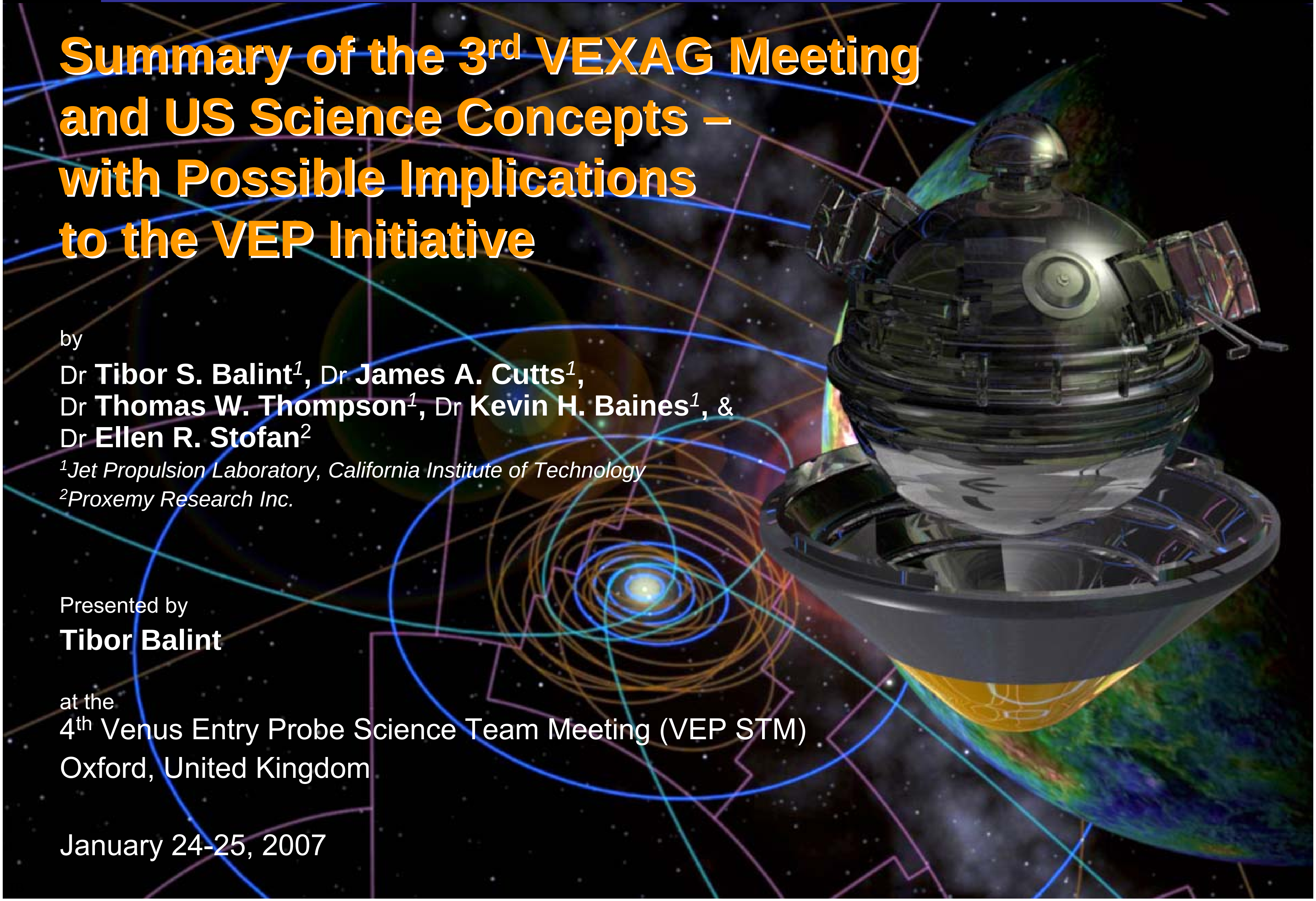

Summary of the 3rd VEXAG Meeting and US Science Concepts – with Possible Implications to the VEP Initiative

by

Dr **Tibor S. Balint**[1], Dr **James A. Cutts**[1],
Dr **Thomas W. Thompson**[1], Dr **Kevin H. Baines**[1], &
Dr **Ellen R. Stofan**[2]

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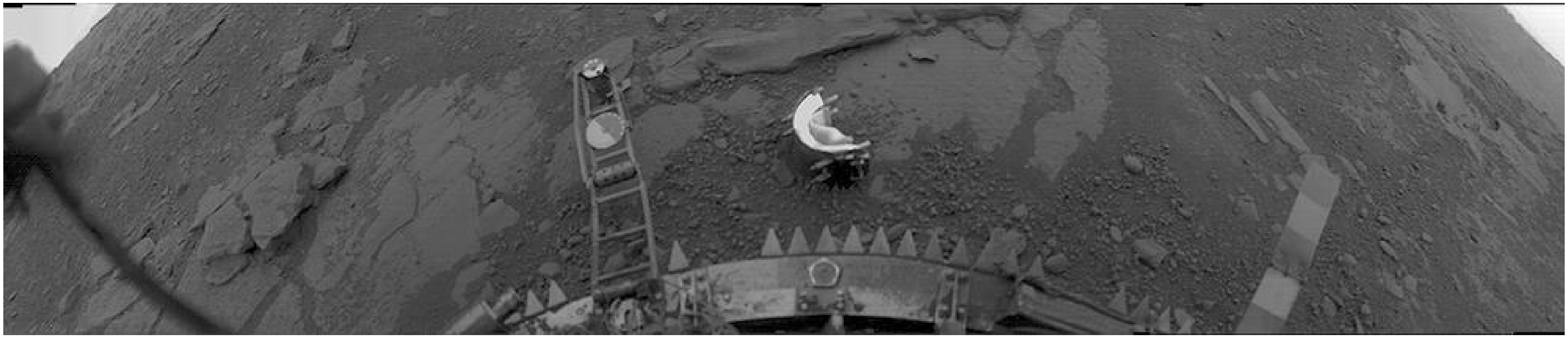
Presented by
Tibor Balint

at the
4th Venus Entry Probe Science Team Meeting (VEP STM)
Oxford, United Kingdom

January 24-25, 2007

Overview

- Brief summary of the 3rd VEXAG meeting
- Overview of the US Venus Exploration Plans
  - NASA's 2006 Solar System Exploration Roadmap
  - VME – Venus Mobile Explorer Concept
  - Extreme Environments – Venus In-Situ
  - Technology Challenges for Long-Lived In-Situ Exploration of Venus
- Implications to the VEP Initiative
  - Potential contributed instruments by the US
- Summary



Venera 13 Image of the surface of Venus

Brief Summary of the 3rd VEXAG Meeting (1 of 3)

- **~100 people attended**, representing NASA HQ, NASA Centers, JPL, APL, universities and industry

- **Jim Green** – Acting Director of the Planetary Science Division (PSD) at NASA HQ
  - **NASA's 2006 SSE Roadmap** is officially out (www.solarsystem.nasa.gov)
  - **Phase A Discovery selections** made; 3 will get funding for the next 7 months; then down-selection will be made probably from 3 to 2 concepts
    - **Discovery concepts**: **GRAIL** (moon gravity mapper); **OSIRIS** (asteroid sample return); **Vesper** (Venus orbiter);
    - **Missions of Opportunity**: **DIXI** (Deep Impact follow on); **EPOCh** (using Deep Impact imager); **Stardust NexT** (Stardust re-fly-by of comet Tempel-1 - Deep Impact's target)
  - PSD selected **4 pre-Phase A studies**: **Europa; Titan; Enceladus; Ganymede**
    - Following the process could potentially lead to a similar Venus study
  - Noted the **ongoing representation** of the Venus community **at VEP meetings**

- **Advisory committees** and groups were discussed:
  - **Planetary Science Subcommittee** of the NASA Advisory Council by Sean Solomon
  - Mars Exploration Program Analysis Group (**MEPAG**) by TommyThompson
  - Outer Planets Advisory Group (**OPAG**) by Sushil Atreya
  - Lunar Exploration Advisory Group (**LEAG**) by Steve Macwell
  - Venus Exploration Analysis Group (**VEXAG**) by Janet Luhmann

Brief Summary of the 3rd VEXAG Meeting (2 of 3)

- Overview of **NASA's 2006 Solar System Exploration Roadmap** – by Jim Cutts
  - Unifying theme: "**Habitability**"; addressing habitability of worlds, architecture of planetary systems; and hazard to Earth
  - Recommended **missions in 3 classes**: competed **Discovery** ($425M); competed **New Frontiers** ($750M); directed **Flagship** ($1.5B to $3B)
  - Electronic version of the roadmap is available at: www.solarsystem.nasa.gov

- **Technology development** discussion – by George Komar and Dave Lavery
  - NASA is trying to integrate technology development across the Agency
  - Set up NASA Technology Federation – to which VEXAG should provide feedback
  - Potential Extreme Environment Technology workshop to address tech needs

- **Technology challenges, mission architectures** presented by Tibor Balint

- **Overview of VEP goals, objectives and proposed architectures** were presented based on the material provided by Eric Chassefiere

- Results and activities related to **ongoing or near future missions**
  - **Venus Express (VEX)** status by Pierre Drossart
  - **Messenger Mercury** – Venus flyby by Sean Solomon
  - **JAXA's Venus Climate Orbiter** by Masato Nakamura and Takeshi Imamura
  - **Vesper** (Discovery candidate) by Gordon Chin

Brief Summary of the 3rd VEXAG Meeting (3 of 3)

- **Preview of Objectives and Investigations** – lead by Steve Mackwell
  - Scored on
    - Importance;
    - Technology readiness of the instruments;
    - Practical sequence of investigations
- The three (equally important) overarching VEXAG Goals are paraphrased as:

