VERITAS (Venus Emissivity, Radio Science, InSAR, Topography, and Spectroscopy): A Discovery Mission

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Abstract— **Deep understanding of planetary habitability requires identifying key factors that govern the surface environment over time. Venus is the ultimate control case for understanding how Earth developed and maintained conditions suited to life. Venus very likely had elements essential to habitability such as past surface water and a dynamo. Tectonism and volcanism, which create chemical disequilibrium, very likely persist today. What caused Earth and Venus to diverge down different evolutionary paths? VERITAS would create foundational, co-registered data sets of high-resolution topography, imaging, spectroscopy, and gravity, on par with those available for Mercury, Mars, and the Moon. VERITAS would answer outstanding fundamental questions about the evolution of Earth's twin.**

The VERITAS payload consists of the Venus Interferometric Synthetic Aperture Radar (VISAR) and the Venus Emissivity Mapper (VEM), plus a gravity science investigation. VISAR is an X-band radar that provides: 1) a global digital elevation model (DEM) with 250-m postings and 6-m height accuracy, 2) Synthetic aperture radar (SAR) imaging at 30-m horizontal resolution globally, 3) SAR imaging at 15-m resolution for >25% of the surface, and 4) surface deformation from repeat pass interferometry (RPI) with 2-cm vertical precision for >12 (~200 x 200 km) targeted areas.

VEM covers >70% of the surface in six near-infrared (NIR) bands sensitive to iron composition located within five atmospheric windows, plus eight atmospheric bands for calibration and water vapor measurements. VEM would provide near-global maps of mafic to felsic rock type and will search for active and recent volcanism.

VERITAS would use two-way Ka-band uplink and downlink from a low circular orbit (< 250 km) to create a global gravity field with 3-mGal accuracy of 155-km resolution (degree and order 123). An onboard technology demonstration, the Deep Space Atomic Clock (DSAC-2), may support radio science and navigation with one-way tracking. VERITAS data would enable estimation of elastic thickness (a proxy for thermal gradient) and density differences due to subsurface structures, as well as constraining interior structure, including core size and state.

Lockheed Martin builds the spacecraft. VISAR is built by JPL, with the Italian Space Agency (ASI) providing the low power electronics. ASI also provides transponders and a high gain antenna for the telecom system. CNES provides the Ka-band traveling wave tube amplifiers (TWTA). The German Space Agency (DLR) provides VEM and contributes algorithms for VISAR ground and onboard data processing.

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1. INTRODUCTION

NASA selected VERITAS as a Discovery class mission on June 2, 2021. VERITAS would launch in late 2027 [to be confirmed], and conduct a three-year science mission. The VERITAS polar orbiter would be the first mission since the Magellan mission concluded in 1994 to investigate Venus' surface processes and interior structure. Many factors make

Venus a compelling target for investigation now. The decades-old topography and radar imaging datasets from Magellan were once revolutionary, but are now far behind the datasets acquired by recent suites of orbital missions to the Moon, Mars, and Mercury.

As Earth's twin, Venus is in many ways the cornerstone of comparative planetology. Many critical processes cannot be fully investigated without Venus datasets on par with those of other terrestrial planets. Venus also holds the potential to provide insights into Earth's early evolution in the Archean era when plate tectonics evolved and continents began to form. These events have been linked to the formation of Earth's oxygen-rich atmosphere. Venus' 460°C surface temperature creates a hot lithosphere, with similarities to Earth's initially hot Archean lithosphere. Processes occurring on Venus today may provide a glimpse of those on early Earth. As discussed below, the key processes that shape Venus evolution are also the processes essential to predicting whether the hundreds of exoplanets discovered already discovered around other stars are likely to be habitable.

2. Science Overview

Venus is a treasure trove for unlocking the secrets of rocky planet evolution. It was likely the first habitable planet in our solar system, with a surface ocean that could have persisted until as recently as 1 billion years ago [1]. It has (or had) the building blocks of a habitable world. For example, Venus' young surface is evidence of its robust internal engine, needed to drive active volcanism/tectonism, release volatiles to maintain an atmosphere, and create the surface chemical disequilibria needed to fuel life. Today, Venus lacks a dynamo to create a magnetic field that acts as a shield for radiation. However, it is very plausible that Venus had a dynamo earlier in its history.

Venus is a laboratory for testing hypotheses about rocky exoplanet habitability [2]. Even the most advanced telescopes that explore exoplanets cannot reveal thermal evolution, tectonics, or weathering processes and are unlikely to determine volcanic outgassing and surface composition [3]. VERITAS would measure surface rock type, look for volcanic outgassing of water, and determine Venus' weathering and tectonic processes and thermal evolution. By revealing Venus' past and present-day surface and interior conditions, VERITAS would identify the critical factors that led Venus and Earth down different paths and improve predictions of exoplanet habitability.

Earth is both our reference point for understanding rocky planet evolution and still the only confirmed habitat for life. Plate tectonics links Earth's atmosphere, surface, and interior through its pervasive impact on geology, continents, volcanism, volatile cycles, and dynamo formation, all of which strongly influence Earth's habitability. For example, the formation and erosion of continents may be responsible for the great oxygenation event [4] when bacterial life first flourished in Earth's oceans. How did plate tectonics start? How do continents form? There is consensus that subduction

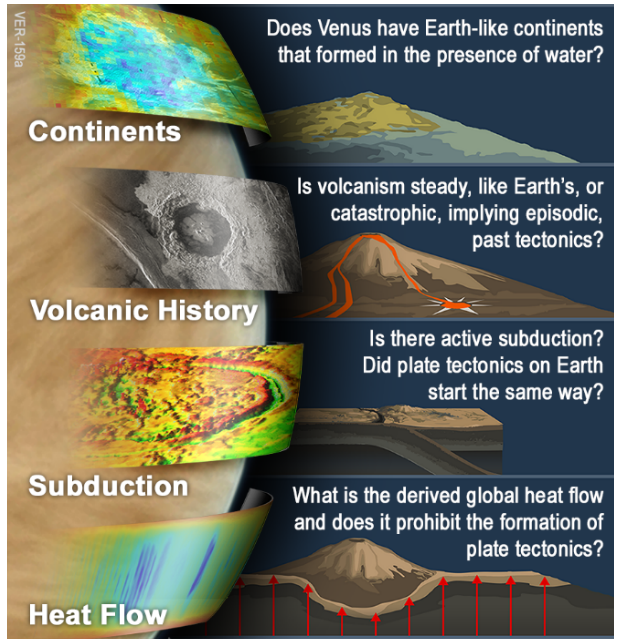


Figure 1. Venus is the only rocky planet laboratory for observing the steps that lead to plate tectonics. Earth's habitability is shaped by its continents, active volcanoes, and subduction. VERITAS reveals the conditions that enable these processes, yielding critical constraints for exoplanet habitability models.

is the first step in plate tectonics, but a lack of data allows for numerous theories for initiating subduction. Earth's active surface has destroyed most rocks from billions of years ago when plate tectonics began. Venus today offers the opportunity to observe the processes that form subduction, absent plate tectonics. Like early Earth, Venus has a hot lithosphere today due to its greenhouse. It is the only place in the solar system that may have analogs of Earth's continents, active hotspot volcanism, and numerous subduction zones (Fig. 1). Venus today illuminates Earth's early history and may reveal the origins of plate tectonics and continent formation.

VERITAS would answer three essential science questions:
1. What processes shape rocky planet evolution?
2. What geologic processes are currently active?
3. Is there evidence of past and present interior water?

VERITAS ends many 30-year-old debates for Venus, such as whether volcanism has been steady or catastrophic, why it lacks terrestrial-style plate tectonics, how it loses its heat, and if it has continents. It also charts new territory by providing numerous firsts at Venus: constraints on the core size and state (relevant to dynamo formation), surface rock type, high resolution topography and radar imaging, and a search for active surface deformation and active or recent volcanism.

3. Mission Overview

Mission Design

The planned VERITAS mission begins with a short cruise to Venus. The 20-day launch period would span mid-to-late

December 2027 with arrivals late June to mid-July 2028. These trajectories have relatively large launch energies, and so VERITAS requires a comparatively high-performance launch vehicle such as a partially re-usable Falcon Heavy or the Vulcan Centaur 4 to launch the fully-fueled flight system. These vehicles would offer significant performance in excess of VERITAS requirements, estimated at almost 1500 kg, which could be leveraged for ride-share opportunities.

Following Venus Orbit Insertion (VOI), VERITAS performs a second large maneuver to reduce the orbit period from 120 hrs to 13 hrs (Fig. 2). Aerobraking is then used to place the flight system in its two science orbits. VERITAS has two planned science phases: Science Phase I (SP1) and Science Phase II (SP2). Science Phase I uses a 6.1-hour orbit, and Science Phase II has a 91-minute orbit period at a mean orbit altitude of 217 km. Both have a nearly polar orbit inclination.

The planned aerobraking campaign begins about two weeks after the Period Reduction Maneuver and uses atmospheric drag to provide an equivalent ΔV to the spacecraft of ~2 km/s. The aerobraking campaign is divided into two segments: Aerobraking I (AB1, 7 months) and Aerobraking II (AB2, 9 months), with the 4-month SP1 embedded between them. During aerobraking, the spacecraft lowers periapsis into the upper atmosphere, using the additional drag to reduce its apoapsis altitude from over 40,000 km to 400 km. The aerothermal heating that would bring the solar arrays or other components of the spacecraft to their maximum allowable flight temperature is a function of orbit period and geometry relative to the sun. The mission design includes a minimum 135% margin against this limit. During AB2, this margin is slowly increased to delay and target the aerobraking exit (ABX) to March 2030 so that periapsis is on the far side of Venus as seen from Earth, to ensure sufficient time is available for communications.

