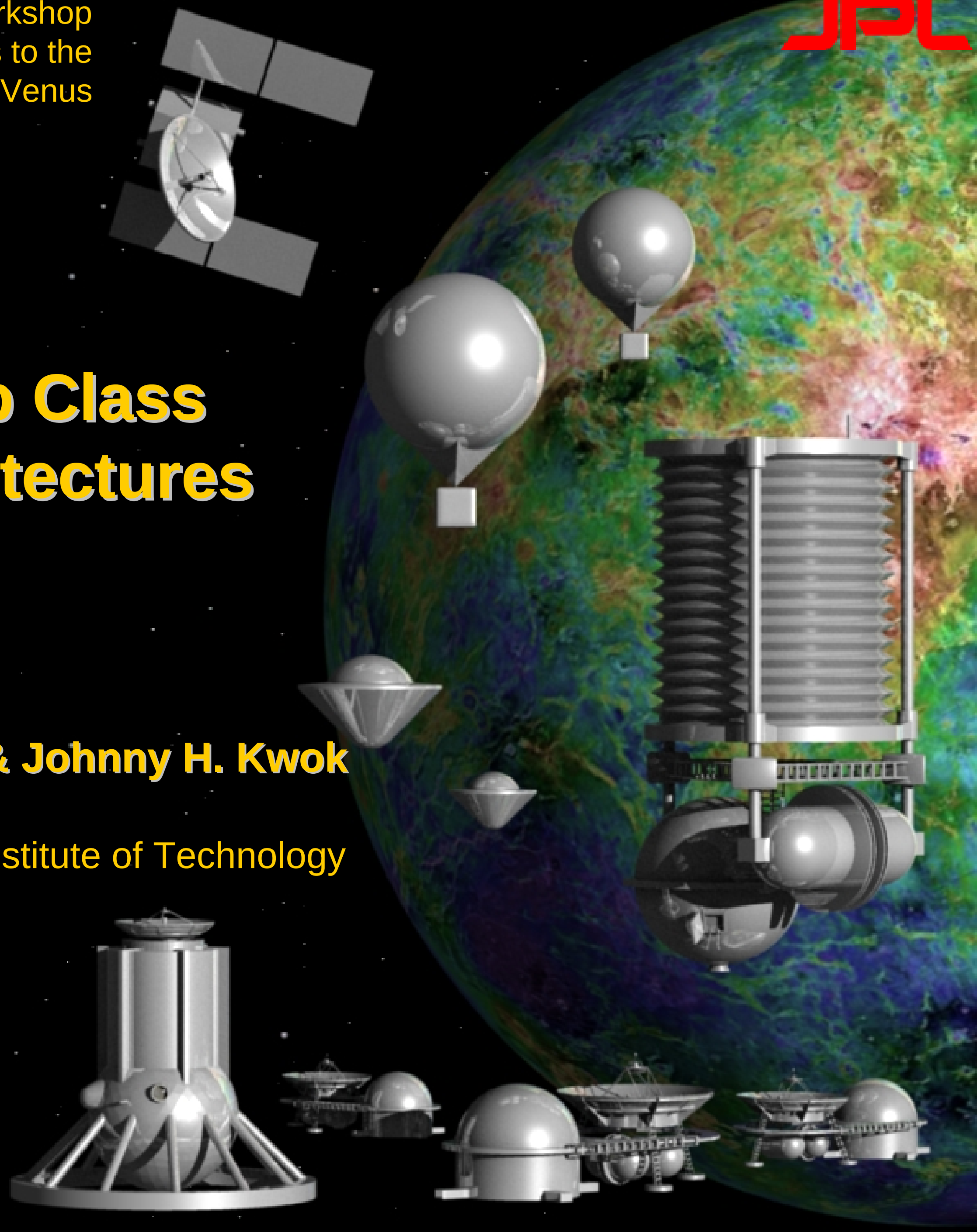
6th International Planetary Probe Workshop
IPPW-6, Session III: Probe Missions to the Giant Planets, Titan and Venus



Overview of Flagship Class Venus Mission Architectures

by
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Outline

- Introduction
  - Venus STDT & Study Overview
  - A world of contrasts
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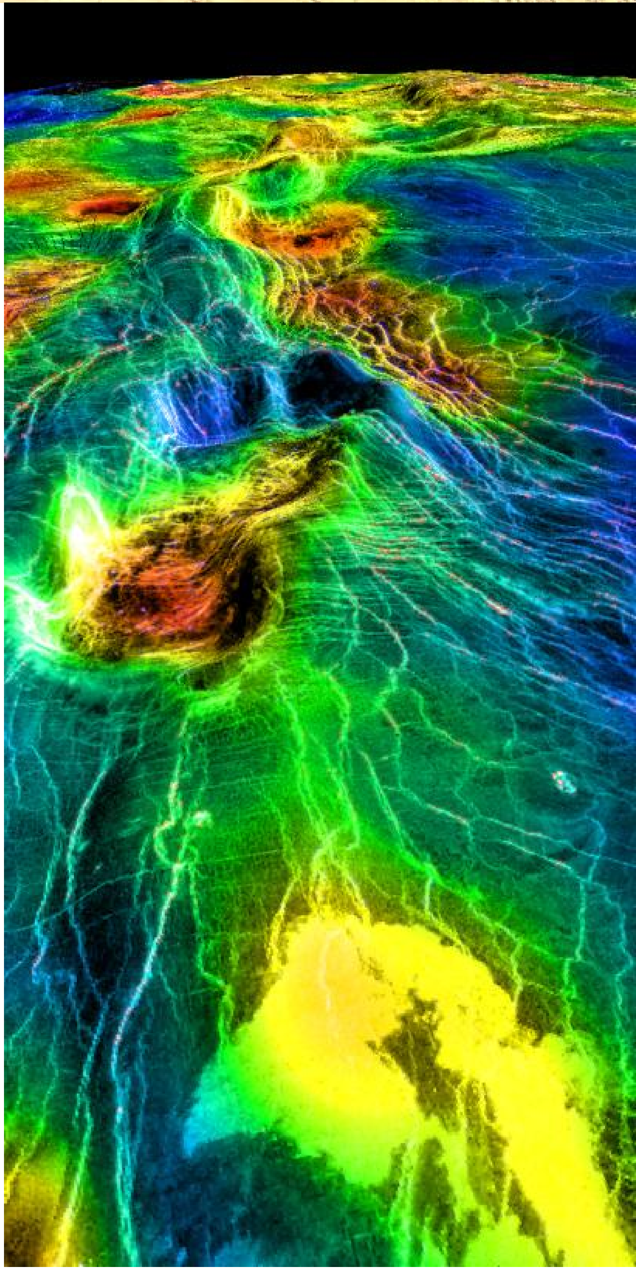
  - Science & Technology Traceability & FOM
- Interim Study Results
- Conclusions



