OPERATION OF SC5 RAPID SCAN PARTICLE SPECTROMETER ON SCATHA SATELLITE*

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SUMMARY

The SC5 Rapid Scan Particle Spectrometer has two identical sets of particle detectors viewing parallel and perpendicular to the SCATHA Satellite's spin axis. A complete spectral measurement is made every second, so 54 complete spectra are measured every satellite rotation (54 seconds). By ground-commanding the instrument into a fixed energy channel, a time resolution of 0.2 second is obtained. The instrument can also be connected to a broad-band FM channel which provides 250 μsec time resolution. Each particle detector set consists of two electron/proton ESA's (low energy, 0.05 - 1.7 keV, and high energy, 1.7-60 keV), and a pair of solid state detector spectrometers (30-1000 keV electron, and 100-8000 keV protons).

The normal operation mode of SC5 uses the ESA's in an auto-shutoff mode, in which the SEM bias is turned off while the perpendicular ESA's view the sun. This reduces degradation of the SEM's by solar UV; the large geometric factor and broad energy resolution result in substantial sensitivity to scattered solar UV. The ESA SEM gains are checked a few times a week by a SEM bias level calibration cycle. The normal SEM gain degradation with total accumulated counts was observed to recover partially when the ESA's were turned off, so the ESA's were operated in a mode of on one day and off one day. This has allowed reliable ESA operation for in excess of one year.

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The rapid time response of the SC5 instrument has been most useful in conjunction with the electron/ion gun operation. Data from some of the ICE events show that the satellite can take about a second to discharge when the ion beam is turned off. High time resolution FM band data from electron gun operations show that the satellite potential rises in less than 1 msec, with some ESA energy channels indicating that final adjustment of the ambient populations can have a time constant as long as one second. Electron beam turn off results in initial decay of most of the satellite's potential within a few msec, but a low energy (50 - 100 eV) electron component takes closer to 1 second to decay.

INSTRUMENT DESCRIPTION

A general outline of the SC5 instrument is shown in figure 1 along with the various particle detector apertures. The electrostatic analyzers (ESA's) are dual electron/proton assemblies, two for each view direction to cover the range 0.05-60 keV in a total of eight (8) energy ranges. The solid state spectrometers (SSS's) are two detector telescope configurations used in anticoincidence for the low energy range and coincidence for the high energy range. The SSS's cover 30-1000 keV for electrons and 100-8000 keV for protons. More detailed descriptions of the SC5 instrument are given in references 1 and 2, while a description of detector calibration is given in reference. 3. The ESA detection characteristics are summarized in tables 1 and 2 and are based on the detailed measured responses given in reference 3. The SSS detection characteristics are summarized in tables 3 and 4.

The SC5 instrument is located on the bellyband of the SCATHA satellite as shown in figure 2. The perpendicular detectors look out between the +Y and -Z axes in the spin plane, while the parallel detectors look out the forward end of the satellite, parallel to the spin axis. The electron gun, SC4-1, is located on the bellyband about 45° away from SC5, while the ion gun, SC4-2, is located on the aft end of the satellite at 180° from the SC5 perpendicular apertures.

The normal mode of operation for SC5 has an energy channel dwell of 0.2 sec, so a complete spectrum is measured once every second. For the 54 second spin period this gives a rotational angular resolution of about 7° for the perpendicular detectors. By ground command, the ESA's and/or SSS's can be fixed in any desired energy channel (including the fifth, or background, channel for the ESA's), so 0.2 sec time resolution can be achieved.

The SC5 output can also be connected to a broad-band FM channel which provides 250 μsec time resolution. Any single detector can be connected to the FM channel, as can certain permutations of detectors, by ground command. By fixing to a particular energy channel, the FM data allow continuous measurement of one particle type/energy bin with the 250 μsec time resolution.

IN-ORBIT OPERATION

The SCATHA satellite is oriented with the spin axis in the orbital plane and normal to the earth-sun line, so the perpendicular detectors view the sun once per spin. Since the ESA's have broad energy bins and large geometrical factors, they are moderately sensitive to solar UV, and this contributes to gain degradation of the Spiraltron Electron Multipliers (SEM's) used for particle detection. SEM's generally suffer gain degradation at high total accumulated counts (reference 4), and solar UV adds to the total counts. The ESA's are thus operated in an auto-shutoff mode where a sun-sensing photodiode causes the SEM high voltages to be turned off while the perpendicular ESA's view the sun. Operations with and without this auto-shutoff mode enabled show that it significantly reduces the SEM gain degradation rate.

In-orbit tests also showed that the SEM gains partially recovered when the SEM's were off. The ESA's were thus operated in a cycle of one day on and one day off to reduce the net SEM gain degradation with total counts and thus maximize useful SEM lifetime. With this mode of operation, the ESA's have given useful data for more than a year.

The ESA SEM gains are checked a few times a week by a SEM bias level calibration cycle. By measuring the relative count rates as a function of bias level, the SEM efficiencies for the operating bias level are obtained. These efficiencies vary slowly with time for the normal SC5 operating conditions. Certain operations, such as SC4-1 electron gun operations, result in very high count rates for some of the ESA's and thus may give a significant change in some SEM efficiencies in a short period. Occasionally, intense fluxes of ambient particles, generally electrons in the 1 keV region, are observed for long periods of time, and these too can result in a significant SEM efficiency change for one or two ESA's.

The SC5 solid state spectrometers (SSS's) are on almost continuously since they do not degrade at the rate the SEM's do. The electron SSS's were calibrated with electron beams to about 45 keV, and this calibration was extrapolated to higher energies (reference 3). The two lowest electron SSS bins overlap the two highest ESA bins, and they agree moderately well in this overlap region, with the lowest SSS bin tending to be somewhat low, on the order of 50%. The higher energy SSS bins are in reasonable agreement with the extrapolated ESA spectra. The proton SSS's appear to be operating properly although a detailed study of the data has not yet been made. More detailed study of both the electron and proton SSS data and comparison with the ESA data will be done in the near future.

REDUCTION OF ESA SPECTRA

The SC5 ESA's have broad energy bins to allow rapid measurement of 0.05 to 60 keV particles. The typical calibrated energy channel responses are shown in figure 3, which gives the parallel electron ESA G(E) factors from reference 3. These responses are for saturation SEM efficiencies and must be multiplied by the fractional SEM efficiencies obtained from the SEM bias level calibrations when used with actual data.

The ESA energy channels have about 100% full-width-at-half-maximum (FWHM) energy resolution and a significant high energy tail in G(E). The ESA responses are thus dependent on the spectral shape, and adjacent energy channels have significant overlap in response. To obtain the best spectral estimates within the resolution of a given set of ESA's (8 channels for the parallel electron ESA's, etc.), a set of eight central energy bins, corresponding closely to the FWHM energies, is used to define the basic energy detection range. These energies are the same for both electron and for both proton ESA sets, as shown in table 5 which also includes a Low and High bin for corrections in the edge channels. The high energy tail for the LE ESA's is subtracted using the background channel, which has a G(E) closely matching the high energy tails.

The counts from a given ESA set are used to derive corrected spectra by first calculating a zero order spectrum using the GΔE values in tables 1 and 2. The zero order spectra are then used to calculate spectral power law values ($dj/dE = j_o E^{-\gamma}$, with γ the power law value) which are then used to calculate corrected response values for the central bin and at least one adjacent bin on the low and high energy side for each ESA channel. The resulting response matrix, which is very nearly diagonal, is then easily solved from the ESA counts, obtaining the corrected dj/dE values (particles/(cm^2-sec-sr-keV)) for each of the eight Central Bins of table 5. The proton ESA's are done after the electron ESA's and use the corrected electron spectra to subtract the proton ESA response to electrons (see reference 3). The entire procedure is iterated a number of times until the power law exponents (γ values) of the corrected spectra are in close agreement with the input values.

A typical result of the flux correction procedure is shown in figure 4, where the uncorrected and corrected fluxes are plotted for the parallel electron ESA's. The largest correction is for regions of steeply rising or falling spectra. The spectrum in figure 4 is approximately Maxwellian with a temperature near 3 keV. A different type electron spectrum is shown in figure 5, where a two-component power law spectrum is shown. Corrections for a typical proton spectrum are shown in figure 6, where the low energy region (< 1 keV) is below the background-limited threshold for the given electron flux conditions. The data in figures 5 and 6 were taken at the same time, so the electron spectrum in figure 5 was used to correct the electron contribution to the proton spectrum in figure 6.

ESA DATA SUMMARIES

The SC5 instrument provides enormous quantities of data which must be conveniently summarized to provide an overview from which more detailed studies can be made. Since the most intense fluxes are generally measured by the ESA's, and since the perpendicular detectors generally measure over a large pitch angle range, the perpendicular ESA's are used to provide a daily summary for average energy, energy density, and number density. The measured pitch angle distributions are extrapolated to cover 0° to 180°, and the summaries are given for the full (extrapolated) pitch angle range for electrons and for protons.

Typical summary data plots are shown in figure 7 for electrons and figure 8 for protons. The number density is in particles/cm^3, the energy density is in eV/cm^3, and the average energy is in eV. The pitch angle range for the measured data of figures 7 and 8 is shown in figure 9. The narrow double spikes at 0800 and 2030 GMT are from ESA bias level calibrations, while most of the remaining structure is true particle variation. The data in figures 7 and 8 have not had the SEM efficiency divided in as is illustrated by the overshoot in electron number density for the two SEM bias level calibrations. The major structure of the particle flux behavior is, however, still evident and the summary plots are quite useful.

ESA DATA FROM ION GUN OPERATIONS

The SC5 instrument has provided much data from operations with the ion gun, SC4-2. A typical spectrum during ion gun operation when the satellite was charged to about -400V is shown in figure 10, which shows the corrected and uncorrected parallel proton ESA spectrum for the Induced

Charging Event no. 1 (ICE #1) on day 47 of 1979. The sequence of four consecutive (1 second) spectra during gun turn-off is shown in figure 11, where the spectrum for 0818:24 indicates that beam turn-off/satellite discharge has a time constant on the order of a second, the time resolution of a complete SC5 ESA spectrum.

