KECK INSTITUTE FOR SPACE STUDIES

Jet Propulsion Laboratory
California Institute of Technology

Venus In Situ Sample Capture and Analysis: Role of Aerial Platforms

Presentation to KISS workshop

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Role of Aerial Platforms- Scope of this Presentation

The VeGa Balloon Mission - 1985: The first, and so far, the only aerial platform to have flown at Venus was also the very first microspacecraft to visit a planet.

Architecture of Venus Surface Sample Return: Alternative **c**oncepts for acquiring a sample of Venus's surface and bringing it back to Earth.

Lifting samples from the surface to the cloud layer: Balloon concepts and technology for accomplishing this developed between 1995 and 2005 by JPL and partners.

Aerial Laboratory –Venus Aerobot Technology Development: Alternative **c**oncepts for aerial exploration of the Venus cloud layer and relevance to design of a long-lived aerial laboratory.

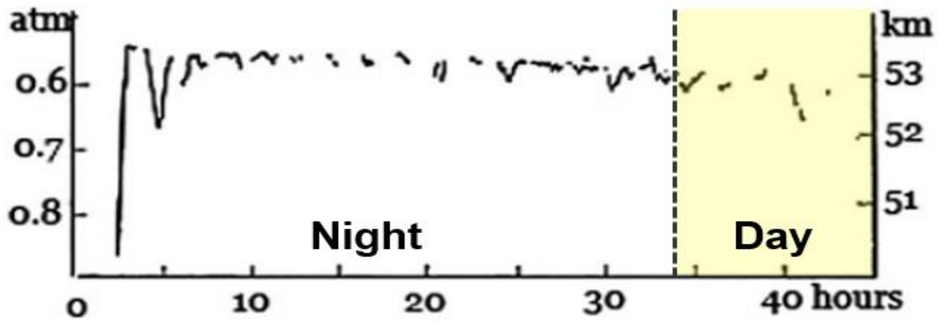
Sample Site Selection and Sample Transfer: Role of mobile aerial platforms in identifying sampling sites and for transferring samples from the ascent balloon to the aerial laboratory.

VeGa Balloon Mission 1985
Demonstration of Venus Aerial Platform Feasibility

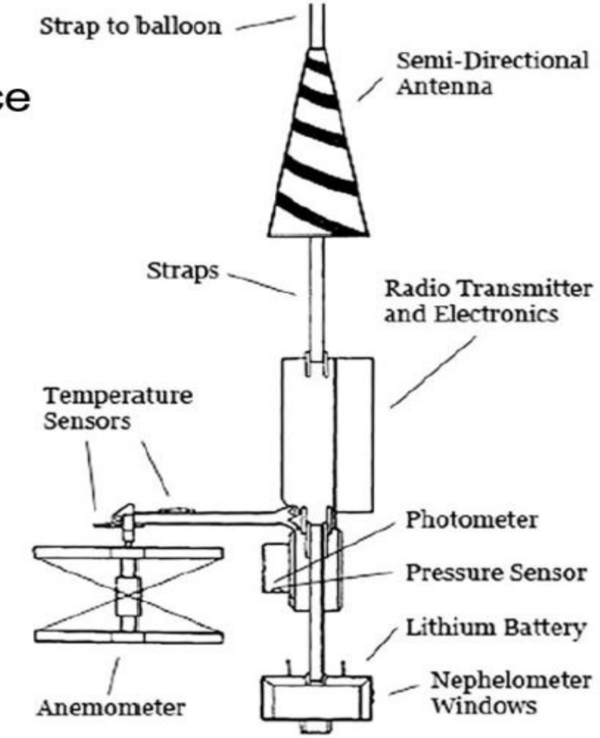
Science driver: **global-scale mobility** and **in-situ measurements**

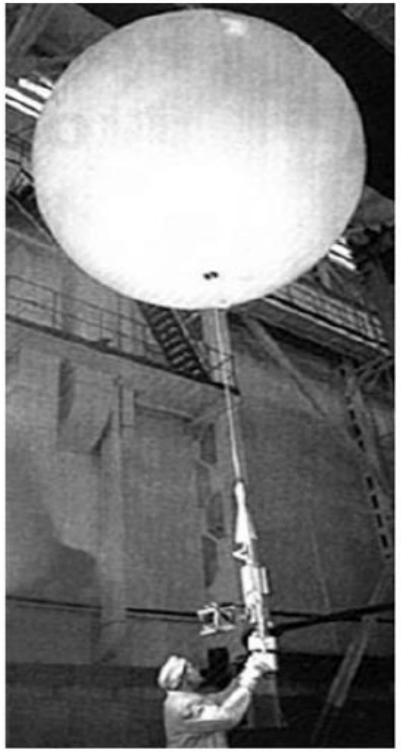
- Vega 1 & 2 (1985) demonstrated concept with small payload
  - 3.4m diameter balloon, 6kg gondola
  - 50hr battery design life
  - Flew one third of Venus circumference
- More recent proposals (VEVA, VALOR) aimed for larger scale

Vega 1 Flight Altitude



[Mitchell, via Huntress & Marov 2011]





Superpressure balloons have been demonstrated on Venus, showing altitude stability and in-situ capability

Venus Surface Sample Return (VSSR) - History

1970s

- Concept for using a balloon was used to lift a sample to an altitude where it could be launched to orbit described by Alan Friedlander and Harvey Feingold.

1980s

- Kerry Nock and Ross Jones of JPL working with Prof Jacques Blamont of CNES further developed the idea of VSSR with a concept in which the sample carried by the balloon "would be retrieved by small robotic airplanes and transferred to an ascent rocket"

Late 1990s

- As NASA's planning of a Mars Sample Return (MSR) mission advanced this stimulated interest in further studies of a Venus Surface Sample Return mission

Early 2000s

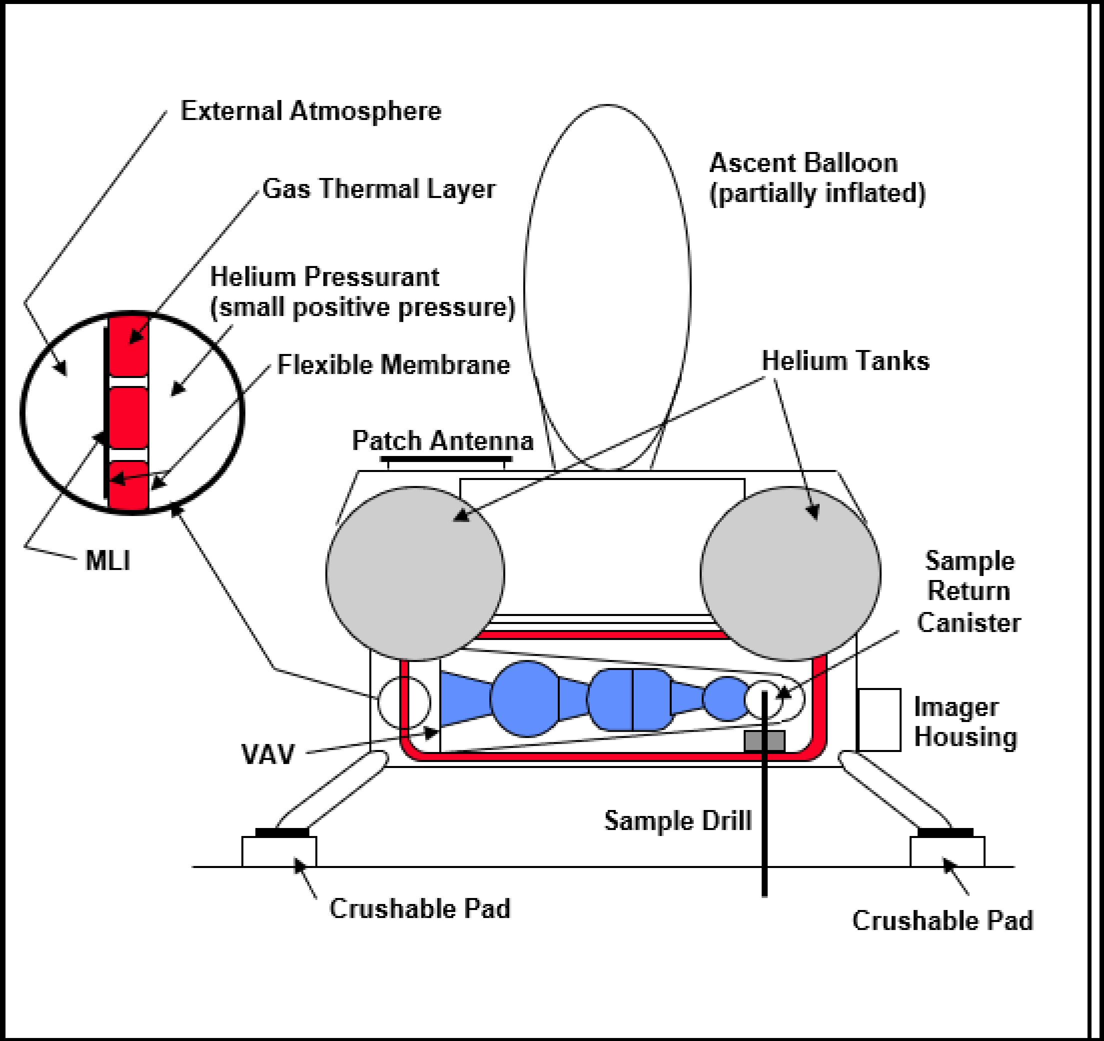
- Planetary Science Decadal Survey proposed the Venus In Situ Explorer (VISE) mission as a precursor to VSSR – would lift samples into the Venus cloud layer for analysis lasting weeks instead of hours

VISE as conceived proved unaffordable in New Frontiers. Since the early 2000s there has been little further work on Venus Surface Sample return or on VISE as originally conceived

Lifting samples from the surface to the cloud layer

Baseline Concept – VSSR Surface Operations

- Ultrasonic drill acquires sample and stores in ascent package
- Panoramic images stored in ascent package
  - Limited transmission of science date to Earth via orbiter
- Helium tank inflates thermal shell and balloon
- 90 minutes on surface



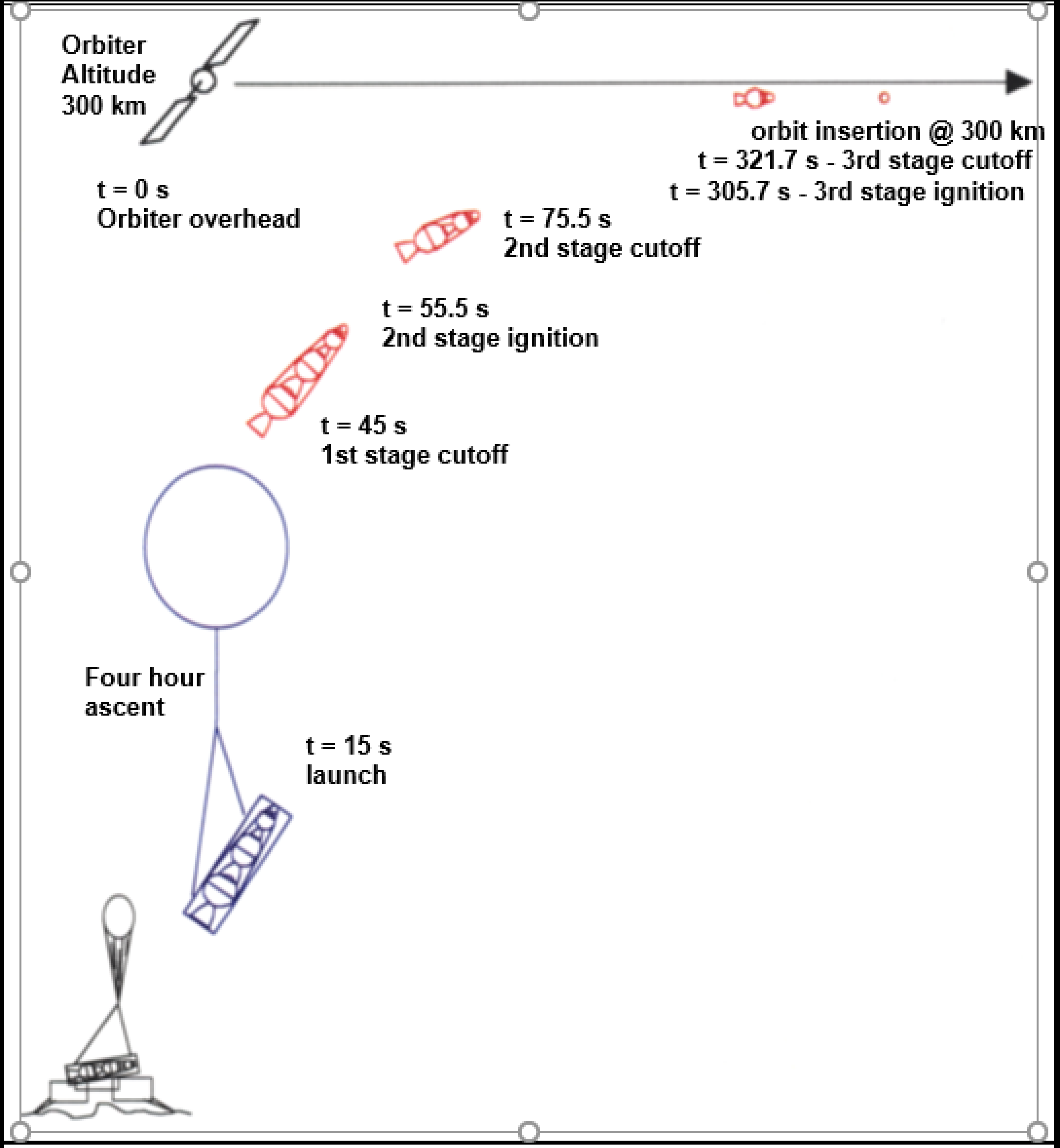
Gershman et al presented at International Conference on Sample Return in Paris, France, Feb 1999

