COSMOLOCATION OF THE SOLAR SYSTEM'S EARLIEST DATED SOLIDS

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As calcium-aluminum-rich inclusions (CAIs) are the oldest dated materials in the Solar System, identifying their formation location is essential for understanding early Solar System dynamics and evolution. Based on the specialized mineralogy, unique isotopic compositions, and inferred initial abundances of certain short-lived radionuclides, it is known that CAI-formation must have occurred under specific environmental conditions. To this point, there has been general agreement that such conditions were only present near the young Sun (<0.1 AU), and as such, CAIs are thought to have formed in this region [1]. Here we challenge the prevailing view by providing isotopic evidence relating CAI formation to a region beyond the orbit of Jupiter.

Recent work employing nucleosynthetic signatures of meteoritic material has shown that the Solar System is divided into non-carbonaceous (NC) and carbonaceous (CC) reservoirs, representing material that formed inside and outside the orbit of Jupiter, respectively [2-4]. The Mo isotope system has proven to be especially useful in "cosmolocation" studies, since the $^{95}Mo/^{94}Mo$ ratio of Solar System materials can readily distinguish between inner or outer Solar System reservoirs. Whereas both reservoirs are defined by notable depletions in *s*-process material relative to Earth, the outer Solar System has a marked enrichment in *r*-process isotopes [*e.g.* 3]. By investigating the Mo isotopic signatures of CAIs, we find that CAIs are genetically linked to the CC reservoir, providing isotopic evidence that CAIs formed in a region outside the orbit of Jupiter.

Furthermore, we show that the environmental conditions mandated by CAI mineralogy, namely temperatures >1700K, can be produced during formation of Jupiter's core. Calculations show that rapid pebble accretion of a proto-Jupiter core will lead to vaporization of solids and dispersal of this vaporized material to the protoplanetary disk beyond [5], potentially consistent with the hypothesized origins of CAIs. While important challenges remain (*e.g.* ^{10}Be abundances in CAIs), CAI formation in the outer Solar System solves the long-standing and perplexing observation that CAIs are vastly more abundant in outer Solar System objects (*i.e.*, carbonaceous chondrites) than objects of the inner Solar System.

References: [1] Wood J.A. 2004. *GCA, 68*, 4007. [2] Warren P.H. 2011. *EPSL, 311*, 93. [3] Budde G. et al. 2016. *EPSL, 454*, 293. [4] Kruijer T.S. et al. 2017. *PNAS, 114*, 6712. [5] Alibert Y. 2017. *Astron. Astrophys., 606*, 69.