ESA DATA FROM ELECTRON GUN OPERATIONS

Some of the most interesting SC5 data have come from operations of the electron gun, SC4-1. A parallel electron ESA spectrum during emission of a 3 keV electron beam, with the satellite charged to +3 keV, is shown in figure 12. Note the large corrections to spectrum channels on each side of the 3 keV peak. The low energy (< 3 keV) part of the corrected spectrum is consistent in shape and intensity with what would be expected from backscattering of the 3 keV electrons.

High time resolution data from the FM channel were obtained from an electron gun operation on day 297, 1979. With a 500V, 0.1 mA beam the satellite charged to about +100V, and at beam turn-on reached the equilibrium potential within 1 msec as measured by the FM data from the 84 eV channel of the parallel electron ESA shown in figure 13. The beam turn-off data are shown in figure 14. Note the presence of a more intense flux after beam turn-off than before beam turn-on. This is quite frequently observed after electron beam turn-off when the satellite has charged significantly.

Later beam operations with 1.5 keV, 1 mA (nominal, actual was near 0.4 mA) resulted in a satellite potential of about +200V. The potential appears to have risen with about a 2 msec time constant to a slightly higher than equilibrium value and then decayed back to equilibrium with a 0.11 sec time constant. This is illustrated in figure 15, which shows the FM data for the 1.22 keV energy channel of the parallel electron ESA's. When the electron beam was turned off in the 1 mA mode, the satellite potential dropped to 50-100V in a few msec, but then decayed to the normal ambient potential with a 0.7 sec time constant. This is shown in figures 16 and 17, which are the 0.085 eV electron channel FM data for turn-off at 500 eV (figure 16) and 1.5 keV (figure 17). Note that the traces are almost identical since the satellite potential was beam-current limited. The data in figures 15, 16, and 17 are noisier than that in figures 13 and 14 because a higher cut-off frequency was used in playback. These data will all be reprocessed and digitized to yield the actual 250 μsec count resolution and thus set more nearly precise values for the electron beam operation rise/fall times. A preliminary summary of some of the day 277 electron beam operation results is given in table 6.

CONCLUSIONS

The SC5 instrument has operated reliably on the SCATHA satellite for in excess of one year. A large amount of ambient particle data have been obtained. Data from electron/ion gun operations have shown how the satellite potential responds and, in particular, have given some information on the various time constants involved.

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2. Stevens, J.R.; and Vampola, A.L.: Description of the Space Test Program P78-2 Spacecraft and Payloads. SAMSO TR-78-24, Oct. 1978, pp. 39-42.

3. Hanser, F.A.; Hardy, D.A.; and Sellers, B.: Calibration of the Rapid Scan Particle Detector Mounted in the SCATHA Satellite. AFGL-TR-79-0167, July 1979.

4. Klettke, B.D.; Krym, N.D.; and Wolber, W.G.: Long-term Stability Characteristics of Commonly Used Channel Electron Multipliers. IEEE Trans. Nucl. Sci., vol. NS-17, no. 1, Feb. 1970, pp. 72-80.

Table 1

Summary of Electron ESA Detection Characteristics

ESA /Ch No.	Flat spectrum calculation: $\bar{E}$ (keV)	ΔE(FWHM) (keV)	$\bar{G}\Delta E$ (cm^2-sr-keV)	From response curves: E_{peak} (keV)	$\bar{E}$(1/2 ht) (keV)	ΔE(1/2 ht) (keV)
‖ ESA's						
LE/#1	0.112	0.138	8.5×10^{-6}	0.073	0.089	0.077
" /#2	0.27	0.30	2.8×10^{-5}	0.18	0.22	0.19
" /#3	0.68	0.87	7.7×10^{-5}	0.44	0.53	0.44
" /#4	1.50	1.55	1.65×10^{-4}	1.05	1.26	1.08
HE/#1	4.6	6.2	1.46×10^{-4}	2.7	3.2	2.7
" /#2	9.0	8.9	2.4×10^{-4}	6.3	7.6	7.2
" /#3	23.	25.	5.4×10^{-4}	16.	20.	19.
" /#4	53.	53.	8.3×10^{-4}	40.	47.	47.
⊥ ESA's						
LE/#1	0.110	0.160	7.0×10^{-6}	0.070	0.084	0.067
" /#2	0.26	0.33	2.7×10^{-5}	0.18	0.21	0.17
" /#3	0.62	0.78	4.7×10^{-5}	0.42	0.49	0.38
" /#4	1.57	1.64	1.52×10^{-4}	1.10	1.22	1.12
HE/#1	4.4	5.7	1.06×10^{-4}	2.7	3.3	3.0
" /#2	9.2	9.1	2.1×10^{-4}	6.7	8.0	7.6
" /#3	24.	26.	4.3×10^{-4}	17.	20.	19.
" /#4	54.	55.	7.1×10^{-4}	49.	47.	46.

Table 2

Summary of Proton ESA Detection Characteristics

ESA /Ch No.	Flat spectrum calculation: $\bar{E}$ (keV)	ΔE(FWHM) (keV)	$\bar{G}\Delta E$ (cm^2-sr-keV)	From response curves: E_{peak} (keV)	$\bar{E}$(1/2 ht) (keV)	ΔE(1/2 ht) (keV)
‖ ESA's						
LE/#1	0.145	0.134	2.4×10^{-5}	0.10	0.125	0.105
" /#2	0.35	0.34	4.3×10^{-5}	0.25	0.30	0.27
" /#3	0.78	0.79	1.38×10^{-4}	0.55	0.67	0.56
" /#4	1.70	1.57	3.7×10^{-4}	1.20	1.44	1.12
HE/#1	4.5	4.3	8.9×10^{-4}	3.1	3.8	2.9
" /#2	10.4	8.1	2.5×10^{-3}	7.8	9.5	7.3
" /#3	25.	20.	5.8×10^{-3}	19.	23.	18.
" /#4	60.	47.	1.37×10^{-2}	44.	55.	43.
⊥ ESA's						
LE/#1	0.148	0.148	1.39×10^{-5}	0.10	0.122	0.101
" /#2	0.34	0.33	2.6×10^{-5}	0.24	0.30	0.25
" /#3	0.84	0.86	8.9×10^{-5}	0.56	0.68	0.56
" /#4	1.80	1.62	2.6×10^{-4}	1.3	1.57	1.31
HE/#1	4.0	3.9	8.5×10^{-4}	2.9	3.4	2.6
" /#2	9.7	7.8	2.3×10^{-4}	7.3	8.3	6.6
" /#3	23.	19.	5.0×10^{-3}	18.	21.	16.
" /#4	55.	45.	1.16×10^{-2}	43.	49.	39.

Table 3

Summary of Electron SSS Properties

Channel No.	Average Energy (keV)	Channel Width (keV)	Effective $\bar{G}\Delta E$* (cm^2-sr-keV)
A0	39	12	1.21×10^{-2}
A1	58	24	5.12×10^{-2}
A2	96	48	0.144
A3	335	430	1.53
A4	218	95	0.337
C0	>950	-	3.55×10^{-1}+
C1	1040	120	4.26×10^{-1}
C2	70-950	-	3.55×10^{-1}+
C3	>950	-	3.55×10^{-1}+
C4	1040	120	4.26×10^{-1}

*Calculated for a flat electron spectrum.
+These values are cm^2-sr for $G(>E)$, or $G(E_1$ to $E_2)$.

Table 4

Summary of Proton SSS Properties

Channel No.	∥ Proton SSS Av. E(keV)	∥ Proton SSS Width(keV)	∥ Proton SSS $\bar{G}\Delta E$(cm^2-sr)*	⊥ Proton SSS Av. E(keV)	⊥ Proton SSS Width(keV)	⊥ Proton SSS $\bar{G}\Delta E$(cm^2-sr)*
A0	126	49	0.328	126	49	0.328
A1	188	75	0.502	188	75	0.502
A2	275	100	0.669	275	100	0.669
A3	388	125	0.836	388	125	0.836
A4	499	97	0.644	465	29	0.194
C0	6430	4360	29.1	5020	3460	23.1
C1	3060	2380	15.9	2380	1830	12.2
C2	1410	910	6.07	1100	731	4.89
C3	779	361	2.42	612	242	1.62
C4	573	51	0.341	(485	≃10	≃0.01)

*Calculated for a flat proton spectrum.

Table 5

Energy Bins for ESA Response Calculation

Bin	Electron ESA's		Proton ESA's	
Designation	Range (keV)	Center (keV)	Range (keV)	Center (keV)
Low	0.030-0.050	0.040	0.030-0.070	0.050
Center 1	0.050-0.120	0.085	0.070-0.170	0.120
Center 2	0.120-0.300	0.210	0.170-0.400	0.285
Center 3	0.300-0.700	0.500	0.400-0.900	0.650
Center 4	0.700-1.80	1.25	0.900-2.20	1.55
Center 5	1.80 -4.50	3.15	2.20 -5.00	3.60
Center 6	4.50 -11.0	7.75	5.00 -13.0	9.0
Center 7	11.0 -25.0	18.0	13.0 -30.0	21.5
Center 8	25.0 -70.0	47.5	30.0 -70.0	50.0
High	70.0 -150.	110.0	70.0 -150.	110.0

Table 6

Summary of Electron Beam On/Off Characteristics for Some of the Day 297, 1979 Operations

Electron Beam on/off	Beam Voltage (V) (Current = 1 mA)	Parallel Electron ESA Energy Channel (E in keV)	Rise/Decay Times (sec)
on	50	1 (0.085)	Rise < 0.001
off	500	1 (0.085)	Rise $\simeq$ 0.001/Decay $\simeq$ 0.7
on	500	3 (0.500)	Rise $\simeq$ 0.001/Decay $\simeq$ 0.001
off	1500	4 (1.250)	Decay $\simeq$ 0.002
on	1500	4 (1.250)	Rise $\simeq$ 0.002/Fall $\simeq$ 0.11
off	1500	3 (0.500)	During Channel ID
on	1500	3 (0.500)	Rise < 0.001/Fall $\simeq$ 0.001
off	1500	2 (0.210)	Decay $\simeq$ 0.005
on	1500	2 (0.210)	Rise < 0.001/Fall $\simeq$ 0.001
off	1500	1 (0.085)	Rise $\simeq$ 0.001/Decay $\simeq$ 0.7
on	1500	1 (0.085)	Rise < 0.001/Fall $\simeq$ 0.002

