MODELING CHONDRULE DUST RIM GROWTH WITH ELLIPSOIDAL MONOMERS C. Xiang, A. Carballido, L. S. Matthews, and T. W. Hyde, Center for Astrophysics, Space Physics and Engineering Research, One Bear Place #97283, Baylor University, Waco, TX, 76798-7283, USA.

Introduction: Fine-grained dust rims (FGRs) surrounding chondrules in carbonaceous chondrites encode important information regarding the processes and conditions in the early solar system. The commonly supported mechanism for the rim formation is the accretion of dust grains onto the underlying chondrule cores in a solar nebula. If this nebular hypothesis is correct, the pre-compaction structural properties of dust rims can be used to infer their formation environments and establish the foundation for the onset of the next assembly stage, where the collision between rimmed-chondrule agglomerates, or the compaction of dust rims by dusty nebular shock waves, with the subsequent incorporation of the final products into the parent bodies, takes place [1, 2].

The radiative plasma environments can cause the dust grains to be charged in the solar nebular, and the resulting electrostatic force can alter the orientation and trajectories of dust grains, affecting their collision rates with chondrules. As a consequence, FGRs formed in different charging conditions have different structures (porosity, monomer size distribution, monomer alignment) and timescales for growth. The effect of the charge on the rim formation is modified by the nebular turbulence level and chondrule size, as dust grains obtain greater relative velocity with respect to large chondrules in strong turbulence, which reduces the interaction time and therefore the effect of the charge.

In this work, we use an N-body code to model the formation of FGRs through the collision between free-floating chondrules dust grains in protoplanetary disks under different turbulence and charging conditions. We compare rims formed from spherical dust grains [1, 3] with those formed from ellipsoidal grains.

Method: The formation of FGRs was modeled for conditions at the midplane of a turbulent protoplanetary disk, at a distance of 1 AU from the sun, with a gas temperature of 280 K. The equivalent radius of the dust monomer [$r = (r_a r_b r_c)^{1/3}$, where r_a, r_b, r_c are the three semi-major axes of an ellipsoid] follows a power law distribution with index -3.5, with $0.3 \leq r \leq 1$ µm. The aspect ratio of the ellipsoidal monomers is 3:1:1. Chondrule formation was modeled in both neutral and ionized gas, with dust surface potentials of -0.061 V, -0.048 V and -0.020 V on spherical dust grains [4]. We assumed weak turbulence ($\alpha=10^{-3}$, 10^{-4}, 10^{-5}) to exclude the effects of the restructuring and fragmentation.

A combination of a Monte Carlo method and the N-body code, Aggregate_Builder (AB), is used to simulate the dust rim formation through the collision between chondrules and dust grains. The Monte Carlo algorithm is used to randomly select dust grains to collide with the chondrule and determine the elapsed time interval between collisions [5, 6]. The detailed collision process is simulated using AB, taking into account the morphology of dust rims, trajectory and orientation of the incoming particle, and the electrostatic interactions [7,8]. The distribution of charge on the grain surface is calculated by the modified Orbital Motion Limited Line of Sight (OML-LOS) method, where the surface points of each constituent monomer are projected to a grid to determine where only surfaces open to the plasma environment are charged [9].

For computational expediency, we restrict dust grains to accumulate on a 50 μm-radius patch of the chondrule surface. In each iteration, the chondrule is placed with its center of mass at the origin, and a dust particle is shot towards a randomly selected point on the patch from a random direction. The incoming particle can either be collected by the dust rim or repelled by the electrostatic force.

Results: The combined effect of the charge, turbulence, chondrule size and grain shape on the rim growth can be characterized by the ratio of the grains' electrostatic potential energy at the point of the collision to the kinetic energy due to the relative velocity at large distances (PE/KE). Sample rims are shown in Fig. 1.

Dust rims comprised of ellipsoidal monomers are more porous than rims comprised of spherical monomers under the same environmental conditions. In the case of low PE/KE or neutral environments, this is mainly caused by the greater gaps between ellipsoidal monomers, while for high PE/KE, the main cause is the higher charge of the ellipsoidal monomers resulting in greater repulsion of small dust particles. The rim porosity increases with increasing charging level above a threshold PE/KE, with the threshold turbulence level decreasing with larger chondrule cores ($\alpha=10^{-4}$ for 150 µm-radius-chondrule and $\alpha=10^{-5}$ for 700 µm-radius-chondrule), as large chondrules develop greater relative velocities with respect to dust particles, which enables them to overcome the electrostatic barrier.

