Abstract:

Although Venus is very similar in size and mass to the Earth (and therefore often referred to as its twin sister), their internal structures might differ in several ways. Indeed, the lack of plate tectonics as means to expel heat probably leads to a hotter interior for Venus. As a consequence, Venus's core should be at least partially, and maybe entirely, molten. The determination of the tidal Love number \( k_2 \) from Magellan data by Kono and Yoder (1996) seems indeed to confirm the presence of a fluid core. However, there is little to constrain the core mass: Cosmochronological models (Fegley, 2005) suggest core mass fractions between 23.6 and 32.0%, implying a mantle mass proportionately similar or greater than Earth's. The Venerean landers returned a number of K, U and Th measurements means to expel heat probably leads to a hotter interior for Venus. As a consequence, Venus's core should be at least partially, and maybe entirely, molten. The determination of the tidal Love number \( k_2 \) from Magellan data by Kono and Yoder (1996) seems indeed to confirm the presence of a fluid core. However, there is little to constrain the core mass: Cosmochronological models (Fegley, 2005) suggest core mass fractions between 23.6 and 32.0%, implying a mantle mass proportionately similar or greater than Earth's. The Venerean landers returned a number of K, U and Th measurements

Mantle composition:

Two different models of composition, that represent end-members in term of core size, have been chosen. The model C1 is the equilibrium condensation model based on temperature- and pressure-dependent thermodynamic equilibrium in a solar nebula model (Lewis, 1972). The model C2 is based on Ringwood’s model (Ringwood, 1977) for planet formation.

Mantle temperature:

Two different temperature profiles have been tested. The hotter one, \( T_1 \), is modeled after 4.5 Gyr of thermal evolution with an episodic lid (Armbrüster and Tackley, 2012). The colder one, \( T_2 \), is obtained by Steinberger (2010), considering an adiabatic state based on the Earth’s PREM density profile.

Density and seismic velocities profiles

The mantle density \( \rho \) and seismic velocity \( v \) wave-speeds are computed in a consistent manner from given temperature and composition using the Perple_X program (Connolly, 2005). This method computes phase equilibria and uses the thermodynamics of mantle minerals developed by Stixrude and Lithgow-Bertollini (2011). The core is supposed to be entirely liquid and is a scaled version of the PREM. For each compositional model and each temperature profile, the radius of the core and the moment of inertia are computed.

Results:

For a tidal period corresponding to Venus case (58.4 d), all obtained results fit into the currently known value of potential Love number \( k_2 \) (0.296±0.066).

Preliminary EnVision radioscience simulations

- Error bars of the order of 0.017% of \( k_2 \) value are induced only by the Doppler noise.
- The determination of \( k_2 \) value presents a bias of 0.35% related to a systematic error on the estimation of the spacecraft position.
- Future simulations will also include errors on the gravity field model and on the spacecraft maneuvers. The larger error on \( k_2 \) value is expected to remain much smaller than the formal error of ±11% reported by Kono and Yoder (1996), and associated to the higher altitude of Magellan's orbit (500 km).

Conclusion:

As shown on Figures 2 and 4, a better determination of \( k_2 \), together with an estimation of the moment of inertia, the radial displacement, and of the time lag, if possible, will refine our knowledge on the present-day interior of Venus (size of the core, mantle temperature, composition and viscosity). Infering these quantities from a future exploration mission will provide essential constraints on the formation and evolution scenarios of Venus.

Tidal deformation:

The viscoelastic deformation of the planet interior under the action of periodic tidal forces are computed following the method of Tobie et al. (2005). The Poisson equation and the equation of motions are solved for small perturbations in the frequency domain using a compressible viscoelastic rheology.

To determine the viscoelastic properties of the interior, we use an Andrade model (Castillo-Rogez et al., 2011), which allows the calculations of complex modulus from the shear modulus, bulk modulus and viscosity.

The deformation of the fluid core, as well as of the atmosphere, is computed assuming a quasi-static formulation (Saito, 1974) for sake of simplicity, viscosity is supposed to be constant in the mantle. However, the computed \( k_2 \) and \( Q \) are comparable when considering a radiatively varying viscosity in a constant viscosity equal to the mean of the profile. We tested 4 different values of mean viscosity: \( 10^8, 10^{10}, 10^{12} \) and \( 10^{22} \) Pa.s.

References: