THE DEVIL IN THE DARK: A FULLY SELF-CONSISTENT INTERNAL SEISMIC MODEL FOR VENUS C. T. Unterborn[1], N. C. Schmerr[2] and J. C. E. Irving[3], [1]Arizona State University, School of Earth and Space Exploration, Tempe, AZ, 85287 (cayman.unterborn@asu.edu)[2]University of Maryland College Park, College Park, MD, 20742 (nschmerr@umd.edu), [3]Princeton University, Princeton, NJ, 08544 (jirving@princeton.edu)

Introduction: The bulk composition and structure of Venus is unknown despite accounting for ∼40% of the mass of all the terrestrial planets in our Solar System. As we expand the scope of planetary science to include those planets around other stars, the lack of measurements of basic planetary properties such as moment of inertia, core-size and state, seismic velocity and density variations with depth, and thermal profile for Venus hinders our ability to compare the uniqueness of the Earth and our Solar System to other planetary systems.

Here we present fully self-consistent, whole-planet density and seismic velocity profiles for various potential Venusian compositions. Using these models, we explore the seismological implications of the different thermal and compositional initial conditions, taking into account phase transitions due to changes in pressure, temperature as well as composition. Using mass-radius constraints, we examine both the centre frequencies of normal mode oscillations and the waveforms and travel times of body waves.

Mineralogical modeling: Potential Venusian mineralogy, density, velocity and adiabatic temperature profiles were calculated using the BurnMan and ExoPlex software packages [1, 2]. For a given composition and mantle potential temperature, ExoPlex combines the solutions of mineral phase equlibria and equation of state calculations from PerPlex [3] and simultaneously calculates the mass and/or radius assuming hydrostatic equilibrium (Figure 1, Table 1). For these models we adopt the self-consistent thermodynamic input data of [4]. The core is assumed to be entirely liquid using the equation of state of [5] with no light elements present for simplicity, although including this aspect is possible with ExoPlex. We adopt two, potentially end-member, compositions for this study: the solar photospheric abundances of [6] and the bulk Earth composition of [7]. Results of mass, core parameters and other potential seismic observables are shown in Table 1. The Solar compositional model predicts masses are within 1% of the actual Venusian value while the chondrite model of [7] predicts higher values. The Earth compositional model, however, has a greater intrinsic magnesium to Fe ratio, a coarse measure of the relative size of a planet's core to mantle. It is the larger relative core size within Venus predicted by the Earth model that creates this increased mass. As such, mass-radius-composition models are most sensitive to changes in the core size and chemistry, which in turn depend on the thermal and chemical state of the planet as a whole.

Seismological predictions: The two different models of composition at different mantle potential temperatures can be interrogated using a range of seismic techniques, including ray-theoretical calculations, normal mode analysis and propagation of seismic waves through the model. Thus we are able to investigate which seismological observables are best able to illuminate different properties of Venus' interior.

For each model of Venus, wavefield simulations [8] are carried out to produce synthetic seismograms at a range of epicentral distances. We use constant attenuation in the mantle and core, with values for both divisions taken from PREM [9].

Though many of the seismic phases we observe are similar to those traveling through the Earth, there are noticeable differences - the lack of a solid inner core in our models means that at antipodal distances the first arriving phases travel through the liquid outer core. At large distances up to three PKP phases may be present. Phases which are sensitive to the mantle transition zone (MTZ) are evident in the wavefield plot, including precursors to PP and MTZ reverberations.

Ray theoretical calculations were carried out to determine paths and travel times of a range of seismic phases. Differential travel times for the pair ScSScS-ScS, shear waves reflected once or more from the core-mantle boundary, are calculated for each model. Overall, models with an Earth-like composition have smaller differential travel travel times than those with a solar composition due to the differences in core radius for the two end-member compositions.

