ROCKET MEASUREMENT OF AURORAL keV ELECTRON FLUXES IN ANTARCTICA

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Abstract: Electron fluxes in auroras were observed with an electron spectrometer (ESM) onboard Japanese Antarctic sounding rockets S-310JA-5 and -6 at Syowa Station. Both rockets successfully penetrated into auroras, each different kind, respectively. The ESM worked successfully and measured the energy spectra and pitch angle distributions of precipitating and upgoing electrons. Electron fluxes of $10^7 \sim 10^9$ (/cm^2·sr·s·keV) were observed in the energy range from 1 to 10 keV. In the S-310JA-5 rocket experiment, there were peaks at 2 keV in the energy spectra of the downward electron flux on the both edges of the auroral arcs and those of 4.5 keV inside of the auroral arcs. The result showed energy spectra of the inverted V shape. The electron fluxes with small pitch angles were higher than those with large pitch angles. The upgoing fluxes are generally lower than the precipitating fluxes. The flux difference strongly depends on the energy and rocket altitudes.

In the S-310JA-6 rocket experiment, the spectral peaks were not observed, and intensities of electron fluxes of several keV showed a good correlation with an appearance of bright auroral arcs in the all-sky camera photographs. The downgoing fluxes are almost isotropic in pitch angles for all energy ranges and all altitudes.

1. Introduction

It has long been known that aurora arcs are caused by charged particles precipitating into the atmosphere. The occurrence of monoenergetic peaks in the auroral electron spectrum was observed by the direct measurements of particles (EVANS, 1968; CHOY and ARNOLDY, 1971; PAZICH and ANDERSON, 1975; BOYD and DAVIS, 1977). CHOY and ARNOLDY (1971) reported the measurements of electric field, magnetic field and charged particles in the auroral arcs. PAZICH and ANDERSON (1975) observed both electron and proton fluxes in the pitch angle range from 0° to 180°. The pitch angle distributions showed that the distribution involves a narrow field-aligned component. Most characteristics of particle precipitation have shown the existence of a parallel electric field with a potential drop of several keV.

We conducted rocket experiments to observe characteristics of several keV electrons which are believed to be responsible for the auroral luminosity. Their energy spectra and pitch angle distributions, and their flux fluctuations were measured with a new type of electron spectrometer called ESM (Electron Spectrometer for Medium energy) which used an electromagnetic analyzer in the S-310JA-5 and -6 Antarctic sounding rocket experiments. The S-310JA-5 rocket was launched at 2256:50 UT on June 10, 1978 from Syowa Station, Antarctica. It reached an altitude of 226 km, and successfully penetrated into a Corona-type aurora. The S-310JA-6 rocket was launched at 2156 UT on August 27, 1978, reaching an altitude of 238 km, and magnificently penetrated into an intense aurora arc.

This paper describes the instrumentation of the ESM and the results of the observations focussed on the energy spectra and pitch angle distributions of electron fluxes with auroral luminosities. Section 2 gives a description of the ESM instrumentation, Section 3 is devoted to presentation of obtained data and Section 4 is for discussion and conclusion.

2. Instrumentation

We have developed a new electron spectrometer for measurements of auroral electron fluxes in the polar ionosphere. It was constructed to satisfy several conditions required for rocket experiment in Antarctica. The first electron spectrometer with a conventional permanent magnet was tested in the S-310JA-1 rocket experiment on February 13, 1976, and observed electron fluxes during the very quiet geomagnetic activity (MATSUMOTO and KAYA, 1978).

The ESM onboard the S-310JA-5 and -6 rockets were improved to achieve a higher energy resolution and to increase the number of measurable electron energy bands, and to widen measurable pitch angles (KAYA and MATSUMOTO, 1978). The ESM consists of two identical 180° electro-magnet analyzers having a secondary electron multiplier (CEM) and electronics. Hereafter, two analyzers are called ESM-Z and ESM-H, respectively. The ESM-Z detector was mounted with its view direction in parallel with the spin axis of the rocket, while the ESM-H is installed in the perpendicular direction. The ESM-Z detector mainly observed downward electron fluxes and the ESM-H observed electron fluxes around the pitch angle of 90°, because the spin axes of the S-310JA-5 and -6 were lined along the geomagnetic field line.

