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Final Report NASW-3395

May 20, 1980 - November 19, 1985

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INTRODUCTION

In the period 1976-1982 seven satellites were launched carrying ion mass spectrometers into various regions of the Earth's magnetosphere. In addition to the advances made from the unique vantage point of each of these individual spacecraft, the fortuitous overlap of their combined data sets offered an opportunity to address many of the issues that cannot be resolved with only the individual data sets.

The types of problems that lend themselves to attack by these combined data may be classified into two types. First are those that require simultaneous measurements by spacecraft in different locations, for instance to monitor widely distributed phenomena or to separate spatial and temporal effects. The second class of problems are those arising from the study of one data set that quite naturally require further information from another data set for proper interpretation. This type of synergism is common as progress in one area either drives or permits an advancement in another. For instance, characteristics of field aligned ions observed by an equatorial spacecraft in the plasma sheet may aid a detailed study of acceleration mechanisms using low altitude data from polar orbit.

Figure 1 shows the coverage of data from the seven mass spectrometers launched in the 1976-1982 period. S3-3 and DE-1 are in low altitude eccentric polar orbits; SCATHA and GEOS-2 are in nearly geosynchronous orbits; ISEE-1, GEOS-1, and Prognoz-7 are in high altitude eccentric orbits. The entire data sets for S3-3, SCATHA, ISEE-1, and DE-1 are available at the Lockheed Palo Alto Laboratory, and a close association exists with experimenters from the others.

ENERGETIC ION COMPOSITION MEASUREMENTS RELATIVE TO SOLAR ACTIVITY

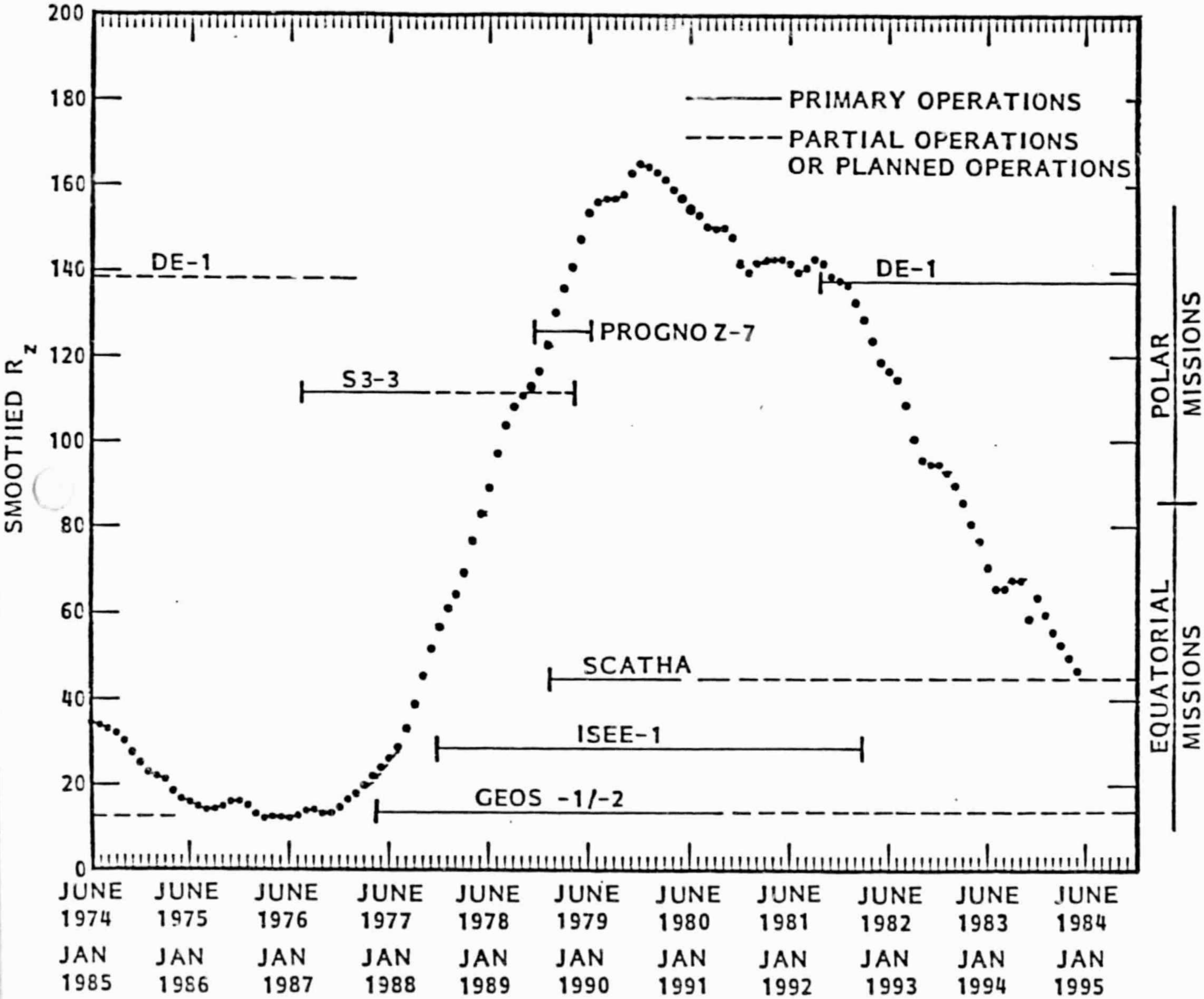


FIGURE 1

The research performed under this grant has covered a broad range of topics, each benefitting from this unique collection of data from different magnetospheric regions. The following report summarizes the progress made in a number of areas.

The Sixth Coordinated Data Analysis Workshop (CDAW-6) was devoted to the study of energy flow from the solar wind through the magnetosphere. In particular, substorms occuring on March 22 and March 31-April 1, 1979 were selected for detailed analysis using the combined data set from an impressive array of satellite and ground based instrumentation.

Participation in CDAW-6 by the Lockheed group began at an early stage and included hosting the first workshop in December 1981. The analysis effort, which concentrated on the March 22 interval with data contributions from ion mass spectrometers on ISEE-1, S3-3, and SCATHA, resulted in the publication of four papers.

Dramatic changes in the composition of the plasma sheet during the March 22 interval were observed by the ISEE spacecraft (Lennartsson et al., 1985, Baker et al., 1985). These changes are illustrated in Figure 2 which shows ion density in the range E/q = 0.1-16 keV/e for four species over a 20 hour period. Total densities are sho by the solid lines while those portions which are due to narrowly collimated beams are indicated by horizontal bars with circular or triangular symbols. Before the substorm onset H^+ and He^{++} ions were responsible for a very large fraction of ion density, indicating plasma with a primarily solar wind source. Within a hour of the onset of substorm expansion, the H^+ and He^{++} densities had dropped while the O^+ density, representing an ionospheric source, rapidly increased to become comparable to H^+.

