# Job for Tomorrow: Fill in the blanks

| VEXAG Goals, Objectives, Investigations, Measurements and Priorities: 2007 | | |
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| Ranking of Objectives within each Goal | | |
| # | | |
| **I** | **Goal I. Origin and Early Evolution of Venus: How did Venus originate and evolve, including the lifetime and conditions of habitable environments in solar systems?** | **Ranking** |
| **I-1** | Objective 1: Determine the elemental and isotopic composition of the atmosphere to identify earlier epochs of Venus' history, and clues to Venus' origin, formation and evolution. | |
| **I-2** | Objective 2: Characterize the history of volatiles in the interior, surface and atmosphere of Venus, including volatile addition due to cometary impact, degassing and atmospheric escape, to understand the planet's geologic and atmospheric evolution. | |
| **I-3** | Objective 3: Map the mineralogy and chemical composition of Venus' surface on the planetary scale for evidence of past environmental conditions (e.g., cooler and wetter) and for constraints on the evolution of Venus' atmosphere. | |
| **I-4** | Objective 4: Seek evidence for biologic markers in Venus' environments, including biogenic rock structures and/or other physical evidence of biological organisms (e.g., fossils), isotopic anomalies suggestive of biological activity, and chemical equilibria or disequilibria that may suggest biological activity. | |
| **I-5** | Objective 5: Determine the ages of the various rock units on the surface in order to unravel the past geological history of Venus. | |
| **I-6** | Objective 6: Understand Venus as one potential analogue for terrestrial extra-solar planets. | |
| **I-7** | Objective 7: Understand the orbital and rotational history of Venus, including its position relative to the solar system "habitable zone", and past planet-atmosphere interactions that may have led to the retrograde superrotation of the atmosphere. | |
| **I-8** | Objective 8: Characterize the subsurface stratigraphy of lowland regions that may record geological processes active under different climatic conditions. | |

| II | Goal II. Venus as a terrestrial planet: What are the processes that have and still shape the planet? | Ranking |
|---|---|---|
| II-1 | Objective 1: Constrain the coupling of thermochemical, photochemical and dynamical processes in the Venusian atmosphere and between the surface and atmosphere to understand radiative balance, climate, dynamics and chemical cycles. | |
| II-2 | Objective 2: Determine the nature of the solar wind interaction with the ionosphere and its role in volatile loss. | |
| II-3 | Objective 3: Characterize three-dimensional atmospheric circulation to understand the zonal super-rotation, the meridional transport of energy and minor constituents, convective activity, and polar vortex dynamics. | |
| II-4 | Objective 4: Characterize the meteorological activity in Venus' atmosphere, including waves, tides, cloud formation, precipitation, lightning, and sporadic and organized dynamical activity analogous to terrestrial weather systems. Determine whether a common theoretical treatment can be applied to weather on Venus and Earth. | |
| II-5 | Objective 5: Characterize the Venus Greenhouse effect, including the interplay of chemistry and physics of the atmosphere, especially the clouds. | |
| II-6 | Objective 6: Constrain the resurfacing history of Venus, and the nature of the resurfacing process(es), including the roles of tectonism, volcanism, impacts of asteroids or comets, sedimentation/erosion, and chemical weathering. | |
| II-7 | Objective 7: Constrain the nature and timing of volcanic activity on Venus, including current and past rates of volcanic activity, and the effects of outgassing on atmospheric and interior processes. | |
| II-8 | Objective 8: Determine the nature and timing of tectonic evolution of Venus, including the style and intensity of current activity, and changes in style and intensity through time. | |
| II-9 | Objective 9: Determine the history of and current state of interior evolution of Venus, including the internal physical, chemical, thermal and dynamical structure, and possible interactions between dynamic and climatic processes. | |

| III | Goal III. What does Venus tell us about the fate of Earth's environment? | Ranking |
|---|---|---|
| III-1 | Objective 1: Search for evidence of past global climate change on Venus, including chemical and isotope evidence in the atmosphere, as well as rock chemistry and characteristics of surface weathering. | |
| III-2 | Objective 2: Search for evidence of past changes in interior dynamics and tectonics, including possible evolution from plate tectonics to stagnant-lid tectonics, which may have resulted in significant changes in the global climate pattern. | |
| III-3 | Objective 3: Characterize the Venus Greenhouse effect, including its interaction with surface and interior, allowing a comparison to atmospheric evolution on Earth, Mars, Titan and extra-solar planets. | |
| III-4 | Objective 4: Using Venus data, determine the evolution of planetary atmospheres in the absence of a shielding magnetosphere, as may have happened in the past or may occur in the future on Earth. | |

