Venus Flagship Study: Exploring Earth's Nearest Planetary Neighbor

Presentation to the Planetary Science Subcommittee of the NASA Advisory Council

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and
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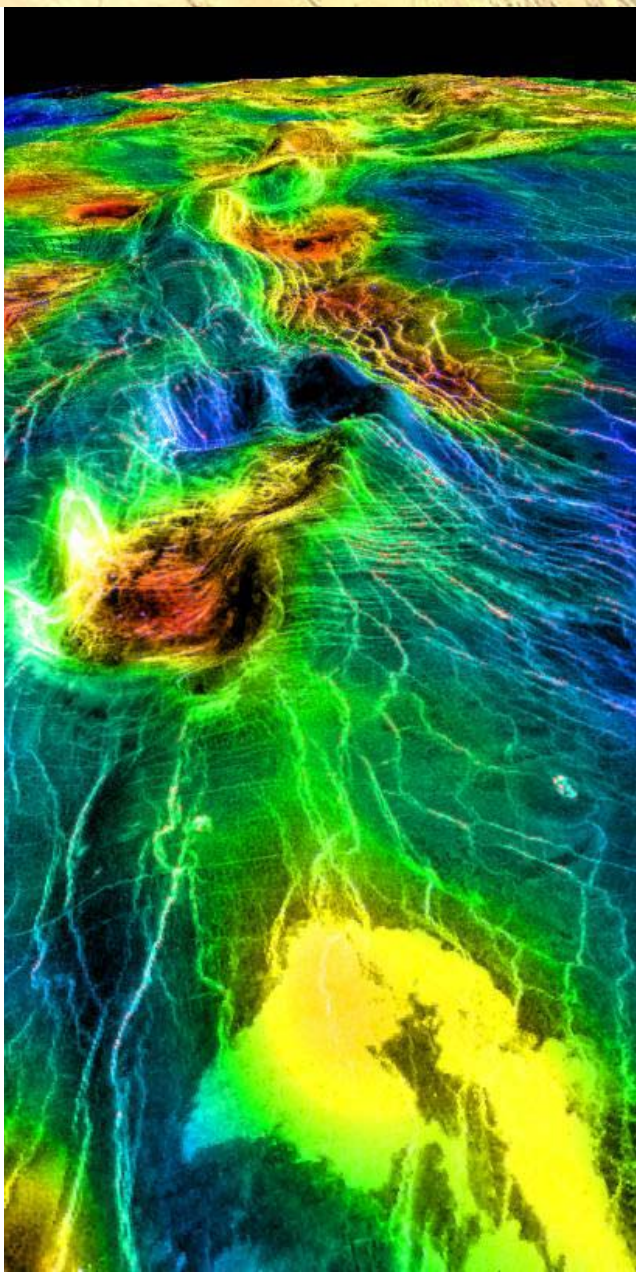
NASA Headquarters
October 3, 2008

