



Venus Flagship Study: Exploring Earth's Nearest Planetary Neighbor

Presentation to the Planetary Science
Subcommittee of the NASA Advisory Council

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Venus STDT Co-Chairs

and
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Study Lead

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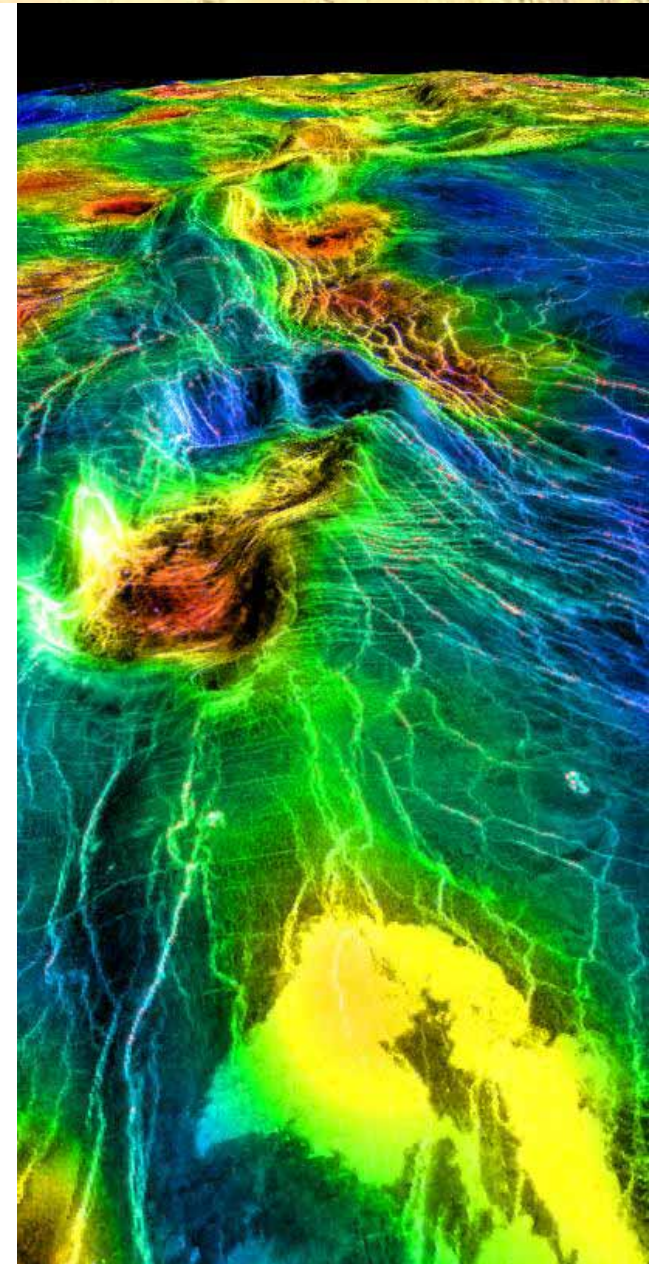
²Jet Propulsion Laboratory / Caltech

NASA Headquarters
October 3, 2008





- Study Overview
- Science Drivers for Venus Flagship
- Venus STDT Process Description
- Technology Considerations
- Design Reference Mission
- Cost Analyses
- Schedule

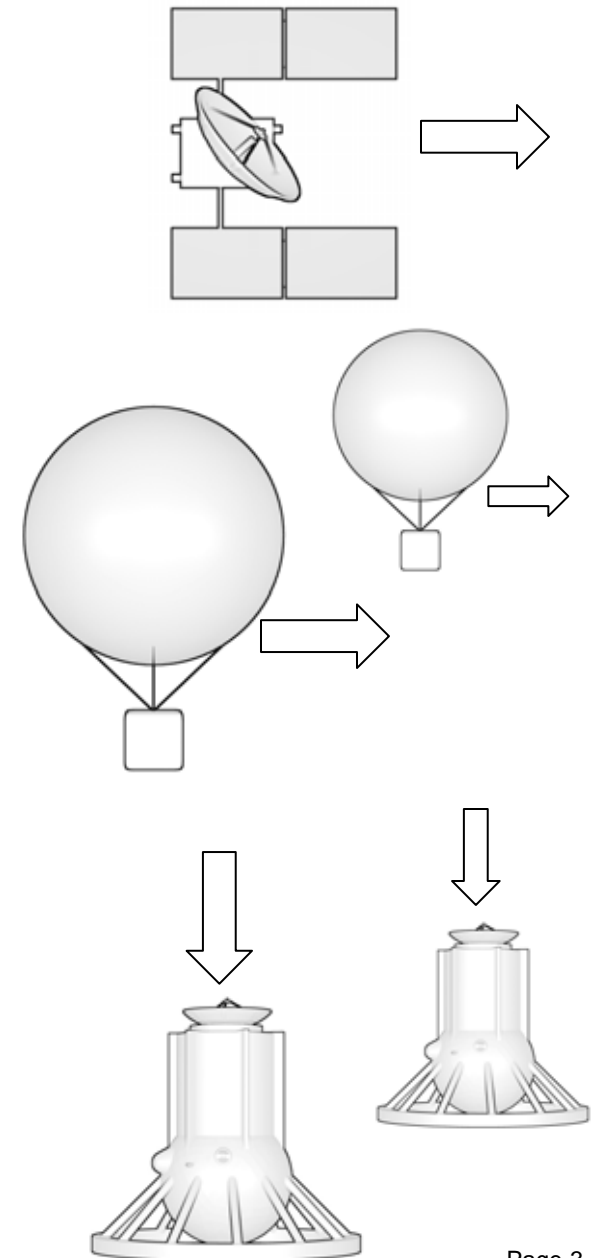


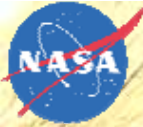


Proposed Mission Architecture for Detailed Study



- 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





Venus STDT & JPL Study Team Membership



Atmosphere Subgroup

- **David Grinspoon** (*DMNS*)
- **Anthony Colaprete** (*NASA Ames*)
- **Sanjay Limaye** (*U. Wisconsin*)
- **George Hashimoto** (*Kobe U.*)
- **Dimitri Titov** (*ESA*)
- **Eric Chassefiere** (*U. of Nantes--France*)
- **Hakan Svedhem** (*ESA*)