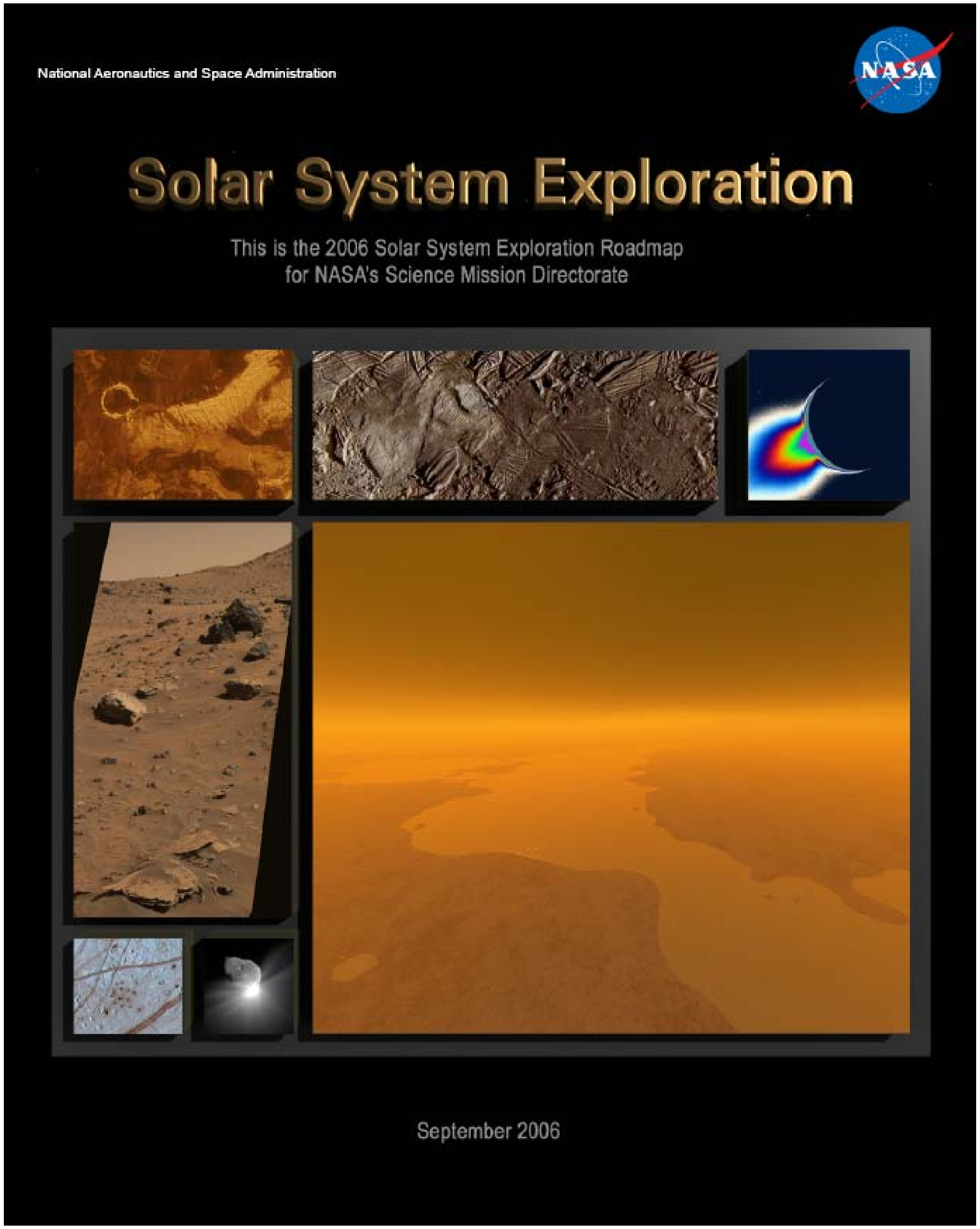
  (1) Search for Evidence of Past Habitability including ancient oceans

  (2) Understand Venus as Terrestrial Planet

  (3) Understand Venus as a model for future states of the Earth

- NOTE: all of the presentations from the 3rd VEXAG meeting can be found at the VEXAG website:
  - URL: http://www.lpi.usra.edu/vexag/jan_2007/presentations.html

NASA's 2006 Solar System Exploration Roadmap



National Aeronautics and Space Administration

Solar System Exploration

This is the 2006 Solar System Exploration Roadmap
for NASA's Science Mission Directorate

September 2006

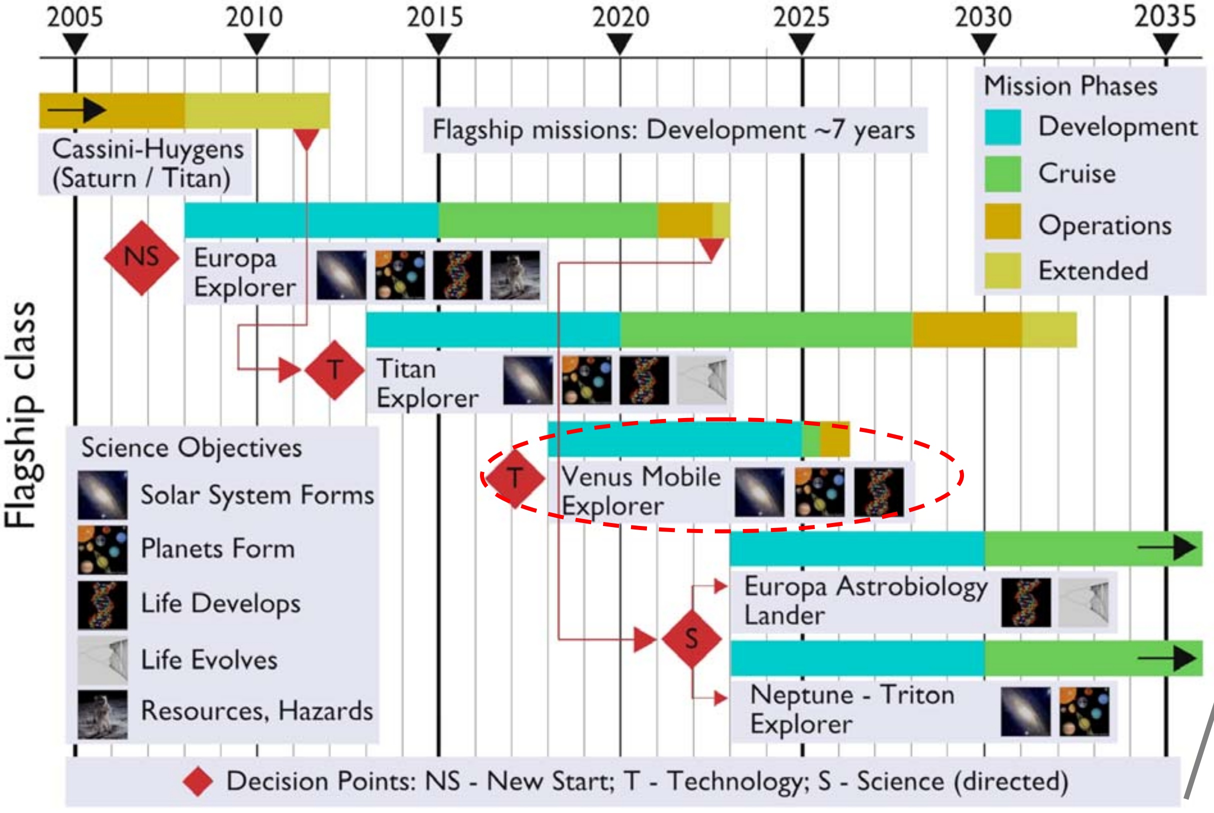
The Roadmap addresses five fundamental questions, in response to the NRC's Decadal Survey. These are:

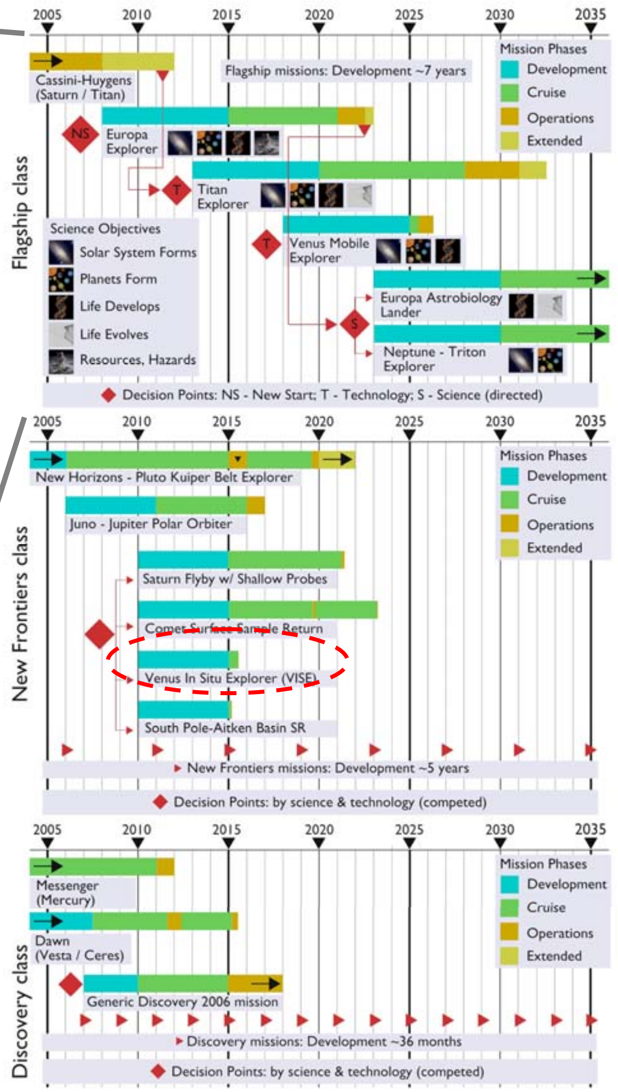
1. How did the **Sun's family of planets and minor bodies originate**?
2. How did the **Solar System evolve** to its current diverse state?
3. What are the characteristics of the Solar System that led to the **origin of life**?
4. How did **life begin and evolve on Earth** and has it evolved **elsewhere 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



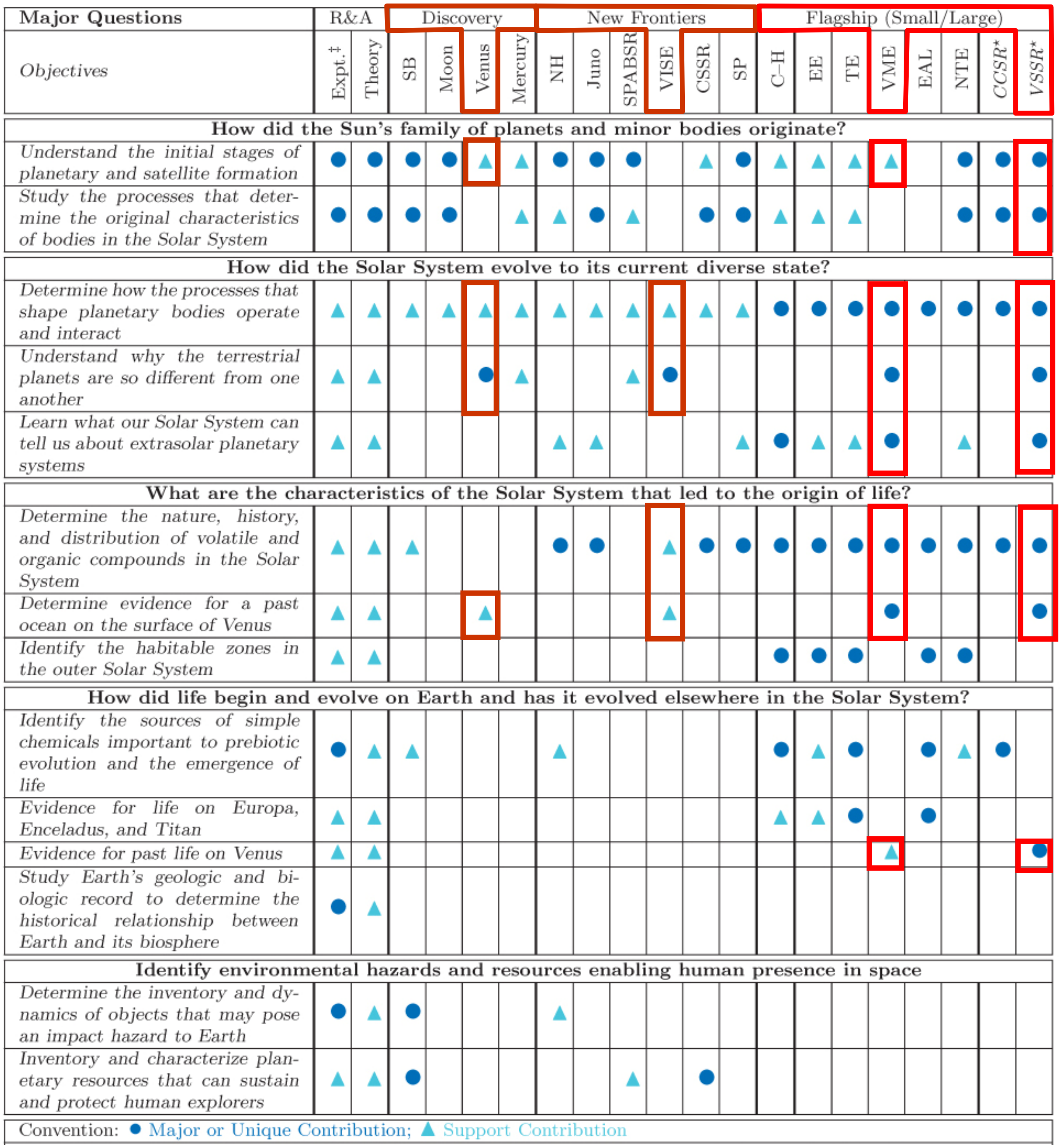


- NASA's **2006 SSE Roadmap** identifies proposed long-lived **Flagship class missions** to Venus
- The Roadmap also identified potential Discovery and New Frontiers class missions to Venus

