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Investigating the Impact of Plasma Interaction on the Retrieval of Europa's Induced Magnetic Field

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Abstract

Determining Europa's magnetic induction signal will be crucial to constraining its oceanic properties with the Europa Clipper mission. However, magnetic perturbations caused by Jupiter's magnetospheric plasma interaction with Europa will be superimposed on the magnetic induction signal and must be accounted for when analyzing spacecraft data. The plasma effects under various external conditions have not yet been thoroughly investigated. In anticipation of Europa Clipper's arrival, this work will incorporate the effects arising from Europa's plasma interaction with Jupiter's magnetosphere, as simulated by a multi-fluid magnetohydrodynamic (MHD) code [1], into magnetic field models constructed to simulate the inducing and induced fields at Europa along designed flyby trajectories. Our goal is to quantitatively evaluate the influence of Europa's plasma interaction on the ability of retrieving the induction signal from multiple close flybys of Europa.

1. Introduction.

Galileo flybys of Europa provided magnetic field measurements consistent with the existence of an induced magnetic dipole, which implied the presence of an electrically conductive subsurface ocean [2]. The magnetic dipole is induced by large, periodic variations of Jupiter's magnetic field as seen by Europa. These variations are dominantly due to the rotational period of Jupiter as seen by Europa at $\approx$ 11.2 hr, with a smaller contribution caused by the ellipticity and inclination of Europa's orbit ($\approx$85.2 hr). The Galileo data set resolved the magnetic induction response at the 11.2 hr rotation period, but a unique solution for the thickness of the ocean and its conductivity could not be determined without the component at the orbital frequency.

The upcoming Europa Clipper mission will provide the necessary coverage to probe the 85 hr signal. However, additional magnetic perturbations superimposed onto the magnetic induction signal will be caused by the magnetospheric plasma-moon interaction, reducing the mission's ability to determine oceanic properties. Sputtering of Europa's water ice surface creates an exosphere dominantly composed of O_2 [3], which becomes ionized then accelerated by the convection electric field imposed by the magnetospheric plasma. This generates a current which modifies the magnetic field into an Alfvén wing structure, where the magnetic field lines become bent and acquire a field component along the plasma flow direction [4]. Thus, the disturbance from plasma effects needs to be taken into account.

Schilling et al. [5], modeled this interaction for several Galileo flybys using a single-fluid magnetohydrodynamic (MHD) simulation approach, which showed improved accuracy in replicating the Galileo data. However, this is only a limited sample of the expected magnetospheric conditions and a single-fluid approach does not capture asymmetries due to the convection electric field and gyroradii effects. The plasma density can vary by an order of magnitude from 35 to 600 cm^{-3}, depending on Europa's location in the plasma torus [6]. Hence, a more extensive investigation of the effects of plasma interaction is needed. In this study, we will analyze the output from a multi-fluid MHD simulation to compare the spatial form and strength of the magnetic perturbations caused by the plasma interaction under different magnetospheric conditions at Europa's orbit with expected induced magnetic fields at Europa for the 11 hr and 85 hr periods.

2. Method

We perform analysis on outputs from a multi-fluid MHD model for the Europa environment based on the BATS-R-US (Block-Adaptive Tree Solar wind Roe-type Upwind Scheme) MHD code [1; 7; 8]. The model tracks 3 ion fluids plus one electron fluid, reflective of the dominant plasma species in the local Europan environment: O^+ sourced from Jupiter's plasma torus, O+ pick-up ions, O_2^+ pick-up ions, and electrons. Sources for the production of ions include electron impact ionization, photoionization, and charge exchange while losses are due to impact onto the moon's surface and ion-electron recombination. The simulations are centered on Europa in the EphiO coordinate system where +X is the direction of the magnetospheric plasma flow, +Y points from Europa to Jupiter, and +Z is parallel to Jupiter's spin axis. For each simulation, the magnetospheric plasma bulk velocity, ion and electron temperatures, Jupiter's magnetic field, and an induced dipole moment at Europa are specified for Europa's location in its orbit. Using these parameters, the model is iterated until a steady state is reached.

Using the outputs from these simulations, we evaluate the degree to which this plasma disturbance affects the ability to retrieve the induction signal. We will create fly-thrus of the model along potential Europa Clipper trajectories and determine the relative strengths of the plasma perturbation fields and expected induction signals for a given spacecraft location. We intend to place bounds on the magnitude of this perturbation expected over the length of the mission. We will analyze how the plasma perturbation varies spatially within each individual run and will determine locations where the perturbation is smallest. This will allow us to recommend trajectory routes that could optimize the retrieval of the induction signal.

Summary

The moon-plasma interaction over the duration of Europa's orbit has not yet been thoroughly explored. This work will expand on previous literature by examining plasma conditions at Europa for a larger parameter space, representative of different plasma and magnetic fields conditions which will be encountered during the Europa Clipper mission. The goal is to quantify the effect of these plasma perturbation fields on the accuracy of the retrieved induction signal.

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