Science Drivers & Technology Challenges for Long-Lived In-Situ Exploration of Venus

by

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Presented at the

3rd Meeting of the Venus Exploration Analysis Group (VEXAG)

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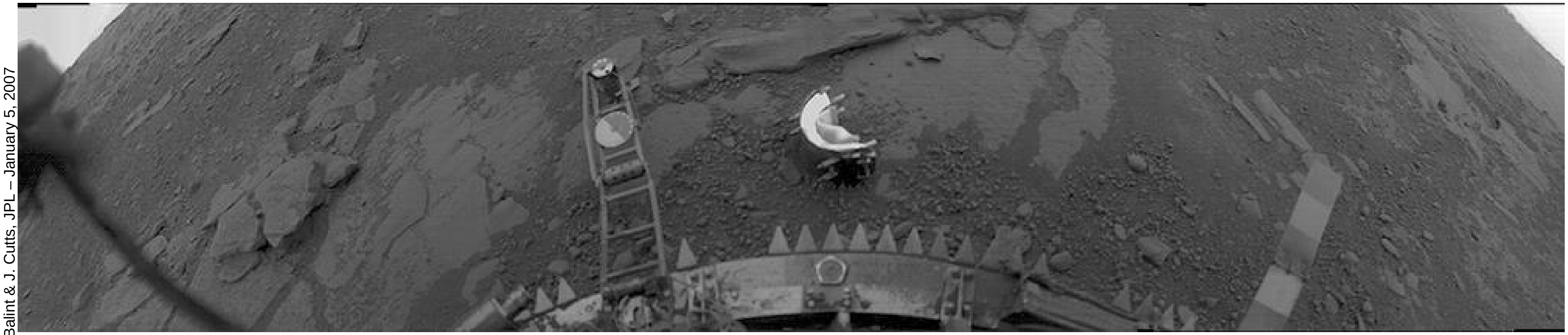
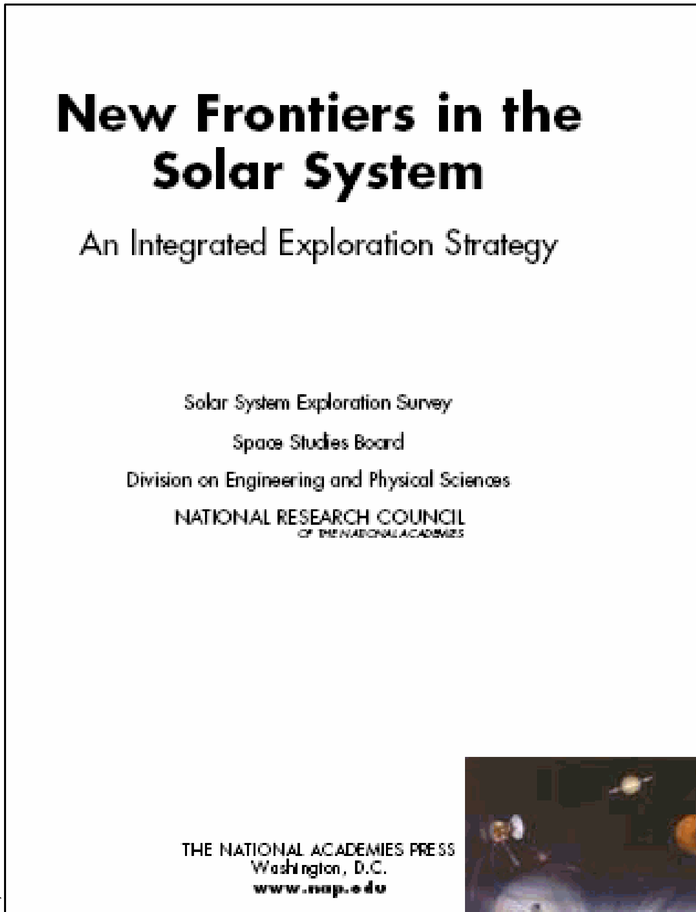
Overview

- Science Drivers
  - NRC SSE Decadal Survey – 2003
  - NASA's 2006 Solar System Exploration Roadmap
- Extreme Environments – Venus In-Situ
- VME – Venus Mobile Explorer Concept
- Technology Challenges for Long-Lived In-Situ Exploration of Venus
- Conclusions
- Future Directions



Venera 13 Image of the surface of Venus

Solar System Exploration Decadal Survey – 2003


New Frontiers in the Solar System

An Integrated Exploration Strategy

Solar System Exploration Survey

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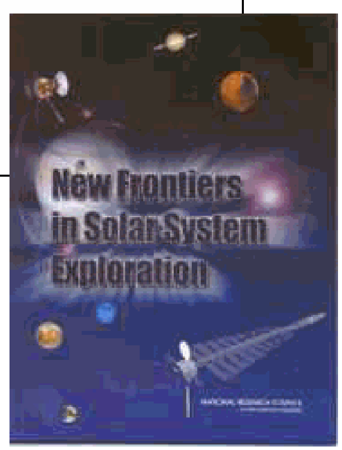

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Integrated Exploration Strategy

- Presents key scientific questions
- Ranked list of conceptual missions
- Recommendations for the decade 2003-2013
- A set of "deferred high priority flight missions for decades beyond that"
- **Recommended significant investments in advanced technology to enable high priority flight missions**

Implementation Approach

- Discovery Program (<$350M) – PI-led and competitively selected (6 to 7 per decade)
- New Frontiers Program (<$650M) – PI-led and competitively selected, but to a specified set of targets – like New Horizons (4 per decade)
- Flagship missions (>$650M) – directed missions – like Cassini-Huygens (1 per decade)