# VEXAG Goals, Objectives, Investigations, Measurements and Priorities: 2007

**Ranking of Investigations within each Objective**

| # | | |
|---|---|---|
| **I** | **Goal I. Origin and Early Evolution of Venus: How did Venus originate and evolve, including the lifetime and conditions of habitable environments in solar systems?** | |
| **I-1** | **Objective 1: Determine the elemental and isotopic composition of the atmosphere to identify earlier epochs of Venus' history, and clues to Venus' origin, formation and evolution.** | **Ranking** |
| **I-1-1** | Measure noble gases and isotopic composition with a precision sufficient to enable understanding of Venus origin, especially measurements of krypton, argon and xenon | |
| **I-1-2** | Measure to high precision H/D, nitrogen (14N and 15N), oxygen, sulfur and carbon isotopes to … | |
| **I-1-3** | Analyze trapped gases in rocks for evidence of relict atmosphere | |
| **I-1-4** | Analyze stable isotopes for major and trace elements to … | |
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| **I-2** | **Objective 2: Characterize the history of volatiles in the interior, surface and atmosphere of Venus, including volatile addition due to cometary impact, degassing and atmospheric escape, to understand the planet's geologic and atmospheric evolution.** | **Ranking** |
| **I-2-1** | Analyze trapped gases in rocks (with ages) for evidence of relict atmosphere | |
| **I-2-3** | Measure gas compositions and flux from volcanic vents to constrain volatile inventory | |
| **I-2-4** | Determine high altitude neutrals and ions to … | |
| **I-2-5** | Determine rock mineralogy and composition in multiple environments to constrain crustal and interior evolution | |
| **I-2-6** | Measure stable isotopes in minerals to … | |
| **I-2-7** | Assess evidence of changes in tectonic styles that would constrain atmosphere and interior evolution | |
| **I-2-8** | Assess signatures of crustal magnetization to constrain the history of the magnetic field | |
| **I-2-9** | Determine rock ages to constrain geologic history | |
| **I-2-10** | Measure noble gas isotopic ratios (e.g., isotopic abundances of radiogenic argon generated by radioactive decay of potassium in the planet's interior) to constrain interior and atmosphere evolution | |

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| **I-3** | **Objective 3: Map the mineralogy and chemical composition of Venus' surface on the planetary scale for evidence of past environmental conditions (e.g., cooler and wetter) and for constraints on the evolution of Venus' atmosphere.** | **Ranking** |
| **I-3-1** | Measure *in situ* mineralogy in multiple environments | |
| **I-3-2** | Measure *in situ* bulk chemistry of rocks in multiple environments | |
| **I-3-3** | Determine surface elemental abundances and mineralogy | |
| **I-3-4** | Assess petrology and petrography of surface rocks | |
| **I-3-5** | Determine ages of and stratigraphic context of analyzed rocks | |
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| **I-4** | **Objective 4: Seek evidence for biologic markers in Venus' environments, including biogenic rock structures and/or other physical evidence of biological organisms (e.g., fossils), isotopic anomalies suggestive of biological activity, and chemical equilibria or disequilibria that may suggest biological activity.** | **Ranking** |
| **I-4-1** | Characterize the nature and composition of mode 3 cloud particles | |
| **I-4-2** | Characterize sources of chemical disequilibrium in the atmosphere | |
| **I-4-3** | Search for evidence of paleochemical disequilibria | |
| **I-4-4** | Measure carbon, sulfur, nitrogen and oxygen isotopes in the atmosphere | |
| **I-4-5** | Determine atmospheric sulfur species – OCS, H2S, SO2, Sx | |
| **I-4-6** | Characterize organic compounds | |
| **I-4-7** | Search for stable isotope biosignatures | |
| **I-4-8** | Measure stable isotopes in the atmosphere and near the surface | |
| **I-4-9** | Determine chemical alteration of the surface as a function of depth | |
| **I-4-10** | Perform *in situ* field analysis of surface units | |
| **I-4-11** | Obtain high-resolution characterization of surface units through remote sensing techniques | |
| **I-4-12** | Determine fine-scale texture of rocks, including those below the surface | |
| **I-4-13** | Search for fossils in surface rocks | |

