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Destruction by Protoplanetary Winds - How Stable are Planetesimals?

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Abstract

In this work we study the wind induced erosion of spherical sub-mm sized glass beads at low gravity and low atmospheric pressure. Our experimental setup combines a centrifuge with a low pressure wind tunnel on a parabolic flight. We determined the threshold friction velocity in dependence of ambient pressure and gravity. This strongly constrains the region in protoplanetary disks where planetesimals built from pebbles are stable against erosion.

1. Introduction

The formation of planets is a process that involves a number of size scales. In the km-range planetesimals have to be formed. Current models predict that a planetesimal consists of a loose collection of mm to cm-sized dust aggregates. On such planetesimals self-gravity as well as cohesion are weak. In protoplanetary disks these small bodies move on Kepler orbits around the central star. They experience head winds of 50 m/s in the surrounding gas [1]. Depending on the ambient pressure this wind can be sufficient to lift dust aggregates and thus erode the planetesimal.

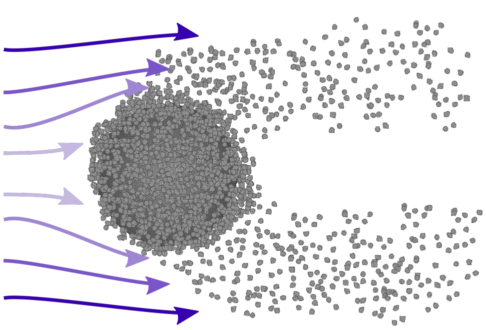

Figure 1: Planetesimals are destroyed under certain conditions of gas flow in protoplanetary disks.

2. Microgravity Experiments

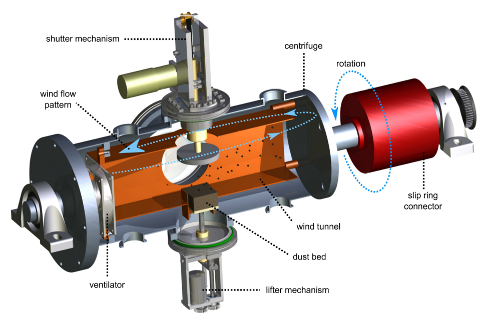

Figure 2: A schematic of the experimental setup [2]. The experiment combines a low pressure wind tunnel and a centrifuge.

We developed a parabolic flight experiment that combines a low pressure wind tunnel and a centrifuge. The wind tunnel is placed inside a vacuum chamber so we can operate it at various ambient pressures p from 10^{-1} to 10^{3} mbar. A fan inside the wind tunnel can generate a gas flow with velocities of up to 15 m/s. With this experiment we study the wind induced lift of dust and fine sand at different gravitational accelerations. The dust bed is placed at the bottom of the tunnel and is observed with a high-speed camera. The chamber which contains the wind tunnel also acts as a centrifuge. During microgravity of a parabolic flight we generate accelerations on the dust bed from 0.05 to 1 g with the centrifuge simulating different gravitational accelerations. On the recent parabolic flight campaign we have determined the threshold wind velocity u^* for spherical glass beads of diameter $d = 425 - 450\,\mu\text{m}$ for gravitational accelerations between 0.11 and 0.22 g and ambient pressures between 3 and 12 mbar. The gas flow is just set high enough for lifting events to occur and the threshold friction velocity u^* is determined. Due to the linear height dependence of the flow velocity $u(h)$ within the viscous sublayer the threshold friction velocity can be calculated as

$$u^* = \sqrt{\frac{\eta}{\rho}\frac{\partial u(h)}{\partial h}}, \qquad (1)$$

with the dynamic viscosity η and the gas density ρ. The height dependent gas flow velocity can be determined by the analysis of trajectories of lifted beads [3].

3. Wind Erosion

Several models predict the threshold conditions for particle lift going back to Bagnolds pioneering work [4]. The idea behind this model is that lift occurs if the gas drag force on the particle is greater than the particle's gravitational force. Shao and Lu [5] extended this model by considering the cohesion between the particles

$$u^* = A_N\sqrt{\frac{\rho_{\mathrm{P}}}{\rho}gd + \frac{\gamma}{\rho d}}. \qquad (2)$$

This equation can be put into the form

$$\rho u^{*2} = A_N^2\left(\rho_{\mathrm{P}}gd + \frac{\gamma}{d}\right), \qquad (3)$$

where the left side describes the gas properties and is proportional to the lift force. The right side of the equation is composed of gravity and cohesion which holds the particles on the bottom. Figure 3 shows the results of the recent parabolic flight campaign. Equation 3 is fitted to the data. The cohesion term is negligible in comparison to gravity for the used glass spheres, so that equation 2 can be reduced to

$$u^* \approx A_N\sqrt{\frac{\rho_{\mathrm{P}}}{\rho}gd}. \qquad (4)$$

4. Summary and Conclusions

We have determined the threshold friction velocity u^* for spherical glass beads at low pressure p and low gravitational acceleration g. We have found that cohesion is negligible for the diameter of spheres which are used in the experiments. Assuming that compact dust agglomerates behave similar to solid glass beads of comparable size, a loose collection of mm to cm-sized dust aggregates are mainly hold together by gravity. Scaled to the pressure conditions in protoplanetary disks and the gravitational accelerations on surfaces of planetesimals the threshold friction velocity can be estimated with current models (see equation 4). The stability of planetesimals and the regions of stability within protoplanetary disks will be presented and discussed at the conference.

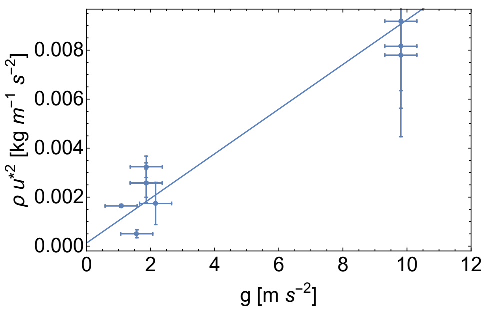

Figure 3: ρu^{*2} in dependence of the gravitational acceleration g.

Acknowledgements

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