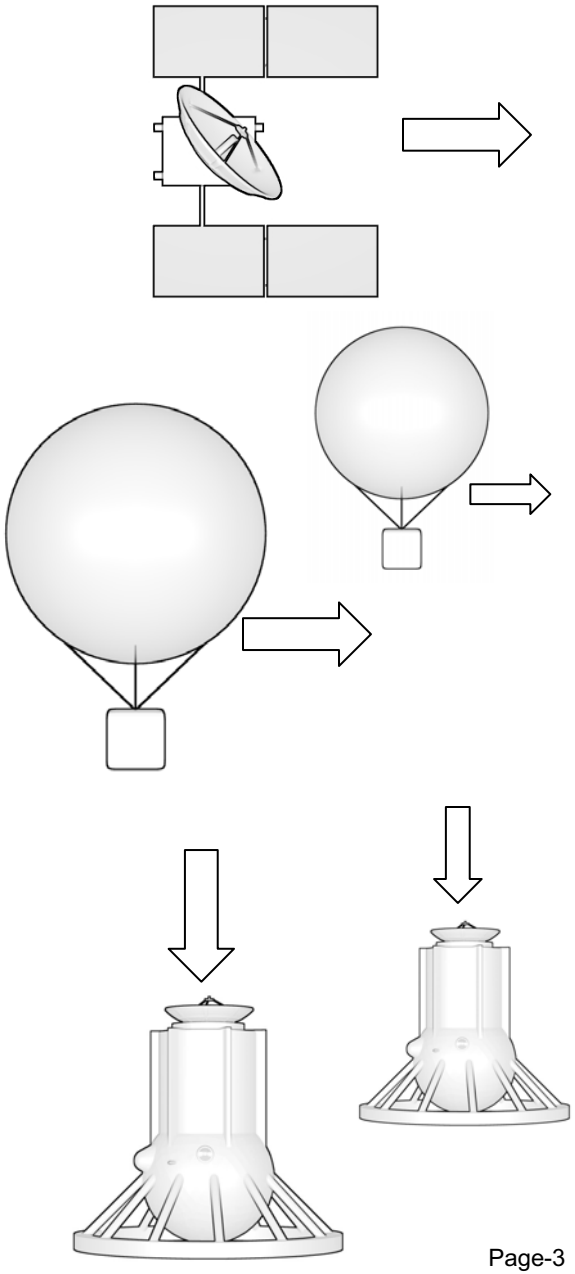
Outline

- 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)*

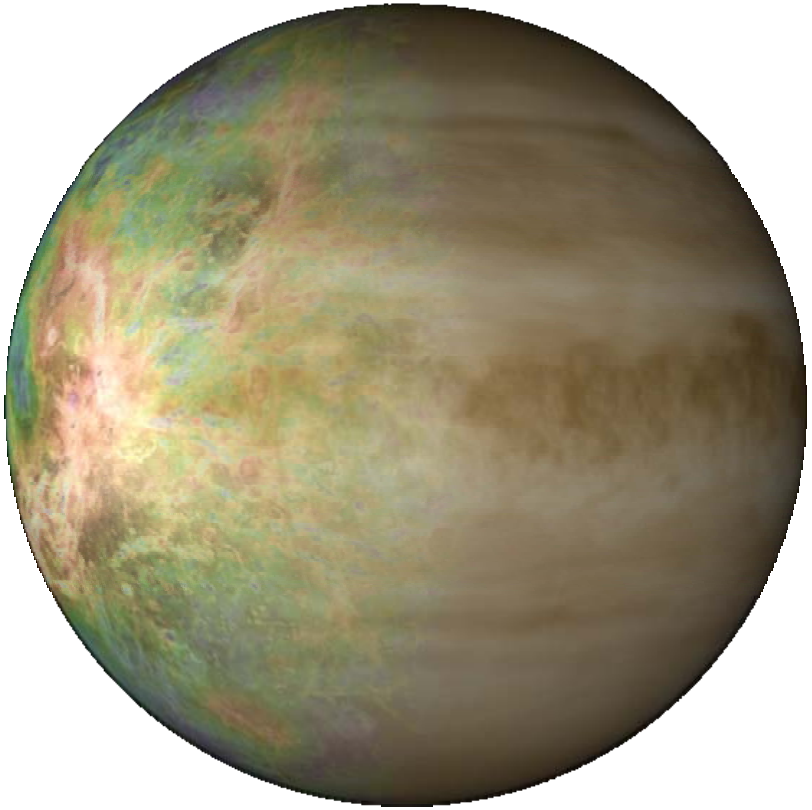
Study Objectives

- 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

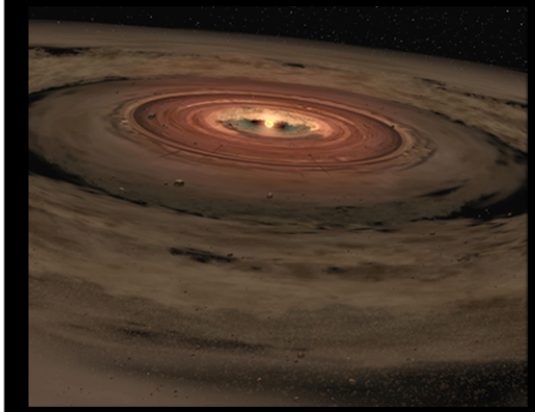
• Launch Years	2020 to 2025
• Technology Maturation	TRL 6 by 2015
• Life Cycle Mission Cost Range	$3 - 4B (FY ’08)
• LV Capability	≤ Delta IVH equivalent
• DSN Capability	up to 34M, Ka band
• International Contribution	No foreign cost contribution

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



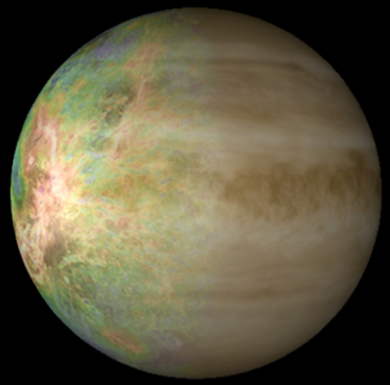
Venus Exploration Goals and Objectives

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



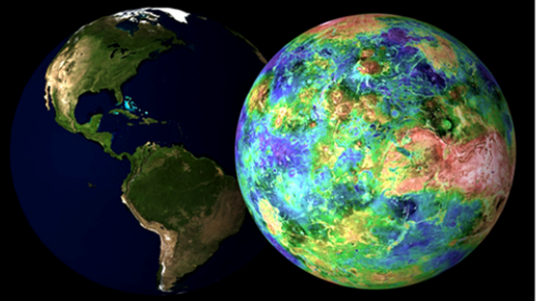
- *Determine isotopic composition of atmosphere*
- *Map the mineralogy and composition of the surface on a planetary scale*
- *Characterize the history of volatiles in the interior, surface and atmosphere*
- *Characterize the surface stratigraphy of lowland regions and the evidence for climate change*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

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

Why is Venus so different from Earth?

