Callisto Plasma Interactions

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Abstract

Information on the internal structure of solar system bodies can be inferred from magnetic field observations. There were several flybys of Jupiter's moon Callisto by the Galileo spacecraft. Magnetic field perturbations associated with Callisto were observed. These field perturbations have been interpreted as due to subsurface currents induced by the external dipole field of Jupiter[3].

However, previous work has not taken into account the effect of the surrounding magnetospheric plasma. The co-rotating plasma flowing by Callisto will induce currents in the moon. We use a self consistent hybrid plasma model to study the interaction between Callisto and the co-rotating plasma in Jupiter's magnetosphere.

The hybrid equations

In the hybrid approximation, ions are treated as particles, and electrons as a massless fluid. The trajectory of the ions is computed from the Lorentz force, given the electric and the magnetic fields. The electric field is

$$\mathbf{E} = \frac{1}{\rho_I}\left(-\mathbf{J}_I \times \mathbf{B} + \mathbf{J} \times \mathbf{B} - \nabla p_e\right) + \eta \mathbf{J}, \qquad (1)$$

where ρ_I is the ion charge density, $\mathbf{J}_I$ is the ion current density, p_e is the electron pressure, and η is the resistivity. The current is computed from, $\mathbf{J} = \mu_0^{-1}\nabla \times \mathbf{B}$, where $\mu_0 = 4\pi \cdot 10^{-7}$ is the magnetic constant.
Then Faraday's law is used to advance the magnetic field in time,

$$\frac{\partial \mathbf{B}}{\partial t} = -\nabla \times \mathbf{E}.$$

Vacuum regions and internal resistivity

In regions of low ion charge density, ρ_I, the hybrid method can have numerical problems. We see from (1) that the electric field computation involves a division by ρ_I.
Here we modify (1) by setting $1/\rho_I = 0$ in vacuum regions and in the obstacle interior. This leads to the solution of a magnetic diffusion equation in those regions,

$$\frac{\partial \mathbf{B}}{\partial t} = \frac{\eta}{\mu_0}\nabla^2 \mathbf{B}.$$

A minimum charge density parameter, ρ_v, decide what cells are vacuum. It is also possible to include arbitrary resistive obstacles, since the resistivity can be a function of position $\eta = \eta(\mathbf{r})$.
Further details on the hybrid model used here, the discretization, and the handling of vacuum regions and internal resistivity can be found in [1].

Galileo observations

Here we focus on the C9 flyby. This flyby is interesting since it is upstream in the co-rotating plasma flow, and no significant ionosphere was detected by occultation observations during the flyby [2]. Without an ionosphere, the observed magnetic field signatures must be due to currents inside the moon. Fig. 1 show the geometry of the flyby and the ionosphere observations.

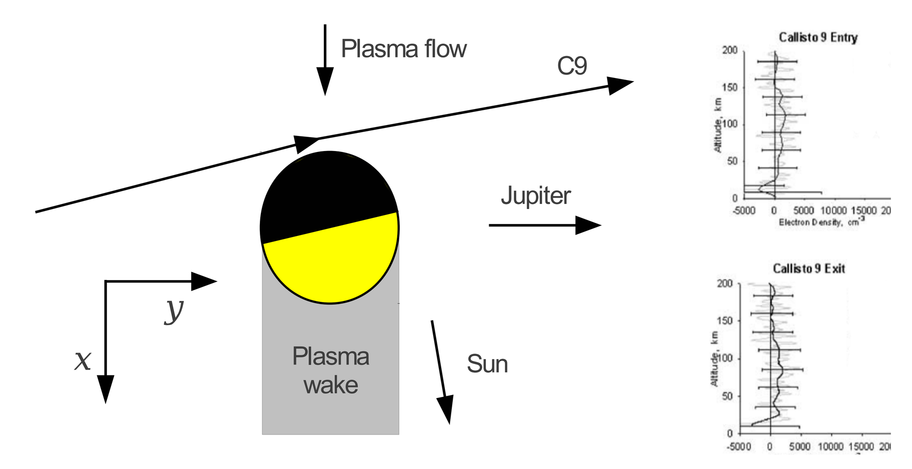

Figure 1: Geometry of the C9 Galileo Callisto flyby (left), and occultation observations of the ionosphere from [2] (right).

