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Initial Hot Plasma Composition Results from the Dynamics Explorer

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Initial observations from the energetic ion composition spectrometer on the DE-1 spacecraft have found mass or charge dependent processes to be operating in the vicinity of an inverted-*V* event in the auroral acceleration region, above the polar cap ionosphere, and in the mid-altitude dayside cusp. Separate color spectrograms for the different ion species provide a synoptic picture of these processes that can contribute significantly to our understanding of both the solar wind and the ionosphere as sources of energetic magnetospheric ions.

1. Introduction

The energetic ion composition spectrometer (EICS) on the Dynamics Explorer (DE-1) spacecraft is very similar to a family of spacecraft borne spectrometers using the same basic ion optics (GEOS-1, GEOS-2, ISEE-1, and the *AMPTE*/-CCE). The earlier instruments are described in detail by BALSIGER *et al.* (1976) and SHELLEY *et al.* (1978) and the EICS is described in detail by SHELLEY *et al.* (1981a). The spectrometer covers the energy per charge range from zero (limited only by the relative effects of spacecraft ram velocity and spacecraft charging) to approximately 17 keV/*e* and the mass per charge range from 1 to approximately 150 amu/*e*. It has a high sensitivity (~ 1 cm^2-sr-eV) and a mass resolution $M/\Delta M$ of ~ 10 at focus with reduced resolution at higher energies and masses.

To accommodate the more spatially and temporally structured plasma regions encountered by the DE-1 spacecraft in the auroral zones, the instrument's measurement cycle period was significantly shortened relative to those of the previous spectrometers of this type. In addition, a high current channel electron multiplier was used to accommodate a wider dynamic range of count rates. The instrument control electronics were also modified to more efficiently utilize the faster instrument measurement cycle capabilities in performing mass, energy, and pitch angle distribution measurements. As with the ISEE-1 spectrometer, specialized modes have been developed to support various geophysical studies. The specific regions of interest include the low latitude plasmaspheric region, the auroral zone, the dayside cusp and the polar cap. These modes differ in their relative concentration on the mass-energy ranges covered and their temporal resolution. Some of the modes will be described in more detail in association with the observations discussed below.

The Dynamics Explorers – 1 and – 2 were launched into coplanar polar orbits on 3 August 1981. The DE-1 orbit is eccentric with an apogee of approximately 4.6 R_E geocentric distance and a low altitude perigee. The initial apogee was over the northern polar region and changes in latitude at a rate of about one degree every three days.

One of the principal objectives of the DE mission is to study the interaction between the cold ionospheric plasmas and the hot magnetospheric plasmas. One important manifestation of this interaction is the acceleration of ionospheric ions to energies of several keV in the suroral zone and their injection into the equatorial magnetosphere. This process was first observed by the ion mass spectrometer on the S3-3 spacecraft (SHELLEY *et al.*, 1976b). (See review paper by SHARP *et al.* in this volume for more details on the S3-3 results). While the S3-3 measurements have provided us with many valuable clues to this process, they left many unanswered questions on which the DE-1 measurements are expected to shed a great deal of light. With the two spacecraft in coplanar orbits, we can obtain measurements at two points on the same field line and thus have an additional handle on the auroral ion acceleration process. The higher apogee and faster spin rate of the DE-1 spacecraft also extends the measurements to much higher altitudes ($\simeq$22,000km versus $\simeq$8,000km) and provides significantly higher spatial and temporal resolution. Furthermore the instrumentation on the DE spacecraft provides global auroral imaging and much more extensive coverage of both particles and waves. In particular the ion composition spectrometer on DE has much greater sensitivity than did the S3-3 spectrometer and extends the energy coverage into the important range below 500eV.

The Dynamics Explorer Mission approach has been to coordinate the moding of the instruments on both spacecraft so that all investigators are concentrating on the same set of geophysical problems at the same time rather than the more traditional approach of performing more or less independent survey experiments. While the operations have been coordinated, the initial results presented here will involve primarily the data from the EICS instrument alone. Many coordinated data analysis projects are underway; however due to their more complex nature they do not lead to publishable results as rapidly as those studies involving a single data set. For a more detailed discussion of the Dynamics Explorer mission and the associated scientific instuments, see the set of papers contained in the special issue of Space Science Instrumentation (HOFFMAN, 1981). For initial scientific results from the Dynamics Explorer mission see the special September, 1982 issue of Geophysical Research Letters.

2. Observations and Initial Results

2.1 Auroral acceleration

Some of the earliest EICS results on the auroral acceleration process are shown in Fig. 1 (SHELLEY *et al.*, 1981b). The data were acquired when the spacecraft was entering the high latitude auroral zone from the polar cap at about 1900 MLT with an altitude of approximately 11,000 km. The data are presented in the form of

