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SEMI-ANNUAL STATUS REPORT

for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Grant NGR 05-002-160

for

1 April 1970 - 30 September 1970

CASE FILE
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California Institute of Technology

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The present report covers the research activities in cosmic rays and interplanetary magnetic fields and plasmas which for the past seven years had been supported mainly with funds from NASA Grant NGL 05-002-007. During the period 1 October 1969 - 31 March 1970, the above activities were supported partially with remaining funds from NASA Grant NGL 05-002-007 and with new funds from NASA Grant NGR 05-002-160. Henceforth the activities in cosmic rays and interplanetary fields and plasmas will be supported completely under NASA Grant NGR 05-002-160.

The report is divided into sections which describe the various separate but interrelated activities, followed by a summary of staff, expenditures, and a bibliography.

For the benefit of the reader who may not be interested in technical detail, the report opens with a brief summary of the various activities.

SUMMARY

I. Cosmic Rays (Vogt, Stone, and Fanselow)

This group's research program is directed toward the investigation of the astrophysical aspects of cosmic radiation and the radiation environment of the earth by means of particle-detector systems flown on spacecraft and balloons. The main efforts of the group have been directed toward the following three categories of experiments.

A. Experiments on NASA Spacecraft

1. A satellite experiment launched on OGO-4 on 28 July 1967. This experiment, which is being carried out jointly by E. C. Stone at Caltech, J. A. Simpson at the University of Chicago, and C. Y. Fan at the University of Arizona, is measuring the time-dependent energy spectra of protons (1.2 to 40 MeV), alpha particles (4 to 160 MeV), and electrons (0.4 to $\sim$ 1 MeV). Results of three different studies will be presented at the Fall Meeting of the American Geophysical Union. J. W. Brown, a graduate student, has investigated the latitude and local time dependence of electron precipitation "spikes", finding one population to be associated with energetic particles in the magnetosheath and a second population to be due to pitch angle scattering of trapped radiation. L. C. Evans, a doctoral candidate, has identified the rapid access of solar electrons into the polar region and is combining these results with those for protons in constructing a model for the access of energetic solar particles into the magnetosphere. Dr. J. L. Fanselow has studied magnetospheric rigidity cutoff effects and has determined that the anomalously low cutoff latitudes cannot be attributed to diffusion inward from the calculated access region.

2. A satellite experiment launched on OGO-6 on 5 June 1969. This experiment is measuring the differential energy spectra of protons and alpha particles between 700 keV and 1 GeV/nucleon and of electrons between 1 MeV and 500 MeV. The differential measurements can be extended to 15 GV by using the geomagnetic field. This broad energy range will permit detailed studies of the solar modulation of galactic cosmic rays, the acceleration and interplanetary propagation of solar cosmic rays, and the penetration of charged particles into the magnetosphere. Results from S. S. Murray's doctoral dissertation on the propagation of solar flare protons will be presented at the Fall Meeting of the American Geophysical Union. These results indicate that for low energy protons ($<$ 10 MeV) the effects of convection and adiabatic deceleration rather than diffusion dominate the decay phase of

the 7 June 1969 flare event. A second doctoral student, J. E. Lupton, is extending the propagation studies.

3. A satellite experiment to be flown on IMP-H and -J in 1971 and 1972. This experiment is designed to measure the differential energy spectrum of electrons (0.18 to 2.8 MeV) and the differential energy spectra of the nuclear isotopes of hydrogen, helium, lithium, and beryllium (0.5 to $\sim$ 50 MeV/nucleon). This experiment will allow studies of solar and galactic cosmic rays and of magnetospheric acceleration of charged particles and the interrelation of those particles to the particles trapped in and precipitated from the magnetosphere. This group has continued to assume responsibility for the solid state detector, scintillator, and photomultiplier test and evaluation programs and for the software aspects of the ground support equipment (GSE). In addition, this group has recently assumed the responsibility for the completion of the GSE hardware. Due to a funding reduction in January, 1970, the subcontractor was forced to interrupt fabrication for 3 months at the end of FY 70. Fabrication has since resumed and electronic modules are being combined into sub-assemblies.

4. A satellite experiment to be flown on HEAO-A.
This experiment has been proposed jointly by this group and M. H. Israel and J. Klarmann (Washington University), W. R. Binns (McDonnell-Douglas Research Laboratories), and C. J. Waddington (University of Minnesota) and is designed to measure the chemical abundances of relativistic high-Z cosmic ray nuclei ($17 \leq Z \leq 130$). The results of such measurements are of significance to the studies of nucleosynthesis and stellar structure, the existence of extreme transuranic nuclei, the origin of cosmic rays, and the physical properties of the interstellar medium. This group's efforts have been directed toward experiment design and proposal preparation, initially as an independent group and then as a member of the collaboration which was formed at NASA's request.

B. Experiments Performed under the NASA Balloon Program.

These experiments generally are either prototypes of experiments on existing or future NASA spacecraft, or they complement such observations.

1. A balloon-borne proton-alpha-electron (pαe) spectrometer which is essentially identical to the above described OGO-6 satellite detector system. Due to curtailments in balloon support, only one flight with the pαe gondola could be scheduled for the 1970 Skyhook program at Ft. Churchill. The flight (see Table I) was timed to occur simultaneously with polar passes of the equivalent detector system aboard OGO-6, and both instruments performed successfully. A series of extensive calibrations of the pαe and OGO-6 detector systems on particle accelerators was completed with runs on the Berkeley 184" cyclotron (see part C). A study of the long term solar modulation effects on protons and alpha particles, based upon pαe data collected over the 1966-1970 interval, has been initiated. Also under investigation are the proton and alpha observations performed simultaneously with the pαe and OGO-6 detector systems in 1969-1970. This work will form part of the doctoral dissertation of T. L. Garrard.

2. A balloon-borne magnetic spectrometer (e±) for the investigation of the energy spectra of negatrons and positrons in the 12 to 800 MeV/c momentum range. The energy range of the instrument, which formerly covered the 10 to 200 MeV region was extended to about 800 MeV by the incorporation of a larger bending magnet and a gas Čerenkov counter. The modified spectrometer was flown four times from Ft. Churchill, Manitoba, during the 1970 Skyhook program for studies of the primary cosmic-ray electron spectrum. Analysis of the 1968 and 1969 e± data has been continued.

   A paper on magnetospheric phenomena ("Diurnal Geomagnetic Cutoff Variations for Positrons and Negatrons near $\Lambda=68^{o}$)," based upon the e± balloon observations, was presented at the Spring Meeting of the American Geophysical Union.

A paper on the propagation of cosmic-ray produced electrons and photons in the atmosphere and the analysis of electron measurements made in the atmosphere has been submitted for publication (K. P. Beuermann: "Secondary Electrons and Photons in the Upper Atmosphere").

Investigations and testing of pressure recording devices for high altitude balloon flights were continued.

C. Experiments on Particle Accelerators.

The accelerator version of the pαe and OGO-6 range telescope (see Status Report NGL 05-002-007 of 1 April to 30 September 1969) has been calibrated with the α-particle beam of the 184" cyclotron of the Lawrence Radiation Laboratory. These results, and those obtained with the proton beam of the synchrocyclotron of NASA's Space Radiation Effects Laboratory, are used with a Monte Carlo type computer calculation to correct the pαe and OGO-6 data for the effects of nuclear interactions in the detector system.

II. Cosmic Rays (Neher, George)

Studies of the behavior of quasi-trapped particles at the edges of the solar plateau have been essentially completed using the ionization chamber data from OGO-2. The physical interpretation of the differences between these and previous results is presently under study. In addition, ion chamber observations of electron precipitation spikes on OGO-4 were correlated with the charged-particle telescope observations by Brown and Stone on the same satellite.

III. Interplanetary Magnetic Field and Plasmas (Davis, Jokipii, Hollweg, Scholer)

Much of the work during the last six months was related to the nature and source of the observed fluctuations in magnetic and plasma parameters and to the effects of inhomogeneities on the propagation of cosmic rays and radio waves in interplanetary space.

1. The analysis by J. W. Belcher, a graduate student, and L. Davis of the outwardly propagating Alfvén waves has been organized on the basis of the solar wind velocity structure. The waves are quite strong and quite pure in the high velocity parts of the streams, including the first half of the return to low velocity. It seems probable that these waves have propagated outward from the lower corona and that they are derived from the waves that heat the corona. The waves are strongest, but not so purely Alfvénic, near the parts of the solar wind streams where the velocity increases rapidly and the high velocity stream is interacting with preceding lower velocity plasma. The high amplitudes and mixed modes may be due partly to local generation of Alfvén and magnetoacoustic waves in this interaction region and partly to amplification and conversion of the Alfvén waves of coronal origin in a region of compression and bending of the field lines.