By T. Balint, J. Cutts, T. Thompson, K. Baines, E. Stofa

Ref: Solar System Roadmap 2006

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 <u>Venus 205 times</u> throughout the document, providing a **strong Venus emphasis.**

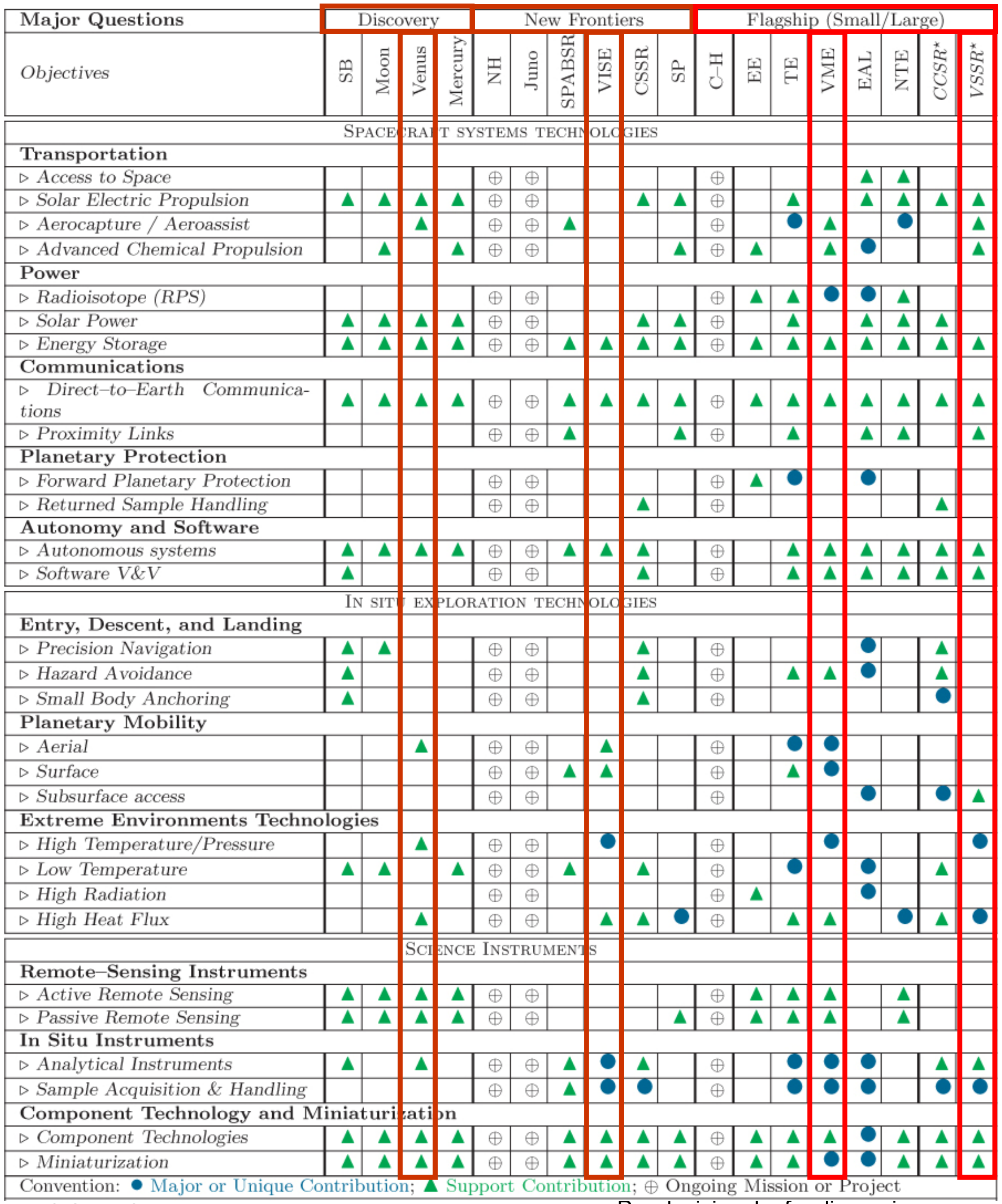
Both the **SSE Roadmap &** the **Chapman Conference**:

Focused on the
Theme of Habitability

By T. Balint, J. Cutts, T. Thompson, K. Baines, E. Stofan – January 17, 2007

Ref: Solar System Roadmap 2006

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

Ref: Solar System Roadmap 2006

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

Flagship class missions drive technology development,

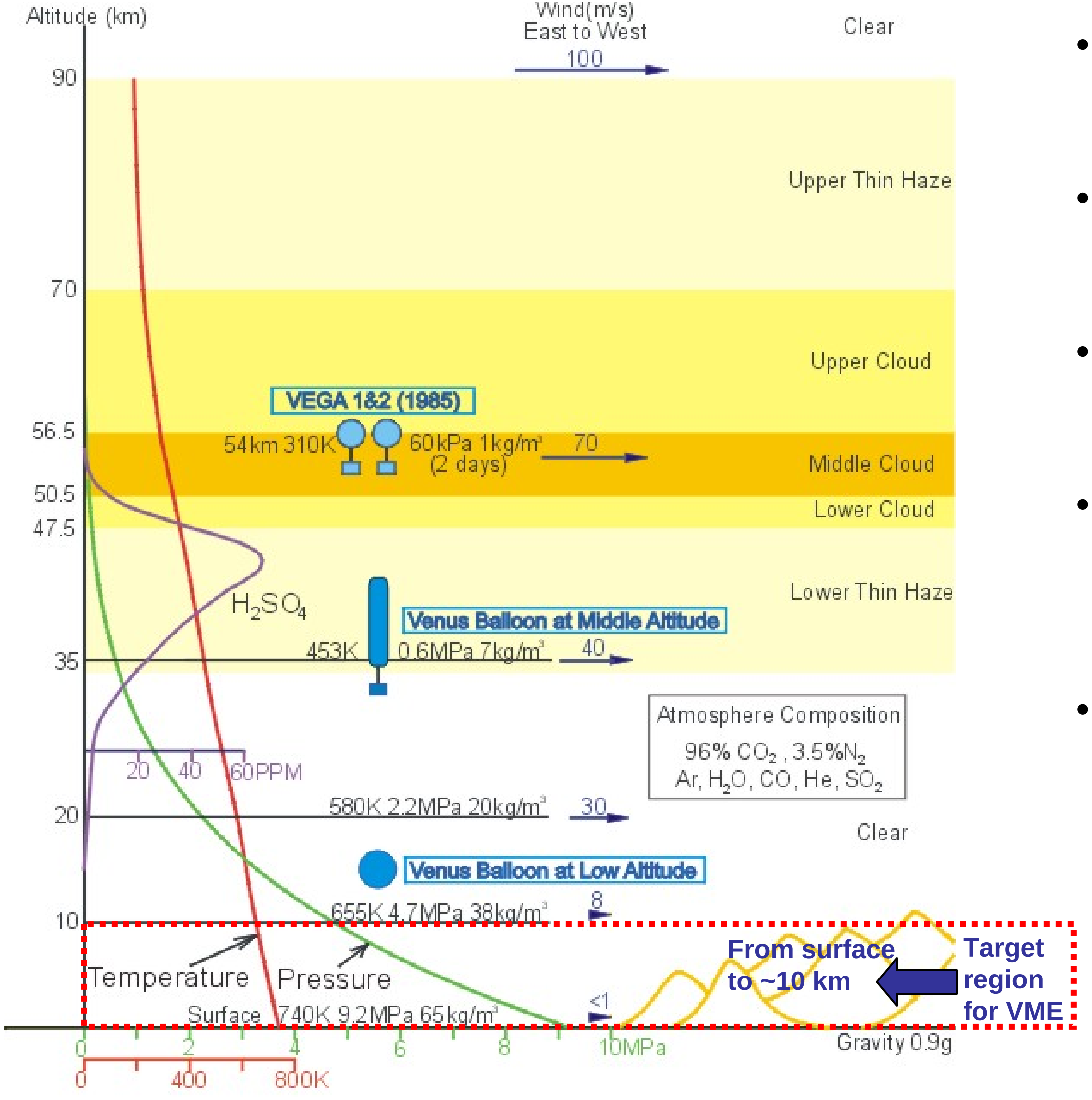
while **smaller** (Discovery & NF) **missions** can significantly **benefit** from technologies developed for Flagship missions

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**.