Venus STDT & Study Overview

- NASA is interested in a high science-return **inner solar system Flagship mission** in addition to Mars Sample Return
  - Target Launch: **2020 – 2025**
  - Life Cycle Mission Cost Range: **$3-4B (FY'08)**
  - Technology Maturation: **TRL 6 by 2015**
- **Venus STDT** formed on 1/8/08 by NASA
  - to define a Flagship-class mission to Venus
- The combined team of **scientists**, **engineers** and **technologists** is tasked to
  - determine prioritized science objectives,
  - recommend suitable flagship class mission architectures,
  - assess cost, and other mission elements
  - recommend a Venus technology development roadmap
- Final report due to NASA by late November 2008

Acknowledgments – VSTDT & Study Team

Atmosphere Subgroup
- David Grinspoon *(DMNS)*
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Geochemistry Subgroup
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- Gary Hunter *(NASA GRC)*
- Steve Gorevan *(Honeybee Robotics)*

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

JPL Venus Flagship Study Core Team
- Johnny Kwok *(Study Lead)*
- Tibor Balint *(Mission Lead)*
- Craig Peterson
- Tom Spilker

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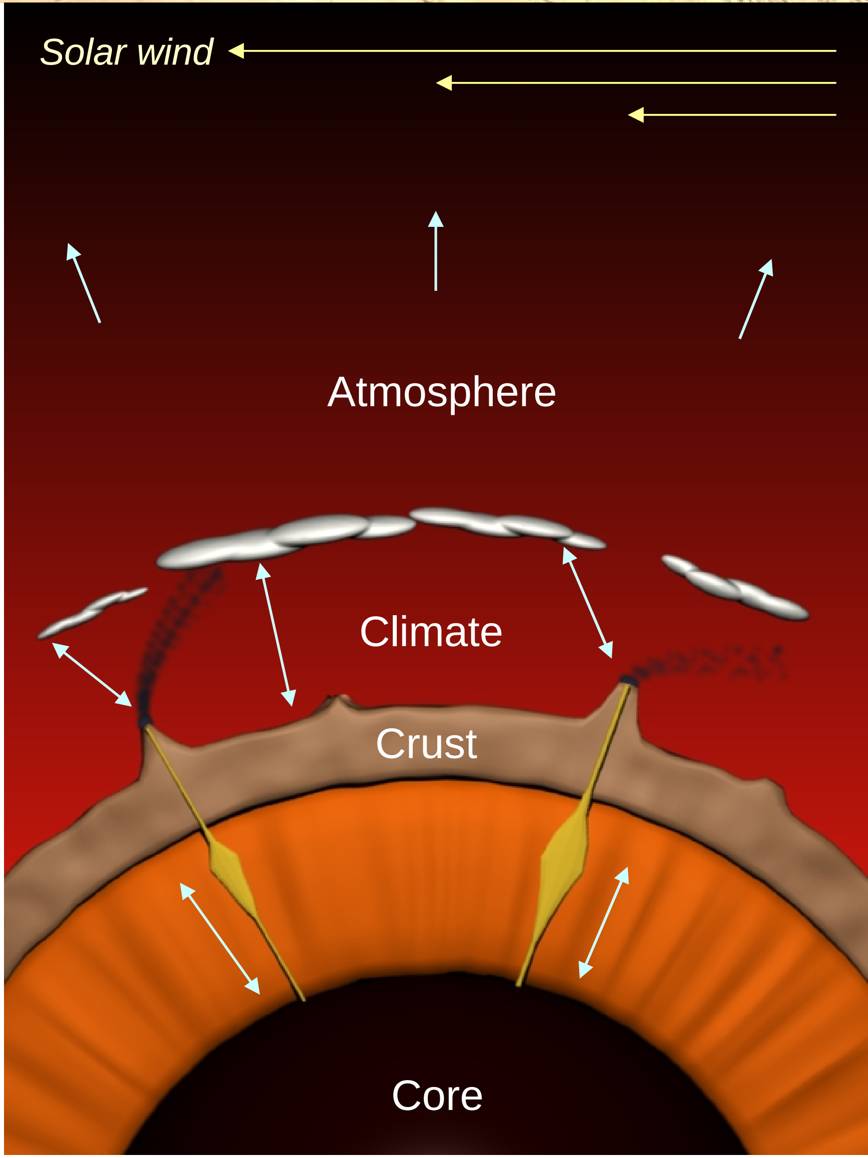
Venus: World of Contrasts

- **Why is Venus so different from Earth?**
  - What does the **Venus greenhouse** tell us about **climate change**?
    - Could be addressed with **probes & balloons** at various altitudes
  - How **active** is Venus?
    - Could be addressed with **orbiters & in-situ elements**
  - When and where did the **water** go?
    - Could be addressed with **landers**

Ref: M. Bullock, D. Senske, J. Kwok, Venus Flagship Study: Exploring a World of Contrasts (Interim Briefing), NASA HQ, May 9, 2008