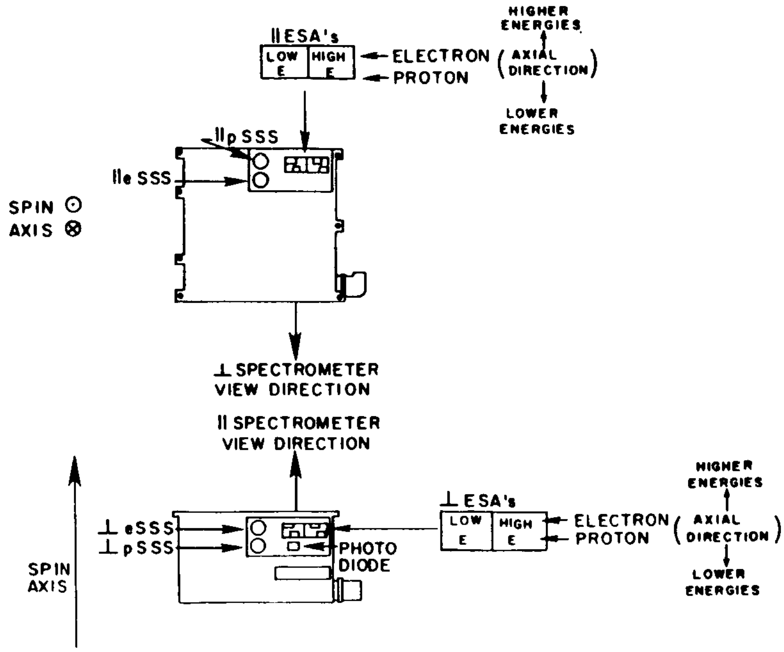

Figure 1. General outline of the SC5 instrument, showing the various particle detection apertures.

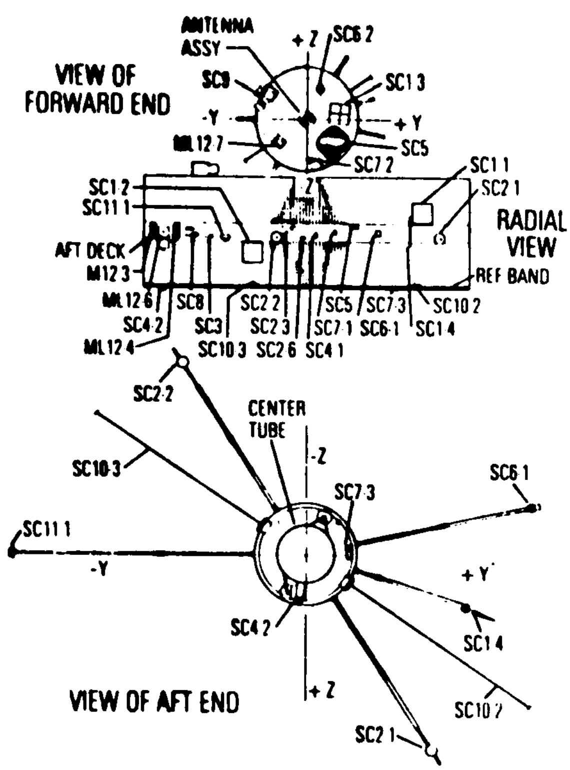

Figure 2. SC5 location on the SCATHA satellite (from reference 2).

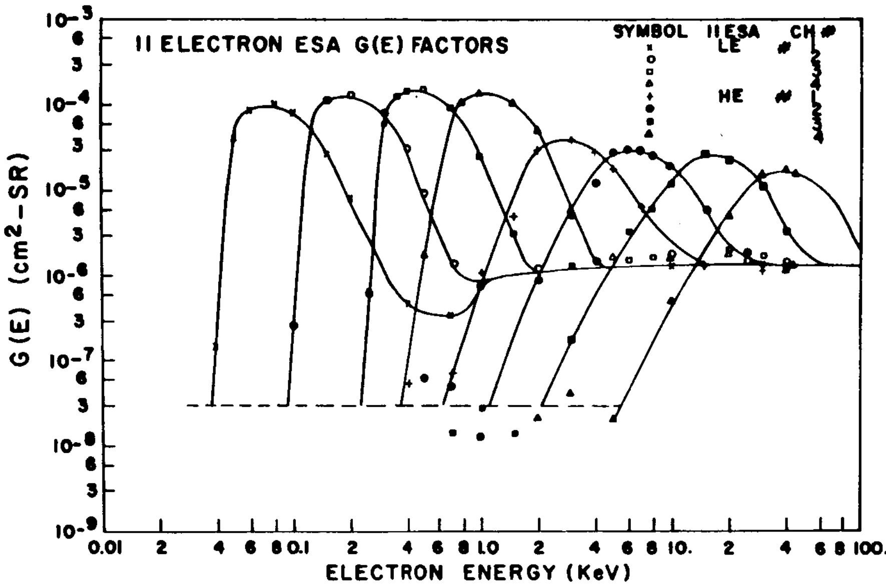

Figure 3. Calibration data and smoothed response curves for the parallel electron ESA's.

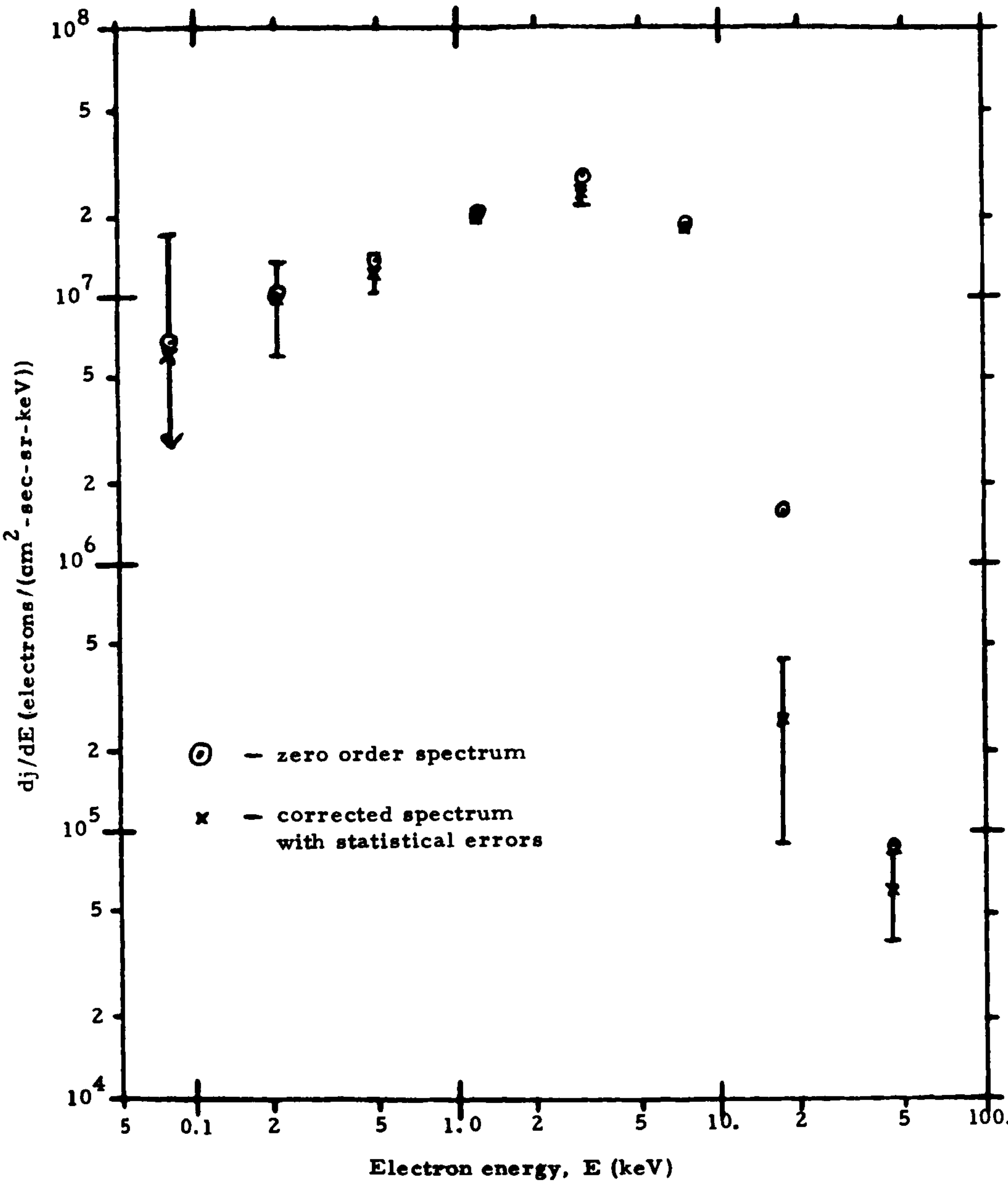

Figure 4. Electron spectrum with an approximately 3 keV temperature.