By T. Balint, J. Cutts, T. Thompson, K. Baines, E. Stofan – January 17, 2007

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

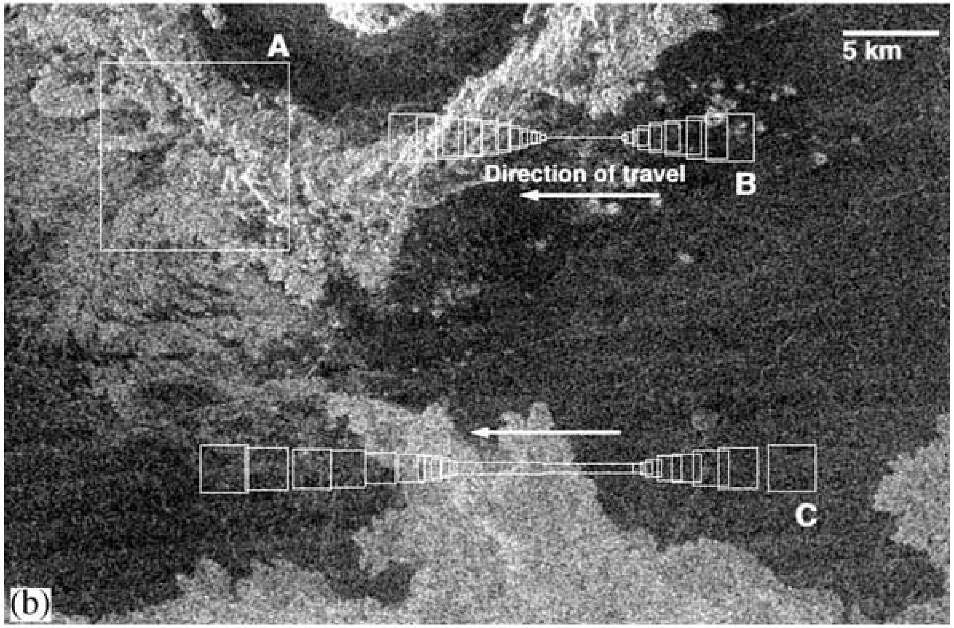
Ref: E. Kolawa, "Extreme Environments Technologies"

By T. Balint, J. Cutts, T. Thompson, K. Baines, E. Stofan – January 17, 2007

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:

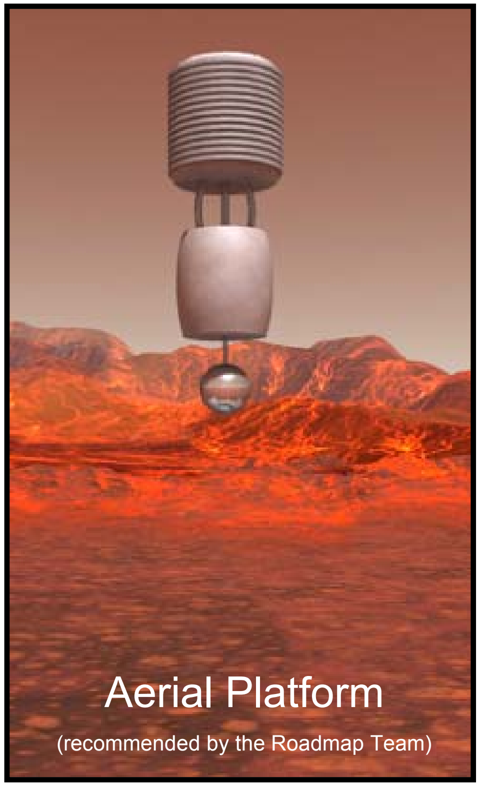
- Survey imaging at a variety of spatial scales
- Acquire & characterize surface samples at multiple sites
- Other physical and chemical measurements TBD

Exploration Metrics:

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

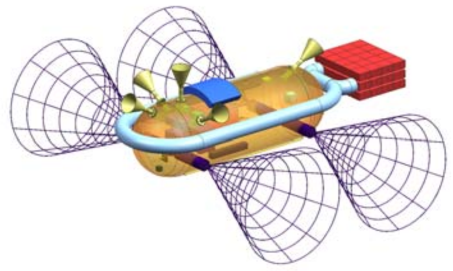
Technology Heritage from Prior Missions:

- 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**.

Venus Mobile Explorer

Summary of Enabling Technologies

Venus Mobile Explorer - VME: artist's concept

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**, common to all mission architectures – VME aerial mobility / rover / static lander

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

By T. Balint, J. Cutts, T. Thompson, K. Baines, E. Stofan – January 17, 2007

Potential US/NASA Contribution to ESA's Cosmic Vision

- This is a follow-up to inputs provided by Tommy Thompson during ESA's Venus Entry Probe Workshop; 19-20 January 2006, ESTEC, Noordwijk, Netherlands

- This summary assumes that a **potential US contribution** would be the result of a Discovery or New Frontiers class **Mission of Opportunity Proposal**, in the 2020 time frame *(note: MOO is currently at ~$35M)*

- Potential **international collaborations at a higher than instrument level** should be further **addressed by** the **Agencies**, governed by appropriate policies;
  - It should take into account the **proposal cycles** at both ESA and NASA
  - ESA – Cosmic Vision proposals:
    - Letter of intent is due by March 2007
    - Initial proposals by June 2007 (40 pages)
    - Selection of 3 medium & 3 large concepts after Oct 2007
    - The final mission selection is expected around 2008-2009
  - NASA – New Frontiers proposals:
    - AO for 3rd NF opportunity is expected in 2008
    - Likely targeting a potential 2015 launch
    - AO date for the 4th NF opportunity is not yet discussed

Note: These are informal statements from the US Venus community, and do not necessarily reflect official NASA policy. Policies should be negotiated at appropriate levels.

Potential US/NASA Contribution to VEP

In-Situ / Low-Altitude / Orbiter Instruments

- **Venus Balloon Borne Magnetometer** (UCLA – C. T. Russell)
- **Venus Integrated Weather Sensor (VIWS) System Using Durable High Temperature Sensors and Electronics** (NASA Glenn RC – Robert S. Okojie, Gary W. Hunter)
- **V-fOx** – Measure Oxygen fugacity (partial pressure) in the Venus atmosphere and soil at the surface and in the lower atmosphere at ambient pressure and temperature. (Washington University in St. Louis – Bruce Fegley; APL – Noam R. Izenberg)
- **InSAR** – Interferometric SAR: A technique validated in earth orbital missions that would provide a better topographic map of Venus than Magellan produced and detect surface changes such as tectonic shifts (JPL – Soren Madsen & Paul Rosen)
- **Radar Sounder** – Based on MARSIS instrument flown on Mars Express this would search for subsurface structures in the first few km's (e.g. structures buried under the plains) (Smithsonian Institution – Bruce Campbell; JPL – Jeff Plaut & Bill Johnson)
- High-Temperature Age-Dating Instrument - Potassium-Argon research performed under PIDDP (Univ of Arizona – Tim Swindle)
- Venus Polarization Nephelometer - currently funded under NASA PIDDP (Cornell University – Donald Banfield)
- Sampling Mechanisms – with potential synergies with NASA New Frontiers mainline missions (JPL – Elizabeth Kolawa)

Note: the items highlighted in blue are further detailed in the backup slides

Potential Joint ESA – NASA Developments for Venus Exploration

Potential New Frontiers – Cosmic Vision Collaboration

- Conceived here from the community’s point of view only
- Requires “buy-in” from the Agencies

Aerial and Descent Vehicles / Entry Probes

- **High- and Mid-Altitude Gliders** (NASA ARC – Larry Lemke)
- **Solar-Powered Airplane to explore the atmosphere of Venus**
  (NASA Glenn RC – Geoffrey A. Landis; Analex Corporation – Anthony Colozza)
- **Venus Dual-wing Balloon Guidance System / DBGS**
  (Global Aerospace Corporation – Alexey Pankine)
- **Metal Balloon for the Lower Atmosphere of Venus (MEBALAV)**
  (JPL – Viktor Kerzhanovich)
- High Altitude Balloons (JPL – Jeff Hall & Kevin Baines)
- Entry Probes – using Thermal Protection System (TPS), which is enabling technology for Venus entry (NASA ARC – Ed Martinez)

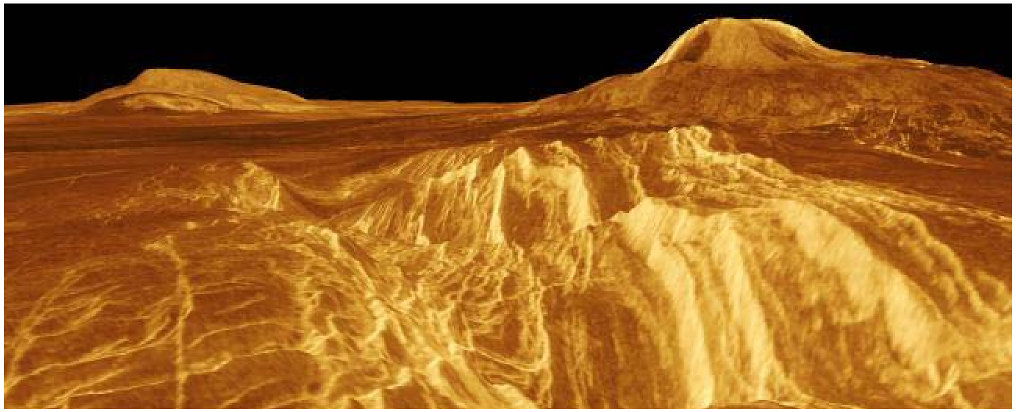
Technologies of interest

- Extreme Environments Technologies (e.g., Pressure Vessel; High Temperature Electronics; Short Terms Temperature Mitigation with Phase Change Materials; Corrosion Mitigation) (JPL – Elizabeth Kolawa)

Note: the items highlighted in blue are further detailed in the backup slides

Summary on
US Venus Exploration Technologies

- **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 (VME) **mission architecture**
- **Technology development** requires **substantial investment,** and **time**



Summary on
US Venus Exploration – Future Directions

- **Science guidance** is now needed **from the VEXAG 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

Summary on
Potential US/NASA Contributions to VEP

- We assumed that a **potential US contribution** would be the result of a Discovery or New Frontiers class **Mission of Opportunity Proposal**, in 2020 time frame

- To date, **5 to 8 potential instruments** were identified for potential US/ NASA contribution to ESA's VEP Initiative
  - Instruments include: *Magnetometer; VIWS; V-fOX; InSAR; Radar Sounder; High-T Age Dating; Nephelometer; Sampling mechanisms*
  - This **list** could be **expanded or refined** as the VEP proposal takes shape

- **International collaboration** options and ideas **at** a **higher than single instrument level** are worth exploring
  - **Strategies** for collaborations between the Cosmic Vision and New Frontiers (or Discovery) Programs could be identified, focusing on the higher science return, and the benefits to the Agencies
  - Promising **concepts** should be **presented to the Agencies** for consideration
  - **Timing between the CV and NF proposal cycles** should be accounted for
  - The 4 to 7 identified higher complexity spacecraft systems or components from the US community include: *High- / mid-altitude gliders; airplane; dual-winged balloon guidance system; metallic balloons; probes; high altitude balloons and extreme environments technologies*