Ref: VEXAG White Paper, 2007-2008



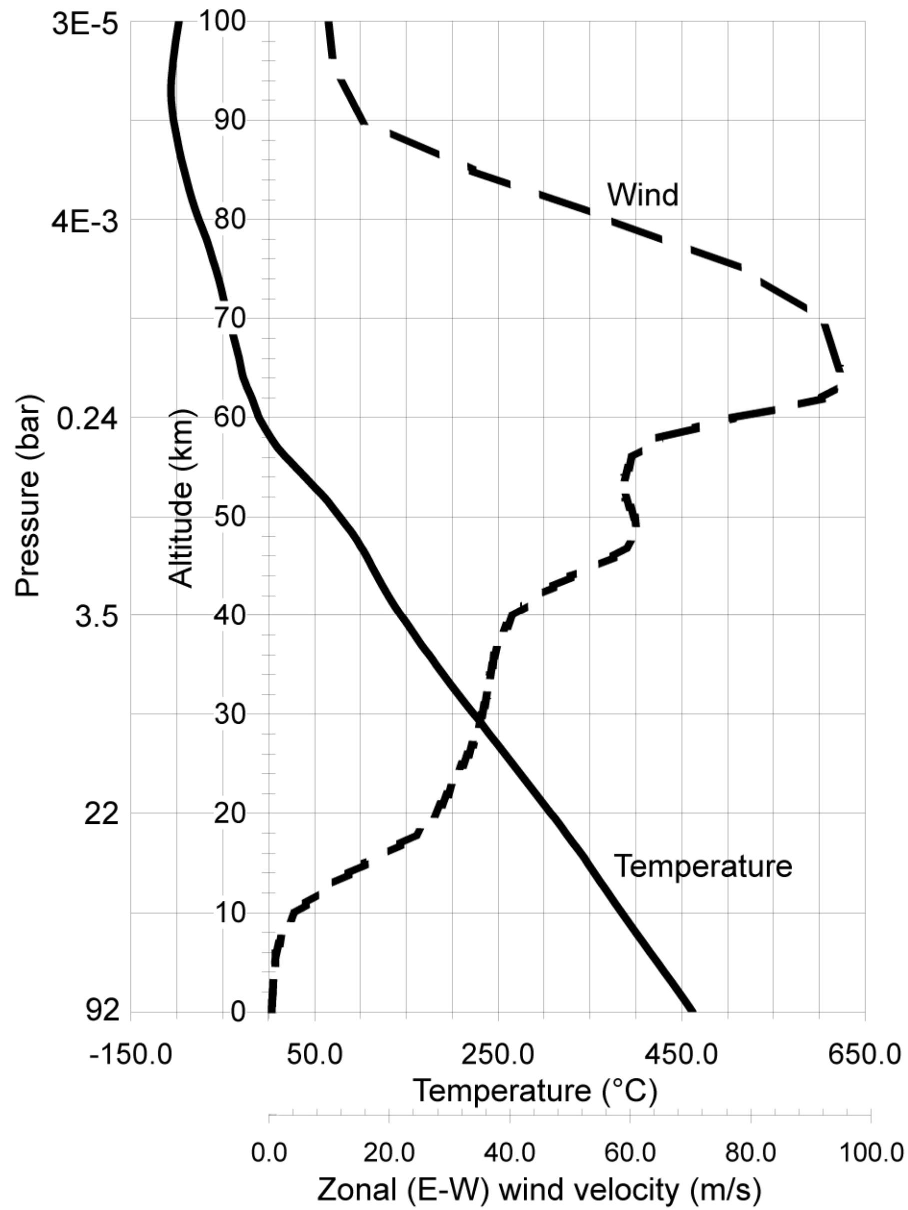
Ref: Image by E. Stofan & T. Balint

The Extreme Environment of Venus

- **Greenhouse** effect results in VERY HIGH SURFACE TEMPERATURES
- Average surface **temperature**:
  ~ 460°C 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 4 km altitude ~1 m/s; at 55 km ~60 m/s; at 65 km ~95 m/s
- **Superrotating** prograde jets in the upper atmosphere

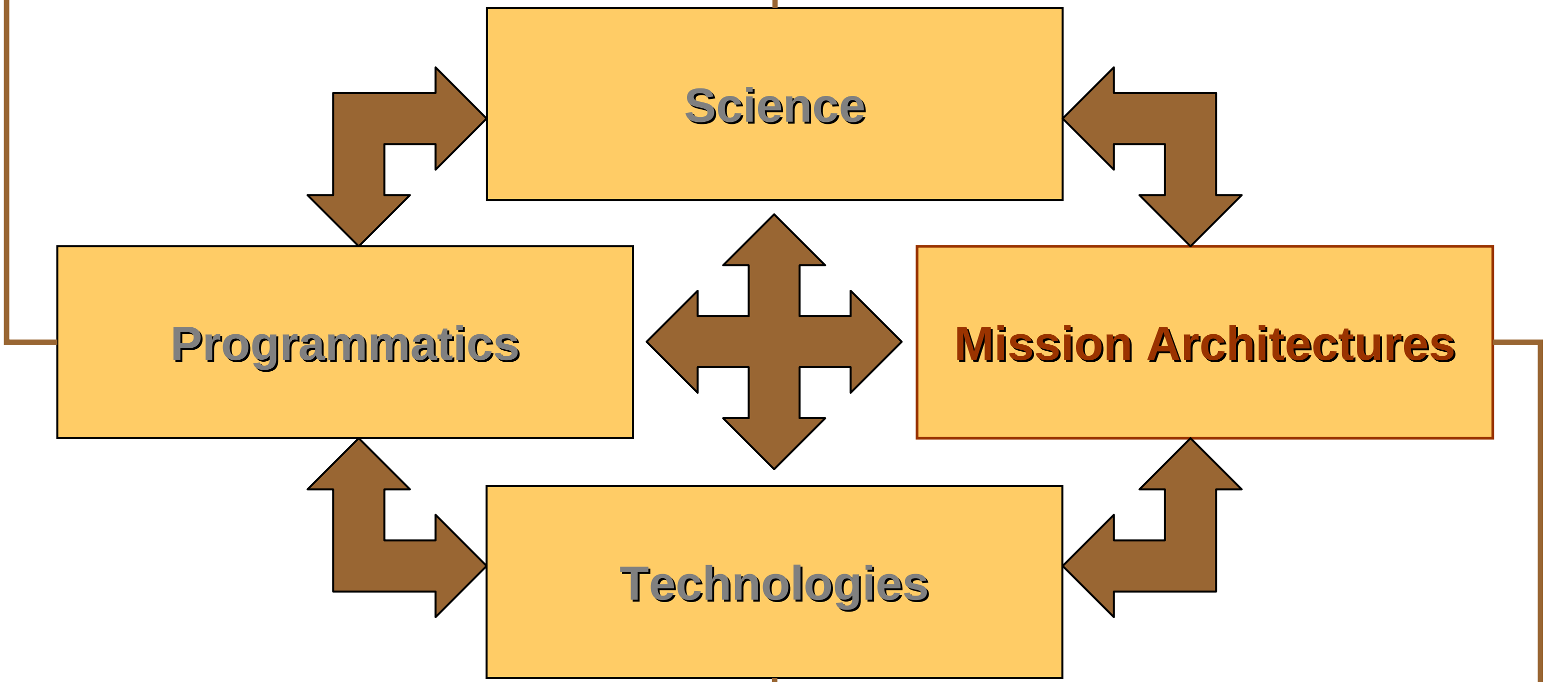


Ref: C. Wilson, U of Oxford, Personal communications
Ref: V. Kerzhanovich et al., "Circulation of the atmosphere from the surface to 100 km",

Role of Mission Architectures

e.g., - mission class (flagship, NF, Discovery)
- mission cost cap
- SSE Roadmap; mission lineup
- international collaboration

e.g., - NRC Decadal Survey;
- VEXAG goals & objectives
- Project science team measurements & investigations

