Experimental Studies on Impacts of Chondrules into porous Dust Agglomerates under Microgravity Conditions

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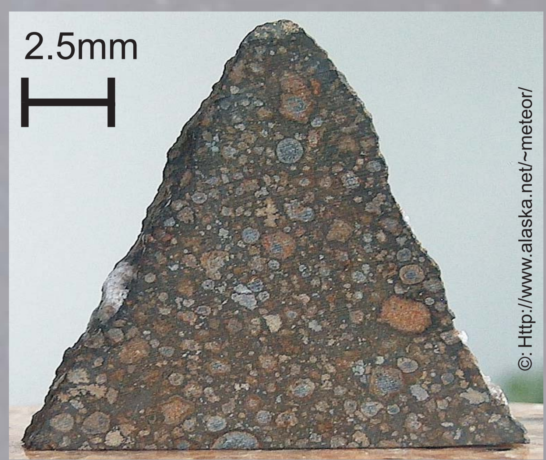
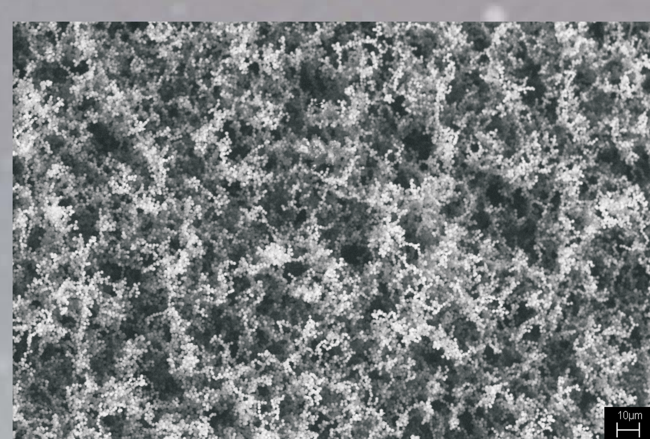
Introduction



Primitive meteorite "NWA-2224-cv3" found in Morocco with embedded chondrules.

A lot of primitive meteorites found on earth consist of millimeter-sized spherules, so-called chondrules, which are embedded in a porous, dusty matrix. These chondrules formed in the early solar system by melting of dust aggregates. Somehow, the chondrules and matrix dust must have merged to form larger objects (meteorite parent bodies).

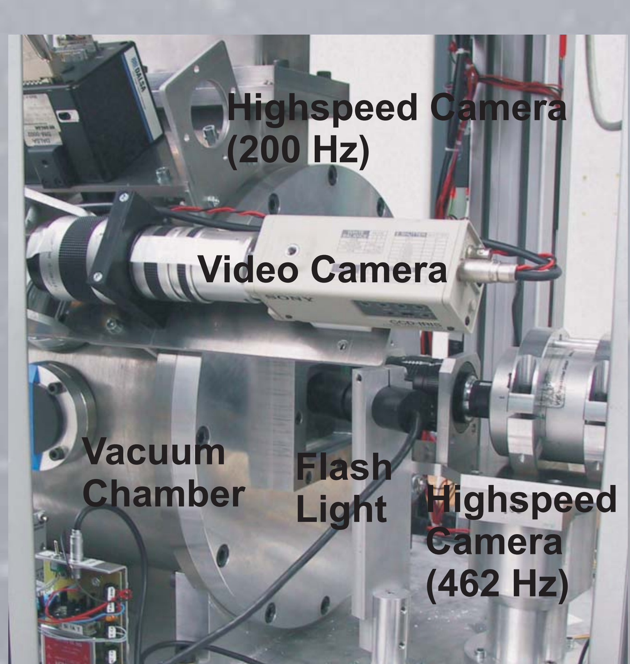
In this experimental study, we try to shed some light onto the formation process of primitive asteroids. We investigate the physical conditions under which the embedding of chondrules into a dusty matrix is possible.