Aerobraking control maneuvers (ABMs) will be scheduled for Monday and Thursday afternoons and are designed such that the spacecraft does not violate the margined limit for at least 72 hours after a missed maneuver. An autonomous pop-up maneuver, which raises periapsis by an atmospheric scale height (about 6 km), is triggered by higher-than anticipated heating. This threshold is tuned to prevent unnecessary pop-ups and simultaneously protect the spacecraft. In the event of a safe mode, the spacecraft would autonomously pop entirely out of the atmosphere (approximately 40 km) until the anomaly is resolved. A comprehensive Engineering Science Investigation would be performed throughout the aerobraking period, collecting critical temperature and accelerometer data during repeated atmospheric passages, as well as radiometric limb-sounding. These data would be used to greatly improve global and regional circulation models of the atmosphere of Venus.

Emissivity mapping with VEM begins in SP1, which would be optimized for coverage of the Vega 2 and Venera 9, 10, 13, and 14 sites to aid in VEM calibration. SP2 has full science operations for VEM, VISAR and gravity science.

Science Phase II begins with a 60-day VISAR calibration phase after the post-ABX 200 × 400 km orbit is reshaped into the final science orbit. This is followed by four ground-track repeat cycles (or simply "cycles") of 244 days. Venus rotates so slowly that the ground track moves only 10 km per orbit at the equator. Venus is so spherical, with an equatorial bulge three orders of magnitude smaller than Earth, that the spacecraft's ascending node processes extremely slowly. These effects create a ground-track repeat cycle slightly longer than the 243-day Venus sidereal day. This causes the orbit to experience the same gravitational perturbations repeatedly over every orbit, which leads to significant eccentricity vector evolution, similar to that experienced by low lunar orbiters such as GRAIL. The mean inclination of 85.5° has been selected to cause this evolution to bend back upon itself (Fig. 3), yielding a near-frozen orbit with altitude variation of 182.6 km to 252.5 km that repeats with the topography. A small radial eccentricity control maneuver (ECM) at the end of each cycle corrects the slight mismatch.

Repeat-Pass Interferometry (RPI) enables cm-scale change detection of the surface and requires that the spacecraft fly within 160 m (3σ) of its previous path over the targeted site. In addition to maneuver execution errors and differential solar tidal torques, the uncertainty in the rotation period of Venus [5,6] affects repeatability. To compensate, VERITAS will process radar tie points on the ground, as demonstrated

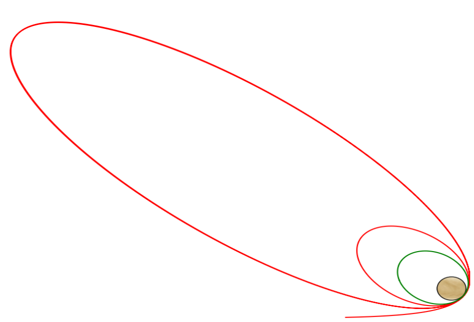


Figure 2. Following VOI, the Period Reduction Maneuver reduces the orbit period from 120 to 13 hours (large red and small orbits). Aerobraking I reduces the orbit period to SP1's 6.1 hours (green) while Aerobraking II reduces it to 91 minutes (black).

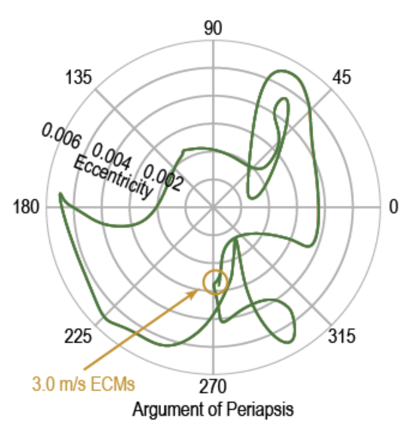


Figure 3. The nearly-frozen orbit of Science Phase II

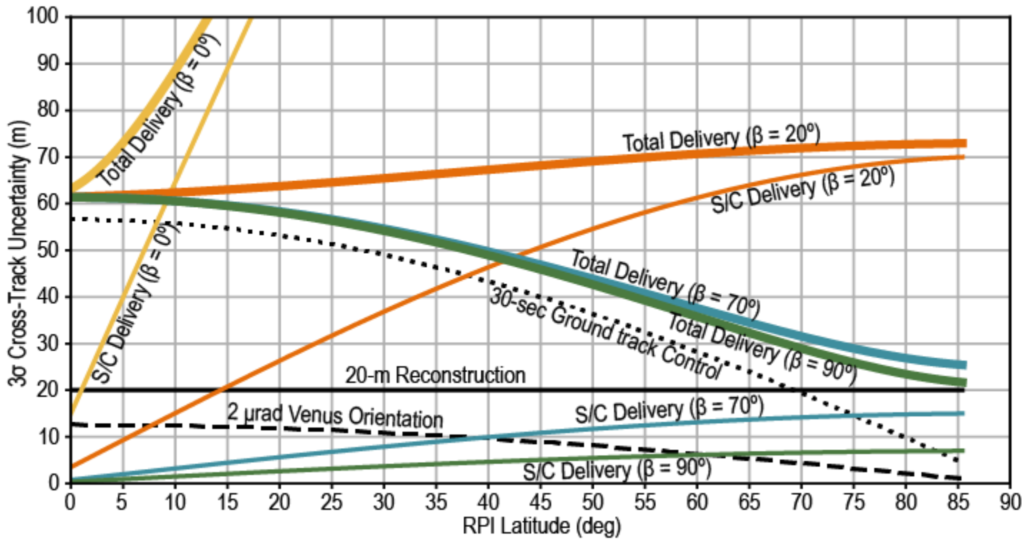


Figure 4. The total cross-track RPI tube entry delivery uncertainty (thick colored lines) is the RSS of the spacecraft delivery errors (thin colored lines), which are dependent on latitude and beta angle and other parameters (black lines). RPI measurements are possible with low Earth Beta angles near the equator.

with Magellan data [7], to improve orbit reconstruction. A prototype radar tie-point observable has been implemented and tested within JPL's navigation software suite [8]. RPI is possible when delivery errors and the relative motion within the tube caused by solar tidal torques are low at any latitude or anytime near the equator (Fig. 4).

The VERITAS mission design for SP2 enables a flexible orbit plan (Fig. 5) that balances 11 science mapping orbits with five downlink orbits each day. For 57% of each 224-day Venus year, science mapping will encompass the entire orbit. In the remainder, eclipses are long enough that additional power management is required. VISAR mapping occurs on a fraction of these orbits selected to optimize coverage within available power balance. This mission design avoids the need for solar array gimbals.

Spacecraft Overview

The Flight System design would be tailored to meet science and mission objectives and implemented via an adaptation of a MAVEN heritage spacecraft to accommodate the VISAR and VEM instruments and the Deep Space Atomic Clock 2 (DSAC-2). Changes to the spacecraft bus would be made with particular attention to aerobraking at Venus and long-term operation in the thermal environment while in a low-Venus orbit. VERITAS' spacecraft (S/C) structural design is based on the MAVEN bus, with propulsion, power, avionics, and pointing performance derived from recent, successful planetary science missions including InSight, MRO, OSIRIS-REx, Juno, and Lucy.

The proposed flight system, shown in the deployed configuration in Fig. 6, has block, functional, and subsystem-internal redundancies. Autonomous fault detection and recovery will ensure successful execution of planned mission phases, including orbit insertion. The flight system includes dual purpose solar arrays with added drag flaps that provide all required spacecraft power and primary drag surface area while aerobraking. Aerodynamic stability during aerobraking will be provided by canting the outboard solar panel in each wing toward +Z by 10° and by canting drag flaps an

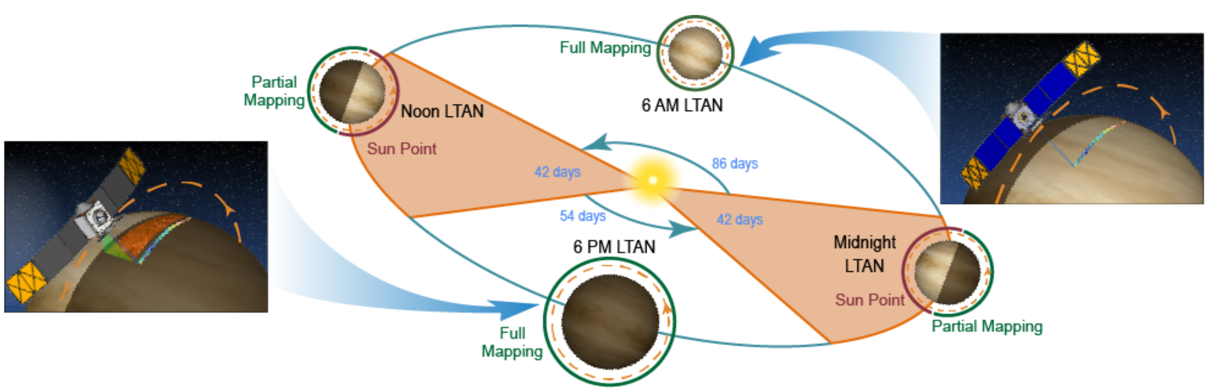


Figure 5. The VERITAS mission design enables a flexible orbit plan. In Science Phase II, VEM would operate on the night side (left inset) while VISAR operates continuously (both insets) while in a "full mapping" mode, which covers 57% of the Venus year. LTAN is the Local Time of the Ascending Node, illustrating how much of the orbit is in eclipse.