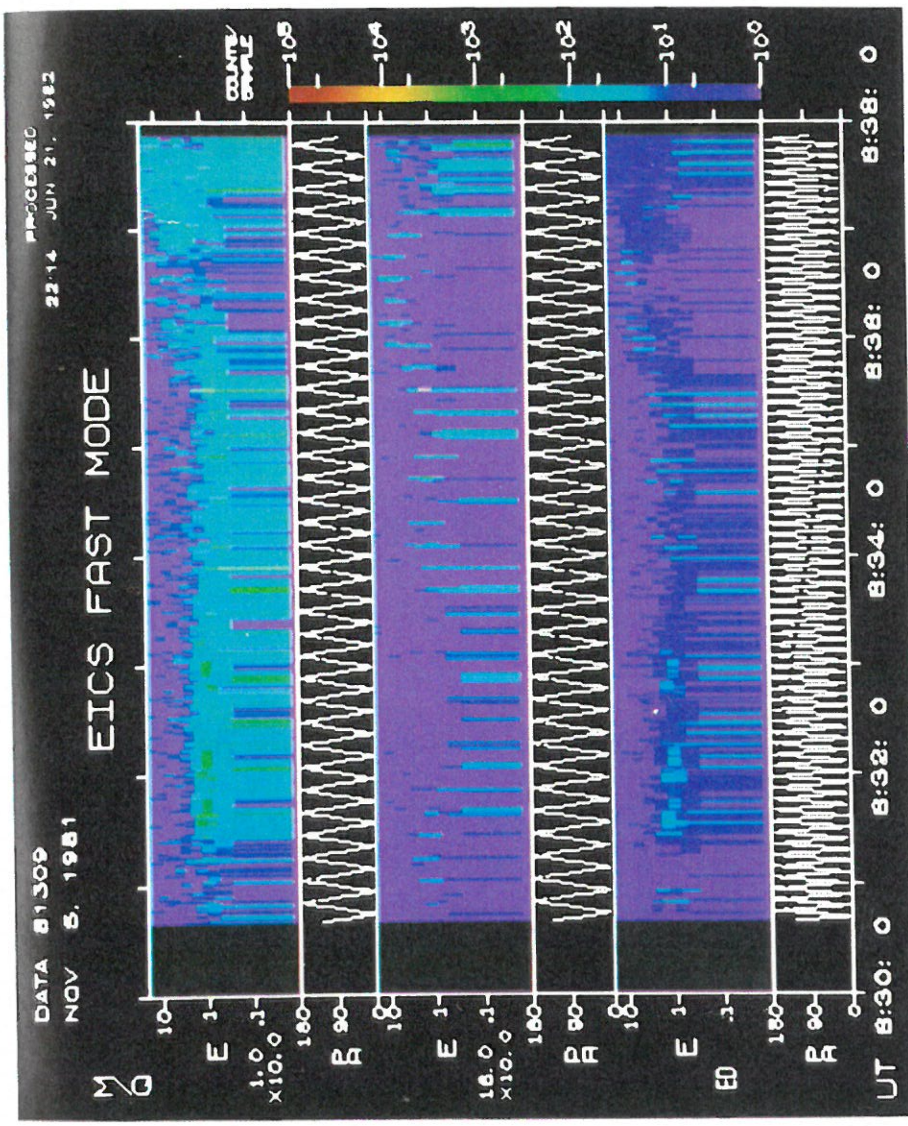

Fig. 1. Energy-time spectrogram from the evening sector (~1915 hours magnetic local time) obtained at ~2.7 R_E geocentric on November 5, 1981. During the 8 min of data shown, the satellite went from an L value of 8.5 to 5.9. Note that both the H^+ and O^+ count rates ($M/Q = 1$ and 16 respectively) have been multiplied by ten before plotting. See text for a description of the format.

energy-time spectrograms similar to those typically used for fast plasma instruments; however, one key difference is that the count rate, coded as indicated by the color bar at the right of the figure, is approximately proportional to differential number flux rather than the more conventional differential energy flux. The count rates for H^+ ($M/Q = 1$), O^+ ($M/Q = 16$) and the total E/Q distributions are shown in the top, middle, and bottom spectrograms respectively. The E/Q count rate is derived from an independent detector following the electrostatic analysis section of the spectrometer but preceeding the mass analysis section. The logarithmic energy scale extending from 10eV/e to 17keV/e is indicated in the left margin of each spectrogram. The panel below each spectrogram indicates the pitch angles for the respective measurements.

For these auroral studies the EICS was programmed to lock onto the H^+ mass channel for 6sec (approximately one spin) while rapidly cycling through a set of eight interleaving energy steps spanning the full range from 10eV/e to $17keV/e$ every 15° of spacecraft rotation. On the succeeding spin the same sequence of measurements were performed for O^+. The next two spins again sequentially sampled H^+ and O^+ but for a second set of interleaved energy steps. Thus, during a single 3sec (1/2spin) period one obtains an 8 × 12point energy-pitch angle distribution measurement for either O^+ or H^+ plus a similar measurement of the total ion (E/Q) distribution. Full 8 × 24 and 15 × 24point, two dimensional distributions are obtained for both species in 12sec and 24sec, respectively. For half of the spins only seven energy steps are covered and the eighth is devoted to a background measurement. Since each species is sampled on only one half of the spins the time scale from each spin is expanded in the spectrograms to eliminate data gaps, thus the time scale has an uncertainty of ± 6sec.

Several features are clear in these data. First, both H^+ and O^+ show a strong enhancement of flux moving upward along the magnetic field ($PA = 180°$). Second, the differential fluxes are frequently peaked in energy. Third, both the O^+ and H^+ fluxes show at least three examples of "inverted-V" structures, i.e., the energy of the peak flux increases and then decreases as the spacecraft moves in latitude. These inverted-V structures are a common feature in both upflowing ions (CLADIS and SHARP, 1979) and downflowing auroral electrons (FRANK *and* ACKERSON, 1971) and are generally interpreted as having resulted from an upward directed electrostatic field parallel to the magnetic field.

