**FORMATION OF CHONDRULES BY PLANETESIMAL COLLISION.** B. C. Johnson[1], F. J. Ciesla[2], C. P. Dullemond[3], and H. J. Melosh[4], [1]Department of Earth, Environmental and Planetary Sciences, Brown University (Brandon_Johnson@Brown.edu).[2]Department of the Geophysical Sciences, The University of Chicago.[3]Heidelberg University, Center for Astronomy, Institute of Theoretical Astrophysics. [4]Department of Earth, Atmospheric, and Planetary Sciences, Purdue University.

**Introduction:** Chondrules are the mm scale previously molten droplets found in chondritic meteorites. These pervasive yet enigmatic particles hint at energetic processes at work in the nascent Solar System. Chondrules and chondrites are well studied and many of the details about their compositions, ages, and thermal histories are well known. Without the proper context of a formation mechanism, however, we can only imagine what chondrules may reveal about the processes at work in the early Solar System. Here, we explore the hypothesis that chondrules were formed by impacts between growing planetesimals. Specifically, we focus on shock heating associated with accretionary impacts as a means for melting chondrule precursor material. We explore the predictions of this model and its implications for our understanding of early solar system history and meteoritics. We also discuss potential issues and uncertainties while identifying avenues for further development and testing of the impact origin hypothesis.

**Jetting model and comparison to constraints:** Here we focus on the often overlooked process of impact jetting, which has recently been suggested as way to reconcile an impact origin for chondrules with observational constraints [1]. Jetting is an extreme process that occurs very early in an impact when the projectile is still coming into contact with the target. A small amount of material is shocked to high pressures and temperatures as it is squirted out from the region where the projectile is coming into contact with the target. This process can now be directly resolved in numerical models. This material is typically ejected at velocities exceeding the impact velocity (Fig. 1).

We compare this model's prediction to the observed sizes of chondrules [2], the overall abundance of chondrules in the meteorite record [3], cooling rates inferred from chondrule textures [4], constraints on dust enrichment and total pressure inferred from chondrule volatile content [5], lack of isotopic fractionation [6], the overall composition of chondrites and observations suggesting while chondrules are depleted in volatiles the surrounding matrix material is enriched [7] and a similar trend for tungsten isotopes [8]. Although there are still large uncertainties, which may be resolved by more detailed modeling, we find the jetting model is currently consistent with all of these constraints.

**Conclusions**: Our understanding of planet formation suggests that planets are built through a series of mergers and impacts. Accretion models imply that the impact velocities necessary to jet partially melted material are an expected outcome of the accretion process [1]. Other models indicate this jetted material would be efficiently accreted onto smaller bodies (<1000 km in diameter) [9]. Thus, in contrast to some other models for chondrule formation, the potentially chondrule forming impact jetting process was very likely occurring at the time of chondrule formation and chondrule formation during planetesimal collisions is the natural consequence of planet formation. Impact jetting is an unavoidable consequence of hypervelocity impacts. If no signs of this process are seen in the meteoritic record, then this implies that Moon-sized bodies never formed in the main belt region.

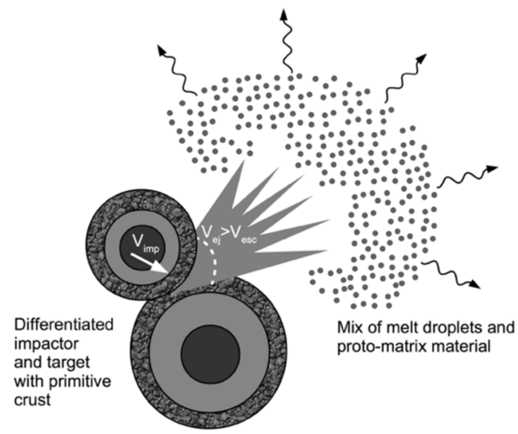


Fig 1: Schematic representation of the formation of chondrules and proto-matrix by impact jetting. Early in the impact primitive crustal material is ejected above the escape velocity of the target body. Some of this material is partially melted and breaks up becoming melt droplets. The rest of the material is only lightly shocked and become proto-matrix material. As the jetted material moves outward it radiatively cools. The vast majority of impact ejecta are bound to the target body.

**References:** [1] Johnson B. C. et al. (2015) *Nature, 517,* 339–341. [2] Scott E. R. D. and Krot A. N. (2003) *In Meteorites, Comets and Planets*. [3] Scott E. R. D. (2007) *Annu. Rev. Earth Planet. Sci*. *35*, 577–620. [4] Desch S. J. et al. (2012) *MAPS 47*, 1139-1156. [5] Alexander C. M. O. et al. (2008) *Science 320*, 1617-1619. [6] Davis A. M. et al. (2005) *Chondrites and the Protoplanetary Disk 341*, 432-455. [7] Bland et al. (2005) *PNAS 102*, 13755-3760 [8] Budde et al. (2016) *PNAS 113*, 2886-2891. [9] Hasegawa Y. et al. (2015) *ApJ Let. 820*, L12.