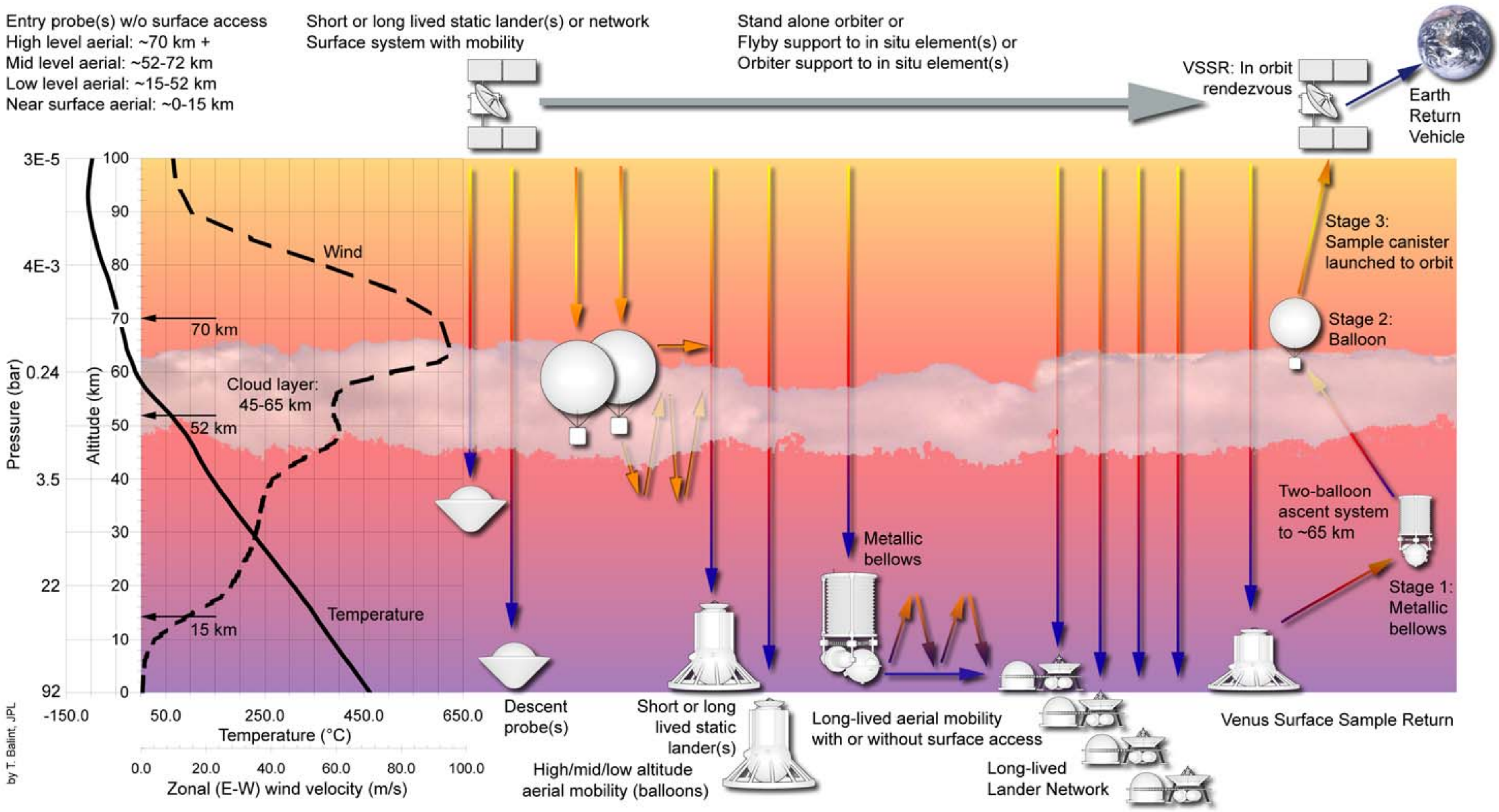


e.g., - extreme environments technologies
- systems approaches: tolerance, protection & hybrid systems
- atmospheric entry, descent, landing, balloon inflation
- instrument technologies

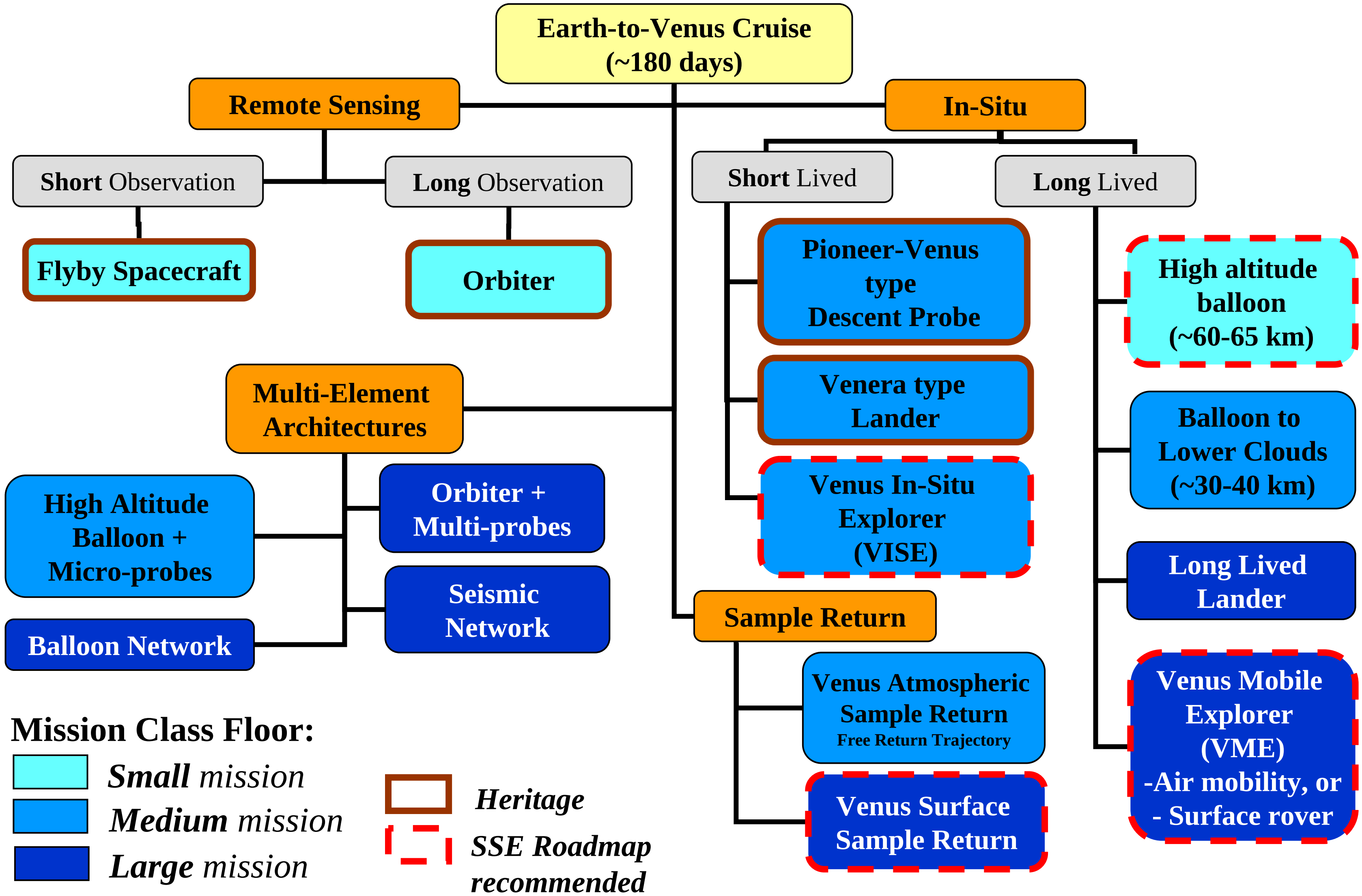
e.g., - single or multi-element architecture
- single or dual launch
- mission elements (orbiter, flyby, balloon, lander, probe, plane)
- lifetime (hours, weeks, years)
- telecom link (relay, Direct-to-Earth)

