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Extrasolar Geochemistry: Predicting Rocky Exoplanet Mantle Mineralogy Using Stellar Abundance Data

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The atmospheric evolution and habitability of rocky planets are heavily influenced by their interior evolution. It is well-established that mantle chemistry controls mantle material properties, making planetary composition a crucial parameter in studying long-term evolution of planetary interiors and surfaces. The compositions of exoplanets are closely tied to elemental abundances of their host stars, which are readily available for a large number of stars. For rocky bodies in the Solar System, most elements exhibit depletion relative to the Sun, where the degree of depletion depends on the 50% condensation temperature of elements in the Solar nebula (e.g., [1]). While studies of rocky exoplanet compositions have considered the Earth-Sun element depletion trend [2], stellar composition can also affect the condensation temperature of an element, which further modifies the compositional relationship between a planet and its host star. Here, we study how element condensation temperatures depend on stellar abundances.

We present a series of equilibrium condensation sequences using the GGChem condensation model [3]. We simulate sequences for 1000 stars using abundances from the GALAH catalogue and statistically analyze how the 50% condensation temperature depends on stellar abundances. We provide parametrizations for the elements Fe, Ni, S, Mg, Si, Al, Ca, and Na, where we find that the condensation behavior of Fe and Ni depend solely on their own abundances, while other elements' condensation temperatures strongly correlate with stellar C/O ratio. Specifically, at C/O ratios greater than 1.0, Si becomes significantly more refractory, whereas all other elements become more volatile, consistent with existing literature. Notably, the transition from Solar-like condensation behavior to high-C/O condensation behavior varies, with some elements transitioning around C/O = 0.9 (Mg) and others at C/O = 1.04 (Si). Planets forming at C/O ratios between 0.9 and 1.0 will be particularly Mg-poor and Fe-rich. We apply these new parametrizations to stellar abundance data to simulate the range of rocky exoplanet compositions, and discuss potential variations in mantle mineralogy among rocky exoplanets.

[1] McDonough and Sun, 1995, Chemical Geology, 120.3-4, 223-253

[2] Spaargaren et al., 2023, the Astrophysical Journal, 948.1, 53

[3] Woitke et al., 2018, Astronomy and Astrophysics, 614, 1