INVESTIGATING THE VENUS CLOUDS FROM BALLOON AND ORBIT

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Introduction

- Future Venus missions to investigate cloud chemistry, climate, dynamics, radiation and life have been studied by NASA centers, universities and the US National Academies of Sciences
- These missions include
  - Venus Atmosphere and Surface Explorer (VASE) and
  - Hyperspectral Observer for Venus Reconnaissance (HOVER)
- The mission proposals have not yet been selected for funding, but their combination would provide a powerful *in-situ* and remote investigation of the evidence for habitability of the Venus clouds

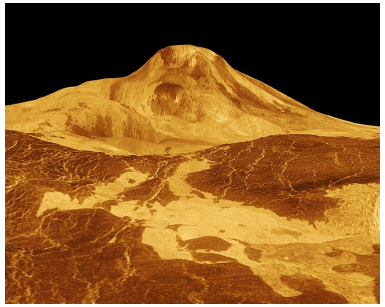
Venus Atmosphere and Surface Explorer (VASE)

- **VASE floats at a fixed altitude in the clouds on a balloon for one Venus circumnavigation,**
- **with a deep atmosphere probe that is dropped.**
- **It is comprised of a 7m superpressure balloon and a 0.3m probe.**
- **Instruments:**
  - **Mass Spectrometer,**
  - **Tunable Laser Spectrometer,**
  - **Descent imager,**
  - **Atmospheric structure (T, P, wind).**
- **The orbiter provides communication and synoptic imaging spectroscopy above the floating platform to give a context for the balloon and atmospheric measurements.**

VASE: Venus Atmosphere and Surface Explorer

Science Objectives:

- Complete the noble gas and light stable isotopes inventory to constrain theories of planetary formation and evolution.
- Descent imaging of the surface
- Atmospheric structure profile from clouds to surface (temp, pressure, wind)
- Trace and reactive gas compositions



Mission Description

- A hybrid mission where the deep atmosphere probe is carried on a balloon for one circumnavigations and then dropped.
- Balloon mission lasts 6-8 days
- Dropped probe mission lasts 1-2 hours
- Quick 4 month trip to Venus
- Direct-to-Earth S-band telecommunications
- Balloon and probe tracking from Earth

Flight System Elements

- ~ 900 kg launch mass (with contingency)
- Simple carrier spacecraft
- Single-string architecture
- Probe and balloon delivered inside PV-like aeroshell, ~ 2.2 m diameter.
- 7 m superpressure balloon, 0.3 m probe.
- Instruments:
  - Mass Spectrometer
  - Tunable Laser Spectrometer
  - Descent imager
  - Atmospheric structure (T, P, wind)

Venus Deep Atmosphere Probe (VDAP)

- Hybrid probe-carried-on-a-balloon architecture offers powerful advantages versus a traditional probe mission:
  - More time to take noble gas & light stable isotope composition measurements.
  - Enough time to analyze composition data on Earth and repeat measurements in case of problems.
  - Obtain additional chemistry and dynamics information while flying through clouds.
- Shallow entry angle plus 2-stage parachute can enable data taking starting at ~70 km.
- Multiple new instrument options exist to obtain information about UV absorber and cloud properties.

Hyperspectral Observer for Venus Reconnaissance (HOVER)

- **HOVER would measure**

the composition, chemistry, dynamics and radiation in the Venus atmosphere from a cloud-synchronous retrograde, low-inclination orbit to determine what forms the clouds and their markings.

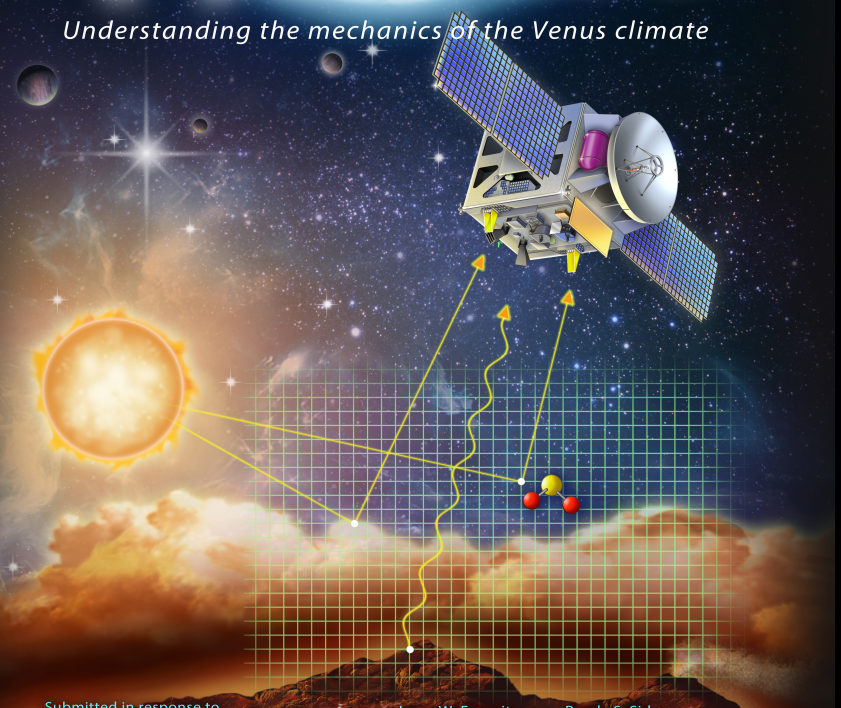
- **It would compare the Venus weather and climate—**