Note: NF – New Frontiers mission class (assumed cost cap: ~$650M w/o launch vehicle)
Flagship class (assumed cost cap: ~$2-4B); Discovery class (assumed cost cap: ~$450M)

Potential Venus Mission Elements



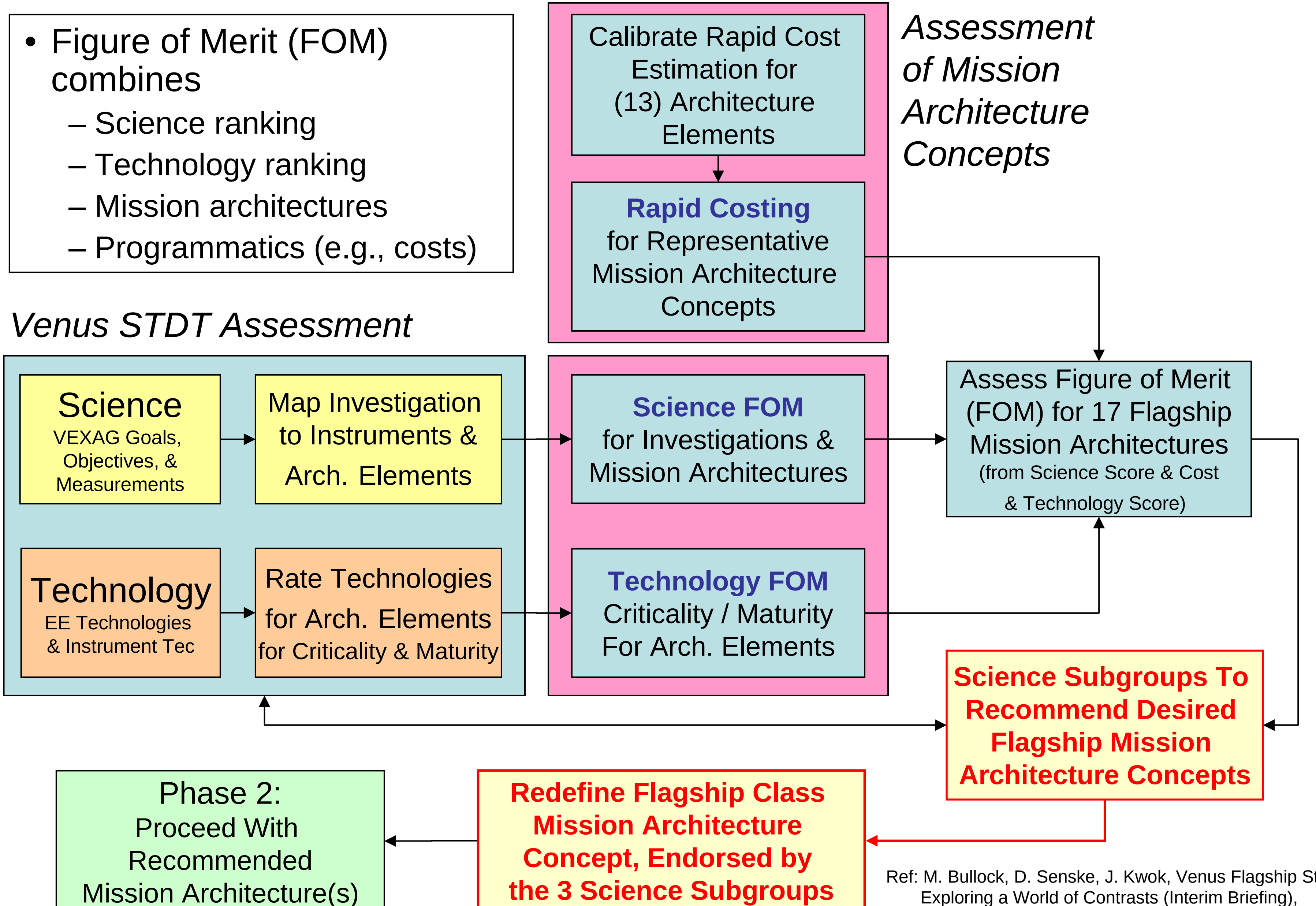
Grouping of Typical Venus Mission Architectures



Ref: Cutts, Balint, “Overview of typical mission architectures”, 3rd VEXAG meeting, Crystal City, VA, Jan.11-12, 2007

