PPS21-16 Room:A02 Time:May 24 14:45-15:00

The thermal structure of the hybrid-type proto-atmosphere of Mars growing in the solar nebula

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According to meteorite chronology, Mars has reached the half of its present mass as within 3 Myr (Dauphas et al., 2011). Since this time scale is much shorter than the estimated lifetime of the solar nebula, the accretion of Mars mostly proceeded within the solar nebula. On the other hand, the energy released by planetesimal collision becomes large enough to induce degassing of the volatile compounds such as H_2O when the proto-Mars gets larger than lunar size (0.1 M_{Mars}). Therefore, growing Mars may have had a proto-atmosphere consist of nebula gas and degassed gas, which is referred as to hybrid-type proto-atmosphere.

In this study, we analyze the thermal structure of hybrid-type proto-atmosphere by building a 1D radiative-convective equilibrium model. Here we assume an atmosphere that consists of two layers: the upper one is dominated by the solar nebula components and the lower one is dominated by degassed components. These layers are unmixed because of their density gap and their boundary is referred as to compositional boundary. The higher the compositional boundary altitude, the larger the mass of degassed components. The degassed components are comprised of H_2, H_2O, CH_4 and CO. The mixing ratio of these molecular species is taken from Kuramoto (1997) that calculates thermochemical equilibrium among fluid, silicate melt and molten metallic iron. Radiative transfer is modeled by taking into account the absorptions by H_2, He, CH_4, CO and H_2O. The effect of H_2O condensation is incorporated for vertical compositional profile and the adiabatic lapse rate. The pressure and temperature of the solar nebula on Mars orbit are adopted from Kusaka et al. (1970). Radiative-Convective equilibrium structures are obtained as a function of accretional heating rate and the amount of degassed component. The accretion time is taken 1 - 6 Myr compatible with the chronology of Martian meteorites and the accretion rate is assumed to be constant.

We first study the dependence of the temperature structure on the mass of degassed component by changing the altitude of compositional boundary. For the pure nebula atmosphere, the surface temperature does not exceed 700 K (Hayashi et al., 1979). As the mass of degassed component increases, the surface temperature also increases. This is because both the mean molecular weight and mean absorption coefficient of degassed component are larger than of the solar nebula components. In our model setting, the surface temperature of Mars exceeds the melting point (1500K) at the final growth stage if the mass of degassed component is more than 1% of the Mars mass and the accretion time is within 6 Myr,

In addition, we analyzed the surface temperature of Mars at each growth stage (0.1 M_{Mars} - 1 M_{Mars}) by fixing the mass ratio of degassed atmosphere to the bulk of growing Mars. When the mass ratio is larger than about 1% or less than 0.001%, the surface temperature increases with the mass of proto-Mars. On the other hand, the mass ratio is between about 0.001 - 1 %, the surface temperature can sometimes decrease with increasing Mars mass. This behavior is likely related to switching the relative locations of compositional boundary and tropopause.