Lifting samples from the surface to the cloud layer

Baseline Concept – VSSR Ascent and Orbital Rendezvous

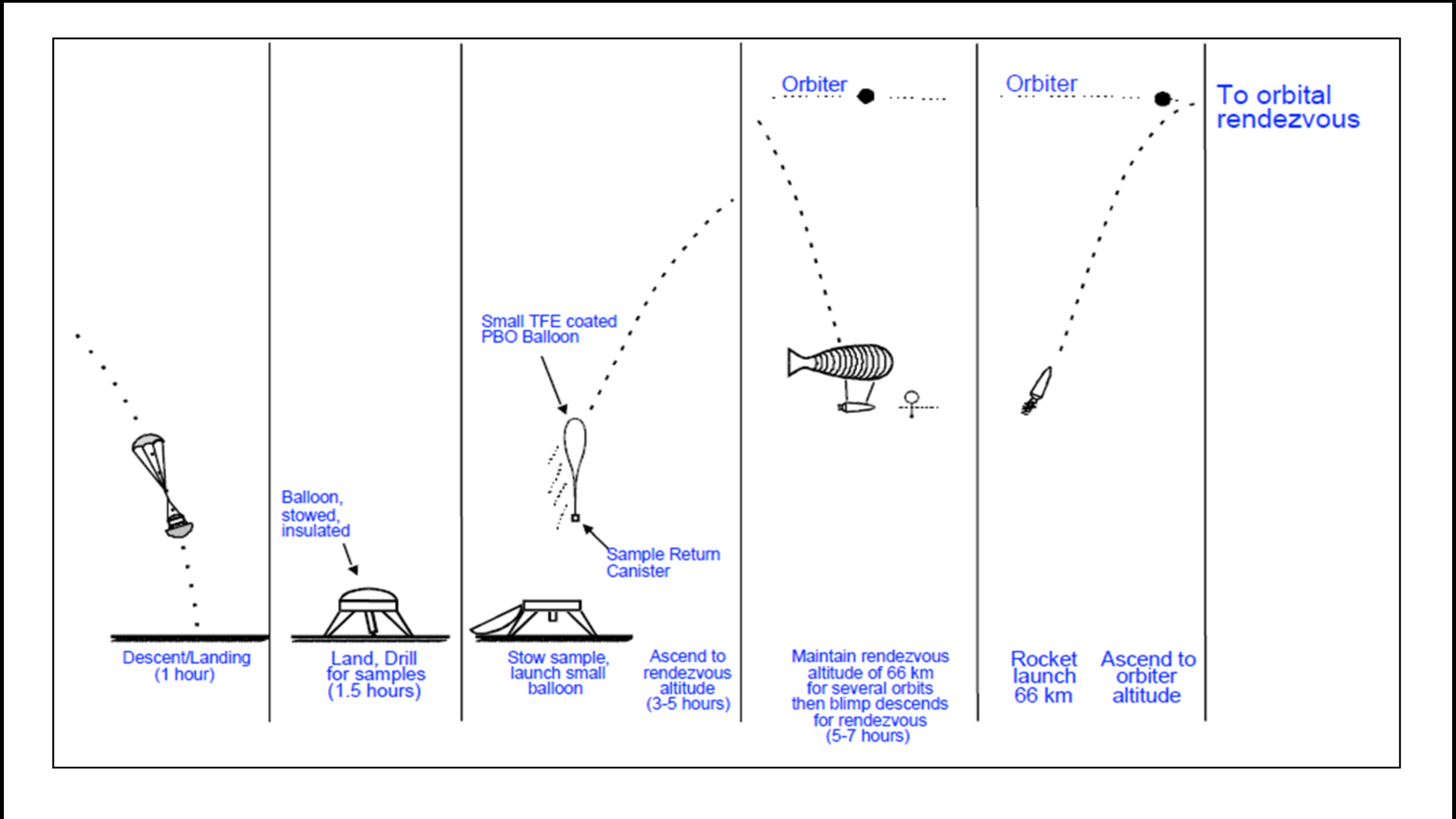
- Balloon ascent to 66 km
- Three stage solid rocket ascent to 300 km orbit with a 2 kg payload
  - Ignition triggered by signal from orbiter
  - First two stages 3-axis stabilized
  - 3rd stage spinning
  - IMU on 2nd stage for orientation
- Orbiter rendezvous
  - Beacon on sample
  - Optical techniques
  - Capture similar to MSR

Gershman et al presented at International Conference on Sample Return in Paris, France, Feb 1999



Lifting samples from the surface to the cloud layer

VSSR Atmospheric Rendezvous – Blimp Option



Cutts et al presented at AIAA Balloon Technology Conference, Norfolk, VA, July 1999

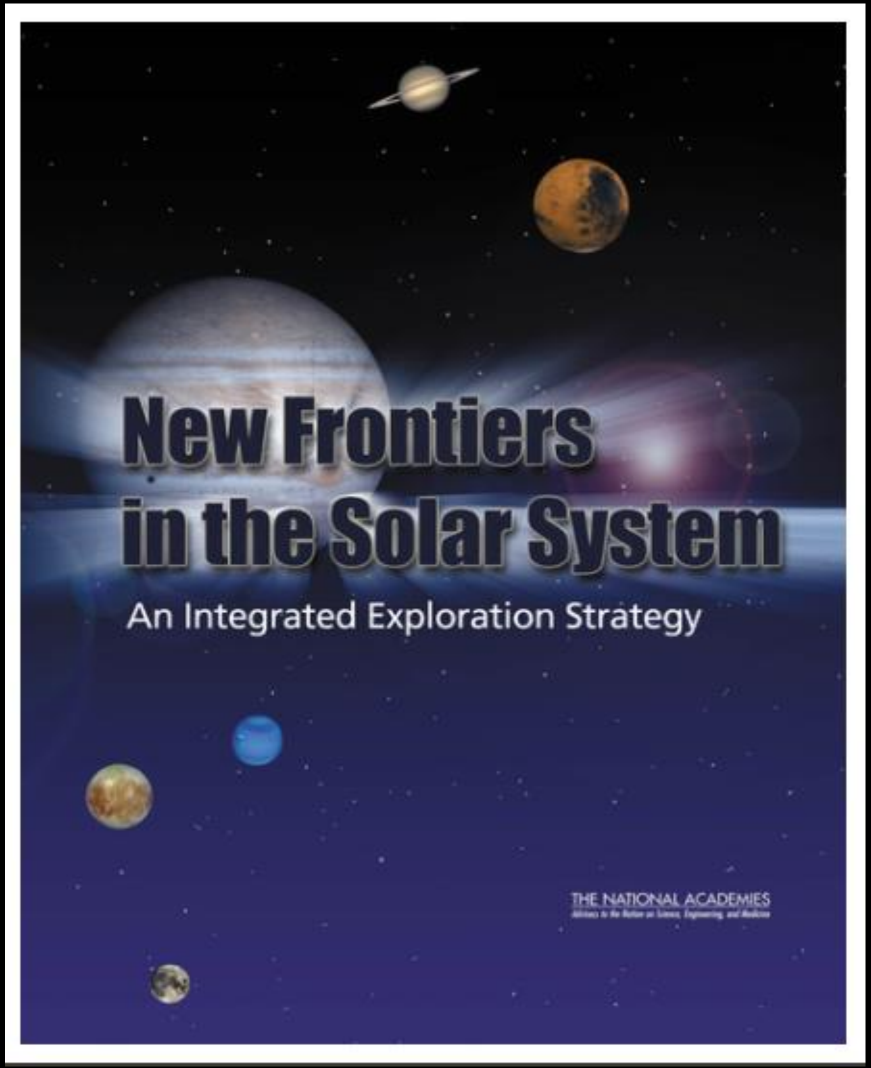
Lifting samples from the surface to the cloud layer

VSSR Architectures - Comparison

Venus Sample Return Atmospheric Segment Option	Baseline	Atmospheric Sample Rendezvous & Sample Transfer		Comments
Vehicles Used	Balloon Only	Balloon/Blimp	Balloon/Airplane	
System Mass	3950	4174 (+5.6%)	3866 (-2.1%	Differences not significant given state of technology readiness
Technology Readiness				
Thermal & Pressure Protection	Low	High	High	
Atmospheric Rendezvous	N/A	Moderate	Moderate	
Atmospheric Sample Transfer	N/A	Moderate	Low	
Orbital Rendezvous	Moderate	Moderate	Moderate	
Orbital Sample Transfer	Moderate	Moderate	Moderate	

Cutts et al presented at AIAA Balloon Technology Conference, Norfolk, VA, July 1999

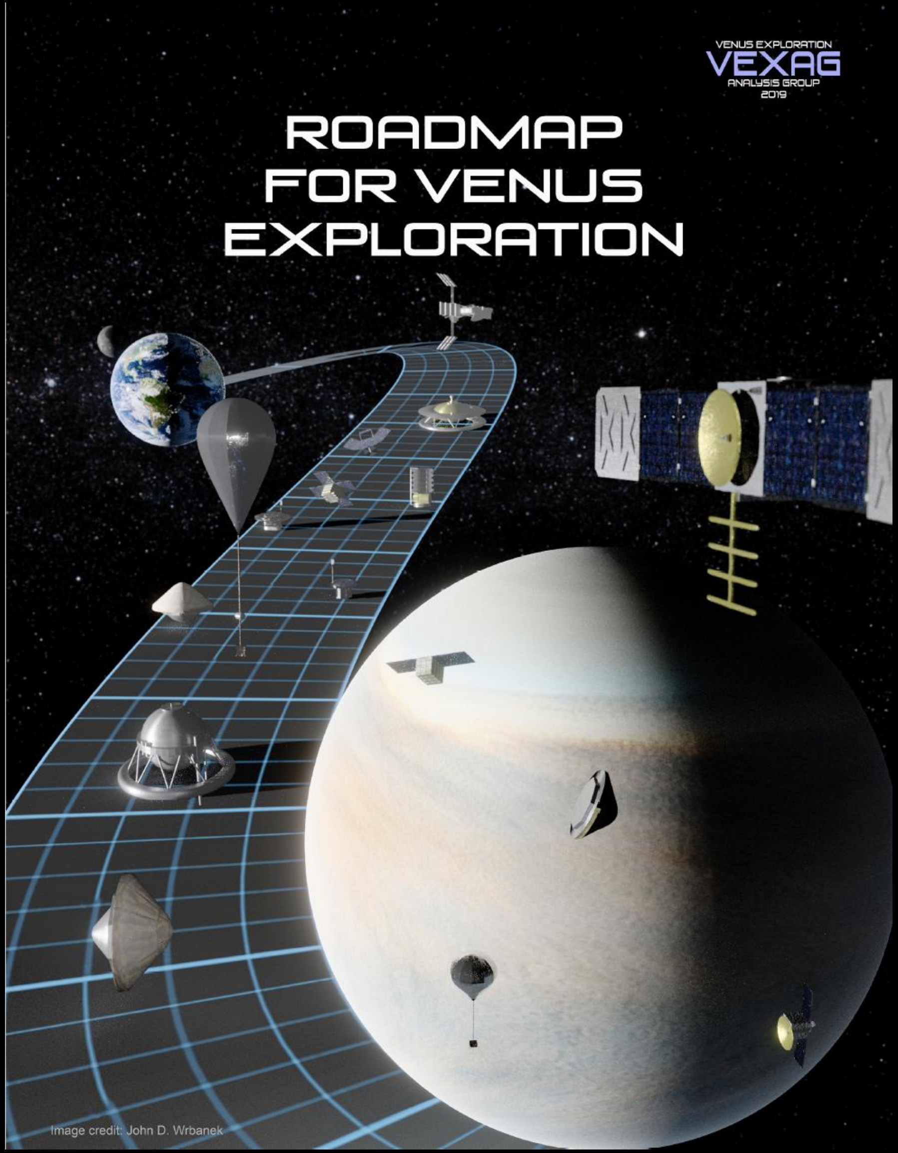
*Venus In Situ Explorer (VISE) Mission Concept**