To demonstrate the relative characteristics of the upflowing O^+ and H^+ ion distributions we show in Fig. 2 the pitch angle distributions for the ions at the peak energy near the midpoint of the inverted V observed near 0636:30 in Fig. 1. We note that both the O^+ and H^+ are strongly peaked near the field line but that the H^+ also contains a lower intensity, nearly isotropic component.

Another way of looking at the distributions is shown in Fig.3a and b where the energy spectra are plotted for ions near 180° (Fig. 3a) and ions trapped near 90° (Fig. 3b). Two features stand out. First, there is essentially no trapped O^+ flux at any energy while the trapped H^+ spectrum is much softer than the field aligned component. Second, the field aligned components of both H^+ and O^+ are strongly peaked in energy with very similar energy spectra except for a lower intensity component in the H^+ similar to the trapped H^+ component. These data suggest a source of ionospheric H^+

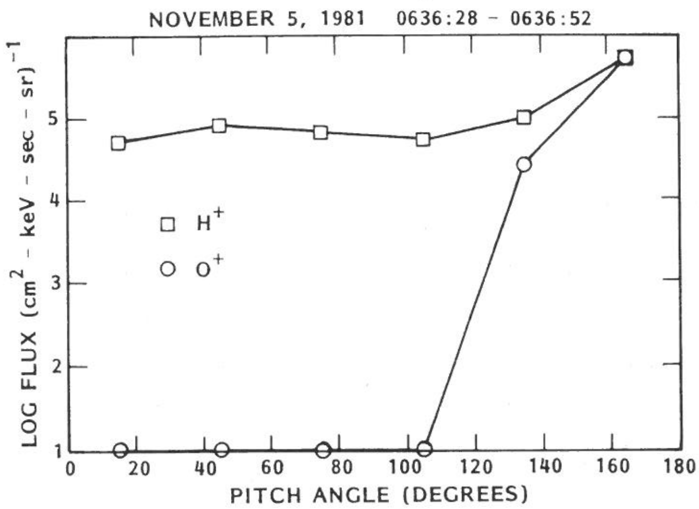

Fig. 2. Pitch angle distributions for ions with energies of ~7 keV near the peaks of the "inverted-*V*" structures at 0636:30 UT shown in Fig. 1.

and O^+ which has been accelerated by a potential drop of 5 to 6keV below the spacecraft plus a trapped component of H^+ which has not experienced such an acceleration.

Plots similar to those in Fig. 2 and 3 were examined for other times throughout the period from about 0635 to 0638 UT and all followed the same general pattern. The results are summarized in Fig. 4 where both the integral flux and the mean energy of the upflowing component (pitch angles = 160°–180°) of the O^+ and H^+ ions are plotted. Two interesting features are apparent. The O^+ and H^+ flux intensities (lower panel) appear to vary independently. This is consistent with the statistical results from the S3-3 data (Collin *et al.* 1981) where they found no systematic correlation between the O^+ and H^+ peak fluxes. Neither the relative flux variations between H^+ and O^+ nor the absolute variations of either with energy (see upper panel) are consistent with simple electrostatic acceleration of a constant low-energy source feeding the acceleration region from below. One possibility is a source which is resonantly driven, for example by electrostatic ion cyclotron heating below the acceleration region, and a spatially or temporally varying wave power spectral density. Another possibility is that downward accelerated electrons are heating the ionosphere locally and altering the relative scale heights of H^+ and O^+. This latter process could be accompanied by a variation in the low altitude extent of the accelerating electrostatic field. It may be possible to resolve this question by utilizing the full DE-1 and DE-2 data sets including waves, fast plasma, electron, and cold plasma data both above and below the acceleration region. Such studies are presently only in their formative stages but show great promise.

In contrast to the relative flux intensities, the mean energies of the two species (upper panel) track very closely over the entire event. The upturn in the H^+ mean energy near 0638 resulted from the much harder isotropic component of H^+ which was

