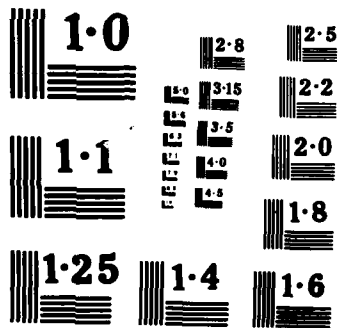


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IMS Contributions to the Understanding of Auroral Precipitation, Transport, and Particle Sources

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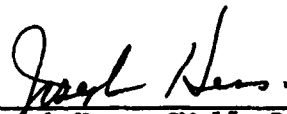
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This technical report has been reviewed and is approved for publication. Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.



Douglas R. Case, 1st Lt, USAF
Project Officer



Joseph Hess, GM-15, Director, West Coast
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the auroral and subauroral ionosphere. Some of the effects auroral ionospheric ions have on the magnetospheric plasma composition are described. A brief overview of pre-IMS results is also given to set the stage for a description of IMS contributions in these areas.

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PREFACE

The author would like to thank all his colleagues who provided reprints of their work as source material for this report. This work was performed in part under USAF Contract F04701-83-C-0084.

I. INTRODUCTION

The International Magnetospheric Study program, or IMS, is a coordinated effort to understand magnetospheric processes. The IMS had two phases, the active phase during which data were gathered (from 1976 to 1979) and the data analysis and modeling phase which is winding down at this time. The major sources of data for the IMS program analysis phase have been identified in two recent publications, (Refs. 88, 137). These publications describe the data coverage and types of measurements made by satellite and ground-based systems plus some results from a few IMS workshops.

The symposium on the Achievements of the IMS took place at Graz, Austria (25-27 June 1984). The session on particle sources, transport, storage and precipitation included results related to auroral processes. In this rapporteur report the pre-IMS status of work in the area of auroral-processes is reviewed and the contributions the IMS program has made are described. The emphasis in this report will be on particles on auroral field lines. This includes the ionosphere as a source of particles, acceleration of auroral electrons and ions plus transport of the plasma. The focus will exclude the distant ($> 10 R_E$ altitude) tail observations which are covered elsewhere in these proceedings.

II. PRE-IMS STATUS OF AURORAL PHYSICS

This summary of the pre-IMS status does not reach back to the origins in auroral physics, that is a task for the historians. Instead, a brief description is presented of the understanding of auroral particle processes that obtained near the beginning of the IMS data collection period. This description is based on reviews of the subject from the 1974-1976 time frame. Emphasis is on the higher latitude polar regions; the auroral zone, polar cap and plasma sheet. By 1976 these regions had been observed by both low and high altitude spacecraft and rockets. Observations were also made from the ground using optical systems, magnetometers, radars etc. These had culminated in a fairly detailed picture of the general auroral morphology.

A. NIGHTSIDE AURORAL STRUCTURE

By 1976, the inverted V structure in the nightside auroral region had been observed and analyzed (Refs. 47, 108, 164). This latitudinal dependence of the precipitating electron energy was interpreted as a signature of electron acceleration via magnetic field-aligned electric fields (see Ref. 45). Such potential drops were also called upon to explain the field alignment of the precipitating electrons observed over discrete auroral arcs. The latitudinal structure of the acceleration was assumed to reflect the structure of the electric fields. Up to 1976 there were no decisive measurements which showed that parallel electric fields ($E_{\parallel}$) existed, that they were at low altitudes (1-2 Re altitude) or what the altitudinal scale length of such potential drops might be. There was, however, indirect evidence (Ref. 38).

There were objections to the concept of field-aligned potential drops, one being the existence of a large low energy component in the precipitating electrons. Evans (Ref. 37) showed that the intensities of precipitating and backscattered low energy electrons should be of similar magnitude. This idea was also supported by observations from spinning satellites (Refs. 7, 67, 107, 164) and rockets (Refs. 8, 9, 13). The precipitating electrons above discrete aurora were observed to be magnetic field-aligned (Refs. 13, 93 and ref. therein). In fact, measurements of the particle angular distributions showed

many features, most of which could be explained if one assumed a field-aligned electric field existed somewhere above the observation point (Refs. 4, 7, 13, 107, 108, 164). At times the precipitating electrons were observed to be strongly field-aligned over a wide range of energies. These observations often occurred at ionospheric levels and were associated with edges or boundaries of auroral displays (Refs. 125, 133, 161). Plasma instabilities at high ionospheric altitudes were suggested as mechanisms for forming such beams (Refs. 12, 81, 123, 126, 152-154).

By 1976 a few mechanisms had been proposed for generating field-aligned potential drops. A plasma instability which would lead to the formation of an anomalously increased resistivity and therefore a large voltage drop was one such mechanism. This required that while the bulk of the electron population is thermally heated the most energetic ones would pass through the instability region without collisions to be accelerated by the voltage drop. Alternatively, the plasma instability could lead to the formation of a confined electrostatic shock or "double layer." Electrons would be freely accelerated in the potential drop that forms across this region (Ref. 14). It was also proposed that parallel electric fields could result from the balance electric forces acting as charged particles in a converging magnetic mirror geometry, such as exists in the earth's magnetic field (Refs. 5, 87, 89-91). While there was some evidence to support each of these mechanisms there was not sufficient data to allow the models to be tested.

During the pre-IMS period observations of the energetic ion composition (< 20 keV/q) showed that the ionosphere was a significant source of ions (Ref. 146). The ionospheric ion content of the outer magnetosphere varied with magnetic activity. While there was much speculation as to how the ionospheric ions were energized and transported it was not until the IMS period that the answers came, as is discussed below.

