The Flyby Model for Chondrule and Chondrite Formation

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Introduction: We expand on our earlier proposal [1,2] that chondrules, and possibly chondrites, can form when pre-existing aggregates of solar nebula solids, in the mm to m size range, have close encounters (*flybys)* with planetesimals that have incandescent lava at their surfaces. We show rigorously that radiative heating from such events has the potential to account for the thermal history of chondrules inferred from laboratory simulations of their textures. We discuss the possibility that chondrites are formed by sintering of the macroscopic aggregate during the same encounter in which the chondrules formed.

Background: Cosmochemists have been unable to agree on a mechanism for chondrule formation that is consistent with all of the observational constraints [3]. Evidence from volatile and isotopic studies shows that the density of solids and the oxygen fugacity in the chondrule formation zone are inconsistent with their having formed in a solar nebula setting [4,5]. Planetary models assume formation during collisions [6,7], but there has been no demonstration that spherules with porphyritic and other chondrule textures can, in fact, form during such colllisions.

Time Constraints: Radioactive dating techniques agree that chondrules formed over a more extended period of time (4-5 Myr) than CAI's, and not at times later than that [8]. Al-Mg dating indicates that there is an ~1 Myr gap between CAI formation and the onset of chondrule formation and that there is no significant spread in age among chondrules within the same meteorite [9].

Our Model in a Nutshell: Following [6], we assume that ~50-100 km sized planetesimals formed very quickly within the solar nebula and fully melted due to heating by ^{26}Al decay. Iron meteorites, which date to that epoch [10], provide an example of evidence in support of this picture. By t ≈ 1 Myr many of these objects will be episodically erupting incandescent lava onto their surfaces, a phenomenon that continues for a few Myr, or several half-lives of ^{26}Al. During this t = 1-5 Myr epoch, fluffy aggregates of pre-chondrule solids may be heated during chance flybys at the right time and sintered into chondrules and perhaps chondrites. The distinctive thermal histories required by observed chondrule textures (heating to subliquidus temperatures for times of minutes to an hour [11]) are a natural by-product of the orbital time scale in our model. As long as the density of the planetesimal is ~3 gm/cm^3, the time scale for the heating event is in the required range of minutes to an hour.

Testing the Model in the Laboratory: Our model makes firm predictions about the possible thermal histories that could be reflected in the chondrule textures if they formed in this way. There are very few free parameters, chiefly only the height at closest approach and the temperature of the surface lava. We have initiated a set of experiments to test the predicted heating and cooling curves in a laboratory setting, employing a programmable oven. Results will be shown during the presentation.

The Role of Chondrules in Planetesimal and Planet Formation: If chondrules actually form by the flyby mechanism then they will not be widespread in the solar nebula, since the amount of material that could make a sufficiently well-timed and close flyby to see a substantial solid angle of molten lava is small. Also, much of the material available for planet formation would already have been taken up in the first generation of planetesimals. Chondrules, then, would be an important component of the fossil (meteorite) record, but would never have been an important component of the proto-solar nebula.

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