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Planet Formation: Light Induced Erosion of Planetesimals and the Production of μm Particles

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Abstract

Radiation in the visible can efficiently erode planetesimals in inner regions (< 1 AU) of protoplanetary disks [8, 3]. We found in laboratory experiments that intense optical light induces particle ejections and eruptions on dust beds. Temperature gradients within the dust bed lead to photophoretic and thermal creep forces (Knudsen compressor effects). The particle ejections work best at mbar pressures and kW/m^2 light intensities - both are present in the inner parts of protoplanetary disks. Planetesimals might lose up to kg/s mass by these particle ejections. In addition, the presented ejection mechanisms produce small particles (μm). This helps to understand how dust can be observed over the entire lifetime of protoplanetary disks [1].

1. Introduction and Experiments

Illuminated dust beds establish a so-called solid-state greenhouse effect: The maximum temperature T_{max} of the dust sample is below the surface [5, 6]. While the radiation heats the dust bed only the surface (top most layers) is able to cool by thermal radiation. Hence, two temperature gradients exist, one pointing from the maximum temperaure towards the cooler and deepers layers of the dust sample and the other one pointing from T_{max} to the surface. The surface dust aggregates therefore have a temperature gradient over themselves. Small particles with temperature gradients are efficiently accelerated by a photophoretic force at mbar ambient pressure [7]. The interaction of the gas molecules with the inhomogeneous heated surface leads to a momentum transfer from the gas to the particle. If this applied force overcomes cohesion and gravity, particles are released from the dust bed's surface (Fig.1). In laboratory experiments we observe that dust beds are eroded at a rate of $\sim 10^{-5}$ kg s^{-1} m^{-2} and that mostly small μm sized particles are released.

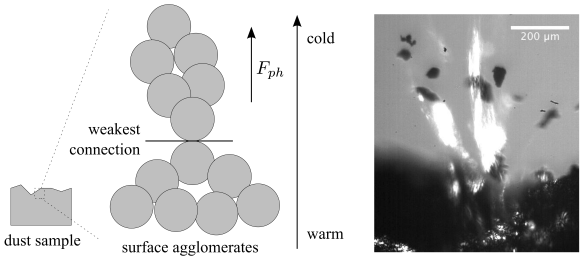

Figure 1: Left: Principle of photophoretic particle ejections; Right: Observed ejection from a basalt dust sample [3].

In addition, if the light source is turned off, the mass loss rate rises up to 10^{-3} kg s^{-1} m^{-2} – but only for approx. 10s after the turn off. Thereafter all particle releases come to rest. After the light switch off the temperature maximum moves deeper into the dust bed due to the more effective thermal cooling of the surface layers. While the absolute temperature gradient gets smaller (spans over more dust layers), the absolute temperature difference gets larger.The pores of the dust bed can be interpreted as a collection of microchannels along which the temperature gradient points [2]. Knudsen showed a century ago [4] that temperature gradients over thin connections may induce overpressures by thermal creep (Knudsen compressor effect) on the hotter end of the connection. Very similar to that, gas creeps through the pores of the dust towards the temperature maximum (Fig.2). If the overpressure overcomes the tensile strength of the surface, particles are eruptively released.

2. Application

In planet formation scenarios in protoplanetary discs the presented ejection mechanisms are relevant in several processes. For e.g. inward drifting bodies might not be lost by accretion but are (partially) eroded by the discussed effects. The released (small) particles (Fig.3) are transported outwards by e.g. photophoresis or upwards towards the disc edges by turbulence

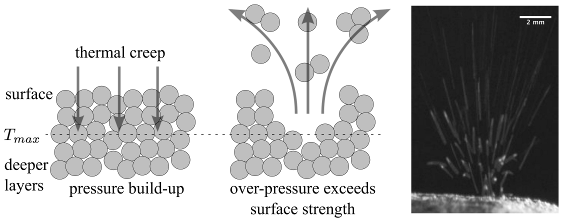

Figure 2: Left: Principle of overpressure induced particle ejections; Right: Observed ejections from a basalt dust sample [3].

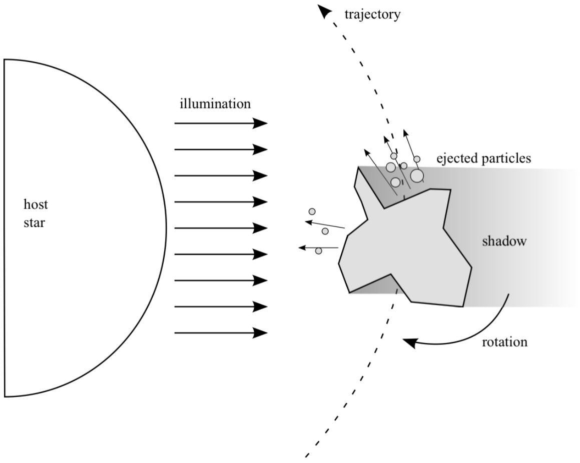

Figure 3: Erosion of a dusty body in a protoplaneraty dick [3].

where they can be observed over the whole lifetime of the disc.

3. Summary and Conclusions

We demonstated that light induces particle ejections from dust beds at mbar pressure. The ejection mechanisms are important for planet formation processes in protoplanetary discs as they can inhibit the accretion of inward drifting bodies by erosion. In addition, small μm sized particles are produced by these ejections which are reintroduced into the aggregation and planet fromation process and/or are transported towards the surface of the protoplanetary disk where the dust is observed.

Acknowledgements

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