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TITLE: CHARACTERISTICS OF THE MAGNETOSPHERIC BOUNDARY LAYER AND MAGNETOPAUSE LAYER IN HIGH TIME RESOLUTION

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CHARACTERISTICS OF THE MAGNETOSPHERIC BOUNDARY LAYER

AND MAGNETOPAUSE LAYER IN HIGH TIME RESOLUTION

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ABSTRACT

A basic problem of magnetospheric physics is to determine how and where solar wind mass, momentum and energy is transferred to the magnetosphere. IMP 6 plasma and magnetic field data indicate that the closed magnetospheric boundary layer is always present adjacent to and earthward of the magnetopause layer at all locations equatorward of the entry layer and plasma mantle. All IMP 6 crossings show some magnetosheath-like plasma earthward of the magnetopause layer and the boundary layer electron spectra are often [illegible] from the magnetosheath electron spectra. In 2[illegible] [illegible] or electron spectra is observed near the magnetopause [illegible] in the plasma parameters occur primarily in the boundary layer. [illegible] boundary layer bulk plasma flow [illegible] and often has a [illegible] field [illegible]. Energetic electron pitch angle distributions indicate that the boundary layer is on closed field lines. [illegible] IMP 6 crossings [illegible] boundary layer plasma flow [illegible] observed [illegible] with [illegible] from the subsolar region [illegible] are not consistent with a [illegible]. We conclude that the boundary layer is [illegible] principally by direct plasma transport through the magnetopause layer.

INTRODUCTION

A basic [illegible]

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boundary. The principal features of this magnetospheric boundary layer are decreasing plasma density and flow velocity with increasing distance earthward from the magnetopause layer. At the outer surface of the boundary layer is the magnetopause layer, identified mainly by its magnetic signature, which typically has a characteristic thickness that is much smaller than the boundary layer thickness. The inner surface of the boundary layer is where magnetosheath-like plasma flow and magnetic noise essentially cease. Boundary layer thickness estimates, assuming a stationary boundary, range from hundreds to thousands of kilometers.

On the basis of the IMP 6 data, Eastman, et al.[3] proposed that the magnetohydrodynamic action of boundary layer plasma flowing transverse to the closed field lines of the boundary layer is an important mechanism for the transfer of plasma, momentum and energy from the magnetosheath to the magnetosphere. They showed that the system I and cusp region field aligned currents might be driven by this generator action of the boundary layer. This picture would be implied by the presence of direct plasma influx from the magnetosheath at all points over the magnetosphere's sunward surface. Such direct plasma entry has been suggested for the entry layer in the polar cusp region only by Paschmann, et al.[2] based on HEOS 2 measurements. Recently, Haerendel, et al.[4] have suggested that heat conduction and wave propagation with subsequent dissipation along the magnetic field could supply the observed energy and ion mobility of the lower latitude boundary layer with direct entry limited to the entry layer. They also discussed another possible source for boundary layer plasma: namely, anomalous [illegible] diffusion or heating of cold magnetospheric plasma. Observations that contradict this source mechanism will be presented in the next section. The basic evidence cited against the presence of direct plasma entry into the boundary layer, apart from the entry layer, was that the [illegible] data seem to show sudden large changes in plasma properties across the magnetopause. However, the time resolution of their density measurements is [illegible] four minutes and our results indicate that the apparent discontinuities observed by [illegible] could be [illegible] of the [illegible]. To evaluate the detailed properties of the boundary layer and magnetopause layer we have examined the IMP 6 plasma [illegible] in the high time resolution data, an electron and proton [illegible].

The Los Alamos Scientific Laboratory (LASL) electrostatic plasma analyzer on IMP 6 [illegible] proton and electron distributions with a [illegible] analyzer fan centered about the ecliptic plane. Plasma spectra are [illegible] second and a rough [illegible] two dimensional velocity distribution is obtained for each spacecraft rotation period [illegible]. The LASL [illegible] analyzer provides a complete [illegible] velocity distribution [illegible] energy spectra [illegible] and protons [illegible]. [illegible] D. H. F[illegible] [illegible].

