

# Calcium and Ti isotopic anomalies of refractory inclusions in carbonaceous chondrites

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Refractory inclusions whose compositions are rich in refractory elements (e.g. Ca and Al) are found in primitive chondrites. It is considered that they formed by high temperature processes that occurred in the early solar nebula. Refractory inclusions have some characteristic isotopic compositions such as the O isotopic anomaly and the  $^{26}\text{Mg}$ -excess that is caused by a decay of  $^{26}\text{Al}$ . Furthermore, it is known that some refractory inclusions have mass-independent isotopic anomalies in  $^{48}\text{Ca}$  and  $^{50}\text{Ti}$ , which are the most neutron-rich isotopes of Ca and Ti. These isotopic anomalies are considered as the evidence for the existence of isotopic heterogeneity in the early solar nebula.

Isotopic anomalies observed in refractory inclusions are considered as important clues to understand the origin of precursor materials and their formation processes in the early solar nebula. Hence, it is important to understand isotopic characteristics of refractory inclusions. It was previously pointed out that refractory inclusions with large isotopic anomalies in  $^{48}\text{Ca}$  and  $^{50}\text{Ti}$  tended to show a small initial  $^{26}\text{Al}/^{27}\text{Al}$  ratio. However, details of the characteristics of isotopic anomalies in  $^{48}\text{Ca}$  and  $^{50}\text{Ti}$  are not well known. The correlation between isotopic anomalies in  $^{48}\text{Ca}$  and  $^{50}\text{Ti}$  and the O isotopic anomaly is not well known, also. The aim of this work is to clarify the correlation among isotopic anomalies of different elements. In this work, O, Mg, Ca and Ti isotopes of refractory inclusions from Murchison (CM2) and Kainsaz (CO3) were measured with an ion microprobe at the University of Tokyo. The correlations of isotopic anomalies of refractory inclusions are discussed based on newly obtained data. Isotopic data of previous works are also included.

Refractory inclusions that have large isotopic anomalies of  $^{48}\text{Ca}$  and  $^{50}\text{Ti}$  (larger than 10 permil) show small initial  $^{26}\text{Al}/^{27}\text{Al}$  ratios (less than  $1.0 \times 10^{-5}$ ). This is consistent with results of previous works and this suggests that isotopic anomalies of  $^{48}\text{Ca}$  and  $^{50}\text{Ti}$  and the  $^{26}\text{Al}$  come from different precursors. Isotopic anomalies of  $^{48}\text{Ca}$  and  $^{50}\text{Ti}$  tend to show a linear correlation. Calcium and Ti isotopic compositions of all measured inclusions, which have various elemental Ca/Ti ratios, are distributed along this linear trend. This cannot be simply interpreted as a mixing trend between two different components such as solar material and presolar grains. This linear trend presumably suggests the macro-scale isotopic heterogeneity in the early solar nebula.

No significant correlation between the O isotopic anomaly and isotopic anomalies of  $^{48}\text{Ca}$  and  $^{50}\text{Ti}$  is observed. Oxygen isotopic compositions of refractory inclusions that have significant Ca and Ti isotopic anomalies are similar to those of normal refractory inclusions that do not have significant Ca and Ti isotopic anomalies.