B. DAYSIDE AURORAL STRUCTURE

Prior to 1976 the polar cusp particle precipitation had been observed and had been studied in some detail. The cusp signature was the simultaneous observation of magnetosheath-like ion and electron precipitation at latitudes

just above the energetic electron trapping boundary in the local noon sector of the auroral zone (Refs. 35, 45, 46, 63, 64, 163). The magnetosheath particles had access to low altitude and the access was highly variable (Refs. 100, 157). The HEOS2 measurements pointed to the existence of an entry layer, inside the dayside magnetopause, which connected to the plasma mantle (Ref. 135) and mid-altitude cusp (Refs. 55, 124). Examination of the plasma parameters near the mantle showed that they were consistent with an open magnetosphere (Ref. 34) as was the dispersion in the energy of precipitating ions in the low altitude cusp (Refs. 64, 132). This energy dispersion of ions in latitude under the control of the electric field ($\vec{E} \times \vec{B}$ drift) was observed at low and high altitudes (Refs. 132, 135, 149). This same mechanism was used to explain the ion temperature changes in the plasma mantle (Ref. 135). While this presented a nice simple picture of the origin of low altitude cusp particles, it wasn't always correct. Antisunward convection was observed near the cusp and there was significant variability in and reversals of the flow being observed there (Refs. 53, 60). These signatures required an interpretation in which the strict antisunward convection occurs only near local noon in the cusp and that away from noon the ExB flow is more consistent with being nearly parallel to the polar cap boundary (Ref. 60).

C. MORNINGSIDE AURORA

The morningside aurora had been somewhat neglected. Prior to 1976 it was depicted as a region of patchy precipitation like the eveningside diffuse aurora (Ref. 2). These precipitations would take on a structured appearance during the recovery phase of substorms, followed by the mantle aurora which spread through the local morning sector (Ref. 66). Satellite and ground-based auroral photographs showed that discrete auroras are generally absent in the morning sector (Refs. 1, 2). The dawnside auroral electron precipitation had the same form as the spectra of the dawnside plasmasheet electrons (Ref. 36). Often the patches of precipitation were associated with pulsations (Refs. 77, 136). The electron spectra of the pulsating aurora were observed to have a high energy tail and were not mono-energetic beams. From these features it was generally concluded that the central plasma sheet was the source of the morningside auroral electrons (Refs. 1, 2).

. POLAR CAP

The region above auroral zone latitudes had been studied to some extent. The polar rain (Ref. 109) and polar arc precipitations had been observed. The polar rain appeared to be controlled by the IMF (Ref 166). Examination of polar flare particle access to the tail lobes and high latitude polar regions provided some information about magnetospheric topography (Ref. 160). The general antisolar convection had been observed and indications of sporadic solar-directed flow were noted (Ref. 60).

are usually soft and smooth varying with relatively low intensities (Refs. 104, 109, 166). The IMF controls the access of these electrons to the tail lobes and polar caps. The observed north-south pole precipitating flux asymmetries and tail lobe fluxes have been shown to be related to interplanetary solar electron anisotropies assuming direct access to the tail lobes and polar caps via an open magnetosphere model (Refs. 39, 52, 109, 166). This topic is currently being reexamined.

regions (Ref. 160). Unfortunately, nature does not cooperate by always providing flare electrons when one is trying to perform auroral observations.

There are particle features which are generally thought to occur in the open field line or polar cap region. A general class of observed features are the polar cap arcs and inverted V structures. These generally occur poleward of the convection reversal which is thought to define the boundary of open and closed field lines most of the time and to demark the northernmost edges of the auroral zones. These polar cap arcs have been described in detail using optical observations (Refs. 1-3, 48, 54, 62, 72, 73, 102, 120). There are relatively few polar cap arc optical observations for which the precipitating electron spectra are available and even fewer where combined particle, E field and current measurements are available (Ref. 17). In most cases either the optical or the particle data were available but not both. During the IMS period and earlier, only ISIS, DMSP and Kyokko could take such data (see for example, Refs. 6, 54, 56, 65, 78, 106, 109, 113). The resultant published correlations are few. Without the images it is difficult to decide whether the intense precipitations are truly in the polar cap. Even with them it is not obvious whether the arc precipitations are on open field lines or not. At present there is considerable controversy as to the source of the precipitating electrons. Are they plasma sheet, magnetosheath or tail lobe particles? There is no generally accepted answer at this time.

Much of the discussion of dayside polar convection patterns referenced in Sec. III.B above addresses this same question. The thing that has been missing is a self-consistent framework in which one can predict what the source of plasma is and how the arcs should appear. Recent papers by Chiu, et al., (23) and Reiff (129) provide probable frameworks. These models are based on an open model of the magnetosphere and discuss various ways magnetic merging occurs. The sources and configurations of the polar cap arcs are predicted by such models. It now remains for the observations to be compared to these models.

Finally, there is both pre- and post-IMS evidence that solar-wind/magnetosheath electrons obtain direct access to the polar cap. These fluxes

is driven by inward-convected anisotropic ions in the equatorial plane. On the eveningside these energetic ions (few keV) are predominately field-aligned, which dampens the mirror instability. On the morningside they are predominantly perpendicular to B. Thus the modulation of the pitch angle diffusion is most likely to occur in the morning sector.

The work on morningside aurora is not complete. As yet there is not a global model of the morningside aurora. Also, there is a question as to whether the discrete arcs associated with inverted V structures at high latitudes on the morningside (Refs. 67, 92) are precipitation of plasma on open or closed field lines. That is, are the inverted V structures observed there generated by accelerated magnetosheath particles and not precipitation from the morning side plasma sheet? There is some evidence pointing to this (Ref. 61).