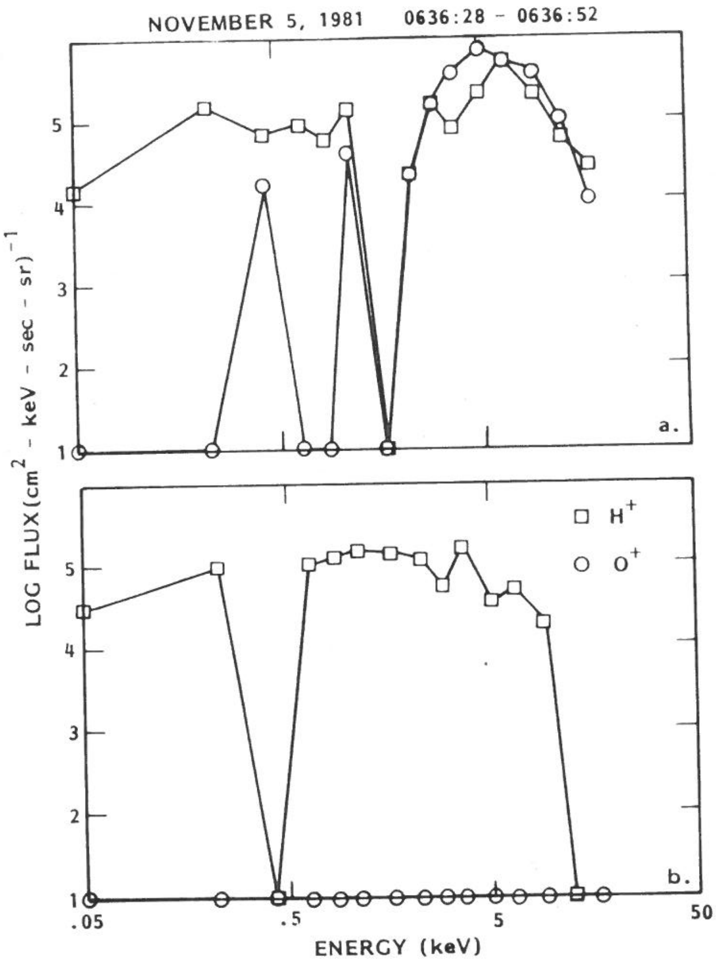

Fig. 3. Energy spectra for ions with pitch angles near 180° (a) and 90° (b) during the same time period a
Fig. 2.

encountered at this time (see Fig. 1). This close relationship between the mean energie of the two species is not consistent with the results of COLLIN *et al.* (1981) who foun that statistically the mean energy of the upflowing O^+ exceeds that of the H^+ by factor of about 1.7. This may simply be an unusual event, however, it may be th comparable energies are not unusual when both species occur with comparab intensities and that events which are primarily O^+ result in greater accelerations tha do events dominated by H^+. The answer to this question could have importa implications on the acceleration process involved. The answer, must await a mu more extensive statistical analysis of the EICS data.

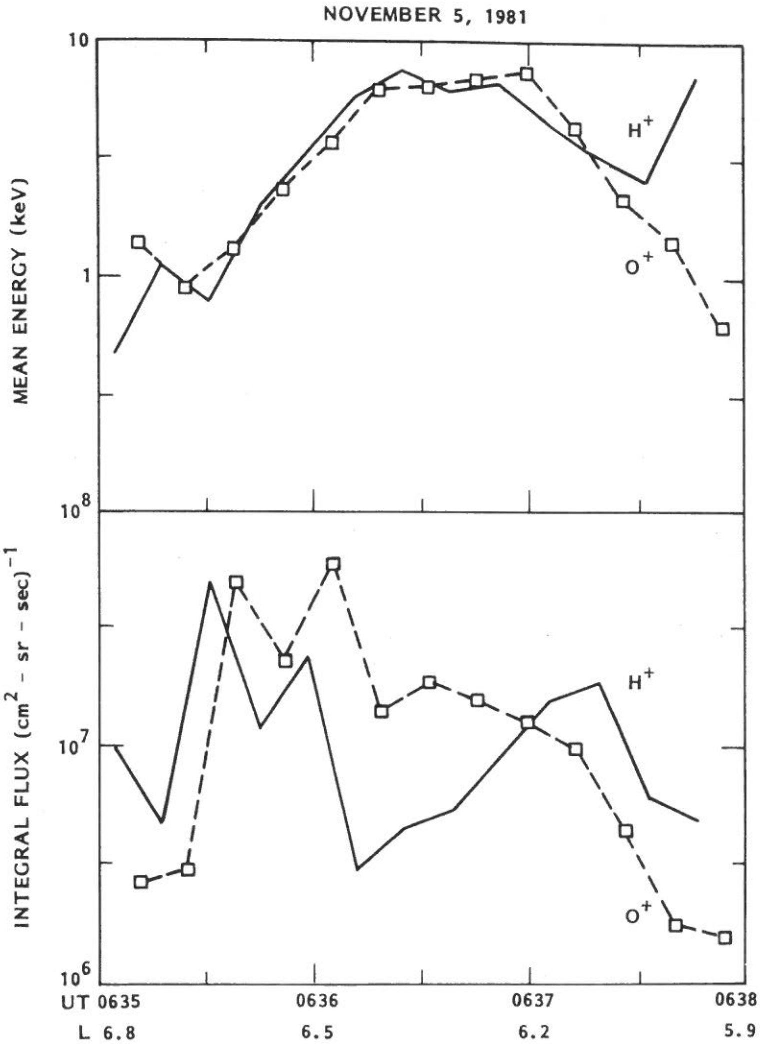

Fig. 4. Mean energy (upper panel) and integral flux (lower panel) of the upflowing ions observed on 5 November, 1981. Universal Time (UT) and L shell (L) of the data are indicated below.

2.2 *Polar cap ion acceleration*

It had long been assumed that the only significant flow of ions out of the high latitude polar cap ionosphere was the polar wind which consists primarily of low energy ($\simeq$ 1 eV) H^+ and He^+ (AXFORD, 1968; HOFFMAN and DODSON, 1980; BRINTON *et al.*, 1971). By contrast, the initial results from ion composition measurements on the DE-1 spacecraft suggest that heavier ions (O^+, O^{++}) as well as the lighter ions (He^+ and H^+) are frequently observed streaming upward over much of the polar cap with energies in the range from about 10 eV to a few hundred eV (SHELLEY *et al.*, 1982, CHAPPELL *et al.*, 1982, GURGIOLO and BURCH, 1982).

