Final Report

Venus Exploration Targets Workshop

May 19–21, 2014, Lunar and Planetary Institute, Houston, TX

Conveners: Virgil (Buck) Sharpton, Larry Esposito, Christophe Sotin

Breakout Group Leads

Science from the Surface	Larry Esposito, Univ. Colorado
Science from the Atmosphere	Kevin McGouldrick, Univ. Colorado
Science from Orbit	Lori Glaze, GSFC

Science Organizing Committee:

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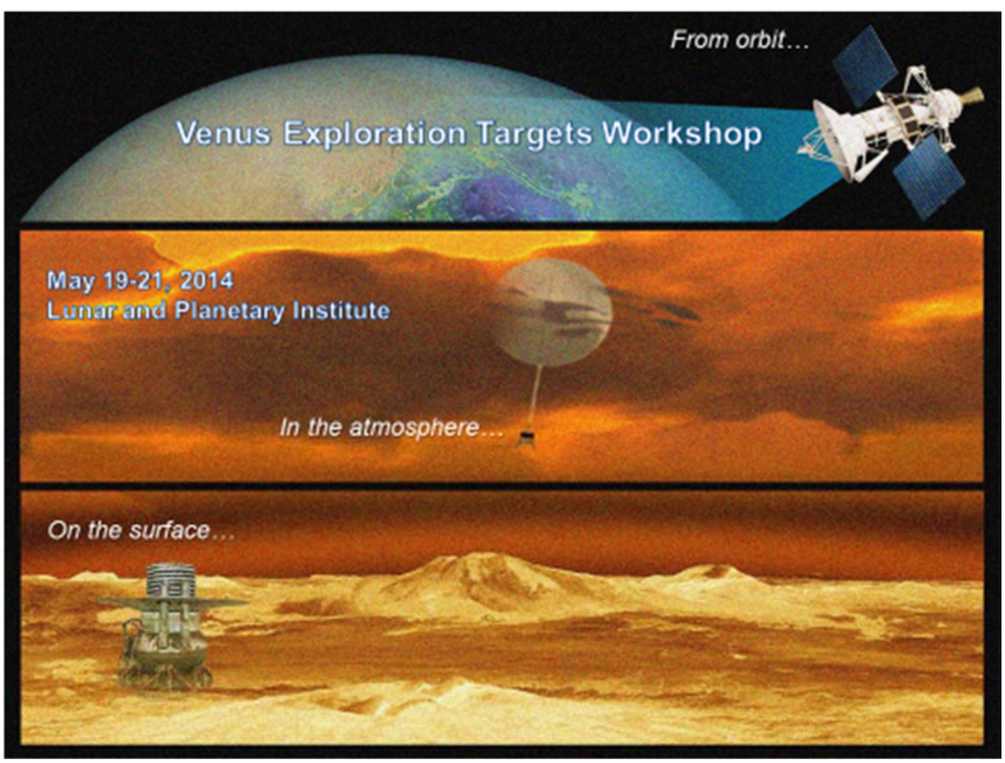
Vision: The intent of this "living" document is to identify scientifically important Venus targets, as the knowledge base for this planet progresses, and to develop a target database (i.e., scientific significance, priority, description, coordinates, etc.) that could serve as reference for future missions to Venus. This document will be posted in the VEXAG website (http://www.lpi.usra.edu/vexag/), and it will be revised after the completion of each Venus Exploration Targets Workshop. The point of contact for this document is the current VEXAG Chair listed at ABOUT US on the VEXAG website.



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Overview

Venus and Earth are intriguingly similar in size, density, and bulk composition; but that is where the resemblance ends. Earth's next-door neighbor is hellishly hot, devoid of oceans, lacks plate tectonics, and is bathed in a thick, reactive atmosphere. How, why, and when the evolutionary paths of Earth and Venus diverged are fundamental and unresolved issues that drive the need for vigorous new exploration of Venus. The answers are central to understanding Venus in the context of terrestrial planets and their evolutionary processes. More importantly, Venus can provide important clues to understanding how our own planet has maintained a habitable environment for so long and how long it can continue to do so. Yet Venus remains the least understood of all planetary bodies in the inner Solar System.

In 2014, the Venus Exploration Analysis Group (VEXAG) embarked on an update to the Goals, Objectives, and Investigations for Venus Exploration (GOI). The GOI is a guiding document that contains a set of prioritized science investigations, and has been developed over many years with input and feedback from the science and technology communities. To spur new exploration activities at Venus, VEXAG also led development of two companion community-endorsed documents: the Roadmap for Venus Exploration, and the Venus Technology Plan. All three documents are available on the web at http://www.lpi.usra.edu/vexag/reports/.

Those three documents collectively indicate that the further investigation of Venus will involve very different considerations than the exploration of Mars, Moon, Mercury and other airless bodies with which we are most familiar. First of all, the severe environment on the surface of Venus limits surface in situ missions using current technology to less than a few hours. The thick atmosphere also blocks the orbital observation of many optical and infrared signatures of surface materials that have been useful in characterizing the surface of Mars, Moon and Mercury. On the other hand, the dense atmosphere makes possible a range of short and long duration aerial platforms that are not practical at these other bodies. This motivated a workshop focused on identifying the targets that could be accessed from these three different observational platforms and vantage points and the science that could be accomplished either independently or by observations made in concert.

Fifty four scientists from around the globe converged on the Lunar Planetary Institute (LPI) during the *Venus Exploration Targets Workshop* held May 19–21, 2014 to identify key targets for future exploration of Venus and to evaluate their potential for answering the fundamental questions posed in the VEXAG GOI and other reports. A set of oral and poster presentations on the first day set the stage for topical breakout sessions held throughout the remainder of the workshop. Breakout groups were organized around where the science payload would be located: on the surface, within the atmosphere, or from orbit. Each group was tasked not only with providing specific science justification for each target but also providing guidance on instrument and mission constraints needed to meet the science Objectives. Following each half-day breakout session, group chairs summarized progress for plenary discussion. The chairs of the three breakout groups were:

- Larry Esposito (University of Colorado): Science from the Surface
- Kevin McGouldrick (University of Colorado): Science within the Atmosphere
- Lori Glaze (NASA Goddard Spaceflight Center): Science from Orbit

The following sections summarize the findings of these breakout groups. The appendix is the traceability matrix of the targets, approaches, requirements for platforms on the surface, in the atmosphere, and from orbit vs. the VEXAG GOI. The intent of this is to be a living document to identify scientifically important Venus targets, as the knowledge base for this planet progresses, and to develop a target database (i.e., scientific significance, priority, description, coordinates, etc.) that could serve as reference of future missions to Venus. This document will be posted in the VEXAG website (http://www.lpi.usra.edu/vexag/), and it will be revised after the completion of each Venus exploration targets workshop. The point of contact for this document is the current VEXAG Chair listed at ABOUT US on the VEXAG website.

1. Science on the Surface

The surface group contained about a dozen attendees with some sharing time with other groups. This group started by characterizing the types of surface targets, then held a set of straw polls to prioritize the target types in terms of perceived scientific importance (Table 1).

The highest priority surface target type is tesserae terrain, a generic term for heavily deformed, usually elevated, areally extensive and relatively radar-bright terrain that covers ~10% of Venus. The composition and other characteristics of this terrain are key to distinguishing between a variety of hypotheses regarding the geologic history of Venus. For example, tesserae could be highly silicic remnants of a past era of plate tectonics on Venus. Expectations are, however, that tesserae are very rugged at a variety of spatial scales and thus challenging as a landing target.

Volcanic plains are a priority target because they pose low mission risk while offering significant advancement of our understanding of Venus's crustal properties. While some basic compositional data were retrieved by the Venera landers, fundamental questions remain unanswered (e.g., GOI report) that can now be addressed by more advanced instrumentation. Furthermore, volcanic plains are relatively safe landing targets, as they are topographically flat and radar-dark (implying smoothness at the centimeter-to-meter-scale wavelengths).