Table 1: Properties of Venusian Composition Models

Mantle Potential Temperature	1500 K	1700 K	1900 K
Solar Composition [6]			
Mass (Venus masses)	1.008	0.999	0.991
Core Mass %	30.03	30.04	30.04
Core Radius %	51.4	51.3	51.2
Core Depth (km)	2943	2950	2955
Earth Composition [7]			
Mass (Venus masses)	1.008	0.999	0.991
Core Mass %	30.03	30.04	30.04
Core Radius %	51.4	51.3	51.2
Core Depth (km)	2943	2950	2955

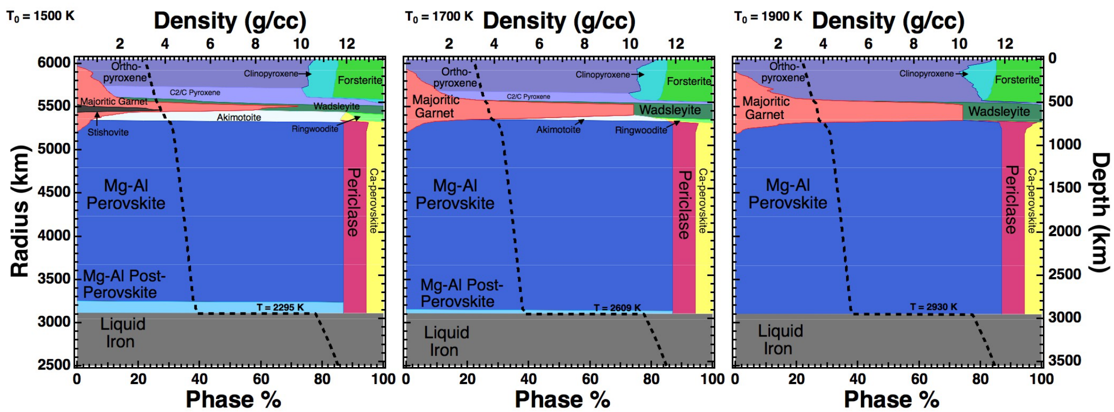

Figure 1: Planetary phase diagrams calculated by ExoPlex for Venusian planet of solar composition [6]. Models are calculated using mantle potential temperatures of 1500 (left), 1700 (middle) and 1900 K (right). Density as a function of depth is shown as a dashed black line.

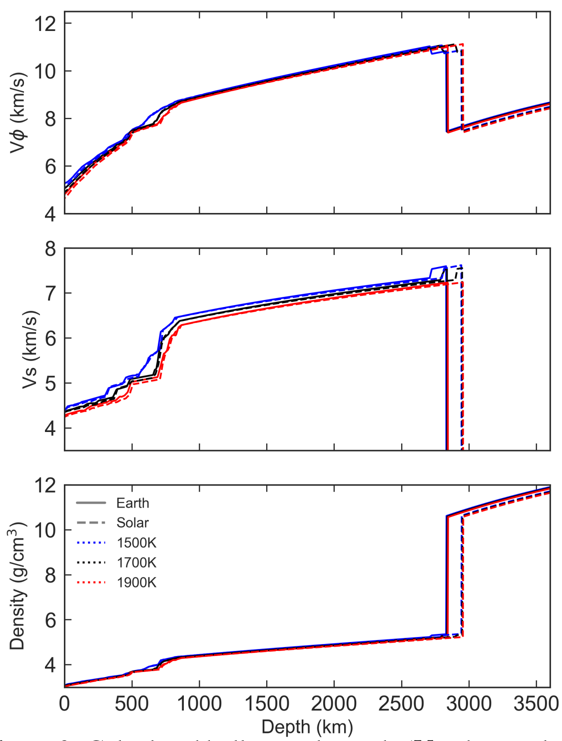

Figure 2: Calculated bulk sound speeds (V_ϕ, shear velocities (V_s) and densities for each Venusian Compositional Model

The effective thickness of the mantle transition zone was estimated from each of the seismic models. On Earth, mantle transition zone thickness is estimated using a number of different seismic phases, including phases converted at the mantle transition zone and precursors to surface reflected phases. For both Solar and Earth compositions the transition zone thins with increasing mantle temperature.

Summary and Discussion: By combining cosmochemical estimates with mineralogical modelling and seismological analysis, we are able to create reference models for Venus' composition and seismic properties. Of the seismological probes shown here ScS multiples are a good tool for determining planetary Fe/Si ratio, with their dependence on core radius. Mantle transition zone thickness is better probe of temperature, though the presence of multiple phase transitions in this region may lead to complex signals. These results and our forward model point to the potential wealth of fundamental scientific insights into Venus and Earth, as well as exoplanets, which could be gained by including a seismometer on future planetary exploration missions to Venus, the devil in the dark.

References

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