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A Multi-Fluid MHD Simulation for Europa's Ionosphere Affected by Variations in the Jovian Magnetospheric Plasma and Magnetic Field

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Europa acts as an obstacle to the plasma corotating with Jupiter's magnetosphere. Through the interaction between Europa's O_2 atmosphere and the magnetospheric plasma, chemical processes generate plasma originating from the atmosphere to form an ionosphere. Europa's ionosphere was observed in several observing events of Galileo's radio occultations, and in some cases, the peak electron density was derived on the order of 10^4 cm^{-3} at an altitude of ~50 km (McGrath et al., 2009). However, Galileo's observations also indicate that the electron distribution varies both in time and space significantly.

The ionization rate in the ionosphere is expected to vary in response to changes in Europa's atmosphere and those in Jupiter's magnetospheric plasma and magnetic field near Europa. A three-dimensional multi-fluid magnetohydrodynamic (MHD) simulation is suitable for characterizing the spatio-temporal variations in Europa's plasma interaction because it calculates the production and loss rates of each ion fluid separately. Several studies presented two- or three-ion-fluid MHD models for Europa's plasma interaction and considered the effects of variations in Europa's atmosphere (Rubin et al., 2015; Harris et al., 2021; Harris et al., 2022). However, the observed variations in the ionosphere have not been fully explained yet.

Inhomogeneity of the magnetospheric plasma due to the interchange instability and the plasma injection was observed by Galileo near the orbit of Europa (e.g., Russell et al., 2005). Occurrence probability of the plasma injection was found to be even higher between the orbits of Europa and Ganymede (Mauk et al., 1999). To describe how the inhomogeneity of the magnetospheric plasma affects Europa's ionosphere, we have performed MHD simulations for Europa's plasma interaction based on the MAESTRO code (Sakata et al., 2024). Firstly, we performed multi-species MHD simulations to optimize the simulation codes for the plasma environment around Europa. Chemical reactions for the simulations are the same as Rubin et al. (2015) and Harris et al. (2021), and the ion species include magnetospheric O_2^+ and the ionospheric O_2^+ and O^+ based on the previous studies. We confirmed that the optimized codes can reproduce density distributions of the ionospheric ions consistent to the results in Harris et al. (2021). After the optimization, we have performed multi-fluid simulations with three ion fluids, the same as the multi-species simulations described above. Electron pressure is separately calculated. Both photoionization and electron-impact ionization are the sources of the ionosphere. We consider the variability of the magnetospheric plasma and the magnetic field based on the Galileo observations and do not consider the changes in the neutral atmosphere.

The multi-fluid MHD simulations can also evaluate the ion escape rate from Europa. The results will be directly compared with Juno's in-situ measurements (Szalay et al., 2024) and Hisaki's spectroscopic observation (Matsushita et al., presentation at the Magnetospheres of Outer Planets 2024) to constrain the ion composition in Jupiter's inner magnetosphere.