Venus Exploration Opportunities within NASA's Solar System Exploration Roadmap

by

Tibor Balint[1], Thomas Thompson[1], James Cutts[1] and James Robinson[2]

[1]*Jet Propulsion Laboratory / Caltech*

[2]*NASA HQ*

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  - Dave Crisp (JPL)

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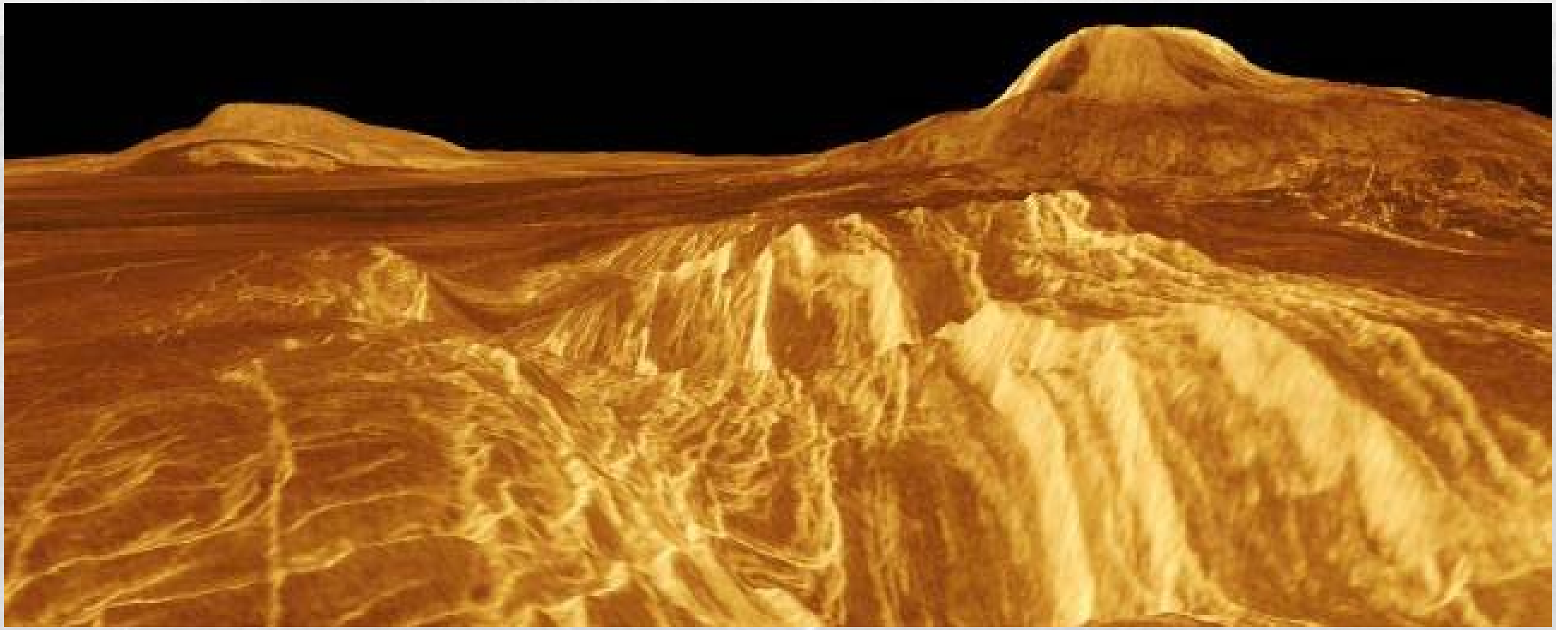
  - David Grinspoon (University of Colorado)

Overview

- Brief Summary of Past Venus In-situ Missions
- Recent Solar System Exploration Strategic Plans
- Potential Future Venus Exploration Missions
- New Technology / Capability Needs
- Conclusions

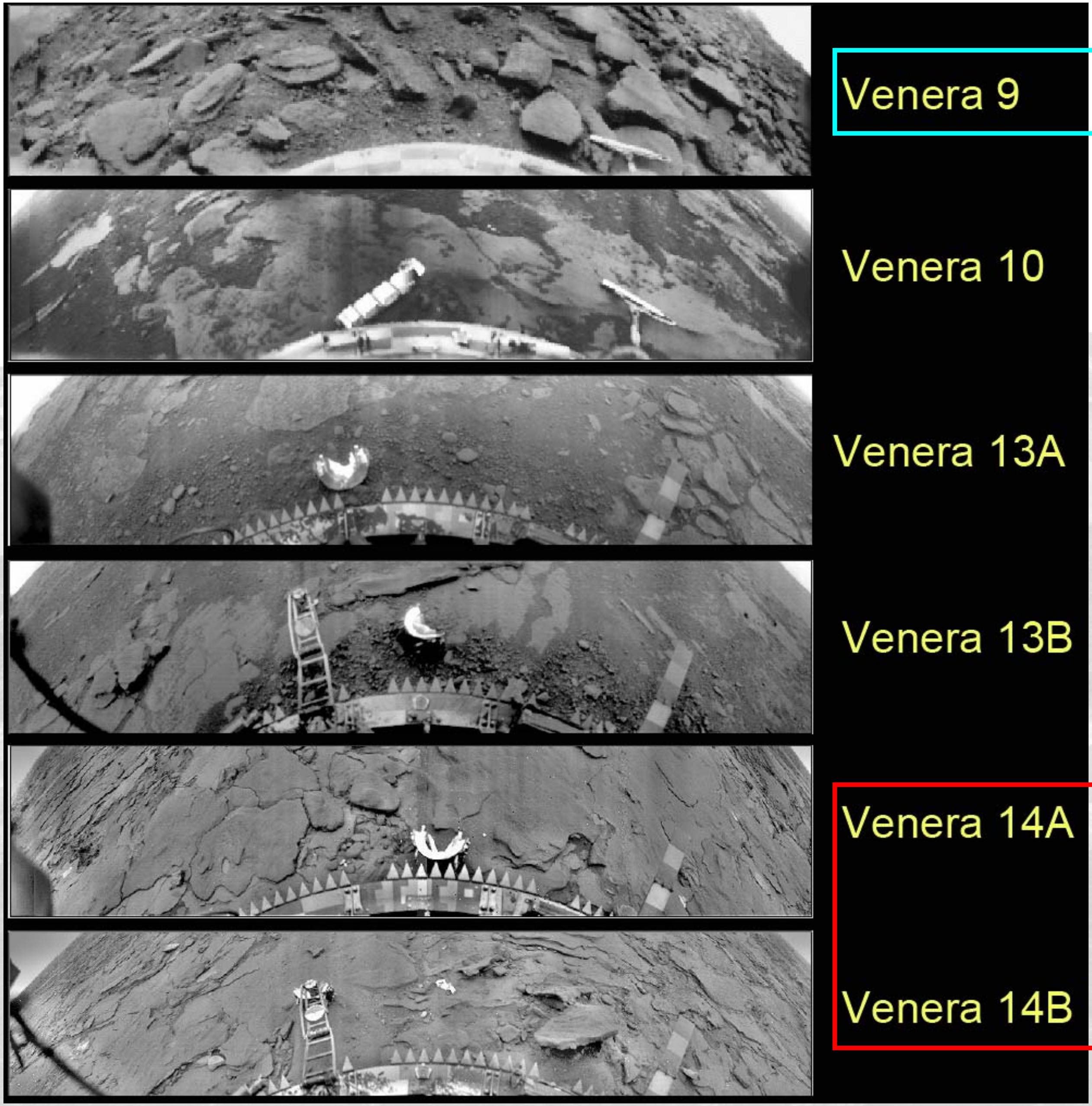


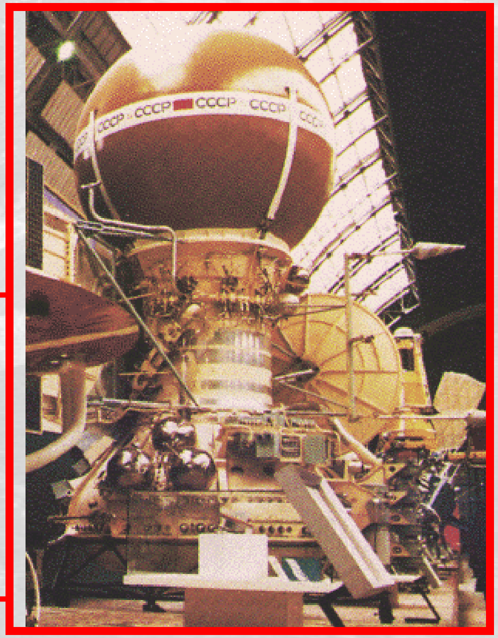
Past Missions: Russian Venus Lander Missions (1965-1981)

