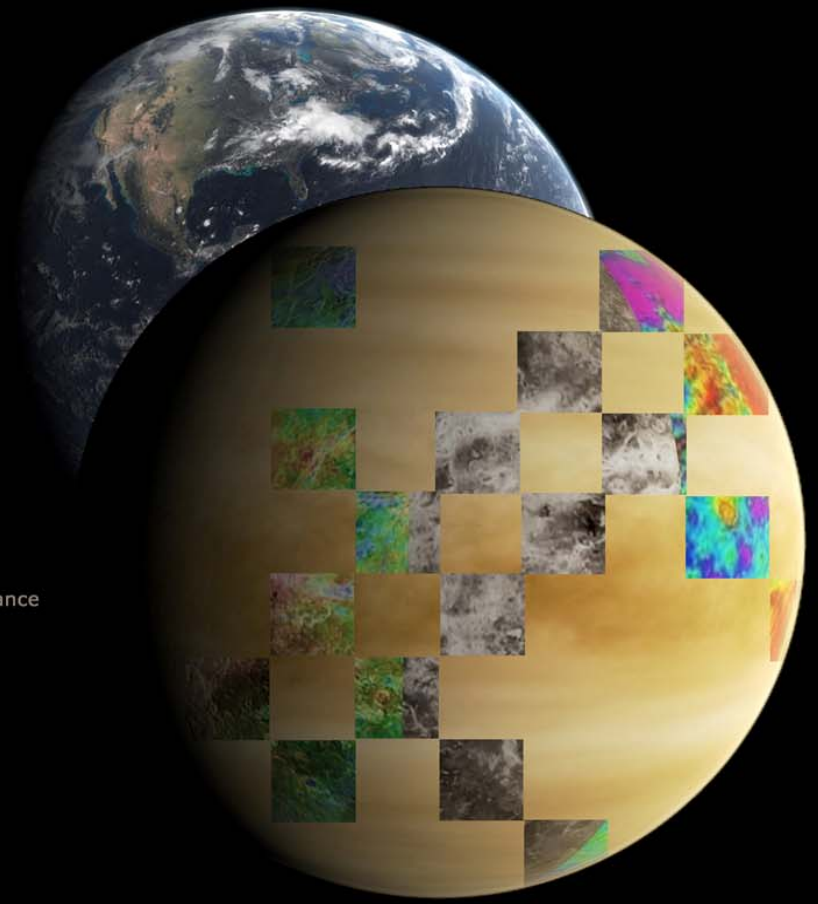
National Aeronautics and Space Administration

JPL

A Venus Flagship Mission: Exploring a World of Contrasts

D. Senske (1), M. Bullock (2), T. Balint (1),
A. Benz (1), B. Campbell (3), E. Chassefiere (4),
A. Colaprete (5), J. Cutts (1), L. Glaze (6),
S. Gorevan (7), D. Grinspoon (8), J. Hall (1),
G. Hashimoto (9), J. Head (10), G. Hunter (11),
N. Johnson (6), W. Kiefer (12), E. Kolawa (1),
T. Kremic (13), J. Kwok (1), S. Limaye (14),
S. Mackwell (12), M. Marov (15) , C. Peterson (1),
G. Schubert (16), T. Spilker (1), E. Stofan (17),
H. Svedhem (18), D. Titov (19), A. Treiman (12)

(1) Jet Propulsion Laboratory, California Institute of Technology, MS 301-350, 4800 Oak Grove Dr., Pasadena, CA 91109, USA
(2) Southwest Research Institute, 1050 Walnut St., Suite 300, Boulder, CO 80302, USA
(3) NASM, PO Box 37012, MRC 315, Washington, DC 20013-7012, USA
(4) CNRS Service d'Aéronomie, Route des Gatines BP 3 FR 91371, Verrieres Buisson, France
(5) NASA Ames Research Center, Moffett Field, Mountain View, California 94035, USA
(6) NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA
(7) Honeybee Robotics, 460 W. 34th Street New York, NY 10001
(8) Denver Museum of Nature & Science, 2001 Colorado Blvd Denver, CO 80205
(9) Kobe University, Nada, Kobe 657-8501, JAPAN
(10) Brown University, Box 1846, Providence, RI 02912 USA
(11) NASA Glenn Research Center, 21000 Brookpark Road Cleveland, OH 44135
(12) Lunar and Planetary Institute, 3600 Bay Area Blvd. Houston, TX 77058
(13) NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA
(14) University of Wisconsin, 1225 West Dayton Street, Madison, WI 53706
(15) Keldysh Institute, Miusskaya pl 4 RU 125047 Moscow Russian Federation
(16) UCLA, 603 Charles E. Young Drive, Los Angeles, CA 90095-1567,USA
(17) Proxemy Research, Rectortown, VA 20140, USA
(18) ESA ESTEC, Keplerlaan 1 Postbus 299 2200 AG Noordwijk, The Netherlands
(19) Max Planck Institute, Max-Planck-Str. 2 37191 Katlenburg-Lindau, Germany



AGU Fall Meeting - San Francisco - 12.16.2008

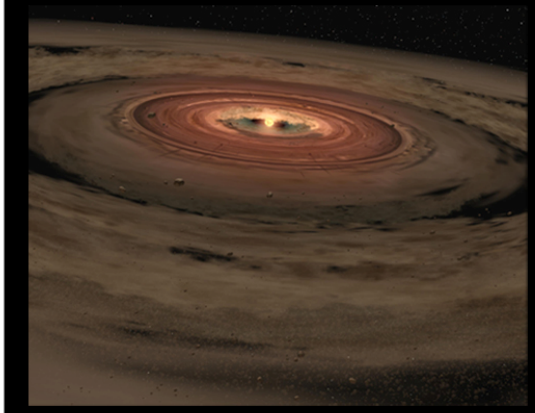
Venus Flagship Mission Assumptions

• Launch Years	2020 to 2025
• Technology Maturation	TRL 6 by 2015
• Life Cycle Mission Cost Range	$3 - 4B (FY ’08)
• LV Capability	≤ Delta IVH equivalent
• DSN Capability	up to 34M, Ka band
• International Contribution	No foreign cost contribution

Pre-decisional – for discussion purposes only

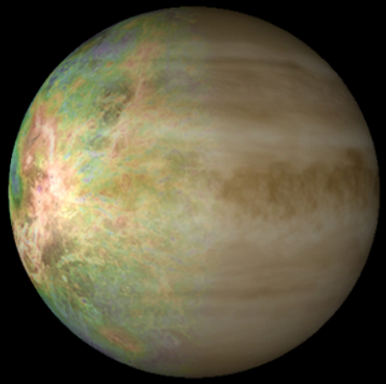
Venus Exploration Goals and Objectives

Goal 1:
Origin and Early Evolution of Venus:
How did Venus originate and evolve?