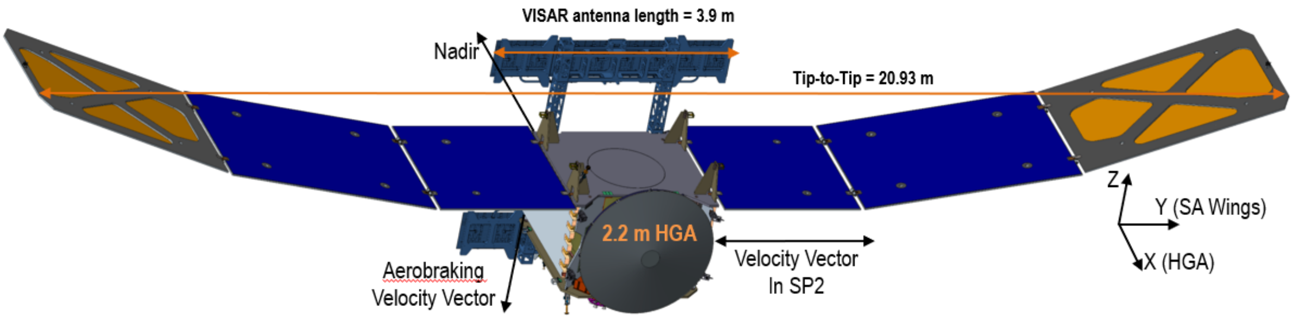


Figure 6. The VERITAS flight system would feature fixed solar arrays and a fixed high-gain antenna. The spacecraft would be adapted from MAVEN to accommodate the VISAR and VEM instruments. The use of drag flaps would significantly reduce the total time required for aerobraking.

additional 10°. Thermal design maintains the spacecraft subsystems within their operating temperature limits in the harsh Venus orbital environment, including high solar heating fluxes during all phases of the science investigation along with an aeroheating load during the aerobraking phases. The two VEM instruments will be aligned with the VISAR antenna but offset ± 30° relative to -X to enable VEM observations in SP2 in each of the spacecraft's primary observing attitudes.

Structural Design— The primary structure features a composite core cylinder sized to accommodate the hydrazine fuel tank. The VISAR antenna is attached to the spacecraft in a quasi-determinant mount to provide minimal constrained degrees of freedom (DOFs) and reduce thermal distortions.

Telecommunication Subsystem—The telecom subsystem has two data paths, an X-band path for receiving commands and transmitting engineering data, and a Ka-band path for science data. The Integrated Deep Space Transponder (IDST) provided by ASI is capable of supporting both channels. A 2.2-m diameter high-gain antenna (HGA), also be provided by ASI, will be used for high data rate communications and the gravity science investigation.

Electrical Power Subsystem—Power generation is provided by two fixed solar array wings with a total active cell area of 14 m^2 producing an estimated 5740 W needed to power the spacecraft and science instruments. Two lithium-ion batteries provide energy storage capability for off-sun pointed operations and the large number of eclipses that will occur over the course of the mission.

Propulsion Subsystem—The monopropellant hydrazine propulsion subsystem utilizes a mix of large and small thrusters for attitude control, trajectory correction maneuvers, and VOI maneuvers. As designed, the propulsion subsystem provides a total ΔV capability of 1620 m/s. Aerobraking provides an additional ΔV of approximately 2000 m/s.

Attitude Determination and Control Subsystem—The spacecraft is three-axis stabilized using reaction wheels, with thrusters for wheel desaturation and slew control. Attitude determination will use star trackers and inertial measurement units, with sun sensors for safe mode. During aerobraking, aerodynamic torques will keep the spacecraft pointed near its aerostable attitude, minimizing the number of thruster firings.

Command and Data Handling (C&DH) Subsystem—The C&DH uses a dual-string, block-redundant, fault-tolerant system architecture as employed on several previous deep space science missions including Juno, MAVEN, OSIRIS-REx, and Lucy. An internally redundant solid-state recorder (SSR) provides 1.5 Tb of science data storage.

Concept of Operations

VERITAS mission operations use heritage processes and a flight-proven mission system for low risk development and operations. We adopt the NASA Advanced Multimission Operations System (AMMOS)—as have more than 10 previous JPL/LM partnership missions—along with DSN-provided tracking resources.

VERITAS mission operations include US and international partners for mission operations and science team internal and external interfaces (Fig. 7). LM is responsible for spacecraft operations, while instrument operations teams at JPL (VISAR), DLR (VEM), GSFC (Gravity Science), and ASI (Gravity Science) will lead instrument and science-related activities. LaRC provides aerobraking operations support and lead the Engineering Science Investigation (ESI) activities. JPL provides mission management, and Navigation/DSN/GDS operations. DSAC-2 Technology Demonstration Opportunity (TDO) activities will be managed by JPL.

The telecom subsystem provides X- and Ka-band transmit and receive capability (Table 1). The design allows simultaneous dual-band capability with X-uplink/X-downlink and Ka-uplink/Ka-downlink to satisfy the mission operations and science requirements.

Table 1. Telecommunication Mode and Capability

Mode	Tele-command	Ranging/ Doppler	ΔDOR	Telemetry	Science Downlink	Antenna
X Uplink	Yes	Yes	--	--	--	HGA / LGA
X Downlink	--		Yes	Yes	No	
Ka Uplink	--	Yes	--	--	--	HGA
Ka Downlink	--		Yes	No	Yes	

VERITAS mission operations design are based on previous missions and define interfaces required to plan, collect, generate, execute, analyze and process information from the uplink and downlink functions. Command and telemetry formats adhere to the Consultative Committee for Space Data Systems (CCSDS) standard. Mission operations data flow (Fig. 7) supports the science data process, receiving raw science and auxiliary data via the Mission Data Management interface. The processed science data will be released regularly to the Planetary Data System (PDS).

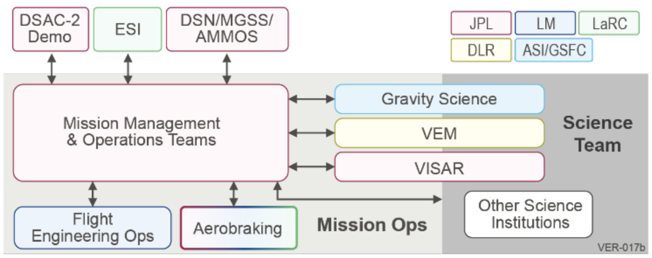


Figure 7. VERITAS bases Mission Operations on existing successful collaborations among JPL, LM, LaRC, GSFC, and instrument institutions.

VERITAS operations would occur in ten phases:

Launch and Initial Acquisition—Launch would extend from the start of the launch countdown through separation, initial S/C acquisition by the DSN and confirmation of power-positive attitude (a critical event supported by dual-station coverage).

Cruise Operations—Cruise operations would last approximately 7 months, from DSN initial acquisition to two months prior to VOI operations. Various engineering calibration activities would be performed. Two Trajectory Correction Maneuvers (TCMs) are planned during cruise: TCM-1 corrects the launch injection error with remaining TCMs to fine-tune the VOI corridor. VISAR antenna deployment occurs five days after TCM-1.

Approach/VOI—Approach would begin 60 days prior to Venus Orbit Insertion (VOI). Except for three TCM activities, approach will nominally be an enforced quiescent period to minimize trajectory perturbations.

Early Orbit Operations—This phase would last about 3 weeks and the major activity would be the Period Reduction Maneuver (PRM) to initialize the orbit period for aerobraking (AB) operations.

Aerobraking Operations— Operations are divided into AB1 and AB2, separated by a 4-month break due to a superior conjunction and Science Phase I (SP1). AB1 would last ~6 months including the walk-in operation and AB2 would last ~9 months. Figure 8 illustrates the aerobraking orbit-event sequence. Each aerobraking orbit is divided into three distinct segments: an Aerobraking Maneuver (ABM) block; a drag-pass block; and a telemetry downlinking/power recharging block. A "down" ABM is used to lower the periapsis altitude into the desired operations corridor, while an "up" ABM is executed to keep the spacecraft from exceeding the heating rate limit or other spacecraft constraints. VERITAS adopts the heritage process and tools from previous AB missions [9].

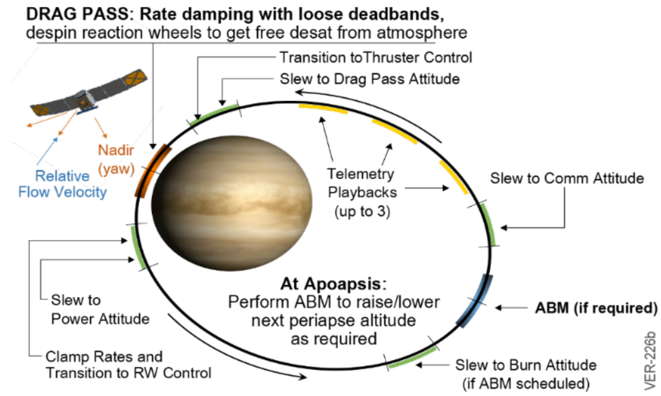


Figure 8. Aerobraking orbit events.

Science Phase I—SP1 would begin after AB1 and continue for ~4 months. During SP1 (190 km × 19,000 km orbit), an onboard sequence acquires VEM data whenever the VEM swath is fully on the night side and the S/C altitude is <8,000 km. There would be a superior conjunction event during SP1. VEM data collection activity continues throughout the conjunction. When the Sun-Probe-Earth (SPE) angle approaches 5°, the telecommunication link may be degraded.

Transition to SP2 Operations—The transition to SP2 would start after the ABX and lasts about two weeks. Key activities include science orbit establishment with two maneuvers and opening of the VEM covers.

Science Phase II— SP2 would start in April 2030, two weeks after the end of AB2. These two weeks are used to do the maneuvers necessary to transition from the post-aerobraking orbit to the SP2 orbit. SP2 consists of a 60-day VISAR checkout and calibration interval, followed by four 244-day ground track cycles of science mapping, and a final 30-day period to complete science-data downlink. VISAR and Gravity Science operations would be suspended during the conjunctions (SPE angles < 5°) that occur in SP2 while VEM data collection continues. There are two power-limited periods during each Venus year when the mapping attitude can be maintained during only a portion of each orbit.