including surface interactions and volcanism— to Earth, Mars and extra-solar planets to identify key observables for Venus-like planets and their habitability

Hyperspectral Observer for VEnus Reconnaissance

HOVER

Understanding the mechanics of the Venus climate



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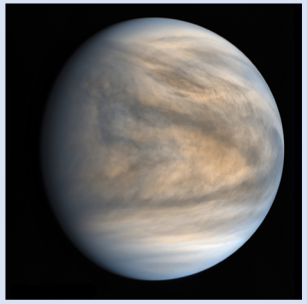
NASA Discovery 2019
HOVER Fact Sheet

Hyperspectral Observer for VEnus Reconnaissance

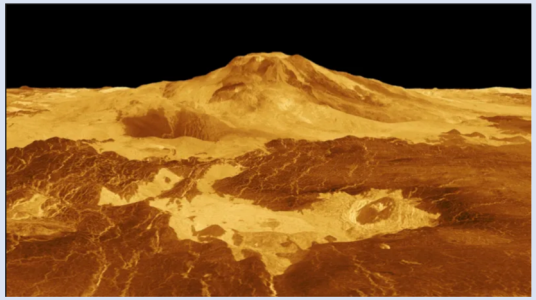
HOVER

Understanding the mechanics of the Venus climate



What Makes the Clouds?

Measure the composition, chemistry, dynamics and radiation in the Venus atmosphere to determine what forms the clouds and where energy is absorbed.



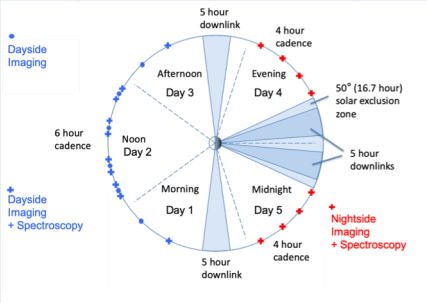
What is the Role of the Surface?

Determine rock composition at large scales to identify granitic materials and study past climates. Measure temporal and spatial chemical constituents to monitor for current volcanic activity that may be driving the climate now.

How Does Venus Compare?

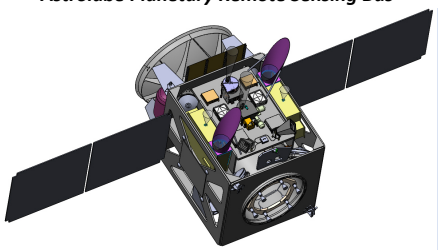
Compare the Venus weather and climate—including surface interactions and volcanism—to Earth, Mars and extra-solar planets. Identify key observables and modeling constraints for Venus-like planets.

Operations Concept



Spacecraft Bus

Astrolabe Planetary Remote Sensing Bus



Science Investigations

- ***UVCAM*** - UV-Vis Camera: cloud-top dynamics
- ***IRCAM*** - IR Camera: night-side images
- ***UVSPEC*** – UV Imaging Spectrometer: trace gases
- ***IRSPEC*** – IR Imaging Spectrometer: mineralogy, trace gases
- ***ROCC*** - Radio Occultations: temperature profiles, cloud composition

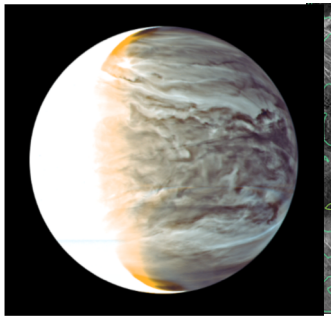
HOVER's 2-year cloud-tracking vantage point collects full-disk spectral, spatial, and temporal data at unprecedented resolution

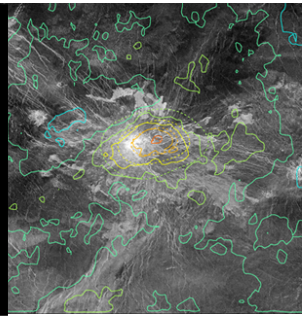
Hyperspectral Observer for Venus Reconnaissance (HOVER): Understanding the mechanics of Venus climate