Model setup

Since there is uncertainty in the ion composition, we study two cases. Each with different mass per charge, M/Q.

Case 1. $M/Q = 10.7$. Gyroradius 610 km = 0.25 R_C.

Case 2. $M/Q = 2$. Gyroradius 115 km = 0.05 R_C.

The ion number density, $n = 0.5$ [cm^{-3}]. The background magnetic field, $\mathbf{B_0}$, is 35 nT approximately toward Jupiter (along y-axis). The plasma flow velocity is 192 km/s along x-axis. The ion temperature is 60 eV, and the electron temperature 60 eV. The internal resistivity of Callisto is 10^5 [Ω m].

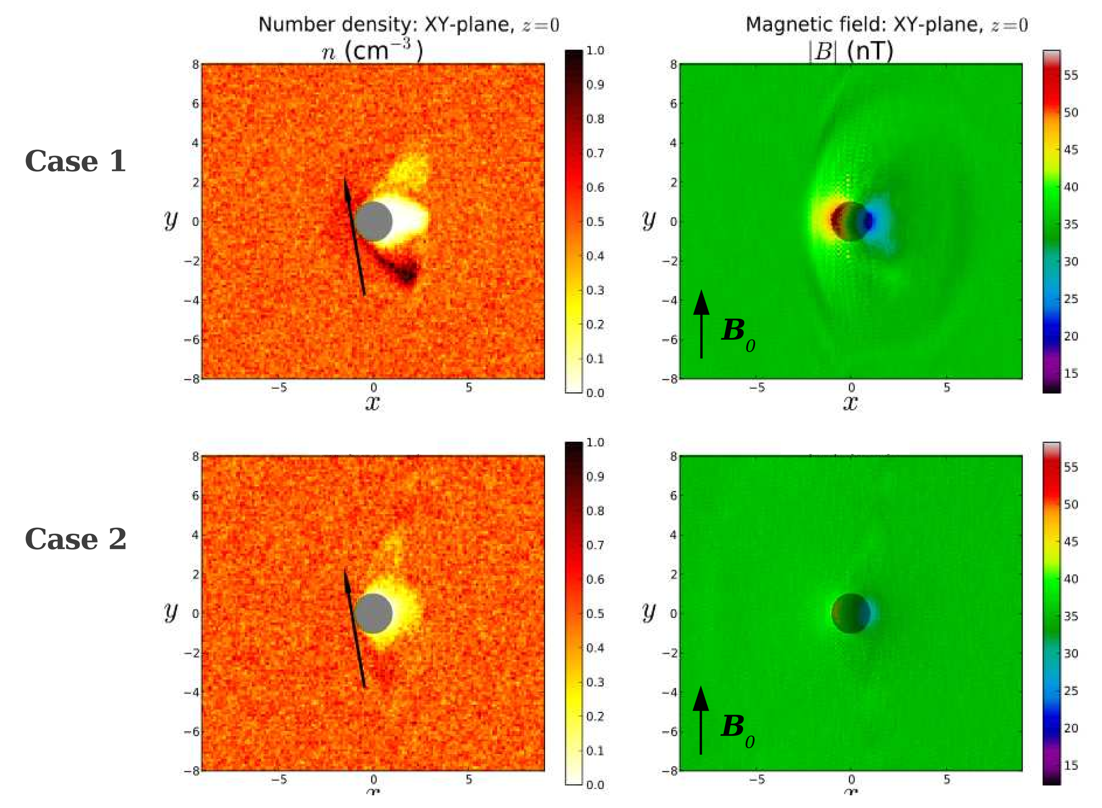

Figure 2: Number density and magnetic field magnitude after 30 seconds. Arrow indicates the C9 trajectory.

