Overview of Past Venus Missions and Potential Architectures for Future Missions

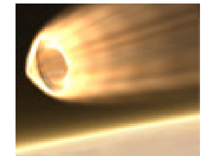
– architectures – issues – failures –

By

Dr. **Tibor S. Balint**

Jet Propulsion Laboratory, California Institute of Technology

Pasadena, CA



6th International Planetary Probe Workshop, Atlanta, Georgia
Short Course on Extreme Environments Technologies

06/21-22 2008

Overview

- Introduction
  - Extreme environments & Science drivers

- Typical Mission Architectures to Explore Venus
  - Role of mission architectures
  - Mission elements & Architectures

- Brief Overview of Venus Missions
  - Past missions
  - Present missions & Missions under development
  - Future mission concepts

- The Good, the Bad, & the Future
  - Lessons learned from past missions
  - Challenges for future missions

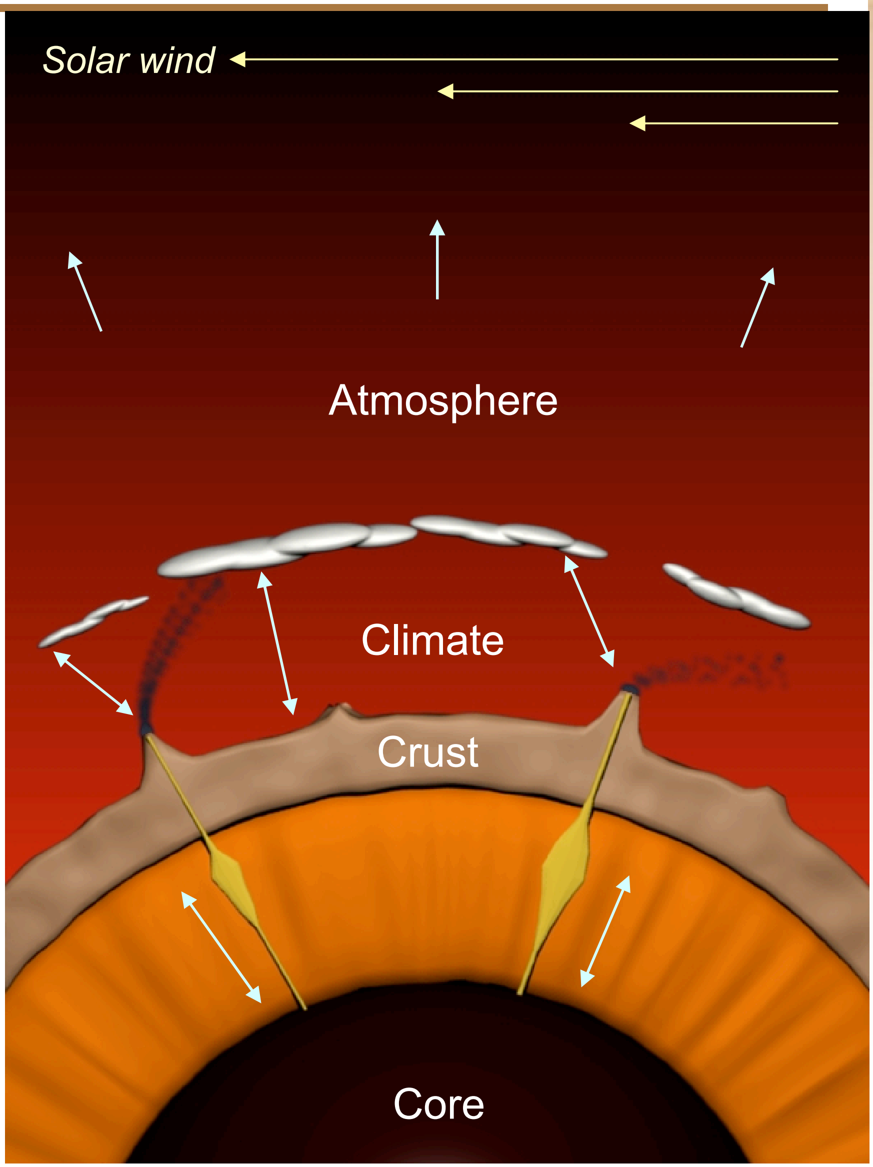
- Conclusions

A First Look at Venus

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

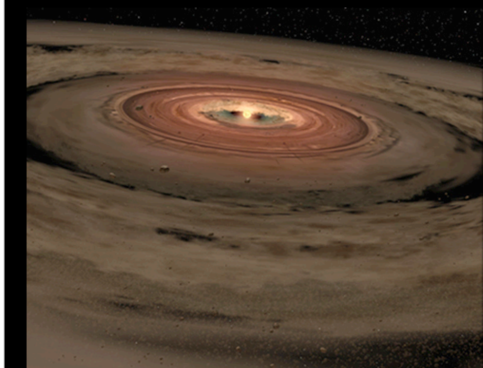


Ref: Image by E. Stofan & T. Balint

Science Drivers for Venus Exploration

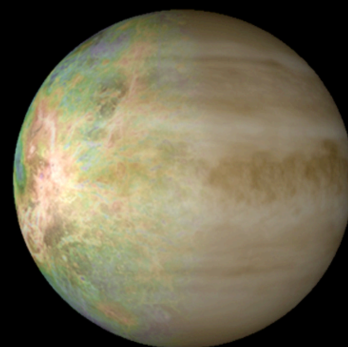
Venus Exploration Goals and Objectives

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



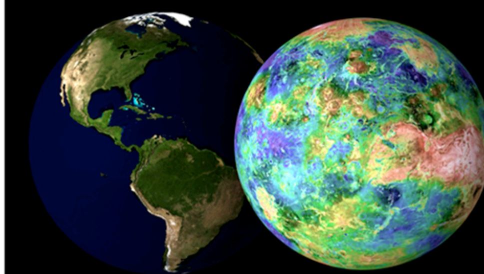
- *Determine isotopic composition of atmosphere*
- *Map the mineralogy and composition of the surface on a planetary scale*
- *Characterize the history of volatiles in the interior, surface and atmosphere*
- *Characterize the surface stratigraphy of lowland regions and the evidence for climate change*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