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| **I-5** | **Objective 5: Determine the ages of the various rock units on the surface in order to unravel the past geological history of Venus.** | **Ranking** |
| **I-5-1** | Determine rock ages from multiple sites using appropriate dating schemes | |
| **I-5-2** | Investigate alternative dating schemes | |
| **I-5-3** | Characterize surface exposure ages | |
| **I-5-4** | Determine relative ages of geologic units (requires higher resolution imagery, at a range of frequencies, and altimetry) | |
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| **I-6** | **Objective 6: Understand Venus as one potential analogue for terrestrial extra-solar planets.** | **Ranking** |
| **I-6-1** | Obtain a complete remote characterization of Venus from UV to radio frequencies at all solar cycles to compare with signatures of extra-solar planets | |
| **I-6-2** | Model the disk averaged spectrum as a function of evolutionary history | |
| **I-6-3** | Characterize Venus's long term evolution to understand terrestrial planets around other stars | |
| **I-6-4** | Determine critical factors leading to limits of habitable zones | |
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| **I-7** | **Objective 7: Understand the orbital and rotational history of Venus, including its position relative to the solar system "habitable zone", and past planet-atmosphere interactions that may have led to the retrograde superrotation of the atmosphere.** | **Ranking** |
| **I-7-1** | Measure the moment of inertia and spin axis variations over time | |
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| **I-8** | **Objective 8: Characterize the subsurface stratigraphy of lowland regions that may record geological processes active under different climatic conditions.** | **Ranking** |
| **I-8-1** | ? | |

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| **II** | **Goal II. Venus as a terrestrial planet: What are the processes that have and still shape the planet?** | |
| **II-1** | **Objective 1: Constrain the coupling of thermochemical, photochemical and dynamical processes in the Venusian atmosphere and between the surface and atmosphere to understand radiative balance, climate, dynamics and chemical cycles.** | **Ranking** |
| **II-1-1** | Determine sulfur cycle processes. Measure relevant trace species (e.g., $H_2O$, $SO_2$, OCS) abundances over the full extent of cloud altitudes. | |
| **II-1-2** | Determine abundances of other reactive species important for understanding thermo-chemical processes (e.g., HCl, HF, $SO_3$) | |
| **II-1-3** | Characterize composition and horizontal/vertical microphysical properties and distribution of aerosols throughout the atmosphere, including putative elemental sulfur particles in the upper atmosphere and metal-based clouds in the lower atmosphere. | |
| **II-1-4** | Determine radiative balance, including cloud and greenhouse gas opacities as a function of altitude, latitude, and longitude | |
| **II-1-5** | Characterize volcanic emission flux (flux of chemically-active species, aerosol in-flux, lava flux, etc.) | |
| **II-1-6** | Determine role of lightning in generating chemically active species (e.g., Nox species). | |
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| **II-2** | **Objective 2: Determine the nature of the solar wind interaction with the ionosphere and its role in volatile loss.** | **Ranking** |
| **II-2-1** | Obtain UV measurements of exospheric profiles of O, H and their global variability over a solar cycle | |
| **II-2-2** | Measure composition and flux of escaping neutrals and ions over all energies under all solar wind and solar EUV conditions | |
| **II-2-3** | Monitor magnetic field and solar wind plasma and energetic particles over a solar cycle | |
| **II-2-4** | Obtain ionospheric composition profiles and characterize their spatial and temporal variations | |