- A core sample will be obtained at the surface and **lofted to altitude,** where further geochemical and mineralogical analyses will be made.
  - In situ measurements of winds and radiometry will be obtained during descent, ascent, and at the balloon station.
  - Scientific data obtained by this mission would help to constrain the history and stability of the Venus greenhouse and the recent geologic history, including resurfacing.

- The technology development achieved for this mission will pave the way for a potentially **paradigm-altering sample-return mission** in the following decade

*The first Planetary Science Decadal Survey recommended VISE as a New Frontiers mission for the Decade 2003 to 2012



- The return of surface samples to Earth, where they can be examined with techniques that in variety and capability, cannot be equaled by in situ instruments remains an important long-range objective.
- Realistically, we need to learn from the experience of the Mars Program where it took a dedicated, funded program of multiple missions for three decades before being able to propose a sample return mission.
- Thus, these capabilities are currently well beyond the time frame of this Roadmap…….(2023 to 2042)

With the selection of three missions to Venus after almost 40 years without a NASA mission we can now feel free to consider more technically aggressive possibilities

Overview

- Balloon materials - Polybenzoxazole
- Single balloon architectures
- Metallic balloons
- Two stage balloon architecture

Lifting samples from the surface to the cloud layer

Balloon materials – use of polybenzoxazole (PBO) film

- Both baseline and alternative concepts required a balloon material that could survive surface conditions on Venus yet was light enough to provide buoyancy very high in the atmosphere

- In the early 1990s, JPL was already studying the concept of a “deep dive” vehicle – Venus Geoscience Aerobot (VGA) – which could make repeated descents to the surface

- A new high temperature material – polybenzoxazole (PBO) (now known as Zylon) was being developed for VGA for providing buoyancy from the surface to the Venus cloud layer

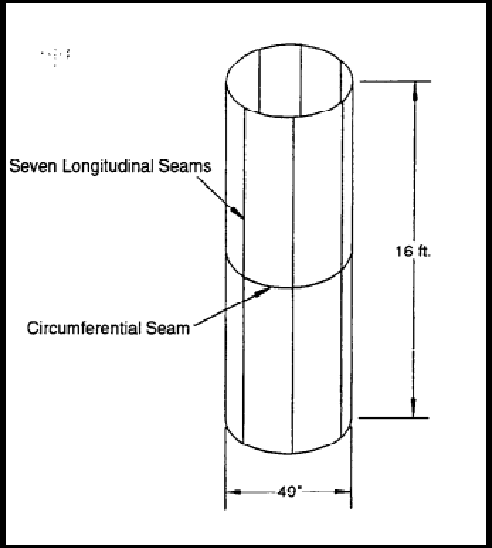
Lifting samples from the surface to the cloud layer

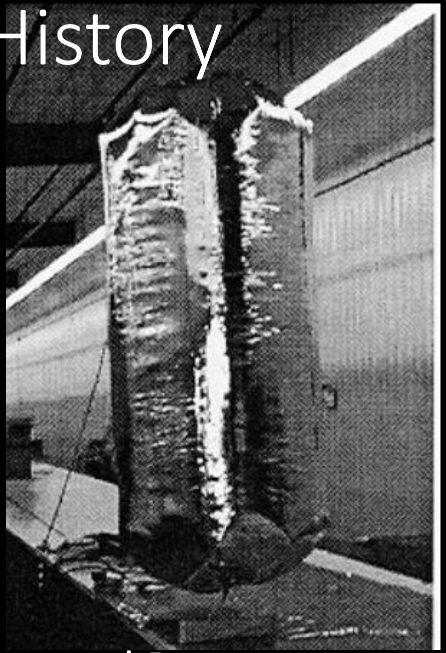
Single balloon concept - Polybenzoxazole Development History

- With JPL support, Foster-Miller and Raven Industries completed a R&D program to develop the processing protocols for making PBO into a film and fabricating Venusian balloons.

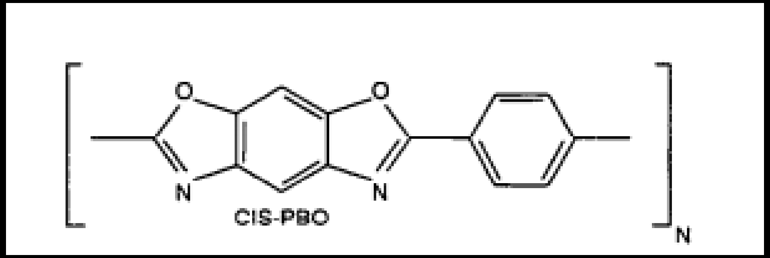
- Two earth/terrestrial PBO balloons (4 to 5 ft in diameter and 16 ft high) were first fabricated to establish baseline fabrication protocols.

- Specialized high temperature seaming techniques and PBO film gold coating processes were then developed to support the fabrication of the Venusian balloons





Balloon Seam Design and Prototype



Chemical structure of PBO

Gold coating did not have the integrity to protect the polymer from sulfuric acid indicating that other approaches were needed for bringing the surface sample to the upper atmosphere

Metallic bellows balloon development

- In 2005, JPL conceived the concept of A Venus Mobile Explorer (VME) as a Flagship mission to follow the New Frontiers class Venus In Situ Explorer
- The VME would exploit the high density of the Venus atmosphere at the surface to simplify locomotion and enable much greater range than the Mars Exploration Rovers which at that time had just arrived at Mars.
- Buoyancy would be provided by a metallic balloon fabricated as a bellows-like structure. Altitude changes would be accomplished by changing the volume of the balloon with either mechanical tethers or pumps.

Venus Mobile Explorer Solar System Exploration Roadmap (2006)

The bellows concepts was demonstrated but technical difficulties in long duration surface operation – power, refrigeration – had delayed further development of the VME concept

Lifting samples from the surface to the cloud Layer:

Two stage balloon concept *

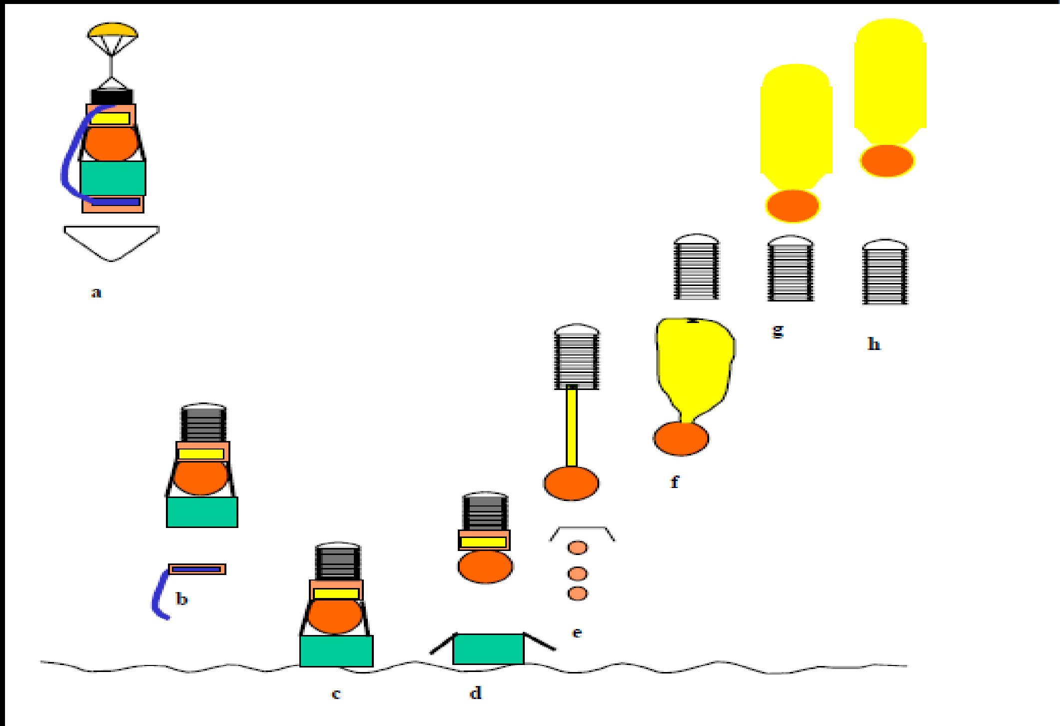
- Addresses the problem that no lightweight material has been identified that is compatible with raising a payload from the surface of Venus to >60 km

- Solution is a two stage balloon
  - Stage 1: Metal bellows balloon
  - Stage 2 Kapton balloon coated with Teflon

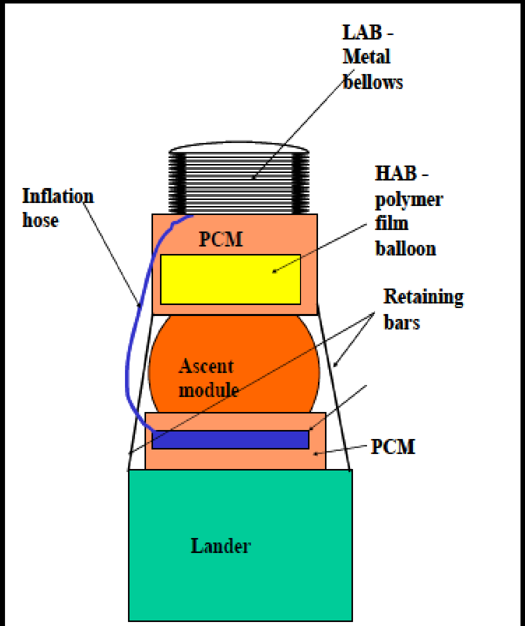
- Metal bellows balloon is partially inflated during descent and after samples are acquired inflation is completed and the balloon rises in the dense atmosphere

- When the metal bellows has completely filled gas is transferred to the Kapton balloon and at an altitude of about 12 km (370C) the metal bellows is jettisoned