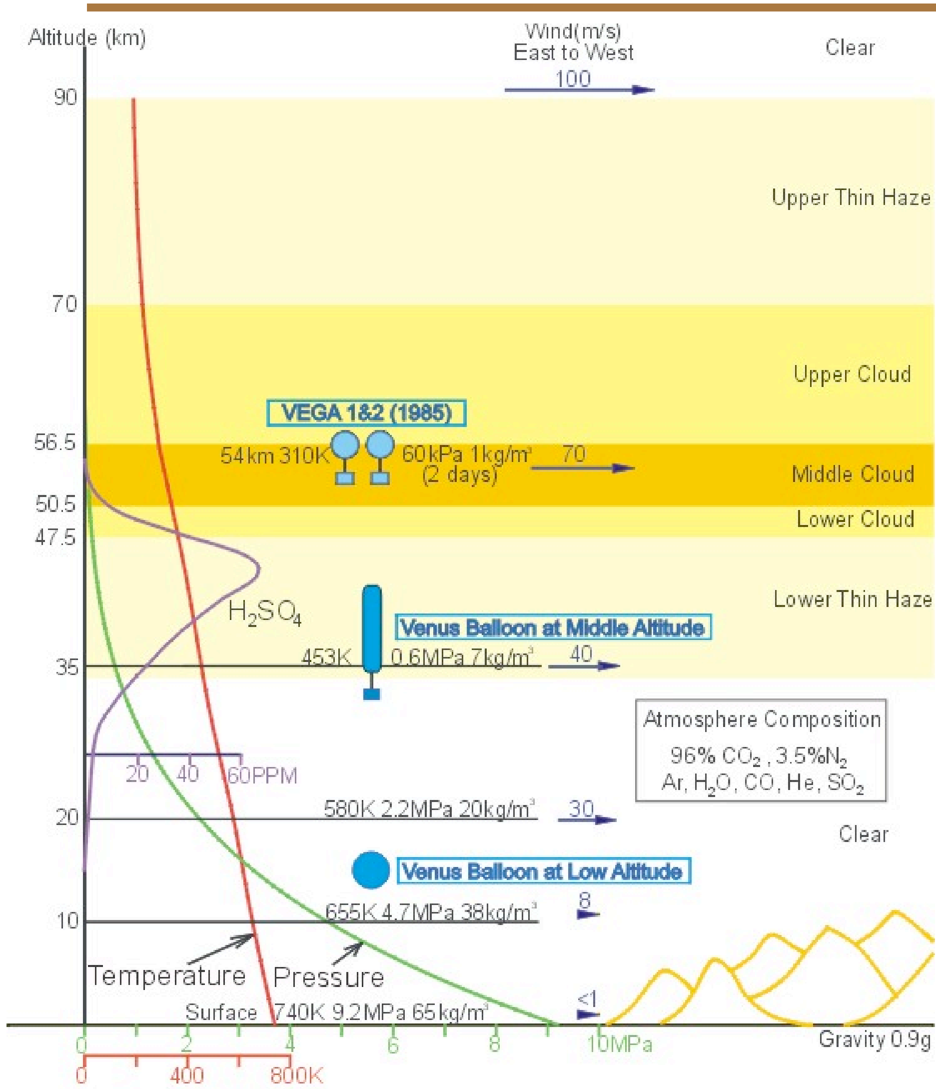
- *Search for fossil evidence of past climate change in the surface and atmospheric composition.*
- *Search for evidence of changes in interior dynamics and its impact on climate*
- *Characterize the Venus Greenhouse effect and its similarities to those on Earth and other planets*

Venus Exploration VEXAG Analysis Group

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

Ref: VEXAG White Paper, 2007-2008

The Extreme Environment of Venus



VENUS ENVIRONMENT AND BALLOONS

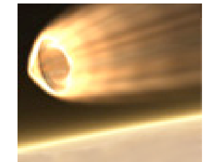
Ref: N.Yajima, N.Izutsu, H.Honda, K.Goto and T.Imamura (ISAS) N.Tomita and K.Akazawa (Musashi Institute of Technology Univ.) “Feasibility and Applicability of Planetary Balloons,” Website: www.isas.ac.jp/home/ Sci_Bal/engplanetary.html

- Greenhouse effect results in **VERY HIGH SURFACE TEMPERATURES**
- Average surface **temperature**:
  - **~ 460°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

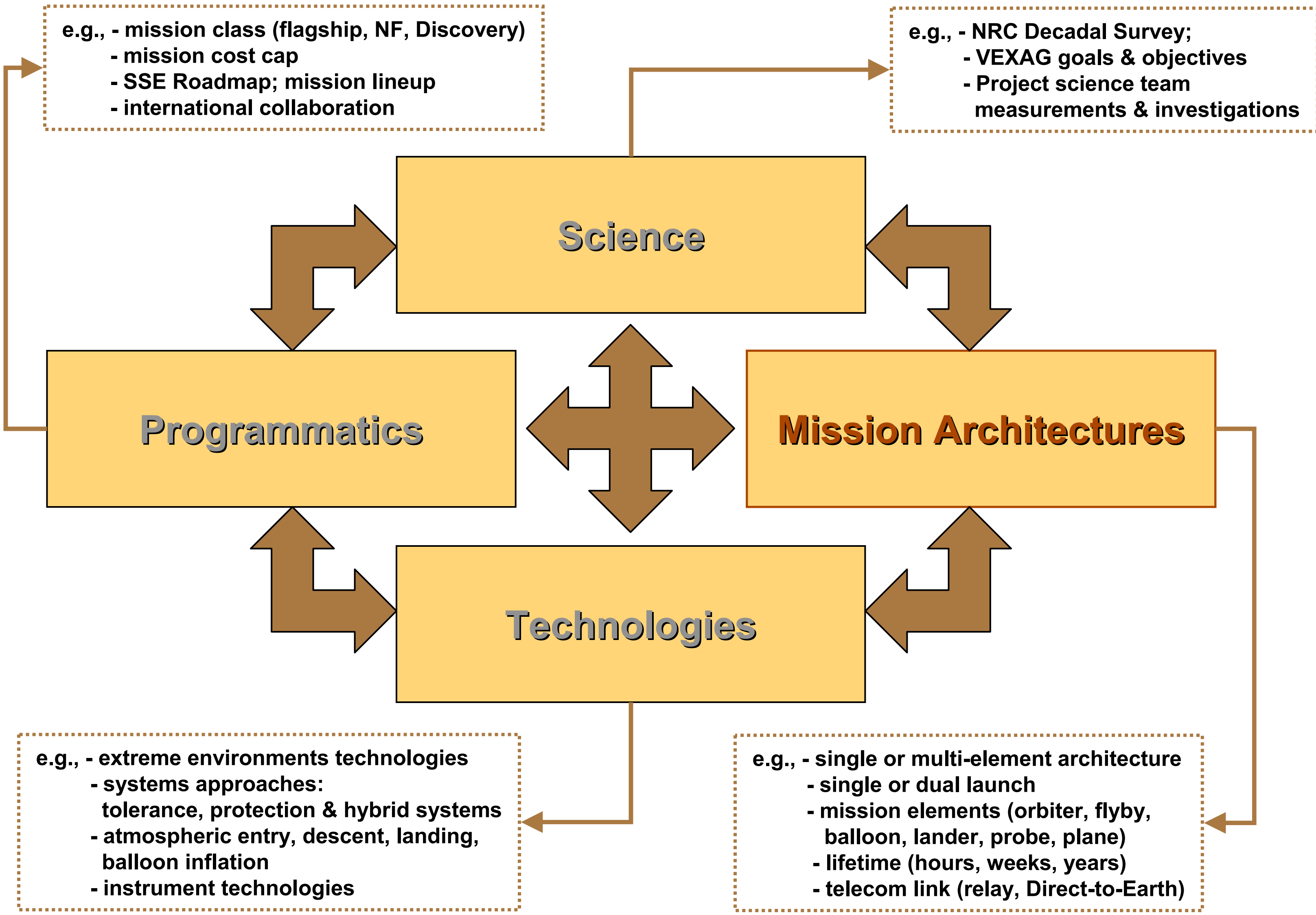
Ref: C. Wilson, U of Oxford, Personal communications
Ref: V. Kerzhanovich et al., "Circulation of the atmosphere from the surface to 100 km",