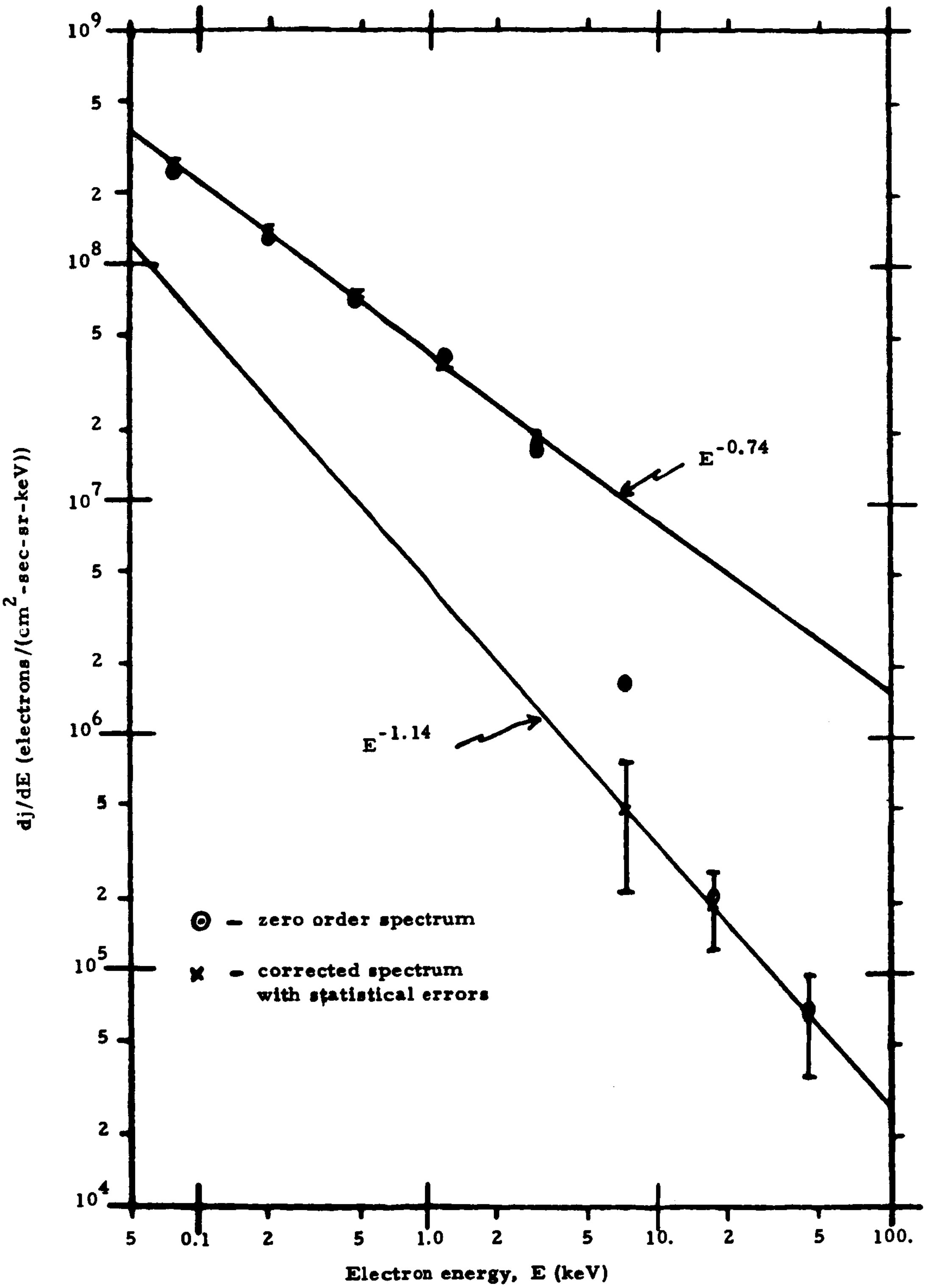

Figure 5. Correction effects on power law electron spectrum.

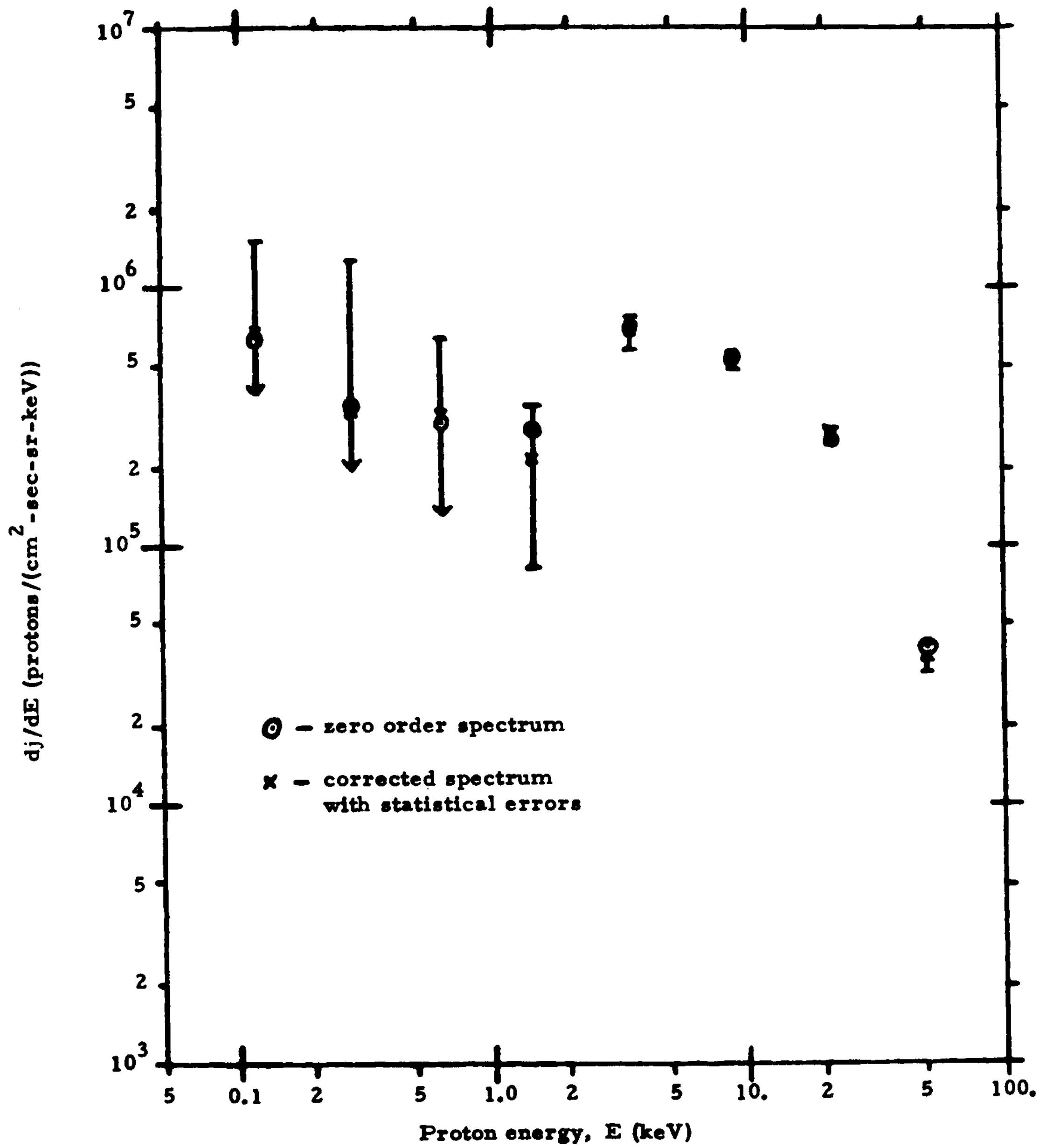

Figure 6. Corrections to a typical proton spectrum.

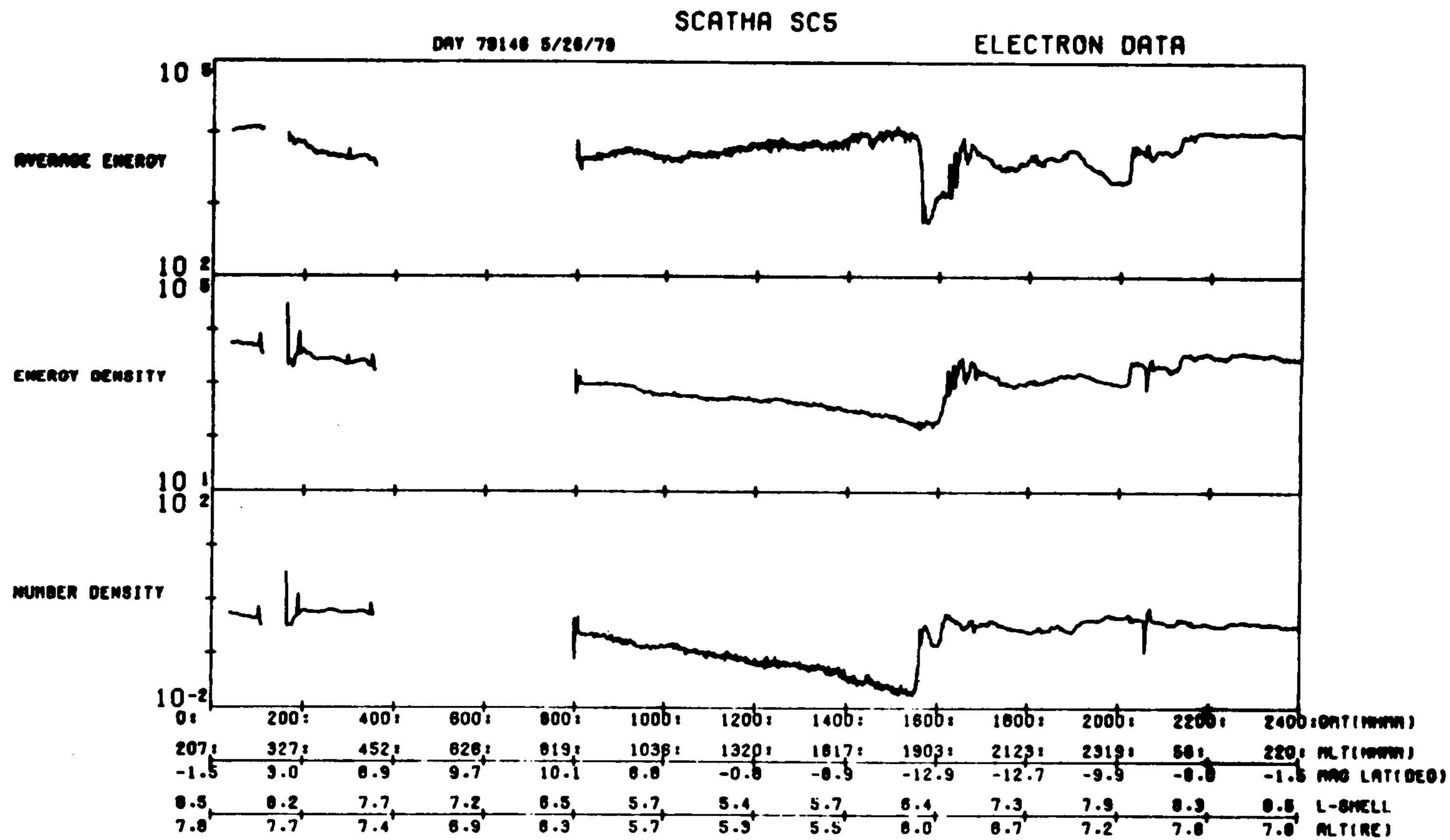

Figure 7. Typical summary plot of SC5 ESA data for electrons.