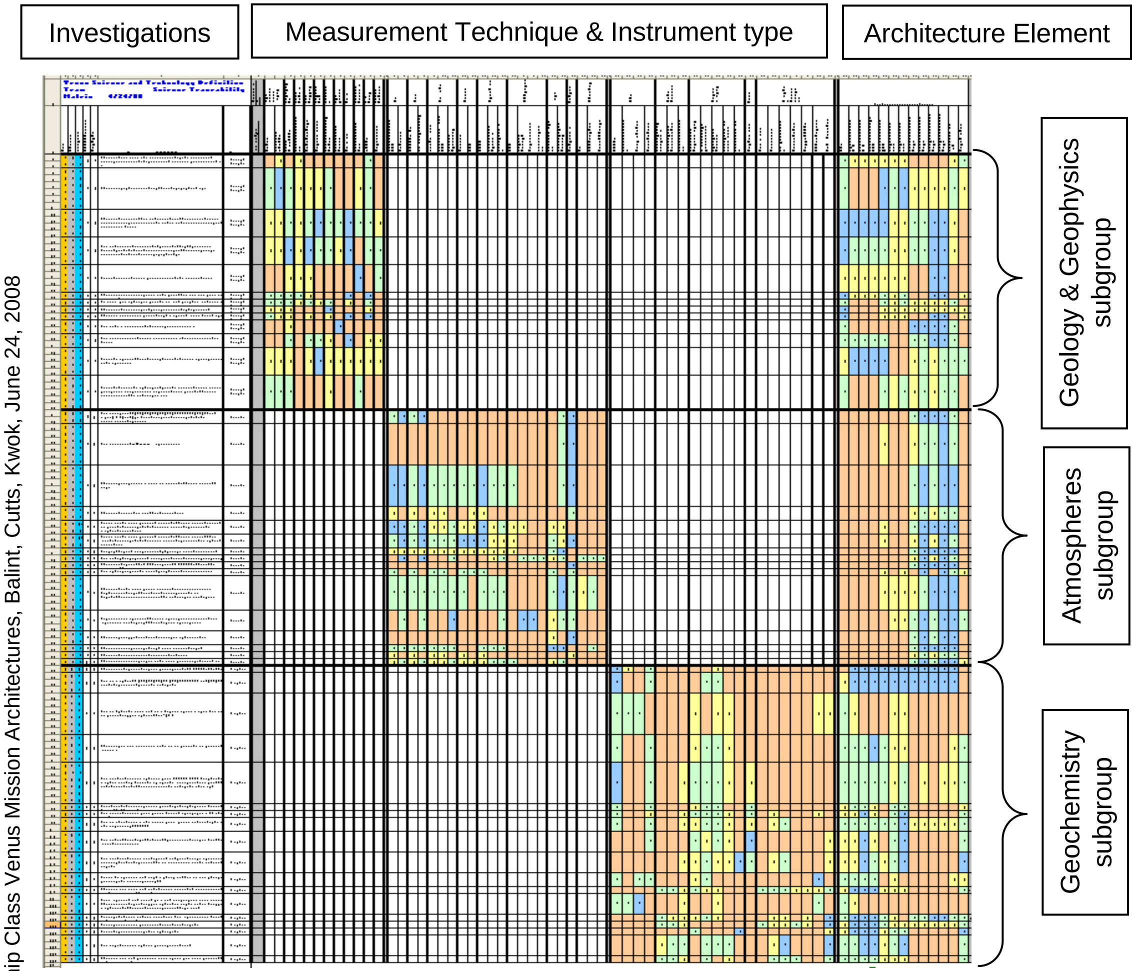
Flowchart for the VSTDT FOM Process

- Figure of Merit (FOM) combines
  - Science ranking
  - Technology ranking
  - Mission architectures
  - Programmatics (e.g., costs)



Ref: M. Bullock, D. Senske, J. Kwok, Venus Flagship Study: Exploring a World of Contrasts (Interim Briefing), NASA HQ, May 9, 2008

Science Traceability Matrix & Technology Assessment



- Two technology categories:
  - For **operation and survivability** of subsystems on architectural elements
  - For **science measurements.**
- Technology Assessment Process:
  - STDT technology sub-group identified major technology drivers for all potential missions
  - Technology Figure of Merit (FOM) was determined using two factors:
    - **Technology criticality** for a specific architecture element – *assessed by the mission architecture team*
    - **Technology maturity** – *assessed by the technology sub-group*

Priorities

Flagship Priority Scoring (Column E)

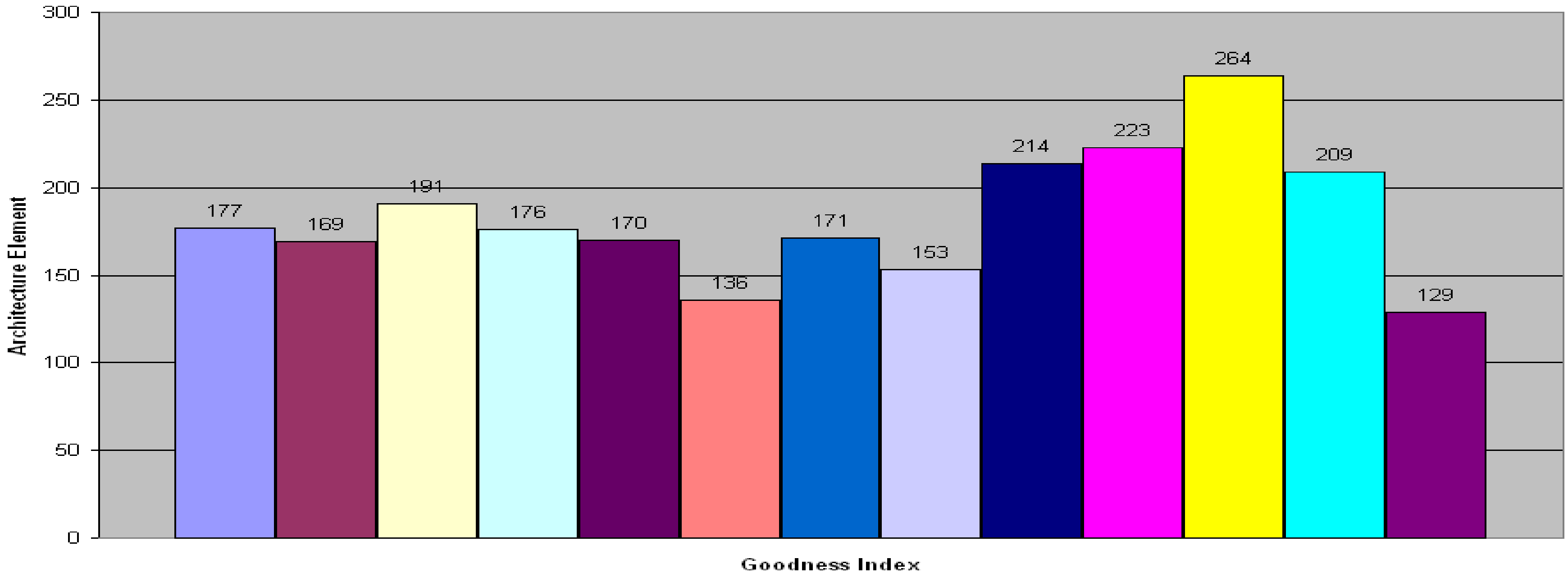
1 = Essential to have
2 = Highly Desirable
3 = Desirable
4 = Very Good to have