	Year	Type / Method	Comment	Method EDL
Venus				
Venera 3 *FAILED*	1965	Venus Lander	Impacted Venus, Contact Lost	Parachute
Venera 4 FAILED	1967	Venus Probe	Failed at altitude 24.96 km	Parachute
Venera 5 FAILED	1969	Venus Probe	During parachute descent data was transmitted from the atmosphere for 53 minutes before failure	Parachute
Venera 6 FAILED	1969	Venus Probe	During parachute descent data was transmitted from the atmosphere for 51 minutes before failure	Parachute
Venera 7 *PARTIAL FAILURE*	1970	Venus Lander	35 minutes of data during descent, 23 min. weak signal from the surface (1st man made object to return data after landing on another planet)	Aerobraking then parachute
Venera 8	1972	Venus Lander	Data during descent, plus 50 minutes after landing	Aerobraking/ D2.5m parachute at 60km
Venera 9	1975	Venus Orbiter and Lander	Operated for 53 minutes after landing	Protective hemispherical shell/ three parachutes/ disk shaped drag brake/ metal, compressible doughnut-shaped landing cushion
Venera 10	1975	Venus Orbiter and Lander	Operated for 65 minutes after landing	See Venera 9
Venera 11	1978	Venus Lander	Transmitted data after touchdown for 95 minutes, until it moved out of range with Earth.	Aerodynamic ~/ parachute ~/ atmospheric braking/ soft landing
Venera 12	1978	Venus Lander	Worked until out of range , transmitted from the surface for 110 minutes.	See Venera 11
Venera 13	1981	Venus Lander	The lander survived for 117 minutes.	Parachute/ at 47km parachute released/ aerobraking
Venera 14	1981	Venus Lander	The lander survived for 57 minutes	See Venera 13

The longest surface mission survived for almost 2 hours

Past Missions:
Close-up Surface Features on Venus (USSR)





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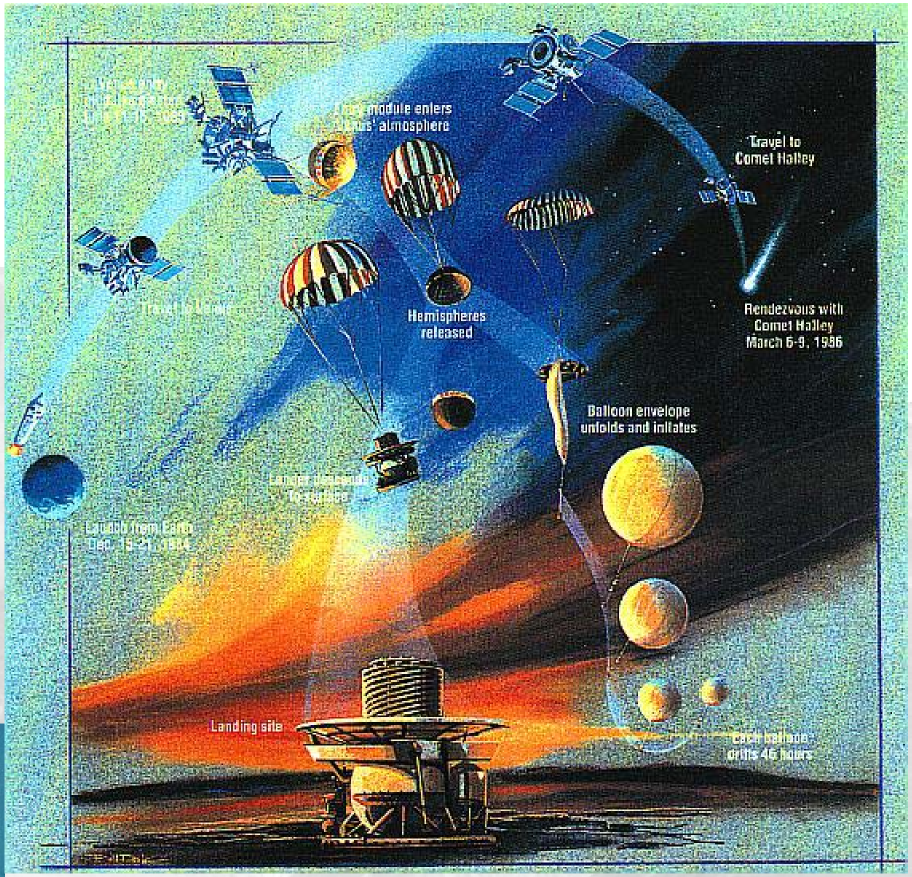
Past Missions:
Venus Exploration, VEGA Mission

- International project: **VEGA 1 & 2**
- Was managed by Space Research Institute (IKI)
- **Combined study of Venus and Halley's comet**
- Developed by Babakin Space Center
- Fabricated by Lavochkin Association (in Khimki, Moscow region)

- Flew by Venus on June 11th and 15th, **1985**;
- Studied the **surface & atmosphere of Venus** with
  - **2 balloons** with 4 scientific experiments &
  - **2 landers** with 9 experiments
- **VERY FRUITFUL INTERNATIONAL COOPERATION**

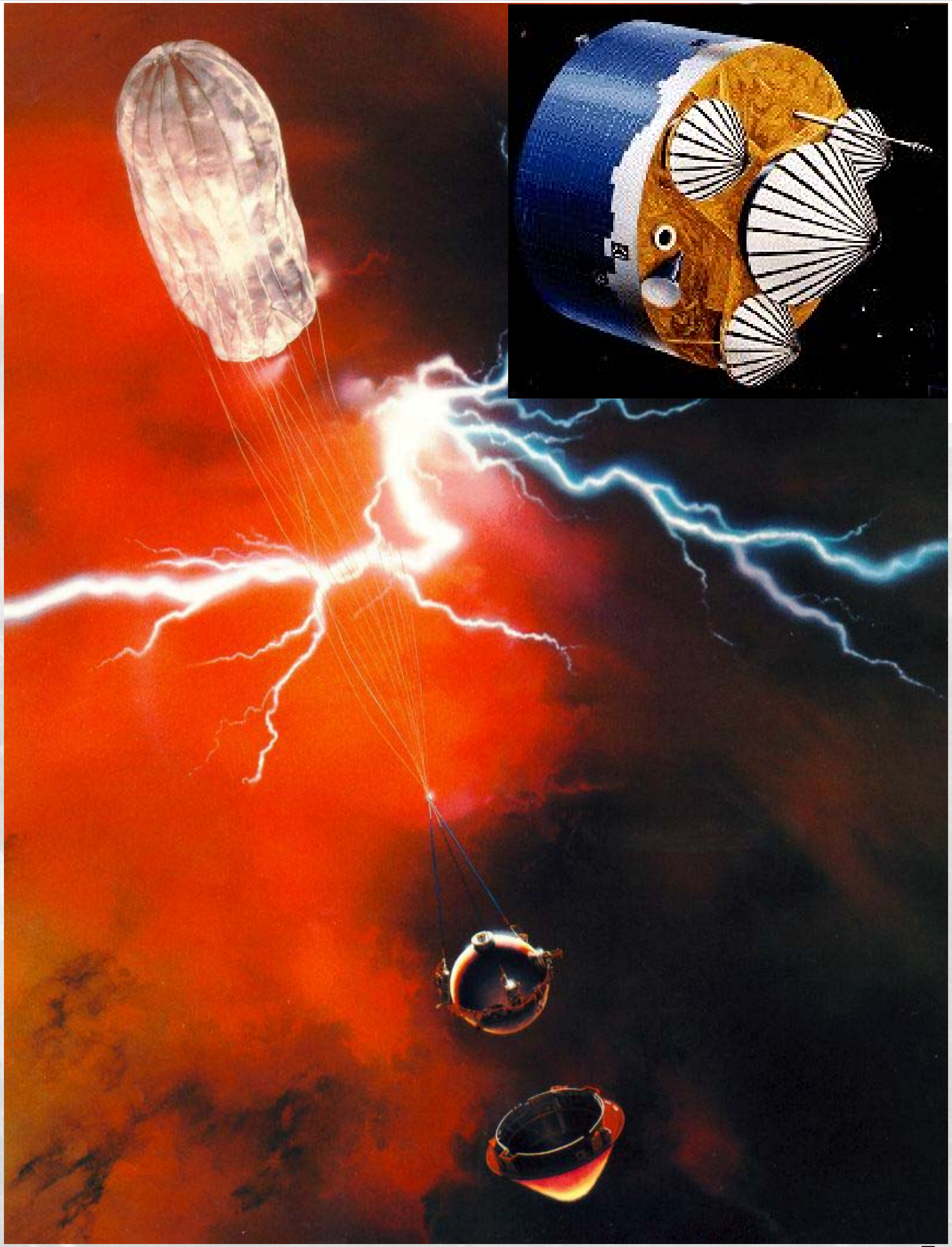


VEGA Mission Profile

VEGA balloon during Earth atmosphere testing

Past Missions:
US Venus Missions

- 1962 - Mariner 2 (U.S.) flew by Venus (12/14/62); Verified high temperatures.
- 1974 - Mariner 10 (U.S.) bound for Mercury, flew by Venus (2/5/74); Tracked global atmospheric circulation with visible and violet imagery.
- 1978 - Pioneer Venus Orbiter (U.S.) radar mapped Venus (12/78); Pioneer Venus Multiprobe (U.S.) dropped four probes through Venusian clouds.
- 1989 - Magellan (U.S.) was launched toward Venus (5/4/89). It arrived at Venus in 1990 and mapped 98% of the planet. Mission ended in 1994.



