Particle trapping and particle manipulation

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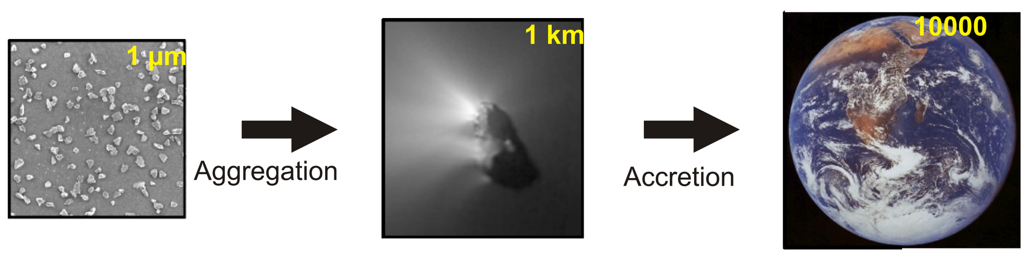
Introduction and objective

General Scope

The initial stages of planet formation occur embedded in a protoplanetary disc around a pre-main-sequence star. However the properties and physical processes of the dust, the dust-dust and dust-gas interaction in those circumstellar discs are not well understood.



Motion of particles is predominantly determined by friction with the ambient gas.

Motion of bodies is predominantly determined by gravity.

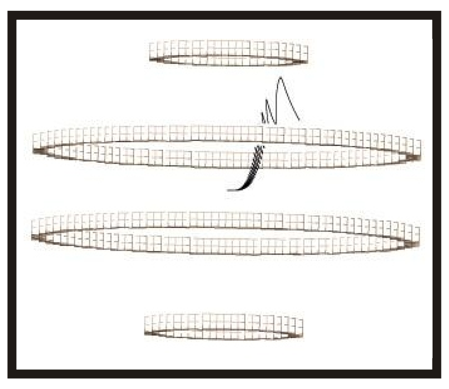
Introduction

Here an introduction is given to methods that allow manipulation and prolonged observation of micron-sized particles in order to determine more extended studies of the physical behaviour of dust. An extended time of observation is especially relevant for long-term space station-based experiments within the ICAPS programme planned to be launched in 2009.

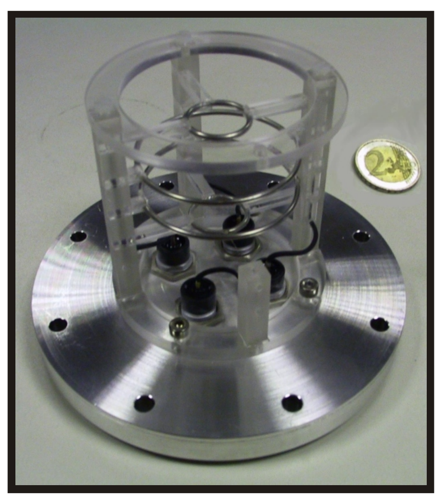
Objective

The aim of this work is to establish means to contain particles within a small volume for durations of $\gtrsim$ 30 minutes against residual forces of the order of 10^{-5}g. Further more, it is envisioned to simulate run-away growth by optical manipulation of dust aggregates.

The Paul trap



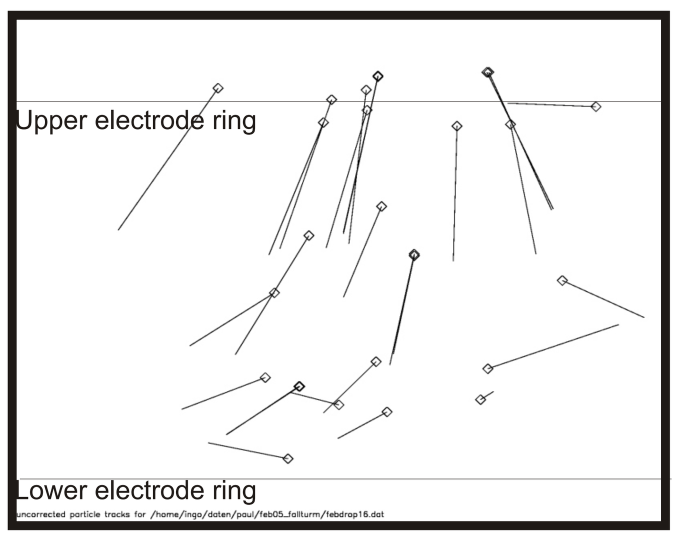
Above: typical track of a particle inside the trap