VISAR onboard processing reduces image and single-pass interferometry data volume for downlink. High-level ground science data processing will be completed at JPL. VISAR data will be unpacked by the mission operations teams and delivered to the JPL SDS for reformatting and calibration (Fig. 9). Image data will be orthorectified and used with tie points for ground reconstructed orbit ephemeris improvement. Single-pass interferometry data will be run through filtering, unwrapping, and height reconstruction processor will generate mosaics of the strip image and DEM data. VEM data are delivered to DLR in CCSDS packets

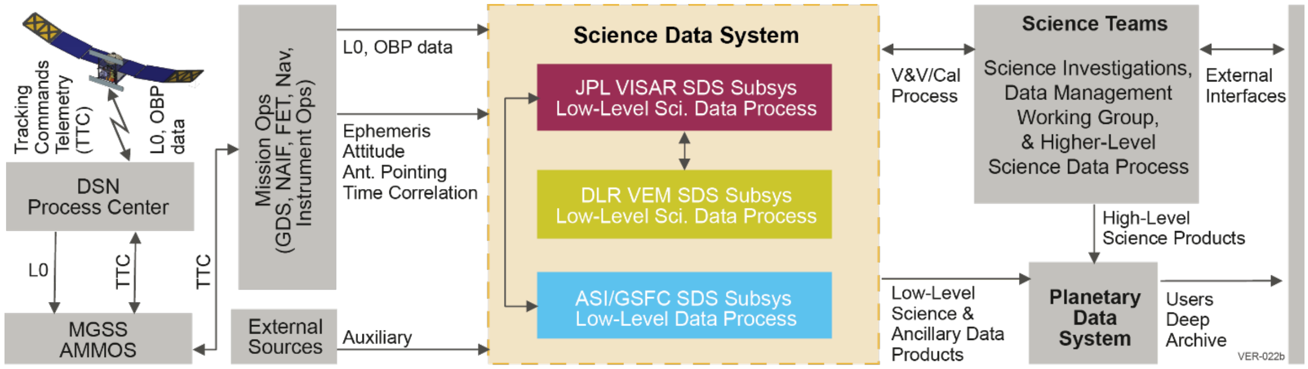


Figure 9. VERITAS Science Data System data flow.

securely via the Internet, where VEM data products will be processing steps to generate strip DEMs. A back-end processed on the ground. Gravity science data will be delivered to GSFC and ASI via secure Internet as well.

For VISAR RPI, a preliminary set of targets would be developed pre-launch and updated as needed by SP1 observations. The target list may be refined in SP2 during the cycle re-planning process, where the operations team will adapt the mission plan to accommodate changes induced by DSN scheduling and other outages. RPI requires two observations of a site separated by one or more mapping cycles in time. The science team will refine targets for VISAR repeat pass interferometry one month prior to each of the four cycles. RPI raw data are downlinked for each of the 200 × 200-km targeted areas for GDS unpacking and delivery to the VISAR SDS.

Decommissioning—The VERITAS S/C would deorbit within 6-12 months after discontinuing drag makeup maneuvers. The S/C's energy sources (propellant, batteries, etc.) would be depleted before deactivating fault protection and turning off the transmitters. The S/C would deorbit without the need for a deorbit maneuver. No special operations are required.

4. Payload

VERITAS's payload is comprised of two instruments crafted to study Venus' surface coupled with a radio science investigation to measure the gravity field. The two instruments are an X-band interferometric synthetic aperture, VISAR, and a fourteen-band infrared spectrometer, VEM.

VISAR

Persistent optically opaque cloud cover of Venus necessitates the use of synthetic aperture radar techniques to obtain high resolution imagery and topography of the surface. The **V**enus **I**nterferometric **S**ynthetic **A**perture **R**adar instrument (VISAR) instrument is an X-band single pass radar interferometer designed to acquire high resolution imagery and topography of Venus as well as to make repeat pass interferometric measurements of surface deformation.

VISAR Specifications—VERITAS requires a Digital Elevation Model (DEM) with 300 m horizontal postings over 90% of the Venus surface, with height accuracy ≤10 m for 95% of the mapped surface. Global imagery with resolution less than 30 m is also required with radiometric resolution better than 3 dB.

VISAR Design Considerations: VISAR operates at a center frequency of 7.9 GHz (0.038 m wavelength), which optimizes topographic mapping accuracy by balancing the impact of atmospheric attenuation effects with baseline and antenna size constraint*s* to fit in the spacecraft fairing. A bandwidth of 20 MHz gives a ground resolution of ~15 m at VISAR incidence angle of 30°. The radar needs to map a swath width of greater than 14 km, spanning the 10 km of surface rotation at the equator during an orbital period with 2 km overlap with adjacent orbits. Table 2 lists key radar design and performance parameters.

Table 2. VISAR Parameters.

Instrument Parameters	Value
Platform Altitude Range (km)	182–252
Polarization	VV
Peak RF transmit power (dBW)	26.0
X-band Wavelength (m)	0.038
Antenna azimuth × elevation dimensions (m)	3.9 × 0.65
Range bandwidth (MHz)	20
Slant Range/Azimuth Resolution (m)	7.5, 2.3
Incidence Angle at swath center (°)	32
Pulse Repetition Frequency (PRF) (Hz)	5500
Pulse length (μs)	35
Baseline length (m), and orientation angle (°)	3.1, 30
Range, Azimuth Ambiguities (dB)	−36, −25
Atmospheric Losses (dB)	-9.5 dB

VISAR Hardware Design—VISAR has three major subsystems: 1) Digital Electronics (DES); 2) RF Electronics (RFES), including redundant (one as a cold spare) Solid State Power Amplifiers (SSPAs); and 3) Antenna Subsystem (AS).

The DES would be built at JPL and is a radar controller and processor used to produce real-time SAR imagery [10]. Its main functions are to: 1) execute S/C commands, 2) acquire and format engineering telemetry, 3) provide control and timing signals to VISAR's digital/RF electronics, and 4) digitize echo returns and perform InSAR Onboard Processing (OBP) for data volume reduction.

VISAR Onboard Processing—VISAR would include an OBP element to meet downlink constraints. Key processing steps in the OBP data flow are range compression, motion compensation, azimuth compression, and look averaging. Our implementation approach would use a pair of off-the-shelf Reconfigurable Computer (RCC5) processor boards from SEAKR Engineering. Onboard processing reduces downlink data volume up to a thousand-fold compared to downlinking raw data which would enable VERITAS to obtain global coverage. In addition to processing echoes, the FPGAs extract phase and amplitude from the radar's internal transmit/receive (Tx/Rx) calibration signals to monitor systematic phase drifts, which would be removed later in post-processing.

The RFES design would be led by JPL in collaboration with ASI (and their subcontractor Thales Alenia Space Italy, TAS-I). ASI provides the RF Low Power Electronics, a single self-contained chassis encompassing the frequency synthesizer, the chirp-generator, two receiver channels, and an upconverter/preamplifier assembly. JPL would procure the SSPAs and the front end switching unit which includes receiver protection.

The antenna subsystem would consist of deployment mechanisms for the two X-band radiating Waveguide Slot Array (WSA) antennas, the WSA panels themselves, the signal distribution network, a structural support system, and the thermal control system (Fig. 10).

The unobstructed field of view of the two antennas, in conjunction with the narrow range and azimuth beamwidths, would minimize multi-path from the S/C, which can impact interferometric phase measurements. Each VISAR antenna would consist of eight 0.5 m × 0.65 m WSA panels, each subdivided into eight 9 × 6 standing wave modules that form an array. The WSA panels would be standard dip-brazed machined aluminum parts forming a compact, all-metal antenna that minimizes thermal gradients, and eliminates radiation environment risk.

An 8-way waveguide corporate feed would distribute RF signals to each WSA panel (Fig. 10). The input of the corporate feed connects to one of the VISAR RF electronics ports via two symmetric waveguides routed along the antenna support structure. The corporate feed would use near-zero Coefficient of Thermal Expansion (CTE) carbon-composite waveguide to meet interferometric phase requirements over temperature. A thin metal plating on the waveguide interior walls provides low RF loss. The symmetrical equal path length design ensures interferometer phase tracking versus frequency. The routing configuration includes design features such as large radius bends and trombones that would facilitate practical fabrication and assembly of the composite parts.

Two types of composite subassemblies would support the VISAR antennas: an Interferometric Metering Structure (IMS) and four deployable Support Antenna Structure (SAS) wings. The IMS would quasi-kinematically mount the antenna assembly to the S/C and establish the 3.1 m interferometric baseline. WSAs and waveguides that do not deploy would be mounted to the IMS, while the SAS would provide mounting for WSAs and waveguides that deploy. The IMS and SAS would be constructed from near-zero CTE carbon composite material with M55J carbon fibers and cyanate ester matrix to limit thermally-induced deformations of the interferometric baseline.

VISAR antennas would be deployed from a stowed configuration, as shown in Fig. 11, shortly after launch using a spring-loaded hinge and damper mechanism. This mechanism would provide a controlled, highly reliable deployment amenable to repeatability testing. A waveguide choke joint integrated into the hinge would provide a simple, high-reliability RF connection.