2. Theoretical work on the propagation of cosmic rays in the solar wind was continued by Jokipii. A lengthy review paper on the modern statistical theory of cosmic-ray transport in the solar wind has been completed for Reviews of Geophysics and Space Physics. It was found that the boundary condition usually applied at the sun in the theory is obviously not correct; further study of this problem is in progress.

3. The earlier work by Jokipii, partially in collaboration with Hollweg, on the scintillation of radio sources produced by inhomogeneities in the solar wind was continued and a start made on extending it to pulsar scintillations produced by density fluctuations in the interstellar medium.

4. Dr. M. Scholer, who had worked in the group for a year on a NASA post-doctoral fellowship, returned to Munich early in September, and Dr. J. V. Hollweg joined the group in August. Dr. Scholer, in collaboration with J. W. Belcher, completed a study of the influence of Alfvén waves on fast magnetohydrodynamic shock waves. Dr. J. V. Hollweg is investigating theoretical aspects of Alfvén waves in the solar medium, including their generation by the supergranular motions in the photosphere, their possible contribution to solar wind heating, and the properties of large amplitude Alfvén waves.

FURTHER DESCRIPTION OF ACTIVITIES

I. Cosmic Rays (Vogt, Stone, Fanselow)

The e± Magnetic Spectrometer

The activities on this project were concentrated upon the preparation and execution of balloon observations and the analysis of data from balloon flights in 1968 and 1969.

The e± magnetic spectrometer used in the 1968 and 1969 studies has been described in Status Report NGL 05-002-007 for 1 April 1968 to 30 September 1968 and in the doctoral dissertation of C. J. Rice ("Primary Cosmic-Ray Positrons and Negatrons in 1968 at Energies between 11 and 204 MeV"). For the 1970 observations, the differential energy range of the e± spectrometer was extended to about 800 MeV by the incorporation of a larger bending magnet (2.3 kG) and a gas Čerenkov counter (See Status Report NGL 05-002-007 for 1 April to 30 September 1969 and NGR 05-002-160 for 1 October 1969 to 31 March 1970).

A series of four balloon flights with the e± spectrometer was made from Fort Churchill, Manitoba, under the 1970 Skyhook program. A flight log is presented in Table I. Flight 70C3M used a 10.6 million ft^3 balloon equipped with contractor supplied valves to allow float levels at several atmospheric depths. The flight did not reach its objectives since the valves failed to close upon command, causing uncontrolled descent with an emergency termination of the flight. No spare balloons were available in the 1970 program, and the reflight had to be performed with a much less desirable unvalved 10.6 million ft^3 balloon. The instrument modifications of the e± spectrometer performed well, and the data analysis has begun.

A paper on magnetospheric phenomena ("Diurnal Geomagnetic Cutoff Variations for Positrons and Negatrons Near $\Lambda=68^{o}$"), was presented at the 1970 Spring Meeting of the American Geophysical Union. The non-dipole character of the geomagnetic field, e.g., the presence of closed field lines at lower latitudes and essentially open field lines (geomagnetic tail) at higher latitudes, is reflected in the geomagnetic cutoff values for cosmic rays. Because of their low charge-to-mass ratio, electrons are particularly suited as probes of the geomagnetic cutoffs down to very low rigidities. Electron data have revealed a diurnal variation of the cutoff rigidities near Fort Churchill, ranging from about 100 MV at day to below 12 MV at night. Trajectory calculations for low rigidity particles in a

non-dipole model magnetosphere have been made by Smart, Shea and Gall. The resulting calculated cutoff rigidities versus local time are shown in Figure 1, their contours are labeled with geographic latitude λ and invariant latitude Λ for the 100^{o} West meridian. The data points resulting from this group's e± observations give the transition times from the day to night-time geomagnetic conditions at specific rigidities. The observed negatron and positron transition times are plotted separately, with local time mirrored through noon in accordance with the charge symmetry of the model calculations. All e± transitions occurred within $1/2^{o}$ of $\Lambda=68^{o}$ N and within 4^{o} of the 100^{o} W meridian appropriate to the calculations. One finds that the general level of the measured cutoffs versus local time agrees reasonably well with some of the calculated curves, giving qualitative support to this model of diurnal variations. However, the data seem to agree best with cutoff conditions calculated for invariant latitudes of 70^{o} to 74^{o}, i.e. 2^{o} to 6^{o} higher than the invariant latitude of the observations. Also, the predicted positron-negatron asymmetry does not appear. These discrepancies may indicate that the model magnetosphere used by Smart, Shea and Gall does not yet adequately describe actual conditions.

In the analysis of measurements taken on balloon flights the relatively small flux of primary cosmic-ray electrons in the 10 MeV to several hundred MeV energy range is difficult to separate from the often equally abundant atmospheric secondary electrons. This group therefore has devoted considerable effort to improvements of this analysis. The intensity of electrons is determined over a wide range of atmospheric depths and then analyzed with the help of detailed calculations on the secondary negatron and positron growth curves in the atmosphere. A description of the calculations has been submitted for publication (K. P. Beuermann: "Secondary Electrons and Photons in the Upper Atmosphere."). Figures 2 and 3, for example, show the intensities of negatrons and positrons respectively as a function of atmospheric depth. The solid data points represent atmospheric secondary fluxes measured near Fort Churchill in 1968, the phantom points indicate, for comparison, total fluxes (atmospheric secondaries plus cosmic-ray primaries) at float altitude. The solid lines show the atmospheric secondary intensities calculated by Beuermann on the basis of production spectra used by Perola and Scarsi. The dashed lines

give the best fit, using the calculated functional depth dependence and adjusting the absolute intensities used by Perola and Scarsi. The calculations show that the functional depth dependence of the electron intensity deviates considerably from the commonly assumed linear growth. Figure 4 gives the exponent n_i of a power law fit $f(x)\alpha x^{n_i}$ to the growth curves of the atmospheric secondary flux as function of energy. The solid curves give n for a fit to the 2 to 15 g/cm^2 depth interval, the dashed curves give n for the 15 to 40 g/cm^2 interval. The functional depth dependence varies only insignificantly with solar cycle changes, hence the results should be generally applicable.

The accuracy of the atmospheric secondary corrections obviously is directly related to the accuracy of the altitude determination. This group investigated the usefulness of the "Metrophysics" thermal conduction type pressure transducers, which are frequently used in Skyhook flights, by flying such an instrument simultaneously with "Wallace-Tiernan" aneroid type reference gauges. One must conclude that the thermal conduction type devices are unsuitable for precise altitude determination on vented balloons. (C. Todd: "The Effect of a Helium Contaminated Atmosphere on a Metrophysics Pressure Transducer, " SRL Internal Report #20). Figure 5 illustrates the response of a Metrophysics transducer to different helium-air mixtures, i.e. output voltage versus pressure. Figure 6 gives a typical example of the altitude profile of a balloon flight as seen by a Metrophysics transducer and the Wallace-Tiernan reference. The numbers attached to the Metrophysics data indicate roughly the percentage of helium contamination which would explain the deviation from the Wallace-Tiernan reference. Rough estimates, using a one-dimensional diffusion equation, indicate the possibilities of the quoted helium contaminations near the vented balloon.

During the 1970 Skyhook program, this group used a "Rosemount" capacitive type pressure transducer. This device shows promise for balloon flights as it is insensitive to the composition of the atmosphere and has very high overall accuracy (< 1%). The agreement with a Wallace-Tiernan reference aneroid was typically better than 0.2 g/cm^2. However, repeated calibrations have shown that zero shifts as large as 0.2 g/cm^2 can arise during a period of a month if the device is left at atmospheric pressure. Generally, much smaller shifts are noted if the calibrations are repeated often.

