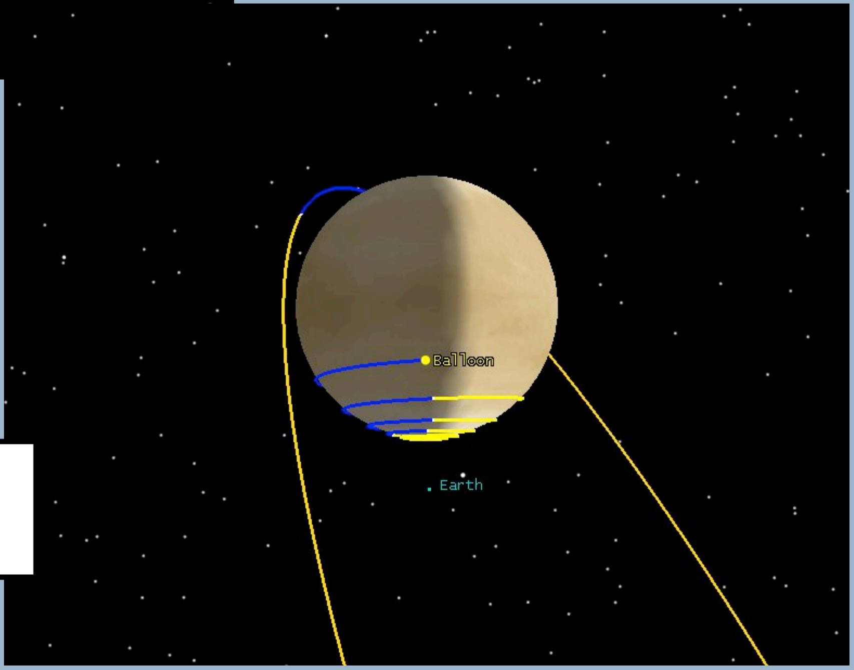
Mission Design: Orbit & Balloon



View of Orbit and Entry Vehicle at time of entry as viewed from Earth.

Note: preliminary

24 hour orbit;
apoapse at 66,000 km

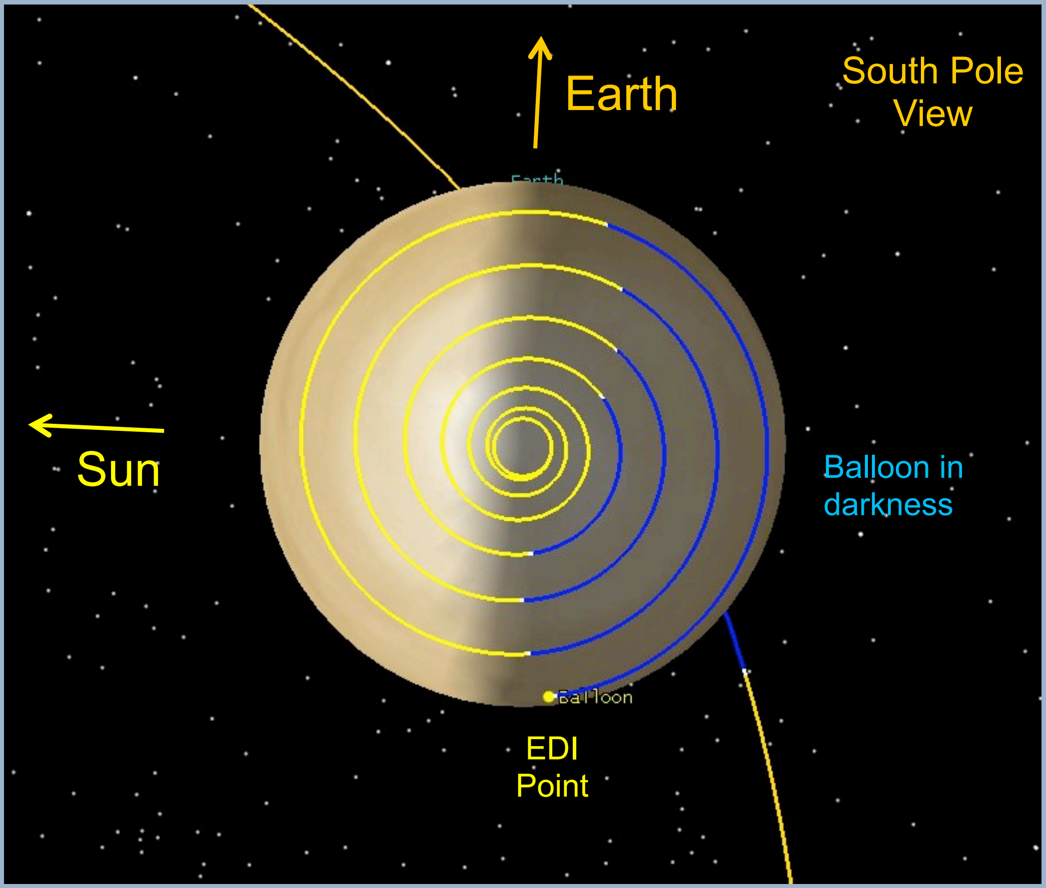


The balloon's initial location and path southward.