Right: photo of the trap with a 2€ coin for comparison

Principle of the Paul trap

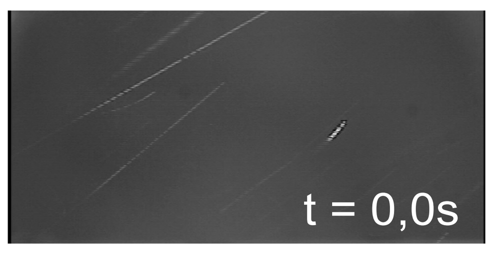
The paul trap is an electrical trap that features an alternating electrical field. Thus the charged particles oscillate. Doing so, they "see" the gradient in the electrical field and subsequently move towards lower field strengths - the centre of the trap.



Trajectories

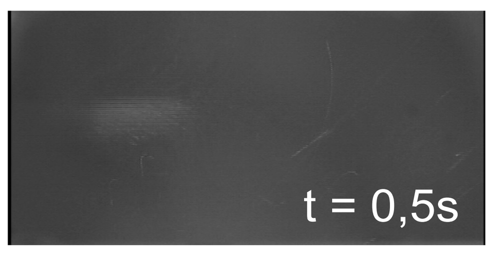
Trajectories as they were observed during a flight in the drop tower in Bremen. The end positions are marked by a diamond.

Clearly visible is the horizontal inward motion of the particles as well as a superimposed motion that is upward. The latter is introduced by a small DC-offset in the vertical direction.

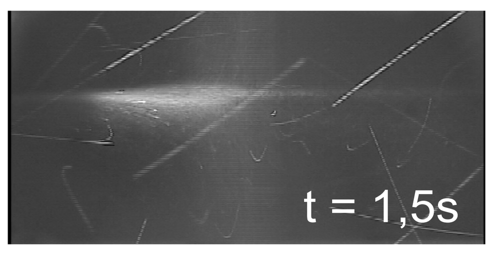


Start of microgravity

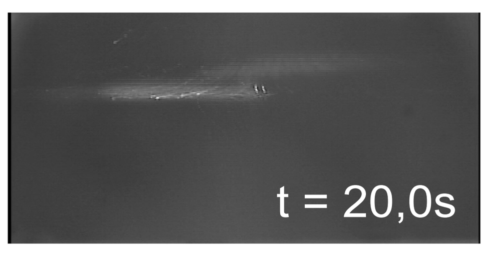
Pressure: 0.1mbar
Max. Charge: 6e-



Formation of a dust cloud

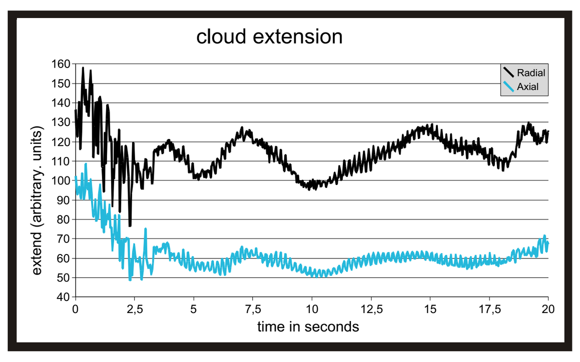


The maximum density of the cloud is reached approx 1..2s after injection.

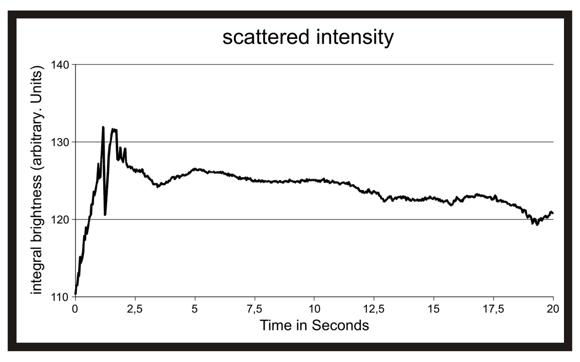


The cloud separates into a positively and a negatively charged one upon application of an electrical field. Neutral particles leave upon contact of the two partial clouds.