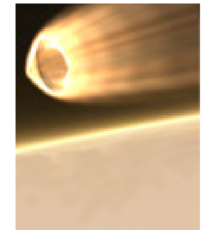


Typical Mission Architectures to Explore Venus

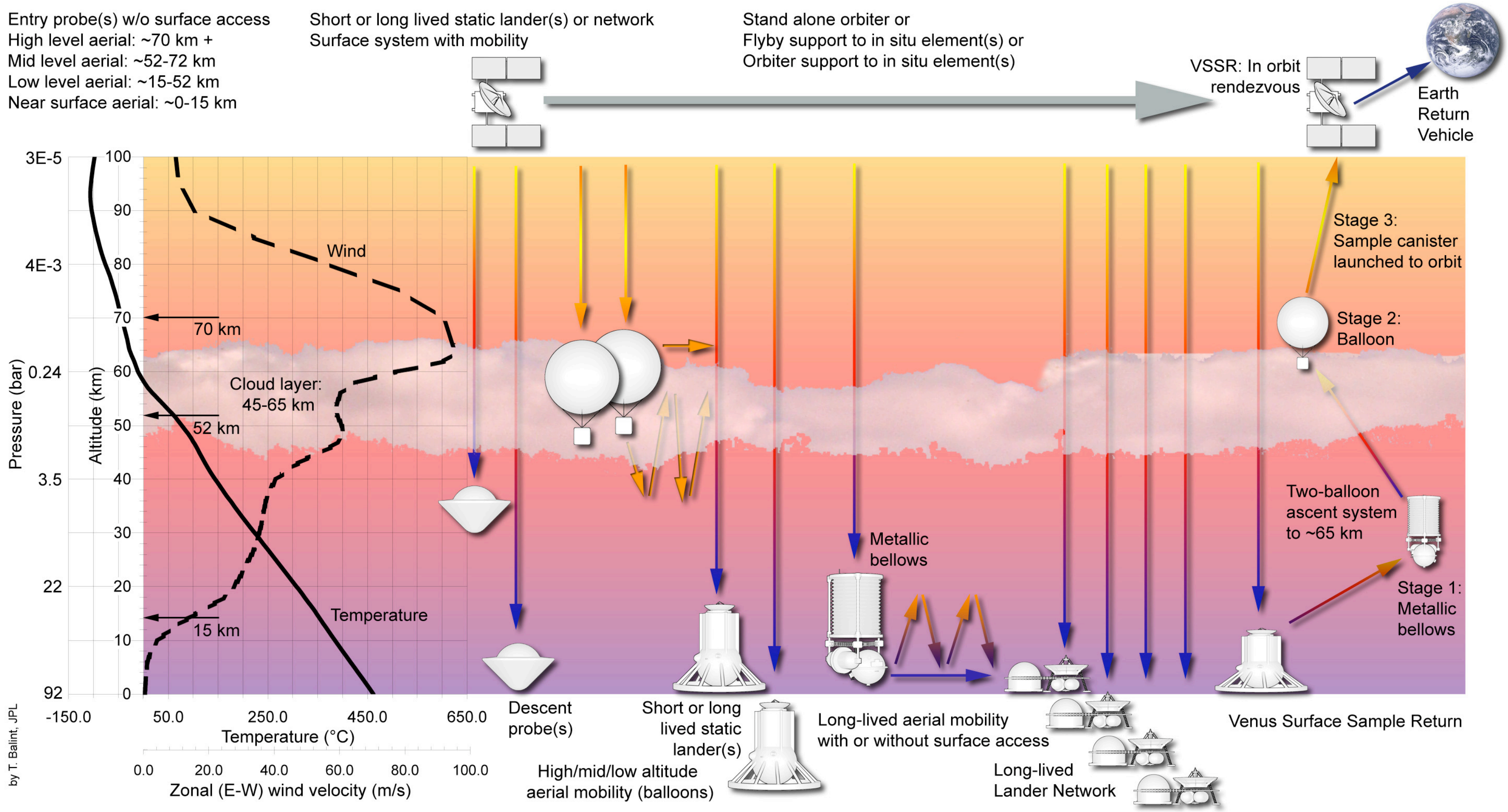
– mission elements – architectures – trajectories –