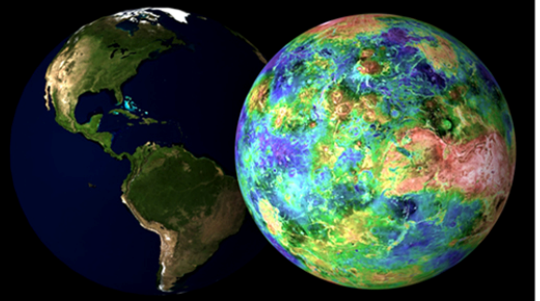
- *Determine isotopic composition of atmosphere*
- *Map the mineralogy and composition of the surface on a planetary scale*
- *Characterize the history of volatiles in the interior, surface and atmosphere*
- *Characterize the surface stratigraphy of lowland regions and the evidence for climate change*
- *Determine the ages of various rock units on Venus*

Goal 2:
Venus as a terrestrial planet:
What are the processes that have and still shape the planet?



- *Characterize and understand the radiative balance of the Venus atmosphere*
- *Investigate the resurface history and the role of tectonism, vulcanism, impact, erosion and weathering.*
- *Determine the chronology of volcanic activity and outgassing*
- *Determine the chronology of tectonic activity*
- *Investigate meteorological phenomena including waves, tides, clouds, lightning and precipitation.*

Goal 3:
What does Venus tell us about the fate of Earth's environment?



- *Search for fossil evidence of past climate change in the surface and atmospheric composition.*
- *Search for evidence of changes in interior dynamics and its impact on climate*
- *Characterize the Venus Greenhouse effect and its similarities to those on Earth and other planets*

Venus Exploration VEXAG Analysis Group

The Past → **The Present** → **The Future**

The Team used the **Science Goals & Objectives from the VEXAG White Paper**

Ref: VEXAG White Paper, 2007

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Venus Flagship Science Themes & Objectives

Why is Venus so Different from Earth?

Science Theme	Science Objective
What Does the Venus Greenhouse tell us about Climate Change?	Characterize the dynamics, chemical cycles, and radiative balance of the Venus atmsphere
	Place constraints on the evolution of the Venus atmosphere
How Active is Venus?	Identify evidence of active tectonism and volcanism and place constraints on evolution of tectonic and volcanic styles
	Characterize the structure and dynamics of the interior and place constraints on resurfacing
	Place constraints on stratigraphy, resurfacing and other geologic processes
When and where did the water go?	Identify evidence of past environmental conditions, including oceans
	Characterize geologic units in terms of chemical and mineralogical composition of the surface rocks in context of past and current environmental conditions

Why is Venus so different from Earth?

- **What does the Venus greenhouse tell us about climate change?**
  - Did Venus diverge from an early Earth-like state?
  - How is the climate forced by the Sun and influenced by clouds?
  - How do the surface and atmosphere interact chemically?
- **How active is Venus?**
  - Is Venus currently geologically active?
  - What caused the extensive resurfacing of Venus during the last Gy?
  - What is the nature of Venus' magnetic field, if any?
- **When and where did the water go?**
  - Was there ever an ocean on Venus, and if so, when did it exist and how did it disappear?
  - Did conditions for life or life in some form ever exist on Venus?
  - How does the upper atmosphere interact with space environment?

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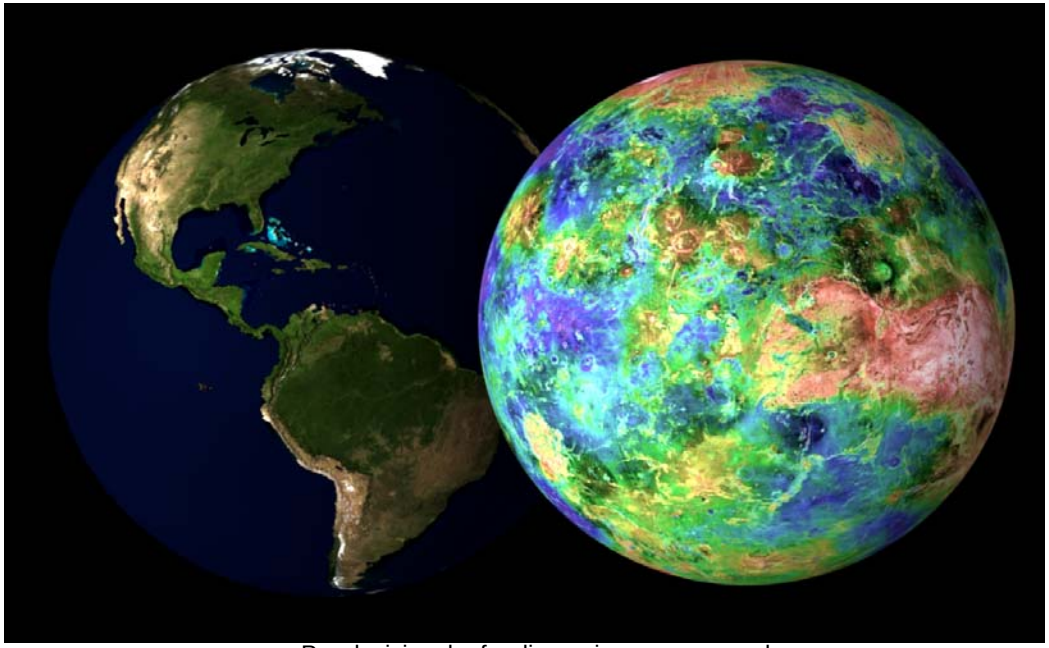
Habitability of Earth & Terrestrial Planets Around Other Stars

- We will not be able to understand observations of terrestrial planets around other stars without understanding Venus.
- The formation and evolution of potentially habitable planets around other stars will require study of Earth, Mars, and Venus.
- The study of Venus has deepened and broadened the study of the Earth



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Flowchart for the VSTDT FOM Process

- Figure of Merit (FOM) combines
  - Science ranking
  - Technology ranking
  - Mission architectures by costs

Assessment of Mission Architecture Concepts

Calibrate Rapid Cost Estimation for (13) Architecture Elements

Rapid Costing for Representative Mission Architecture Concepts

Venus STDT Assessment

Science
VEXAG Goals, Objectives, & Measurements

Map Investigation to Instruments & Arch. Elements

Technology
EE Technologies & Instrument Tec

Rate Technologies for Arch. Elements for Criticality & Maturity

Science FOM for Investigations & Mission Architectures

Technology FOM Criticality / Maturity For Arch. Elements

Assess Figure of Merit (FOM) for 17 Flagship Mission Architectures (from Science Score & Cost & Technology Score)