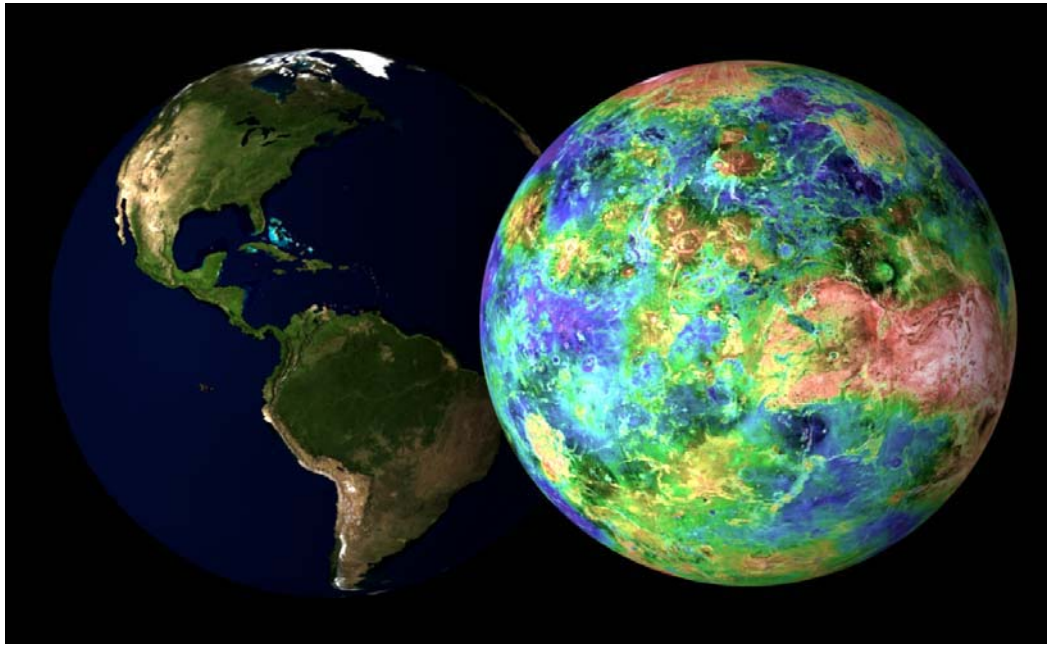
- What does the Venus greenhouse tell us about climate change?
- How active is Venus?
- When and where did the water go?

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?