A photograph view of the ESM is shown in Fig. 1. The dimension of the ESM is $150\phi \times 120$ mm, which is more compact than other kinds of spectrometers. The black circular window on the upper surface of the mesh is a collimator of the ESM-Z detector and that on the side mesh is of the ESM-H. A particular feature of the ESM is in its open structure. The whole unit is covered with double meshes which assure a quick evacuation of the CEM to prevent high voltage discharges. The inner mesh is kept at a potential of -20 V relative to the outer mesh which is grounded to

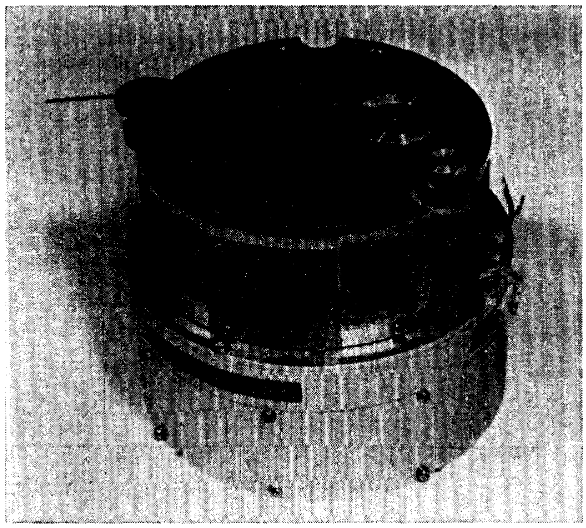

Fig. 1. A photograph view of the ESM. The ESM onboard the S-310JA-5 and -6 rockets are identical.

the rocket body. This prevents the plasma electrons from penetrating into the detector. Leakages of the electric field from the high voltage (3 kV) applied to the CEM and of the magnetic field from the electro-magnet used for energy analysis were examined with a Langmuir probe in a laboratory plasma and a Gauss meter, respectively. No change of the space potential of the plasma nor the change of Langmuir curve was observed when the high voltage was switched on and off, showing a sufficient shielding effect of the double meshes adopted in the ESM. A magnetic field comparable to the Earth's field was measured at a point 1 cm apart from the electro-magnet with 300 gauss gap field.

The magnetic analyzer samples electrons having energy determined by a given strength of the magnetic field. The strength of the magnetic field was swept stepwise in 6 steps (1 step/s) by controlling the current of the electro-magnet. The six steps are for five electron energies (1, 2, 3, 5 and 10 keV) plus dark counts which are caused by non-electron sources such as ultra-violet, high energy particles and X-rays. The dark counts were measured by making the electro-magnet current zero. The selected five energies are in the range of energies of electrons causing auroras. The reason of the slow sweep is to make it possible to observe fast fluctuations in the order of several Hz of electron fluxes with fixed energy.

The analyzers have a high energy resolution; the full width half maximum ($\Delta E/E$) was 1/10.2. Figure 2 displays calculated and calibrated responses of the detector as a function of electron energy. The solid line shows the calculated value and the dashed line the calibrated one. The analyzers actually have wider differential energy window than the result shown in Fig. 2, because the laboratory calibration electron beam was omnidirectional.

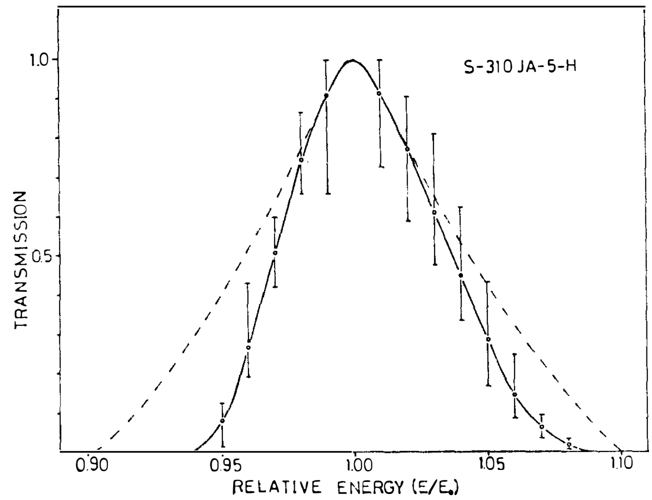

Fig. 2. Energy resolution of the ESM. Dashed and solid lines represent the calculated and calibrated energy resolution, respectively.

The angular resolution was measured by the same electron beam for the laboratory calibration. The solid angle of observation was $20° \times 8°$. The angle of 20° was limited by the open angle of a collimator and 8° by the apertures of the entrance and exit of the analyzer.

3. Presentation of Data

3.1. S-310JA-5 rocket experiment

A sequence of the selected all-sky camera photographs for the flight period is given in Fig. 3. The positions of the rocket projected down along the magnetic field line to an altitude of 110 km are indicated by a dark dot on these photographs. It is seen that the rocket penetrated into a Corona-type aurora around 120 s and passed through the aurora at 370 s. The raw telemetry record of the ESM is reproduced in Fig. 4. The observation was started on 119 s after launch, because the application of the high voltage to the CEM was delayed for safety. No dark counts were detected during the flight. Electron fluxes stopped at an altitude of 140 km on the down leg, which shows there were no precipitating electron fluxes on the north edge of the visual aurora below this altitude. On the contrary, electron fluxes were high on the south edge of the visual aurora. The counts of the ESM-H was spin-modulated, because the detector observed different pitch angle electrons at different phase of the rocket spin. Since the angle of the spin axis with the local magnetic field varied from 3° to 34°, the range of measured pitch angles was from 56° to 124°.