Science Subgroups To Recommend Desired Flagship Mission Architecture Concepts

Redefine Flagship Class Mission Architecture Concept, Endorsed by the Science Subgroups

4/9/08

Phase 2:
Proceed With Recommended Mission Architecture(s)

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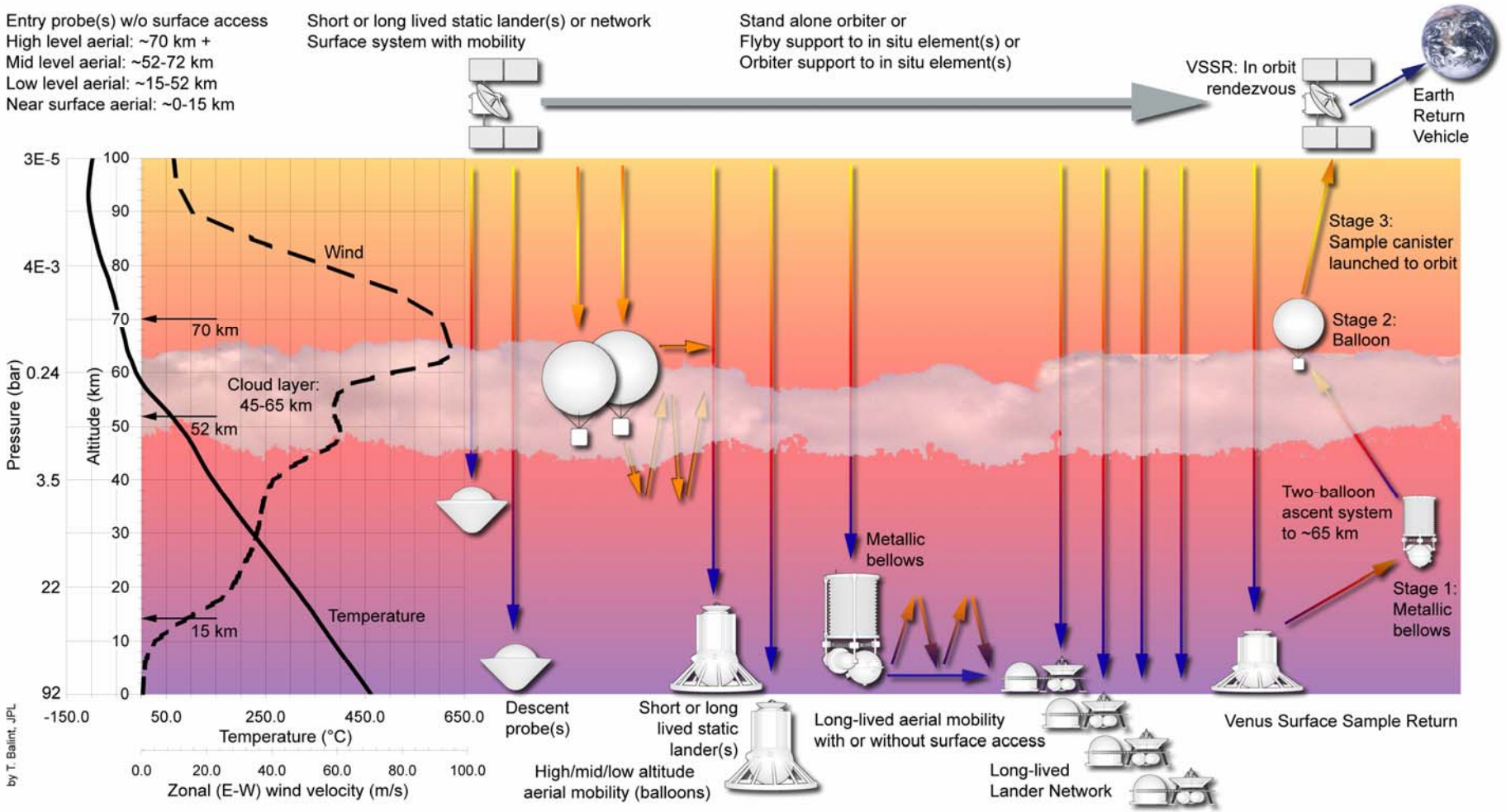
Venus Mission Architecture Elements

Get rid of small words



Mission architectures were constructed from these elements

Definition of 13 Architecture Elements

Architectural Element	Description
Orbital	Low circular science orbit capable of large science payload
Aerial - High	Platform above the clouds > 70 km (weeks)
Aerial - Mid	Platform within clouds, about VEGA balloon altitude. 52-70 km (weeks)
Aerial - Low	Platform below the clouds 15-52 km (weeks)
Aerial Near-Surface	Platform between 0-15 km and surface (days to weeks)
Single Entry Probe	No surface science is included (hours)
Multiple Entry Probes	No surface science is included (hours)
Short-lived Lander (Single)	May include long lived components under ambient conditions (hours)
Short lived lander (Multiple)	May include long lived components under ambient conditions (hours)
Long-lived lander (Single)	(Several weeks)
Long-lived lander (Multiple)	(Several weeks)
Surface System with Mobility	0-5 km altitude Traverse (Several days to weeks)
Coordinated Atmos. Platforms	Multiple small aerial vehicles. (Several days to weeks)

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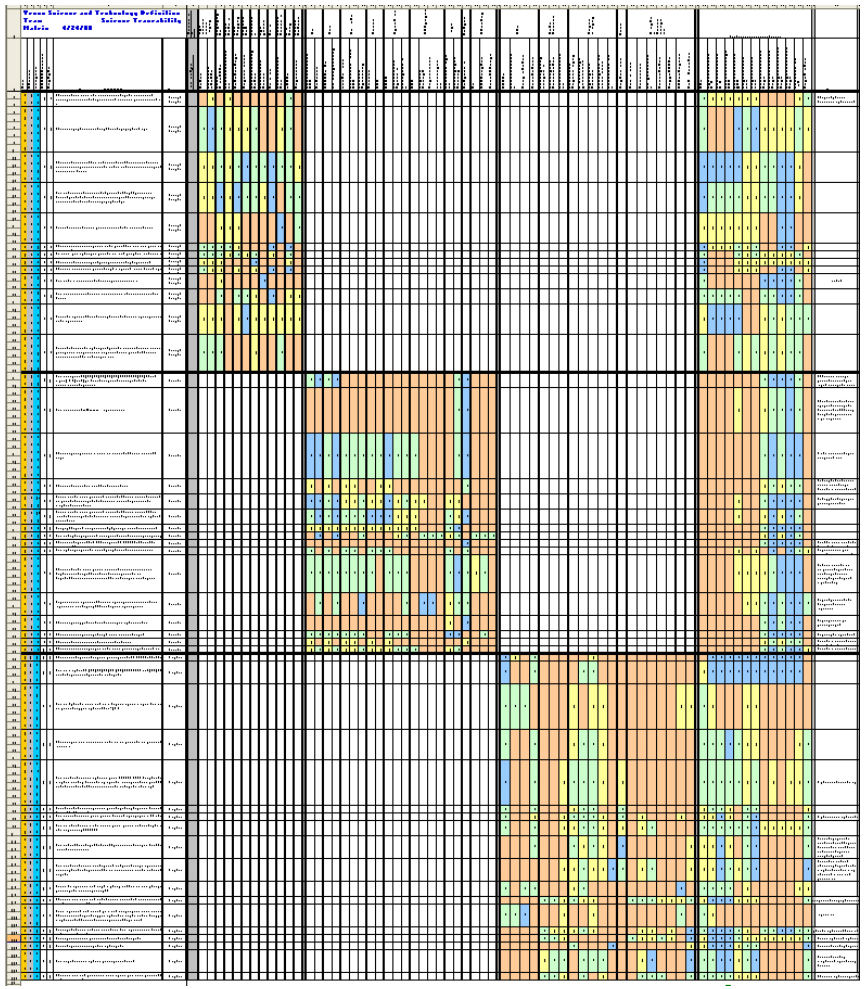
Science Traceability Matrix

Investigations | Measurement Technique & Instrument type | Architecture Element



Geology & Geophysics subgroup

Atmospheres subgroup

Geochemistry subgroup

Priorities

Flagship Priority Scoring (Column E)

1 = Essential to have
2 = Highly Desirable
3 = Desirable
4 = Very Good to have

Instrument & Platform Goodness Scores

- Directly answers
- Major contribution
- Minor contribution or supporting observations
- Dees not address

FY08 Venus Flagship Study Interim Briefing to NASA HQ by the Venus STDT & Study Team, May 9, 2008

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Science Traceability: Identification of Instruments

Science Theme	Science Objective	Instrument type	Observation Platform
What Does the Venus Greenhouse tell us about Climate Change?	Characterize the dynamics, chemical cycles, and radiative balance of the Venus atmsphere	Vis-NIR Imaging Spectrometer	Orbiter
		Sub-millimeter sounder	Orbiter
		Langmuir probe	Orbiter
		Atmospheric Structure (P/T/winds/accel)	Balloon, Lander (on descent)
		Nephelometer	Balloon, Lander (on descent)
		Net Flux Radiometer	Lander (on descent)
		Radio (with USO)	Balloon
	Place constraints on the evolution of the Venus atmosphere	Neutral and Ion Mass Spectrometer (INMS)	Orbiter
		GC/MS	Balloon, Lander (on descent)
How Active is Venus?	Identify evidence of active tectonism and volcanism and place constraints on evolution of tectonic and volcanic styles	InSAR	Orbiter
		Radio (with USO)	Orbiter
	Characterize the structure and dynamics of the interior and place constraints on resurfacing	Magnetometer	Orbiter, Balloon, Lander
		Heat flux plate	Lander
		Seismometer	Lander
	Place constraints on stratigraphy, resurfacing and other geologic processes	Vis-NIR camera	Balloon, Lander (on descent)
When and where did the water go?	Identify evidence of past environmental conditions, including oceans	GC/MS	Balloon, Lander (on descent)
	Characterize geologic units in terms of chemical and mineralogical composition of the surface rocks in context of past and current environmental conditions	Microscopic Imager	Lander
		XRD/XRF	Lander
		Passive Gamma-ray detector	Lander
		Drill and sample acquisition, transfer and preparation	Lander

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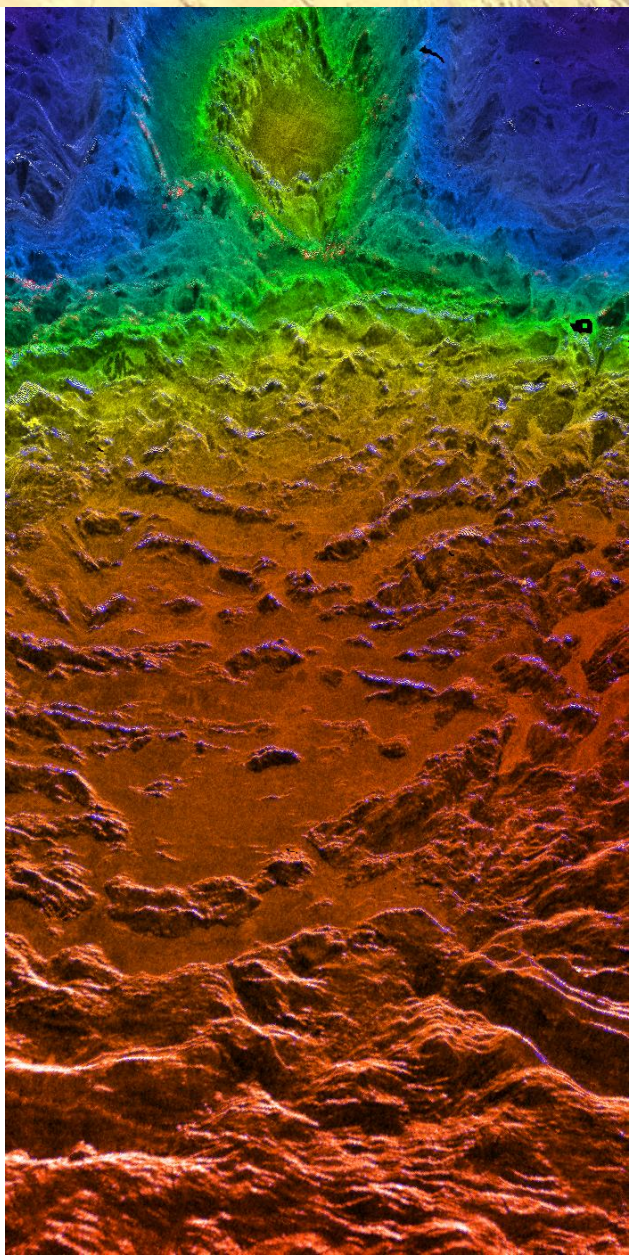
Mission Architecture Tradespace

