FINAL REPORT FOR MDAC SOLAR COSMIC RAY EXPERIMENT ON OGO-6

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16. Abstract

This report describes the instrumentation of the MDAC OGO-6 experiment and discusses the results of data obtained during the satellite lifetime from launch on June 5, 1969 through September 1970.

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PREFACE

The objective of this program was to obtain detailed measurements of the intensities of protons, electrons, and alpha particles from a polar orbiting satellite and to study the measurements in order to better understand the methods of charged-particle entry into the magnetosphere and their propagation into the low-altitude polar regions. The work involved design, construction, testing, calibration, and delivery of a flight unit and a prototype instrument to Goddard Space Flight Center for payload integration, as well as computer data reduction and analysis of the data tapes provided by the contractor. Several conclusions drawn from this study of the data are presented in the report.

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I. INTRODUCTION

This document is the final report on the low energy solar cosmic ray experiment developed by McDonnell Douglas Astronautics Company (MDAC) and orbited on the NASA OGO-6 satellite. The complete program included the design, construction, testing, calibration, and delivery of the flight and prototype units as well as data reduction and analysis. The MDAC experiment was utilized from launch on June 5, 1969 until the loss of satellite programming signals in September 1970. The instrument operated flawlessly during this entire time, measuring the intensities of protons, electrons, and alpha particles during some 20 distinct solar cosmic ray particle increases.

Section II of this report briefly describes the instrument used to make the particle-intensity measurements. For more detail see the Instrument Report submitted as part of this contract in March 1968 or see IEEE Transactions on Nuclear Science, Vol. NS-15, 238 (1968). Section III describes the data-processing procedure and Section IV discusses the scientific investigation.

The following MDAC personnel were involved in this program

A. J. Masley	Principal Investigator
P. R. Satterblom	Co-Investigator
M. H. Wolpert	Electronic Engineering
D. W. Burtis	Electronic Engineering
K. A. Pfitzer	Computer Programming
R. B. Atkinson	Computer Programming

II. INSTRUMENTATION

The OGO-6 MDAC flight unit is shown in Figure 2-1. This self-contained package with the attached charged-particle telescope was mounted on the inside of the -Z door of the spacecraft with the telescope protruding through an aperture in the door. This side was oriented by the spacecraft attitude control system to point radially away from the Earth. The detector system is a charged particle telescope, composed of two silicon double-diffused circular detectors mounted coaxially with a separation of 36 mm giving a cone half-angle of 28 deg. By measuring a particle's energy loss in two detectors, its total kinetic energy and its mass can be determined. The experiment analyzed protons from 5.3 to 78 MeV in 14 channels and alpha particles from 17.5 to 84 MeV in nine channels. Additionally, a minimum ionizing channel measured the intensity of electrons greater than 270 keV along with protons greater than 78 MeV. These channels and their energy boundaries are listed in Table 2-1. The telescope geometry factor is 0.499 cm^2 ster.

The quantities of charge liberated in each detector were converted to voltage pulses by the amplifiers. These voltage pulses were amplitude analyzed by

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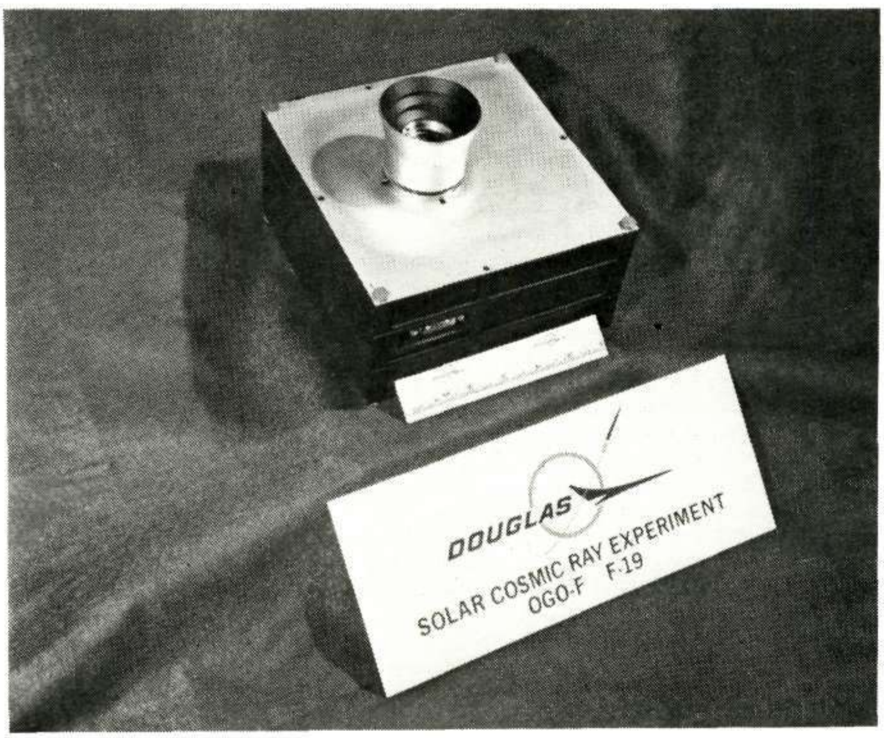

Figure 2-1. MDAC OGO-6 Experiment

Table 2-1

CHANNEL ENERGY BOUNDARIES

Channel No.	Kinetic Energy (MeV)	
P1	5.3 to 6.0	Protons
P2	6.0 to 8.2	
P3	8.2 to 10.5	
P4	11.0 to 12.7	
P5	12.7 to 16.0	
P6	16.0 to 20.7	
P7	20.7 to 24.5	
P8	24.5 to 29	
P9	29 to 35	
P10	35 to 41.5	
P11	41.5 to 49	
P12	49 to 59	
P13	59 to 70	
P14	70 to 78	
A1	17.5 to 20.0	Alpha particles
A2	20.2 to 21.8	
A3	21.8 to 26	
A4	26 to 34.2	
A5	34.2 to 46	
A6	46 to 53	
A7	53 to 62	
A8	62 to 72	
A9	72 to 84	
11	Protons 5 -78 MeV	Integral channels
	Alpha particles 20.2 - 125 MeV	
13	Protons greater than 78 MeV	
	Electrons greater than 270 keV	

a combination of threshold circuits and a clock-type pulse height analyzer. Ten shifting accumulators were used to count the pulses in the data channels using a multiplexing technique which gave a 31 percent on-time for each channel. Of the complete set of 30 data channels, each was sampled for 0.270 sec every 0.864 sec. An electronic in-flight calibration system checked the voltage level of each threshold circuit as well as the pulse height analyzer every 160 min. The experiment weighed 2.62 kg, required 2.2W of spacecraft power, and had dimensions of 20 x 20 x 10 cm^3.

An expanded view of the instrument is shown in Figure 2-2. The electronic components are housed in the three trays. The particle telescope is attached to the bottom of the middle tray and extends through the upper tray with the collimator (not shown) attached to the threaded telescope housing. The detector amplifiers and threshold circuits are mounted close to the telescope in the middle tray. The left tray houses the ten accumulators and associated programming circuitry. The right tray contains the power converter, the logic control circuitry, and all the spacecraft interface devices. Each tray consists of a magnesium housing with a bonded mother board. Discrete components are mounted on cordwood modules and interconnected by welded nickel ribbon.

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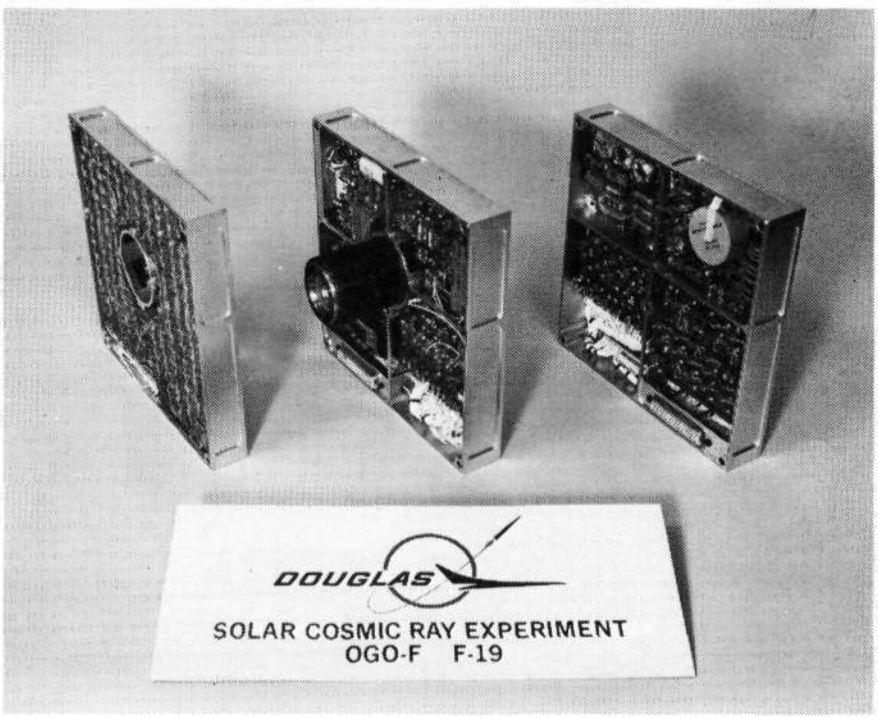

Figure 2-2. Expanded View of Experiment

III. DATA PROCESSING

A. Quick-Look Data

The OGO-6 data were processed in three distinct stages. First, quick-look data were prepared from ROSMAN and ULASKA data tape dumps and real-time passes by the data reduction group at Goddard Space Flight Center (GSFC). The data were presented in the form of printouts and print-plots as specified by the experimenter, and this service was provided for two weeks following the spacecraft launch. It was especially important to receive these data because of a solar particle event that occurred on June 7, 1969, only 53 hours after the spacecraft launch. The data were presented in a paper to the 11th International Conference on Cosmic Rays at Budapest, Hungary, in August 1969.

B. Preliminary Processing

Since data tapes were provided to the experimenters several months before attitude-orbit tapes were ready, a preliminary data-processing program was written to present experiment data as a function of universal time. Selected experiment data channels were summed together so that eight proton channels, two alpha particle channels, one integral channel, and one experiment temperature were plotted on three sheets for the period of one orbit. The program incorporated features which filtered out noisy data, monitored data quality, and adjusted data summation time intervals depending on the count accumulation in a selected channel. The computer used was an XDS-930 with a Calcomp 835 microfilm plotter on-line. Details of this program were given in the Prime Data Analysis Plan which was submitted to GSFC to meet a contractual requirement.

Early data tapes contained many data records which could not be processed due to time errors. Time skips and backups of both short and long duration in a record were not anticipated and could not be handled by the program. At the suggestion of the GSFC OGO data center, it was decided not to alter the preliminary processing program to handle time backups; however, a time skip method was developed. The GSFC OGO data tape line was later improved and a restart made on experimenter tapes on February 16, 1970. Since then, time skips or backups in a data record have not occurred.

C. Final Data Processing

Final data reduction was performed in two steps utilizing an XDS-930 computer. The first step merged experimenter data tapes with the attitude-orbit tapes and produced a compact MERGE tape. During this process, data flags and data quality were checked and data from the in-flight calibration sequence were removed prior to writing the output MERGE tape. The data were sorted and sequenced monotonically in time and all duplicated data deleted. During solar quiet periods, many of the data readouts were zero; therefore, a zero suppression technique was used which shortened the output tape length by more than a factor of 10. In this way, a full MERGE tape could contain six or seven days of experiment data, including data from both the experiment and attitude-orbit tapes. The attitude-orbit data were also filtered and sequenced (periodic time overlaps and skips appeared on these attitude-orbit tapes). The data were converted from UNIVAC or IBM floating-point format to a scaled integer format. The number of bits retained to the right of the binary point varied and was determined by the accuracy requirement for further analysis. Thirty attitude-orbit information words were written on the MERGE tape. The MERGE tape, containing binary scaled attitude-orbit data and zero suppressed experiment data, then constituted the working tape for all subsequent analysis.

The second step of the data analysis consisted of generating microfilm plots and printouts of the desired data. Two basic programs were written, both for the XDS-930 computer with an on-line Calcomp 835 microfilm plotter. The first program generated plots and listings of individual polar passes while the second program was used for long duration profiles of a solar event. Self-scaling linear and logarithmic axis generation subroutines as well as self-scaling linear time axis generation subroutines were developed for use in both of these programs.

The program for plotting polar pass data, OGOPLOT, can calculate time averages of the data from 10 sec up to several minutes. A complete polar pass, determined by selected values of invariant latitude, could be plotted or any portion of the polar cap could be expanded into a separate plot. Up to four data channels arranged in a specific order could be displayed on a single frame.

As many plots as requested to cover all channels or any subset of channels were available in a single pass through the data. This program also plotted the log-log energy spectra of protons and alpha particles averaged over a time interval from 10 sec to several minutes for any specified region of the polar cap.

Figure 3-1 shows an example of a polar pass profile. The information in the upper right of the figure indicates that the plot is for protons, a northern polar pass, on March 24, 1970. The four data channels plotted are 5. 3 to 6. 1 MeV, 6. 1 to 8. 2 MeV, 8. 2 to 11. 0 MeV, and 11. 0 to 12. 7 MeV. The abscissa is labeled in both time and space coordinates. The large numbers at the top of the column are the universal times corresponding to the adjacent vertical bar of the plot. Below the time are the other coordinates which apply to the same universal time. The other coordinates are local time, magnetic local time, the McIlwain L parameter, magnetic latitude, invariant latitude, geographic latitude and geographic longitude of the subsatellite point, and the satellite altitude. The ordinate is in units of differential intensity.

Figure 3-2 shows an energy spectrum of protons taken during this same polar pass. The plot is labeled for protons during a northern polar pass on March 24, 1970. The univeral time at the midpoint of the accumulation period is given. Below this is the same coordinate values occurring for that time as are shown in Figure 3-1. DT shows that the accumulation interval was 2. 00 min. The ordinate of the plot is in differential intensity units. The crosses that indicate the data points show the energy width of the channel (the horizontal line) and the statistical error in the differential intensity (the vertical line). The horizontal axis gives the kinetic energy of the particle.

Figure 3-3 shows an alpha-particle energy spectrum for data during the November 2, 1969 event.

The second plotting program, OGOPROF, permitted a time history of an event or sequence of events to be generated for any given channel or set of channels. The plot time duration could be chosen from one day to several months.

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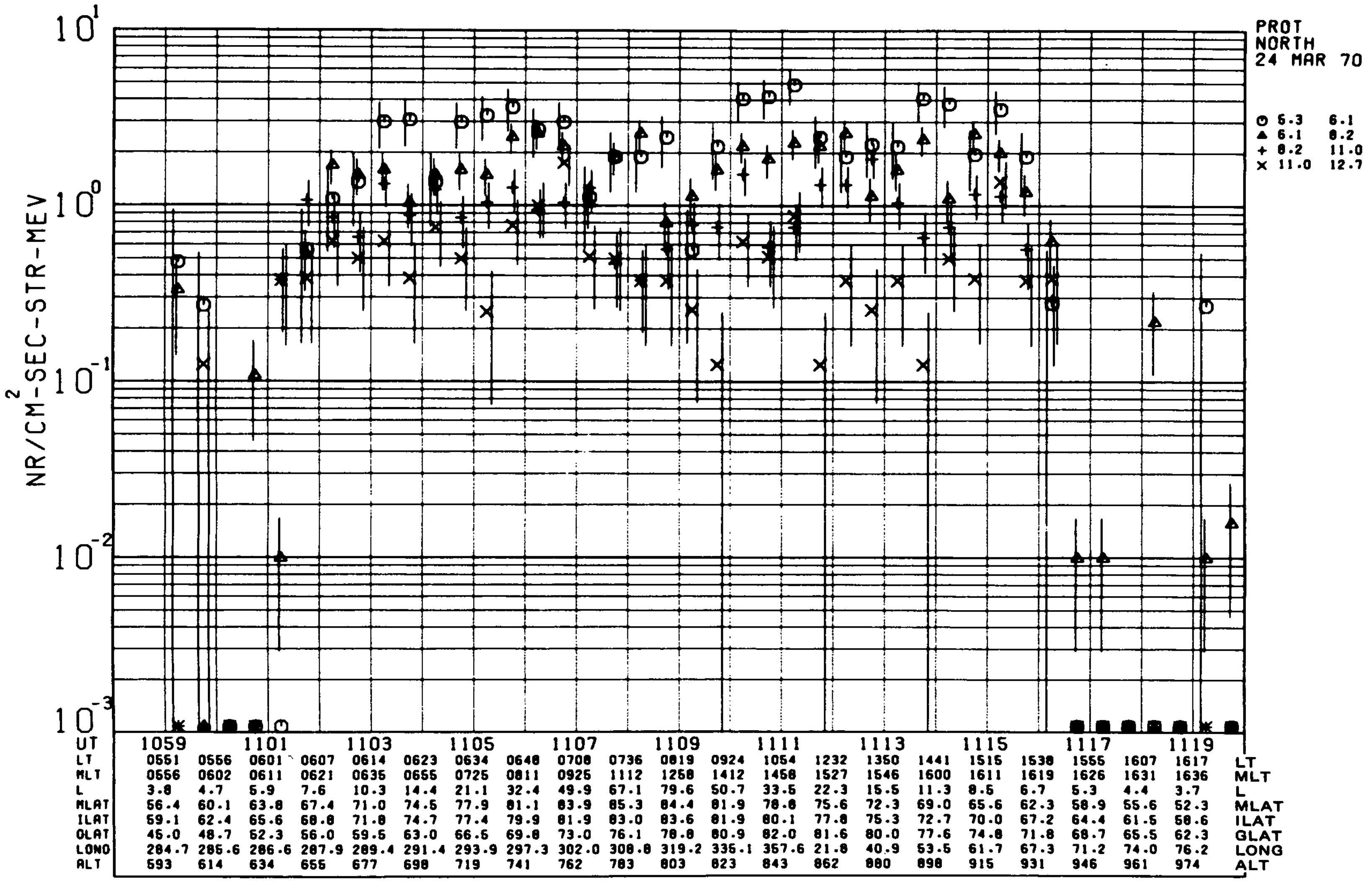

Figure 3-1. Polar Pass Profile

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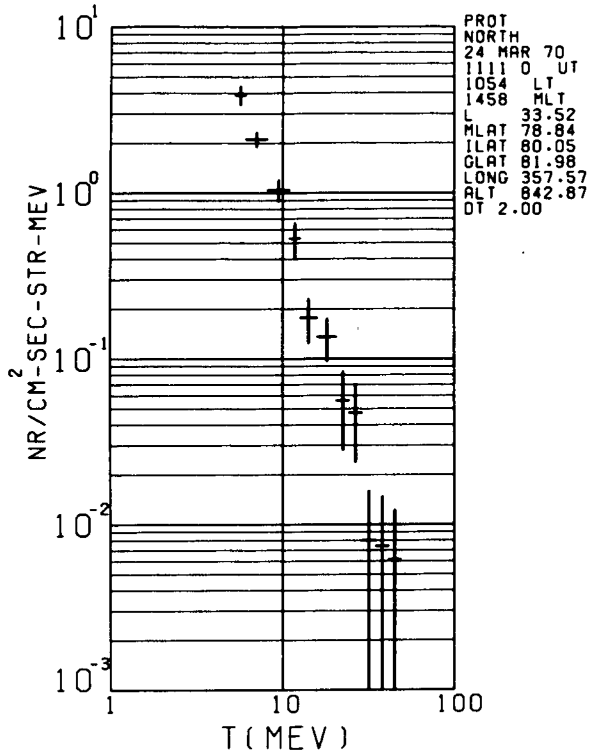

Figure 3-2. Proton Energy Spectrum

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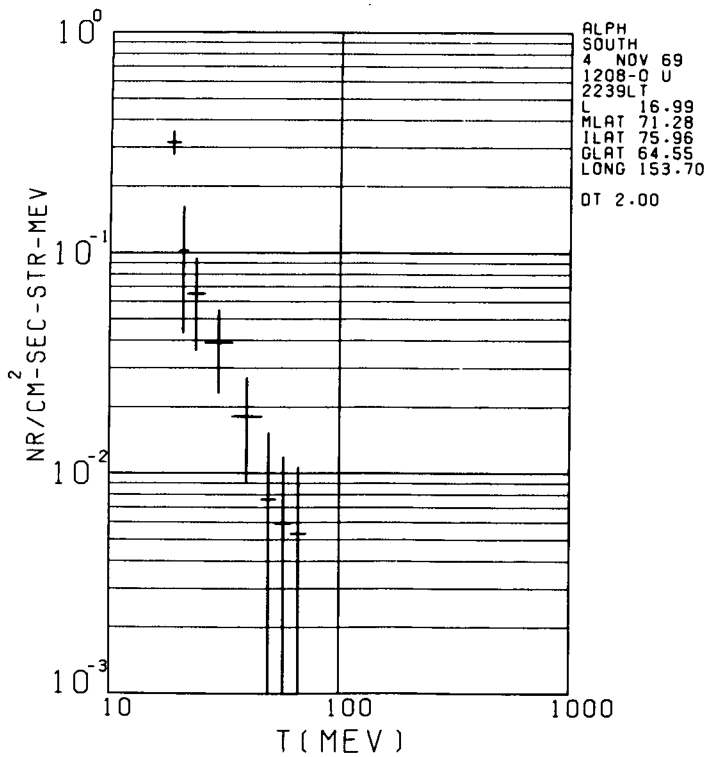

Figure 3-3. Alpha Particle Energy Spectrum

Each data point consisted of the average over one polar pass of the data from one channel or group of channels, as determined by a selected invariant latitude. North and South polar passes were indicated by different symbols. The program was also capable of plotting the sum of any arbitrary set of channels or the ratio of the sums of two sets of channels.

Figure 3-4 shows an example of a profile plot for the interval from March 23, 1970 through April 1, 1970. Two channels of data are plotted, P1 being protons from 5.3 to 6.0 MeV and P6 being protons from 16.0 to 20.7 MeV. In the upper left of the figure, these two channels are labeled, indicating that the ordinate is in differential intensity units. Each channel has a different symbol for northern and southern polar passes. The factor stated for each channel is the number that converts the average number of counts per channel readout to a differential intensity. The program version is dated so that it is possible to document the current state of the program, e.g., the channel factors used. MINLAT is the minimum absolute value of the invariant latitude for data to be included in the plot.

During the life of the OGO-6 satellite there were 20 time intervals totaling 146 days which had higher than background intensities of charged particles as measured by this instrument. The data from these periods were compacted onto 29 MERGE tapes and underwent subsequent analysis. Event profiles from the OGOPROF program were plotted for these 20 intervals. Some of the profiles were done in several formats due to the length of the interval or to some peculiar feature of the data. The profile of the ratio of the proton and alpha particle intensities was plotted for many combinations of proton and alpha particle energies for the ten events with highest particle intensity. For nine of the highest intensity events, the OGOPLOT program was used to obtain individual polar-pass intensity profiles and proton and alpha particle spectra during most of the event. These types of plots were not made routinely due to the large number of plots which were generated. For even a two minute averaging time (a ten sec average can be statistically significant during the most intense periods of several events), 320 plots per day of data were produced. The total number of plots produced by these two programs is on the order of 1.5×10^4.

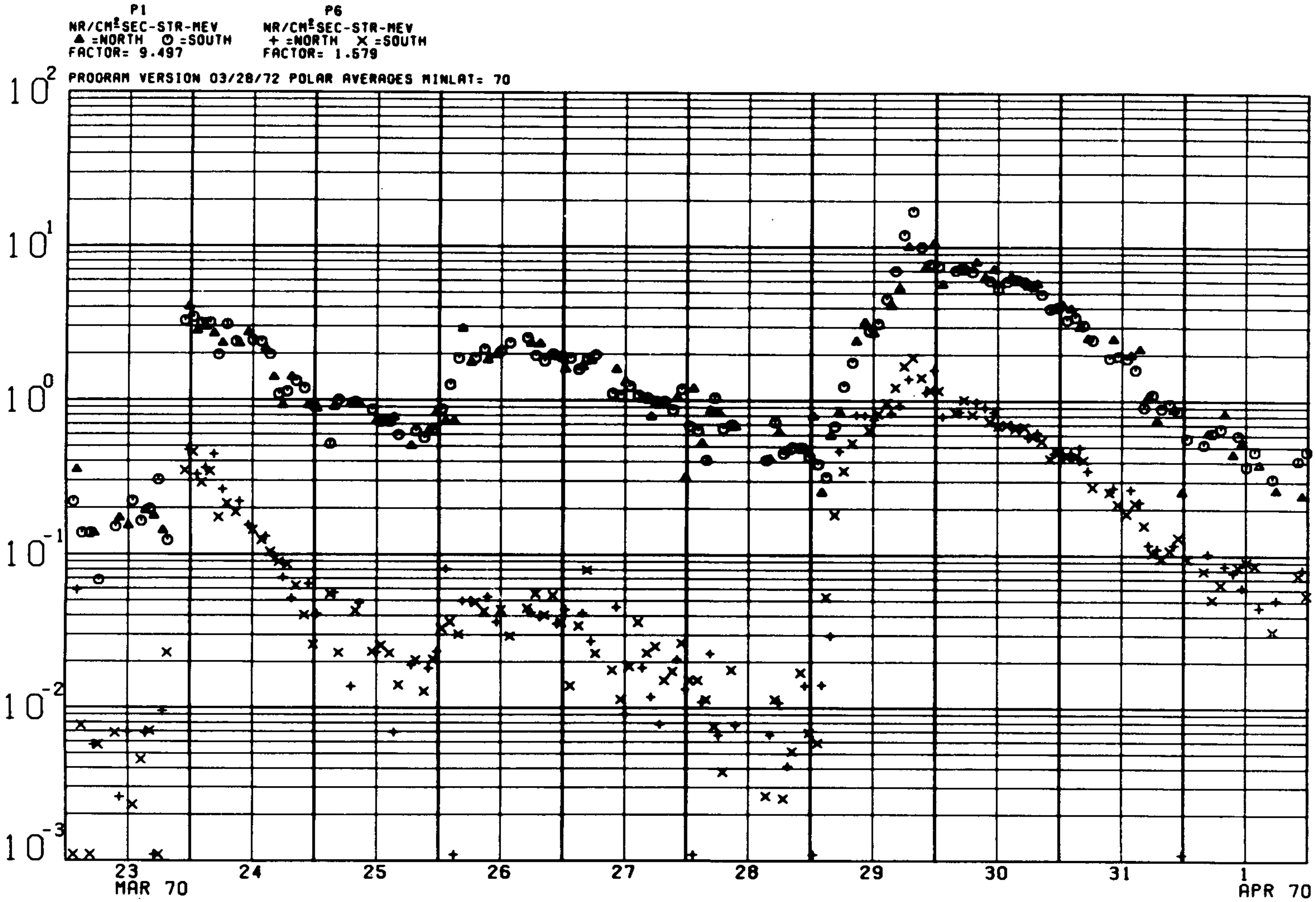

Figure 3-4. Event Profile

IV. SCIENTIFIC INVESTIGATION

This section discusses in detail the solar cosmic ray events that occurred during the life of the OGO-6 satellite. Also included are the theoretical cutoff calculations with which the data can be compared. Comparisons are also made with data from the MDAC riometer program. A summary discusses the extent to which the proposal goals were achieved.

