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Europa and Ganymede's Water-Product Exospheres.

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Abstract

Europa and Ganymede are thought to possess globally similar exospheres, in spite of the possibility that Europa is currently cryovolcanically active, and Ganymede's intrinsic magnetic field. Ions in Jupiter's magnetosphere bombard the icy surfaces, and produce predominantly O2, with slightly less H_2O and H_2 due to freezing and escape respectively. We investigate and compare the water-product exospheres of the two satellites under rotation, using our 3-D Exosphere Global Model (EGM). In previous works ([1], [2]), we focused on the *near-surface* $z < 1.25r_s$, oxidized component of the exosphere, dominated by thermalized O_2, which undergoes a dusk-over-dawn asymmetry due to diurnal solar insolation of the surface over the satellite's orbit. This was observed by asymmetries in oxygen aurorae. Here, we focus on characterizing the hydrogen-species: H, H_2, and H_2O which have been far more elusive as lyman-α auroral emission has multiple production pathways, even in the absence of endogenic sources.

1. Introduction

Water is produced exogenically on Europa and Ganymede by two mechanisms: sublimation and magnetospheric ion sputtering. The former yields a thermal profile of water vapor which is quite similar to molecular oxygen. The latter is energetic as the water molecules are thought to leave the amorphous (Europa trailing) or crystalline (Ganymede) water ice lattice at high velocities. A portion of these water molecules undergo radiolysis in the regolith, and eject large quantities of molecular hydrogen and oxygen, in a 2:1 ratio. Smaller quantities of atomic hydrogen along with other trace species are also thought to be ejected into the exosphere. The sputtering production rates are difficult to constrain in the laboratory, due to uncertainties in surface ice concentration, grain sizes, and porosities. At Europa, we have employed the globally-averaged sputtering rates by [3] and find that these rates are able to reproduce the behavior and magnitude of the near-surface O2 component reasonably well [1]. However,auroral profiles by the HST seem to suggest the corona $z \gtrsim 1.25r_s$, is in an energetic state of expansion. One mechanism could be O2 collisions with the background H_2O and H_2 atmosphere mentioned above. Additionally, the interaction with the Io-plasma torus could result in ion-neutral scattering of the near-surface component, enhancing escape rates, which are uncertain at the present. At Ganymede, [2] showed that uncertainties in water vapor sublimation fluxes can produce vastly different behavior of the H_2O column density over the orbit.

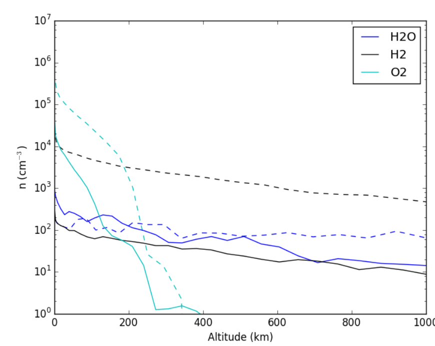

Figure 1: Surface densities for the dominant species in Europa (solid) and Ganymede's (dashed) exospheres at the sunlit trailing hemisphere.The H_2O case represents a low-sublimation case[2].

1.1. Observations

Recently, [4] has helped constrain the atomic hydrogen column density at Europa, via HST transit observations. The Ly-α absorption at 1216 Å appears to indicate a column of $N \sim 10^{12}$ H cm^{-2} corresponding to $\sim$ 80 Rayleighs of hydrogen auroral emission. The derived number densities range from $n_E \sim 1.5 - 2.2$ H cm^{-3}. Comparing to Galileo observations of Ganymede by [5], the derived atomic hydrogen surface densities at Ganymede are larger by a factor of ten, with an emission of ~ 560 Rayleighs.

