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Studying the boulder morphology on comet 67P using discrete element simulations

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1. Introduction

Our overall aim is to investigate the physics of volatile-related surface features on asteroids and comets. In the present work, we focus on studying the morphology of boulders and cliff collapses on comet 67P/Churyumov-Gerasimenko's surface (Fig. 1). This study continues and complements previous work, where we have been investigating dynamical processes that are implied by surface features on comet 67P [1] and on asteroid Vesta [2].

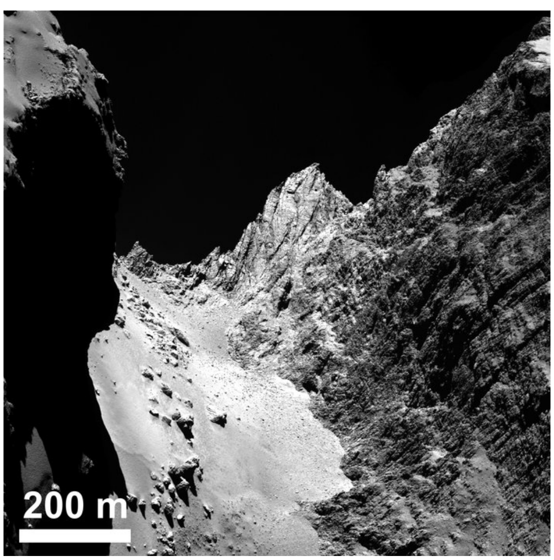

Figure 1: Boulders in the smooth Hapi region on comet 67P's neck, in front of the Hathor cliff (to the right). Credits: ESA/Rosetta/MPS for OSIRIS Team MPS/UPD/LAM/IAA/SSO/INTA/UPM/DASP/IDA.

2. Methods & Setup

As shown by Mottola et al. [3] cometary surfaces are a granular material. We model the dynamics of this material with the open source Discrete Element Method (DEM) simulation code LIGGGHTS [4]. Generally, we assume that the grains are small polydisperse spheres with sizes in the micro- to centimeter range, which consist of dust or ice and interact according to the Hertz contact model. Additionally, we consider friction, rolling friction [5] and cohesion [6] as well as the typical ambient surface acceleration on comet 67P (0.18 mm/s^2). Stronger inter-particle forces resulting from sintering are modeled by breakable parallel bonds [7]. To facilitate the simulation of macroscopic scenarios with small particles, we apply the method of 'coarse graining' [8]. Here several particles are represented as computational parcels, whose contact force parameters are scaled in a way that the computational parcels have statistically the same dynamics as the original particles.

The simulated cometary material is a mixture of two types of particles thought to be composed of dust or ice. For simplicity, they are assumed to differ only in two properties – the mass density (dust: $\sim$2000 kg/m^3, ice: $\sim$920 kg/m^3) and in their ability to form bonds from sintering (dust–dust: no, ice–dust: no, ice–ice: yes). In particular, it is assumed that both particle types have the same size distribution and the same mechanical and contact force parameters. The dust-to-ice volume-ratio is varied from 4:1 to 1:1 in different models, and the porosity of the dust-ice mixture is between 65% and 75%, resulting in a mean bulk density of about 500 kg/m^3, which is based on the measured value of 533 kg/m^3 for 67P [9].

3. Scenarios

To study the morphology and size distribution of boulders on comet 67P, we have designed two test scenarios that differ in their degree of complexity and build upon each other.

3.1. Boulder drop

We start with the requirement that boulders of sizes observed on the nucleus surface have to be stable without collapsing under their own weight or when falling from small (e.g. during cliff collapses) or larger heights (from the coma). For this purpose, we assume a large spherical boulder to be made up of small particles and investigate conditions for it to be reasonably stable when being dropped from small altitudes above a hard surface (Fig. 2).

This simple scenario is suited to study the effects of changing the size of the boulder, the dust-to-ice ratio, parameters of the particle size distribution, the bond strength, the cohesional force, Young's modulus and other parameters, information that can be used for setting up the more complex *Cliff collapse* scenario.

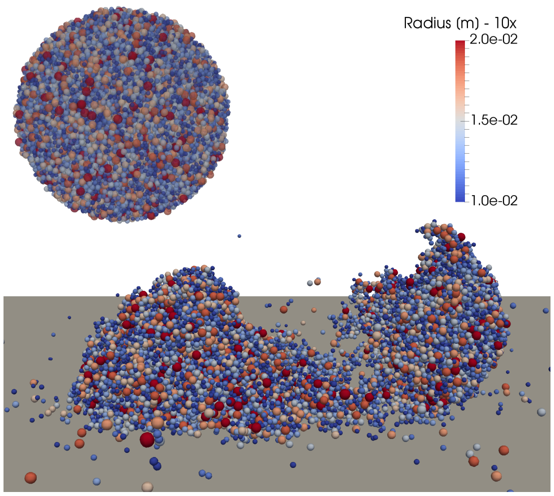

Figure 2: 1 m-boulder made up of a 1:1 dust-ice-mixture of 10x coarse-grained millimeter-sized particles, broken into two major parts, simulated with LIGGGHTS. Oblique impact with 30 m free-fall velocity.

3.2. Cliff collapse

Cliffs and overhangs are stable most of the time, but collapses have been observed on the nucleus surface [10], possibly caused by thermal or mechanical fracturing or weakening of the material by sublimation or seismic shaking [11]. We developed a corresponding simulation, where we assume a cliff or overhang of given height and front face slope angle and introduce artificial cracks to trigger the collapse.

Starting with the settings from the *Boulder drop* scenario, we further refine the model parameters by a direct comparison of the simulated post-collapse morphology with Rosetta observations of boulder fields in front of 67P's cliffs.

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