A. Event Coverage by OGO-6 During Solar Maximum

The MDAC experiment functioned perfectly from "turn on," on June 6, 1969, up to September 1970 when the spacecraft digital data assembly malfunctioned. This period was during the maximum of Sunspot Cycle 20, as illustrated in Figure 4-1. The experiment was on over 99 percent of the time and excellent data were obtained for all 23 events which occurred (Table 4-1). The maximum intensities of 5 to 21 MeV and 10 to 80 MeV (essentially >10 MeV) are given in Table 4-1 as well as the maximum 30 MHz riometer absorption. Figure 4-2 shows the solar particle event distributions from 1962 through 1971. The crosshatched boxes illustrate how the OGO-6 event coverage fits into the nine-year distribution.

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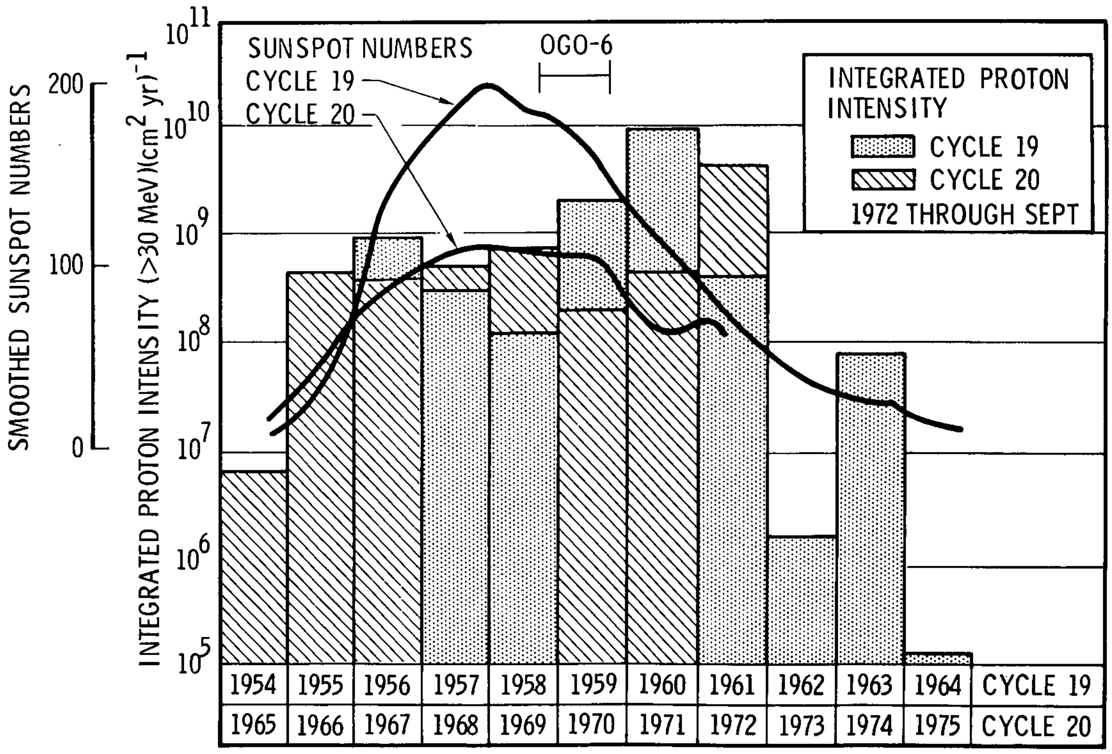

Figure 4-1. Integrated Solar Proton Intensity

Table 4-1

SOLAR COSMIC RAY EVENTS

Date	Preliminary Flare Candidates Start Time (UT)	Imp	Position	Solar Radio Emission Type - Intensity		Maximum Absorption (dB at 30 MHz)	OGO-6 5-21 MeV (cm^2 sec ster MeV)	OGO-6 10-80 MeV (cm^2 sec ster MeV)
June 7, '69	0749	2N	S16 E42	IV-2		1.4	10.0	0.41
July 13, '69						0.4		
Sep 25, '69	0630	3N	N13 W15			0.7	2.4	0.17
Sep 27, '69						3.4	13.0	0.18
Oct 14, '69						0.4	0.1	0.01
Nov 2, '69	0943	?	Behind West Limb			14.5	100.0	16.0
Nov 7, '69	1804	3B	N29 E31			1.4	11.	0.2
Nov 24, '69	0914	2B	N15 W32			0.7	0.5	0.06
Dec 18, '69	0950	2F	N13 E08			0.6	0.085	0.02
Dec 19, '69	1202	2F	N13 W12			1.3	1.60	0.16
Dec 31, '69						0.4	0.36	0.018
Jan 29, '70	1024	1B	S13 W42			0.8	0.55	0.09
Jan 31, '70	1512	2B	S25 W62	IV-3	II-3	3.0	6.0	0.58
Mar 6, '70	1321	1N	S14 E60	IV-2		1.0	2.18	0.08
Mar 7, '70	0138	2B	S12 E10		II-1	3.8	30.0	1.30
Mar 23, '70	1545	1N	N18 W62	IV		0.5	1.60	0.16
Mar 29, '70	0032	2B	N13 W37	IV-3	II-3	1.8	5.50	0.66
Apr 16, '70				IV-1 on 15th		0.6	0.80	0.03
May 30, '70	0248	2N	S08 W32			1.9	7.0	0.32
June 25, '70						0.8	4.2	0.17
July 7, '70							0.40	0.055
July 24, '70	1823 (23rd)	2B	N10 E08	IV-3		3.6	140.	5.6
Aug 14, '70	1605	1N	N15 W73	IV-2		2.6	75.	2.8

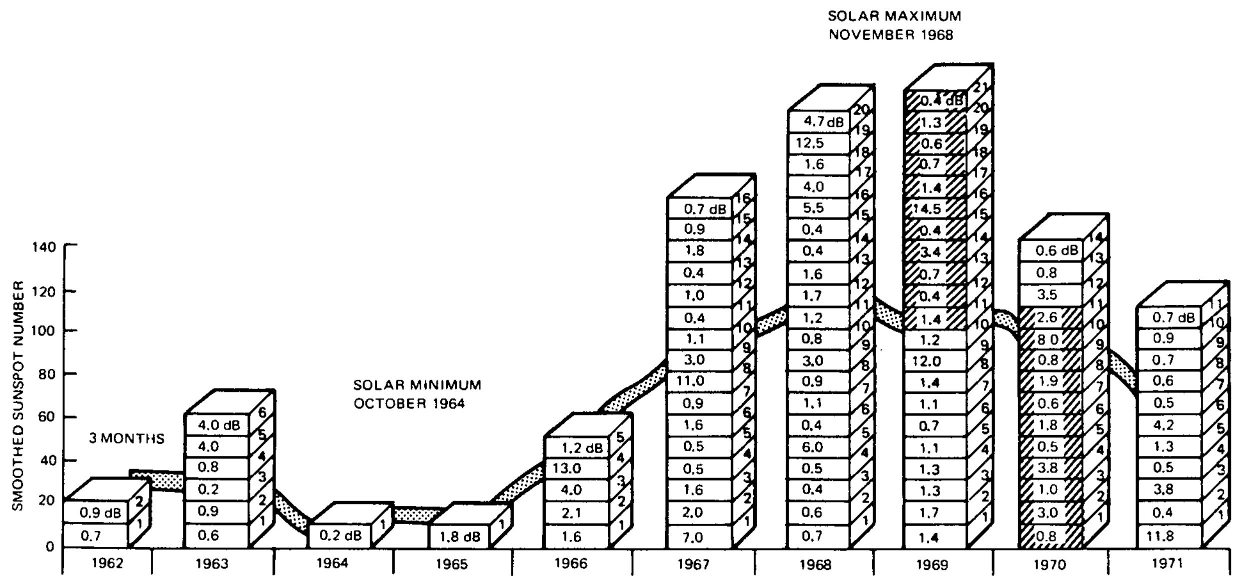

Figure 4-2. Solar Cosmic Ray Event Distribution

B. Discussion of Specific Events

June 7 Event (Papers 2, 4 and 8)

Figure 4-3 shows the June 7 event as observed by 30 MHz riometers at Shepherd Bay and McMurdo Sound and by the MDAC experiment. For about five hours after the onset near 2000 UT on June 7, significant anisotropies were observed as the satellite crossed a given polar cap. Variations in count rate up to a factor of ten were observed. From onset to the second maximum at 1600 UT on June 8, no significant asymmetry was observed between the North and South polar regions. From this time on, a larger intensity was observed over the North polar cap. The northern excess was about 50 percent for several hours, after which it was reduced to 20 percent for the next two days. The decrease in the southern hemisphere is not a low-energy cutoff effect but a depression of the entire spectrum. A regression plot of the riometer and OGO-6 data indicates good agreement with $A(db) = KI^{1/2}$ for both the increasing and decreasing phases.

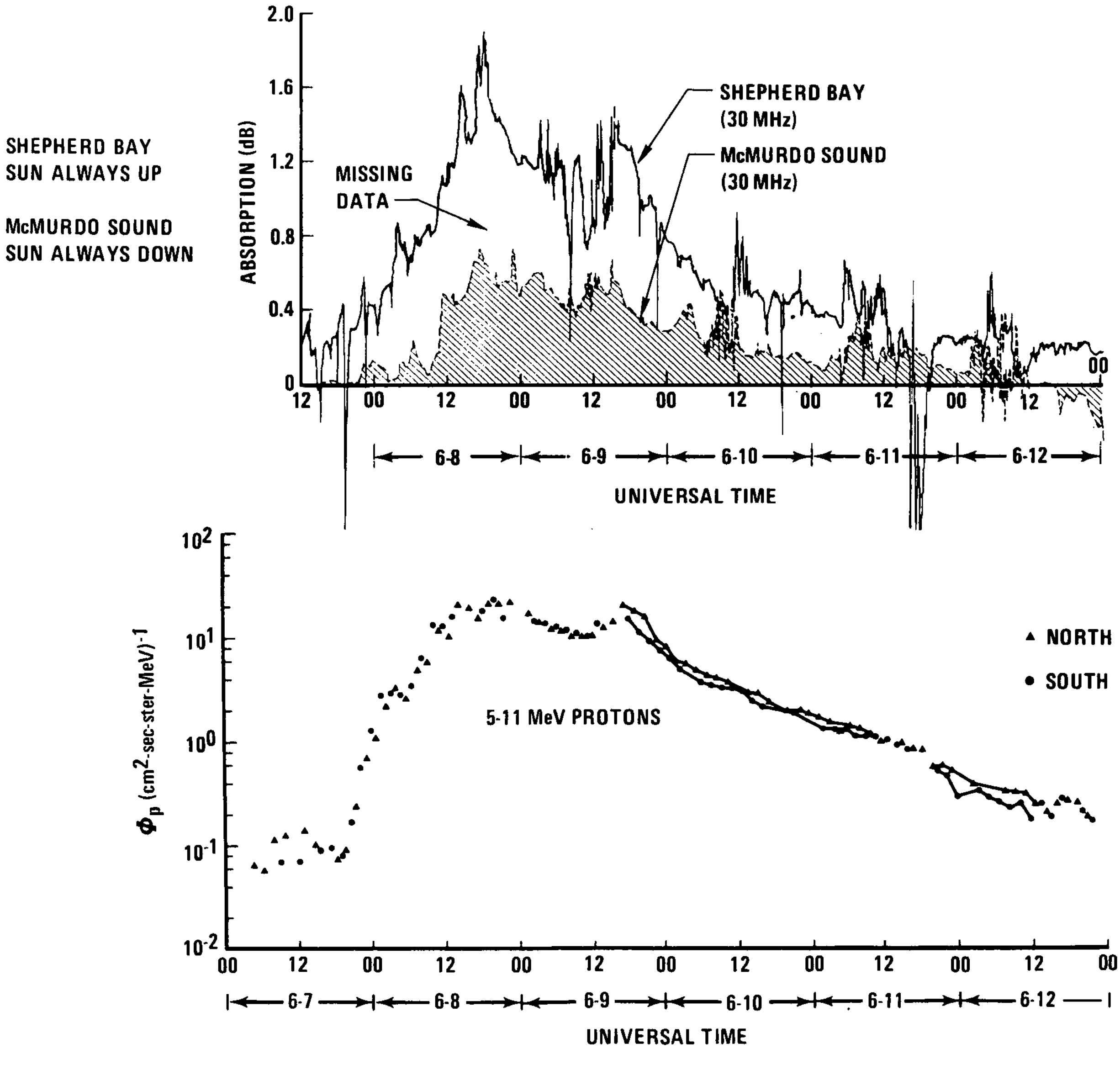

Figure 4-3. OGO-6 7 June 69

September 25 and 28, 1969 Events (Papers 7, 8, 14, 17, and 18)
Figure 4-4 shows the OGO-6 5.3 to 6.1 MeV proton and McMurdo riometer profiles during the September 25 and 28, 1969 events. Figure 4-5 shows two low energy and the greater than 80-MeV profiles. A 2N flare at N14 W14 was reported to begin at 0700 UT on September 25. At 0759 UT, protons were observed only in the >80 MeV channel during a southern polar pass. Figure 4-6 shows the classical buildup of the spectrum on succeeding passes. The high-energy particles arrived first, with low energies arriving later due to velocity dispersion.

On September 27 a 3B flare was observed beginning at 0347 UT and located N09 E02. The major increase due to this flare occurred with the SC at 2125 UT. This event with particles confined behind the shock wave demonstrated very little velocity dispersion as particles at all energies were present from the beginning, as shown in Figure 4-7.