1. NRC Decadal Survey – 2002
   "New Frontiers in the Solar System, an Integrated Exploration Strategy". Technical Report, Space Studies Board, National Research Council, Washington, D.C. http://www.nap.edu
2. Solar System Exploration Roadmap – 2003
   The 2003 Solar System Exploration Roadmap is available on line at http://solarsystem.nasa.gov/multimedia/download-detail.cfm?DL_ID=3
3. Strategic Road Map for Solar System Exploration – 2005
   Available from the Outer Planets Assessment Group (OPAG) website: http://www.lpi.usra.edu/opag/announcements.html

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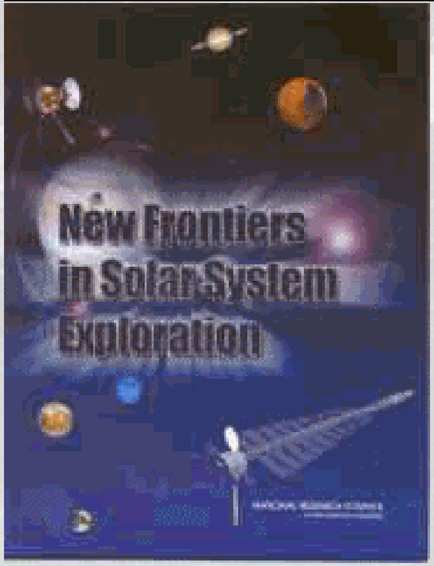

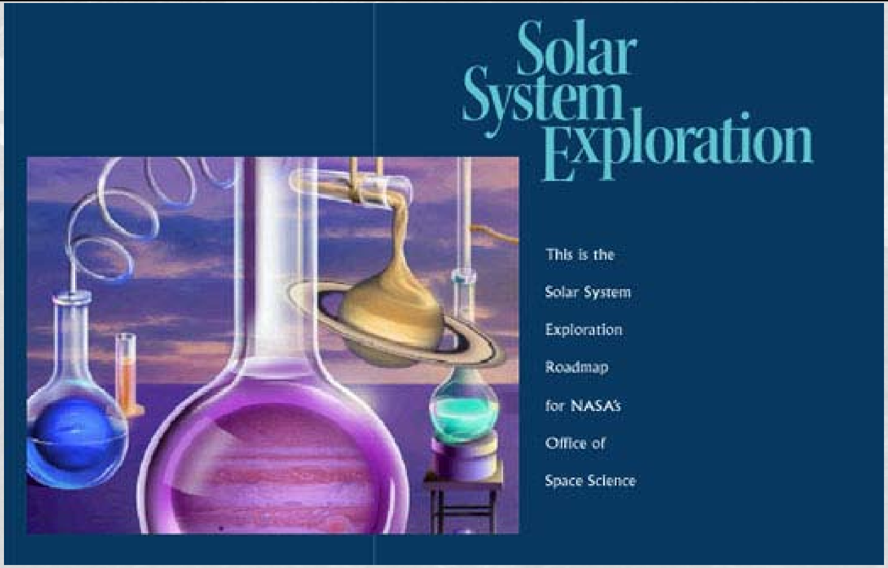

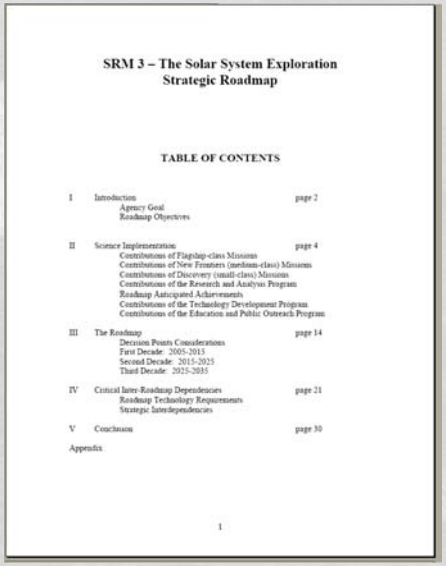
SRM 3 – The Solar System Exploration Strategic Roadmap

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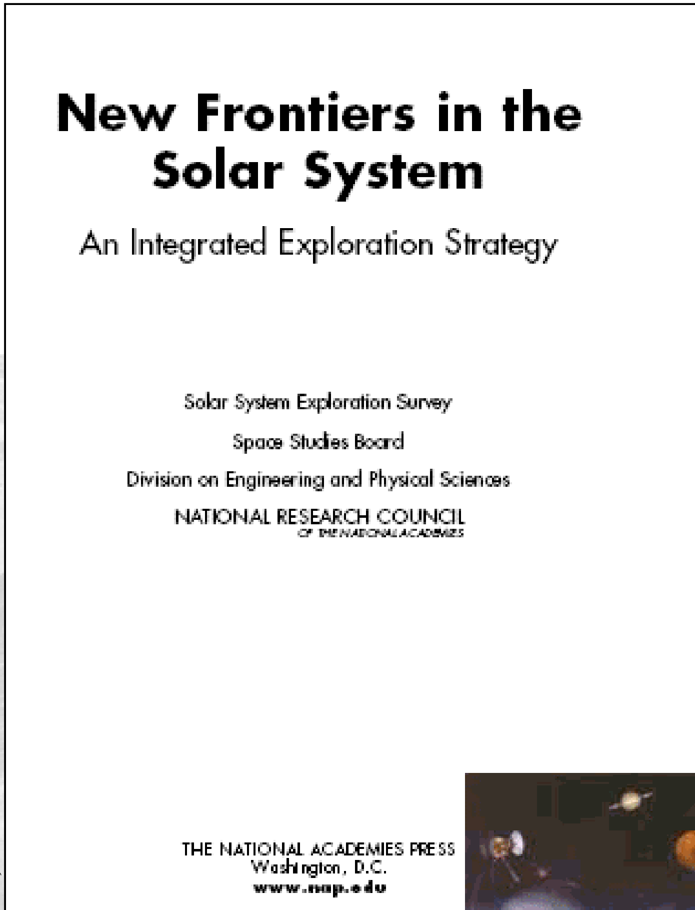
New Frontiers in the Solar System

