Erosion by Photophoresis and Natural Knudsen Compressors in Microgravity

UNIVERSITÄT DUISBURG ESSEN | PHYSIK

Protostars & Planets VI
Heidelberg, Juli 2013

C. De Beule ★
T. Kelling, J. Teiser, G. Wurm, T. Jankowski
Universität Duisburg-Essen, Fakultät Physik

Abstract. Experiments have shown that dust beds eject small, micron sized particles under illumination at mbar pressure [1-4]. This is caused by a solid-state greenhouse effect and photophoresis within the upper layers of the illuminated dust bed. Low gravity experiments showed that this effect strongly depends on gravity, which is in agreement with a developed model. In addition to experiments on parabolic flights, it was possible to get data in drop tower experiments, where light induced dust erosion is even more efficient.

Photophoresis and the Solid State Greenhouse effect.

An insolated dust bed develops an inverse temperature gradient [1]. The incoming radiation heats up the dust bed, but the surface can cool by thermal radiation. Hence the maximum of temperature is below the surface (Fig. 1) [6, 7]. Now photophoresis can act on the surface particles (Fig. 2): Because of the temperature gradient over the particles' surface and the low pressure enviroment, gas molecules accomodating the cold side of the dust particle leave it with a smaller momentum than gas molecules on the warm side [8]. The result is an acting force, acclereating the surface particles in the direction of the light source (Fig. 3).

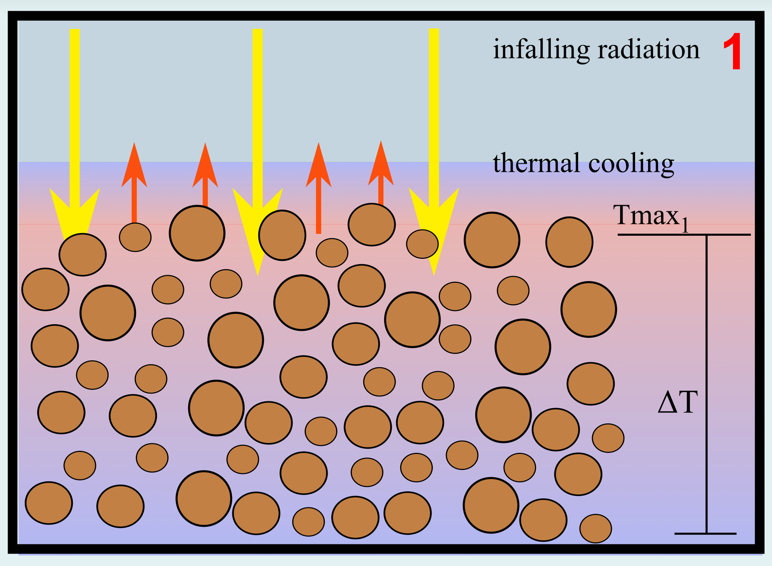


Fig. 1: Infalling radiation heats up the dust bed. The surface can cool by thermal radiation. The maximum of temperature is below the surface [6,7].

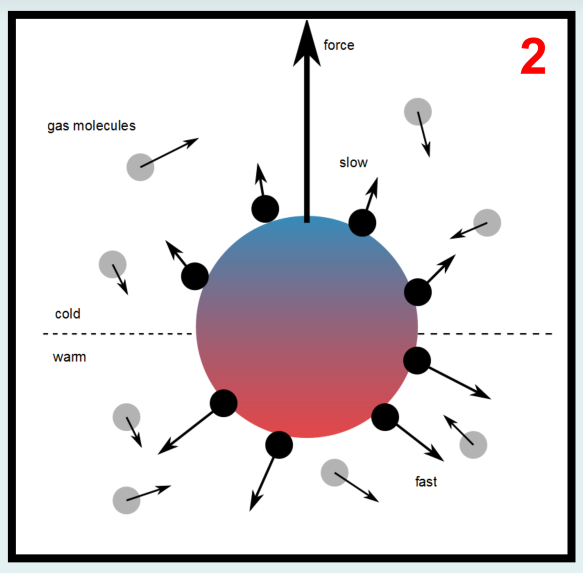


Fig. 2: If a particle has a temperature gradient over its surface in a low pressure enviroment, gas molecules accomodating the warm side of the particle leave it with a greater momentum than on the cold side. The resulting force accelerates the particle into the direction of the cold side [8].