* Viktor Kerzhanovich et al 2005



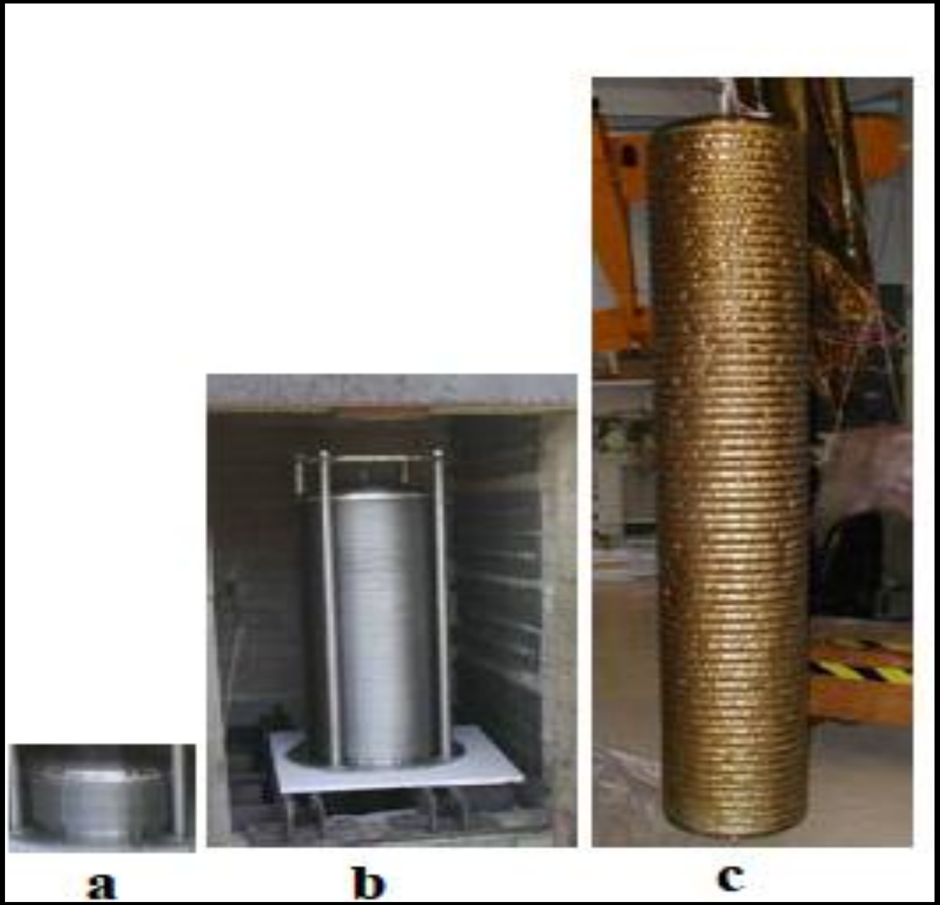
Deployment sequence of two balloon concept



Landed configuration of the two balloon sample acquisition system

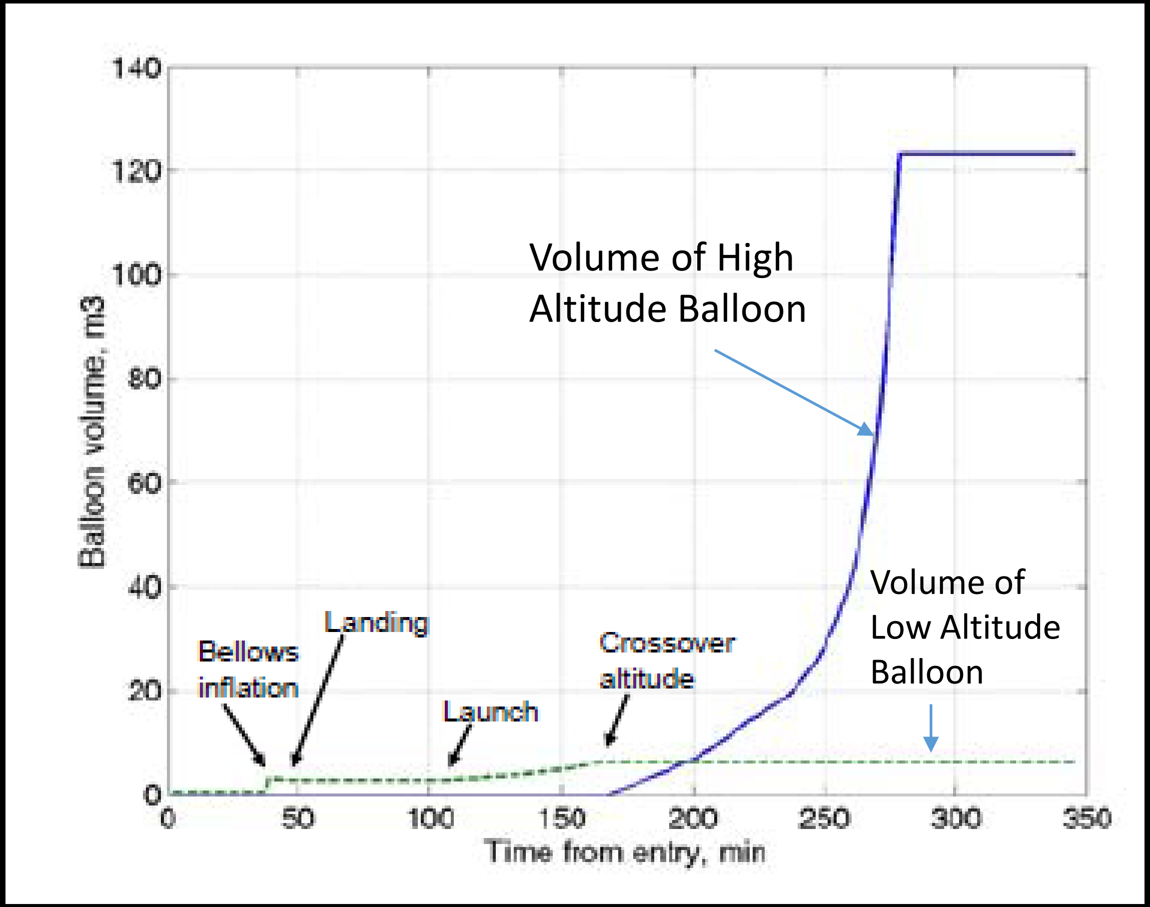
Lifting samples from the surface to the cloud Layer:

Two stage Balloon System – technical details



Metal bellows for first low altitude balloon

a) Fully compressed condition (ΔP = - 84mB)
b) Partially inflated (ΔP = + 114mB)
c) Fully inflated (ΔP = + 630mB) plus Venus environment



Inflated volumes of two balloons as a function of time from initial inflation to arrival at altitude needed for rendezvous with VAV

Summary and Implications for the KISS Study

- The two stage balloon concept has no obvious show stoppers although many engineering details need to be worked.
  - Time line for initial inflation of the metal bellows balloon
  - Packaging and separation of the metal bellows balloon from the Kapton balloon

- Options that might be explored further in this study include
  - Integration with a conventional lander capable of precision landing
  - Concepts for a grab sample where no landing is required

Overview

- Venus Aerial Platform Study, 2018
- Variable Altitude Aerobot
- Venus science with the Variable altitude aerobot
- Technology options for the Aerial Laboratory

Venus Aerial Platform Study (2018)

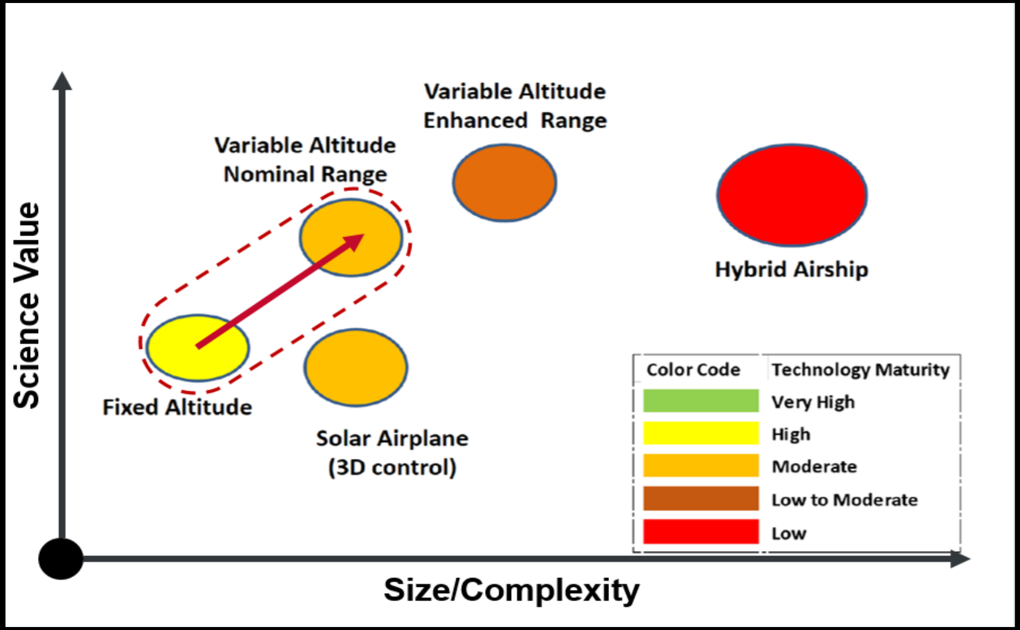
Pumped Compression

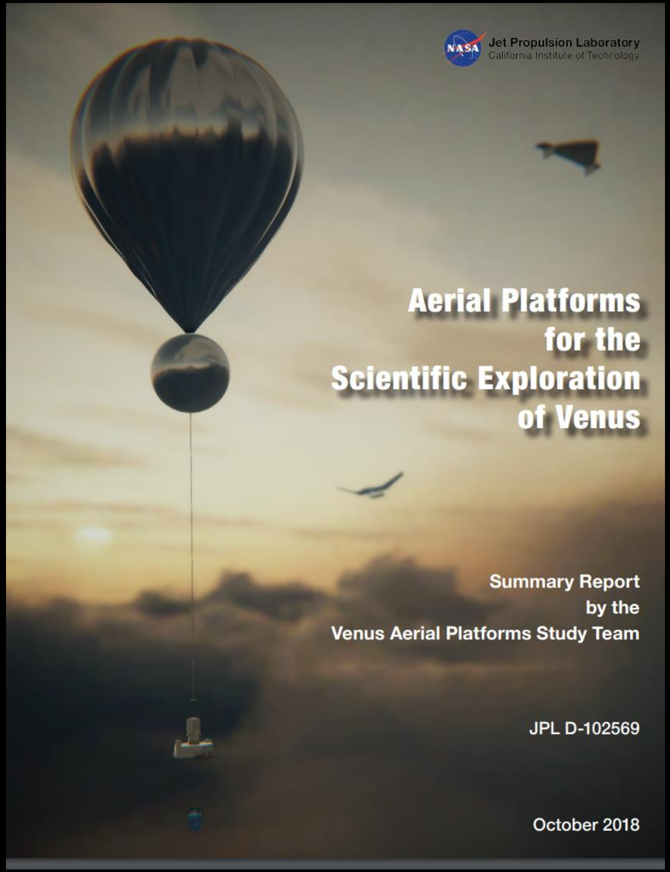
Mechanical Compression

Variable Altitude Aerobot

Hybrid Airship (VAMP)

Fixed Altitude Aerobot





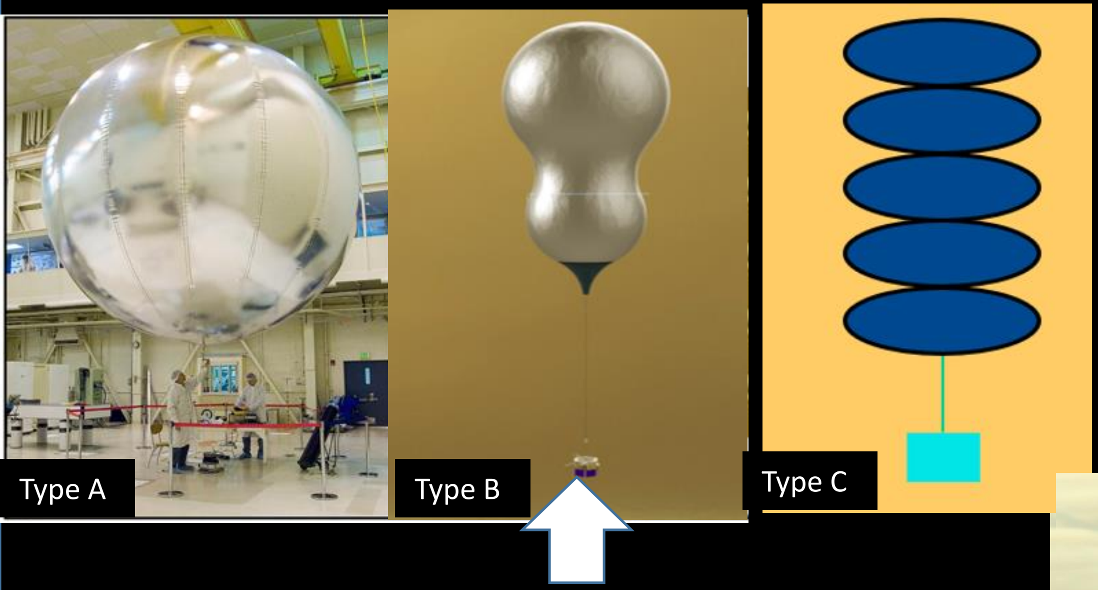
Product of two workshops with 52 scientists, engineers and technologists held at Keck Institute for Space Studies

