NIEDERSÄCHSISCHE STAATS- UND
UNIVERSITÄTSBIBLIOTHEK GÖTTINGEN

Werk

Jahr: 1981
Kollektion: fid.geo
Signatur: 8 Z NAT 2148:49
Digitalisiert: Niedersächsische Staats- und Universitätsbibliothek Göttingen
Werk Id: PPN1015067948_0049
PURL: http://resolver.sub.uni-goettingen.de/purl?PPN1015067948_0049

LOG Id: LOG_0023
LOG Titel: On the relation between magnetic field-aligned electrostatic electron acceleration and the resulting auroral energy flux
LOG Typ: article

Übergeordnetes Werk

Werk Id: PPN1015067948
PURL: http://resolver.sub.uni-goettingen.de/purl?PPN1015067948
OPAC: http://opac.sub.uni-goettingen.de/DB=1/PPN?PPN=1015067948

Terms and Conditions

The Goettingen State and University Library provides access to digitized documents strictly for noncommercial educational, research and private purposes and makes no warranty with regard to their use for other purposes. Some of our collections are protected by copyright. Publication and/or broadcast in any form (including electronic) requires prior written permission from the Goettingen State- and University Library.
Each copy of any part of this document must contain there Terms and Conditions. With the usage of the library's online system to access or download a digitized document you accept the Terms and Conditions.
Reproductions of material on the web site may not be made for or donated to other repositories, nor may be further reproduced without written permission from the Goettingen State- and University Library.

For reproduction requests and permissions, please contact us. If citing materials, please give proper attribution of the source.

Contact

Niedersächsische Staats- und Universitätsbibliothek Göttingen
Georg-August-Universität Göttingen
Platz der Göttinger Sieben 1
37073 Göttingen
Germany
Email: gdz@sub.uni-goettingen.de

J. Geophys. 49, 69–73 (1981)

Journal of Geophysics

On the Relation Between Magnetic Field-Aligned Electrostatic Electron Acceleration and the Resulting Auroral Energy Flux

K. Wilhelm
Max-Planck-Institut für Aeronomie, D-3411 Katlenburg-Lindau 3, Federal Republic of Germany

Abstract. Supra-thermal electron fluxes measured above auroral arcs aboard two Porcupine sounding rocket payloads in 1977 and 1979 were used to study the relation between the acceleration potential difference as deduced from the position of the peak in the energy spectrum and the resulting electron energy flux. It was found, contrary to the findings of other authors, that the dependence of the energy flux on the acceleration voltage could be described by a linear relationship to a good approximation, above discrete auroral arcs. A stronger dependence of the energy flux on the acceleration voltage was however observed near the edges of auroral forms. Supported by model calculations, the suggestion is put forward that different distribution functions of the source electron populations might be responsible for the change of the relationship.

Key words: Auroral electron flux – Field-aligned electrostatic acceleration.

Introduction

The acceleration or post-acceleration of electrons by electrostatic fields along magnetic lines of force above discrete auroral forms appears to be the only physical concept available for explaining a variety of distinct features of auroral electron distribution functions, such as spectral peaks and field-aligned pitch angle distributions (Whalen and McDiarmid 1972; Evans 1974; Arnoldy et al. 1974; Kaufmann et al. 1976; Mizera and Fennell 1977; Croley at al. 1978; Sharp et al. 1979; Wilhelm 1979). On the other hand, our present knowledge is not sufficient to allow us to understand the acceleration process and the subsequent interactions of the electron beam with the magnetospheric plasma in any detail, as was recently pointed out by Whalen and Daly (1979). Further clarification can be expected to result mainly from observational programmes. Lyons et al. (1979) studied auroral electron fluxes on board several sounding rocket payloads and found a relationship between the net electron energy flux ε into the ionosphere and the acceleration potential difference V_0 of the form $\varepsilon = K V_0^2$ with values of the constant K between 0.1 and 0.96 erg cm^{-2} s^{-1} kV^{-2}, for various auroral conditions. The authors interpret their findings to mean that a direct physical connection exists between the acceleration voltage and the field-aligned current carried by energetic electrons, as derived from the electron energy flux.