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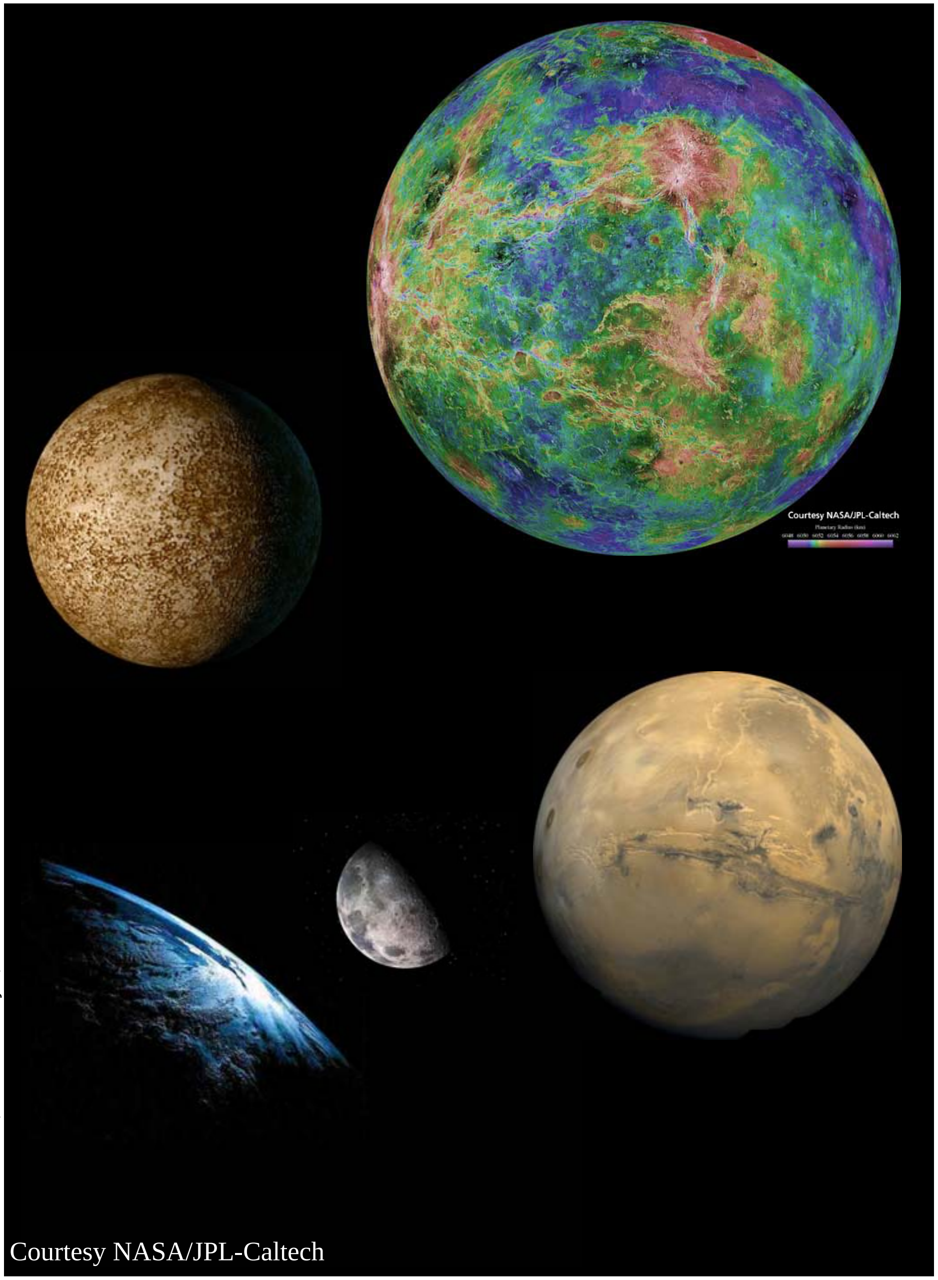

Courtesy NASA/JPL-Caltech

Exploration Strategy

- Sample Return Missions from targets of increasing difficulty
  - Moon first
  - Mars next
  - Mercury-***Venus***
- In-Situ Exploration of ***Venus***
  - Investigate surface and atmospheric chemistry
  - Demonstrate key technologies for sample return
- Network Science at ***Venus*** and Mercury
  - Seismology and magnetic fields
  - Heat flow
  - Atmospheric circulation for ***Venus***
  - Technologies for extreme environments

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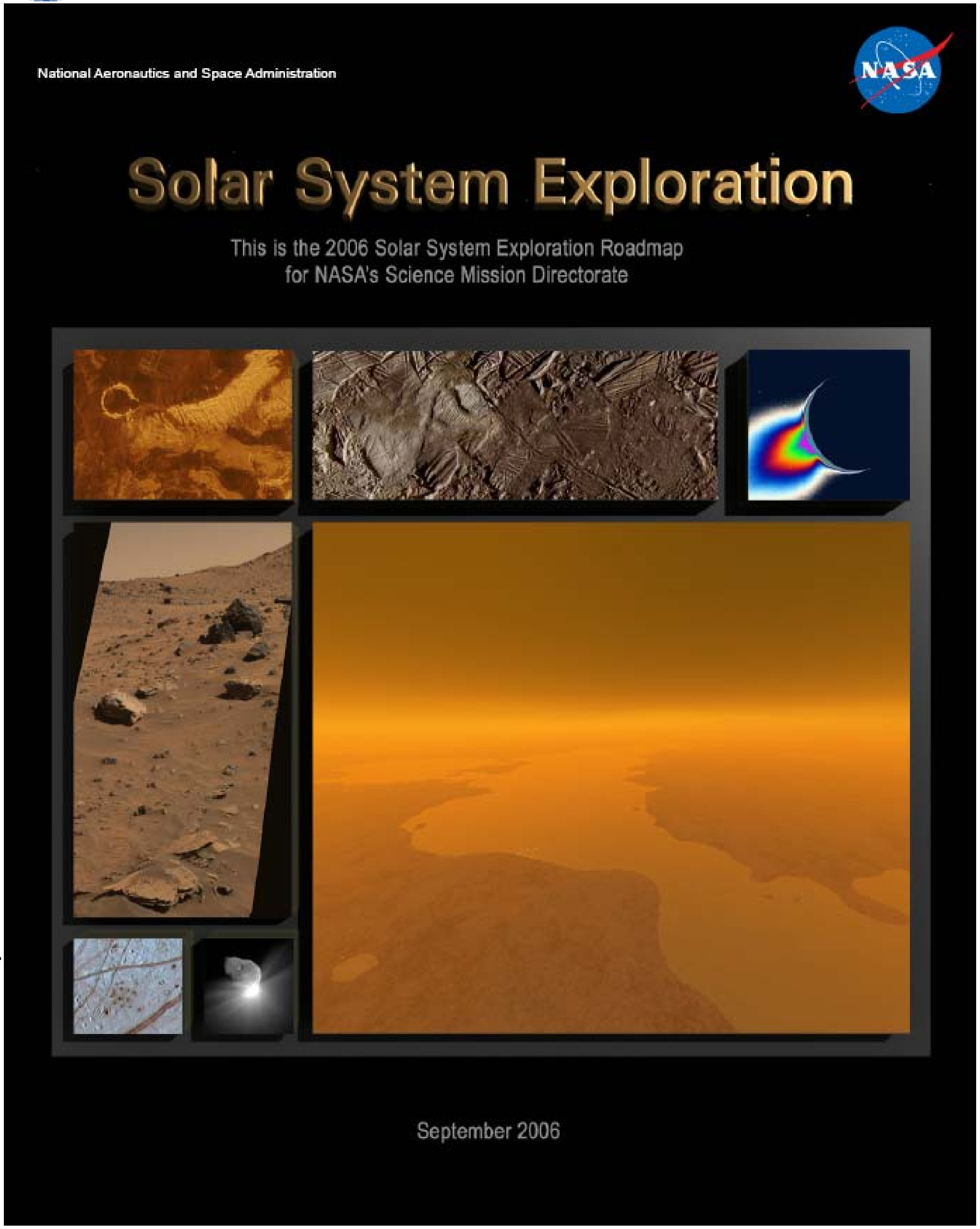
NASA's 2006 Solar System Exploration Roadmap