Figure 5 is a set of color spin-phase vs. time spectrograms for data obtained by the EICS between 1230 and 1306 UT on 20 September, 1981 while the DE-1 spacecraft was located over the northern polar cap (~90° latitude) at a geocentric distance of approximately 4.6 R_E. By contrast to the energy vs. time spectrograms shown in Fig. 1, here the ordinate is spin phase with 0° corresponding to the spacecraft velocity or ram direction. At this time the magnetic field direction is at approximately 90° spin phase. The five spectrograms starting from the top are for H^+ ($M/Q = 1$), O^+ ($M/Q = 16$), O^{++} ($M/Q = 8$), He^+ ($M/Q = 4$) and E/Q. The color coding is the same as was described for Fig. 1, but note that the O^{++} and He^+ count rates have been multiplied by ten to emphasize their lower flux levels. For these polar cap studies the EICS was programmed to rapidly cycle between the four mass components while remaining locked on a single energy step for 6 sec ($\simeq 1$ spin). The energy range from 0 eV to 2 keV was covered by 16 retarding potential analysis (RPA) steps below 100 eV plus seven electrostatic analysis steps ranging up to 2 keV. The energy step sequence is indicated by the bottom panel plus the RPA/ESA flag between the upper two spectrograms. When the flag is on (white) the step indicator range is from 0 to 100 eV; when the flag is off (black) the range is from 0 to 17 keV as indicated in the right margin. A total measurement sequence, including one spin of background, requires 192 sec ($\simeq 32$ spins). The background, which is negligible over the polar cap, is color coded between the second and third spectrograms. The flag above the E/Q (labeled ED) spectrogram indicates the programmed sensitivity of the E/Q measurement. When the flag is on (white) the sensitivity is reduced by about a factor of ten relative to the other measurements.

Figure 5 clearly shows the existence of highly directed fluxes of all four ion species sampled, streaming upward approximately along the geomagnetic field. (The very narrow feature observed at approximately 180° in both the H^+ and O^+ spectrograms during the RPA measurements is a contaminant resulting from photoionization of residual neutral gas in the RPA section of the analyzer each time the instrument looks directly into the sun and should be ignored.) It can be seen that O^+ is generally the dominant ion during this period and in fact was the dominant ion streaming out of the polar cap during most periods sampled. Most of the flux is observed in the RPA range ($\lesssim 100$ eV) but it clearly extends to several 100's of eV. To investigate the distribution functions in more detail, the period centered at about 1241 UT, when the fluxes appear to be relatively stable, was selected. Figure 6 shows the count rate vs. retarding potential for the four ions. It should be possible to determine the flow speed, temperature and density for each species by independently fitting a Maxwellian distribution to each of these curves; however, due to the variability of the fluxes during the measurement cycle, a reasonable fit was obtained only for the O^+. The result was a bulk flow of $\simeq 24$ km/sec (46 eV), a temperature of $\simeq 3$ eV and a density of $\simeq 0.3$ cm^{-3}.

Table 1 shows the results of comparing the knee potential (100% transmission), the cut-off potential (10% transmission), and the plateau count rates (upward flux) for the four ion species. The values illustrated for these parameters are considered characteristic of the accelerated polar cap ion fluxes examined to date. That is, O^+ is