Sponsored by PSD and supported by VEXAG acknowledgements to Dr Adriana Ocampo

https://www.lpi.usra.edu/vexag/reports/Venus_Aerial_Platforms_Final_Report_Summary_Report_10_25_2018.pdf

Aerial Laboratory – Venus Aerobot Technology Developments

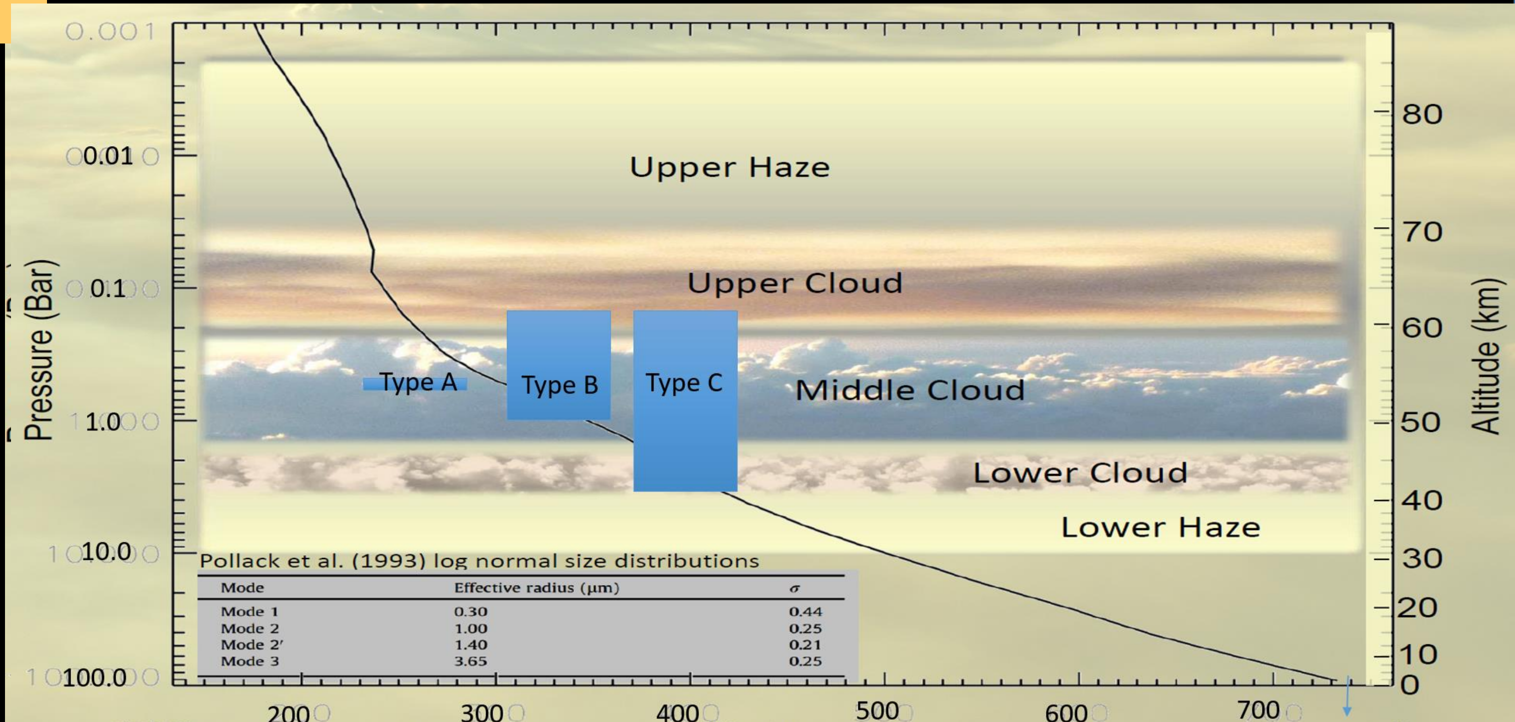
Variable Altitude Aerobot Option Space



Aerobots are classified by altitude range

- Type A Fixed Altitude, Mid Cloud Aerobot
- Type B Variable Altitude, Mid Cloud Aerobot
- Type C Variable Altitude, Sub Cloud aerobot

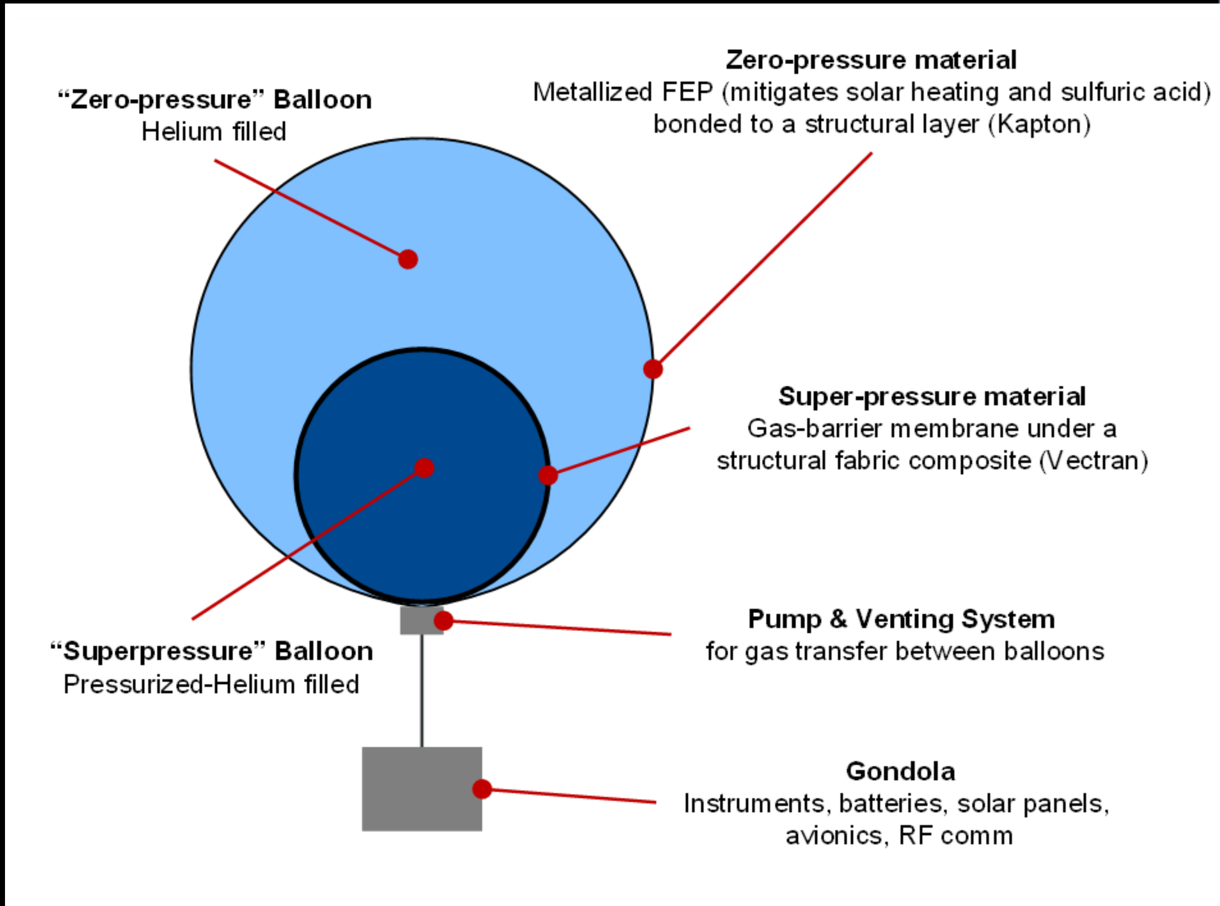
- JPL's current developments are focused on the pumped compression mid cloud aerobot (Type B)
- Provides both a large payload fraction for scientific instruments and a wide altitude range



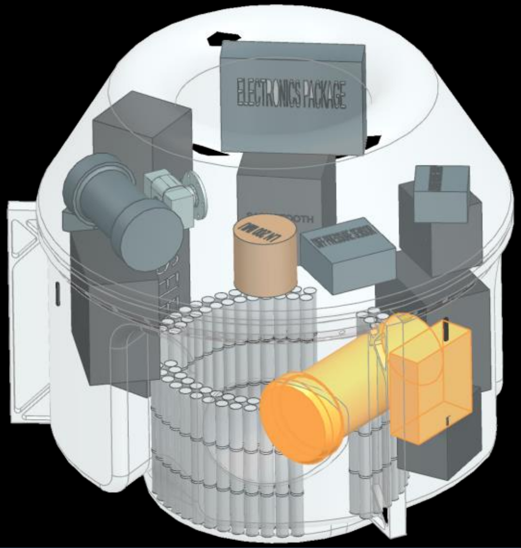
Aerial Laboratory – Venus Aerobot Technology Developments

Variable Altitude Mid Cloud Aerobot

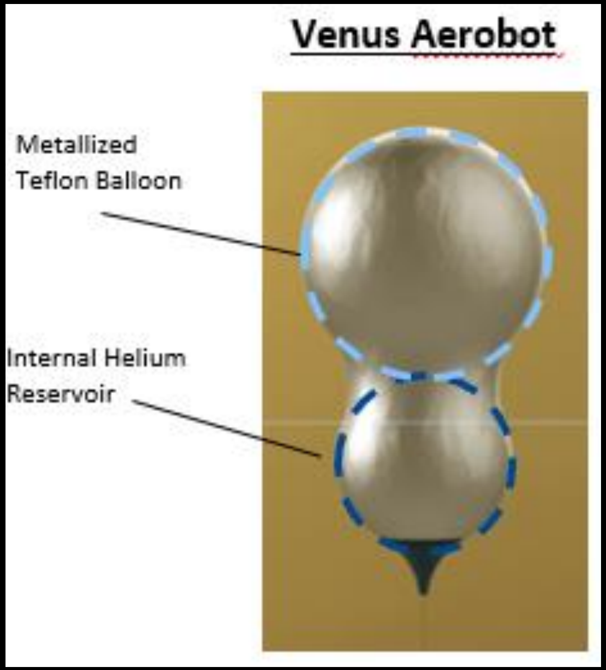
- Exchange of helium between the inner and outer balloon modulates buoyancy and hence controls altitude.
- The outer balloon is coated with Teflon to protect from the sulfuric acid and metalization underneath to reflect sunlight and limit solar heating.
- Any helium leakage out of the pressurized inner balloon gets captured by the outer balloon.