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

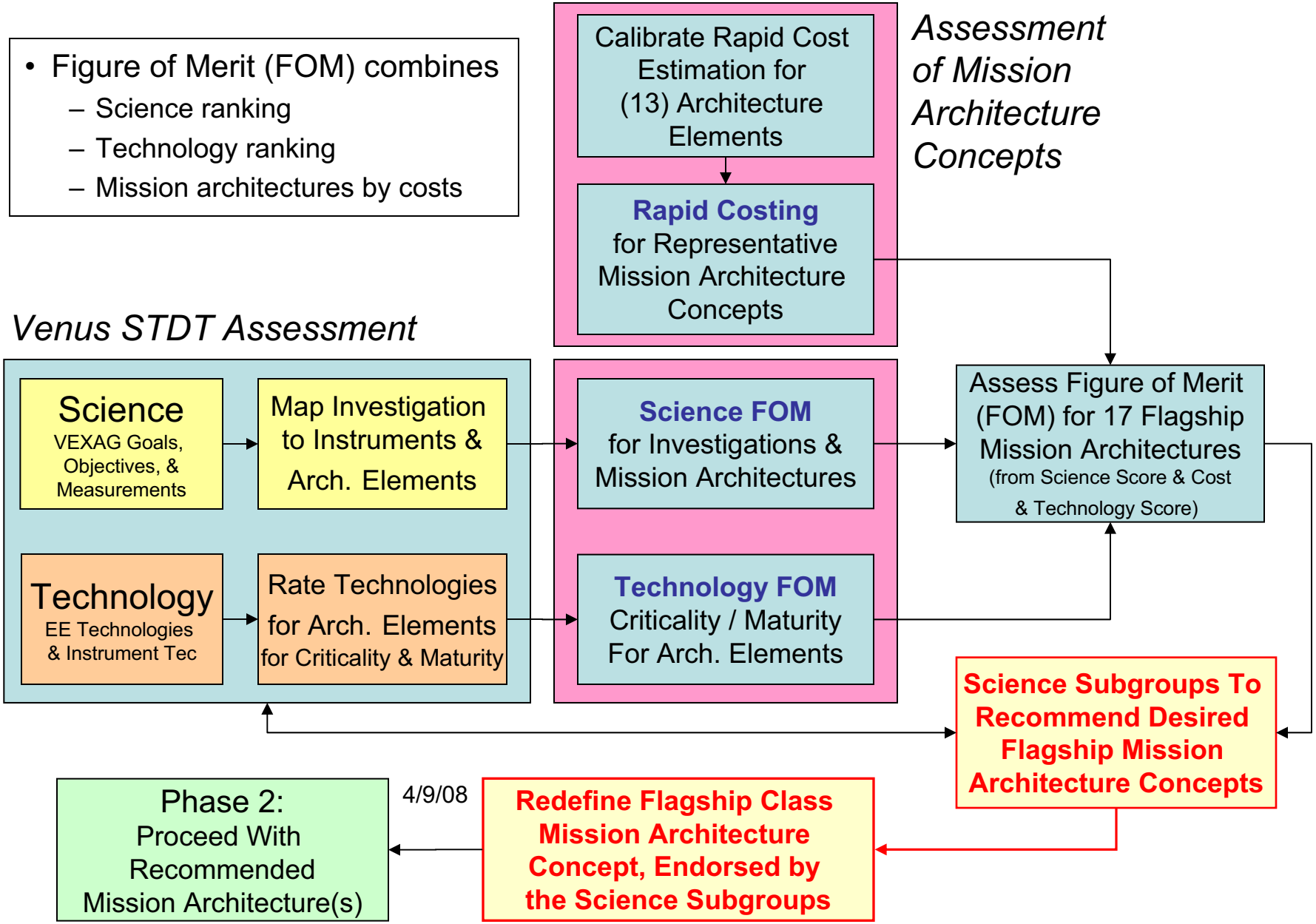


Venus STDT Process for Choosing Mission Architectures

Ref: Venus surface image from Venera 14

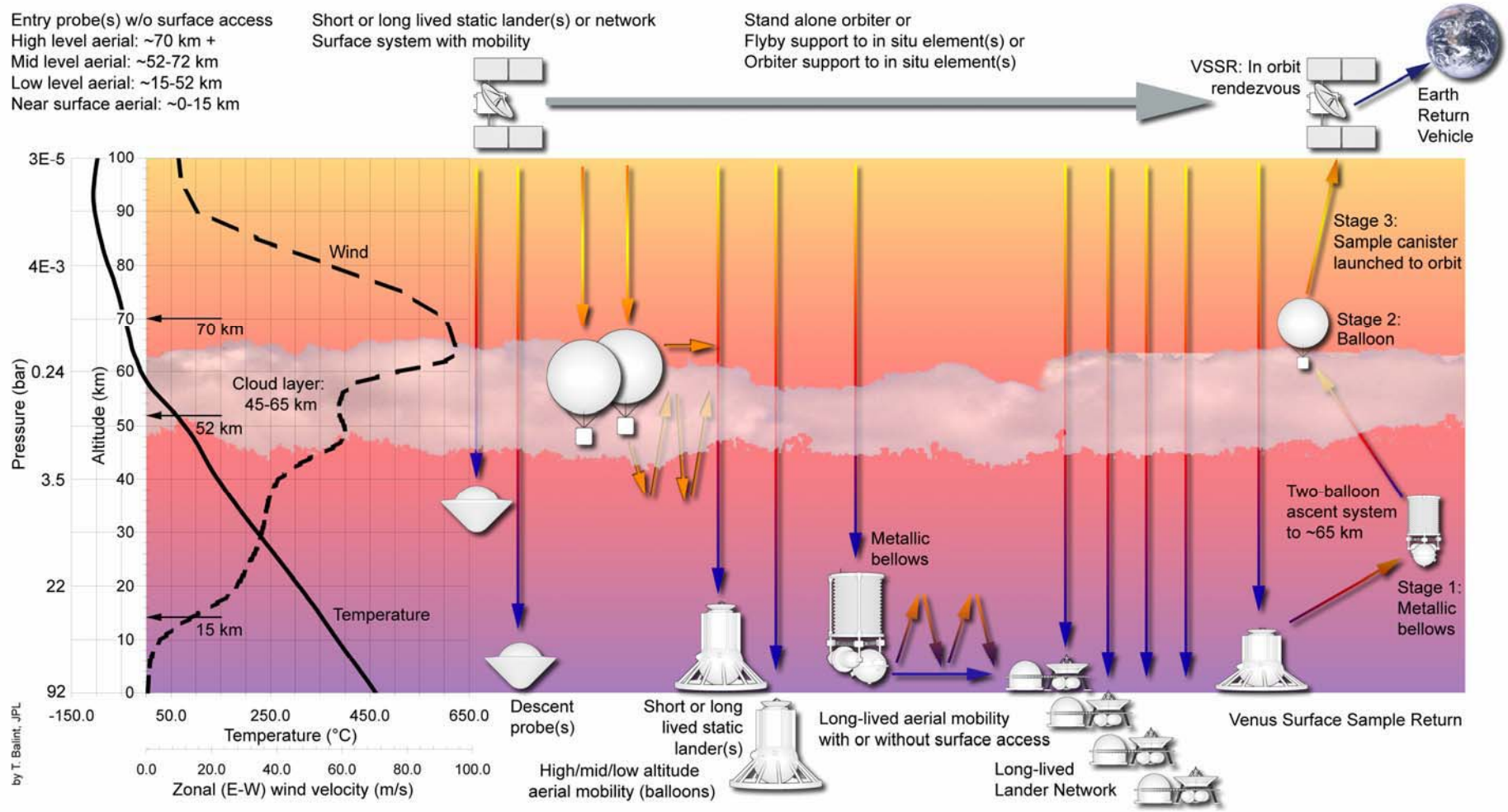
Flowchart for the VSTDT FOM Process

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



Venus Mission Architecture Elements

Get rid of small words



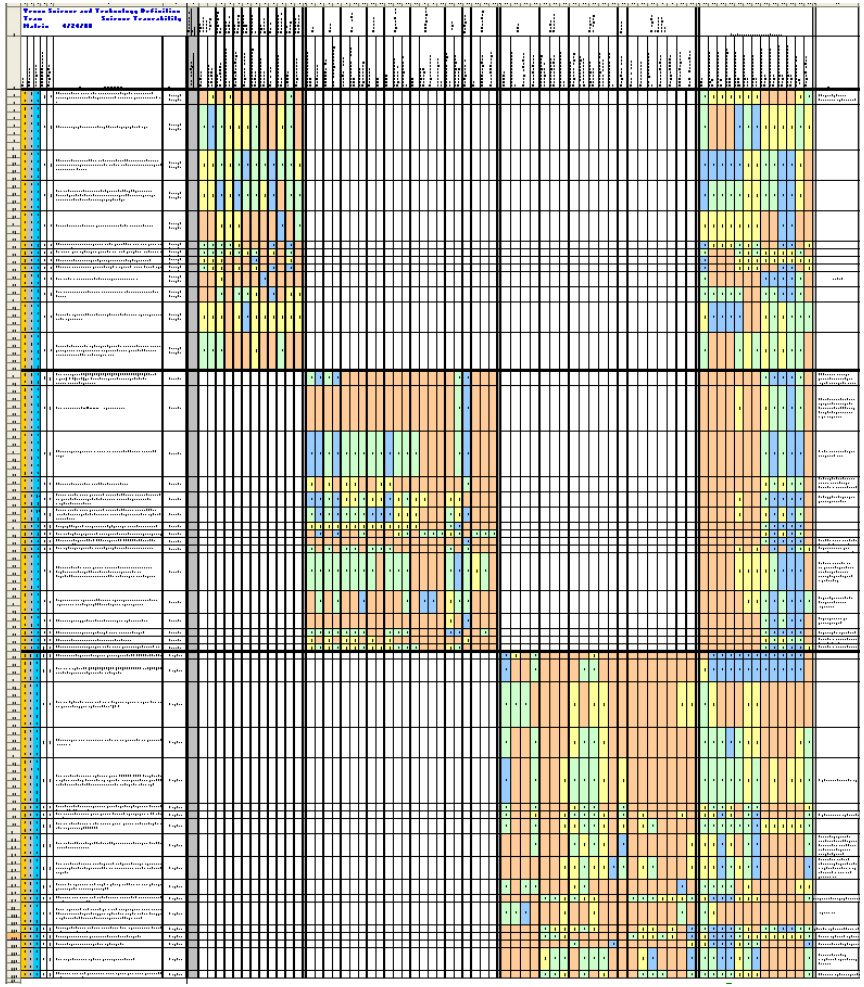