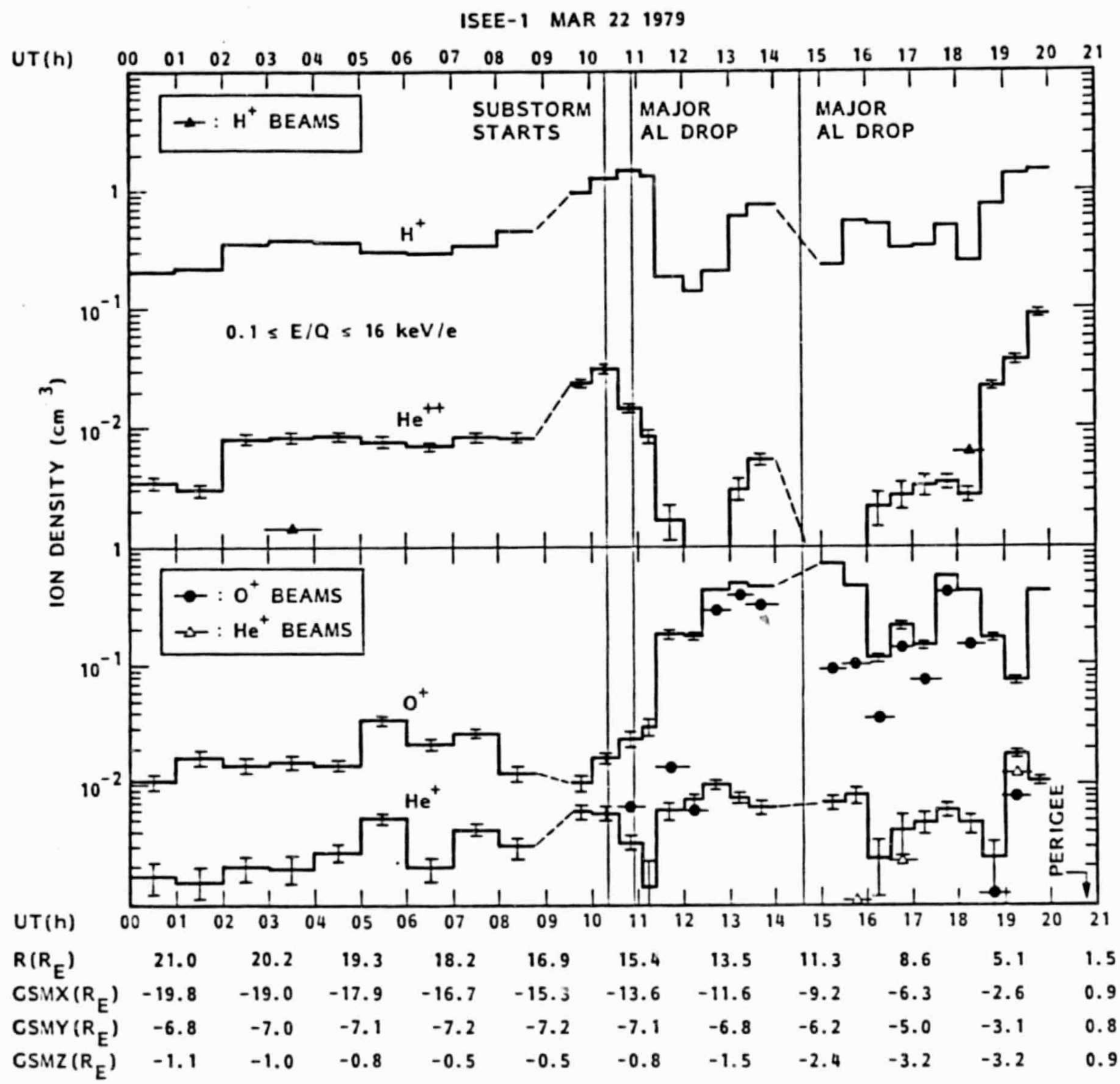

ISEE-1 MAR 22 1979
UT(h)
00 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21
: H+ BEAMS
SUBSTORM STARTS
MAJOR AL DROP
MAJOR AL DROP
H+
0.1 ≤ E/Q ≤ 16 keV/e
He++
ION DENSITY (cm-3)
: O+ BEAMS
: He+ BEAMS
O+
He+
PERIGEE
R(RE) 21.0 20.2 19.3 18.2 16.9 15.4 13.5 11.3 8.6 5.1 1.5
GSMX(RE) -19.8 -19.0 -17.9 -16.7 -15.3 -13.6 -11.6 -9.2 -6.3 -2.6 0.9
GSMY(RE) -6.8 -7.0 -7.1 -7.2 -7.2 -7.1 -6.8 -6.2 -5.0 -3.1 0.8
GSMZ(RE) -1.1 -1.0 -0.8 -0.5 -0.5 -0.8 -1.5 -2.4 -3.2 -3.2 0.9

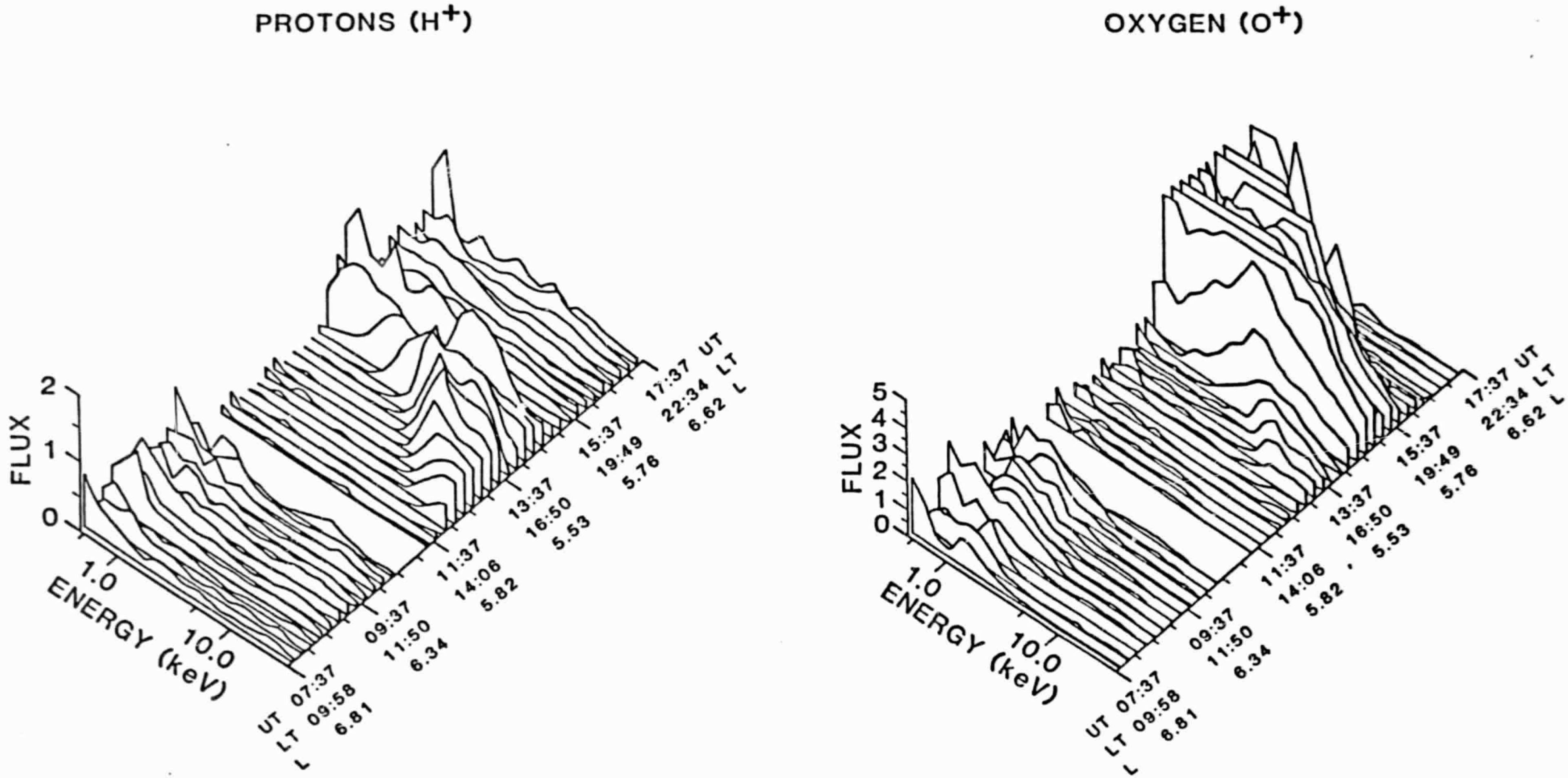
FIGURE 2

Signs of ionospheric injection during the substorm were also clearly observed at the location of SCATHA in its lower L, nearly geosynchronous orbit (Strangeway and Johnson, 1983a, 1983b). The substorm onset at 10:54 UT occured when SCATHA was in the early afternoon sector. Figure 3 shows a three dimensional plot of H^+ and O^+ differential energy flux as measured by the ion composition instrument on SCATHA in the energy range 0.1-32 keV. Substorm injected ions are first seen (following the data dropout) at about 11:37. These ions have gradient and curvature drifted from the nightside giving a clear dispersion signature in both species as the highest energy ions arrive at the spacecraft first. A simple model of magnetic and convection fields was used to track ions from the Mauk and McIlwain injection boundary to the SCATHA location. Comparison of this model to the actual arrival times of the dispersing ions yielded good agreement.

