OPEN-SOURCE THERMODYNAMICS FOR PLANETARY INTERIORS

PALEOS

Multiphase Equations of State for Rocky Planet Interiors

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Attia et al. (2026)
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THE PROBLEM & THE SOLUTION

01 One validated, multiphase equation-of-state toolkit.

Building a rocky-planet model means assembling equations of state for iron, silicate, and water, and today these are assembled by hand from scattered sources, re-derived again and again, with the same mistakes waiting to be made. Consolidating them into one tested place even **surfaced and corrected published errors.**

The deeper opportunity is old thermodynamics: if pressure is known as a function of volume and temperature, P(V, T), the Maxwell relations give every other quantity analytically — with **no numerical differentiation** and **consistency by construction.** PALEOS (Planetary Assemblage Layers: Equations Of State) is an open-source Python package built on exactly this principle.

`P(V, T)` → **Maxwell relations** → `density ρ` `internal energy u` `entropy s` `$C_p$` `$C_v$` `expansion α` `$\nabla_{ad}$` `stable phase`

Fe core
5 phases. `α-bcc` `δ-bcc` `γ-fcc` `ε-hcp` `liquid`

$MgSiO_3$ mantle
6 phases. Pyroxene polymorphs, bridgmanite, postperovskite, liquid.

H_2O volatile envelope
Ice polymorphs Ih–X, liquid, vapor, and supercritical phases via corrected AQUA tables.

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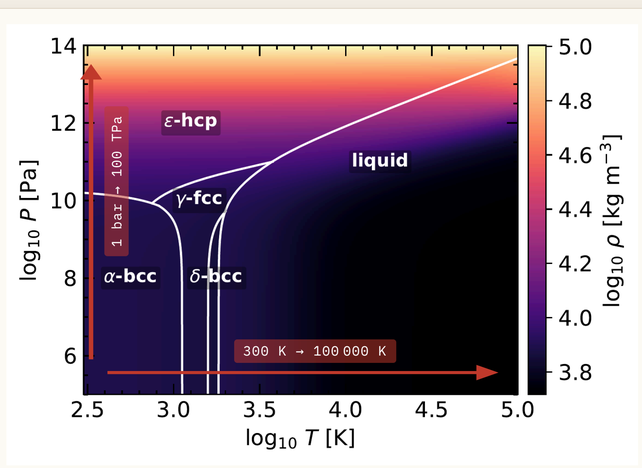
materials / phases, with automatic phase selection

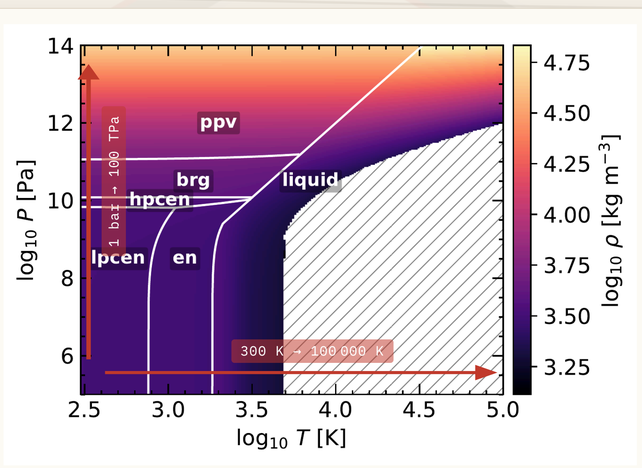
98% & 100%
Maxwell-relation residual below 0.01 across the iron domain and $MgSiO_3$

Python API
`pip install paleos` — density at any P–T point in a few lines.
`github.com/maraattia/PALEOS`

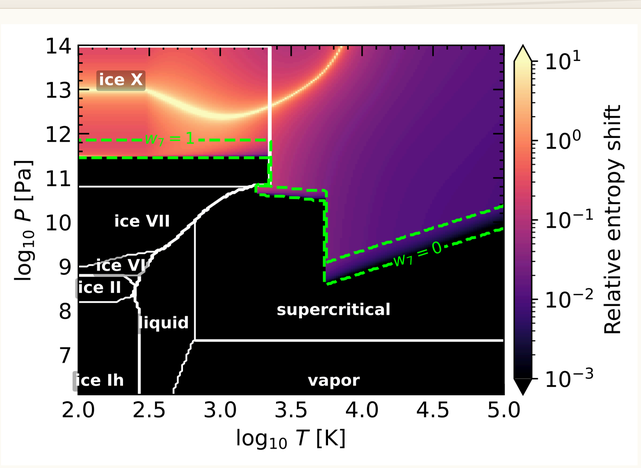
Lookup tables
Ready-to-use P–T tables up to 100 TPa and mass–radius tables. No installation. On Zenodo.



Iron (Fe). Density over pressure–temperature (log–log), with the five solid/liquid phase fields bounded by highlighted phase curves.



Silicate ($MgSiO_3$). The same treatment for the mantle material: full coverage, phase boundaries drawn crisp, automatic phase selection underneath.