D. POLAR CAP

The discussion of the polar cap is a tricky one. First, by the polar cap one usually means the extension of the magnetotail lobes to low altitudes. This corresponds to the region of open field lines. The exact point at which an observer defines the transition from open to closed (or vice versa) field lines to occur is generally biased by one's expectations of the physical processes which occur at that boundary combined with one's observational technique. So far, we have not been able to uniquely identify an open field line and this has led to much controversy in terms of interpretation of observations and in physical modeling.

Generally, in terms of particles, a field line is defined as open if a particle cannot perform bounce motion, i.e., it doesn't have a double loss cone. This has problems, for example, if the motion of particles is non-adiabatic, they will not always have an empty loss cone on a closed field line. If a potential drop forms on a field line, in a converging magnetic geometry, then a low energy particle component which cannot penetrate the potential structure will appear to be trapped, even if the field line is open. One technique, using particles which has been successful, has been to examine the access of energetic (> 40 keV) solar flare electrons to the polar

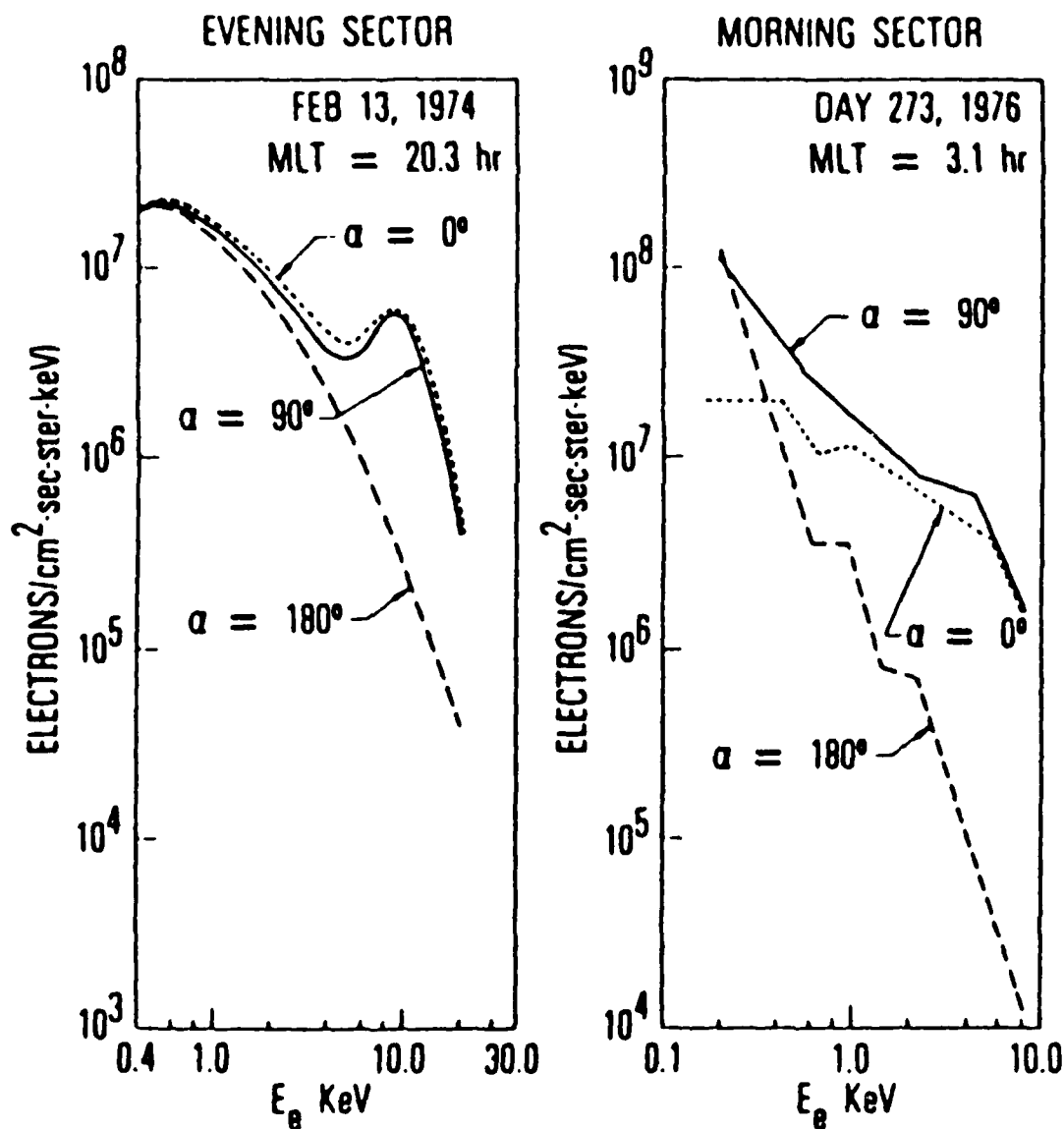


Figure 5. Comparison of evening (left panel) and morning (right panel) sector auroral electron spectra. The evening spectra show the usual electron beam formed by a field-aligned potential drop. The morning spectra is intense but monotonic, reminiscent of the morning plasmashet.

Crooker (31) has generated a model of dayside merging which predicts the convection pattern in the dayside cusp. This description represents fairly well the observed features. More recently this kind of model has been expanded to include all local times and to make it more quantitative (Ref. 23).

C. MORNINGSIDE AURORA

Progress has also been made, both observationally and theoretically, in understanding the morningside aurora during the IMS. Observationally, the emphasis has been on finding the sources and mechanisms for the diffuse and pulsating electron precipitation (Refs. 3, 11, 24, 25, 30, 33, 105). On the morningside the separation of diffuse and discrete aurora has not been as clear cut as on the evening side where the diffuse aurora is located within the central plasma sheet and the discrete arcs are located in the boundary plasma sheet. The morningside discrete arc auroral fluxes generally do not show the monoenergetic peak associated with the eveningside arcs (Refs. 3, 24).