The Role of Mission Architectures

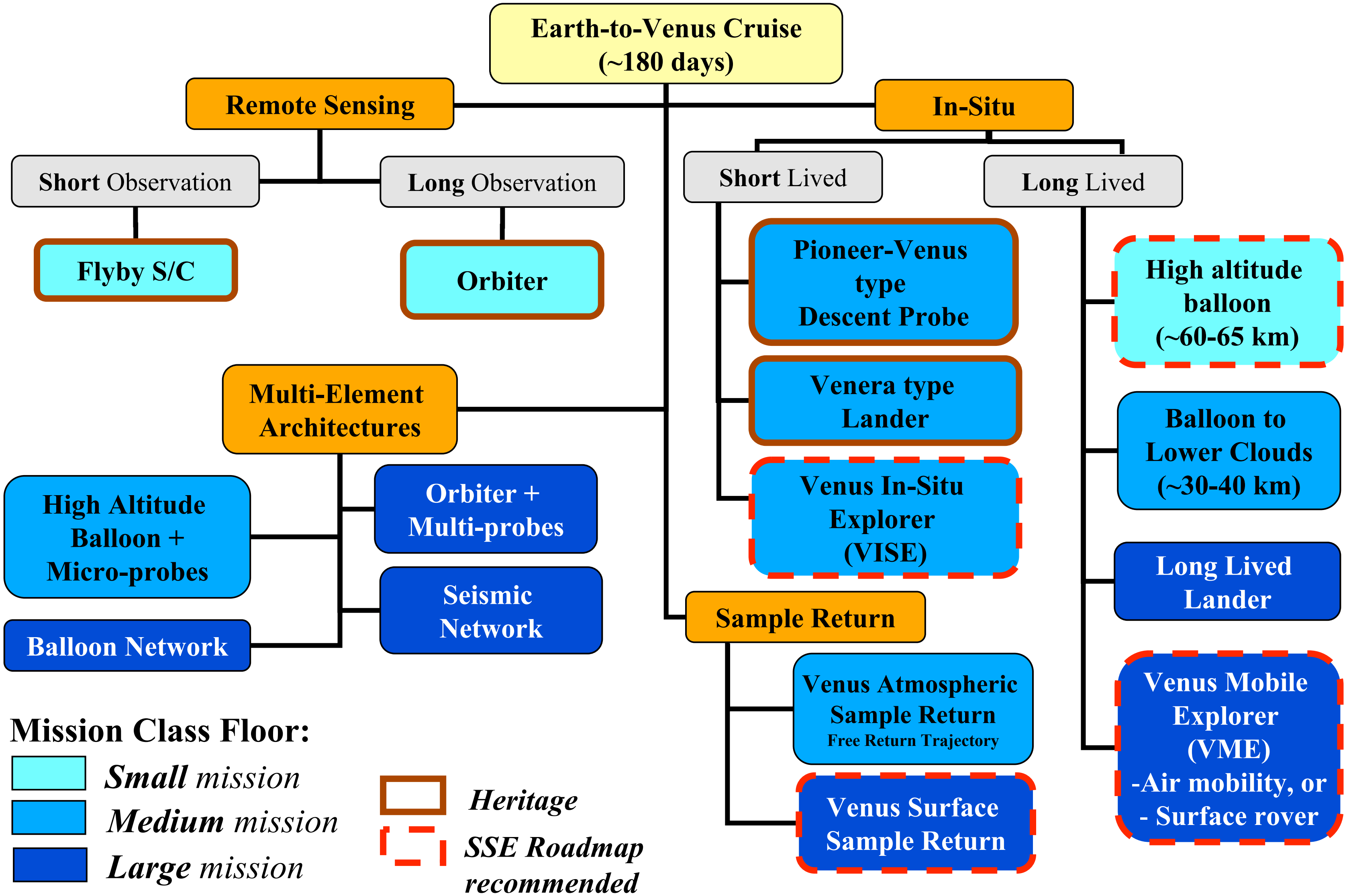




Potential Venus Mission Elements



Grouping of Typical Venus Mission Architectures



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

Brief Overview of Venus Missions

– past – present – future –

Past: Russian Missions to Venus

- Between **1961 & 1984**/(1985) **Russia** carried out the most successful Venus exploration **program** among nations
- **Launched 29** missions to Venus:
  - Failed: 12
  - **Succeeded (fully or partially): 17 !!**
- The program included
  - **Venera-1** and **Sputnik-7** probes (failed)
  - **Venera** orbiters, landers
  - **Cosmos** landers and flybys (failed , *see note on page 20 about Cosmos designation*)
  - **Zond-1** lander (failed)
  - **Vega** landers and balloons
- Achieved multiple firsts, e.g.,
  - First to reach Venus; entry; landing; longest surface operation (127 minutes); surface pictures (also in color); international Venus mission

Venera 3 stamp

Venera 4 stamp

Venera 5 stamp

Venera 8 stamp

Venera 9 stamps

Venera 11 stamp

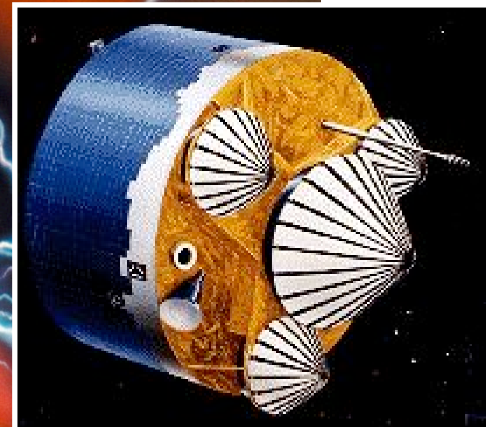
Venera 13 stamp

Ref: Kolawa, Balint, Delcastillo, Mojarradi, "Instruments for Extreme Environments", IPPW-4, Short Course, Pasadena, CA, June 2006
Ref: http://www.russianspaceweb.com/spacecraft_planetary_venus.html
Ref: Balint, "Summary of Russian Planetary Lander Missions", JPL, 2002
Ref: images – various from the web