The average monomer size within the rim increases with PE/KE for 0.04<PE/KE, and dust rims comprised of ellipsoidal monomers have larger grain size than rims with spherical monomers under the same environmental conditions (Fig. 2). In the case of high PE/KE where considerable repulsion of small particles takes place, the

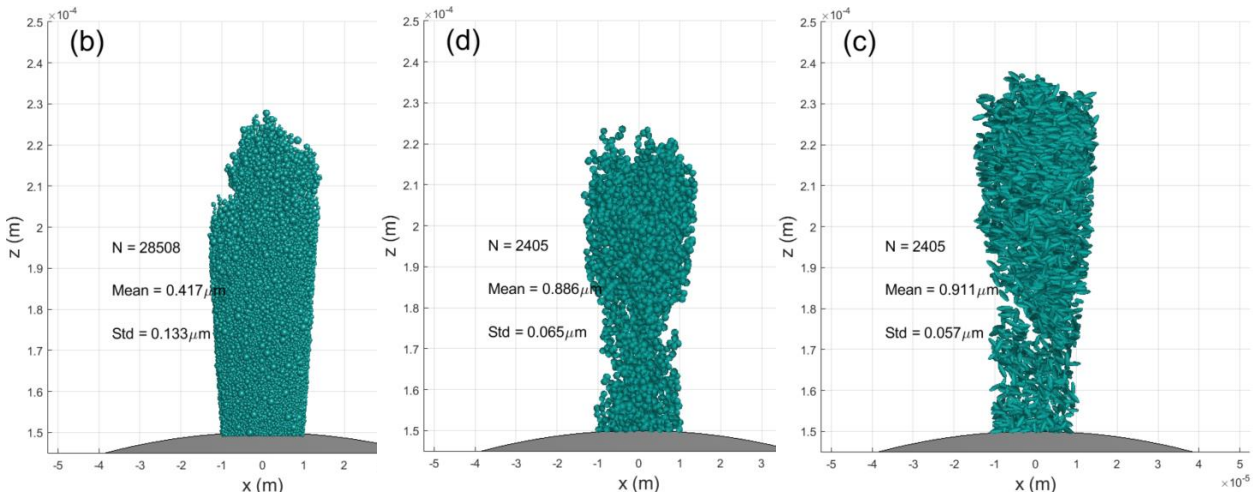

Figure 1. Comparison of rims: Spherical monomers, neutral (a) and charged (b) grains; (c) ellipsoidal charged grains.

minimum grain size depends on the turbulence level, chondrule size, charging level and monomer shape. For lower PE/KE, dust grains of all sizes are collected in the rim. However, the distribution and proportion of grains vary with PE/KE, as small dust grains are prevented from reaching the inner region of the rim by the electrostatic repulsion.

The orientation of incoming dust monomers is affected by the strength of the electrostatic force, the time for rotation (depending on the relative velocity), and the size of dust monomer. For PE/KE<0.2, the average polar angle (the angle between the longest axis of the monomer and the normal to the chondrule surface) of the ellipsoidal monomers increases with PE/KE. For PE/KE > 0.2, the opposite is true.

The growth rate of rim thickness is affected by the rim porosity and the level of electrostatic repulsion. For low PE/KE, the porosity has a greater impact than the repulsion, and dust rims comprised of ellipsoidal monomers grow faster than those comprised of spherical monomers, as the former is more porous and thus requires fewer monomers to build a rim of a certain thickness. For medium PE/KE, initially the growth rate is mainly affected by the porosity. As dust rims grow and obtain a greater surface potential, the repulsion becomes more dominant. As a result, the growth rate of the rims comprised of ellipsoidal monomers is surpassed by the rims comprised of spherical monomers, and highly charged rims grow more slowly than weakly charged and neutral rims. For high PE/KE, the charge can prohibit the formation of dust rim or cause the dust rims to cease growing after some time, and small chondrules are more susceptible to this growth barrier.

Conclusions: The properties and evolution of dust rims depend on the plasma condition, turbulence level, chondrule size and grain shape, which are characterized by PE/KE. A greater PE/KE (i.e., higher charging level, lower turbulence level, smaller chondrule size, greater aspect ratio of dust monomers) leads to higher rim porosity, larger grain size within the rim, and lower growth rate, while the grain orientation within the rim first increases with PE/KE, followed by a decrease.

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References: [1] Ormel, C. W. et al. (2008) ApJ, 679:1588–1610. [2] Carballido, A. (2011) Icarus, 211, 876. [3] Loesche, C. and Wurm, G. (2012) A&A 545, A36. [4] Matthews, L. S. et al. (2012) ApJ, 744 (1): 8. [5] Ormel, C. W. et al. (2007), A&A 461, 215-232. [6] Gillespie, D. T. (1975) AMS 32 (10): 1977-1989. [7] Ma, Q. et al. (2013) ApJ 763 (2): 77. [8] Matthews, L. S. et al. (2016) IEEE 44 (4): 519–24. [9] Xiang, C. et al. (2021) Icarus, 354, 114053.

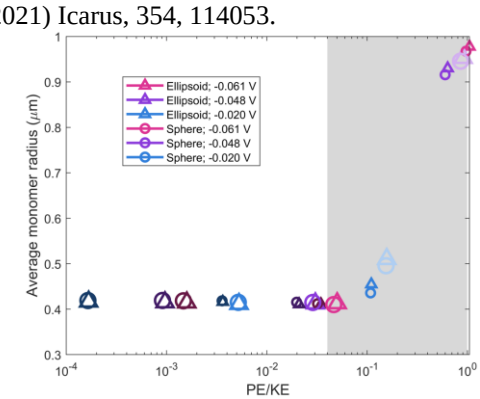

Figure 2. Average monomer size as a function of PE/KE. Chondrule size, charging level and turbulence level are represented by marker size, color and shade, respectively. The grey area indicates the range of PE/KE where the grain shape has an impact on the average monomer size in the rim.