Discussion

We can note that

- Larger global effects on the plasma density and magnetic field magnitude for larger M/Q (Case 1). Possibly due to gyro radius effects and/or different plasma charge densities
- Case 1 fits the observation better, while the magnetic field signature is weaker for Case 2.

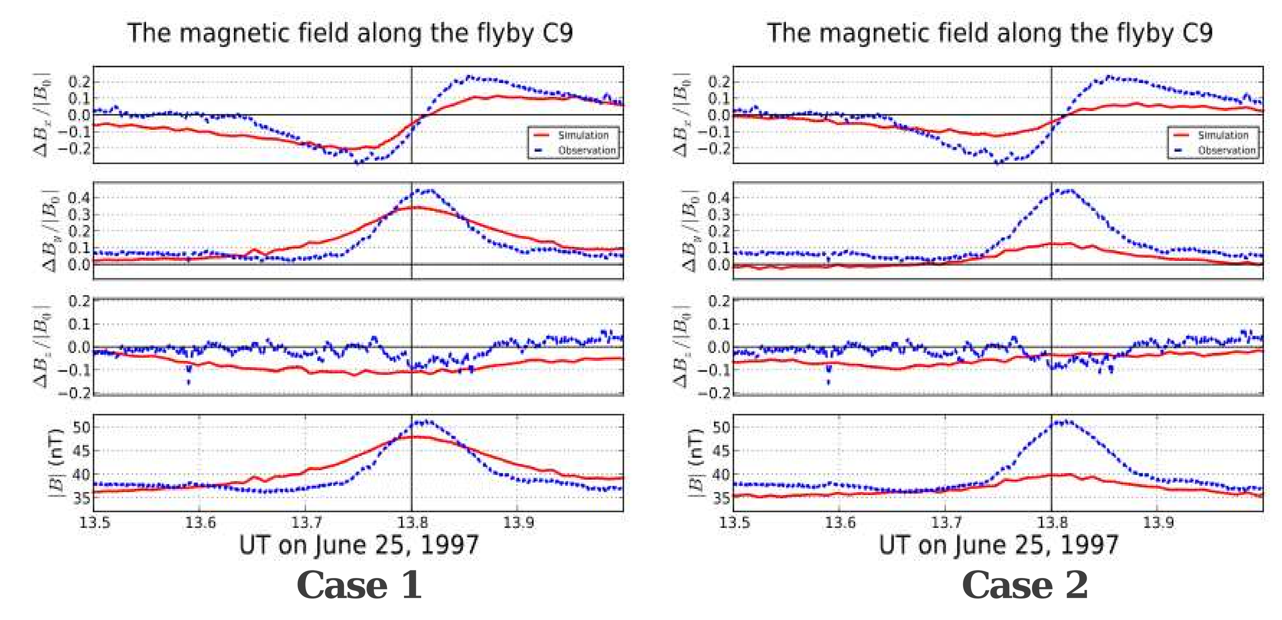

Figure 3: Comparison of magnetic field observations and simulations during the C9 flyby. The solid line indicates the time of closest approach.

Conclusions

- We have studied Callisto's plasma interactions using a hybrid plasma model where the internal resistivity can be varied
- In particular we have focused on a comparison with the Galileo C9 flyby. Since there was no observed ionosphere, the magnetic signatures should be due to internal currents
- We find that the interaction is sensitive to the state that we assume for the surrounding magnetospheric plasma, especially the ion composition (M/Q) and charge density
- Currents induced by the plasma flow can lead to significant global effects and need to be considered in addition to currents induced by the external dipole field of Jupiter
- The study of other flybys when there is a significant ionosphere is a topic for future studies

References

[1] Holmström, M., in *Numerical modeling of space plasma flows (ASTRONUM-2012)*, ASP conference series, 474, 202–207, 2013. ArXiv:1010.3291

[2] Kliore, A. J., et al., Ionosphere of Callisto from Galileo radio occultation observations, Journal of Geophysical Research, 107(A11), 1407, 2002.

[3] Khurana, K. K., et al., Absence of an internal magnetic field at Callisto, Nature, 387, 262-264, 1997.

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