Concept for an experimental study of dust rim formation on chondrules. Jens Schmidt[1,2], Augusto Carballido[1], Lorin S. Matthews[1], René Laufer[1,], Georg Herdrich[2,1], Truell W. Hyde[1], [1]Center for Astrophysics, Space Physics and Engineering Research (CASPER), Baylor University, One Bear Place #97283, Waco, Texas 76798-7283 Jens_Schmidt@baylor.edu [2] Institute of Space Systems, University of Stuttgart, Pfaffenwaldring 29, 70569 Stuttgart, Germany.

Introduction: Chondrules are one of the primary components of chondritic meteorites, and chondrules in carbonaceous chondrites are commonly surrounded by fine-grained dust rims (FGR) [1]. Analysis of the physical characteristics of FGRs preserved in meteoritic samples [2] may be able to give insight into early processes in the early solar nebula. We propose an experimental method to investigate rim growth to compare against previous experimental studies [3] and verify prior simulations of the aggregation of dust rims on chondrules [4]. This study focuses on FGR growth under three different conditions: low pressures where particle-gas interactions are negligible, higher pressures where neutral particles are entrained in a gas flow, and charged particles entrained in an ionized gas flow.

Figure 1: Electrostatic probe measurements in the IPG6-B facility during operation with argon

Experimental facility: Experiments will be conducted within the IPG6-B experimental facility at Baylor University [5]. The facility consists of a 1.2 m^3 vacuum tank 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), shown in operation in Figure 1, which is capable of producing an inductively coupled discharge with electrical powers between 150 and 15000 W in various gases. A light gas gun can be used to shoot dust into the facility as well as to create gas-dynamic shocks with a wide range of velocities [6].

Scaling: Appropriate representation of the environment in the solar nebula at the time of FGR formation requires thoughtful design of the experiment. Fortunately, some of the processes involved can be reproduced directly in the laboratory, as all relevant parameters of the experiment (size of the chondrules and dust particles, dust velocity) are on the laboratory scale. The Knudsen number, the ratio between the mean free path $\lambda = 1/(\sqrt{2}\,N\sigma)$ of the background gas (with number density N and collisional cross section σ) and dust diameter d_p, $Kn = \lambda/d_p$, plays an important role in defining the interaction of the dust with the gas. In Figure 2 it can be seen that for the range of pressures in the experimental facility (indicated by the blue area) and anticipated dust sizes, $Kn \gg 1$, leading to the conclusion that particle-gas interaction is in the Epstein regime. In this case, the neutral drag in gas flowing with velocity v_g becomes [7]

$$F_d = \frac{4\pi}{3} N m \bar{v}_{th} {r_p}^2 (v_p - v_g) \qquad (1)$$

for a particle of radius r_p and velocity v_p, where m and $\bar{v}_{th}$ are mass and mean thermal velocity of the gas particles.

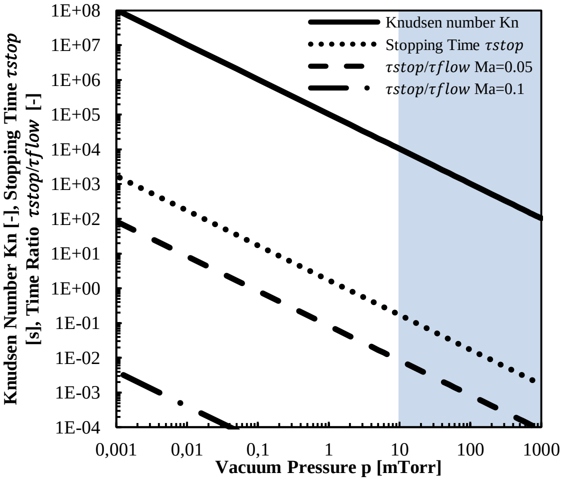

Figure 2: Knudsen number (solid line), stopping time (dotted line) and ratio between stopping time and characteristic timescale in flow at Mach Numbers of 0.05 (dashed line) and 0.1 (dashed-dotted line) of 1-µm particles at T = 300K as function of vacuum pressure. Blue area indicates pressure range of the IPG6-B facility.