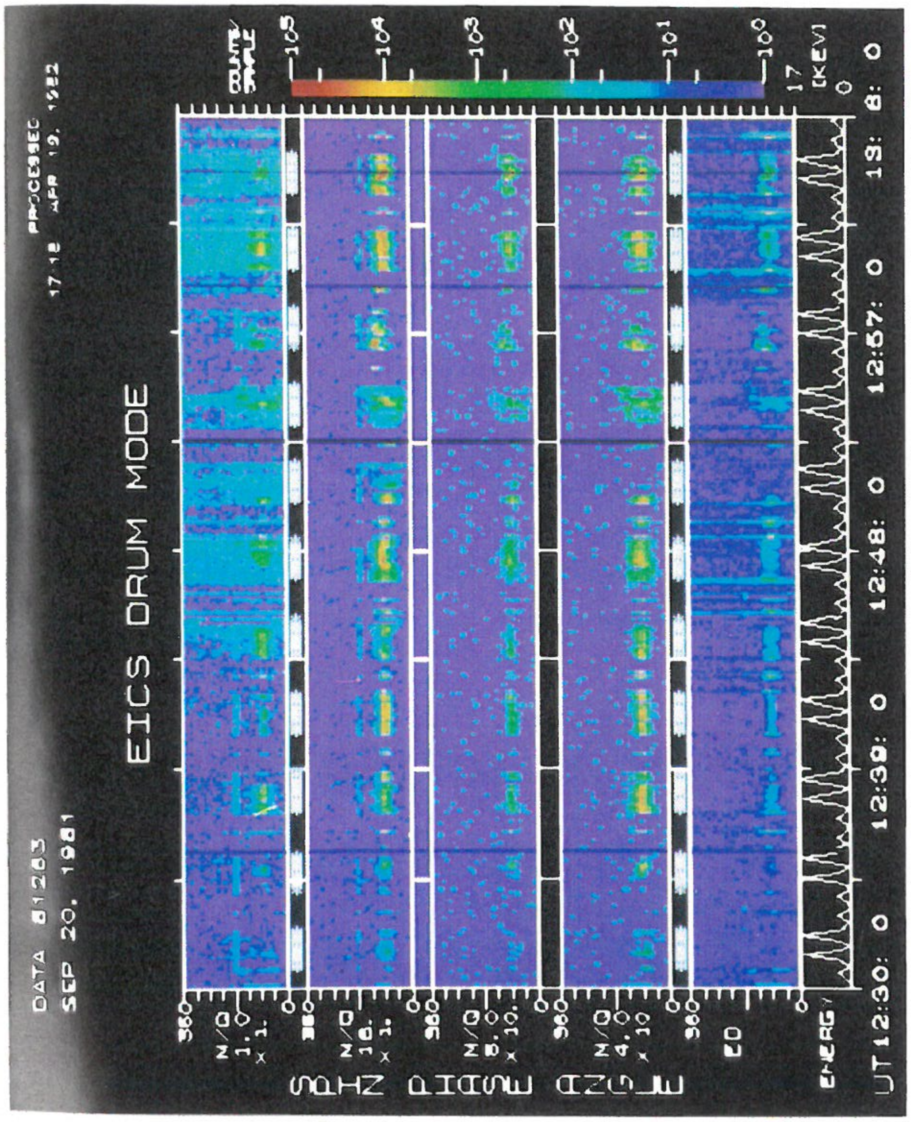

Fig. 5. Spin phase angle-time spectrograms acquired at $\sim 4.6\ R_E$ over the northern polar cap on September 20, 1981. Note that both the O^{++} and He^{+} count rates ($M/Q = 8$ and 4 respectively) have been multiplied by ten before plotting.

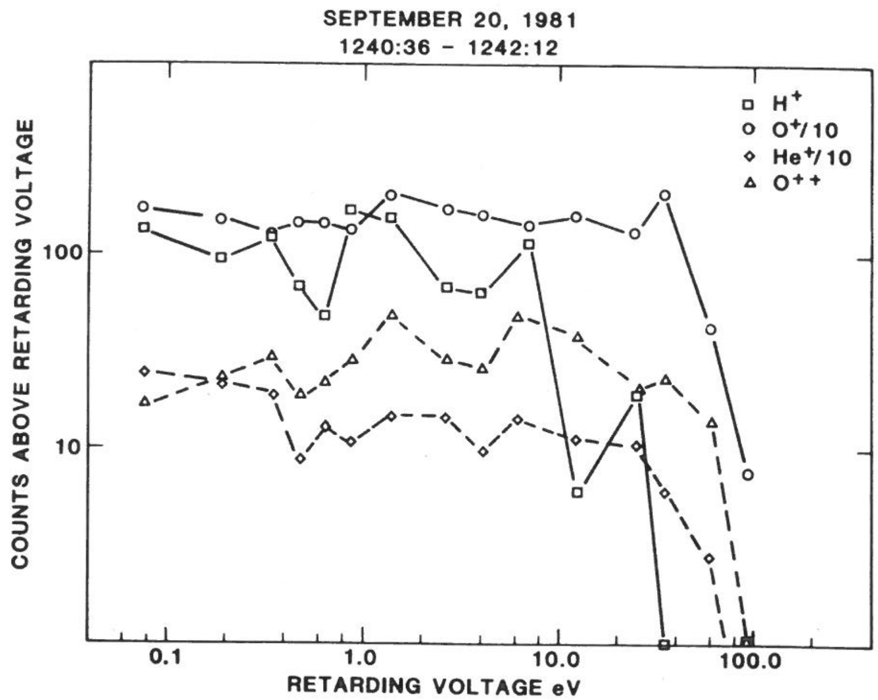

Fig. 6. Count rate vs. retarding potential analyzer voltage for ions streaming out of the polar cap ionosphere.

Table 1. Parameters derived from the data in Fig. 6.

Species	(RPA Voltage) Transmission 100%	10%	Upward Flux $(cm^2\text{-sec})^{-1}$
O^+	35 ± 5	75 ± 10	$7 \times 10^5 \pm 15\%$
He^+	25 ± 10	75 ± 10	$7 \times 10^4 \pm 20\%$
H^+	7 ± 3	20 ± 7	$5 \times 10^4 \pm 40\%$
O^{++}	35 ± 15	80 ± 10	$1 \times 10^4 \pm 35\%$

generally dominant followed in order by H^+ and He^+ with comparable intensities. O^{++} is frequently observed at a level of a few % of the O^+. The three heavier species have comparable energies but the H^+ is frequently observed to be less energetic. Effects of spacecraft charging, thus far, limit the ability to perform detailed quantitative assessments of the relative velocities and densities.

Based on approximately 9 hrs of polar cap observations, SHELLEY *et al.* (1982) concluded that fluxes comparable to those given in Table 1 are present approximately

50% of the time. They estimated that such a polar cap source ($\simeq 10^{25}$ ions/sec) would be significant in maintaining the plasma sheet population. They also concluded that these ions were the source of the tail lobe ion streams reported by SHARP *et al.* (1981) and BAME *et al.* (1968) but were not consistent with polar wind expectations. These initial polar cap observations raise many questions concerning the polar wind mechanism and magnetosphere ion sources but much more extensive and detailed studies will be required to answer those questions.

2.3 Dayside polar cusp observations

The DE-1 orbit and instrumentation are well suited to study the low to mid-altitude dayside cusp region. Although no detailed analysis of the EICS data have yet been performed for data acquired in the cusp region, a survey of these data have confirmed earlier observations and suggest that this data set will in fact contribute significantly to our understanding of both the solar wind and ionospheric source processes.