Laboratory for Atmospheric and Space Physics
University of Colorado **Boulder**

Science Objectives:

- Determine how chemistry & dynamics produce the clouds, including the distribution of key absorbers and parent gases of the clouds
- Measure temperature & compare spectra to Venus greenhouse models
- Characterize super-rotation and solar to anti-solar circulation & compare to GCMs with assimilation
- Regional rock mineralogy to infer the distribution of continental crust
- Monitor for volcanic eruptions





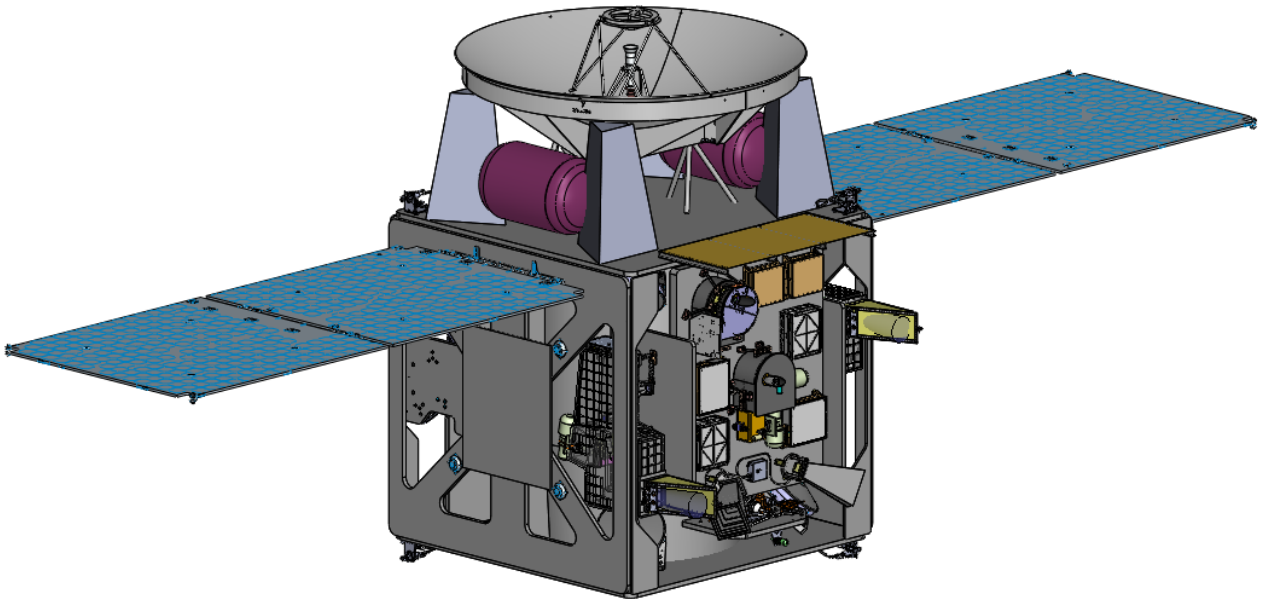
Mission Description

- EMM 'Astrolabe' bus
- Mission design:
  - 5-day near-circular equatorial retrograde orbit, Venus cloud synchronous at periapsis
  - Launch May 2026
- 2-yr science mission; LASP operations & SDC
- Simultaneous high resolution, high cadence multi-spectral images and imaging spectroscopy

