EXPERIMENTAL STUDY OF CHONDRULE RIM FORMATION.

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Introduction: The chondrules within the chondritic meteorites found on Earth contain fundamental information about the origin of both our solar system and our planets. Although chondrules are abundant and integral to the creation of Earth-like planets, their formation process is not well understood. The rims of fine-grained dust surrounding the chondrules within the chondritic meteorites found on Earth may provide data important to this question. These fine-grained rims (FGRs) have been postulated as having served as the 'glue' that helped hold chondrules together, allowing them to form the centimeter-sized aggregates which became the building blocks for asteroids and later planetesimals [1]. Research suggests that FGRs may have formed in a nebular setting, before the rimmed chondrules were incorporated into their parent bodies [2]. If so, FGRs are a key element in the formation of the chondrite parent bodies, providing insight into both their collisional history and the development of our protoplanetary disk.

While slow collision speeds are generally accepted to lead to the formation of chondrule rims, little experimental or theoretical attention has been given to the role of faster collisions. This collision regime is important since Connolly & Love [3] showed that collision speeds between a 1-μm dust grain and a 1-mm chondrule may reach ~ 1 km/s in post-shock regions of the solar nebula. More recently, Liffman [4] suggested that high-speed collisions could produce 'coatings' on chondrule surfaces as a result of the fragmentation of impinging micron-sized grains.

The current study utilizes a coordinated experimental / numerical approach across an operating parameter space designed to better establish the FGR formation process for both low and higher speed particle / chondrule collisions. Both the morphology of FGRs (i.e., porosity, thickness, grain size distribution) and structural development of the rim itself will be examined.

Experimental facility: The experiments discussed here are being conducted within the IPG6-BU experimental facility within CASPER at Baylor University [5], [6], [7], [8]. The IPG6-BU consists of a 1.2 m^3 vacuum tank with a diameter of 0.9 m connected to a vacuum system capable of maintaining a base pressure of 2 Pa. This vacuum tank is connected to an inductively-heated plasma generator (IPG), which is capable of producing an inductively coupled discharge with electrical powers between 150 and 15000 W in various gases such as air, Argon, Helium and Nitrogen.

Experimental setup: A manually operated dust shaker is placed inside the vacuum chamber within a distance of 300 mm from the exit of the discharge tube of the plasma generator and on the center axis of the cylindrical vacuum tank. A pressure of 50 Pa is maintained with dust in the shaker introduced into the system by tapping the handle with an engineering hammer. The dust is illuminated using a high-power tungsten lamp introduced through a quartz-glass window. A camera on the opposite side of the tank collects the dust data using a highly magnifying tele/microscope lens. In this setup, the dust is visible against the background lighting.

Collision regimes to be examined: The following collision regimes will be examined in detail:

1. Low speed particle / chondrule collisions ($v \lesssim 1$ m/s) with no restructuring. Such velocities are generally associated with vertical settling of chondrules towards the midplane of the protoplanetary disk, the radial drift of chondrules towards the central star and / or weak turbulence.
2. Moderate speed particle / chondrule collisions ($1 \lesssim v \lesssim 10$ m/s) with restructuring. These relative velocities are often attributed to stronger turbulence regimes.
3. Higher speed particle / chondrule collisions ($v > 10$ m/s) comparable to those expected in protoplanetary disks experiencing strong turbulence or nebular shock waves.

Preliminary results: Dust has been dropped for the following conditions in Argon at a pressure of 50 Pa:

1. Vacuum without gas flow (as a control);
2. Gas flow at different flow rates;
3. Plasma ignited in the discharge tube, but no gas flow initiated; and
4. Through plasma jets at different powers and various flow rates.

Dust velocities have been calculated using the known exposure time of 500 μs and resolution of 50 μm per pixel of the imaging system, yielding the results shown in Figures 1, 2 and 3. Due to frame rate limitations of the system, only streaks of moving particles have been observed and a single particle has not yet been verified across multiple frames. The following preliminary results have been achieved:

1. In vacuum, the dust falls at the expected free fall velocity as shown in Figure (a);
2. When interacting with the gas jet, the dust is visibly dragged by the jet in the direction of the flow as seen in Figure (b);
3. For an ignited plasma but no gas flow, the dust is dragged in the direction of the discharge tube as seen in Figure (a); and
4. When a plasma jet interacts with the dust, the dust is visibly dragged, as seen in Figure (b), but this interaction is smaller than expected.

Other than the results observed for condition 3, all of these are expected and explainable. That the dust moves in the direction of the discharge tube under condition 3 might be caused by temperature or density gradients within the vacuum chamber. Even if no additional gas flow is present, the particles might be 'dragged' due to the gas flow induced by such gradients.