Experiments on Particle Accelerators

This group's OGO-6 and pαe detector systems use a range versus energy-loss technique for the measurement of the differential energy spectra of protons and helium below about 300 MeV/nucleon. If a particle undergoes a nuclear interaction in the material of the range telescope, its unique dE/dx versus range relationship may be sufficiently altered to cause errors in the determination of its charge and energy. In order to correct the data for the effects of nuclear interactions a special computer program (FLINT) has been developed. FLINT uses Monte Carlo techniques to calculate the probability of a proton or alpha particle of a given energy having a certain range in the telescope stack. Cross-sections for nuclear interaction processes are needed as input parameters for FLINT. Their values, in the initial calculations, are based on nuclear emulsion results from cosmic-ray data, on accelerator measurements, and on Monte Carlo calculations. The program is affected by two major errors. First, the available emulsion data generally have poor statistics and the possibility of systematic errors. Secondly, no results are available on correlations between secondary particles from an interaction; the measurement of statistically significant correlations in interactions producing on the order of 10 secondaries would require forbiddingly large amounts of accelerator time. For these reasons, the initial FLINT results are being compared with results from a direct accelerator calibration of a special "fast" version of the OGO-6 pαe instrument. (See Status Report NGL 05-002-007, 1 April - 30 September 1969). The accelerator data are being used to adjust the input parameters of FLINT for optimal agreement. Calibrations were performed at the 600 MeV synchro-cyclotron of NASA's Space Radiation Effects Laboratory (Langley) with protons at energies ranging from 115 MeV to 570 MeV. Alpha-particle calibrations at 187 MeV/nucleon and 213 MeV/nucleon were performed at the 184" cyclotron of the Lawrence Radiation Laboratory (Berkeley). An example of initial (pre-calibration) FLINT results and the corresponding acceleration derived data points is shown in Figures 7 and 8. Given are the percentages of protons (or α-particles) as function of energy which stop in a certain telescope range interval (34 to 66 g/cm^2 W equivalent) without triggering the anticoincidence shield. The statistical uncertainities of the FLINT calculations are roughly comparable to those of the measured calibration points. After a best-fit adjustment has been made, the FLINT results will be combined with energy-

loss calculations (based upon theory and direct accelerator calibrations) to create a response function for the OGO-6 and pαe range telescopes. The telescope response function will be used to accurately derive cosmic-ray spectra from the range-telescope data.

TABLE I: FORT CHURCHILL BALLOON FLIGHTS 1970

Caltech Flight No.	70C1P	70C1M	70C2M	70C3M	70C4M
Caltech Instrument	pαe	e±	e±	e±	e±
Raven Flight No.	1283	1289	1292	1296	1302
Balloon Size	$10.6 \times 10^6 ft^3$	$15 \times 10^6 ft^3$	$15 \times 10^6 ft^3$	$10.6 \times 10^6 ft^3$	$10.6 \times 10^6 ft^3$
Launch Date	6/22/70	6/25/70	7/5/70	7/11/70	7/18/70
Launch Time (UT)	06:02	00:33	02:50	17:57	23:44
Start Float (UT)	09:50	03:54	05:45	20:24	02:41
Termination (UT)	20:32	14:33	17:32	07:54	21:30
Float Altitude (g/cm^2)	2.1	2.3	2.4	3.5 (7hrs)*	3.7

*Valved balloon. Descended to 32 g/cm^2 in 3 hours, descent could not be stopped due to valve failure.

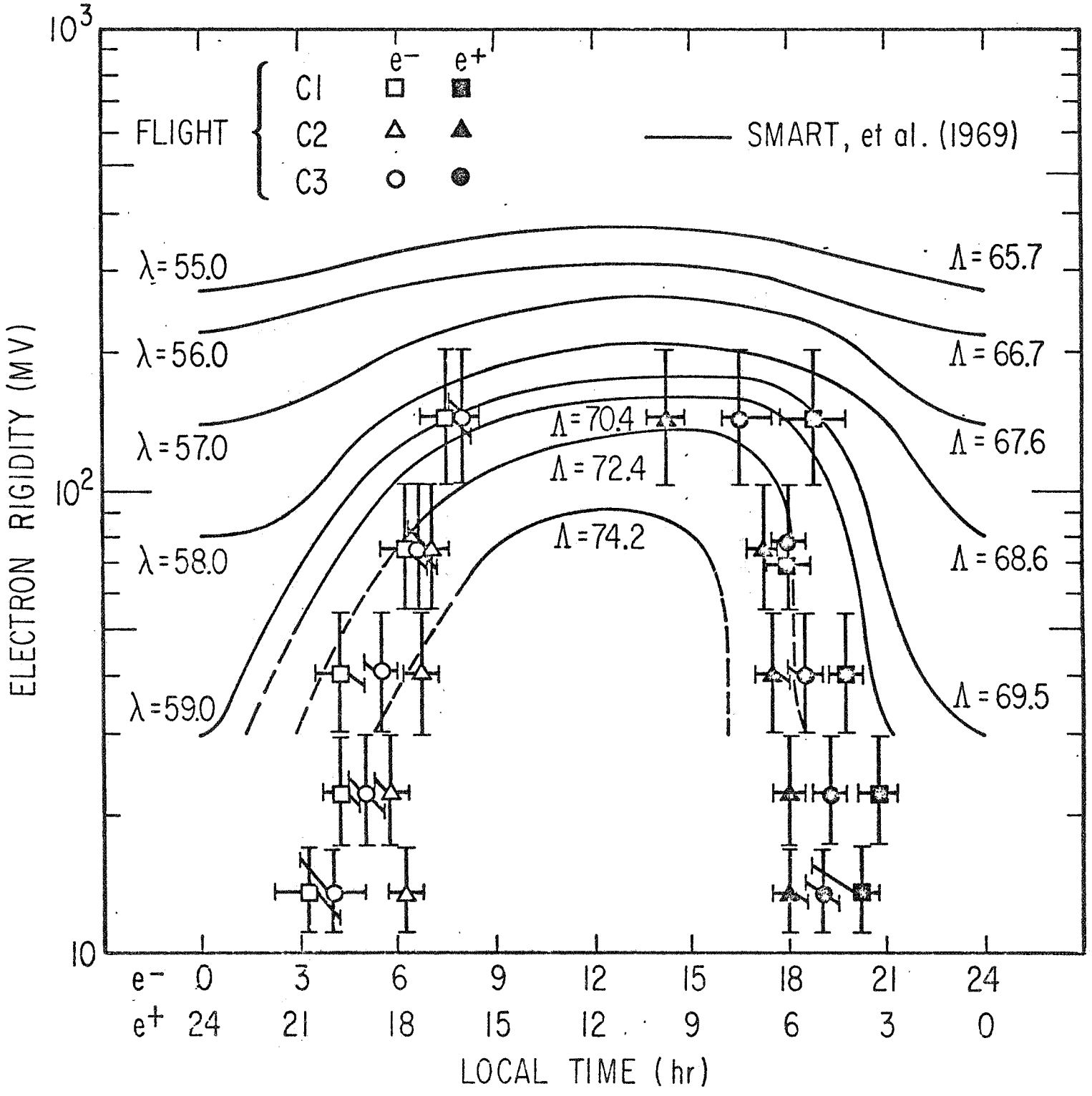
10^3
10^2
10
ELECTRON RIGIDITY (MV)
FLIGHT
C1
C2
C3
e−
e+
SMART, et al. (1969)
λ=55.0
λ=56.0
λ=57.0
λ=58.0
λ=59.0
Λ=65.7
Λ=66.7
Λ=67.6
Λ=68.6
Λ=69.5
Λ=70.4
Λ=72.4
Λ=74.2
e− 0 3 6 9 12 15 18 21 24
e+ 24 21 18 15 12 9 6 3 0
LOCAL TIME (hr)