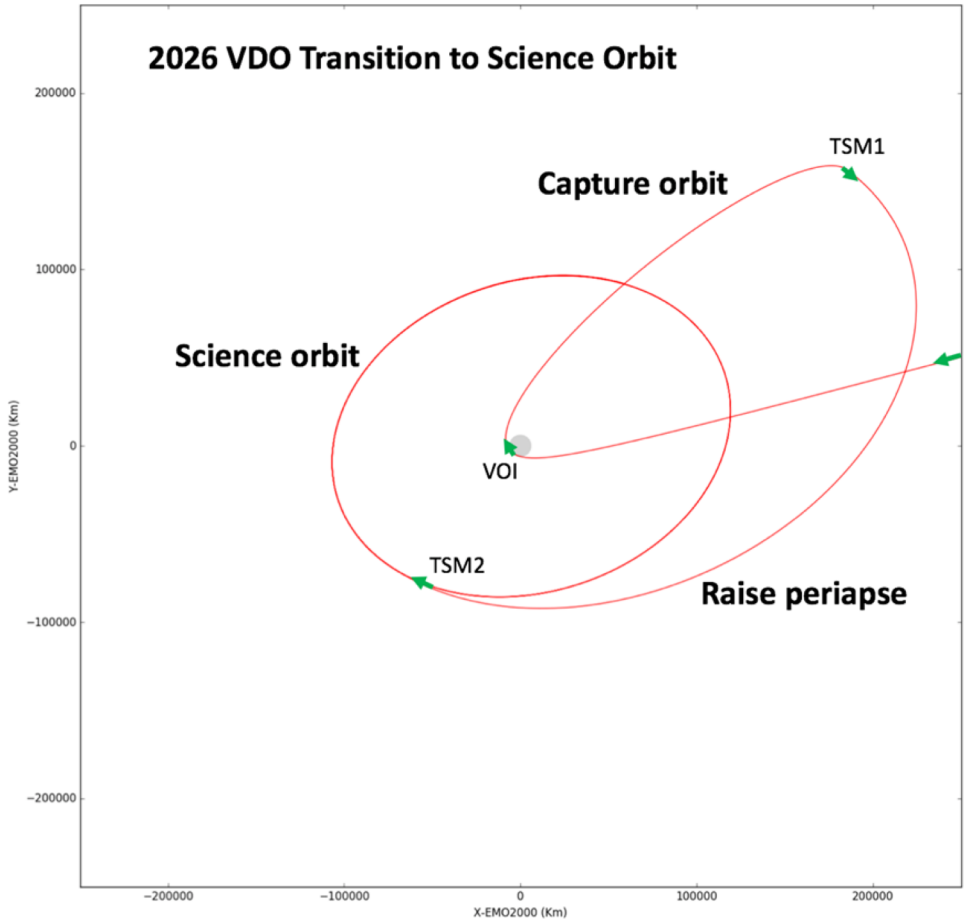
Flight System

- EMM 'Astrolabe' bus (2020 launch)
- Fully redundant sub-systems
- Ka-band data rate allows high cadence
- Propulsive capacity: 1.9 km/sec
- Instruments:
  - UV/Vis imaging spectrometer (UVSPEC)
  - Multispectral imagers (UVCAM & IRCAM)
  - SWIR imaging spectrometer (IRSPEC)
  - Radio occultation (ROCC, via HGA)

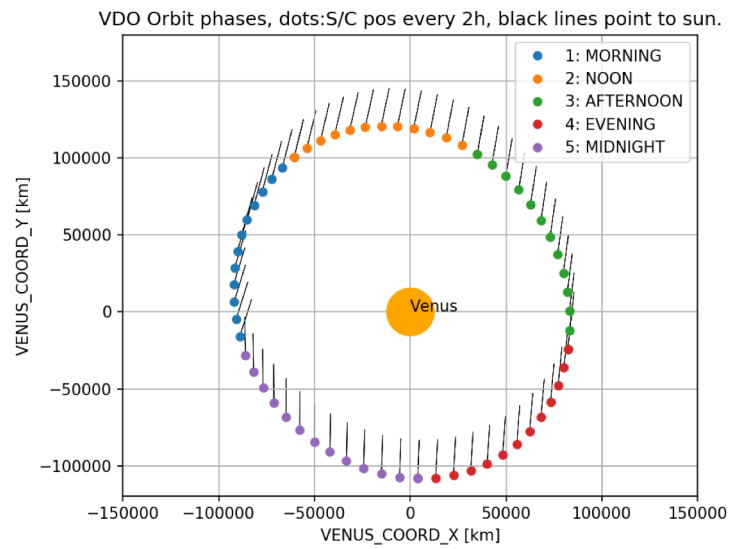
HOVER BUS
EMM ‘ASTROLABE’ Heritage



Orbit Implementation



5 day science orbit with a periapse speed of a 4 day circular orbit:
Radius of peri: **106,800 km**
Radius of apo: **123,900 km**
Eccentricity: **0.074**
Inclination: **170°**
Periapse speed: **1.81 km/sec**
Deterministic dv total: **~1800 m/sec**



Campaigns:
Replace HOVER's regular observations on a data volume neutral basis

- High phase angle (155°) dayside (UVSPEC, UVCAM) [monthly]
- Stellar occultations (UVSPEC, IRSPEC, UVCAM, IRCAM) [most orbits]
- Radio occultations (ROCC) [70]
- Airglow (UVSPEC, IRSPEC) [monthly]
- High cadence observations at nadir (e.g., at morning terminator) (UVSPEC, IRSPEC) [monthly]
- Calibrations [quarterly]

VASE + HOVER Summary

- Compelling science: New, better observations and numerical models can explain the mechanics of Venus climate
- Orbit and payload for simultaneous high-cadence, high-resolution imaging and spectroscopy provide a comprehensive, global data set
- *In-situ* balloon & probe measurements provide ground-truth & characterize the cloud environment; with nested descent images
- Orbiter Investigations: UVCAM, IRCAM, UVSPEC, IRSPEC, ROCC
- Balloon Investigations: Mass Spectrometer, Tunable Laser Spectrometer, IR spectrometer (better spatial resolution than from orbit)
- Probe Investigations: Descent imager, Atmospheric structure (T, P, wind), tracking
- These results can be compared to Earth and to extra-solar planets