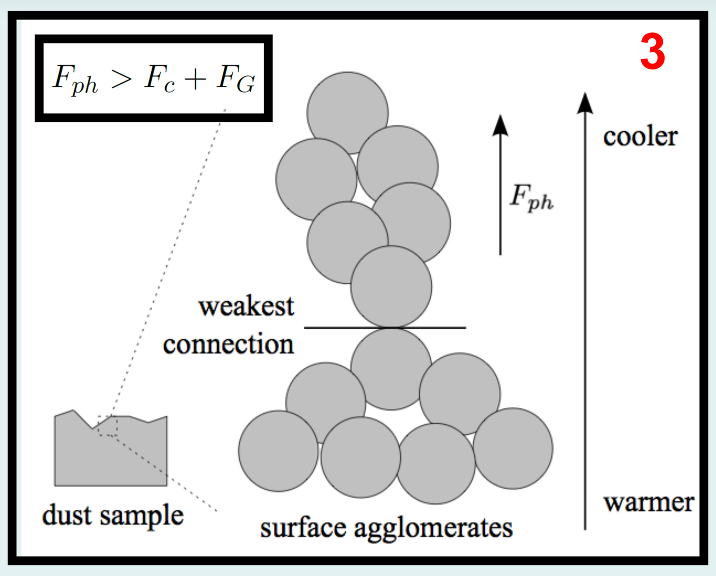


Fig. 3: The combination of the solid state greenhouse effect and photophoresis leads to a lifting force acting on the surface particles of an illuminated dust bed in a low pressure enviroment. When the photophoretic force overcomes gravity and cohesion, particles are lifted in the surroundings [6,7].

Parabolic Flight Experiments.

Basalt powder (0-125 µm grain size) is placed in a vacuum chamber (6 mbar) and illuminated by a red laser with an intensity of 13 kW/m².
This chamber is installed on a slow rotating centrifuge to avoid negative gravity for the dust bed. Another benefit is the possibility to set the gravity between 0.1*g* and 0.3*g* (*g* = 9.81 m/s²).

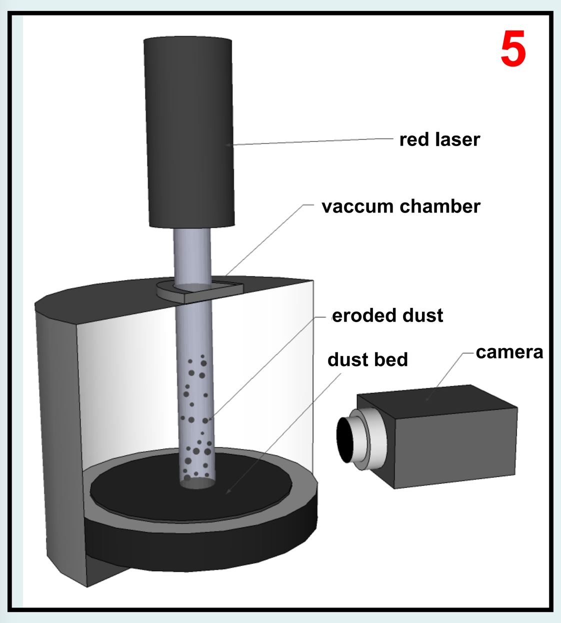


Fig. 5: Experimental setup on parabolic flight. A dust bed (2 cm diameter) of Basalt powder (0-125 µm) in a vaccum chamber with 6 mbar ambient pressure. A red laser is focused on the dust bed (13 kW/m², 8 mm spot).

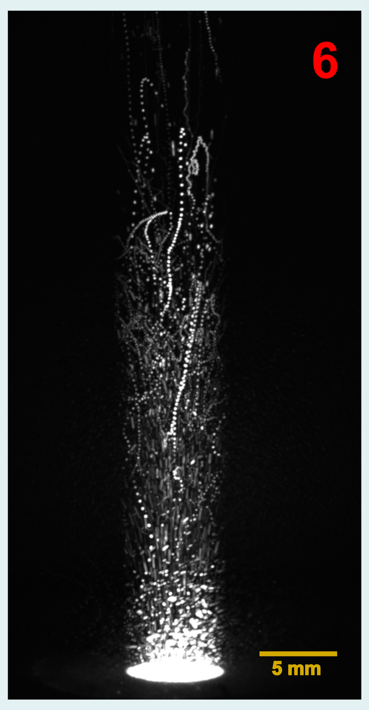
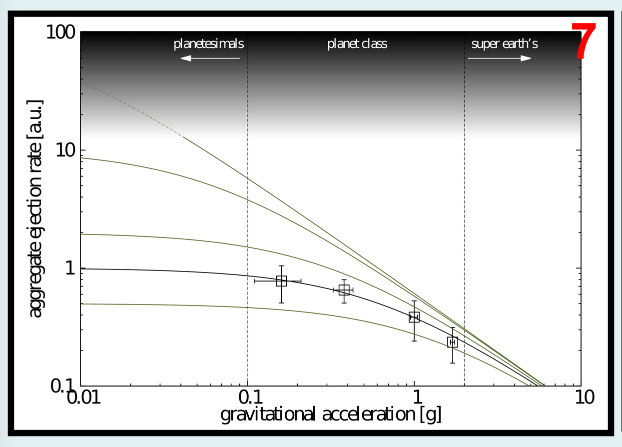