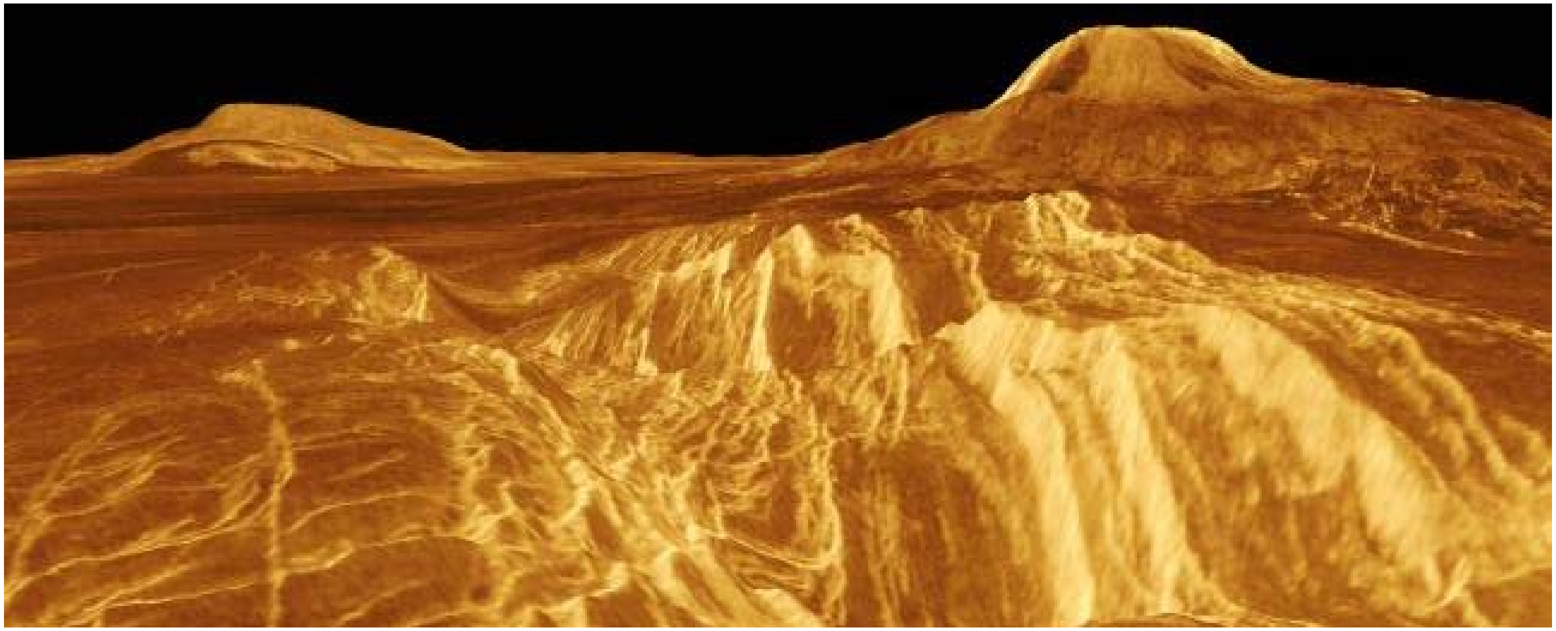
Note: These are informal statements from the US Venus community, and do not necessarily reflect official NASA policy. Policies should be negotiated at appropriate levels.

Acknowledgements

The authors wish to thank:

- Dr **Adriana Ocampo**, NASA HQ, SMD PSD;
- Dr **Janet Luhmann**, University of California, Berkeley, Space Science Laboratory;
- Dr **Sushil Atreya**, University of Michigan, Coupled Dynamics & Chemistry;
- Dr **Elizabeth Kolawa**, Program Manager for Extreme Environments Technologies at JPL;
- Dr **Andrea Belz**, Planetary Program Support Team member at JPL;
- **Craig Peterson**, Planetary Program Support Team member at JPL;

The views and opinions expressed here are those of the authors and do not necessarily represent official NASA policy.



The End

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

Venera Perspectives

Key Agenda Items from the 3rd VEXAG Meeting

3rd Meeting of the Venus Exploration and Analysis Group (VEXAG)
- January 11–12, 2007; Crystal Gateway Marriott Hotel, Crystal City, Virginia

Major Items of the VEXAG Meeting Agenda:
- VEXAG Meeting #3 Objectives – Sushil Atreya & Janet Luhmann
- VEXAG Introduction – NASA Headquarters Overview / Expectations – Jim Green – NASA HQ
- VEXAG Inputs into NASA's Planetary Sciences Subcommittee – Sean Solomon – NASA PSS
- Overview of NASA Advisory Groups – Ray Arvidson – MEPAG; Sushil Atreya – OPAG; Steve Mackwell – LEAG
- Recap of NASA Strategic Plan Report – Ellen Stofan & Jim Cutts
- Overview of VEXAG Goals and Objectives – Janet Luhmann
- Mission architectures for Venus exploration – James Cutts & Tibor Balint
- Science Drivers & Technology Challenges for Long-Lived In-Situ Exploration of Venus – Tibor Balint and James Cutts
- Recap ESA's Venus Entry Probe Workshop and Cosmic Vision Proposal – Eric Chassefiere (presented by T. Balint)
- Status Report: ESA's Venus Express – Hakan Svedhem
- Messenger Flybys – Sean Solomon, Noam Izenburg, Ralph McNutt
- JAXA's Venus Climate Orbiter – Masato Nakamura and Takeshi Imamura
- NASA'S Discovery Candidate VESPER – Gordon Chin
- Recap of International Planetary Probes Workshop – Jim Cutts
- Chapman Conference Update – Larry Esposito
- Special Science Briefing – Venus Express VIRTIS Science Results – Pierre Drossart / Giuseppe Piccioni
- Education and Public Outreach – Rosalyn Pertzborn

- Open Mike Presentations 1-2 slides, up to 10 minutes
- Focus Group Splinter Session Previews and Reports
  - Overview of VEXAG Goals, Objectives, Investigations, & Priorities Document – Steve Mackwell & Kevin Baines
  - Confirm Goals and Objectives in VEXAG Document and review NASA Strategic Plan findings
    - Atmospheric Evolution Focus Group – Kevin Baines
    - Planetary Formation and Evolution Focus Group – Steve Mackwell
    - Technology for Venus In-Situ Exploration Focus Group – Jim Cutts

NASA’s 2006 SSE Roadmap:
Science Objectives for Venus Exploration

NASA’s 2006 SSE Roadmap mentions Venus 205 times throughout the document

Science Objectives	*Investigations and Measurements*
Question 2: How did the **Solar System evolve** to its current diverse state?	
Determine how the **processes** that shape planetary bodies operate and interact	Comparative studies of the **climate evolution** of Earth, Mars, and **Venus**.
Understand **why the terrestrial planets** are so **different** from one another	Study **Venus’ atmospheric chemistry** and **surface / atmosphere interactions**.
Question 3: 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 the **chemical and isotopic composition** of Venus’ **surface and atmosphere**.
Determine the **evidence for and age of an ocean** on the surface of **Venus**	Search for **granitic and sedimentary rocks**. Analyze the **mineral composition** of hydrated silicates and oxidized iron. Investigate the interplay of **volcanic activity and climate change**.
Question 4: How did **life begin and evolve on Earth** and has it evolved **elsewhere in the Solar System**?	
Search for **evidence for past life** on **Venus**	Search **Venus** samples for **chemical and structural signatures of life**.

Ref: NASA’s 2006 SSE Roadmap

Questionnaire on Potential Contributed Instruments

- This is a follow-up to inputs provided by Tommy Thompson during ESA's Venus Entry Probe Workshop - 19-20 January 2006, ESTEC, Noordwijk, Netherlands

- Assumes a **potential US contribution** would be the result of a Discovery or New Frontiers **Mission of Opportunity Proposal** in 2020 time frame
(note: MOO is currently at ~$35M)

- A questionnaire was distributed to the US Venus community with the following points:

1. *Contact Person (name, institution and contact information):*
2. *Instrument Name/Acronym:*
3. *Scientific purpose:*
4. *Basis of the Technique:*
5. *Main Advantages of the Method:*
6. *Main Measured Parameters and Expected Measurement Range:*
7. *Limitations:*
8. *Short Instrument Description:*
9. *Expected mass and power requirements:*
10. *Heritage of technique as applied to Venus:*
11. *Heritage of instrument development (other planets/missions):*
12. *Technical Readiness Level:*

NOTE: "Selection for implementation of these instrument/technology are subject to NASA approval via peer-reviewed proposal process."

Venus Exploration VEXAG Analysis Group

Venus Balloon Borne Magnetometer

1) Contact Person (name, institution and contact information):

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2) Instrument Name/Acronym:

Venus Balloon Borne Magnetometer

3) Scientific purpose:

Perform magnetic field measurements of possible crustal magnetic anomalies, their distribution and morphology. To determine the strength of the time variable field beneath the ionosphere and to use these signals to sound the metallic core of Venus.

4) Basis of the Technique:

Miniature boom mounted triaxial fluxgate magnetometer to perform in-situ measurements on an aerostat or balloon.

5) Main Advantages of the Method:

Measurements must be below the ionosphere in a 'cool' region of the atmosphere. Fifty km altitude or 1 bar pressure are ideal.

6) Main Measured Parameters and Expected Measurement Range:

- Vector magnetic fields ± 1000 nT, 3 orthogonal components
- Raw sampling rate: 1 sample/sec per component 50 bps.
- System error ± 0.1 nT
- Required sensor pointing knowledge with respect to inertial frame: +/-0.5 degrees (end-to-end).
- Required position knowledge error: +/-1 km with respect to reference body.

7) Limitations:

Mechanical deployment of boom may be necessary.

8) Short Instrument Description:

Triaxial fluxgate sensor assembly mounted at end of 1 to 2 meter boom or natural aerostat appendage. Card mounted in aerostat drives sensors. Selection for implementation of this instrument is subject to NASA approval via peer-reviewed proposal process.

9) Expected mass and power requirements:

- Estimated minimum boom length (or equivalent): 1-2 meters.
- Estimated mass (Sensor+electronics): 500 grams
- Estimated additional mass if independent unit (housing+power converter+ boom+cabling): 650 grams
- Estimated power consumption: 500 mW

10) Heritage of technique as applied to Venus:

Venus Express (MAG), Pioneer Venus Orbiter magnetometer

11) Heritage of instrument development:

UCLA provided PVO magnetometer and C. T. Russell is co-I on Venus Express.

12) Technical Readiness Level:

9

Selection for implementation of this instrument/technology is subject to NASA approval via peer-reviewed proposal process.

Venus Integrated Weather Sensor (VIWS) (1 of 2)

1) Contact Person (name, institution and contact information):

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2) Instrument Name/Acronym:

Venus Integrated Weather Sensor (VIWS) System Using Durable High Temperature Sensors and Electronics

3) Scientific purpose: **<u>In-Situ/Low-Altitude Systems/Landers - Instruments</u>**

The purpose of this instrument is provide the base technology to characterize the surface of Venus in-situ by simultaneously measuring pressure, temperature, wind velocity, seismic activities, and chemical species as well as local temperature and heat flux on the sur-face and above surface of Venus. Thus, this instrument provides weather and surface climate information from a system directly exposed to the environment and able to operate for extended dura-tions.

4) Basis of the Technique:

- NASA Glenn Research Center (GRC) is presently leading the development electronics and sensors capable of prolonged stable operation in harsh 500°C environments. Given the previous lack of electronics that could collect and transmit scientific data in Venus's scorching 450°C lower-atmosphere, almost all proposed missions to explore this impor-tant planetary environment have been based on very limited duration (on the order of hours) of data collection and return. The ability of a spacecraft (including its electronics) to function and return useful data for far longer time periods (months) would undoubtedly greatly improve the scientific return gained from Venus surface missions.
- For example, the recent emergence of wide bandgap semiconductors, including silicon carbide (SiC), diamond, and gallium nitride (GaN), has enabled short-term electrical de-vice demonstrations at temperatures from 500°C to 650°C [[1]]. Until recently however, these wide bandgap devices have demonstrated only a few minutes to a few hours of du-rability when electronically operated at these high temperatures. In order to support the needs of long-duration Venus surface operations, wide bandgap electronics technology must first demonstrate that it can achieve stable, long-term operation under electrical bias at 450°C temperature without significant changes in electrical operating parameters.

-Further, characterization of Venus surface conditions requires durable sensor technol-ogy which can operate in harsh environments. This sensor technology should be small, lightweight, low power consumption, and multi-parameter sensing capability. The advent of harsh environ-ment MEMS technology is enabling technology for new generation of Venus surface in-strumentation. A range of sensor technologies is available for measuring a number of parame-ters of interest in a potential Venus mission. Although technology development continues, a number of sensor systems have been tested in a range of high temperature en-gine applications often exceeding that of the Venus surface.

