New Electrostatic Charge Models Show Dust Lofting at Ryugu and Bennu.

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Introduction: Charged dust lofting has been postulated as a means of transporting dust across the surface of small bodies, particularly bodies such as Eros where dust ponds have been observed [1]. While no direct observation of this phenomena has been reported to date, the Hayabusa2 mission to Ryugu and OSIRIS-REx mission to Bennu provide key opportunities to observe current dust particle distributions and behaviors on their surfaces, as well as to test predictions made by current charged dust transport models.

Past studies [2] have shown that the electric field strength required for dust lofting is far larger than what has been observed in nature. However, recent studies [3,4] suggest that newer charge models, such as the patch charging and supercharging models which predict orders of magnitude larger electric fields at the grain-scale, may be able to explain how dust becomes lofted at these bodes.

We use these new charging models, coupled with existing gravitational and plasma sheath models, to simulate single particle lofting from an asteroid's surface. Overall we find that dust lofting can occur frequently and across a range of sizes for various surface conditions at Ryugu. Additionally, simulations of Ryugu rotating at a faster rotation rate show loss of smaller particles from the body, suggesting that electrostatic lofting may have contributed to Ryugu's particle depletion over the course of its natural evolution. In this way, we may be able to explain why smaller grains are not seen in the first images of Ryugu's surface, as well as gain insight into how small bodies of this size have evolved and continue to evolve over time. We will also apply these models to the asteroid Bennu and expect similar results to hold true.

Methodology: There are four main components to the small body environment model—the gravitational model, the solar radiation model, the global electrostatic charging model (for the surrounding plasma sheath), and the grain-scale supercharging model (to determine grain initial conditions). The models are applied simultaneously to a single dust particle over a range of initial conditions. Each model is discussed briefly below.

Gravitational Model. A simple spherical body is used to model each asteroid's shape and gravity [5] with densities applicable for Ryugu and Bennu. More complex and irregular geometries will be assessed in future simulations.

Solar Radiation Pressure Model. A simple cannonball model is used to determine the solar radiation pressure on the grain. The additional challenge of accounting for solar eclipsing when the dust particle passes behind the small body with respect to the Sun is handled through implementation of an ellipsoid eclipsing model developed by Xin and Scheeres [6].

Electrostatic Charging Model. The global plasma sheath model used was developed originally by Grard and Tunaley [7] and more recently implemented to analyze dust accumulation in the craters of Eros by Colwell [1]. The model assumes a constant solar wind density, which enables analytical expression of the electric field strength as a function of height from the surface. The electric field strength at the surface of the small body is determined using current balance between solar wind electrons and photoemission particles. Note that this value is dependent on the solar incident angle, and thus the location of the particle.

To determine the particle charge over time, three main currents are considered—the current of photoelectrons to the particle, the current of photoelectrons emitted by the grain, and the current due to the collection of solar wind electrons. As the particle tends to charge positively in the sunlight, the flow of solar wind ions is neglected. Overall, the dust particle's charge changes over time as result of these currents.

Grain-Scale Supercharging Model. Because the behavior of dust grains is so sensitive to initial conditions, a method of determining realistic lofting conditions is necessary. Grain-scale supercharging has been postulated as a possible mechanism for grain launching, shown experimentally in [3] and theoretically in [4]. In this new patched charge model, charge unequally accumulates on the surface of a dust grain—with positive charge on the sunlit portions and negative charge on the shadowed surfaces—as opposed to the more traditional shared charge model where charge is equally distributed. In this new model, large electric fields build up in the shadowed regions between adjacent particles, giving these particles sufficient electrostatic force to overcome the forces holding them to the surface.

Zimmerman et al. [4] developed equations describing the electric field and associated force generated between oppositely charged adjacent particles. If we set the total upward (electrostatic) force equal to the total downward (gravitational + cohesive) force, we can explicitly solve for the particle charge required for lofting. Furthermore, we can coordinate the rotation rate of the small body with the charging rate of the grain to determine the exact location and time of day when the dust particle separates from the surface. The simulation begins at this lofting point, and the resulting particle behavior is recorded over time. Note that the grain-scale supercharging model is only applied while the particle is within two particle radii of the surface. Otherwise, the electrostatic model developed in [7] is used. Note that the maximum cohesion a given particle can overcome is limited by the half-rotation period of the small body, past which the particle does not have sufficient time to acquire adequate charge for separation from the surface.