Figure 7 is a set of two spectrograms showing data acquired during a pass through a mid-altitude ($\simeq$ 21,000 km) dayside cusp on 24 October, 1981 (see Table 2 for orbit parameters for this interval). The presentation in Fig. 7 is similar to that for Fig. 5. except that the ordinates are pitch angle rather than spin phase. Here from top to bottom, the spectrograms are for H^+ ($M/Q = 1$), O^+ ($M/Q = 16$), He^{++} ($M/Q = 2$), O^{6+} ($M/Q = 2.7$) and E/Q respectively. At lower latitudes one observes moderate intensity isotropic H^+, plus a mix of soft isotropic and field aligned O^+. At approximately 1005 UT the spacecraft enters the cusp as indicated by the intensification of the H^+ and He^{++}. The O^{6+} flux levels are near background and would require integration for any quantitative analysis. One clearly sees the softening of the energy distributions of both the H^+ and He^{++} at higher latitudes. This has previously been observed and explained in terms of velocity dispersion resulting from poleward convection of the cusp field lines (SHELLEY *et al.*, 1976a; REIFF *et al.*, 1977). The upward streaming O^+ ions in the form of beams and conics are also clearly visible. They intensify in the heart of the cusp region but extend well into the polar cap. These measurements provide significantly improved temporal and spatial resolution compared to those previously reported for the S3-3 observations (SHELLEY *et al.*, 1979) and should lead to a better understanding of the acceleration process.

Figure 8 shows a distinct feature in the mid-altitude dayside cusp H^+ and He^{++} energy-pitch angle distributions. The instrument mode and data presentation are similar to those in Figure 1 except that H^+ and He^{++} rather than H^+ and O^+ are being sampled. Both species show a *V* like structure. Close examination reveals that as the pitch angle increases, the energy also increases. This feature has been explained by BURCH *et al.* (1982) as resulting from time of flight dispersion caused by poleward convection of ions originating from a relatively localized source region. A comparison of the relative energy-pitch angle distributions for H^+ and He^{++} confirm that indeed they have the same velocity dependence as would be expected from the model of Burch *et al.*