Highly porous dust aggregate, which is similar to a predicted early solar system body. It is formed by random ballistic deposition. [1]

For the simulation of growth processes in the early solar system, we perform impact experiments of artificial chondrules into dust aggregates under microgravity conditions. We use glass spherules (d=1 mm, m=2.01 mg) as artificial chondrules. The targets consist of cm-sized highly porous dust agglomerates, which are produced by random ballistic deposition and are similar to the predicted bodies in the solar nebula . As the experiments require microgravity, we performed them in the Drop Tower in Bremen.

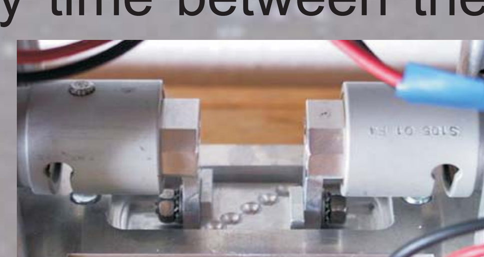
Experimental Setup



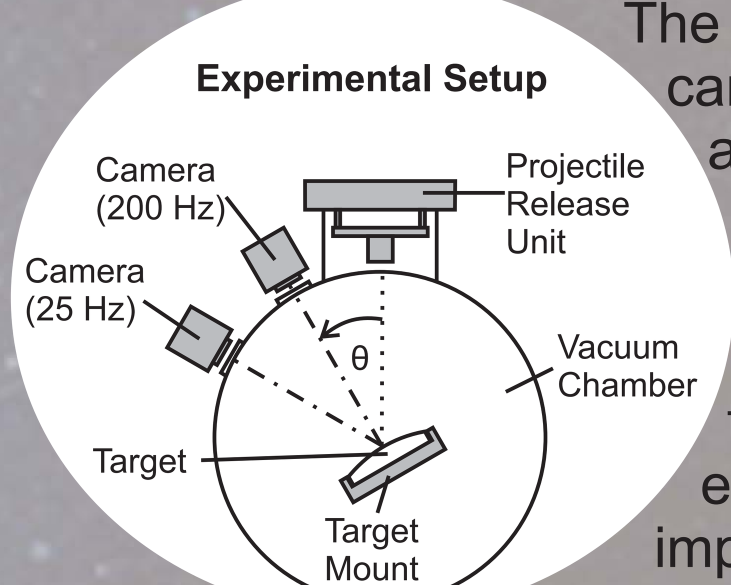
Experimental setup, integrated into the drop capsule.

The experimental setup consists of a vacuum chamber with three different cameras for impact observation. The camera installed at the front side of the chamber is operated at 462 frames/s and is the most important one for data analysis.

The artificial chondrules are released during normal gravity by the projectile release unit. By choosing a delay time between the projectile release and the drop of the capsule (i.e. the onset of microgravity), a relative velocity between projectiles and target can be reached. By variation of this delay time, impact velocities between ~0.5 m/s and ~3 m/s can be achieved.



The projectile release unit consists of two modified solenoid valves and 5 conical projectile carriers.