The third major target type of interest is a geologically young volcanic flow, potentially from a volcanic structure that is currently active. An appealing aspect of this type of target is that it offers the potential to see a relatively unweathered rock specimen. Comparison with samples from the plains could provide critical knowledge about variations in volcanic processes spatially and with time.

Within these three high-priority target types, there were a couple of specific targets of interest. Maat Mons, by virtue of its extensive flows, enormous geoid height and high radar emissivity at its summit, was a particularly favored target for sampling a young volcanic flow. Cleopatra crater is located high on the flanks of Maxwell Montes, which suggests that its samples should be entirely derived from tessera materials (other than a small contribution from the impacting body). Thus, the area inside its 60-km diameter peak ring represents a relatively flat, smooth area for a landing site that would enable tessera terrain to be sampled.

Table 1. Rank order of surface targets (with 1 being best), following two straw votes (SV1, SV2). The second straw vote was limited to the top-ranked targets. Tesserae, plains and flows were the top three targets in both polls.

Rank	Targets	Rationale	SV1	SV2
1.	Tesserae Examples: Alpha, Tellus	Crustal history and composition; deformation. Provides the best chance to access rocks derived from the first 80% of the history of the planet, for which we have no information.	11	10
2.	Plains Example: SE of Artemis Chasma, centered at 45 S, 155 E	Baseline	10	10
3.	Young Flows Examples: Mylitta Fluctus, Tuli Mons	Youngest features, volcanic process	8	8
4.	Maat	Young volcanic structure Series of summit collapses would make a risky landing site, but walls of these pits would reveal stratigraphy. Broad flanks provide easier targets	6	3
5.	Cleopatra	Flat, high altitude tessera structure; impact exposes deep crust. Safe landing ellipse should be anywhere inside the 60-km diameter peak ring	5	3
6.	Bright Floor Crater Examples: Stanton (Diameter=107.0 km), Stowe (D=75.3 km), Aurelia (D = 31.0 km)	Deep crust exposed in central structure, melt rock.	5	5
7.	Ishtar Terra Examples 63N, 325E; 69N, 330E	"Continent"? Landing sites in the smooth plains are suitable for geophysical stations.	4	5
8.	Active sources Example: none known.	Surface-atmosphere interaction; out-gassing	4	3
9.	Dunes	Aeolian process, deposits	3	NA
10.	Canali	Exotic composition	3	N/A
11.	High/ low reflectivity	Weathering, exotic materials	2	N/A
12.	High emissivity (IR)	Composition, weathering, age	2	N/A
13.	Geologic Contacts	Stratigraphy	1	N/A
14.	High altitude	Composition variations	1	N/A
15.	Wrinkle ridges	Deformation	1	N/A
16.	Low altitude	Composition variations	0	N/A
17.	Impact Crater Parabolas	Aeolian process, deposits	0	N/A

A few additional generic target types garnered less support but warrant mention. The floors of large craters may expose samples derived from several kilometers beneath the surface. As the only areally extensive high plateau on Venus, the surface of Lakshmi Planum represents both a geologically and geophysically interesting target that would be an ideal location for part of a planetary seismic network. The group spent a significant amount of time formulating and discussing measurement guidelines for those targets that meet or partly address the investigations listed in the VEXAG GOI (Tables 2 through 5).

Although the VEXAG investigations cover a broad range of goals and objectives, varying in difficulty and breadth, scientific evaluation of most target types can address a number of objectives with some targets meeting some objectives better than others. Some objectives could not be met at some target types.

Table 2. Geochemistry measurement requirements for surface targets linked to investigations listed in the VEXAG GOI document.

Needs	GOI indices from VEXAG document (see appendix)				
Major Elements	II.B.1	III.B.2	III.A.3		
Sulfur	II.B.1	III.B.2	III.A.3	III.B.4	
Chlorine	II.B.1	III.B.2	III.A.3		
Heat Producing Elements		III.B.2			II.B.5
Mineralogy	II.B.1	III.B.2	III.A.3		
Wants					
Trace Elements	II.B.1	III.B.2			
Fluorine	II.B.1	III.B.2	III.A.3		
Fe-Oxidation State	II.B.1	III.B.2	III.A.3		
Carbon	II.B.1	III.B.2	III.A.3		

For many atmospheric objectives, the identified targets have identical measurement guidelines as those for measurements made from a platform 'in the atmosphere'. See Appendix for our proposed guidelines, organized by GOI investigations.

Table 3. Surface measurement requirements for minerals.

Mineralogy		Minimum Detection Limits	
		For Low Concentrations	For High Concentrations
Silicates	Olivine	3 +/- 2 vol%	50 +/- 10 vol %
	Pyroxenes	3 +/- 2 vol%	50 +/- 10 vol %
	Plagioclase	3 +/- 2 vol%	50 +/- 10 vol %
	Alkali Feldspar	3 +/- 2 vol%	50 +/- 10 vol %
	Silica-polymorphs	3 +/- 2 vol%	50 +/- 5 vol %
Hydrous	Amphibole	Detection - absolute presence	
	Mica	Detection - absolute presence	
Salts, Oxides, etc.			
	Carbonates	Detection - absolute presence	
	Phosphates	Detection - absolute presence	
	Sulfates	3 +/- 2 vol%	50 +/- 10 vol %
	Hematite	3 +/- 2 vol%	50 +/- 10 vol %
	Magnetite	3 +/- 2 vol%	50 +/- 10 vol %

Table 4. Requirements for major elements (represented as oxides weight percent) for surface targets. Major elements refer to an average basalt on Earth. Uncertainties are based on that average basaltic composition chosen but will vary for exotic compositions (i.e., granites and carbonatites)

Mineral	Basalt (wt %)	± (wt %)
SiO_2	51.6	2
TiO_2	0.8	0.1-0.2
Al_2O_3	15.9	1
Cr_2O_3	0.8	0.2
FeO	8.5	0.5
MnO	0.2	0.1
MgO	6.7	0.5
CaO	11.7	0.8
Na_2O	2.4	0.2
K_2O	0.4	0.05
P_2O_5	0.1	0.1
SO_3	<3	0.3
Cl	<1	0.1

Table 5. Measurement requirements for determining concentrations of heat producing elements at a surface target site. Values are for Earth with uncertainties based on average composition chosen.

Element	PPM	Uncertainty (±10%)
Potassium	3000	300
Thorium	2.4	0.2
Uranium	0.6	0.06

A general concern expressed by the group was that some targets are easier to reach than others. For instance, some proposed targets may be smaller than the landing ellipse likely for a future Venus mission (a typical landing ellipse would likely exceed 75 km in width). Furthermore, some scientifically interesting targets such as tesserae may be risky to reach safely, because of surface slopes, roughness, and boulder distributions. Because the extent of these hazards is unknown, a precursor mission may be necessary before attempting to land on these target sites. Consequently, some of the surface targets (Cleopatra, Maat Mons, interiors of craters, young flows etc.) may require precision landing and/or hazard avoidance technologies to access scientifically interesting sites.

2. Science within the Atmosphere

The three dimensional nature of the atmosphere meant that this breakout group needed to consider not only latitude and longitude (both geographic and solar) but also the relevant altitude range of specific exploration targets. Furthermore, the location of both the observer and the observed needed to be considered, as some measurements become impossible at certain altitudes due to opacity variations. Unlike a surface lander (which can be placed at a specific location, having descended through a specific atmospheric column) or an orbiter (which can observe the planet remotely with a variety of orbital parameters), the in situ atmospheric platforms to be considered were as varied as the observation targets. As such, the panel was cognizant of the differences in measurement capabilities of drop sondes, super-pressure balloons, and three-dimensionally mobile atmospheric platforms.

