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AZIMUTHAL FIELD PERTURBATIONS IN THE JOVIAN MAGNETOSPHERE: *ULYSSES* OBSERVATIONS

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RESUMEN

Las perturbaciones azimutales del campo magnético observadas por el satélite *Ulysses* durante la entrada y salida de la magnetósfera joviana son comparadas con los valores calculados con la tranferencia de momento angular de la ionósfera a la magnetósfera debido a plasma magnetosférico que no está corrotando. Durante la entrada se observó una configuración "retrasada" del campo, correspondiente a flujos con subcorrotación. Se encontró que los valores máximos del campo azimutal disminuyen con la distancia como $r^{-1.4}$. Los valores teóricos resultan similares a los observados usando una conductividad de Pedersen de 0.136 ± 0.028 mho. Este valor es menor al obtenido por Vasyliunas, 0.4 mho, del análisis de los datos del *Pioneer* 10 y los *Voyager* 1 y 2. La diferencia se debe a los campos mayores observados por el último satélite. A la salida, la teoría da un buen ajuste con dos trazas de campos "retrasados" donde el campo es nuevamente subcorrotacional. Sin embargo, a distancias grandes se observa la presencia de una configuración de campo "adelantado" que no es predicho por la teoría ya que el flujo es subcorrotacional. Se sugiere que el campo "adelantado" es debido al sistema cola-magnetopausa.

ABSTRACT

Azimuthal magnetic field perturbations observed by the *Ulysses* spacecraft during the inbound and outbound passes of the Jovian magnetosphere are compared with theoretically calculated values based on the transfer of angular momentum from the ionosphere to the magnetosphere due to departures from corotation of the magnetospheric plasma. On the inbound pass a "lagging" field configuration was observed corresponding to regions of subcorotational flow. The peak azimuthal fields were found to fall with radial distance as $r^{-1.4}$. Good theoretical agreement is obtained with the observed values using a value for the Pedersen conductivity of 0.136 ± 0.028 mho. This value is smaller than the 0.4 mho obtained by Vasyliunas from the analysis of the *Pioneer* 10 and the *Voyager* 1 and 2 data. The difference is due to the larger fields observed by the latter spacecraft to which the theory was fitted. On the outbound pass the theory gives good agreement with two large "lagging" field signatures where the flow is again subcorotational. At larger distances, however, the presence of a consistently "leading" field configuration is observed which is not predicted by the theory, since the flow was still subcorotational in this region. This "leading" configuration is suggested to be due to the tail-magnetopause current system.

Key Words: **INTERPLANETARY MEDIUM — MAGNETIC FIELDS — PLANETS AND SATELLITES: INDIVIDUAL (JUPITER) — PLASMAS**

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1. INTRODUCTION

A central concept in the physics of the Jovian magnetosphere is that the majority of the plasma originates from the moon Io (5.9 R_J, R_J=71,393 km). This plasma then diffuses outwards into the middle magnetosphere current sheet and beyond (Hill 1979; Vasyliunas 1983). In the inner magnetosphere, 10 R_J, the plasma approximately corotates with the planet. As the plasma diffuses outwards, its velocity falls below that required for corotation due to the conservation of angular momentum. These departures from corotation generate a torque from the ionosphere, via the Pedersen conducting layer, to the magnetosphere. The effect is then that this torque acts to speed up the magnetosphere while at the same time braking the atmosphere. In this way momentum is transferred from the planet to the magnetosphere. This torque imposes a current system in the Pedersen layer of the ionosphere to the magnetosphere. This current flows equatorwards in conjugate ionospheres, radially outwards in the magnetosphere and closes via field aligned currents between these regions. The result of this current system is that the magnetic field lines are bent out of meridian planes into a "lagging" field configuration which, due to the southward polarity of the Jovian field, results in a negative azimuthal field perturbation north of the magnetic equator and a positive azimuthal field perturbation south of the magnetic equator. Previous analyses of the *Pioneer* and *Voyager* data has shown the presence of azimuthal field perturbations on the dawn side of the planet corresponding to times of subcorotating flow (Van Allen 1976; McDonald, Schardt, & Trainor 1979; Carbary et al. 1981). These perturbations have been interpreted in terms of momentum transfer from the solar wind (Ness et al. 1979), and in terms of momentum transfer from Jupiter (Vasyliunas 1983). There is, however, no way to distinguish between the two since *Pioneer*/ *Voyager* did not traverse the dusk side of the planet where the two predict different signs for the perturbations. We now wish to analyse the perturbations observed by *Ulysses*,(Dougherty et al. 1993) in terms of magnetosphere-ionosphere coupling.