Mission architectures were constructed from these elements

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)

Science Traceability Matrix

Investigations | Measurement Technique & Instrument type | Architecture Element



Geology & Geophysics subgroup

Atmospheres subgroup

Geochemistry subgroup

Priorities

Flagship Priority Scoring (Column E)

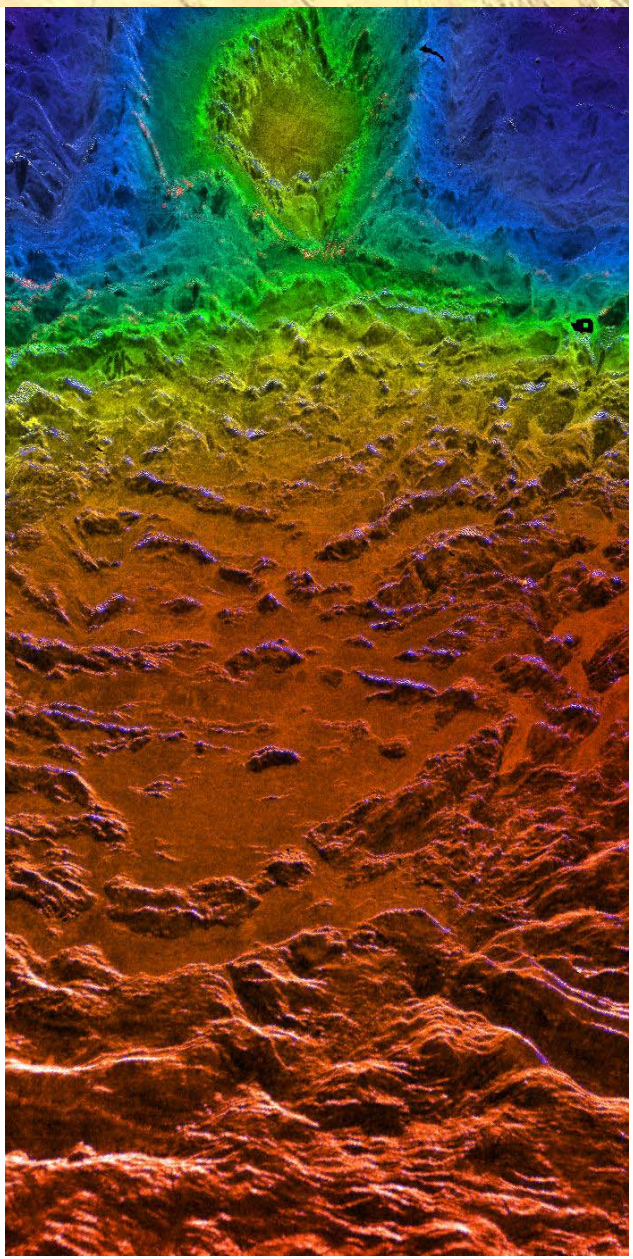
1 = Essential to have
2 = Highly Desirable
3 = Desirable
4 = Very Good to have