In an attempt to verify these observations, the electron flux observations made during the Porcupine sounding rocket flights F-2 and F-4 were studied whenever a well developed peak in the electron energy spectrum could be detected. The results obtained seem to be consistent with the observations by Lyons and co-workers near the edges of auroral forms, but show characteristic differences above discrete auroral arcs.

Observations

Electron spectrometers (denoted KL 7) operating in the suprathermal energy range, from 0.1–25 keV, were flown aboard the Porcupine payloads F-2 and F-4 launched from ESRANGE, Kiruna, on 20 March 1977 at 19:22 UT and on 31 March 1979 at 22:29 UT, respectively. Both flights encountered auroral electron precipitation over discrete auroral forms with maximum energy fluxes in the range 0.1–25 keV of 12 erg cm^{-2} s^{-1} on F-2 and 28 erg cm^{-2} s^{-1} on F-4. No electron fluxes with strongly field-aligned pitch angle distributions could be found during the time intervals showing peaked electron spectra. It was thus possible to simplify the data analysis by selecting an instrument channel (A2) essentially sensitive to downgoing electrons. The measurements of upgoing electrons were limited to a pitch angle range just above 90° thus precluding a determination of the net electron fluxes. However, it has been established in other investigations (Evans et al. 1977; Wilhelm 1979) that a reduction of 15% – 25% of the downcoming energy flux leads to a good estimate of the net flux.

The spectral information obtained during flight F-4 has been compiled in a three-dimensional co-ordinate system in Fig. 1. The payload flew into and over a bright auroral form on its upward flight path and left the intense aurora shortly after 300 s from launch. Within the region of auroral activity, a distinct electron energy peak was developed at an energy of 9 keV at the beginning of the flight, decreasing to less than 1 keV near the nothern edge of the arc. North of this region irregular spectral features prevailed until a knee distribution with low-intensity and a change in slope at 2 keV energy formed for the remaining portion of the flight. In addition to the peak at high energies, a secondary maximum at approximately 2 keV can be noticed before 200 s elapsed time. Details of the spectral features during the time period with peaked energy spectra can be seen in Fig. 2, as well as the continuation to higher energies (Stüdemann, personal communication).

Using the data displayed in Fig. 1, the electron number and energy fluxes were computed and are presented in Fig. 3 together with the values of the peak energies when such a determination was possible. In a similar fashion, the data of flight