Results Paul trap

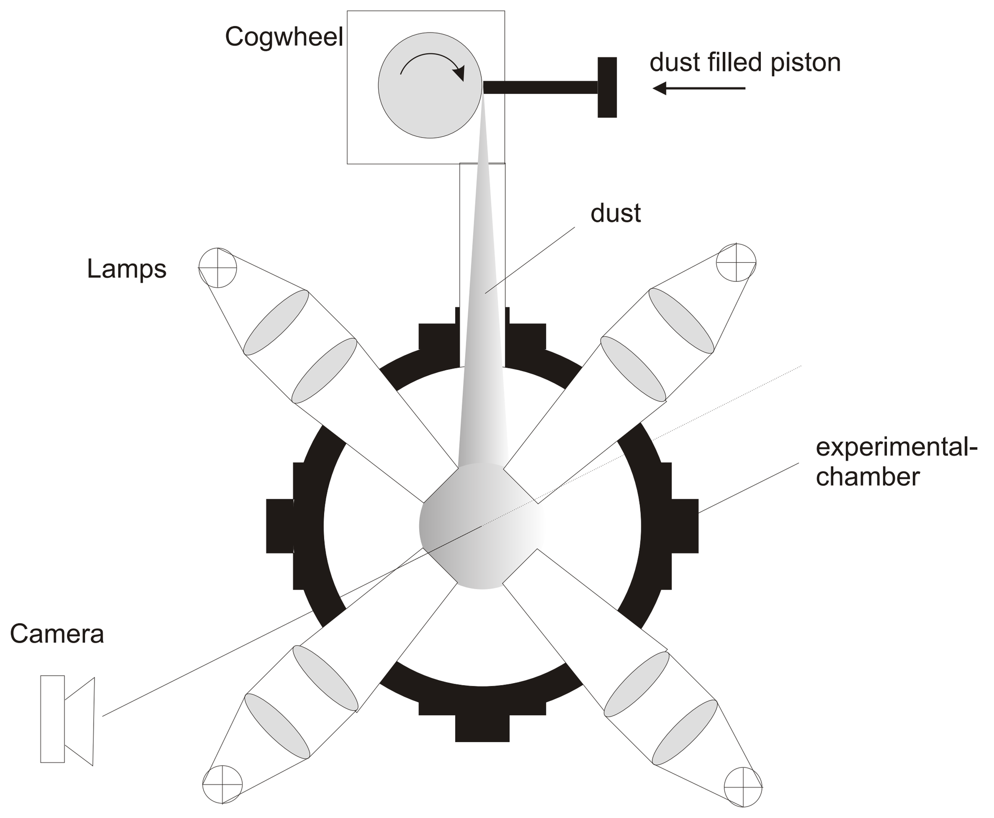


The trap can capture particles at accelerations up to $5 \cdot 10^{-2}$g.



To be solved remains the problem of mutual neutralisation upon collision of particles of opposite sign.

Photophoresis



Sketch of an experimental set-up that allows investigation of the strength of the photophoretic effect.

The photophoretic effect

Photophoresis happens if opaque particles are illuminated inhomogeniously. The surface of an illuminated particle will heat on the bright side. Therefore molecules of the ambient gas, that hit the particle will leave the particle on the illuminated side slightly faster than on the dark side, giving the particle a net momentum away from the light source.

The photophoretic force reads (Beresnev et al, 1993):

$$F_{ph} = -\frac{\pi}{3} \frac{R^2 I p J_1}{[\lambda_p T/R + 4\varepsilon\sigma T^4 + p(2kT/\pi m_g)]^{1/2}}$$

Where:

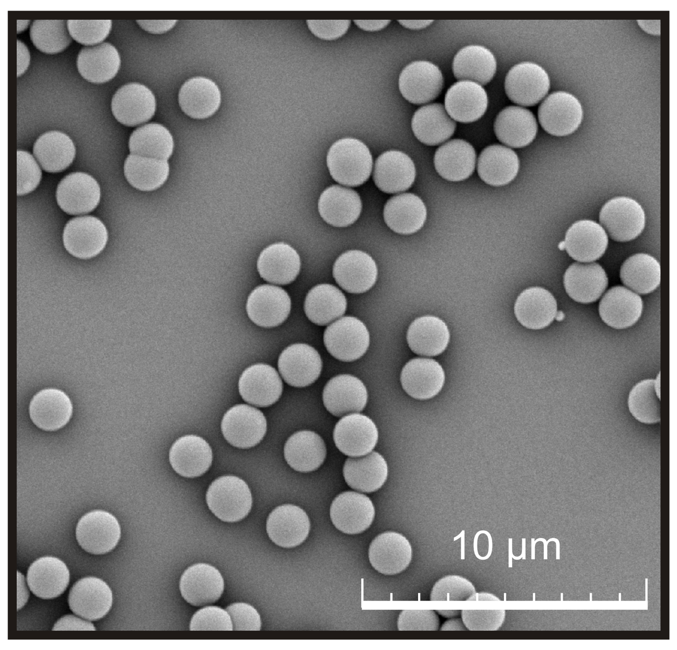
R: particle's radius	λ_p: particle's heat conductivity
I: light intensity	ε: particle's emissivity
p: ambient pressure	σ: Stefan-Boltzmann constant
J_1: Asymmetry-factor	k: Boltzmann constant
T: absolute temperature	m_g: particle's mass

