CHONDRULE FORMATION, COMPLEMENTARITY, AND PERVASIVE, HIGHLY LOCAL HEATING BY CURRENT SHEETS

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The Problem: Chondrule formation requires rapid heating to nearly 2000K, followed by cooling at 100-1000K/hr[1,2]. Chondrules and matrix have been shown to be complementary in major [3] and minor [4] element compositions. Complementarity [5] requires rapid, local heating of chondrule precursors followed by rapid accretion, consistent with self-gravitation [6]. Such heating must affect only small regions, leaving organic matter [7] and presolar grains [8,9] relatively unaffected. Multiple heating, and remelting of chondrules is revealed in multiple igneous rims and re-equilibration of crystals and melt [10,11]. Retention of volatile Na in some chondrules has been used to argue that chondrules formed in self-gravitating regions of high solid density [6]. Yet chondrule-like objects are found in Kuiper belt comet Wild 2 [12]. Reconciling these disparate observations is a major problem in cosmochemistry.

Previous Work: The assumption that chondrule-forming temperatures can only occur near the sun [e.g.,13], requires highly efficient, disk-wide mixing of inner material to at least 40AU [14]. Such mixing must preserve the near-solar ratios of all the elements more refractory than Mg, as observed in primitive chondrites [5]. Furthermore, the chondrules themselves must mix in exactly the right proportions to retain, e.g., the solar Fe/Si ratio in the accreted body [11]. Strong shock waves produced by gravitational instabilities can act as localized heating mechanisms to produce chondrules [15], however it is not clear what would such shocks, particularly outside of Jupiter's orbit.

A Way Forward: The viscosity necessary to accrete protostellar disks can result from magnetic turbulence driven by magnetorotational instability (MRI) [e.g., 16]. This turbulence generally forms current sheets that dissipate energy in highly localized regions [17]. Because resistivity in the gas drops dramatically above 1000K, current sheets may be concentrated, leading to sharp temperature spikes similar to those formed by electrical short circuits [18]. The ubiquity and power in MRI turbulence, active even in outer disk regions, make it a promising mechanism for chondrule formation that meets the hard constraints with which 'complementarity' is consistent.

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