THE DETERMINATION OF VENUS GRAVITY FIELD WITH VERITAS.

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Introduction: The Venus Emissivity, Radio Science, InSAR, Topography and Spectroscopy (VERITAS) NASA Discovery mission will address important scientific questions about Venus' evolution, structure, and past and on-going geological processes by collecting data from a gravity science experiment, and two instruments: an X-band interferometric SAR (VISAR), and a near-infrared imaging spectrometer (VEM).

VERITAS, during the Science Phase 2, relevant for gravity data collection, will orbit Venus for 4 Venusian cycles (2.7 years) on a near - polar, near – circular, low altitude orbit.

Gravity Science Experiment: The gravity investigation utilizes radiometric tracking data to tell us about the crustal and interior structure of Venus, using a radio signal link between spacecraft and ground antennas. The experiment will be enabled by an Integrated Deep Space Transponder that will be part of the communication subsystem: it can simultaneously lock to either an X- or Ka-band link and retransmit coherently to ground X- or Ka-band signals. This will allow to obtain a Doppler noise level of 18 $\mu m/s$ at 10 s integration time for a Sun-Probe-Earth angle larger than 15°, well below the requirement of 33 $\mu m/s$. Additionally, the telecom system enables ranging at the level of 4 cm at 2 s integration time.

The current resolution of Venus' gravity field [1], based on tracking data from Magellan and Pioneer Venus Orbiter, is uneven with a spatial resolution ranging between 475 km and 170 km. The VERITAS mission, given the lower noise level of the Doppler data and the orbit chosen for Science Phase 2, will enable to generate a gravity map with a substantially higher and more uniform spatial resolution. Gravity science investigations provide important information on the interior structure of the planet, thus a higher accuracy will help to better constrain Venus' interior from core to crust.

Methods: The capabilities of VERITAS' gravity science experiment have been assessed through a covariance analysis using JPL's orbit determination software MONTE. A multi – arc approach, that is best suited for data analysis of long duration gravity experiment, has been adopted with 2- or 3-days long arcs. Synthetic Doppler data are generated according to VERITAS' operational scenario that consists in five Doppler tracking passes a week, collected by NASA's Deep Space Network ground stations, with an observation schedule that entails approximatively a daily contact to ground for 8 hours.

White Gaussian noise has been superimposed to the data; to reproduce VERITAS Doppler noise a detailed model has been developed, considering several sources related to the media crossed by the radio link (plasma, troposphere, and ionosphere, that are variable with Sun – Earth – Probe angle and season) and to the spacecraft and ground station instrumentation. Currently, we are working on the Doppler noise model improvement by including colored noise in order to see how this more realistic assumption for the noise sources will affect results.

The dynamical model adopted is in agreement with Cascioli, et al. 2021 [2] taking into account important characteristics of the Venus system as thermal tides and short-term sidereal period oscillations of the solid planet.

The data have been processed in a least – square estimation filter (ORACLE) in order to retrieve the state of the orbiter and the gravity field, for which a spheric harmonic expansion up to degree and order 220 has been considered. In addition, other estimated parameters, important for Venus's interior structure, are: the Tidal Love number (real and imaginary part), the Load Love number, Venus pole location and precession rate, the MOIF, and Venus sidereal period, that has some short term oscillations in time as recently observed by Margot et al. 2021 [3].

Results:

Gravity Field Spectrum. The gravity field spectrum can be used to represent the global accuracy of the gravity field and it is closely tied to the spatial resolution. In the plot below, in addition to the magnitude of the gravity field measured by Magellan, the Root Mean Square (RMS) of the formal uncertainties on the gravity field coefficients from VERITAS and Magellan are compared. For VERITAS two power spectrum of the recovered gravity field are here reported: in one case the field is unconstrained, in the other case a Kaula – like $\frac{1}{l^2}$ regularization is applied during the inversion, where l is the degree of the gravity field spherical harmonics expansion.

$$RMS(\sigma_l) = \sqrt{\frac{\sum_m \left(\sigma_{C_{lm}}^2 + \sigma_{S_{lm}}^2\right)}{2l+1}}$$

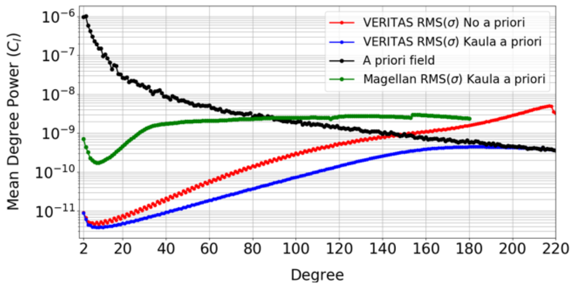

Figure 1: Gravity Field Spectrum comparison between Magellan and VERITAS

Degree Strength: The degree strength [1] represents the gravity resolution attained on different areas of the planet. It is computed by comparing the spectra of anomaly error and expected acceleration, calculated from Kaula's rule:

$$(a_l)_{RMS} = \frac{GM}{a_e^2} K \sqrt{\frac{2}{l}} \quad (for\ l \gg 1)$$

Where a_e is the reference radius of Venus ($6051.0\ km$), GM is Venus' gravitational parameter, l is the degree of the gravity field spherical harmonic expansion, and K is a constant related to the planet (1.2×10^{-5} for Venus).

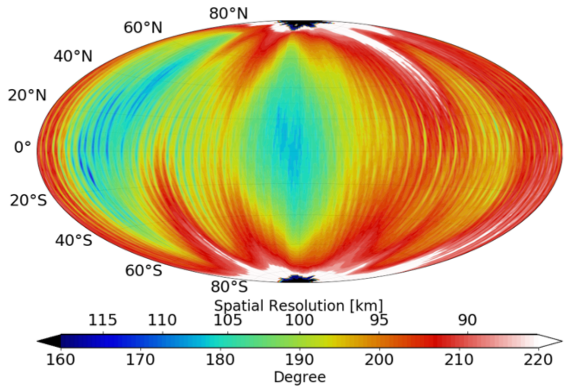

Figure 2: VERITAS degree strength and gravity field spatial resolution, based on [1] definition.

Due to the selected orbit and the instrumentation used, a high and uniform spatial resolution can be attained: the spatial resolution is better than $105\ km$ (~ 180 degree strength) in more than $90\ \%$ of the planet.

Conclusions: By simulating VERITAS gravity science experiment, we show that VERITAS will allow an improvement in the gravity field spatial resolution with respect to Magellan. This will help to better constrain Venus' interior structure (*e.g.,* size and state of the planet's core), and to detect small gravitational signals, as the one generated by thermal tides and atmospheric loading. In addition, the improved uniformity of the gravity field knowledge would provide precise global maps of elastic thickness and heat flow, which are clues to the planet past evolution and interior composition.

References:

[1] Konopliv A. S. et al. (1999), *Icar., 139,* 3-18
[2] Cascioli G. at al. (2021), *PSJ, 2,* 220
[3] Margot J.L. et al. (2021), *NatAs, 5,* 676-683