Instrument & Platform Goodness Scores

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

Science & Technology FOMs were then used in the overall proposed mission architecture selection

Summary of FOM & Costing for Mission Architecture Elements



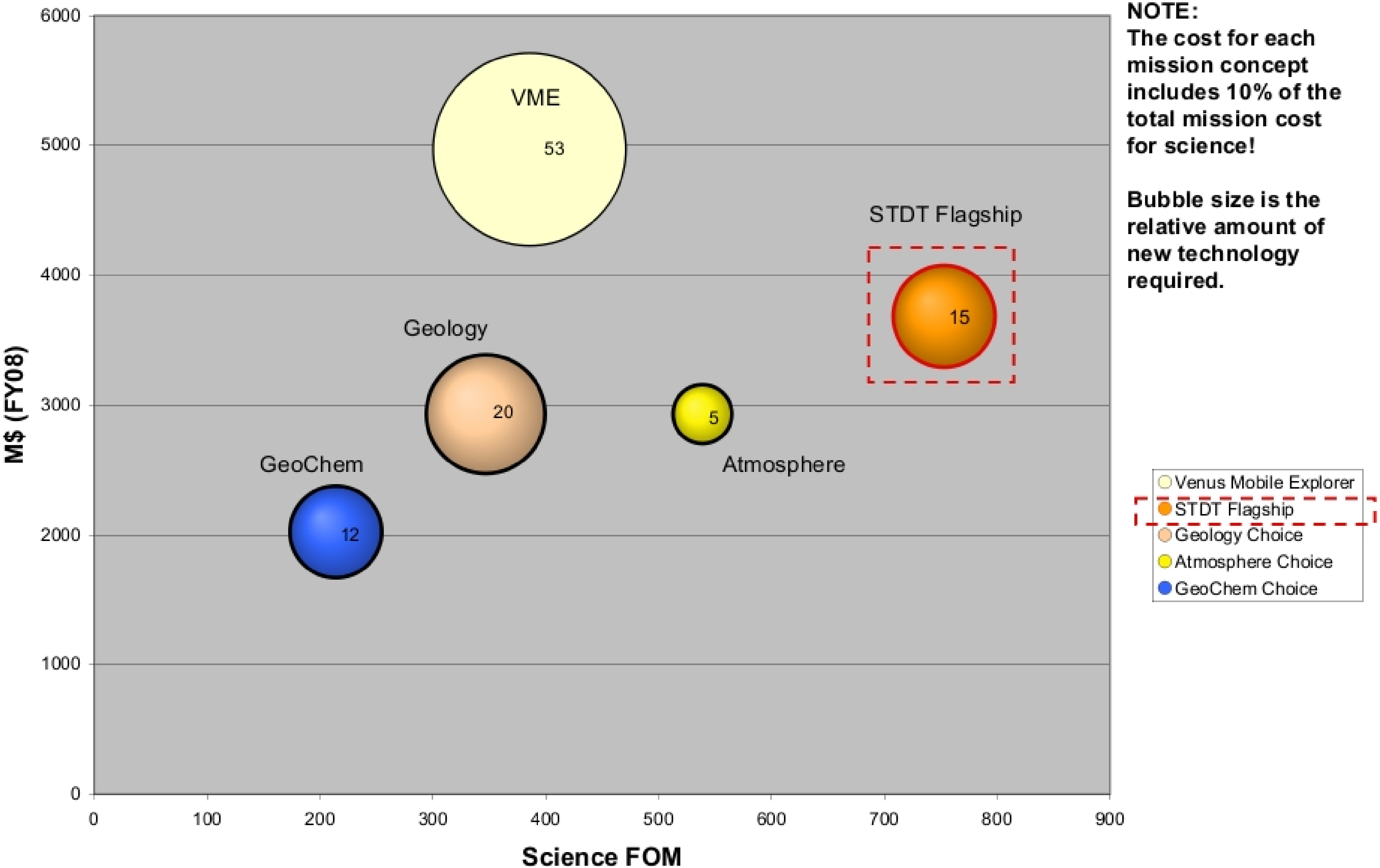
	Architecture Element												
	Orbiter	High-Level Aerial (> 70 km)	Mid-Level Aerial (52-70 km)	Low-Level Aerial (15-52 km)	Near-Surface Aerial (0-15 km)	Single Entry Probe (no surf.)	Multiple Entry Probe (no surf.)	Short-Lived Lander (Single)	Short-Lived Lander (Multiple)	Long-Lived Lander (Single)	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 (in $B)	0.5	0.6	0.9	1.5	2.1	0.51	0.54	1.0	1.1	2.3	2.3	3.6	2.0

Potential Venus Flagship Mission Architectures

Selected Mission Architecture Concepts	Architecture Elements															
	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	Cost (08M$)	Science Score	Technology Score
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				$3.7B	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**

Science FOM vs. Mission Cost & Technology Scores

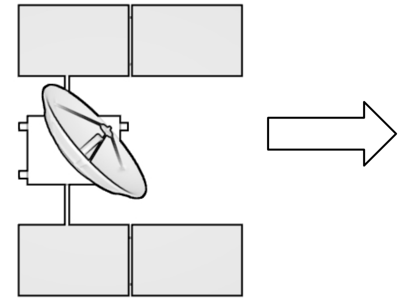


NOTE:
The cost for each mission concept includes 10% of the total mission cost for science!

Bubble size is the relative amount of new technology required.

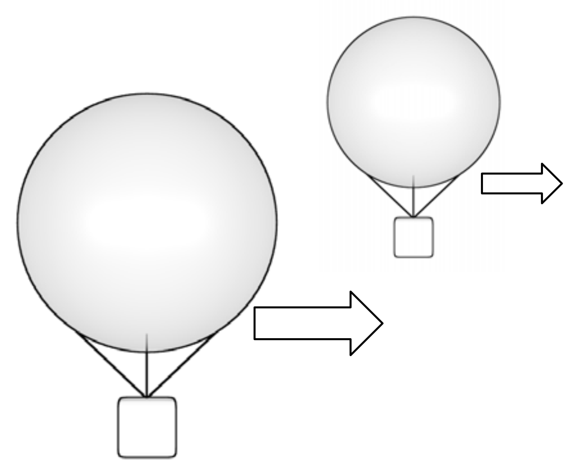
Ongoing Mission Architecture Study

- Based on these, a **mission architecture** was identified, that
  - **Meets all the highest science priorities**, and
  - Has the **highest Figure of Merit** (FOM)

