Chondrule Formation from Ejecta Melts with Adaptive Mesh Refinement

M. L. A. Richardson[1] and M. A. Morris[2]. [1]Department of Physics, University of Oxford: Mark.Richardson@physics.ox.ac.uk. [2]Physics Department, State University of New York at Cortland

Introduction: Understanding protoplanetary disks (PPDs) requires a synergy of astronomical observations and meteoritic analysis. While recent observations with e.g. *ALMA* are beginning to reveal the physical scale and thermal properties of PPDs, such millimeter measurements can only probe dust of limited size [1]. Meteoritic data, on the other hand, can be used to probe the nature of our Sun's PPD over a range of time and length-scales. Chondrules, small igneous inclusions found in chondrites, are a useful probe of the disk environment. While most chondrules formed roughly 2-3 Myr after the oldest solids (calcium-aluminium-rich inclusions, or CAIs) [2][3], those found in CH and CB chondrites are consistent with a formation time of 5-6 Myr after CAIs. Thus CH/CB chondrules allow us to study the nature of the changing disk environment.

Motivation: We aim to understand the origin of CH/CB chondrules, gaining insight into the nature of our PPD 5-6 Myr after its formation. Our model considers melts in an ejecta fan resulting from the collision of small bodies at speeds near the local escape velocity. This ejected material will eventually disrupt through turbulence and condensation. Previous models of this scenario [4] use *Smoothed Particle Hydrodynamics (SPH)* methods, which have difficulty capturing the turbulent interaction between ejecta and the ambient disk, and are incapable of resolving low densities and small length scales. Recent simulations considered impacts between much larger, solid bodies as a formation method for the more common porphyritic chondrules [4].

Numerical Methods: To overcome the difficulties inherent to SPH methods, we use the *Adaptive Mesh Refinement (AMR)* code `FLASH` for our simulations. AMR is better able to model shocks, turbulence, and mixing [5], and can select regions for refinement to high resolution. Initial conditions are mapped from an SPH dataset, using methods previous employed for cosmological simulations [6]. The SPH simulation models the impact, where SPH conserves angular momentum and better accounts for the advection of the planetesimals, while the AMR simulation models the evolution of the resulting ejecta fan and the subsequent formation of *in situ* melts. Here, we focus on the AMR simulations during which chondrules form.

Outline: We discuss in detail collisional ejecta as a progenitor of CH/CB chondrules. We present the mapping method, and discuss new challenges that arise during its implementation on planetary scales. This includes the addition of an ambient medium, angular momentum conservation, pressure balance, and further advection issues.

References: [1] Williams J. P. and Cieza L. A. 2011 *The Annual Review of Astronomy and Astrophysics* 49:67-117 [2] Kurashi E., Kita N. T., Nagahara H. and Morishita Y. 2008 *Geochimica et Cosmochimica Acta* 72:3865 [3] Villeneuve J., Chaussidon M. and Libourel G. 2009 *Science* 325:985-988 [4] Johnson B. C., Minton D. A., Malosh, H. J. and Zuber M. T. 2015 *Nature* 517:339-341 [5] Asphaug E., Jutzi, M. and Movshovitz N. 2013 *Earth and Planetary Science Letters* 308:369-379 [6] Agertz O., Moore B., Stadel J. et al. 2007, *Monthly Notices of the Royal Astronomical Society*, 380:963-978 [6] Richardson M. L. A., Scannapieco E. and Thacker R. J. 2013 *The Astrophysical Journal* 771:81-93