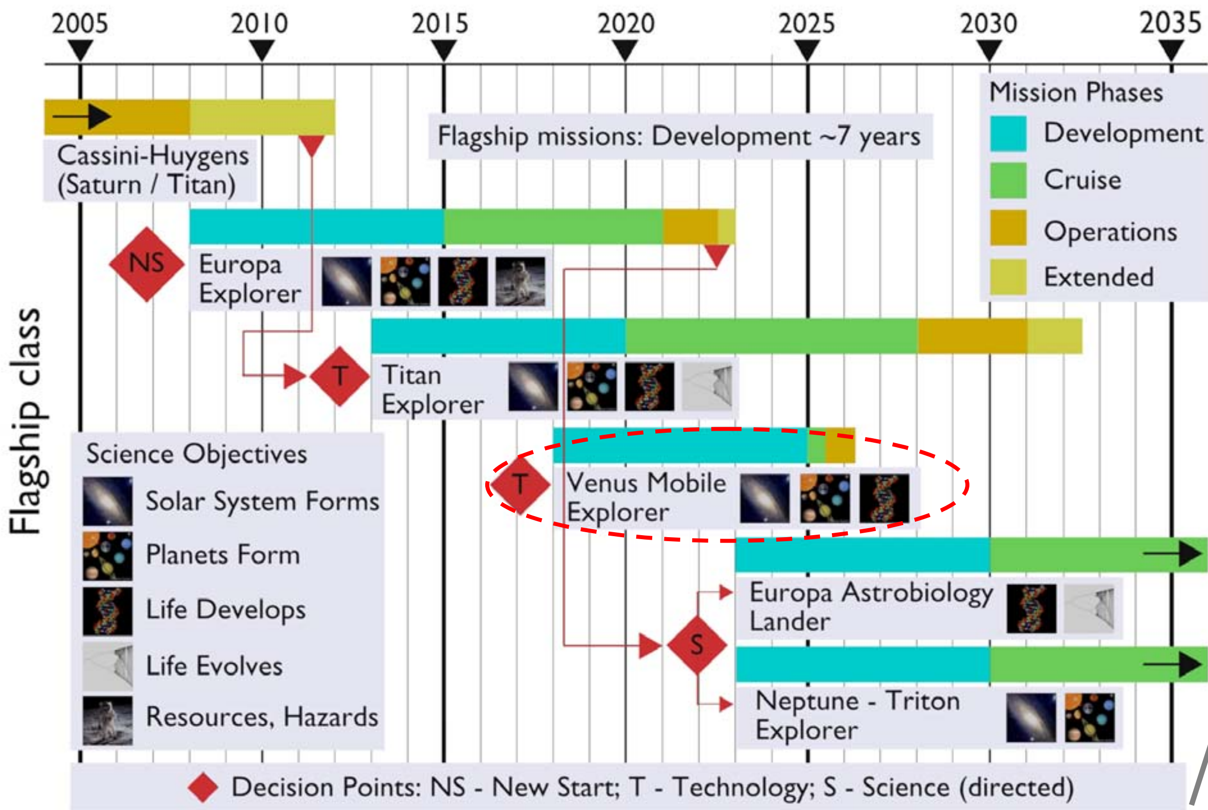


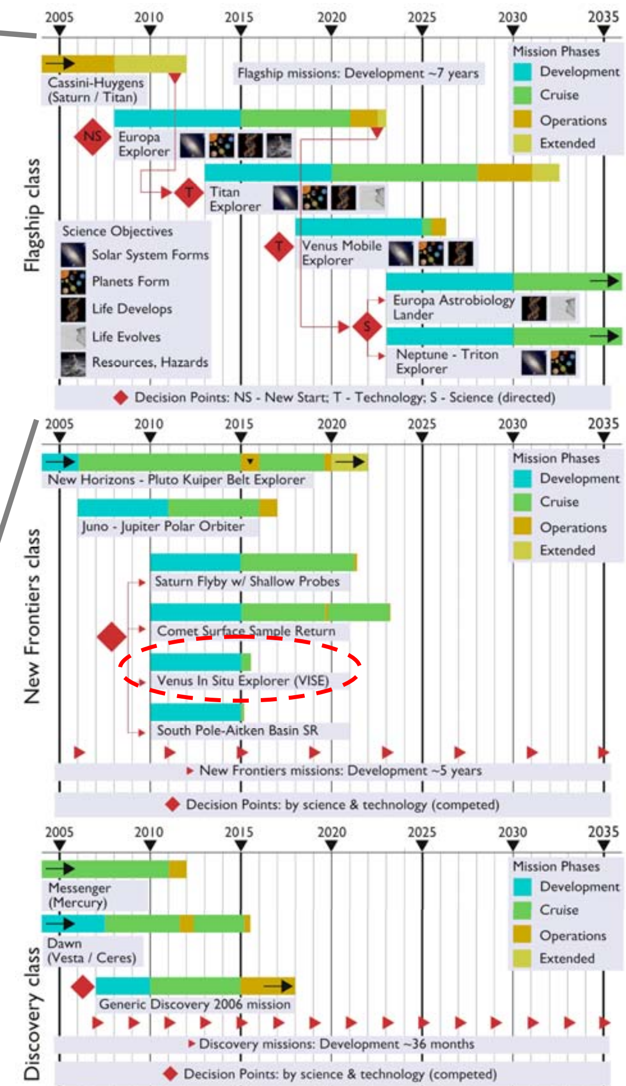
The Roadmap addresses five fundamental questions, in response to the NRC's Decadal Survey. These are:

1. How did the **Sun's family of planets and minor bodies originate**?
2. How did the **Solar System evolve** to its current diverse state?
3. What are the characteristics of the Solar System that led to the **origin of life**?
4. How did **life begin and evolve on Earth** and has it evolved **elsewhere in the Solar System**?
5. What are the **hazards** and **resources** in the Solar System environment that will affect the extension of human presence in space?

Ref: NASA SMD PSD – SSE Roadmap Team, "Solar System Exploration – Solar System Exploration Roadmap for NASA's Science Mission Directorate", NASA Science Missions Directorate, Planetary Science Division, Report Number: JPL-D-35618, September 15, 2006.

NASA's 2006 SSE Roadmap:
Mission Set Recommended by the Roadmap Team





- NASA's **2006 SSE Roadmap** identifies proposed long-lived **Flagship class missions** to Venus

- The Roadmap also identified potential Discovery and New Frontiers class missions to Venus

NASA's 2006 SSE Roadmap:
Science Traceability Matrix (Scientific Questions, Objectives, & Missions)

Major Questions	R&A		Discovery				New Frontiers						Flagship (Small/Large)							
Objectives	Expt.‡	Theory	SB	Moon	Venus	Mercury	NH	Juno	SPABSR	VISE	CSSR	SP	C-H	EE	TE	VME	EAL	NTE	*CCSR**	*VSSR**
How did the Sun's family of planets and minor bodies originate?																				
Understand the initial stages of planetary and satellite formation	●	●	●	●	▲	▲	●	●	●		▲	●	▲	▲	▲	▲		●	●	●
Study the processes that determine the original characteristics of bodies in the Solar System	●	●	●	●		▲	▲	●	▲		●	●	▲	▲	▲			●	●	●
How did the Solar System evolve to its current diverse state?																				
Determine how the processes that shape planetary bodies operate and interact	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	●	●	●	●	●	●	●	●
Understand why the terrestrial planets are so different from one another	▲	▲			●	▲			▲	●						●				●
Learn what our Solar System can tell us about extrasolar planetary systems	▲	▲					▲	▲				▲	●	▲	▲	●		▲		●
What are the characteristics of the Solar System that led to the origin of life?																				
Determine the nature, history, and distribution of volatile and organic compounds in the Solar System	▲	▲	▲				●	●		▲	●	●	●	●	●	●	●	●	●	●
Determine evidence for a past ocean on the surface of Venus	▲	▲			▲					▲						●				●
Identify the habitable zones in the outer Solar System	▲	▲											●	●	●		●	●		
How did life begin and evolve on Earth and has it evolved elsewhere in the Solar System?																				
Identify the sources of simple chemicals important to prebiotic evolution and the emergence of life	●	▲	▲				▲						●	▲	●		●	▲	●	
Evidence for life on Europa, Enceladus, and Titan	▲	▲											▲	▲	●		●			
Evidence for past life on Venus	▲	▲														▲				●
Study Earth's geologic and biologic record to determine the historical relationship between Earth and its biosphere	●	▲																		
Identify environmental hazards and resources enabling human presence in space																				
Determine the inventory and dynamics of objects that may pose an impact hazard to Earth	●	▲	●				▲													
Inventory and characterize planetary resources that can sustain and protect human explorers	▲	▲	●						▲		●									

Convention: ● Major or Unique Contribution; ▲ Support Contribution

In NASA's 2006 SSE Roadmap, science objectives are mapped against proposed mission concepts under Discovery, New Frontiers and Flagship classes

Flagship class missions are required **to address major or unique science questions**, identified in the Roadmap.

(as recommended by the Roadmap Team)

Note: ***Venus related science objectives*** *are identified in the following* ***9 subgroups****:*
Q2.1.1; Q2.1.2; Q2.1.4; Q.2.2.1; Q3.1.3; Q3.2.1; Q3.2.2; Q3.2.3; Q.4.3.1

NASA's 2006 SSE Roadmap mentions Venus 205 times throughout the document, providing a **strong Venus emphasis.**

Both the **SSE Roadmap &** the **Chapman Conference**:
Focused on the
Theme of Habitability

NASA's 2006 SSE Roadmap:

Impact of Advanced Technology Development

Major Questions	Discovery				New Frontiers						Flagship (Small/Large)							
Objectives	SB	Moon	Venus	Mercury	NH	Juno	SPABSR	VISE	CSSR	SP	C–H	EE	TE	VME	EAL	NTE	*CCSR**	*VSSR**
SPACECRAFT SYSTEMS TECHNOLOGIES																		
Transportation																		
▷ *Access to Space*					⊕	⊕					⊕				▲	▲		
▷ *Solar Electric Propulsion*	▲	▲	▲	▲	⊕	⊕			▲	▲	⊕		▲		▲	▲	▲	▲
▷ *Aerocapture / Aeroassist*			▲		⊕	⊕	▲				⊕		●	▲		●		▲
▷ *Advanced Chemical Propulsion*		▲		▲	⊕	⊕				▲	⊕	▲		▲	●			▲
Power																		
▷ *Radioisotope (RPS)*					⊕	⊕					⊕	▲	▲	●	●	▲		
▷ *Solar Power*	▲	▲	▲	▲	⊕	⊕			▲	▲	⊕		▲		▲	▲	▲	
▷ *Energy Storage*	▲	▲	▲	▲	⊕	⊕	▲	▲	▲	▲	⊕	▲	▲	▲	▲	▲	▲	▲
Communications																		
▷ *Direct–to–Earth Communications*	▲	▲	▲	▲	⊕	⊕	▲	▲	▲	▲	⊕	▲	▲	▲	▲	▲	▲	▲
▷ *Proximity Links*					⊕	⊕	▲			▲	⊕		▲		▲	▲		▲
Planetary Protection																		
▷ *Forward Planetary Protection*					⊕	⊕					⊕	▲	●		●			
▷ *Returned Sample Handling*					⊕	⊕			▲		⊕						▲	
Autonomy and Software																		
▷ *Autonomous systems*	▲	▲	▲	▲	⊕	⊕	▲	▲	▲		⊕		▲	▲	▲	▲	▲	▲
▷ *Software V&V*	▲				⊕	⊕			▲		⊕		▲	▲	▲	▲	▲	▲
IN SITU EXPLORATION TECHNOLOGIES																		
Entry, Descent, and Landing																		
▷ *Precision Navigation*	▲	▲			⊕	⊕			▲		⊕				●		▲	
▷ *Hazard Avoidance*	▲				⊕	⊕			▲		⊕		▲	▲	●		▲	
▷ *Small Body Anchoring*	▲				⊕	⊕			▲		⊕						●	
Planetary Mobility																		
▷ *Aerial*			▲		⊕	⊕		▲			⊕		●	●				
▷ *Surface*					⊕	⊕	▲	▲			⊕		▲	●				
▷ *Subsurface access*					⊕	⊕					⊕				●		●	▲
Extreme Environments Technologies																		
▷ *High Temperature/Pressure*			▲		⊕	⊕		●			⊕			●				●
▷ *Low Temperature*	▲	▲		▲	⊕	⊕	▲		▲		⊕		●		●		▲	
▷ *High Radiation*					⊕	⊕					⊕	▲			●			
▷ *High Heat Flux*			▲		⊕	⊕		▲	▲	●	⊕		▲	▲		●	▲	●
SCIENCE INSTRUMENTS																		
Remote–Sensing Instruments																		
▷ *Active Remote Sensing*	▲	▲	▲	▲	⊕	⊕					⊕	▲	▲	▲		▲		
▷ *Passive Remote Sensing*	▲	▲	▲	▲	⊕	⊕				▲	⊕	▲	▲	▲		▲		
In Situ Instruments																		
▷ *Analytical Instruments*	▲		▲		⊕	⊕	▲	●	▲		⊕		●	●	●		▲	▲
▷ *Sample Acquisition & Handling*					⊕	⊕	▲	●	●		⊕		●	●	●		●	●
Component Technology and Miniaturization																		
▷ *Component Technologies*	▲	▲	▲	▲	⊕	⊕	▲	▲	▲	▲	⊕	▲	▲	▲	●	▲	▲	▲
▷ *Miniaturization*	▲	▲	▲	▲	⊕	⊕	▲	▲	▲	▲	⊕	▲	▲	●	●	▲	▲	▲