Clear flux fluctuations with a frequency of about 10 Hz were observed in the energy range from 1 keV to 5 keV only in the downward fluxes. These are similar to the microbursts in the several tens keV range (ANDERSON and MILTON, 1964).

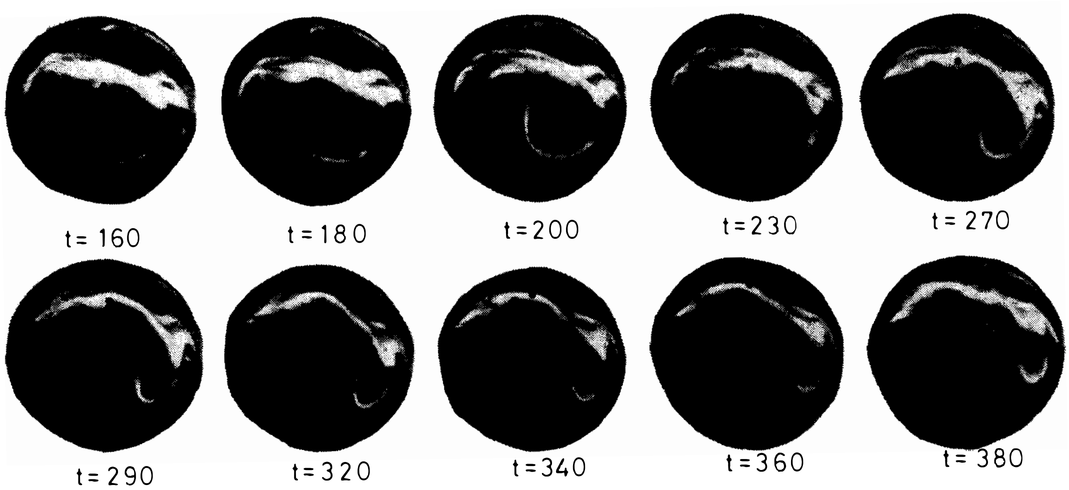

Fig. 3. *Selected all-sky camera photographs to show the general features of the auroral luminosity in the S-310JA-5 rocket experiment. The position of the sounding rocket projected down along the magnetic field lines to the 110 km level is shown by a dark dot.*