- STDT & JPL Team assessed the **mission architecture trade space**:
  - Identified 13 **architectural elements**
    - e.g., orbiter, landers, balloons, probes
  - Targeting various **altitude regimes**
    - e.g., from surface to low/mid/high altitudes and orbit
  - Beside **single elements, multiple elements** were also considered
    - e.g., networks, multi-probes
- These architecture **elements assembled into mission architectures**



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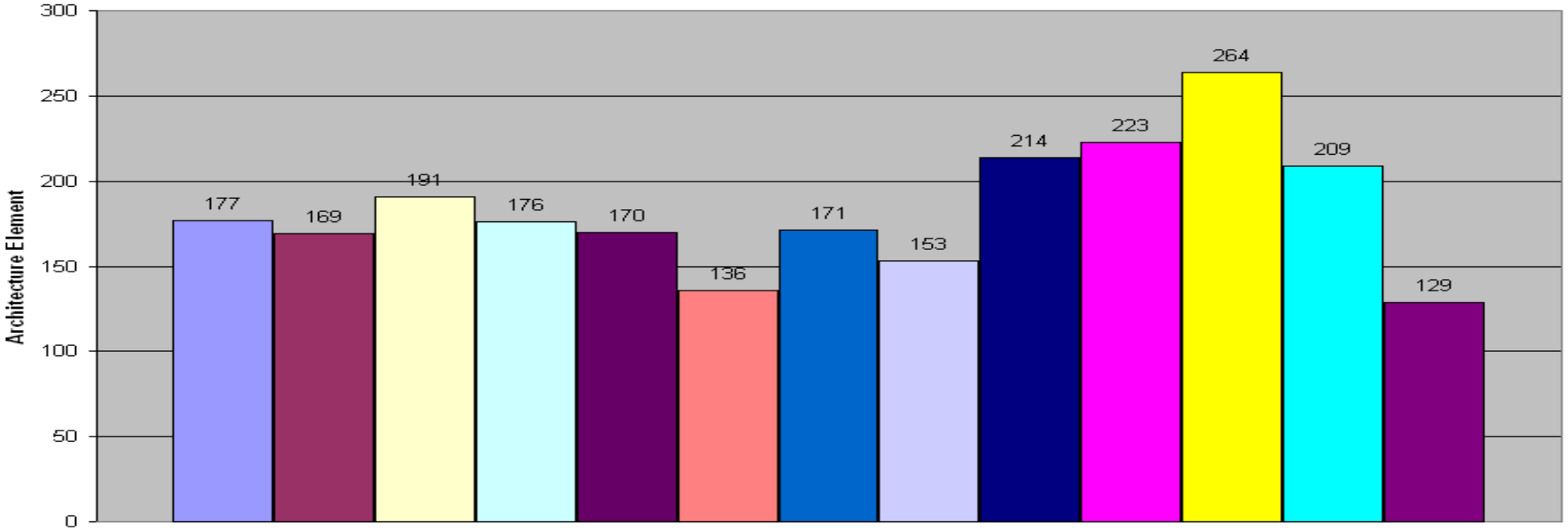
Summary of FOM & Costing for Mission Architecture Elements



	Architecture Element												
	Orbiter	High-Level Aerial (> 70 km)	Mid-Level Aerial (52-70 km)	Low-Level Aerial (15-52 km)	Near-Surface Aerial (0-15 km)	Single Entry Probe (no surf.)	Multiple Entry Probe (no surf.)	Short-Lived Lander (Single)	Short-Lived Lander (Multiple)	Long-Lived Lander (Single)	Long-Lived Lander (Multiple)	Surface System with mobility	Coordinated Atmospheric Platforms
Science FOM	177	169	191	176	170	136	171	153	214	223	264	209	129
Technology FOM	0	3	3	14	20	2	2	12	12	21	21	53	21
Cost Estimate $B	0.48	0.55	0.91	1.45	2.1	0.51	0.54	1.02	1.05	2.3	2.33	3.59	1.98

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Potential Venus Flagship Mission Architectures

Selected Mission Architecture Concepts	Architecture Elements													Cost ($B 08)	Science Score	Technology Score
	Flyby	Orbiter	High-Level Aerial (> 70 km)	Mid-Level Aerial (52-70 km)	Low-Level Aerial (15-52 km)	Near-Surface Aerial (0-15 km)	Single Entry Probe (no surf.)	Multiple Entry Probe no surf.	Short-Lived Lander (Single)	Short-Lived Lander (Multiple)	Long-Lived Lander (Single)	Long-Lived Lander (Multiple)	Surface System with mobility			
Venus Mobile Explorer (VME)		1											1	**$5B**	**386**	**53**
Geology Subgroup's Choice		1				1								**$3.2B**	**347**	**20**
Atmospheric Subgroup's Choice		1		2				2						**$2.9B**	**539**	**5**
GeoChem Subgroup's Choice	1									2				**$2B**	**214**	**12**
STDT Flagship		**1**		**2**						**2**				**$3.7**	**753**	**15**

- A total of 17 mission architecture concepts were assessed
- Including **3 science subgroups recommended** mission architectures
  - one desired mission architecture per subgroup
- **One single architecture that combined all science goals**

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Technology Considerations

- The proposed preliminary **science-driven architecture** combines technologically mature elements (TRL 6) with **moderate technology development requirements**

  - Requires system level technology development for
    - Environmental Testing (High P,T, CO_2, Corrosion)
    - pressure & temperature mitigation
    - sample acquisition & handling

  - Requires instrument technology development
    - InSAR
    - High temperature *in situ* instrumentation

For more high value science

- High P,T Seismometers
- High T power generation and storage
- High T electronics and telecom

Recommendations for FY09 Activities

- Technology investigations for:

In Situ

- NEED Venus environment facility for testing and science
- Materials, components, and science testing under simulated Venus surface conditions
- High T sample acquisition and handling

Orbital

- InSAR for Venus

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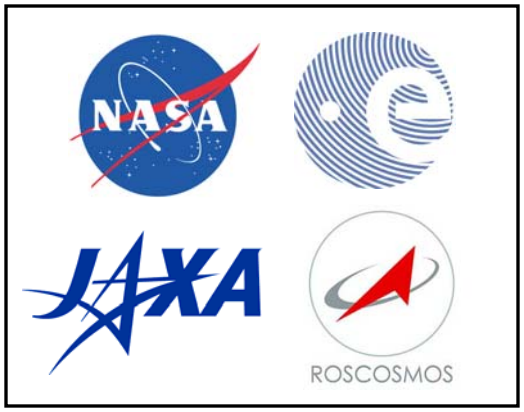
International Collaboration

