# WERE CHONDRULES MADE BY THE 'SPLASHING' OF MOLTEN PLANETESIMALS?

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**Introduction:** We have argued that many chondrules formed in dense impact plumes created by low-speed collisions between substantially molten planetesimals heated by $^{26}$Al [1]. Studies of thermal histories of particles in impact plumes lend support to such a 'splashing model' [2]. Here we discuss recent arguments against it.

**Chondrule ages:** Chondrules are mostly ~ 2 Myr younger than CAIs, consistent with the calculated duration of $^{26}$Al-induced planetesimal meltdown. Connelly et al. [3] claim that chondrules they found with Pb-Pb ages similar to CAIs preclude an origin by splashing. We disagree. The earliest meltdown (and splashing) could have been ~ 0.3 Myr after CAIs, within error of [3]'s Pb-Pb ages. Most older chondrules, incidentally, may have been destroyed following accretion to planetesimals that melted.

**Complementarity:** In carbonaceous chondrites the matrix typically has higher Fe/Mg and Si/Mg than the bulk meteorite (which is close to solar); chondrules have correspondingly lower ratios. Palme et al. [4] claim that this 'complementarity' precludes the splashing model because it requires the dispersal and oxidation of molten metal core(s). We believe that, regardless of the fate of metal, complementarity arises because Fe and Si will evaporate from hot chondrule droplets, even when formed by splashing, and end up as condensates in matrix dust.

**Relict grains:** These are xenocrysts in porphyritic chondrules, typically Mg- and $^{16}$O-rich, distinct from the otherwise uniform phenocrysts present. Nagashima et al. [5] claim they rule out splashing because, like many others, they regard them as unmelted relics from precursor dust clumps. We suggest instead that they are $^{16}$O-rich dust grains from the cold planetesimal regolith(s), or from the nebula, that were entrained in the plume, and became engulfed and variably digested by the liquid droplets, spreading oxygen isotopic compositions along mixing lines.

**Primitive chemistry:** Johnson et al. [6] proposed that chondrules result from jetting due to hypervelocity impacts on bodies with a primitive chondritic outer layer. They doubt low-velocity splashing, suggesting that 'ejection of previously molten and differentiated material would produce chemically unfractionated chondrules'. We disagree because with total internal meltdown, chondrules would, in fact, have primitive compositions.

**Initial $^{26}$Al/$^{27}$Al:** Schiller et al. [7], while not specifically discussing the splashing model, raise an issue that threatens its viability. They argue from Pb-Pb and Al-Mg ages of angrites that $^{26}$Al/$^{27}$Al was only $1.3 \times 10^{-5}$ at the start of the solar system in the region where chondrules were produced and planetesimals accreted. If so, total meltdown and splashing would only be possible, if at all, > 3 Myr after CAIs, after most chondrules were made, and chondrules produced then would have negligible $^{26}$Al. However, inconsistencies between other Pb-Pb and Al-Mg age intervals [8] ensure that the initial $^{26}$Al/$^{27}$Al remains uncertain.

**References:** [1] Sanders I. S. and Scott E. R. D. 2012. *MAPS* 47:2170-2192. [2] Dullemond C. P. 2014. *ApJ* 794:91 (12pp). [3] Connelly J. N. et al. 2012. *Science* 338: 651-655. [4] Palme H. et al. 2015. *EPSL* 411:11-19. [5] Nagashima K. et al. 2015. *GCA* 151:49-67. [6] Johnson B. C. et al. 2015. *Nature* 517:339-341. [7] Schiller M. et al. 2015. *EPSL* 420:45-54. [8] Koefoed P. et al. 2015. 46th LPSC abstract #1842.