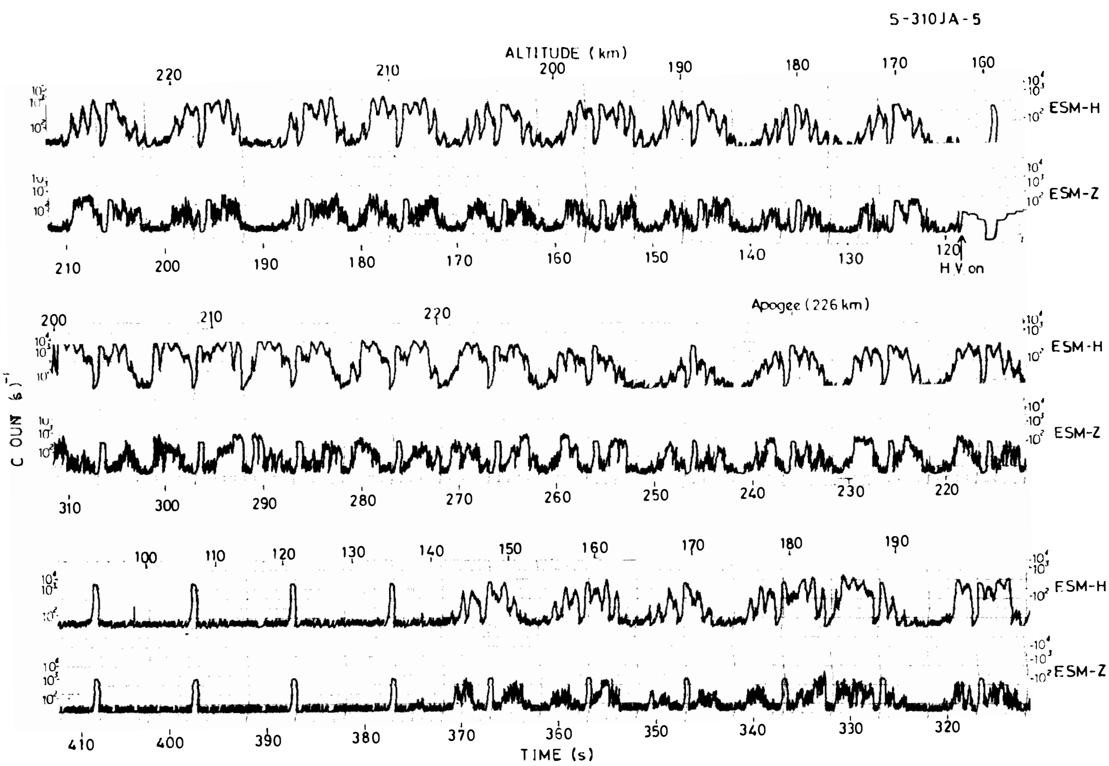

Fig. 4. *The raw telemetry record of the ESM counting rate onboard the S-310JA-5 rocket.*

Such microbursts in the low energy range below 5 keV have never been reported. The details of the fluctuations are discussed in a companion paper (MATSUMOTO *et al.*, 1981).

Figures 5 and 6 display the electron fluxes in the pitch angle range from 3° to 34° (downward flux) and that at fixed 90° pitch angle as a function of flight time. The energies shown in the figure are the calibrated mean energies in each band. Figure 5 shows that the downward electron fluxes in 1.1 keV were enhanced from 180 s to 230 s and from 320 s to 360 s (the period shown by "a" in Fig. 5), those in 2.1 keV from 190 s to 260 s ("b"), and those in 4.5 keV from 270 s to 330 s ("c"). Figure 6 shows that the electron fluxes at 90° pitch angle increased from 260 s to 340 s in 3.8 keV ("e") and from 260 s to 330 s in 5.6 keV ("d"). The electron fluxes in the other energy bands showed no clear time variations except a sharp drop near the apogee. Energy spectra observed at times corresponding to the all-sky camera photographs in Fig. 4 are shown in Fig. 7. The downward electron fluxes have a beam component around 3 keV from 120 s to 230 s which is consistent with observations by EVANS (1968). This monoenergetic beam is split into double peaks at 2 keV and 4.5 keV at 270 s and 290 s. The electron fluxes at 90° pitch angle show small similar

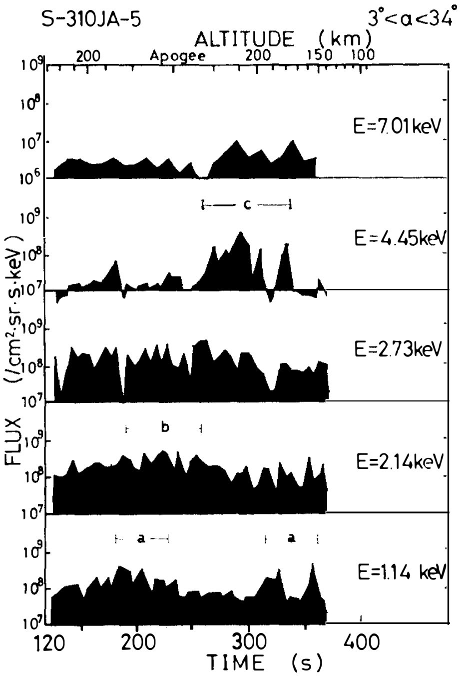

Fig. 5. Time profiles of 1-s counts of electrons measured by the ESM-Z detector onboard the S-310JA-5 rocket. Electron fluxes increased in the periods shown by "a", "b" and "c".

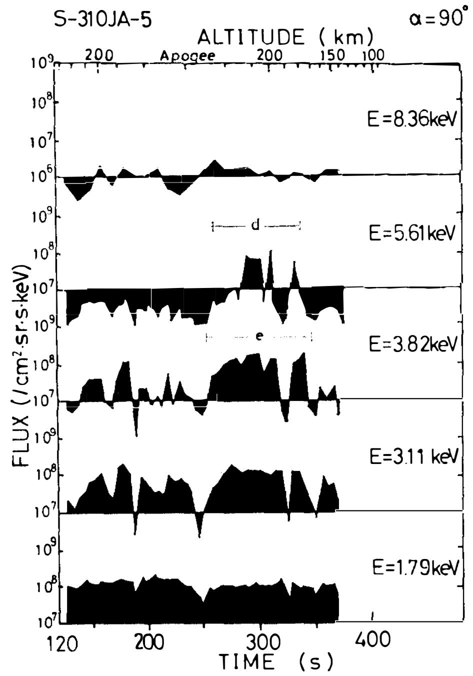

Fig. 6. Time profiles of electron fluxes at 90° pitch angle measured by the ESM-H detector onboard the S-310JA-5 rocket. Electron fluxes increased in the periods shown by "d" and "e".

