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The effects of terrestrial exoplanet bulk composition on long-term planetary evolution

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The study of exoplanets can provide a more general understanding of planetary systems and terrestrial-planet evolution. How terrestrial exoplanets differ from Earth has so far mostly focused on planet size and orbital distance. In contrast, bulk planet composition has gained much less attention, even though it controls key physical properties of planetary interiors, and thus interior dynamics and long-term evolution. Bulk planet composition is related to core size as well as mantle chemistry and mineralogy. To better understand the variability of interior properties among terrestrial exoplanets, we attempt to constrain the range of bulk terrestrial exoplanet compositions.

To constrain the compositional range of terrestrial exoplanets, we use the compositional link between rocky planets and their host stars. At least in the Solar System, planetary building blocks (chondrites) correspond to the devolatized star (Sun) composition. Accordingly, we apply devolatilization to stellar compositions in the galactic neighbourhood (i.e., within 500 pc) according to the approach of Wang et al. [1]. These bulk compositions are then split into core and mantle reservoirs by considering interior oxygen fugacity during core formation equal to that of Earth.

We find compositional ranges of molar mantle Mg/Si-ratios from 0.9 to 2.0, core sizes between 18 and 35 wt%, and mantle molar MgO+FeO+SiO2 abundances between 88 and 94 mol%. We summarize our results by defining 20 end-member compositions that represent the full range of bulk terrestrial exoplanet compositions in the Solar neighbourhood. A Gibbs energy minimization algorithm, Perple_X, shows that these planets all have mantles dominated by Fe-Mg-Si minerals, such as olivine, pyroxene, bridgmanite and periclase. The relative abundances of these minerals control mantle viscosity, where Mg-rich minerals (periclase) are weaker than Si-rich minerals (olivine, bridgmanite). We continue by simulating mantle dynamics using a 2D geodynamic model. Most of our end-member planets have a lower mantle viscosity than Earth, and their mantles are more fertile than Earth's. Accordingly, we find that mantle cooling is more efficient than for Earth for most Earth-sized exoplanets in the solar neighborhood. Future work is needed to further

constrain the coupled interior-atmosphere evolution of Earth-like exoplanets, and how bulk planet composition affects it.

[1] Wang, H.S., Lineweaver, C.H., Ireland, T.R. (2019). The volatility trend of protosolar and terrestrial elemental abundances. Icarus, 328, 287-305