MULTIPLE SPACECRAFT STUDY OF WESTWARD TRAVELING SURGE

In 1982 - 1983 Dr. Eigil Ungstrup of the Danish Space Research Institute spent a year at the Lockheed Space Sciences Laboratory. During his visit Dr. Ungstrup worked on a detailed case study of the westward traveling surge associated with a substorm on April 20, 1981. This cooperative analysis involved data from several instruments on 3 different spacecraft.

The surge signature was identified by several instruments on the ISEE-1 satellite at an intermediate altitude of approximately 10,000 km. Groundbased magnetometer data confirmed the onset of a substorm preceeding the ISEE-1 observations by several minutes. Shortly after the substorm onset, measure-



PROTONS (H^+)
FLUX
0
1
2
1.0
10.0
ENERGY (keV)
UT 07:37
LT 09:58
L 6.81
09:37
11:50
6.34
11:37
14:06
5.82
13:37
16:50
5.53
15:37
19:49
5.76
17:37 UT
22:34 LT
6.62 L
OXYGEN (O^+)
FLUX
0
1
2
3
4
5
1.0
10.0
ENERGY (keV)
UT 07:37
LT 09:58
L 6.81
09:37
11:50
6.34
11:37
14:06
5.82
13:37
16:50
5.53
15:37
19:49
5.76
17:37 UT
22:34 LT
6.62 L

FIGURE 3

ments by the low altitude NOAA-6 and the geostationary 1976-059 satellites, which were very nearly on the same field line, recorded substorm injection signatures.

One of the clearly observed features of this event were upward moving ions with conical pitch angle distributions. Figure 4 shows the H^+ and O^+ ion conic distributions sampled by the Lockheed ion mass spectrometer on ISEE-1. Pitch angle distributions are plotted for eight energy values of each species in seven consecutive time periods. A steady increase of the observed conic pitch angles indicates that the altitude of the perpendicular energization region moved downward as the event progressed.

The results of this very comprehensive work have been submitted for publication by authors from seven institutions (Ungstrup et al., 1984).

STORMTIME ENVIRONMENT

A major focus of this contract has been the analysis of magnetospheric conditions during geomagnetic storms. As part of this analysis, data from the SCATHA spacecraft were used to determine the average baseline (non-storm) characteristics of the hot plasma between 5.3 and 7.8 RE. This study, spanning four months in 1979, used some 25 days of data for which DST was positive.

The density distributions as a function of L for the four major species are shown in Figure 5 The data show a clear increase in O^+ and He^+ density with decreasing L, while H^+ has the opposite dependence. When the data were sorted

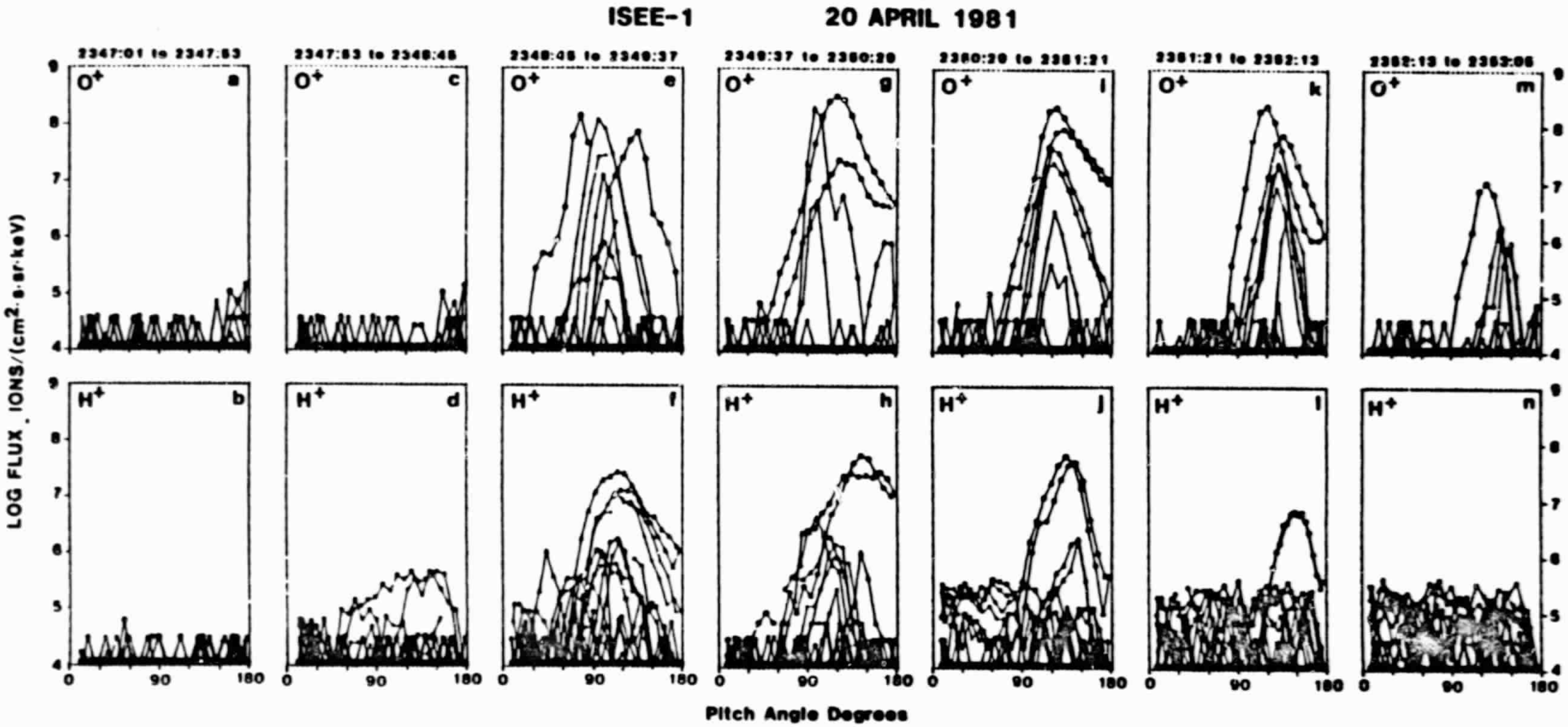
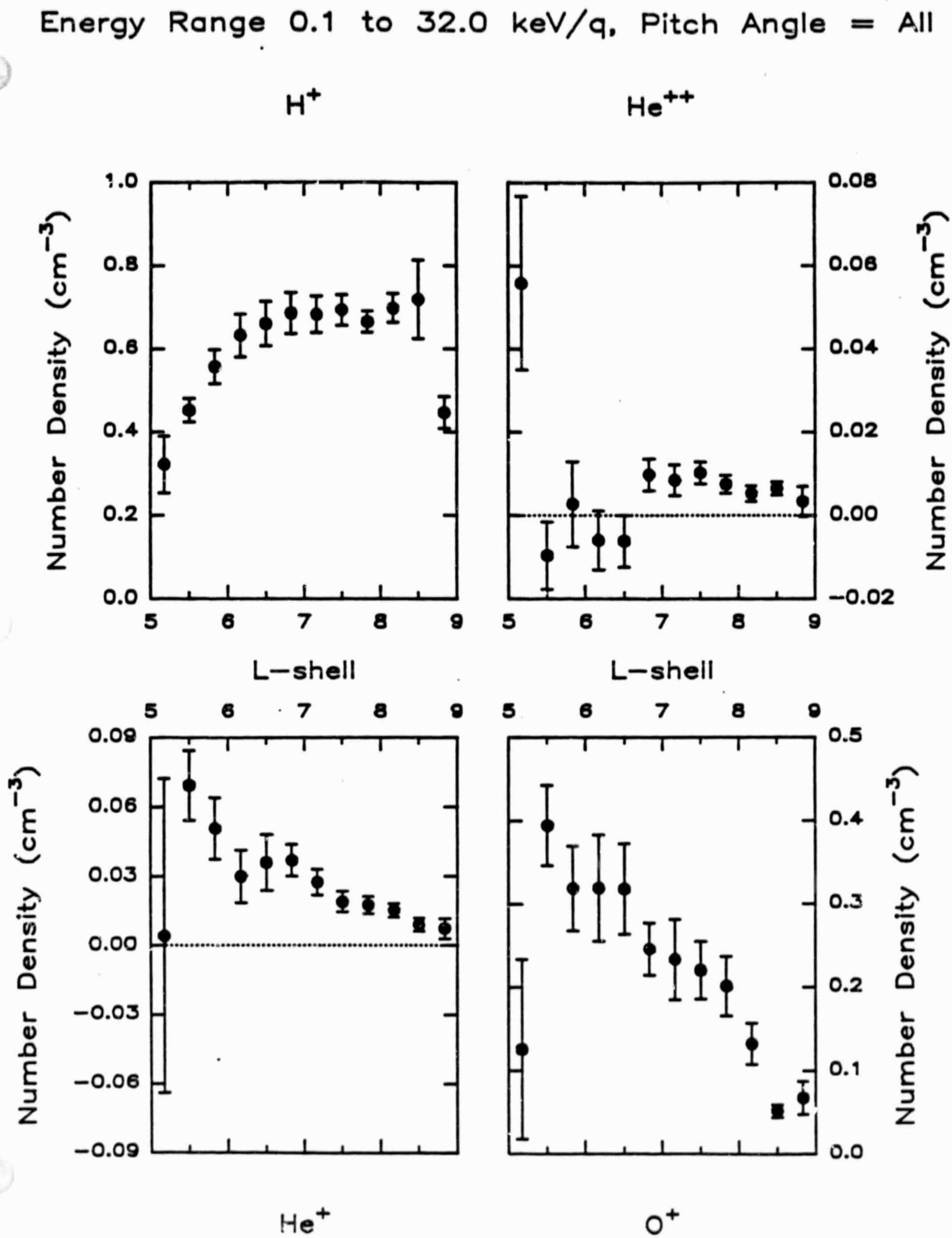