Under astrophysically relevant conditions only the highlighted red parts of the formula are of relevance. Measurement of the photophoretic velocity allows the determination of the unknown heat conductivity of dust aggregates. Using photophoresis, optical manipulation of single particles within a dust cloud, and thus the study of run-away growth, will be feasible.

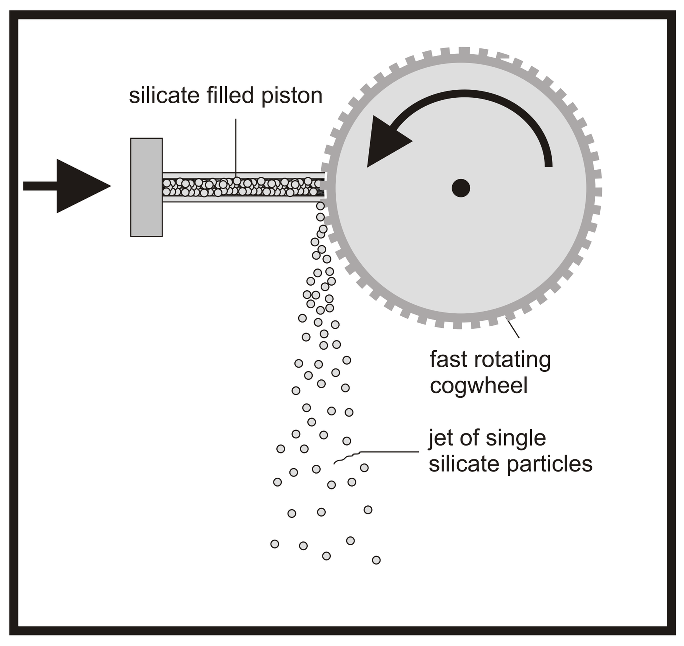
First Results

Recently, the photophoresis experiment was successfully flown under microgravity conditions on the DLR parabolic flight campaign. A first analysis of the data suggests that the photophoretic velocity increases with aggregate mass. Therefore the prerequisite for run-away growth are fulfilled.

Dust and dust deagglomeration



Electron microscope image of used dust particles.



Sketch of the "cogwheel" that is used to deagglomerate the silica spheres. The dust-filled piston is pushed upon the rotating cogwheel.

Charge

Determination of charge

Upon deagglomeration, particles sediment through a tube. Passing a capacitor inside the tube, the particles are imaged using a high-speed camera. The particles' tracks are determined based on sequences of images taken immediately before the capacitor is charged and sequences taken immediately after charging the capacitor, in order to allow tracking of single particles without exposure to an electrical field (reference measurements). While the particles pass the capacitor the electrical field is applied. Particle tracks are subsequently determined and compared to their velocity vector without an electrical field (see figure 1). In order to obtain the charge of the particles, the "data" measurements have to be deconvolved with the reference measurements.

The charge was determined as a function of the particle size, time after deagglomeration and surface properties of the cogwheel deagglomerator.

The average charge does not show significant deviation from zero charge with varying width of the distribution.

The width of the charge distribution depends strongly on the size of the particles and the surface properties of the cogwheel.

Further experiments are in preparation to investigate the long-term evolution of the average charge of a dust cloud.

