From Planetesimal to Planet: How Does Stellar Composition Affect Exoplanet Composition?

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There is no direct method to measure the interior composition of exoplanets. In our Solar system, though, the Earth's refractory abundances of elements mirror Solar abundances to within ~10%, most notably Mg, Si, and Fe, allowing the adoption of Solar abundances as proxies for Earth's. Volatile elements, in contrast, make up an insignificant fraction of the Earth's composition and can be neglected when considering the first-order structure and mineralogical makeup of the planet. Oxygen, however, has a dual nature, refractory, condensing from the protoplanetary disk as silicates and oxides, and volatile, condensing as ices. 48% of the Earth by mole is oxygen, yet O/(Mg+Si+Fe) for the Sun is 460% of the equivalent ratio in the Earth. It is this ratio that controls the gross structure of the Earth: the relative proportions of the mantle and core. This discrepancy between stellar and planetary oxygen abundances requires then the modeling of the condensation sequence for extrasolar planetary systems in order to constrain the extent of oxidation of refractory phases within the system. From these calculations then we can model the interior structure, mineralogy and dynamic state of terrestrial exoplanets. Currently, however, all code for ascertaining these sequences are commercially available or closed-source. We present, then, the open-source Arbitrary Composition Condensation Sequence calculator (ArCCoS) and it to calculating the extent of oxidation of terrestrial exoplanets.

We demonstrate that a change in stellar Mg/Si directly affects the percentage of total oxygen in nebular refractory phases. We further find change in the molar abundance of either of these cations, Si is more efficient at removing oxygen from the disk. If this change in refractory oxygen is assumed to be a lower bound on the total oxygen budget from which terrestrial planets are constructed, this model provides a prediction for the relative size of the oxidized mantle and reduced core within an exoplanet that can be directly compared to observation. These results represent a direct comparison between stellar elemental abundance, planetesimal composition and possible planet mineralogy and structure, providing the foundation for understanding how special the Earth and our Solar System may be.