EARLY PLANETESIMAL SPLASHING: RECONCILING CHONDRULE FORMATION WITH DISK EVOLUTION.
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Disk evolution and chondrules: Historically it has often been tacitly supposed (e.g. [1]) that the protoplanetary disk evolved through four sequential stages: (1) production of CAIs and chondrules by the rapid (flash) melting of clumps of dust; (2) accretion of primitive planetesimals; (3) metamorphism and melting of those planetesimals; (4) collisional break-up of planetesimals and their aggregation into planets. However, this view of an orderly progression of events is now known to be wrong because, in particular, tungsten isotopic evidence shows that the parent bodies of iron meteorites had already accreted and melted some 2 Myr before most chondrules were formed [2].

Instead, in a new conceptual framework for the disk, many researchers now recognize that primitive dust was so radioactive with short-lived ^{26}Al that planetesimals which accreted during the first 1.5 million years, and which were more than about 30 km in radius, suffered total internal meltdown below a thin crust [3]. While molten, these planetesimals would readily have produced copious volumes of incandescent chondrule spray on disruption by close mutual encounter or impact, even at a low velocity. The resulting chondrules would have been preserved only if they accreted to chondritic bodies later than about 1.5 Myr, i.e. after the power of ^{26}Al heating had become too weak to induce further melting. Thus chondritic meteorites, far from being the earliest, turn out to be amongst the latest materials to have accreted.

Not only does the process of molten planetesimal splashing account for the observed 2 Myr ages of chondrules, but it also provides a clear explanation for many other features of chondrules, as reviewed in [4]. The features include rare cm-sized chondrules (hard to explain by flash melting), primitive chemistry of chondrules (reflecting near-total melting), the high volume percentage of chondrules (efficient production), and cooling over a matter of hours, from a near-liquidus starting temperature.

Sodium retention: Recently reported levels of sodium in olivine crystals in chondrules imply enormously high concentrations of droplets to saturate the gas and prevent evaporative loss of Na [5]. This observation is easily reconciled with planetesimal splashing, but not with other chondrule-forming models.

Chondrules from dust clumps? Despite current knowledge that chondrules formed 2 Myr after the first planetesimals, their interpretation as flash-melted dust balls (as envisaged in the conventional pre-planetesimal first stage of the disk) still persists in many quarters. On close scrutiny there is little evidence that chondrules began as dust clumps. Actual dust clumps, called 'matrix lumps' in chondrites, may be fragments of the sintered outer parts of colliding planetesimals. Relict grains in chondrules could be dust grains in the post-impact plume that were captured and engulfed by the molten droplets. 'Rapid heating' is commonly inferred because of the need to conserve volatiles, but the heating environment is unconstrained. Only the cooling cycle of chondrules is constrained. The only well understood heating process is radioactive decay within planetesimals.

References: [1] McSween H. Y. 1999. *Meteorites and their Parent Planets*. Cambridge. [2] Burkhardt C. et al. 2008. *GCA* 72:6177-6197. [3] Hevey P. J. and Sanders I. S. 2006. M&PS 41:95-106. [4] Sanders I. S. and Taylor G. J. 2005. *ASP Conference Series* 341:915-932. [5] Alexander C. M. O'D. et al. 2008. *Science* 320, 1617-1619.