0340-062X/81/0049/0069/$01.00

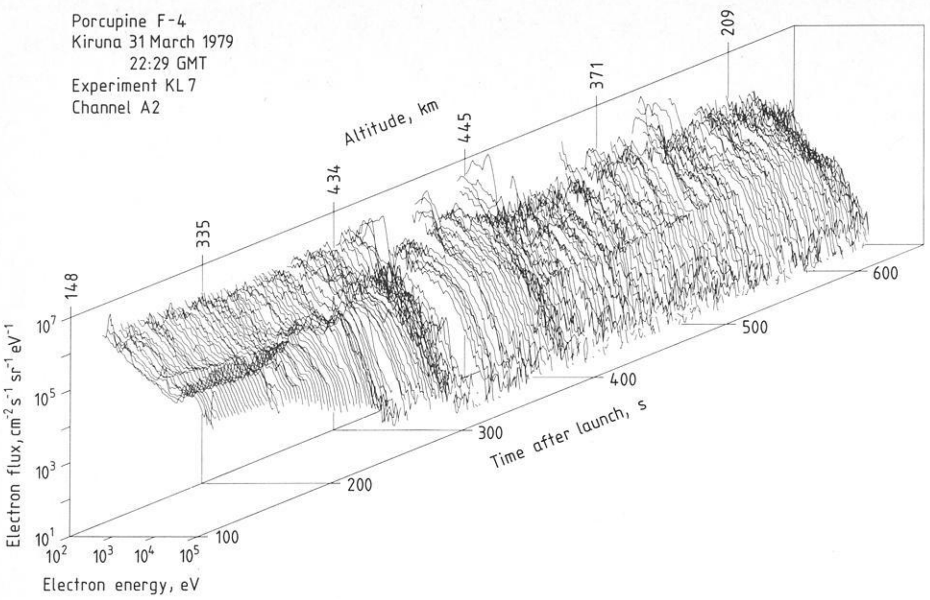

Fig. 1. Electron energy spectra observed during Porcupine flight F-4. The lower energy limits of all spectra were at 0.1 keV and the upper cutoffs at 25 keV. A well developed peak was present during the first part of the flight. Several high-intensity low-energy bursts superimposed on a knee distribution were observed after about 400 s elapsed time

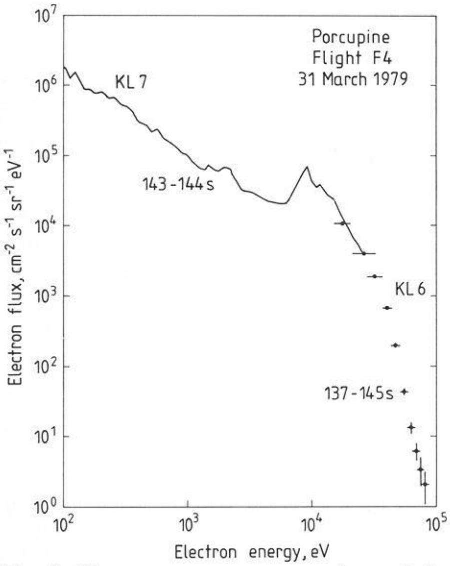

Fig. 2. Electron energy spectrum observed during an interval with a pronounced peak near 9 keV. The measurements have been obtained by two different instruments KL 7 in the energy range 0.1–25 keV and KL 6, 15–100 keV

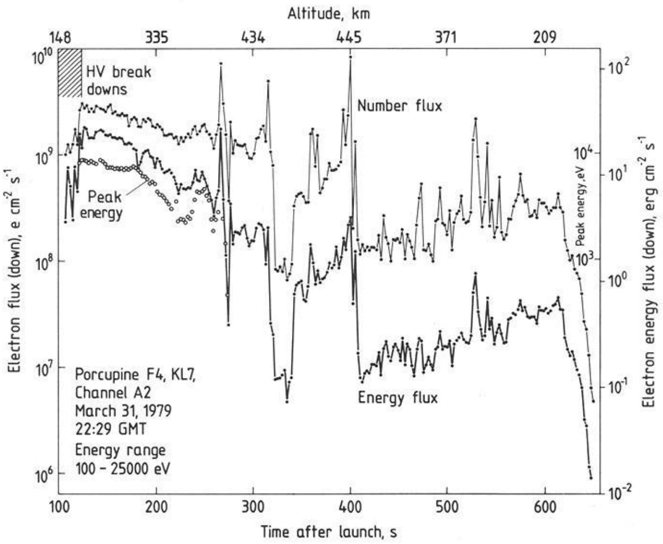

Fig. 3. Electron number and energy fluxes for flight F-4 calculated by using the data of Fig. 1 have been plotted together with the peak energy at the beginning of the observations. The first 20 s of the measurements were influenced by high voltage breakdown within the instrument caused by artificial plasma releases

F-2 have been summarized in Fig. 4. The geophysical conditions during this flight were characterized by several homogeneous auroral arcs. The spectral features allowed a determination of the peak energy for most of the flight time.