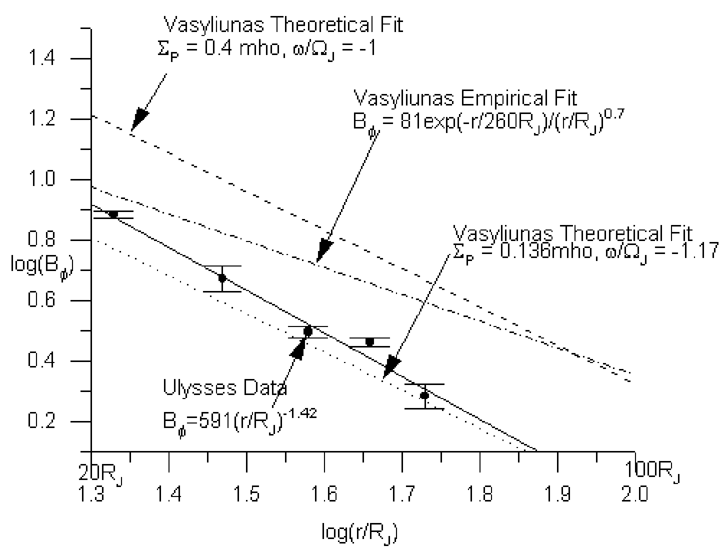

Fig. 1. *Ulysses* data and Vasyliunas's theoretical and empirical fits to the *Pioneer*/ *Voyager* data.

2. THEORETICAL RELATIONSHIP BETWEEN FIELD PERTURBATIONS AND PLASMA FLOW

We first assume steady state conditions. Equilibrium is established between the ionosphere and the magnetosphere by the propagation of Alfven waves. Departures from corotation are associated with a rotation, ω, of the field lines about the magnetic axis (inclined at 10^o to the spin axis) in the planetary rest frame such that the total plasma velocity is given by $\mathbf{V} = \mathbf{V}_c + \omega \times \mathbf{r}$. This differential rotation induces an electric field

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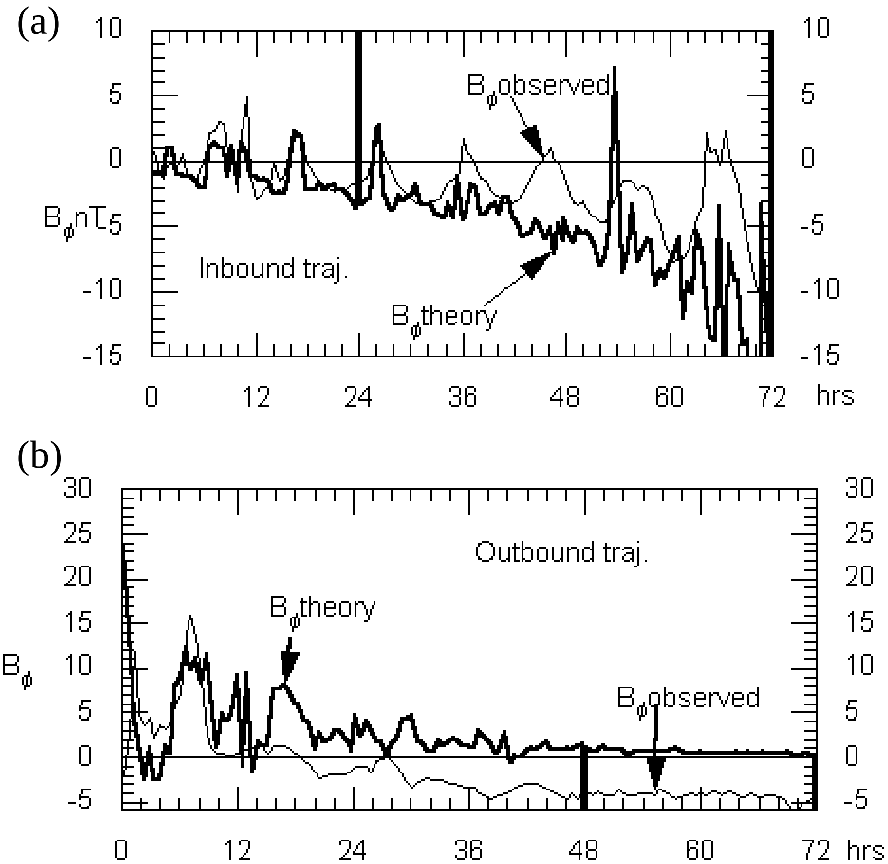

