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STUDIES OF PLASMA FLOW PAST JUPITER'S SATELLITE IO

PROGRESS REPORT: FIRST YEAR

(2/07/95–2/06/96)

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PRINCIPAL INVESTIGATOR:

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Studies of Plasma Flow Past Jupiter's Satellite Io

P.I.: Jon Linker

Progress Report: First Year (2/07/95-2/06/96)

Introduction

Here we describe progress performed under Contract NASW-4941, awarded to Science Applications International Corporation, San Diego, for the period 2/07/95 to 2/06/96. Under this contract, we have investigated the interaction of Io, Jupiter's innermost Galilean satellite, with the Io plasma torus.

The interaction of Io with the plasma surrounding it has been a subject of interest for almost 30 years, dating from the discovery by Bigg (1964) that radio emissions from the Jovian magnetosphere are controlled by Io's position. Since that time, both ground-based and spacecraft observations have shown that Io is a unique satellite that influences the Jovian magnetosphere in important ways. In particular, material from Io is a major source of plasma for the magnetosphere, and the energy that this plasma harnesses from Jupiter's co-rotating magnetic field is an important power source for the magnetosphere [e.g., Dessler 1980; Eviatar and Siscoe 1980].

It is apparent that the local interaction of the torus plasma with Io plays a key role in the formation, composition, and energetics of the Io torus; the interaction is also highly nonlinear. We have modeled this interaction using time-dependent three-dimensional magnetohydrodynamic (MHD) simulations. During the past year, we have used our NASA support to develop a new MHD code to study the interaction. This code is more versatile and efficient than our previous code, primarily because of the use of implicit methods. The new code is based on a code we have used for problems in solar physics; Mikić and Linker (1994) describe the methods employed.

As part of the Galileo spacecraft's recent successful insertion into orbit around Jupiter, the spacecraft passed within 900 km of Io's surface. Our calculations have focused on using Galileo particles and fields data to examine a question that was not resolved by the Voyager observations: Does Io have an intrinsic magnetic field? In this progress summary we describe our efforts on this problem to date.

Progress Summary

(a) Conducting Model of Io

The first investigations we performed with the new code focused on the "basic" interaction; i.e., effects that will be present regardless of whether or not ionization, charge-exchange, or other plasma-neutral interactions are occurring in Io's exosphere. This was done to insure that the solutions from this code and the previous code were in agreement, and as a basis for comparison with magnetized models. The simulations show the formation of the Alfvén wings, a fundamental result expected from analytic theory (see Figures 1-2, which show tracings of the magnetic field lines). Here an Alfvén Mach number of 0.5 was used to exaggerate the bend in the field. The surface contours show the value of the normalized parallel current at 1.2 R_{Io}; the dark regions show upward current, the yelllow regions downward current (red is the zero level). The "footprint" of the Alfvén wings (regions of parallel current) are visible.

In addition to the Alfvén wing, the simulations show perturbations associated with the other MHD modes. In particular, a standing slow mode wave attached to Io (with a rarefaction in pressure) forms. This can be seen in Figure 2, which shows the plasma pressure in a plane parallel to the background magnetic field. The wave is qualitatively consistent with the slow mode propagating nearly parallel to $\vec{B}$ (the sonic Mach number was 1.0). Perturbations caused by all three MHD modes spatially overlap close to Io, and the Alfvén and sound speeds are themselves altered by the interaction. Despite these nonlinear effects, descriptions of the interaction based on the initial values of the characteristic velocities are qualitatively correct. These results have been described previously (Linker et al. 1988; Linker et al. 1991).

