Hydrodynamic escape of H_2-H_2O atmospheres on terrestrial planets orbiting pre-main sequence M dwarfs

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Terrestrial planets in the habitable zones around M dwarfs experience a long-term runaway greenhouse condition due to the stars' extended pre-main sequence phase. Accordingly, they might have lost most of their atmospheres including water vapor at high concentration by hydrodynamic escape induced by the strong stellar XUV irradiation. However, the atmospheric escape rates remain highly uncertain due to the uncertainty of the effect of the radiative cooling in the escape outflows. Here we carry out 1-D hydrodynamic escape simulations considering radiative processes and chemical processes for H_2-H_2O atmospheres derived from impact degassing and gravitational capture of nebular gas to estimate the atmospheric escape rates and the atmospheric evolution during the early runaway phase.

The atmospheric escape rate decreases with the basal H_2O/H_2 ratio due to the energy loss by the radiative cooling of H_2O and chemical products such as OH and H_3^+: the escape rate of H_2 becomes one order of magnitude smaller when the basal H_2O/H_2=0.1 than that of the pure hydrogen atmosphere. The timescale for H_2 escape exceeds the duration of the early runaway greenhouse condition depending on the initial atmospheric amount and composition, indicating that H_2 and H_2O could be left behind after the end of the runaway phase. Our results suggest that moderate and reduced environments with ocean could be formed on terrestrial planets around M dwarfs.

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