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Dust transport in photoelectron layers and the formation of dust ponds on Eros

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Abstract

We investigate the electrostatic transport of charged dust in the photoelectron layer over the dayside surface of an asteroid. Micron-sized dust particles may be levitated above the surface in the photoelectron layer. Horizontal transport within the layer can then lead to net deposition of dust into shadowed regions where the electric field due to the photoelectron layer disappears. We apply a 2D numerical model simulating charged dust dynamics in the near-surface daytime plasma environment of Asteroid 433 Eros to the formation of dust deposits in craters. We find that dust tends to collect in craters and regions of shadow. This electrostatic dust transport mechanism may contribute to the formation of smooth dust ponds observed by the NEAR-Shoemaker spacecraft at Eros. The size distribution of transported dust depends on the particle density and work function, and the work function of the surface and solar wind electron temperature and density. With reasonable values for these parameters, µm-sized and smaller particles are levitated at Eros. Micrometeoroid bombardment is not a sufficient source mechanism for electrostatic transport to create the Eros dust ponds. Laboratory measurements of dust in a plasma sheath show that dust launched off the surface by direct electrostatic levitation can provide a sufficient source for transport to produce the observed Eros ponds.

Keywords: Eros; Surfaces, asteroids; Regoliths

1. Introduction

Dusty regoliths are produced on the surfaces of virtually all airless bodies in the Solar System through ongoing bombardment by the interplanetary micrometeoroid flux. If these dust particles become charged, they may be transported across the surface by electrostatic interactions with the near-surface plasma environment. For example, lunar electrostatic dust dynamics are believed to be responsible for several observed dust phenomena (Zook et al., 1995; Zook and McCoy, 1991; Berg et al., 1974, 1976; Rennilson and Criswell, 1974; McCoy and Criswell, 1973). The spokes in Saturn's rings are most likely clouds of particles electrostatically levitated from the surfaces of larger bodies in the rings (Nitter et al., 1998; Goertz, 1989). In addition, electrostatic dust transport processes have been proposed on the surface of Mercury (Ip, 1986) and comets (Mendis et al., 1981).

The surface of Asteroid 433 Eros reveals a complex regolith in high resolution images taken by the NEAR-Shoemaker spacecraft (e.g., Veverka et al., 2000; Cheng et al., 2001; Kerr, 2001). Smooth deposits, or "ponds" were observed in craters ranging in size from 20 to 300 m in diameter (Veverka et al., 2001). The deposits are smooth down to 1.2 cm per pixel resolution indicating they are composed of particles significantly smaller than 1 cm (Robinson et al., 2001). The colors of the pond material, large boulders, and the background landscape are nearly indistinguishable (Veverka et al., 2001), though the ponds are slightly bluer in the visible than the surrounding terrain. The homogeneity of the surface colors can be explained by a layer of fine dust

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over the surface and is consistent with the ponds being composed of dust. The small color differences of the ponds can also be explained by a size distribution of grains $\ll 50$ µm (Robinson et al., 2001).

The mapped distributions of larger ponds correspond well with local regions of particularly long terminator durations, and there is an excellent correlation between ponds and low gravity areas (Robinson et al., 2001). Of the 255 large ponds (> 30 m diameter) 231 are located within 30° of the equator. These areas therefore also see the Sun rise and set, a factor that is required if terminator electric fields play a role in their formation. The observed characteristics of the Eros ponds require a mechanism that separates the fine fraction of regolith and a mechanism to concentrate particles in the depression that is most efficient along the equatorial belt. Global ejecta blanketing events can be ruled out by the correlation between pond depth and crater diameter.

