# EXPLORING THE VENUS CRUST AND LITHOSPHERE WITH THE VERITAS GRAVITY SCIENCE INVESTIGATION.

Erwan Mazarico[1], Luciano Iess[2], Gael Cascioli[3,1], Daniele Durante[2], Fabrizio De Marchi[2], Scott Hensley[4], Suzanne Smrekar[4]. [1] NASA Goddard Space Flight Center, Greenbelt, MD (erwan.m.mazarico@nasa.gov), [2] University of Rome La Sapienza, [3] University of Maryland, Baltimore County, [4] NASA Jet Propulsion Laboratory, Pasadena, CA.

**Introduction:** The Venus Emissivity, Radio Science, InSAR, Topography And Spectroscopy (VERITAS) mission [1] was selected under NASA's Discovery program in June 2021. Along with DAVINCI and EnVision, the decade of Venus is now on the horizon. VERITAS will answer key questions related to the geologic and volcanic history of Venus and inform on the current structure of the interior, from crust to core [2]. This will address important gaps in our understanding of the diverging evolutionary paths taken by Earth and Venus over the courses of the past few billions of years. The interferometric radar VISAR [3] will map the planet morphology and topography at high resolution, well surpassing the Magellan datasets and bringing our knowledge of Venus in line with other terrestrial bodies (Moon, Mars, Mercury). The gravity science investigation will constrain the subsurface structure by measuring the gravity field to high resolution, as well as the deep interior through its low-degree gravity and orientation dynamics. Here, we focus on the former, and particularly the crust and lithosphere. Other work addresses the latter [4].

**Science Objectives:** VERITAS seeks to answer three essential questions: What processes shape rocky planet evolution? What geologic processes are currently active? Is there evidence of past and present interior water? Gravity science primarily addresses the first, through several science objectives. The mapping of subsurface density various to recognize possible continental roots can inform the origin of the major geologic terrains. Similarly, the detection of buried gravity features such as impact basins, rift zones, or tessera inliers provides a unique contribution to establishing the record of prior geologic regimes. The thermo-chemical evolution of Venus can be tackled by the measurement of crustal and lithospheric thickness over the major different geologic provinces. The deep interior structure is accessible through modeling to explain the Venus orientation dynamics and tidal response.

**Data:** The VERITAS telecom subsystem benefits from the Integrated Deep Space Transponder (IDST) contributed by the Italian Space Agency (ASI). It draws on significant heritage of the BepiColombo transponder, en route to Mercury orbit. It is capable of simultaneously coherently transmitting both Ka-band and X-band signals and allows independent two-way radio tracking by DSN in both bands. The Ka-band Doppler noise level requirement is 0.033 mm/s over 10-s integration times at a Sun-Probe-Earth angle (SPE) of 15° (where plasma effects are already not negligible). The anticipated performance is 0.018 mm/s [5]. A 10-second integration time is needed to achieve high-resolution gravity field recovery, as the VERITAS spacecraft travels >430 km in a more typical 60-second interval. These VERITAS geodetic observations are complemented by the VISAR radar tie point datasets, which are particularly important for the recovery of the Venus tidal Love number $k_2$ and obliquity [6].

The gravity science data will be collected during the VERITAS Science Phase 2 (SP2) after completion of the aerobraking phase. The orbit is a low-altitude (180-220 km) polar orbit which provides increased sensitivity to gravitational perturbations. The orbit nearly repeats over the four cycles of the primary mission, to benefit the VISAR observation campaign, but the Earth tracking geometry varies between cycles.

**Simulation Results:** We have conducted numerous comprehensive simulations of the recovery of the gravity field spherical harmonics coefficients and other geophysical parameters. These were performed in support of the Discovery mission proposal, but some have more recently also been focused on novel measurements that would supplement the primary objectives [6,7]. We used two independent orbit determination software: JPL's MONTE and GSFC's GEODYN. Simulations with GEODYN have primarily dealt with the high-degree gravity field recovery [8], which are more challenging due to the large number of parameters to be estimated (>30,000 for a field to degree and order 180). Improvements to measurement and force models were targeted at the MONTE simulations [6,7].

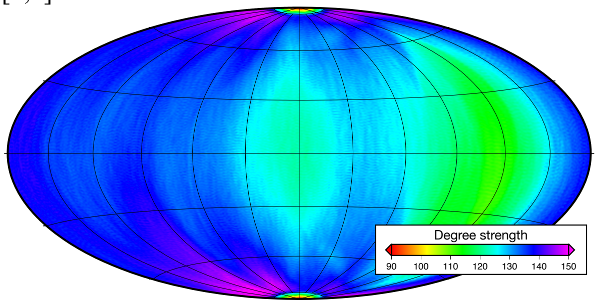

**Figure 1.** Simulated recovery of the Venus gravity field with VERITAS Ka-band tracking (0.033mm/s). The color shows the degree strength over the globe. Hammer projection centered at 0° longitude.

We will present updates to the previous results of the gravity field recovery (Fig. 1). While the overall performance is unchanged, there are changes spatially due to the different launch dates and Earth-Venus geometry. These results are typically presented in the form of a *degree strength* map, which indicates up to what degree (or conversely, spatial resolution) the gravity anomalies are known to a SNR of 1 (that is, estimation error at a location is at the level of the expected gravity signal at that wavelength).

**Analysis:** We utilize the covariance matrix of our recovered gravity field to evaluate how well derived geophysical parameters of interest can be estimated. While the knowledge of the gravity anomalies is a natural focus for the performance of the gravity field measurement, bounds on the estimation uncertainties of parameters such as lithospheric thickness and crustal density are more closely linked to the VERITAS objectives. With the higher resolution and accuracy expected vs. Magellan [8], we will be able to provide further insights than current knowledge [9]. The topography of Venus will be measured by VISAR at much higher resolution than the gravity field resolution, and it is considered an input to spectral analysis methods.

Our goal is to go beyond our previous efforts, and most past studies which do not consider the correlation between gravity field coefficients. The use of the covariance matrix or of 'clone fields' (used in GRAIL analysis, which are statistically consistent with the nominal solution given the covariance matrix) is important to properly evaluate the errors in the derived parameters.

We will discuss how well the crustal density and the lithospheric thickness can be estimated, choosing several locations to span the range of gravity field accuracy.

**References:** [1] Smrekar S.E. et al., 2022 IEEE Aerospace Conf.; [2] Smrekar S.E. et al., LPSC 51, 2020; [3] Hensley S. et al., 2020 IEEE Radar Conf.; [4] Cascioli G. et al., LPSC 54, 2023; [5] De Marchi F. et al., AGU Fall Meeting, 2022; [6] Cascioli G. et al., The Planetary Science Journal, 2021; [7]; Cascioli G. et al., The Planetary Science Journal, submitted; [8] Mazarico E. et al., AGU Fall Meeting, 2019; [9] Smrekar S.E. et al., Nature Geoscience, 2022.