Modeling Venus's Polar Motion:
preparing for EnVision measurements

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Five Venus missions are under development to study the planet in the next decade, with both NASA's VERITAS and ESA's EnVision featuring a geophysical investigation among their objectives[1]. Their radar and gravity experiments will determine Venus's orientation, enabling spin dynamics analyses to infer geophysical and atmospheric properties.

Polar motion refers to the motion of a planet's spin axis relative to its surface. It is distinct from precession-nutation, which describes the motion of the spin axis relative to the fixed celestial sphere. Both motions provide complementary constraints for interior models.

In this study, to support the potential detection of polar motion by future Venus orbiters, we developed a polar motion model for a triaxial planet accounting for solar torque, centrifugal and tidal deformations of a viscoelastic mantle, and atmospheric dynamics. Core-mantle coupling effects were analyzed separately considering a simplified spherical core. We revisited the expression for the period of free motion known as the Chandler wobble. Solar torque is the dominant phenomenon affecting Venus's Chandler period, accelerating the wobble by a factor of 2.75, while solid deformations slow it down by less than 1.5%.

Using available interior models[2], we predict a Chandler period in the range [12 900; 18 800] years (core not fully crystallized) or [18 100; 18 900] years (core fully crystallized). During EnVision's four-year primary mission, the Chandler wobble manifests as a linear drift of about 90 meters of the spin pole on Venus's surface, near the resolution limit of EnVision's VenSAR. We also computed the forced polar motion using the Venus Planetary Climate Model[3]. The forced oscillations have an amplitude of approximately 20 meters, driven roughly equally by atmospheric dynamics and solar torque.

These results suggest that Venus's polar motion may be detectable by future orbiters. Venus's precession period has already been measured with a 7% relative uncertainty[3], but is expected to be better determined by EnVision[4] and VERITAS[5]. A combined measurement of both the precession and Chandler periods will reveal the physical state of the core. If the core is not fully crystallized, the Chandler period would serve as a proxy for the mantle's moment of inertia, providing complementary constraints for the size of the core and for thermo-chemical properties of Venus's interior. Therefore, polar motion should be incorporated into rotation models when anticipating these missions.

[1] Widemann et al. (2023), Space Science Reviews, doi:10.1007/s11214-023-00992-w
[2] Shah et al. (2022), The Astrophysical Journal, doi:10.3847/1538-4357/ac410d
[3] Lai et al. (2024), JGR Planets, doi:10.1029/2023je008253
[4] Margot et al. (2021), Nature Astronomy, doi:10.1038/s41550-021-01339-7
[5] Rosenblatt et al. (2021), Remote Sensing, doi:10.3390/rs13091624
[6] Cascioli et al. (2021), Planetary Science Journal, doi:10.3847/psj/ac26c0