Figure 1

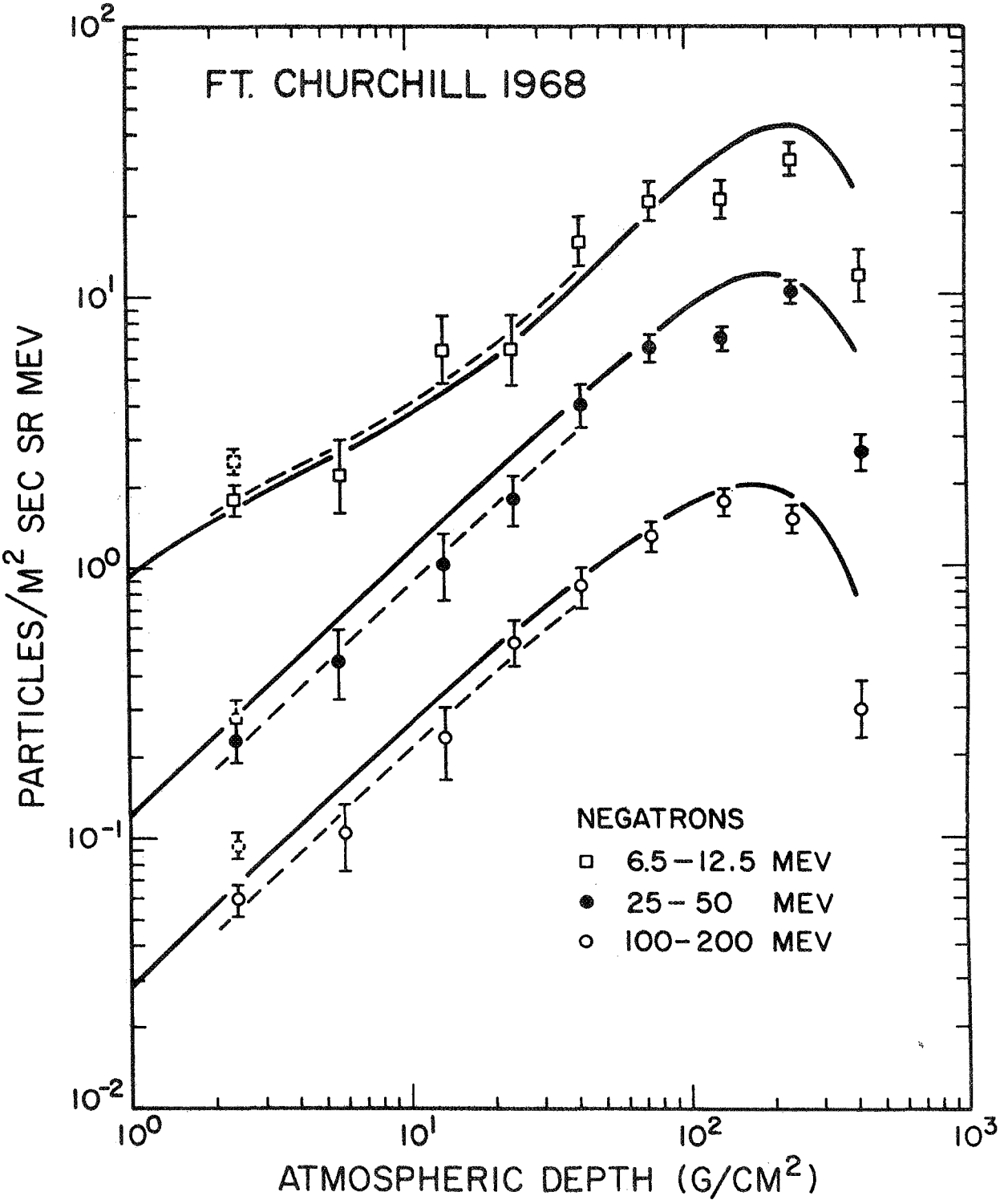
FT. CHURCHILL 1968
PARTICLES/M² SEC SR MEV
ATMOSPHERIC DEPTH (G/CM²)
NEGATRONS
6.5–12.5 MEV
25–50 MEV
100–200 MEV
10²
10¹
10⁰
10⁻¹
10⁻²
10⁰
10¹
10²
10³

Figure 2

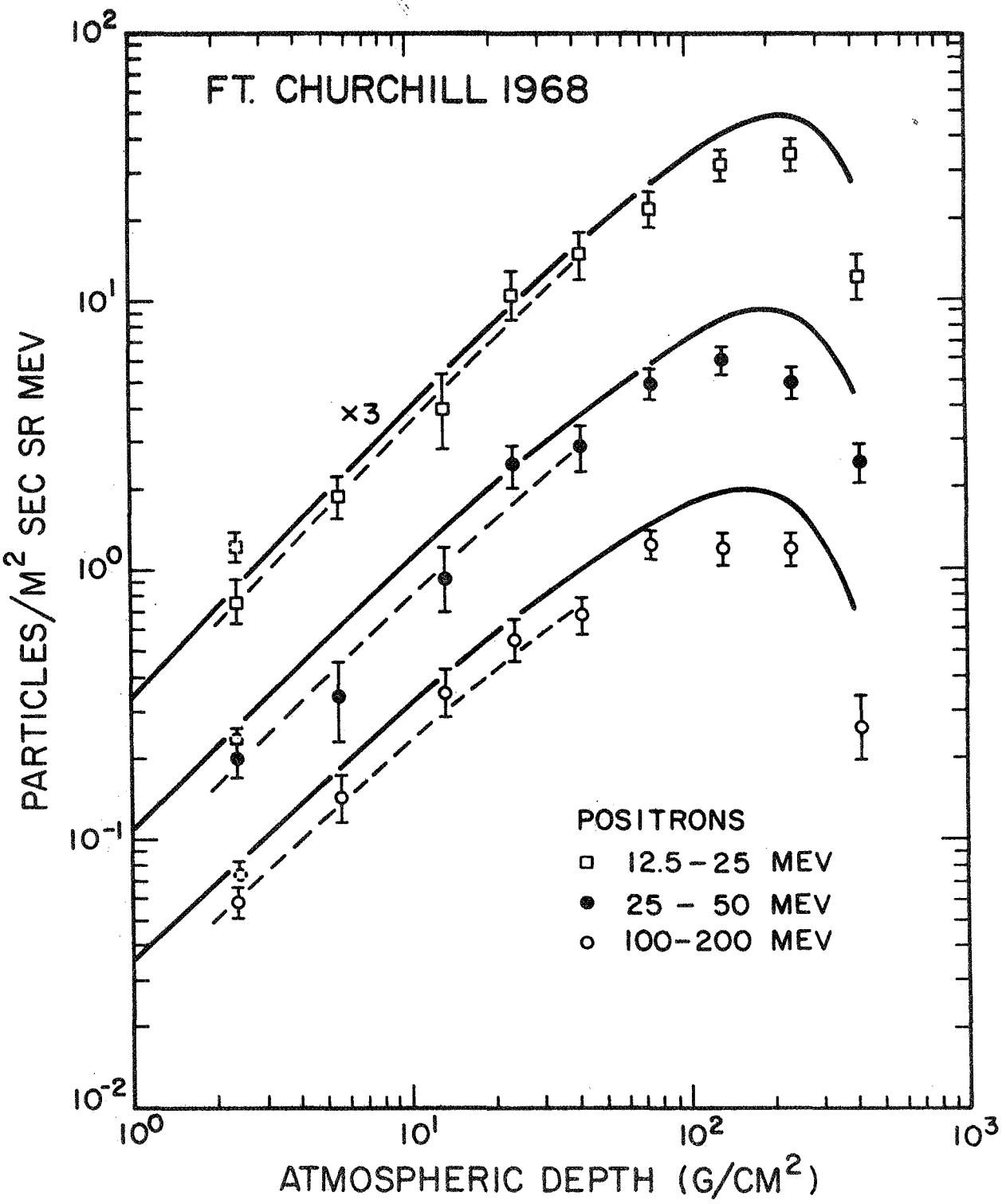
FT. CHURCHILL 1968
PARTICLES/M² SEC SR MEV
ATMOSPHERIC DEPTH (G/CM²)
×3
POSITRONS
12.5 – 25 MEV
25 – 50 MEV
100–200 MEV
10²
10¹
10⁰
10⁻¹
10⁻²
10⁰
10¹
10²
10³