VISAR Antenna Thermal Control System would maintain the antenna components within their allowable flight temperature ranges. During cruise flight software-controlled heaters

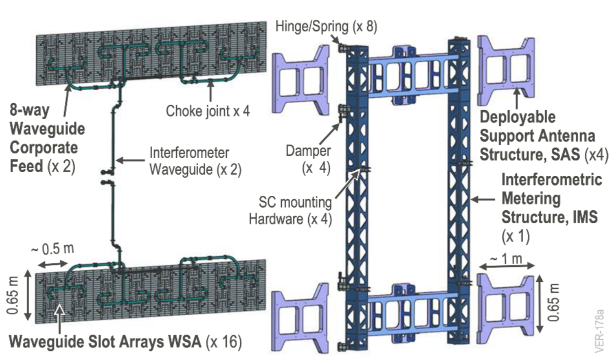


Figure 10. VISAR's passive antenna system ensures RF phase and interferometric baseline stability over a wide range of thermal conditions.

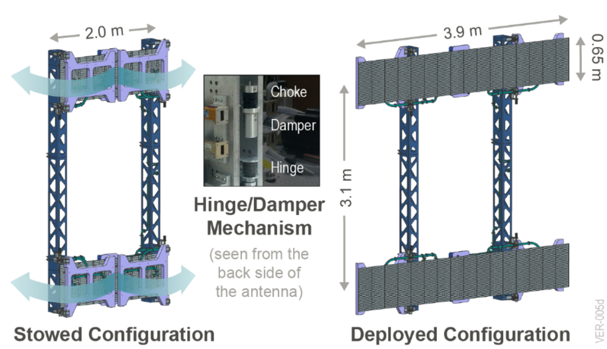


Figure 11. Two waveguide antennas deploy using a hinge mechanism (prototype shown center) from a stowed configuration (*left*) that fits in the launch shroud, to full operational configuration (*right*).

would be used to ensure the antenna does not get too cold. To prevent antenna overheating during aerobraking, and maintain low thermal gradients during science mapping, Multi-Layer Insulation (MLI) would be used around the IMS and on the back of the SAS. MLI cannot be used on the WSA radiating surface, but white paint would prevent over-heating and reduce gradients.

VISAR Modes of Operation—The radar has one science-mapping mode with several data downlink options that would accommodate different interferometric and imagery resolutions. For nominal science operations during SP2, we would upload a command table twice weekly specifying, as a function of S/C clock time, the radar parameters needing adjustment.

VISAR Calibration—Preflight VISAR instrument calibration activities would include measurements of the SSPA power output, pulse shape, receiver gain, ADC characteristics, Tx-cal-loop phase and amplitude over temperature, and antenna composite waveguides phase and amplitude variation over temperature. For in-flight radar calibration the radar would collect raw data from the two antennas to be downlinked for ground analysis. These data would be used to update calibration parameters needed for the proper collection and onboard processing of the radar data. Primarily, these data would be residual differential time delay between the two radar receive channels any yaw or pitch angle bias adjustments needed for the S/C pointing control to achieve zero-Doppler steering.

VISAR Data Acquisition—Topography data would be acquired on ascending and descending passes with at least two observations (also called revisits) for 95% of Venus' surface, with more than 80% acquired 3–6 times. Revisits would provide the opportunity to detect surface changes. During descending passes for the VISAR left-looking sensor, matching the dominant East-Looking data acquired by Magellan, data would be acquired to obtain a combination of MedRes (30 m resolution) imagery for nearly 100% coverage and HiRes (15 m resolution) imagery with 27% coverage. VERITAS would be capable of targeting 17 sites with RPI, acquiring each site at least twice to form a repeat pass interferogram. If active regions of Venus experience similar levels of activity as Earth analogs we predict detection of 3–7 events for 17 acquired sites.

VISAR Expected Performance—We developed a comprehensive model to evaluate radar performance at Venus including imaging, radar stereo, single and repeat pass interferometric modes [11,12]. The radar performance model elements specify the observing geometry and scenario, the instrument configuration and product specification parameters, propagation and scattering parameters that are used to determine radar performance depending on mode, time and location of measurement. Backscatter information is derived from Magellan S-band data using a physical scattering model to convert S-band backscatter measurements to the desired radar frequency and incidence angle, [13] Fig. 12a. The impact of atmospheric attenuation as a function of terrain height is derived from a model described in [14]. Two-way losses at X-band as a function of elevation (in km) relative to the 6051 km reference sphere is roughly -9.5 dB. In assessing the interferometrically derived height accuracy we have assumed a "bundle adjustment" procedure to remove residual cross-track tilts due to baseline and phase errors. Bundle adjustment uses tie points between adjacent orbits and between crossing ascending and descending passes in a least squares procedure to estimate cross-track tilt and elevation bias between the swaths.

VISAR would also collect repeat pass radar data for 12-17 targeted 200×200 km sites. The deformation accuracy including atmospheric variations, mostly due to SO_2 variations, at 50 m posting is about 1.5 cm. These data would be the first deformation interferometry at another planet.

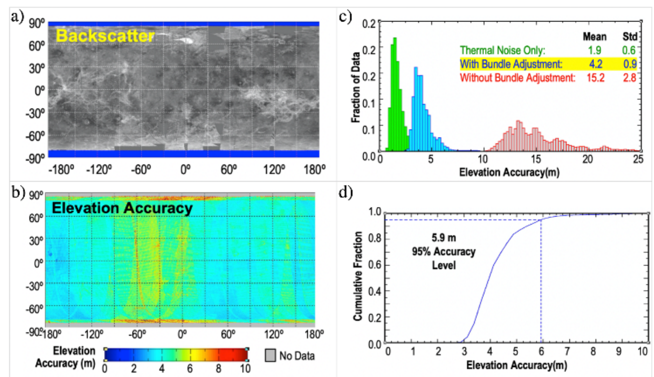


Figure 12. (a) Map of the VISAR elevation mapping accuracy, (c) histograms of elevation mapping accuracy with the bundle adjustment and (d) cumulative elevation accuracy showing a 5.9 m 95% accuracy level.

To demonstrate VISAR's end-to-end performance we simulated raw VISAR data (I,Q ADC sample data like that acquired in flight) [15] using TanDEM-X data from Taftan Volcano (28.61°, 61.12°). The selected scene has both rugged topography, 2700 m of topographic variation over a 15 km cross-track by 60 km along-track area, as well as smooth, less rugged terrain (Fig. 13b,c).

The expected elevation mapping accuracy of the VISAR instrument is shown in Fig. 13. Backscatter contributions to SNR and attenuation losses are factored in the overall performance. Elevation accuracy is computed every 10 km based on the orbital geometry. Phase noise limited elevation accuracy (in green in Fig. 12c) is compared to elevation accuracy before and after bundle adjustment (blue and green in Fig. 12c). The cumulative elevation accuracy is shown in Fig. 12d and shows that 95% of the surface is mapped with elevation accuracy better than 5.9 m.

Three simulated data sets were generated by scaling the TanDEM-X backscatter data (Fig. 13.a) to have means of −7.5, −11.5 and −14.5 dB. These values span the expected X-band backscatter on Venus. The simulation used the VISAR imaging geometry, sensor parameters including bandwidth

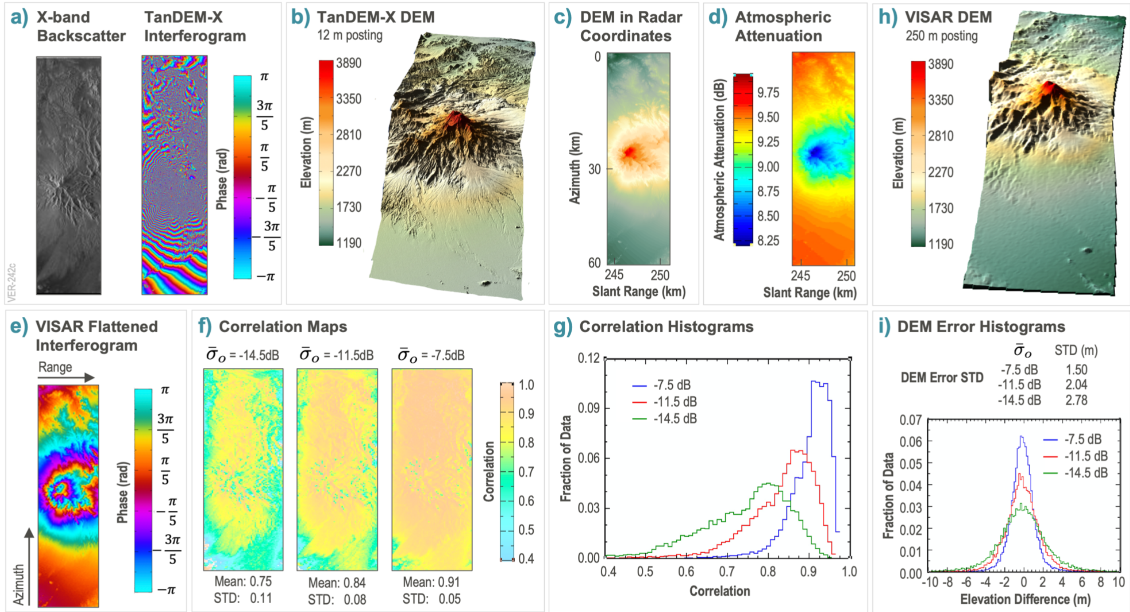


Figure 13. Demonstration of the VISAR end-to-end processing chain shows good agreement with VISAR performance model Top row (from left to right): (a) Original TanDEM-X backscatter, interferogram, and (b) DEM; (c) then DEM in radar coordinates using the same color bar as (b), and (d) terrain variant atmospheric loss used in the simulations. Bottom row (from left to right): (e) Interferogram derived from the simulated VISAR data for the mean −14.5 dB backscatter data, (f) interferometric correlation maps and (g) histograms for the three mean backscatter cases. Right column: (h) VISAR DEM derived from −14.5 dB mean backscatter data, and (i) the histogram of elevation error compared to the truth DEM for the 3 mean backscatter cases.

and sampling frequency, thermal noise and multiplicative noise characteristics, antenna pattern, and terrain dependent atmospheric attenuation model (Fig. 13). Raw data were processed using a range-Doppler focusing algorithm to form imagery, as done onboard the S/C, and then phase filtered, unwrapped, and geocoded as done in the VISAR ground processing [16]. Notice the reduced fringe rate of the VISAR interferogram (Fig. 13e) compared to the TanDEM X (Fig. 13a) owing to the much greater ambiguity height resulting in reduced fringe rates of VISAR compared to TanDEM-X. This reduced fringe rate coupled with the much larger number of looks allows the whole scene to be unwrapped for all mean backscatter levels and in both rugged and flat terrain. Correlation maps and histograms (Fig. 13f) show values that span the range of values expected for VISAR data.