Instrument & Platform Goodness Scores

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

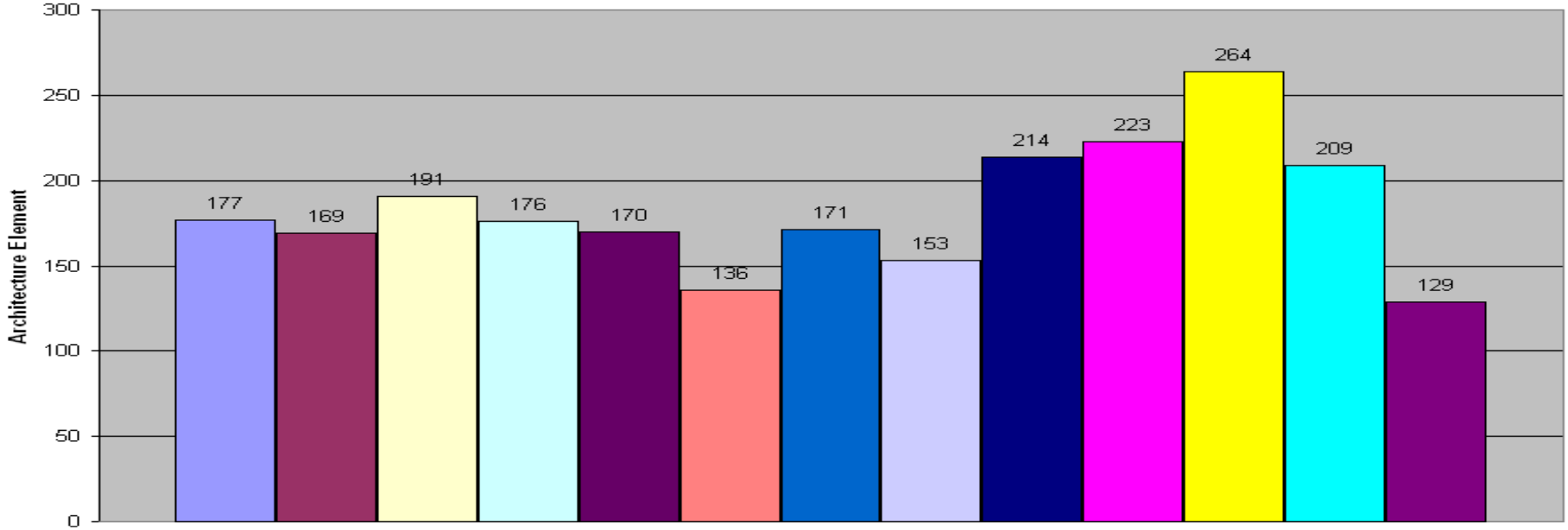
Mission Architecture Tradespace

- 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**



Ref: PIA00316.jpg – Fortuna Tessera

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

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**

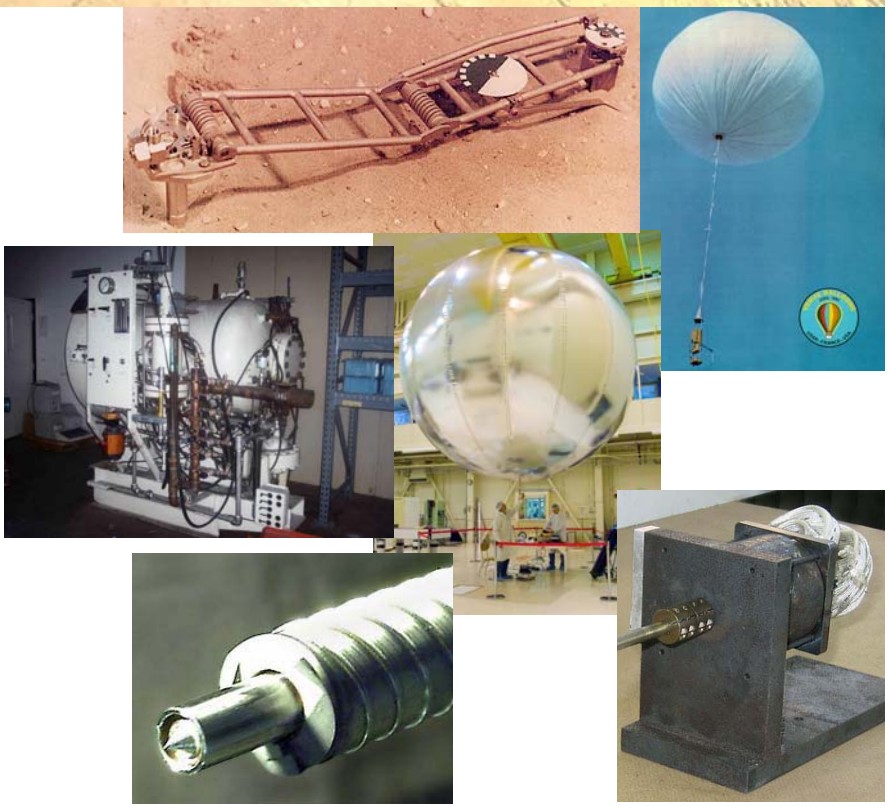
- A total of 17 mission architecture concepts were assessed
- Including **3 science subgroups recommended** mission architectures
  - one desired mission architecture per subgroup
- **One single architecture that combined all science goals**