Figure 3

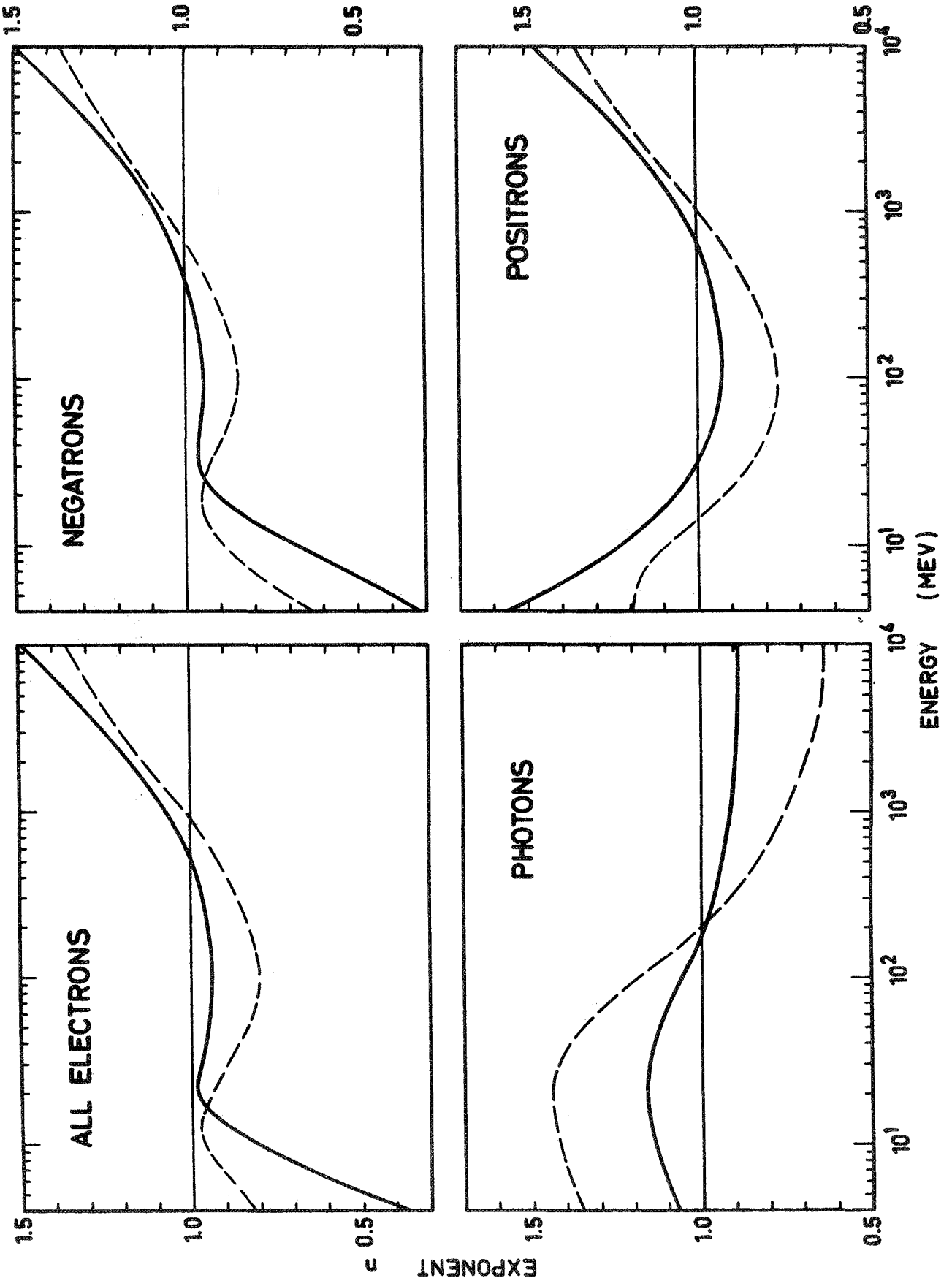
NEGATRONS
POSITRONS
ALL ELECTRONS
PHOTONS
EXPONENT n
ENERGY (MEV)
1.5
1.0
0.5
10^1
10^2
10^3
10^4

Figure 4

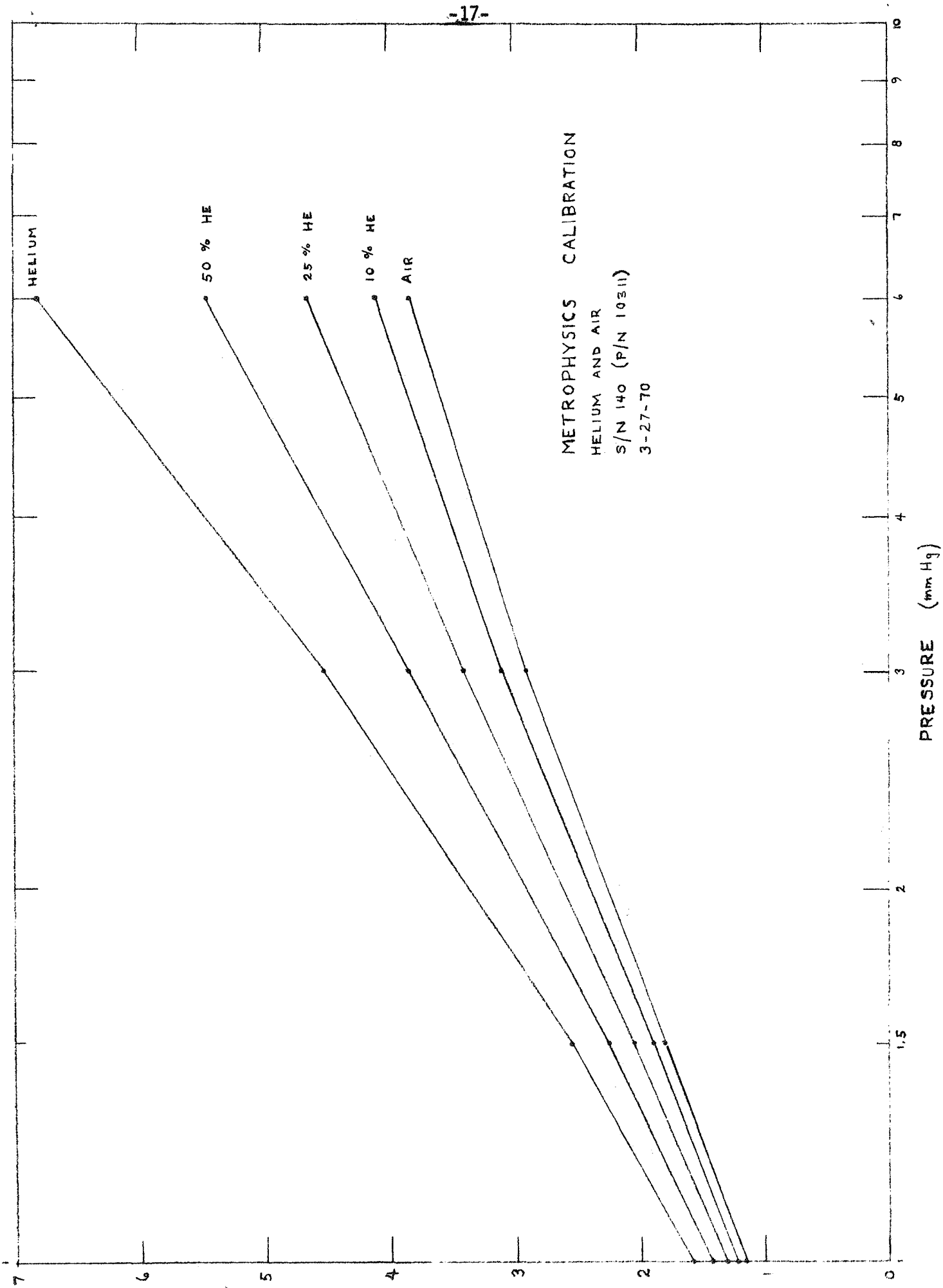
METROPHYSICS CALIBRATION
HELIUM AND AIR
S/N 140 (P/N 10311)
3-27-70
HELIUM
50 % HE
25 % HE
10 % HE
AIR
METROPHYSICS OUTPUT (volts)
PRESSURE (mm Hg)
0
1
2
3
4
5
6
7
1.5
2
3
4
5
6
7
8
9
10