2. Exosphere Modeling

We simulate the icy satellite exospheres by employing a parallelized Monte Carlo routine we refer to as an Exosphere Global Model (EGM). We track particles in a rotating, non-inertial reference frame, in spherical coordinates (r, θ, ϕ), extending up to $\sim 15 r_s$. Ejected test particles are on ballistic (collisionless) trajectories, and can escape, stick, and be re-emitted from the surface depending on their surface interactions. At Ganymede, the magnetic field impedes low latitude sputtering, particularly on the ram facing hemisphere. In this way, most exospheric production in the low sublimation case, occurs at the poles. Most relevant for this work are the numerous electron impact and photodissociation reactions of H_2O and H_2, tabulated in [2]. These reactions are critical to the production of atomic hydrogen and the resultant Ly-α emission as H sputtering is thought to be $\sim 1\%$of H_2O. Figure 1 presents our simulated atmospheric density profiles of Europa and Ganymede for water, molecular hydrogen, and molecular oxygen, the dominant 'background' atmosphere for the trace atomic hydrogen.

3. Results and Discussion

We simulate the orbital evolution of the dominant hydrogen species to gain an understanding of the range of column densities Europa and Ganymede experience throughout their orbit (Figure 2), some of which will be observed as Ly-α emission. These simulations represent modest cases, where there are no enhancements due to ion interactions, nor are there endogenic water plumes contributing to the exospheres. This permits one to first assess the steady-state component of the exosphere, and its orbital variations. From sunlit trailing to leading, we calculate Europa's exosphere to decrease by $\sim 36\%$ in atomic hydrogen, 60% in H_2, and 43% in H_2O. The atomic hydrogen column is $\sim 10^{10} H cm^{-2}$, whereas H_2 and H_2O are $\sim 10^{13} cm^{-2}$. Ganymede's atomic H ($N_H \sim 10^{11} cm^{-2}$) peaks at the poles and also decreases by $\sim 50\%$, whereas H_2 ($N_{H2} \sim 10^{15} cm^{-2}$) and H_2O ($N_{H2O} \sim 10^{14} cm^{-2}$) fall by an order of magnitude at sunlit leading.

The observed hydrogen column densities appear to be 1-2 orders of magnitude higher than our atomic H simulations, possibly suggesting more efficient atomic H sputtering rates, or more efficient exospheric H production via H_2 and H_2O. A similar conclusion was reached in the case of Ganymede with respect to Galileo observations [2], where it was suggested that e^- impact of H_2O may be a source of Ly-α emission.

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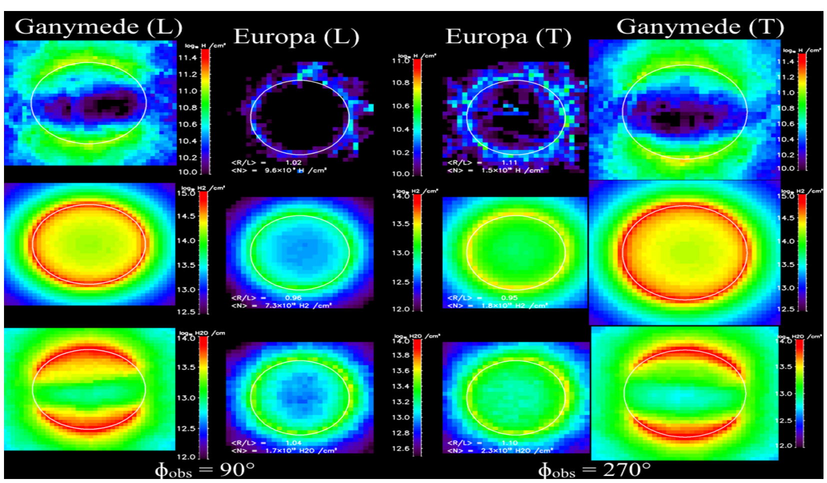

Figure 2: Line-of-sight column density maps for the dominant hydrogen species on Europa and Ganymede. The right hand side is the sunlit trailing hemisphere, and the left hand side is the sunlit leading hemisphere.