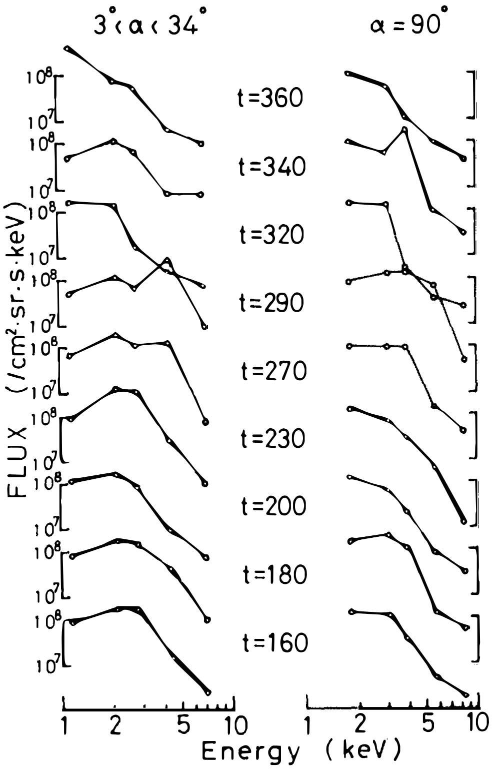

Fig. 7. Energy spectra observed at the same times as the all-sky camera photographs were taken.

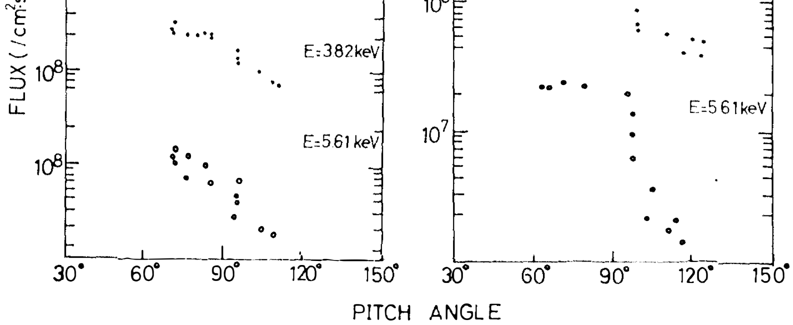

Fig. 8. The pitch angle distributions in the different energy bands at two altitudes.

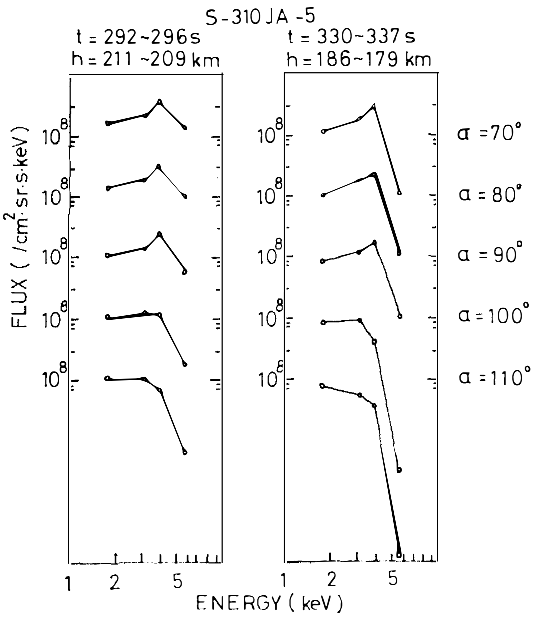

Fig. 9. Energy spectra at the same pitch angles. The downward fluxes have a beam of 4 keV.

peaks. The drops in electron fluxes with 90° pitch angle near apogee are clearly seen but the reason is not well understood.

Figure 8 displays typical pitch angle distributions in each energy band. They exhibited a strong asymmetry between upward and downward fluxes, but the difference depends on the energy band. The asymmetry was observed more clearly in the higher energy and at the lower altitudes. This may well be interpreted by that the energy of upgoing electrons have already lost their energy by collisions. The energy spectra with fixed pitch angles are shown in Fig. 9. It is interesting to note that the monoenergetic spectral peaks around 4 keV were observed in the downward fluxes and not in the upward fluxes.

3.2. S-310JA-6 rocket experiment

In the same way as that for the S-310JA-5 rocket experiment, the sequence of all-sky camera photographs and the raw telemetry record of the ESM are shown in Figs. 10 and 11, respectively. As seen in Fig. 10, the S-310JA-6 rocket penetrated into an intense aurora. No dark counts were detected either in this flight. Electron counts in all energy bands stopped at an altitude of 110 km even in the visual aurora. It shows that electrons with energies higher than 1 keV, which is minimum measured energy, lost their energy at locations higher than an altitude of 110 km.

