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Escape and fractionation of elements from planetary embryos

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Abstract

In the early evolution of planetary systems, protoplanets originate from the coagulation of dust and ice and initially reside embedded in the gas of the circumstellar disks. From isotope studies, it is expected that the Earth (and terrestrial planets) formed from pre-fractionated differentiated planetary embryos and a few percent carbonaceous chondrites. Additionally the importance of enstatite chondrites for the evolution of Earth can also be argued by isotope studies. Large planetesimals and planetary embryos are differentiated bodies with sizes of several hundred to a few thousand kilometers. Planetary embryos form protoplanets via mutual collisions, which can lead to the development of magma oceans. During their solidification, significant amounts of the mantles' volatile contents may be outgassed. We show that the resulting steam atmospheres can be lost efficiently via hydrodynamic escape that drag heavier elements like noble gases, K, Na, Si, Mg, Rb etc. into space so that they are also lost. Planetary embryos that are later involved in terrestrial planet formation can be drier than previously expected. We model the outgassing and subsequent hydrodynamic escape of steam atmospheres from such embryos, including the efficient outflow of H that drags along heavier species like O, CO2, CO, K, Na, Si, Mg, Rb etc., and noble gases (Ar, Ne) and their isotopes. The full range of possible EUV evolution tracks of a young solar-mass star is taken into account. We investigate the atmospheric/elemental escape from 0.5Mars-, Mars- and 1.5Mars-sized planetary embryos at different orbital distances and the fractionation of these planetary embryos. Finally, we discuss the implications of our findings in relation to elemental composition of the bulk silicate Earth composition.

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