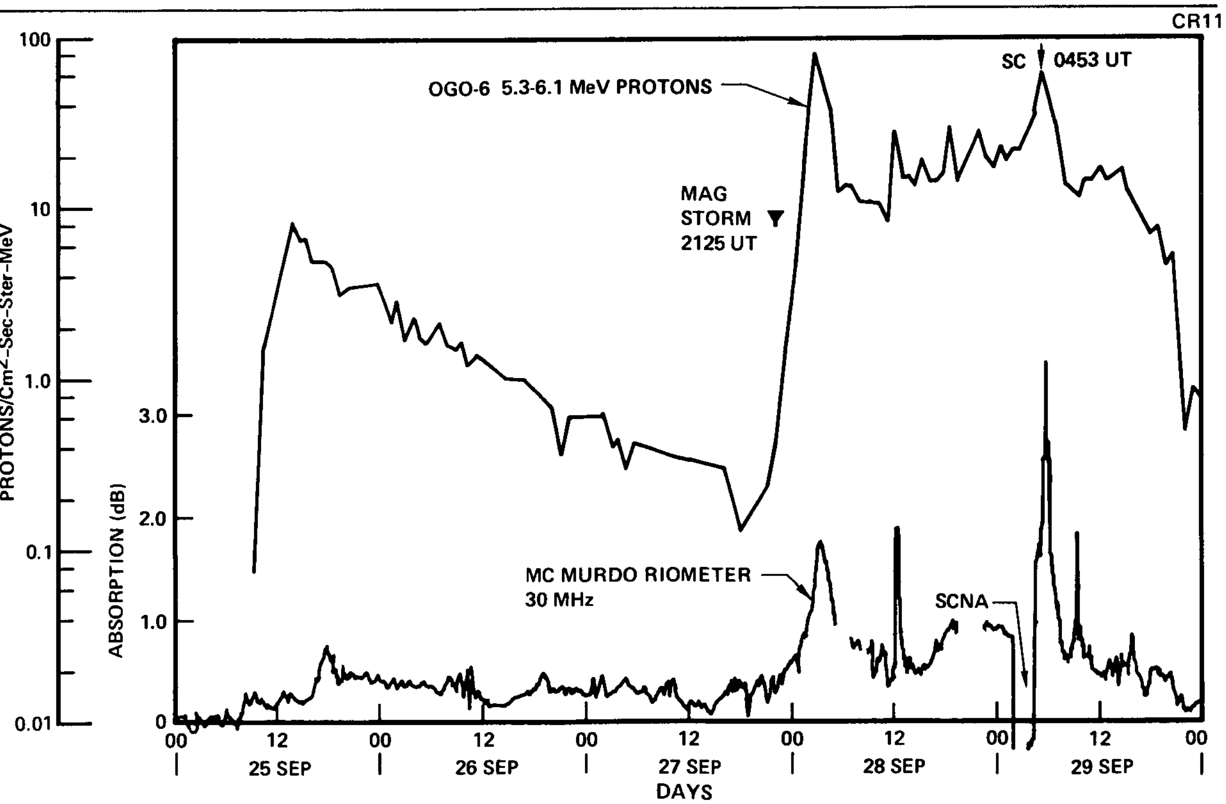

Figure 4-4. 25 Sept 1969 Solar Cosmic Ray Event

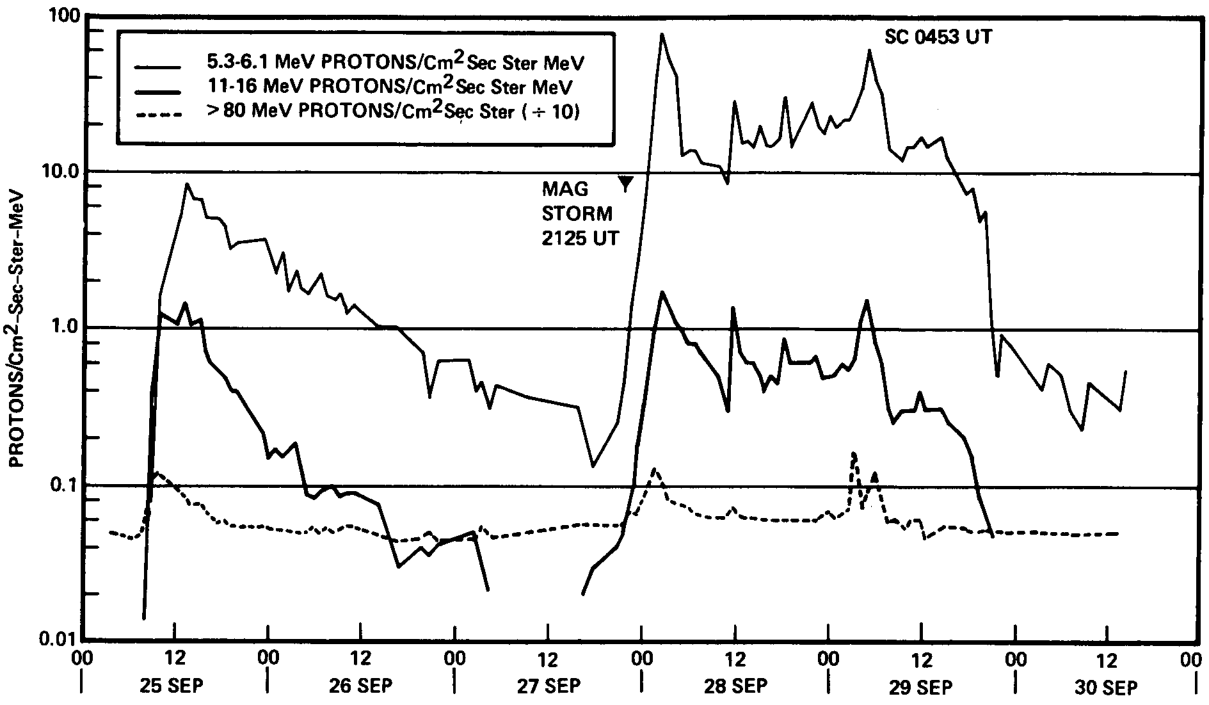

Figure 4-5. 25-30 September 1969 Intensity Profiles

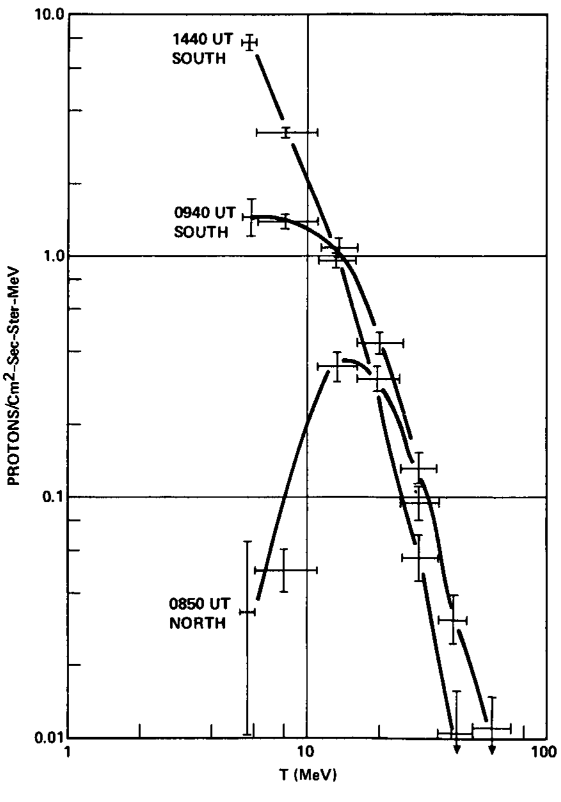

Figure 4-6. 25 September 1969 Differential Energy Spectra

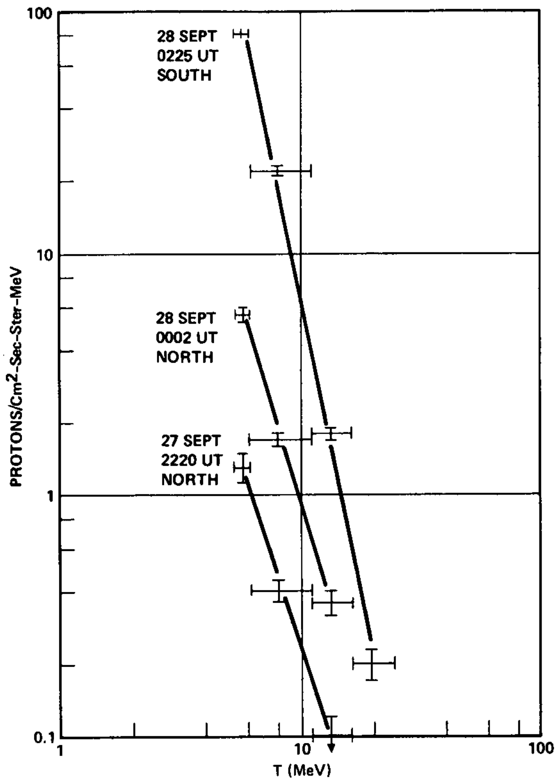

Figure 4-7. 27-28 September 1969 Differential Energy Spectra

A final increase was observed coincident with the SC at 0453 UT on September 29, as shown in Figure 4-8. The spectrum is identical before and after the SC although the total intensity increased. The event began to decrease rapidly about 16 hours after the SC similar to the April 1960 and May 23, 1967 events.

November 2, 1969 Event (Papers 3, 5, 6, 8, 9, 10, and 11)
The November 2 event was one of the largest observed since November 1960. McMath Region 385 rotated into view November 20, 1969. This region was one of the most complex visible spot groups of the current cycle. In spite of this, it rotated out of view on November 1 without producing any major particle event.

At 0943 UT on November 2, about one day behind the limb, a major flare occurred. Importance 2 loops, a large 10-cm radio noise burst, and the most energetic X-ray event of the year were observed.

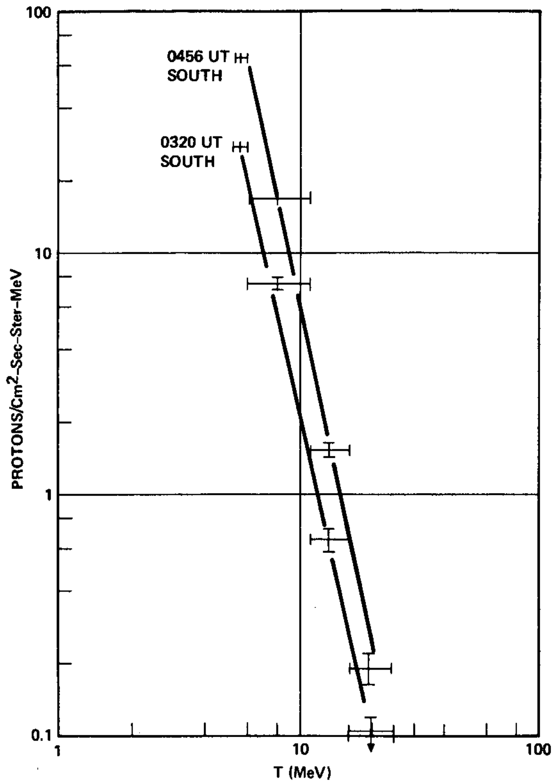

Figure 4-8. 29 September 1969 Differential Energy Spectra

Figure 4-9 shows OGO-6 and McMurdo Riometer observations. The southern riometer saw the event start at about 1100 UT in daylight. The first OGO-6 observation was a northern polar pass at 1100 UT. Particles were observed only in the greater than 80 MeV channel. On the following southern polar pass at 1150 UT, particles over the entire energy range were present, with the spectrum maximum at 35 MeV. The intensity of the greater than 80 MeV protons increased abruptly, reaching its maximum at 1230 UT, the same time as the riometer. The 5 to 80 MeV particles reached their maximum from 1400 to 2300 UT.

Figure 4-10 shows a regression plot of OGO-6 and riometer observations showing excellent agreement with and confirming earlier theoretical work.