Figure 5

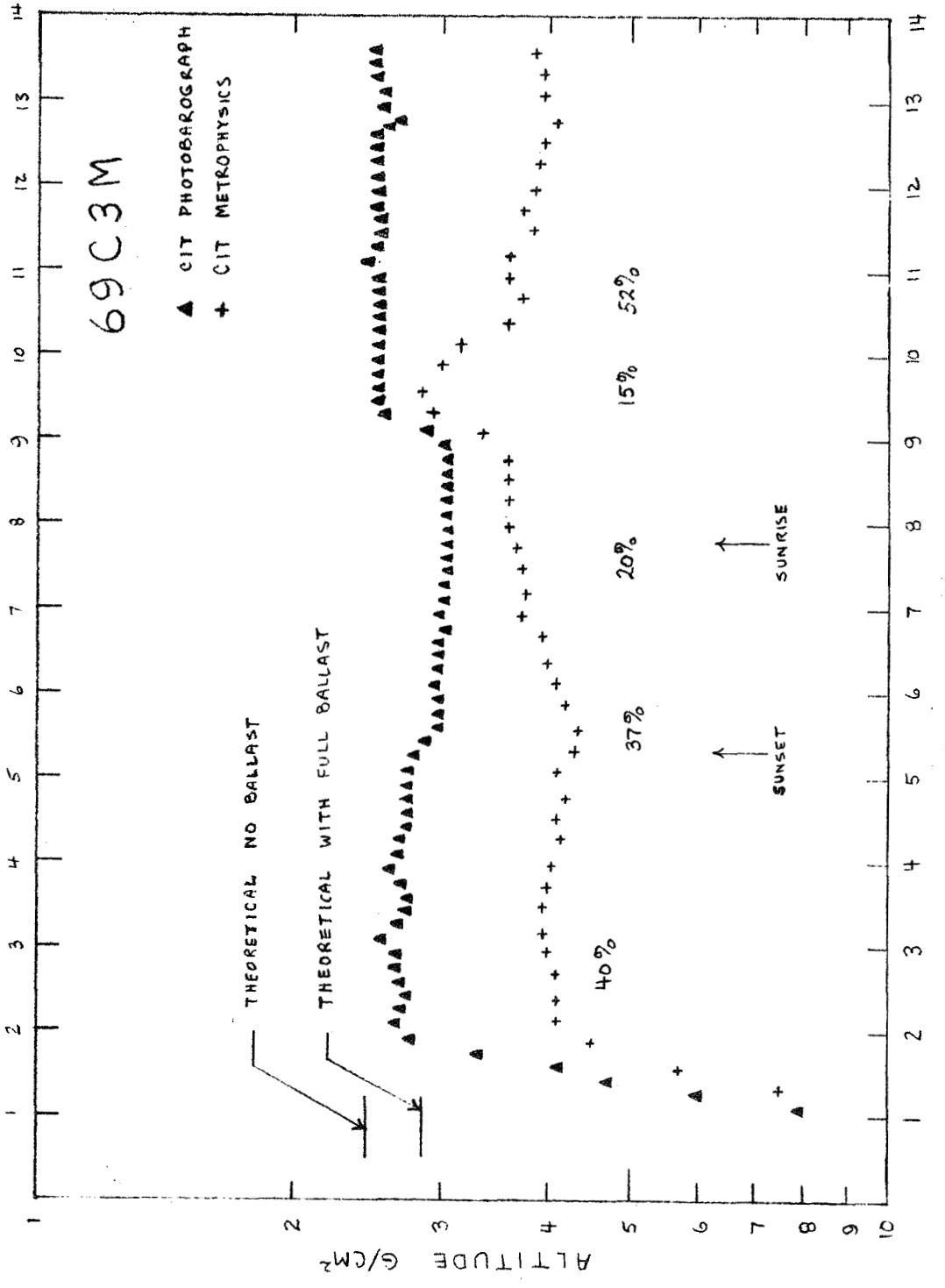
69C3M
CIT PHOTOBAROGRAPH
CIT METROPHYSICS
THEORETICAL NO BALLAST
THEORETICAL WITH FULL BALLAST
40%
37%
20%
15%
52%
SUNSET
SUNRISE
ALTITUDE G/CM²
UNIVERSAL TIME