Convention: ● Major or Unique Contribution; ▲ Support Contribution; ⊕ Ongoing Mission or Project

In the SSE Roadmap, advanced technologies are also mapped against proposed missions

Flagship class missions drive technology development;

while **smaller** (Discovery & NF) **missions** can significantly **benefit** from technologies developed for Flagship missions

For **in-situ Venus Exploration**:

- **Significant technology development** is required;
- To mitigate the **extreme environments**;
- **Development times** can be long;
- Many of these technologies are at a **low TRL**.

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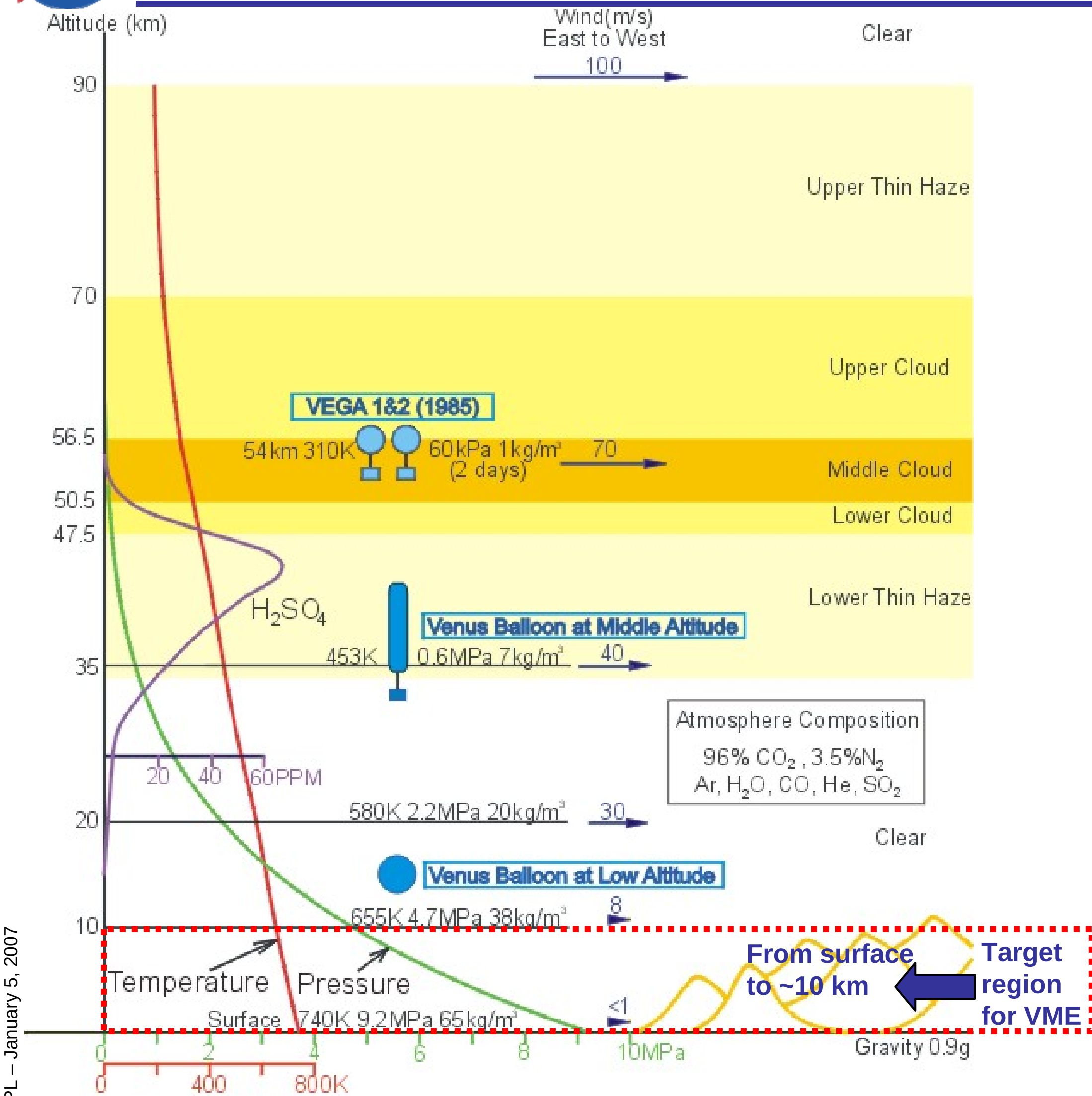
Extreme Environments for Venus In-Situ Missions



VENUS ENVIRONMENT AND BALLOONS

Ref: N.Yajima, N.Izutsu, H.Honda, K.Goto and T.Imamura (ISAS) N.Tomita and K.Akazawa (Musashi Institute of Technology Univ.) "Feasibility and Applicability of Planetary Balloons," Website: www.isas.ac.jp/home/ Sci_Bal/engplanetary.html