Geochemistry Subgroup

- **Allan Treiman** (*LPI*)
- **Steve Mackwell** (*LPI*)
- **Natasha Johnson** (*NASA GSFC*)

Geology and Geophysics

- **Dave Senske** (*JPL*)
- **Jim Head** (*Brown University*)
- **Bruce Campbell** (*Smithsonian*)
- **Gerald Schubert** (*UCLA*)
- **Walter Kiefer** (*LPI*)
- **Lori Glaze** (*NASA GSFC*)

Technology

- **Elizabeth Kolawa** (*JPL*)
- **Viktor Kerzhanovich** (*JPL*)
- **Gary Hunter** (*NASA GRC*)
- **Steve Gorevan** (*Honeybee Robotics*)

Ex Officio

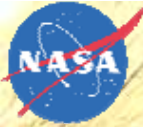
- **Ellen Stofan** (*VEXAG Chair*)
- **Tibor Kremic** (*NASA GRC*)

JPL Venus Flagship Study Core Team

- **Jeff Hall** (*Study Lead*)
- **Tibor Balint** (*Mission Lead*)
- **Craig Peterson**
- **Tom Spilker**

NASA and JPL

- **Jim Cutts** (*JPL*)
- **Adriana Ocampo** (*NASA HQ*)



Study Objectives



- Develop and prioritize **science goals, investigations, measurements**
 - Consistent with the NRC Decadal Survey (2003)
 - NASA's SSE Roadmap (2006)
 - VEXAG White Paper (2007)
- Develop **mission architectures** and required **instrumentation** capabilities
 - assess performance, cost, risk, and technology readiness
- Identify **technology investment** and maturation schedule that
 - supports the mission architectures
 - target launch date ~2020 to 2025
- Assess the **precursor observations & technology validation experiments**
 - for New Frontiers class concepts
 - leading to enable or enhance the Flagship mission
- Show path towards a future **Venus Surface Sample Return** concept



Venus Flagship Mission Assumptions



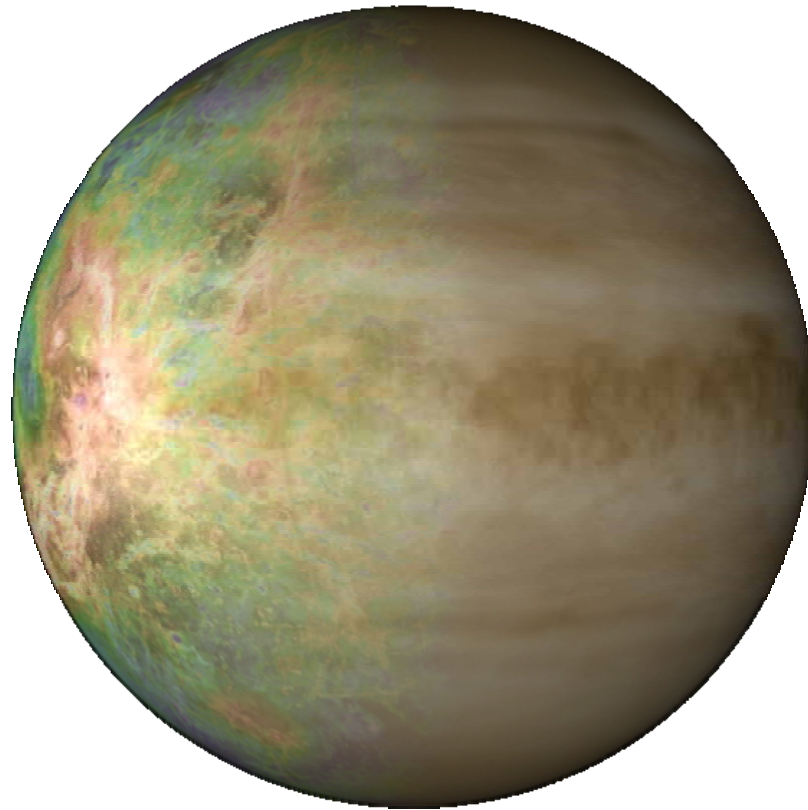
- Launch Years 2020 to 2025
- Technology Maturation TRL 6 by 2015
- Life Cycle Mission Cost Range \$3 - 4B (FY '08)
- LV Capability \leq Delta IVH equivalent
- DSN Capability up to 34M, Ka band
- International Contribution No foreign cost contribution

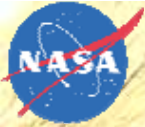


Venus: World of Contrasts



The Mysteries of Venus: Science Drivers for a Venus Flagship Mission



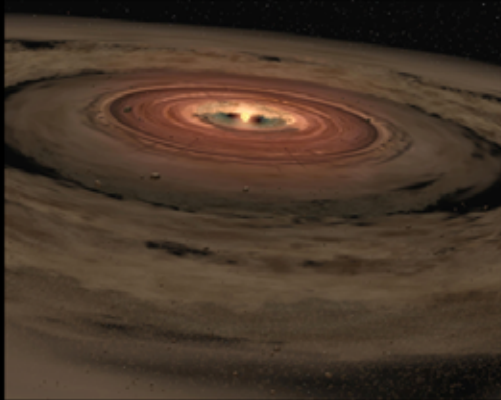


Venus Exploration Goals and Objectives



Goal 1:

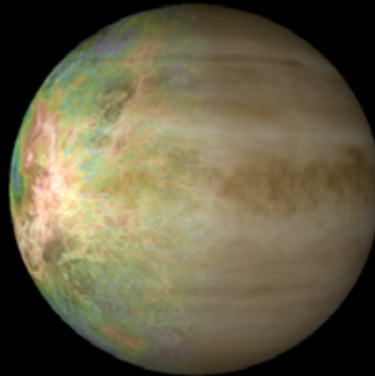
Origin and Early Evolution of Venus:
How did Venus originate and evolve?



