VENUS Team

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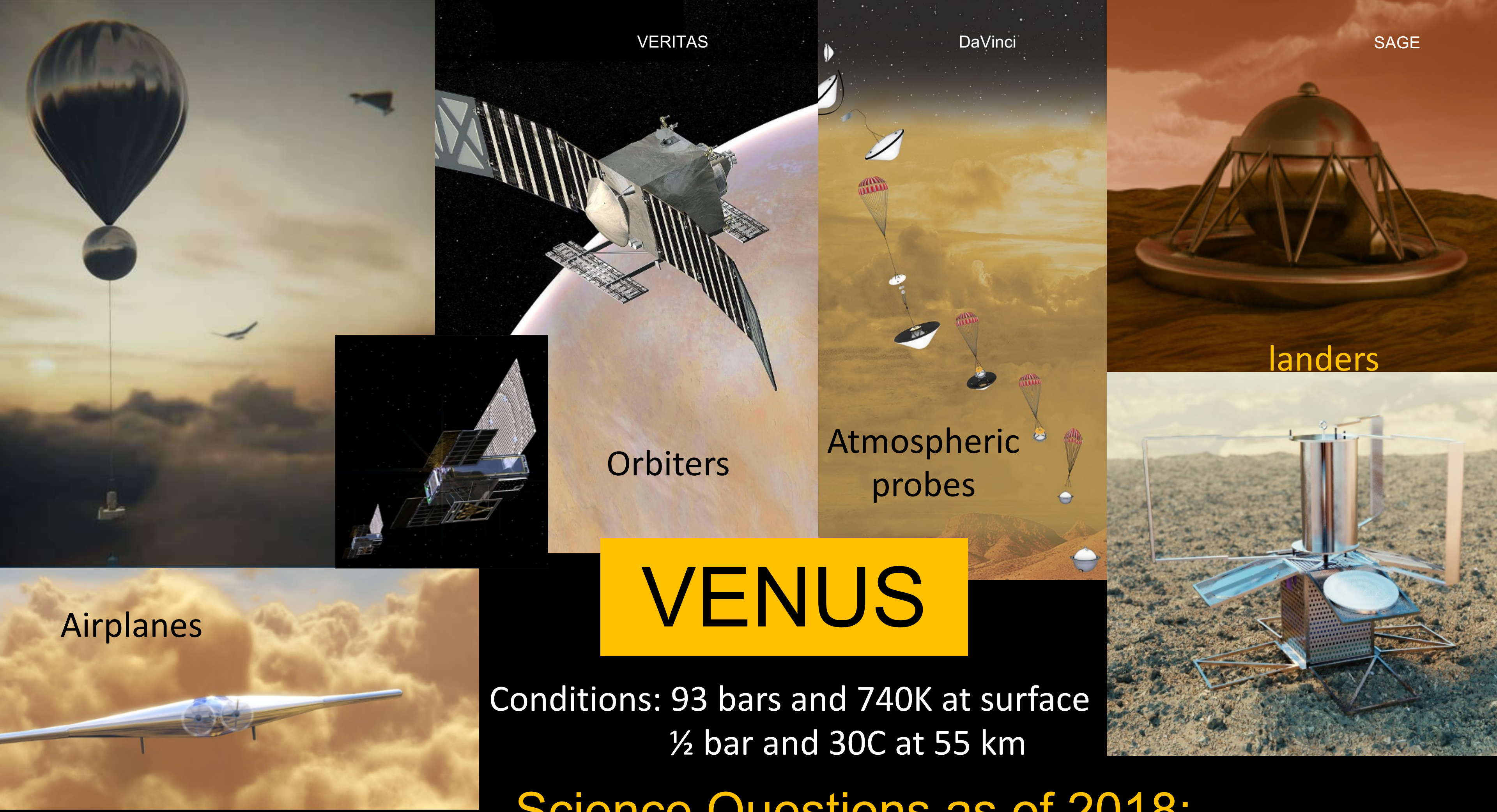
DRM Breakout Report