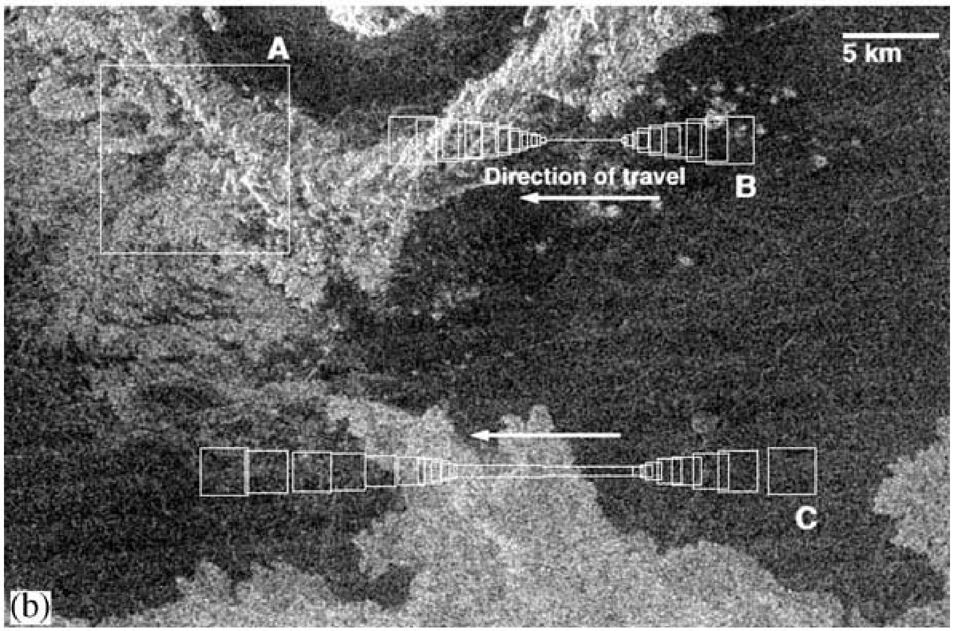
- Greenhouse effect results in **VERY HIGH SURFACE TEMPERATURES**
- Average surface **temperature**:
  ~ 460 to 480°C
- Average **pressure** on the surface:
  ~ 92 bars
- Cloud layer composed of **aqueous sulfuric acid droplets** at ~45 to ~70 km attitude
- Venus atmosphere is **mainly CO_2 (96.5%)** and N_2 (3.5%) with:
  - small amounts of noble gases (He, Ne, Ar, Kr, Xe)
  - small amount of reactive trace gases (SO_2, H_2O, CO, OCS, H_2S, HCl, SO, HF …)
- **Zonal winds**: at near surface ~1 m/s; while at 60 km altitude ~ 60+ m/s

Ref: E. Kolawa, "Extreme Environments Technologies"

Venus In-Situ Exploration Regions

A range of mission types operating in different regions of the atmosphere

Upper atmosphere	- atmospheric sensing; dynamics	~55 km to ~65 km
Middle atmosphere	- investigation of atmospheric circulation	~35 km to ~55 km
Lower atmosphere and surface	- in-situ surface exploration and surface sample return - ground launched balloon for surface sample return	Surface to ~10-15 km



Surface Coverage with Air Mobility Platforms

Mission duration and **exploration depth** are expected to influence: **science return, mission complexity, technology needs,** and **cost**.

For example:

- Venus balloon at 65 km: Discovery class
- Venus Mobile Explorer: Flagship class

The success of **MER** (Mars Exploration Rover) has **demonstrated** the capability of **long duration mobile vehicles** for **achieving significant science objectives**.

The proposed Venus Mobile Explorer mission is expected to provide the same benefits.

Venus Mobile Explorer (VME)

Measurement Objectives:

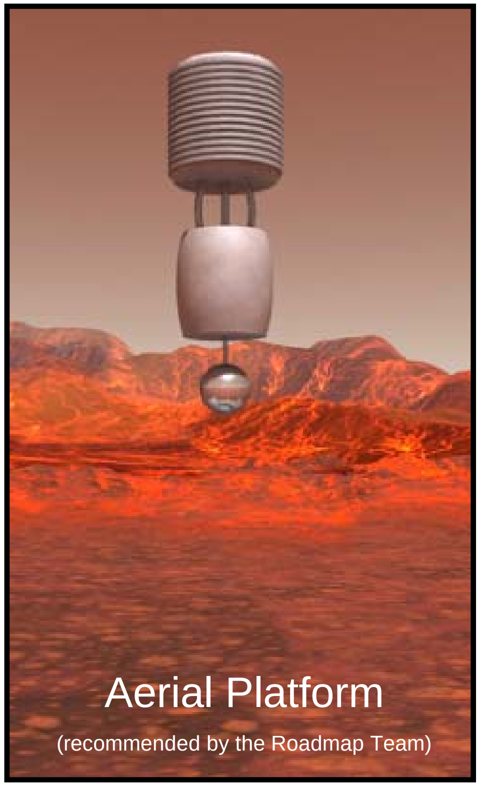
- Survey imaging at a variety of spatial scales
- Acquire & characterize surface samples at multiple sites
- Other physical and chemical measurements TBD

Exploration Metrics:

- Operate in Venus surface environment for 90 days+
- Mobility attributes TBD

Technology Heritage from Prior Missions:

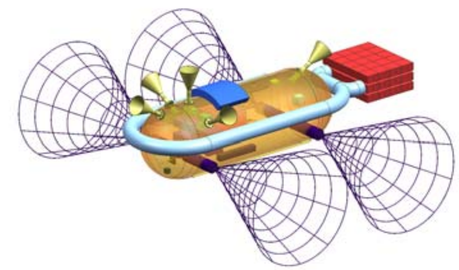
- Sample acquisition and handling in Venus environment
- Thermal control technology



Aerial Platform

(recommended by the Roadmap Team)

OR



Surface Rover

(Maybe a Static Lander?)

New Technology Capabilities:

- Mobility on surface or through the atmosphere
- Long duration operation at or near the surface

Following the MER experience, the Roadmap Team recommended an **aerial mobility platform for VME**; however, **further studies might be necessary – with the help of a Venus SDT – to find the most suitable mission architecture, that combines science objectives, enabling advanced technologies, and programmatic considerations**.