The counts of the ESM-H were almost free from spin-modulation because the rocket flew almost along the magnetic field line with a very small coning precession angle of 10.5°. Therefore, the ESM-H detector observed only the electron fluxes in the vicinity of 90° pitch angle.

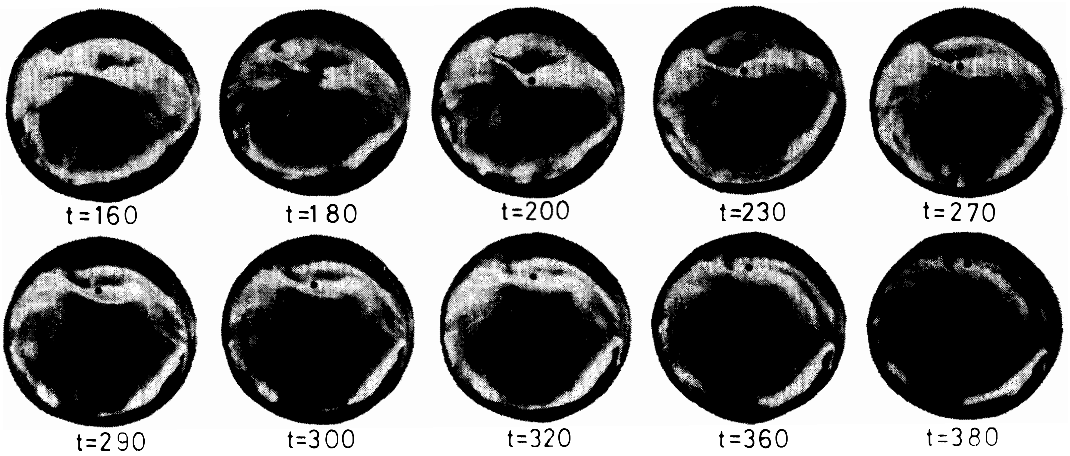

Fig. 10. Selected all-sky camera photographs to show the general features of the auroral luminosity in the S-310JA-6 rocket experiment.

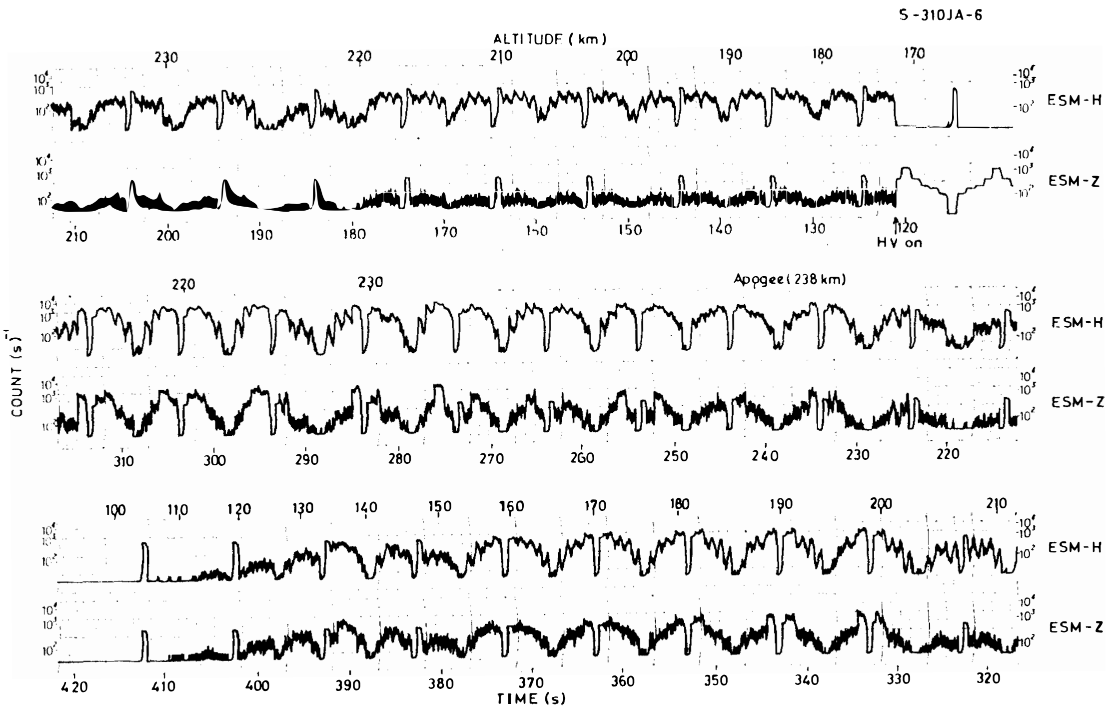

Fig. 11. The raw telemetry record of the ESM counting rate onboard the S-310JA-6.