Although an atmospheric in situ measurement platform is ideally suited for atmospheric investigations, it also is clear that under the right conditions and with the appropriate instrumentation, such a platform can also make a substantial contribution to surface and surface-atmosphere investigations. Consequently, given the wide range of potential observational targets (and observational platforms), and the large variety in potential science questions to be answered, this group's discussions were focused primarily by the VEXAG GOI document, rather than by specific targets of observation. Thus, the conclusions of this group are somewhat less quantitative than those of the other two breakout groups. At times, the wide range of potential targets of observation required a subdivision of the group, in which one sub-group would tackle the surface science investigations while the other subgroup addressed atmospheric investigations. Consequently, contributors to the discussion were varied, as individuals would move among this and the other two main panels, as well as among these two subpanels with this group.

1) Atmospheric Science Subgroup

In order to facilitate our discussions and summaries of the desired observations, we arbitrarily divided the atmosphere in several dimensions. Specifically, we defined equatorial (0°–30°), mid-latitude (30°–60°) regions, and polar (60°–90°); local solar times: midnight (21^h–03^h), dawn (03^h–09^h), noon (09h–15h), and dusk (15^h–21^h); and altitudes based on both dynamical and compositional criteria: upper hazes (above 70 km), photochemical clouds (60–70 km), condensational clouds (50–60 km), lower hazes (40–50 km), and deep atmosphere and boundary layer (below ~40 km).

For many atmospheric investigations, the ideal modes of operation involve long-term, high spatial and temporal resolution measurements of meteorological parameters, concentrations of trace species, and compositions and distributions of aerosols. However, this would produce a volume of data that is difficult to achieve even for the Earth, let alone a remote spacecraft at an alien world. Therefore, the panel chose to comparatively prioritize the utility of measurements among those domains. A qualitative summary of the findings of the subpanel can be found in Table 6, with a more complete summary of the findings found in the spreadsheet(s) in the Appendix. For example, to address the investigation on the radiative balance of Venus (I.B.2), the panel concluded that broad spectral coverage that is capable of encompassing the entire radiative spectrum was preferred to high spectral resolution studies that might be able to identify concentrations of trace species and their spatial and temporal variations.

Finally, the subpanel recognized that in situ observations represent a compromise in which the certainty of the measured sample is increased at the expense of the global context. To that end, many of our target and approach suggestions would benefit greatly from a coincident orbital observation. For example, in-situ measurements of aerosol composition and size distributions in the condensational cloud (I.C.1) would be even more valuable if paired with an orbital observation of near-infrared night-side emission of the sampled region. Over the course of the workshop, this group worked closely with the "Science from Orbit" group, and relevant overlaps are noted in the summary table.

Table 6: Qualitative Findings of the Atmospheric Platform Subpanel

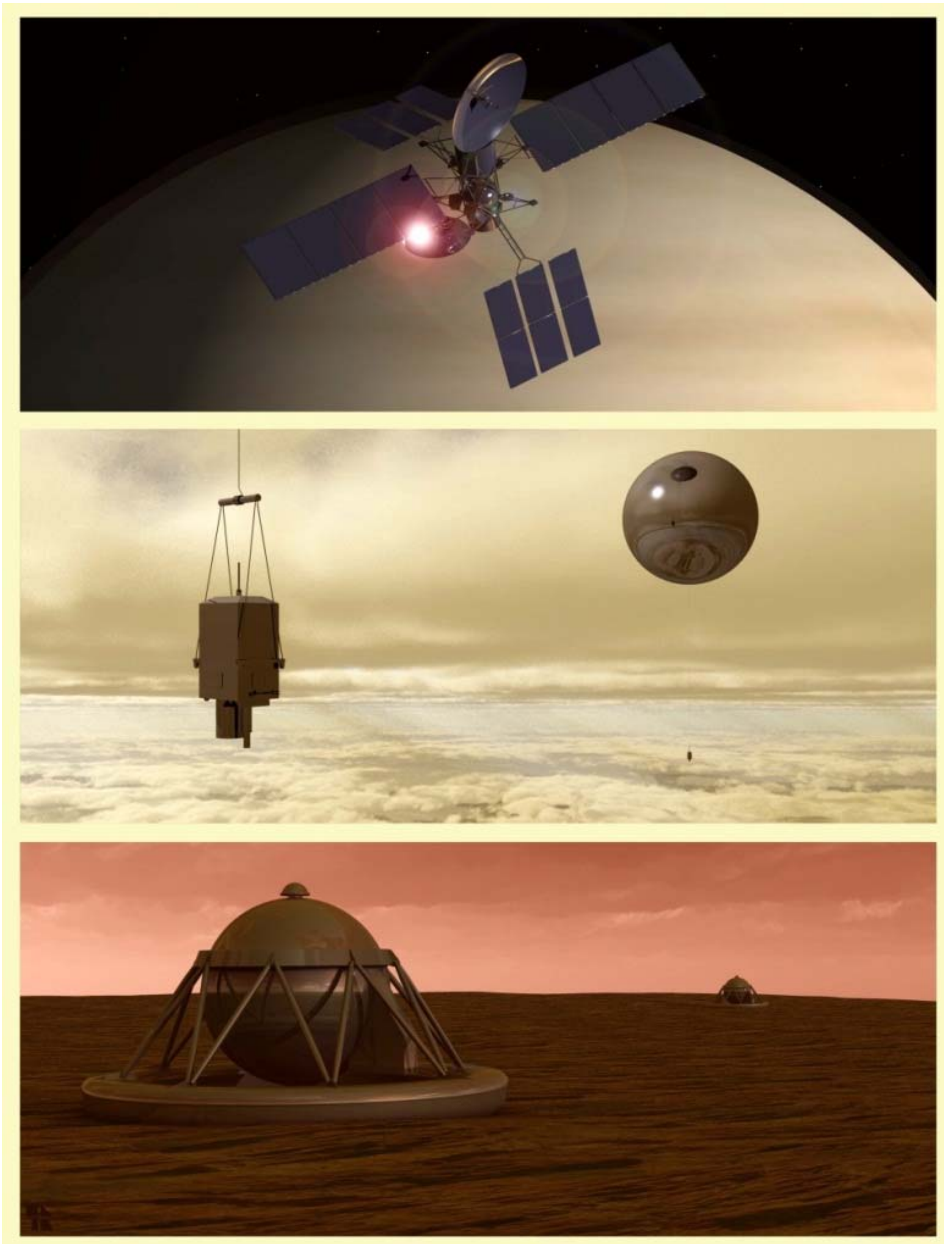
GOI	Preferred Platform and/or Measurement Technique	Requirements
I.A.1	Long-term for improved accuracies	Measure most gaseous abundances and ratios to at least 5% levels.
I.A.2	Spatially separated measurements (mobile platform or multiple probes)	
I.B.1	Long-lived aerial platform or multiple probes	Global momentum and energy transport. Horizontal resolution preferred to vertical
I.B.2	Multiple probes or constant altitude mobile platform for spatial coverage	Order of resolution preferences: Spectral, Vertical, Horizontal
I.B.3	Sustained aerial platform	Vertical resolution preferred to horizontal. Measure accelerations (precision not noted)
I.C.1	Mobile platform and aerosol characterization	Vertical resolution to 0.5 km. Spatial resolution to 10^4 km for diurnal variability. 10-100km resolution for small scale dynamics
I.C.2		
I.C.3	Long term observation for statistical significance	Subpanel did not quantify E-field measurement precision
I.C.4	See I.A and I.C.1,2	See I.A and I.C.1,2
II	Most requirements for this Goal made from an atmospheric platform mirror those from orbit and the surface, or are impossible from a platform not bound to the surface. It was noted that observations from a lofted platform can allow observation of multiple physiographic terrain types.	
III	Most requirements here mirror either those described from Goal I or those associated with observations of the surface from the surface or atmosphere.	

2) Surface Investigations Subgroup

The discussions regarding possible investigations of the surface from an atmospheric platform derived from interaction of a few members from each of the other two groups (Science from Orbit and Surface) instead of a consensus from a larger group. The two primary conclusions reached are that aerial platforms i) can either furnish the capability of targeting specific surface features or provide regional coverage, and ii) bridge capability gaps that exist between orbital and surface platforms, be it in resolution or observational technique.