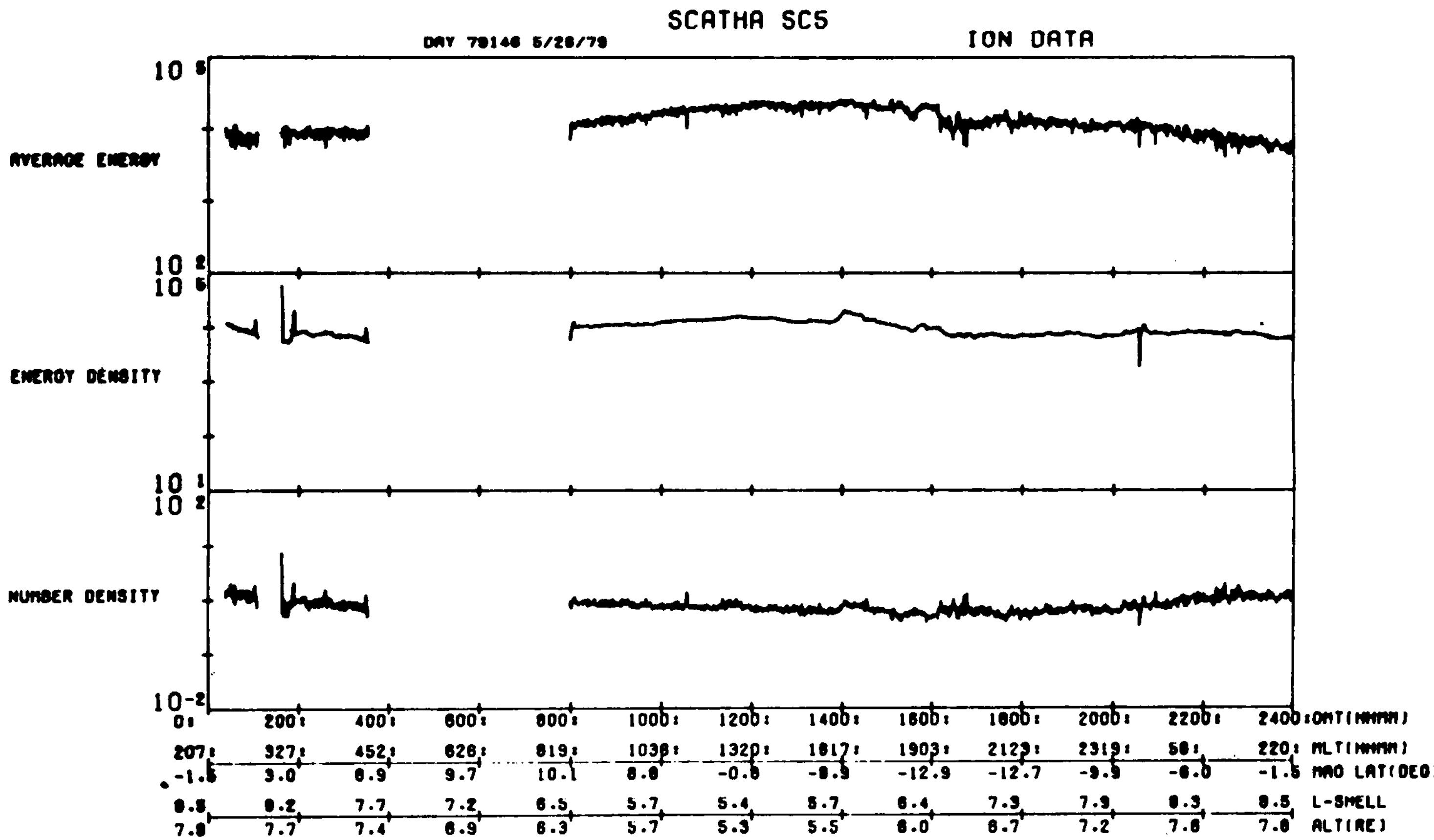

Figure 8. Typical summary plot of SC5 ESA data for protons (ions).

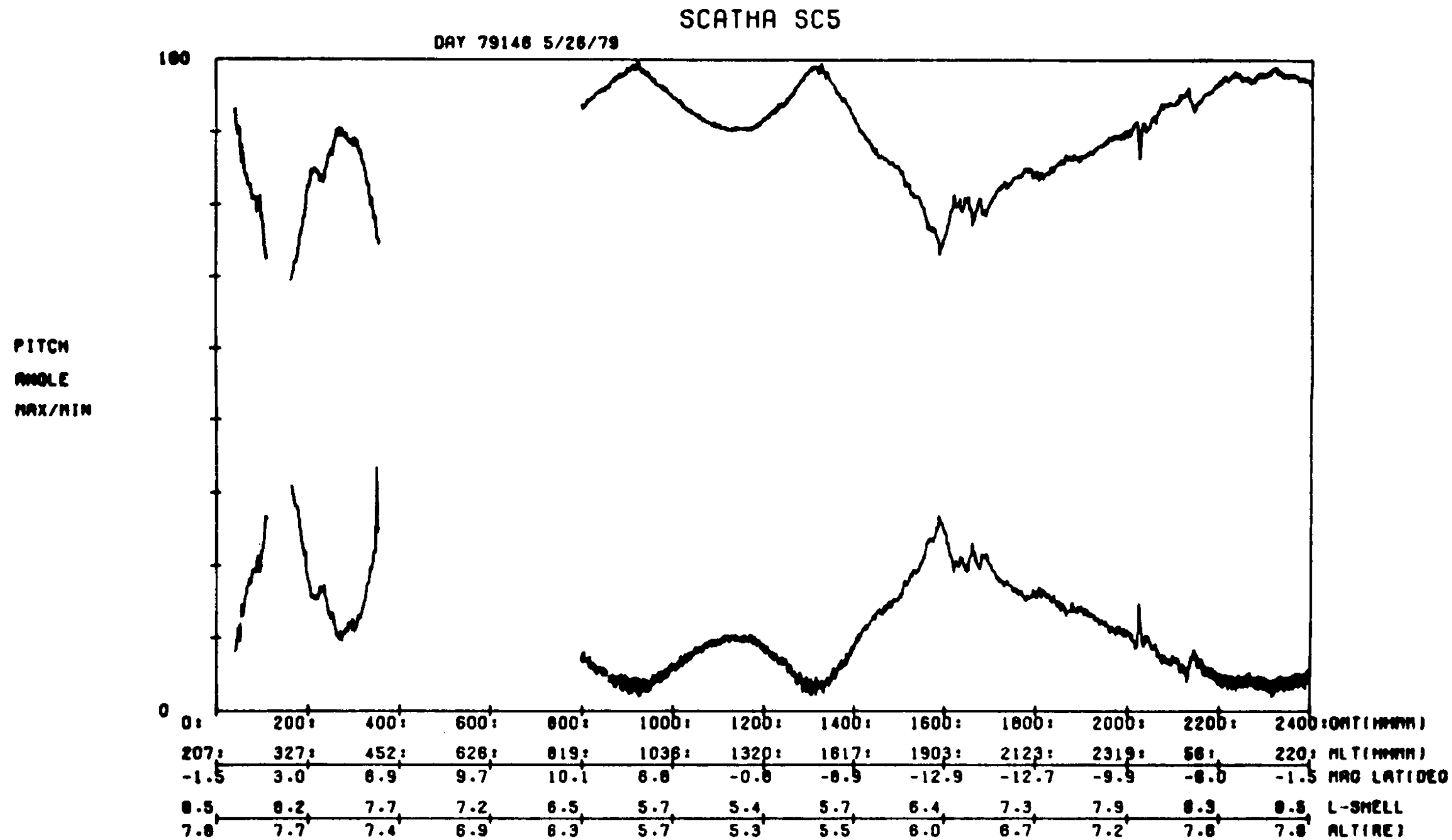

Figure 9. Pitch angle range of measured data for the summary plots in Figures 7 and 8.