VEM

The permanent cloud cover of Venus prohibits observations of the surface with traditional imaging techniques over much of the EM spectral range. Therefore, it was once thought that information about the surface composition of Venus could only be derived from lander missions. Given the harsh environmental conditions on the surface, any type of landed mission will have high complexity and therefore a higher associated risk than orbiting missions. In addition, mission concepts for Venus landers typically focus on one landing site instead of a global reconnaissance, forcing difficult choices to be made between different types of surface units.

The mapping of the southern hemisphere of Venus with VIRTIS instrument on Venus Express using the 1.02-µm thermal emission band can be viewed as a proof-of-concept for an orbital remote sensing approach to surface composition and weathering studies for Venus [17-20]. Recent advances in high-temperature laboratory spectroscopy at the Planetary Spectroscopy Laboratory at DLR show that the five atmospheric windows in the CO_2 clouds of the Venus atmosphere, ranging from 0.86 µm to 1.18 µm, are highly diagnostic for surface composition [21-22].

The Venus Emissivity Mapper [23,24] builds on these recent advances. It is the first flight instrument specially designed with a focus on mapping the surface of Venus using the narrow atmospheric windows around 1 µm. By observing with six bands, VEM would provide a global map of surface composition as well as redox state of the surface (Fig. 14). Continuous observation of Venus' thermal emission would also provide tight constraints on current day volcanic activity [20,25]. Measurements of atmospheric water vapor abundance as well as cloud microphysics and dynamics would permit accurate correction of atmospheric interference.

VEM is a pushbroom multispectral imaging system. The telecentric optics images the scene onto a filter array, and the image is relayed by a three-lens objective onto the detector. VEM's optical sub-system sits on top of the electronics compartment, which includes the MERTIS-derived instrument controller and the power supply. A two-stage baffle protects VEM from scattered light. A 45° FOV yields a swath width of 207 km at an altitude of 250 km, providing

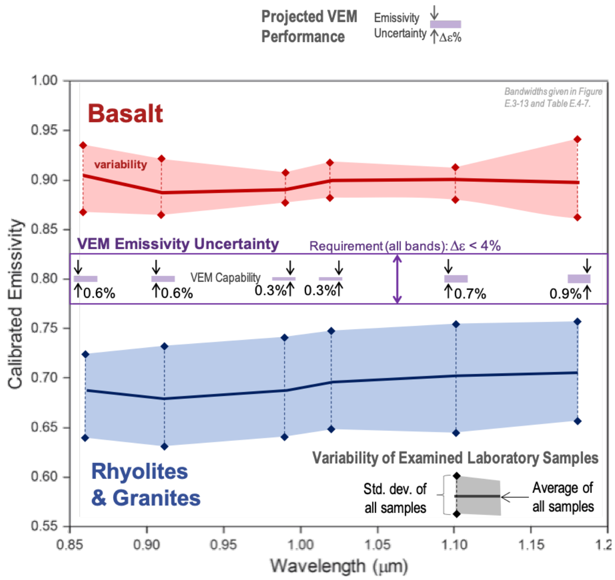


Figure 14: The projected VEM performance in all surface bands far exceeds the requirement and will allow to provide the first global map of rock types on the surface of Venus.

a thorough sampling of surface emissivity and orbit-orbit repeat coverage.

VEM uses a multilayered dielectric-coating ultra-narrow-band filter array to split the light into 14 bands. The filter array is located at an intermediary focus of the optical path. Each band is imaged by a two lenses relay optic onto 33×640-pixel rows on the FPA. Surface composition bands are spatially interleaved between cloud bands to provide before and after calibration. The core element of the focal plane array is the 640×512 pixel Xenics XSW-640 InGaAs detector. With the FOV of 30°×45º; each 20-µm-pitch pixel sees a 0.07°×0.07º FOV. An integrated thermo-electric cooler is used to stabilize the working point of the detector. The FPA requires no cryogenic cooling, avoiding a single point failure. The same detector is currently successfully operating in the ACS instrument on the ESA ExoMars Trace Gas Orbiter [26].

Scattering at the cloud particles limits the achievable spatial resolution at the surface to approximately 50-100 km [27,28]. The VEM optical system has a theoretical on-ground resolution of 300 m from a 250-km orbit. Using digital TDI, the data are reprocessed in the instrument at a spatial resolution of 1 km, providing a significant gain in signal-to-noise ratio (SNR). Due to the low orbit required for the radar, the wide field of view of the VEM instrument would allow every spot on the surface to be viewed between 5 and 10 times in consecutive orbits. This would allow short-term variability in the atmosphere of Venus to be accounted for. To distinguish between surface and atmospheric contributions, VEM would use an updated version of the extensively tested data pipeline developed to process VIRTIS surface data [18], combined with a radiative transfer model (RTM) [30-33]. Data would be processed at 10 km spatial resolution and the data from consecutive orbits would be stacked. Both provide an additional increase in the SNR.

Of VEM's 14 bands, six would see the surface through all Venus atmospheric windows; three compensate for stray light; three measure cloud transparency; and two measure water abundance. The water vapor and cloud opacity channels would be used as RTM inputs to constrain near-surface water vapor abundance and cloud particle distributions. Water concentrations at 1.16 µm have sufficient accuracy and precision to enable a search for active volcanic outgassing. Multiple observations over the duration of the mission would be used to account for additional unknown atmospheric variability not accounted for in the RTM. This would reduce both atmospheric and instrument noise by averaging image swaths acquired at different times. Applying an updated analysis [33] of atmospheric error for VEM parameters, and taking multiple look averaging into account, our capability for emissivity precision is between 0.3 and 1.2%

During the concept study phase for the NASA Discovery VERITAS proposal a laboratory prototype (LP) of the VEM instrument was integrated and successfully tested [25]. This prototype (Fig. 15) includes the development version of the VEM optics with a filter array with two active filter strips. The optics underwent a set of calibration measurements on sub-unit level at LATMOS prior to delivery to DLR. The detector is the commercial version of the flight detector and off-the-shelf front-end electronics are used with a laptop as electrical ground support equipment (EGSE). Form and function are already representative of the top part of the VEM flight instrument. The LP has been integrated and passed functional verification in July of 2016. A first performance evaluation of the VEM LP was performed using two Venus analog samples heated to Venus surface temperatures. The retrieved emissivities match the laboratory values and the error from a single exposure is less than 0.35% [25].

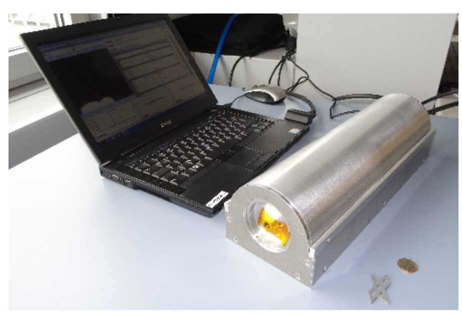


Figure 15. The VEM prototype, developed to validate the design and demonstrate performance (see text).

Gravity Science

Science objectives. The gravity investigation of VERITAS aims to fill the large knowledge gap on the internal structure of Venus as compared to the other terrestrial planets and the Moon. Geophysical models of the interior are based on limited data for mass, radius, gravity, and topography. One direct existing constraint is provided by the tidal Love number k_2 estimated from Doppler tracking of Magellan and Pioneer Venus Orbiter (k_2=0.295 ± 0.066 [33]), but the large uncertainty does not allow distinguishing between a liquid vs. solid core [34]. Recent determinations of the pole precession and the moment of inertia factor (MOIF=0.337 ± 0.024) are also too uncertain to provide useful constraints (>500 km uncertainty in core radius) [35].

Precise measurements of the MOIF through the pole precession rate, the tidal Love number, k_2 and the tidal phase lag, ε, will permit the first useful comparisons between the interior of Venus and other terrestrial planets. Work by Dumoulin et al. [34] indicates that the state of the core and its size, as well as the viscous response of the interior, can be well constrained by the VERITAS requirements, that is a determination of k_2 to ±0.01 and of ε to 0.25°. Additional constraints come from the moment of inertia, determined by measuring the precession rate with an accuracy of 50 arcsec/cycle. This information is crucial to model the thermochemical evolution of Venus' interior including differentiation, as well as key surface processes; e.g., core size which is a key parameter in predicting vigor of mantle convection and the size and number of hot mantle plumes.

The knowledge of crustal processes, essential to determine why and how Venus and Earth diverged, would greatly benefit from high fidelity mapping of the gravity field. By combining global high-resolution gravity and topography VERITAS would look for possible subduction, buried features (e.g., as observed on Mars and the Moon) and unrecognized deformation. In addition, the improved uniformity of the gravity field knowledge would provide precise estimates globally of the elastic thickness, a proxy for heat flow.

