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Generation of Europa's exosphere

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Abstract

In this work, we look at the space weathering processes, responsible for the generation of Europa's exosphere. The heavy energetic ions of the Jovian plasma (H^+, O^+, S^+, C^+) can erode the surface of Europa via ion sputtering (IS), ejecting up to 1000 H_2O molecules per ion. UV Photons impinging the Europa's surface can also result in neutral atom release via photon-stimulated desorption (PSD) and chemical change (photolysis). In this work, we study the efficiency of the IS and PSD processes for ejecting water molecules, simulating the resulting neutral H_2O density. We also estimate the contribution to the total neutral atom release by the Ion Backscattering (IBS) process and by Micrometeoroid Impact Vaporization (MIV).

1. Introduction

The radiation environment of Europa includes fluxes of energetic electrons, protons, O^{n+}, S^{n+}, H^+ solar photons, and meteoroids. As a consequence of the existence of such an environment, the surface of Europa can be modified both physically (via sputtering, i.e., the erosion of a surface) and chemically (via radiolysis). IS and PSD are commonly thought of as two of the leading processes that drive neutrals from an icy surface. However, the surface erosion rate depends on the efficacy of all processes that take place on the satellite's surface, i.e.: a) IS, b) IBS, c) PSD, d) Thermal desorption (TD), e) Electron stimulated desorption (ESD) and f) MIV. In this work, we attempt to quantify the neutral particle fluxes emerging from the icy surface of Europa as a result of its interaction with impacting plasma, photons and meteoroids. The main results of our simulations are discussed in Section 3.

2. Model assumptions

The IS process, active, for instance, at Mercury [1] and the Moon [2], is defined as the removal of atoms or molecules from a solid surface, due to the interaction of a projectile ion with target electrons and nuclei [3]. In this study the IS yields for ice are taken from [4], whereas the impacting ion fluxes were taken from [5] and [6]. However, IS occurs mostly when the moon's atmosphere cannot impede the precipitating ion from reaching the surface or the liberated neutrals from escaping. In this study the moon is treated as atmosphereless, since the mean free path of the impacting particles (ranging from 13 km to 78 km) is of the same order of magnitude with the atmospheric scale height [7]. When ions impinge on a surface, IBS can take place; since impacting ions with energy less than about 1 MeV will interact with the surface as neutrals, the IBS process, in this model, is treated as a mechanical elastic collision between impinging ions and target surface molecules. PSD refers to the desorption of neutrals or ions as a result of direct excitation of surface atoms by an incident photon [8]. In TD molecules are released into gas phase due to the heat content of the surface. The ESD refers to the surface neutral release process via electron impact. Finally MIV refers to the impact vaporization caused by micrometeorites hitting the surface of a planet. In this model an interplanetary meteoroid mass flux of $7 \cdot 10^{-12}$ g s^{-1} m^{-2} in the region of Jupiter [9] is assumed. The particles released from Europa surface are either lost in space or they return to the surface if their energy is less than that corresponding to the escape velocity (Eesc= 0.38 eV). All neutral particles escaping from the moon's gravity are assumed either to remain on a ballistic trajectory or to be ionized.

3. Results - Discussion

Application of the model shows that among all the processes considered, IS is the most effective process in ejecting molecules with sufficient energy to escape. It is also found that contrary to IS and PSD, the IBS does not seem to contribute significantly to the total neutral particle release from Europa, in the energy range from some eV up to 1 keV (Fig. 1).

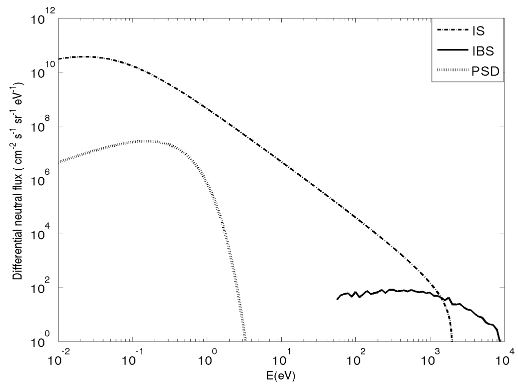

Figure 1: Intensity versus energy spectrum of the sputtered, back-scattered and PSD-ed neutrals.

The H_2O density due to PSD ($6 \cdot 10^8$ H_2O /m^3, on the surface of the illuminated side) is lower than that due to sputtering about 1.5 orders of magnitude. Considering that the emitted particles in the dayside travel to the night side have to cross a longer path inside the atmosphere, only 0.3% to 3% of the particles are able to reach the night-side. The most significant sputtered-particle flux and density come from the S^+ impinging ions and they are equal to 66% and 59% of total ones ($3.2 \cdot 10^{13}$ H_2O /m^2 /s and $2.7 \cdot 10^{10}$ H_2O/m^3, respectively). These results are in general in good agreement with estimates obtained by other studies. For disk-averaged temperature of 106K, on the basis of the equations given in [10], a sublimation rate of 10^{11} H_2O m^{-2} s^{-1} is estimated. However, locally, at sites where the temperature is relatively high, the H_2O vapour pressure and the sublimation rate increase. Therefore the TD process cannot be considered negligible everywhere. The neutral emission from the ESD process has a minor contribution to the total neutral density since the ESD-flux is 1.5 and 3 orders of magnitude less than that due to PSD and IS respectively. Moreover, the MIV process on Europa's surface, in general, can be considered of less significance since the energy input from meteoroids is of several orders of magnitude less than the particle energy fluxes [5]. In the higher energy range, above 1 keV, IBS (efficient for the light ions) dominates. The fraction of escaping particles via IS is 22% of all the sputtered ones, thus meaning a total rate of $4.4 \cdot 10^{26}$ s^{-1}, while the fraction of escaping particles via PSD is 30% of all the PSD-produced particles, thus meaning a total rate $3.3 \cdot 10^{24}$ s^{-1}. This mean that the major agents for Europa's surface erosion are IS and the micrometeoroid bombardment on both the non-illuminated and illuminated side. A suggestion for defining the locally active release process is to discriminate the particle energy spectra and detect the high energy (>10 eV) particles of IS origin and /or to have a good mass spectrometer able to detect the low component of refractories [1], [11]. The flux of these high energy atoms at Europa's surface is calculated to be $5.2 \cdot 10^{12}$ /m^2/s. At Europa, both the relevant laboratory yields and radiation fluxes have considerable uncertainties, and the source rate is highly variable due to temporal variability in the plasma conditions [12]. Therefore, new in situ observations will be needed to separate the effect of surface reactions from the stimulating radiation flux.

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