Fluctuations of electron fluxes were not observed as clear as those observed in the S-310JA-5 rocket experiment. Figures 12 and 13 display the electron fluxes at 3.5°~17.5° pitch angles and at a fixed 90° pitch angle as a function of flight time. The electron fluxes observed in the S-310JA-6 rocket experiment were higher than those in

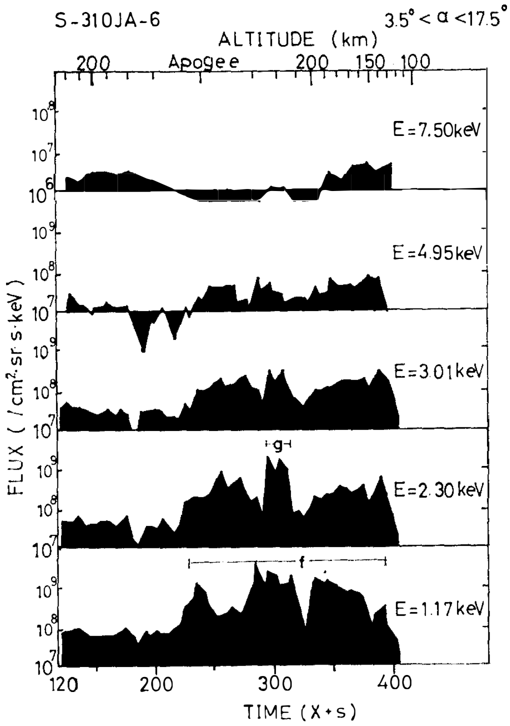

Fig. 12. Time profiles of 1-s counts of electrons measured by the ESM-Z detector onboard the S-310JA-6 rocket. Electron fluxes increased in the periods shown by "f" and "g".

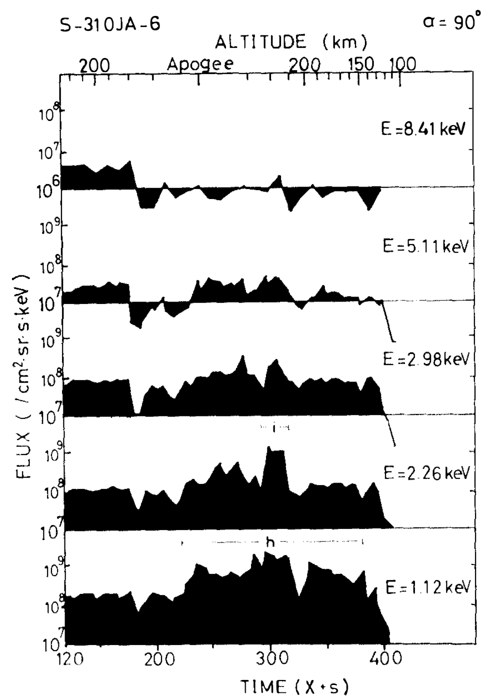

Fig. 13. Time profiles of electron fluxes at 90° pitch angle measured by the ESM-H detector onboard the S-310JA-6 rocket. The time variation is similar to that in Fig. 12.

the S-310JA-5. The time variation of the downward fluxes and that of the electron fluxes at 90° pitch angle are quite similar to eath other. The downward fluxes were characterized by features of the enhancements from 220 s to 390 s (the period shown by "f" in Fig. 12) and from 290 s to 320 s ("g") and the decreases at 290 s and 320 s. Energy spectra observed at times corresponding to the all-sky camera photographs in Fig. 10 are shown in Fig. 14. No prominent monoenergetic spectral peaks are seen in the spectrum except at 270 s. These spectra are different from the case of the S-310JA-5 rocket experiment.

4. Discussion and Summary

We first examine a correlation between the electron fluxes and the intensity of the auroral luminosity observed in the S-310JA-5 rocket experiment. Though the determination of the position of the rocket in the all-sky camera photographs is not very accurate, it may well be stated that the rocket had already been in the feeble auroral arc when the observation was started, stayed at the southernmost boundary

