

Impacts of water supply from cosmic dust on the isotopic composition of the Martian and Venusian atmospheres

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The D/H ratios in the atmospheres of the Earth, Mars, and Venus are completely different; those of Mars and Venus are ~5 and >100 times higher than the terrestrial value, respectively. These isotopic features are thought to be indirect evidence of the abundant water that once existed on Mars and Venus, but the processes that led to such high D/H ratios are complex and not yet fully understood.

Atmospheric photochemical models are one of the most powerful tools when evaluating such isotopic enrichment quantitatively. Previous studies calculated deuterium profiles in the atmospheres of these planets. For example, Liang and Yung (2009) developed a photochemical model of the Venusian upper atmosphere to evaluate a photochemically induced isotopic fractionation of H₂O and HDO. A recent study by Cangi et al. (2023) provided an elaborate photochemical model of Mars to calculate the amount of escaping H and D and estimate the amount of water escaped into space. Their models, however, were unable to simultaneously explain both the observed isotopic profiles and the geological estimates of the amount of water that once existed. As these authors stated, some processes that are not incorporated in existing photochemical models should be considered.

In this study, we investigated the effect of water supply by ablation of cosmic dust on the isotopic composition of the atmospheres of Mars and Venus. Various observations have revealed that ~100 t/day of cosmic dust falls into the Earth's atmosphere, and such dust is similar to carbonaceous chondrites in composition, which contain ~10-20 wt% of water as hydrous minerals. If the water supply rate is comparable to (photo)chemical reaction rates in the atmospheres, cosmic dust ablation plays an important role in determining the isotopic compositions. We employed a 1-D photochemical model of Nakamura et al. (2023) to simulate atmospheric photochemistry, and standard chemical reactions are taken from Cangi et al. (2023) for Mars and Krasnopolsky (2012) for Venus. The supply rates of H₂O and HDO from cosmic dust are estimated from the observed accretion rate of dust, the amount of hydrous minerals, and the experimental values of D/H ratio in chondrites (Plane, 2012; Broadley et al., 2022). There is no previous study that estimated the vertical profiles of the water ablation rate in the atmospheres of Mars and Venus; therefore, we assume similar profiles to that of the Si ablation rate. Our preliminary result shows that the HDO/H₂O ratio significantly reduced in the Martian upper atmosphere, while that in the Venusian upper atmosphere slightly changed. These results imply that the isotopic composition of Mars is affected by cosmic dust ablation, and the estimate of the amount of escaped water from photochemical simulations should be modified. The result about Venus, on the other hand, suggests that the differences in isotopic distribution between observations and simulations cannot be explained even if the effect of cosmic dust ablation was included.

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