Final Report

for

P-6

Studies of Magnetopause Structure

NASA Grant NAGW-1054

Name and Address of Institution:	The Regents of the University of Colorado Campus Box B-19 Boulder, Colorado 80309-0019
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Principal Investigator:	Theodore W. Speiser, Professor Department of Astrophysical, Planetary, & Atmospheric Sciences The University of Colorado Campus Box 391 Boulder, CO 80309-0391 Phone: (303) 492-8767 email: SELVAX::TSPEISER (SPAN) or SPEISER@NISTCS2.BITNET
NASA Technical Officer:	Dr. M. Mellott Code ESM NASA Headquarters Washington, DC 20546 Phone: (202) 453-2077

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"Studies of Magnetopause Structure"

A. Summary of Completed Project

1. Magnetopause Ion Signatures and Flux Transfer Events

From ISEE 1 magnetopause crossings on November 10, 1977, three-dimensional distribution functions for energetic ions (24-120 *keV*) were studied in the magnetosphere, through the magnetopause, and in the magnetosheath [*Speiser and Williams*, 1982]. The particle distributions were particularly examined at and near the times that *Russell and Elphic* [1978] identified as flux transfer events (FTE). Using a simple, one-dimensional, quasi-static model, particle orbits were followed numerically, from the magnetosphere into the sheath. The inner, trapped, distribution initializes the distribution function. Liouville's theorem allows the inner distribution to be mapped into the sheath following the orbits.

This mapping is shown in Figure 1 [*Speiser and Williams*, 1982, Figure 4] for four magnetosheath ion flows (MIF's), corresponding to four flux transfer events for this date. It is found that the modeled distribution function agrees quite well with that of the observed MIF's for an inward-pointing, normal magnetic field component and the magnitude of any reconnection-like tangential electric field must have

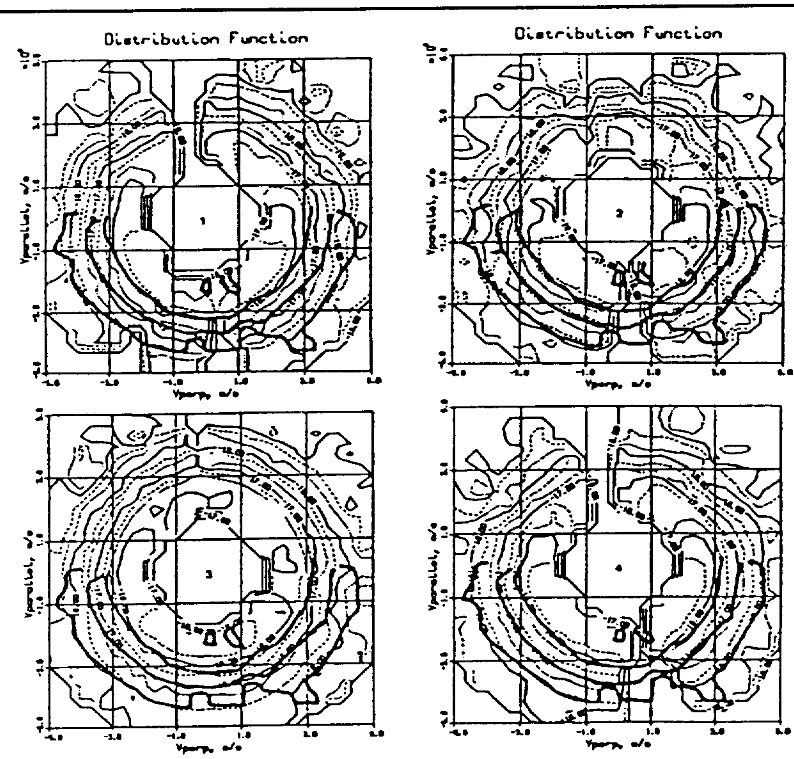

Fig. 1. Magnetosheath contour maps of log F ($s^3\, m^{-6}$) for FTE's 1-4, labeled in the center of each figure. Heavy lines are even model contours (-16, -17, -18) overlaid. Model parameters: MP thickness = 500 *km*; B = 8 *nT*, inward; E tangential = 0; initialization of F and magnetospheric field - same as Figure 3 of Speiser, Williams and Garcia (SWG) [1981]; initialization of sheath field - same as Figure 4 of SWG.

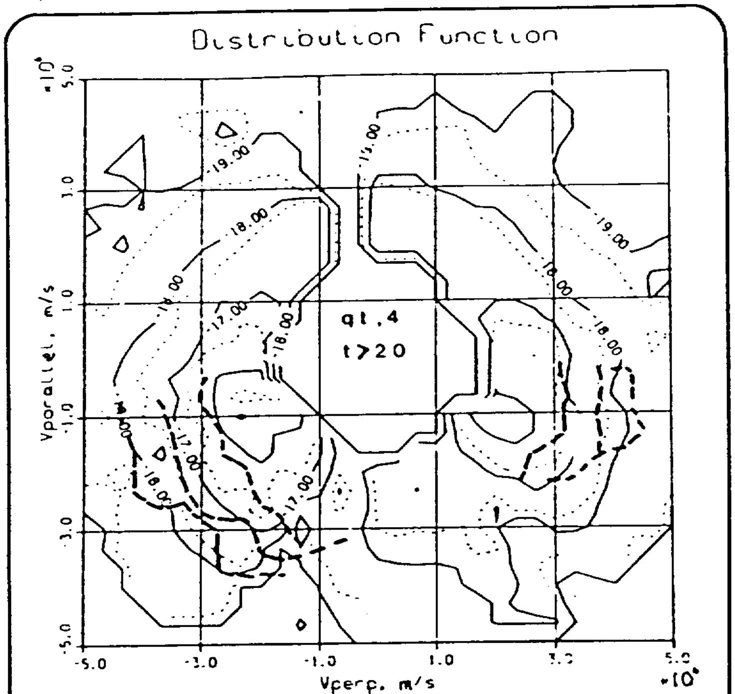

Fig. 2. Magnetosheath contour maps of log F (s^3m^{-6}). Heavy dashed lines are even model contours (-16, -17, -18) overlaid.

been less than about $1/2\,mV/m$. A tangential field up to about this limit may supplement gradient and curvature drifting, repopulating freshly "opened" flux tubes. Electric fields associated with tangentially convecting sheath plasma are mapped along a connected flux tube, but do little to change the distribution function of the energetic ions. A quasi-trapped (QT) population in the sheath usually seems to "sandwich" the FTE distributions. These QT distributions are probably due to slow, large pitch angle, outward moving particles, left behind by the outward rush of the ions more field aligned at the time the flux tube was "opened." If this interpretation is correct, the spatial extent of "open" field lines near the boundary is broader, not quite as localized as previously thought. Figure 2 [*Speiser and Williams*, 1982, Figure 5] shows a QT distribution in the magnetosheath following an MIF, and modelled contours overlaid as heavy dashed lines. The modelled distributions are formerly trapped particles exiting on open field lines, but doing so more slowly than the MIF distributions. The higher energy, outflowing particles with small to large pitch angles penetrate the magnetopause several thousand kilometers from the low energy particles. This result of the model, combined with two of the FTE observations, gives qualitative support to the suggestion that localized tangential electric fields above our upper limit may have existed for this time period.

