COMPLEMENTARITY AND THE FORMATION OF CHONDRITE PARENT BODIES: A WINDOW ON DUST COAGULATION.

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Introduction: Abundances in bulk chondrites are roughly solar, despite large differences between chondrules and matrix, and varying chondrule fractions [1,2,3]. This complementarity implies that the chondrules and matrix within a given chondrite derive from a common reservoir of material, ruling out multiple reservoir explanations. Further, chondrule sizes in chondrites are quite heterogenous [4], ruling out carefully tuned models for parent body formation. Thus, complementarity also constrains how chondrite parent bodies were assembled, and from what pieces: if the parent body assemblage process filtered out or preferentially included either chondrules or matrix, the correlation between the two would be destroyed.

Complementarity: The bulk elemental and isotopic abundances of chondritic meteorites are flat across chondrite classes [1,2,3], even though the subcomponents both have and are present in quite different abundances. Thus chondrules and matrix within a given chondrite were co-genetic, drawn from a single reservoir of near-solar composition in a fashion that preserved that composition. This also restricts the delay between chondrule formation and chondrite assembly to being shorter than the viscous timescale in the disk [5].

Parent body assemblage (Streaming Instability): The Streaming Instability (SI, [6]) allows direct formation of chondrite parent bodies through the gravitational collapse of dense dust clouds in the Solar Nebula. Once gravitational collapse begins, it is too late to mix in either matrix or chondrule material, so both must already be in the cloud. Given instances of the SI select for dust grains with specific aerodynamical stopping times, so given the spread in chondrule size ranges and chondrule-to-matrix ratios between chondrites, complementarity requires both that the dust clouds were made up of chondrule-matrix agglomerations, and that the clouds were representative of the overall solid mass reservoir.

Naked chondrules are too small to trigger the SI, so the need for chondrule-matrix agglomerations is not unexpected [7]. More surprising would be for the SI generated dust cloud to be representative of the overall solid mass reservoir. The chondrules and especially the chondrule-matrix agglomerations would be expected to have been significantly settled compared to free-floating matrix material. A settled population of large dust grains can trap smaller grains [8], but this requires adhesion, and chondrule precursors presumably sampled the largest free-floating grains. Thus, chondrule-matrix agglomerations would signal a different adhesion regime than mere agglomerations of sub-micron presolar grains.

Parent body assemblage (direct sweep-up): A small planetesimal can sweep up free-floating dust grains with its geometrical cross section as long as the dust grains are large enough not to be affected by the gas flow around the body. Matrix grains were presumably similar to chondrule precursor grains, and thus comparable in mass to chondrules, while having volume filling factors of perhaps 12% [9]. The matrix grains associated with CO chondrites' small chondrules would then interact with the gas flow around planetesimals exceeding a mere 10 km in radius.

In this scenario, complementarity allows chondrule-matrix agglomerations as in the SI case, but it also allows independent matrix and chondrule grains so long as neither population is significantly settled compared with the other (which would upset the local complementarity).

Parent body assemblage (pebble accretion): Once the planetesimal grows sufficiently, the gas flow around the body can both trap and deflect dust grains of appropriate sizes [10]. The heterogeneity of chondrule sizes and chondrule-to-matrix ratios, combined with pebble accretion's aerodynamical sorting requires the production of condrule-matrix agglomerations to maintain complementarity, as in the case of the SI.

Conclusions: The need to maintain complementarity through chondrite parent body assembly implies that chondrules were not strongly settled compared with non-thermally processed material (aka pro-matrix). It further strongly suggests the formation of intermediate chondrule-matrix agglomerations larger than chondrule precursors, suggesting that dust coagulation in the presence of chondrules is different than in their absence. That suggests that chondrule or chondrule-like objects provide a path to the formation of terrestrial planets.

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