In all of these discussions, the focus naturally gravitated towards the different techniques for imaging the surface (visible, IR, stereo) and characterizing topography (laser altimetry or lidar), and the measurement requirements that would enable goals and objectives to be addressed. Such requirements represent a trade between that attained by globe-spanning orbital and the local to microscopic scale of landers. Imaging the surface from low altitudes, for example, may not only complement radar imaging data in terms of surface properties, but would also attain greater spatial resolution. The discussions generated a large number of examples for potential targets that spanned the different physiographic provinces of Venus and that bear on heat-flow, tectonic, volcanic and resurfacing histories, as well as the interaction between the surface and the atmosphere. Another aspect that arose from these discussions was the potential of different observational techniques that could be used to investigate the surface from aerial platforms. While some could be developed in the relatively near future, others would require greater development and would only be available further in the future.

Because of the restricted nature of the interactions among few panelists of different groups, it is recommended that a larger group of surface-oriented individuals further discuss the applicability of atmospheric platforms to addressing the science goals and objectives of the solid portion of Venus.



Artist's concept of the Venus Flagship Design Reference Mission elements: orbiter, balloons, and landers, developed by the Venus STDT in 2008–2009.

3. Science from Orbit

The “Science from Orbit” group began by reviewing the *VEXAG Goals, Objectives and Investigations* document and table. Efforts during the breakout sessions focused on those investigations that are amenable to remote sensing observations from orbit. Because there are a large number of diverse scientific topical areas that can be addressed from orbit, the group was split into five subgroups in order to identify important targets and develop observational strategies. The five “Science from Orbit” target subgroups were:

1. Atmosphere (chemistry and dynamics)
2. Volcanism
3. Crustal structures and tectonics
4. Impact craters and weathering
5. Global (this group was focused on observational strategies that require a global perspective, e.g., gravity field).

Many of the atmospheric measurements and observations from orbit provide important regional-to-global contextual information for detailed in situ measurements. In addition, the target regions and measurements are similar to or highly complementary to those from atmospheric in situ platforms. As a result, the atmospheres target subgroup met primarily with the “From Atmosphere” group to ensure consistency across the breakout groups for the investigations focused on atmospheric measurements. Additionally some members of the “Science from Orbit” group sat in on the “Science from Atmospheres” group to provide surface geology expertise.

The four “Science from Orbit” target subgroups that focused on observations of the Venus surface developed lists of important groups of targets for addressing each investigation. They also developed guidelines for important considerations for selecting specific observational sites within a target category (coronae, chasmata, etc.) in order to adequately address the full range of surface expressions seen on Venus. Finally, each group identified the types of measurements and observations that are needed to address each investigation, including guidelines for resolution, precision, and other metrics for measurement performance. Interestingly, each group independently identified very similar guidance for a small number of measurement categories that re-occur as important contributors in several investigations. These are:

- Moderate spatial resolution images at contextual scales
- Targeted high spatial resolution images
- Regional scale topography
- Targeted finer scale topography

Moderate spatial resolution imaging is defined here as an improvement of a factor of 3 over Magellan (or ~40 m resolution cells) with image quality that is equal to or better than Magellan and adequate for quantitative interpretation.

High spatial resolution imaging is defined here as an improvement of a factor of ~10 over Magellan with image quality that is equal to or better than Magellan and adequate for quantitative interpretation.

Regional-scale topography is defined here as having a spatial resolution with "MOLA-class-horizontal-scales" (1–2 km postings). In the vertical, the ability to resolve slopes of a few degrees (~5 degrees over a 1 km baseline) would be capable of resolving features below the resolution of Magellan. Certain investigations may benefit from targeted finer postings and vertical precision. Covering about 20% of the planet with moderate resolution imaging and a few percent with targeted high-resolution imaging will address many important, currently unresolved questions. Specific coverage requirements and sampling strategies for different target types are addressed in the appendix.

In addition to these measurement types, a small number of additional measurement types were identified that, when combined with the imaging and topography, provide the needed observations to address each investigation. These additional measurement types are:

- improved globally resolved gravity field
- global infrared emission
- global microwave emission
- magnetic field

Finally, some investigations would benefit from more specialized targeted observations such as microwave polarimetry, and surface penetrating radar.

4. High-level Workshop Findings

Surface Platforms: Precision targeting, hazard avoidance and potential robust landing (e.g., self-righting) are key technologies in the future exploration of Venus. Although there may be a few targets (e.g., plains which have been visited several times already in past missions), which are accessible with existing techniques, the most potentially transformative landing sites with require new technologies. While these techniques can leverage navigation and guidance work done for Mars and Europa, control in the dense atmosphere of Venus will require techniques unique to Venus.

Atmospheric Platforms*:* While many different types of platforms can be emplaced within the atmosphere of Venus, they will differ in terms of the altitude ranges that can access and the degree of vertical and horizontal control they offer. The breakout group was only able to scratch the surface of what is possible with atmospheric and surface targets from vantage points within the atmosphere. A future dedicated workshop on this topic might be appropriate at some time. The technology for only a subset of atmospheric platforms (super-pressure [SP] balloons and probes) exists, and so further development work will be needed

Orbital Platforms: The strength of the orbital vantage point is the breadth of access which is a key discriminator from the surface and even the atmospheric platforms. While certain remote sensing approaches are not possible at Venus (e.g., Gamma ray, X ray and near-IR surface studies, but radio science and thermal IR technologies have advanced greatly since Magellan last visited Venus. The broad, long duration, repeat coverage offered by orbital payloads offer unique exploration advantages that address many of the outstanding goals and objectives identified by VEXAG and play key role as a precursor (for more precise targeting) to future in situ payloads.

Multimodal Observations: The value of multimodal observations comes up in the sections on each of the above topics. For Venus, because of the dynamic atmosphere there is great advantage to synchronous observations of the same target from two or more platform types as opposed to observations at different times.

Attendees

Name	Affiliation
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Pioneer Venus (atmosphere) and Magellan (surface) views of Venus.

Acronyms and Abbreviations

D/H	deuterium/hydrogen (ratio)
EGA	exhaust gas analyzer
EM	electromagnetic
GOI	Goals, Objectives, and Investigations (for Venus Exploration)
GRS	Gamma Ray Spectrometer
IR	infrared
LIBS	Laser-induced breakdown spectroscopy
LIDAR	light radar
LPL	Lunar Planetary Institute
MOLA	Mars Orbiter Laser Altimeter (instrument on Mars Global Surveyor)
N/A	not applicable
NIR	near infrared
NMS/TLS	Neutral Mass Spectrometer
RLS	Raman Laser Spectrometer
SV	Straw Vote
TBD	to be determined
TLS	Tunable Laser Spectrometer
VET	Venus Exploration Target(s)
VEXAG	Venus Exploration Analysis Group
XRD	X-ray powder diffraction
XRF	X-ray fluorescence

The following appendix is best if printed on 11 X 17 ledger sheets landscape.