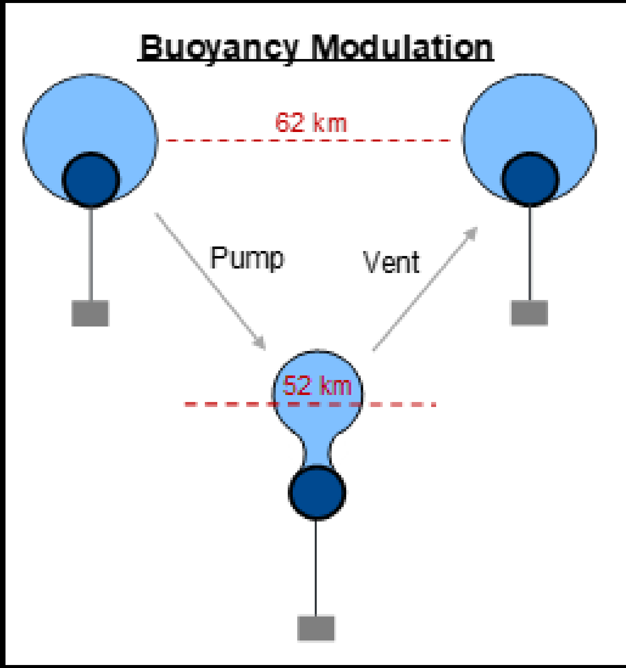


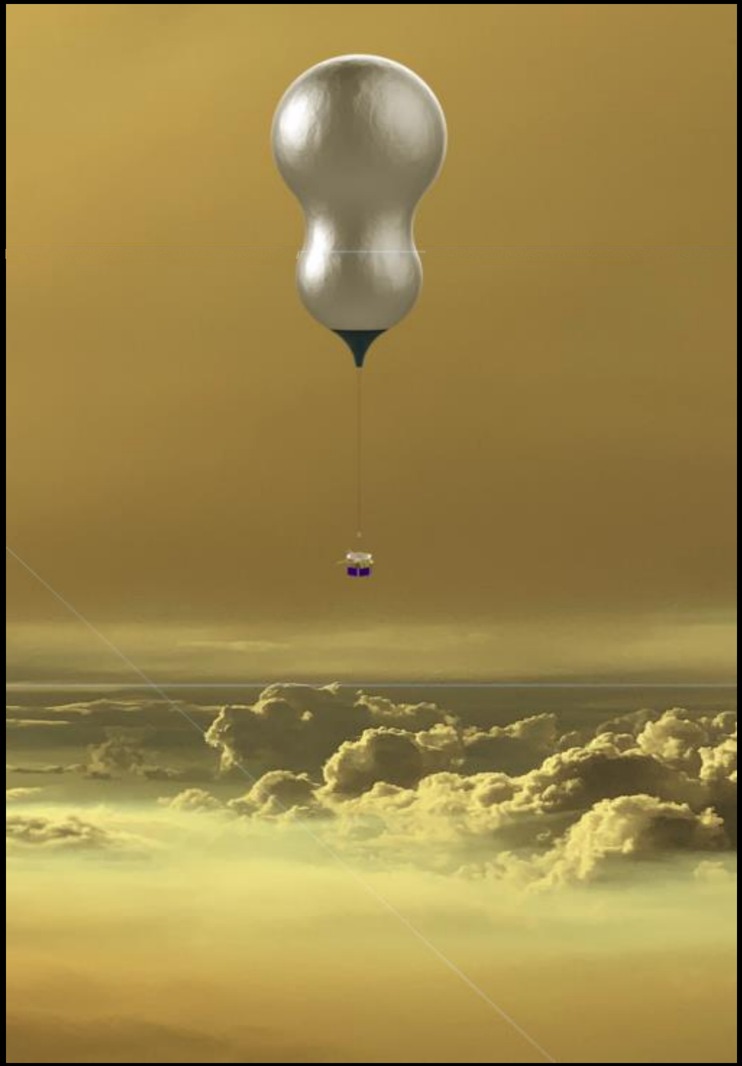
Gondola suspended beneath the balloon includes instruments, batteries, avionics, telecom and solar panels (not shown)



Variable Altitude Aerobot – Mechanism of operation?

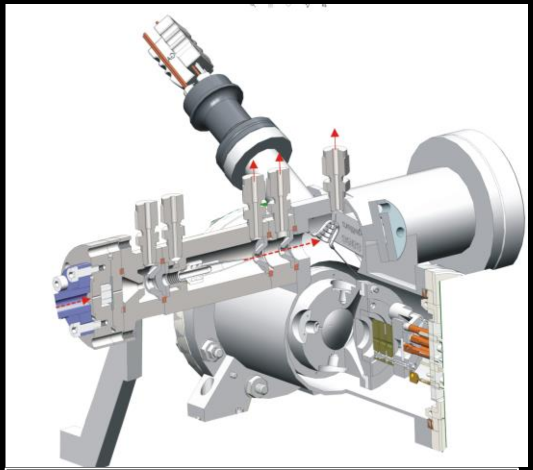




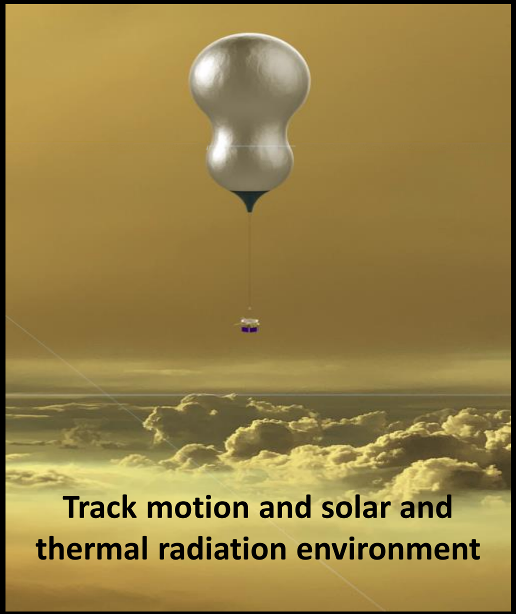


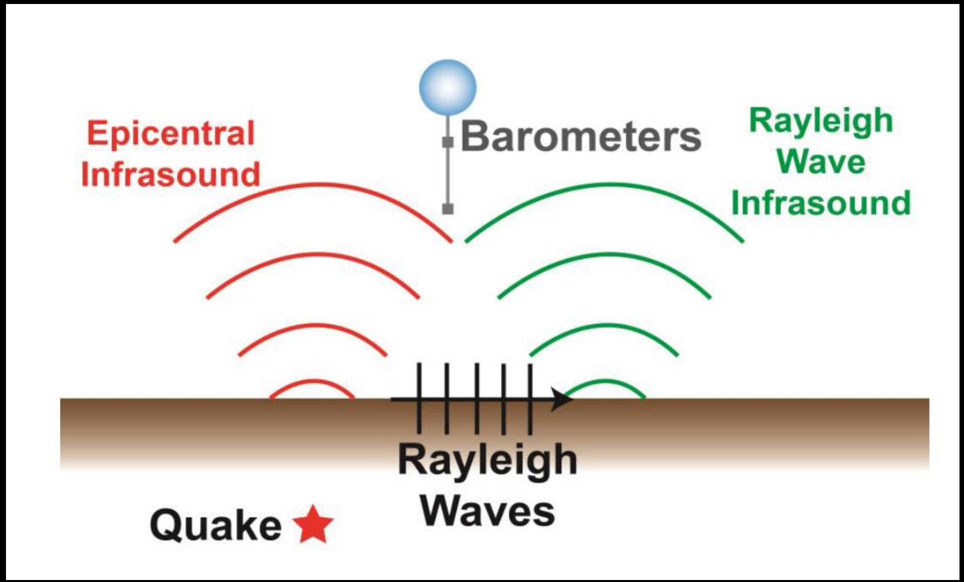
- Helium gas must be pumped into the inner superpressure balloon to cause the aerobot to descend and requires energy.
- Venting of gas from the inner balloon causes the balloon to rise and requires minimal energy

Aerobot Science and Payload?



Venus Aerosol Mass Spectrometer (VAMS)





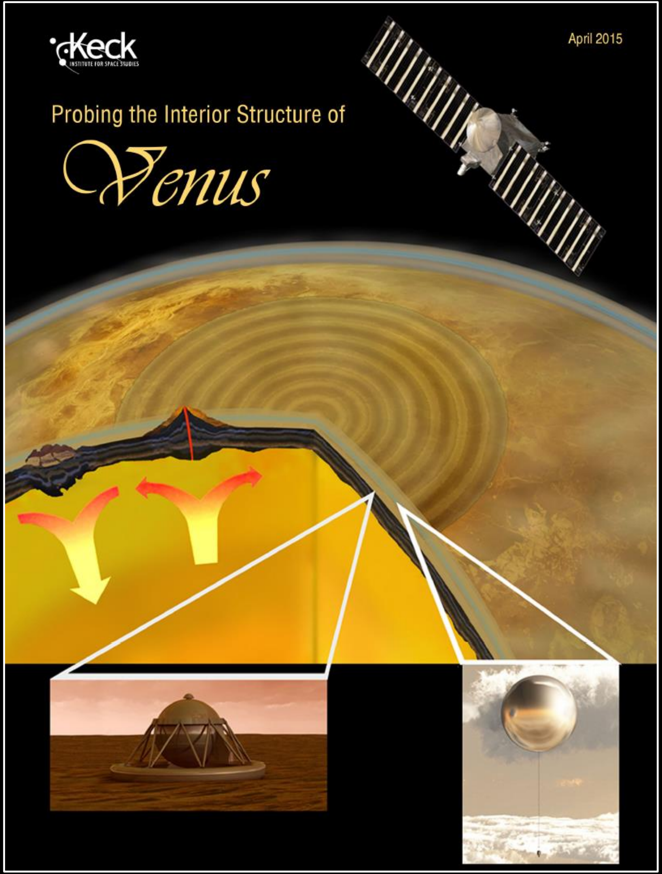
Atmospheric chemistry and Astrobiology

Atmospheric dynamics and radiation balance

Geophysics- Seismology & Remanent Magnetism

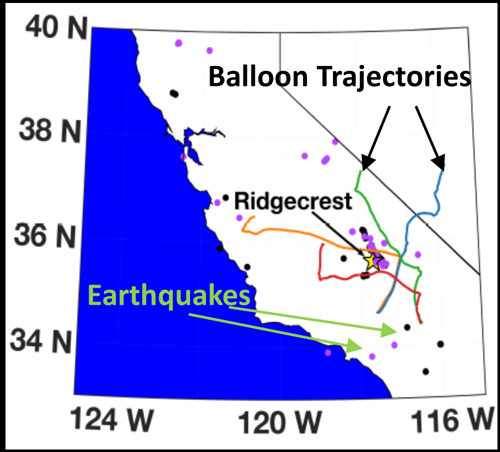
Aerial Laboratory – Venus Aerobot Technology Developments

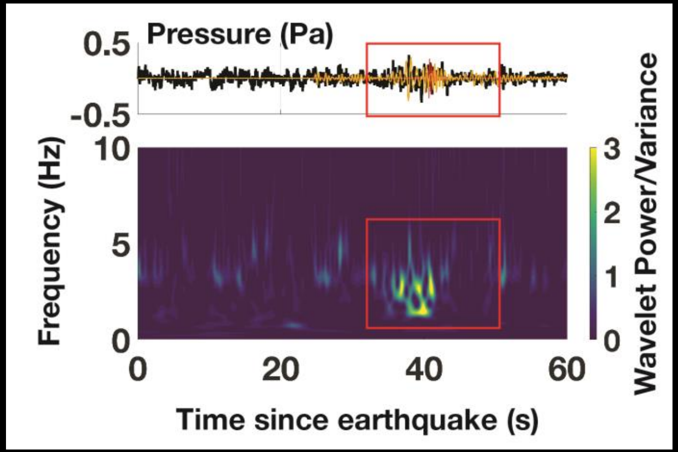
Detecting seismic events with infrasound?