2018 Workshop on Autonomy for Future NASA Science Missions

October 10-11, 2018

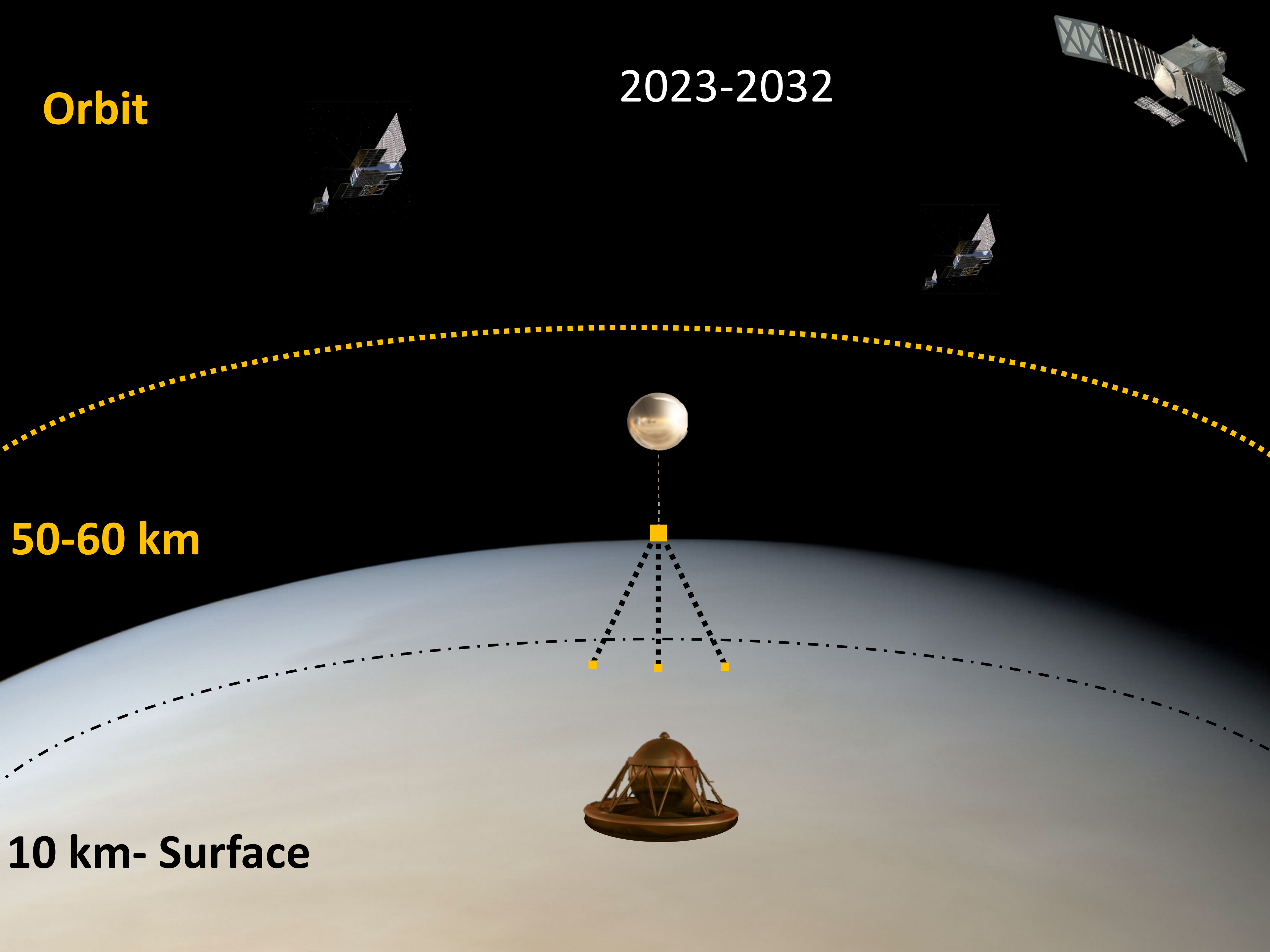


VENUS

Conditions: 93 bars and 740K at surface
½ bar and 30C at 55 km

Science Questions as of 2018:

1. Venus' early evolution (including possible habitability), and the evolutionary paths of Earth-sized terrestrial (exo)planets?
2. Atmospheric dynamics, composition, and climate history on Venus?
3. How physical and chemical processes interact to shape the modern surface of Venus?



