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Generation of H_2O and O_2 exospheres around Europa and Ganymede

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Abstract

The exospheres of Europa and Ganymede are mixtures of different species among which sputtered H_2O and H_2 dominate in the highest altitudes and O_2, formed mainly by radiolysis of ice and subsequent release of the produced molecules, prevail at lower altitudes. Several observations have demonstrated that these neutral environments are spatially non-uniform. In the present study we investigate Europa's exospheric H_2O and O_2 characteristics under the external conditions that are likely in the Jupiter's magnetospheric environment, applying the Europa Global model of Exospheric Outgoing Neutrals (EGEON, [1]). The H_2O and O_2 exospheres of Jupiter's moon Ganymede are simulated through the application of a 3-D Monte Carlo modeling technique that takes into consideration the combined effect in the exosphere generation of the main surface release processes (i.e. sputtering, sublimation and radiolysis) and the surface precipitation of the energetic ions of Jupiter's magnetosphere. We discuss the modeled densities at both Galilean satellites and we compare them, a posteriori, with the analysis results from observations in order to validate the models.

1. Introduction

The atmospheres of Europa and Ganymede are expected to be quite similar in composition since in both cases the surface is composed mostly of water ice and the physical conditions (temperature and moon dimensions) as well as the radiation environments are comparable. Nevertheless, Ganymede's internal magnetic field [2] makes this body unique in the Solar System. The existence of tenuous exospheres at the Galilean moons has been demonstrated through different kinds of observations [3], [4], [5], [6], [7], [8], [9]. The mechanisms expected to be predominantly responsible for the generation of a neutral environment around Ganymede are the release of surface material via direct ion sputtering and radiolysis [10], [11] and the sublimation of water ice [12], that is strongly temperature dependent. The Galileo photopolarimeter (PPR) measurements [13] showed that Ganymede's surface temperature has a maximum value of ~150 K near the subsolar point whereas it remains constant (and equal to ~80 K) on the unilluminated hemisphere. At Europa, the measured surface temperature range is narrower (from ~86 K up to ~130 K, according to [14]) hence the averaged expected contribution of sublimated water-ice to the moon's exospheric density is expected to be in general negligible, except at small altitudes above the subsolar point [15]. On the contrary, at Ganymede, the estimated surface release rate due to sublimation is expected to have a wider range of variation and a stronger spatial dependence being substantial on the whole illuminated side [12]. The spatial distribution of the O_2 exosphere of Europa is expected to depend mainly on the illumination of the moon, since its surface temperature is responsible for the efficiency of radiolysis [16] as well as for the sublimation rate [17]; secondarily, the exosphere distribution depends on the ion flux that impacts the trailing hemisphere more intensively [18], [1], [19]. At Ganymede, the situation is expected to be more complex, since its intrinsic magnetic field, reconnecting with the external Jovian magnetic field, partially shields the surface from the ion impact, especially at the equatorial latitudes (e.g.: [2]).

2. Modeling

In order to simulate the effects of surface irradiation on the generation of Europa's H_2O and O_2 exosphere we apply EGEON, a single-particle Monte Carlo model that provides the spatial density distribution of the released species (for an extended description of the model see [1], [19]). In order to model the magnetospheric ion precipitation to Ganymede's surface, we used as an input the electric and magnetic fields from the global MHD model of Ganymede's magnetosphere [20]. Then, we develop a 3-D MC particle model that for the first time takes into consideration the inhomogeneity of the plasma impact on the surface of Ganymede, determined by the morphology of the moon's intrinsic magnetic field. The assumed exospheric sources are sputtering and sublimation, for H_2O, and radiolysis of the surface water molecules, for O_2; collisions between neutrals and ions or between neutrals themselves are not taken into account. The current simulation of Ganymede's exosphere refers to a specific configuration between Jupiter, Ganymede and the Sun in which the Galilean moon is located close to the center of Jupiter's Plasma Sheet (JPS) with its leading hemisphere illuminated.

3. Results and Conclusions

At Europa, at low altitudes, O_2 is the dominant exospheric species and has the largest column density; at higher altitudes H_2O becomes the dominant species (Fig. 1). The spatial distribution of Europa's O_2 exosphere is explicitly time-variable due to the time-varying relative orientations of solar illumination and the incident plasma direction. The EGEON results on the O_2 column densities, at Europa, are consistent with the surplus of OI emission at the 90^0 west longitude (leading hemisphere) observed by HST [19].

At Ganymede, at small altitudes above the moon's subsolar point the main contribution to the neutral environment comes from sublimated H_2O. Plasma precipitation occurs in a region related to the OCFB and its extent depends on the assumption used to mimic the plasma mirroring in Jupiter's magnetosphere. At Ganymede, the spatial distribution of the directly sputtered-H_2O molecules exhibits a close correspondence with the plasma precipitation region and extends at high altitudes, being, therefore, well differentiated from the sublimated water [21]. Similar to the Europa case, the O_2 exosphere at Ganymede, comprises two different regions: the first one is an homogeneous, relatively dense, close to the surface thermal-O_2 region (extending to some 100s of km above the surface) whereas the second one is less homogeneous and consists of more energetic O_2 molecules sputtered directly from the surface after water-dissociation by ions has taken place. The spatial distribution of the energetic surface-released O_2 molecules depends both on the impacting plasma properties and the moon's surface temperature distribution (that determine the actual efficiency of the radiolysis process).

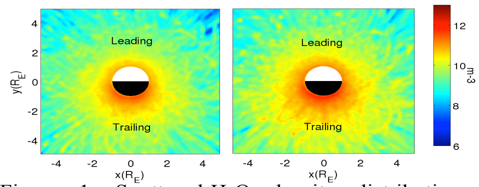

Figure 1: Sputtered-H_2O density distribution around Europa due to S^+ (left) and O^+ (right) impact. The color-scale is logarithmic. The leading hemisphere is illuminated in this configuration. Jupiter is along the negative x-axis.

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