VENUS EXPLORATION TARGETS WORKSHOP TRACEABILITY MATRIX

VEXAG Goal I – Atmospheric Formation, Evolution, and Climate History

GOI Index	Platforms on the Surface			Platforms in the Atmosphere			Platforms in Orbit		
	Targets	Approach	Requirements	Targets	Approach	Requirements	Targets	Approach	Requirements
I.A.1.	Anywhere on the surface (All targets)	Neutral Mass Spectrometer (NMS)	Same as "From the Atmosphere"	Any location in the atmosphere below 100km regardless of altitude, latitude, and longitude.	Accuracy improves with long term platform. Quantification of current-day meteoritic influx from orbit using transient camera	Xe: a first measurement of bulk abundance and isotope ratios Kr: to the 5% level bulk abundance measurement Ne: isotopic ratios to within 5% O: 17/16: 0.02% (this may need a TLS)	N/A	N/A	N/A
I.A.2.	Anywhere on the surface (All targets)	Neutral Mass Spectrometer (NMS)/Tunable Laser Spectrometer (TLS)	Same as "From the Atmosphere"	Any location in the atmosphere below 100 km regardless of altitude, latitude, and longitude; D/H is variable and should be observed at multiple locations with vertical profiles/gradient of light isotopes. Avoid volcanically active regions to avoid "contamination" from surface production (see Goal III.B.3) (a mobile platform could sample both active and non-active regions)	Need to have multiple vertical profiles of light isotopes to investigate spatial variability. Possible to obtain and analyze sample rapidly (i.e., on descent: whether probe or lander) Measure total escape rates (neutral + ionized) from orbit. (Measure C, N and O isotope ratios from orbit using sub-mm or other techniques)	Xe: 3% in isotopic ratio (128/130) Kr: 1% in isotopic ratio (82/84) D/H: 5% N (15/14): 5% Vertical gradient (single location correlated with vertical wind) might be more appropriate than vertical profile O loss rate: from orbit H loss rate: from orbit	N/A	N/A	N/A
I.B.1.	Most targets, excluding those with steep slopes	Same as "From the Atmosphere	Same as "From the Atmosphere"	Meteorological measurements as functions of: latitude (pole to pole) altitude (z<=~70km; priorities: cloud tops, convective region, peak in momentum & energy (boundary layer up to 20km)), solar time (all longitude)	Aerial platform and/or multiple vertical probes. Multiple vertical probes for vertical winds profiles; Long term measurement of winds at a particular altitude over a range of longitudes with aerial platform. Remote sensing from orbit: Cloud/feature tracking at multiple wavelengths; Doppler wind speed determination; temperature field determination; airglows to characterize Upper mesosphere - lower thermosphere transition	Goals of atmospheric meteorological measurements: Global Momentum and energy transport Call for a Hierarchy of models (varying spatial scales and complexity). Horizontal coverage (in situ measurements) more useful than vertical resolution For climate change/variability characterization, long duration is needed (up to and including solar cycle timescales) Short duration measurements with larger spatial coverage (lat/LST) equally useful	Global cloud layer, upper mesosphere, lower thermosphere	Remote sensing from orbit can be used to track clouds/features at multiple wavelengths; wind speeds can be measured directly using Doppler techniques; temperature field can be determined; airglows can be observed to characterize the upper mesosphere - to - lower thermosphere transition.	Same as "From Atmosphere" group
I.B.2.	Anywhere on the surface (All targets)	Measure surface temperature	Same as "From the Atmosphere"	Vertical profile of radiative fluxes (both visible wavelength and infrared). For solar: Cloud top energy deposition (60-70km; observations made from above (and/or within) the absorbers in the upper clouds) Range (significant fraction of diurnal cycle) of solar time measurements (esp. visible wavelength measurements)	Multiple probes or constant altitude measurements; cycling/mobile balloon measuring from multiple altitudes/locations. Measurements from orbit: Infrared emission/imaging; measurement of opacities trace species; Broadband solar and thermal fluxes. Radio occultation, solar occultation, stellar occultation for thermal structure. Passive thermal (IR-sub-mm-radio) sounding of atmospheric temperatures.	Vertical resolution preferred to horizontal resolution above clouds Spectral coverage (i.e. broadband) preferred to spatial resolution both above, within, and below clouds Contextual information helpful (from orbit or remote) Spatial (vertical and horizontal) coverage preferred to seasonal (time) coverage (in infrared).	Orbital observations of the global atmosphere provide context for in situ measurements, in particular vertical profiles of radiative fluxes (both visible wavelength and infrared).	Key approaches for global atmosphere observations from orbit include infrared emission/imaging, measurements of trace gas species opacities, broadband solar and thermal fluxes, radio occultation, solar occultation, stellar occultation for thermal structure, and passive thermal sounding of atmospheric temperatures.	Same as "From Atmosphere" group
I.B.3.	N/A	N/A	N/A	50-60km range; orography driven waves: near surface topographies (e.g. Maxwell Montes, Ishtar terra); solar driven gravity waves (equatorial latitudes). 60-70km region: gravity waves and local absorbers. 0-20km for orographic waves	Sustained aerial platform Measure accelerations Correlate with thermal contrasts/microphysics Difficult to do with rapidly falling probes Characterization of waves in/above upper clouds from orbit (imaging and/or occultation)	Horizontal coverage low priority High vertical resolution	50-60km range; orography driven waves: near-surface topographies (e.g. Maxwell Montes, Ishtar terra); solar driven gravity waves (equatorial latitudes (up to ~30?)). 60-70km region: gravity waves and local absorbers. 0-20km for orographic waves	Characterization of waves in/above upper clouds form orbit (imaging and/or occultation)	Same as "From Atmosphere" group

I.C.1.	N/A	N/A	N/A	Clouds and hazes exist over range (40-80 km); All latitudes and local times uncharacterized aerosols at z<50km (40-50, around 20km, near surface) Condensational clouds: ~50-60km Photochemical clouds at 60-70km Hazes at z>60km Range of latitudes.	Multiple profiles preferred over single profiles; horizontal path of constant altitude preferred with possibly a range of latitudes Measurements of aerosol composition and size distributions and geometry (particle shape/phase); gas composition; local dynamics (winds), radiative flux Global mapping of sulfur species (SO, SO_2, H_2SO_4), chlorine species, nitrogen species, photochemical byproducts etc. from orbit. Profiling of upper cloud profile and scale heights using LIDAR or other technique). Precipitation radar to search for rain etc.	Vertical resolution to ~500m Horizontal resolution: 10^4km for diurnal processes; 10-100km for local dynamical phenomena Descent profile with contextual imagery (In situ LIDAR or orbital supplementary data) Multiple profiles option (equatorial/mid lat/ polar); For upper cloud/hazes: polar versus "not-polar" Contextual coverage (from orbit; low spectral resolution sufficient) helpful for particle size distributions	Clouds and hazes exist over a range (40-80 km); all latitudes and local times. ~50-60km.clouds deck. Photochemical clouds at 60-70km; range of latitudes.	Global mapping of sulfur species (SO, SO2, H2SO4), chlorine species, nitrogen species, photochemical byproducts etc. from orbit. Profiling of upper cloud and scale heights. Search for rain using precipitation radar may provide new information.	Same as "From Atmosphere" group
I.C.2.	Anywhere on the surface (All targets, especially active areas)	Same as "From the Atmosphere"	Same as "From the Atmosphere"	Optically thick cloud region (~0-70km) over all latitudes and local times ~50-60km cloud deck. Need for lower atmosphere opacity (Improved Abs. Coeffs; opacity of Green House gases – Lab investigations) Photochemical clouds at 60-70km; range of latitudes. Vertical profiles of relevant chemical species (list of "relevant" species found in III.B.4)	See I.B.2: in context with aerosol measurement properties. Either simultaneous measurements or in context with orbital observations Multiple profiles preferred over single profiles; horizontal path of constant altitude preferred may need a range of latitudes. Measurements of aerosol composition, size distributions, and geometry (particle shape/phase; existence of meteoritic dust); gas composition; local dynamics (winds) and radiative flux Context imagery/spectroscopy from orbit to characterize local chemistry & morphology. Radio occultation for temperature profiles through the clouds	Same as I.C.1	Optically thick cloud region (~0-70km) over all latitudes and local times. ~50-60km cloud deck. Need for lower atmosphere opacity. Photochemical clouds at 60-70km; range of latitudes. Vertical profiles of relevant chemical species	Context imagery/spectroscopy of the clouds from orbit to characterize local chemistry & morphology. Radio occultation for temperature profiles through the clouds	Same as "From Atmosphere" group
I.C.3.	Anywhere on the surface (All targets)	Electromagnetic (EM) and optical remote sensing	Same as "From the Atmosphere"	Upper cloud region; nearer to surface; location of lightning still unconstrained; Range of solar times and latitudes; Vertical profile of electric/magnetic fields	Measure electric or magnetic field in situ; Local atmospheric conductivity; Measure charge of aerosols; Orbital: optical and electrical search for lightning. Magnetic field determination from orbit, to understand propagation of magnetic lightning signatures; Aural (microphone) measurements; establish acoustic background	Need days to weeks to generate sufficient statistics (stochastic events: can be measured from probes but possibly low likelihood); High speed imaging assistance/correlation from orbit would be helpful (whether optical or radio)	Upper cloud region; nearer to surface; location of lightning still unconstrained; Range of solar times and latitudes; Vertical profile of electric/magnetic fields	Optical and electrical surveys can be conducted from orbit to search for lightning. Magnetic field measurements can be used to understand propagation of magnetic lightning signatures.	Same as "From Atmosphere" group
I.C.4.	Anywhere on the surface (All targets)	NMS/TLS	Same as "From the Atmosphere"	Cloud regions: range of temperatures consistent with life.	Measurements of C12/13 in balloon/aerial platform at cloud altitudes; Chemical environment oxidation, pH, radiative environment; Cloud particle lifetimes	Same as "natural" C 13/12 ratio; Similar constraints (vertical resolution, temporal sampling) to aerosol measurements and chemistry measurements	Cloud level, globally	Measure aerosol abundances, particle sizes and sulfur species through radio occultation and IR studies.	Same as "From Atmosphere" group