The morningside diffuse aurora is not as smooth and uniform as seen on the nightside. It develops patches which appear to drift with the background plasma and which often are pulsating (Refs. 24, 120). The precipitating electrons in these patches are still thought to be due to pitch angle scattering of the electrons and not due to field aligned potential drops (Refs. 105, 120). An example of a morningside precipitating electron spectrum is shown in Figure 5. There are few published electron spectra from the IMS period for the morningside auroral arcs for comparison with the surrounding diffuse-patchy structures. The majority of spectra were presented in the pre-IMS era (Refs. 47, 49).

Taking what is known about the morningside aurora and precipitation plus what has been recently learned about the equatorial plasma distribution on the morningside of the magnetosphere, Chiu, et al. (24) have constructed a theory of the morningside aurora. The theory is based on the spatial modulation of the warm plasma density caused by the mirror instability which in turn modulates the precipitation rates of the hot electrons. The mirror instability

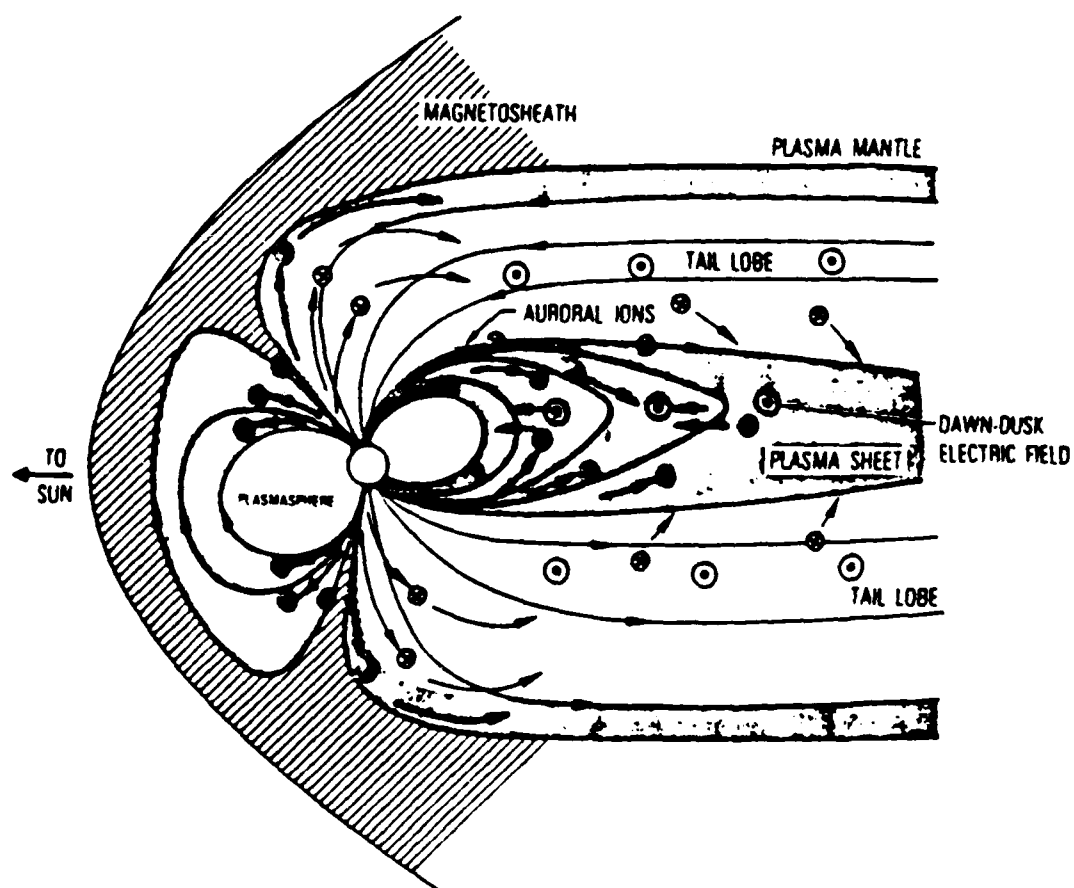


Figure 4. Ionospheric ion outflow and convection. Ion outflow is shown in and near the cusp, nightside auroral region and at subauroral latitudes of the plasmasheet. Convection transports these ions into the tail lobes and central plasmasheet.

are seen preferably at local noon in and near the cusp for moderate magnetic conditions (Refs. 51, 84). Klumpar (84, 85), using the ISIS data, found that the conic ions populate the cusp region field lines primarily in the summer hemisphere and that they are associated with intense beams of precipitating electrons. These cusp conics are often on nominally open field lines. This indicates that the ionosphere is providing ions to the magnetosheath in a layer next to the magnetopause (Refs. 127, 145) and to the polar cap regions via convection (Refs. 130-132, 135, 141). The composition and energy of the ionospheric ions in this layer will be determined by the acceleration mechanism and by convection as the ions move upward along the magnetic field lines. Generally the energies will be relatively low (< 1 keV or so). The convection electric field should also separate the ion species by acting as a crude velocity filter as has been observed elsewhere (Refs. 122, 135, 165) and as sketched in Figure 4. This has been observed recently by the DE-1 composition experiment (Refs. 21, 114).

The magnetosheath provides particles to the cusp as was discussed above. During IMS it was determined that some acceleration of the magnetosheath ions occurs at injection (Refs. 20, 158). So this source of cusp precipitation encompasses more than just particle scattering.

