What a Mess! Mixing it Up in the Solar Nebula

FRED J. CIESLA[1] & SEBASTIAAN KRIJT[1]

[1]Department of the Geophysical Sciences, The University of Chicago, 5734 South Ellis Avenue, Chicago IL 60637

Over the last decade, many mechanisms have been proposed to explain the inferred large-scale radial transport that occurred in protoplanetary disks [e.g. 1-4]. Much of this was motivated by the results of the Stardust mission, which collected CAI-like and crystalline silicate grains from Comet Wild 2 [5]. As these materials are believed to record high temperature environments in our solar nebula and mhave isotopic properties that match similar grains in chondritic meteorites, this was interpretted as evidence for the processing of planetary materials near the Sun and subsequent transport to the outer solar nebula where comets would form. These models generally imply that the nebula would become more homogenized over time.

Recent observations, however, suggest that isotopic heterogeneities were preserved in the solar nebula, reflected in differences between carbonaceous and non-carbonaceous chondrites [e.g. 6,7], with this possibly being extended to differentiated meteorite parent bodies [e.g. 8]. These findings appear to be at odds with the mechanisms that had been invoked to explain the observations of the Stardust mission, and have led us to question the origin of the high temperature materials found in primitive bodies and the extent to which radial mixing took place in the solar nebula.

We are currently investigating whether such heterogeneities may be preserved within the context of the different transport mechanisms that have been proposed. We have recently reported on how mixing/transport from the disk midplane to the disk surface is less efficient than previously believed, possibly allowing for spatial gradients in dust properties to be preserved for extended periods of time [9]. We will discuss our findings and the implications for understanding the timing and manner by which materials were transported in the solar nebula.

References: [1] Ciesla F. (2007) *Science* 318: 613-615. [2] Boss A. (2008) *Earth Planet. Sci. Let.* 268:102-109. [3] Moudens A. et al. (2011) *Astron. & Astrophys.* 531:#A106. [4] Salmeron R. and Ireland T. (2012) *Meteorit. Planet. Sci.* 47:1922-1940. [5] Brownlee D. et al. (2006) *Science* 314:1711-1716. [6] Warren P. *Earth Planet. Sci. Let.* 311:93-100. [7] van Kooten E. et al. (2016) *Proc. Nat. Acad. Sci.* 113:2011-2016. [8] Kruijer et al. (2017) *48th Lunar Planet. Sci. Conf.* #1386. [9] Krijt S. and F. Ciesla (2016) *Astrophys. J.* 822:#111.