VEXAG Goal II – Evolution of the Surface and Interior

GOI Index	Platforms on the Surface		Platforms in Orbit	Platforms in the Atmosphere			Platforms on the Surface		
	Targets	Approach		Targets	Approach	Requirements	Targets	Approach	Requirements
II.A.1.	Tessera, plains, flows, Ishtar, Maat Mons, Cleopatra	Multi-spectral descent imaging, panoramic surface images	Spatial resolution 1-100 m, spatial resolution 1 mm	• Imagery and altimetry of tessera fabric (fine structure) and its relationship with surrounding units - <20 m imagery, <100 m altimetry. • Imagery and altimetry of suspected (micro) dunes (sedimentary budget, mobility) • Imagery and altimetry of small-shied fields (resurfacing, plains emplacement, superposition) • Imagery and altimetry of areas of radar backscatter contrast (halos, nature impact/volcanic, are they ash fall or lava flow; subtle flows sources) (impacts weathering, volcanic resurfacing). • Young craters for distinguishing impact melt from volcanics (energy partitioning, modification) • Craters - statistical depth/diameter determination for fresh craters, weathering/infilling • Canali - width/depression with cross-regional profile (flow rate), single vs. multiple episode (flow rate), distal end (flow direction and composition), truncation (not identifiable for radar) (volcanic types) • Rift zones imaging and topography for fault/wall geometry (stratigraphy/nature of fine layering, lack of volcanic/sedimentary fill e.g. Devana Chasma, Ganis Chasma) • Coronae & rifts flexural signature (crustal/lithospheric processes) • Snowline observations (weathering and atmosphere/surface interactions, precise elevation determination) • Visible-IR Imaging at altitudes low enough to prevent scattering problems <5 km or well < 3km. May desire multispectral data • Need to distinguish specific occurrences for targets that are ubiquitous.	Visible imaging, stereo, descent cameras, laser altimetry, lidar	• Tessera <20 m imagery, <100 m altimetry • (Micro) dunes: micro <10 m imagery, larger dunes <100 m; topography < ~1 m for larger dunes • Small-shied fields ~ 10 m imagery & topography • Radar backscatter contrast (halos, nature impact/volcanic, are they ash fall or lava flow?; Are they subtle flows, sources?) <1 m imagery for characterization, larger for identification • Young craters for distinguishing impact melt from volcanics • Craters - statistical depth/diameter determination for fresh craters, weathering/infilling: imagery <=20 m, <=10 m topo • Canali - <=10 m imagery and topography • Rift zones imaging and topography for fault/wall geometry <10 m imagery, < 1 km posting for topography, <= 100 m vertical • Coronae <=100 m imagery and topography posting, < 10 m vertical • Snowline topo 1 km lateral, <= 100 m vertical. NB: These constraints are more on the high-precision side than the minimum necessary for advancing the field (here, and in column "Targets" for this investigation).	Volcanism: Volcanic targets include surface expressions of a range of volcanic styles, including lava plains, corona, festoon flows, lava flows, pancake domes, canali, calderas, shield fields, medium shields, large edifices, and pyroclastic deposits. Sampling strategies of these targets should consider features over the full range of sizes and at a variety of altitudes. To better understand sequence relationships - some volcanic features associated with tectonic features (e.g., Parga Chasma) and some that are isolated should be considered. For coronae and pancake domes a full range of observed morphologies should be included in the sample targets. Long features like canali should be observed over their entire length. Volcanic vents associated with structural rises and some not associated with rises should be included. A systematic search for vents associated with plains flows would be useful. While every feature need not be examined to address the investigation, a sampling strategy that includes ~30% of each feature style would be adequate. The exceptions to this percentage-based strategy are the volcanic plains where reasonably large sample areas of several units covering a range of Magellan-mapped plains types may be more appropriate. Weathering: Characterization of fresh impact craters on Venus, their ejecta, impact melt, and crater outflows are critical to understanding weathering processes and for characterizing stratigraphy. An impact crater target sampling strategy should include ~20 or more pristine craters that span the full range of sizes and different target types. Example targets include Mead, Cleopatra, Markham, and Adivar. To better understand what processes modify craters and what is the nature of radar-dark floors, a sampling strategy should include ~20 or more modified craters for morphological analysis. In addition, all craters with diameters greater than10 km should be observed for morphometric measurements Structures: Identify and measure size and elevation of faults, folds, lineaments for ≥20% tessera, with a focus on tesserae that are least modified (Alpha, Tellus, W. Ovda, Fortuna). Look for stratigraphic relationships; examine detailed morphology of tessera materials for selected areas (geographically diverse areas, structural domains, plains-tessera boundaries, tessera inliers; ~20% of total). Look for craters in a survey of all tesserae. Measure size and wavelength of structures in rift belts (Devana, Hecate, Parga, Hecate, Ganis), ridge belts (Lavinia, Atalanta), mountains (Ishtar, Akna, Freya), and coronae (sample range of corona morphology, stage, region, on-axis vs. off-axis: e.g., Artemis, Parga, Hecate, Diana, Dali). Focus on selected transects of rifts, ridges, mountains and coronae. Measure ≥20% of each of the terrain types. Measure size, shape and wavelength of wrinkle ridges for ~20 examples.	Approach requires both imaging and topography with the ability to characterize surface structure and roughness as well as the presence of possible mantling deposits. The ability to detect small-scale features (e.g. domes, graben, etc.) on the order sub-km diameter shields, 30-40 m high would be very helpful.	Volcanism: Can be accomplished with contextual moderate resolution imaging and targeted high-resolution images of targets. Regional-scale topographic mapping is sufficient for most features, with some targeted higher resolution topography required for smaller features such as thin lava flows and small shields. Weathering: Targeted high-resolution images would help resolve morphologic features at impact crater targets. Image coverage is of highest value with coverage 4 times the diameter for each crater of diameter D. Images with different incidence angles are also useful. Regional-scale topography is sufficient for most targets. Some targeted high-resolution topography would be useful for measurements of wall steepness. Structures: Moderate spatial resolution imaging and regional-scale topography are adequate for observations of all tesserae and selected transects for rifts, ridges and coronae. High spatial resolution imaging of selected tesserae regions is useful to examine morphology. High-resolution topography is useful for characterization of a sub-sample of wrinkle ridges.

