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Oxygen Isotope Evolution in Dynamically Evolving Protoplanetary Disks

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Ca-, Al-rich inclusions with Sun-like ^{16}O-rich oxygen isotope compositions formed within the first several 10^5 years of the Solar System evolution, followed by formation of chondrules with Earth-like ^{16}O-poor oxygen isotope compositions. This transition in oxygen isotopes has been interpreted as a result of oxygen isotope exchange among dust, ^{16}O-poor H_2O, and ^{16}O-rich CO in the protosolar disk, particularly due to enrichment of H_2O [1]. We developed a numerical framework to simulate oxygen isotope exchange between amorphous silicate dust and disk gas (H_2O and CO) in a viscously evolving disk to investigate the spatial and temporal evolution of oxygen isotopes.

We developed a viscously evolving protoplanetary disk model that connects a steady accretion solution for the inner region with a self-similar solution for the outer region [e.g., 2]. The model tracks the transport of dust, H_2O, and CO as super-particles, where H_2O and CO behave as pebbles with Stokes numbers of 10^{-4}–10^{-2} outside their snowlines. Oxygen isotope exchange between amorphous silicate dust and H_2O or CO is modeled based on experimentally determined reaction kinetics [3, 4].

The oxygen isotope compositions of dust, H_2O, and CO inside effective exchange lines [5] become equal to each other, and the resulting composition is controlled by the degree of H_2O enrichment [1]. The onset timing of H_2O enrichment is determined by the crossing the H_2O snowline and the dust stagnation line, inside which dust accrete inward. The locations of these lines evolve with time in a viscously evolving disk.

The H_2O enrichment in the inner region is controlled by the Stokes number of H_2O pebbles; a larger Stokes number results in more H_2O enrichment. We found that a relatively compact and massive disk with the viscous parameter of 10^{-3} and the effective transport of mm-sized H_2O pebbles reproduce the oxygen isotope evolution in the inner Solar System over the first few million years.

[1] Yurimoto and Kuramoto (2004) *Science* 375, 1763. [2] Ida et al. (2026) *A&A* 591, A72. [3] Yamamoto et al. (2018) *ApJ* 865, 98. [4] Yamamoto et al. (2024) *GCA* 374, 93. [5] Ishizaki et al. (2023) *ApJ* 957, 47.