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, 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

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

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)

Design Reference Mission

Ref: Venus surface image from Venera 14

Phase 2: Mission & Systems Trade Studies

- 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

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)
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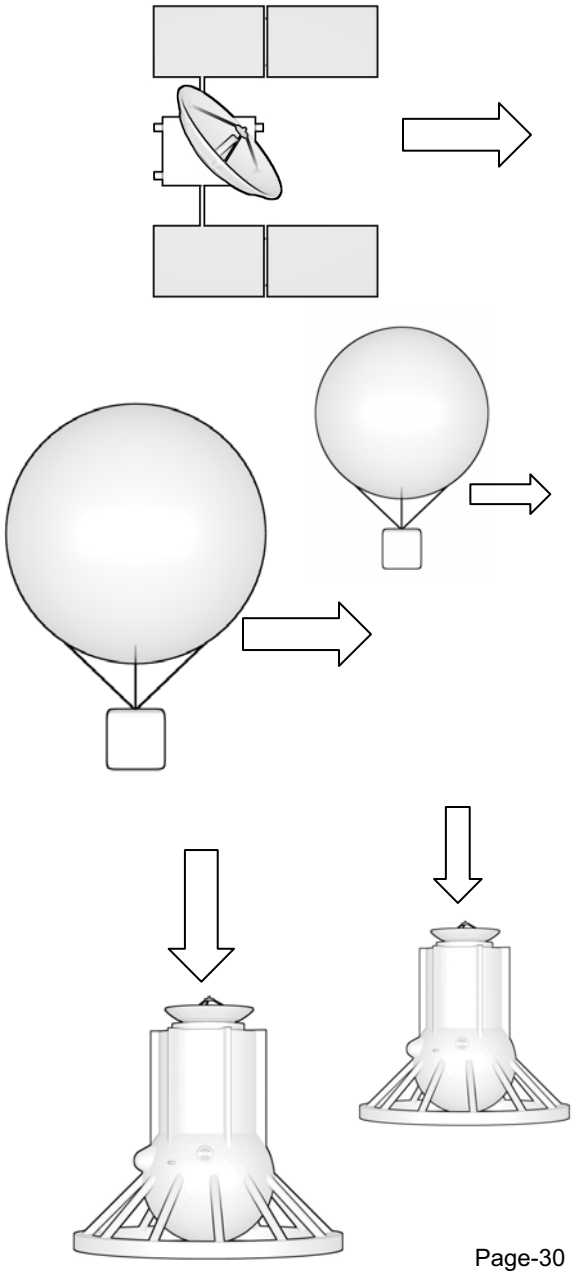
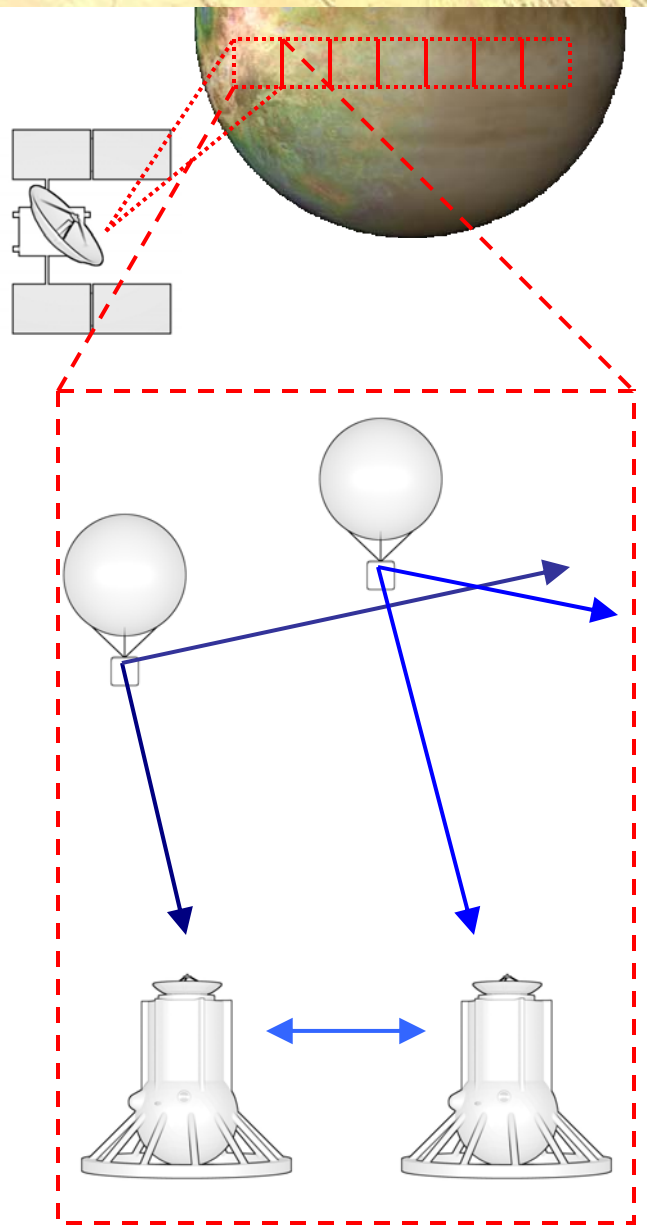