Figure 6

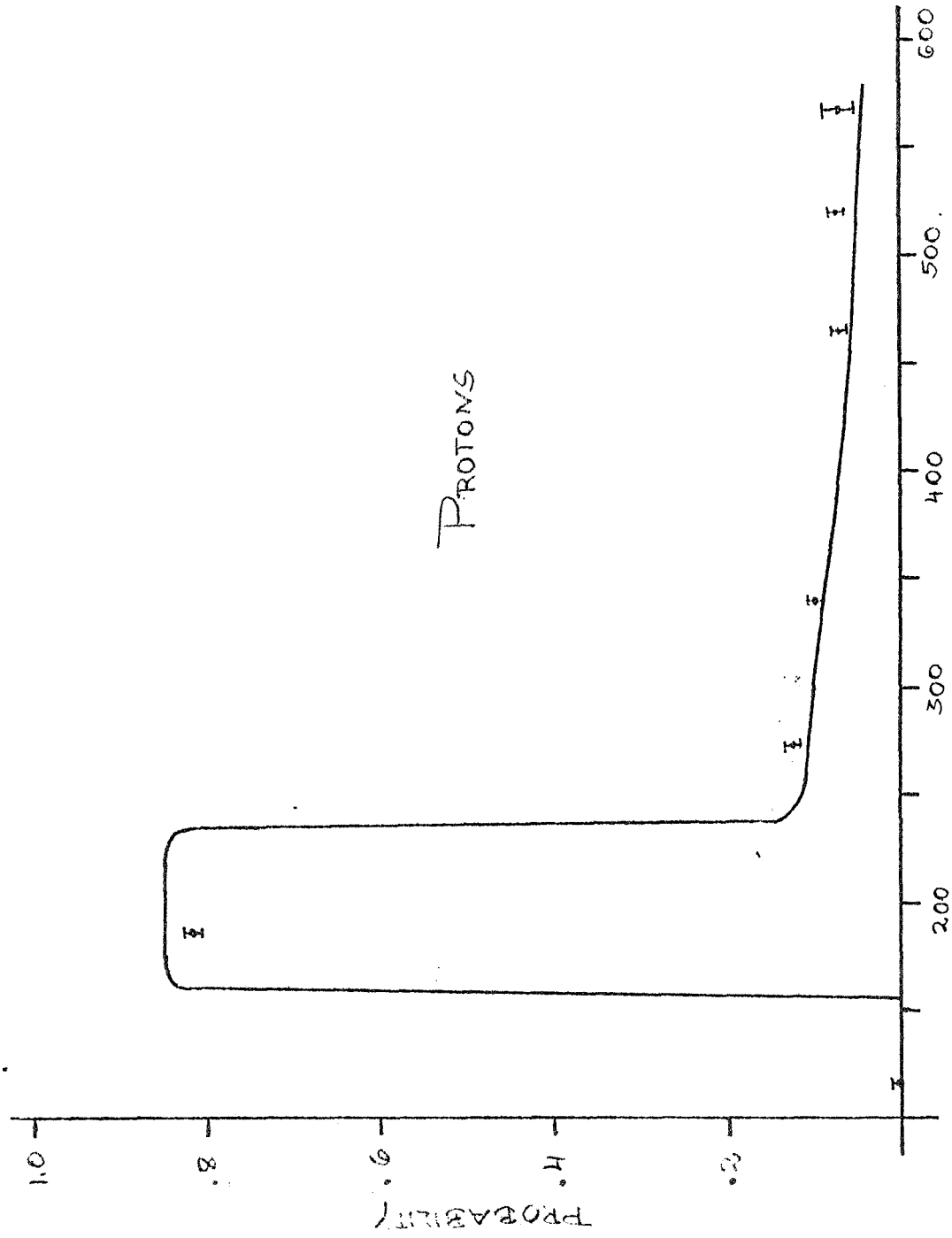

Figure 7

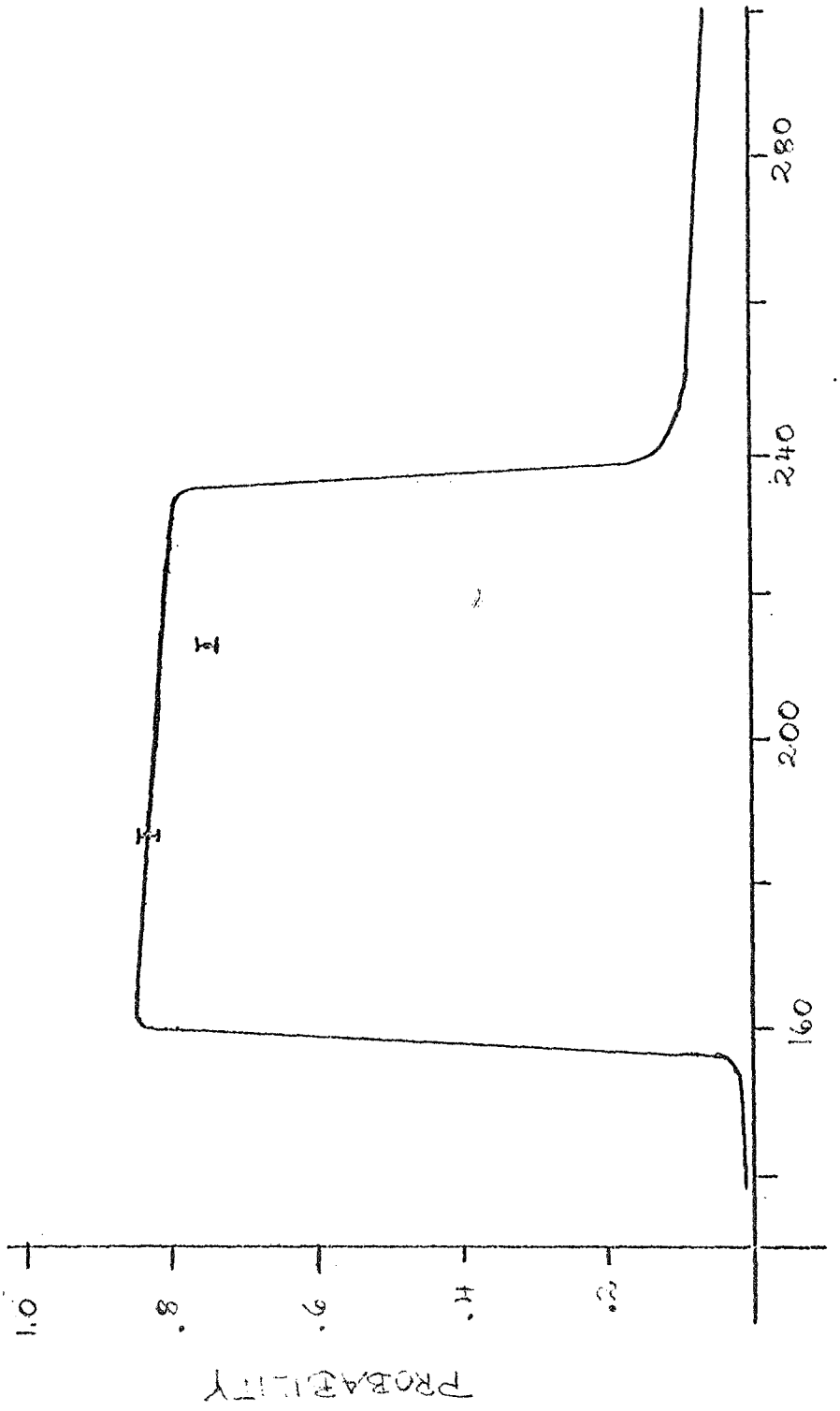

Figure 8

II. Cosmic Rays (Neher, George)

From April, 1970, through September, 1970, work has continued on the study of quasi-trapped particles using the OGO-2 and OGO-4 ion chamber data in the latitude range $68 < \Lambda < 80^{o}$. Data analysis has now been completed. The iso-intensity contours of the quasi-trapped particles have been found to depend on local time, invariant latitude, and the geomagnetic activity index K_p. There is not sufficient resolution in the data for the determination of any possible effect of altitude, longitude, or tilt-angle of the earth's magnetic dipole axis. The results of this study have been compared with those from the Injun 2, Alouette 1 and Alouette 2 studies. There is basic agreement with the previous work, but small differences do exist. The physical interpretation of these differences is presently under study.

In addition, OGO-4 ion-chamber data have been prepared for correleation with the observations of high-latitude electron "spikes" by J. W. Brown and E. C. Stone. The object of this work is to correlate the data from the OGO-4 particle telescope with ion-chamber data from the same time periods. It is hoped that more accurate values of the spectral index and angular distribution of these fluxes will result.

III. Interplanetary Magnetic Fields and Plasmas (Davis, Jokipii, Hollweg, and Scholer)

1. The analysis of the Mariner 5 magnetometer and plasma data has progressed to the point where an extensive paper has been completed by J. W. Belcher and L. Davis and a substantial block of reduced data is nearly ready for submission to the Data Center. In this paper, the earlier arguments for the Alfvénic character of the waves have been strengthened, and the estimate of their fractional contribution to the fluctuations has been

somewhat increased. The analysis is organized on the basis of a model of the solar wind velocity structure. Most of the Alfvén waves in the interplanetary medium seem likely to be the undamped remnants of waves generated at or near the sun. The high level of wave activity in high velocity, high temperature streams can be interpreted as evidence for the extensive heating of these streams by wave damping near the sun. The highest level of Alfvénic activity, which is found in the compression regions at the leading edges of high velocity streams, may be due either to the amplification of ambient Alfvén waves in high velocity streams as they are swept into the compression regions or to the fresh generation of waves in these regions by the stream-stream interactions. The observed very low level of the magnetoacoustic modes is evidence for their strong damping. The $\underset{\sim}{e}_B x \underset{\sim}{e}_R$ anisotropy is viewed as due to the partial conversion of the Alfvén waves into the damped magnetoacoustic modes as they are convected away from the sun; this process continually transfers energy from the microscale field fluctuations to the thermalized solar wind plasma.

2. Jokipii has completed an extensive review of the modern, statistical theory of the transport of cosmic rays in the solar wind for Reviews of Geophysics and Space Physics. Observations are discussed only as they illustrate the phenomena under discussion. A brief introductory section surveys the historical development of the theory. The dominant effect on the motion of cosmic rays in the solar wind is the interplanetary magnetic field, which is irregular and which is therefore best treated statistically, using random functions. The magnetic irregularities scatter the cosmic rays in pitch angle, so that to a good approximation the cosmic rays diffuse through the irregular magnetic field. Using a statistical analysis of the equations of motion, one may relate the diffusion tensor to the power spectrum of the magnetic field, which is in principle measurable. The resulting general transport theory relates the motion of cosmic rays, statistically, to the solar wind velocity and magnetic field.

Application of the theory both to the modulation of galactic cosmic rays by the solar wind and to the propagation of solar cosmic rays is discussed in detail. It is concluded the present theory explains the principal phenomena quite well. Future theoretical work will probably be devoted to obtaining better solutions of the equations, to obtaining better values of the parameters, and to treating higher order or more subtle effects.

3. M. Scholer and J. W. Belcher extended the usual Rankine-Hugonoit equations for fast shocks to include the momentum and energy flux in Alfvén waves. The resulting equations were solved numerically for a wide range of parameters. The presence of waves lowers the post-shock density and temperature. For values of the pre-shock fast Mach number smaller than a critical value, the post-shock fast Mach number is greater than 1, resulting in a so-called non-evolutionary shock. M. Scholer also studied the broadening and distortion of artificial ion clouds in an ionized background with a homogeneous magnetic field.

4. Jokipii served on the Space Astronomy Panel of the Astronomy Survey Committee of the National Academy of Sciences. He attended the Solar Terrestrial Physics Symposium in Leningrad in May, 1970, and served as Secretary of Commission 43 of the International Astronomical Union at its General Assembly in Brighton, England. Davis served on the National Academy of Sciences, June, 1970, Summer Study on the exploration of Venus and on the Magnetometer Instrument Team for the 1973 Mercury-Venus Design Study. He presented an invited review paper entitled "The Configuration of the Interplanetary Magnetic Field" at the Solar Terrestrial Physics Symposium in Leningrad in May, 1970. He served as President of Commission 43 at the General Assembly of the International Astronomical Union in Brighton, England, in August, 1970.

STAFF AND EXPENDITURES

1 October 1969 - 30 September 1970

ACTIVITY	FACULTY	GRAD. STUDENTS	ENGR. AND TECH. FULL	ENGR. AND TECH. PART+	LABOR	MATERIALS	OVERHEAD	TOTAL	1 YEAR BUDGETED
I. Cosmic Rays	Vogt Stone Fanselow	10	3	10	50,912	76,281	32,002	159,195	187,000
II. Cosmic Rays	Neher George	0	0	0	7,505	1,414	4,437	13,356	13,000
III. Interplanetary Magnetic Field and Plasmas	Davis Jokipii	2	0	0	20,893	7,930	12,326	41,149	50,000
TOTALS		12	3	10	79,310	85,625	48,765	213,700	250,000

+: Includes part-time and summer time student technicians

BIBLIOGRAPHY

1968

Althouse, W. E., E. C. Stone, R. E. Vogt and T. H. Harrington, "A Solar and Galactic Cosmic Ray Satellite Experiment", IEEE Transactions on Nuclear Science, NS-15, No. 1, 229 (1968).

Beuermann, K. P., C. J. Rice, E. C. Stone, and R. E. Vogt, "Cosmic-Ray Electrons and Positrons Between 6 and 200 MeV", Bull. Am. Phys. Soc., Ser. II, 13, 11, 1411 (1968).