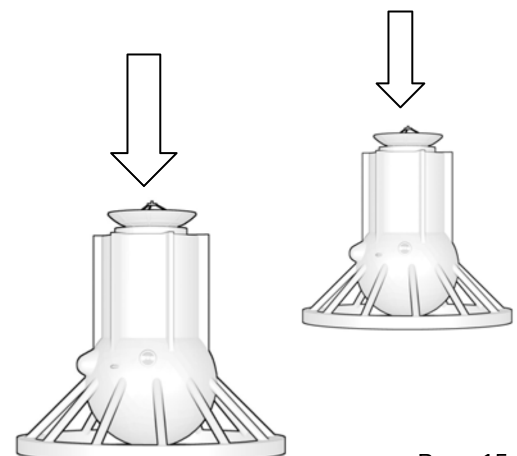


- A **capable orbiter** (years) with high resolution radar imaging and topography

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

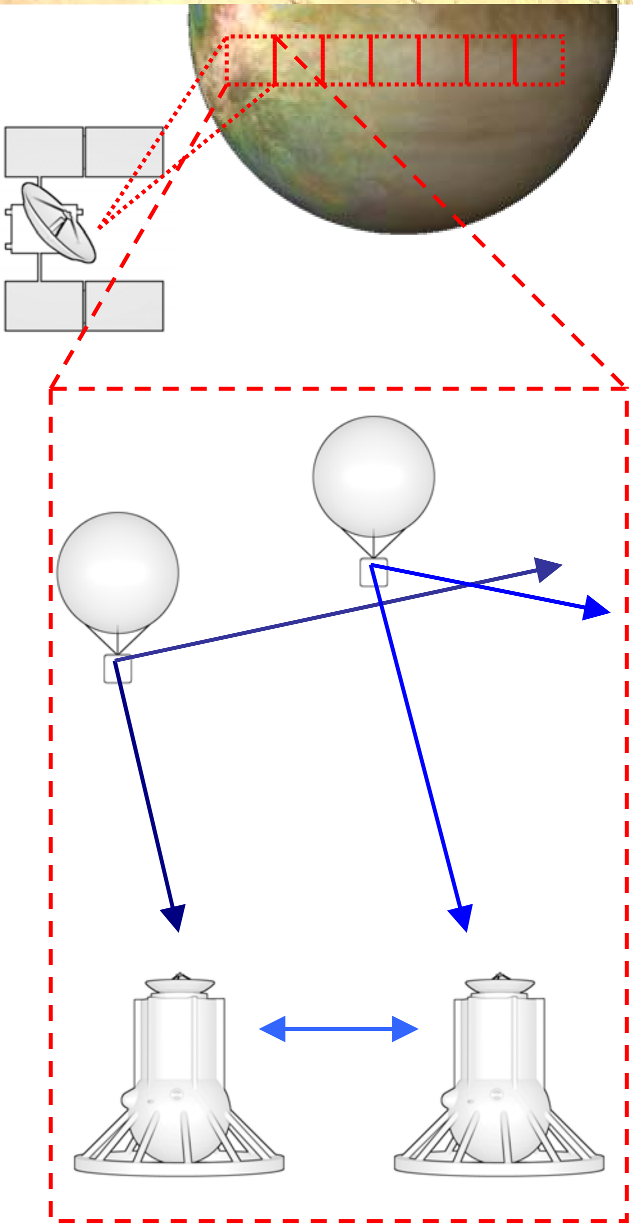


- **2 landers with extended surface life** (hours) that also would acquire detailed atmospheric data on descent
  - Potential **add-on science with single long lived instrument** is **not excluded**, and could enhance science return



Science Synergies for the Proposed Flagship Architecture

- **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 would give vertical slices of the atmosphere during descent
  - 2 balloons would 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



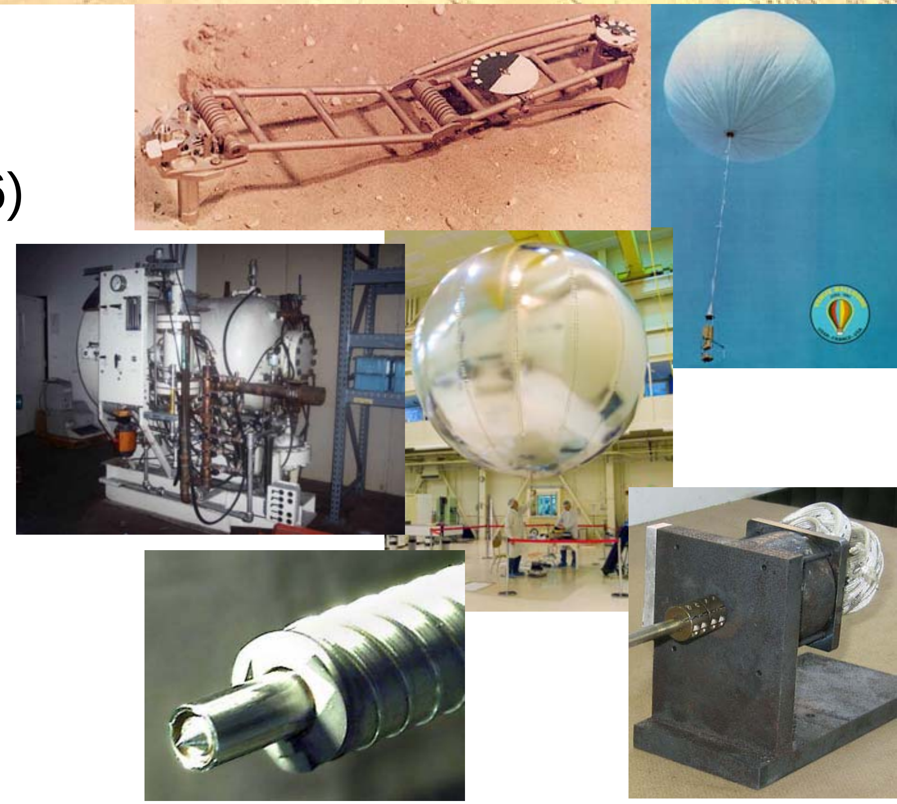
Ref: M. Bullock, D. Senske, J. Kwok, Venus Flagship Study: Exploring a World of Contrasts (Interim Briefing), NASA HQ, May 9, 2008

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 example:
    - environmental testing (high P,T, CO_2, Corrosion)
    - pressure & temperature mitigation
    - sample acquisition & handling

  – **Requires instrument technology development** for example
    - 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

International Collaboration

- Multi-element architecture lends itself to international collaboration

- Proposed 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)

The End

… or just the beginning …