Design and performance. Gravity science data would be acquired using the two coherent radio links (uplink and downlink), in both X- and Ka-band. The spacecraft telecom subsystem would also be used to for commanding from and providing telemetry to the Deep Space Network (DSN). The key onboard element would be the Integrated Deep Space Transponder (IDST), built by Thales Alenia Space Italia under contract with the Italian Space Agency. The IDST can handle several link configurations and can also accept a frequency input from the atomic clock (DSAC-2) that would be carried onboard VERITAS as a technology demonstration. The IDST enables both synchronous and asynchronous two-way links, as well as one-way downlink driven by DSAC-2. In addition, the IDST supports a 24 Mcps pseudo-noise ranging system with internal delay calibration, providing range accuracies of 1-4 cm at 4 s integration time [36]. Two-way Ka-band Doppler data quality is approximately 0.018 mm/s at 10 s integration time (vs. 0.033 mm/s noise level requirement). The detailed Doppler error budget is shown in Fig. 16, in terms of Allan deviation. Well-established methodology and software would be used to perform precise orbit determination and thereby compute gravity field coefficients and the interior tidal and MOIF parameters. The VERITAS Science Phase 2 orbit would enable a recovery of the gravity field to 155 km spatial resolution (vs. 200 km requirement), with an accuracy of < 3 mGal at degree and order 123 (vs. the 7 mGal at degree and order 95 requirement). VERITAS' high-resolution, globally uniform gravity field would provide 2–3x improvement over Magellan (Fig. 17). Although Magellan gravity was estimated to degree and order 180 to avoid aliasing [37], the average Magellan degree strength is 70 (range 40–100).

The investigation requires high frequency stability over a broad range of time scales, from 10 s to 10000 s, corresponding to gravity field spatial scales from 100 km to the planetary radius. In addition to a low-altitude nearly-circular polar orbit, short time scale stability (down to 10 s) is of primary importance to recover a field with higher fidelity and resolution than Magellan. Longer time scales are important for determining the pole position and spin rate. The spacecraft center of mass would be stable over relevant orbital time scales because VEM, VISAR, the HGA and the solar panels have fixed orientations.

We would acquire data at the DSN with no onboard sequencing required. Gravity science data acquisition would not interfere with the nominal telemetry/telecommand flow. Each daily 8-hour DSN pass would correspond to five VERITAS telecom orbits. The nominal seven DSN passes per week with 2-way Ka-band would provide 40% margin to the five passes per week requirement. Data would be delivered from the DSN to the Gravity Science Team for processing using well proven orbit determination codes [38].

There are three primary sources of error in gravity data and recovery:

1. Dispersive propagation media effects are strongly suppressed at Ka-band frequencies, and no calibration is necessary at Sun-Probe-Earth (SPE) angles >15°. At smaller SPE angles, i.e., close to superior solar conjunctions, dispersive media effects can be calibrated to 75% [7] by differencing simultaneous dual-frequency fully-coherent X- and Ka-band signals.

2. Nondispersive Earth troposphere and ionosphere zenith path delay corrections are computed using standard dry and wet calibration data. These are provided by the DSN for each tracking session using on-site weather stations and Global Navigation Satellite System (GNSS) data.

3. Non-gravitational forces such as atmospheric drag and other force modeling errors are accounted for in the orbit determination process. A shape model of the spacecraft with associated thermo-optical properties enables computation of the cross-sectional area and the nongravitational perturbations acting on it. Spacecraft orientation is derived from telemetered attitude quaternions in the form of SPICE kernels.

In addition to calibration, ancillary data would be necessary to fully exploit the Doppler and range measurements. The commanded state of the Integrated Deep-Space Transponder

(IDST), particularly antenna usage, would be used in the computation of the observables. The spacecraft center-of-mass position would bring further accuracy to the observation modeling. The spacecraft mass history and attitude would be considered as well. Given that the residual accelerations of

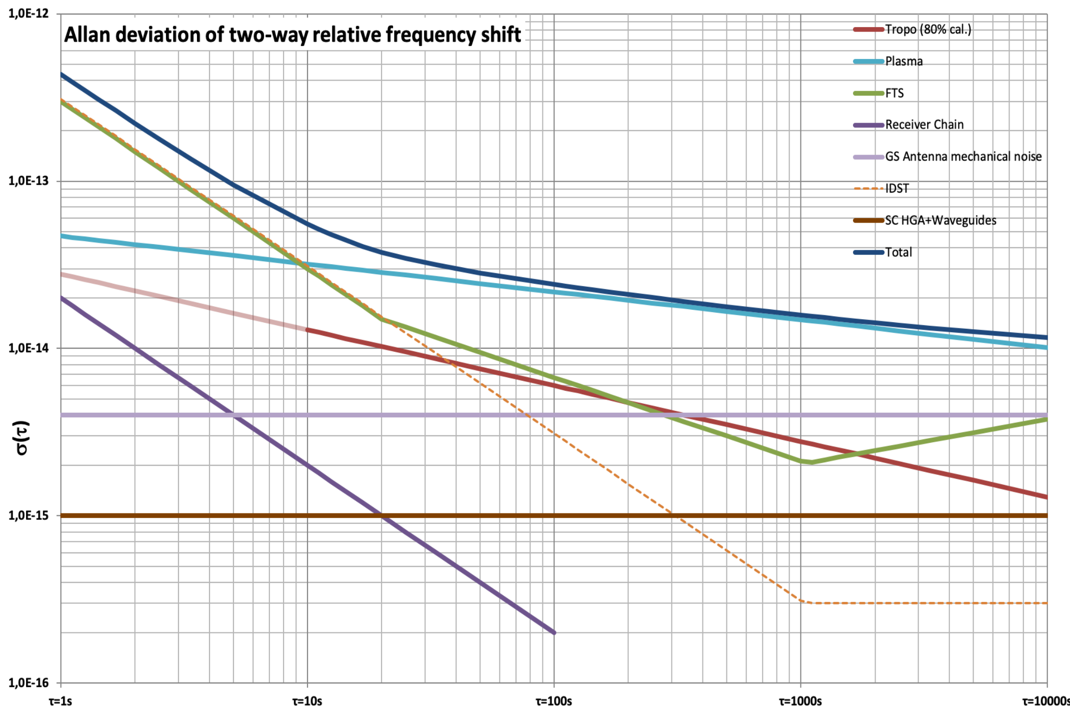
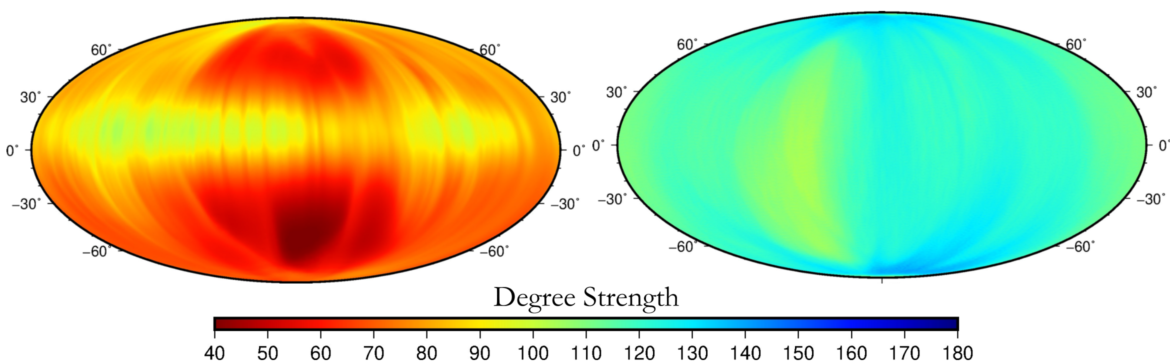


Figure 16. Error budget of VERITAS Doppler radio system, in terms of Allan deviation. σ(1000 s)=10^{-14} is equivalent to a range rate of 3 µm/s two-way.

(a)



(b)

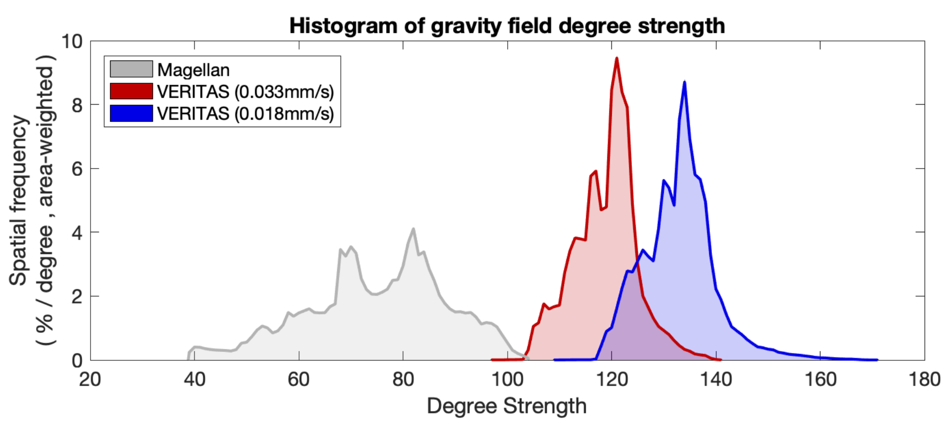


Figure. 17. (a) Gravity recovery performance from Magellan (left) and from VERITAS (right). The degree strength is defined as the spherical harmonics degree (inversely proportional to the effective resolution) where the signal to noise region falls below unity. (b) Histogram of the degree strength from Magellan and for the VERITAS Doppler noise requirement (0.033 mm/s) and expected performance (0.018 mm/s).

even balanced angular momentum desaturation events exceed the measurement error, the timing and magnitude of the spacecraft maneuvers over the course of the mission would also be accounted for. A special type of geodetic constraints, called radar tie points, would be derived from overlapping VISAR swaths and would be ingested during the POD processing to further improve the low-degree gravity field knowledge and the recovery of the Venus rotational state and precession [39].