The plasma transport in the dayside auroral regions has been a topic of much interest. The visual evidence of auroral forms emanating from the polar cusp and discrete features extending into the polar caps (Refs. 2, 103, 104, 129, 131, 132) have resulted in a concerted effort to understand the plasma transport in this region (Refs. 23, 31, 57, 58). Observationally the auroral emissions are consistent with a throatlike convection of the plasma in the cusp and poleward (Refs. 57, 60, 61, 131). Similarly the direct measurements of plasma convection by AE-C show a throatlike convection pattern with the position of the throat and angle of flow into the polar cap being controlled by the interplanetary magnetic field (Refs. 57, 58, 62). More recently, it has been shown that a long term steady convection can effect the near cusp thermospheric flow when the interplanetary $B_y > 0$ (Ref. 101).

subauroral regions during substorms (see Sec. 2 and Refs. 75, 146). The post-IMS observations near the equator (Refs. 70, 71, 74, 76, 79, 80, 102, 122, 150, 168-171) showed that ionospheric ions are often present in the outer magnetosphere at the equator and are observed to be field-aligned (Refs. 18, 19, 42, 43, 70, 79, 80, 95, 96). These facts lead to the conclusion that the auroral ionosphere is a significant source of plasma to the outer magnetosphere. At times, especially during large storms, it is the dominant source and the relative strength may vary with the solar cycle (Refs. 29, 74, 168-170). ISEE-1 observations have shown that in the plasma sheet and tail lobes there is a population of low intensity streaming ions of recent ionospheric origin which form the dominant plasma constituent (Refs. 141, 143). All of the IMS results indicate that the auroral ionosphere supplies a significant fraction of the plasma sheet and outer magnetosphere plasma.

More recently, the near earth central plasma sheet has been restudied as part of the IMS (Refs. 10, 40) with emphasis on the plasma motions. One study (Ref. 40) has concluded that the inner edge plasma sheet electrons are seldom strongly pitch-angle-scattered and their motions through the magnetosphere are convection-dominated. Other studies organize the plasma motion by calling on a near-earth source or injection boundary with convection controlling the motions earthward of the boundary (Refs. 98, 99). In another area, examinations of the afternoon radar-aurora signatures shows these to be most likely associated with the inner edge of the diffuse precipitation of plasma sheet electrons and the weakening of the convection electric field (Ref. 121). Recently auroral images have shown that the equatorward edge of the evening diffuse aurora has undulations probably related to the plasma convection just outside the plasmasphere (Ref. 94). The processes which form these structures are not known yet.

B. DAYSIDE AURORAL REGIONS

The IMS dayside studies have not had the great impact on the auroral physics problem that the nightside studies have. Nevertheless, there has been advancement in our understanding. The auroral ion sources seen on the nightside are also present on the dayside. In fact, the upflowing conic ions

less than the potential drop across the shocks (Ref. 155). The shocks themselves typically span a latitudinal width of 0.01° to 0.1° and it has been proposed that discrete auroral arcs are produced by electron acceleration in the shocks (Refs. 83, 159). The sizes of the electrostatic shocks scale as the ion gyroradius and their electric field orientation is predominantly perpendicular to $\underline{B}$ (Refs. 116, 117, 159). These shocks are also imbedded in regions of coherent electrostatic ion cyclotron (EIC) waves.

It has been shown (Ref. 82) that the EIC waves are associated with the beams of upflowing ions. The temperature of these ion beams (see Figure 2) indicates that some heating of the ions has occurred. The energy of the beam is assumed to represent the field-aligned potential drop below the observation altitude (Refs. 42, 43, 50, 155). The observation of ion conics (Refs. 44, 51, 74, 84, 86, 139, 162) on ISIS, S3-3 and on rockets gave some ideas for the source of this ion heating. The conics were found to be accelerated preferentially perpendicular to the magnetic field and to originate predominantly at lower altitudes (< 4000 km) in the auroral zone (Ref 51), as low as a few hundred kilometers altitude (Ref. 162).

The composition of the upflowing ions showed that oxygen was a significant fraction of the total ion density in the inverted V regions (Refs. 139-142, 148). A study by Collin, et al., (Ref. 27) showed that the upflowing oxygen ions derived about half of their energy from a mass dependent process (heating?) whereas the hydrogen ions derived most of their energy from a quasistatic parallel potential drop. The oxygen ion energy always exceeded that of the hydrogen giving rise to the speculation that the oxygen ions may be the dominant ion in the conic energization process. The energy of the upflowing oxygen was found to track the energy of the precipitating electrons (Ref. 140 and references therein), as did the hydrogen. This is consistent with the concept that ions and electrons are simultaneously accelerated on the auroral field line, partially in a parallel potential drop and partially via waves.

The observation of these upflowing ionospheric ions fit well with the pre-IMS observation of ionospheric ions being present and precipitating in the