Past: US Missions to Venus

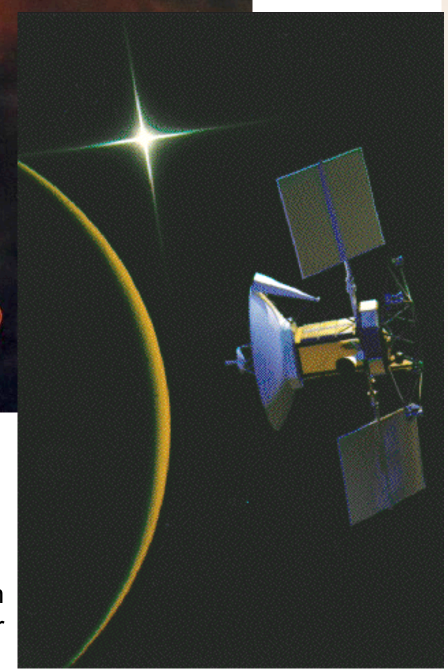
- 1962 - Mariner 2
  - flew by Venus (12/14/62);
  - Verified high temperatures.
- 1974 - Mariner 10 to Mercury,
  - flew by Venus (2/5/74);
  - Tracked global atmospheric circulation with visible and violet imagery
- 1978 – Pioneer-Venus Orbiter
  - radar mapped Venus (12/78)
- Pioneer-Venus Multiprobe
  - dropped four probes through Venusian clouds
  - Orbiter & probes launched separately
- 1989 - Magellan
  - launched to Venus (5/4/89)
  - arrived at Venus in 1990
  - mapped 98% of the planet
  - mission ended in 1994

P-V Large Probe



P-V Carrier w/ Probes

Mariner-10

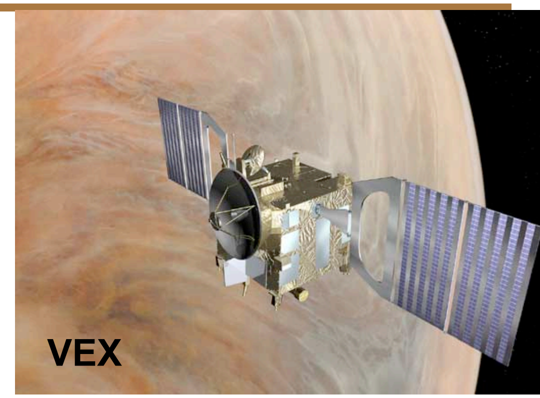


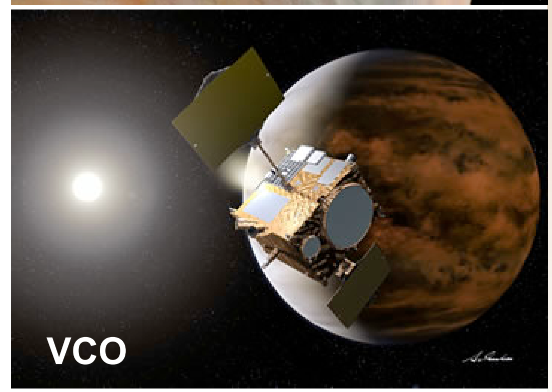
Magellan Orbiter

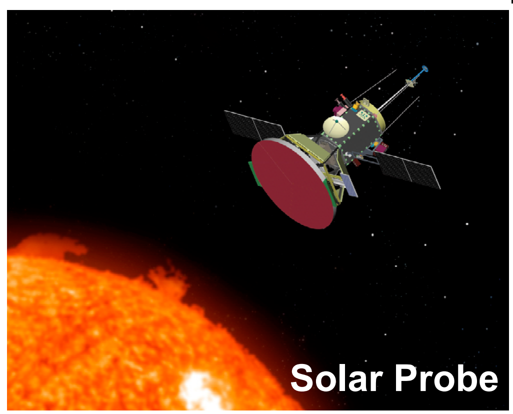
Ref: Images – various from the web

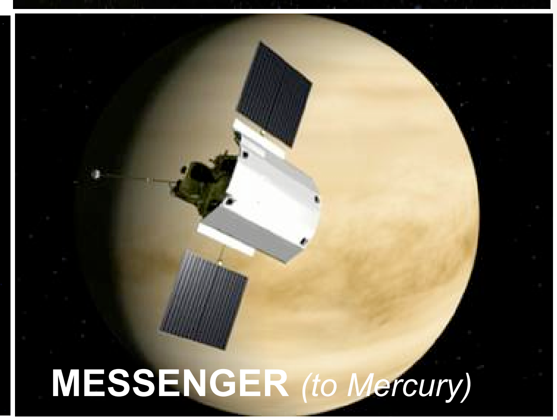
Present/Ongoing: VEX, VCO, Other Flybys

- ESA's **Venus Express** (VEX) orbiter
  - Launched: November 9, 2005
  - Mission ends: May 2009 (extended lifetime)
- JAXA's **Venus Climate Orbiter** (VCO)
  - Planned launch: June 2010
  - Mission lifetime: 2 years
- APL's **MESSENGER** (with Venus flybys)
  - Launched: August 3, 2004
  - 2 Venus Flybys (10/24/2006 & 6/5/2007)
  - Mission to Mercury
- APL's **Solar Probe** (with Venus flybys)
  - Planned Launch: 2015
  - 9 Venus Flybys

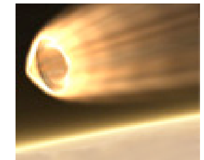




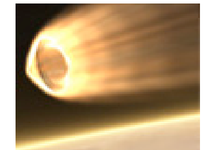




Ref: Images – various from the web



Future: The Road Ahead for US Venus Missions



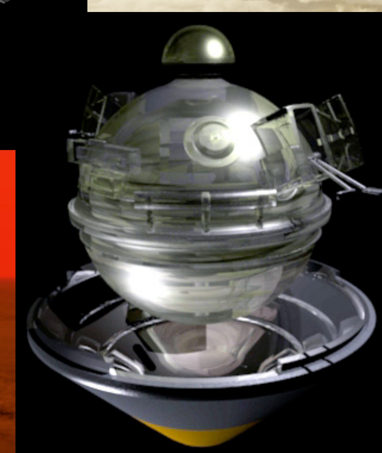
- Future Venus missions are expected to be **science driven**
  - with input from programmatics (e.g., cost cap)
  - and support through enabling or enhancing technologies

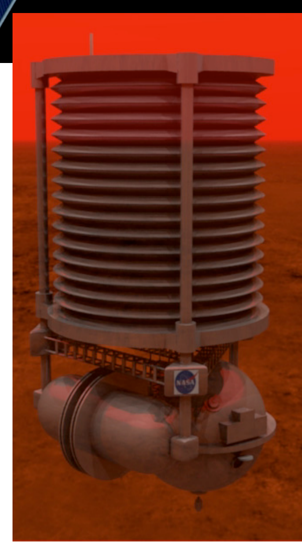
- NASA's 2008 **Venus Flagship study** (ongoing):
  - NASA appointed a Science & Technology Definition Team
  - **STDT** assessed science figure of merit
  - **Recommended** a science driven mission architecture
    - **Orbiter + 2 mid-cloud balloons + 2 short lived landers including an extended life element**
  - Assumed launch period: between 2020 and 2025

