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(LMSC-D350709) ANALYSIS OF LOW ENERGY ELECTRONS Final Report (Lockheed Missiles and Space Co.) 15 p HC $3.00

CSCL 20H

G3/24

N73-31638

Unclas

15396

Lockheed

MISSILES & SPACE COMPANY

A GROUP DIVISION OF LOCKHEED AIRCRAFT CORPORATION

SUNNYVALE, CALIFORNIA

Enclosure (1) to LMSC/D350709
1 June 1973

FINAL REPORT
ANALYSIS OF LOW-ENERGY ELECTRONS

Contract NASw 2253

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FINAL REPORT

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This was a cooperative research program undertaken by the Lockheed Palo Alto Research Laboratory (LPARL) and the Massachusetts Institute of Technology (MIT) to analyze simultaneous observations of low-energy electrons in the plasma sheet and in the auroral zone. Data from the MIT Plasma Experiment on the OGO-3 satellite and from the Lockheed experiment on the OV1-18 satellite (1969-25B) were processed and intercompared. The principals involved were Professor Vytenis M. Vasyliunas of MIT and Dr. Richard D. Sharp of Lockheed. This report describes the effort expended and the results obtained under the Lockheed portion of the program.

1. Lockheed Experiment Description

The Air Force satellite OV1-18 was launched on 18 March 1969 into a 99° inclination orbit with apogee at 590 km and perigee at 469 km. An experiment by the Lockheed Palo Alto Research Laboratory included an assortment of low-energy particle detectors designed to measure the intensity, angular and energy distributions of the auroral electrons and protons in the energy range below about 50 keV. The detectors of primary interest for the comparison with the MIT plasma experiment are a set of 13 magnetic electron spectrometers. They utilize channel-electron-multipliers as the sensing elements and cover the energy range from 0.8 to 37 keV. They are similar in design to the Lockheed detectors flown on the ATS-5 satellite and have been described in the literature[1]. A matched set of four of these detectors was positioned at each of three angles spanning a range of 90°. The characteristics of the individual detectors are shown in

[1] "A Low-Energy Channel-Multiplier Spectrometer for ATS-E," R. D. Reed E. G. Shelley, J. C. Bakke, T. C. Sanders and J. D. McDaniel, IEEE Trans. Nucl. Sci., NS-16, 359, Feb. 1969; "Channel-Multiplier Instrumentation for the Measurement of Low-Energy Auroral Particles," M. F. Shea, G. B. Shook, J. B. Reagan, L. F. Smith, and T. C. Sanders, IEEE Trans. Nucl. Sci., NS-14, 96, 1967.

Table I. The other instruments comprising the satellite payload included a set of three scintillator-photomultiplier threshold detectors which measured the lower energy electron fluxes (thresholds at 0.2 and 1.2 keV) at three different angles, and various foil threshold detectors measuring the more energetic electrons as well as an assortment of proton detectors. Due to a malfunction in the stabilization system, the satellite is slowly tumbling. A three-axis magnetometer provides aspect information, however, and for the purposes of this intercomparison, no serious degradation of the data results from the tumbling.

2. Computer Programs

A substantial amount of effort under this contract was devoted to the development of two computer programs which were required for the reduction of the OV1-18 data. These are described below.

2.1 Survey Program

Modifications and revisions were made to a previously-existing computer program for unpacking the Air Force-supplied digital tapes and producing survey plots showing the outputs of the various detectors on the satellite as a function of time on a scale of approximately 100 seconds per cm. These plots are needed to evaluate the quality of the data and the magnitude of any background corrections which are applied in later stages of the analysis. The program also produces as output a computer-compatible digital tape containing the satellite data in a suitable form for further analysis on the Lockheed computers.