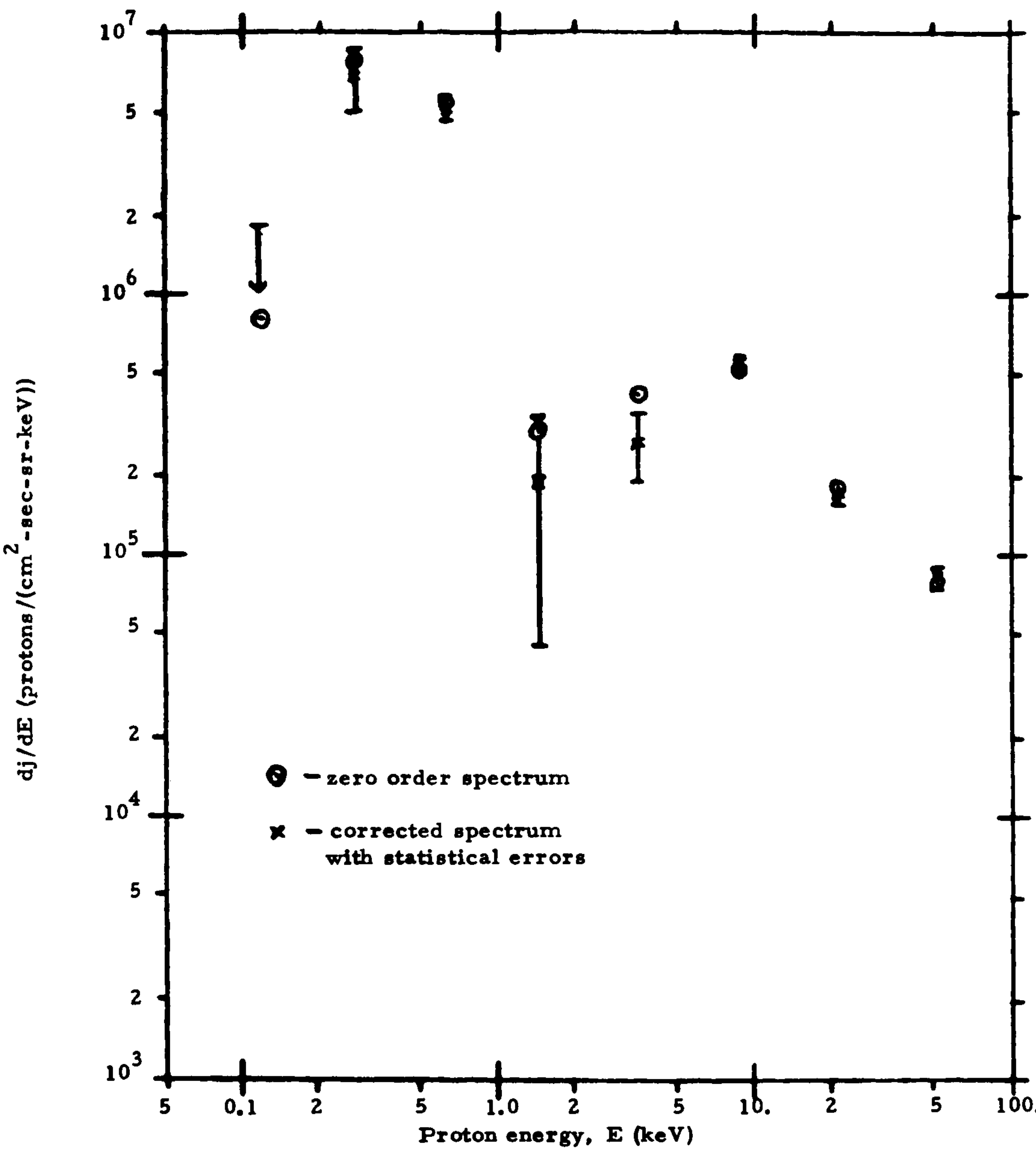

Figure 10. Typical proton spectrum during ion gun operations, corrected and uncorrected.

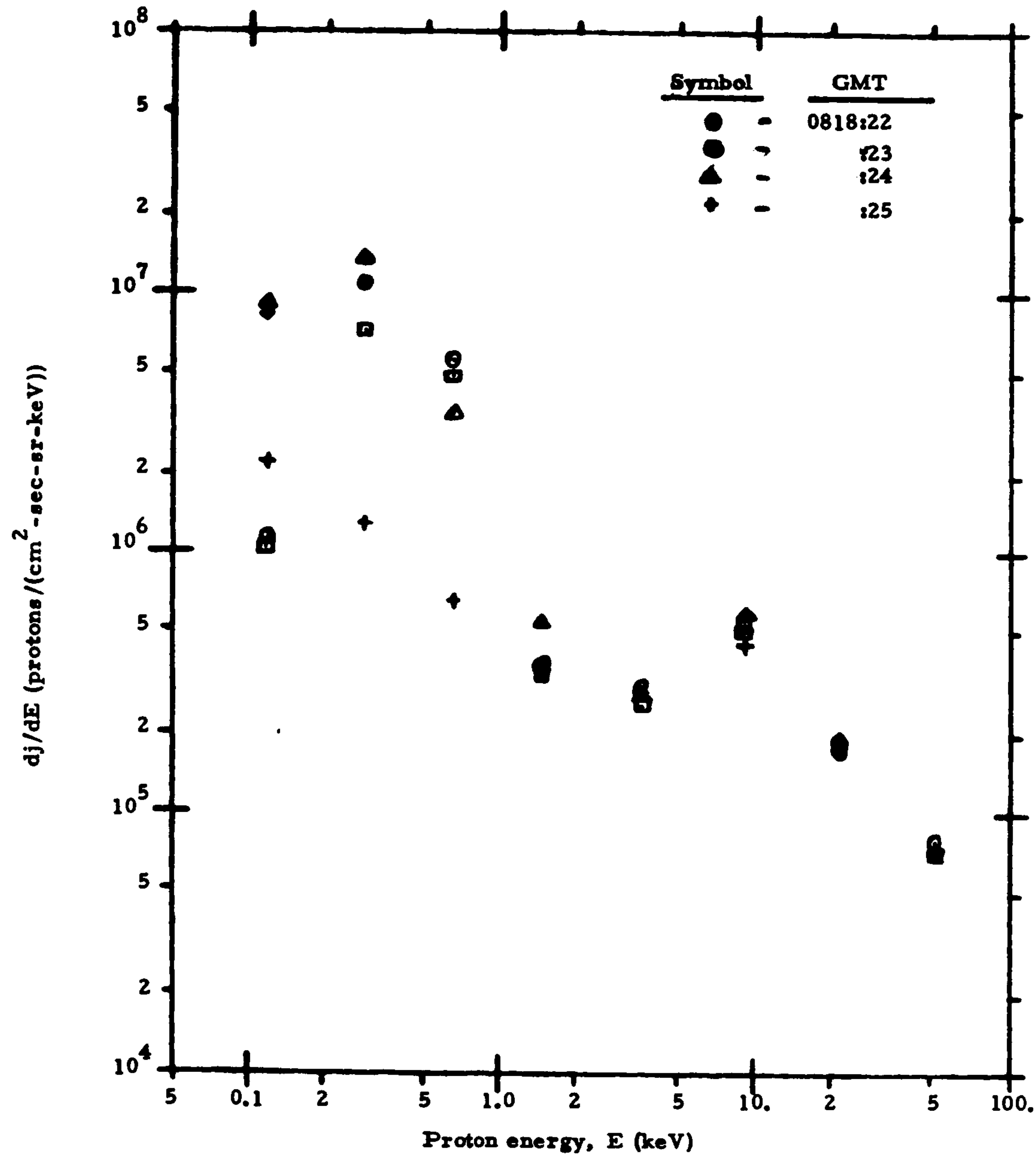

Figure 11. Four consecutive corrected ion spectra during ion beam turn-off in ICE #1 (day 47, 1979).

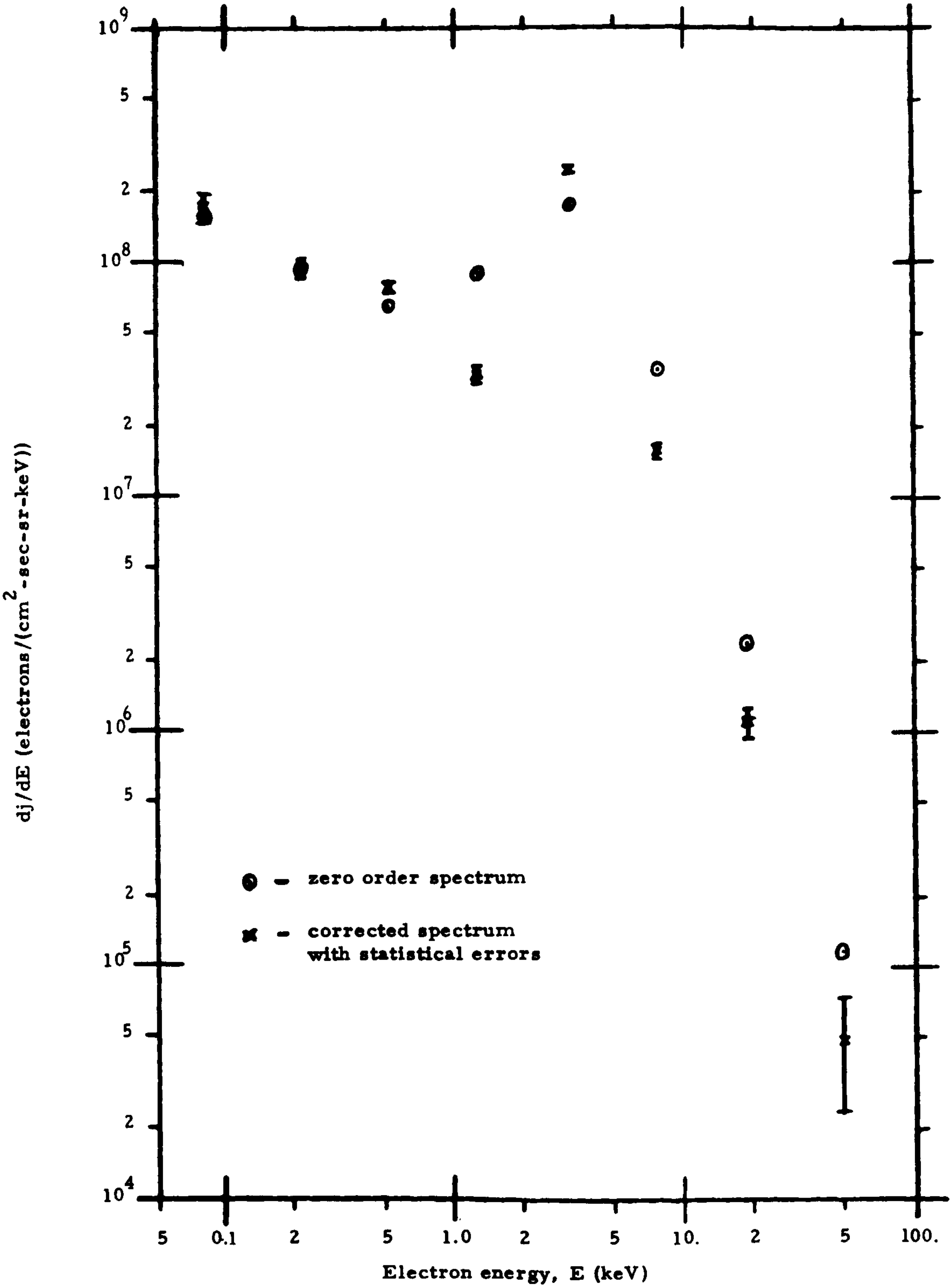

Figure 12. Typical electron spectrum with a strong monoenergetic peak, during electron gun operations.