- 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:

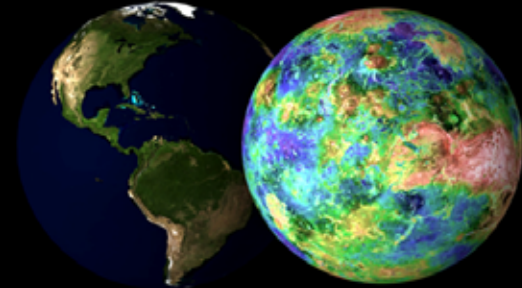
Venus as a terrestrial planet:
What are the processes that have and still shape the planet?



- 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



The Past



The Present



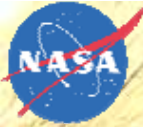
The Future

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



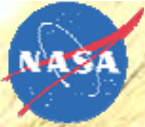
Why is Venus so different from Earth?

- **What does the Venus greenhouse tell us about climate change?**
- **How active is Venus?**
- **When and where did the water go?**

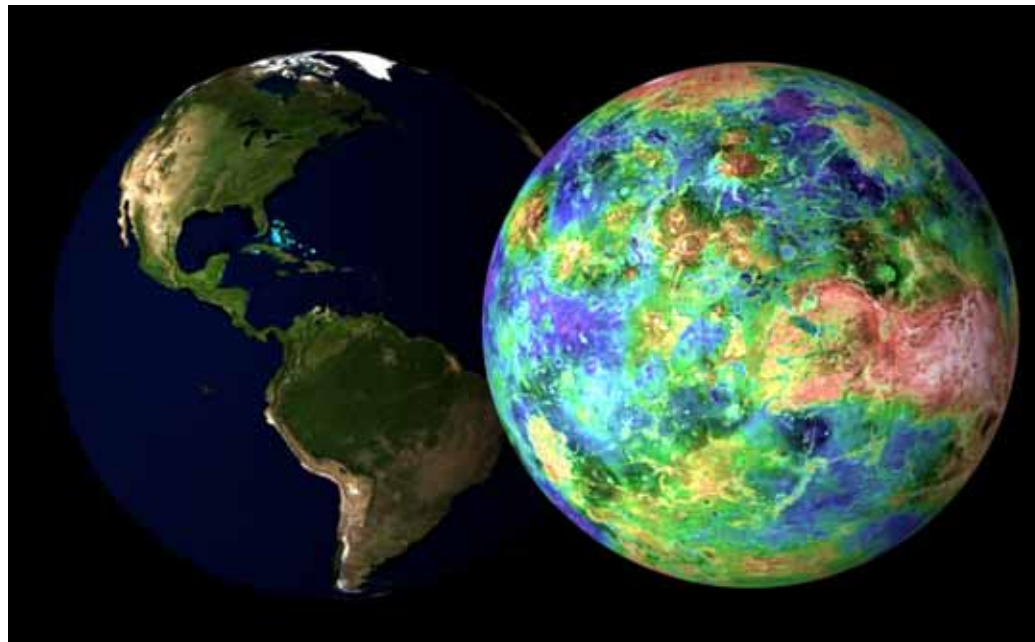


Why is Venus so different from Earth?

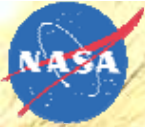
- **What does the Venus greenhouse tell us about climate change?**
 - Did Venus diverge from an early Earth-like state?
 - How is the climate forced by the Sun and influenced by clouds?
 - How do the surface and atmosphere interact chemically?
- **How active is Venus?**
 - Is Venus currently geologically 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?