2023-2032

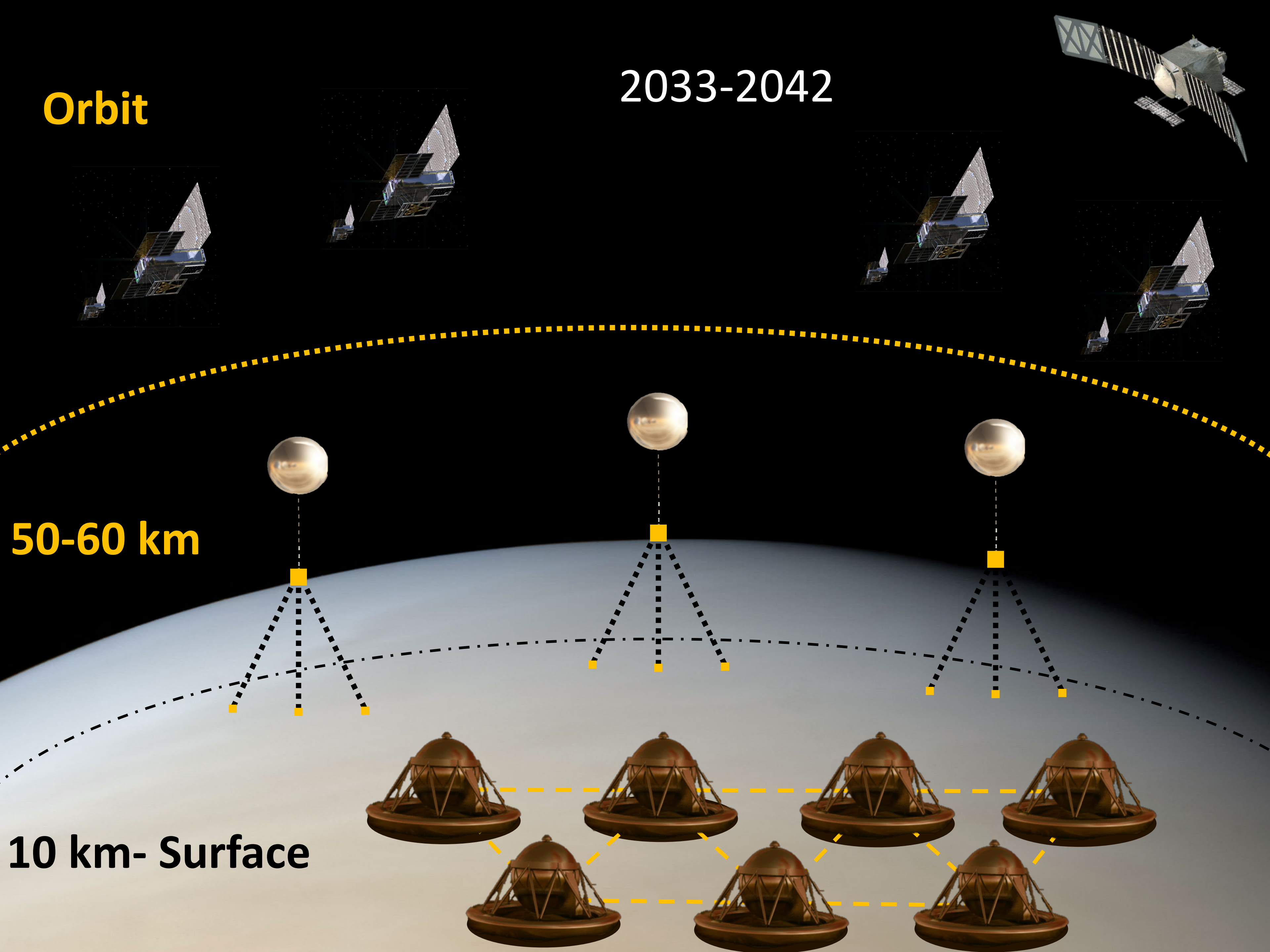
Orbit

50-60 km

10 km- Surface

Venus DRM ca. 2023-2032

ITEM	Question	Response
A	Describe a specific Design Reference Mission objective or mission requirement to be addressed with autonomy.	Characterize Venus interior, surface, and atmosphere while demonstrating increasing autonomy. **1. Orbiter and smallsat(s)**: Acquire gravity, topography (radar), and spectral image data to constrain landing site, create geologic map. **2. Aerial vehicle:** Test aerobraking and **c**ontrol of flight/altitude mobility (balloon or airplane) at 50-60 km altitude and examine UV absorber. **3. Dropsonde(s):** Acquire data on P, T, chemistry, wind velocity in atmosphere **4. Lander system:** detect rock types and mineralogy, analyze atmosphere, obtain images, test drilling, cooling systems
B	Describe an autonomous capability that could be used to accomplish (A).	**Test autonomy: SURVIVE, DETECT, COMMUNICATE!** Lander system networked with orbiter, aerial vehicle, dropsonde, and smallsat(s). Demonstrate autonomous navigation of aerial vehicle. Test techniques for measuring attitude.
C	List the core autonomy technologies needed by (B). Refer to the Autonomous Systems Taxonomy table for technologies.	**1. Fail-operational algorithms** and models for hardware degradation under Venus conditions. 2. Sensors for dropsondes. 3. Communication across multiple platforms (network topology). 4. Demonstrate individual **situational awareness and adaptability** to enhance survivability 5. Planning, scheduling, smart execution, and resource management algorithms.