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| **II-3** | **Objective 3: Characterize three-dimensional atmospheric circulation to understand the zonal super-rotation, the meridional transport of energy and minor constituents, convective activity, and polar vortex dynamics.** | **Ranking** |
| **II-3-1** | Measure global horizontal winds over several Venus days at multiple vertical levels (day and night) from surface to thermosphere | |
| **II-3-2** | Measure profiles of vertical component of wind at all latitudes and longitudes | |
| **II-3-3** | Global vertical temperature profiles | |
| **II-3-4** | Characterize planetary waves, especially gravity waves generated by underlying topography | |
| **II-3-5** | Measure deposition of solar energy in the atmosphere globally | |
| **II-3-6** | Characterize solar wind input in the upper atmosphere | |
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| **II-4** | **Objective 4: Characterize the meteorological activity in Venus' atmosphere, including waves, tides, cloud formation, precipitation, lightning, and sporadic and organized dynamical activity analogous to terrestrial weather systems. Determine whether a common theoretical treatment can be applied to weather on Venus and Earth.** | **Ranking** |
| **II-4-1** | Measure gravity waves near the surface and throughout the atmosphere | |
| **II-4-2** | Measure locally within the 49-60 km clouds the abundances of cloud-forming gases and associated aerosol densities, particle sizes | |
| **II-4-3** | Measure the frequencies and strengths of lightning and associated chemical species (e.g., NOx) | |
| **II-4-4** | Measure local vertical winds associated with convection, cloud formation processes | |

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| **II-5** | **Objective 5: Characterize the Venus Greenhouse effect, including the interplay of chemistry and physics of the atmosphere, especially the clouds.** | **Ranking** |
| **II-5-1** | Measure the abundances of greenhouse gases and other species that play a role in cloud formation | |
| **II-5-2** | Determine aerosol and cloud properties to … | |
| **II-5-3** | Obtain energy deposition profiles to … | |
| **II-5-4** | Obtain temperature profiles to … | |
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| **II-6** | **Objective 6: Constrain the resurfacing history of Venus, and the nature of the resurfacing process(es), including the roles of tectonism, volcanism, impacts of asteroids or comets, sedimentation/erosion, and chemical weathering.** | **Ranking** |
| **II-6-1** | Constrain the rate of interior activity and determine interior structure (seismology, gravity data) | |
| **II-6-2** | Measure heat flow and surface temperature to constrain thermal structure | |
| **II-6-3** | Determine crustal structure | |
| **II-6-4** | Constrain regional and global stratigraphy utilizing high resolution imagery | |
| **II-6-5** | Measure surface heights to high resolution to constrain models of surface evolution | |
| **II-6-6** | Constrain active volcanic processes through changes in surface topography (interferometry) | |
| **II-6-7** | Determine absolute ages of surface rock units to constrain surface evolution | |
| **II-6-8** | Characterize surface geologic units, mineralogically, compositionally and isotopically | |

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| **II-7** | **Objective 7: Constrain the nature and timing of volcanic activity on Venus, including current and past rates of volcanic activity, and the effects of outgassing on atmospheric and interior processes.** | **Ranking** |
| **II-7-1** | Constrain the rate of interior activity and determine interior structure (seismology, gravity data) | |
| **II-7-2** | Measure heat flow and surface temperature to constrain thermal structure | |
| **II-7-3** | Determine crustal structure | |
| **II-7-4** | Constrain regional and global stratigraphy utilizing high resolution imagery | |
| **II-7-5** | Measure surface heights to high resolution to constrain models of surface evolution | |
| **II-7-6** | Constrain active volcanic processes through changes in surface topography (interferometry) | |
| **II-7-7** | Determine absolute ages of surface rock units to constrain surface evolution | |
| **II-7-8** | Characterize surface geologic units, mineralogically, compositionally and isotopically | |
| **II-7-9** | Identify and characterize volcanic plumes and gases in the atmosphere, chemically and temporally | |
| **II-7-10** | Characterize the geochemical budgets and cycles including temporal changes | |
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| **II-8** | **Objective 8: Determine the nature and timing of tectonic evolution of Venus, including the style and intensity of current activity, and changes in style and intensity through time.** | **Ranking** |
| **II-8-1** | Constrain the rate of interior activity and determine interior structure (seismology, gravity) | |
| **II-8-2** | Measure heat flow and surface temperature to constrain thermal structure | |
| **II-8-3** | Determine crustal structure | |
| **II-8-4** | Constrain regional and global stratigraphy utilizing high resolution imagery | |
| **II-8-5** | Measure surface heights to high resolution to constrain models of surface evolution | |
| **II-8-6** | Constrain active tectonic processes through changes in surface topography (interferometry) | |
| **II-8-7** | Determine absolute ages of surface rock units to constrain surface evolution | |
| **II-8-8** | Characterize surface geologic units, mineralogically, compositionally and isotopically | |