During the first southern polar pass, there were large variations across the polar cap (Figure 4-11). The variation was nearly 100 to 1 for the 1330 UT, November 2 southern pass. The distinctive stable features (sharp increase, valley near the local noon side, and a double peak on the local midnight side)

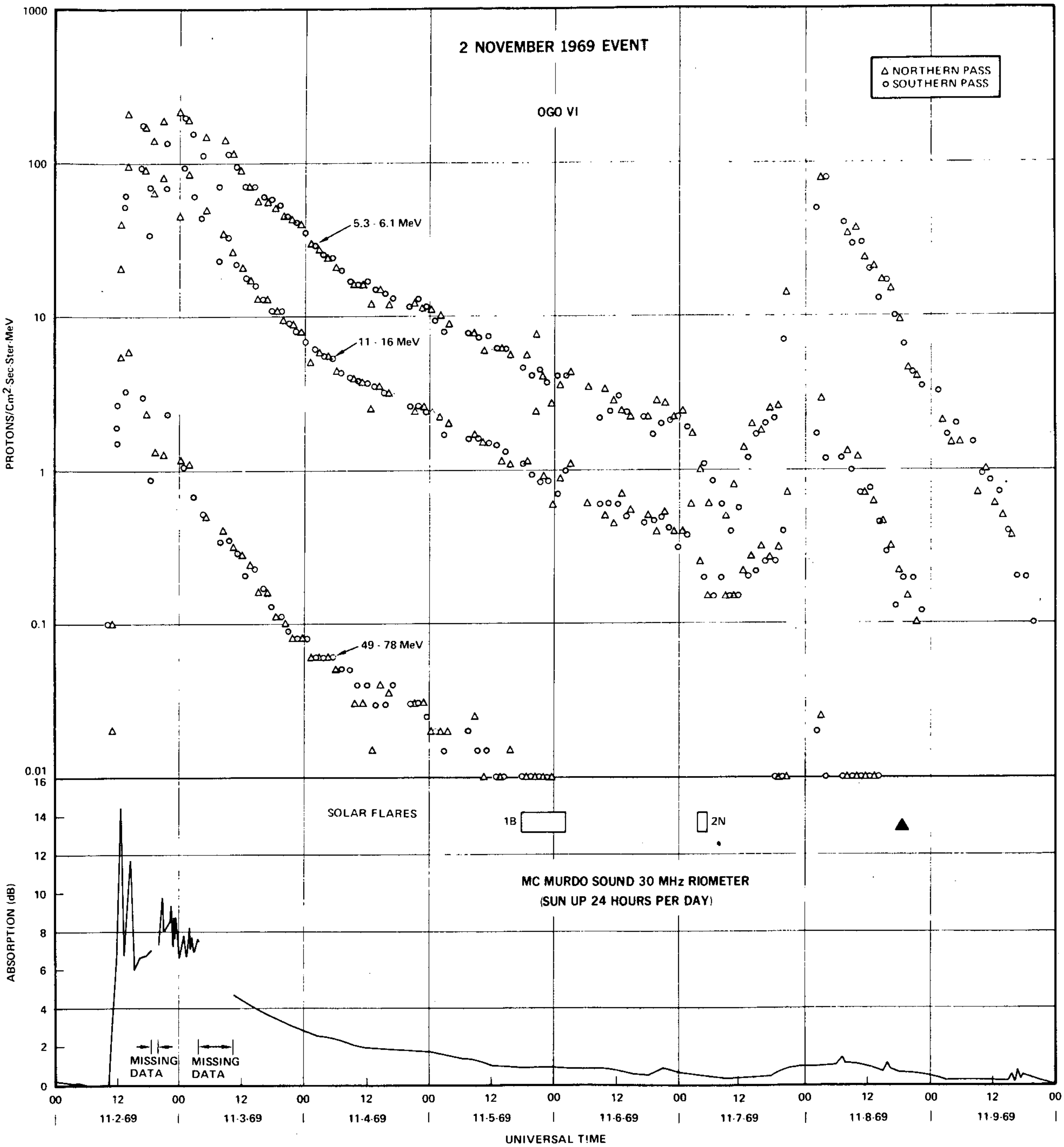

Figure 4-9. 2 November 1969 Event

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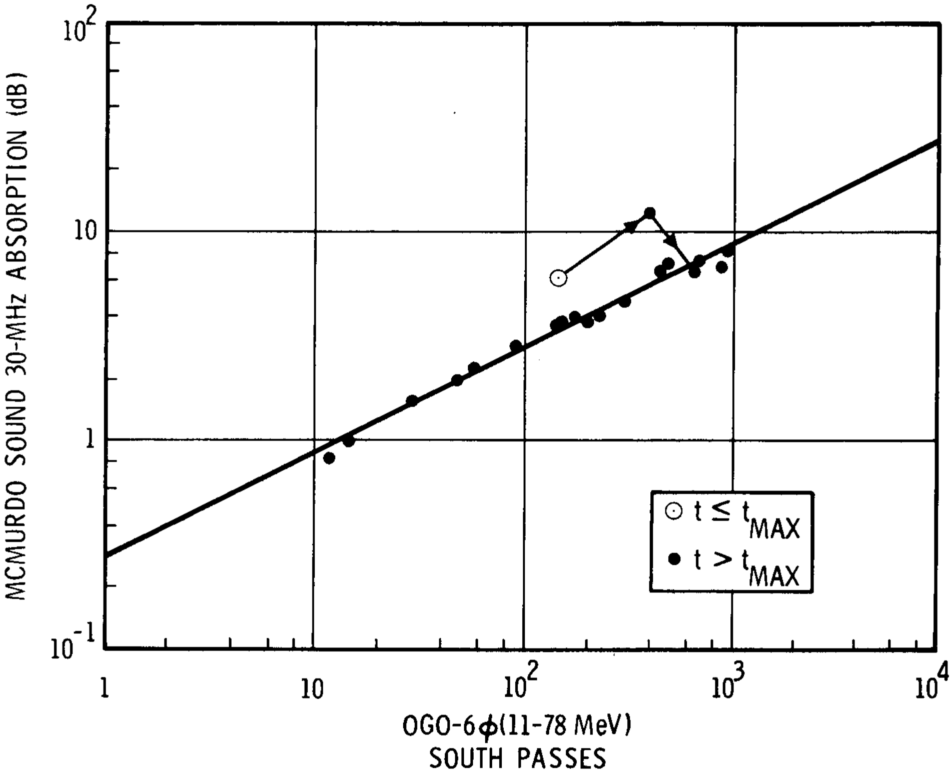

Figure 4-10. 2 November 1969 Regression Plot

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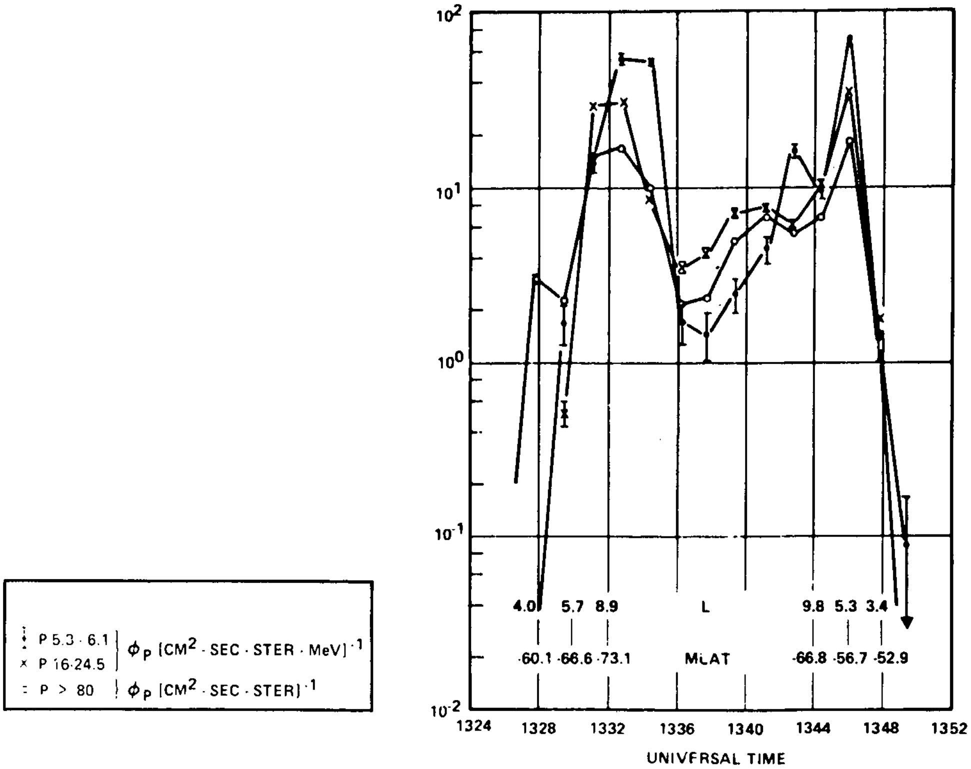

Figure 4-11. 2 November 1969 South Polar Pass

can be followed for about 12 hours to about 0000 UT, November 3, the variation decreasing from 100 to 1 to about 6 to 1 over this period. The earliest northern polar passes show some variation (about 25 to 1, see Figure 4-12), but shortly thereafter the northern passes become more uniform (Figure 4-13).

Spectra at three points during the buildup of the event are shown in Figure 4-14, which illustrates the energy dispersion or differential arrival time. The first spectrum was taken during the first southern polar pass after the event started. Since most lower energies had not yet arrived, the spectrum increased with energy. During the next spectrum, at 1245 UT on the following northern pass, the intensity increased and there was a broad maximum centered near 40 MeV. Spectra near the peak of the event, which have a spectral shape typical of the remainder of the event, indicate that low energies have arrived, causing the intensity to decrease at higher energies.

In general, the event had a significant number of high energy particles, with the middle energies, 50 to 300 MeV, relatively abundant. The lack of response on neutron monitors indicates that there were essentially no particles of

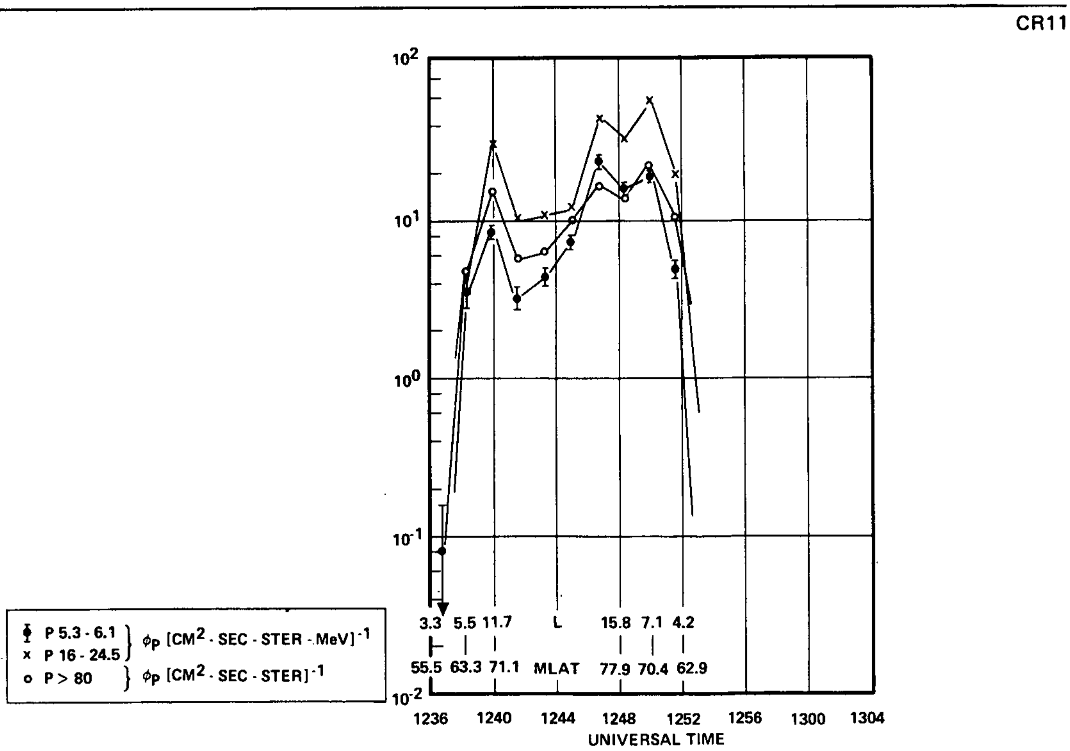

Figure 4-12. 2 November 1969 North

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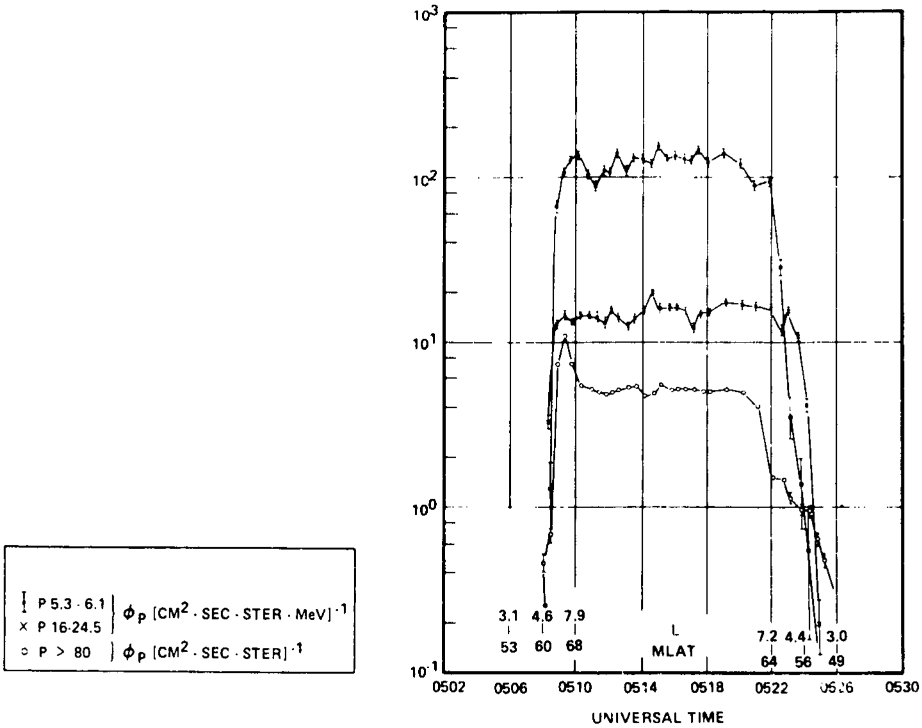

Figure 4-13. 3 November 1969 North

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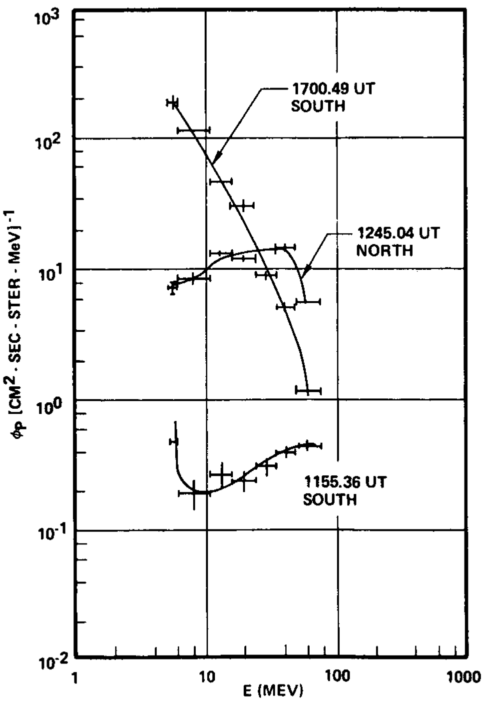

Figure 4-14. 2 November 1969 Solar Cosmic Ray Event

greater than 500 MeV, although there were significant numbers greater than 80 MeV particles throughout the event.