Similar considerations hold for the scaling of the chondrule analogs. In such a flow, dust couples to the gas flow (with the gas density ρ_g and mean thermal velocity v_{th}) within the characteristic time scale

$$\tau_{stop} = \frac{3}{4}\frac{m_p}{v_{th}\rho_g \pi {d_p}^2}. \qquad (2)$$

The characteristic time for the gas to travel the distance L between nozzle and sample holder is $\tau_{flow} = v_g/L$. As shown in Figure 2, the stopping time is $\tau_1 \leq 10^{-1}s$ in the pressure regimes of the facility, while the ratio $\tau_{stop}/\tau_{flow} \ll 1$, leading to the conclusion that the particles reach the gas velocity before interacting with the chondrules.

Experiment: Manufactured chondrule analogs are mounted on a sample holder within the vacuum chamber by using very thin needles connected to the chondrule. As shown in Figure 3, the vacuum chamber is aligned vertically with the gas and particle injector head on top of the chamber. Micrometer-sized olivine dust is injected into the vacuum chamber and directed onto the sample holder. The velocity $v(z)$ of the dust at a distance z from the dust injection device can be calculated using equation 1, as velocity profiles of the gas flow are known. The position of the sample holder can be varied to achieve different velocities. For a dust particle with mass $m_p = (\pi/6)\, d_p^3\, \rho_p$ and density ρ_p the equation of motion is given by

$$m_p \frac{dv_p}{dt} = m_p g + F_d. \qquad (3)$$

Knowing velocities and trajectories of the dust, the aggregation on chondrules is then studied for three different cases:

Low pressure. In this condition, particles are dropped on the sample with no gas flow at very low pressure. Thus the particles are not entrained in the gas and have very low-velocity collisions with the chondrule surface. This condition is similar to the environment in a minimum-mass solar nebula at a distance of 1 AU to the center of the nebula and serves also as a control condition for the two other cases.

Neutral dust in gas flow. A small gas flow is introduced in the experimental chamber. This enables the influence of relative velocity between dust and gas on FGR growth to be investigated. Background gases used are Argon and Helium.

Charged dust in a plasma flow. A special focus of this study is to investigate the difference in aggregation between neutral grains and charged grains. For this case, a low power inductive discharge is ignited, ionizing the gas flow. Electron temperature and density are known from prior characterization of the plasma generator. Dust grains injected into this plasma flow will be charged.

The dust flow and collisions with the chondrule analogs will be illuminated using a laser and tracked using particle image velocimetry (PIV). After dust rims are collected on the chondrule surface, the light gas gun can be used to induce gas-dynamic shocks which compact the dust. Samples of chondrules will be studied using optical and electron microscopy as well as computer tomography before and after treatment in the facility to observe differences in the collected dust rims.

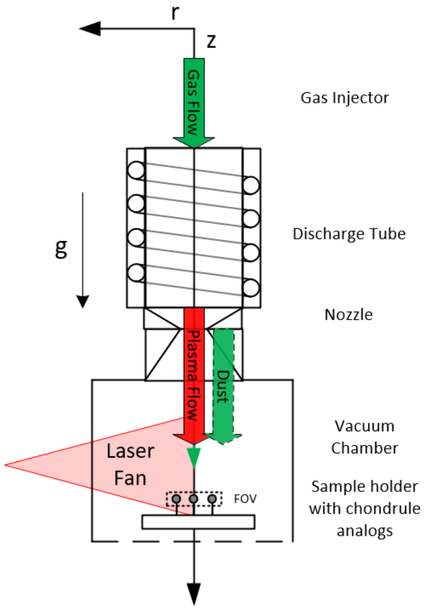

Figure 3: Schematic of the experiment (not to scale).

Impact of results: With this experiment, fundamental processes affecting the formation of chondrule dust can be studied, allowing verification of numerical models which show that the porosity and thickness of FGRs collected in a protoplanetary nebula depends on the relative velocity and charge of the dust grains [4, 8]. Comparison with rims observed on meteoritic samples may help elucidate the conditions and processes present in the solar nebula.

References:

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