D	List any other supporting technologies needed by (B), including assets from potential commercial partners.	**1. Flight hardware and sensors** that can operate under harsh conditions, and/or long-lived cooling systems. Includes longer-lived electronics (processors and memory) that can operate in harsh environments (P, T, chemical). 2. Test architecture for **communications and navigation** capabilities (across platforms). 3. Mechanical systems to control (maintain and vary) altitude of aerial vehicles 4. Theoretical environmental models of Venus near-surface conditions (<10 km) for landers and dropsondes.
E	List any related/relevant R&D projects for (C) and (D). Include references.	LLISSE: https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20180000692.pdf Venus Aerial Platforms: https://www.colorado.edu/event/ippw2018/sites/default/files/attached-files/innersys_2_cutts_presid617_presslides_docid1136.pdf Planetary aero-vehicles: https://link.springer.com/article/10.1007/BF00710794 See publications by from HOTtech program, S. Chien, L. Matthies, etc.
F	Is (B) enabling or enhancing for (A)?	**Enabling AND Enhancing:** Demonstrating autonomous systems technologies in harsh environments enhances current science objectives and enables future missions. The atmospheric science to be obtained is **enabled** by smallsats and dropsonde(s).
G	Provide a rough estimate of the development costs for (B), and describe how (B) will affect overall mission cost (development or ops).	This capability will require investment comparable to the development cost of a New Frontiers mission.
H	Describe how (B) will increase (or decrease) mission risk (development or ops). Risk can be performance, schedule, etc.	Injecting autonomous elements into this mission concept will demonstrate science capabilities, reducing risk overall. This would buy down risk for a future mission. This mission could test synchronization of assets.