Discussion

The measurements made during both flights suggest that a linear relationship exists between the value of the peak energy and the electron energy flux at times of intense electron precipitation. A stronger dependence of the energy flux on the peak energy could be detected near the edges of the auroral forms, in particular near 200 and 330 s elapsed time of flight F-2 and 270 s of F-4. The energy flux was, however, nearly independent of the peak energy during the time interval 470 to 530 s of flight F-2 in Fig. 3. These observations imply that the functional form $\varepsilon = KV_0^2$ derived by Lyons et al. (1979) may not be representative for all auroral conditions. For periods when a linear approximation of the form $\varepsilon = K^* V_0$ was appropriate, the factor K^* was calculated to be equal to 3.2 and 3.0 erg $\mathrm{cm^{-2}\,s^{-1}\,kV^{-1}}$ for F-2 and F-4, respectively. The degree of linearity can be seen in Fig. 5 where the electron energy fluxes observed during the first portion of flight F-4 have been plotted as a function of the peak energy, together with the corresponding linear regression. A reduction of the K^* value by 20%, thereby accounting for reflected electrons, gives about 2.5 erg $\mathrm{cm^{-2}\,s^{-1}\,kV^{-1}}$. Assuming $\varepsilon = KV_0^2$ to be valid between 200 and 250 s elapsed time of F-2, the value of K has to be chosen to be 0.8 erg $\mathrm{cm^{-2}\,s^{-1}\,kV^{-2}}$ in reasonable agreement with the figures obtained by Lyons

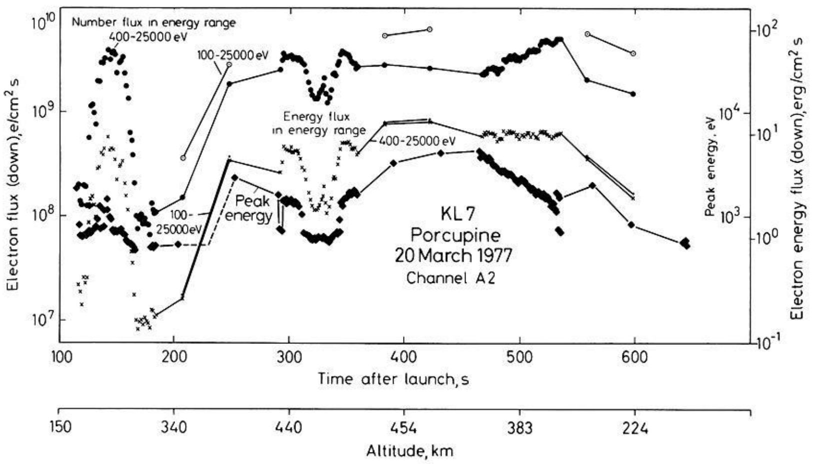

Fig. 4. Electron number and energy fluxes for flight F-2 are shown in the upper graphs. The instrument automatically switched between different modes during this flight leading to varying time resolutions and energy ranges. A peaked spectrum could be observed for most of the flight time with peak energies given in the lower graph

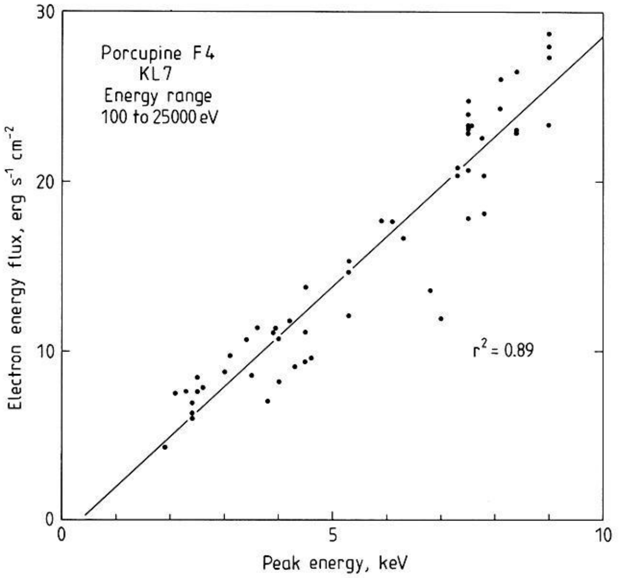

Fig. 5. Electron energy flux in the energy range 0.1–25 keV as a function of the peak energy observed during Porcupine flight F-4. The line of regression and the coefficient of determination are also given

et al. (1979). Both approximations give the same energy flux of 7.8 erg $\text{cm}^{-2}\,\text{s}^{-1}$ for a peak energy of 3.1 keV. Whether this crossing point has any physical significance could not be determined from the available data. However, the conclusion seems to be justified that changes of the functional form have occurred near the edges of auroral arcs.