- 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

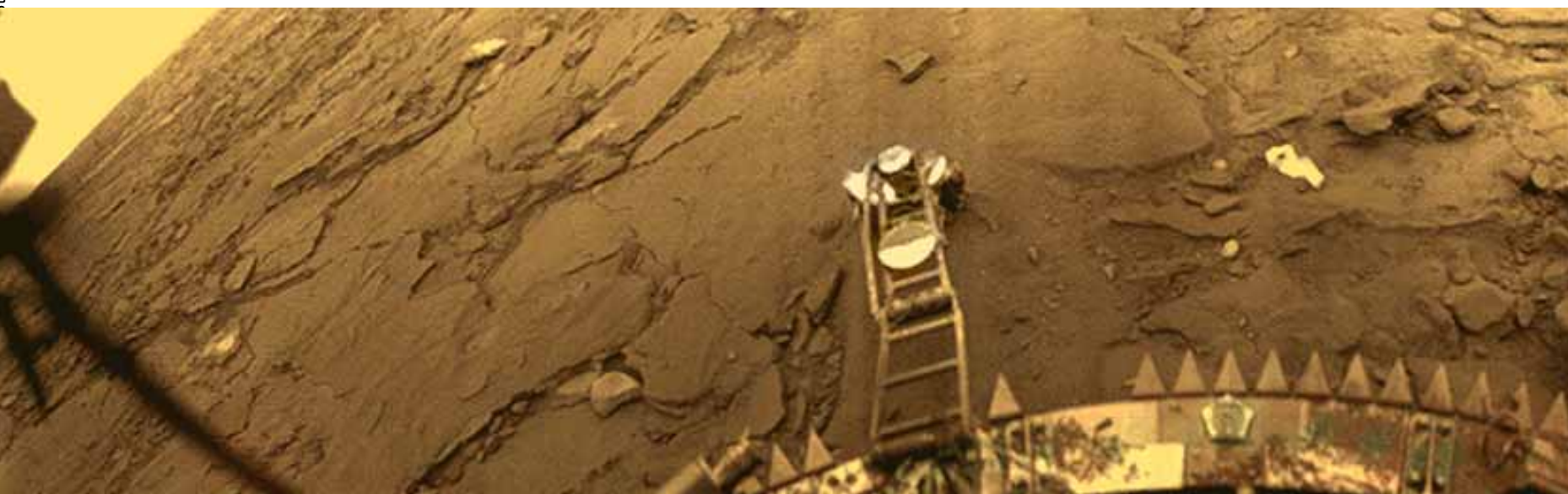


Pre-decisional – for discussion purposes only



Venus STDT Process for Choosing Mission Architectures

FY08 Venus Flagship Study, Interior Profound to NASA HQ by the Venus STDT Study Team, May 9, 2008



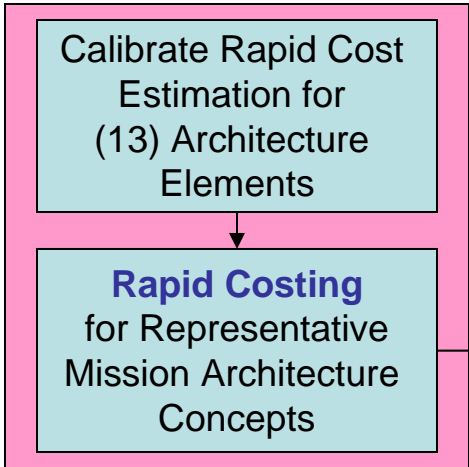
Ref: Venus surface image from Venera 14



Flowchart for the VSTDT FOM Process

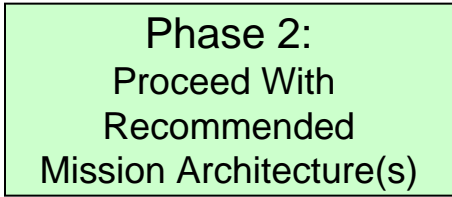
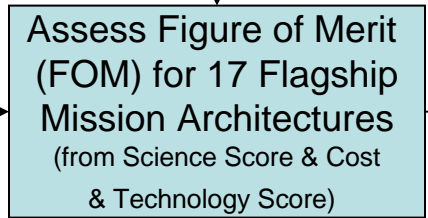
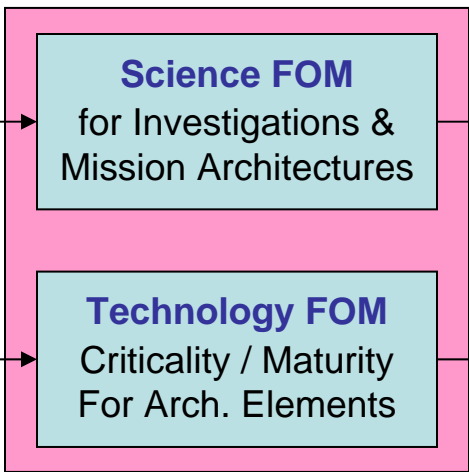
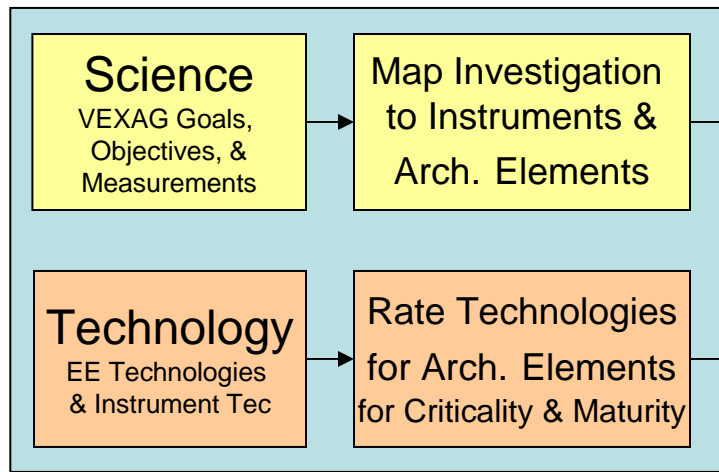


- Figure of Merit (FOM) combines
 - Science ranking
 - Technology ranking
 - Mission architectures by costs