2033-2042

Orbit

50-60 km

10 km- Surface

Venus DRM ca. 2033-2043

	Question	Response
A	Describe a specific Design Reference Mission objective or mission requirement to be addressed with autonomy.	Volcanic eruption causes volcanic plumes, releasing clouds of volatiles. OR Seismic event occurs. **1. Orbiter(s) and smallsats**: Range of instruments to target locations of interest across the planet, and communications and computational infrastructure to allow coordination across the different vehicle platforms. Need at least 3-4 high altitude (10K km) to provide positional accuracy. **2. Aerial vehicle(s):** Controlled flight/altitude mobility (balloon or airplane) exploring atmosphere from 20-70 km with coordinated flight between vehicles. Drop/raise dropsondes, atmospheric probes/small landers for atmospheric profiling or targeted surface investigations. **3. Lander system(s)** of varying level of size/complexity providing geophysical data and selective sensors of atmospheric chemistry on surface (SO_2, H_2S, etc.). Varying degrees of processing capabilities depending on lander types (cooled enclosure vs in-situ operation).
B	Describe an autonomous capability that could be used to accomplish (A).	**Design for autonomy: SURVIVE, DETECT, COMMUNICATE, COORDINATE, AND RESPOND!** Networked lander systems and/or orbiter(s) detect event. Orbiter would detect volatiles and/or detects seismic waves. Aerial platform confirms seismic event and releases dropsondes to measure chemistry of volcanic plume.
C	List the core autonomy technologies needed by (B). Refer to the Autonomous Systems Taxonomy table for technologies.	**1. Fail-operational algorithms** and models for hardware degradation under Venus conditions. 2. Venus **terrain relative navigation** ± hazard avoidance, station-keeping capability 3. Control algorithms/models for dropsonde transit through dense, rapidly-moving atmosphere. 4. Sensors and controllers for dropsondes. 5. Communication across multiple platforms to share common mental models (network topology). 6. Coordination of rapid response to varying conditions and inputs. 7. Develop **situational awareness and adaptability** to enhance survivability 8. Planning, scheduling, smart execution, and resource management algorithms.
D	List any other supporting technologies needed by (B), including assets from potential commercial partners.	**1. Flight hardware and sensors** that can operate under harsh conditions, and/or long-lived cooling systems. Includes long-lived electronics (processors and memory) that can operate in harsh environments (P, T, chemical). 2. Create **communications and navigation** infrastructure for Venus. 3. Variable-altitude mobility systems. 4. Theoretical environmental models of Venus near-surface conditions (<10 km).
E	List any related/relevant R&D projects for (C) and (D). Include references.	LLISSE: https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20180000692.pdf Venus Aerial Platforms: https://www.colorado.edu/event/ippw2018/sites/default/files/attached-files/innersys_2_cutts_presid617_presslides_docid1136.pdf Planetary aero-vehicles: https://link.springer.com/article/10.1007/BF00710794 See publications by from HOTtech program, S. Chien, L. Matthies, etc.
F	Is (B) enabling or enhancing for (A)? Can this capability only be enabled with autonomous technology? Explain.	**Enabling:** The harsh environmental constraints plus the rapid response times needed in situ will require coordination and communication across the agents. These cannot be joysticked from the ground.
G	Provide a rough estimate of the development costs for (B), and describe how (B) will change.	This capability will require investment comparable to the development cost of MSL or any flagship mission. Thus, it encompasses a majority of the cost of the mission.
H	Describe how (B) will increase (or decrease) mission risk (development or ops).	Injecting autonomous elements into this mission concept will enable necessary science, potentially at the cost of managing additional risk and safety. However, many of the autonomies developed in C above will reduce risk.

Venus DRM Autonomy Summary

DRM Scenario	Autonomy Requirements/Goal	Key Question & Knowledge Gaps	Technology Innovations and Partnerships	Current SOA, Projects and Products
Characterize Venus interior, surface, and atmosphere while demonstrating increasing autonomy.	**Test autonomy: SURVIVE, DETECT, COMMUNICATE!** Lander system networked with orbiter, aerial vehicle, dropsonde, and smallsat(s). Demonstrate autonomous navigation of aerial vehicle. Test techniques for measuring attitude.	**1. Fail-operational algorithms** and models for hardware degradation under Venus conditions. 2. Sensors for dropsondes. 3. Communication across multiple platforms (network topology). 4. Demonstrate individual **situational awareness and adaptability** to enhance survivability 5. Planning, scheduling, smart execution, and resource management algorithms	**1. Flight hardware and sensors** that can operate under harsh conditions, and/or long-lived cooling systems. Includes longer-lived electronics (processors and memory) that can operate in harsh environments (P, T, chemical). 2. Test architecture for **communications and navigation** capabilities (across platforms). 3. Mechanical systems to control (maintain and vary) altitude of aerial vehicles 4. Theoretical environmental models of Venus near-surface conditions (<10 km) for landers and dropsondes.	Transfer autonomy technologies being developed for a range of Earth applications toward operation in Venus harsh environments (DOD tool). Additions to this include architecture for communications, and DOD mechanical control of variable altitude systems and vehicles. Current work at Google Loon, multi-agent ocean surveillance assets (also DOD). See publications from LLISSE, HOTtech programs, S. Chien, L. Matthies, B. Williams, etc.