Electrostatic dust levitation and transport has been proposed as a possible explanation for the observed dusty features on Eros (Cheng et al., 2002; Robinson et al., 2001; Pieters, 2001; Tepliczky and Kereszturi, 2002). This explanation was anticipated by Lee (1996) who recognized that levitated charged dust grains over asteroids could be transported to "smooth, flat, and/or perennially shaded areas, or where the particles become physically trapped, e.g., in topographic asperities and/or lows in dynamic height." Pond-like deposits have been observed in topographic depressions that are not craters (Veverka et al., 2001), consistent with the electrostatic model. The boundary between the smooth, flat, pond surface and crater walls can be quite abrupt (Robinson et al., 2001), and these craters "do not show… evidence of downslope movement on the crater walls" (Veverka et al., 2001). These observations are consistent with electrostatic transport of dust playing a role in the formation of the pond deposits. Other mechanisms that may be responsible for part or all of the formation of ponded deposits on Eros include seismic shaking (Cheng et al., 2002) and size sorting through evaporative processes (Kareev et al., 2002). We present results on the transport of charged dust near the surface of Eros and apply it to the question of the formation of the ponded deposits.

This work provides a numerical approach to the analysis of dust levitation and subsequent redistribution, and concentrates on the conditions at Asteroid 433 Eros. We investigate the role of electrostatic processes in redistributing material on the surface of Eros and producing some of the unusual features of its regolith, and we present a numerical model that simulates dust transport in a photoelectron sheath above a surface on Eros. A description of electrostatic dust levitation on asteroids is presented in Section 2. Our numerical model for transport on Eros is described in Section 3, and the results are presented in Section 4. Section 5 provides a discussion and conclusions. Our numerical simulations demonstrate that this mechanism may play an important role in the formation of the dust ponds seen at Eros.

2. Electrostatic dust levitation

2.1. Sheath and dust charging processes

The primary charging currents for the sunlit side of an asteroid are solar wind electrons, solar wind ions, and photoemission. On a sunlit, airless surface in interplanetary space, where the plasma density is that of the tenuous solar wind, photoelectric charging usually exceeds plasma charging. In the absence of other charging processes these surfaces become positively charged. The floating potential is dependent on the energy of the incoming photons and the photoelectric work function of the surface material. In equilibrium, the surface potential becomes positive enough to return emitted photoelectrons to the surface. These outbound and inbound electrons form a photoelectron sheath, or layer, above the surface. The photoelectrons in the sheath generate a vertical electric field which acts to return negatively charged particles to the surface and accelerate positively charged particles away from the surface.

Dust particles resting on the surface may become positively charged due to photoemission. If positively charged particles detach from the surface, they can thus be levitated in the photoelectron sheath. Conversely, dust particles that collect enough photoelectrons in the sheath to become negatively charged are accelerated down to the positively charged surface. When a particle leaves the surface the current of photoelectrons to the particle exceeds the current of photoemitted electrons and it can attain a negative charge as it passes through the photoelectron layer. If its initial velocity is high enough it will make it through the layer and attain a positive charge due to its own photoemission, making it possible for the particle to be stably supported by the upward electric field in the sheath. If, on the other hand, the particle spends too much time in the sheath, it will be negatively charged and accelerated toward the surface. The dynamics of a charged dust particle near the surface of an asteroid or other airless planetary body thus depend on the local plasma environment, the gravity of the body, and the variable charge of the grain. The levitation of dust particles in plasma sheaths has been studied numerically (e.g., Nitter et al., 1994, 1998) and experimentally (Doe et al., 1994; Arnas et al., 1999; Robertson et al., 2003).

Over small spatial scales, such as along the terminator of a rough surface, UV illuminated regions are adjacent to unilluminated regions. The photoemission from the illuminated regions leads to differential charging. Therefore, horizontal electric fields can occur in a photoelectron sheath in addition to the existing vertical field. Dust particles released from the surface may be transported across the surface in these fields. Also, if particles have any horizontal velocity when they enter the sheath, or if there are enough dust particles in the sheath to interact with each other electrically, then horizontal transport of dust will occur, with a deposition of dust where the topography changes or the electric field strength is reduced. The electric field may be greatly