As has been indicated, the OV1-18 satellite was tumbling and this introduced occasional backgrounds to the detectors due to scattered ultraviolet light and to the ambient cold plasma when the detectors were pointing in the direction of the velocity vector. In order to evaluate these effects, the outputs of all 48 low-energy particle detectors contained in the payload were included in the survey plot outputs. These included

Table I. CHARACTERISTICS OF PERMANENT MAGNET-ELECTRON SPECTROMETERS ON OV1-18

Detector	Energy Range	Geometric Factor	Nominal Pointing Angle (With Respect to Zenith)	Angular Acceptance Full Angle in Degrees	Sensitivity Threshold Particles/ cm^2-sec
Group 1					
CME-1A	0.8-1.5	0.79×10^{-5}	0°	10x10	4×10^5
CME-1B	1.75-3.3	0.81×10^{-5}	0°	10x10	3×10^5
CME-1C	3.75-7.0	0.96×10^{-5}	0°	10x10	3×10^5
CME-1D	8.3-16.3	0.26×10^{-4}	0°	10x10	1×10^5
CME-1E	17.3-37.0	0.40×10^{-4}	0°	10x10	5×10^4
CME-1F	Penetrating Background	---	0°	---	---
Group 2					
CME-2A	0.8-1.5	0.67×10^{-5}	55°	10x10	3×10^5
CME-3B	1.8-3.3	0.84×10^{-5}	55°	10x10	3×10^5
CME-3C	3.75-7.0	0.98×10^{-5}	55°	10x10	2×10^5
CME-2D	8.2-16.5	0.22×10^{-4}	55°	10x10	1×10^5
CZU-2	Ultraviolet Background	---	55°	---	---
Group 4					
CME-4A	0.8-1.5	0.69×10^{-5}	90°	10x10	4×10^5
CME-4B	1.8-3.25	0.94×10^{-5}	90°	10x10	3×10^5
CME-4C	3.7-7.0	0.85×10^{-5}	90°	10x10	4×10^5
CME-4D	8.4-16.3	0.25×10^{-4}	90°	10x10	7×10^4

ultraviolet and penetrating radiation background detectors. A typical section of this output (for one of the coordinated cases), including data from four of the electron spectrometers used in this analysis, is shown in Figure 1. The voltage outputs shown are approximately logarithmically related to count rate over a four-decade dynamic range. Ephemeris information, magnetic local time (AT = auroral time), and L values are computed in a separate program.

2.2 Plasma Properties Program

A computer program which takes the unpacked digital tape produced as output by the survey program and computes the various plasma properties at one-second intervals as a function of Universal Time (UT) and pitch angle was developed specifically for this project in a form agreed upon in the course of discussions with Vasyliunas. This is a versatile program which has provisions for easy modification of spectral shape assumptions, background levels, detection efficiencies, etc. It produces a series of ten plots showing, as a function of time:

- The gross counting rates of the thirteen relevant detectors (3 plots);
- Pitch-angle distributions at one-second intervals (1 plot);
- Electron spectra at each of three pitch angles at one-second intervals (3 plots); and
- The electron plasma properties: number flux, number density, flux-weighted average energy and density-weighted average energy, at each of three pitch angles at one-second intervals (3 plots).

In addition, it sorts the events into 15 categories depending on the number of channels responding above their in-flight calibration levels in order to allow for the utilization of different approximations for the different classes of events. Some typical outputs of this program are shown in Figures 2 through 5.