Using a sample of ISEE 1 and 2 magnetopause crossings previously identified as times of quasi-steady reconnection (QSR), we identified flows of medium energy ions in the magnetosheath. We then investigated the particle pitch angle distribution immediately before and after each of these events for the signature of the QT distributions of energetic ions. Several of the ion flows that we identified were observed simultaneously with previously identified FTE's. While FTE's identified from the magnetometer tracings typically show evidence of ion flows, the converse is not necessarily true. Figure 3 [*Neff, Speiser, and Williams*, 1987, Figure 2] shows the B_n signature for 18 cases where we have found MIF's. While there is a clear FTE signature for some of the cases (e.g. 1-4) it would be difficult to find such a

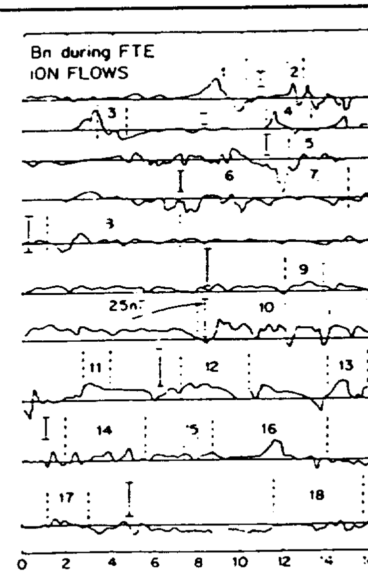

Fig. 3. Plots of B_n, the boundary normal magnetic field. The coordinates were rotated assuming that the boundary approximates a tangential discontinuity. The vertical bar on each curve represents a scale of 25 nT.

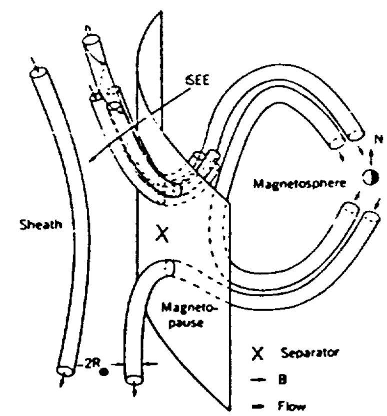

Fig. 4. Model of a QTD/MIF/QTD event. The MIF is interpreted as a recently opened "flux tube" in which there is a rapid outrush of (primarily field aligned) particles. The size of this tube is several earth radii. It is embedded in a much larger region of interconnected field lines. Near the MIF, low-energy, large pitch angle particles could be explained as particles left behind by the outrush of the more field aligned particles. Farther out, and for higher energy particles, high pitch angle particles must be preferentially repopulated onto the open field lines and then flow out into the magnetosheath. MIF's, though somewhat local in character, are thus seen to be part of a much larger region of interconnected magnetic field, at least during these times of QSR.

signature for many of the other cases. All properties of the magnetosheath ion flows are the same regardless of whether an FTE can be identified from the magnetometer data. We find evidence for small-scale reconnection processes (FTE's, ion flows) embedded within a larger region of interconnected field, which is traced out by the quasi-trapped particles. Again, quasi-trapped distributions of medium-energy ions are seen to sandwich reconnection-morphology for reconnection events that incorporates both large- and small-scale features, as sketched in Figure 4 [*Neff, Speiser, and Williams*, 1987].

We have extended our survey to one year (November, 1977 - October, 1978) of the ISEE 1 medium energy ion data, wherein the satellite made 257 encounters with the magnetopause. For this larger data set, we find that about 95% of the time, when we observed MIF's, QT distributions are observed next to the MIF's. This would tend to support the model of slow leakage discussed above. However, for this data set, although MIF's show a nice negative correlation with the interplanetary B_z (Figure 5), the QT cases have very little correlation with B_z (Figure 6).

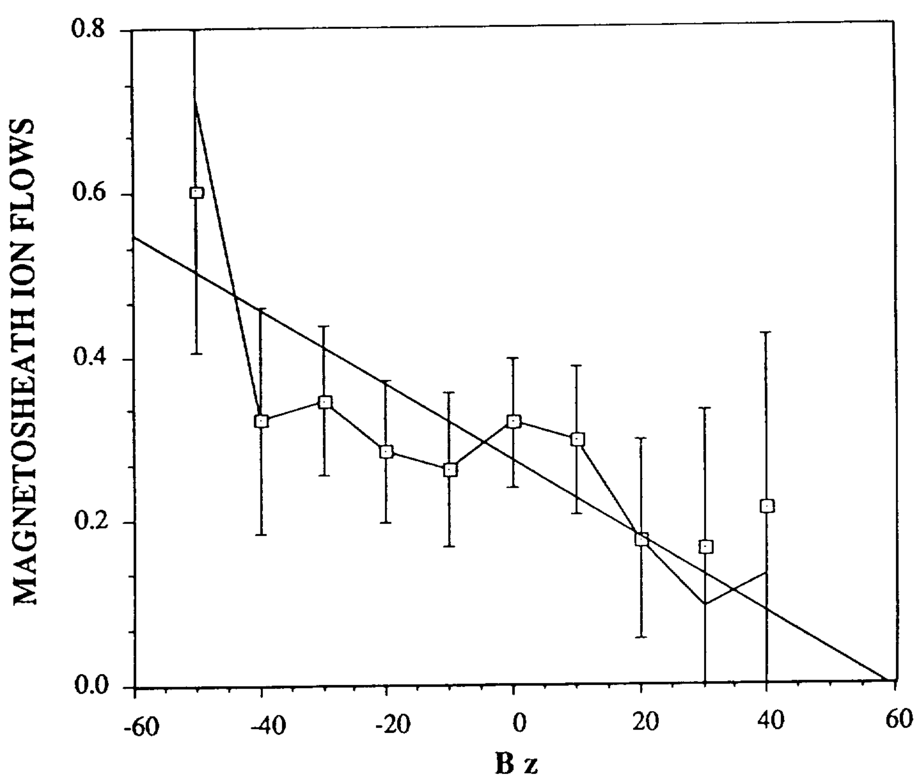

Fig. 5. Magnetosheath Ion Flows vs B_z. Relative occurrence rate. Correlation significance level = .0026.

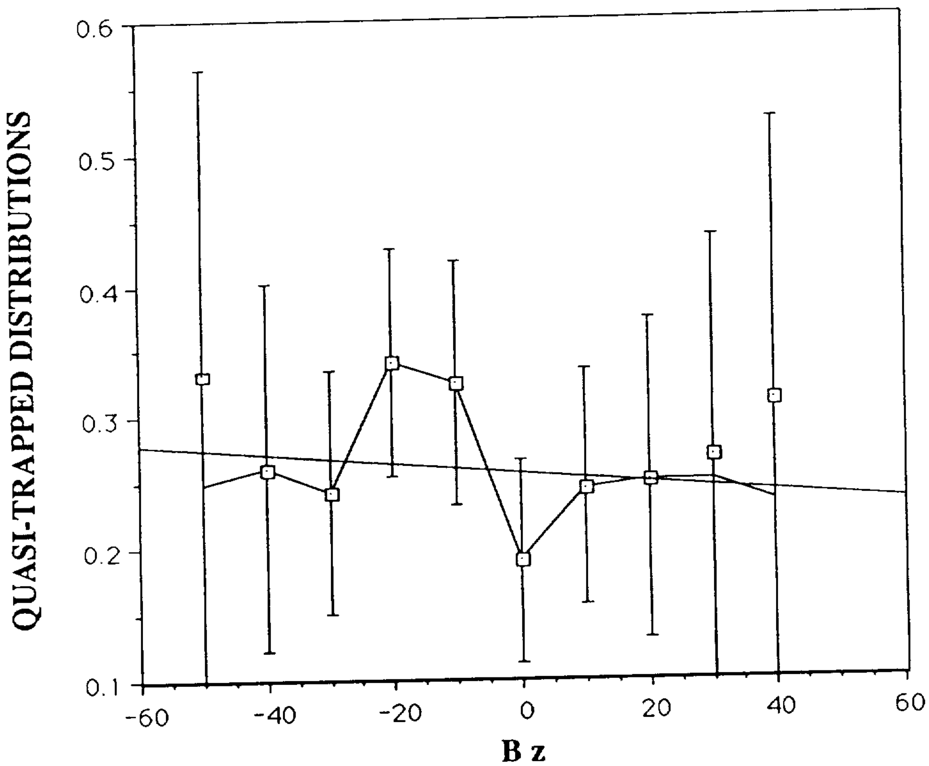

Fig. 6. Quasi-trapped Distributions vs B_z. Relative occurrence rate.

Perhaps the model still applies, i.e. the QT particles escaped earlier along open field lines, but now that connection has ceased. It is also possible that leakage of near 90° particles at a closed magnetopause make some contribution to the QT populations.

2. Current Sheet Particle Motion

In the magnetosphere, the major current sheets are the magnetopause current sheet and the tail current sheet. It is therefore relevant to review the theory of particle motion in current sheets [Speiser, 1991; Speiser et al., 1991]. For small, approximately constant normal magnetic field, B_z, particles oscillate about the current sheet and "live" within the sheet for one-half gyroperiod based on B_z. This lifetime replaces the mean collision time in the Lorentzian conductivity and thus gives rise to the concept of an inertial (or gyro-) conductivity. A substorm model by Coroniti [1985] utilizes this conductivity to allow reconnection to proceed without anomalous processes due to wave-particle interactions. Chaotic particle orbits may at times be important to the dynamics, depending on parameters such as particle energy, current sheet thickness, and field line curvature. A current sheet model with neutral line predicts a ridge structure and asymmetries in the distribution function. Observed ion distributions near the plasma sheet boundary layer, during the CDAW 6 interval, are consistent with the model predictions.

B. Relevant Publications

Hartsell, T.P., T. W. Speiser, and D. Williams, Flux Transfer Events from Energetic Particle Signatures: A Synoptic View, *EOS, 44*, 1369, 1988.

Hartsell, T.P., T. W. Speiser, and D. Williams, Magnetosheath Ion Flows from Energetic Particle Signatures: A Synoptic View, *EOS, 70*, 435, 1989.

Neff, J. E., T. W. Speiser, and D. J. Williams, Magnetosheath quasi-trapped distributions and ion flows associated with reconnection, *J. Geophys. Res.*, *92*, 1177, 1987.

Russell, C. T. and R. C. Elphic, Initial ISEE magnetometer results: Magnetopause observations, *Space Sci. Rev., 22*, 681, 1978.

Speiser, T. W. and D. J. Williams, Magnetopause Modeling: Flux Transfer Events and Magnetosheath quasi-trapped Distributions, *J. Geophys. Res.*, *87*, 2177, 1982.

Speiser, T. W., D. J. Williams, and H. A. Garcia, Magnetospherically trapped ions as a source of magnetosheath energetic ions, *J. Geophys. Res., 86*, 723, 1981.

Speiser, T. W., P. B. Dusenbery, R. F. Martin, Jr., and D. J. Williams, Particle Orbits in Magnetospheric Current Sheets: Accelerated Flows, Neutral Line Signature, and Transitions to Chaos, in Modeling of Processes in Magnetospheric Plasmas, *Geophysical Monograph*, in press, 1991.

Speiser, T. W., Geomagnetic Tail, in Geomagnetism 4, J. Jacobs (ed.), *Academic Press Limited*, London, p. 333, 1991.

C. Conferences

Magnetosheath quasi-trapped distributions and ion flows associated with reconnection, Neff, J. E., T. W. Speiser, and D. J. Williams, *SCOSTEP-STP COSPAR Meeting*, Toulouse, France, June 1986.

Flux Transfer Events from Energetic Particle Signatures: A Synoptic View, Hartsell, T.P., T. W. Speiser, and D. Williams, *Front Range Branch American Geophysical Union Meeting*, Golden, CO, February 1988.

Magnetosheath Ion Flows from Energetic Particle Signatures: A Synoptic View, Hartsell, T.P., T. W. Speiser, and D. Williams, *Front Range Branch American Geophysical Union Meeting*, Golden, CO, February 1989.