Summary:
The event was due to activity one day behind the west limb of the sun.
The event was one of largest during cycle 20, having:

Maximum absorption: 14.5 dB

Maximum 5 to 80 MeV flux: 1,700/cm^2 sec-ster, and

Integrated free space flux > 30 MeV ~ 3 x 10^7/cm^2

There were significant stable features in the polar profile lasting more than 12 hours.

C. Solar Particle Entry and Propagation (Papers 10, 12, 13, and 15)
The November 2, 1969 event, which was one of the largest during this solar cycle, had quiet magnetic conditions throughout and high intensities of solar protons, alpha particles, and electrons (Figure 4-9). The MDAC OGO-6 data provide detailed information on the entry and propagation of solar particles within the magnetosphere. The location of the first open field line at low latitude on the noon side has been directly measured. This location was monitored for 30 crossings during quiet magnetic conditions. The average value of the invariant latitude was 76 deg for the northern hemisphere and 75 deg for the southern hemisphere. This represents good agreement with the cusp region as measured by Heikkila.

The location of the first open field line is demonstrated by a sharp increase in the intensity of 270 keV solar electrons (Figure 4-15, upper section). This location is then used as an onboard reference for interpretation of proton and alpha particle measurements.

Figure 4-16 is a model which illustrates conditions during this event. The Earth was in a positive interplanetary magnetic sector. The northern hemisphere, with possible field line merging along the tail, had a better connection to the interplanetary field than the southern hemisphere. There was a large variation in intensity across the southern polar cap for protons (Figures 4-15, lower section) and alpha particles. The variation for 5 MeV protons in the South decreased from a maximum of 285 to 1 to 1.4 to 1 over a 20-hour period.

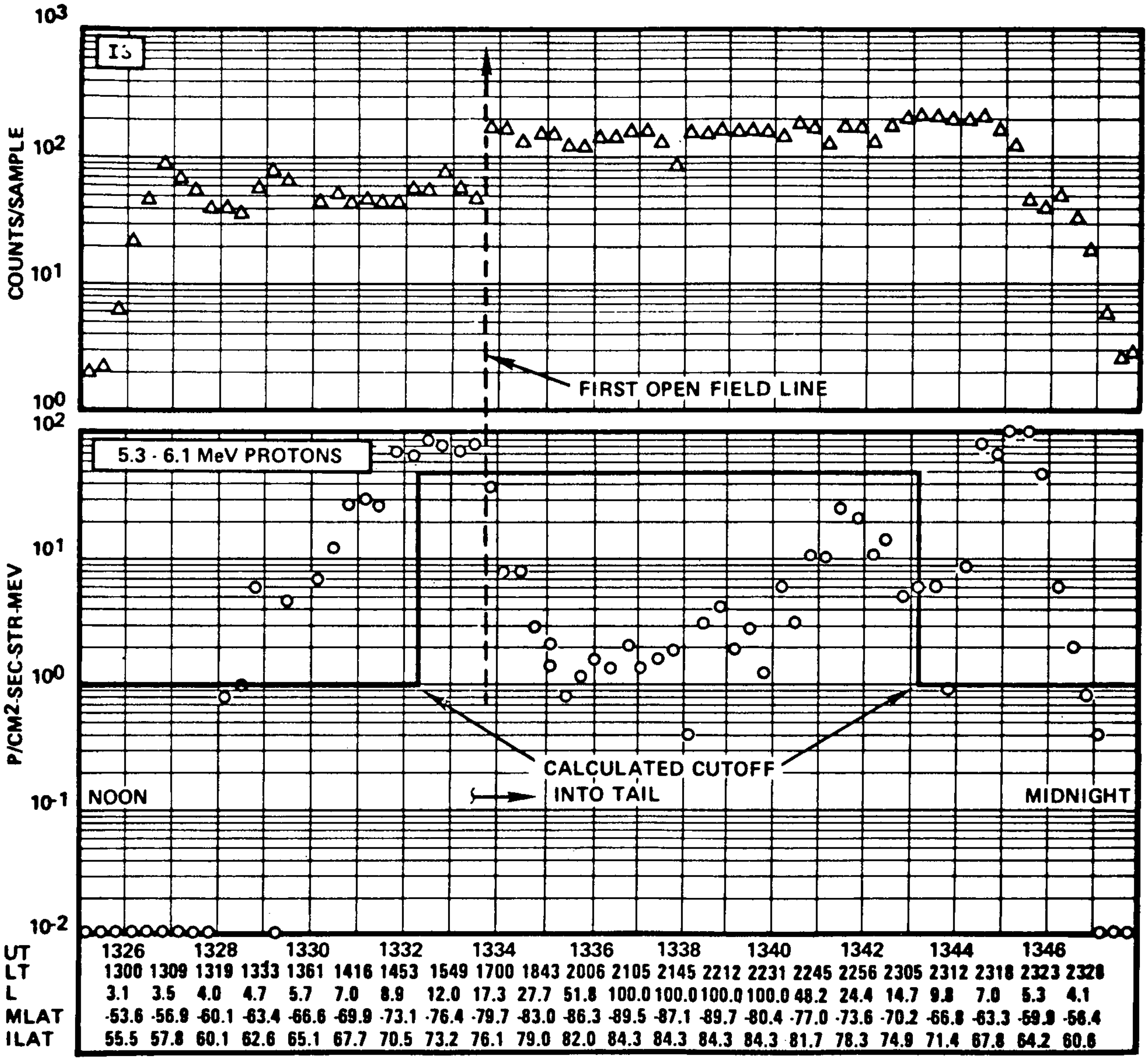

Figure 4-15. OGO-6 Observations and Theoretical Cutoff Results

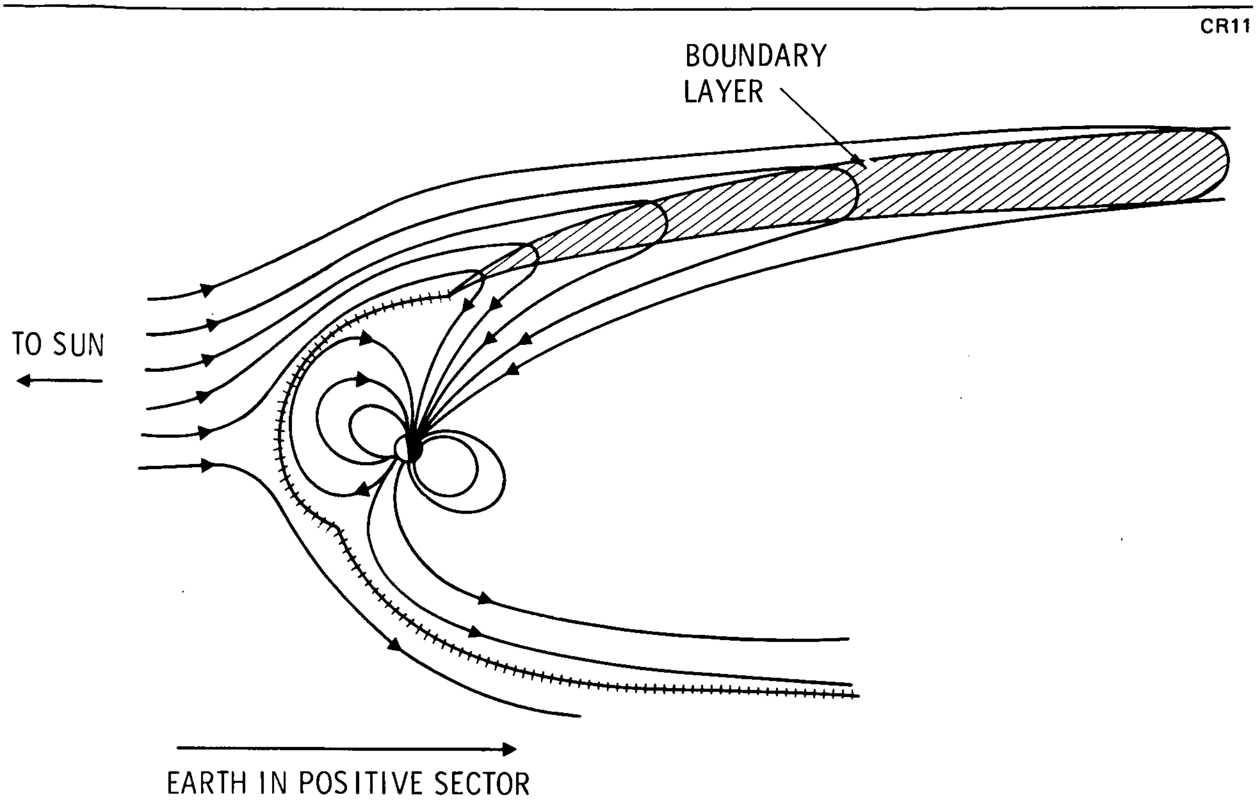

Figure 4-16. Magnetic Field Configuration

In the northern hemisphere, the variation ranged from 20 to 1 to 1.4 to 1 during the same period. The two low-latitude, high-intensity regions shown in Figure 4-15 are located below the predicted cutoff latitudes. The entry of these particles is not understood and is the subject of current study by us. Figure 4-17 shows spectra measured through this region in the southern hemisphere. The persistent double hump suggests two entry mechanisms for the particles.

Protons are nearly absent on the first open field line and the boundary of the southern tail in a region where they are clearly allowed using theoretical cutoff calculations. This suggests no diffusion across the boundary of the southern tail region. The absence of protons and alpha particles is presumably due to the anisotropic flux in interplanetary space, so that the particles cannot find a path to get on to adjacent parallel field lines (same direction) near the tail boundary.

This area of investigation is currently being developed into a PhD thesis by the Principal Investigator. The thesis, which is being carried out with the

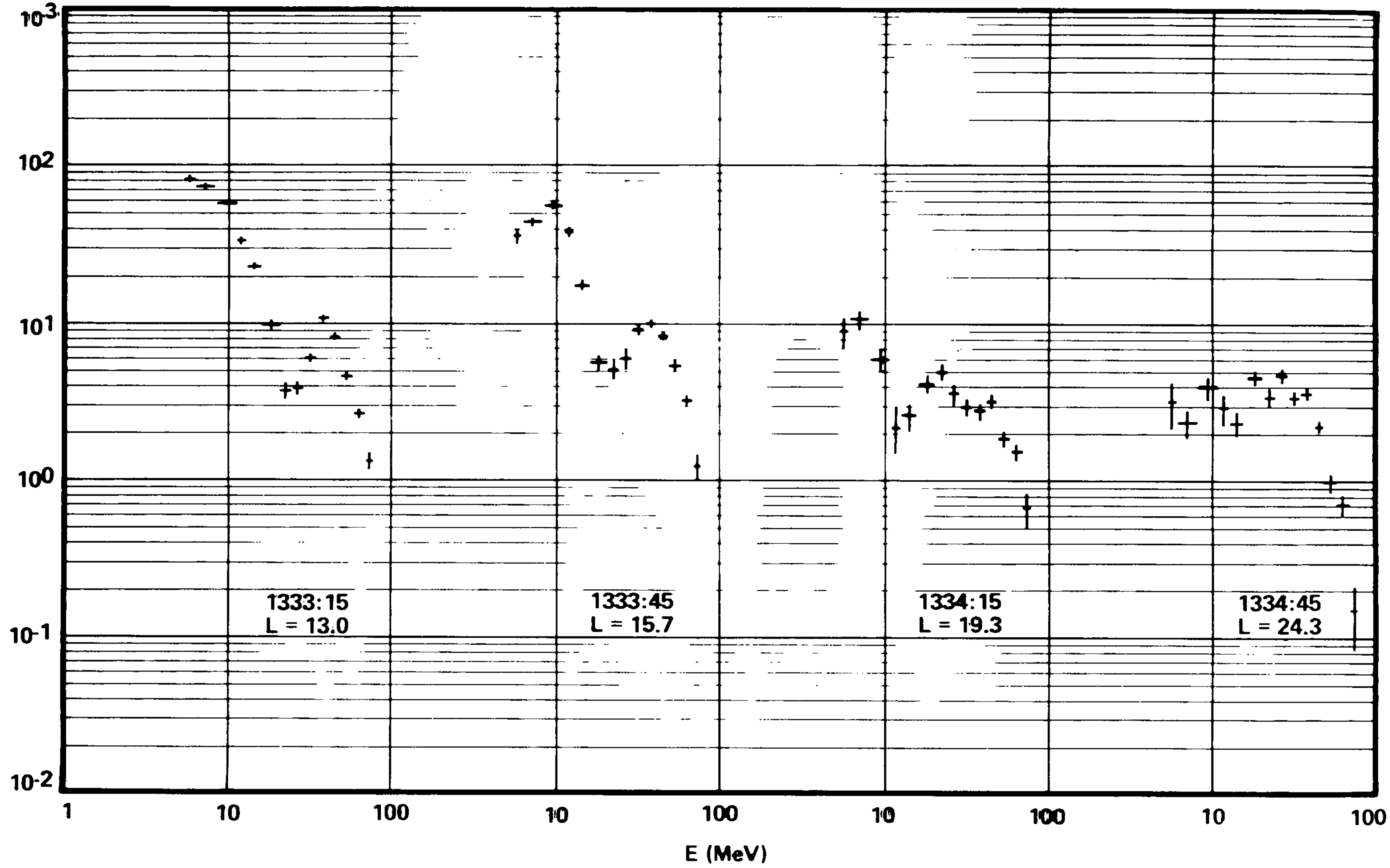

Figure 4-17. 2 November 1969 South Spectra

University of Melbourne, Australia, is based on OGO-6 observations and related theoretical interpretations.

