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Atmospheric formation and thermal evolution of a proto-Mars growing in the solar nebula

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It is widely accepted that Mars is a survivor of proto-planets formed by oligarchic growth i.e., the runaway accretion of planetesimals. Numerous planetesimals impacts onto the growing proto-Mars likely cause shock-melting, resulting into the early core formation as constrained by the chronology of Martian meteorites. Such impacts should also induce the degassing of H_2O and other molecular species from accreting materials, which contributes to atmosphere formation. Since the oligarchic growth proceeds within the solar nebula, a growing Mars probably acquired a proto-atmosphere consisting of the mixture of nebula gas component and degassed component. Such a hybrid-type proto-atmosphere may play important role in thermal balance and volatile partitioning between the planetary surface and interior. However, the structure and behavior of such atmosphere has been poorly investigated so far.

In this study, we build a one-dimensional radiative-convective (RT) equilibrium model for a hybrid-type proto-atmosphere assuming a compositional double layer structure. Here the upper layer is dominated by H_2-He continuing from the solar nebula and the lower one is dominated by degassed components enriched in H_2O. Radiative transfer is modeled, taking into account the absorptions by H_2, He and H_2O. RT equilibrium structures are obtained as a function of thermal luminosity that would be balanced with accretional heating rate and the amount of degassed component. The degassed component consists of H_2O and H_2 with molar ratio 1:5 in equilibrium with metal and silicate. The accretion time is taken 10^6-10^7 years.

For the pure H_2-He atmosphere, the surface temperature is kept lower than 700 K. Supply of degassed component increases the surface temperature that can exceed 1500 K given the mass of degassed component more than 1% of the Mars mass. If planetesimals contain enough proportions of H_2O and other heavy volatiles, growing Mars would have global magma ocean sustained by the blanketing effect of proto-atmosphere. This would promote core formation and transport of dissolved volatiles.