A THERMO-MECHANICAL 'GOLDILOCKS' REGIME FOR IMPACT SPLASH CHONDRULE FORMATION. T. Lichtenberg[1,2], G. J. Golabek[3], C. P. Dullemond[4], M. Schönbächler[5], T. V. Gerya[1], M. R. Meyer[2,6], [1]Institute of Geophysics, ETH Zürich, Sonneggstrasse 5, 8092 Zürich, Switzerland, [2]Institute for Astronomy, ETH Zürich, Wolfgang-Pauli-Strasse 27, 8093 Zürich, Switzerland, [3]Bayerisches Geoinstitut, University of Bayreuth, Universitätsstrasse 30, 95440 Bayreuth, Germany, [4]Institute for Theoretical Astrophysics, Heidelberg University, Albert-Ueberle-Strasse 2, 69120 Heidelberg, Germany, [5]Institute of Geochemistry and Petrology, ETH Zürich, Clausiusstrasse 25, 8092 Zürich, Switzerland, [6]Department of Astronomy, University of Michigan, 1085 S. University Avenue, Ann Arbor, MI 48109, USA.

Introduction: Still, a conclusive and astrophysically consistent chondrule formation scenario remains elusive. Major constraints include chemical, isotopic and textural features of chondrules, in particular retained metal abundances, bulk Fe/Mg ratios, porphyritic textures and the intra-chondrite chemical diversity. Here, we suggest a new coupled evolution-collision scenario where chondrules originate from the collision aftermath of low-mass planetesimals, which are only partially molten from aluminum-26 decay. The model is consistent with the vast majority of thermal and chemical constraints and invokes a diversity of pre-chondrule material compositions. The thermo-mechanical 'Goldilocks' regime favored in our scenario constrains the timing and formation conditions of the earliest planetesimal families and thus the onset of terrestrial planet formation.

Metal-silicate segregation constrains impact splash models: Asphaug and co-workers [1] revived collision models by suggesting that chondrules may originate from low-velocity impacts among fully molten planetesimals. In *Figure 1* we show, however, that the ubiquity of Fe-Ni metal rings/blebs [2] in the direct vicinity of chondrules and their chemical heterogeneity rule out excessively molten (and thus differentiated) planetesimals as chondrule precursors.

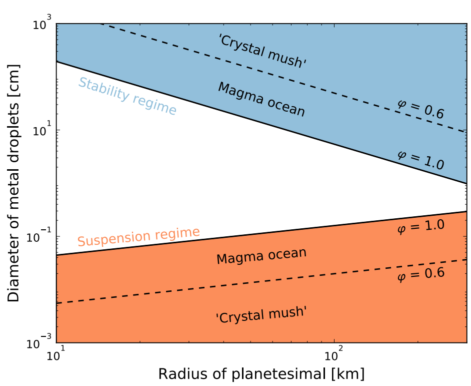

Figure 1: *Metal droplets cannot be suspended in planetesimals with vigorously convecting magma oceans. The likely metal droplet sizes for various planetesimal radii and silicate melt fractions φ ['stability', 3] in a magma ocean is shown versus the droplet sizes which can be suspended in liquid magma by convection ('suspension').*

Mutual collisions between radiogenically pre-heated, but undifferentiated, planetesimals: Planetesimals of preferentially low-mass, however, were significantly pre-heated but did not differentiate extensively (*Figure 2*). They allow chondrule formation from subsonic (~1 km/s) impacts, which are chemically, isotopically and texturally consistent with observations, and fit well to recent dynamical models of planet formation [5, 6].

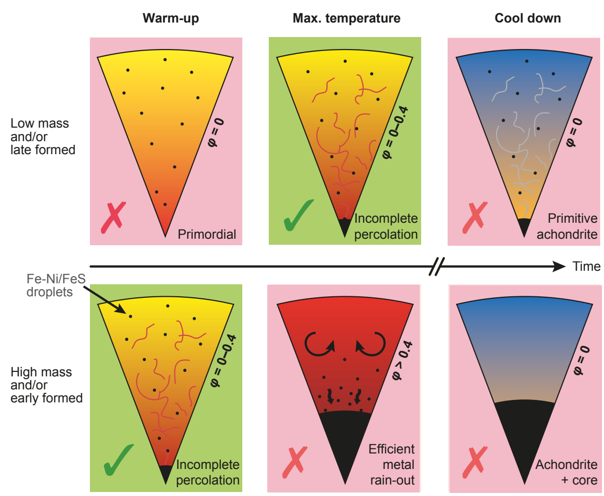

Figure 2: *Suggested 'Goldilocks' regime for chondrule precursor planetesimals (green). Red scenarios are either chemically, texturally or isotopically inconsistent with laboratory measurements [2, 7] or dynamical models [1, 2, 5].*

Repeated collisional recycling in separate annuli: If different parent bodies accreted from isolated feeding zones without mutual mixing, chondrule-matrix complementarity [2] and distinct nucleosynthetic anomalies in individual chondrules can be retained.

References: [1] Asphaug E. et al. (2011) *EPSL, 308,* 369–379. [2] Connolly H. C. Jr. & Jones R. H. (2016) *JGRP, 121,* 1885–1899. [3] Rubie D. C. et al. (2003) *EPSL, 240,* 589–604. [4] Lichtenberg T. et al. (2016), *Icarus, 274,* 350–365. [5] Morbidelli & Raymond (2016) *JGRP, 121,* 1962–1980. [6] Wakita S. et al. (2016) *arXiv:1611.0551.* [7] Alexander C. M. O'D. et al. (2008) *Science, 320,* 1617–1619.