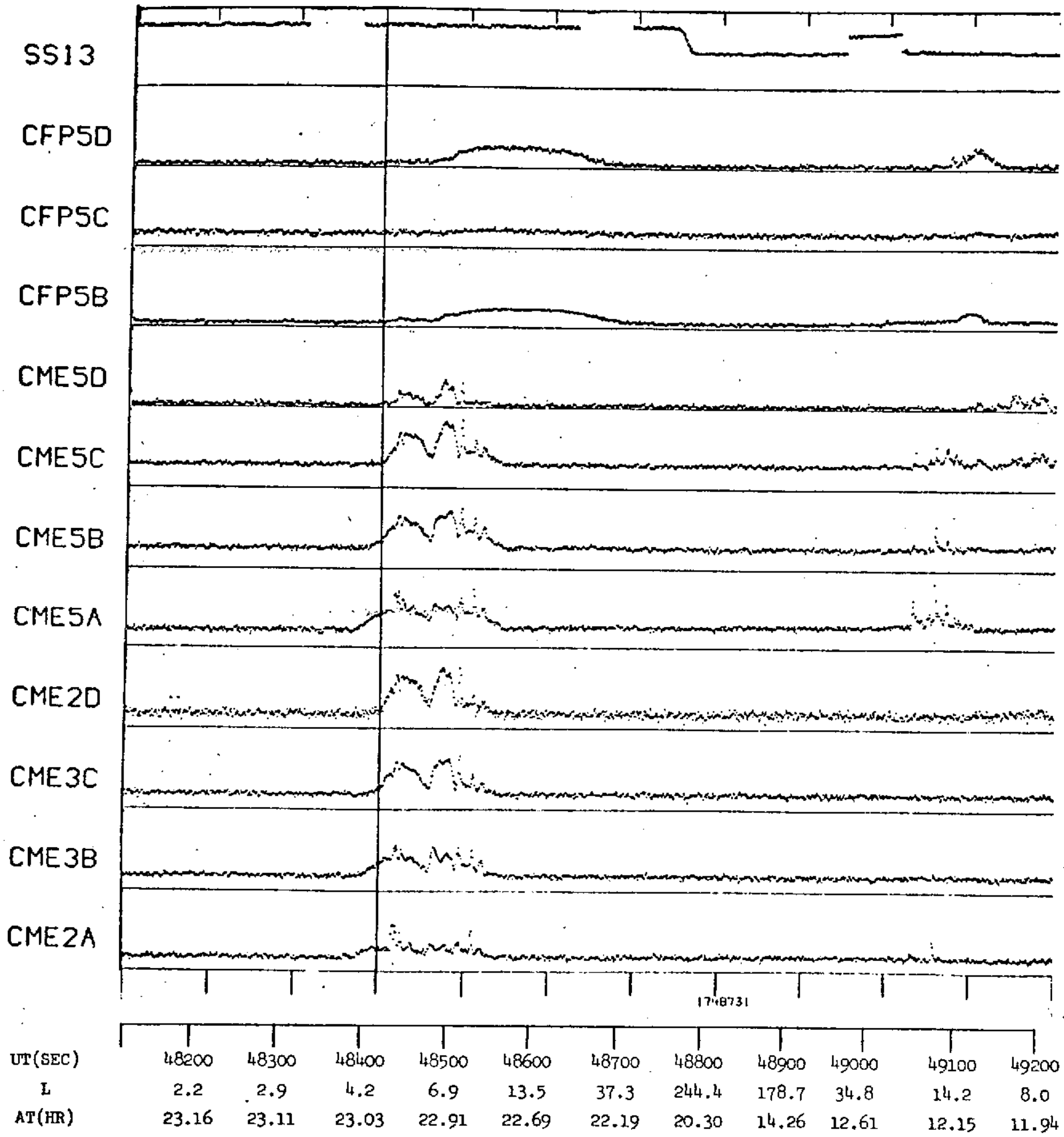
SS13
CFP5D
CFP5C
CFP5B
CME5D
CME5C
CME5B
CME5A
CME2D
CME3C
CME3B
CME2A
UT(SEC) 48200 48300 48400 48500 48600 48700 48800 48900 49000 49100 49200
L 2.2 2.9 4.2 6.9 13.5 37.3 244.4 178.7 34.8 14.2 8.0
AT(HR) 23.16 23.11 23.03 22.91 22.69 22.19 20.30 14.26 12.61 12.15 11.94

FIGURE 1

Figure 2 shows the count rates of the group 2 electron detectors for a portion of the pass illustrated in Figure 1. They are semi-log plots with the ordinate beginning at one count/sec. Each division represents one decade and the curves are offset from each other by two decades. The abscissa is UT in seconds.