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VME – Summary of Enabling Technologies

Telecom *(not shown)*
-Pointing DTE vs. Relay
-Power requirements

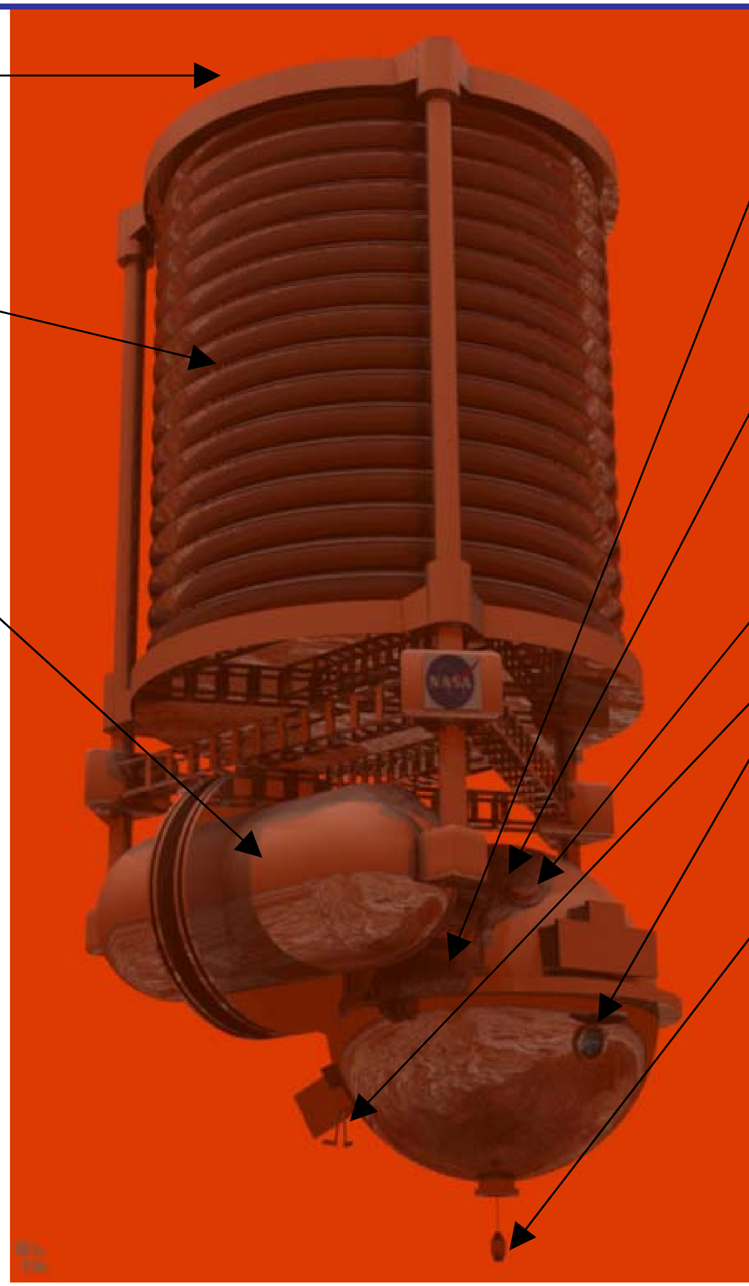
Mobility Technologies
- Metallic bellows ("balloon")
- Buoyancy control
- Lifetime / leak rate / corrosion
- Materials (bellows; parachute)
- *Surface mobility (not shown)*

RPS & Active Cooler
- Heat rejection at high T
- Active cooling to payload

Energy Storage (not shown)
- High temperature batteries inside pressure vessel

Technologies must mitigate the extreme environments
- High temperature (~460°C)
- High pressure (~92 bars)
- Corrosion (supercritical CO_2)

Long-lived in-situ exploration of Venus requires **significant technology development**, that is common to all mission architectures – VME aerial mobility / rover / static lander



Venus Mobile Explorer - VME: artist's concept

Pressure Control
- Materials (e.g., titanium, honeycomb, composite shell; beryllium shelf)
- Material creep
- Mass reduction with developments
- Volume (component miniaturization)

Thermal Management & Control
- Passive control: aerogel; PCM; MLI
- Active control: see RPS

Component Hardening
- Inside pressure vessel
- High temperature electronics
- Electronic packaging
- Science instruments
- External components / sensors
- Imagers / Optics (at interface)

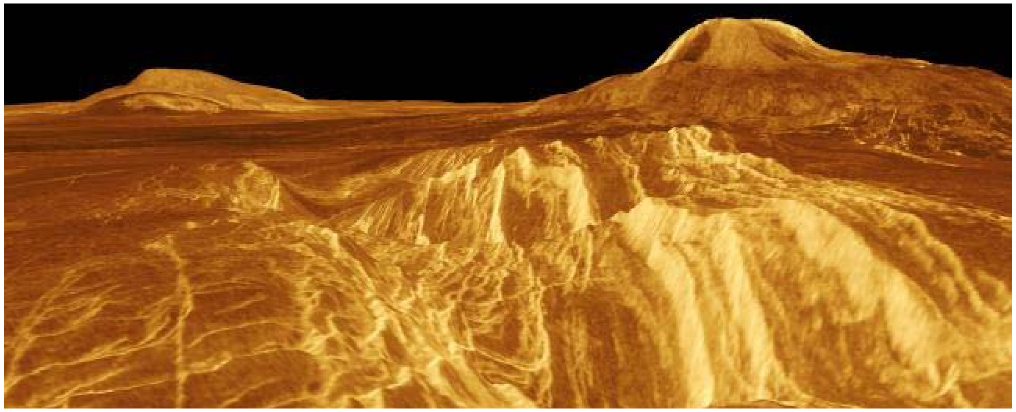
Electro-Mechanical Systems
- Exposed to external environment
- Actuators, arms, moving parts
- Sample acquisition and transfer
- External valves
- Antenna gimbals

Testing for Extreme Environments
- At relevant pressure, temperature, atmospheric composition

Hypervelocity Entry *(not shown)*
- TPS; aeroshell

Conclusions

- **NASA's 2006 SSE Roadmap** has laid the ground work for a future Solar System Program with a **strong Venus emphasis**
- Success of the **MER rovers** has demonstrated the capability of long duration mobile vehicles for **achieving significant science objectives**
- This points to the potential **benefits of long-lived mobile exploration capability on Venus**
- Technologies must be tailored **to tolerate** and sometimes **exploit** the **extreme environments** of Venus, requiring **new technologies**
- **Certain** extreme environment **technologies are** expected to be **the same, regardless of** the final Venus Mobile Explorer **mission architecture**
- **Technology development** requires **substantial investment,** and **time**



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Future Directions

- **Science guidance** is now needed **from the community** to help with the formulation of in-situ Venus exploration
- Formulation of the **Venus Mobile Explorer (VME)** mission concept would **require** a **dedicated mission study;** addressing the interplay between *science*, *mission architectures, technologies* and *programmatics* (including *cost* and *feasibility)*
- **Technology investment** is also required:
  - To **mitigate** the **extreme environments** near the surface of Venus
    - *Near the surface: ~460°C; ~92 bars; corrosive supercritical* CO_2
    - *Middle-to-Lower clouds/haze (~20-55km): corrosive sulfuric acid droplets*
  - Allowing sufficient **time & funding for technology development**
  - To **enable** a long-lived (90+ days) Flagship class in-situ Venus mission (**VME**)
- A **credible long range strategy** would animate a set of prior missions – some of which would permit validation of technologies needed for VME.
- Potentially, an **NRA on Extreme Environment component development could be considered**, that would help with the development of these capabilities