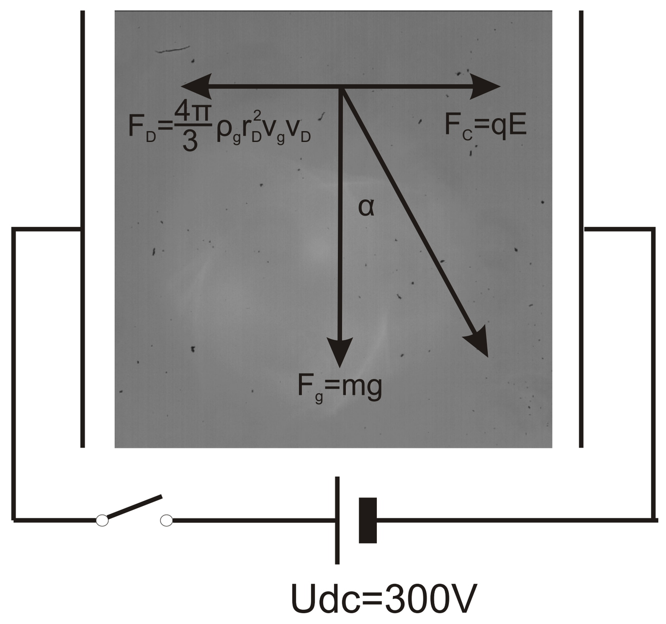


Figure 1: Sketch of the set-up used to determine the charge of the particles.

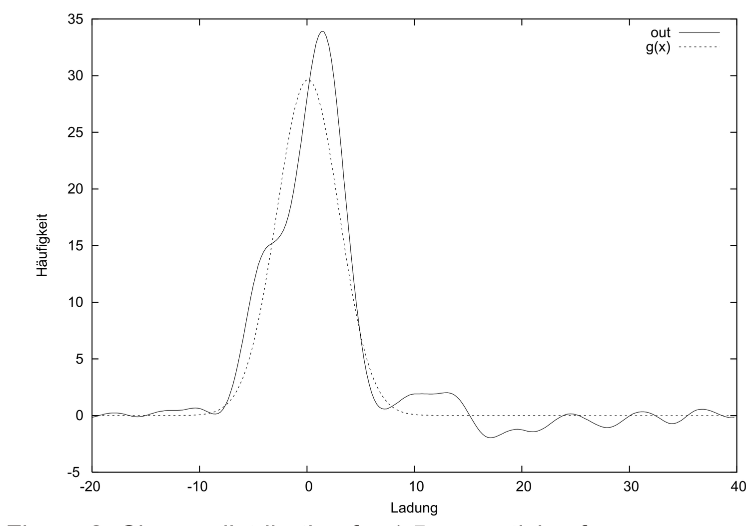


Figure 2: Charge distribution for 1.5µm particles from Lancester.

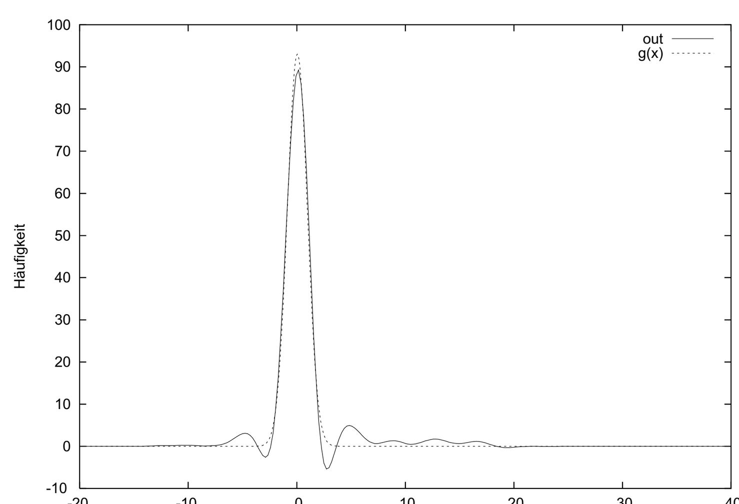


Figure 3: Charge distribution for 1.2µm particles from Micromod.
μ=0.05±0.02 e⁻, σ=0.91±0.02 e⁻

Results

The Paul trap experiments clearly show its functionality as a particle trap for slightly charged particles. The charge of the deagglomerated particles was measured and is within the limit (1..5 electronic charges) to allow observation of the dust-dust and dust-gas interaction without significant contribution of the Coulomb force. However, mutual neutralisation due to a symmetric charge distribution and the charge-evolution need further assessment and are currently investigated.

The preliminary results of the photophoresis experiment support a use of the effect to simulate experimentally run-away growth processes in protoplanetary dust clouds.

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