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SELECTED IMP 6 MAGNETOPAUSE/BOUNDARY LAYER CROSSINGS

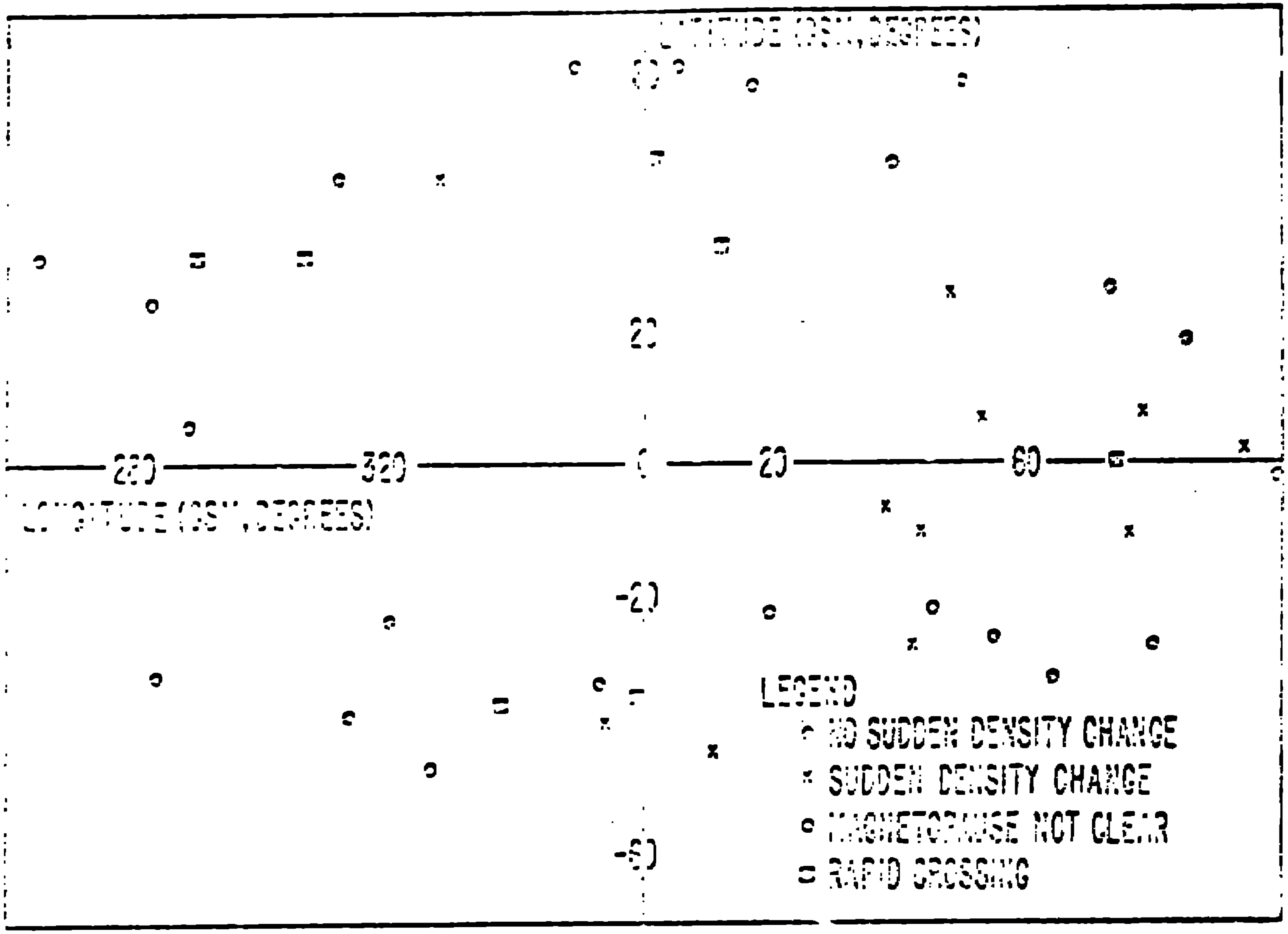


Figure 1

analysis. This set include the seven most rapid crossings found from over 100 IMP 6 crossings of the magnetosphere's sunward surface. The basic boundary layer signatures were never found to be completely absent in any crossing including those rapid crossings where the nominal boundary layer thickness was observed to be as small as one or a few ion gyroradii. Local plasma density and electron spectra, sampled every three seconds, showed no distinct change at the magnetopause layer in 24 out of 40 crossings. However, 4 minute averages of the data would often show abrupt changes near the magnetopause in agreement with the HEOS results. Three of the seven most rapid crossings also showed no change at the magnetopause layer.

