The Pressure and Temperature Phase Space of Rocky Exoplanets

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More than 4000 exoplanets have been discovered to date with the rate of discovery due to increase with the launch of new missions such as TESS. The composition, structure, mineralogy and thermal state of these planets are unknown and unlikely to ever be directly observed. Mineral physics, however, can help us infer and constrain these planetary parameters and help us understand the diversity of rocky worlds in our Galaxy. Our current dataset of planetary properties is biased to Earth-like compositions. Stellar compositions, however, outline a range of potential rocky planet compositions that are likely quite different than the Earth for both major and minor elements. The lack of fundamental datasets such a conductivity, water storage, and phase relations limits our ability to model these planets. Such data from the mineral physics community is vital for our understanding of whether a given exoplanet may be habitable and worthy of time-intensive observation by the astronomical community.

Ab-initio modeling and shock-wave measurement efforts for rocky exoplanets currently explore the properties of silicates >1 TPa in an effort to build a database of materials properties relevant to exoplanets, despite these physical conditions being indicative of all but the most rare of rocky planets to be discovered.

Recent work in the astronomical community (Fulton et al., 2017) has observed a maximum size of purely rocky planets of ~1.5 Earth radii super-Earths, above which planets are more likely to have large gas envelopes and become mini-Neptunes. We present here results from the mass-radius-composition code, ExoPlex, that outline the pressure and temperature regime of rocky planet mantles and cores across a wide variety of planetary compositions. We also empirically demonstrate that for purely rocky planets smaller than 1.5 Earth-radii core mantle boundary pressure and temperature is independent core mass fraction, reaching a maximum of 600 GPa and ~4000 K despite central core pressures varying by over 1000 GPa. Inclusion of a volatile layer, extended atmosphere or light elements within the core only lowers this CMB pressure for a given radius, and thus this pressure represents a potential upper bound of the phase space of the “average” rocky planet. Therefore, experiments may be safely limited to these pressures for exploration of terrestrial exoplanetary physical properties.

We further explore the effects of propagating correlated uncertainties in the temperature-dependent equations of state such extrapolation of the relatively well-constrained iron and post-perovskite equations of state result in a maximum of <0.15% uncertainty in the core-mantle boundary pressures and temperature for a given bulk composition.