THE INTERACTION OF ENCELADUS' WATER PLUME WITH SATURN'S MAGNETOSPHERE. Krishan K. Khurana[1], Matt H. Burger[2], Jared S. Leisner[1], Michele K. Dougherty[3], and Christopher T. Russell[1], [1]Institute of Geophysics and Planetary Physics, UCLA, Los Angeles, CA, 90095, kkhurana@igpp.ucla.edu, [2]NASA-GSFC, Greenbelt, Maryland., [3]Imperial College, Department of Physics, London SW7 2AZ, U.K..

Introduction: In this presentation, we analyze the magnetic field data from the three close flybys and several distant flybys of Enceladus by the Cassini spacecraft. We show that Enceladus acts as an obstacle to the magnetized flow resulting in field line draping around it. Detailed modeling using an Alfvénic interaction model reveals that the center of the draping region is offset below Enceladus by several Enceladus radii consistent with a plume generated tenuous atmosphere located below Enceladus. We show that the effective diameter of the plume generated obstacle is at least 6 moon radii (R_E) and the obstacle is displaced by several R_E south and downstream of Enceladus. The strength of the interaction current that links Enceladus with Saturn's ionosphere is < 10^5 Amps (40-60% of the Neubauer limit [1]). From the strength of the current produced by the interaction, we estimate that the mass picked up by the magnetospheric plasma within 5 R_E of Enceladus is < 3 kg/s. In addition, we show that Enceladus does not possess a measurable internal magnetic field or an induction interaction field because there is little inducing field in Saturn's magnetosphere.

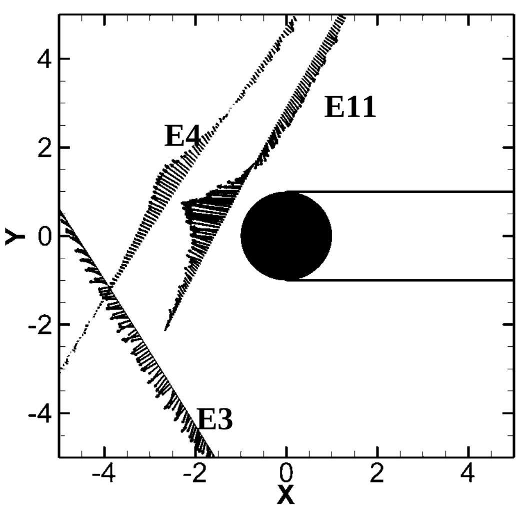

Figure 1. The trajectories of Cassini and perturbation field vectors in the XY plane of Enceladus interaction (ENIS) coordinates. In this coordinate system, X points along the orbital motion of Enceladus, Y points towards Saturn and Z completes the triad. Only those portions of the trajectories are shown which satisfied the criterion -5 R_E < X, Y < 5 R_E.

Trajectory and Data: Figure 1 shows the flyby trajectories in the XY projection of the ENIS coordinate system described in the caption of the figure. During all three close flybys, Cassini was upstream of Enceladus near the closest approach. Also superposed on the trajectories are the magnetic perturbation vectors (observation - background) projected into this plane. The perturbations are observed over a large region of space suggesting that the interaction region is several times larger than Enceladus. In addition, the field strength is seen to strengthen (not plotted) consistent with the diversion of a flow around an obstacle. The observed magnetic field perturbations rule out an internal magnetic field in Enceladus because a scalar field should fall off as r^{-3} or faster from Enceladus [2]. The perturbations are also inconsistent with a dipolar electromagnetic induction field originating from an interior conductor. This is expected because in the frame of Enceladus, there is no appreciable changing field imposed by the axisymmetric field of Saturn. The perturbations however are consistent with an origin in an Alfvén-wing current system as discussed in the next section.

Modeling: We use a model of the current system first used to model Io's interaction with Jupiter's magnetosphere [3,4]. The model was originally devised for studying the Alfvénic interaction of a conducting object with a flowing magnetized plasma. Neubauer [5] showed how it can be modified for the mass-loading situation by replacing the ion/neutral and electron/neutral collision frequencies with effective collision frequencies. Figure 1 shows a cartoon representation of the model used in this work. The mass-loading region is assumed to be spherical and displaced below and downstream of Enceladus. The plasma pick-up currents flow across the plasma pick-up region in the direction of the background electric field which is directed outwards from Saturn. The currents enter and exit the interaction region through the Alfvén wings. The computational Alfvén wings are composed of 180 "infinite" length line-segments (90 in northern and 90 in southern hemisphere) each of which originates from the pick-up region and extends infinitely to the Saturnian ionosphere along the two characteristics given by

$$\mathbf{V_A}^{\pm} = \mathbf{V_0} \pm \mathbf{B_0} \Big/ \sqrt{\mu_0 \rho} \qquad (1)$$

where $\mathbf{V_0}$ is the flow velocity, $\mathbf{B_0}$ is the background vector field and ρ is the plasma mass density. The magnetic field from the currents is calculated from Biot-Savaart equations.

