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Constraining Tidal Dissipation in Rocky Planets from Mineral Physics: Toward a Refined Habitable Zone

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Tidal dissipation is a fundamental process that distinguishes many close-in rocky exoplanets from our Earth. As a dominant internal heat source, it profoundly reorganizes the planetary thermal evolution and thereby shapes long-term habitability. The efficiency of tidal dissipation depends not only on the planetary orbital parameters, but also on the viscosity and shear modulus of planetary materials, which remain poorly constrained under super-Earth mantle conditions. Here, we use first-principles calculations to determine the viscoelastic properties of three major mantle minerals relevant to super-Earth interiors: post-perovskite $MgSiO_3$, I-42d-type Mg_2SiO_4, and $P2_1/c$-type $MgSi_2O_5$. We find that, rather than monotonically increasing stiffness with depth, super-Earth mantles may instead experience viscosity reductions associated with mineral phase transitions, leading to the formation of multiple rheologically weak layers. The presence of these weak layers can substantially enhance tidal dissipation. For a modest orbital eccentricity of 0.01, tidal heating becomes comparable to radiogenic heating at an orbital period of ~10 days, and can reach Io surface heat fluxes at ~5 days (Fig. 1). Such intense tidal heating can strongly enhance the volatile degassing from the deep interior and reshape the planetary surface tectonics, especially for planets orbiting M-dwarfs, whose close-in habitable zones amplify tidal forcing.