(b) Magnetized Model of Io: Anti-Aligned Dipole

An unmagnetized Io with a conducting ionosphere has been the predominant paradigm for describing Io's perturbation of the Jovian magnetic field, but the possibility of an intrinsic magnetic field at Io is not ruled out by observations. The nature of Io's interaction with the plasma torus in the event Io is magnetized has been discussed (Neubauer 1978; Kivelson et al. 1979; Southwood et al. 1980), but detailed models have not been attempted. Data from the Galileo spacecraft's flyby

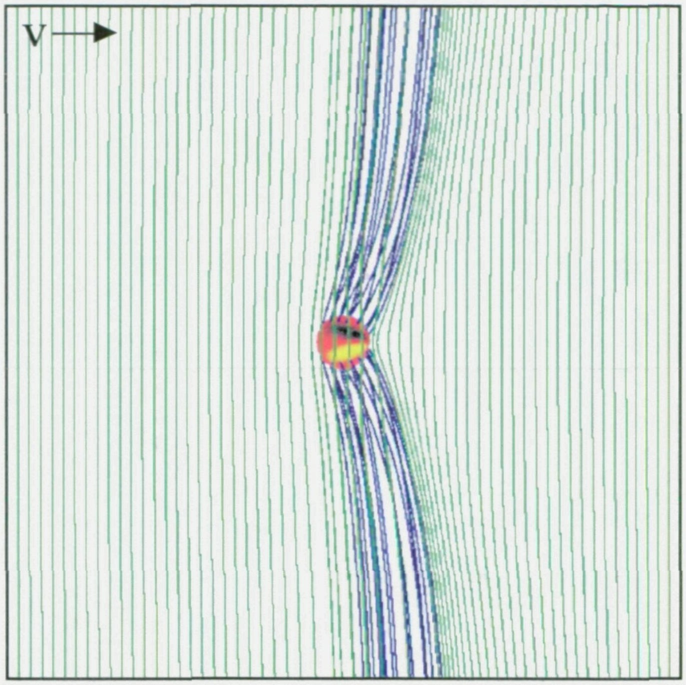

Figure 1. Tracings of magnetic field lines near Io, from a simulation of flow past a conducting Io (M_A=0.5). Green field lines are outside of Io, blue field lines intersect Io. Formation of the Alfven wing is shown by the bend in the field lines. The normalized current parallel to B is contoured at 1.2 R_{Io}, with the dark region showing upward current and the yellow region showing downward current.

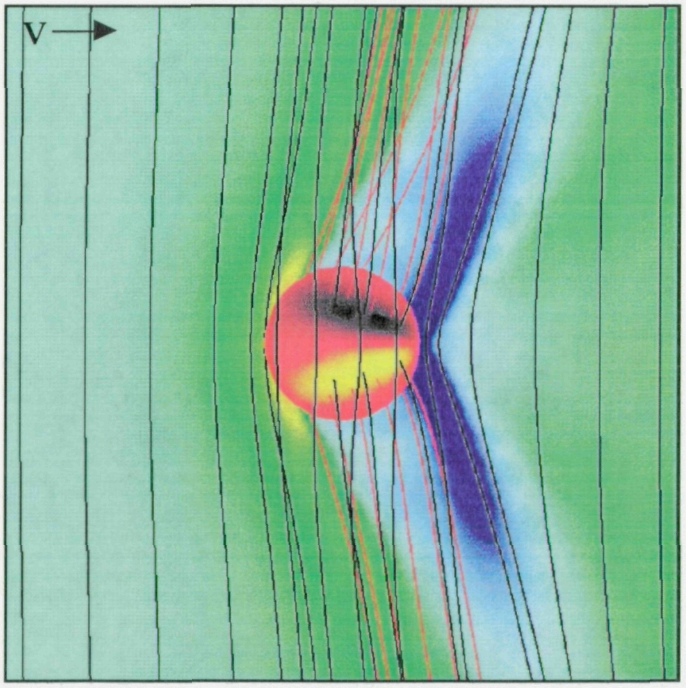

Figure 2. The same as Figure 1, but a closeup showing the plasma pressure in a plane passing through Io and parallel to the background magnetic field. The rarefaction in pressure (blue regions) is caused by a standing slow mode perturbation. Here black field lines are outside of Io and red field lines intersect Io. Note that black field lines pass through the maximum parallel current region (contours on the sphere at 1.2 R_{Io}).

