PALEOS: Multiphase Equations of State for Rocky Planet Interiors

Determining the interior structure and thermal state of rocky exoplanets is a key challenge in characterizing the growing population of super-Earths and sub-Neptunes. For ultra-short-period planets such as TOI-1807 b and WASP-47 e, mass–radius measurements alone cannot distinguish between a cold, geologically inert world with a solid mantle and frozen core, and a geologically active planet hosting a deep magma ocean and fully liquid core. Resolving this degeneracy requires accurate thermodynamic properties of planetary materials, including melt phases, across extreme pressure–temperature conditions.

We present PALEOS (Planetary Assemblage Layers: Equations Of State), an open-source Python package providing validated, analytically-derived thermodynamic properties for planetary interior modeling. For any pressure–temperature point, PALEOS returns density, specific internal energy, specific entropy, isobaric and isochoric heat capacities, thermal expansion coefficient, adiabatic gradient, and the stable phase—quantities essential for structure integration and thermal evolution calculations.

The package covers iron across its full phase diagram relevant to planetary cores (ε-hcp, γ-fcc, α-bcc, δ-bcc, and liquid), $MgSiO_3$ for silicate mantles (pyroxene polymorphs, bridgmanite, postperovskite, and liquid), and H_2O for volatile envelopes (ice polymorphs Ih–X, liquid, vapor, and supercritical phases via corrected AQUA tables). Phase boundaries are implemented to ensure numerical stability at transitions.

Alongside the Python API, we provide ready-to-use pressure–temperature tables up to 100 TPa, and updated mass–radius relationships featuring rocky thermal expansion. We apply PALEOS to the ultra-short-period rocky planets introduced above to demonstrate the critical influence of internal phase state on the geophysical character of their interiors. By enabling self-consistent comparisons between solid and molten states, PALEOS offers a path toward breaking the compositional degeneracies that currently limit our understanding of rocky exoplanet interiors.