- Multi-element architecture lends itself to international collaboration
- Timing for international collaboration:
  - NASA (Venus Flagship)
  - ESA's (VEX Current-2011 Cosmic Vision EVE > 2020)
  - JAXA (VCO 2010 follow on, mid-low-cloud balloon > 2016)
  - Russia (Venera D)



Science and Technology to Enhance Venus Flagship Mission

- Science
  - Descent imaging
  - High resolution topography in selected areas (e.g. tessera). And roughness for landing site characterization.
  - Optimized mapping of the surface and lower atmosphere in the near-IR from orbit (VCO may contribute data).
  - Entry into Venus atmosphere with any in situ science

- Demonstration Technology Experiments
  - Test of high temperature electronics (sensors, telecom, data storage)
  - Improved lifetime with passive T control
  - Test high temperature power generation and storage - RPS and high T batteries
  - Palette of different materials for testing
  - Flotation device under high T,P
  - Lander lifetime information

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Valuable Precursor R&A Science

- Chemical reactivity of Venus atmosphere at its surface.
  - Stability of spacecraft materials, and rates of reaction/corrosion.
  - Chemical weathering of surface materials (basalts). Mineralogical changes and reaction rates.
  - Chemical transfer of elements from surface into atmosphere (and onto spacecraft windows?)
- We need to understand how the various ferric/ferrous, silicate, sulfate, and hydroxide near-IR and visible spectra change as rocks are brought to Venus surface conditions.
  - This requires a moderate (10-20 cm) chamber with feedthroughs and an optical port that can sustain Venus-like conditions for weeks at a time.
- There is a fairly urgent need now for an additional chamber that can provide several meters of path length through a Venus-like surface atmosphere.
  - No one has really looked at CO_2 and H_2O at long path lengths under Venus conditions. So we have a real lack of information about the far wings of absorption lines and whether they constitute a continuum.
- Photoabsorption cross-sections for the conditions in the upper atmosphere.
- Aerosol formation and properties of the products (cloud microphysics)
- Thermal expansion coefficients
- Equation of state of the atmosphere (including C_p)
- GCMs
- Modeling: Radiative Transfer and Climate Modeling
- Venus-Earth connections
- Reaction rates – surface and photo and thermal chemistry
- 12.5 km anomaly (chemical modeling)
- Magellan data analysis

Enabling Venus Sample Return

- Site selection
- Landing on Venus
- Sample Acquisition and Handling
- Balloon technology (for sample ascent)

- Single vs dual launches
- Comm
  - Optical vs DSN array
  - Relay orbit vs Direct-to-Earth
  - Storage vs real time
- Orbit Insertion – Chemical, aerobraking, aerocapture
- Site Selection
- Mass – Material, packaging, etc.
- Thermal Control – Active, passive, phase-change cooling
- Power - Solar power vs energy storage
- GNC capabilities
- Long-lived platform vs long-lived payload
- Orbital remote sensing vs Aerial remote sensing

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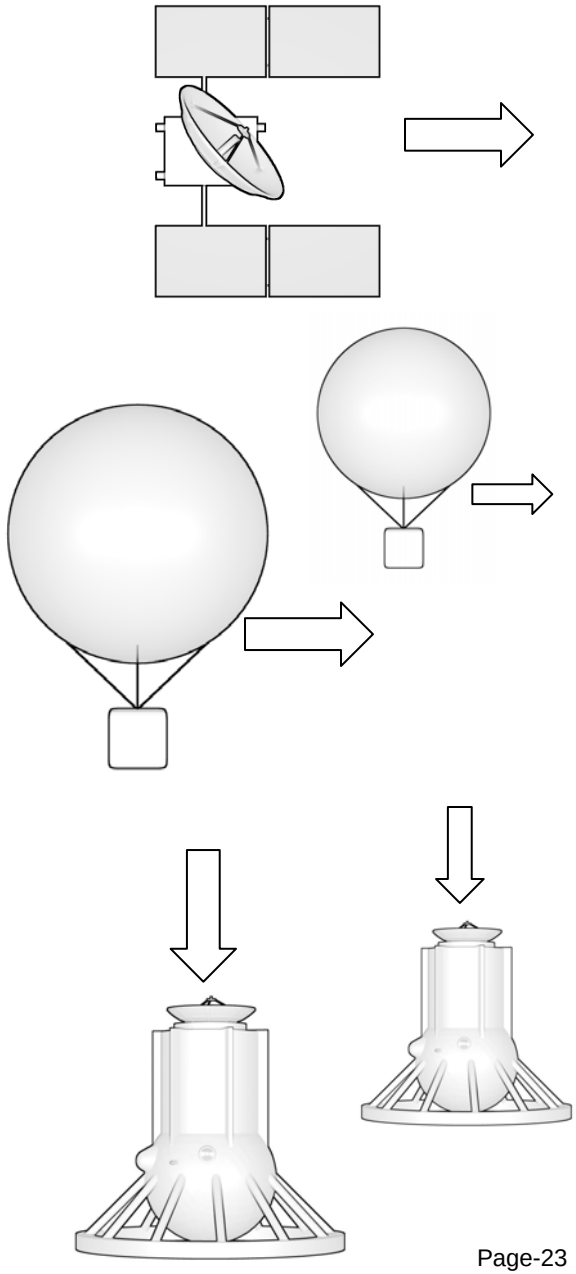
Phase 2: Design Reference Mission

- Earth to Venus Opportunities
- Orbit Design
- Targeting
- Deployment & Entry (Probe & Aerial Vehicle)
- Entry Descent & Landing
- In-Situ Payload Deployment
- Science Data Acquisition
- Communications Strategy

Proposed Mission Architecture for Detailed Study

- Based on these, a **robust mission architecture** was identified, that
  - **Meets all the highest science priorities**, and
  - Has the **highest Figure of Merit** (FOM)
- A **capable long-lived orbiter** (years) with high resolution radar imaging and topography
- **2 instrumented balloons** between 52 and 70 km (weeks)
- **2 landers with extended surface life** (hours) that also acquire detailed atmospheric data on descent
    - Potential **additional science with long lived instrument package** (months) would greatly enhance science return



