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The gas temperature in the dissipating solar nebula around protoplanets; effects on the formation of solar-type atmospheres

Akiko Sakamoto[1]; Yutaka Abe[2]

[1] none; [2] Earth Planetary Sci., Univ. Tokyo

It is considered that our solar system was formed from the proto-solar nebula. When protoplanets become as massive as the present mars, they attract the surrounding solar nebular gas and gain the solar-type atmospheres (Hayashi et al., 1979; Nakazawa et al., 1985). Mizuno et al. (1980; 1982) calculated the amounts of rare gases captured by the growing proto-Earth. They concluded that the nebular gas must be lost before the mass of the proto-Earth is less than about half of the present mass.

On the other hand, recent study indicates that thin nebular gas must remain in the inner solar system at the final stage of planetary formation. According to Kominami & Ida (2002), nebular gas with 10^(-4)~10^(-3) times of the minimum mass solar nebula (MMSN) model is necessary to damp the eccentricities of protoplanets to the present level (order of 0.01). This density of the nebular gas is much smaller than that of the MMSN, but it is still large enough to make massive solar-type atmosphere on an Earth-sized planet.

In order to resolve this problem, we examined the possibility that the gas temperature in a thin proto-solar nebula is much higher than that of the previous estimates. Previous studies adopted the gas density of the MMSN model and assumed that the gas temperature in the solar nebula was 225K near the Earth's orbit (e.g., Mizuno et al., 1980; 1982). However, at the final stage of planetary formation through giant impacts, the proto-solar nebular gas is dissipating and its density should have been lower than that of the MMSN model. Dumping of the eccentricity requires only 10^(-4)~10^(-3) times of MMSN model. In a thin gas, cooling efficiency is bad because of inefficient collision. Therefore, its temperature is expected to be much higher than that in the assumption of Mizuno et al. (1980; 1982). Increase of gas temperature results in increase of thermal energy of gas compared to the gravitational potential. Thus, it results in order of magnitude decrease of the amount of nebular gas attracted by planets.

We calculated the temperature of the solar nebular gas whose density became 10^(-4)~10^(-3) times that of the minimum mass solar nebula model. Our result shows that the gas temperature was much higher than 225K near the Earth's orbit. Therefore, it is expected that the amount of the nebular gas (i.e., the amounts of rare gases) captured by the proto-Earth was much smaller than that in the results of Mizuno et al. (1980; 1982). Thus, the problem of the rare gas abundance and eccentricity is likely reconciled.