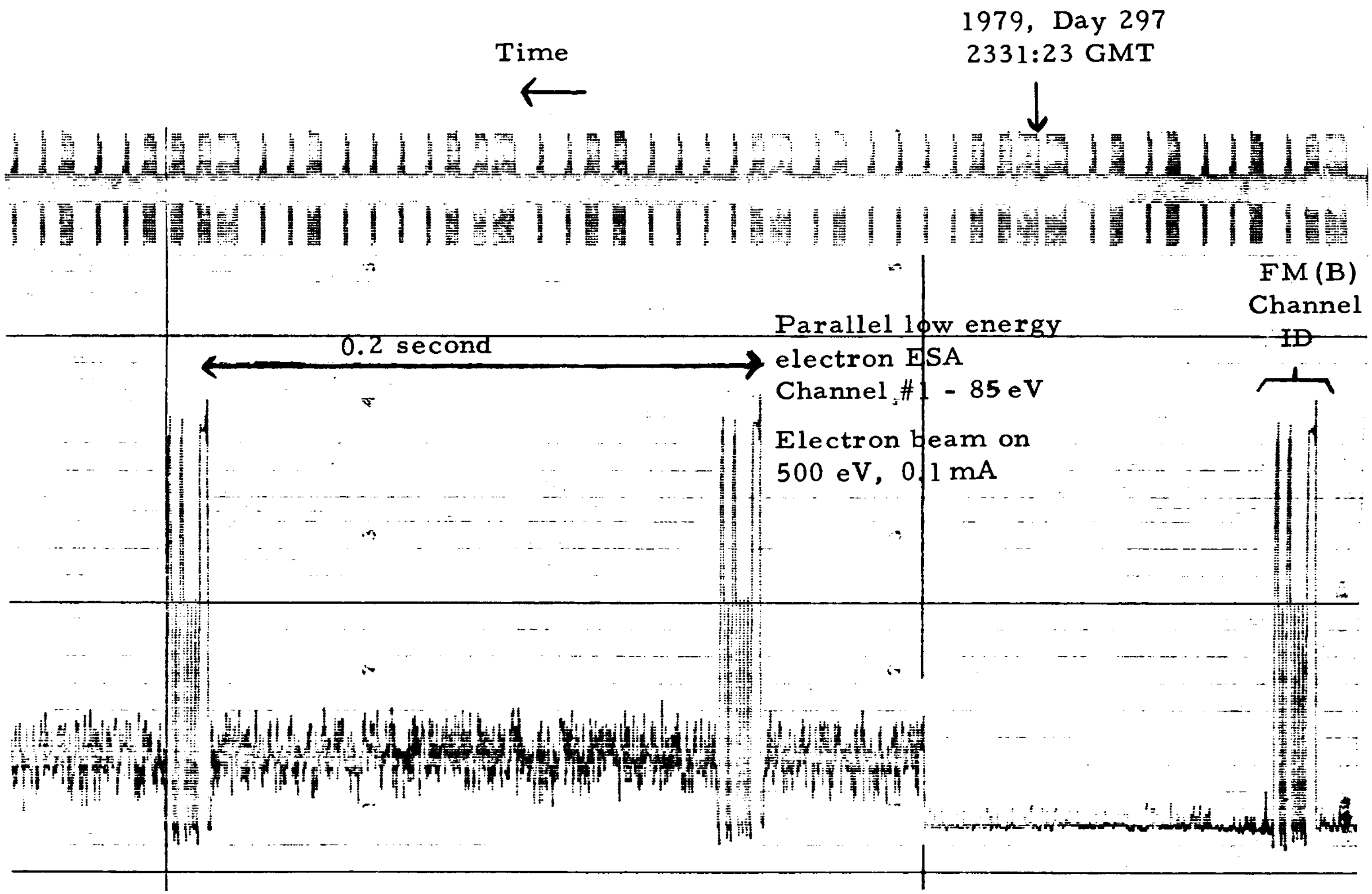

Figure 13. FM data from the low energy parallel electron ESA, in energy channel 1 (85 eV), for electron beam turn-on at 500V, 0.1 mA, on day 297, 1979.

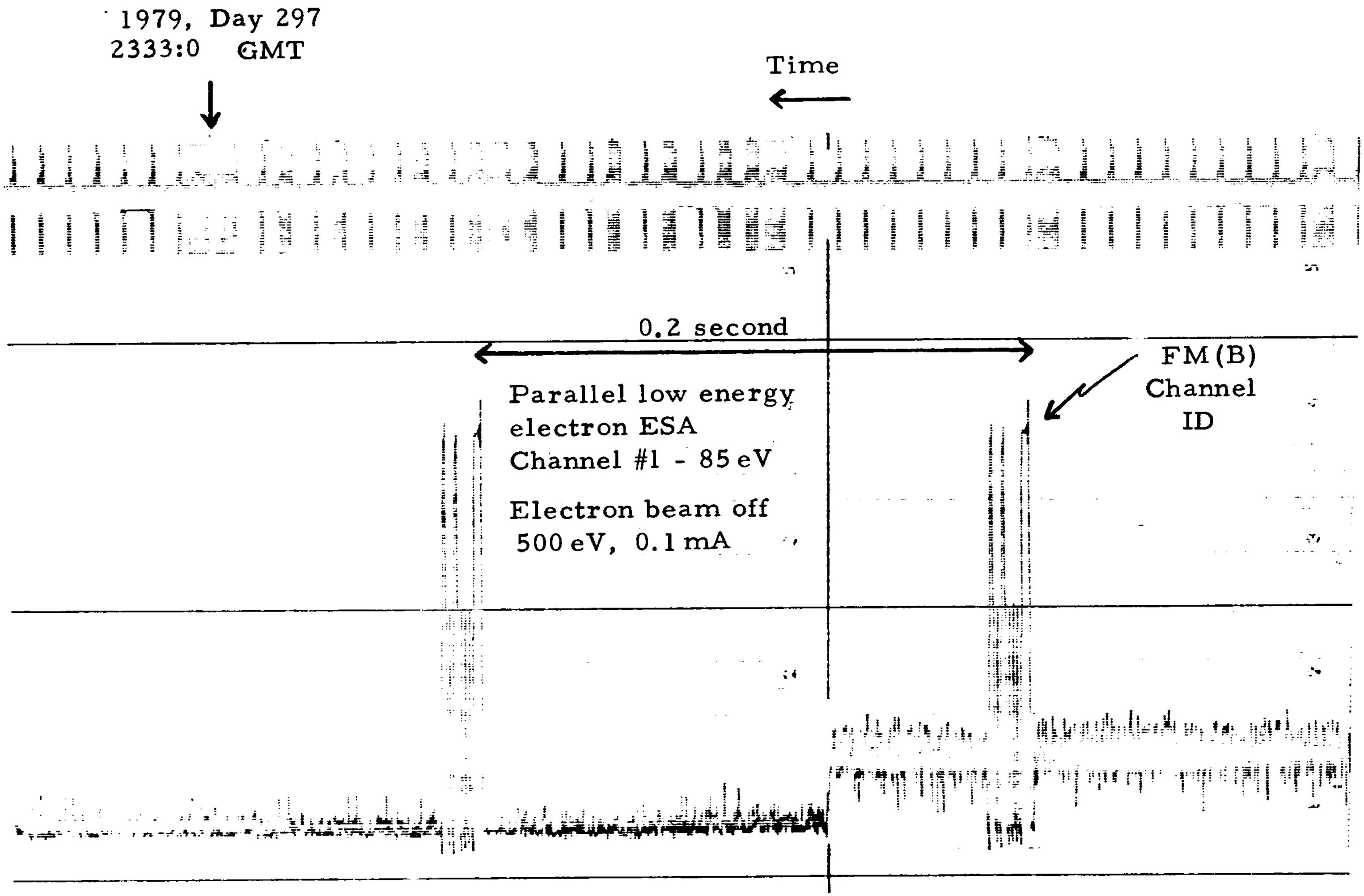

Figure 14. FM data from the low energy parallel electron ESA, in energy channel 1 (85 eV), for electron beam turn-off at 500 V, 0.1 mA, on day 297, 1979.