Results: The first simulation of a spherical Ryugu involves three different particle sizes (5μm, 10μm, 35μm) at a single latitude (40 deg) over a range of regolith cohesions and for a body rotating with a period of 7.627 hours. The results are shown in Figure 1.

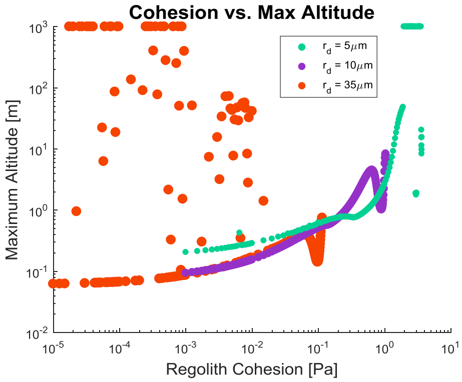

Figure 1. Cohesion vs. max altitude for various particle sizes at a single latitude. Body has a 7.627 hour rotation period. Escaped particles are shown at 1km.

From Figure 1, we see that there exists characteristic particle curves for the maximum altitudes reached as a function of particle size. Smaller particles (5μm) tend to reach the highest altitude and have the largest escape rate at 16.2%. This is because smaller particles require smaller charges for the same cohesion and gravity due to their smaller surface areas and masses. Surprisingly, larger particles (35μm) are also able to reach significant heights above the surface and some are even able to escape at the lowest cohesions with an escape rate of 12.7%. While it is more difficult for larger particles to acquire sufficient charge to overcome the greater gravity and cohesion they experience, if they do acquire adequate charge, they experience a much greater upward acceleration once separation has occurred. None of the intermediate-sized particles (10μm) escaped because their size is too large to be easily lofted, but also too small to gain sufficient acceleration for escape. It was also observed that smaller particles tend to escape at times around, but not at, local noon, while larger particles only escape in early morning.

The second simulation involves the same particle sizes and location but with a faster small body rotation period of 3 hours. This rotation period represents the fastest the body could spin without experiencing negative gravity, and one which may have existed in the body's early history. The results are shown in Figure 2.

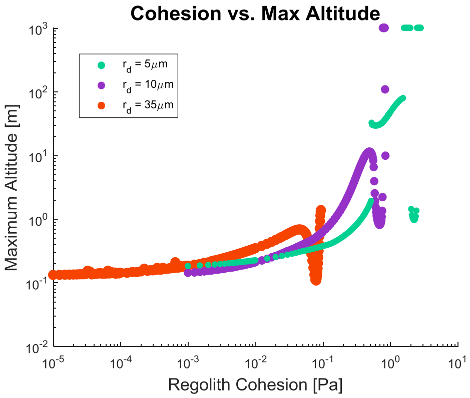

Figure 2. Cohesion vs. max altitude (left) for various particle sizes at a single latitude. Body has a 3 hour rotation period. Escaped particles are shown at 1km.

From Figure 2, we see again that there exists characteristic curves for the maximum altitude reached as a function of particle sizes, and that the smaller particles (5μm) still have the largest maximum altitudes and greatest escape rate of 11.9%. However, in this faster rotating case, the intermediate sized particles (10μm) are able to reach much greater altitudes than they were in the slower rotating case, with some even escaping from the body completely (4.0% escape rate). This is likely due to the greater rotational acceleration experienced by the particles in this faster rotating case. Note that the larger particles are not able to escape the body because the faster rotation period does not give them ample time to acquire sufficient charge for separation.

Conclusions: Overall our simulations show that charged dust lofting may be a common occurrence at small bodies like Ryugu and Bennu, and that it may have contributed to small particle population depletion at these bodies in the past. Future work will include application of the simulation to the unique shape models of these and other small bodies.

References: [1] J. Colwell et al. (2005) *Icarus*, *175*, 159-169. [2] C. Hartzell and D. Scheeres. (2011) *Planet. and Space Sci.*, *59*, 1758-1768. [3] X. Wang et al. (2016) *Geophys. Research Letters*, *43*, 6103-6110. [4] M. Zimmerman et al. (2016) *JGR: Planets*, *121*, 2150-2165. [5] R. Werner and D. Scheeres. (1997) *CMDA*, *65*, 313-344. [6] X. Xin, D. Scheeres, and X. Hou. (2016) *CMDA*, *126*, 405-432. [7] R. Grard, J. Tunaley. (1971) *JGR*, *76*, 2498-2505.