Fig. 6: Example of dust eruptions during 0.1*g*. The sample is Basalt (0-125 µm) illuminated by a red laser (13 kW/m²). The ambient pressure is 6 mbar. Frames of 16 seconds were superimposed.

Results. The experiments show increasing dust eruptions to lower gravity levels. The number of eroded particles is about 2 times higher in 0.16*g* than in 1*g*.



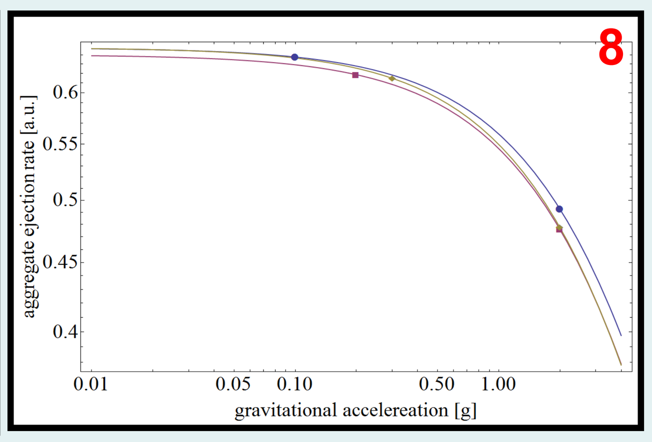


Fig. 7 & 8: Results of the parabolic flight campaigns. The left figure shows in addition to the data of 0.16*g*, 0.38*g*, 1*g* and 2*g* possible trends for different Fc/Δm (see equation below) between the dust particles, decreasing from bottom to top [5]. The right figure shows the last results of the centrifuge experiment with 0.1*g*, 0.2*g*, 0.3*g* and 2*g*.

Model. We developed a model [5], considering the photophoretic force [8], overcoming the gravitational force and cohesion (Fig. 3). This leads to a mass ejection rate of

$$N(g) = \frac{\Delta m}{\Delta t} = \frac{\omega}{g + {}^{F_C}/_{\Delta m}}$$

with the ejected mass Δm, Fc the cohesion force and the gravitational acceleration *g*. ω is a scalabel factor and contains informations about measurement details.

Drop Tower Experiments.

Two dust beds of Basalt powder (0-125 µm grain size) or blackened glass spheres (150-250 µm) are placed in a vacuum chamber (4 mbar) (Fig. 10). The small one is illuminated by a red laser (13 kW/m², 8 mm spot diameter) and the bigger one is illuminated by an infrared laser (20 kW/m², 3.4 cm spot diameter, Fig. 11).

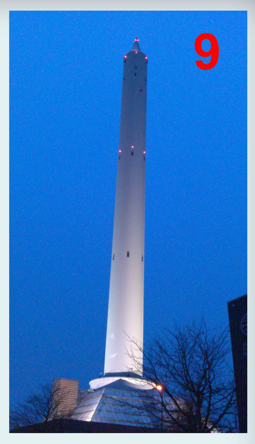


Fig. 10: Experimental setup of the drop tower experiment. Two dust beds containing Basalt (0-125 µm grain size) or blackened glass spheres (150-250 µm) with different diameters (3 cm and 7 cm) are placed in a vacuum chamber with an ambient pressure of 4 mbar. The small dust bed is illuminated by a red laser (655 nm, 8 mm spot diameter) and the larger bed by a IR laser (940 nm, 34 mm spot diameter). The light flux was varied between 6 kW/m² and 13 kW/m² for the red laser and 13 kW/m² and 27 kW/m² for the IR laser.