Venus DRM Autonomy Summary

DRM Scenario	Autonomy Requirements/Goal	Key Question & Knowledge Gaps	Technology Innovations and Partnerships	Current SOA, Projects and Products
Volcanic eruption causes volcanic plumes, releasing clouds of volatiles. OR Seismic event occurs.	**Design for autonomy: SURVIVE, DETECT, COMMUNICATE, COORDINATE, AND RESPOND!** Networked lander systems and/or orbiter(s) detect event. Orbiter would detect volatiles and/or detects seismic waves. Aerial platform confirms seismic event and releases dropsondes to measure	**1. Fail-operational algorithms** and models for hardware degradation under Venus conditions. 2. Venus **terrain relative navigation** ± hazard avoidance, station-keeping capability 3. Control algorithms/models for dropsonde transit through dense, rapidly-moving atmosphere. 4. Sensors and controllers for dropsondes. 5. Communication across multiple platforms to share common mental models (network topology). 6. Coordination of rapid response to varying conditions and inputs. 7. Develop **situational awareness and adaptability** to enhance survivability 8. Planning, scheduling, smart execution, and resource management algorithms.	**1. Flight hardware and sensors** that can operate under harsh conditions, and/or long-lived cooling systems. Includes long-lived electronics (processors and memory) that can operate in harsh environments (P, T, chemical). 2. Create **communications and navigation** infrastructure for Venus. 3. Variable-altitude mobility systems. 4. Theoretical environmental models of Venus near-surface conditions (<10 km).	Transfer autonomy technologies being developed for a range of Earth applications toward operation in Venus harsh environments. Additions to this include architecture for communications, TRN, and DOD mechanical control of variable altitude systems and vehicles. Current work at Google Loon, multi-agent ocean surveillance assets (also DOD). See publications from LLISSE, HOTtech program, S. Chien, L. Matthies, B. Williams, etc.

Candidate Venus DRM White Papers

Propose one or more white papers that should be published in order to define and promote the key autonomy innovations identified by this working group.

Design for Autonomy On Venus: SURVIVE, DETECT, COMMUNICATE, COORDINATE, AND RESPOND!

Exploration of Venus is constrained by its dense, corrosive atmosphere and high-temperature. Autonomous capabilities will enable multi-agent exploration of Venus. Innovative topics include:

- Fail-operational algorithms and models for hardware degradation under Venus conditions.
- Venus terrain relative navigation ± hazard avoidance, station-keeping capability
- Control algorithms/models for dropsonde transit through dense, rapidly-moving atmosphere.
- Sensors and controllers for dropsondes.
- Communication across multiple platforms to share common mental models (network topology).
- Coordination of rapid response to varying conditions and inputs.
- Develop situational awareness and adaptability to enhance survivability
- Planning, scheduling, smart execution, and resource management algorithms.

Venus DRMs Demand Autonomy!

Scenarios that demand autonomy include (but are not restricted to):

1. Constrained communications with Earth and among assets on Venus.
2. Time-critical decisions involving events such as lifetime constraints, Venus quakes and volcanic eruptions.
3. Internally data-heavy decision processes such as TRN, onboard data analysis, and processing and between assets.
4. System architecture simplification through independent decision-making.
5. Situational complexity that exceeds the limits of useful human input such as responding to surface events or changing atmospheric conditions. Aerial assets are moving 5,600 km/day.

Windows in Venus’ atmosphere to enable spectroscopy