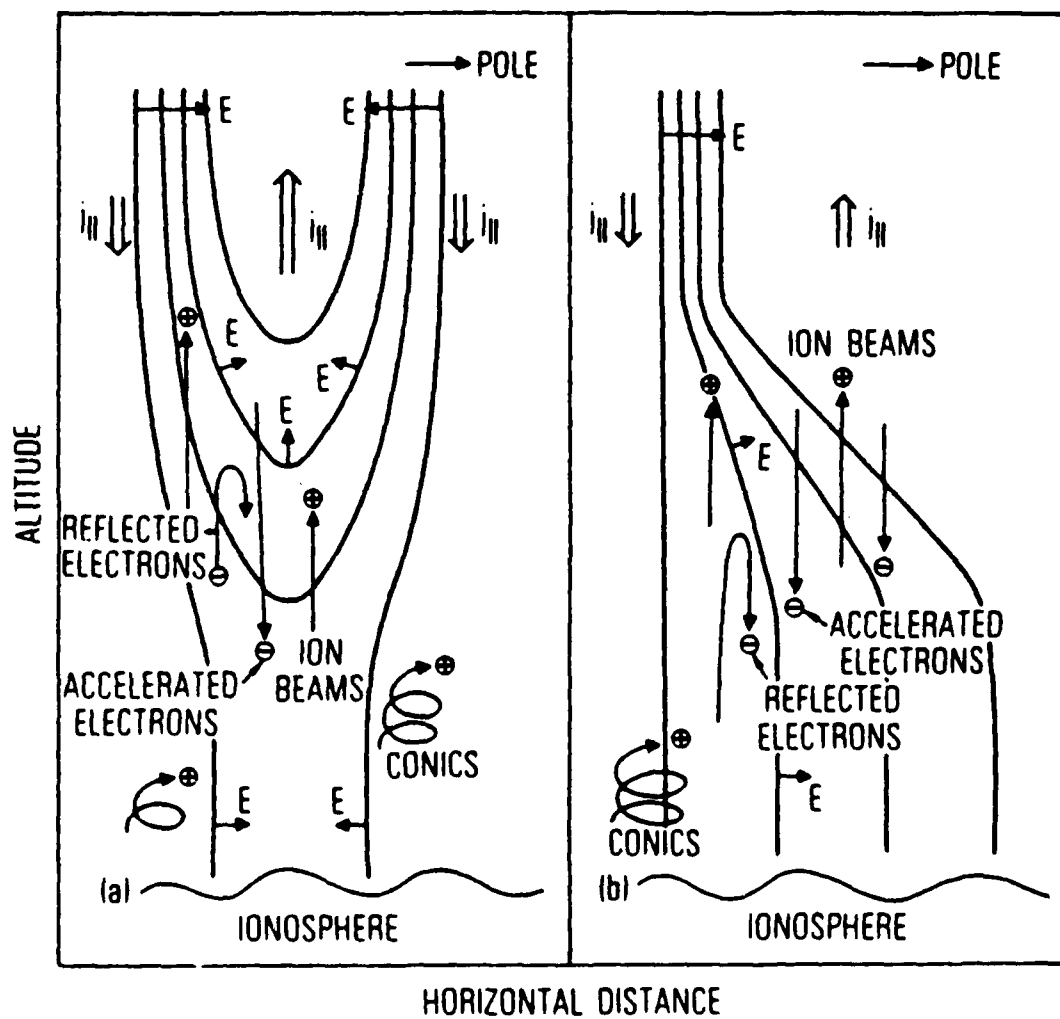


Figure 3. A sketch of V-shaped (left panel) and S-shaped (right panel) shocks. The kinds of particle distributions seen near and in the shocks are also shown (after Refs. 112 and 118).

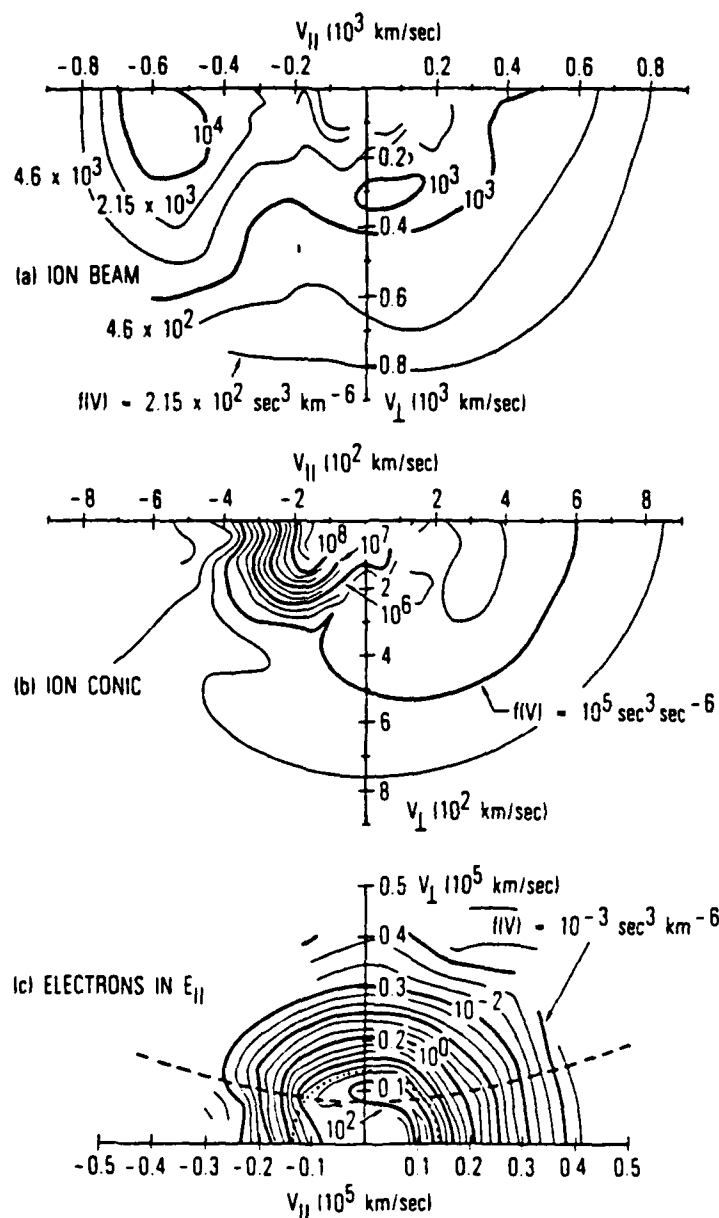


Figure 2. Typical auroral particle distributions observed at $\sim 1 R_e$ altitude. (a) Upflowing ions in the dusk sector which show effects of a potential drop below the observation altitude. Note perpendicular spread of beam. (b) Upflowing ion conic distribution with peak of $f(v)$ lying near a cone with opening angle of $\sim 35^\circ$ relative to $-V_{||}$ axis. (c) Accelerated electrons with a peak in the downgoing direction. The distribution shows effects of a potential drop above and below the observation point (after Ref. 22).