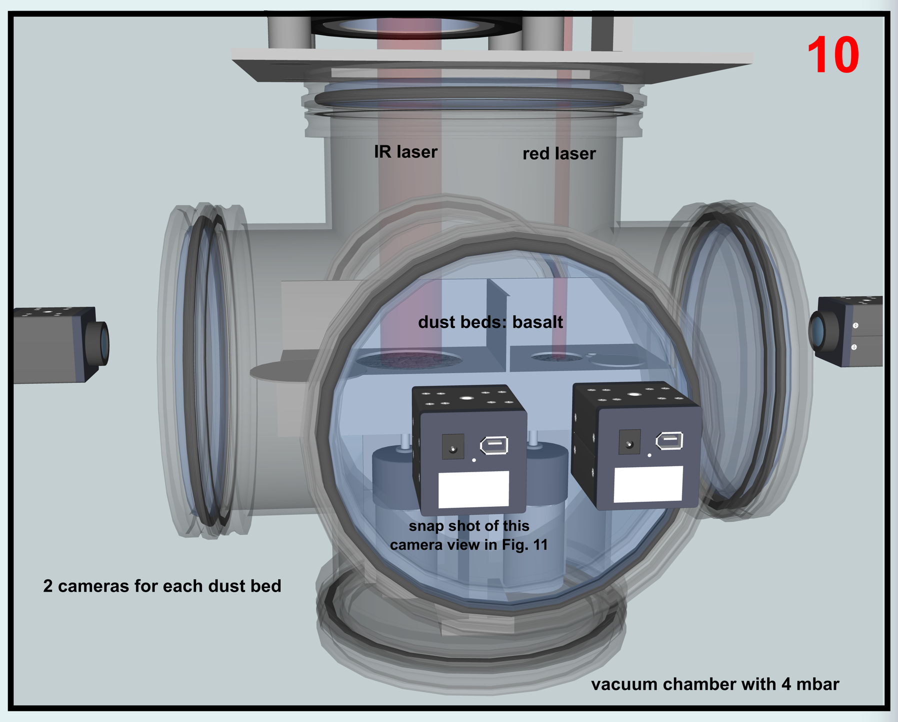
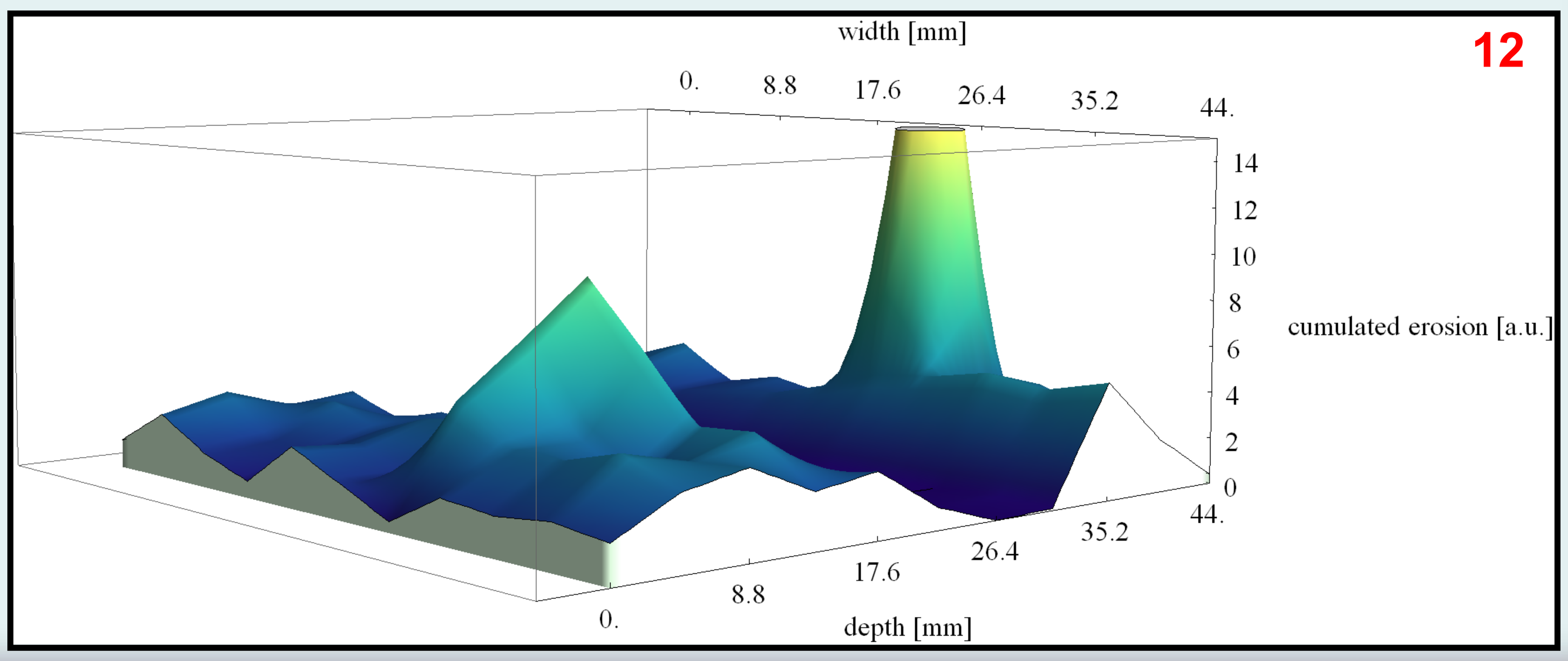