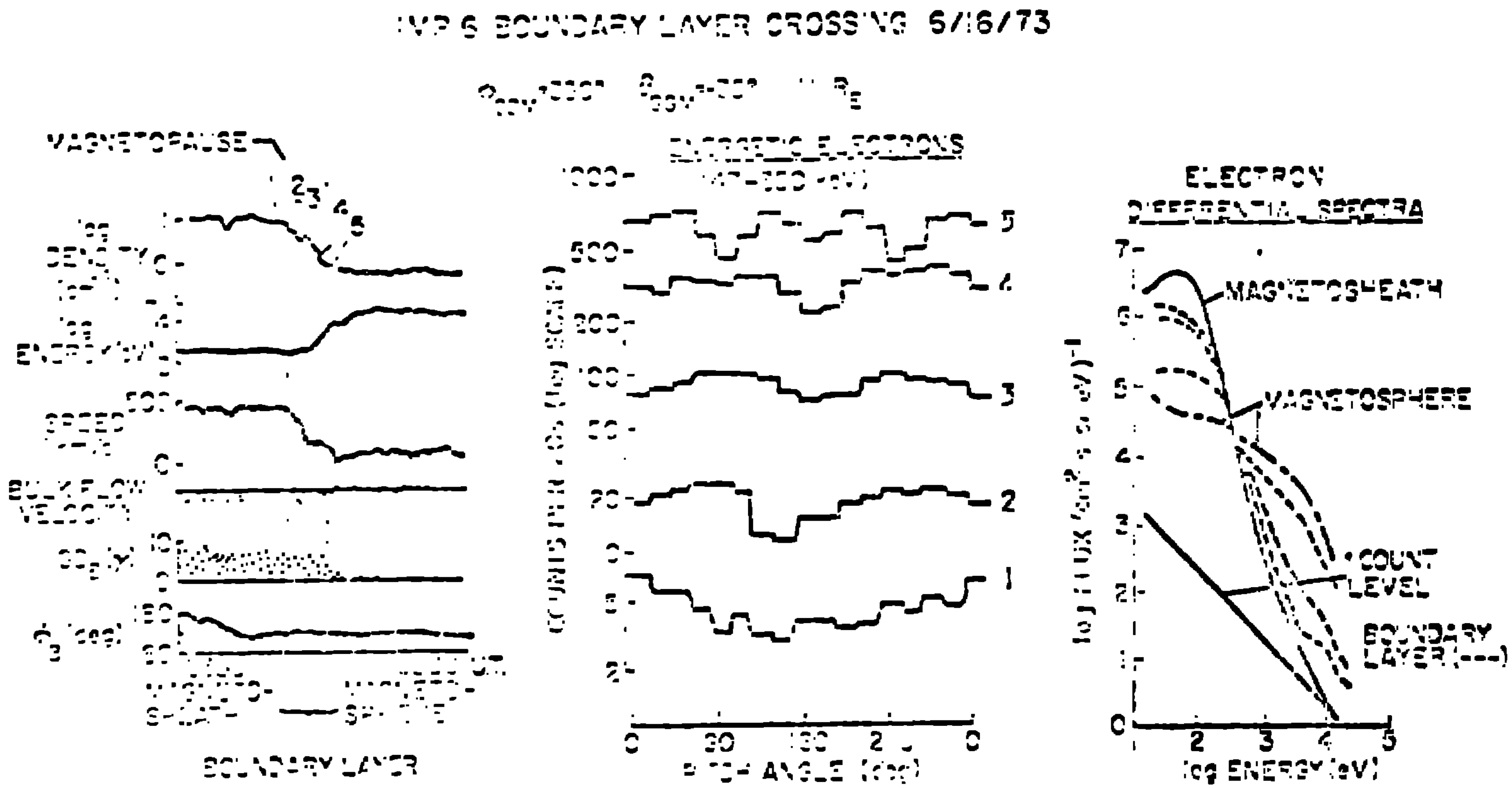
IMP 6 plasma experiments provide good coverage of the dayside magnetopause layer except within ~ 25° of the subsolar point. From a larger sample of 76 crossings, we found that nominal boundary layer thickness increase with increasing distance from the subsolar region to more than 10 ion gyroradii near the dawn-dusk meridian plane. No statistically significant correlation has yet been found between boundary layer thickness and latitude, geomagnetic activity, or interplanetary magnetic field (IMF) parameters.