ISEE-1
20 APRIL 1981
2347:01 to 2347:53
2347:53 to 2348:45
2348:45 to 2349:37
2349:37 to 2350:29
2350:29 to 2351:21
2351:21 to 2352:13
2352:13 to 2353:05
O+
H+
a
b
c
d
e
f
g
h
i
j
k
l
m
n
LOG FLUX, IONS/(cm2·s·sr·keV)
Pitch Angle Degrees
0
90
180
4
5
6
7
8
9

FIGURE 4



Energy Range 0.1 to 32.0 keV/q, Pitch Angle = All
H+
He++
Number Density (cm-3)
L-shell
He+
O+

FIGURE 5

according to local time and pitch angle, the low L O^+ ions were found to be concentrated in the dusk to midnight sectors with dominantly field aligned distributions.

Simultaneous ion composition measurements, obtained on the S3-3 and SCATHA satellites, were used in a case study of the magnetic storm period on February 21-22, 1979 (Strangeway and Johnson, 1984). Figure 6 shows the orbital segments for both spacecraft plotted versus L and local time. Tic marks on the SCATHA orbit indicate times on February 21, while for S3-3 the solid curves represent orbits on February 21 and the dashed curves are for the next day.

Figure 7 summarizes ion composition data for the two days as measured at SCATHA. The figure shows H^+ and O^+ densities and energy density ratios, as well as Kp and Dst for the period. Large increases in O^+ content are clearly associated with each of the two periods of enhanced Dst. More detailed analysis showed multiple dispersion signatures in the O^+ fluxes indicating recent injection.

The radial composition profiles measured by S3-3 are shown in Figure 8. In each of the storms it was found that the ionospheric plasma enhancements apparently moved to lower L during the recovery phase. This apparent motion was analyzed with of convection modeling and found to be largely due to time of flight effects. The convection modeling also indicated that the ionospheric plasma was injected in the nightside, over a fairly broad energy range, at L > 5.