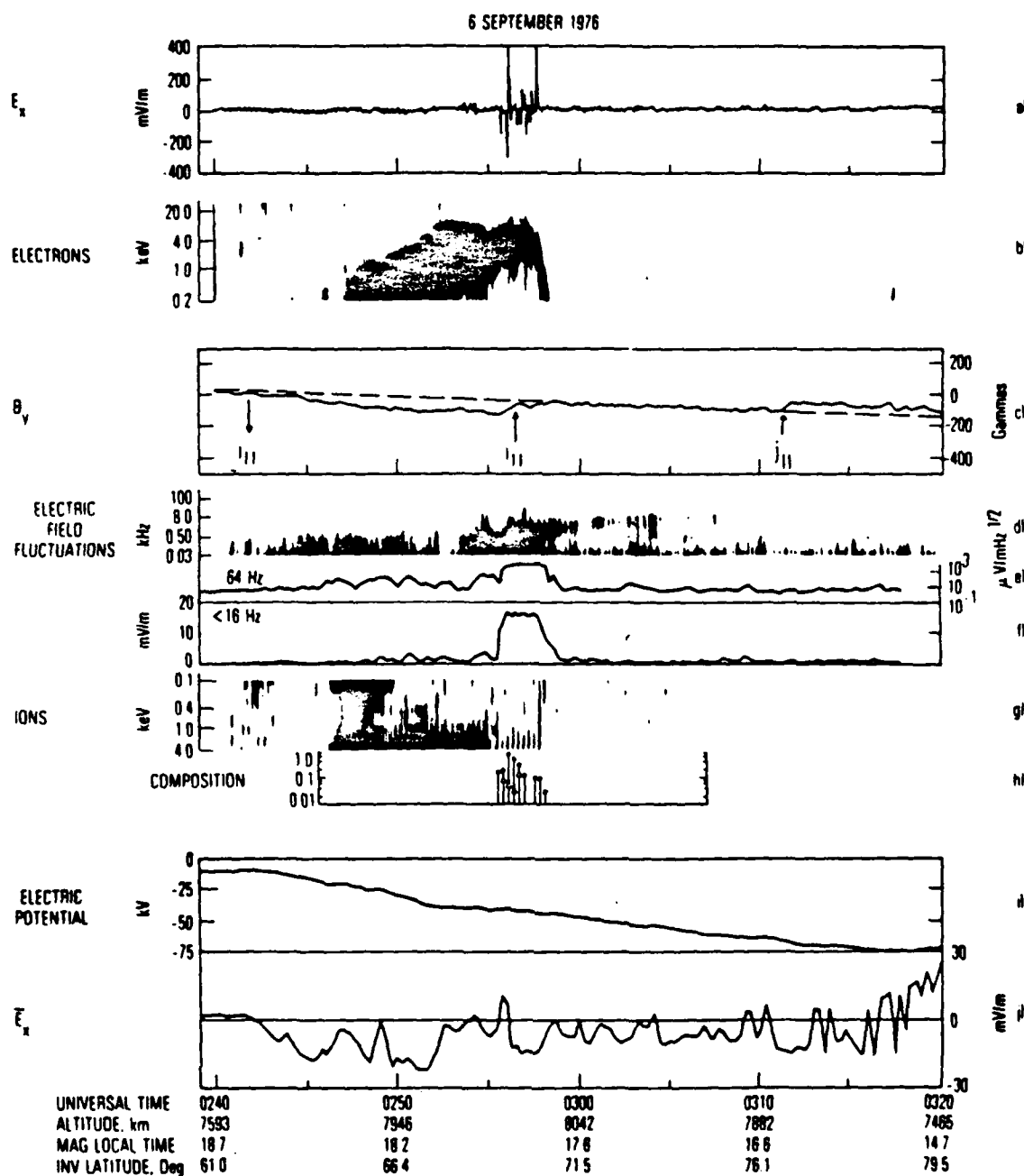


Figure 1. Auroral crossing of the S3-3 satellite on September 6, 1976 showing measurements from the UC Berkeley, Lockheed, and Aerospace instruments: (a) high resolution dc electric field in the north-south direction; (b) energy-time spectrogram of electrons with $0.17 < E < 33$ keV; (c) east-west currents inferred from averaged magnetic perturbations; (d) frequency-time spectrogram of ac electric fields with $0.032 < f < 100$ kHz; (e) frequency band near 64 Hz; (f) frequency band near 16 Hz; (g) energy-time spectrogram of ions with $0.09 < E < 3.9$ keV; (h) the fraction of helium oxygen and hydrogen in the upflowing ion beams; (i) integrated electric field potential; and (j) spin averaged north-south electric field (after Mizera et al., 1981).

ISEE1 and 2 provided detailed looks at the outer magnetosphere especially the magnetopause, nightside plasmasheet and tail lobes.

Figure 1 shows a summary of the kinds of data obtained from S3-3 (Ref. 110). Essentially, such data were used to ascertain that the field-aligned potential drops in inverted V structures extended a few thousand km above and below the observation altitude (Refs. 22, 43, 118, 140, 142). The physical mechanisms which formed the potential drop left the electron distribution functions with the appearance of a relatively scatter-free motion along the auroral field lines (Refs. 22, 32). This led to a series of models of the auroral potential structure which emphasized the kinetic theory approach based on the Maxwell-Vlasov equations (Refs. 22, 23, 26, 28, 30, 145). Figure 2 shows typical examples of such electron and ion distribution functions. Other authors have presented significantly different points of view concerning the generation of the potential drop, which were also mentioned in Section II (Refs. 41, 68, 69, 97, 118, 144 and references therein).

