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The climate and redox state of early Mars: insights from isotopes

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Exploration missions have found the evidence of a warmer and wetter on Mars in the past. The small size of Mars and the absence of magnetic field allow atmospheric escape to remove the atmosphere and water. Because the atmospheric escape preferentially removes light species: hydrogen, this processes led to the secular oxidation of planetary surface. The mass-dependent nature also induce the isotopic fractionation: the preferential loss of light isotopes leaves heavy isotopes on the planet.
In order to understand how the amounts of atmosphere and surface water have evolved through time, we utilized isotopic compositions of hydrogen, carbon, nitrogen, and noble gases recorded in Martian meteorite and measured by exploration missions. We combined the data to a box model of the supply and loss of volatiles from/to the atmosphere and hydrosphere. The obtained constraints are then used in the atmospheric photochemistry model to simulate the evolution of the redox state.
Our model showed that Mars had a moderately dense atmosphere ($> \sim$0.5 bar) at 4 billion years ago and lost it after the period. In contrast, the loss of water predates that of atmosphere: about the half of initial water inventory has lost at 4 billion years ago. These results suggest that the ancient atmosphere oxidized through time. We discuss the possible evolution scenarios of the climate and redox state on Mars.