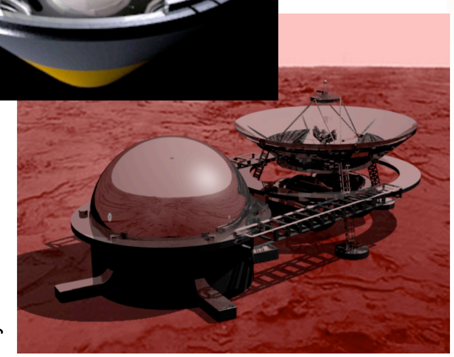
- **Smaller missions** could occur before that:
  - **New Frontiers-3** proposals could target a 2015+ launch date
  - **Discovery** missions could target a 2013-15+ launch date
  - There might be 2-3 competed opportunities before Venus Flagship

Future: Potential Venus Missions

- **Orbiters**
  - Discovery or New Frontiers class
  - Single element architecture
  - Lifetime: years
- **Balloons**
  - Discovery or NF class; NASA/ESA/JAXA
  - 1 or 2 balloons; orbiter or flyby support
  - Lifetime: weeks
- **Landers and probes**
  - NF or Flagship class; NASA/Russia
  - Lifetime: hours for passive cooling; weeks to months for active cooling
- **Multi-element architectures**
  - Likely Flagship class
  - NASA Flagship Study 2008:
    - orbiter + 2 mid-balloons + 2 landers
    - Short lived landers with extended life element
    - Potential for future international collaboration
  - Cosmic Vision EVE
    - orbiter + high-balloon + mid-balloon + lander
    - ESA lead international collaboration proposal
  - Other concepts:
    - Network with 4 landers over a year lifetime
    - Venus Mobile Explorer (SSE Roadmap recommended) with near surface metallic balloon and orbiter
- **Venus Surface Sample Return**
  - Multi-element for delivery; descent; short lived lander; multi-stage ascent balloons; ascent vehicle; Venus orbiter; and Earth return capsule







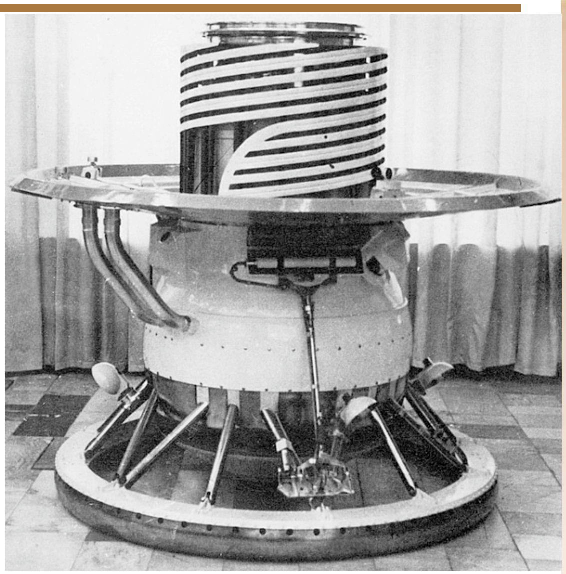
Ref: Images by T. Balint

The Good, the Bad, & the Future

– lessons learned – future challenges – considerations –

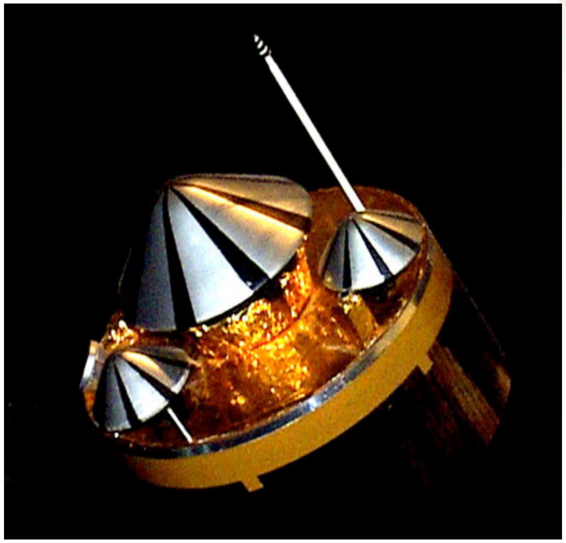
Mission Architecture Philosophies

- **Russian (Soviet) approach:**
  - Incremental development & learning,
    - through a full fledged program
    - while flying a large number of missions
    - program continuation was independent of public opinion
  - Launched in pairs, using
    - identically built s/c and lander/probe
    - simple, cost effective, brute force approach



Ref: Venera-9

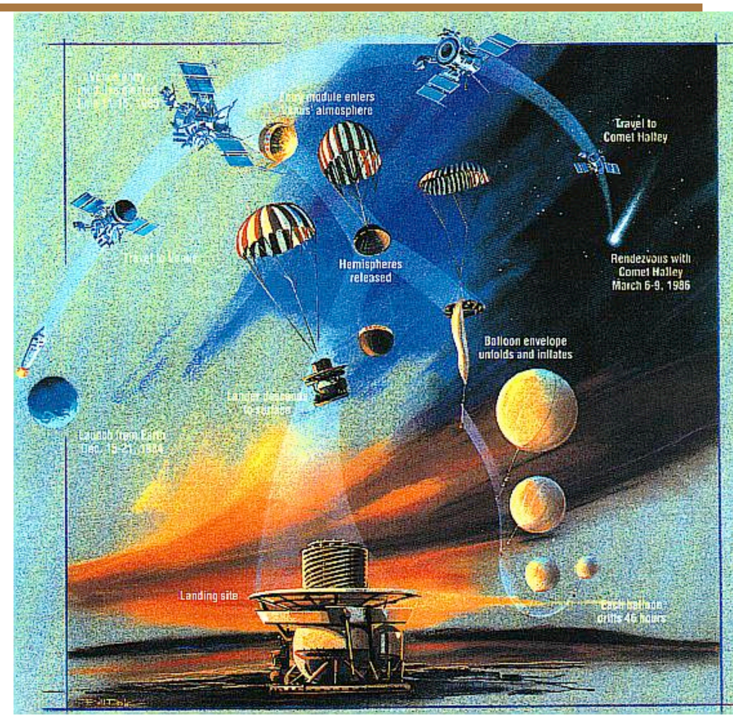
- **US approach:**
  - Missions selected to diverse destinations based on science priorities
    - no dedicated Venus program exists (e.g., compared to Mars exploration)
  - Mitigating risk through
    - ground based development and testing
    - with low risk tolerance