Figure 3 shows the pitch-angle distributions of the integral number fluxes in the range ($0.8 \leq E \leq 17$ keV). The asterisks represent the group 1 detectors, the circles the group 2, and the crosses the group 4 (See Table I). Each square represents a one-second measurement with ten of them stacked vertically in a region of abscissa corresponding to the ten seconds of UT over which the measurements were acquired (time progresses from top to bottom). The UT scale matches that of Figures 2, 4 and 5. The abscissa of each individual square is pitch angle over the range 0^o (particles coming down the field line) to 180^o (particles going up). Since the vehicle is tumbling these values change slowly with time. The ordinate is flux on a logarithmic scale from 10^6 to 10^{10} $(cm^2\text{-sec-sterad})^{-1}$.

Figure 4 shows normalized electron spectrums from the four group 2 detectors with a stacking arrangement similar to Figure 3. Energy is plotted approximately logarithmically along the abscissa of the individual squares (See Table I for the actual energy values). The ordinate is a two-decade logarithmic scale normalized to the peak value in units of $(cm^2\text{-sec-sterad-keV})^{-1}$.

Figure 5 shows the computed plasma properties from the group 2 detectors ($0.8 \leq E \leq 17$ keV) as a function of UT. From top to bottom are: 1) integral number flux on a four-decade log scale over the range 10^6 to 10^{10} $(cm^2\text{-sec-sterad})^{-1}$; 2) number density on a four-decade log scale over the range 10^{-3} to 10^1 (cm^{-3}); 3) flux-weighted average energy on a linear scale from 0 to 20 keV; 4) density weighted average energy on the same scale as 3); and 5) pitch angle on a linear scale from 0^o (particles coming down) to 180^o (particles going up).

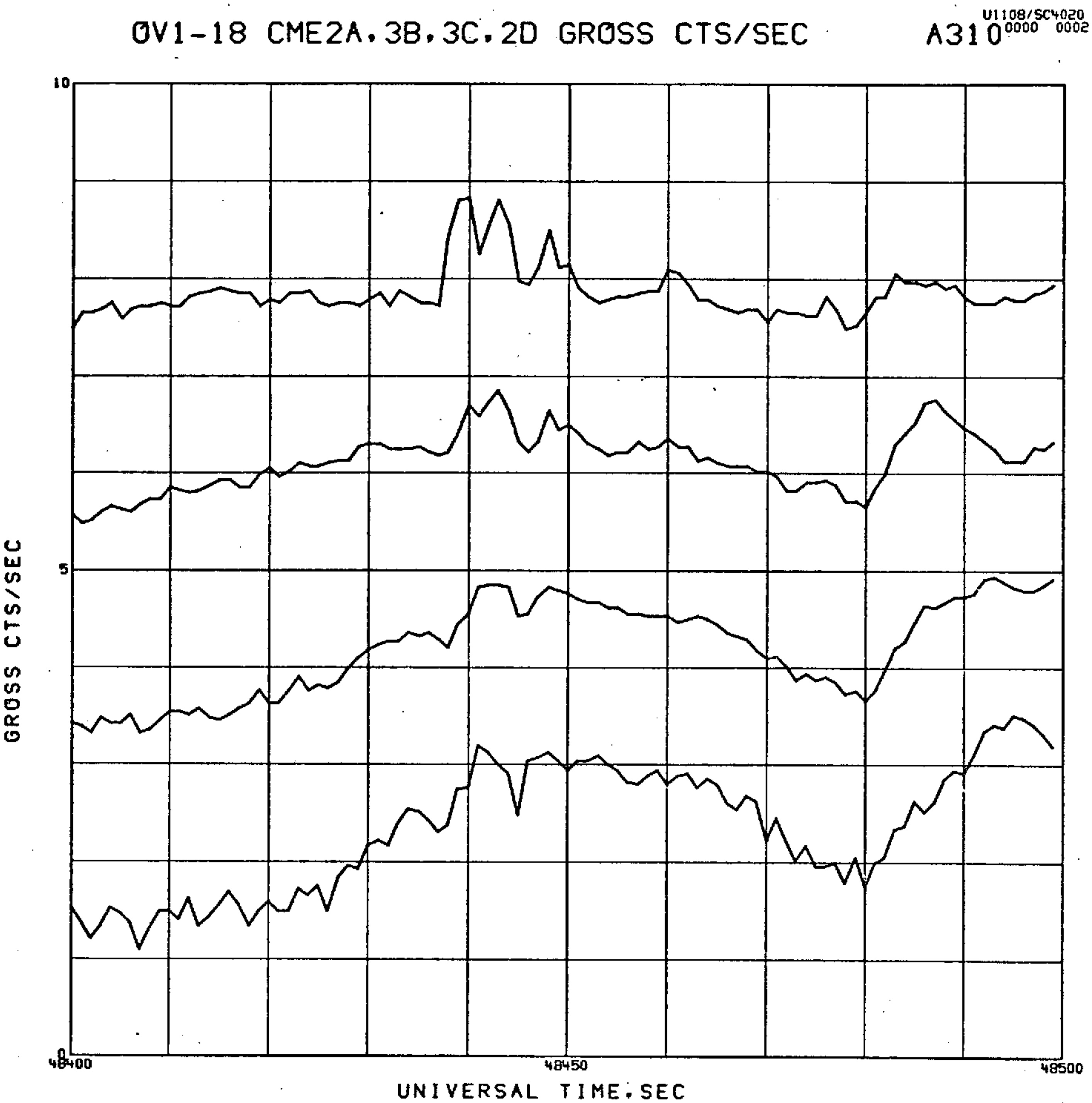
OV1-18 CME2A,3B,3C,2D GROSS CTS/SEC
U1108/SC4020
A310 0000 0002
10
5
0
GROSS CTS/SEC
48400
48450
48500
UNIVERSAL TIME,SEC