An Integrated Exploration Strategy

Solar System Exploration Survey

Space Studies Board

Division on Engineering and Physical Sciences

NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES

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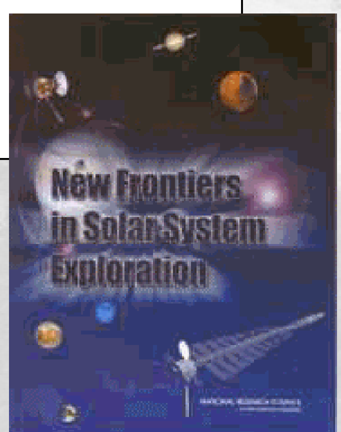
www.nap.edu



http://www.nap.edu

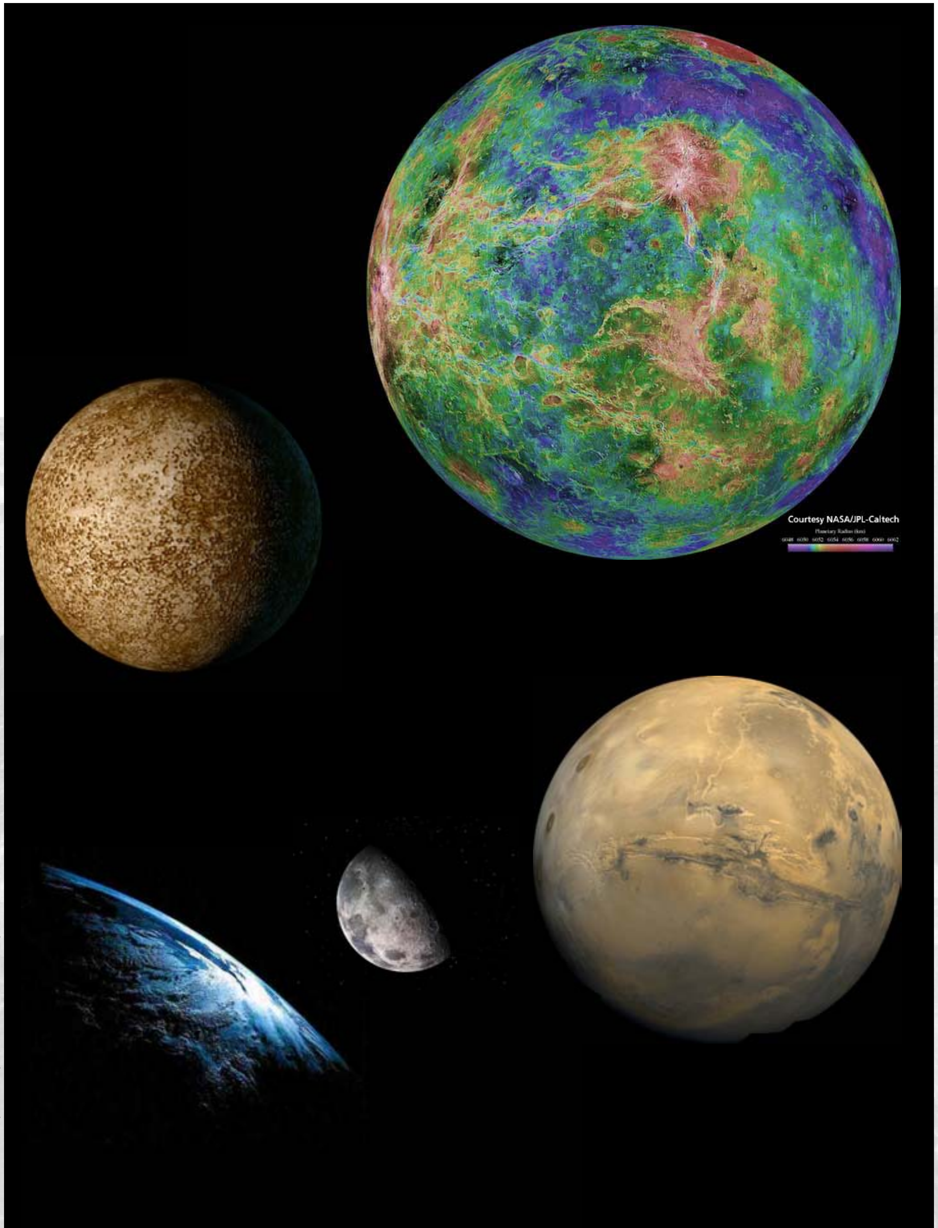
Integrated Exploration Strategy

- 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 (4 per decade) – Jupiter Orbiter w/ Probe, Lunar Sample Return, Comet Sample Return and Venus In Situ Explorer
- Flagship missions (>$650M) – directed missions – like Cassini Huygens, 1 per decade

SSE Decadal Survey: Inner Solar System: Keys to Habitable Worlds



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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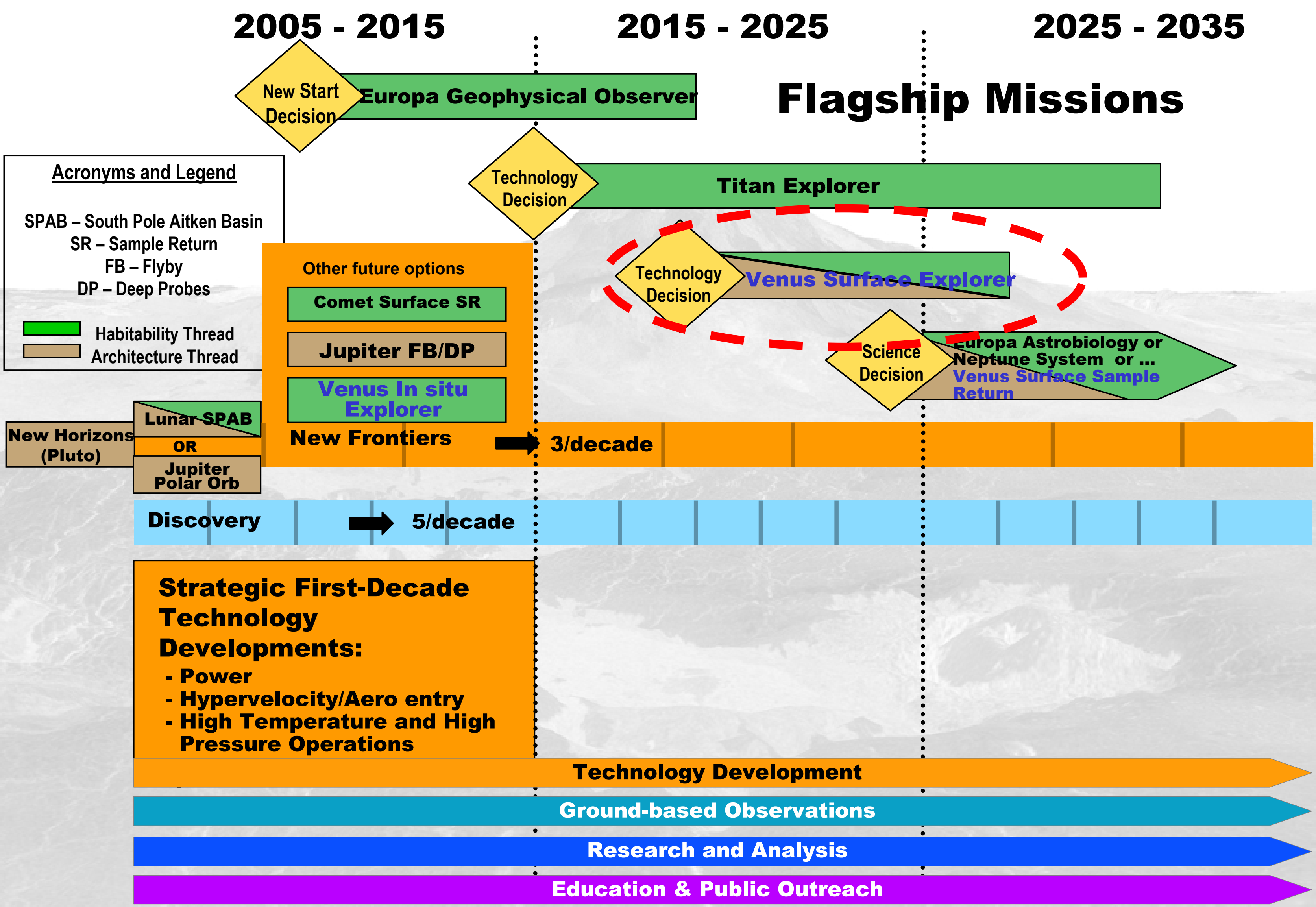
Chronological Sequence of Missions & Criteria for Setting Priorities

- **Scientific Merit**
  - Significance of progress on high priority science objectives
  - Creates new or changes existing paradigms
  - Affects direction of future research
  - Improves predictive models
- **Opportunity**
  - Orbital Mechanics
  - Relationship to other missions
  - International cooperation
  - Scientific discovery making this the right time for the mission
  - Public Interest
- **Technological Readiness**
  - Often drives choices between missions with equal scientific merit and no clear opportunity based discriminators
  - Major element of cost risk equation
  - Requires intensive mission trades and projection of future technological progress