D. Theoretical Investigation of Solar Particle Entry and Propagation within the Magnetosphere (Papers 10, 12, and 13).

Trajectories of solar particles were calculated to determine the cutoff latitude and entry and propagation paths for specific cases. This was done using the best field models available (Olson's tilted magnetosphere, a realistic tail model, and the Fairfield-Mead empirical model). The results are shown in Table 4-2. Over 200 trajectories were run for 5 MeV protons at noon and midnight. Examples of these trajectories are shown in Figure 4-18. These theoretical results were directly compared with measurements by the MDAC experiment on OGO-6. The calculations give cutoffs 6 deg higher than observed at midnight and 8 deg higher at noon. Recent unpublished work using a new version of Olson's magnetospheric model with distributed currents have reduced this disagreement to 2 or 3 deg.

E. OGO-6 and Riometer Studies (Papers 8, 19, 20, and 22)

OGO-6 and riometer data were used to study the November 2, 1969 event. Proton energy spectra and proton/alpha particle ratios measured on OGO-6 at the times of passes close to the geomagnetic field line terminating at the McMurdo Sound riometer station were used to calculate the 30 MHz riometer absorption expected. The calculations were made by MDAC computer programs developed previously to understand riometer absorption. There were five close passes when good data were obtained (Figure 4-19). Riometer absorption was calculated due only to the protons, to protons and alpha

Table 4-2

CALCULATED 5 MeV PROTON CUTOFFS

Investigator	Gall et al. 1968	Masley, Olson, and Pfitzer 1971				OGO-6 Measurement
Tilt	0	0	+30	-30	-20	-20
Noon (Direct)	78	78	76	76	77	~ 69
Noon (Tail)	70	74	--	--	--	
Midnight	68	69	69	70	69	~63

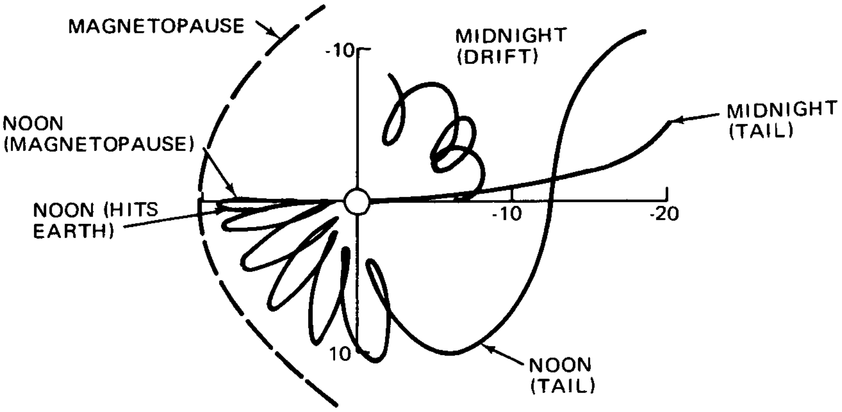

Figure 4-18. Equatorial Projections of Particle Trajectories

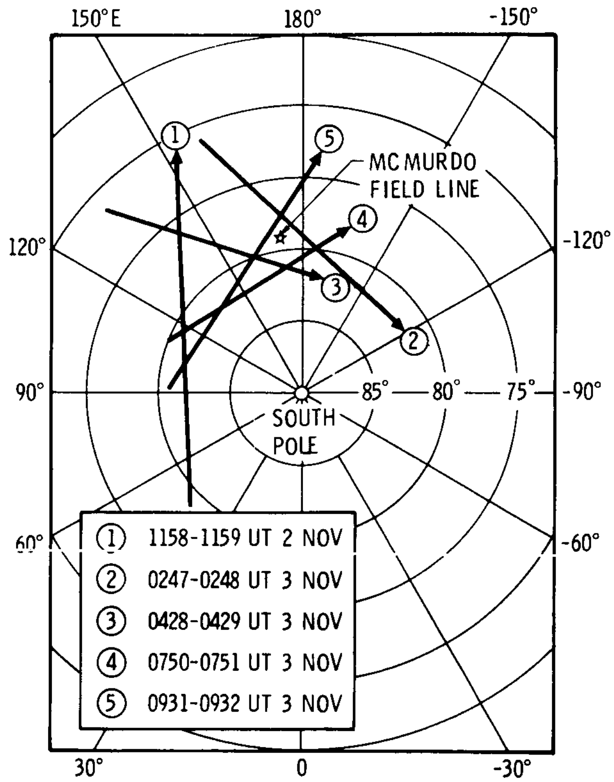

Figure 4-19. OGO-6 Trajectories Over South Polar Region

particles, and to electrons. The contribution from alphas was always very small.

The total absorption calculated and the actual 30 MHz absorption simultaneously measured at McMurdo Sound are shown in Figure 4-20. Extremely good agreement was obtained. A regression plot of McMurdo Sound 30 MHz riometer versus the OGO-6 (11-78) MeV intensity illustrates good agreement with the relationship $A = K\phi^{1/2}$, with $K = \sim 0.3$ established for earlier events.

F. Proton/Alpha Particle Studies (Papers 16 and 21)

OGO-6 measurements of the ratio of proton and alpha particle intensities at 5 to 21 MeV were analyzed in detail for the nine largest solar cosmic ray events observed in the MDAC data. The ratio ranges from 25 to 1,000 for these events. The typical value is between 100 to 300 and varies by a factor of 2 during an event. In most cases, the ratio was not dramatically affected at the time of a sudden commencement, as has been discussed in earlier literature. There were, however, two significant cases of SC effects on the ratio. On September 27, 1969, the alpha particles appeared after the SC

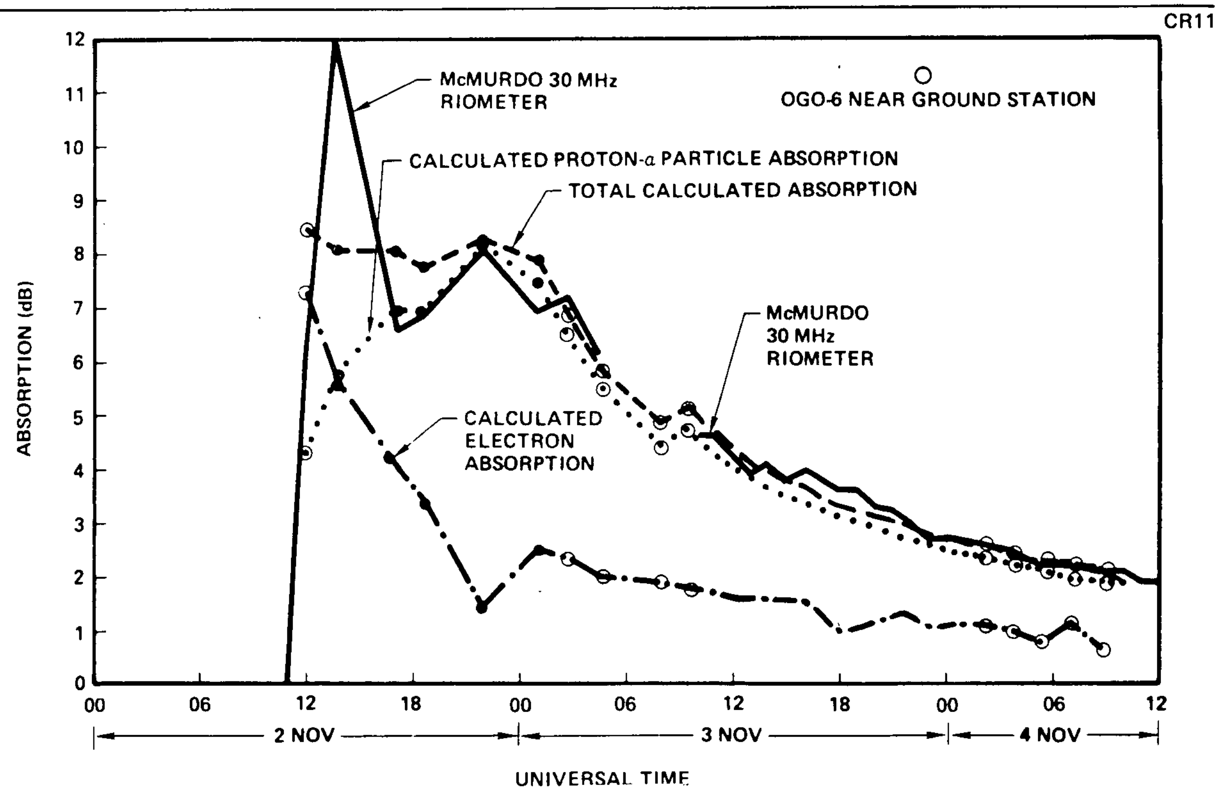

Figure 4-20. Calculated and Measured Absorption, 2 November 1969

and on July 23, 1970, a sharp decrease in ratio was observed at the time of the second SC. As an example, the July 23, 1970 event is shown in Figure 4-21.

The ratios were further analyzed in equal velocity, equal rigidity, and equal energy/charge groups. The data are presented in these three groups for the nine events in Figures 4-22 through 4-24. The analysis is proceeding to attempt to understand the propagation effects from the sun so that particle acceleration and storage can be studied. To investigate the importance of the longitudinal effect, the data were organized with respect to the location at 1 AU of the solar magnetic field line from the flare or injection region. In this manner, the events were divided into approaching or receding cases. Preliminary results show that the ratio was similar and best organized for receding events for equal rigidity intervals and the organization was improved for approaching events for equal rigidity groups.

G. Summary

Excellent data were obtained for the 15 months of coverage provided by the MDAC OGO-6 experiment. Data transmission was terminated in September of 1970 due to a spacecraft malfunction, although the experiment was still working perfectly. Data transmission was also terminated for several other experiments due to this malfunction. Twenty-three events were measured during this period near the peak in Solar Cycle 20.

All of the solar cosmic ray objectives in the original proposals (July 1964, revised February 1965) were accomplished by the experiment. In some cases, the investigation would preferably have been carried out more completely or in greater depth, but time limits and funding constrains prevented this. Several of the studies underway will continue in more depth and the results will be published in future journal articles.

Specific objectives achieved include the following:

A. Radio noise (riometer) absorption measured by the MDAC polar stations as a function of particle energy and type as measured by OGO-6 was investigated and earlier theoretical work verified.