FIGURE 2

OV1-18 PITCH ANGLE DISTRIBUTION

U1108/SC4020

A310 0000 0004

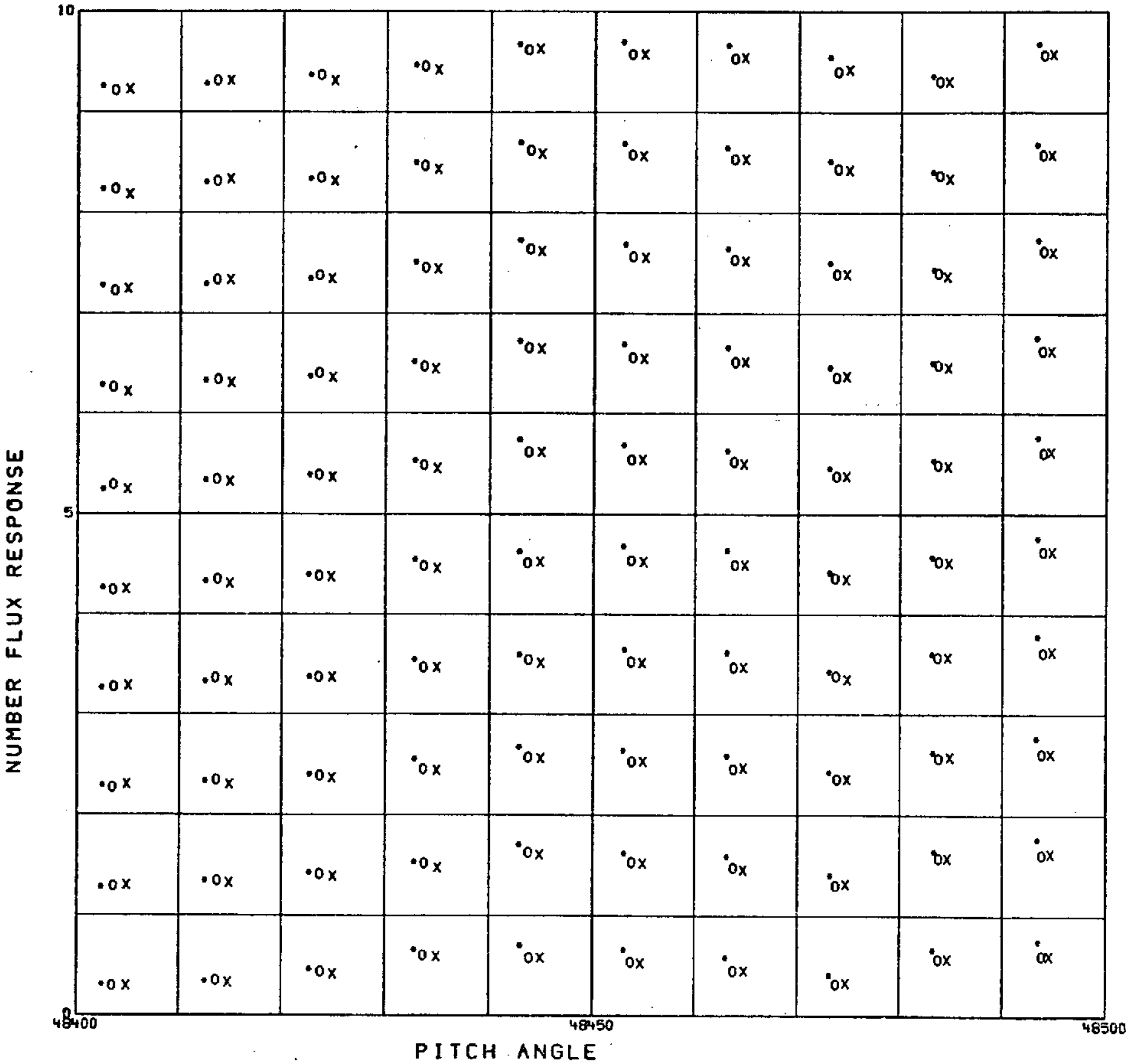

FIGURE 3

OV1-18 GRP 2 ELECTRON SPECTRA A310

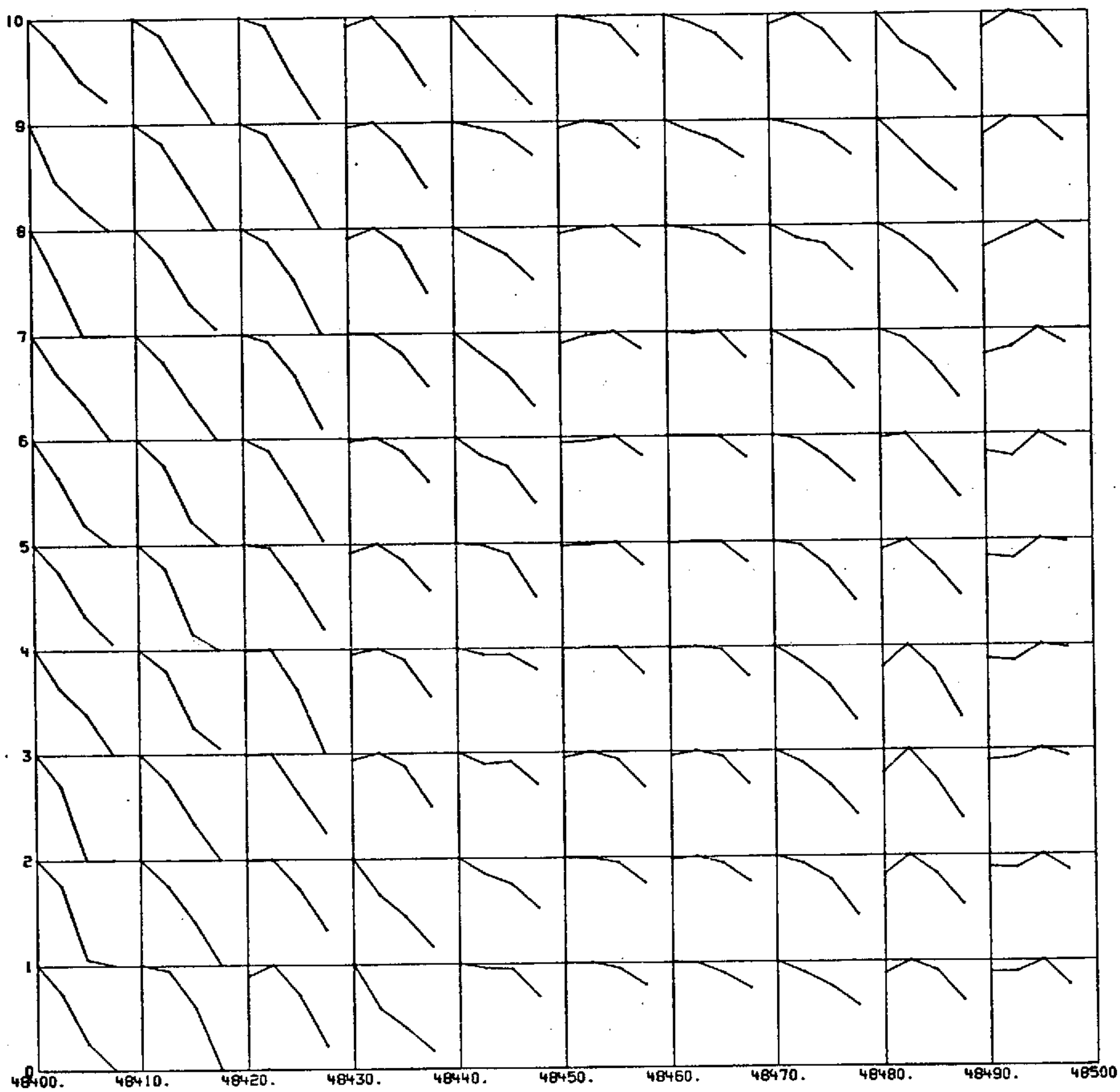

FIGURE 4

ØV1-18 PLASMA PRØPERTIES GRP 2

A310

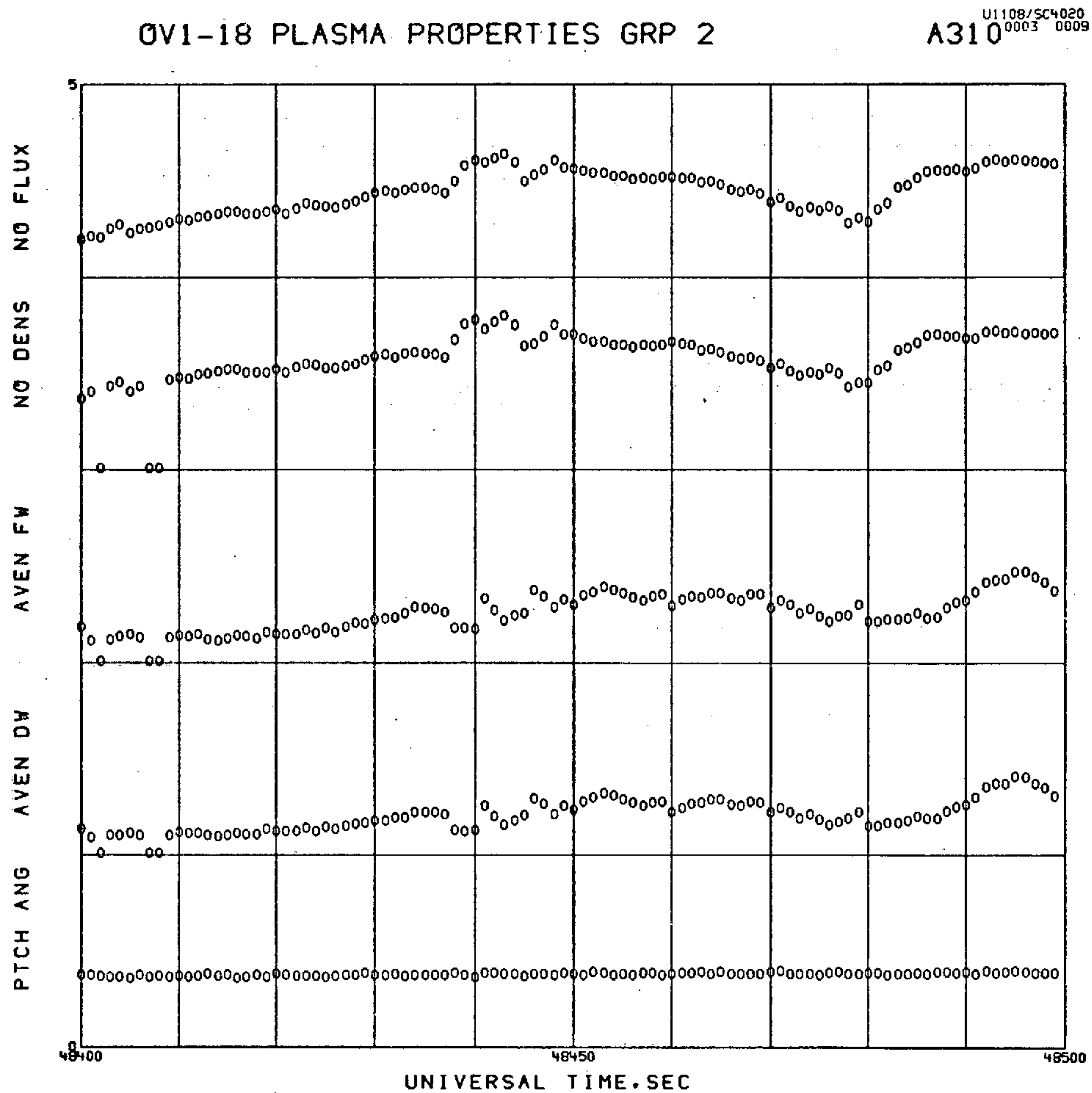

FIGURE 5

3. Analytic Approximations

Several different approximations were investigated for the computation of the plasma properties from the outputs of the four or five broadband spectrometers oriented at any one pitch angle. Initial calculations were done with an equivalent rectangular response function for the spectrometers and a simple histogram approximation to the electron spectrum shape. The upper channels were fairly broad, however, particularly in the group 1 detectors (See Table I) and since the flux was generally falling off rapidly with increasing energy in this range, we investigated some more realistic approximations. In one study, an assumed exponential flux shape was fitted to the two upper