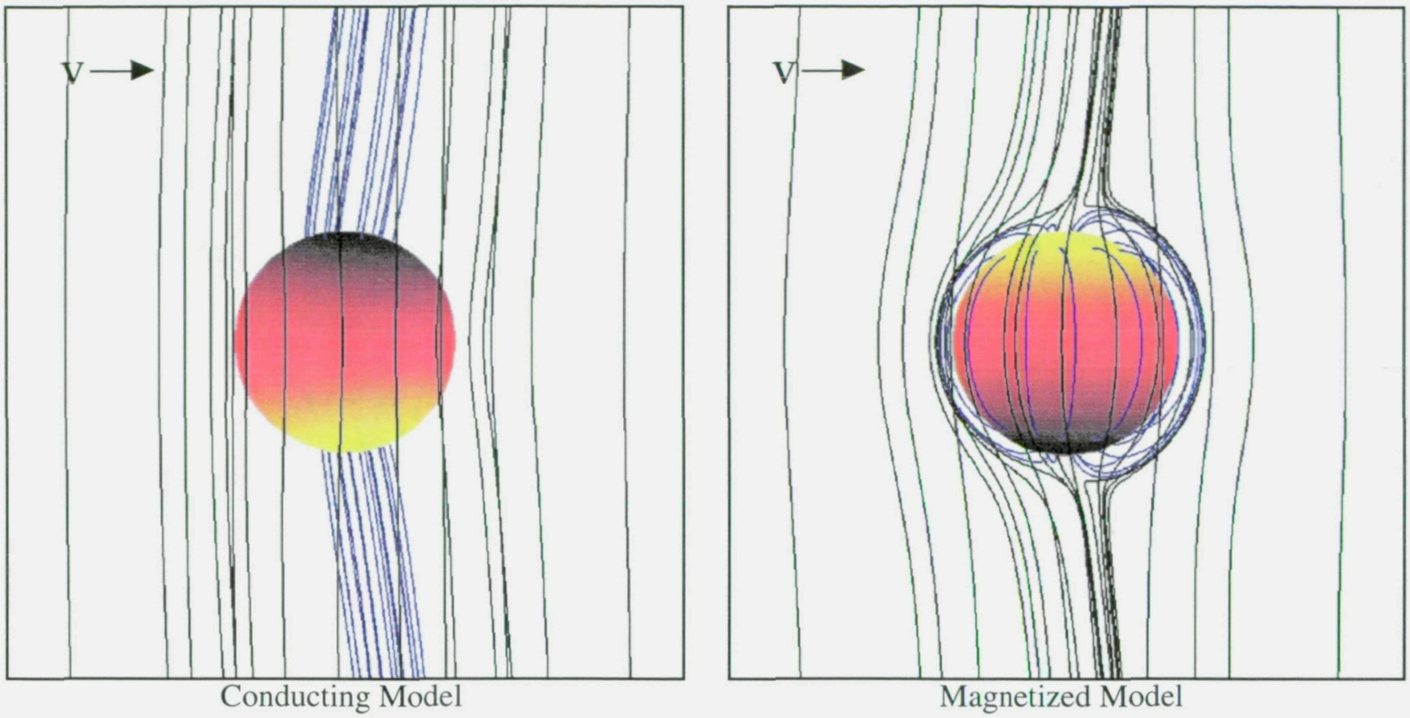

Figure 3. Comparison of magnetic field line tracings near Io for a simulation of flow past a conducting Io (left) and a magnetized Io (right); the dipole moment in the magnetized case is anti-aligned with the background (Jovian) magnetic field. The magnetic flux is contoured on the surface of Io, with the dark regions corresponding to inward flux and the yellow regions corresponding to outward flux. The background field is downward. Both simulations have $M_A = 0.2$, and show the formation of Alfven wings. In the (finite) conducting case, magnetic field lines diffuse into Io, whereas in the magnetized case a "bubble-like" region of magnetic field surrounds Io.