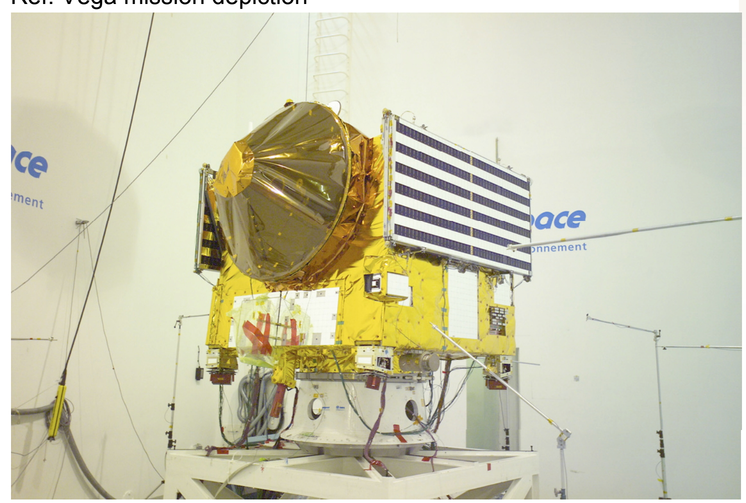
Ref: Pioneer-Venus 2 model (bus and probes)

Mission Impact of Multiple Elements & Lifetime

- **Multi-element architectures:** Pioneer-Venus & Vega
  - simultaneous in-situ exploration
  - at multiple locations (synergy)
  - relatively simple, short lived elements (balloons, probes, landers, orbiters, flybys)
  - international collaboration (on Vega)
- **Long lived orbiters:** Magellan & Venus Express
  - Long duration exploration of Venus yielded significant amount of scientific data
- Trades between long lived single element vs. short lived multiple elements (science, technology, cost)



Ref: Vega mission depiction



Ref: Venus Express

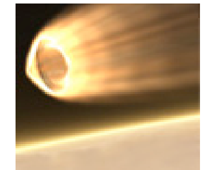
Failures on Past Russian Venus Missions

Missions	Failures
Sputnik-7	Stranded in Earth orbit: 4th stage failure (probably due to faulty timer)
Venera-1	Missed Venus by 100,000 km: probably due to the overheating of a solar-direction sensor
Sputnik-19	Stranded in Earth orbit: escape stage failure
Sputnik-20	Stranded in Earth orbit: escape stage failure
Sputnik-21	Unsuccessful flyby mission: reason unknown
Cosmos-21	Stranded in Earth orbit (unknown mission, possibly designated as a Venus flyby)
Cosmos-27	Stranded in Earth orbit: likely due to escape stage failure
Zond-1	Failed on its way to Venus
Venera-2	Missed Venus by 24,000 km; s/c systems failed before reaching Venus; no data return
Venera-3	Communication system failed before any data return (but was the first to land on another planet)
Cosmos-96	Failed on Earth orbit: reason unknown
Cosmos-167	Failed on Earth orbit: reason unknown
Venera-7	Success, but weak signal. Lander may have bounced into its side, impacting antenna pointing
Cosmos-359	Failed on Earth orbit: reason unknown
Cosmos-482	Stranded in Earth orbit: escape stage failure (was similar to Venera-8 design)
Venera-11	**Success**, but failed to return images. Lens cover didn't separate after landing due to design fault
Venera-12	**Success**, but failed to return images. Lens cover didn't separate after landing due to design fault

Note: If the engine at Earth parking orbit misfired or the burn was not completed, the probes was left in Earth orbit and given a Cosmos designation.

Most Russian mission failures were due to propulsion system problems

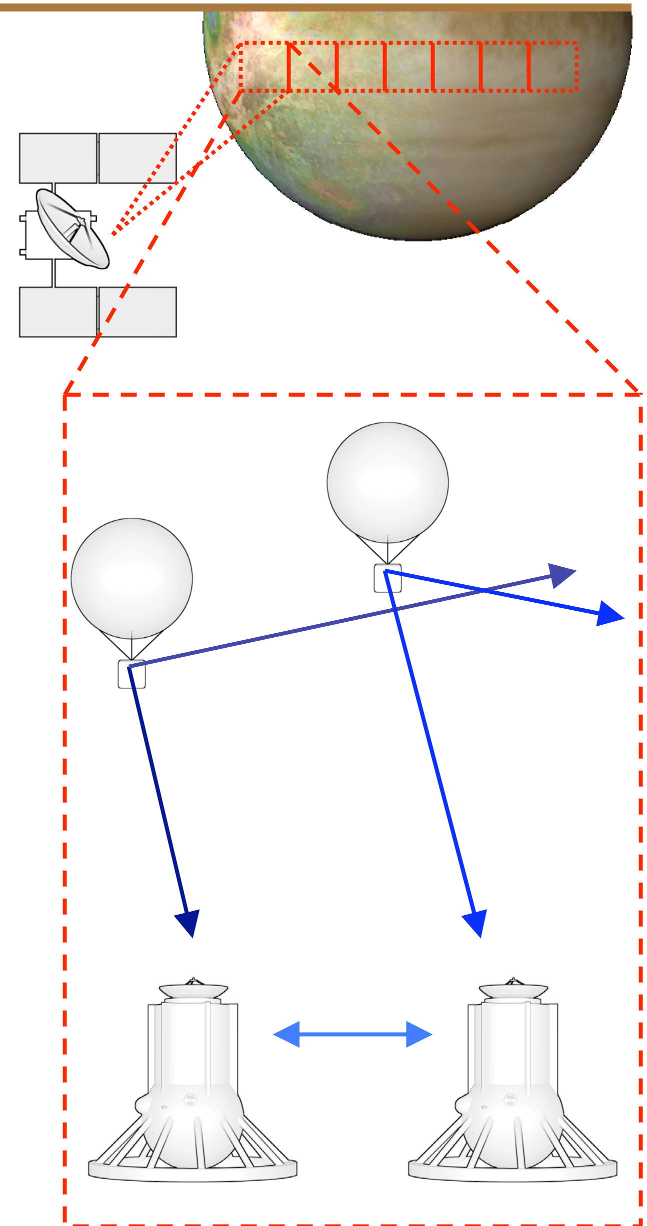
Failures on Past US Venus In-situ Missions