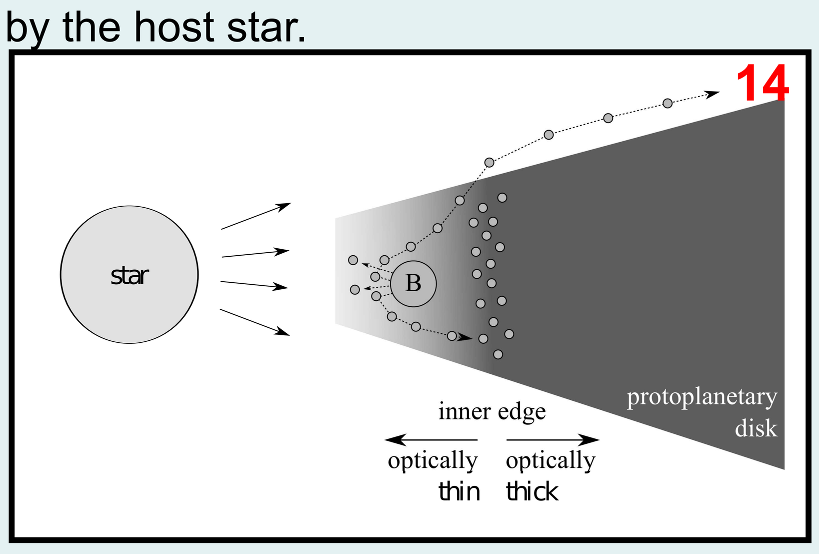
Fig. 11: Snap shot of the eroded particles during microgravity. This frame shows the dust bed of 7 cm diameter from the front (Fig. 10). The lightened part indicates the spot of the IR laser (34 mm spot diameter) upon the dust bed. The light flux is 27 kW/m² and the ambient pressure is 4 mbar.

Fig. 12: Cumulated erosion rate of one flight. The surface of the dust bed was fragmented in 11x11 squares with 4.4 mm width. The ejections were located in each of these boxes and cumulated over 6 seconds. Hence, the peaks show the active spots on the dust bed.



Application (1).

The effect of light induced dust ejections can be a key process of recycling dust during the formation of planets in protoplanetary disks (Fig. 13) [5]. It can be very efficient for small dusty bodies at the optically thin inner edges of the disk [2]. The produced dust can be transported outwards by photophoresis, so that significant parts of planetesimals are secured from being accreted by the host star.



Application (2).

Another Application can be found on Mars (Fig. 15, 16) . Wind speeds are in generally too low to explain dust lift on Mars. By adjusting the conditions (light flux and temperature) of light induced dust eruptions to Mars, dust entrainment in the atmosphere might be explained [9, 5].

References.
[1] Wurm, G. ,& Krauss, O. 2006, *PhRvL*, **96**, 134301
[2] Wurm, G. 2007, *MNRAS*, **380**, 683
[3] Kelling, T., & Wurm, G. 2009, *PhRvL*, **103**, 215502
[4] Kelling, T., & Wurm, G. 2011, *ApJ*, **733**, 122
[5] de Beule, C., Kelling T., Wurm, G., Teiser, J., Jankowski, T., 2013, *ApJ*, **763**, 11
[6] Kelling, T., Wurm, G., Kocifaj, M., Klacka, J., & Reiss, D. 2011, Icar., 212, 935
[7] Kocifaj, M., Klacka, J., Wurm, G., Kelling, T., & Kohut, I. 2010, *MNRAS*, **404**, 1512
[8] Rohatschek, H. 1995,*JAerS*, **26**, 717
[9] Wurm, G., Teiser, J., & Reiss, D. 2008, *GeoRL*, **35**, 10201

This work was supported by the Deutsches Zentrum für Luft- und Raumfahrt (DLR) and the Bundesministerium für Wirtschaft und Technologie (BMWi).

E-mail me!

★ **Contact**
Caroline De Beule
Universität Duisburg-Essen
Lotharstr. 1, 47057 Duisburg (Germany)
caroline.de-beule@uni-due