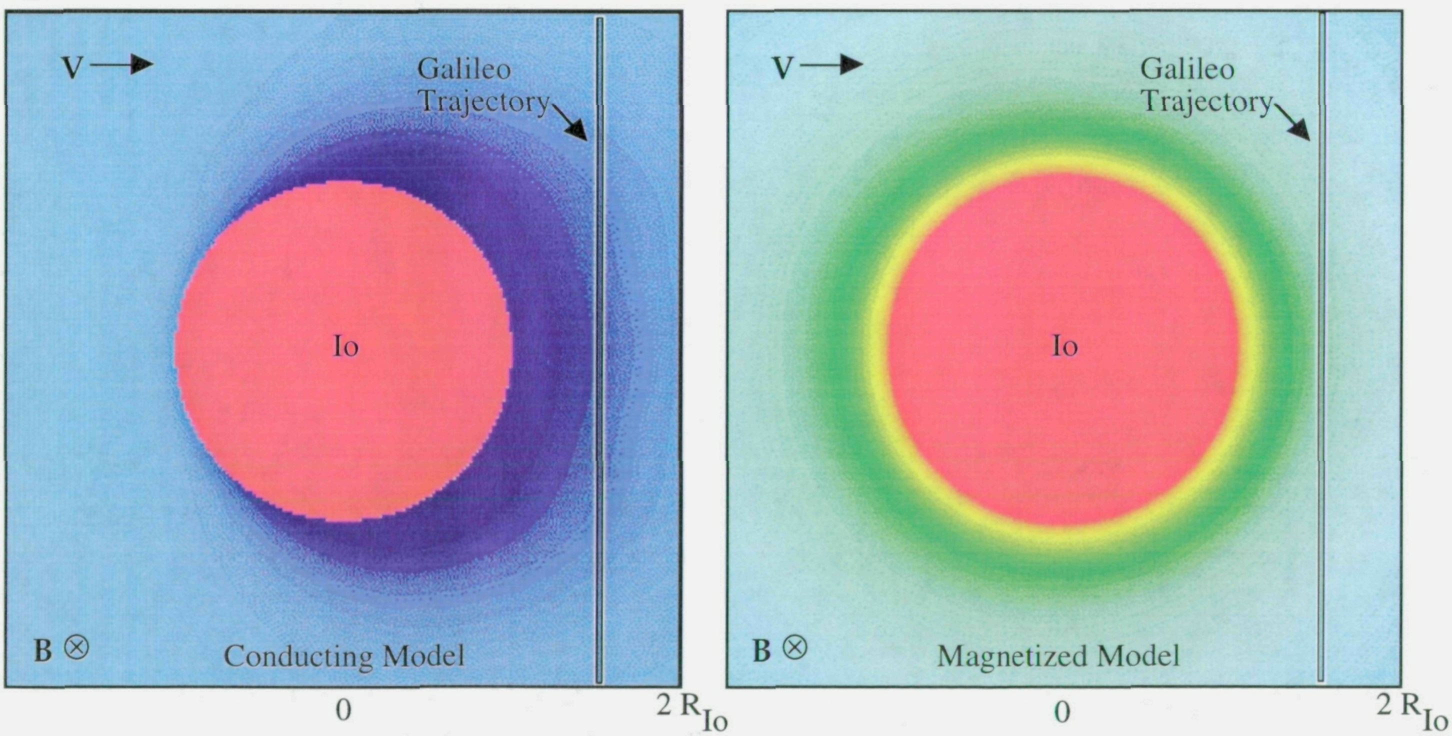

Figure 4. Magnitude of the magnetic field in a plane passing through Io, and perpendicular to the background field, for the same two simulations as Figure 3. Io is the orange sphere, and the approximate trajectory of the Galileo spacecraft is shown. Yellow and green show the largest |B|, and blue the smallest |B|. The magnetic field strength is decreased in the conducting case, increased in the magnetized case.

past Io will give us a unique opportunity to settle this question. Accordingly, we have computed models of the Io interaction when Io contains an intrinsic dipole moment.

The first case we have considered is where Io has a relatively small (surface field equal to twice the background field) dipole moment anti-aligned with the Jovian magnetic field. Figure 3 shows a comparison of this case (right) with a simulation of flow past a conducting Io (left). The Alfvén Mach number was 0.2 (the nominally expected value). Both computations show the formation of Alfvén wings, but in the magnetized case an enclosed magnetic bubble region near Io forms the obstacle. Figure 4 shows the magnitude of the magnetic field near Io for the plane close to Galileo's trajectory for both cases, and Figure 5 shows the approximate variation of the magnetic field strength along Galileo's trajectory. Our computations show that in the event of Io possessing an anti-aligned dipole moment, even a small intrinsic magnetic field will be discernible.