Taking for granted the concept of electrostatic field acceleration as the cause of the peaked energy spectra, an interpretation of the observations might be obtained by the following consideration:

The velocity distribution function of the unaccelerated electron population

$$f_e(\mathbf{v}) = (m_e^2/2W)\, j_e(W, \alpha) \tag{1}$$

where $\mathbf{v}$ is the electron velocity, m_e the electron mass, W the electron energy, α the pitch angle and j_e the directional electron flux, should have a special form defined by

$$j_e(W) = A W^{-\gamma} \tag{2}$$

with $A = 8 \times 10^{11}\ \text{cm}^{-2}\,\text{s}^{-1}\,\text{sr}^{-1}\,\text{eV}^{-1}$, W measured in eV and $\gamma = 2.5$. No dependence of the downgoing flux on pitch angle was assumed as the observations did not show such a dependence even after the acceleration process. Justification for this rather arbitrary selection may be found in the fact that the high-energy portion of the spectra at 500 s elapsed time given in Fig. 1 could be approximated by such a function and that these spectra do not indicate any post-acceleration effects.

Applying Liouville's theorem to the distribution function above and below the accelerating potential difference, along the dynamical path of the particles, provides the electron flux of the accelerated electron population

$$j_e^*(W^*) = \begin{cases} A \dfrac{W^*}{W^* - \Delta W} (W^* - \Delta W)^{-\gamma} & \text{for } W^* > \Delta W \text{ and } \alpha^* \leqq \alpha_0 \\ 0 & \text{otherwise} \end{cases} \tag{3}$$

with

$$\alpha_0 = \sin^{-1} \left\{ \frac{B^*}{B_0} \frac{W^* - \Delta W}{W^*} \right\}^{1/2}.$$

ΔW is the electron energy gained in the acceleration process and B_0 and B^* are the magnetic field values at the positions considered. Provided the lowest initial energy before the acceleration was $W_0 > 0$, it follows that $W^* \geqq W_0 + \Delta W$. The pitch angle cone $\alpha^* \leqq \alpha_0$ opens up to $\alpha_0 = 90°$ when

$$\frac{B^*}{B_0} \frac{W^* - \Delta W}{W^*} \geqq 1. \tag{4}$$

The observational evidence that no significant dependence of the downgoing electron flux on pitch angle was present during the intervals under discussion suggests that condition (4) was fulfilled for all directly precipitated electrons. Assuming a vertical magnetic field direction and $B \propto R^{-3}$, an electron source distribution at $1\,R_E$ (Earth's radius) would thus lead to

$$8(W^* - \Delta W) \geqq W^* \tag{5}$$

showing that the energy W^* after the acceleration could not be greater than 8 times the initial energy of a particular electron.

Alternative explanations involving isotropization by pitch angle scattering that might be appropriate for interpreting the data will not be considered here mainly because of lack of quantitative information on such processes.

Without a dependence upon α^* the electron energy flux

$$\varepsilon = 2\pi \int_0^{\frac{\pi}{2}} \int_0^{\infty} W^* j_e^*(W^*) \sin\alpha^* \cos\alpha^* \, dW^* \, d\alpha^* \tag{6}$$

can, in a certain energy range, be determined analytically by solving

$$\varepsilon'(W_2, W_1) = \pi \int_{W_1}^{W_2} W^* j_e^*(W^*) \, dW^*. \tag{7}$$

As $j_e^*(W) = 0$ for $W^* < W_0 + \Delta W$, the integral reduces to

$$\varepsilon'(W_2, W_0, \Delta W) = \pi A \int_{W_0+\Delta W}^{W_2} \frac{W^*}{W^* - \Delta W} (W^* - \Delta W)^{-\gamma} \, dW^*. \tag{8}$$