Assessment of Mission Architecture Concepts

Venus STDT Assessment



4/9/08



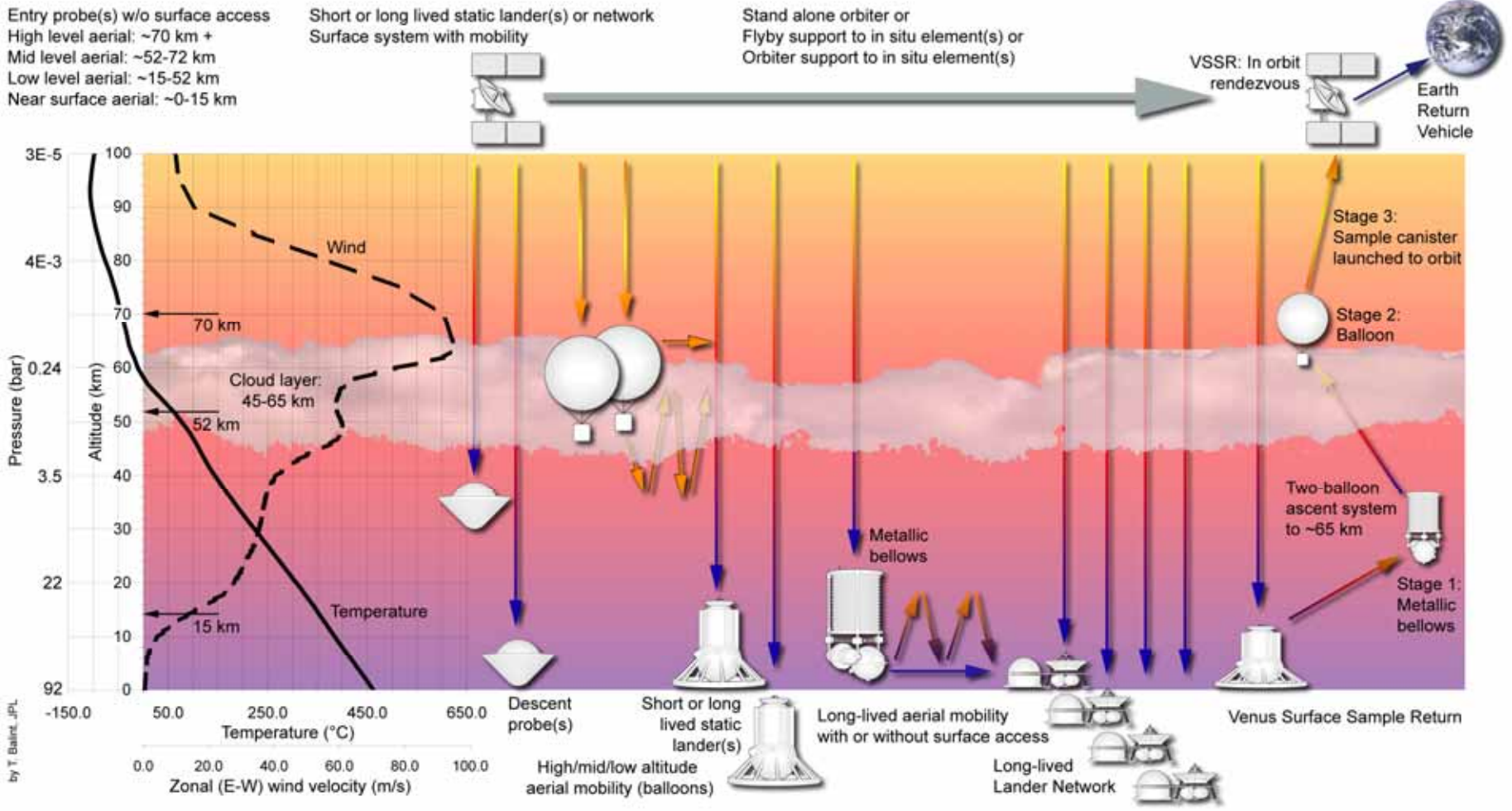
FY08 Venus Flagship Study Interim Briefing to NASA HQ by the Venus STDT & Study Team, May 9, 2008



Venus Mission Architecture Elements

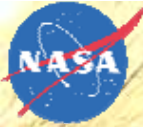


Get rid of small words



Mission architectures were constructed from these elements

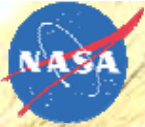
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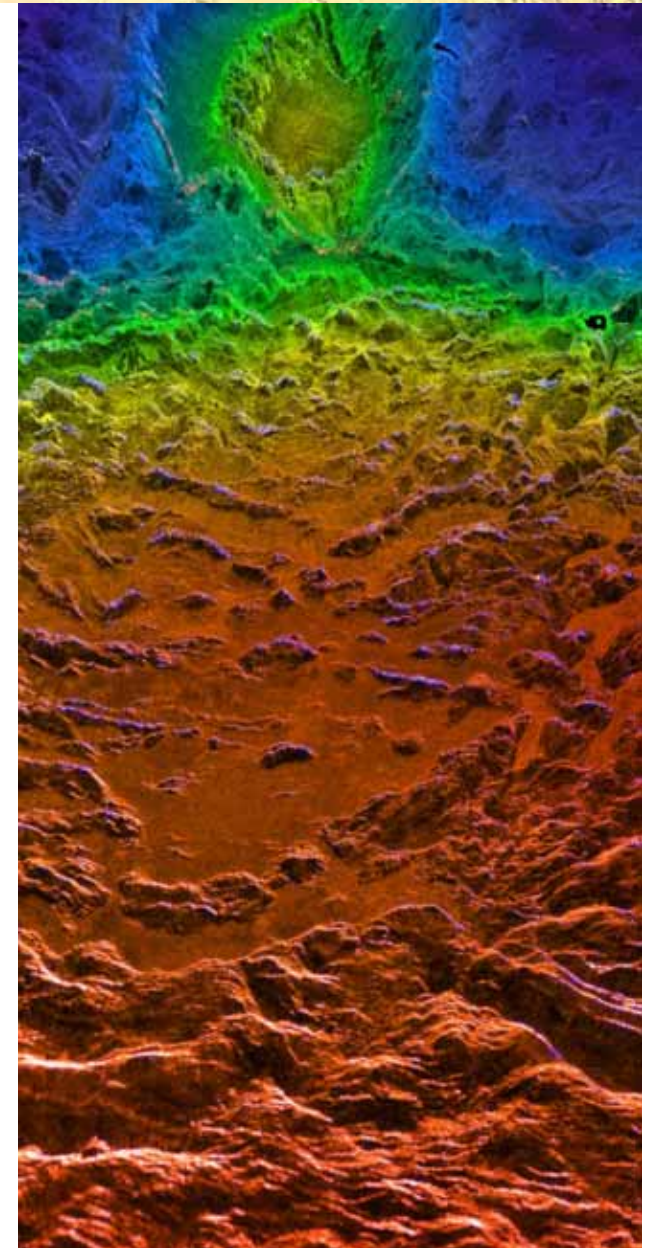
Definition of 13 Architecture Elements