- NASA GRC is a world-leader in harsh environment electronics and sensor technology and is uniquely positioned to contribute to future Venus instrumentation systems. An overview of these capabilities can be found at reference [2]. Activities include:

-**High Temperature Electronics:** NASA Glenn has developed SiC-based transistor tech-nology (including packaging) that has demonstrated continuous electrical operation at 500°C for over 2000 hours [[3]]. No other reported semiconductor transistor has demon-strated such continuous prolonged electrical operation in an ambient comparable to or exceeding Venus atmospheric temperature. In contrast to other proposed high tempera-ture electronics approaches (such as miniature vacuum tubes), the NASA GRC SiC tran-sistor technology is inherently compatible with integrated circuit manufacturing tech-niques, so that increasingly complex electronics could be implemented on a single SiC chip. (Extended Laboratory Demonstration)

Atmospheric Physical Sensors: The basic technique is the utilization of the well known pie-zoresistive properties of silicon carbide (SiC) to sense pressure changes (absolute pressure sensor), wind velocity (cantilever based anemometer), and fully passivated resistance tem-perature differential sensor. These three functionalities are integrated on a single chip to make it a weather sensor chip. The high temperature operation (600oC) of SiC pressure sen-sor and anemometer has been previously demonstrated as separate discrete sensing devices [[4]-[5]]. On going research effort is geared toward integrating the three functionalities by the utilization of advanced SiC MEMS Microsystems technology. (Testbed Demonstration)

Atmospheric Chemical Sensors: NASA GRC has led the development of a MEMS based chemical sensor array (High Temperature Electronic Nose) for engine emission sensing applications. Sensors available, at varying levels of maturity, include carbon monoxide, sulfur dioxide, hydrocarbons, nitrogen oxides, and oxygen. The approach is to use platform technology which can be changed for the application to measure other gases as required [[6]]. (Engine testing)

Surface Condition Physical Sensors: Multifunctional thin film sensors have been devel-oped which can provide surface temperature, strain, and heat flux in a single MEMS based sensor [[7]]. This would enable monitoring of local thermal conditions embedded on a surface both to understand the surface conditions and also provide information on vehicle conditions. (Testbed Demonstration)

Venus Integrated Weather Sensor (VIWS) (2 of 2)

(cont.) Summary:

Therefore, this technology can very feasibly be incorporated into small and lightweight functional modules (without need for a cooling system), in order to help maximize science return while minimizing exploration vehicle size and weight. These multiple component technologies will be modularized on to a single platform. Thus, in a sin-gle system, measurements of pressure, wind velocity, temperature, chemical species, as well as strain and heat flux can be obtained. If funded, NASA GRC would focus on inte-grating even more reliable and complex high temperature electronics and sensors into a small functional module(s) to collect and transmit sensor data from the Venus surface for prolonged (as long as power can be supplied) durations.

5) Main Advantages of the Method:

The overall advantage of this approach is that using harsh environment electronics and sensors provide a multi-parameter weather and environment monitoring system able to operate in-situ in Venus environments. The range of information available is broad and can significantly contribute to understanding the Venus environment. These systems are MEMS based without the need for a cooling system and thus are small and lower in power consumption relative to conventional weather instruments. For example, the power consumption for the Atmospheric Physical Sensors is estimated to be 5-20 mW at these temperatures. Other advantages include the fact that these systems are meant for engine operation and so the near chemical inertness of the starting materials, esp. SiC, makes them highly resistant to chemical attack. Being small and lightweight allows high resolution, broad terrain coverage, or distribution using Venus wind as dispersal agent.

6) Main Measured Parameters and Expected Measurement Range:
Temperature (-40 to 600 oC), Pressure (0.05 to 100 bar); Wind speed (up to 400 mph); Chemical species (species dependent but standardly to ppm); Heat flux: very high heat fluxes up to 2.3 MW/m2.

7) Limitations: Piezoresistor strain sensitivity drops with temperature, hence may need amplification. Power is not presently addressed in this description but can be addressed.

8) Short Instrument Description:

The size of the system will vary depending on the sensor elements from above that are in-cluded. Example component: Atmospheric Physical Sensor is a single crystal silicon carbide cantilever beam about 8 mm long, 2.5 mm wide and 0.3 mm thick. One end contains bond pads for plug-in connection into a socket of a probe head.

9) Expected mass and power requirements:

Example component: Atmospheric Physical Sensor chip has a power consumption of between 5 and 20 mW). The dry mass of chip is less than 1 g.

10) Heritage of technique as applied to Venus:
Discrete functionalities have been demonstrated in environments harsher that Venus (Testing relevant to jet en-gine sections where temperature is > 500 °C)

11) Heritage of instrument development (other planets/missions):
None.

12) Technical Readiness Level:
The technical readiness level for Venus applications depends on the component but varies form TRL 2-6.

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[2]. http://www.grc.nasa.gov/WWW/sensors/

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[5]. R. S. Okojie, G. C. Fralick, G. J. Saad, C. A. Blaha, J. J. Adamczyk, and J. M. Feiereisen, "A Single Crystal SiC Plug-and-Play High Temperature Drag Force Transducer", Digest of Technical Papers for Transducers '03, The 12th International Conference on Solid State Sensors, Actuators and Microsystems, Boston, MA June 8-12, 2003. p 400-403 (IEEE Catalog Number 03TH8664C).

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[7]. "A Thin Film Multifunction Sensor for Harsh Environments," John D. Wrbanek, Gustave C. Fralick, Lisa C. Martin, Charles A. Blaha. NASA TM-2001-211075, AIAA–2001–3315 (July 2001).

V-fOx (Measure Oxygen Partial Pressure)

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2) Instrument Name/Acronym:

- V-fOx

3) Scientific purpose:

Measure Oxygen fugacity (partial pressure) in the Venus atmosphere and soil at the surface and in the lower atmosphere at ambient pressure and temperature.

4) Basis of the Technique:

- The oxygen sensor is a solid-state, solid electrolyte oxygen concentration cell (henceforth called a ceramic oxygen sensor). Ceramic oxygen sensors have been used to measure oxygen fugacity (partial pressure, fO2) in hot gases for nearly 50 years. They are currently used to measure the oxygen fugacity of molten metals such as Fe, Co, Ni, and Cu; of automotive exhaust gases, of gases in industrial and laboratory furnaces, and of terrestrial volcanic gases (e.g., at Etna, Kilauea, Kudryavyi, Merapi, and Momotombo).
- Ceramic oxygen sensors function over wide ranges of temperature (about 645-1873 K) and oxygen fugacity (fO2 = 10^{-35} to 1 bars). The operational range for a solid electrolyte is in the regime where (T-fO2) ionic conduction dominates electronic conduction. This range is known from literature data and overlaps the expected fO2 values for high temperature planetary environments (see Figure 1 below).

5) Main Advantages of the Method:

- V-fOx would be solid state, the sensor using laboratory proven technology. It requires little power and mass, has no moving parts, and provides an extremely important measurement for the study of atmospheric chemistry, geochemistry of Venus' surface, and surface-atmosphere equilibrium. It can be used on the surface and during descent.

6) Main Measured Parameters and Expected Measurement Range:

- Ceramic oxygen sensors function over wide ranges of temperature (about 645-1873 K) and oxygen fugacity (fO2 = 10^{-35} to 1 bars). The operational range for a solid electrolyte is in the T, fO2 regime where ionic conduction dominates over electronic conduction. This range is known from literature data and overlaps the expected fO2 values for high temperature planetary environments.

7) Limitations:

- Currently fO2 is the only gas the sensor can measure, but refinements or alterations for sulfur gases may be possible. Ceramic sensors may crack or break on impact on hard landers or penetrators. This limit needs to be tested, and can likely be overcome with alternate constructions and/or materials.

8) Short Instrument Description:

- The active part of the oxygen sensor is an oxide ceramic, such as doped zirconia (ZrO2) that conducts oxygen ions. A voltage (or electromotive force, EMF) is developed between the two sides of the solid oxide electrolyte that are exposed to different oxygen fugacities (fO2 = O2 partial pressure in bar). One side of the sensor is exposed to a sample with an unknown oxygen fugacity and the other side of the sensor is exposed to a reference oxygen fugacity. The potential differential gives the oxygen fugacity via the Nernst equation.

9) Expected mass and power requirements:

- The electronics package will consist of signal conditioning circuitry, an analog multiplexer, a 12-bit analog to digital converter, an 8-bit microcontroller, voltage regulation, an oscillator, and memory. Estimated power consumption is 400 mW and the estimated size is 4” x 4” x 2”. The electronics will be designed and assembled to survive +300°C and above. Initially, the electronics package will monitor three fugacity sensors and their respective temperatures. It will also monitor the environmental temperature and the internal temperature of the electronics. This will provide a method of monitoring the electronics during high temperature testing and provide a method of simultaneously evaluating sensor to sensor behavior.

Sensor and electronics for three Sensors:

Estimated mass: Under 400 grams

Estimated power consumption: 400 mW

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10) Heritage of technique as applied to Venus:

- Ceramic fO2 sensors have a multi decade history of laboratory operations at conditions near Venus surface temperature and pressure, including long-standing use in planetary atmospheres and thermodynamic experiments at Washington University in St. Louis.

11) Heritage of instrument development (other planets/missions):

- JHU/APL has seen dozens of planetary instrument developments through from initial concept to flight model construction to operations.

12) Technical Readiness Level:

- The sensor is TRL 4-5, with a rapid path to 6.

Supporting electronics are at 4 (using conventional technology) or 3 (for supporting dedicated high temperature electronics)

Selection for implementation of this instrument/technology is subject to NASA approval via peer-reviewed proposal process.

InSAR – Interferometric Synthetic Aperture Radar

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2) Instrument Name/Acronym:

InSAR – Interferometric Synthetic Aperture Radar

3) Scientific purpose:

- Map Surface elevation with vertical accuracies a few meters
- Detect Surface elevation changes on the order of centimetres
- Map surface radar reflectivity with horizontal resolutions of a few 10's of meters

4) Basis of the Technique:

Repeat-Pass Synthetic Aperture Radar Interferometry

5) Main Advantages of the Method:

- Only practical method of detecting surface change on the order of centimetres
- Provide accurate (a few meters vertical, a few 10's of meters elevation maps of the surface
- Map the surface through the clouds

6) Main Measured Parameters and Expected Measurement Range:

- Surface elevations to a few meters vertical, a few 10's of meters horizontal
- Changes in surface elevation on the order of centimetres
- Surface radar reflectivity to 1-2 db (+/- 20-60 %)

7) Limitations:

- Needs circular or near-circular (slightly) orbits with pericentres below about 500 km
- Needs precision orbit control to accomplish repeat-pass interferomtery

8) Short Instrument Description:

Radar Electronics Box with a Mesh Antenna (5-8 meters shared with Earth-Venus communications)

9) Expected mass and power requirements:

Mass – 40-80 Kg – Less mass if in lower orbit and/or single-string

Power – 200-440 watts when operations (1/4 -> 1/2 orbit) – 15 watts stand-by

10) Heritage of technique as applied to Venus:

Magellan, Venera and Pioneer-Venus radars

11) Heritage of instrument development (other planets/missions):

Terrestrial – Shuttle Imaging Radars (SIR), Shuttle Radar Topography Mission (SRTM),

European Remote Sensing Satellite (ERS), Japanese Remote Sensing Satellite (JERS)

Magellan (S-Band SAR at Venus, Cassini (K-band SAR at Titan)

12) Technical Readiness Level:

6-7

13) Caveat:

To be selected through a NASA peer review process for a Mission of Opportunity ($30-50M, FY06 $'s)

Venus Radar Sounder

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2) Instrument Name/Acronym:

Venus Radar Sounder

3) Scientific purpose:

To probe the upper 1-3 km of the Venus crust and reveal subsurface layering linked with geologic processes such as impact cratering, volcanism, and tectonism.