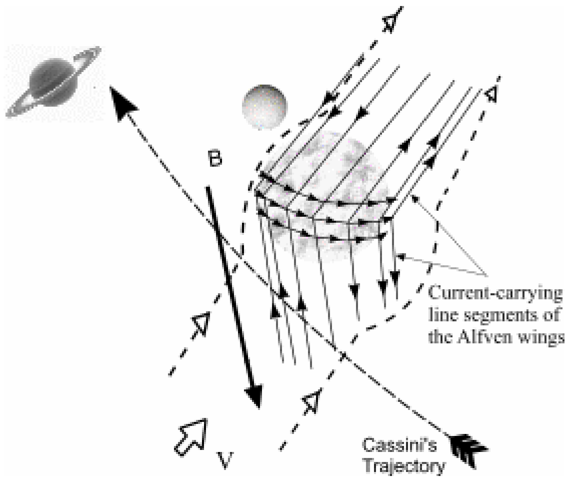

Figure 2. A cartoon of the current systems through the modified source region located below Enceladus. The currents are drawn into the source region along the Alfvén characteristics and then move along the surface of the source region. The currents exit the source region on the side away from Saturn.

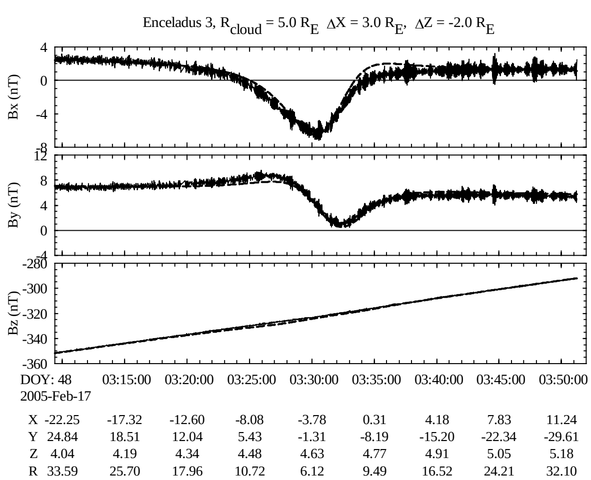

Figure 3. Magnetic field data obtained during the E3 flybys of Enceladus (solid) and the best fit model field (dashed) using the model shown in Figure 2. The model fit parameters are indicated in the title of the figure.

We treat the effective size and the location of the source as fit parameters. The resulting best fit for the first Enceladus flyby (E3) is shown in Figure 3. The required size of the source and the shift required for the source location are displayed in the title of the figure. For the E4 and E11 flybys, we were able to get solutions with a source size of ~ 3 R_E. However, for the E3 flyby, both the source size and its location had to be changed significantly from the E4 and E11 values. These differences point to temporal changes in the interaction presumably from changes in the extent and strength of the plume.

We have also examined several distant flybys of Enceladus by Cassini (not shown here). They show that an extended pick-up region exists around the orbit of Enceladus. The pick-up appears to be enhanced in the downstream region of Enceladus.

Summary and Discussion: The modeling results confirm that the water plume located near Enceladus' south pole is the source of neutrals and plasma in Saturn's magnetosphere. The plume strength appears to be variable and only a fraction (< 3 kg/s) of the 300 kg/s of neutral material gets ionized in the immediate vicinity of Enceladus. Additional pickup must be occurring in the neutral torus extending outward from the orbital location of Enceladus. Thus Enceladus' plume is a source for both the magnetospheric plasma and the neutral cloud (6).

Recently Burger *et al.* [7] simulated Enceladus' plume by a three-dimensional Monte-Carlo neutral cloud model. They show that the observations require two sources of water to fit the observations from the INMS instrument. One of the sources is a distributed global neutral component with a source rate of 8×10^{25} H_2O/s (2.4 kg/s). However the dominant source is a plume from the southern regions with a neutral source rate of 10^{28} H_2O/s (300 kg/s). They further show that out of this ~ 300 kg/s neutral source rate, the amount that gets picked up by the plasma (that is ionized, mainly through charge exchange) in the vicinity of Enceladus is between 1.5 and 3 kg/s, an estimate that is very close to our estimate of 0.6–2.8 kg/s. Complete results of the modeling from all three flybys will appear in a JGR manuscript which is in press [8].

References: [1] Neubauer, F. M. (1980), *JGR*, 85, 1171. [2] Dougherty, M.K. et al. (2006), *Science, 311*, 1406-1409. [3] Herbert, F., *JGR*, (1985), *90,* 8241. [4] Khurana, K. K. et al.(1997), *Geophys. Res. Lett., 24,* 2391. [5] Neubauer, F. M., (1998) *JGR*, 104, 3863. [6] Johnson R.E. et al. *APJ*, 644:L137–L139. [7] Burger et al. (2007), *JGR* in press. [8] Khurana et al. (2007), *JGR*, in press.