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An Evaluation of Electrostatic Lofting as the Source of the Bennu Particle Ejection Events

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Abstract

Electrostatic lofting is the phenomenon of particles detaching from a surface once the electrostatic force on the particles exceeds gravity and cohesion (which bind the particles to the surface). The surface of an airless body (e.g., the Moon or an asteroid) interacts directly with the solar wind plasma, which charges the regolith particles and produces a near-surface electric field. Beginning in January 2019, the OSIRIS-REx mission observed the ejection of cm-scale regolith particles at velocities up to m/s from the surface of the asteroid Bennu. We will present an evaluation of the feasibility of electrostatic lofting as the source of the ejected particles observed at Bennu.

1. Introduction

Electrostatic lofting occurs when the electrostatic force on a particle exceeds the gravitational and cohesive forces holding the particle on the surface of a planetary body, causing the particle to detach from the surface. The electrostatic force is the product of the charge on a particle and the local electric field. Regolith particles on the surface of an airless body are charged through their interaction with the solar wind plasma and solar UV radiation. Recent work has demonstrated computationally [6] and experimentally [5] that intense, small-scale electric fields are generated by the exchange of charge between neighboring particles. The surface of an airless body also accumulates some non-zero net charge, in addition to these particle-scale charge fluctuations. A plasma sheath near the surface forms and accelerates particles that have been detached.

We evaluate whether or not electrostatic lofting could produce the key characteristics of the observed Bennu particle ejection events: particle size and velocity.

2. Force Models

Particles on the surface of an asteroid are affected by three main forces: gravity, cohesion, and the electrostatic force. The gravitational force (F_g) on a particle is calculated assuming a spherical gravity model, with a gravitational parameter of 4.892 $\mathrm{m}^3/\mathrm{s}^2$ and an asteroid radius of 245 m [3]. Regolith particles are assumed to be spherical with a density of 2 $\mathrm{g/cm}^3$.

The cohesive force is proportional to $S^2 r_d$, where S is a non-dimensional measure of the cleanliness of the regolith (ranging from 0 to 1), and r_d is the radius of the regolith particle. Perko *et al.* [4] predicted that $0.75 \leq S \leq 0.88$ on the Moon. While this model of cohesion does not explicitly consider particle asphericity, using smaller values of S reduces the cohesion of particles, as might be expected due to particle surface roughness.

The electrostatic force (F_{es}) is the product of the charge on a particle and the local electric field. We model the charge on regolith particles using the method described by [6].

3. Particle Size

A particle will be electrostatically lofted if $F_{es} \geq F_{co} + F_g$. As described in [1, 2], because $F_{es} \propto r_d^2$, $F_g \propto r_d^3$, and $F_{co} \propto r_d$, there is some intermediate particle size that requires the smallest electric field to loft. Fig. 1 shows the electric field required to detach particles as a function of particle size and charging mechanism. During the day on an asteroid, we expect that the charging will follow the “Photoemission + Solar Wind" curve. Fig. 1 shows that, considering a conservatively low estimate of the cleanliness ($S = 0.1$), particles up to several mm in size are easiest to electrostatically loft. This curve shifts to larger particle sizes as the cleanliness is increased. Thus, with a slightly larger cleanliness (still far below the [4] prediction), cm-sized particles would be easiest to electrostatically loft, in agreement with the Bennu ejection event observations.

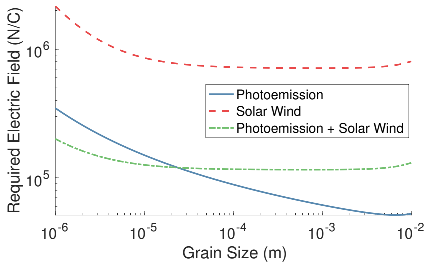

Figure 1: Electric field required to loft regolith as a function of particle size and charging mechanism for $S = 0.1$, assuming steady state charge as described by [6].

Secondly, Fig. 1 shows that electric fields on the order of 10^5 N/C are required to electrostatically loft particles. Zimmerman *et al.* [6] predict that electric fields as large as 10^7 N/C may be present in the gaps between regolith particles. Thus, it is possible that cm-sized particles could be electrostatically lofted on Bennu. Future work will evaluate the significance of dielectric breakdown and conductivity on these predictions.

4. Particle Velocity

At the instant of lofting, the cohesive bond is broken and there is an excess force on the particle that is equal to the strength of the missing bond. After the particle is more than one particle radius away from the surface, the particle will begin to interact with the plasma sheath electric field, rather than the local electric field. In order to approximate the velocity of lofted particles, we assume that the initial acceleration acts until the particle reaches an altitude of 1 cm above the surface. Fig. 2 shows the resulting velocity. This analysis suggests that cm-sized particles are unlikely to reach the average velocities observed at Bennu, unless additionally accelerated away from the surface by electrostatic forces or solar radiation pressure. However, mm-sized particles are able to achieve the velocities of $\mathcal{O}(0.1)$, without additional accelerations.

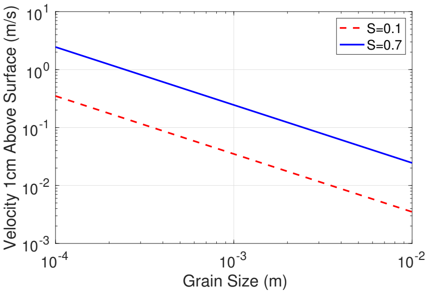

Figure 2: Velocity of particles 1 cm above the surface, assuming a constant initial acceleration.

5. Conclusions and Future Work

A preliminary investigation of the feasibility of electrostatic lofting as the Bennu particle ejection event source mechanism has been presented. We see that it is feasible to electrostatically loft mm to cm-sized particles on Bennu. Preliminary calculations indicate that the observed velocities of cm-sized particles require additional accelerations, beyond the initial lofting repulsion. Future work will refine these predictions via numerically propagation, including solar radiation pressure and a spatially varying plasma environment, of particle trajectories.

Acknowledgements

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