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Forming Mercury-analog planets in the solar neighborhood

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Rocky exoplanets with high core mass fraction (CMF) are broadly defined as Mercury-analog planets due to their high bulk densities. Mercury, in our solar system, serves as a benchmark due to its exceptionally high CMF of 0.7 [1]. Mercury however also has distinctive chemical attributes, with a mantle nearly free of Fe (0.17 wt.% [1]) and differentiated under an extremely reduced conditions (oxygen fugacity, fO_2: IW-3 to IW-6 with IW referring to iron-wüstite equilibrium; [2-3]), which results in a significant amount of light elements partitioning into its core [2]. In this study, we are interested in asking: what are the compositions and interior structures of Mercury-analog planets, how do they form, are they rare or common, are there multiple pathways to form a Mercury-analog planet?

We consider the elemental abundances of key rock forming elements (O, S, Na, Si, Mg, Fe, Ca and Al) from the host star in the solar neighborhood (< 200 parsec). We employ a devolatilization model based on elemental condensation in a steady protoplanetary disk that considers size and temperature distribution of the star to predict the compositions of hypothetical Mercury-analog planets. Crucially, the extent to which oxygen can condense into solid silicates during planetary formation significantly influences their core size, and compositions of both core and mantle. We found that only 5-7% of the stars may form Mercury-analog planets. Mercury-analog planets can have CMF spanning from 0.3 to 0.6, with bulk planet fO_2 varies between IW-2.5 to IW<-7. Their mantle typically has low Fe/Si ratio (< 0.1), while the core can be Si dominated (50 wt.% Si + ~ 50 wt.% Fe). These distinct compositions imply that Mercury-analog planets likely have different interior structures and may preserve unique atmospheric compositions. Our models are then used to classify whether the identified exoplanets may resemble Mercury-analog or not. Additionally, we highlight the uniqueness of Mercury within our solar system, suggesting a lateral event such as a giant impact or mantle evaporation may have stripped its mantle, contributing to its unusually high CMF.

[1] McDonough & Yoshizaki 2021
[2] Namur et al., 2016
[3] Cartier & Wood 2019