LAYERED DISKS AS A SOLUTION TO DYNAMICAL AND COSMOCHEMICAL CONSTRAINTS ON CHONDRULE FORMATION. M.-M. Mac Low[1], A. Hubbard[1], and D. S. Ebel[2], [1]Department of Astrophysics, American Museum of Natural History (ahubbard@amnh.org; mordecai@amnh.org), [2]Department of Earth and Planetary Sciences, American Museum of Natural History (debel@amnh.org)

Introduction: Astrophysical models provide understanding of collisional dust growth, dust transport, concentration and aerodynamical sorting, and planetesimal formation in protoplanetary disks [1,2,3]. Cosmochemists have found increasing evidence for the correlation between abundances in chondrules and matrix in chondrites known as complementarity [4,5,6]. Combined, these advances make striking predictions about the physical partitioning of protoplanetary disk regions associated with chondrule formation that match well with a standard global picture of protoplanetary disks as accreting through magnetically active surface layers while the midplanes are quiescent [7], or alternatively from a global magnetocentrifugal wind, which also structures surface layers [8].

Complementarity: Across a wide range of elements and isotopes, the composition of matrix and chondrules within a given chondrite differs significantly. Further, the ratio of chondrules to matrix varies strongly between chondrites. Nonetheless, the bulk elemental and isotopic abundances of chondritic meteorities are flat across chondrite classes [4,5,6]. This implies that chondrules and matrix within a given chondrite were co-genetic, forming from a single reservoir of near-solar composition. It also implies that parent body assemblage had to have occurred shortly after and spatially near chondrule formation [9].

Spatial sorting: One mystery associated with complementarity is how the chondrules and matrix can have different compositions in the first place. This challenge was made particularly pressing by the recent W/Hf isotope measurements of Budde et al. [6]. Separating matrix from co-genetic chondrule precursor grains would require strong aerodynamical sorting [9]. While radial pressure perturbations can concentrate large dust grains and act as a sorting mechanism [2], chondrules are too small to have been easily concentrated in such a fashion.

Planetesimal formation and chondrule size: It has become clear that naked chondrules (on order of 500 μm diameter and smaller) could not have directly proceeded to planetesimal formation, and must have stuck together to form large agglomerations [10]. However, outside of a few rare examples [11], meteorites do not record the thermal processing of such agglomerations. Thus, in tension with complementarity, chondrule formation regions must have been separate (either in space or in time) from the parent body assemblage regions.

Layered disk structure: These challenges and constraints point to vertical separation as a self-consistent solution. Chondrule formation events in this picture would be restricted to upper layers well above a cool midplane. In that case, strong vertical stratification and settling would allow the spatial sorting of chondrule precursors and matrix grains. Once the newly formed chondrules settle to the midplane, they could agglomerate without those agglomerations being thermally processed. Further, the low aspect ratio of protoplanetary disks means that this scenario would require only relatively small vertical distances with concomitantly short transport times. Thus, the matrix and chondrules in a narrow radial annulus could remain co-genetic through the stages of aerodynamical sorting, chondrule formation and parent body formation.

This scenario meshes well with the conventional astrophysical picture of magnetically accreting layered protoplanetary disks: quiescent, low ionization midplanes and non-thermally ionized, magnetically active surface layers [7,8]. However, it also places a constraint on chondrule formation models: the mechanism must preferentially occur in the upper reaches of disks. The strong vertical gradients invoked to allow spatial sorting might allow lightning [12], since spatial sorting is a mechanism to drive charge separation over large length scales. However, resistive heating in current sheets formed by the dissipation of magnetic turbulence or reconnection appears to be the most robust mechanism consistent with this constraint [13].

References: [1] Pan L. et al. (2014) *ApJ*, 792, 69. [2] Dittrich K. et al. (2013) *ApJ*, 763, 117. [3] Johansen A. et al. (2007) *Nature*, 448, 1022-1025. [4] Bland et al. (2005) *PNAS*, 102, 13755-13760. [5] Hezel D. C. and Palme H. (2010) *Earth & Planet. Sci. Letters,* 294, 85-93. [6] Budde G. et al. (2016) *PNAS*, 113, 2886-2891. [7] Gammie C. (1996) *ApJ*, 457, 355. [8] Gressel et al. (2015) *ApJ*, 801, 84 [9] Goldberg A. et al. (2015) *MNRAS*, 452, 4054-4069. [10] Hubbard A. and Ebel D. S. (2015) *Icarus*, 245, 32-37. [11] Metzler K. (2012) *Meteoritics & Planet. Sci.*, 47, 2193-2217. [12] Desch S. J. and Cuzzi, J. N. (2000) *Icarus*, 142, 87-105. [13] McNally et al. (2014) *ApJ*, 791, 62.