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The oxygen isotope anomaly in the solar system and the chemistry in molecular clouds

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We review the heterogeneity in O isotope compositions in the solar system and its possible relationships with chemical processes within a parent molecular cloud. Then significance of ALMA observations to understand the origin of solar system materials is discussed.

1. Anomalies in O isotope compositions in the solar system

The varieties in solid materials in the solar system have been clarified from the analysis of meteorites. In spite of the sampling coverage limited to the inner solar system, the meteorites exhibit significant variations in elemental composition and degree of metamorphism. However, most of major elements contained in these meteorites have uniform isotope compositions.

The exception to such uniformity in isotope composition is O. O has three stable isotopes of mass numbers from 16 to 18. Its isotope composition is expressed in terms of abundance ratios 17O/16O and 18O/16O, which can change through the processes of evaporation, condensation, chemical reactions and so on. In usual cases the percentage of change in 18O/16O ratio is nearly the twice of that in 17O/16O ratio depending on the mass difference between each isotope pairs. However, heterogeneities in O isotope composition in meteorites deviate from this rule. Refractory mineral grains in primitive meteorites are found to have the largest deviations, reaching several percents from the standard isotope ratios (values for standard mean ocean water). Even when we compare bulk meteorite compositions, variation in O isotope compositions is identified over several per mils.

The origin of such O isotope heterogeneity has been an enigma in the solar system study so far. The interpretation assuming multiple reservoirs produced by different nucleosynthesis events cannot explain why the other elements show uniform isotope compositions. Some gaseous reactions have been found to fractionate the O isotope independent of the isotope mass difference, but such reactions seem difficult to occur in the solar nebula.

2. Connection with molecular cloud chemistry

The O isotope composition heterogeneity in the solar system may be originated from molecular cloud chemistry. CO is the most abundant O-bearing gas species within molecular clouds. Recent radio observations reveal that C18O has different distribution pattern from that of C16O in diffuse molecular clouds. This is interpreted by the self UV shielding effect of C16O. In a molecular cloud, predissociation by line UV absorption is the major process of CO dissociation. Since C16O is abundant, it dissociates only near the skin of cloud core, whereas tenuous C18O, which has shifted absorption lines owing to the difference of rotation energy levels, can dissociate even in inner region, resulting into the distribution pattern difference.

Within the inner region of a molecular cloud core, therefore, CO molecules bearing 17O and 18O are preferentially dissociated into atoms. Subsequently, atomic O is converted into H2O ice on dust grains. Thus, production of 16-O poor ice and 16-enriched CO gas molecules likely proceeds in a molecular cloud. In the solar nebula, the mixing ratio of gas and dust varies both spatially and temporarily because of their relative motion. Mineral grains may acquire 16O-rich or -depleted isotope compositions in nebular gases with various degree of contamination of H2O ice component.

3. Test by ALMA observation

Mapping observations of isotope compositions of gas species in molecular clouds under various evolutionary stages is useful to understand the isotope fractionation processes in molecular clouds. The problem of heterogeneity in O isotope composition is equivalent with that why the most of other elements have uniform isotope compositions. To understand this, we have to know the processes of fractionation as well as mixing in molecular cloud. ALMA observations may provide important clues to understand the processes of fractionation and mixing in molecular clouds.