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The possibility of the homogeneization of the isotopic ratio in the primordial solar nebula

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Introduction:

Star and planetary systems are formed through gravitational collapse of molecular cloud cores. Since molecular clouds consist of materials from various super novae and red giant stars, it is naturally considered that dust particles in molecular cloud cores have various isotopic ratios. On the other hand, it is known that solid materials in our solar system, especially materials of the Earth, moon, mars, and meteorites, have almost identical isotopic ratios. To homogenize isotopic ratios in solid materials, it seems that the material should be evaporated completely once, mixed well, and re-solidified. So, the homogeneous isotopic ratio in the current solar system suggests that our solar system experienced some massive evaporation events in its formation phase. However, it is not well understood which process can be responsible for such a high temperature event in the solar nebula.

Goal of this study:

We clarify if the homogenization of the isotopic ratio among all the solid materials in the solar nebula can be realized in the course of the formation and evolution of the solar nebula.

Model:

We suppose a molecular cloud core whose mass is one solar mass. The core is assumed to rotate rigidly and to consist of gas and dust particles. Dust particles have various isotopic ratios, but they are mechanically well mixed in the core.The collapse of the molecular cloud core, and the following formation and evolution of the solar nebula are modeled based on Cassen & Moosman (1981). Landing places of infalling materials from the core is estimated depending on the angular momentum. Turbulence is present in the solar nebula and the viscous torque due to the turbulence works. Also, the gravitational torque produced by the self-gravity of the solar nebula is taken into account (Nakamoto & Nakagawa 1995). The motion of dust particles relative to the gas is calculated using the turbulence diffusion model (Wherstedt & Gail 2002). The temperature of the solar nebula is obtained based on the balance between the viscous heating and the radiative cooling. The model parameters are the initial temperature and the angular velocity of the molecular cloud core.We assume that dust particles evaporate completely at the temperature of 2,000 K, and when the gas temperature becomes less than that, isotopically homogeneous dust particles are produced.

Results:

The temperature of the solar nebula becomes a decreasing function of the distance from the Sun. So, when the initial temperature of the core is high, and the initial rotation velocity of the core is low, the radius of the solar nebula becomes small and the fraction of isotopically homogeneous dust particles becomes high. For example, almost all the solid materials in the solar nebula becomes isotopically identical, when the initial temperature of the core is 15 K and the angular velocity is (2-3)x10^14 s^-1.

Discussion:

According to observations, angular velocities of molecular cloud cores are around from 10^-14 s^-1 to 10^-13 s^-1 (Goodman et al. 1993). So, it is implied that the molecular cloud core that formed our solar system might have a smaller angular velocity compared to typical values. This may be consistent with a fact that our Sun is a single star: it is shown that molecular cloud cores having higher angular momentum tend to form binary systems, while those having lower angular momentum tend to form single star (Matsumoto & Hanawa 2003).

Conclusions:

We investigated the formation and evolution of our solar nebula following the gravitational collapse of the molecular cloud using numerical simulations. And we found that isotopic ratio of solid materials in the solar nebula can be completely homogenized, if the radius of the solar nebula is small enough due to the high temperature or the low angular velocity of the initial molecular cloud core.