| II-9 | **Objective 9: Determine the history of and current state of interior evolution of Venus, including the internal physical, chemical, thermal and dynamical structure, and possible interactions between dynamic and climatic processes.** | **Ranking** |
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| **II-9-1** | Characterize magnetic signatures of surface rock units in multiple environments, with ages (hafnium/tungsten?) | |
| **II-9-2** | Measure the magnetic field below the ionosphere | |
| **II-9-3** | Understand evolution and structure of the core | |
| **II-9-4** | Measure topography and gravity to high resolution to constrain models of surface feature and interior evolution | |
| **II-9-5** | Measure the moment of inertia to …. | |
| **II-9-6** | Determine interior structure and levels of seismic activity to constrain models of interior evolution | |
| **II-9-7** | Measure heat flux to constrain thermal structure | |

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| **III** | **Goal III. What does Venus tell us about the fate of Earth's environment?** | |
| **III-1** | **Objective 1: Search for evidence of past global climate change on Venus, including chemical and isotope evidence in the atmosphere, as well as rock chemistry and characteristics of surface weathering.** | **Ranking** |
| **III-1-1** | Characterize the mineralogy of rocks | |
| **III-1-2** | Measure trapped gases in rocks from earlier epochs | |
| **III-1-3** | Assess paleoclimate indicators, stable isotopes (O, S, H …) | |
| **III-1-4** | Search for geomorphological evidence of climate change | |
| **III-1-5** | Search for evidence of past life, such as fossils | |
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| **III-2** | **Objective 2: Search for evidence of past changes in interior dynamics and tectonics, including possible evolution from plate tectonics to stagnant-lid tectonics, which may have resulted in significant changes in the global climate pattern.** | **Ranking** |
| **III-2-1** | Characterize surface signatures of past tectonic/volcanic regimes (high-resolution imaging and topography) | |
| **III-2-2** | Obtain high-resolution gravity date to constrain models of evolution | |
| **III-2-3** | Measure chemical and isotopic composition | |
| **III-2-4** | Search for paleomagnetic signatures | |
| **III-2-5** | Constrain interior structure | |

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| **III-3** | **Objective 3: Characterize the Venus Greenhouse effect, including its interaction with surface and interior, allowing a comparison to atmospheric evolution on Earth, Mars, Titan and extra-solar planets.** | **Ranking** |
| **III-3-1** | Measure abundance of greenhouse gases and other species that play a role in cloud formation | |
| **III-3-2** | Constrain aerosol and cloud properties | |
| **III-3-3** | Measure energy deposition profiles | |
| **III-3-4** | Obtain atmospheric temperature profiles | |
| **III-3-5** | Characterize surface geochemistry including alteration rind depth and composition | |
| **III-3-6** | Constrain rate of volcanic outgassing and composition of gases | |
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| **III-4** | **Objective 4: Using Venus data, determine the evolution of planetary atmospheres in the absence of a shielding magnetosphere, as may have happened in the past or may occur in the future on Earth.** | **Ranking** |
| **III-4-1** | Measure current flux of various atmospheric species into space | |
| **III-4-2** | Measure composition of the upper atmosphere (above ~130 km) | |