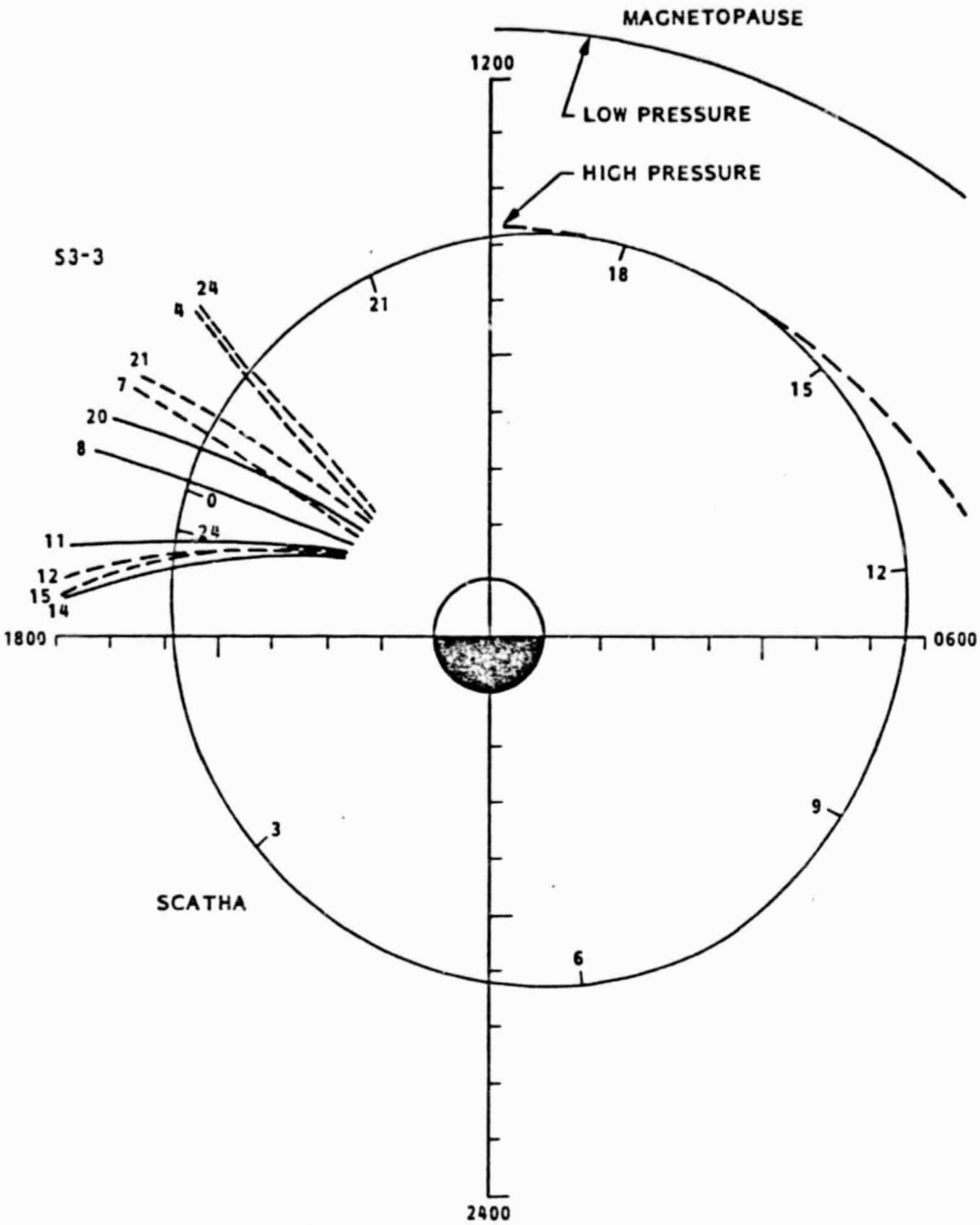
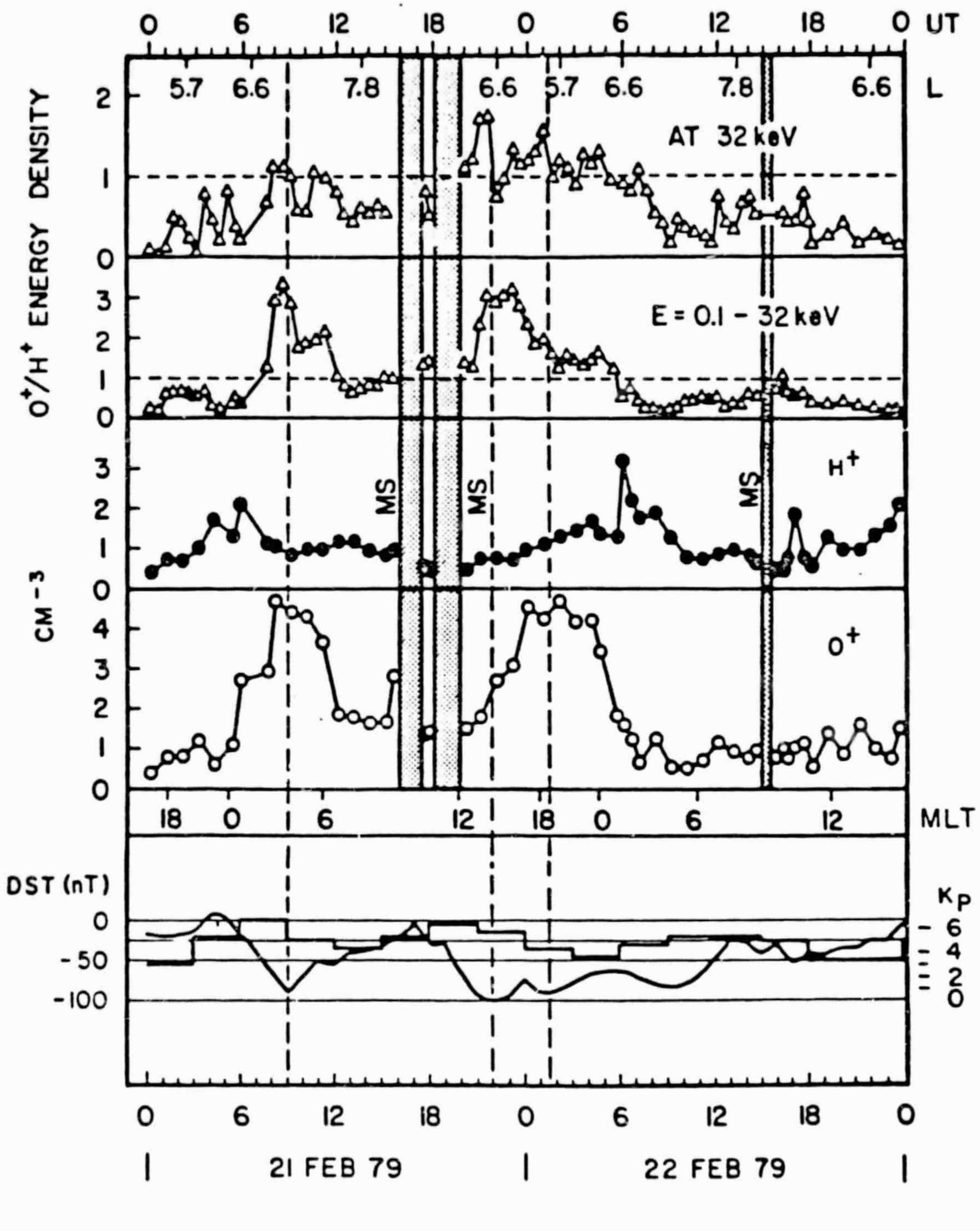
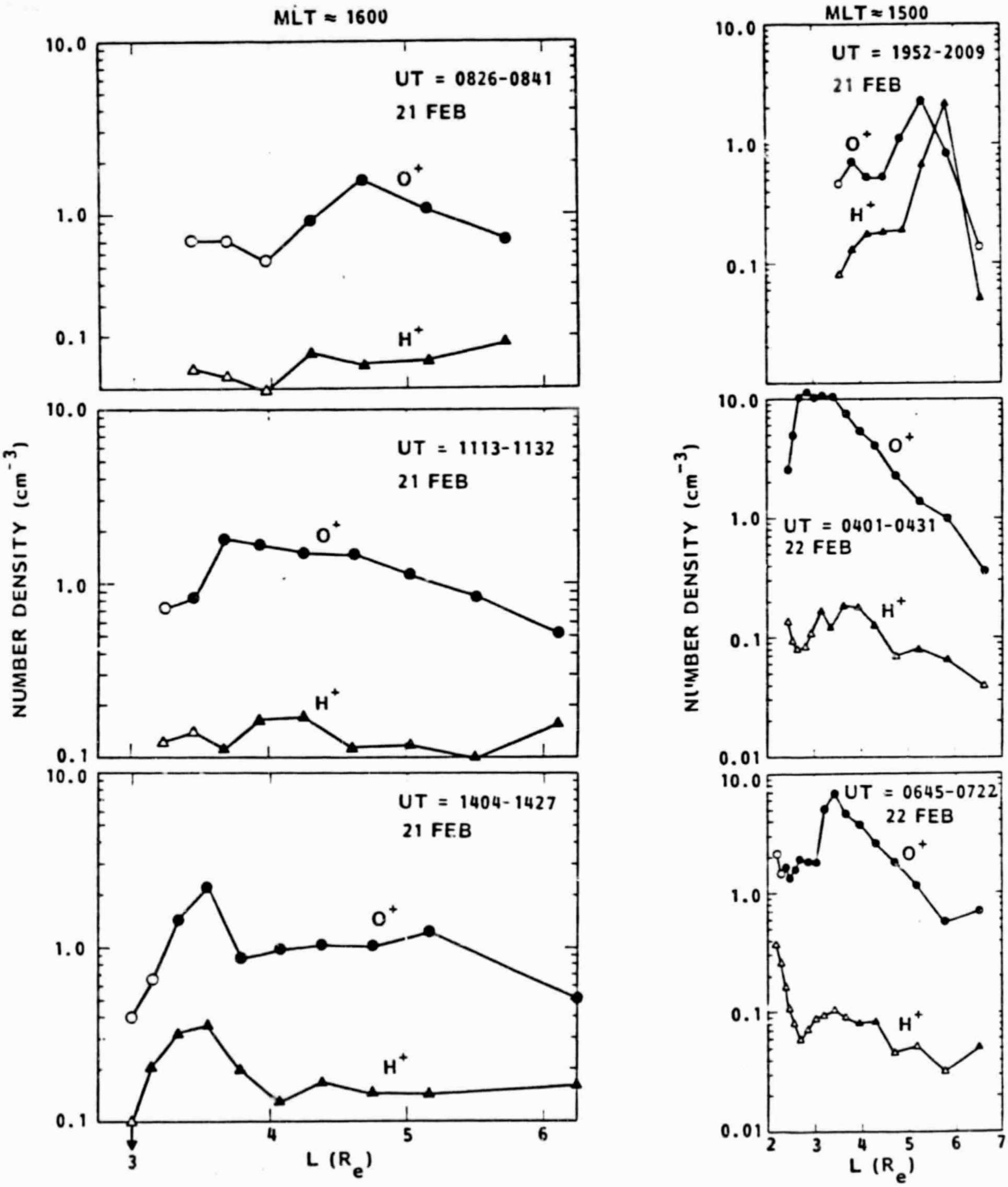

