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Dynamics of levitating dust near equilibria on asteroids

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Abstract

The electrostatically-dominated movement of dust particles on asteroids has important implications both for our understanding of the morphological evolution of these bodies and the design of future exploration vehicles. We numerically demonstrate that it is possible to stably levitate micron and submicron particles 3-13 m above the surface of the asteroids Eros and Itokawa. We show that the timescales of dust motion are short enough (on the order of minutes) to allow dust to exhibit levitation in a relatively constant plasma environment on a rotating asteroid. Finally, we constrain the initial launching velocities that lead to dust particle levitation (a cm/s window) above Itokawa.

1. Introduction

The first observational evidence of electrostatically-dominated dust motion was the Lunar Horizon Glow seen by the Surveyor missions [1]. The hypothesis was extended to asteroids [2]. Electrostatically-controlled dust motion was hypothesized to have caused the ‘dust ponds’ on Eros [3]. The prospect of electrostatic forces controlling the motion of the smallest dust particles is of interest because it could be an important factor in the evolution of the surfaces of these bodies. Additionally, levitating dust (lofted through either natural or man-made means) could have implications for the surface activities of future exploration vehicles on asteroids [4].

The equations of motion of a dust particle are:

$$m_d \ddot{h} = Q_d E - \frac{m_d \mu}{(h + r_c)^2} \tag{1}$$

$$\dot{Q}_d = \sum I(h, Q_d) \tag{2}$$

where m_d is the mass of the dust, h is the altitude of the dust particle, Q_d is the charge of the dust particle, E is the local electric field strength, μ is the gravitational parameter of the body, and r_c is the radius of the central body. The electric field varies with altitude and solar incidence angle. The currents (I) experienced by the dust particle include photoemission, interaction with solar wind ions and electrons, and recombination with photoemitted electrons. We use the descriptions of currents and potential profiles given by Nitter *et al.* for the non-monotonic sheath [5].

2. Predictions

The equilibria about which dust particles will levitate are shown in Figure 1 as a function of particle size. We see that only dust particles smaller than ten microns (radius) will be capable of stable levitation and that this levitation is likely to occur at altitudes between three and thirteen meters above the surface of Itokawa. Increasing the central body gravity decreases the size of the largest particle that stably levitates.

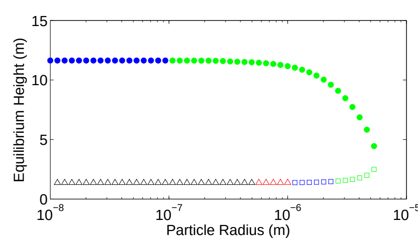

Figure 1: Equilibrium states as a function of particle size above the asteroid Itokawa at the subsolar point. Points are colored according to the number of electrons of the equilibrium charge: $[0, 1)e$, black; $[1, 10)e$, red; $[10, 100)e$, blue; $\geq 100e$, green. Solid circular points show the stable equilibria. Others are unstable.

From eigenvalue analysis, we have estimates of the characteristic times of the motion of dust particles both towards and about the equilibrium states. The characteristic times for the stable equilibria of Eros and Itokawa range from tens of seconds to tens of minutes. The oscillation periods about the stable equilibria on Eros and Itokawa range from fractions of seconds to minutes. Note that the plasma environment near the surface of airless bodies changes as the body rotates due to the dependence of photoemission on the solar incidence angle. Since the rotation periods of Eros and Itokawa are approximately 5.27 hours and 12 hours, respectively, it is possible for dust particles to approach and complete several oscillations about the stable equilibria under relatively constant plasma conditions. However, the characteristic time of the oscillation decay is on the order of days, indicating that particles are unlikely to ever reach the equilibrium state.

Given the timescales of the levitation motion, we expect that levitating dust particles will oscillate about a center that moves towards the surface as the asteroid rotates away from high noon due to the weakening of the plasma sheath. Eventually, the dust particle will reimpact the surface when the sheath becomes too weak to support altitude oscillations, potentially resulting in the formation of dust ponds.

Electrostatic dust lofting remains a poorly understood launching method [6]. We can constrain the initial launching conditions that will result in dust particle levitation. Figure 2 shows several trajectories started with initial conditions near the lower unstable equilibrium. For a small range of initial velocities (cm/s), dust particles will oscillate about the stable state. If the initial velocity of the particle is too high, it will either exhibit ballistic motion or escape. If the initial velocity is too low, the dust particle will fall to the surface. From Figure 3, it is clear that large variations in the particle's initial charge do not significantly influence the range of initial velocities that result in levitation.

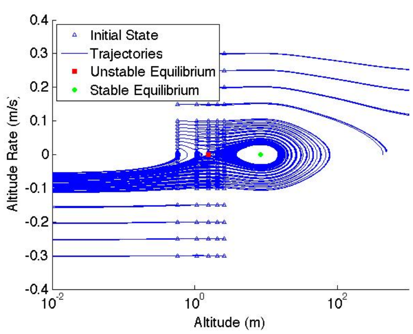

Figure 2: Trajectories for a 3.05 micron radius particle near Itokawa. The initial charge for all trajectories is the equilibrium charge at the unstable equilibrium.

3. Conclusions and Implications

We have shown that micron and submicron dust particles are capable of stable levitation at altitudes of 3-13m above the surface of Itokawa. It can be seen that there is a very small window of initial velocities that results in dust levitation above this body. Based on the expected timescales of motion, it is reasonable to expect levitation to occur on rotating bodies.

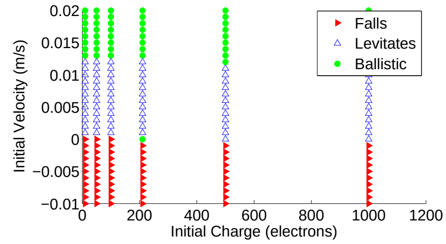

Figure 3: Fate of 3.05 micron radius particles near Itokawa as a function of initial conditions. The initial altitude for all trajectories is the equilibrium altitude at the unstable equilibrium (∼ 1 m).

Dust levitation may be a significant process in the morphological evolution of asteroids. Additionally, future exploration missions will want to avoid creating dust clouds. This work gives predictions of the sizes and altitudes of levitating dust particles that could be verified by future observations.

References

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