II.A.2.	Anywhere on the surface (All targets)	NMS	Same as "From the Atmosphere"	See I.A.1 and I.A.2	See I.A.1 and I.A.2	See I.A.1 and I.A.2	NA from orbit	N/A	N/A
II.A.3.	Tessera, plains, Ishtar Terra	Short-lived lander: heat flow, EM, remnant magnetization; Long-lived lander: seismology, rotational dynamics	Seismology: 3 components, 2 or more stations; heat flow: 5 mW/m²; magnetization: 1 nT; Electric: 1 uV/m, 2 components; Magnetic: 1 pT; frequency: 10-100 Hz	Gravity for subsurface structure, especially at volcanic edifices, coronae, tesserae. Atmospheric (infrasonic) Seismology (VQs rates, strength). Skin-depth resistivity for plains and volcanic rises.	Magnetometer on aerial platform to search for remnant crustal magnetic field; Gravity gradiometry, magnetic, infrasonic seismology, magneto-telluric sounding from balloon.	Sustained aerial platforms. 10-100 km sensitivity for magneto-telluric technique	Volcanism: Targets for understanding the type of support for current volcano topography (and possibly for placing constraints on sub-surface magmatic plumbing) are broad volcanic rises (e.g., Beta Regio, Western Eistla Regio, and Ishtar Terra) and volcanic regions associated rift zones (e.g., Parga Chasma and Maat Mons). Structures: Measure size and wavelength of tessera structures (Alpha, Tellus, W. Ovda, Fortuna) and Ishtar Terra (Akna, Freya), which may be remnants of extinct tectonic regimes. Imaging required for ≥20% of the regions. Global: Global characterization of the gravity field is a required component to address this investigation. A global constraint on the maximum strength of magnetic field would also be useful.	Approach requires combined use of improved (over Magellan) global gravity, combined with images and topography. Approach also includes orbital detection of remnant magnetic field (or at least place constraints on maximum strength based on minimum detection limit from orbit).	Volcanism: moderate resolution imaging and regional-scale topography combined with global gravity field (as defined below) Structures: moderate resolution images and regional-scale topography, with targeted high resolution topography for selected regions. Global: Global gravity field of degree and order 120 (TBR) in spherical harmonics, globally resolved in both longitude and latitude (i.e., with uniform latitude and longitude coverage). For reference, gravity of degree and order 120 could properly determine the amplitude of gravity anomalies as small as 160 km across. Also, global constraint on magnetic field.
II.A.4.	Active sources, young flows	Seismology, NMS, infra-sound	Seismology: 1 component; NMS, infra-sound: TBD	Thermal anomalies/gas outflows (SO_2) Isotopic ratios (see III.B.1). Weathering from imaging (e.g., albedo). RF/Sounder for compositional proxy and subsurface structure.	Imaging at 1 µm would get high spatial resolution below cloud deck	Sustained aerial platforms	Volcanism: Targets include examination of features with known microwave and infrared emissivity anomalies as well as volcanic centers that have been postulated to be active (e.g., Gula Mons, Maat Mons, Sacajawea, Sapas Mons, Sif Mons, Tuulikki, Tuli, and Mylitta Fluctus). Structures: targets include examination of rift floors and environments for selected major rifts (Devana Chasma, Parga Chasma, Hecate Chasma, Ganis Chasma) and coronae; mapping of volcanic deposits. Imaging for 20% of total.	First approach is identification of surface changes in morphology and topography (horizontal displacement, inflation, deflation, pit crater formation, new flows) over time. Second approach is to use IR and microwave emission. This approach is to identify anomalies in global emission maps associated with volcanic centers. Third approach is to measure the global distribution and variability of water vapor near the surface (lowest 5 km) to identify anomalies associated with volcanic centers.	Volcanism: for IR emissivity ability to resolve anomalies of ~100K relative to background; for microwave emissivity ability to detect anomalies of a few Kelvin (~5K) relative to the background; repeat observations (2 or more within a mission for surface change detection; for deformation differential interferometry and knowledge of atmospheric variability with time and space may be applicable; multiple observations for IR and microwave emissivity and for water vapor); small targeted areas at high spatial resolution images; broader coverage at moderate resolution. Structures: moderate resolution images of specified target regions.
II.A.5.	Anywhere on the surface (All targets), especially tessera and plains	NMS, sample handling, lasers; requires significant development	TBD	N/A from atmospheric platform	N/A from atmospheric platform	N/A from atmospheric platform	N/A from orbit.	N/A	N/A
II.B.1.	Anywhere on the surface (All targets), especially tessera and plains	GRS, XRD, XRF, Raman, LIBS, IR-spectroscopy, microscopic imaging	TBD	All targets, see II.A.1	Raman-LIBS for mineralogy in a mobile probe at distinct geologic targets with imaging targets. IR emissivity. Drop sondes	See attached diagram of surface science from an atmospheric platform	N/A from orbit.	N/A	N/A
II.B.2.	N/A	N/A	N/A	All targets, see II.A.1	Raman-LIBS for mineralogy in a mobile probe at distinct geologic targets with imaging targets. IR emissivity. Mobile aerial platforms at low altitudes.	See attached diagram of surface science from an atmospheric platform	Image all major geomorphologic regions, particularly tesserae, Ishtar Terra and plains materials for context.	IR and microwave surface emission in as many bands as possible relative to the global mean for specified targets.	Structures: for IR emissivity ability to resolve anomalies of ~100K relative to background; for microwave emissivity ability to detect anomalies of a few Kelvin (~5K) relative to the background.
II.B.3.	Anywhere on the surface (All targets),, especially tessera, plains, and Ishtar (benefits from multiple stations)	Seismology	2 or more stations	Same as II.A.3	E/M sounding from a balloon may provide constraints on crustal thickness and subsurface conductivity; Magneto-telluric sounding from balloon for conductivity profiles	See attached diagram of surface science from an atmospheric platform	Structures: Measure size and wavelength of tessera structures (Alpha Regio, Tellus Regio, W. Ovda Regio, Fortuna Tessera), rift belts (Devana Chasma, Hecate Chasma, Parga Chasma, Hecate Chasma, Ganis Chasma), ridge belts (Lavinia Planitia, Atalanta Planitia), mountains (, Akna Montes, Freya Montes), and coronae (sample range of corona morphology, stage, region, on-axis vs. off-axis: e.g., Artemis, Parga, Hecate, Diana, Dali). Focus on selected transects of rifts, ridges, mountains and coronae. Measure ≥20% of each of the terrain types. Global gravity required.	Approach requires combined use of improved (over Magellan) global gravity, combined with images and topography. Identification of sub-surface stratigraphy may also be useful.	Structures: moderate resolution images and regional-scale topography with targeted finer resolution topography for selected regions. Global gravity field of degree and order 120 in spherical harmonics, globally resolved in both longitude and latitude (i.e., with uniform latitude and longitude coverage). For reference, gravity of degree and order 120 can resolve structures 160 km across.

II.B.4.	Anywhere on the surface (All targets), (benefits from multiple stations)	Long-lived seismology and beacon	Duration: several months	Possibly from within the atmosphere. TBD.	N/A	See attached diagram of surface science from an atmospheric platform	Global target	The approaches here characterize properties of the deeper interior.	Measurement of time variations of spin state, electromagnetic sounding and seismology from orbit could contribute to knowledge of the deeper interior.
II.B.5.	Anywhere on the surface (All targets), except active sources	Assuming radioactive heat sources this requires GRS	N/A	Any isotopic atmospheric measurements close to the surface	N/A	See attached diagram of surface science from an atmospheric platform	N/A from orbit	N/A	N/A
II.B.6.	Anywhere on the surface (All targets), (geophysical measurements of layered terrain)	Seismology, descent imaging and panoramic imaging	Seismology: multiple stations	RF/Sounder of shallow subsurface for compositional, stratigraphic and dynamic nature of plains and tessera/plains contacts. Intratessera basins - volcanism or airfall (as in MiniRF on Moon with visible imaging).	RF/Sounding	Sounder: <10's m vertical ~1 km lateral	Volcanism: targets should include near surface (sub-surface) stratigraphy of volcanic terrains, including a sample of volcanic plains and volcanic centers (e.g., Gula Mons, Maat Mons, Sacajawea, Sapas Mons, Sif Mons, Tuulikki, Tuli, Mylitta Fluctus) Structures: Examine materials exposed by major fault scarps (Devana Chasma, Ganis Chasma, and Latona). Examine materials exposed in tessera scarps and crater walls.	Volcanism: Surface penetrating radar Structures: Some insights into sub-surface stratigraphy can be gained though images of fault scarps and crater walls.	Volcanism: Surface penetrating radar can be used to identify sub-surface interfaces. Structures: Moderate resolution images may be sufficient in some cases but may also require high resolution images of selected targets.