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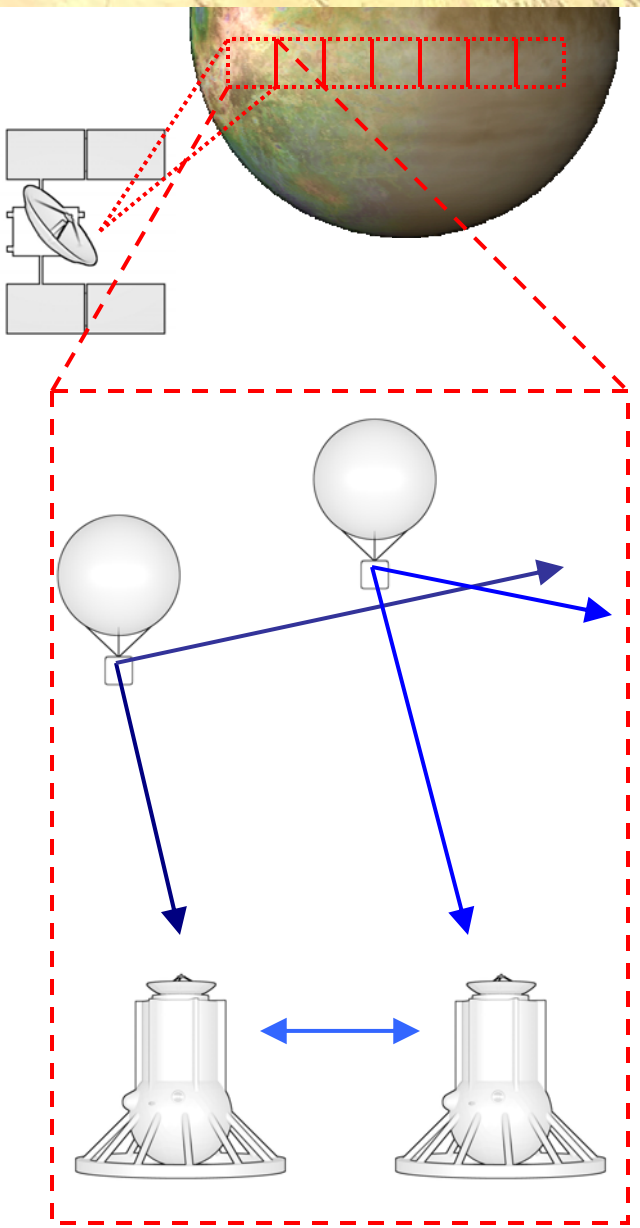
Flagship Science Synergies

- **Deployment** of in-situ elements:
  - 2 landers + 2 balloons deployed at the same time
  - Probe descents to be targeted to go near balloon paths

- **Measurement synergies** for atmospheric science
  - 2 landers give vertical slices of the atmosphere during descent
  - 2 balloons give zonal and meridional slices roughly intersecting balloon paths

- **Science synergies** between **geochemistry and atmosphere**
  - Simultaneous geochemical and mineralogical analysis
  - Spatial and temporal atmospheric gas analysis
    - Two disparate locations at the same time

- **Science synergies** between **geology and geochemistry**
  - Landings on tessera and volcanic plains
    - for comparative geology and geochemistry



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Payload Summary

- Orbiter
  - inSAR
  - INMS
  - Vis-IR-UV imaging spectrometer
  - Submm sounder
  - Magnetometer
  - Langmuir probe
  - Radio subsystem

  170 kg instruments

  $200M payload

- Balloon
  - Mass spectrometer
  - Nephelometer
  - Net flux radiometer
  - Atmospheric structure
  - Optical lightning detector
  - Radio subsystem
  - Magnetometer

  23 kg instruments

  $33M payload

- Lander
  - Mass spectrometer
  - Nephelometer
  - Net flux radiometer
  - Atmospheric structure
  - Descent and panoramic cameras
  - Radio subsystem
  - Magnetometer
  - Sample handling and acquisition
  - XRD/XRF
  - Microscopic imager
  - Intrinsic γ-ray spectrometer
  - Microwave corner reflector
  - Heat flux plate

  105 kg instruments

  $115M payload

  - Long duration package:
    - Seismometer
    - Meteorological station
    - Radio subsystem

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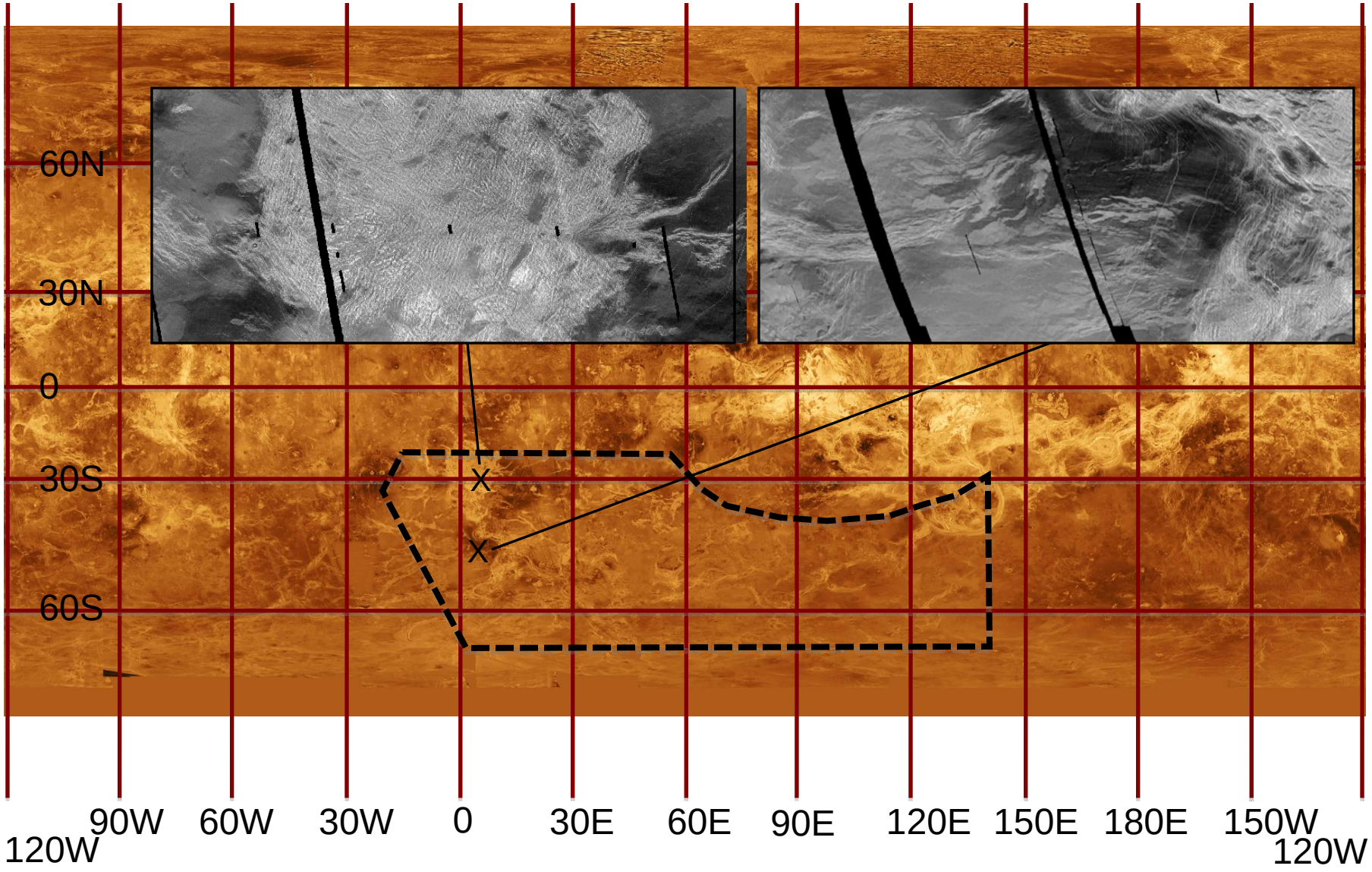
Landers: Surface Access