Solar System Exploration Strategic Road Map – May 2005



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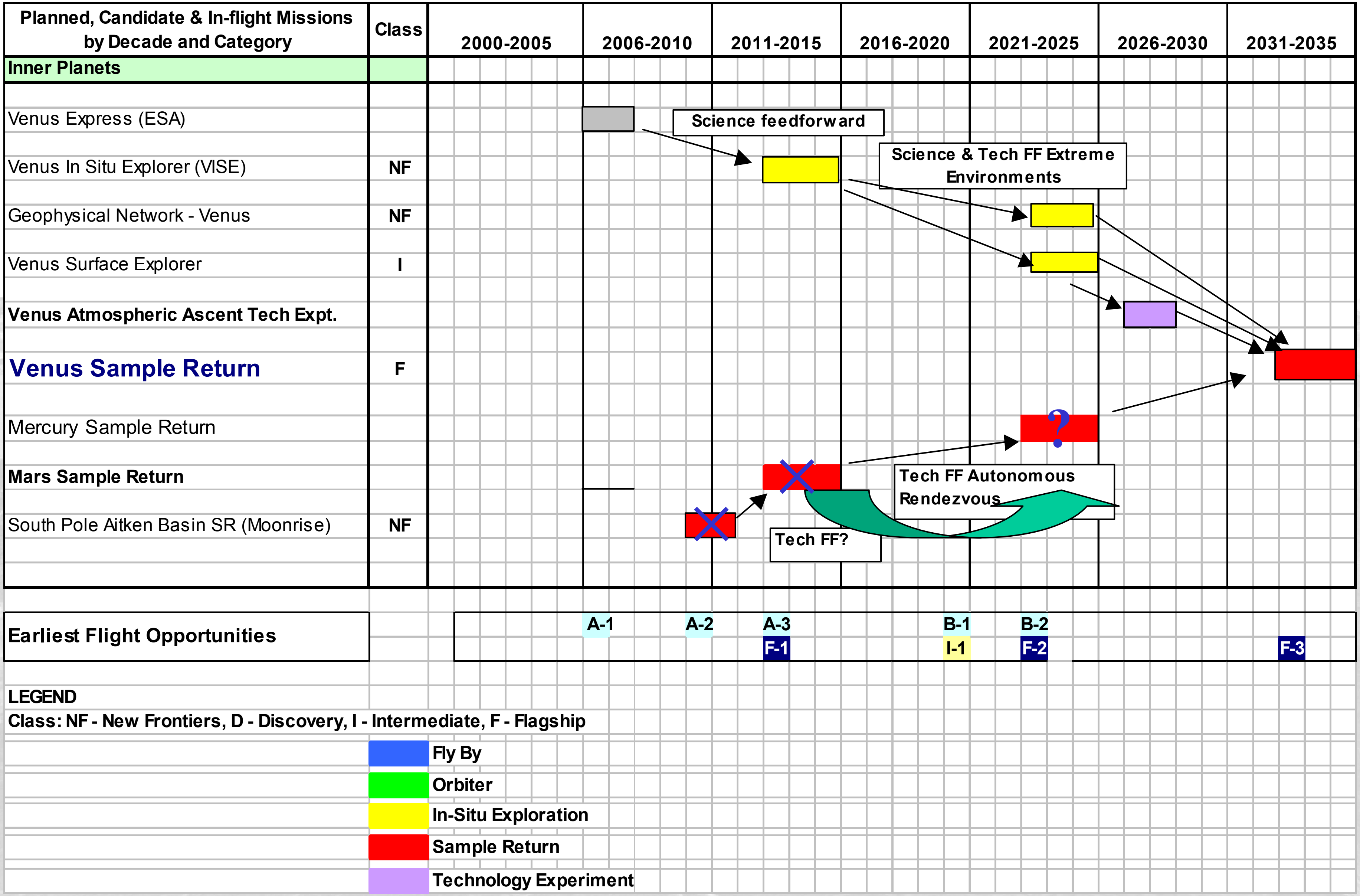
Status of Competitive Venus Programs

- **Discovery Program**
  - Venus concepts have been proposed at each opportunity;
  - Include orbiter, probe, lander and balloon concepts;
  - No Venus concept has been selected to date;
  - Because the competition continues (Discovery 12 AO is expected soon) no information on current concepts is available.

- **New Frontiers Program**
  - Decadal Survey called for a Venus In Situ Explorer (VISE) mission that would target Venus geochemistry; and also would be a precursor for a Venus Surface Sample Return (VSSR);
  - New Frontiers call dropped the precursor requirements, thus reducing demands for new technology;
  - Only the Jupiter Polar Orbiter (Juno) and Lunar Sample Return (Moonrise) deemed technologically ready in New Frontier 2 (2004) competition (Juno selected);
  - Expect another NF opportunity in two to three years, where VISE type proposals would be expected to be invited again.

Inner Planets Exploration:
Notional Scenarios Leading to Venus Surface Sample Return



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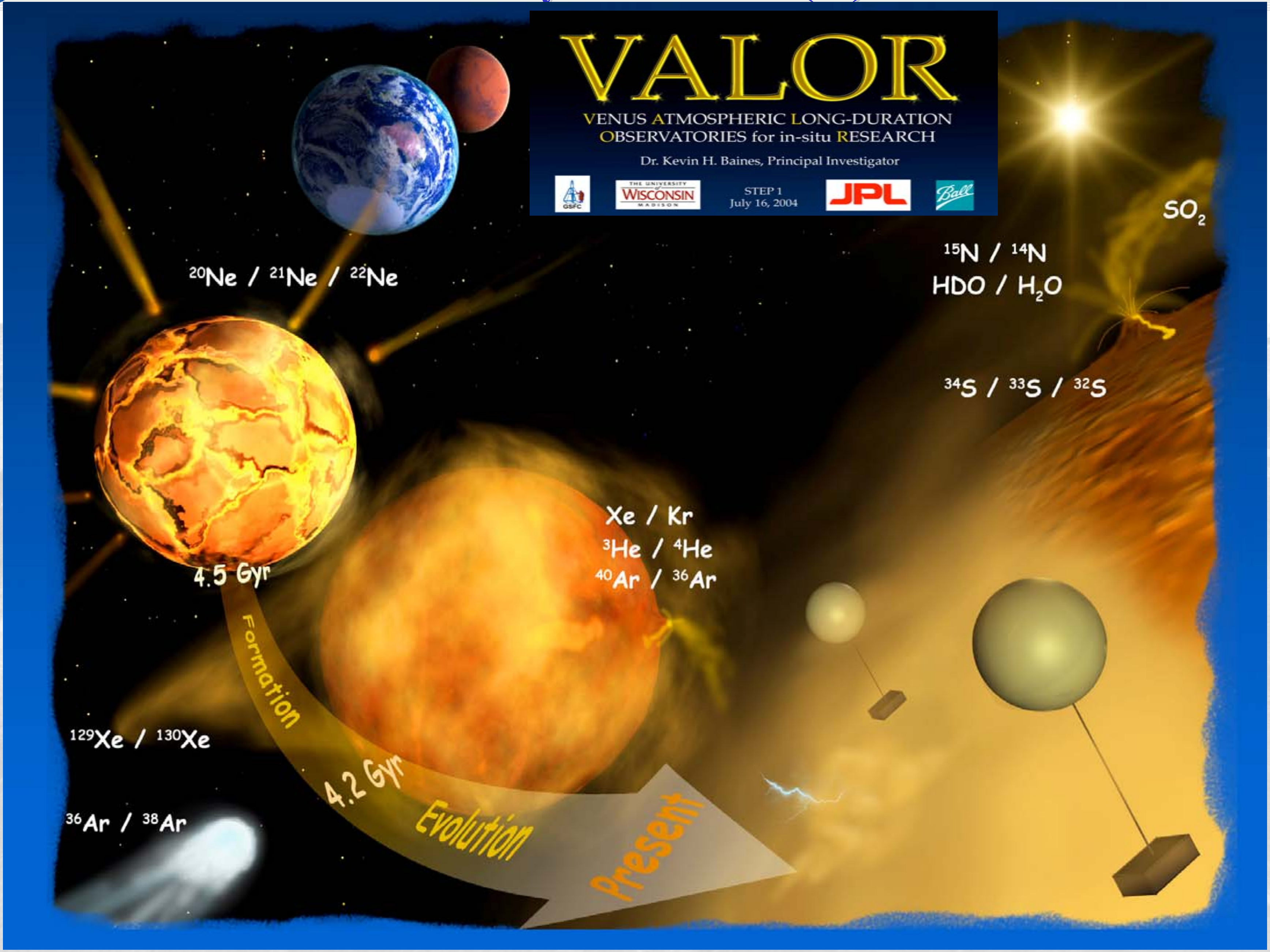
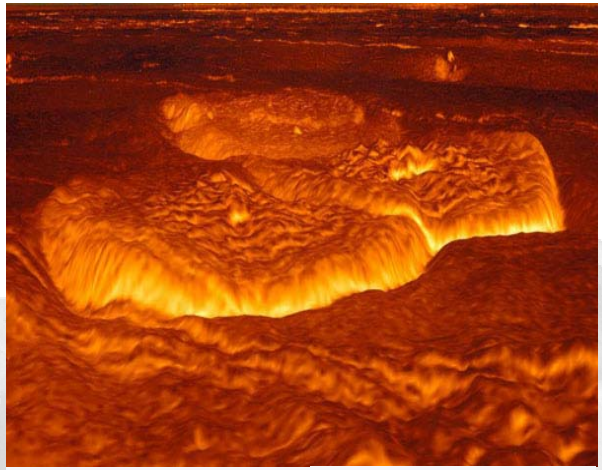
Proposed Missions: Discovery Class
VALOR by Kevin Baines (PI)

