

## FURTHER (PETROGRAPHIC) EVIDENCE THAT CV CAIS HAD A PRESOLAR ORIGIN

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**Introduction:** Isotopic compositions of several elements in CAIs are so different from those in the chondrite groups and in the Earth Moon and Mars that it seems impossible to devise a scenario that allows formation of CAIs from any of these materials; the simplest explanation seems to be that they formed in the nebula around another star, perhaps one formed in the same large ( $\sim 10^3$  stars) protostar cluster as the Sun [1]. Time scales for mixing molecular clouds are too long to expect all stars in the cluster to have a uniform composition. If this formation scenario is correct, it has strong implications for solar system chronology and the cosmochemical formation of the meteorites and inner planets.

**Isotopic evidence.** As shown in Fig. 1, isotopic compositions of elements that record non-mass-dependent fractionations (e.g., O, Cr, Ti) are so different in CAIs than those in carbonaceous, ordinary and enstatite chondrites that it is not possible for simple fractionation processes to produce CAIs from chondritic starting compositions. Note that evaporation should make O have a heavier composition whereas it is lighter in CAIs.

**Petrographic approach:** We have focused our petrographic considerations on the coarse-grained type-B CAIs; we assume that all 16-O-rich CAIs originated under similar conditions and that the differences among the different types mainly reflect differences in physical conditions related to the details of local conditions.

The type-B CAI formed igneously, perhaps by the evaporation of precursors that were chondrite-like in terms of their mix of minerals. Because isotopes of elements such as Mg record isotopic compositions similar to those of chondrites we can be sure that fractional distillation did not occur. Thus, the melting and evaporation must have occurred rapidly, with too little time to allow the mixing of the residual liquid while the process was occurring. Although some workers suggest that CAIs formed by condensaton, equilibrium condensation cannot produce liquids at plausible nebular pressures [3].

**Late arrival of CAIs at the CV formation location:** Many (about 50% of) CV chondrules are surrounded by igneous rims, and many have surfaces made irregular due to collisions [2]. These show that energetic processes were continuing throughout the chondrule forming period. In contrast, type-B CAIs do not host igneous rims, and most show relatively intact surfaces. This is strong evidence that these were the last materials added to the CV region before planetesimal formation, and is consistent with the conclusion that these were only accreted to the solar nebula very late. This strongly supports the idea that they are foreign materials arriving from another stellar system.

**Conclusions: Chaotic accretion of the solar nebula:** As the number of isotopic studies of elements such as Cr and Ti that show non-mass dependent fractions (i.e., in  $\epsilon^{54}\text{Cr}$  and  $\epsilon^{50}\text{Ti}$ ) increases it becomes increasingly clear that the solar nebula was never well mixed, and that it continued to accrete throughout the period within which chondrites were forming. We have known for decades that tiny presolar grains can have isotopic compositions unlike those in the common elements in chondrites. It simplifies many aspects of planetary formation if CAIs are large presolar grains which obtained their compositions in another stellar system.

**References:** [1] Wasson J. T. (2017) *Meteoritics Planet. Sci* Santa Fe abstract,. [2] Rubin A. E. *Geochim. Cosmochim. Acta* 48, 1779 [3] Grossman L. and Clark S. P. (1973) *Geochim. Cosmochim. Acta* 37, 635.

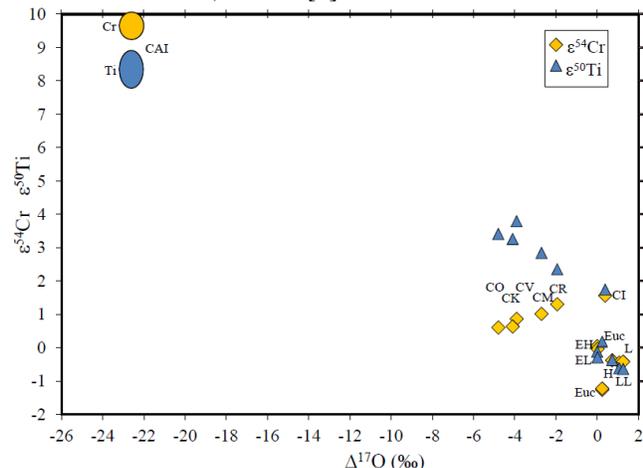


Fig. 1 Distribution of non-mass dependent  $\Delta^{17}\text{O}$ ,  $\epsilon^{54}\text{C}$  and  $\epsilon^{50}\text{Ti}$ .