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)

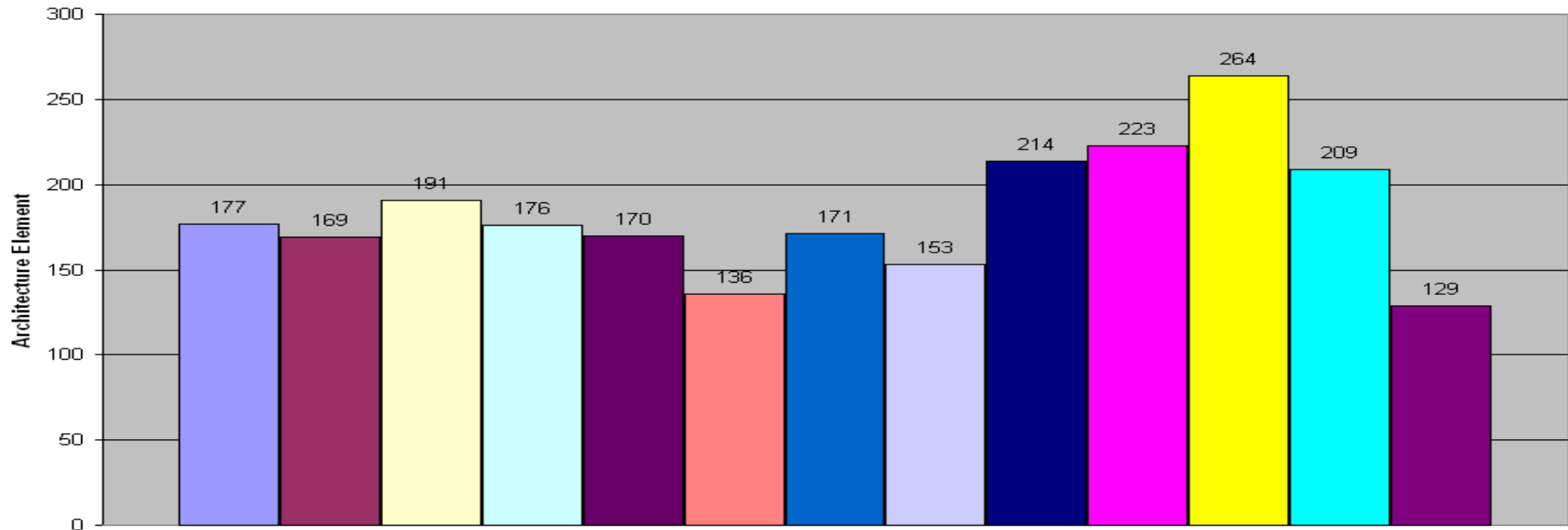


- STDT & JPL Team assessed the **mission architecture trade space**:
 - Identified 13 **architectural elements**
 - e.g., orbiter, landers, balloons, probes
 - Targeting various **altitude regimes**
 - e.g., from surface to low/mid/high altitudes and orbit
 - Beside **single elements, multiple elements**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



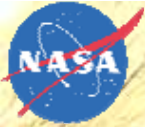


Summary of FOM & Costing for Mission Architecture Elements



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

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



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

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

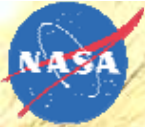
- A total of 17 mission architecture concepts were assessed
- Including **3 science subgroups recommended** mission architectures
 - one desired mission architecture per subgroup
- **One single architecture that combined all science goals**



Technology Considerations



Ref: Venus surface image from Venera 14



Technology Considerations



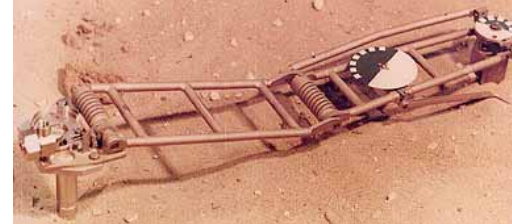
- The proposed preliminary **science-driven architecture** combines technologically mature elements (TRL 6) with **moderate technology development requirements**

– Requires system level technology development for

- Environmental Testing (High P,T, CO₂, Corrosion)
- pressure & temperature mitigation
- sample acquisition & handling

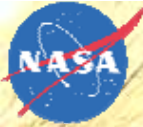
– Requires instrument technology development

- 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



- 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

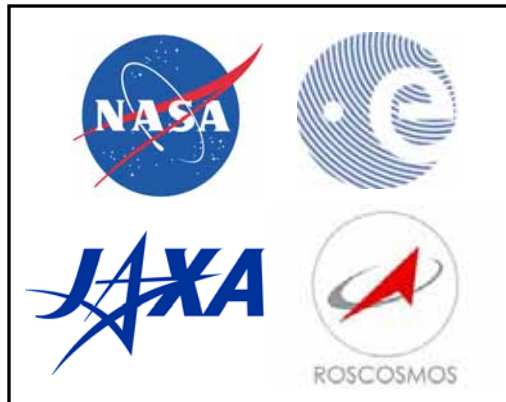
- InSAR for Venus

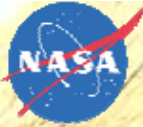


International Collaboration



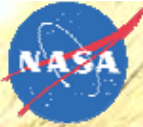
- Multi-element architecture lends itself to international collaboration
- Timing for international collaboration:
 - NASA (Venus Flagship)
 - ESA's (VEX Current-2011 Cosmic Vision EVE > 2020)
 - JAXA (VCO 2010 follow on, mid-low-cloud balloon > 2016)
 - Russia (Venera D)