- Pioneer-Venus probes:
  - **12.5 km anomaly** resulted in electrical failures
  - Cause investigated (workshop at NASA ARC)
  - Latest views point to **supercritical CO_2** ,which may have dissolved the protective coating on electrical wires
  - Components were tested in high-T/p Nitrogen
    - justified by the assumption that both N & CO_2 are inert gases
- For future in-situ missions, **testing in a relevant environment is critical**
  - That is: testing in high temperature & pressure CO_2

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 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



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

Technologies

- **Technologies** could play a significant role to
  - **enable or enhance** future Venus missions
- Mission and **technology impact** would **increase**
  - for **near surface** descent,
  - combined with **longer lifetime**
- **Technology and science trades** vary and should be assessed between
  - **short lived multi-element** platforms and
  - **long lived single** near surface missions
- E.g., short lived near surface missions
  - may not require active cooling
  - may require technology development for
    - pressure & temperature mitigation; sample acquisition & handling; and others
    - Instruments technologies

Ref: Images – various from the web

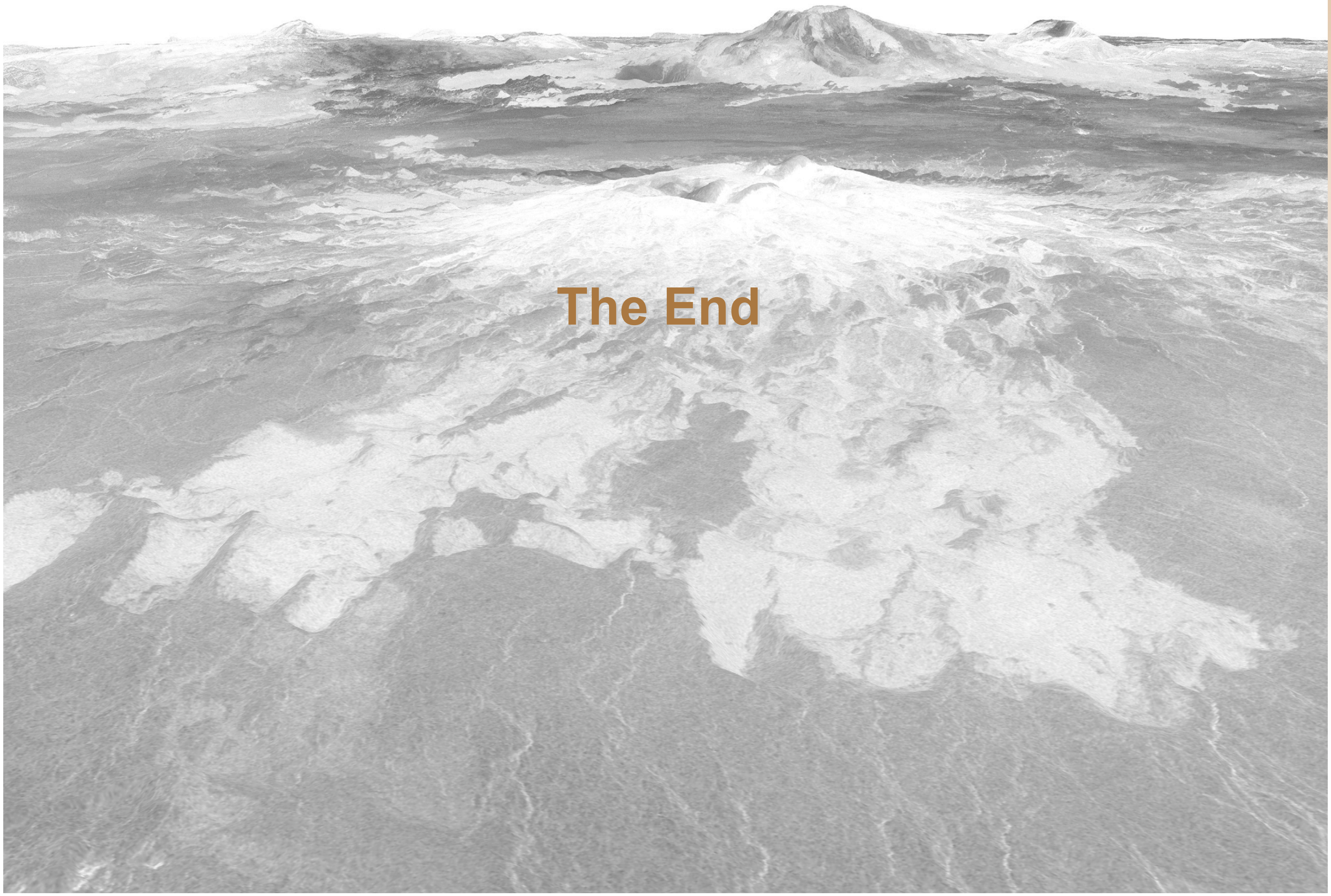
International Collaboration

- **Multi-element architectures** lend themselves to international collaboration
- It was recommended in
  - ESA’s Cosmic Vision EVE proposal (2007)
  - NASA’s 2008 Venus Flagship Study (ongoing)
- Timing for international collaboration:
  - **NASA’s Venus Flagship** targets 2020-2025
  - **ESA's** Cosmic Vision **EVE** will be re-proposed
  - **JAXA’s mid-cloud balloon** is tentatively proposed for EVE, might be ready in 2016+
  - The **Venera-D** lander by **Roscosmos** was proposed for EVE, and the work is ongoing

Conclusions

Conclusions

- **Venus exploration** is expected to continue the tradition of highly successful past missions
  - such future missions will be **science driven**,
  - in the framework of programmatics, mission architectures and technologies
- **Mission architecture trades** between short lived multi-element missions and long-lived in-situ missions should be carefully evaluated **against the best science return**
- **Technologies** could significantly enable or enhance potential future missions
  - **Testing in relevant environments** is critical for future technologies
- **International collaboration** will likely play a significant role to maximize science return


The End