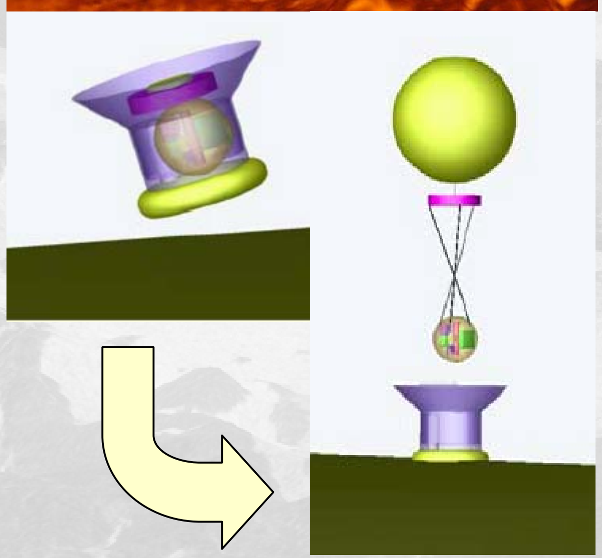


Proposed Missions: New Frontiers Class
Venus In Situ Explorer – VISE

Scientific Objectives:

- Composition and isotopic measurements of surface and atmosphere
- Near IR descent images
- Acquire and characterize a core sample.
- **Demonstrate key technologies for VSSR**





Mission & LV Class:

- New Frontiers Class
- Launch Vehicle Class: TBD

Science Payload:

- Neutral mass spectrometer with enrichment cell.
- Instruments to measure elements and mineralogy of surface materials.
- Imaging microscope

Technology & Heritage:.

- Sample acquisition and handling in Venus environment
- Passive insulation and survival at Venus

Mission Technology Studies:

- Decadal Survey 2002 of ***Surface & Atmospheric In Situ Explorer (SAIVE)***
- JPL proposal in response to New Frontier Mission solicitation.
- Technology studies in In Space Propulsion, Low temperature materials and autonomy.

Earliest Launch Opportunity: Technology Readiness: 2010 Programmatic Slot: 2013

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POC: Tibor.Balint@jpl.nasa.gov

Proposed Missions: Flagship Class
Venus Surface Explorer

Scientific Objectives:

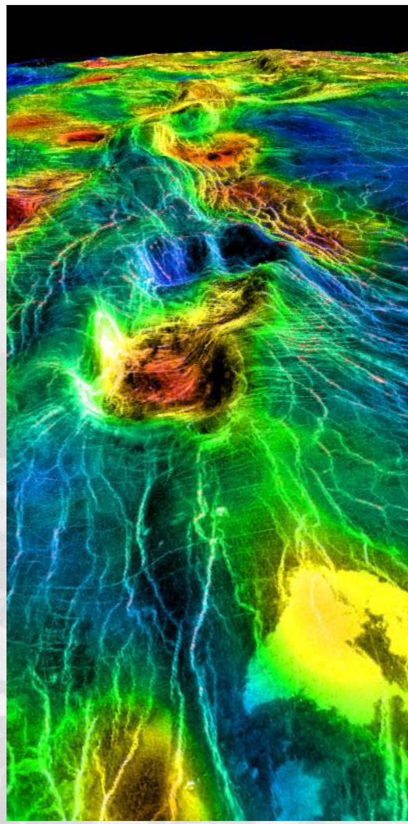
- Composition and isotopic measurements of surface and atmosphere
- Near IR descent images
- Acquire and characterize a core sample.
- **Demonstrate key technologies for VSSR**

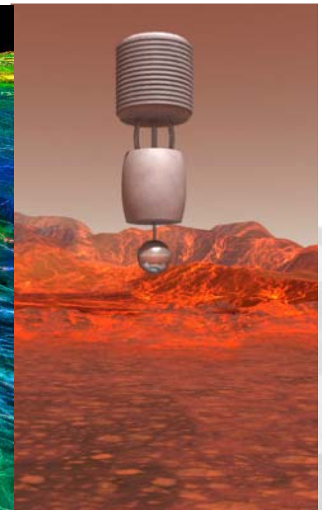
Exploration Metrics:

- Operate in Venus surface environment for 90 days
- Range across surface if rover TBD
- Range and altitude if aerial vehicle TBD

Mission & LV Class:

- Flagship Class
- LV: Delta-IV-H / Atlas V





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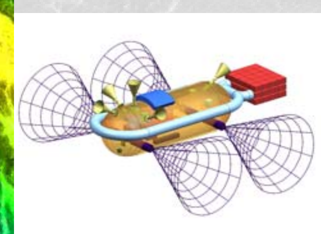

Science Payload:

- Neutral mass spectrometer with enrichment cell.
- Instruments to measure elements and mineralogy of surface materials.
- Imaging microscope

Technology & Heritage:.

- Sample acquisition and handling in Venus environment
- Passive insulation and survival at Venus

Mission Technology Studies:

- Decadal Survey 2002 - none.
- Technology studies for definition of advanced RPS systems, 2005
- Ongoing studies in FY06.

Earliest Launch Opportunity: Technology Readiness: 2017 Programmatic Slot: 2020

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POC Tibor.Balint@jpl.nasa.gov

Future Missions: Flagship Class
Background for Long Duration Venus Explorations

- Long duration operation on the surface of Venus is an enabling requirement for missions in the Solar System Exploration Roadmap, such as for
  - Venus Surface Explorer
  - Venus Surface Sample Return

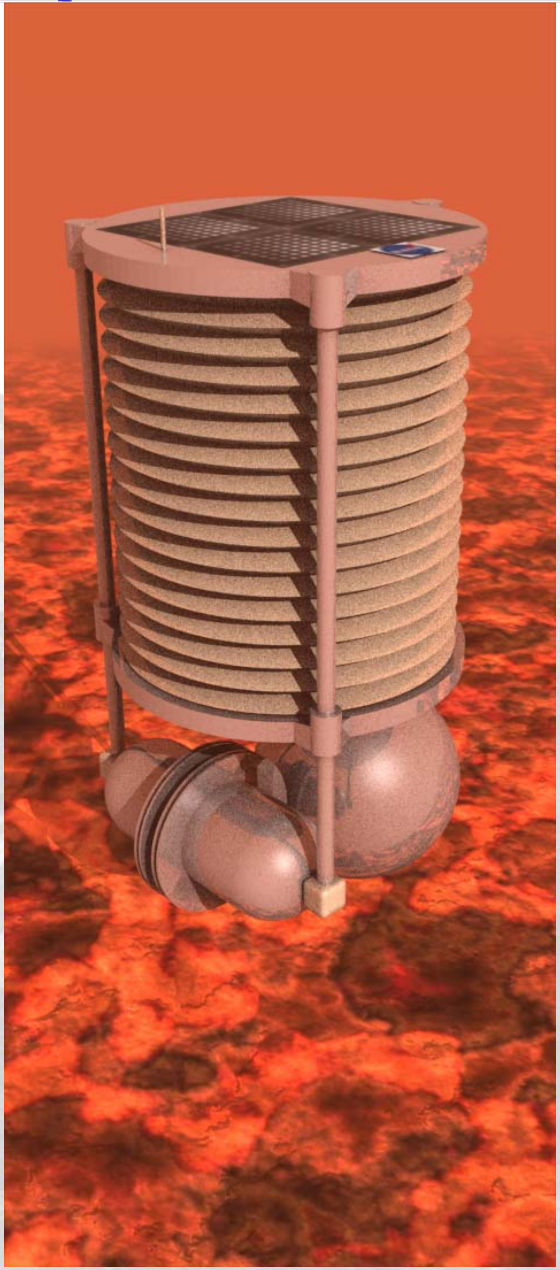
- A long duration operation capability could enable other potential Venus missions, including:
  - Venus Seismic Network
  - Venus Lower Atmosphere Balloon network