The upper limit will, for all practical purposes, be determined by the restricted energy range of the instrument employed. Here a value of $W_2 = 25$ keV has been used throughout the calculations. However, electrons with higher energies were measured aboard the payload F-4 (Stüdemann, personal communication) and it was therefore possible to evaluate the contribution of electron fluxes with energies above W_2. At 143 s after launch, for instance, when the energy peak was located near 9 keV (Fig. 2), the contribution was 5 erg $\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$ as compared to 27 erg $\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$ carried by low-energy electrons. The bulk of the energy flux was, therefore, contained in the restricted energy range under the conditions prevailing during the flight.

Equation (8) can be integrated to give the energy flux up to 25 keV

$$\varepsilon'(W_0, \Delta W) = \pi A F(W^*) \Big|_{W_0+\Delta W}^{25\,\mathrm{keV}} \tag{9}$$

with

$$F(W^*) = \frac{(W^* - \Delta W)^{2-\gamma}}{\gamma} \left\{ \frac{2}{1-\gamma} \frac{W^*}{W^* - \Delta W} - \frac{W^{*2}}{(W^* - \Delta W)^2} - \frac{2}{(1-\gamma)(2-\gamma)} \right\}.$$

The energy flux ε' thus becomes a function of W_0 and ΔW. It can easily be shown that ε' can be approximated by a quadratic form of $W_0 + \Delta W$ for values W_0 much smaller than ΔW. This can also be seen from Fig. 6, where examples with $W_0 = 0.05$, 0.1 and 0.2 keV are given. Condition (5) would require that, in this case, field-aligned fluxes should be observable unless the acceleration occurred much higher than $1 R_E$. For higher initial energy cutoffs, e.g., 1, 2 and 4 keV, the dependence of ε' on $W_0 + \Delta W$ becomes weaker and can be described reasonably well by a linear function, at least for certain energy ranges, as demonstrated for the three examples. The sum $W_0 + \Delta W$ was chosen as the independent variable, because this value should be related to the peak energy and thus be conveniently observable.

By comparing the absolute energy flux values in Figs. 5 and 6, it can be concluded that a cutoff energy W_0 of approximately 1.2 keV was required to generate the observed energy flux. Considering again condition (5), this cutoff would be consistent with the observed lack of field-aligned precipitation up to energies of 9 keV.

Before any conclusions can be drawn from this model calculation, the physical significance and a method of observation of ε has to be considered. Lyons and his co-workers argued and demonstrated that, in contrast to the electron number flux, the energy flux was not significantly dependent upon the lower limit of the instrumental energy range. This fact is also borne out by the data presented in Fig. 4, where electron number and energy fluxes were evaluated for two different lower cutoff values during some portions of the flight time. Although the contribution of electrons in the energy range from 0.1 to 0.4 keV to the number flux was significant, the energy flux did not depend upon the low-energy limit used for the integration, even at times when the peak energy approached the 0.4 keV limit. It thus appears as if the energy flux ε' calculated above can be compared with the observed electron energy flux in the energy range from 0.1 to 25 keV. In this sense, the linear relationship between the peak energy value and the energy flux above bright auroral arcs might be indicative of an energetic electron population above the acceleration region, whereas electrons with less energy constitute the source population near the edges of the arc, resulting in a quadratic dependence.

