A New Mechanism for Chondrule Formation: Radiative Heating by Hot Planetesimals.

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Introduction: A decade ago, Ciesla [1] described the many known features of chondrules that must be explained by any succesful theory of their formation. He also reviewed theories of that time, categorizing them as *planetary* and *nebular*. Collisions between planetesimals create chondrules in planetary hypotheses, while in nebular hypotheses they form within a (gaseous) disk. Despite decades of intense effort and some spectacular recent advances it remains fair to say that community opinion has not yet coalesced around either a planetary or nebular model for chondrule formation. Some authors continue to regard the formation of chondrules as "the major unresolved question in cosmochemistry" [2].

Our Proposal: We propose that chondrules are formed by radiative heating of pre-existing clumps of solids in the vicinity of planetesimals with incandescent lava at their surfaces. Our proposal, therefore, contains elements of both planetary and nebular mechanisms; it is, perhaps best described as a nebular theory without the gas. We propose that the pre-chondrule dust blebs are heated directly by radiation from the hot planetesimals and that no nebular gas is required to mediate the process. This is consistent with the the inference from Na_2O measurements [3] that chondrules form in regions of extremely high solids density.

Analysis: We show that our model accounts for the inferred peak temperatures and cooling rates of 100-1000 K/hr in a very natural manner. Dust aggregates of the required density passing within ~1.5 planetesimal radii should form chondrules with dominantly porphyritic textures, consistent with what is found in chondritic meteorites. The planetesimals can be of any size large enough to fully melt (10-100 km). The heat source is ^{26}Al, incubated to the required temperatures (~2100 K) within planetesimals. That takes ~1 Myr, accounting for the age gap between the CAIs and the bulk of the chondrules.

Results: Our model accounts for the observed cooling rates and predicts symmetric heating rates. It meets the severe constraints of complementarity [2] since it has a local heat source acting on a reservoir of bulk solar composition. In our scenario it is likely that the meteorites themselves form in the gravitational wakes of hot planetesimals from the just-formed chondrules and hot matrix. Our model explains the age gap between CAIs and chondrules as the ^{26}Al incubation time and the termination of the chondrule formation era as the loss of power in the source after several half-lives. It predicts strong temperature gradients and, probably, oxygen fugacity gradients, within the chondrule formation zone owing to the high solids density and resultant opacity of the heated objects. It accounts for the high volume fraction of chondrules within many chondritic meteorites by linking the heating event that formed the chondrules to the heating event that formed the meteorite. Chondrule formation experiments should be able to test whether the rather highly constrained and symmetric heating and cooling curves predicted by this model are compatible with features observed in nature.

References: [1] Ciesla F. J. 2005. in *Chondrites and the Protoplanetary Disk*, ASP Conf. Series 341:811. [2] Palme H. et al. 2015. *Earth and Planetary Science Letters* 411:11. [3] Alexander C. M. et al. 2008. *Science* 320:1617.