- A study effort has been formulated for FY06 to address these objectives, supported by NASA Solar System Exploration Division
  - Venus Exploration Assessment Group – Steve Saunders
  - Planetary Program Support – Jim Robinson
  - Radioisotope Power System Program – Ajay Misra

Potential Future Study: Required Capabilities for Venus Surface Explorer

Technologies for Extreme Environments

- Protection against high temperatures and pressures
- Electronics for high temperature operation
- Sample Acquisition mechanism
- Mobility – aerial and surface
- Power – only radioisotope power
- Active Thermal Control – at Venus surface
- Science Instruments



Initial Conditions

- T = 460°C; P = 90 bar; Atmosphere: CO_2
- Supercritical, highly corrosive and reacting with various metallic and non-metallic materials
(e.g., Titanium and Kapton; re: 12.5 km anomaly – for the Pioneer-Venus probes)

Boundary Conditions

- T = 460°C; P = 90 bar; Atmosphere: CO_2
- Mission duration: 90 days to 1 year+
- Active cooling by power system to pressure vessel and electronics inside
- Electric power generation by custom RPS to systems and instruments

Additional considerations:

- Operations through all mission phases:
(1) Earth storage;
(2) Launch environment;
(3) Cruise phase inside & aeroshell;
(4) EDL;
(5) Venus in-situ operations.

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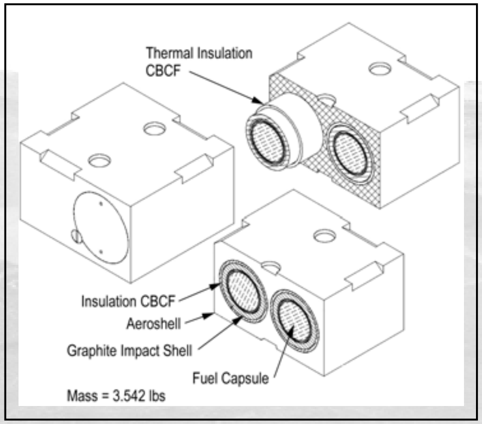
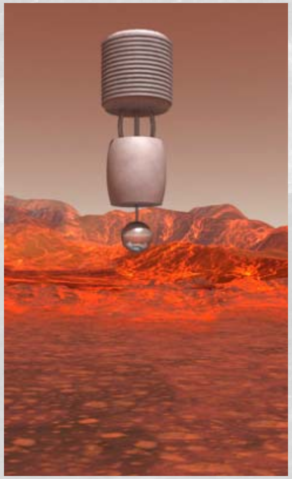
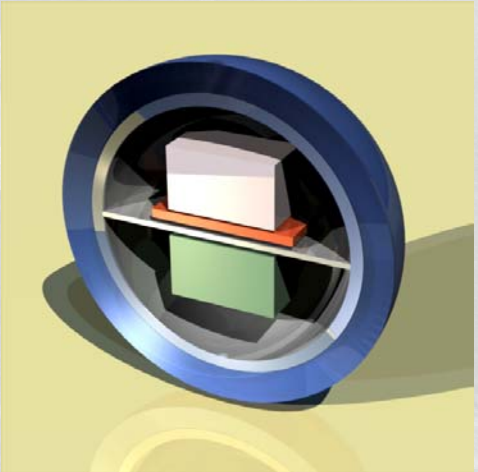
- **Power / Energy Storage:**
  - A new type of RPS is needed for Venus surface / in-situ missions
  - Nuclear Systems and Technologies Programs Office (Prometheus) to provide significant contribution on RPS configuration and performance details to this SSE Venus In-situ study
  - Use Energy Storage technology report
- **Extreme Environments:**
  - Pressure Vessel – use Extreme Environments results
  - High temperature electronics – use EE results
  - Air mobility (balloon, aerobot) – consult with J. Jones / J. Hall
  - Autonomy and navigation – use GN&C technology studies
- **Trajectories & EDL**
  - Aeroshell / TPS issues – consults with NASA Ames / Langley
  - Trajectories – JPL Trajectories Group
- **Telecom**
  - DTE or orbiter relay







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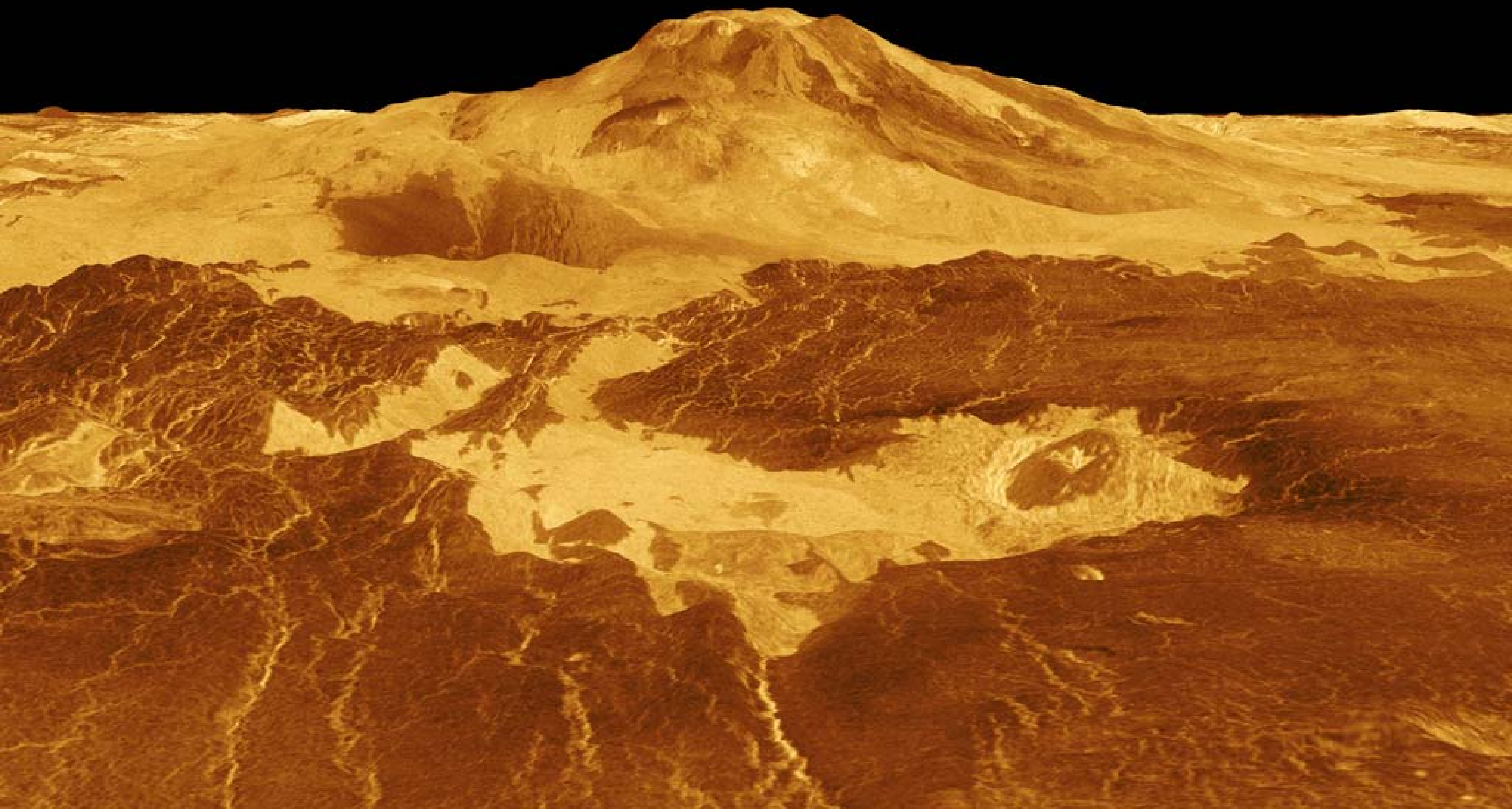
Conclusions

- The Solar System Exploration Road Map has laid the ground work for a future solar system program with a strong Venus emphasis, including long duration in situ exploration.
- Success of Mars Exploration Rover has demonstrated the capability of long duration mobile vehicles for achieving significant science objectives
- A long duration mobile exploration capability for Venus must be tailored to the surface conditions at Venus. This will require new capabilities for tolerating and in some cases exploiting the severe environment.
- This capability will require substantial investment and will not be achieved soon. However, a credible long range strategy will animate a set of prior missions some of which will permit validation of technologies needed for this mission.
- Science guidance is now needed to help formulate the in situ exploration of Venus.