Flagship Science Synergies

- **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



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

Cost Analyses

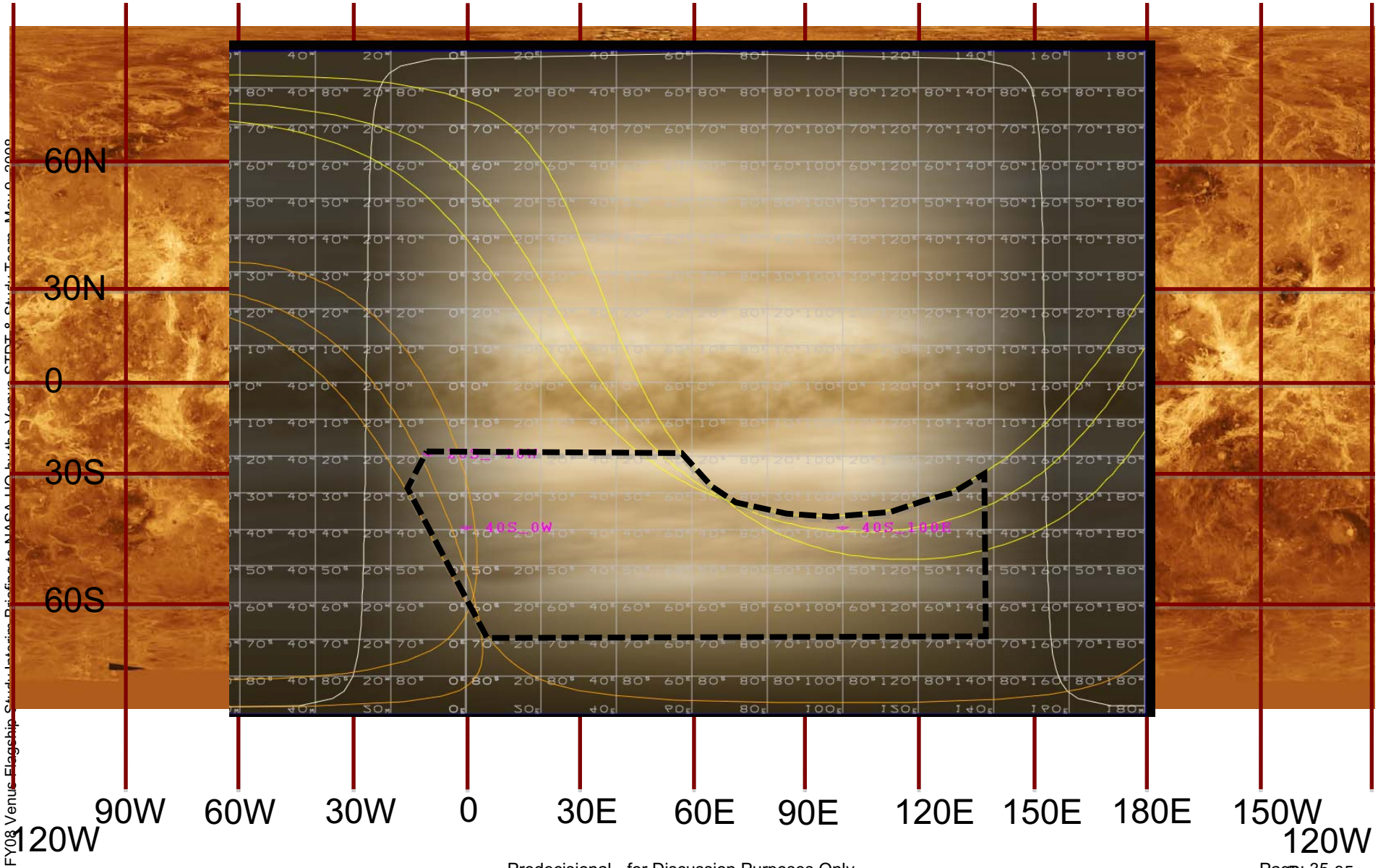
- So far – Instruments only, based on comparable instrument heritage
- JPL Team X study Oct 3-8
- ‘Rapid Cost Estimate’ method (Cutts, Peterson) based on large database of past missions and exponential complexity indices
- Independent Cost Estimate by Aerospace just approved

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



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)	***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**
Fourth meeting (Boulder)	***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.**