The electric field data from both S3-2 and S3-3 show the signature of electrostatic shocks (Refs. 15, 16, 116, 118, 155). These were first observed during the IMS. The small scale ones have been interpreted as double layers (Ref. 156). At ionospheric altitudes shocks were rare whereas at $\sim 1 R_e$ altitude they were fairly common. The higher altitude shocks were seen with E field magnitudes as large as a few tenths of a volt per meter. Using ISEE-1 data, Mozer (Ref. 115) has shown that the auroral electrostatic shocks are most likely confined to altitudes less than a few R_e . Some times (< 50% of the time) these structures consist of paired oppositely-directed electric fields; at other times (> 50% of the time) these structures consist of electric fields of one sign and are usually called S-shaped shocks (Refs. 112, 115, 116, 155). Schematic electric equipotentials for each kind of shock are shown in Figure 3 along with the types of particle distributions observed. Normally these shocks are imbedded in a region of low frequency turbulence and are often associated with VLF saucer emissions (Refs. 116, 118). They are generally found within the inverted V structures and are associated with upstreaming beams of ions (Ref. 111) that have an energy comparable but somewhat

III. IMS CONTRIBUTIONS

During the period from the beginning of the IMS in 1976, through the observation phase in 1979, and to the present, an enormous amount of effort was put forth to understand the auroral system. As far as particle observations are concerned, not all the studies during 1976 to the present were strictly IMS-related. Many had begun prior to the IMS or utilized data sets generated prior to 1976. Nevertheless, they are included here because many pre-IMS data sets have been more thoroughly analyzed under the auspices of the IMS and they are important to our present understanding. The results from the AE (see Refs. 57-61, 92, 93, 130, 131), the ISIS (Refs. 63, 84-86, 164), and the DMSP (Refs. 2, 103-108, 113, 119, 120 and references therein) satellites have been invaluable in bringing us to our present understanding of the physical processes which occur on auroral and polar cap field lines. These pre-IMS data were combined with IMS data sets (Ref. 137) to yield a much more detailed understanding of the sources, transport, and precipitation of particles on auroral field lines. The sections that follow treat the auroral regions in the same manner as in Section II above, by separating different local time and latitude regions.

A. NIGHTSIDE AURORAL REGION

As was described above, the mechanisms for generating the nightside diffuse aurora were fairly well understood but several different theoretical descriptions of the discrete aurora and inverted V structures existed prior to the IMS. Significant new data sets were added very early in the IMS period with the orbiting of the AE-D, S3-2, S3-3, and GEOS satellites. These were joined by the many ground-based networks, new DMSP satellites, and the ISEE, Prognost, SCATHA and MAGSAT satellites. In particular, the GEOS, ISEE and SCATHA satellites (Ref. 137) gave us a more detailed picture of the outer plasmasheet structure and S3-3 provided, for the first time, a direct look at the nightside auroral acceleration region. S3-2 and AE-D and AE-C provided a detailed look at the processes which occurred at ionospheric altitudes.

IV. FUTURE EFFORTS

The gaps in our understanding of the sources, transport and precipitation of particles on auroral field lines are many. Some we have started to look at. For example, we are already looking into the sources of the polar cap plasmas and arcs with the Dynamics Explorer satellite (Refs. 21, 48). More detailed studies of these regions are planned for in the ISTP program which we hope will see observation platforms being launched late this decade. More detailed studies of the auroral acceleration, convection, and precipitation processes in the auroral oval are needed. Again we have started some of this work with Dynamics Explorer (Refs. 147, 165, 167) which emphasizes the auroral regions. AMPTE was recently launched and will be joined in 1985 by the VIKING satellite. AMPTE will try to solve the global plasma source and transport problem in the equatorial magnetosphere while VIKING will emphasize the auroral regions in the 1 to 2 R_e altitude polar regions. These programs will help fill observational gaps which presently exist, especially when it comes to plasma sources and in analyzing plasma transport and wave-particle interactions. These satellites will have comprehensive plasma composition and AC-DC field measurements necessary to provide the details now missing.

The ground-based observatories are continuing to be upgraded. The observational coverage is nearly worldwide now and ranges from simple magnetometer stations to sophisticated radar systems for tracking conductivities and plasma motions in the ionosphere. Shortly we will have continuous maps of the auroral and polar cap ionospheric conditions to use in the sophisticated models which are being built. The rest of this decade should indeed continue the rapid advancement of understanding of the auroral processes which has occurred during the IMS period.

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LABORATORY OPERATIONS

The Laboratory Operations of The Aerospace Corporation is conducting experimental and theoretical investigations necessary for the evaluation and application of scientific advances to new military space systems. Versatility and flexibility have been developed to a high degree by the laboratory personnel in dealing with the many problems encountered in the nation's rapidly developing space systems. Expertise in the latest scientific developments is vital to the accomplishment of tasks related to these problems. The laboratories that contribute to this research are:

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Chemistry and Physics Laboratory: Atmospheric chemical reactions, atmospheric optics, light scattering, state-specific chemical reactions and radiation transport in rocket plumes, applied laser spectroscopy, laser chemistry, laser optoelectronics, solar cell physics, battery electrochemistry, space vacuum and radiation effects on materials, lubrication and surface phenomena, thermionic emission, photosensitive materials and detectors, atomic frequency standards, and environmental chemistry.

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Space Sciences Laboratory: Magnetospheric, auroral and cosmic ray physics, wave-particle interactions, magnetospheric plasma waves; atmospheric and ionospheric physics, density and composition of the upper atmosphere, remote sensing using atmospheric radiation; solar physics, infrared astronomy, infrared signature analysis; effects of solar activity, magnetic storms and nuclear explosions on the earth's atmosphere, ionosphere and magnetosphere; effects of electromagnetic and particulate radiations on space systems; space instrumentation.

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