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Large scale transportation of materials and hcemical evolution in protoplanetary disc

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Introduction: Large scale material transport in protoplanetary disks has been proved by finding of the high temperature components in comet Wild 2, and it has been supported by physical consideration (e.g., Ciesla, 2009). Meteorites show a wide range of variation of oxygen isotopic compositions, which have been thought to be inherited from the precursor molecular cloud. However, recent high precision by ion microprobes has revealed that the variations are a mixture of isotopic mixing and mass-dependent isotopoic fractionation [e.g., Tenner et al., 2012].

Model: In order to understand material transport and oxygen isotopic characteristics recorded in meteorites in a protoplanetary disk, we have developed a model that describes mixing of two components, one transporting outward from the inner edge and one transporting inward by accretion of a protoplanetary disk with different oxygen isotopic compositions. We assume that the proto-sun had 16O-rich composition as suggested by the solar wind component captured by the Genesis mission, which is represented by refracotry inclusions and forsterite grains in primitive chondrites. The planetary composition is represented by the Earth with slight deviation as Mars and asteroids. The materials from outer region were assumed to have oxygen isotopically heavy composition, which we tentatively assume to be that observed in tmagnetite in a unique carbonaceous chondrite.

The model investigates isotopic trajectory of solid materials condensed at high temperature region with proto-Sun composition, which changed the composition by isotopic exchange in gas with heavy oxygen isotope composition. The solid materials cools exponentially with time. The system has the composition of the solar abundance elemental rations except for H2O as a source of heavy oxygen isotope in gas; isotopic exchange is temperature dependent; material transport flux is a steady state. The model contains two free parameters; one is cooling rate and the other is isotopic mixing rate.

Results and Discussions: The solids become isotopically heavier with time due to isotopic exchange, and the time of the increase is shorter and the final composition becomes heavier when the mixing rate is large. The time of the increase of the heavy isotope becomes later and the final composition becomes isotopically lighter with decreasing mixing rate. Considering that the planetary composition of oxygen isotopes is delta18O=zero by definition, the most plausible mixing rate is obtained. We have confirmed that the mixing lines on the three oxy-gen isotopic plot are straight for both solids and gas, which means that the solid changed its composition from -50 to 0 permil and that the gas from +200 to 0 permil.

A plausible range of the mixing rate was obtained for a range of cooling rates. The mixing ratio of solids with light oxygen and gas with heavy oxygen and cooling rate are linearly related in logarithmic plots. In other words, more abundant low temperature component with heavy oxygen is required if the solid materials cool rapidly. The model results are converted to the real scale for forsterite grains condensing in light oxygen gas, which moves outward, cools, and exchanges oxygen isotopes with ambient gas with heavy composition. Cooling rate of the model corresponds to advection or diffusion rate at the midplane and the mixing rate corresponds to the ratio of inward flux of isotopically heavy water ice to outward flux of high temperature condensates with light oxygen isotopes. Larger values of cooling rate and mixing rate may be realized at the early stage of disk evolution.

In summary, planetary oxygen isotopes were achieved through the evolution of the disk due to larger inward and outward transportation of materials and ice at the early stage and smaller transportation at the later stage.

Keywords: protoplanetary disc, solid materials, transportation, oxygen isotope