channels of the group 1 detectors by using the laboratory-measured response functions and the plasma properties were computed from this exponentially falling flux at the higher energies and the assumed histogram flux shape at the lower energies. We processed considerable data to compare this approximation with the more simple approximation and concluded that the differences were generally in the range of 20 to 30 percent. We felt that this precision was sufficient for satisfying the principal objectives of this program and since there was a decided advantage to using the same approximations for all angular groups, we settled on the histogram approximation for the final analysis.

4. Results

A preliminary field line mapping technique was developed by Vasyliunas in order to project the OGO-3 position down to the altitude of the OV1-18 orbit and determine the approximate coordination time. We utilized this technique to select the most favorable half of the initially available cases (when OGO-3 was located in the plasma sheet at local times near those at which OV1-18 crossed the auroral zone) for processing and examined the survey plots in each case in order to determine the quality of the data, the approximate flux intensity, the degree of spatial and temporal structure and the magnitude of the background phenomena. Then we processed these cases through our plasma properties program. At that point (Dec. 1971) we decided to postpone any further effort until the OGO data became available. Due to a changeover in computers at MIT, there was an unavoidable delay of about one year before these data could be processed. At that time (Dec. 1972) it became apparent that on more than half of the original cases, OGO data would not be available because of data gaps, missing tapes, etc. A total of 32 cases remained and we processed the OV1-18 data for those of them that had not previously been analyzed and did the further detailed analysis of the in-flight calibration data necessary to insure the quantitative precision of the computed plasma properties.

At that time (April 1973) we exchanged data with Vasyliunas and were able to make our first preliminary intercomparisons. The results look quite promising. Clearly apparent signatures of the expanding and contracting plasma sheet are evident in the OGO data. The OV1-18 data generally exhibit the high degree of variability associated with substorm controlled phenomena. After discussion with Vasyliunas we agreed that the next step should be a study of ground-based magnetograms during the period of interest, and a further refinement of the field line tracing technique in order to establish more accurately the time of the coordination. Vasyliunas has had considerable experience in both these areas and he indicated that he would undertake these tasks. At this point our resources under this grant are expended and we cannot undertake any further extensive analysis effort. However, we will participate in the final writeup of the results for publication.