Large scale material transport in the protoplanetary disk and its relevance to the "planetary" oxygen isotopic composition

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Protoplanetary disk evolvess basically due to the change of the accretion rate with time, of which most significant conseqnece is the change of temperature as a function of the location within the disk and time. Despite most physical models and astrophysical bservaitons, meteoritic and planetary evidence strongly suggest the presence of high temperature stage at least in the early stage that resulted in isotomic homogenization of the inner solar system. Furtherore, the inner edge of the disk was faced to the proto-Sun for a long duration, where condensation /evaporation of planet-forming minerals should have occurred, and it is now well known that some of condensates were transported to the asteroid belt or even the comet regions. Oxygen isotope is one of the exceptions that retained isotopic heterogeneity in chondrites but approximate homegeneity in planets.

Large scale material transport was investigated by using the model by Ciesla (2011; ApJ 740) and the possibility of homogenization by oxygen isotopic exchange during drift of grains within the disk. The basics of the model is the radial advection and diffusion equation, where the stochastic diffusion term is introduced by the Monte Carlo method. The evolution of temperature and density radial profiles were described as a funciton of distance from the proto Sun, and therefore the trajectory of grains enables us to evaluate the thermal history. The disk is in a steady state, number of grains were 10000, oxygen isotope of dust formed in the inner edge is assumed to be -50 permils and ice from outside is +100 permils. We assume that T~1000K is the boundary when grains exchange oxygen isotopes with the ambient gas.

The calculation results show that the average position moves inward with time, and grains larger than cm in order fell quickly to the Sun, but smaller grains remain in the disk, although large fraction of the grains fell into the Sun in 10^6 years witht some grains experiencing T>1000K. If the viscosity of the disk is as small as a=0.0001, most grains remai after 10^6 years. The results suugest that it it impossible to change oxygen isotopic composition of all the dust grains in the inner disk, and therefore, oxygen isotopes homogenization took place at the very early stage and that was retained through the disk evolution.

Molybdenum Isotopic Compositions in Allende Chondrules

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Chondrules are primordial materials formed in the early Solar system. They have various characteristics of the texture and petrography as well as $\Delta^{17}O$ values that generally correlate with the classes of their host chondrites. It is argued that chondrules have formed in multiple reserviors separated in time and space in the early Solar System. This is also supported by variable $^{84}Sr/^{86}Sr$ ratios in chondrules from different chondrite groups [1]. However, there still remains unclear how individual chondrules have obtained the nucleosynthetic Sr isotope anomalies, nor is clear the linkage between isotope anomalies and the other characteristic properties of chondrules. In this study, we focus on Mo isotopes in chondrules to further constrain their formation processes. Molybdenum has seven isotopes produced by different nucleosynthetic processes (s-, r- and p-process). The Mo isotope anomalies recorded in bulk meteorites and CAIs would provide a clue to decode the material transport in the solar nebula [2], yet no Mo isotope data are available regarding chondrules.

Chondrules samples prepared by the freeze-thaw method. were dissolved using a mixture of HF-HNO_3 (3:1) in Teflon vessels at 180 °C. After drying at 120 °C, they were dissoleved in 0.5M HF and centrifuged for several hours. Mo was purified by a two-step anion exchange column chemistry employing HCl-HF-HNO_3 (modified from [3]]. Molybdenum isotopic compositions in the chondrules were measured by N-TIMS (TRITON *plus* at Tokyo Tech).

Allende chondrules are found to have Mo isotope anomalies (e.g., $\mu^{95}Mo/^{96}Mo$ = 94 ±27 ppm) that are resolvable from those in bulk Allende [4] and Allende CAIs [2]. The anomalies in Allende chondrules are also distinctive from bulk Murchison [2,4], which has an s-process deficit in Mo isotopes. Thus, it is conceivable that chondrite matrices, CAIs and chondrules are formed from separated, isotopically distinctive reservoirs at least for Allende. Our result is consistent with Sr isotope anomalies observed in Allende meteorite [1].

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