Fig. 2. Theoretical B_ϕ: *(a)* Inbound trajectory *(b)* Outbound trajectory.

in the planetary rest frame given by $\mathbf{E}' = -(\omega \times \mathbf{r}) \times \mathbf{B}$ which for a positive ω gives a poleward electric field in the ionosphere which drives a poleward Pedersen current. Noting that the angular momentum flux per unit magnetic flux is $-\rho B_\phi/\mu_0$ and that this is conserved along the field between the source and sink regions and that the Pedersen current produces field perturbations solely in the azimuthal direction just above the ionosphere, then we have a final expression for the field perturbation due to departures from corotation as $B_\phi = \pm\mu_0 \Sigma_P \frac{\rho_i^2}{\rho} B_i \omega$. Here ρ_i is the $\perp$ distance of the field line footprint in the ionosphere from the magnetic axis, ρ is the $\perp$ distance to the spacecraft from the magnetic axis, B_i is the polar field strength and Σ_p is the height integrated Pedersen conductivity. The positive and negative signs refer to conditions above and below the magnetic equator respectively.

3. APPLICATION TO *ULYSSES* DATA

In order to determine B_ϕ we need the angular velocity of the field lines about the magnetic axis in the planetary frame. This is done by subtracting the corotational velocity from the field perpendicular MeV proton veocities, as provided by Laxton et al. (1997). We also need an estimate for the Pedersen conductivity. This is obtained by calculating Σ_P using the observed B_ϕ values and averaging over one hour during the peaks in the B_ϕ profile observed by *Ulysses*. These peak values are found to correspond to a value for Σ_P of 0.136 $\pm$0.028 mho and a value for the ratio ω/Ω_J of -1.17$\pm$0.26. This value for Σ_P is much smaller than the 0.4 mho obtained by Vasyliunas (1983). One reason for this could be due to a difference in the plasma velocity. However, Vasyliunas had no detailed plasma velocities and assumed that the plasma was stationary in the inertial frame i.e., ω/Ω_J=-1. Our value of -1.17 is very close to this and so this is unlikely to be the reason. Another possible reason could be due to the field model used to calculate the ρ_i's. To investigate this we have repeated Vasyliunas's analyses using his values of Σ_P and ω/Ω_J and our values to highlight the difference in the ρ_i's. This is shown in Figure 1. Here we can see that using the Vasyliunas values does not provide a good fit to the *Ulysses* data. However, using the values determined here we can see that the Vasyliunas theoretical model provides a good fit, thus refuting the contention that the ρ_i's are the source of the discrepancy. If we now look at the Vasyliunas empirical fit to the *Pioneer*/*Voyager* data we can see that at small distances we have good agreement but at larger distances we do not. We therefore conclude that the discrepancy is due to larger B_ϕ values observed by *Pioneer*/*Voyager* at large radial distances. We now calculate B_ϕ for the inbound and outbound passes using the values we have obtained. Figure 2*a* shows the calculated B_ϕ and the observed B_ϕ for the inbound pass. Here we can see we have very good agreement. Figure 2*b* shows the calculated B_ϕ and the observed B_ϕ for the outbound pass. Here we have reasonable agreement for the first two observed peaks in B_ϕ but at larger radial distances a consistently "leading" configuration is observed which has no counterpart in the theory since the flow was still subcorotational. We suggest that this is due to the tail-magnetopause current system.

REFERENCES

Carbary, J. F., Krimigis, S. M., Keath, E. P., Gloeckler, G., Axford, W. I., & Armstrong, T. P. 1981, J. Geophys. Res., 86, 8285

Dougherty, M. K., Southwood, D. J., Balogh, A., & Smith, E. J. 1993, P&SS, 41, 291

Hill, T. W. 1979, J. Geophys. Res., 84, 6554

Laxton, N. F., Balogh, A., Cowley, S. W. H., Dunlop, M. W., Forsyth, R. J., Hynds, R. J., & Staines, K. 1997, P&SS, 45, 1143

McDonald, F. B., Schardt, A. W., & Trainor, J. H. 1979, J. Geophys. Res., 84, 2579

Ness, N. F., Acuña, M. H., Lepping, R. P., Behannon, K. W., Burlaga, L. F., & Neubauer, F. M. 1979, Nature, 280, 799

Van Allen, J. A. 1976, in Jupiter, ed. T. Gehrels (Tucson: Univ. Arizona Press), 928

Vasyliunas, V. M. 1983, in Physics of the Jovian Magnetosphere, ed. A. J. Dessler (Cambridge: Cambridge University Press), 395

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