MAGNETOPAUSE
LOW PRESSURE
HIGH PRESSURE
1200
S3-3
24
4
21
7
20
8
0
24
11
12
15
14
21
18
15
12
1800
0600
9
3
SCATHA
6
2400

FIGURE 6



UT
L
5.7
6.6
7.8
AT 32 keV
E = 0.1 - 32 keV
O^+/H^+ ENERGY DENSITY
CM^{-3}
MS
H^+
O^+
MLT
DST (nT)
K_P
21 FEB 79
22 FEB 79

FIGURE 7



MLT ≈ 1600
UT = 0826-0841
21 FEB
UT = 1113-1132
21 FEB
UT = 1404-1427
21 FEB
MLT ≈ 1500
UT = 1952-2009
21 FEB
UT = 0401-0431
22 FEB
UT = 0645-0722
22 FEB
O+
H+
NUMBER DENSITY (cm-3)
L (Re)

FIGURE 8

IONOSPHERIC SOURCES AND PROCESSES

Considerable progress has been made in the past several years in identifying and understanding the processes responsible for extracting and accelerating ionospheric plasma into the magnetosphere. Ion composition data have played a key role in this progress because of the mass dependent interactions of the ionospheric ions (primarily O^+ and H^+) within the acceleration regions. The signatures of these interactions in the ion distributions can provide highly specific tests between various theories.

Two recent studies (Collin et al., 1985; Ghielmetti et al., 1985) have addressed the transverse energization of ions that are observed above regions of upward directed parallel electric fields. Figure 9, obtained from S3-3 data, is a plot of ion beam energies versus the potential below the spacecraft as determined from widening of the electron loss cone. As expected, plots show a general correlation of beam energies with potential drops for both species. However, the O^+ energies are on average somewhat larger than the the potential drop while the H^+ energies are somewhat less. These data apparently indicate that the O^+ ions have accumulated consistently more energy than the H^+, presumably due to a mass dependent transverse energization mechanism.

This hypothesis is supported by measurements of H^+ and O^+ pitch angle distributions of the upflowing ions. H^+ beams were found to be broader at low energies and more tightly field aligned at higher energies, while O^+ beams had the opposite behavior. These characteristics are illustrated in Figure 10. The figure shows the beam pitch angle widths at different energies for several spins of S3-3. Simultaneous measurements are connected by straight lines.

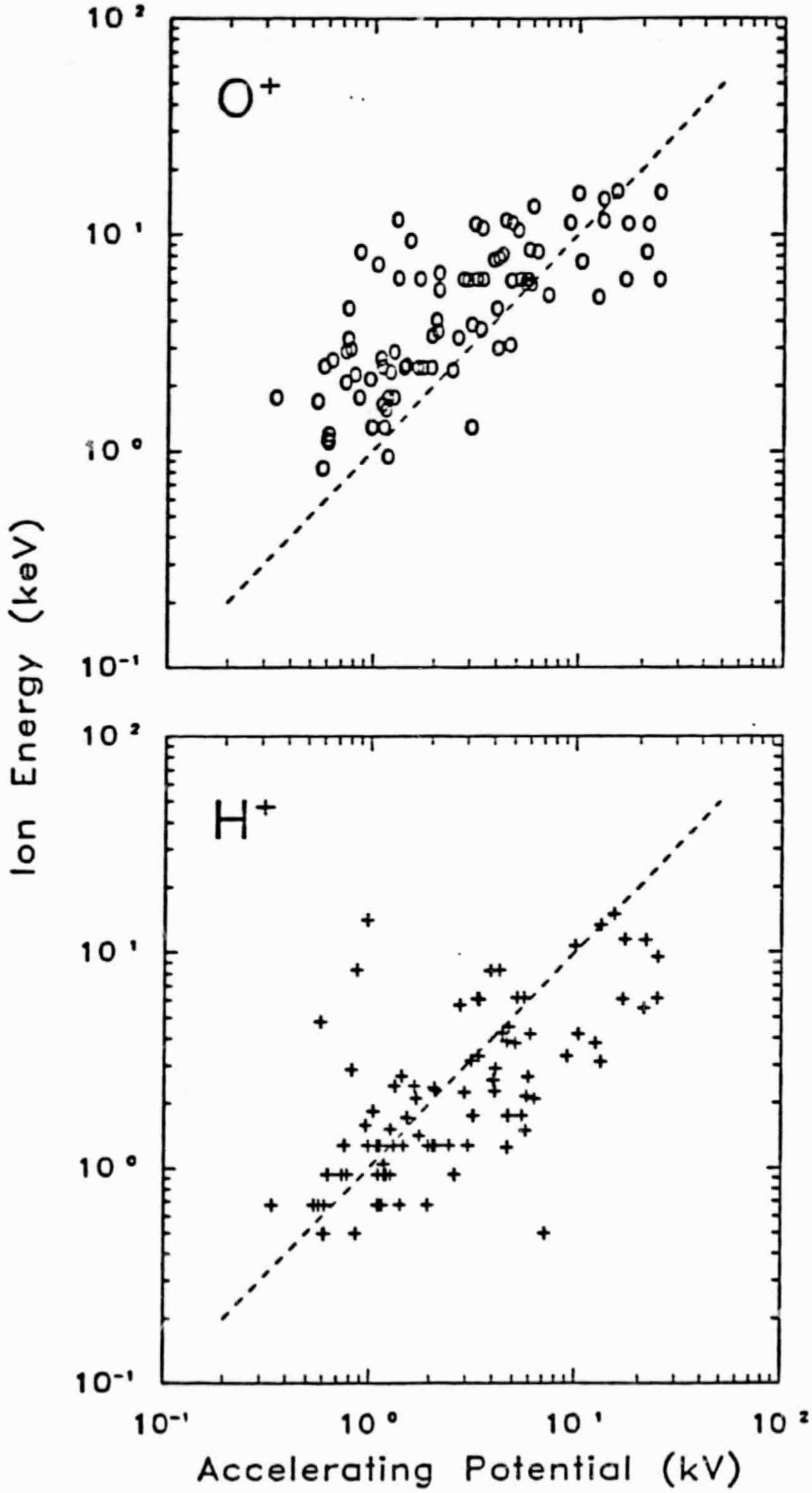


FIGURE 9

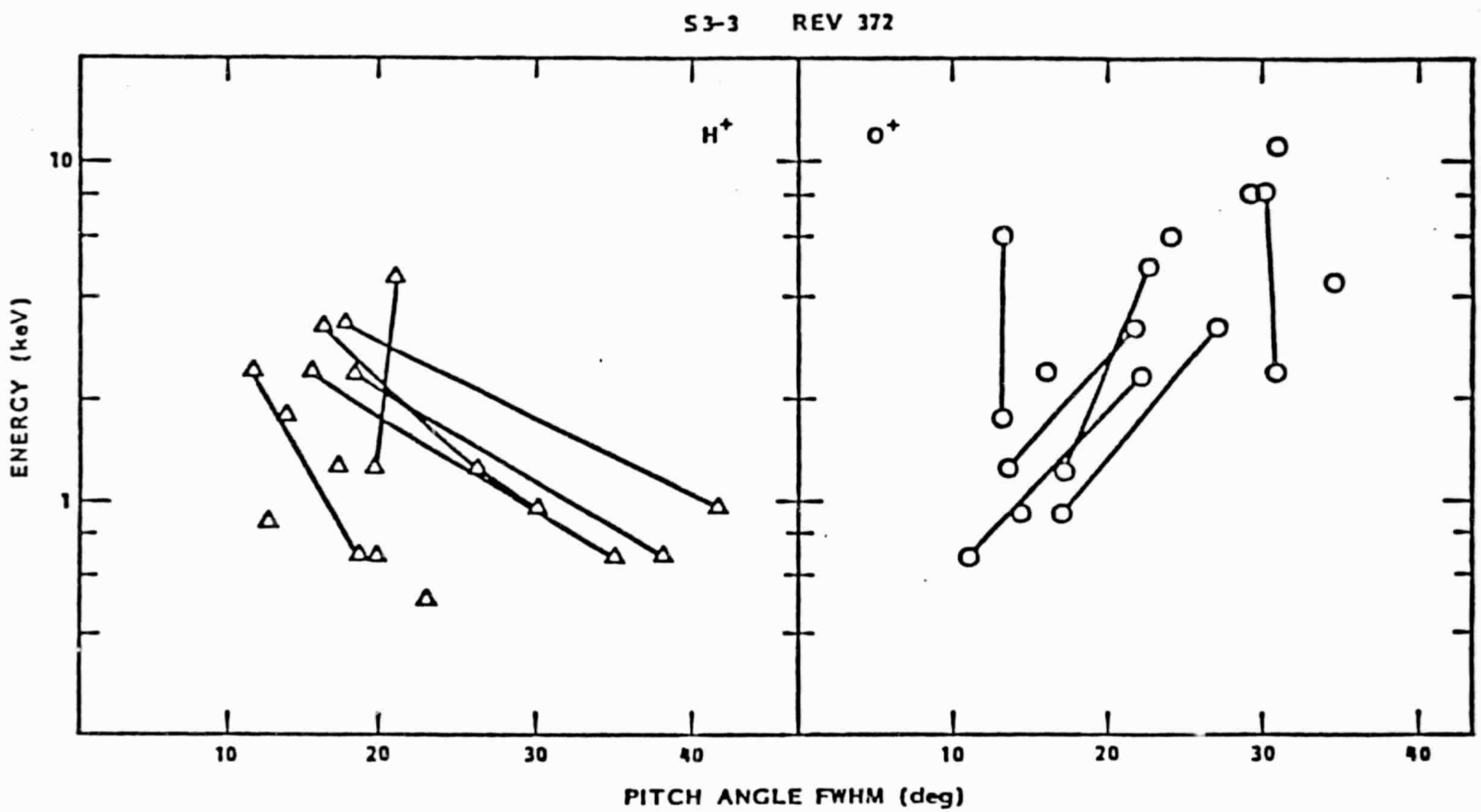

S3-3 REV 372
H+
O+
10
1
ENERGY (keV)
10
20
30
40
10
20
30
40
PITCH ANGLE FWHM (deg)

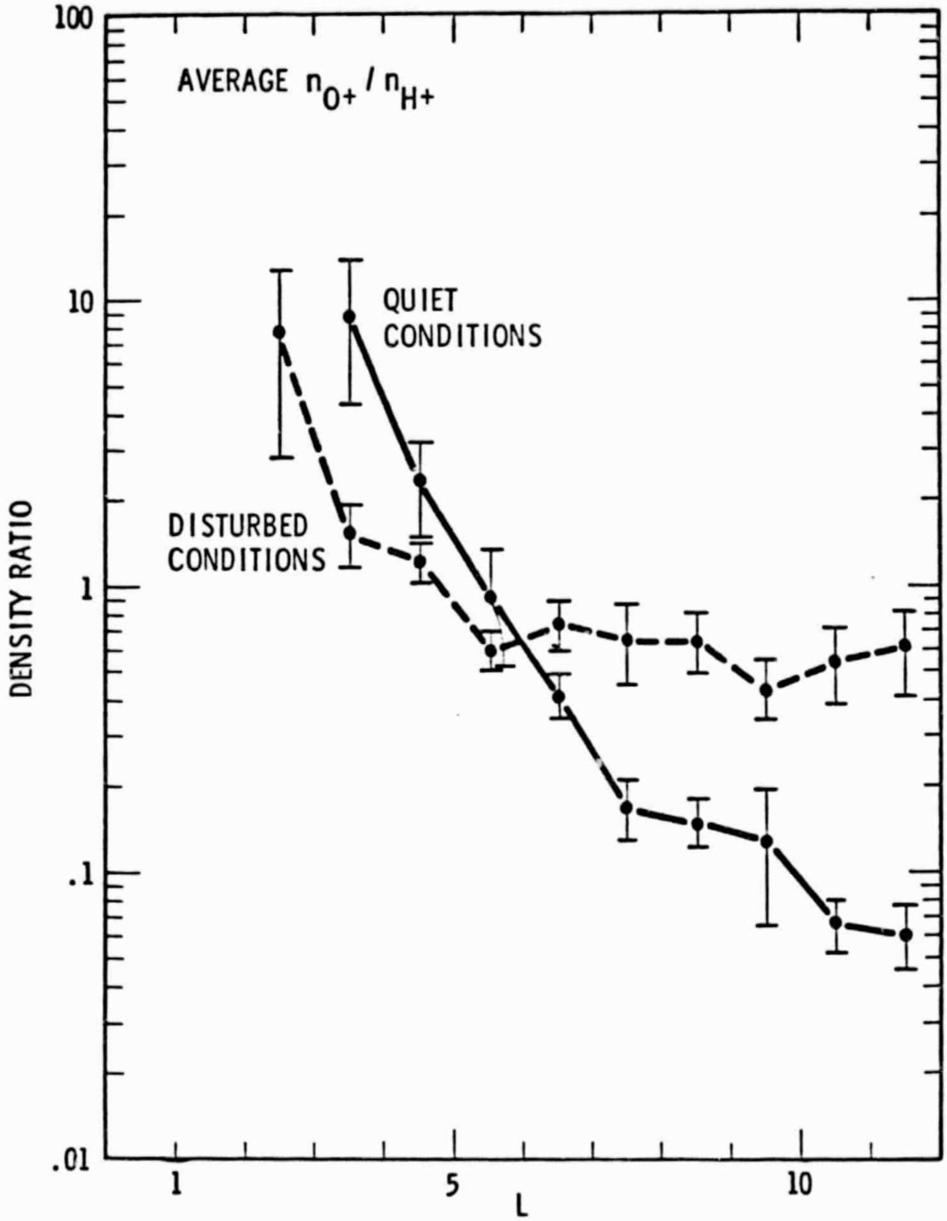
FIGURE 10

One area in which data on the ionospheric plasma source have a very direct application is in the study of spacecraft interactions with the plasma and energetic particle environment. These interactions (e.g. charging, surface degradation, radiation effects) often depend on the composition of the ions impinging on the spacecraft surfaces. Variations in magnetospheric composition from the influx of ionospheric plasma were analyzed using data from ISEE-1 and SCATHA (Sharp et al., 1985).

Figure 11 shows large variability of the ionospheric component, both as a function of radial distance and of magnetic activity. The data plotted were averaged from 48 passes of ISEE-1 through the magnetosphere from December 1977 to February 1979. The "quiet" data were selected on the basis of DST and Kp over [illegible] day interval, while the "disturbed" data were from periods with DST < -100. The very strong radial and activity dependences are evident in the figure. In particular, during disturbed times, the O^+ density is seen to be comparable to that of H^+ at altitudes well beyond geosynchronous orbit.

REVIEWS AND SYNTHESES OF RESULTS

In addition to the many topical studies described above, the multi-spacecraft ion composition data has provided the basis for advances in our understanding of global magnetospheric processes. The combined data from widely varying orbits has been particularly important in synthesizing models of magnetospheric plasma circulation (Shelley, 1985). One result from this work has been the conclusion that during magnetically active period, energetic ionospheric ions are transported directly into the plasma sheet boundary layer and central plasma sheet from the auroral acceleration region.



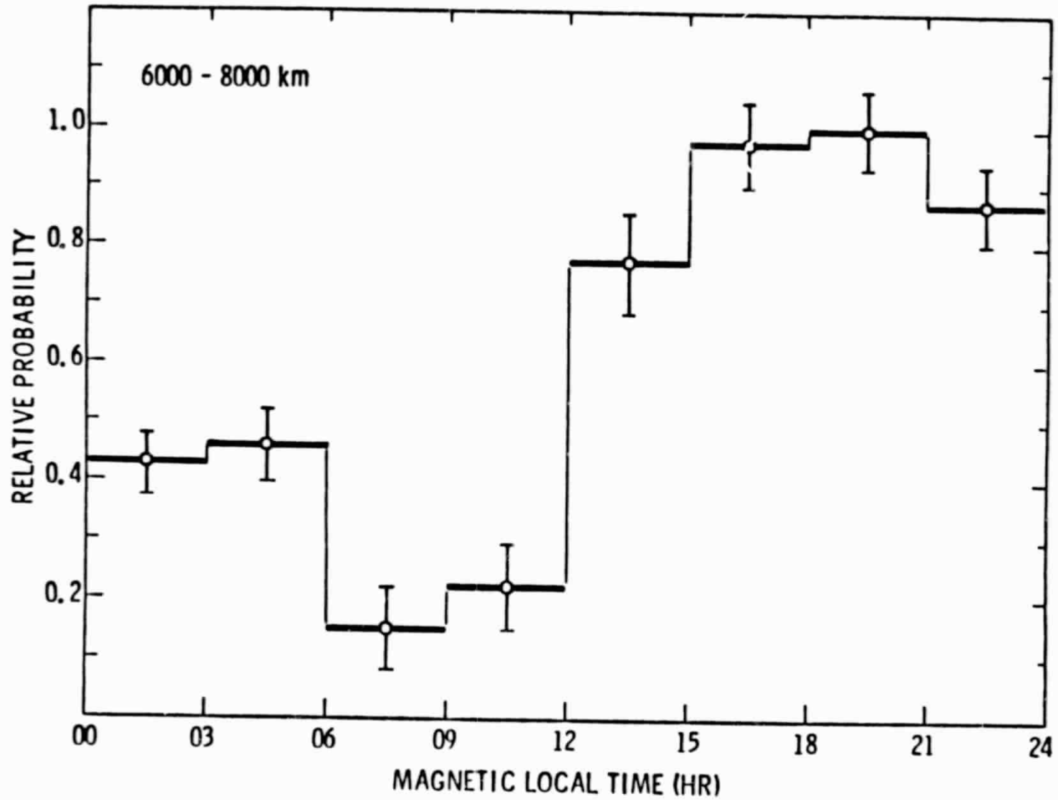
100
10
1
.1
.01
AVERAGE n_{O+} / n_{H+}
QUIET CONDITIONS
DISTURBED CONDITIONS
DENSITY RATIO
1
5
10
L

FIGURE 11

Another important task has been the compilation of major results, distilled from the rather voluminous data sets, into a review format more easily accessible to workers in the field (Sharp et al., 1983, Quinn and Shelley, 1984). An example of such results is the morphology of upward flowing ions as determined by S3-3 observations. Figure 12 shows the relative probability of upward flowing ion occurences at different local times. These probabilities are separated into magnetically quiet and disturbed periods in Figure 13 (top panel). Also shown in Figure 13 (bottom panel) are the local time dependences of the average energies of peak flux for H^+ and O^+, as well as the maximum energies at which O^+ flux was observed.

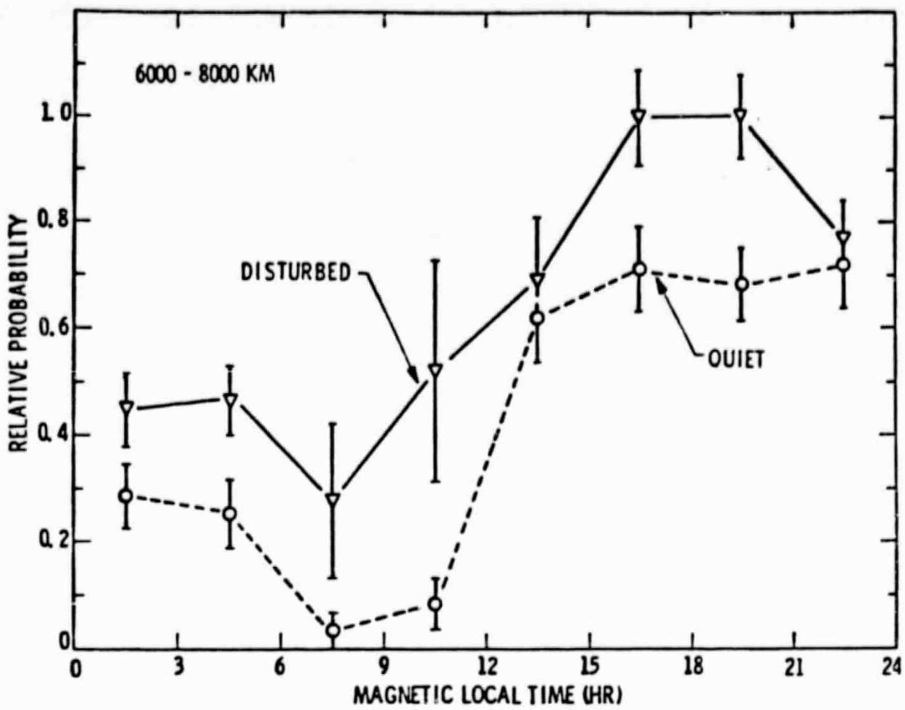
SUMMARY

Ion composition data sets from Lockheed instruments on a variety of spacecraft have been used in combination with each other as well as with data from other instruments to address a variety of problems regarding plasma sources, energization and transport within the magnetosphere. The availability of data from several differing orbits has allowed a highly flexible approach to attacking the continually evolving questions of magnetospheric physics. This approach has been very successful and should be continued in the future.

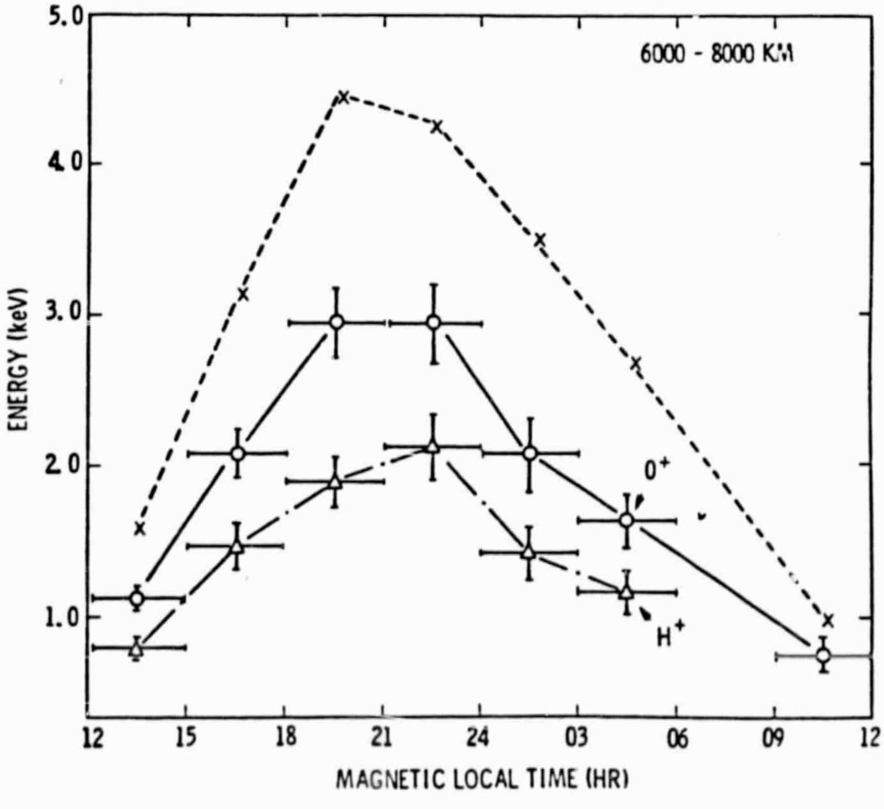


Relative probability of occurrence of upward flowing ions as a function of magnetic local time.

FIGURE 12



A comparison of the probabilities of upward flowing ions between quiet and disturbed periods.



Average of the energies at which at the peak energy flux was observed as a function of magnetic local time (circles represent O^+ and triangles represent H^+) and average of the maximum energies at which O^+ flux was observed (crosses).

FIGURE 13

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