The combination of Doppler tracking and radar tie points strongly ties the spacecraft position to the planetary body-fixed frame, increasing the sensitivity to the rotational state parameters even in the presence of the recently discovered irregular rotation [35]. By combining the two datasets in the data analysis, VERITAS would be able to measure the precession rate to 10 arcsec/cycle (vs. 50-arcsec/cycle requirement), the MOIF with an accuracy of 0.3% its expected value (vs 1.5% requirement), the Love number k_2 to 5.0×10^{-4} and its phase lag ε to 0.045° (vs. a requirement of 0.01 and 0.25°, respectively; all values are formal 3σ) [39].

5. Deep Space Atomic Clock 2

NASA's Deep Space Atomic Clock (DSAC) Technology Demonstration Mission recently completed its two-year mission in low-Earth orbit (operations ended on September 18, 2021). DSAC successfully showed the technology's viability for sustained, reliable operations and for providing the most stable frequency ever demonstrated in space (~3×10^{-15} at one-day and a drift of <3×10^{-16})/day [40]. This success has warranted development of a next generation DSAC, called DSAC-2, that is planned to be hosted on VERITAS as a Technology Demonstration Opportunity (TDO) and supported by NASA's Space Technology Mission and Science Mission Directorates. The DSAC-2 design is intended to use less power, be smaller, and longer-lived than DSAC-1, while maintaining excellent performance. DSAC-1 lessons learned will be applied to the design and development of DSAC-2 to facilitate achieving DSAC-2's desired design improvements and making it ready for future NASA, DoD, or commercial applications.

While DSAC-1 was a foundational advance that met its program requirements and proved the technology's space operability, it could not demonstrate DSAC's beneficial impact to deep space navigation and radio science. Nor was DSAC-1 designed for the long-lived operation needed for a typical NASA mission. The DSAC-2 Technology Demonstration Opportunity (TDO) intends to rectify this. With DSAC-2 operating as an external reference to the VERITAS' IDST, it would become possible to collect X-band, Ka-band, and combined X/Ka one-way Doppler to characterize data quality and show equivalent (sometimes superior) accuracy to its ground-based, two-way Doppler counterparts. Via collection of this high precision one-way radiometric tracking, key demonstration objectives of the DSAC-2 TDO include:

1. Perform one-way Doppler-based navigation and compare it to traditional two-way Doppler navigation in various flight phases including cruise, aerobraking, and orbiting.
2. Demonstrate the *potential* of onboard OD to significantly ease the burden and risk of complex, time-critical operations such as aerobraking. In a ground-based experiment, the TDO will generate orbit solutions using the one-way data collected during orbit and, potentially, aerobraking to assess their viability for onboard navigation; thus, providing critical information for use of DSAC-2 derived radio data as part of a future autonomous orbit navigation solution.
3. Perform tests to validate DSAC-2 derived radio data is suitable for radio science. Some examples include comparing solutions using one-way data for gravity field recovery, solar plasma characterization, and, potentially, radio occultations to their two-way counterparts. There is even the potential to perform general relativity tests using the effect it has on DSAC-2 and orbital motion.

On a non-interference basis with VERITAS, DSAC-2 TDO operations would take place in the first two years after launch during VERITAS's cruise to Venus and orbital operations up to the start of SP2. When the TDO mission is complete, DSAC-2 would become available to the VERITAS mission for their navigation and radio science needs.

An important aspect of the DSAC-2 project is to advance the trapped ion clock technology beyond DSAC-1 to include: 1) superior stability, 2) increased lifetime, 3) reduced size, weight, and power (SWaP), and 4) improve the fabrication yield percentage and robustness. A functional block diagram of the DSAC-2 clock with external interfaces is shown in Figure 18. The DSAC-2 design concept reduces the DSAC-1 design from multiple boxes to a single box under 410mm x 145mm x 211mm = 12.5 liters, equivalent to the GPS atomic frequency standard footprint. The unit takes 28V unregulated in, uses RS422 as its communication interface with the VERITAS CD&H, and provides a frequency output at 76.549382 MHz to the IDST.

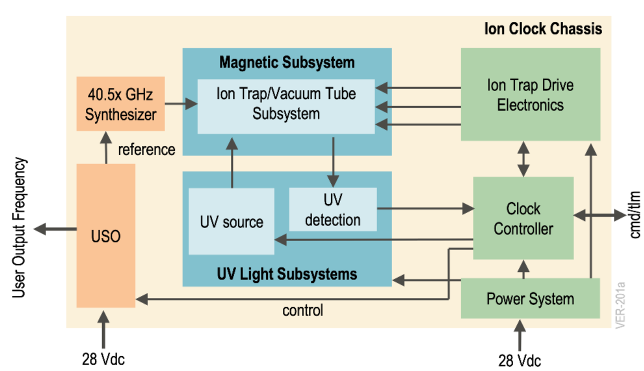


Figure 18. DSAC-2 Block diagram with key clock subsystems and DSAC-2's inherently simple external interfaces.

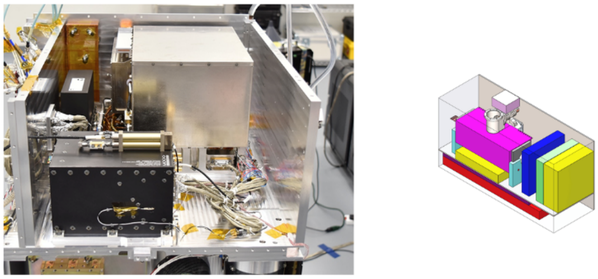


Figure 19. On the left is a photo of the DSAC-1 instrument (silver box) during space craft integration (a GPS receiver, shown in the foreground, will not be part of DSAC-2). On the right is shown to scale the DSAC-2 system concept.

DSAC-2 will have a stability of $2\text{x}10^{-13}/\sqrt{\tau}$ in the short term and 3×10^{-15} at one day – similar to DSAC-1 stability achieved on the ground. The DSAC-1 instrument lifetime is limited by its DUV light source at 3-5 years. While DSAC-2 would only have a 2-year lifetime requirement, it is very desirable to improve this aspect of the technology for future applications. DSAC-2 would meet this goal by using an enhanced light source fabricated with different materials and a calibrated process that is likely to have a life span well beyond two years. To address the DSAC-2 SWaP requirements of 13 L, 13 kg, and 42 W, DSAC-2 would simplify the ion trap and frequency chain architectures used in DSAC-1, thereby reducing components and size as well as power, with current design estimates falling well below these requirements. Figure shows a scale comparison of DSAC-1 and DSAC-2. In addition to design simplification, use of COTS parts and removal of high tolerances where possible will increase instrument and reliability.

DSAC-2 has the potential to be a true, multi-mission atomic clock with a design that is ready to support an array of NASA (DoD and commercial telecom applications as well) with smaller SWaP and longer life than DSAC-1.

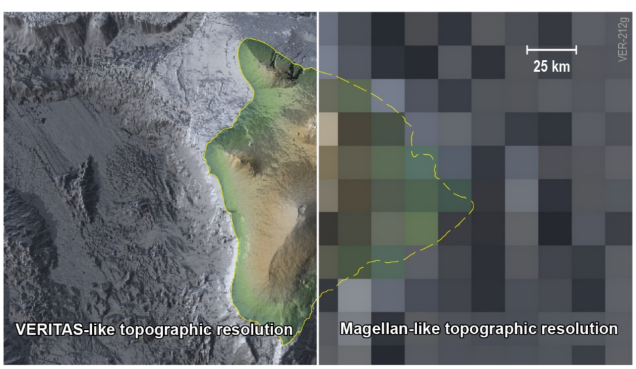


Figure 20. The VISAR DEM provides a two order of magnitude increase in resolution. Images based on USGS composite of bathymetry in grey scale (-6.2 km of relief) and topography in color scale (4.2 km of relief) at Hawaii.

6. CONCLUSIONS

The Decade of Venus begins with VERITAS. NASA has successfully demonstrated the value of global high-resolution reconnaissance followed by in-situ measurements. Every time a planet has been examine with datasets that increase the resolution by an order of magnitude, completely unexpected processes have been discovered. The VERITAS DEM would be two orders of magnitude higher resolution than Magellan altimetry (see Fig. 20). VEM would provide the first ever map of surface rock type, thus addressing the critical question of the history of near-surface water via the search for felsic rocks. VERITAS would examine Venus' activity through change detection, the search for active flows, outgassed water, and recent volcanism, as well as the first ever deformation maps of another planet. The gravity investigation would provide the first meaningful constraints on core size and state. VERITAS would reveal an entirely new Venus. These foundational data sets would both allow for an unprecedented leap in our understanding of Venus and pave the way for future exploration. The DAVINCI atmospheric probe mission [41] to Venus was selected in the same opportunity as VERITAS for a later launch. The European Space Agency selected EnVision [42] within weeks of the VERITAS and DAVINCI selections. Together these 3 missions would provide synergistic datasets that would make the Decade of Venus a decade of discovery.

ACKNOWLEDGEMENTS

The research described in this paper was carried out in part at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration. We would like to thank the many contributions from the VERITAS science team members and from the engineers and scientists at JPL, LM, DLR, ASI, and CNES that made this mission possible. We would also like to thank Leon Alakali, Mimi Aung, Tony Freeman, David Lehman and Mike Lisano whose leadership during various phases of the mission formulation and proposal development that were so integral to the mission being selected.

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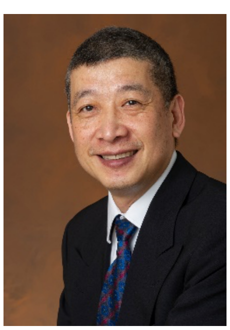

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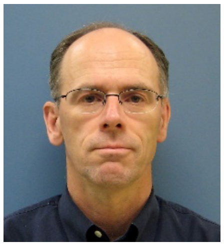

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