VEXAG Goal III – Interior-Surface-Atmosphere Interaction

GOI Index	Platforms on the Surface			Platforms in the Atmosphere			Platforms on the Surface		
	Targets	Approach	Platforms in Orbit	Targets	Approach	Requirements	Targets	Approach	Requirements
III.A.1.	Anywhere on the surface (All targets)	NMS	During descent and landing, Same requirements as "From the Atmosphere"	Any location in the atmosphere below 100km. No dependence on altitude, latitude, or longitude. D/H is variable: might be necessary to observe at multiple locations. Need vertical profiles/gradient of light isotopes. Might be necessary to avoid volcanically active regions. Need to determine how to avoid "contamination" from surface production	Need to have vertical profiles of light isotopes; i.e., mobile? In situ from atmosphere limited to below ~70km altitude. Escape rates form orbit. Measurement of mesospheric C, O, N, S isotopic ratios from orbit	See I.A.2	For atmospheric escape, global upper atmosphere; for D/H and C, N, and O isotope ratios, global measurements at all altitudes < 100 km - D/H is variable should be characterized temporally and spatially.	Measure total escape rates (neutral + ionized) from orbit. Measurement of mesospheric C, O, N, S isotopic ratios from orbit	N/A
III.A.2.	Not identified yet; tessera a possible target	Descent multi-spectral imaging	Spatial resolution 1-100 m	Same as "From the Surface"	Spectroscopy in lowest km Descent / low altitude imagery with a spatial resolution of 1 to 100 m		Areas in the tesserae, and other areas likely to be relatively old terrains exposed at the surface	Look for small-scale drainage patterns, sedimentary structures, and other geologic formations indicative of running water on the surface.	High-resolution* images.
III.A.3.	Tessera would be best, large impact crater	GRS, XRD, XRF, Raman, LIBS, IR-spectroscopy, sample handling, EGA (for greenhouse gases)	TBD	Same as "From the Surface"	Raman/libs Aerial platforms may give access to steep slopes not accessible by landers		N/A	N/A	N/A
III.B.1.	Anywhere on the surface (All targets)	NMS with EGA	TBD	Any location in the atmosphere below 100km. No dependence on altitude, latitude, or longitude; D/H is variable, necessary to observe at multiple locations. Need vertical profiles/gradient of light isotopes. Might be necessary to avoid volcanically active regions. Need to determine how to avoid "contamination" from surface production (see Goal I)	See I.A.1 and I.A.2 Escape rates form orbit; also need surface material measurements	He: measurement of isotope ratio to within ~20% Ar (40/36): isotope ratio to better than 1% Ne, Xe, Kr: same as above (see I.A.1,2)	N/A	N/A	N/A

III.B.2.	All targets, especially high radar reflectivity	microscopic imaging, RLS, IR-spectroscopy, XRD; removed weathering rind; long-lived to observed dis-equilibrium processes	TBD	Comparison between surface emissivity anomalies and non-anomalous terrain.	Descent or low altitude imagery	Surface/atmosphere momentum and energy transfer (see I.B.1)	Weathering: Several types of targets and observations are needed to adequately address this investigation. Five key target types are identified here. A) Extended impact crater ejecta deposits: Do we see evidence of absence of super-rotation in the past older craters (also relevant to I.A)? What processes modify extended deposits (in-situ chemical weathering, aeolian transport, overprinting by volcanism, etc.)? Targets should include ~50 representative samples of radar-dark parabolas, emissivity parabolas, radar-dark halos, surroundings of craters without parabolas; (B) Splotches: What is the nature of splotches? Are they formed in the present-day climate conditions? What are the difference between regions with splotches and without them? How? Targets should include ~20 splotches of different size, bright/dark, etc.; ~5 samples of terrains with and without splotches; (C) Aeolian features: What is the nature of wind streaks and other aeolian features? Is there global aeolian transport on Venus? What is the roles of circulation-related winds and impact-induced winds? What are sources of saltating material (impacts, local weathering, and volcanism? What are sinks of particulate material (induration, sedimentation)? What is the nature of fines in tesserae? Strategy should include ~100+ sample targets that cover different types of wind streaks, dunes, putative micro-dunes, and just random surface samples + Global to regional (e.g. a few pole-to pole transects); (D) Active transport: Is aeolian transport active today? Sampling strategy for (C) above should include several sites (~6+) for monitoring for changes over time. (E) Microwave "snow line": Is the correlation between microwave emissivity and altitude a function of, or influenced by, weathering processes? What are the processes associated with the emissivity change and what are the dependencies on altitude and geologic context? Targets should include ~10 representative samples (e.g., the festoon flow in Ovda, Thetis, Maxwell, and Maat) that cross the Magellan-determined snow line. Structures: Measure electrical characteristics of surface fines in tesserae. Selected regions ≥20% of total representing different regions, structural fabrics, proximity to crater deposits.	Weathering: Approach to this investigation requires a combination of imaging, microwave radiometry, polarimetry, IR imaging (in atmospheric windows). For active transport processes (D), repeat imaging and repeat topography are necessary to look for changes Structures: imaging, including polarimetry	Weathering: (A)For each target: context area of sufficient size to extend well beyond extended ejecta deposit for background characterization, (1) moderate resolution image*, polarimetric data are desirable, two wavelengths are good but not essential (2) microwave emissivity map (3) NIR emissivity. Targeted high-resolution images* that sample different areas of the ejecta deposit for each target. (B) For each target: context area of sufficient size to extend well beyond splotch for background characterization, (1) moderate resolution image*, polarimetric data are desirable, two wavelengths are good but not essential (2) microwave emissivity map (3) NIR emissivity. Targeted high-resolution images* that sample splotch gradient for each target. (C) For each target: context area of sufficient size to extend well beyond features for background characterization, (1) moderate resolution image*, polarimetric data are desirable, two wavelengths are good but not essential (2) microwave emissivity map (3) NIR emissivity. Targeted high-resolution images* for each target. (D) (1) repeating high resolution images*, at least 1 Venus day between images (the longer the better), with the same incidence angle (2) Differential interferometry at high spatial resolution, 1 Venus day between observations; more than two repeating observations are desirable. (E) For each target: context area of sufficient size to extend well beyond features for background characterization, (1) moderate resolution image*, polarimetric data are desirable, two wavelengths are good but not essential (2) microwave emissivity map (3) NIR emissivity. (4) Regional-scale topography** may be adequate, but finer-scale topography** desired; Targeted high-resolution images* for each target.
III.B.3.	All targets, especially active sources (benefits from multiple altitudes)	NMS, TLS	Same as atmosphere	Volcanically active regions (e.g., 46S 214.5E (Idunn Mons))	Targeted probe multiple probes Global mapping from orbit of reactive species.	See I.C.1,2	N/A	N/A	N/A
III.B.4.	All targets, especially active sources (benefits from multiple altitudes)	NMS, TLS	Same as atmosphere; TBD for rock samples	See I.A.2	See I.A.2 Escape rates form orbit; also need surface material measurements	S: 0.1% over range of altitudes to discriminate chemical pathways D/H: See above I.A.2 O: See above I.A.2 C: 0.1% isotopic ratio to determine chemical pathways N: See above I.A.2	N/A	N/A	N/A