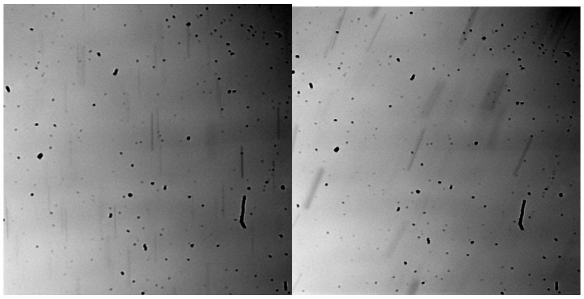
(a) (b)

Figure 1: Behavior of 20 µm alumina dust in Argon gas at 50 Pa for: (a) free falling dust and (b) dust influenced by a gas jet at a volume flow of one SLM and a velocity of approximately 100m/s coming from the right. The black dots in the foreground are on the quartz glass window. The background lighting of these images was not homogenous, therefore the background fades from white to black. FOV is approximately 5.5 x 5.5 mm. The exposure time is 500 µs. The discharge tube is positioned to the right of the window.

Conclusions: Preliminary experiments with alumina dust particles having an average size of 20 µm have been conducted within the IPG6-B facility. It has been shown that dust is observable within the facility and responds to different experimental conditions in an expected manner. Preliminary data has also shown evidence of dust agglomeration and dust particle restructuring (see Figure 4) occurring during these experiments. Future work will collect data for the collision regimes described in the section above and compare this data to numerical simulations.

Acknowledgments: Support from NASA and NSF is gratefully acknowledged.

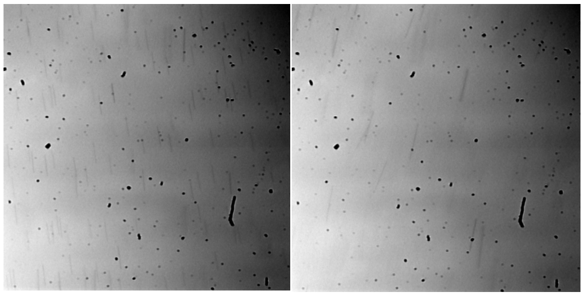
(a) (b)

Figure 2: Behavior of 20 µm alumina dust in Argon plasma with a coupled electrical power of 1 kW at 50 Pa: (a) Falling dust with no gas jet and (b) dust influenced by a plasma jet at a volume flow of one SLM and a velocity of approximately 100 m/s coming from the right. The discharge tube is positioned right of the window.

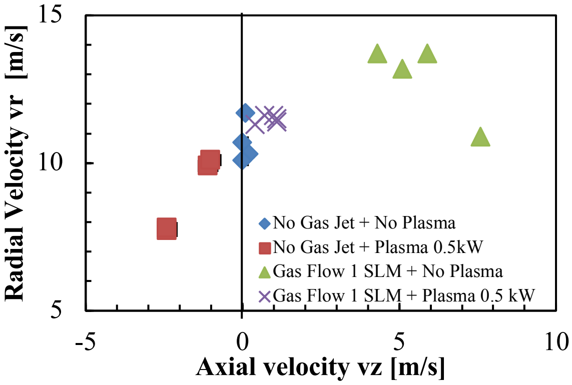

Figure 3: Axial velocity v_z and radial velocity v_r of 20 µm alumina dust for the four experimental conditions discussed as estimated from the length of dust streak and the exposure time. Possible acceleration during imaging is neglected.

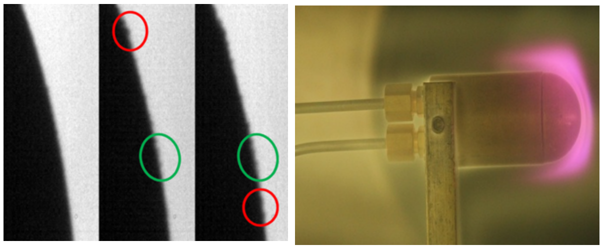

Figure 4: Experimental setup showing accretion of 20 µm alumina dust on a Blunt Body probe inside the IPG6-BU. Red circles show dust agglomeration on the surface. Green circles show movement and restructuring of the particles.

References: [1] Ormel, C.W., Cuzzi, J.N., Tielens, A.G.G.M. (2008) *Astrophys. J.,* 679, 1588. [2] Morfill, et al. (1998) *Icarus* 134, 180. [3] Connolly, H. C. and Love, S. G. (1998) *Science*, 280, 62. [4] Liffman, K., (2019) *Geochim. Cosmochim. Acta* 264, 118–129. [5] Dropmann, et al. (2013) *IEEE TPS*, 41, 4, 804–810. [6] J. Schmidt, et al. (2019) *70th IAC,* Washington, D.C., USA [7] J. Schmidt, et al. (2018) *Proc. 7th RGCEP*, Leipzig, Germany, 2018. [8] J. Schmidt, et al. (2020) *Vacuum*, 176, 109338.