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3D Monte-Carlo Simulation of Callisto's Varying Ionosphere

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Abstract

Callisto's atmosphere is known to consist mainly of neutral O_2 [1, 2], CO_2 [3], and O [2], while H_2O and other water related radiolysis products (e.g., OH, H_2, O_3) are also expected to be present in Callisto's atmosphere [4] but have so far not been confirmed. In addition to these neutral species, Galileo radio occultation measurements [1] showed that Callisto can have a substantial ionosphere, but only when the sun-illuminated hemisphere coincides with the hemisphere experiencing plasma precipitation. In this paper we present a 3D Monte-Carlo model [5] of Callisto's thermal and surface-sputtered neutral exosphere, and derive ionospheric particle profiles for illumination and plasma precipitation conditions matching the Galileo observations.

1. Introduction

[1] reported on four radio occultation technique measurements of Callisto's ionosphere conducted by the Galileo spacecraft. During all four flybys, Callisto's trailing hemisphere (the hemisphere that is impacted by Jupiter's co-rotating plasma) either almost perfectly coincided with or almost completely opposed the sunlit hemisphere (see Figure 1). Detectable electron densities were obtained from six of the eight opportunities (two per flyby). Out of these six detections, four were termed 'weak detections' while only two observations were designated as 'strong detections'. For the 'weak detections', [1] inferred peak electron densities of 3,000–8,500 cm^{-3}, whereas for the 'strong detections' electron densities of 15,300-17,400 cm^{-3} were inferred.

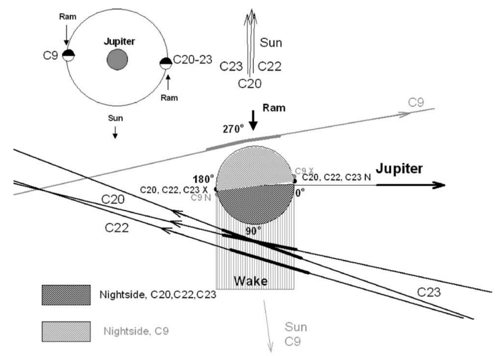

Figure 1: Callisto flyby geometries for the Galileo radio occultations. Taken from [1].

2. Monte-Carlo Model

In the study presented herein, particles are released from Callisto's surface either through sublimation (on the sunlit hemisphere) or through sputtering (on the trailing hemisphere). Depending on the the flyby to be modeled, these two hemispheres are either identical or oppose each other. Four different processes can lead to ionization: (i) photo-ionization, (ii) electron-ionization, (iii) symmetric charge-exchange and (iv) asymmetric charge-exchange. Again, in the studies presented herein all four processes either act on the same hemisphere or on opposing hemispheres. Particles that are ionized are immediately picked up by the Jovian plasma sweeping over Callisto, i.e., are immediately removed from Callisto's atmosphere.

3. Results

Figures 2 and 3 show exemplary neutral density disributions for sublimated O_2 and sublimated CO_2. The Sun is located to the right in both images. With O_2 being completely non-sticking, an almost uniform exosphere is formed, whereas the sticking CO_2 produces a highly asymmetric exosphere.

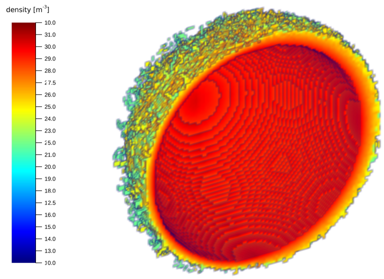

Figure 2: Sublimated O_2 neutral density distribution.

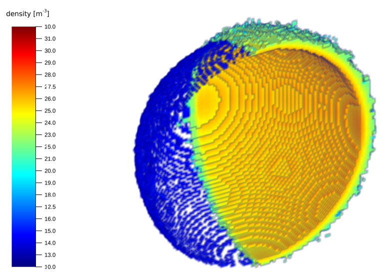

Figure 3: Sublimated CO_2 neutral density distribution.

For three out of the four flybys, the sunlit hemisphere coincides with the hemisphere experiencing plasma precipitation. In view of ion-creation, this is the most favorable configuration, since all four ionization processes act on the hemisphere with the highest neutral densities. Figures 3 and 4 show the number of ions created in our simulation (for ∼100,000 neutral particles). Again, a clear difference in magnitude and symmetry is evident for the two different species.

4. Summary and Conclusions

Our simulations show that for favorable conditions (when the sunlit hemisphere coincides with the hemisphere experiencing plasma precipitation) a substantial ionosphere can indeed be created, whereas the ionosphere diminishes when particles are not only released on opposite hemispheres by the two different release processes (sublimation and sputtering), but when the ionization processes themselves also act on two different hemisphere. These modeling results thus

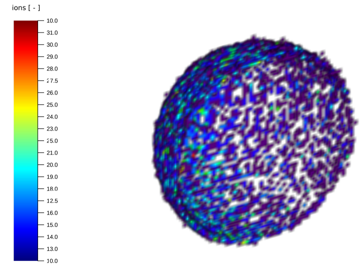

Figure 4: Number of created O_2^+ ions.

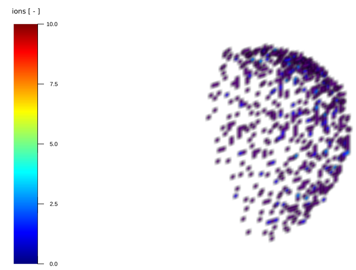

Figure 5: Number of created CO_2^+ ions.

confirm the varying nature of Callisto's ionosphere as observed by the Galileo spacecraft.

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