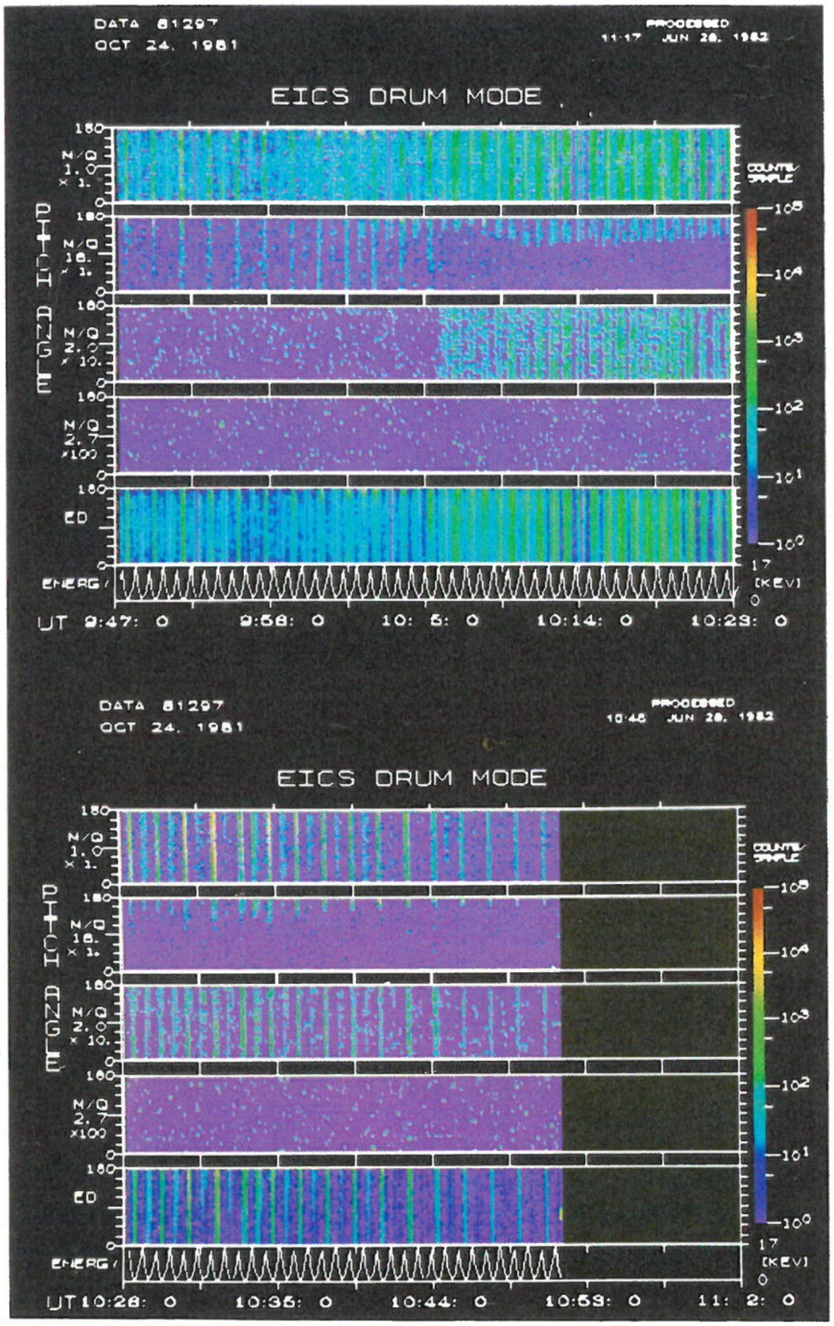

Fig. 7. Pitch angle-time spectrograms from the cusp region acquired on October 24, 1981. Geocentric distance, magnetic local time and L values for four times during this interval are given in Table 2. Note that the He^{++} data ($M/Q = 2$) have been multiplied by ten, and the O^{6+} data ($M/Q = 2.7$) have been multiplied by 100 before plotting.

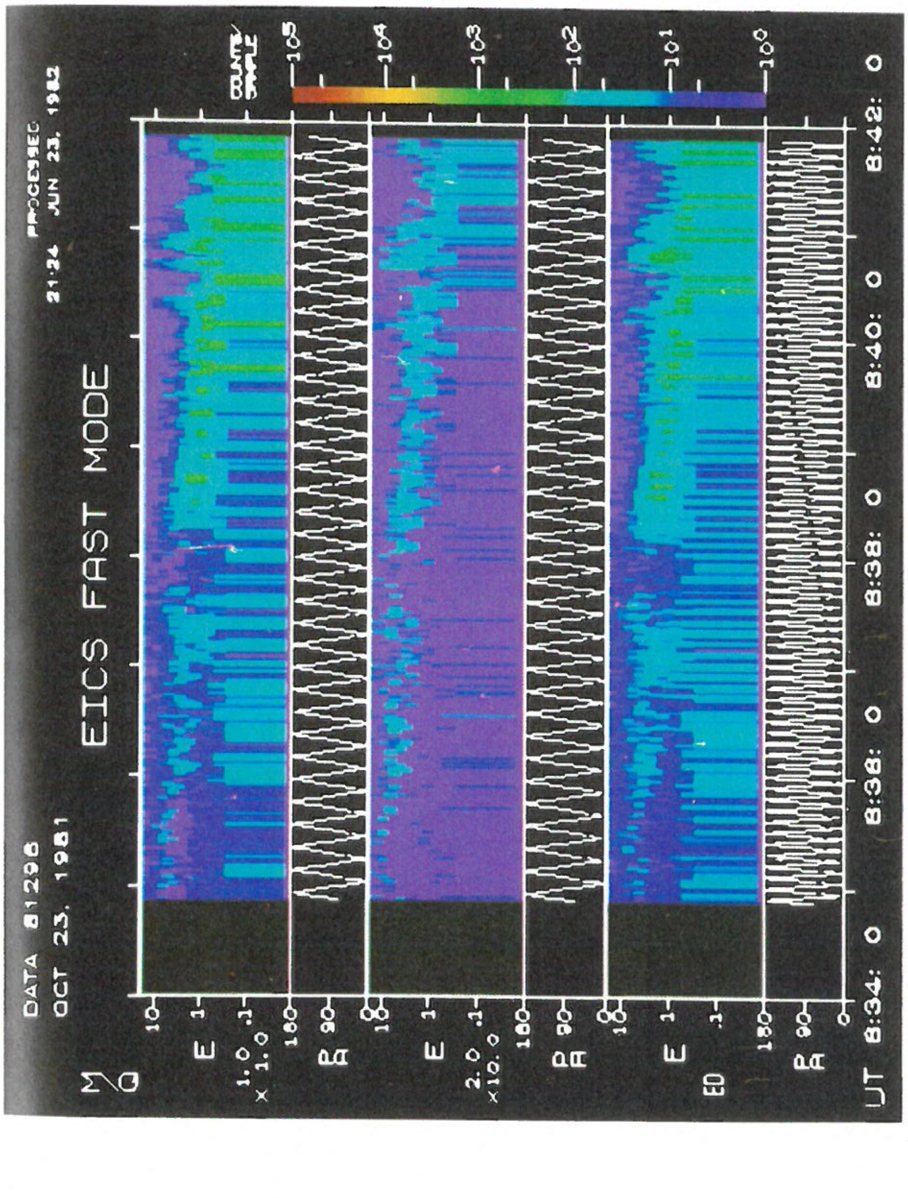

Fig. 8. Energy-time spectrogram from the dayside cusp (~0957 magnetic local time 4.2, R_E, L value 9.7) on October 23, 1981. Note that the He^{++} data ($M/Q = 2$) have been multiplied by ten before plotting.

Table 2. Orbit parameters for the period displayed in Fig. 7.

Universal time	Geocentric distance (R_E)	Magnetic local time	L value
0947	4.0	0947	10.6
1005	4.2	0957	16
1028	4.4	1013	29
1047	4.6	1032	51

3. Comments

At this early stage of the DE mission the level of data analysis is relatively limited but already some new discoveries have been made and much improved data on previously observed phenomena have been obtained. Significant progress in our understanding of the coupling between the hot magnetosphere plasmas and the dense cold ionospheric plasmas and neutral atmosphere will surely result as the analysis of these combined data sets from the two DE spacecraft proceeds.

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