Any questions?



- Backup slides

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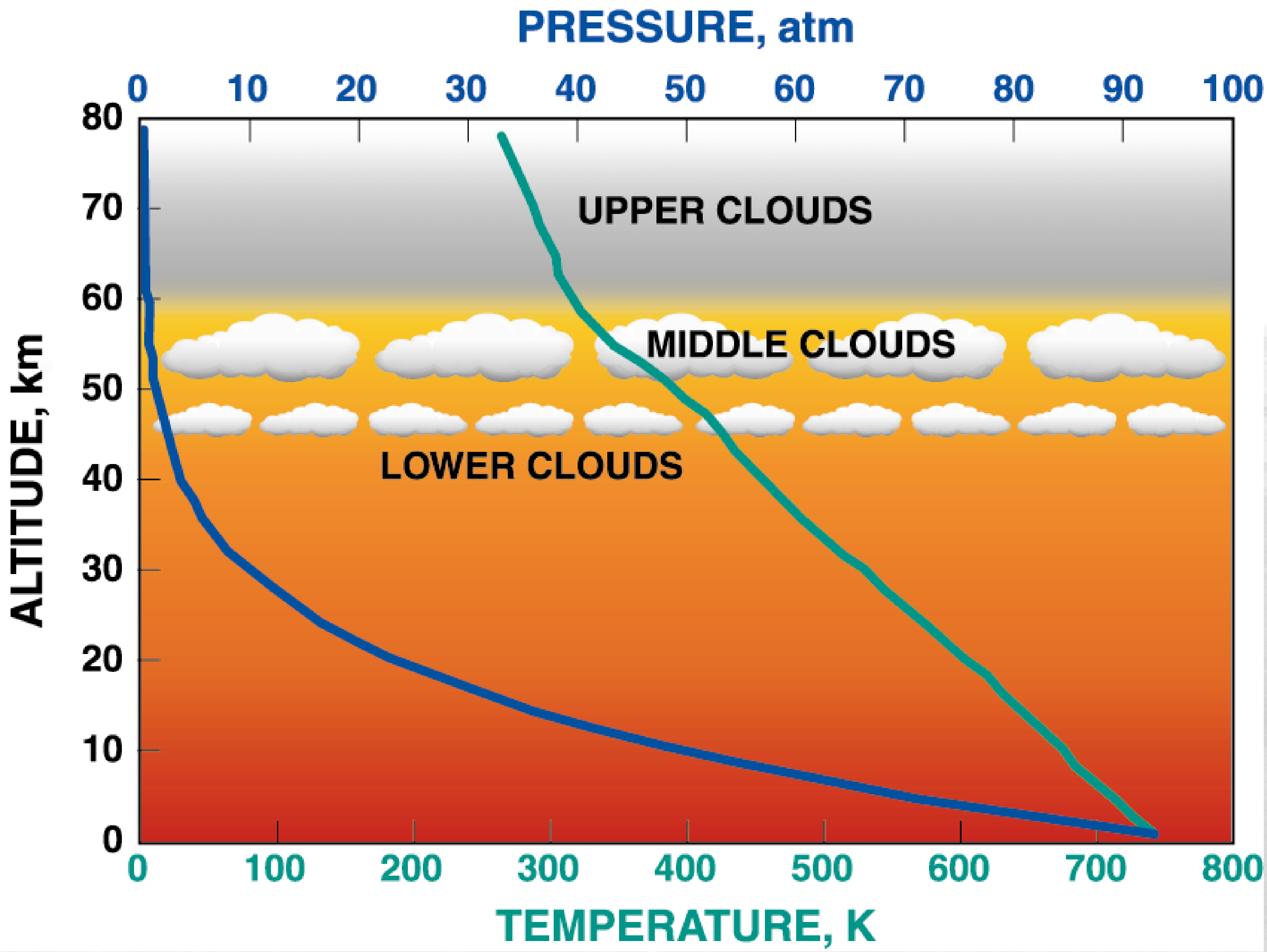
Venus Environment



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Previous and Ongoing Studies & Planned Venus Missions

- **Past: Decadal Survey Studies (2002)**
  - Surface and Atmospheric In-Situ Explorer (SAIVE)
  - Venus Surface Sample Return (VSSR)
- **Past: New Frontiers/Discovery Proposals for Venus Exploration**
  - Venus In-Situ Explorer (VISE)
  - Venus Atmospheric Long-Duration Observatories for in-situ Research (VALOR)
- **Past: Team-X Studies**
  - Venus Lander (1998)
  - Venus Atmospheric Sample (1998) (multiple studies / various configurations)
  - Venus Surface Sample Return (1999) (multiple studies / various configurations)
- **Past: Prometheus Office / Advanced RPS Studies**
  - Venus Rover (2005 – Randolph, Evens, ed: Abelson)
- **Past: Other Venus Studies**
  - Venus Geoscience Aerobot (1997 - Stofan)
  - Venus Multiprobe Mission (VMPM) (1994 – Goody & Tucker)
- **Present: Venus In-situ Studies in Support of the SSE Strategic Road Map (FY06)**
  - Technology Focused Study on Venus Long Lived In-Situ Exploration (JPL – ongoing / Balint)
  - Radioisotope Power Systems for Venus Exploration (JPL – ongoing)
- **Present/Future: Foreign Venus Mission Plans and Studies**
  - Venus Sample Return (ESA study) (1998)
  - Venus Express (ESA) (launched: November 9, 2005)
  - Venus Climate Orbiter (JAXA) (planned launch 2007)

To be Presented at the Venus Entry Probe Workshop; European Space Agency (ESA); European Space and Technology Centre (ESTEC); The Netherlands; January 19-20, 2006

VENUS EXPLORATION OPPORTUNITIES WITHIN NASA'S SOLAR SYSTEM EXPLORATION ROADMAP

by
Tibor Balint[1], Thomas Thompson[1], James Cutts[1] and James Robinson[2]
[1]Jet Propulsion Laboratory, California Institute of Technology
[2] National Aeronautics and Space Administration, Headquarters
e-mail: tibor.balint@jpl.nasa.gov

Science goals to understand the origin, history and environment of Venus have been driving international space exploration missions for over 40 years. Past missions include the Magellan and Pioneer-Venus missions by the US; the Venera program by the USSR; and the Vega missions through international cooperation. Furthermore, the US National Research Council (NRC), in the 2003 Solar System Exploration (SSE) Decadal Survey, identified Venus as a high priority target, thus demonstrating a continuing interest in Earth's sister planet. In response to the NRC recommendation, the 2005 NASA SSE Roadmap included a number of potential Venus missions arching through all mission classes from small Discovery, to medium New Frontiers and to large Flagship class missions. While missions in all of these classes could be designed as orbiters with remote sensing capabilities, the desire for scientific advancements beyond our current knowledge – including what we expect to learn from the ongoing ESA Venus Express mission – point to in-situ exploration of Venus.

For the in-situ exploration objective, Discovery class mission concepts could include entry probes as well as long-lived balloon operating in the upper atmosphere above ~60km. A New Frontiers class Venus In-Situ Explorer (VISE) mission could make measurements at the surface but only for a few hours due to the environment. The relevant extreme environments at the surface of Venus can be characterized by the highly corrosive supercritical CO_2 atmosphere, with pressures and temperatures reaching ~90bar and ~460°C, respectively. Thus, in order to explore Venus near the surface and at multiple locations, a suitable mission architecture would require a long-lived in-situ element. These ambient conditions introduce a design challenge, which must be mitigated through appropriate technologies. The temperature environment could be addressed by high temperature electronics and cooling; while high pressures could be moderated by a pressure vessel design.

Such a long-lived Venus in-situ mission would also likely require a specially designed dynamic Stirling Radioisotope Generator (SRG) power system that could provide both electric power and active cooling to the spacecraft. An air mobility platform, possibly employing metallic bellows, could allow for all axis control, long traversing and surface access at multiple desired locations, thus providing an advantage over static lander or rover based architectures. The SSE Roadmap also identified Venus Sample Return (VSR) as a potential third decade Flagship class mission. It is expected that VSR would build on technology heritage from other proposed sample return missions to easier planetary targets with less severe environments, such as the Moon, Mars and Mercury. Consequently, NASA's Venus exploration plans over the next three decades – as identified in the SSE Roadmap – are anticipated to greatly contribute to our understanding of this planet, which subsequently would advance our overall knowledge about the Solar System.