Venera 14 Image of the surface of Venus – post processed by Don P. Mitchell

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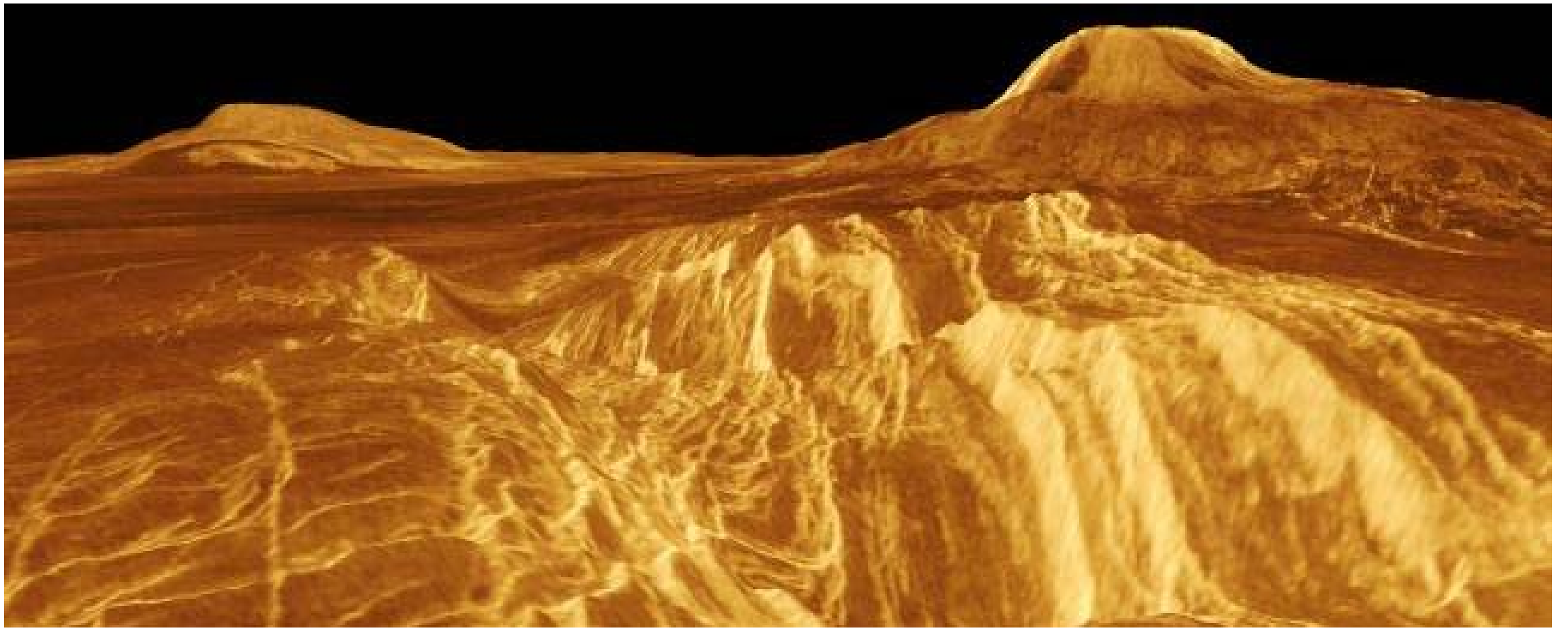

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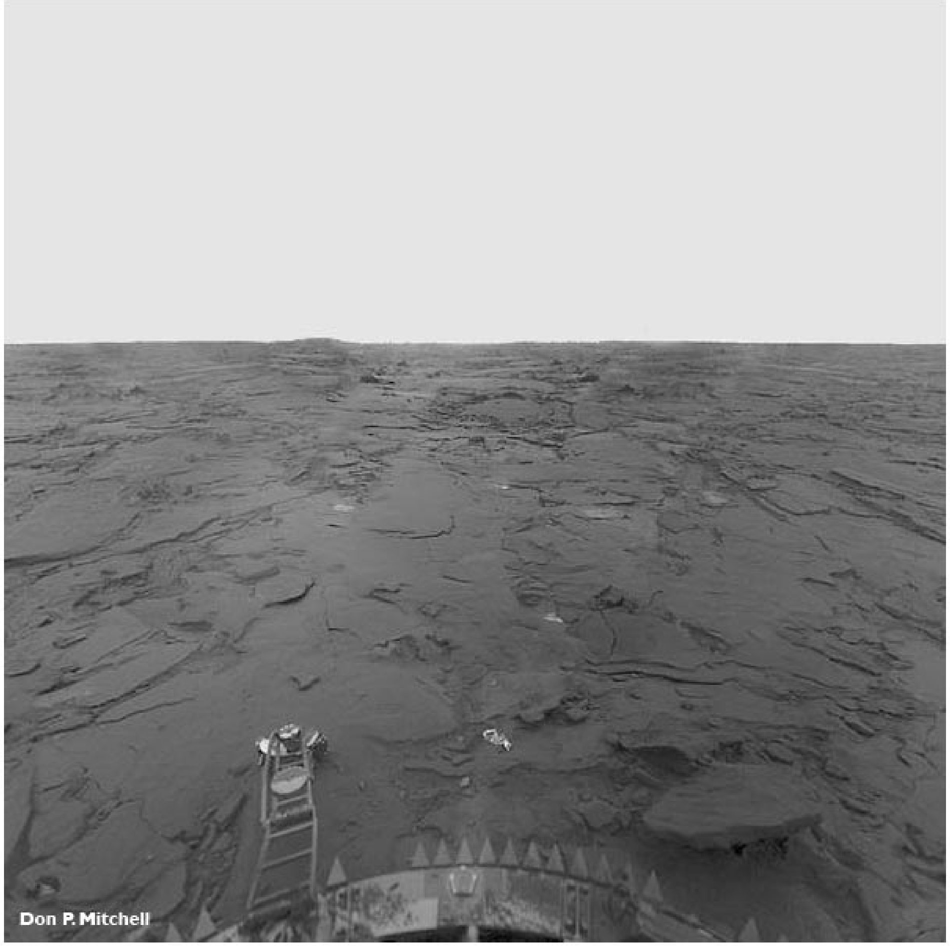

Venera Perspectives

(Venera data post-processed by Don P. Mitchell)