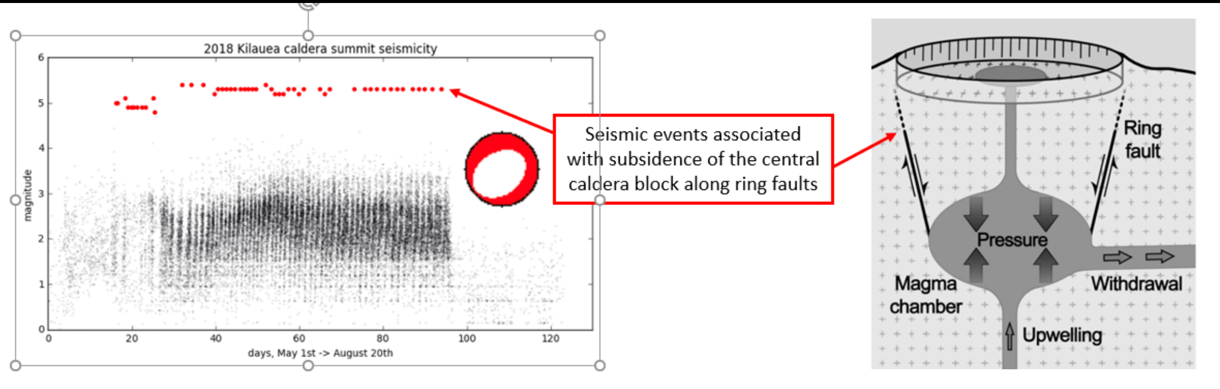
Concept
KISS Workshop 2014

Evidence from Hawaii that volcanic calderas may be seismically hyperactive



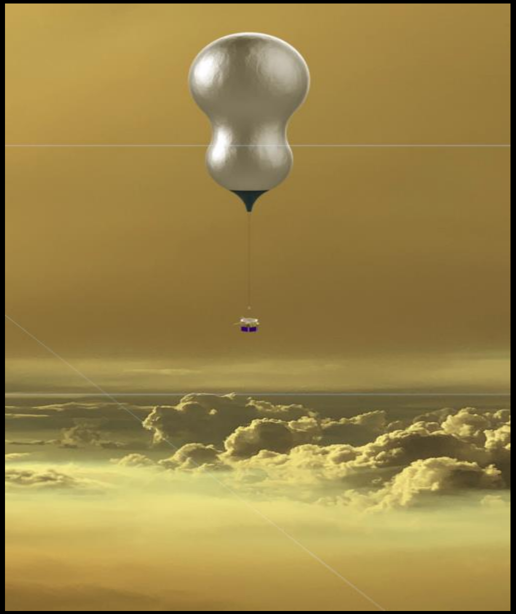


First detection of an earthquake from its Acoustic Signal, 2019



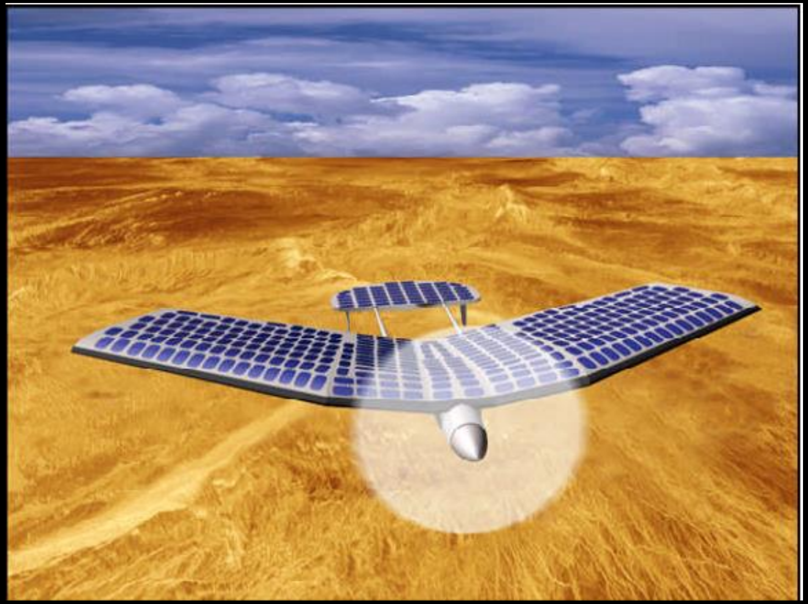
Jack Wilding, Zach Ross, Jennifer Jackson (Caltech), Léo Martire (JPL)

Technology Options for the Aerial Laboratory ?



Variable altitude Balloon

High Altitude Venus Operational Concept (HAVOC, blimp)



Solar Airplane

Solar airplane may be the best option for the Aerial Laboratory

- **Station Keeping:** The only option that can station-keep over the sampling site
- **Long Duration:** Can fly indefinitely on the dayside of the planet near the subsolar point

Overview

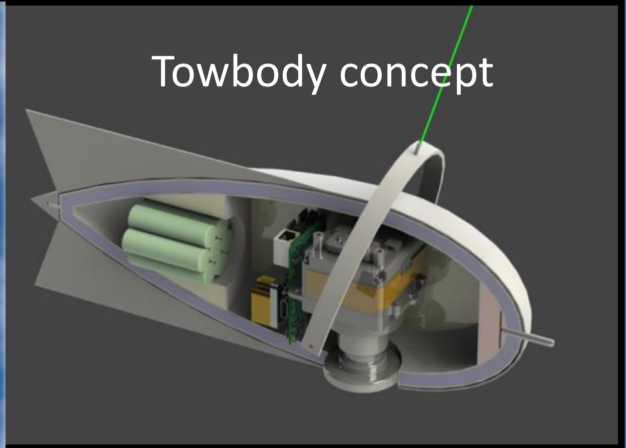
- Selecting the site to sample
- Survival time on the surface
- Navigating to the sampling site
- Transferring the sample to the aerial laboratory

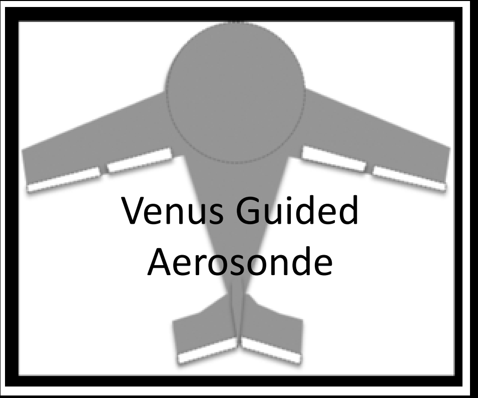
Selecting the site to sample

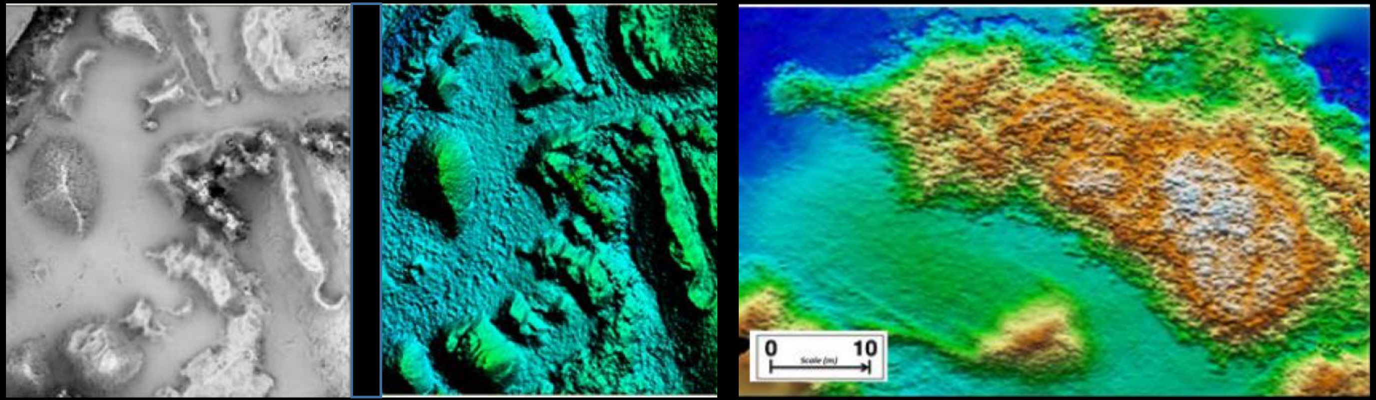
- Imaging of the "nightglow" from the hot surface of Venus at 10 m resolution below the clouds:
  - Mechanical Compression Balloon
  - Tow body deployed from mid cloud aerobot

- Very high resolution imaging (<1m) would be feasible from a vehicle that descends to the surface
  - Unguided descent probe (e.g. DAVINCI+)
  - Guided Descent probe

- Extremely high resolution imaging is possible from descent probes and guided sondes. However, data communications constraints will limit data returned to the aerial platform that deployed the vehicle



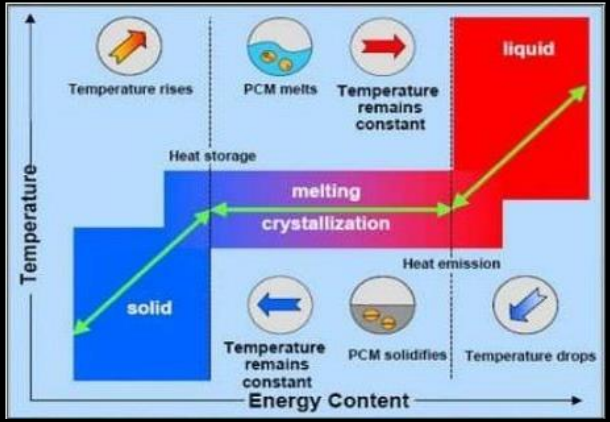




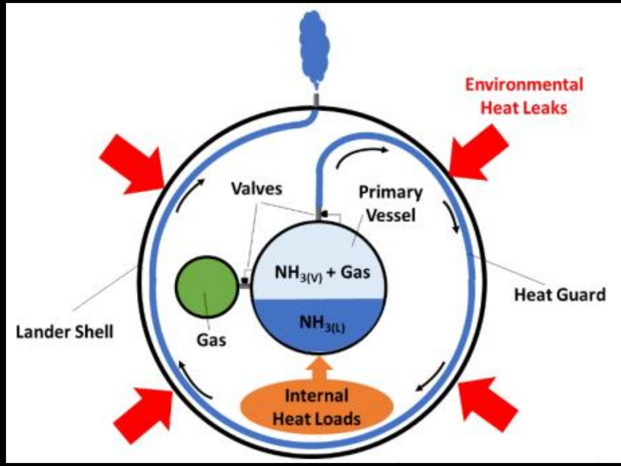
Simulated Venus descent image at 30cm/pixel (left and center) and 3cm/pixel right From Garvin et a; 2018

Survival time on the surface of Venus

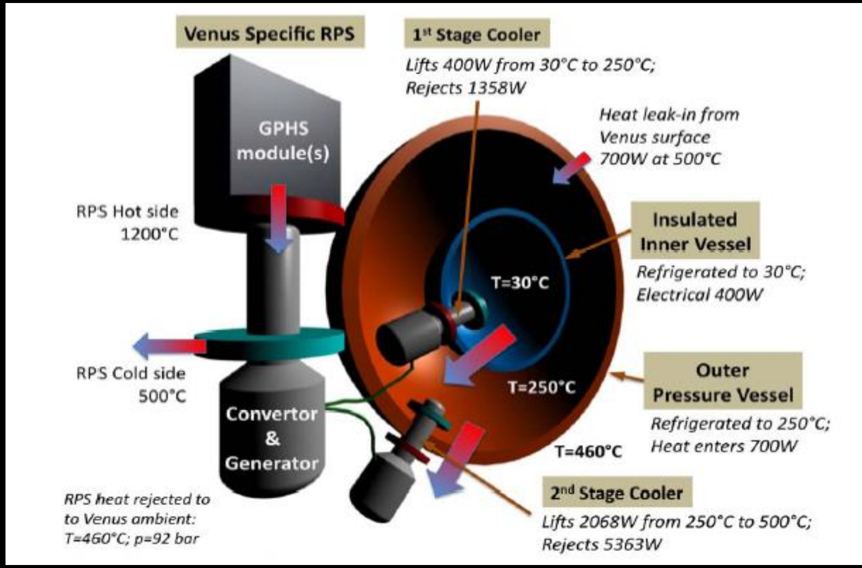
2-5 hour lifetime
Phase Change Material



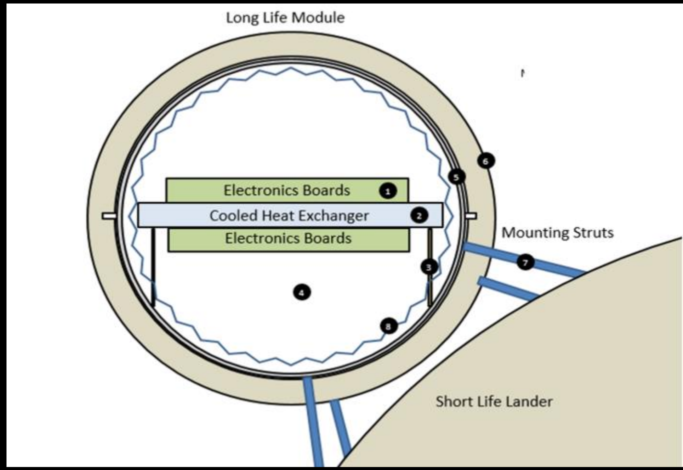
24 hour lifetime
Expendable Cooling
Enables "human in the loop"