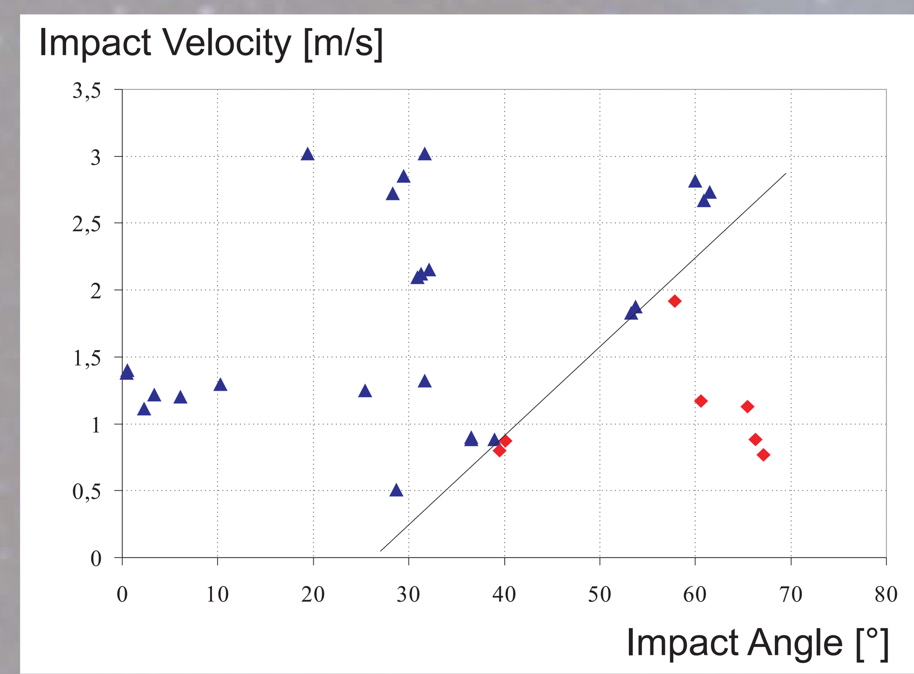


The target mount can be adjusted to three different angles with respect to the horizontal (θ=0°, 30°, 60°).

The real impact angles, differ from these ideal angles because the target surface is not perfectly even. For determination of the true impact angle, every target surface is scanned by a laser prior to the experiments so that the topography of the target surface can be determined.

At the Drop Tower in Bremen, 15 microgravity experiments were performed in December 2005. The velocity range between 0.5 m/s and 3 m/s was covered. The targets consisted of monodisperse, spherical SiO_2 graines (d=1.5 µm).

Results



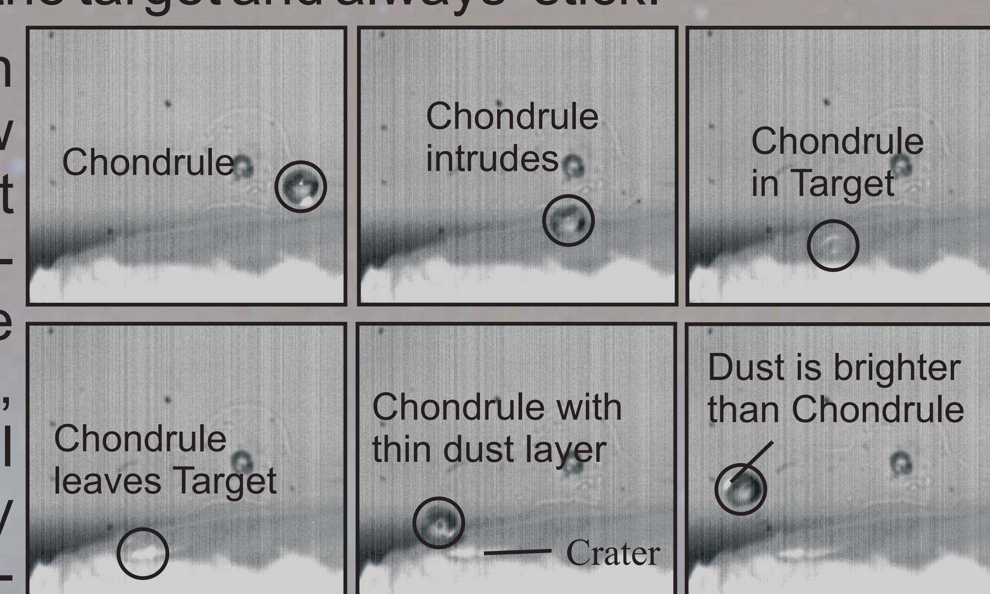
Velocity distribution as a function of the impact angle. Chondrules which stuck in the target are shown as blue triangles, non-sticking chondrules as red diamonds.

Experiments under normal gravity show very consistent results. The projectiles always intrude into the dust agglomerates and form a cylindrical intrusion channel. Under microgravity conditions, the impact results are different from our laboratory experiments.

The results depend on impact velocity and impact angle. The diagramm shows an overview over the impact experiments performed in the Drop Tower in December 2005.