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



- 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 CO₂ and H₂O 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



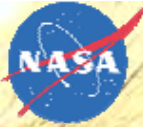
- Site selection
- Landing on Venus
- Sample Acquisition and Handling
- Balloon technology (for sample ascent)



Design Reference Mission



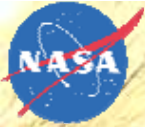
Ref: Venus surface image from Venera 14



- **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**



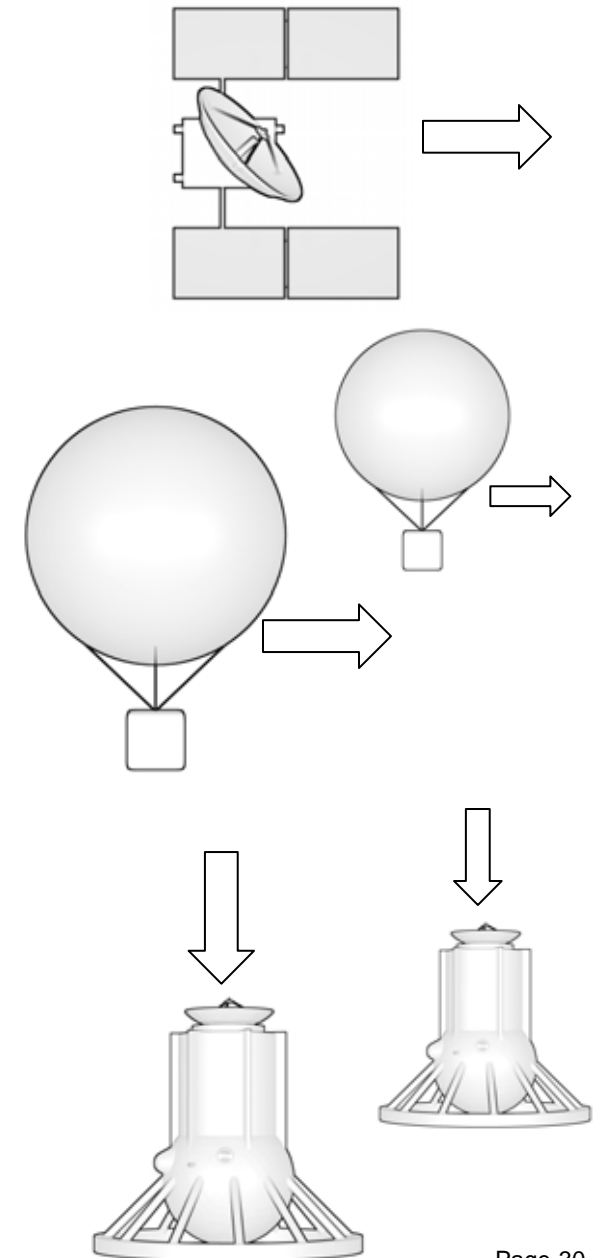
- **Earth to Venus Opportunities**
- **Orbit Design**
- **Targeting**
- **Deployment & Entry (Probe & Aerial Vehicle)**
- **Entry Descent & Landing**
- **In-Situ Payload Deployment**
- **Science Data Acquisition**
- **Communications Strategy**

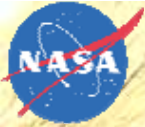


Proposed Mission Architecture for Detailed Study



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- **2 instrumented balloons** between 52 and 70 km (weeks)
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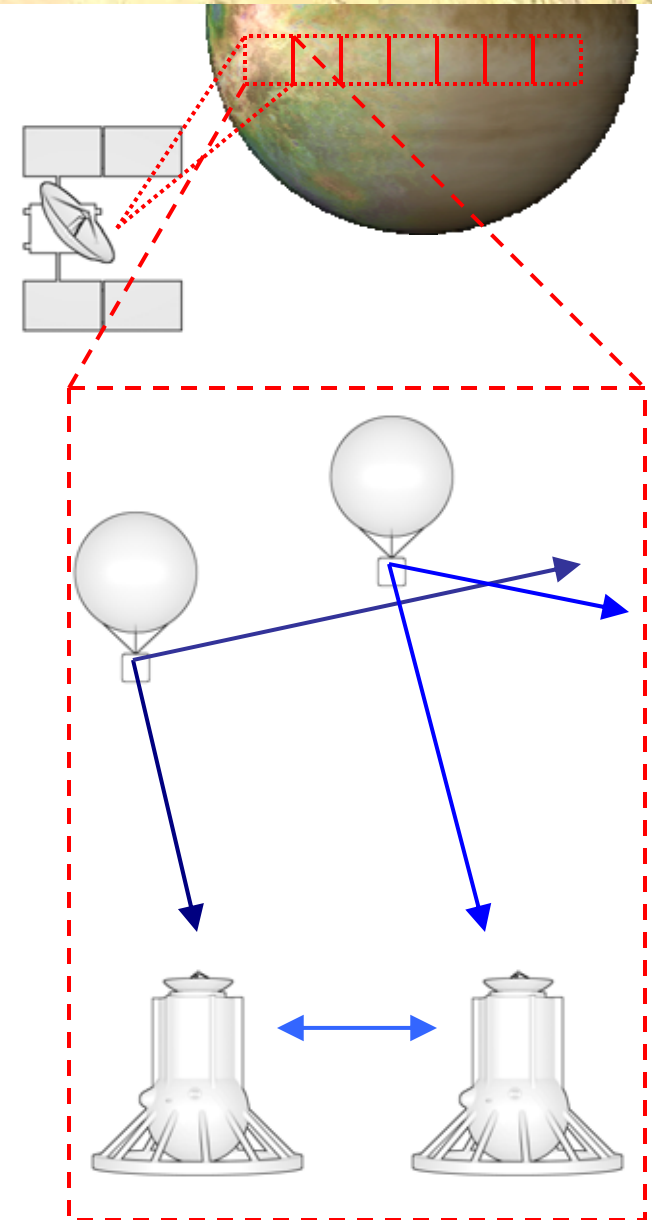