(c) Magnetized Model of Io: Aligned Dipole

We have also begun to investigate the case where Io has a dipole moment aligned with the background Jovian magnetic field. In this case, Io's magnetic field both upstream and downstream is anti-aligned with the background field, and the possibility of continued magnetic reconnection has been suggested (Kivelson et al. 1979; Southwood et al. 1980). Figure 6 shows a comparison of the results for the aligned dipole case (magnitude of the dipole moment is the same as the case shown in Figure 3) with a simulation of flow past a conducting Io. With a small aligned dipole moment, no closed field region appears, and the interaction is essentially between the background field and the conductor. These preliminary results suggest that a small aligned dipole at Io would not survive (the diffusion time for even the best conductors is generally much less than the age of the solar system). We plan to perform further investigations of this case, including the possibility of larger dipole moments.

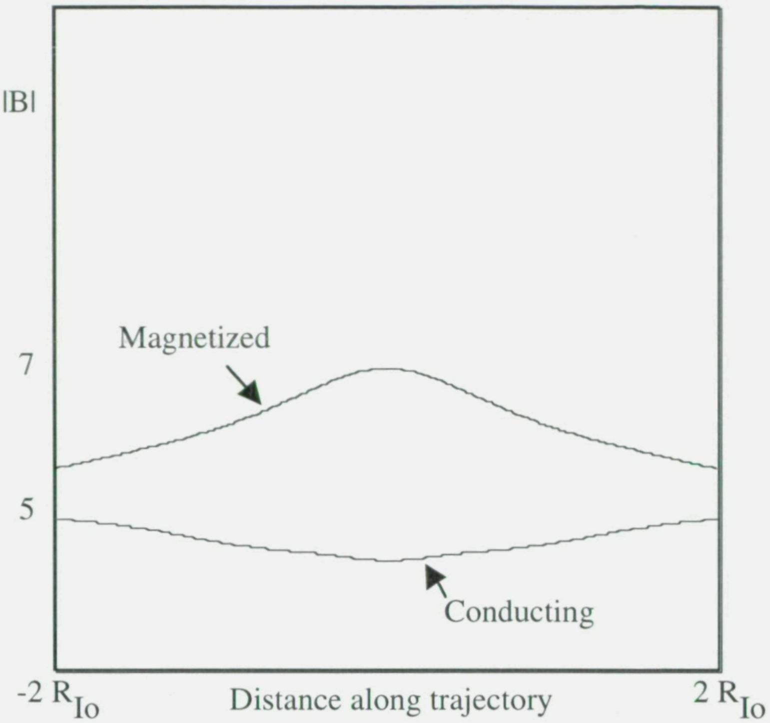

Figure 5. Magnitude of the magnetic field strength along the approximate Galileo trajectory shown in Figure 4. |B| = 5 (normalized units) corresponds to the Jovian magnetic field strength at Io's orbit (~2000 nT).

