Linking molecular cloud collapse with formation of refractory inclusions

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Our understanding of the stellar formation process and, specifically, the evolution of the circumstellar disk that became the Solar System, relies heavily on numerical models and analogs from nascent stellar systems. Details about both the composition of material added during stellar accretion and the timescale of this process are not well constrained, primarily due to a perceived lack of physical samples. Candidates for such samples are the Solar System's earliest dated objects, calcium-aluminum-rich inclusions (CAIs). However, to this point, the temporal relationship and compositional link between accretion of material from the molecular cloud that built the Solar System and formation of its first solids remain speculative.

In this work, we shed light on the Solar System's formation period by studying multiple isotopic systems in a wide variety of CAI types, revealing the nucleosynthetic character of the Solar System's earliest dated solids. For the Mo isotope system in particular—a system that can fully distinguish nucleosynthetic processes—we find that CAIs record the full range of *r*-process variability known to exist in the Solar System, far larger than any variability seen among or between bulk meteoritic materials in the non-carbonaceous (NC) or carbonaceous (CC) reservoirs. Interestingly, CAIs that have a full complement of REEs (*i.e.*, chiefly igneous CAIs with flat REE/CI patterns) in general exhibit relative enrichments in isotopes created by the *r*-process. More primitive CAIs that lack an ultra-refractory component (*i.e.*, chiefly fine-grained CAIs that have group-II REE patterns) exhibit *r*-process signatures more similar to bulk CC and NC meteorites.

CAIs, regardless of their type, are generally thought to have formed in a geologically short window of time, likely less than 200,000 years [*e.g.* 1-4]. As such, our new data show that during this window of time the CAI-forming process captured the evolving isotopic character of the infalling material that built the Solar System. This work, therefore, directly links CAI-formation and molecular cloud input to the forming disk, thereby providing critical information about the dynamics of the nascent Solar System and its early evolution.

[1] Bizzarro et al. (2004) *Nature* **431**. [2] Jacobsen et al. (2008) *EPSL* **272**. [3] MacPherson et al. (2012) *EPSL* **331-332**. [4] Kawasaki et al. (2019) *EPSL* **511**.