EPSC Abstracts
Vol. 6, EPSC-DPS2011-154, 2011
EPSC-DPS Joint Meeting 2011

Experiments on the formation of chondrule rims and their influence on the formation of larger bodies

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Motivation

The physical processes driving the formation of planetesimals are still under debate. Actual studies can explain the growth of dust particles to sizes of the order of millimeters. These are the typical sizes of chondrules from which we know that they were formed early in the solar system [1] and that they are ubiquitous, accounting for up to 80 % of the volume of chondrites [2]. Most of these once molten particles are surrounded by a dusty layer whose origin requires special conditions. There are several hypotheses on the formation of dust rims around chondrules. The most popular are (1) the formation of fine grained rims by compaction processes on their parent bodies [3], (2) the accretion of dust particles on solidified chondrules freely floating in the solar nebula [2], and (3) a combination of both [4]. We experimentally study the formation conditions that are required to form dusty rims and their influence on the collision behavior of chondrules. We developed an experimental setup to test the hypothesis that the rims were formed by shock compression events on larger bodies. Furthermore, we developed two methods to form dust rims with different morphologies and porosities. In this latter set of experiments, we also consider how temperature effects can influence the rim occurrence and morphology. According to the second formation scenario, it is likely that a large number of dust-coated chondrules were freely floating in the early solar nebula. These would mutually collide and the results of these collisions are studied in our multiple collision experiment. Additionally, we investigated the collision behavior between artificial chondrules and dust aggregates of the same size referring to a scenario in which a large population of dust aggregates was present concurrently with the chondrules.

Impact Experiments

For testing the hypothesis that chondrule rims were formed in shock compression events on larger parent bodies, we designed a new experimental setup to dynamically compress a dusty target by a projectile with velocities up to 1000 m/s. The target consists of glass beads (artificial chondrules) and SiO_2 dust with various morphologies. In the first experiments, we varied the target compositions to experimentally test which chondrule abundances and velocities are required to form fine grain rims around the surviving chondrules. Our results are that for few glass beads embedded in dust, the target was compressed into a pellet, even for low velocities of around 75 m/s. However, a clear rim structure could not be found for these velocities, and also the porosity is still much higher than expected for chondrule rims. For a target of glass beads without any dust, we found a break-up of about 80% of the glass beads for velocities of 450 m/s. In these experiments, the crushed glass beads formed a pellet which could be embedded in epoxy resin and analyzed. Here, we found a rim like structure of fine grained particles which was radially symmetric around the surviving glass beads.

Coating Experiments

Following the hypothesis of solar nebula origin of the accretionary rims around chondrules, we used two experimental methods to form rims with different morphologies and porosities around artificial chondrules. One method uses the aerodynamic levitation of millimeter-sized glass beads (our chondrule analogs) in a gas flow, enriched with μm-sized, monodisperse, spherical SiO_2 dust. Here, the artificial chondrules accrete the dust very evenly, forming highly porous rims with a porosity of 82%. The second method aims at producing dust rims formed in multiple low-velocity collisions of chondrules with dust aggregates of the same size. Here, dust from the dust aggregates is transferred to the surface of the solid chondrule. This is realized by shaking a glass bead for a defined time in a dust filled container. These collisions also tend to form rims but less evenly and with a significantly lower porosity of 60%. Chondrules coated with both

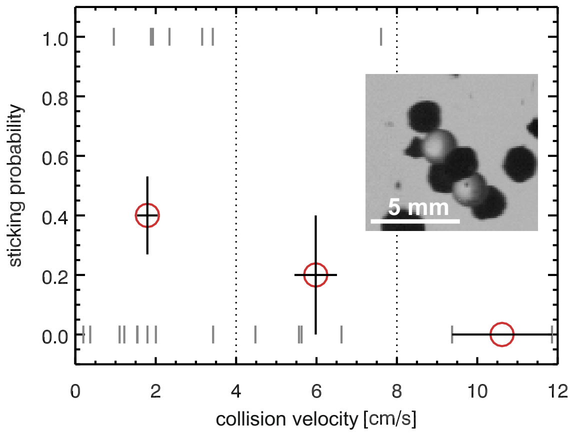

Figure 1: Sticking probabilities for collisions between dust aggregates and glass beads of 2 mm diameter. The averaged sticking probability (circles) decreases with increasing collision velocity. Collisions between dust particles and collisions between glass beads are not taken into account, because these collisions only leads to bouncing in the conducted velocity range. The inset shows a cluster of 5 dust aggregates (black) and 2 glass beads (white / transparent).

methods were used in a multiple collision microgravity experiment. An important parameter for the accretion of dust rims is the temperature. Metzler et al. [5] assumed that there is no reaction zone between the chondrule and the dust rim, therefore it is clear that the chondrules were solidified before accreting their rims. However, it is likely that these chondrules could still have been very hot when starting to accrete dust. Thus we extended our experimental setup by attaching a laser to heat chondrule analogues (realistic compositions) while coating these with olivine dust. In this experiment we found sintering effects between the dust grains and analyzed the influence on their morphology with SEM imaging and micro-CT analysis.

Multiple Collisions Experiments

To constrain the influence of the different rim structures on the collision behavior, and thus on the formation of larger bodies in the solar nebula, we set up a multiple collision experiment for studying free particle-particle collisions under microgravity conditions (see abstract by R. Weidling and [6]). Here, we found that dust coated particles are much more cohesive compared with non coated chondrules and even dust aggregates of the same size [7]. Additionally, we learned that a system consisting of both, solid particles and fluffy dust aggregates of the same size, does also much easier lead to the growth of larger particles than a single-composition ensemble. The sticking probability for collisions between 2 mm glass beads and dust aggregates with a volume filling factor of $\phi = 0.35$ is shown in Fig. 1. In this experiment, subsequent sticking collisions lead to clustering of glass beads with dust aggregates. This is evident from the inset picture of Fig. 1 which shows that glass beads and dust aggregates align alternatingly and are not sticking among the same kinds.

Acknowledgements

E.B. thanks the Deutsche Forschungsgemeinschaft (DFG) for support under grant Bl 298/13-1. We thank A. Pack and R. Mathieu from the Göttingen University for providing us with the hardware for the chondrule heating experiment and supporting us with artificial chondrule material. We thank M. Rott from the TU Munich for the support with the exploding wire gun accelerator for the high velocity impact experiments. We thank the Deutsches Zentrum für Luft- und Raumfahrt (DLR) for financial support (grant 50WM0936) and for providing us with drop tower flights.

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