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Space Weathering on Near-Earth Objects

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Abstract

The ion-sputtering process is active in many planetary environments in the Solar System where plasma precipitates directly on the surface (for instance, Mercury, Moon, Europa). In particular, solar-wind sputtering is one of the most important agents for the surface erosion of a Near-Earth Object, acting together with other surface release processes, such as Photon Stimulated Desorption, Thermal Desorption and Micrometeoroid Impact Vaporization. Since all other release processes produce particles of lower energies, the presence of neutral atoms in the energy range above 10 eV and below a few keVs identifies the IS process. The investigation of the active release processes, as a function of the external conditions and the NEO surface properties, is crucial for obtaining a clear view of the body's present loss rate as well as for getting clues on its evolution, which depends significantly on space weathering. In this work, we analyze the processes that take place on the surface of these small airless bodies, as a result of their exposure to the space environment, applying the Space Weathering on NEO (SPAWN) Model.

1. Introduction

The Near-Earth Objects (NEOs) are asteroids and comet nuclei in an evolving population with a lifetime limited to a few million years, having orbits with perihelion distances <1.3 A.U.. Due to space weathering, NEOs suffer erosion and surface alteration. The most important surface release processes at these distances from the Sun are Ion Sputtering (IS), Photon Stimulated Desorption (PSD), Thermal Desorption (TD) and Micrometeoroid Impact Vaporization (MIV). The IS process, active in many planetary environments in the Solar System - for instance, Mercury (e.g., [1]), Moon (e.g., [2]), Europa (e.g., [3])-, is defined as the removal of a part of atoms or molecules from a solid surface, due to the interaction of a projectile ion with target electrons and nuclei, as well as secondary cascades of collisions between target atoms [4]. Its products depend on the composition and the chemical structure of the surface. The PSD refers to the desorption of neutrals or ions as a result of direct excitation of surface atoms by photons [5], whereas the TD exists when the thermal energy of an atom exceeds the surface binding energy. The MIV refers to the impact vaporization caused by micrometeorites hitting the surface of an asteroid.

Different release processes produce particles within different energy ranges [6]. TD and PSD are more effective for volatiles (like H, He, Na, K, S, Ar, OH) and have typical energy lower than 1 eV. IS and MIV are relatively stoichiometric processes and are effective also for refractory species. Nevertheless, the particles produced via MIV have a Maxwellian distribution with a peak energy of ~0.6 eV. The IS is the most energetic release process among all others, being capable of releasing particles at energies above 10 eV [1] as well as refractory species (e.g., Si, Al, Mg). Discriminating the contribution of different processes permits to speculate on the surface erosion under different environmental conditions and to obtain clues on the history evolution of the body. In this study we focus on the IS process, presenting a Monte Carlo (MC) space weathering model for estimating the emerging particle flux and density distribution [7].

2. The SPAWN model

The SPAce Weathering on NEO (SPAWN) model is a new model intended to study space weathering effects taking place on the surface of an asteroid in the near-Earth interplanetary environment. The model takes into consideration the IS process as well as the PSD and TD processes and assumes a NEO composition similar to that of a CI chondrite type asteroid [8]. Deflection of the solar-wind ions by possible intrinsic magnetic fields possessed by the NEO [9] is considered negligible; consequently sputtering occurs only on the dayside of the NEO. A detailed description of the SPAWN model can be found in [7]. A brief presentation of the parameters used in the model is given in Table I.

3. Results - Discussion

In Fig. 1 the simulated intensity of the total sputtered flux produced by all species of sputtered particles emerging from a NEO surface, is presented. Up to an altitude of about 1 km above the NEO surface, the intensity of the sputtered-particle flux is about 10^{11} particles $m^{-2} s^{-1}$. The higher energy (>10eV) particle flux derived by previous considerations results in about 10^{9} particles $m^{-2} s^{-1}$.

Table 1: Input parameters of the SPAWN model

Parameter name	Suggested Value
Solar-wind flux	10^{12} $m^{-2}s^{-1}$
Energy of the incident particle	1keV
NEO Radius/Mass	500 m/10^{12} kg
Mass of the ejected particle	1, 12, 24, 27, 28, 32, 40, 56, 59
Sputtering Yield	see Plainaki et al. (2009)
Binding energy	2 eV

Considering the radius of the NEO equal to 0.5 km, the maximum global release rate of sputtered neutral atoms is calculated to be about $3.14 \cdot 10^{17}$ particles/s [7].

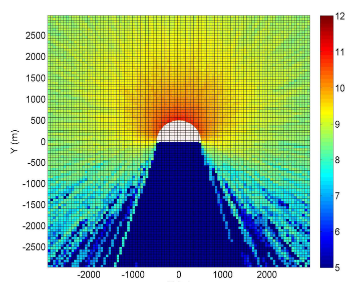

Figure 1: Sputtered-particle total flux for impinging particle of energy ~1keV. Colorbar unit is $m^{-2}s^{-1}$.

[10] have calculated for the asteroid (2867) Steins (radius ~ 4.6 km, distance from the Sun ~ 2.364 AU) a sputtering rate of $6.84 \cdot 10^{17}$ particles/s, for the emerging oxygen atoms. Similar escape rates for different asteroid sizes can be explained since our simulation mostly considers hydrogen atoms, while [10] consider only oxygen particles, which have the highest relative composition on the surface of asteroid Steins. Therefore, although the asteroid Steins is bigger in dimensions than the NEO studied, the different surface characteristics result in similar sputtered particle rates for the two cases. Moreover, from simulating both PSD and TD , we find that the total released particle flux can be up to ~10^{13} particles/m^{-2}/s.

The NEO erosion rate under sputtering is 0.3 Å/year [7]. On the other hand, the erosion rate under PSD is estimated at ~10 Å/year, if the corresponding neutral release rate is considered to have been constant. As much as the erosion rate due to TD is concerned, one should consider that in the past NEO was located farther from the Sun and its temperature was lower. Thus the erosion due to TD must have been negligible.

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