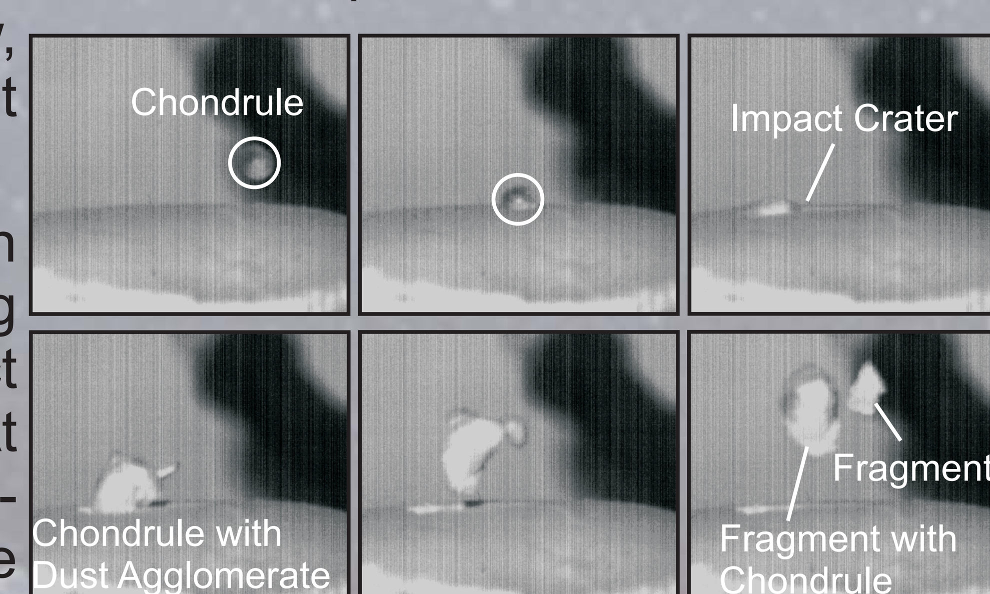
For low impact angles, impact results are similar to our laboratory experiments. Projectiles intrude into the target and always stick.

At high impact angles (e.g. 60° with respect to the target normal) and low velocities, no sticking is observed. At these parameters, the artificial chondrules intrude into the dust aggregate and compress the top dust layers, leave again and drag dust material along with them. Mostly the material dragged along is only a thin dust layer around the glass spherule. In these cases, the impacts show quasi-elastic characteristics as shown on the image series above.



Example for a quasi-elastic impact (v_{in} = 1.13 m/s, θ_{in} = 65.4°, v_{out} = 0.33 m/s, θ_{out} = -40.4°).

Sometimes, the compressed dust material of the target sticks to the projectile and leaves a bigger impact crater on the target. These compressed dust agglomerates are even larger than the projectile to which they stick. In some cases, this compressed material fragments into two pieces. As shown on the picture series below, these impacts are not elastic at all.



Example for an impact with mass loss and projectile fragmentation (v_{in} = 1.17 m/s, θ_{in} = 60.6°, v_{out1} = 0.098 m/s, θ_{out1} = 12.3°, v_{out2} = 0.12 m/s, θ_{out2} = 31.0°).

The boundary between sticking and non-sticking seems to depend on impact angle and impact velocity. At high impact angles, embedding processes require high impact velocities (e.g. for 60° v $\geqslant$ 2 m/s). At low impact angles the growth of the target starts at much lower velocities (e.g. for 40° v $\geqslant$0.9 m/s).

Conclusions and Outlook

We performed microgravity impact experiments between artificial chondrules and high-porosity, macroscopic dust agglomerates in the velocity regime between ~0.5 m/s and ~3 m/s to simulate early-solar-system processes in which chondrules were embedded into meteorite parent bodies. We found that the embedding of chondrules is feasible for low impact angles ($\leqslant$ 30 degrees) in the full velocity range. For more oblique impacts, however, the lower-velocity impacts did not lead to sticking but rather to a mass loss of the target. Preliminary results show that the minimum velocity required for the sticking of the chondrules increases with impact angle.

For a better understanding of the compression of the dust layers by chondrule impacts, x-ray experiments are planned. By taking x-ray pictures with a spatial resolution of 5 µm, the compression of the dust aggregates can be measured. To enhance our statistics at the boundary between sticking and non-sticking, further microgravity experiments in the Drop Tower in Bremen are planned for April 2006.

References: [1]: Blum,J, Astrophysics of Dust ASP Conferences Series, Vol. 309, 2004

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