4) Basis of the Technique:

Radar sounding uses low-frequency (1-5 MHz) radio signals to penetrate long distances into rock and sediment. Uses a long (30-40 m) dipole antenna to illuminate the surface. Onboard processing limits the returned data to only those echoes from close to the spacecraft nadir track.

5) Main Advantages of the Method:

Radar sounding is the only method that can characterize the upper crust of Venus, at high vertical and horizontal spatial resolution, from orbit (gravity measurements limited to spatial resolution similar to orbital altitude). Radar sounder has horizontal footprint of order 5 km, vertical resolution in rock ~50 m.

6) Main Measured Parameters and Expected Measurement Range:

Radar echo complex voltage as a function of time after pulse transmission. Range of values dictated by analog-to-digital converter; typically 50-60 dB system dynamic range. Pointing requirements modest, as dipole antenna pattern very broad.

7) Limitations:

Ionospheric interaction will limit subsurface probing to night-side operations (solar zenith angles of 120 degrees or more). Loss tangent of surface material may be higher due to elevated temperature, but probing to 1 km appears feasible in high-loss scenario.

8) Short Instrument Description:

Low-frequency radar transmitter and receiver, antenna matching network, and deployable dipole antenna similar to MARSIS.

9) Expected mass and power requirements:

Similar to MARSIS.

10) Heritage of technique as applied to Venus:

No previous application at Venus.

11) Heritage of instrument development (other planets/missions):

Successfully employed for Moon (ALSE) and Mars (MARSIS).

12) Technical Readiness Level: Flight heritage from MARSIS. Subsystems may be TRL 6-9 for system optimized to Venus sounding.

"Selection for implementation of this instrument/technology is subject to NASA approval via peer-reviewed proposal process."

Venus Glider (1 of 2)

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2) Instrument Name/Acronym: VENUS GLIDER

3) Scientific purpose:

Actively controlled glide of an atmosperic sonde permits rapid (≈ 10 min.) dive through high and mid altitudes of Venus' atmosphere to allow more science data collection time at low altitude and on the surface before heat-soak terminates the mission. Alternatively, actively controlled glide can be used to increase descent time (≈ 5 hr.) at cooler high and mid altitudes with a resulting cross-range glide of from 0 to 100 km from atmospheric entry point. Unpowered glide in the surface Hadley cell (altitude ≤ 25 km) permits high resolution nested and/or stereo imaging of extended geological units. Gliding under control of inertial guidance permits significant improvement in sonde targeting accuracy relative to previous missions (i.e., precision landing).

4) Basis of the Technique:

An aerodynamically tailored Titanium-skin airframe is wrapped around a conventional sonde pressure vessel (e.g., Titanium sphere) and used to fly the sonde to Venus' surface. The airframe planform is chosen to fit efficiently inside a conventional 450 half-angle sphere-cone entry vehicle and provide adequate lift, drag, and stability properties. A blended wing-body delta-wing planform, for example, has been shown by analysis to serve this purpose, although other planforms are under study and may prove more optimal. The bottom half of the pressure vessel protrudes from the bottom of the glider to enable data collection in flight and on the surface (see figures). In non-lifting flight (i.e., a vertical dive) the airframe will produce a reduction in the drag coefficient (relative to a spherical sonde) by a factor of ≈ 4, and therefore reduce the time to reach the surface by a similar factor, thus providing more useful lifetime on or near the surface. If the airframe is used to generate lift in steady-state glide, a lift-to-drag (L/D) ratio of ≈ 4 is expected. Although this L/D ratio is small by terrestrial aircraft standards, it is adequate for flight inVenus' reduced gravity field and thicker atmosphere. Unlike a Mars airplane, large wing areas and high speeds are not required to generate adequate lift, and the wings do not need to be folded to fit inside the entry vehicle. This L/D ratio may be exploited for an actively directed flight path of from 0 to 100 km, horizontal from the point of entry. Horizontal and vertical flight segments may be combined in any combination to serve the needs of the science investigations planned. For example, a long duration steady-state horizontal glide immediately after separation from the entry vehicle could allow a long glide (≈ 5 hr) for atmospheric structure and chemistry measurements. Alternatively, an altitude ≈ 5 km above the surface could be reached in ≈ 10 minutes by a vertical dive. If the dive is followed by a pull-up maneuver to place the vehicle in a descending glide at a velocity of ≈ 10 m/s, a horizontal ground track of ≈ 20 km can be reached before landing. A soft landing would be effected by pitching the nose of the vehicle up into a deep stall, producing a touchdown velocity of ≈ 2 m/s. Control of the vehicle may be effected by 2 split-flap flaperons on the trailing edge of the airframe. When acting differentially, they produce primarily a roll moment. When acting collectively, they produce primarily a pitch moment. (Because very simple and slow maneuvers are planned, independent yaw control for highly coordinated accelerated turns is not required). When upper and lower flap panels are split, they function as drag brakes.

5) Main Advantages of the Method:

All previous atmospheric sondes at Venus have been passively controlled, high-drag aerodynamic shapes (e.g., the Venera sphere and-flat-plate drag stabilizer; the Pioneer Venus sphere-cone entry vehicle). Previous sonde designs result in relatively invariant descent time (≈ 1 hr.) determined entirely by atmospheric density profile, and invariant impact velocity (≈ 10 m/s). Previous sonde designs result in landing zone determined entirely by atmospheric entry error and wind profile at time of entry. Proposed method allows mission designers to choose wide range of descent times, precision soft landing, significant cross range (≈ 20 km) at low altitude and extended life near or on the surface.

6) Main Measured Parameters and Expected Measurement Range:

- Winds aloft from separation altitude (≈ 40 km) to surface.
- Atmospheric chemistry, opacity from separation altitude to surface.
- Nested, high resolution descent imagery over ≈ 20 km horizontal track.
- Surface regolith elemental and mineralogical characteristics at selected landing site.

Venus Glider (2 of 2)

7) Limitations:

To employ this technique, the glider, the entry vehicle, and the sonde must be designed as an integrated set. Lifetime at altitudes < 5 km ≈ 1.5 hr.

8) Short Instrument Description:

This is not a science instrument, *per se,* except to the extent that an actively controlled glider can be used to resolve atmospheric structure and winds aloft. (These data products will be generated automatically by the autopilot). This is an instrumentation delivery system which will enable increased quality and, in some cases unique, science investigations.

Examples:

- Instruments performing surface elemental or compositional analysis (mass spectrometer, XRDF, APX, etc.) which require a sample of surface material to be acquired from the surface could be placed on a specific geological unit via precision landing.
- A high resolution descent imagery data set from 5 to 0 km altitude and 20 km cross-track could be generated, which would increase by orders of magnitude the quantity of such descent imagery currently in existence.
- Horizontal variability of atmospheric structure and chemistry could be investigated *in-situ*, for the first time.

9) Expected mass and power requirements:

An integrated sonde, airframe, and entry vehicle system can be designed in the mass range from 100 to 300 kg. During cruise, stay-alive power of ≈ 20 W may be required. During descent, glider would be self powered.

10) Heritage of technique as applied to Venus:

The sonde (pressure vessel) and entry vehicle are direct heritage from Pioneer Venus Large Probe, developed by NASA-Ames Research Center. The airframe would be a new development.

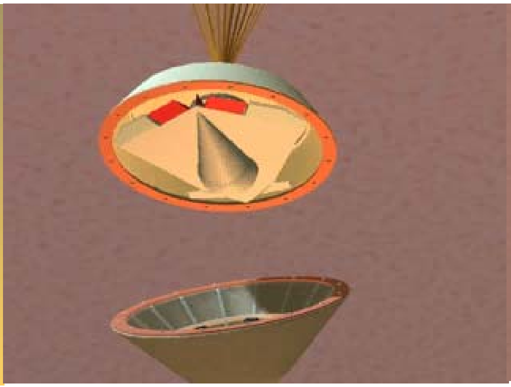
11) Heritage of instrument development (other planets/missions):

Concept is extension of lessons learned from numerous Mars Airplane mission designs conducted by NASA-Ames Research Center from 1996 to 2006.

12) Technical Readiness Level:

Entry vehicle and sonde are TRL=9. High temperature airframe is TRL = 3.

Cutaway View of Glider in Entry Vehicle.



Separation of Entry Vehicle from Fore-Body.

Glider Separating From Entry Vehicle; Pressure Vessel Exposed on Under Side.

Glider Executing Landing Flare.

Selection for implementation of this instrument/technology is subject to NASA approval via peer-reviewed proposal process.

Venus Airplane (1 of 2)

1) Contact Person (name, institution and contact information):

Geoffrey A. Landis, NASA John Glenn Research Center, geoffrey.a.landis@nasa.gov

Anthony Colozza, Analex Corporation, Anthony.Colozza@grc.nasa.gov

2) Instrument Name/Acronym:

Venus Airplane

3) Scientific purpose:

Solar-Powered Airplane to explore the atmosphere of Venus

4) Basis of the Technique:

Conceptual design for a solar powered airplane to support a Venus atmospheric mission.

5) Main Advantages of the Method:

Powered airplanes have the advantage of being able to operate at a specified location in the Venus atmosphere, rather than drifting with the wind. For example, this could be used to correlate atmospheric measurements at specific locations at the same time.

6) Main Measured Parameters and Expected Measurement Range:

Design for operation at the Venus cloud tops.

7) Limitations:

Conceptual design.

8) Short Instrument Description:

We analyzed a conceptual design for a small solar-powered airplane to operate above the Venus cloud deck. A requirement was that the airplane must be able to move faster than the local windspeed, in order to remain at or near the subsolar point to remain in sunlight.

9) Expected mass and power requirements:

(depends on details of mission) baseline mass: 103 kg

baseline power: 2500 watts

10) Heritage of technique as applied to Venus:

Not yet flown on Venus.

11) Heritage of instrument development (other planets/missions):

Continues work on Mars airplane development and on solar airplane design and operation in the Earth's atmosphere.

12) Technical Readiness Level:

TRL 3. "Selection for implementation of this instrument/technology is subject to NASA approval via peer-reviewed proposal process."

