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Study of ion acceleration in Ganymede's polar magnetosphere based on Galileo spacecraft observations

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Abstract

We study the plasma environment observed in Ganymede's polar region by the Galileo spacecraft and report evidence of an ion outflow based on the density distribution derived from the Plasma Wave Subsystem (PWS) measurements. First, we identify the Upper-Hybrid Resonance (UHR) frequency and calculate the plasma density at the point of observation. Second, based on the results of the analysis, we study the distribution of the plasma density in the altitude range from 264 km to 5,262 km and found that the number density decreases rapidly with distance from Ganymede. Third, in order to study the physical process that produce the plasma density profile, we examine an ion outflow from Ganymede's polar region.

1. Introduction

Ganymede is one of the Jovian moons and is known as the only satellite that has an intrinsic magnetic field [1]. Ganymede is located in the Jovian magnetosphere and is immersed in the magnetospheric plasma corotating with Jupiter's rotation [2]. Since the spatial scale of Ganymede's magnetosphere is comparable to the Larmor radius of magnetospheric ions, the characteristic plasma environment is formed around Ganymede through the interaction between Ganymede's magnetosphere and Jovian magnetospheric plasma. Ganymede's magnetospheric plasma is produced by ionization processes of Ganymede's atmosphere which is generated from Ganymede's icy surface. Although previous studies discussed the morphology of Ganymede's magnetosphere and its plasma environment, most of the details are still unknown and understanding of the interaction is necessary to reveal processes occurring in Ganymede's magnetosphere. Previous studies have suggested ion outflow from Ganymede's polar region, but detailed physical process contributing to an ion acceleration is uncertain. In the present study, we discuss the plasma environment observed in Ganymede's polar region by the Galileo spacecraft and report evidence of the ion outflow based on the density distribution derived from the Plasma Wave Subsystem (PWS) measurements.

2. Observation

We identify the Upper-Hybrid Resonance (UHR) frequency observed by the PWS and determine the electron density at the point of observation. We analyze four Ganymede encounters including those on orbits G01 and G02 which have been analyzed in the previous study. Based on the results of the analysis, we plot the distribution of the plasma density in the altitude range from 264 km to 5,262 km and find that the number density decreases rapidly with distance from Ganymede. At an altitude of 264 km corresponding to the closest approach during G02 encounter, the density reaches approximately 200 cm^{-3}, and the density converges to the plasma density of the Jovian magnetosphere, 5 cm^{-3}, at some distance from Ganymede.

3. Analysis of plasma distribution

In order to study the physical process that produce the plasma density profile, we examine an ion outflow from Ganymede's polar region. Since the most dominant ion species in Ganymede's magnetosphere has been considered to be O^+ [3], we assume that the obtained plasma density distribution reflects that of the O^+ density in Ganymede's magnetosphere. Based on the obtained distribution, we find that the density distribution can be expressed by $r^{-5.98}$, where r is the distance from Ganymede. Assuming that the flux is conserved along the path of the ion outflow and that the cross section of the flux tube of outflow is proportional to r^2 or r^3, we estimate that the ion velocity reaches 17.3 km/s or 14.5 km/s, respectively, at the distance of 500 km from Ganymede. These results suggest that ions produced in Ganymede's ionosphere are accelerated during their motion away from the polar region of the magnetosphere near Ganymede (< 2 R_G; R_G is the radius of Ganymede), as has been suggested by the previous studies of the O^+ outflow velocity from observations of the Galileo Plasma instrumentation (PLS) [3].

4. Figure

Analyzed electron density variation as a function of radial distance. We identify this profile as O^+ density because of charge neutrality.

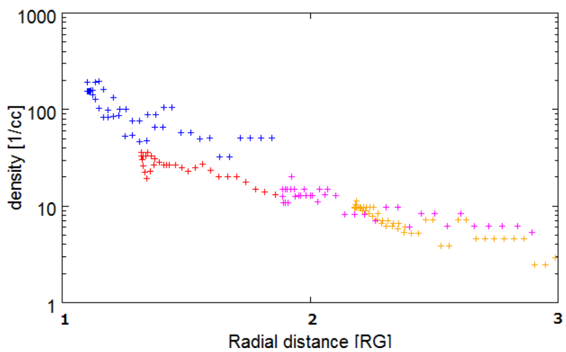

Figure 1: The electron density as a function of the radial distance. (I R_G = 2631 km)

5. Summary and Discussion

We discuss the plasma environment observed in Ganymede's polar region by the Galileo spacecraft and report the evidence for ion outflow based on the density distribution derived from the PWS measurements. Using the electron plasma density calculated from the PWS observations, we determined a density profile above Ganymede from 264 km to 5262 km. We examine an ion outflow from Ganymede to explain this density profile and find that ions have to be accelerated 17.3 km/s or 14.5 km/s, respectively assuming that the cross section of the flux tube is proportional to r^2 or r^3, at the distance of 500 km from Ganymede. The results of the present study revealed that ions are accelerated in the polar magnetosphere of Ganymede.
We discuss candidate mechanisms for the ion outflow from Ganymede's polar region. We infer that one of the most plausible acceleration mechanisms is the centrifugal acceleration, which is more pronounced in the case of the small radius of curvature of the magnetic field. So as to discuss the centrifugal acceleration, we develope a test particle simulation code, which enables us to quantitatively investigate the particle trajectory and acceleration in the magnetosphere.

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