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Sluggish hydrodynamic escape of early Martian atmosphere with reduced chemical compositions

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Mars may have obtained a proto-atmosphere enriched in H_2, CH_4, and CO during accretion. Such a reduced proto-atmosphere would have been largely lost by hydrodynamic escape, but its flux is highly uncertain. To estimate the evolution of the proto-atmosphere of Mars correctly, an exact escape modeling including exact radiative balance and chemical processes is required partly because those reduced species and their photochemical products may act as an effective coolant that suppresses the escape of atmosphere. Here we develop a one-dimensional hydrodynamic escape model that includes radiative processes and photochemical processes for a multi-component atmosphere and apply to the reduced proto-atmosphere on Mars.

Under the enhanced XUV flux suggested for young Sun, the escape flux decreases by more than one order of magnitude with increasing the mixing fraction of CH_4 and CO from zero to > 10 % mainly because of the energy loss by radiative cooling by these infrared active chemical molecules. Concurrently, the mass fractionation between H_2 and other heavier species becomes to be enhanced. Given that the proto-Mars initially obtained > 10 bar of H_2 and carbon species equivalent to 1 bar of CO_2 was then left behind after the end of the hydrodynamic escape of H_2, the total amount of carbon species lost by hydrodynamic escape is estimated to be equivalent to 20 bar of CO_2 or more. Such a severe loss of carbon species may explain the paucity of CO_2 on Mars compared to Earth and Venus. If the proto-Mars obtained > 100 bar of H_2, the timescale for H_2 escape exceeds ~100 Myr. This implies that an atmosphere with reduced chemical compositions allowing the production of organic matter deposits may have been kept on early Mars traceable by geologic records.