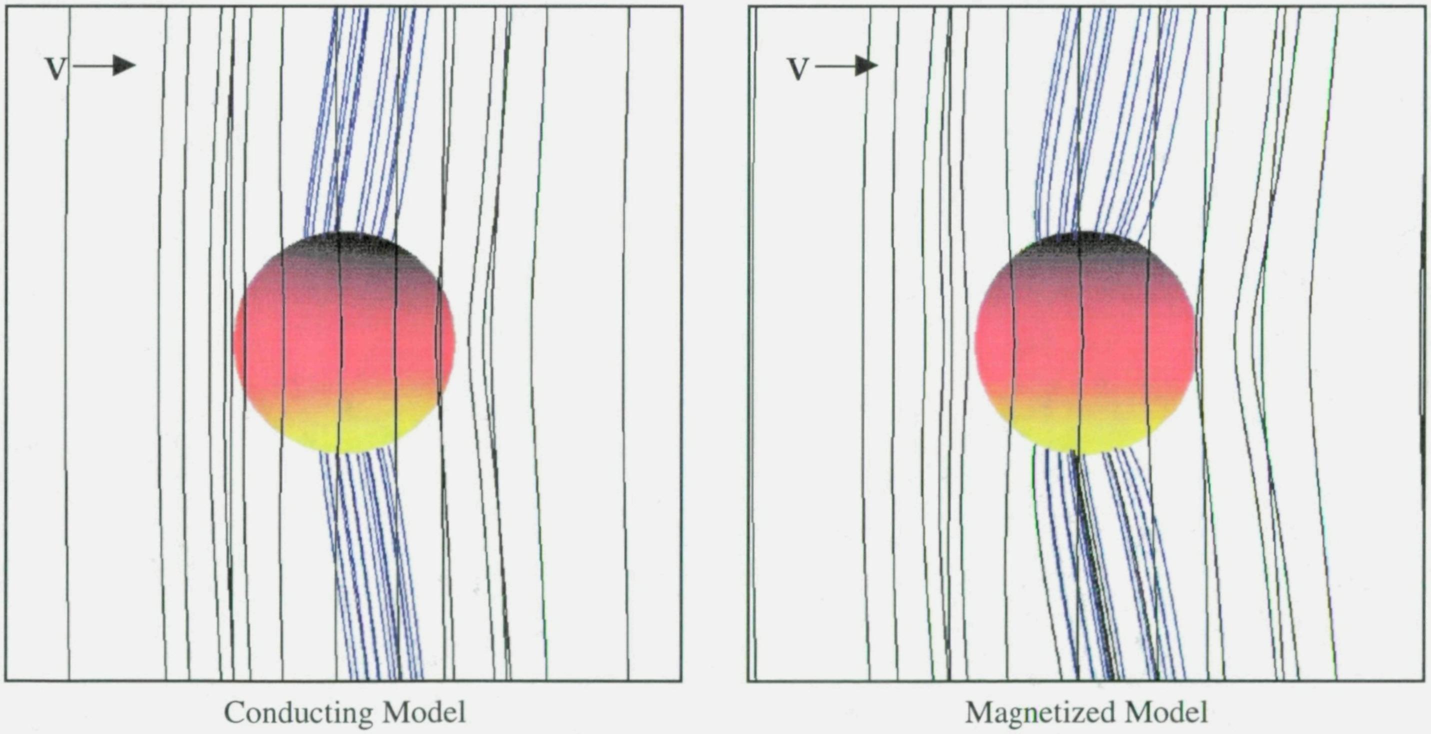

Figure 6. The same as Figure 3, but the dipole moment in the magnetized case is aligned with the background field. Both simulations show Alfven wings. Unlike the anti-aligned, magnetized case, the aligned magnetized case has no closed field region.

(d) Publications and Presentations

Linker, J. A., Modeling the Io torus-Io atmosphere interaction, Io torus workshop, Las Cruces, New Mexico, 1995.

Linker, J. A.,Galileo's Flyby Past Io, *Eos. Trans. AGU 76*, F342, Fall AGU meeting, San Francisco, 1995.

References

Bigg, E. K., Influence of the satellite Io on Jupiter's decametric emission, Nature, 203, 1008, 1964.

Dessler, A. J., Mass injection rate from Io into the Io plasma torus, Icarus, 44, 291, 1980.

Eviatar, A. and G. L. Siscoe, Limit on rotational energy available to excite Jovian aurora, Geophys. Res. Lett., 7, 1085, 1980.

Kivelson, M. G., J. A. Slavin, and D. J. Southwood, Magnetospheres of the Galilean satellites, Science, 205, 491, 1979.

Linker, J. A., M. G Kivelson, and R. J. Walker, An MHD simulation of plasma flow past Io: Alfvén and slow mode perturbations, Geophys. Res. Lett., 15, 1311, 1988.

Linker, J. A., M. G Kivelson, and R. J. Walker, A three-dimensional MHD simulation of plasma flow past Io, J. Geophys. Res., 96, 21037, 1991.

Mikić, Z., and J. A. Linker, Disruption of coronal magnetic field arcades, ApJ, 430, 898, 1994.

Neubauer, F. M., Possible strengths of dynamo magnetic fields of the Galilean satellites and of Titan, Geophys. Res. Lett., 5, 905, 1978.

Southwood, D. J., M. G. Kivelson, R. J. Walker, and J. A. Slavin, Io and its plasma environment, J. Geophys. Res., 85, 5959, 1980.