- **Landing Region for an April 2021 Launch**



FY08 Venus Flagship Study Interim Briefing to NASA HQ by the Venus STDT & Study Team, May 9, 2008

- So far – Instruments only, based on comparable instrument heritage
- JPL Team X study Oct 3-8
- 'Rapid Cost Estimate' method (Cutts, Peterson) based on large database of past missions and exponential complexity indices
- Independent Cost Estimate by Aerospace just approved

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Payload Costs

Platform	Number	Payload Cost/Vehicle	Total Payload Cost
Orbiter	1	$205M	$205
Balloon	2	$33M	$50M
Lander	2	$115M	$173M
Total			**$428M**

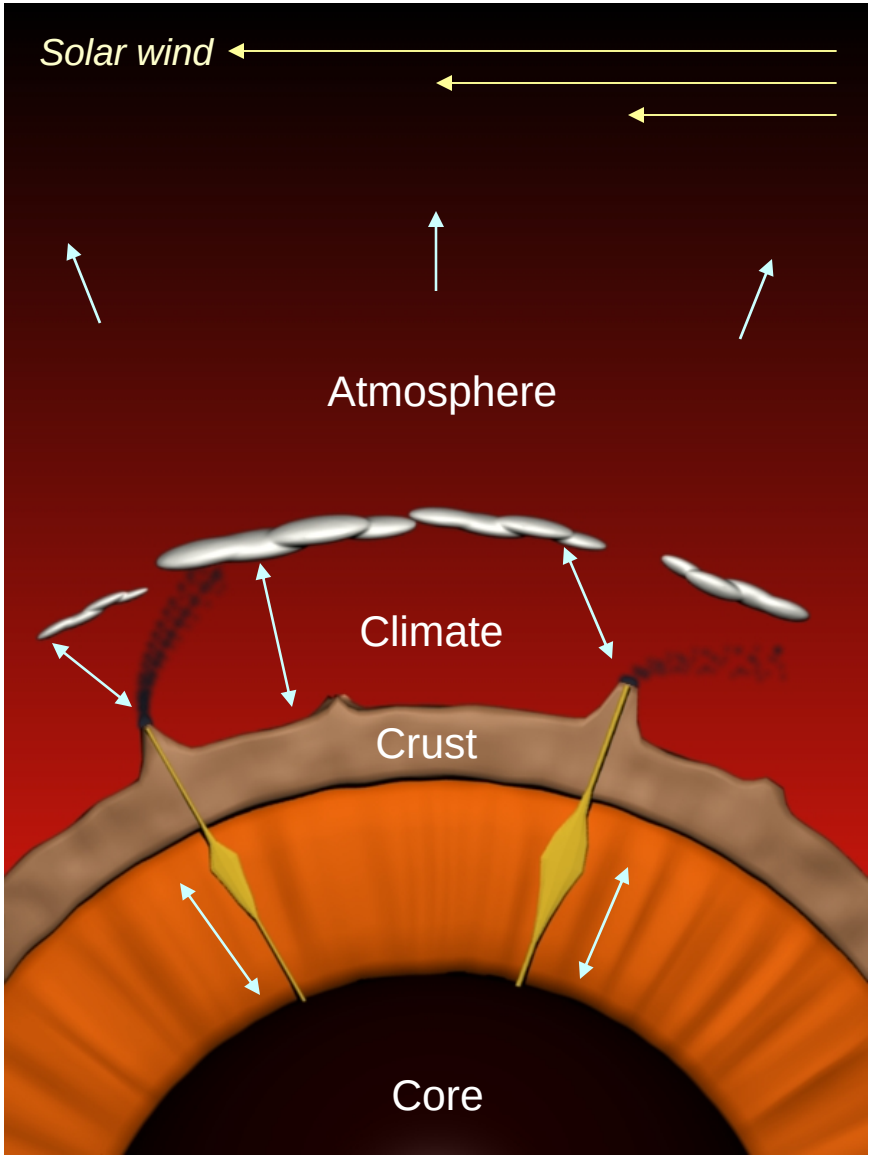
*2nd identical payload at 50% cost

Schedule & Milestones

Kickoff meeting (NASA HQ)	***1/8/08***
First telecon	1/15/08
First meeting (JPL)	***2/4/08 – 2/5/08***
Progress report at LPSC	Week of 3/10/08
Second meeting (U. Maryland)	***5/5/08 – 5/6/08***
VEXAG meeting (U. Maryland)	5/7/08 – 5/8/08
1st interim status report (NASA HQ)	**5/9/08**
Third meeting (Boulder)	***9/3/08 – 9/4/08***
2nd interim status report (NASA HQ)	**10/3/08**
Team X Analysis of DRM	**10/3/08 – 10/8/08**
Progress report at DPS	Week of 10/10/08
Fourth meeting (Boulder)	***10/20/08-10/21/08***
Report at Fall AGU	12/16/08
Final Report Draft	**End January 09**
Final Report for Review	**Mid February 09**
Final Report Release	Mid March 09

Venus Flagship – Interim Conclusions

- **What does the Venus greenhouse tell us about climate change?**
  - Probes through atmosphere simultaneously with balloons
- **How active is Venus?**
  - Highly capable orbiter with high resolution radar imaging, topography, and temporal changes. InSAR probably cannot be done with NF.
- **When and where did the water go?**
  - Geochemistry and mineralogy at 2 locations on Venus. Cannot be done with NF.
- **A Venus Flagship mission in 2020-2025 can be done with a low technology investment and relatively low risk.**



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