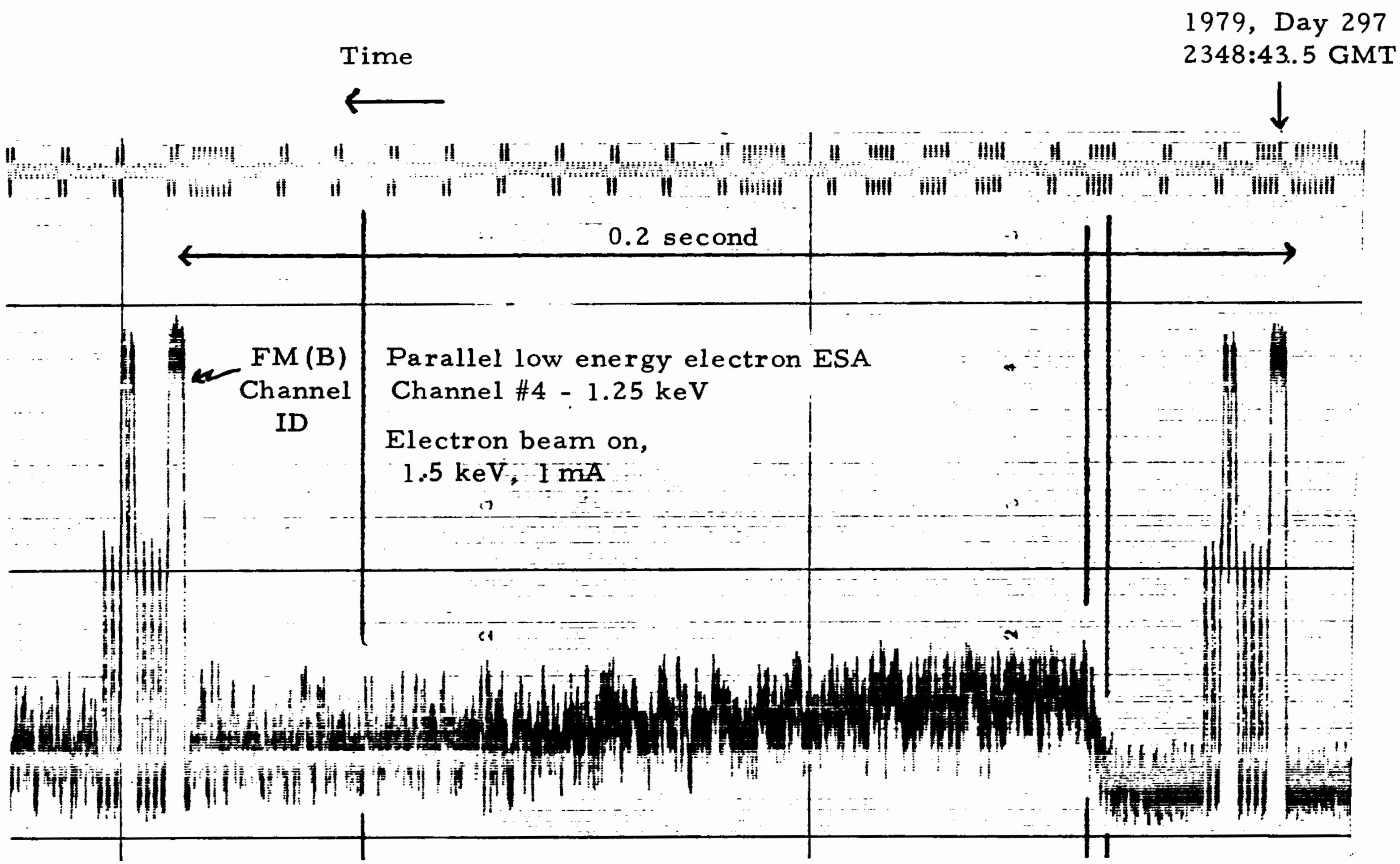

Figure 15. Response of the 1.25 keV parallel electron ESA energy channel to electron beam turn-on at 1.5 keV, 1 mA, on day 297, 1979.

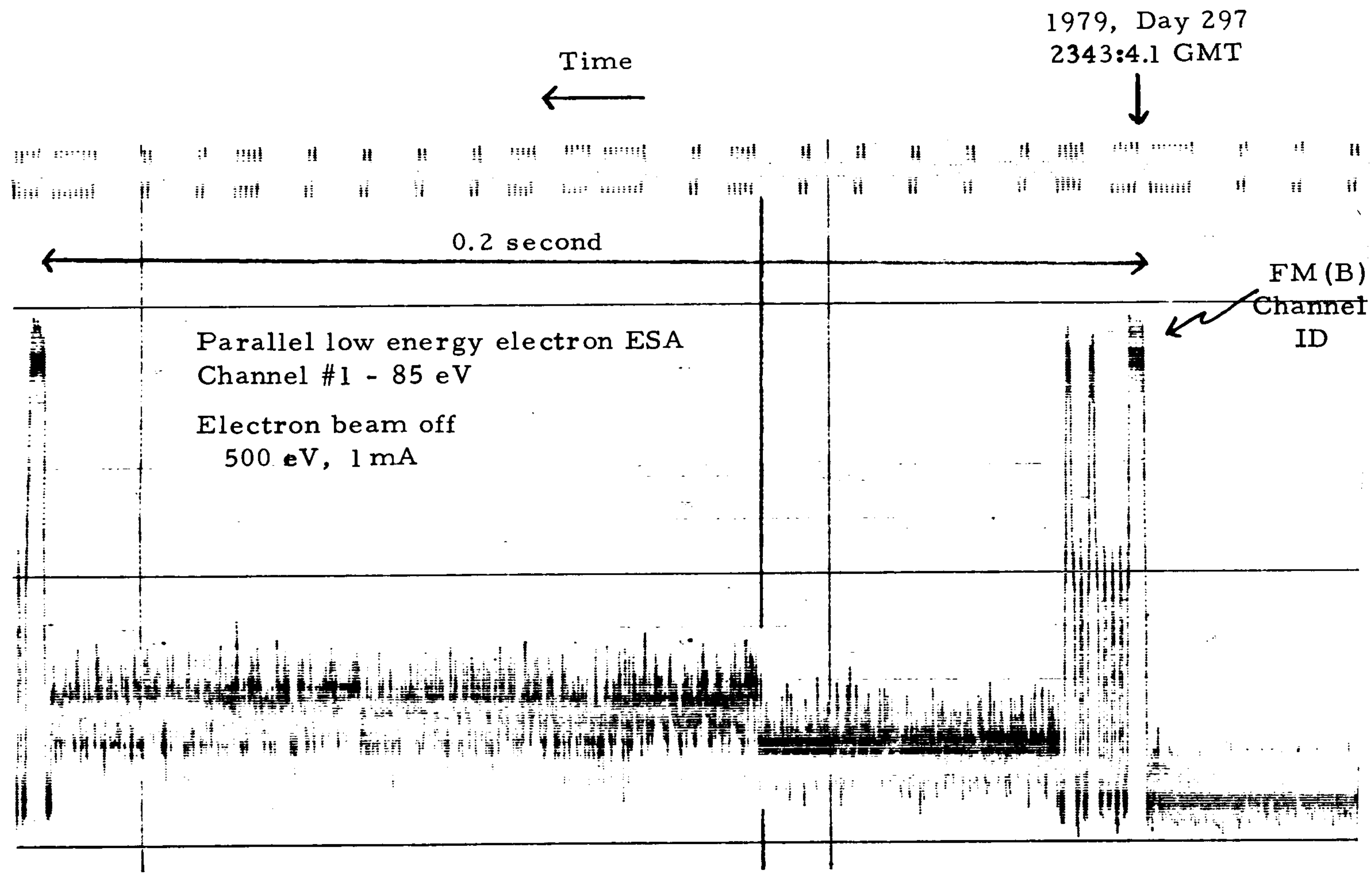

Figure 16. Response of the 85 eV parallel electron ESA energy channel to electron beam turn-off at 500 V, 1 mA, on day 297, 1979.

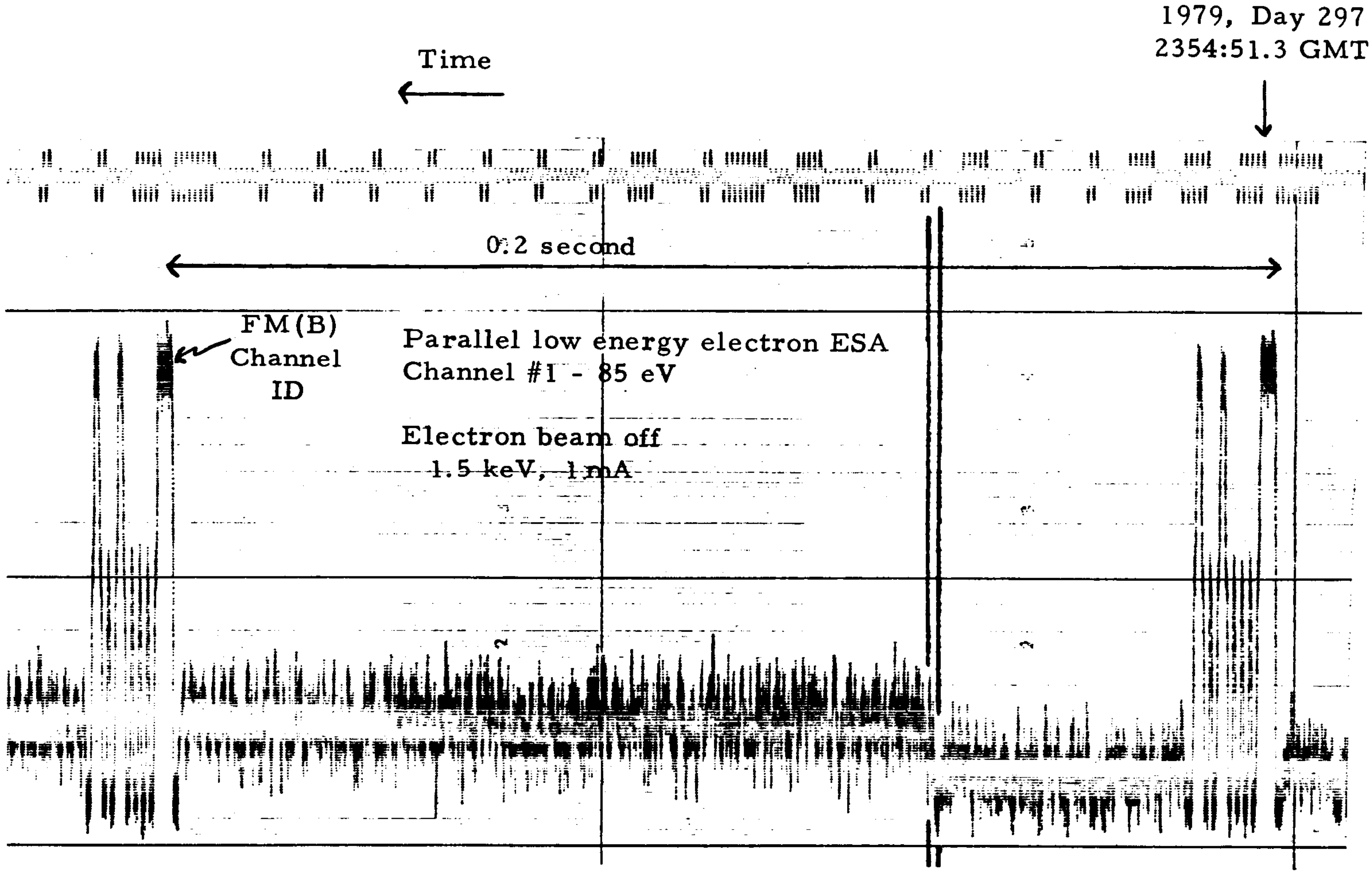

Figure 17. Response of the 85 eV parallel electron ESA energy channel to electron beam turn-off at 1.5 keV, 1 mA, on day 297, 1979.