Our high time resolution data has led us to distinguish two regions with the following empirical definitions:

Magnetopause Layer: the region, separating the magnetosheath from the boundary layer, through which the magnetic field shifts in direction;

Magnetospheric boundary layer: the outermost plasma region of the magnetosphere, containing tangentially flowing, magnetosheath-like low energy plasma of progressively decreasing density and flow velocity. It is bounded on the magnetosheath side by the magnetopause layer and is bounded on the earthward side by the low density, higher mean energy magnetospheric plasma of the plasma sheet.

Basic characteristics of the boundary layer are illustrated in Figure 2. The density and velocity decrease from the magnetopause layer to the inner surface of the boundary layer is accompanied by an increase in average energy and continued magnetosheath level magnetic field fluctuations. The plasma β usually drops below one in the inner portion of the boundary layer consistent with the decay of field fluctuations. Within the boundary layer the flow directions are more variable and usually shift into a direction that is more tangent to the magnetopause surface. The electron spectra are similar to magnetosheath spectra up to the inner surface of the boundary layer. Simultaneously, the pitch angle distributions of 47-300 keV electrons progress from a streaming distribution in the magnetosheath, through low intensity trapped distributions in the boundary layer, to a "butterfly" distribution in the nearby magnetosphere. Other cases show trapped distributions in the boundary layer on the dawn side through noon; however, dusk side crossings have low intensity isotropic or butterfly distributions. The depletion of the high pitch angle portion of the distribution, as described by H. West,[5] is caused by magnetopause shadowing of drift paths as the energetic electrons drift around the [illegible] side. Whenever a distinct magnetopause layer is present, the dawn or dusk side boundary layer has the same basic features as in this example with the boundary layer in the region of closed, magnetospheric field lines.



IMP 6 BOUNDARY LAYER CROSSING 6/16/73
MAGNETOPAUSE
ELECTRON DIFFERENTIAL SPECTRA
MAGNETOSHEATH
MAGNETOSPHERE
COUNT LEVEL
BOUNDARY LAYER (---)
BOUNDARY LAYER

Figure 2

To check whether the boundary layer is always present, we selected the seven most rapid IMP 6 boundary crossings. Figure 3 shows one of the four rapid crossings that exhibited a sudden change at the magnetopause layer. Even in this case, a distinct region of magnetosheath like plasma, based on both electron density and spectra, is present earthward of the magnetopause layer, identified by the magnetic field direction change. This case shows a large apparent charge separation near the magnetopause layer where the electron spectra and densities have dropped to very low values while spin-modulated magnetosheath protons continue inwards. In this crossing, low energy plasma, above or below the threshold of the LASL plasma probe, must be present to maintain approximate charge neutrality. Two other crossings have been observed with this same spatial structure, one on the dusk side and one on the dawn side. In all of these three rapid crossings, showing an unusual difference of plasma populations, the cold, magnetospheric plasma shows no sign of heating while magnetosheath-like plasma is observed within the magnetopause layer. This observation indicates that heating of magnetospheric plasma does not provide the source for boundary layer plasma. In addition, the magnetosheath like spectra and plasma flow of the boundary layer combined with the observed usual continuity of plasma properties through the magnetopause layer indicates that any magnetospheric source or any nonlocal source is unlikely.

Analysis of the magnetic field data for this unusual rapid crossing of 2/12/74 indicates that it is a tangential discontinuity with a near zero normal field component. The normal direction, *i.e.*, the direction of minimum B variance, is ~ 41° solar ecliptic longitude which is within 5° of the direction of arrival of magnetosheath protons in the last high proton peak. Further inward the spin modulated proton observations are consistent with field aligned flow that is tangent to the magnetopause surface. The magnetosheath-like electrons observed concurrently probably came in to preserve charge neutrality. Their source must also be relatively local because of the close spectral comparison with the local magnetosheath electrons.

The boundary layer bulk plasma flow is often not field aligned. We have found several boundary layer crossings where the observed plasma flow velocity has a significant cross-field component. For example, the 6/16/73 crossing shown in Figure 2 has a sustained boundary layer flow velocity angle that is $\gtrsim$ 50° away from the field direction. G. Haerendel, *et al.*[4] have also reported HEOS crossings that show significant cross-field components of plasma flow in the boundary layer.

PLASMA FLOW AL : THE NOON MERIDIAN

Recently, G. Haerendel, *et al.*[4] have suggested that heat conduction and wave propagation with subsequent dissipation along the magnetic field could supply the observed energy and ion mobility of the lower latitude boundary layer with direct entry limited to the entry layer. This source mechanism should often lead to plasma flow in the noon meridian, equatorward of the entry layer, that has a sunward flow component. We have found only three isolated cases of sunward component flow in the boundary layer and they were all in the cusp region (*i.e.*, entry layer). In each case the sunward component flow was of short duration and mixed in with the predominate anti-sunward

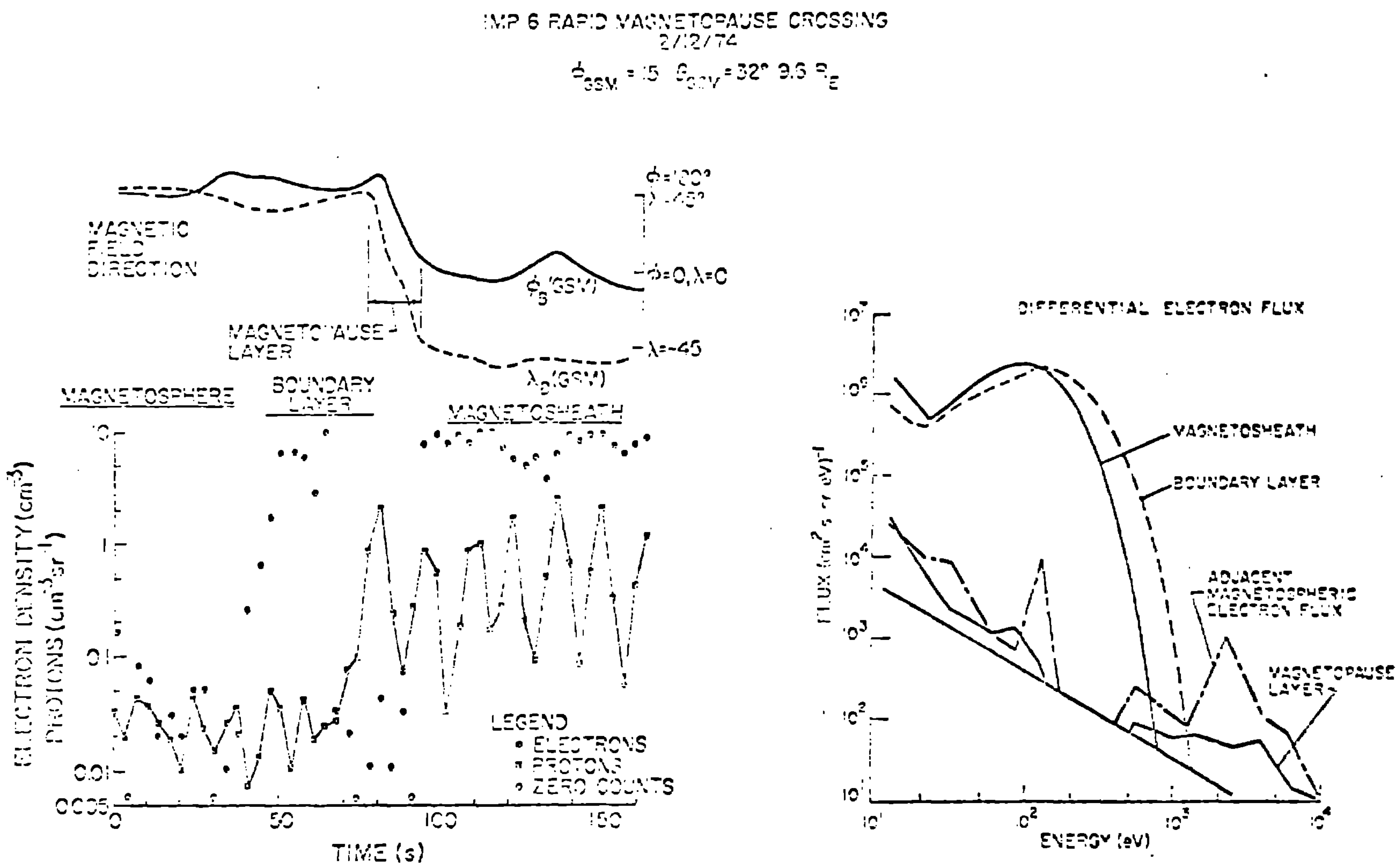

IMP 6 RAPID MAGNETOPAUSE CROSSING
2/12/74
MAGNETIC FIELD DIRECTION
MAGNETOPAUSE LAYER
MAGNETOSPHERE
BOUNDARY LAYER
MAGNETOSHEATH
ELECTRON DENSITY (cm^{-3})
PROTONS (cm^{-3}sr^{-1})
LEGEND
ELECTRONS
PROTONS
ZERO COUNTS
TIME (s)
DIFFERENTIAL ELECTRON FLUX
MAGNETOSHEATH
BOUNDARY LAYER
ADJACENT MAGNETOSPHERIC ELECTRON FLUX
MAGNETOPAUSE LAYER
ENERGY (eV)

Figure 3

flowing plasma. In all other IMP 6 boundary layer crossings, sunward component boundary layer plasma flow has never been observed. Even though the IMP 6 plasma analyzer only samples up to ± 45° about the ecliptic plane, five near noon meridian crossings have been identified where the field direction is within the electrostatic analyzer aperture. In a sixth crossing (located at -21° latitude) the field angle is only 10° out of the sampling cone which still allows a good sampling of flow directions for magnetosheath like distributions. Figure 4 shows plasma and magnetic field data for one of these crossings near noon, equatorward of the cusp region. Although this crossing was recorded in Figure 1 as having a distinct change near the magnetopause layer, only the density changed significantly (including a temporary recovery further in) while the spectra are consistently magnetosheath-like throughout the boundary layer. Also, note the basic boundary layer features that are again exhibited in the density, velocity and magnetosheath-like plasma flow present on the magnetospheric field lines earthward of the magnetopause layer.

If the boundary layer plasma in this crossing was supplied via the entry layer, then we expect to observe flow directed away from the cusp region. However, we observe anti-sunward plasma flow directed generally toward the cusp region. Figure 5 presents projected flow vectors for all six near noon crossings that occurred with favorable field directions. The flow vectors are projected onto a view of the front-side magnetopause surface. These projections clearly indicate that the observed systematic anti-sunward flow corresponds to flow away from the subsolar region or, perhaps, into the cusp region. Could the entry layer be supplied in part by the subsolar region boundary layer which is supplied in turn by plasma transfer through the magnetopause layer? For increasing distances from the subsolar region, direct entry may become less efficient although the divergence of magnetospheric field lines that are being stretched back into the magnetotail, combined with any continued transfer processes within the boundary layer, would be expected to lead to the observed increase in boundary layer thickness with increasing distance away from the subsolar region.

If the boundary layer plasma observed in any of the IMP 6 crossings was supplied by any nonlocal source, then we would not expect (1) the observed continuity in density and electron spectra across the magnetopause layer, (2) the observed systematic anti-sunward component boundary layer flow, or (3) any crossings with cross-field bulk flow components.

SUMMARY OF OBSERVATIONS

We have made several observations that directly relate to the nature of the magnetospheric boundary layer.

1. In all IMP 6 crossings, some magnetosheath-like plasma is observed earthward of the magnetopause layer. The boundary layer electron spectra are often indistinguishable from the nearby magnetosheath electron spectra.

2. In 24 out of 40 crossings, no change in density or electron spectra is observed near the magnetopause layer. In most remaining cases, changes in the plasma parameters occur primarily in the boundary layer.

3. Observed boundary layer bulk plasma flow always has an anti-sun

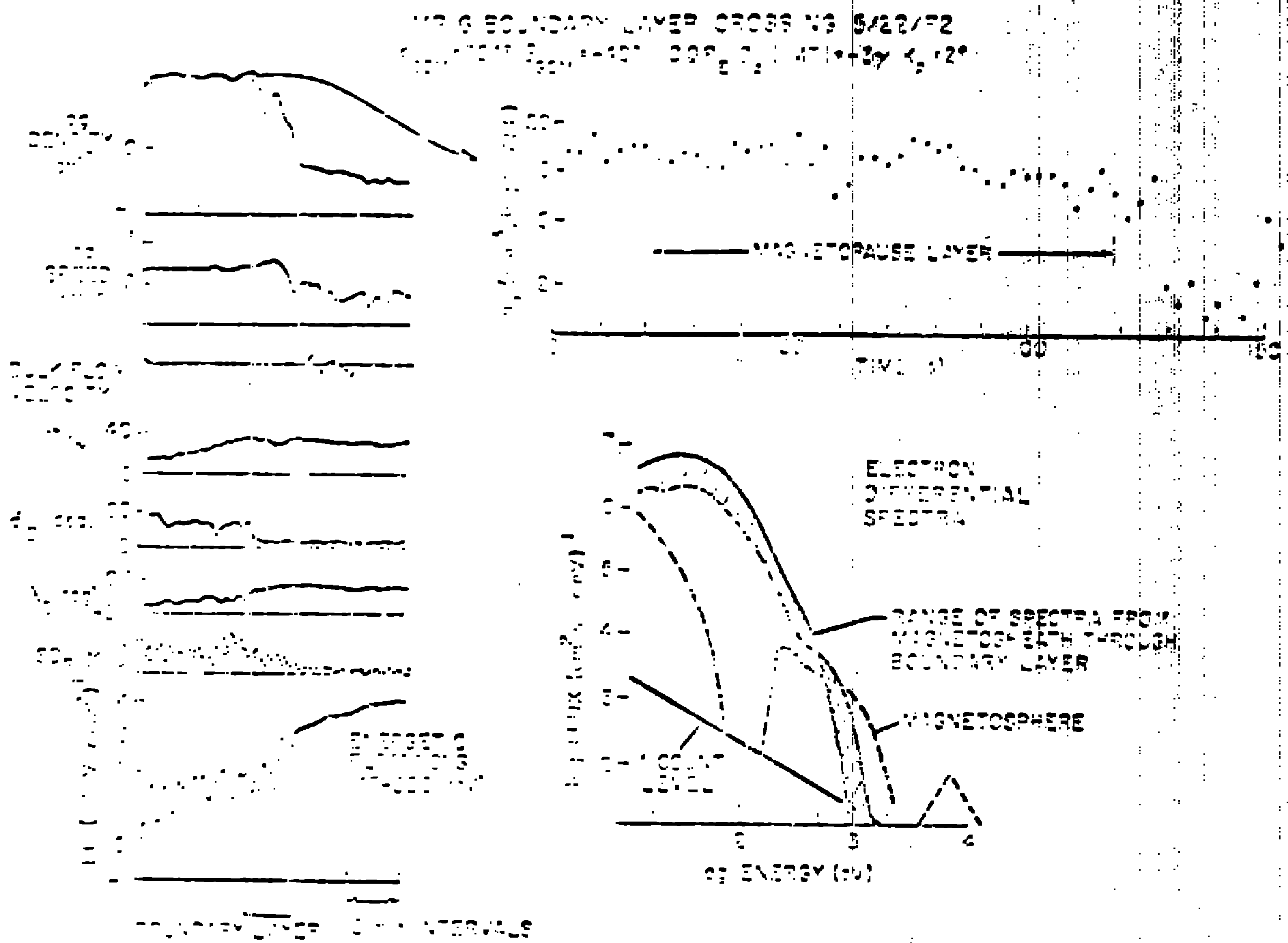


Figure 4

ward component and often has a cross-field component. Energetic electron pitch angle distributions indicate that the boundary layer is on closed field lines.

4. During six crossings near local noon, equatorward of the cusp regions, boundary layer plasma flow was observed to have an anti-sunward component consistent with flow away from the subsolar region of the nearby magnetosheath. The observations are not consistent with a primary source in the cusp region (i.e., the entry layer) or any other nonlocal source.

CONCLUSIONS

Our observations lead to the following conclusions.

1. The boundary layer is populated principally by diffusive transport through the magnetopause layer.

2. [illegible] ward of the magnetopause [illegible] and plasma mantle.

REFERENCES

1. [illegible]

2. [illegible]

3. [illegible]

4. [illegible]