Water (H_2O). Magnitude of the AQUA correction — the relative entropy shift — over the affected part of the phase diagram: ice X and the supercritical region.

THE THERMAL PAYOFF

02 The first temperature-dependent rocky mass–radius tables.

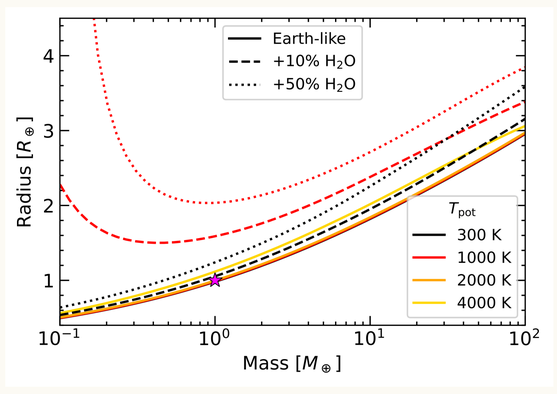
From these equations of state we computed **17,900 mass–radius models** — rocky planets from 300 to 4000 K, water worlds from 300 to 1000 K, at 99.99% convergence.

At 300 K the thermal effect is negligible. At 4000 K, low-mass rocky planets **inflate by up to 16%.** That shift changes which compositions are consistent with a given measurement.

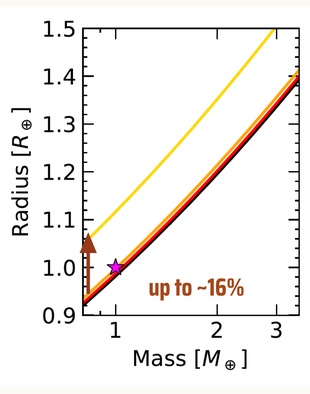
17,900
mass–radius models computed

300–4000 K
rocky-planet temperature range

99.99%
model convergence



Mass–radius relations, 300 K (black) to 4000 K (yellow). Earth marked with a magenta star.



Zoomed view at low mass. The arrow spans the thermal inflation.

THE DEGENERACY — THE CLIMAX

03 One planet, two faces.

Same mass, same radius, two completely different worlds: a **sleeping giant (a frozen tomb)** or an **active volcano (a boiling cauldron).**

Solution A
the sleeping giant

CORE MASS FRACTION
0.003

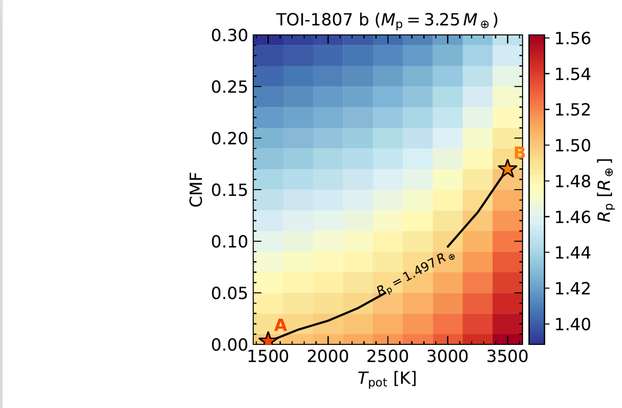
POTENTIAL TEMPERATURE
1500 K

MANTLE
Solid

CORE
Solid ε-hcp

DYNAMO
No

VERDICT
Geologically dead (a frozen tomb)



Every point on the iso-radius curve is the same planet.
TOI-1807 b · M_p = 3.25 $M_\oplus$ · R_p = 1.497 $R_\oplus$

Solution B
the active volcano

CORE MASS FRACTION
0.170

POTENTIAL TEMPERATURE
3500 K

MANTLE
Magma ocean

CORE
Liquid iron

DYNAMO
Yes

VERDICT
Living world (a boiling cauldron)

Mass and radius are not enough.

For the young ultra-short-period super-Earth TOI-1807 b, every combination of core mass fraction and temperature on the curve reproduces its measured radius — yet the endpoints are different worlds.
Phase-aware equations of state are necessary, not optional.

AN HONEST LIMITATION

04 Three materials is a foundation, not a ceiling.

Real planets have more than iron, silicate, and water:

`iron alloys — FeS, Fe–Si` `oxides — $SiO_2$, MgO` `volatiles — $CO_2$, $NH_3$, H/He`

PALEOS does not yet cover them. The framework is material-agnostic, though: give it P(V, T), and it returns the same eight quantities. These are the next tables.

If you work on any of these materials, come talk to me.

THE ASK

05 Use PALEOS.

Get the code
`github.com/maraattia/PALEOS`
Python API · `pip install paleos`

Read the paper
Attia et al. (2026)
`arXiv:2605.03741`

Get the tables
Zenodo — ready to use, no install.
EoS up to 100 TPa
`10.5281/zenodo.19000315`
Temperature-dependent M–R
`10.5281/zenodo.19221215`

Extend it
Your P(V, T) + the PALEOS framework = the next PALEOS table.