MEASURING VENUS' GRAVITATIONAL RESPONSE TO ATMOSPHERIC LOADING WITH VERITAS.

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Introduction: The complex dynamics of the Venus atmosphere produces a periodic mass redistribution pattern which creates a time-variable modulation of the gravity field of Venus. This gravity signal results from the solar-driven transport of mass across the globe and the solid body also responds to this normal atmosphere loading of its crust. In this work, we explore the possibility of observing this phenomenon with VERITAS (Venus Emissivity, Radio Science, InSAR, Topography and Spectroscopy [1]), a NASA Discovery mission. By simulating the gravity science experiment, we quantify the measurement accuracy of the response of Venus to the atmospheric loading, parametrized by the loading Love numbers (k_l'), and assess the dependency of these parameters on fundamental interior structure properties. Using the most recent models of Venus' interior, we compute the Venus Love numbers in a compressible viscoelastic setting and compare them with the predicted uncertainty of the VERITAS measurements. We also leverage the frequency-dependent relation between tidal and loading Love numbers and consider the constraints on the Venus interior which could arise from a simultaneous measurement of the response of the planet at the tidal and loading forcing frequencies.

Atmospheric tides and loading Love numbers: The combination of Venus' long solar day and dense atmosphere gives rise to a strong atmospheric mass redistribution, also known as thermal tide. The thermal tide, and the associated surface pressure anomalies move eastward with respect to Venus' surface with a leading period equal to the Venus' Solar day (~117 days, Figure 1). This mass redistribution phenomenon can be detected as a time-variable component of the Venus gravity field [2,3].

The gravitational potential spherical harmonics coefficients ΔC_{lm}^U can be written as a function of the spherical harmonics expansion of the surface pressure anomaly field ΔC_{lm}^P [3]:

$$\Delta C_{lm}^U(t) = \frac{3(1+k_l')}{(2l+1)R\rho g_0}\Delta C_{lm}^P(t) \qquad (1)$$

where R, ρ, g_0 are the Venus radius, mean density, and surface gravity, respectively. Equation 1 shows that the time variable contribution of the tide is both due to the direct effect of the moving atmospheric masses (the 1 in the $(1 + k_l')$ term) and to an indirect effect due to the planet's response to the surface loading (parametrized through the load Love numbers k_l'). Similarly to the tidal Love numbers, k_l' describe the ratio between the forcing and response gravitational potential, therefore bearing the signature of the interior structure of the planet [5]. It has been already shown that VERITAS will be sensitive to the atmospheric tides [2]. Here we assess whether this sensitivity can be exploited to determine the loading Love numbers themselves and thus to provide improved constraints on the Venus interior structure.

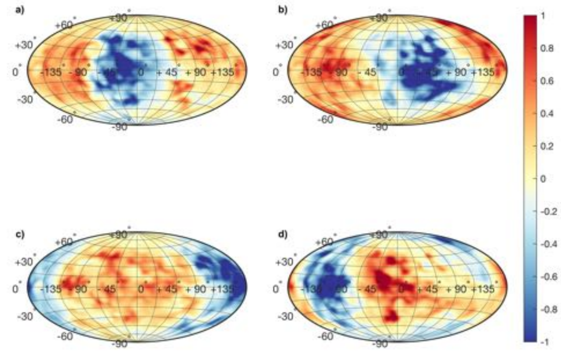

Figure 1 – Snapshots of global surface pressure anomalies during one Venus solar day. The sub-solar point is at 0, 90, 180, 270 degrees longitude in a) b) c) d), respectively.

Computing the loading Love numbers:

The computation of the Love numbers is possible only when a Venus interior model is adopted. To this aim we have used the models by [6] and [7] which differ by temperature profiles, mantle composition, and core radii. By doing so we have been able to compute and explore the large range of expected Venus loading Love numbers. The computations have been performed under the assumption of a compressible visco-elastic interior using the method by [8]. We find a strong sensitivity of the loading Love numbers to the different interior structure models with relative variations of low degree k_l', on the order of 50% for the subset of models with a purely liquid core and 25% when a solid inner core is present (Figure 2). This is an indication that a precise determination of the load Love numbers would provide additional constraints for the determination of the Venus interior.

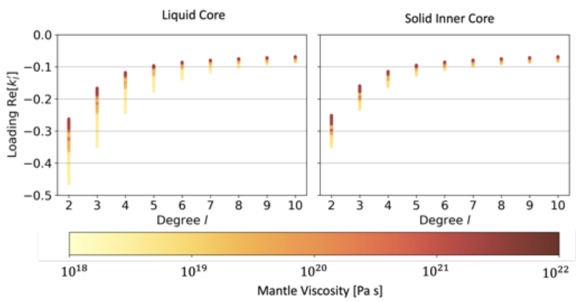

Figure 2 – Loading Love numbers variations with mantle viscosity.

Results:
To assess VERITAS' capability of measuring k_l' we have run detailed simulations of the gravity science experiment (similar to those reported in [2]). We have used a detailed Ka-band radio tracking noise model which accounts for all the main noise sources and is in line with the VERITAS requirements. The time-variable gravity signal, determined by the surface pressure perturbations, have been simulated using the output of Venus GCMs [9]. To test the robustness of the results we have conducted an extensive set of perturbed simulations.

By comparing the estimated loading Love numbers and their predicted estimation errors with the spread from the computation of the models we show that VERITAS will be able to measure the loading Love number of degree 2 at the 4% level and will have a good sensitivity to the degrees 3 and 4 as well. Moreover, comparing the predicted retrieval capabilities of the loading Love numbers with the interior structure models we highlight the potential to provide new constraints on the interior structure of Venus by determining the load Love numbers. We show in particular that the determination of k_2' can provide independent, and complementary, information on the mantle viscosity and composition. Furthermore, we discuss the frequency-dependency of the tidal and loading response of Venus and devise a data analysis strategy, exploiting other measurements gathered by the VERITAS gravity science investigation, in combination with k_2', to probe the planet's response at different forcing frequencies simultaneously. Recognizing a frequency-dependent relationship between k_2, k_2' and h_2:

$$k_2'(\omega) = k_2(\omega) - h_2(\omega) \qquad (2)$$

where ω is the forcing frequency, we show that a simultaneous measurement of the tidal response (k_2, h_2) and loading response (k_2') can be used to provide finer bounds on the mantle viscosity, serve as a independent sanity check of the data analysis, and possibly constrain the mantle rheology and probe the rheological response at different forcing frequencies.

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