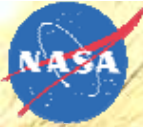


Flagship Science Synergies



- **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





- 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



- 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



Payload Costs

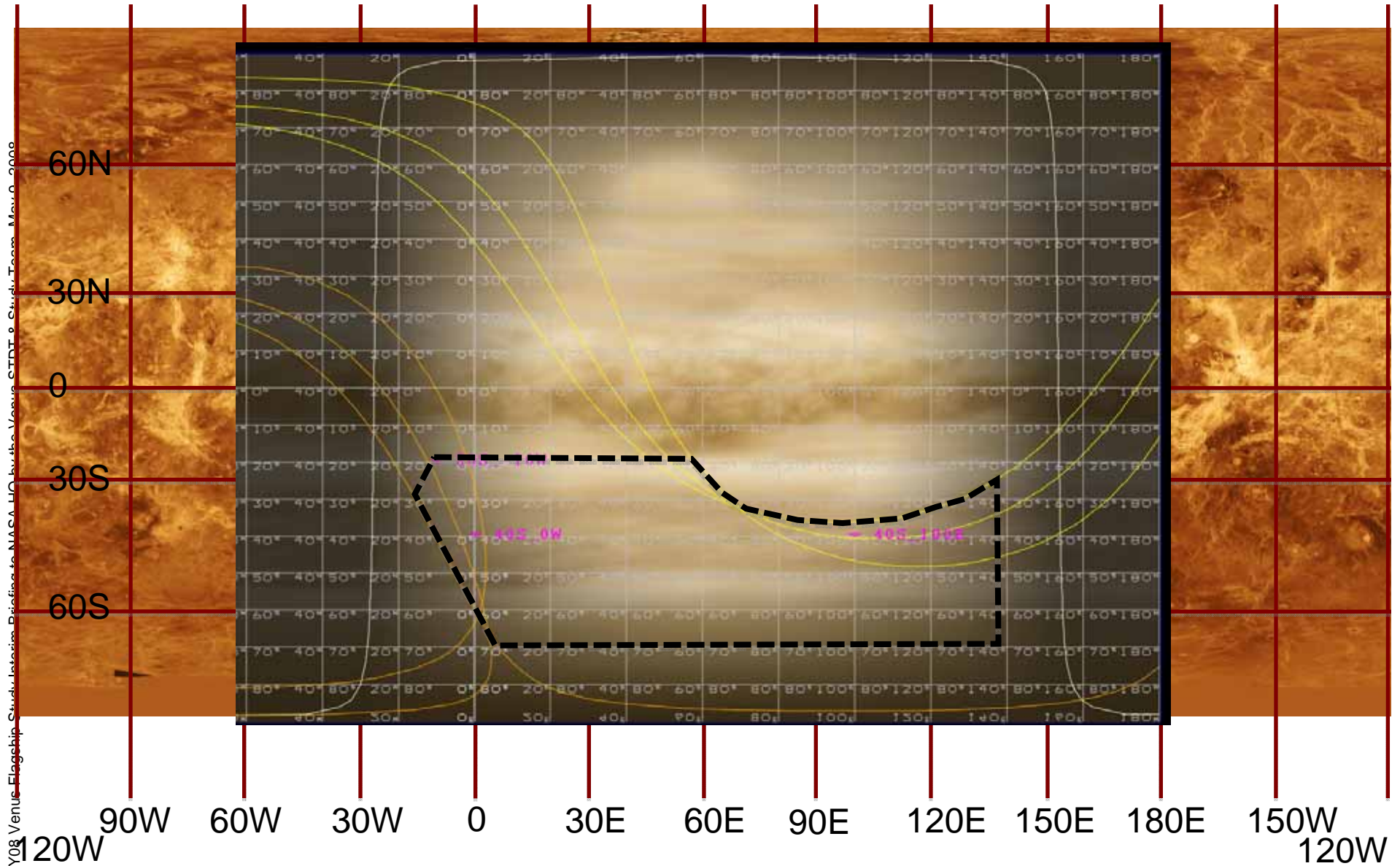


Platform	Number	Payload Cost/Vehicle	Total Payload Cost
Orbiter	1	\$205M	\$205
Balloon	2	\$33M	\$50M
Lander	2	\$115M	\$173M
Total			\$428M

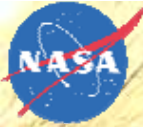
*2nd identical payload at 50% cost



Overlay of landing circles



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Schedule & Milestones



<i>Kickoff meeting (NASA HQ)</i>	1/8/08
First telecon	1/15/08
<i>First meeting (JPL)</i>	2/4/08 – 2/5/08
Progress report at LPSC	Week of 3/10/08
<i>Second meeting (U. Maryland)</i>	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
<i>Third meeting (Boulder)</i>	8/4/08 – 8/5/08
2nd interim status report (NASA HQ)	10/3/08
Team X Analysis of DRM	10/3/08 – 10/8/08
<i>Fourth meeting (Boulder)</i>	8/20/08
Progress report at DPS	Week of 10/10/08
Final Report Draft	Early November
Final Report for Review	Mid-December
Report at Fall AGU	Mid December



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.**

