Initial Results from an MHD Simulation of Ganymede’s Magnetosphere

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Three-dimensional resistive MHD simulations were conducted to study the interaction between Jupiter’s corotating plasma and Ganymede’s internal magnetic field. In the simulation we’ve found a small closed field line region near the equator and a large polar cap region containing filed lines that link to Jupiter. The results gave good agreements between the observations and the simulation model. The locations of the separatrices between Jovian field lines and those field lines connected to Ganymede at one or both ends are consistent with the results inferred from a vacuum superposition model [Kivelson et al., 1998] and the energetic particle observations. Slow mode waves were found to be formed right after reconnection in the simulation in which the plasma density and the magnitude of the magnetic field were out of phase.

1. Introduction

Ganymede, Jupiter’s third Galilean satellite, was found to have a permanent internal dipole field. Ganymede’s permanent dipole moment has an equatorial strength of 719nT. The dipole axis is tilted by 176° from the spin axis with the southern hemisphere pole rotated by 24° from the Jupiter-facing meridian plane toward the trailing hemisphere [Kivelson et al., 2002]. The intrinsic magnetic field is sufficiently large to shield itself from the corotating plasma and magnetic field of Jupiter and then create its own mini-magnetosphere embedded within Jupiter’s magnetosphere. This makes Ganymede’s magnetosphere a unique case in the solar system in which a small magnetosphere is right inside of another larger magnetosphere [Kivelson et al., 1996; Frank et al., 1997a,b; Williams et al., 1997a,b]. On Ganymede’s orbit Jupiter’s rotating plasma is subsonic and sub-Alfvénic [Williams et al., 1997a; Frank et al., 1997b], which provides us an opportunity to study a magnetosphere without a bow shock. Since the direction of Ganymede’s internal field is opposite to the Jovian magnetic field, Ganymede’s magnetosphere is reconnecting due to the antiparallel field topology. The plasma environment around the orbit of Ganymede varies with Jupiter’s rotation period. However, this temporal variation is more predictable than the changes imposed by the solar wind on planetary magnetospheres. We can model the variation at Ganymede by using the currently existing Jupiter’s magnetospheric field model of Khurana [2003] and plasma sheet observations. Ganymede may provide a unique example of reconnection in a slowly and predictably changing magnetic and plasma environment.

Kivelson et al. [1998] have developed an empirical superposition model of Ganymede’s magnetosphere. They superimpose an external magnetic field from a model of Jupiter’s magnetospheric magnetic field [Khurana, 1997] to the field of a Ganymede-centered magnetic dipole. This model gives good agreement between the model magnetic field and Galileo’s observations, because this simple model is only an intrinsic dipole superimposed on the ambient Jovian magnetic field and does not include the motion of plasma, the effects of Alfvénic-wing currents associated with the interaction between Ganymede and Jupiter’s magnetospheric plasma cannot be produced in it. It is expected that the corotating Jovian plasma will compress the upstream hemisphere while extending the downstream hemisphere, similar to the case in which solar wind flow shapes the planetary magnetosphere.

Hubble Space Telescope (HST) observations of the Oxygen airglow [Hall et al., 1998] suggest the possibility that Ganymede exhibits polar aurora. The OI emissions appear in both hemispheres and are confined to polar regions (latitudes above 40°), implying the motions of those energetic particles along the opened field lines which connect one end to Ganymede and the other to Jupiter. This indicates that Ganymede’s environment is quite active and dynamic in terms of plasma dynamics.

2. Methodology

We conducted three-dimensional resistive MHD simulations to study the interaction between Jupiter’s corotating plasma and Ganymede’s internal magnetic field. The source code was provided by Jon Linker and associates at Science and Applications
International Corporation (SAIC) which was previously used to model the interaction between Jovian plasma and Io [Linker et al., 1998]. We ran the simulations using different initial states that represent the different plasma and magnetic field environments corresponding to the six Galileo encounters (G1, G2, G7, G8, G28 & G29).

3. Initial results
The results showed that a small closed field line region was formed near the equator and a large polar cap region containing filed lines that link to Jupiter existed in the magnetosphere. The magnetic fields from the simulation were evaluated along each flyby trajectory and compared with Galileo observations. The results gave good agreements in both the magnitude and the trend between the observations and the simulation. The locations of the separatrices between Jovian field lines and those field lines connected to Ganymede at one or both ends are consistent with the results inferred from a vacuum superposition model [Kivelson et al. 1998] and the energetic particle observations. Right after the reconnection in the simulation, slow mode waves were found to be formed in which the perturbations of the plasma density and the magnitude of the magnetic field were out of phase.

References