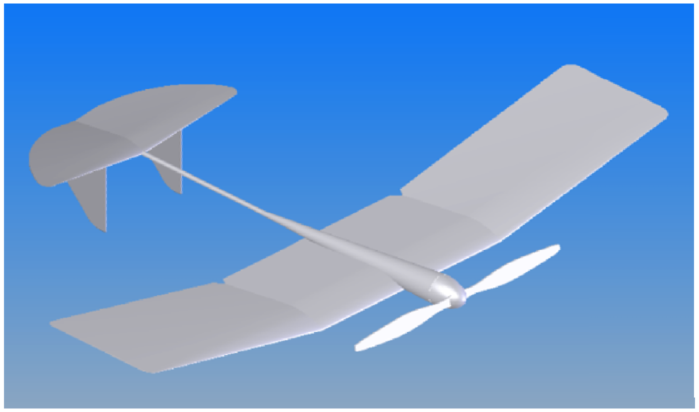
Venus Airplane (2 of 2)

- The evolution of the Venus airplane design has been documented in a number of papers:

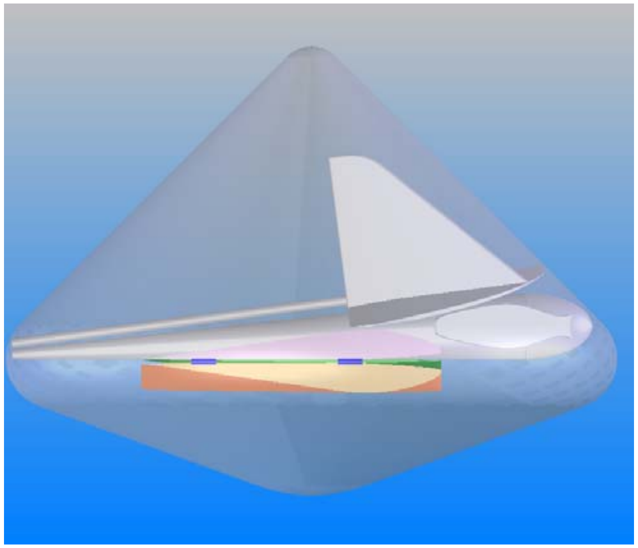
- G. Landis, "Exploring Venus by Solar Airplane," presented at the STAIF Conference on Space Exploration Technology, Albuquerque NM, Feb. 11-15, 2001. *AIP Conference Proceedings Volume 552*, 16-18.
- G. Landis, C. LaMarre and A. Colozza, "Atmospheric Flight on Venus: A Conceptual Design," *Journal of Spacecraft and Rockets, Vol 40,* No. 5, 672-677 (Sept-Oct. 2003).
- G. Landis, C. Lamarre, and A. Colozza, "Venus Atmospheric Exploration by Solar Aircraft," *Acta Astronautica, Vol. 56,* No. 8, April 2005, 750-755. (Paper IAC-02-Q.4.2.03)
- A. C. Colozza, "Solar Powered Flight on Venus," NASA CR-2004-213052, April 2004.

- Design flight altitude is 70 km. The airplane can fly above or below this altitude to explore deeper or higher atmospheric layers, but returns to this altitude for optimum cruise speed. The wingspan is 9 meters (deployed), folding to 3 meters. A significant design factor is the ability of the aircraft to be folded into an aeroshell and deployed into the Venus atmosphere. A folding and deployment system has been demonstrated and tested for the ARES Mars aircraft design, showing complete deployment and subsequent transition to controlled flight. The Venus design is similar. The denser atmosphere of Venus makes the deployment simpler. To fit into the aeroshell for entry, the wing folds at two places. The fuselage also folds, to bring the horizontal tail over the wing. The folding was designed to fit the aircraft into an entry body based on either the Mars Pathfinder aeroshell or the Pioneer-Venus entry probe aeroshell..

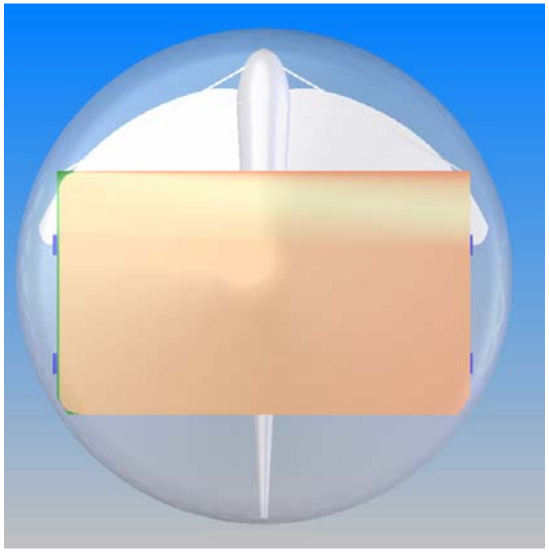
Attached are views of the most recent evolution of the airplane design



Venus Airplane: perspective view



Venus airplane folded into aeroshell: side view



Venus airplane folded into aeroshell: top view

By T. Balint, J. Cutts, T. Thompson, K. Baines, E. Stofan – January 17, 2007

Venus Dual-Wing Balloon Guidance System / DBGS

1) Contact Person (name, institution and contact information):

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626-345-1200

2) Technology Name/Acronym:

Venus Dual-wing Balloon Guidance System / DBGS

3) Scientific purpose:

Enable horizontal path guidance control for Venus balloons with possibilities of targeted overflight of surface sites and extended latitudinal range of operations.

4) Basis of the Technique:

The DBGS consists of a glider-like aerodynamic structure (the wing) attached to the balloon gondola by a very long (several kilometers) lightweight tether. The balloon floats with the zonal atmospheric flow and drags the DBGS below and behind it. The difference in the wind speeds at the latitude of the balloon and the DBGS creates relative wind about the DBGS. DBGS generates lifting forces in the relative winds, which can be used to "pull" the whole system (the balloon and the DBGS) in the horizontal direction perpendicular to the direction of the prevailing zonal winds. This enables "steering" of the balloon system. As the balloon is being carried around the planet by the zonal winds, it can be nudged northward or southward continuously to change the latitude of the balloon. Path guidance capabilities in the latitudinal direction combined with the zonal winds enable overflight of any surface site on the planet with a single balloon. A dynamically scaled single wing balloon guidance system designed for Earth has been successfully flight-tested proving the basic concept feasibility. Because of the high atmospheric density and strong wind gradients with altitude, Venus is an ideal planet for the operation of this technology.

5) Main Advantages of the Method:

- DBGS uses the power of the winds to control the path of a Venus balloon. Minimal levels of power are needed to control the attitude of the wing – the forces used in "steering" the balloon are generated by the aerodynamic surfaces of the DBSG in the atmospheric winds. Hence the whole system can be much lighter than an alternative active propulsion system. Alternative propulsion methods for planetary balloons (propellers) require large levels of power to overcome the drag forces acting on the balloon surface as it is being moved relative to ambient flow. As the drag force grows as the square of the balloons velocity, the required power levels for meaningful atmospheric trajectory control grow exponentially. The mass of the propulsion system also grows exponentially with increasing requirements on trajectory control velocity.
- Estimates show that DBGS is capable of providing control velocities of 2-6 m/s for wind shear observed at Venus. Higher wind shear produces higher control velocity. These levels of control velocities may be sufficient to overcome the meridional winds and enable directing the balloon to fly over any site on the surface of the planet.
- DBGS can be inflatable or made of lightweight materials resistant to Venus atmospheric environment. The long tether made out of strong polymer fiber would have masses of 1 to 2 kilograms.

6) Main Measured Parameters and Expected Measurement Range: N/A

7) Limitations:

- Operation of DBGS requires mechanical deployment on a long tether from stowed configuration.
-The level of control velocity produced by the DBGS depends on the wind shear between the altitudes of the balloon and the DBSG wing, which is expected to be large at Venus for reasonable tether lengths.

8) Short Instrument Description:

A glider-like aerodynamic structure (dual-wing) attached to the balloon gondola by a very long (4-6 km) lightweight tether. DBGS wing is released from below the gondola upon completion of balloon inflation and stabilization at floating altitude. DBGS-generated control forces are controlled by changing the attitude of the DBGS wing via actuators at the DBGS wing. DBGS receives control commands from Venus balloon onboard computer via radio link.

9) Expected mass and power requirements:

- Estimated DBGS wing mass: 10 kg
- Estimated DBGS power consumption (averaged): 100 mW

10) Heritage of technique as applied to Venus:

Balloons have been flown in the atmosphere of Venus. Incorporating guidance technology to future Venus balloons that carry targeted payloads and/or measurements are the next logical step in Venus exploration by balloons.

11) Heritage of instrument development (other planets/missions):

Aerodynamically scaled model and prototype for Earth stratospheric balloons developed by Global Aerospace Corporation under NASA funding.

12) Technical Readiness Level:

5-6 for Earth applications, 4 for Venus application.

Metal Balloon for the Low Atmosphere of Venus (MEBALAV)

1) Contact Person (name, institution and contact information):

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Pasadena, CA 91109, USA. E-mail: Viktor.V.Kerzhanovich@jpl.nasa.gov

2) Instrument Name/Acronym:

Metal Balloon for Low Atmosphere of Venus (MEBALAV)

3) Scientific purpose:

Provide mobile platform for in situ studies of the Venus surface and surface-atmosphere interactions or use as the first stage balloon for Venus Sample Return mission

4) Basis of the Technique:

Metal bellows inflated with light gas during descent. Light gas provides necessary buoyancy.

Mechanical device or heat from RTG source used for buoyancy modulation and altitude change. Propeller and aerodynamic lift can be utilized for trajectory control

5) Main Advantages of the Method:

Metal balloons tolerate high temperature of the low atmosphere of Venus and have practically unlimited lifetime. They combine advantages of proximity to the surface with vast surface coverage. Even a free drifting balloon may traverse 40-80 km per 24 hours with weak near-surface winds of 0.5-1 m/s and several hundreds of kilometres at the 10 km altitude.

6) Main Measured Parameters and Expected Measurement Range:

Metal balloons use advantage of high density in the lower atmosphere of Venus. Their practical range is from surface to approximately 15 km altitude.

7) Limitations:

Practical range for metal balloons is 0-15 km. Altitude can be modulated within several hundreds of meters or more.

8) Short Instrument Description:

Metal balloon with attached payload, buoyant and inflation system will be delivered inside an entry vehicle into the atmosphere of Venus. The metal bellows balloon will be inflated with either light gas (hydrogen, helium, ammonia or water vapour) during the initial descent. Inflation tanks will be jettisoned upon completion of inflation and balloon with attached payload will ascend to nominal cruise altitude where science investigations begin. There are different balloon payload operation scenarios that can be adjusted to maximize science return.

9) Expected mass and power requirements:

Mass of bellows depends on payload mass. For example, a metal bellows made from stainless steel and filled with helium may carry 100 kg payload at 1 km above the surface of Venus.

Additional mass is required for light gas and its storage.

10) Heritage of technique as applied to Venus:

Balloon inflation during descent has been validated by VEGA balloon missions in 1985.

11) Heritage of instrument development (other planets/missions):

Metal bellows technology was developed for other applications. The bellows was tested successfully at temperature of 460 C – temperature near the Venus surface.

12) Technical Readiness Level:

5 – for metal bellows component (validated in relevant environment)

Reference:

V.V. Kerzhanovich, A.H.Yavrouian, J.L.Hall and J.A.Cutts. Dual Balloon Concept For Lifting Payloads From The Surface Of Venus. Paper presented at AIAA Balloon Technology Conference, Washington, Sep 2005.