Mission Design: Balloon Path Over 21 Days

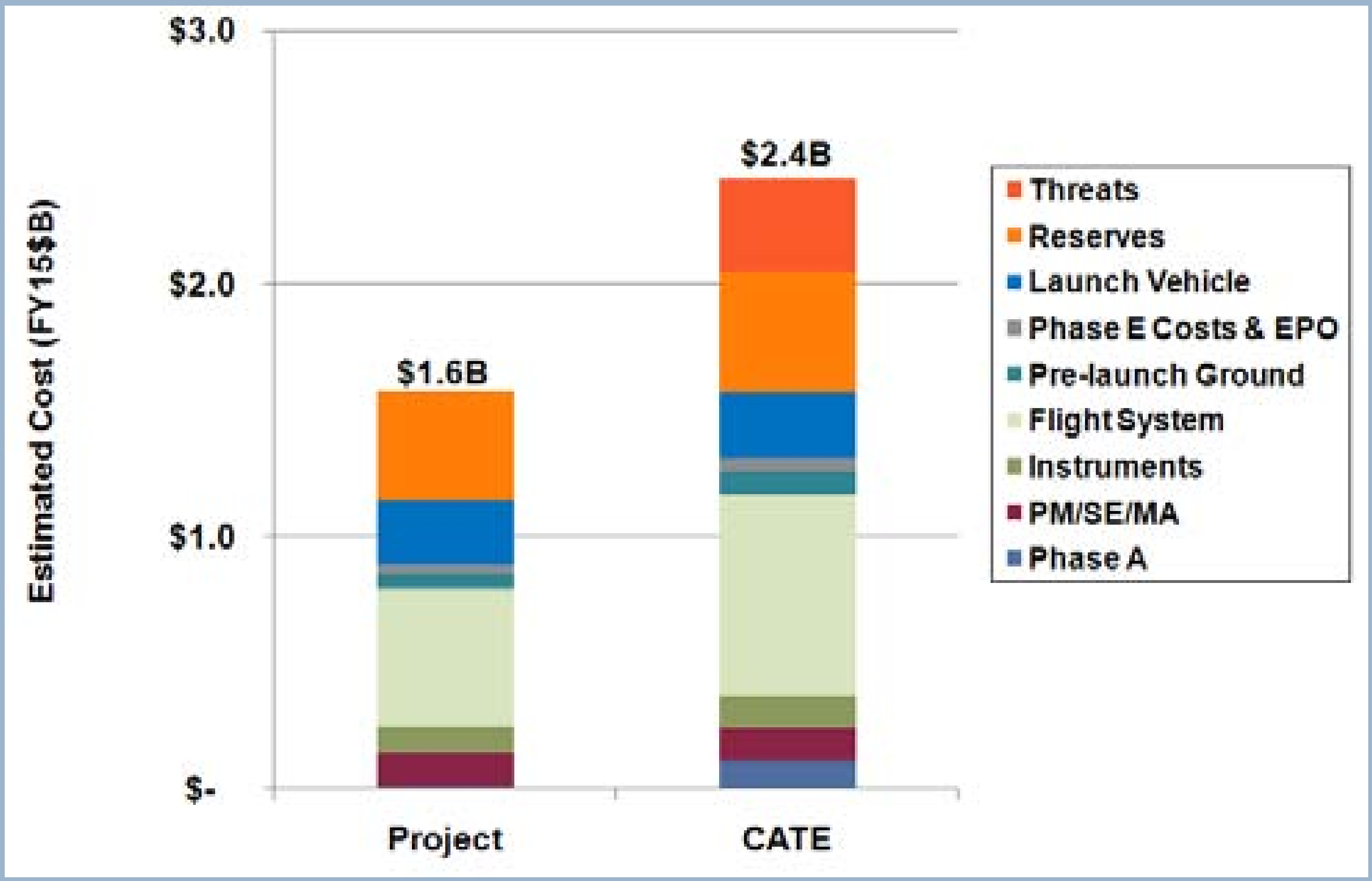
The path of the balloon in Venus' atmosphere, assuming:

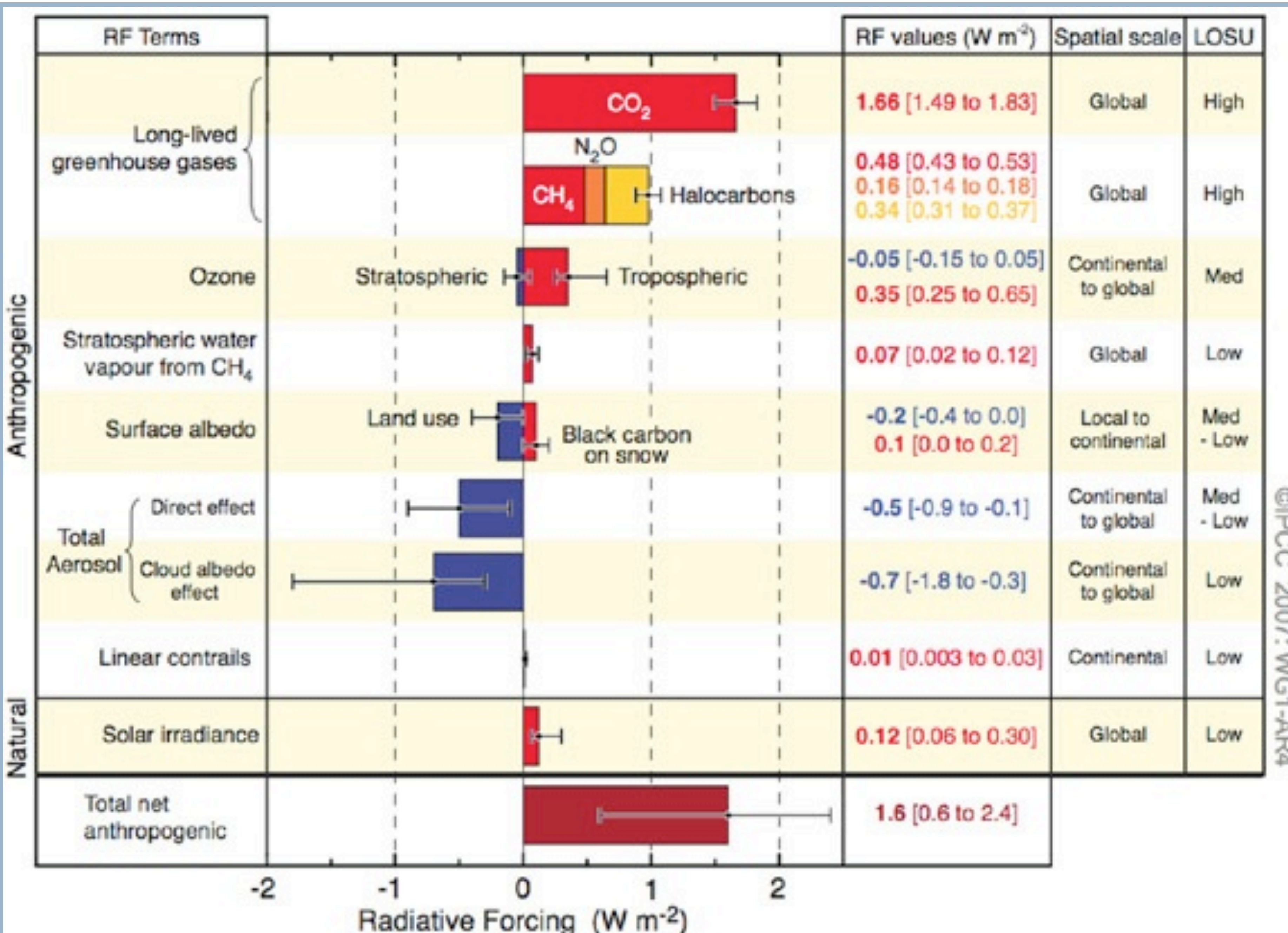
- Constant Zonal wind velocity of 60 m/s.
- Constant Meridional wind velocity of 4 m/s (poleward motion).
- Motion ceases at +/- 85° latitude.



Depending on the wind conditions, the balloon will circumnavigate Venus about 5 times

Key Cost Element Comparison





RADIATIVE FORCING COMPONENTS

Conclusions

The Venus Climate Mission will produce fundamental new advances by creating a detailed portrait of climate and global change on Venus.

This will contribute greatly to understanding of terrestrial planet system science and the mechanisms of climate stability and climate change on Earth-like planets.

This will also help to evaluate, validate and contextualize terrestrial climate models and their applications.

These important applications include understanding the divergent history of Venus, Earth and Mars, evaluating the habitability of extrasolar terrestrial planets, assessing the likely magnitude of anthropogenic climate change under various projected forcings, and learning the long term fate of the Earth.

Conclusions

The current VCM concept is not optimized
for mass / volume / power; this will allow future proposers
to design a broader science concept for similar or lower costs.

International contributions could ease cost pressure and/or provide additional mission elements to broaden this flagship mission into a wider science science investigation including surface mapping and in situ surface science.