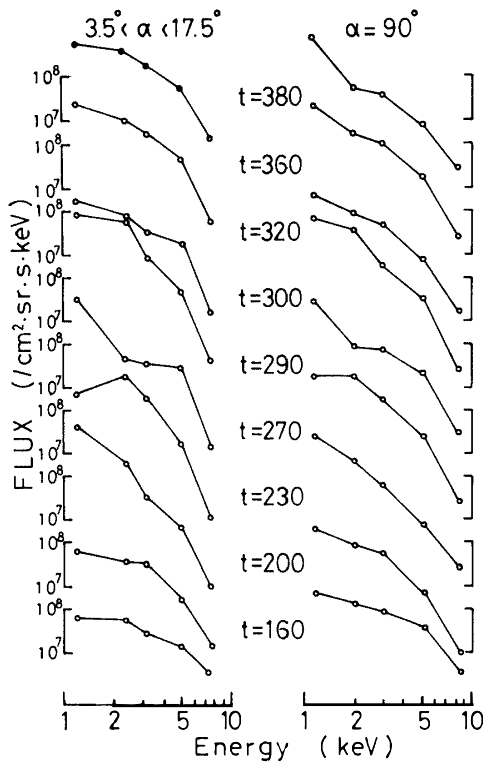

Fig. 14. Energy spectra observed at the same times as the all-sky camera photographs were taken. These show the energy spectrum of electron fluxes precipitating into an intense aurora.

of the bright auroral arc during the period from 190 s to 230 s, and penetrated into the bright arc from 230 s to 320 s. The aurora arc passed over the position of the rocket and the rocket was again located in the southernmost boundary of the damping aurora at 320 s and passed through the aurora from 320 s to 370 s.

The "a" enhancement in Fig. 5 corresponds to the electron fluxes precipitating on both edges of the auroral arc, and the "c" enhancement is correlated with the highest intensity of the auroral luminosity in the all-sky camera photographs. Energy spectra shown in Fig. 7 identically indicate that the energy of the spectral peaks changes with the changes of the rocket's positions in the aurora arc. It shows the energy spectrum of an inverted V shape.

In the case of the S-310JA-6 rocket experiment, the all-sky camera photographs indicate that the rocket stayed in the feeble aurora at 120 s when the observation was started and passed over the aurora arc from 190 s. The reason of decreases of electron fluxes in all energy bands at 180 s is that the rocket encountered the local dark point among the aurora arcs. The increase ("f" and "h") of the electron fluxes from 240 s to 350 s is correlated with the intense luminosity of the aurora. However, a high intensity of auroral luminosity was not seen in the all-sky camera photographs which correspond to the "g" and "i" enhancements of electron fluxes.

Energy spectra in Fig. 14 show no monoenergetic spectral peaks except at 270 s.

This is a typical energy spectrum of electron fluxes precipitating into the intense aurora.

We may well infer that the pitch angle distributions in the S-310JA-5 rocket experiment may have a peak near 0° pitch angle in all energy ranges except in 1 keV by comparing electron fluxes of low pitch angle (Fig. 5) and of 90° pitch angle (Fig. 6). This suggests that the observed electron fluxes near 0° pitch angle are components of the field-aligned current associated with the aurora arc. In the S-310JA-6 rocket experiment, however, electron fluxes at 90° pitch angle are equal to or a little higher than the electron fluxes near 0°. These results reflect the different features of the two different auroras.

These data are similar in many respects to spectra obtained in other rocket flights by other authors. A common feature is a relative peak in 1 to 10 keV in an arc aurora and no peaks in an intense aurora.

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References

ANDERSON, K. A. and MILTON, D. W. (1964): Balloon observations of X rays in the auroral zone, 3. High time resolution studies. J. Geophys. Res., **69**, 4457–4470.

BOYD, J. S. and DAVIS, T. N. (1977): Rocket measurement of electrons in a system of multiple auroral arcs. J. Geophys. Res., **82**, 1197–1205.

CHOY, L. W. and ARNOLDY, R. L. (1971): Field-aligned particle currents near an auroral arc. J. Geophys. Res., **76**, 8279–8298.

EVANS, D. S. (1968): The observations of a near monoenergetic flux of auroral electrons. J. Geophys. Res., **73**, 2315–2323.

KAYA, N. and MATSUMOTO, H. (1978): Modified electron spectrometer for medium energy. Mem. Natl Inst. Polar Res., Spec. Issue, **9**, 43–50.

MATSUMOTO, H. and KAYA, N. (1978): Rocket observation of keV electron fluxes at Syowa Station. Mem. Natl Inst. Polar Res., Spec. Issue, **9**, 34–42.

MATSUMOTO, H., KAYA, N. and YAMAGISHI, H. (1981): keV electron microbursts above auroral arcs. Mem. Natl Inst. Polar Res., Spec. Issue, **18**, 422–426.

PAZICH, P. M. and ANDERSON, H. R. (1975): Rocket measurement of auroral electron fluxes associated with field-aligned currents. J. Geophys. Res., **80**, 2152–2160.

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