Davis, L., E. J. Smith, and J. Belcher, "The In-Flight Determination of Spacecraft Magnetic Field Zeros", Trans. Am. Geophys. Union 49, 257 (1968).

Griffel, D. H., "The Kinetic Theory of the Solar Wind and its Interaction with the Moon", Thesis, California Institute of Technology (1968).

Israel, M. H., "Primary Cosmic Ray Electrons and Albedo Electrons at Energies between 12 and 1000 MeV", Thesis, California Institute of Technology (1968).

Israel, M. H. and R. E. Vogt, "Diurnal Intensity Variations of Cosmic Ray Electrons Observed at Balloon Altitudes near Fort Churchill, Manitoba", Trans. Am. Geophys. Union 49, 240 (1968).

L'Heureux, J., P. Meyer, S. D. Verma and R. Vogt, "Long-Term Variations of the Primary Cosmic-Ray Electron Component", Can. J. Phys. 46, 896 (1968).

Sisco, G. L., L. Davis, Jr., P. J. Coleman, Jr., E. J. Smith and D. E. Jones, "Power Spectra and Discontinuities of the Interplanetary Magnetic Field: Mariner IV", J. Geophys. Res. 73, 61 (1968).

Smith, E. J., L. Davis, Jr., D. E. Jones, P. J. Coleman, Jr., "Magnetic Measurements in the Earth's Magnetosphere and Magnetosheath: Mariner V", Trans. Amer. Geophys. Union 49, 278 (1968).

Snyder, C. W., E. J. Smith, L. Davis, Jr., A. J. Lazarus, P. J. Coleman, Jr., and D. E. Jones, "The Interaction of Venus with the Solar Wind", Trans. Amer. Geophys. Union 49. 224 (1968).

Stone, E. C., R. E. Vogt and K. P. Wenzel, "Messungen der Albedo-Protonen der Kosmischen Strahlung", Verhandlungen der Deutschen Physikalischen Gesellschaft, 6 (1968).

Wenzel, K. P., "Primaere, Sekundaere, und Albedo-Protonen aus der Kosmischen Strahlung", Thesis, Ruprecht-Karl-Universitaet, Heidelberg (1968).

1969

Belcher, J. W., L. Davis, Jr., and E. J. Smith, "Large Amplitude Alfven Waves in the Interplanetary Medium: Mariner 5", J. Geophys. Res. 74, 2302 (1969).

Beuermann, K. P., C. J. Rice, E. C. Stone, and R. E. Vogt, "Cosmic-Ray Negatron and Positron Spectra between 12 and 220 MeV," Phys. Rev. Letters 22, 412 (1969).

Beuermann, K. P., "Elektronen und Photonen der Sekundaeren Kosmischen Strahlung in der Oberen Atmosphaere", Vortr. Ex 47, Argeitsgemeinschaft "Extraterrestrische Physik", Berlin, March 1969

Dolginov, Sh. Sh, E. G. Eroshenko, and L. Davis, "On The Nature of the Magnetic Field near Venus", Kosmicheskiye Issledovaniya, 7 747 (1969).

Evans, L. E. and E. C. Stone, "Access of Solar Protons into the Polar Cap: A Persistent North-South Asymmetry", J. Geophys. Res. 74, 5127 (1969).

Griffel, D. H., and L. Davis, Jr., "The Anisotropy of the Solar Wind", Plan. Spac Sci. 17, 1009 (1969).

George, Michael James, "New Measurements on the Absolute Cosmic Ray Ionization from Sea Level to 1540 Kilometers Altitude, " Thesis, California Institute of Technology, (1969).

Israel, M. H., "Cosmic-Ray Electrons Between 12 MeV and 1 GeV in 1967," J. Geophys. Res. 74, 4701 (1969).

Israel, M. H., and R. E. Vogt, "Characteristics of the Diurnally Varying Electron Flux near the Polar Cap", J. Geophys. Res. 74, 4714 (1969).

Jokipii, J. R. and L. Davis, Jr., "Long Wavelength Turbulence and the Heating of the Solar Wind", Ap. J. 156, 1101 (1969).

Jones, D. E., E. J. Smith, L. Davis, Jr., and P. J. Coleman, "Search for a Lunar Wake at Large Distances from the Moon: Mariner 4", J. Geophys. Res. 74, 3037 (1969)

Rice, C. J., "Primary Cosmic-Ray Positrons and Negatrons in 1968 at Energies between 11 and 204 MeV", Thesis, California Institute of Technology (1969).

Stone, E. C. and L. Evans, "A Persistent North-South Asymmetry during a Polar Cap Proton Event:, Trans. Am. Geophys. Union, 40, 306 (1969).

Stone, E. C. and L. Evans, "Diffusion of Solar Cosmic Rays into the Magnetotail", XI. Int. Conference on Cosmic Rays, Budapest, Hungary (1969).

1970

Belcher, J. W. and L. Davis, "Anisotropy in the Microscale Fluctuations of the Interplanetary Magnetic Field", Trans Am. Geophys. Union, 51, 413 (1970)

Beuermann, K. P. "Secondary Electrons and Photons in the Upper Atmosphere", (submitted for publication).

Beuermann, K. P., C. J. Rice, E. C. Stone, and R. E. Vogt, "Cosmic-Ray Negatron and Positron Spectra Observed near Fort Churchill in 1968", Acta Physica Academiae Scientiarum Hungaricae 29, Suppl. 1, 173 (1970).

Brown, J. W. and E. C. Stone, "High Energy Electron Spikes", Trans Am. Geophys. Union, 51, 807 (1970).

Davis, L. Jr., "The Configuration of the Interplanetary Field", Proc. Leningrad Symposium on Solar-Terrestrial Physics, (in press).

Davis, L. and M. Goldstein, "Magnetic-Dipole Alighment in Pulsars", Ap. J. Letters 159, L81-85 (1970).

Evans, L. C. and E. C. Stone, "Access of Solar Flare Protons and the Configuration of the Magnetospheric Tail", Trans. Am. Geophys. Union, 51, 800 (1970).

Fanselow, J. L., "Cosmic-Ray Cutoffs from 1-40 MeV", Trans. Am. Geophys. Union, 51, 800 (1970).

George, M. J., "New Data on the Absolute Cosmic-Ray Ionization in the Lower Atmosphere", J. Geophys. Res. 75, 3693 (1970)

George, M. J., "The Altitude Dependence of the Quiet-Time Cosmic-Ray Ionization Over the Polar Regions at Solar Minimum", J. Geophys. Res. 75, 3154 (1970).

George, M. M., "Observations of the Cosmic-Ray Knee with a Polar Orbiting Ionization Chamber", J. Geophys. Res. 75, 3159 (1970).

Greenstadt, E. W., L. Davis, and E. J. Smith, "Possible Dependence of Venus and Mars Bow Shock Characteristics on Interplanetary Field Orientation", Trans. Am. Geophys. Union 51, 408 (1970).

Jokipii, J. R., "The Transport of Cosmic Rays in Space", Bull. Am. Phys. Soc. 15, 589 (1970).

Jokipii, J. R., "On the Thin-Screen Model of Interplanetary Scintillations", Ap. J. 161 , 1147 (1970)

Jokipii, J. R., "Propagation of Cosmic Rays in the Solar Wind", Reviews of Geophysics and Space Physics, (in press).

Murray, S. S., E. C. Stone, and R. E. Vogt, "Non-Diffusive Effects in the Propagation of 1-10 MeV Solar Protons", Trans. Am. Geophys. Union, 51, 798 (1970).

Rice, C. J., K. P. Beuermann, E. C. Stone, and R. E. Vogt, "Diurnal Geomagnetic Cutoff Variations for Positrons and Negatrons near $\Lambda = 68^{o}$", Trans. Am. Geophys. Union, 51, 230 (1970).

Smith, E. J., J. W. Belcher, L. Davis, and P. J. Coleman, "The Identification of Interplanetary Field Fluctuations as Traveling Waves", Trans. Am. Geophys. Union, 51, 412 (1970)

Smith, E. J. and L. Davis, Jr., "Magnetic Measurements in the Earth's Magnetosphere and Magnetosheath: Mariner 5", J. Geophys. Res. 75, 1233 (1970).

Stone, E. C. and J. W. Brown, "High Latitude Electron Spikes", Trans. Am. Geophys. Union, 51, 240 (1970).