Thermal effects on the bulk density of rocky planets: the Earth-like composition band

A. Aguichine(1), F. Nimmo (2), N. Batalha(1), J. Fortney(1)

(1) Department of Astronomy and Astrophysics, University of California, Santa Cruz, CA, USA
(2) Department of Earth and Planetary Sciences, University of California Santa Cruz, Santa Cruz, CA, USA

The diversity of masses and radii of terrestrial exoplanets is commonly attributed to a difference in bulk composition. In the mass-radius plane, terrestrial planets typically lie around the Earth-like iso-composition curve computed from theoretical planet interior structure models. This thought is reinforced by the fact that theoretical interior models predict a mere 1% change in radius when thermal expansion of the rocky material in the deep interior is included. However, the density of the material is not only affected by thermal contraction, but also phase transitions, in particular between the solid and molten states. It is well established that rocky planets are fully molten at their formation, but the rate at which they solidify is still under debate. Unlike thermal expansion, phase transition between the molten and solid state is accompanied by a greater change in density. We show that fully molten interiors can be up to 15% less dense than their condensed analogs, which challenges the current interpretation of the composition of rocky super-Earths. This result highlights a new degeneracy between the composition and the thermal state of the interior of rocky planets, which has important implications for the evolution of atmospheres and hydrospheres on terrestrial planets, and their habitability.

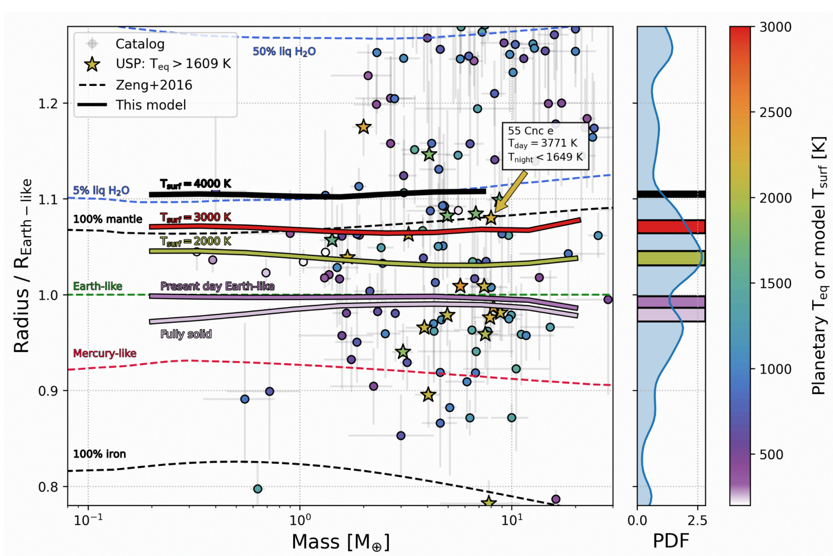

Figure 1. Mass-radius curves produced by our model, showing the range of planetary radii accessible with an Earth-like composition, by modifying the temperature profile and physical state of the interior alone. Conventional mass-radius iso-composition curves from Zeng et al. 2016 are shown for comparison. The exoplanet catalog is limited to a subsample of planets with mass errors smaller than 50%, in which we highlight Ultra Short Period (USP) planets, for which the equilibrium temperature is higher than the melting point of pyrolite at 1 bar (1609 K). All radii are normalized by the present-day Earth-like composition from Zeng et al. 2016. The Probability Density Function (PDF) of normalized planetary radii is shown on the right panel, computed using a gaussian Kernel Density Estimation (KDE). The PDF highlights the bimodal nature of terrestrial planets.