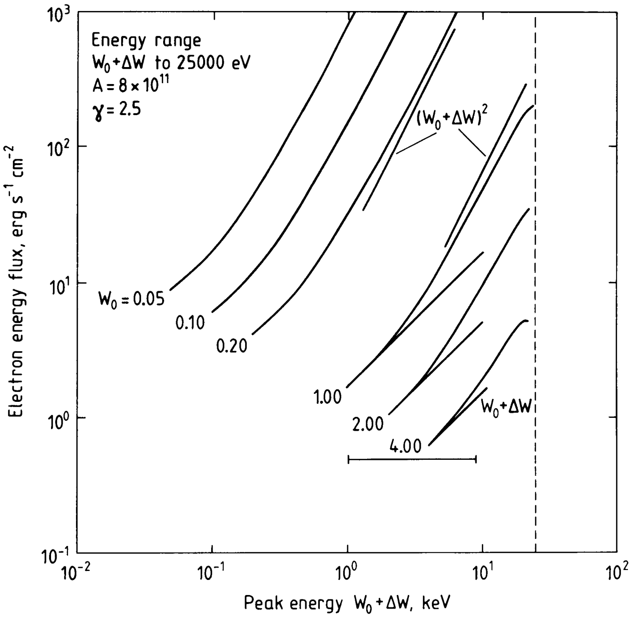

Fig. 6. Model calculations for the dependence of the energy flux upon the peak energy for some electron source distributions of the form $j_e(W) = AW^{-2.5}$ with $W > W_0$. Some segments of linear and quadratic functions of the peak energy $W_0 + \Delta W$ have been added for comparison. The bar in the lower portion of the diagram indicates the energy range in which peaked energy spectra and a linear relation have been observed during the flights F-2 and F-4

Acknowledgements. The contributions of C. Becker and R. Schmidt to the development and calibration of the electron spectrometer are greatly appreciated. The efforts of G. Haerendel and B. Häusler as project scientist and experiment co-ordinator were essential for the success of the Porcupine programme. This work was supported by the German Bundesministerium für Forschung und Technologie through the DFVLR grant No. 01 OM 015-B21 WRK 274:3 (KL 7). I should also like to thank D.S. Evans for his criticism and comments on the first version of this paper. W. Stüdemann kindly provided unpublished data covering the high-energy continuation of the observations considered here.

References

Arnoldy, R.L., Lewis, P.B., Isaacson, P.O.: Field-aligned auroral electron fluxes. J. Geophys. Res. 79, 4208-4221, 1974

Croley, D.R., Mizera, P.F., Fennell, J.F.: Signature of a parallel electric field in ion and electron distribution in velocity space. J. Geophys. Res. **83**, 2701–2705, 1978

Evans, D.S.: Precipitating electron fluxes formed by a magnetic field aligned potential difference. J. Geophys. Res. **79**, 2853–2858, 1974

Evans, D.S., Maynard, N.C., Tröim, J., Jacobsen, T., Egeland, A.. Auroral vector electric field and particle comparisons. 2. Electrodynamics of an arc. J. Geophys. Res. **82**, 2235–2249, 1977

Kaufmann, R.L., Walker, D.N., Arnoldy, R.L.: Acceleration of auroral electrons in parallel electric fields. J. Geophys. Res. **81**, 1673–1682, 1976, 1976

Lyons, L.R., Evans, D.S., Lundin, R.: An observed relation between magnetic field aligned electric fields and downward electron energy fluxes in the vicinity of auroral forms. J. Geophys. Res. **84**, 457–461, 1979

Mizera, P.F., Fennell, J.F.: Signatures of electric fields from high and low altitude particles distribution. Geophys. Res. Lett. **4**, 311–314, 1977

Sharp, R.D., Johnson, R.G., Shelley, E.G.: Energetic particle measurements from within ionospheric structures responsible for auroral acceleration processes. J. Geophys. Res. **84**, 480–488, 1979

Whalen, B.A., Daly, P.W.: Do field-aligned auroral particle distributions imply acceleration by quasi-static parallel electric fields? J. Geophys. Res. **84**, 4175–4182, 1979

Whalen, B.A., McDiarmid, I.B.: Observations of magnetic-field-aligned auroral electron precipitation. J. Geophys. Res. **77**, 191–202, 1972

Wilhelm, K.: Auroral particle fluxes in the ionosphere. J. Geophys. **46**, 151–169, 1979

Received May 5, 1980; Revised Version June 30, 1980
Accepted August 8, 1980