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Predicted bulk compositions and geodynamical properties of terrestrial exoplanets in the Solar neighbourhood

Rob Spaargaren[1], Haiyang Wang[2], Maxim Ballmer[3], Stephen Mojzsis[4], and Paul Tackley[1]
[1]Institute of Geophysics, ETH, Zurich, Switzerland
[2]Dept. of Physics, ETH, Zurich, Switzerland
[3]Dept. of Earth Sciences, UCL, London, UK
[4]Origins Research Institute, Research Centre for Astronomy and Earth Sciences, Budapest, Hungary

Our knowledge of the physical, chemical, and mechanical (i.e., rheological) properties of terrestrial planets is based almost entirely on our Solar System. Terrestrial exoplanets, however, show a startling diversity compared to our local experience. This observation challenges our understanding of terrestrial planet formation and of the thermal and mechanical behaviour of such worlds, some of which are vastly different from our own. To better understand the range and consequences of exoplanetary diversity, we integrate results from astrophysical models and observations, geodynamical simulations, and petrological experiments. Terrestrial exoplanet modelling requires plausible constraints to be placed on bulk planet compositions; bulk composition modulates interior properties, including core size, mantle mineralogy, and mantle melting behaviour. This may in turn affect the interaction between the planet's interior and atmosphere, and thereby impact its potential to host a biosphere. Bulk composition may leave a signature on the mass and composition of the atmosphere, which could be detected in the future.

Here, we constrain exoplanetary diversity in terms of bulk planet composition, based on observations of stellar abundances in the Solar neighbourhood. We apply the devolatilization/fractionation trend between a planet and its host star [Wang+, 2019], to stellar abundances from the Hypatia catalogue [Hinkel+, 2014]. After applying a simplified model of rock-metal differentiation, we predict bulk planet and bulk silicate compositions of hypothetical exoplanets in the habitable zones of nearby stars. We further select 20 end-member compositions that span the full range of hypothetical bulk compositions based on our analysis.

With the compositions of these 20 end-members and by assuming Earth-like planetary masses and radii, we infer mineralogy and density profiles, as well as physical properties (e.g., viscosity) of the mantle using thermodynamic model Perple_X [Connolly, 2005]. These profiles and physical properties are prescribed in geodynamical models of exoplanet mantle evolution. We use convection code StagYY [Tackley, 2008] to model mantle convection and surface tectonic behaviour in a 2D spherical annulus geometry. We find that mantle viscosity increases with decreasing Mg:Si ratio of mantle rocks, with strong effects on planetary cooling and the likelihood of plate tectonics. In turn, the propensity of plate tectonics regulates the heat and chemical

exchange between mantle and crust, affecting surface conditions and, by extension, atmospheric composition. This establishes a link between interior composition and surface conditions, and shows the importance of studying this aspect of planetary diversity. We recommend our 20 suggested end-members of terrestrial exoplanet compositions for subsequent modelling work.