RESOLUTION OF THE CAI STORAGE PROBLEM AND THE TIME AND PLACE OF FORMATION OF MOST METEORITE PARENT BODIES

S.J. DESCH[1], A. KALYAAN[1], AND C.M. O'D. ALEXANDER[2]
[1]ARIZONA STATE UNIVERSITY (STEVE.DESCH@ASU.EDU)
[2]DEPARTMENT OF TERRESTRIAL MAGNETISM, CARNEGIE INSTITUTION OF WASHINGTON

Introduction: Calcium-rich, aluminum-rich inclusions (CAIs) are the first objects formed in the solar nebula. They are meteoritic inclusions up to cm in size that contain abundant refractory lithophile elements (Ca, Al, Ti, etc.) and minerals that condense at high temperatures (> 1400 K). They appear to have formed close to the Sun, and their presence in chondrites is surprising, as they are predicted to spiral in the Sun by aerodynamic drag on < Myr timescales [1]. CAIs are rare in ordinary and enstatite chondrites but are commonly found in carbonaceous chondrites, even though they formed later (2.5 – 4 Myr after CAIs), and farther from the Sun (based on their volatile content). This paradox is the CAI storage problem.

Model: To explain this paradox we have developed a model of the formation and transport of CAIs in the Sun's protoplanetary disk [2]. We build on a 1-D alpha disk model with proscribed turbulence parameter alpha. Based on evidence of two isotopic reservoirs in the solar system [3], we include the formation of Jupiter's ~30 M_E core at 3 AU at 0.6 Myr. This creates a pressure maximum beyond Jupiter in which CAIs are trapped. We hypothesize carbonaceous chondrites form there. With this model, the abundances of CAIs and refractory lithophiles can be used to determine the time and place at which most meteorite parent bodies accreted. These times and places match radiometric constraints on their formation time, and are consistent with other constraints on their formation.

Discussion: This modeling provides insights into meteorites and the protoplanetary disk, as follows. CI chondrites must be depleted in refractories relative to the Sun; we predict by 9% =0.04 dex. Migration of meteorite parent bodies was limited; asteroids like 4 Vesta and maybe 6 Hebe seem to have formed in place. Planet formation was extremely rapid; most planetary embryos form in 1-2 Myr. The disk must have been subject to low levels of turbulence ($\alpha \sim 10^{-5} - 10^{-4}$) characteristic of hydrodynamic instabilities, not the magnetorotational instability. These models show the power of meteoritic data to constrain disk processes.

References: [1] Weidenschilling, S.J. (1977) *MNRAS* 180, 57-70. [2] Desch, S.J., Kalyaan, A., and Alexander, C.M. O'D., *Ap.J.*, in revision. [3] Kruijer, T.S., Burkhardt, C., Budde, G. and Kleine, T. (2017) *PNAS* 114, 6712-6716.