3 month lifetime
Active Cooling of part of lander to 30°C



3 month lifetime
Active Cooling of module to 250°C



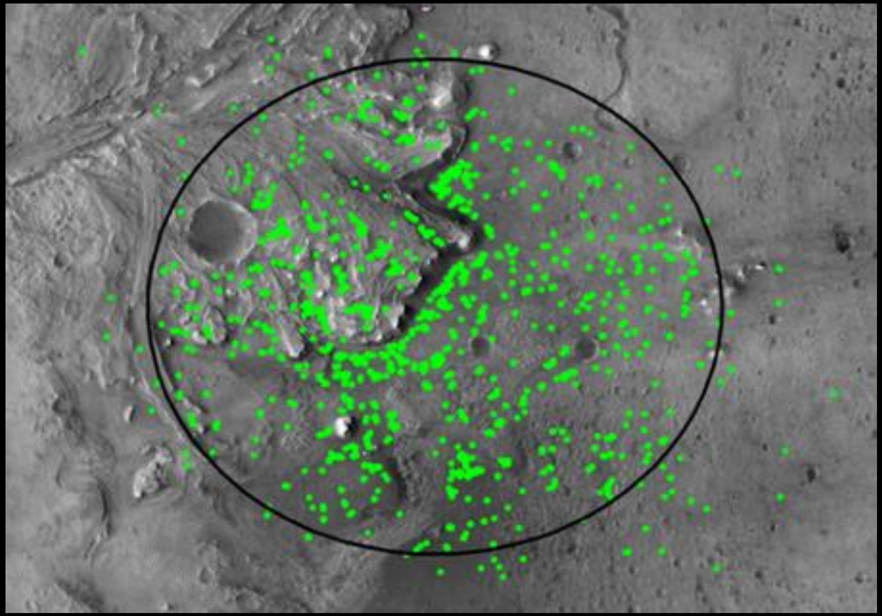
- Practical thermal control limitations will limit the time available for sample selection and acquisition to less than 10 hours.
- The lander must therefore be targeted directly to the sampling site. There is no time to "rove" from the landing site to the sampling site.

Sample Site Selection and Sample Transfer

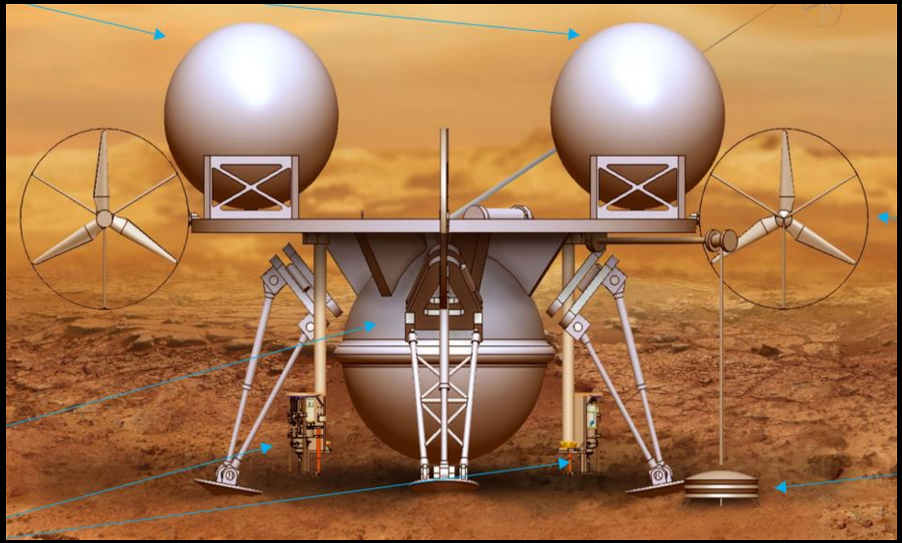
Navigating to the Sample Site

- To acquire samples from the tessera a highly capable lander is required to
  - Avoid hazards in this area of steep slopes and uncertain boulder abundances
  - Target sampling sites designated by prior missions
  - To assure accuracy of sampling achieve landing accuracy of ~ 1m

- Achieving this landing performance will require
  - Hazard avoidance and pin point landing systems conceptually similar to those developed for Mars 2020 **adapted to conditions on Venus**
  - A control system which can guide the vehicle to the target



Save landing area at Jezero Crater, Mars



Concept for a venus landing with rotors for steering to a safe landing area

Sample Site Selection and Sample Transfer

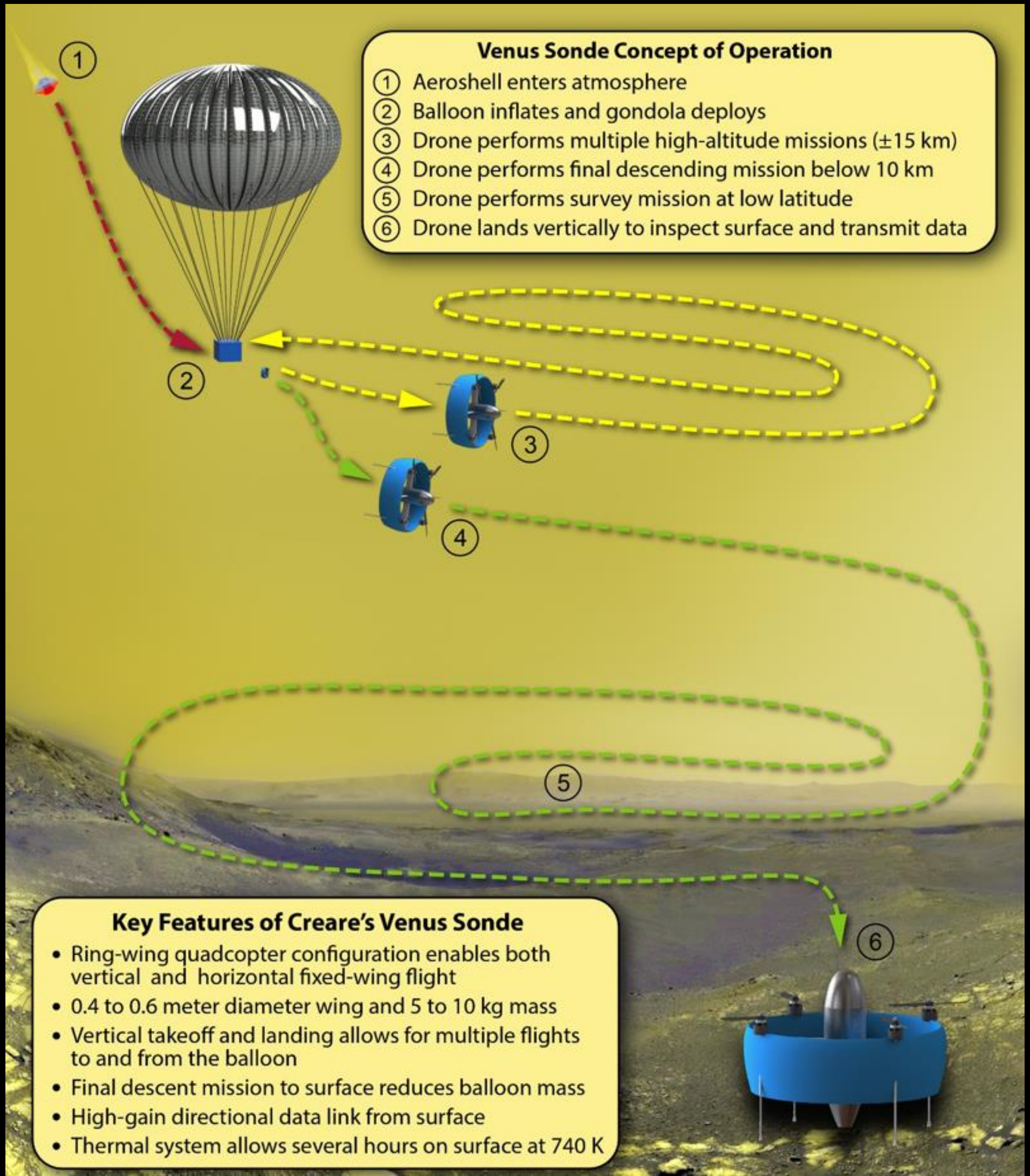
Transferring sample to Aerial Laboratory

- A sample retrieval drone deployed from the Aerial Laboratory would travel out to the ascent balloon with surface samples retrieve them and return the samples to the Aerial Laboratory.

- The Creare company is pursuing the development of a novel type of Venus Sonde capable of both docking with a balloon and efficient horizontal flight

- Initial concepts for this drone (illustrated) are focusing on science conducted in the upper atmosphere, just below the clouds and during a final descent to the surface

- This drone may be applicable for the sample transfer task. Feasibility would depend on how close the aerial laboratory approaches the sample ascent balloon



Summary and Implications for the KISS Study

- Aerial vehicles capable of imaging from below the clouds and descending to targeted regions on the surface will play a key role in selecting sampling sites on the surface of Venus

- Lifetime of vehicles capable of sophisticated operations like imaging on the surface of Venus is extremely limited - less than 10 hours - and so the descent vehicle must go directly to the sampling site

- The sampling vehicle must locate the site to be sampled during descent and navigate to it using an aerodynamic control system. Samples must then be drilled, transferred to the ascent balloon and lofted into the cloud layer

- A sample retrieval drone would retrieve the sample from the ascent balloon and return it to the Aerial Laboratory

Challenges – Lift Balloon and Aerial Laboratory

- Ascent balloon:
  - The two stage balloon approach seems viable but it is very immature
  - Need better definition of the staging process before proceeding further

- Aerial Laboratory:
  - A solar airplane may have advantages over a variable altitude balloon and a blimp because it can station keep in the winds and survive for long periods on the dayside of the planet.
  - Variable altitude balloon is an alternative but will place demanding requirements on sample transfer and need gas replenishment options to extend lifetime.
  - Blimp option is complex, limited life and will not have the control authority to station keep in the winds.

Challenges – Sample Selection and Lander Targeting

- Sample Selection:
  - Nightside imaging from below the clouds and close up visible imaging from controllable aerosondes are both essential for sample selection.
  - Daylight imaging of the tessera will be demonstrated by DAVINCI+
- Targeting the sampling lander:
  - There is as yet no reliable scheme for locating the sampling target area from the lander during descent nor a control system for flying to the sampling site.

Challenges – Sample Transfer in the Atmosphere

- Requirements for the sample retrieval drone will depend on the technology used for the Aerial Laboratory

- Solar airplane option
  - Aerial Laboratory will be able to rendezvous with the lift balloon.
  - The sample retrieval drone must be capable of docking with both the lift balloon and the solar airplane which requires high speed flight

- Variable Altitude Aerobot Option
  - Aerial Laboratory will approach within 100 km altitude of the Lift Balloon
  - Sample retrieval drone must have sufficient range to travel to the lift balloon and back.

Summary

- The Venus environment presents formidable challenges for in situ sample retrieval and analysis but recent and ongoing developments in aerial platform technology mean that we can now begin to chart out a strategy for accomplishing this.
- The strategy adopted for Mars Sample Return in 2008 of dividing the mission into several component missions which have scientific value independent of the composite mission should also be followed for surface sample investigations on Venus
- A long-lived Aerial Laboratory needs to be part of the strategy and will require rendezvous and sample transfer in the cloud layer.
- High resolution imaging of the surface of Venus and precision targeting to samples identified in those images will be the key to ensuring that high value samples are acquired.
- The three Venus missions that were approved for implementation this month will each provide important data for planning this strategy. However, we also need to carry out the next phases of aerial and surface exploration before we can moved to these more ambitious missions.

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