B. The anisotropy between the North and South polar regions was investigated in detail.

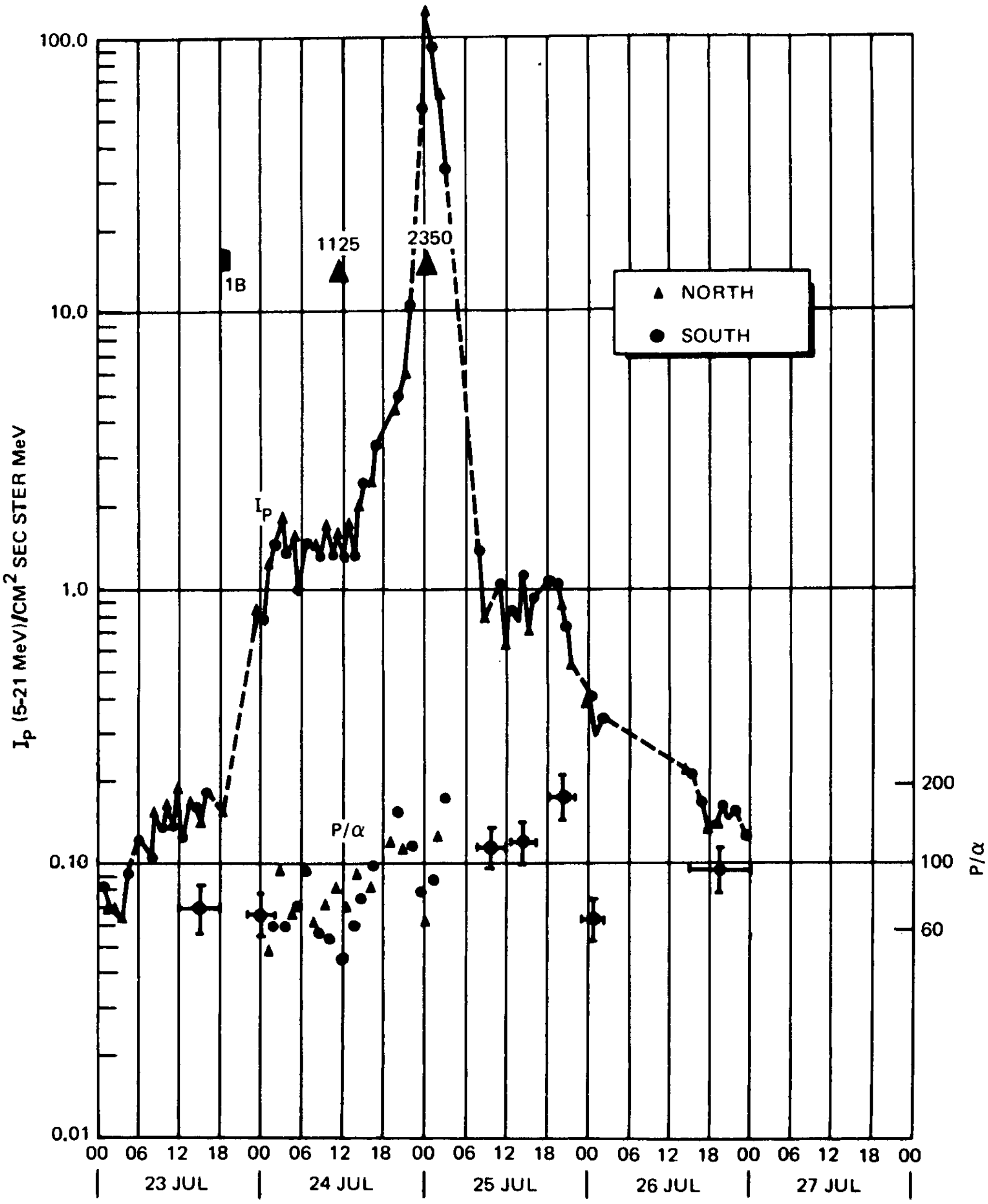

Figure 4-21. 23 July 1970 Solar Particle Event

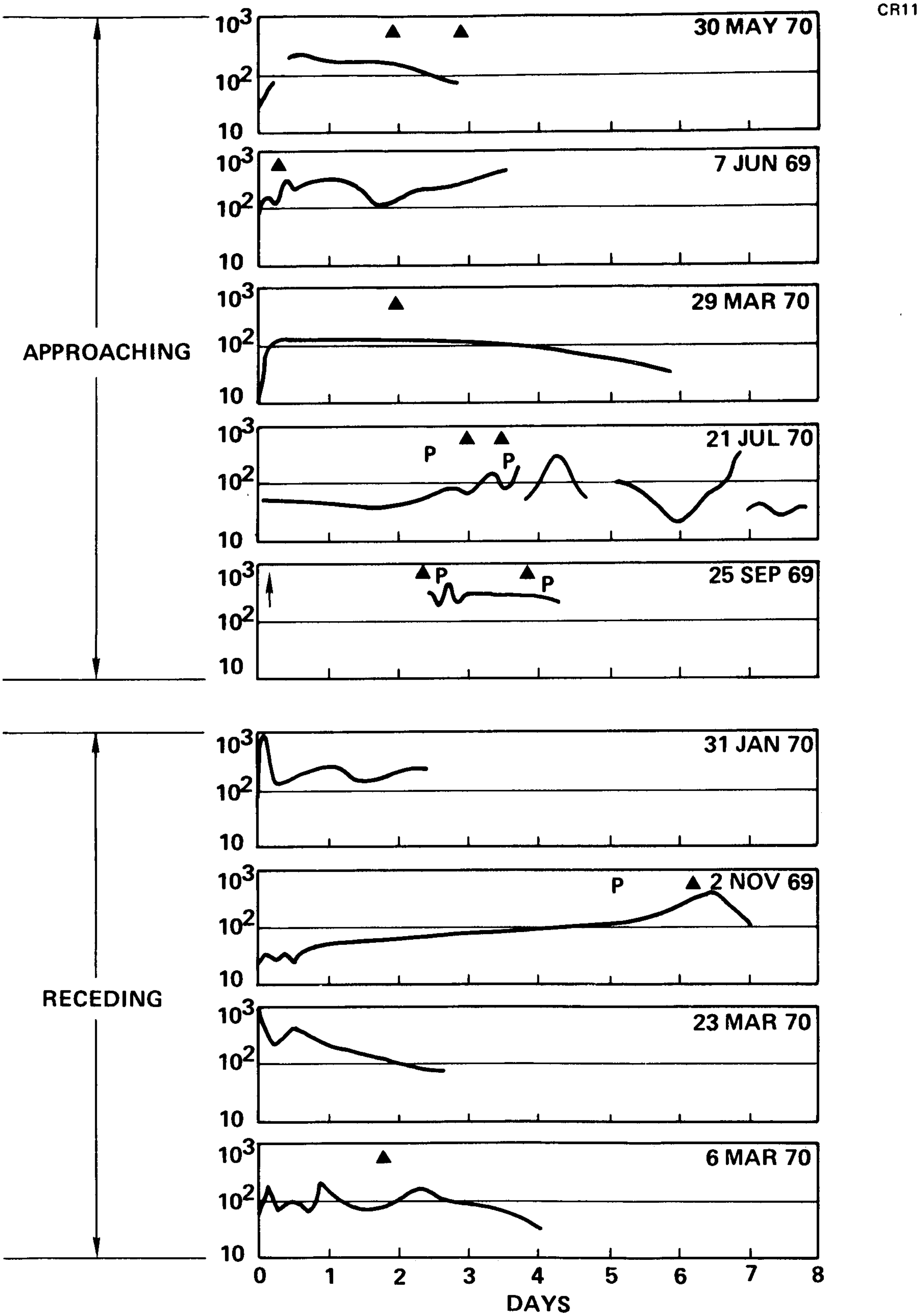

Figure 4-22. Proton/Alpha 5-21 MeV/Nucleon

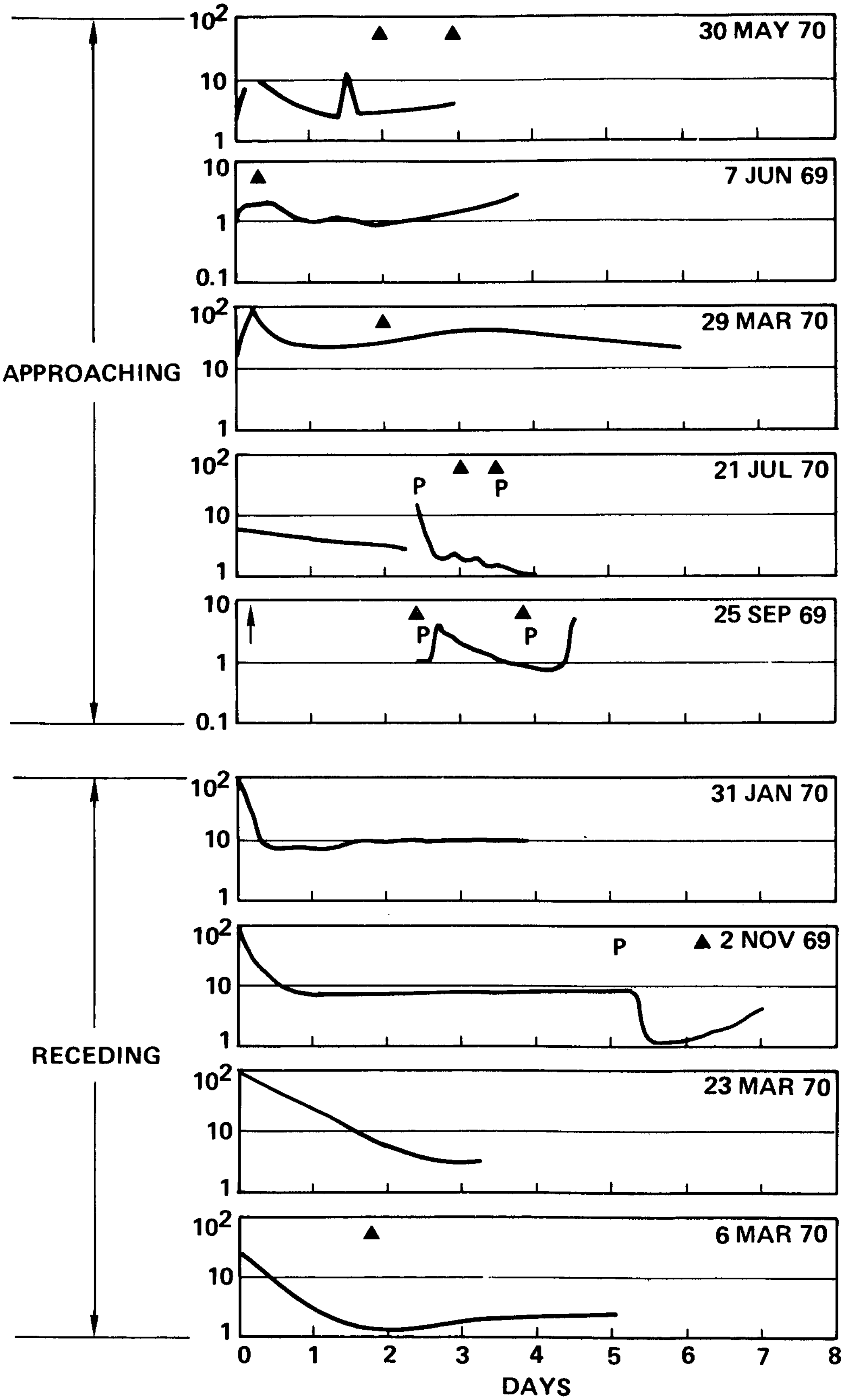

Figure 4-23. Proton/Alpha 16-35 MeV

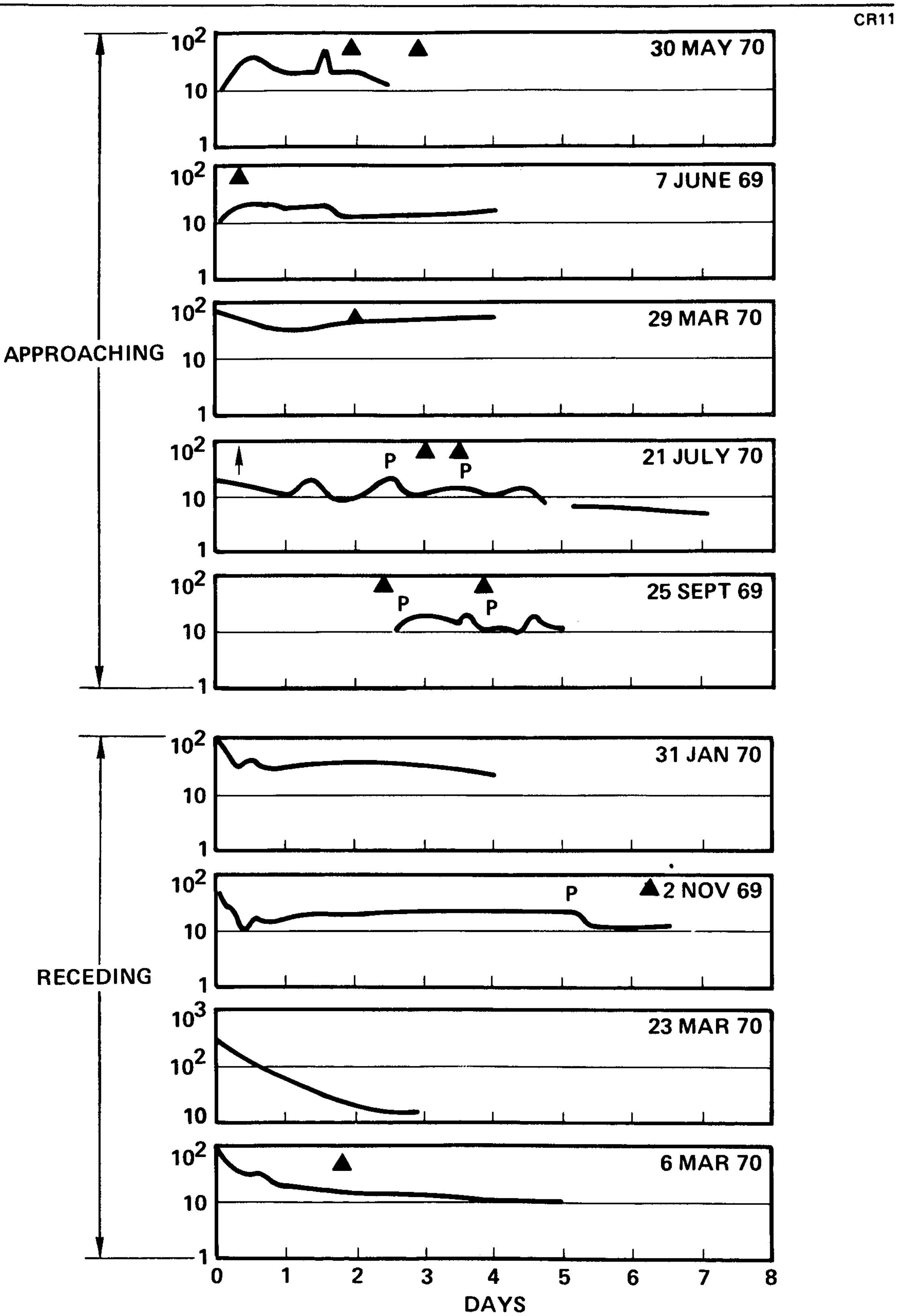

Figure 4-24. Proton/Alpha 8-16 MeV/Q

C. The study of variations in particle access to a given polar region was given as an objective in the proposal, based on our earlier ground observations. These early observations and suggestions were presented several years before they were discussed by any other investigator based either on ground or satellite measurements.

D. Primary emphasis was put on charged-particle entry and propagation in the analysis and interpretation of the data. This area of investigation is currently being developed into a PhD thesis at the University of Melbourne by the Principal Investigator, A. J. Masley.

E. Considerable effort has been expended on study and interpretation of the proton-to-alpha particle ratio and the effects of interplanetary propagation.

A large number of presentations and papers have been based on the MDAC OGO-6 experiment, as shown in Section V. Papers are currently in preparation for publication on: (1) OGO-6 and riometer observations, (2) entry and propagation, (3) proton-to-alpha particle ratios, and (4) theoretical studies of particle trajectories.

Several papers should also result from the PhD thesis currently being prepared. These will include a discussion of entry and propagation mechanisms and detailed results on the latitude cutoff for protons and alpha particles as a function of local time and season.

Many of the OGO-6 results have been and will continue to be used to guide investigations to be carried out on the ATS-F experiment furnished by the same investigator team and due for launch in early 1974. The OGO-6 results will also allow a more complete interpretation of data continuously provided by the MDAC North and South polar ground stations.

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4. Satterblom, P. R., and A. J. Masley, "The 7 June 1969 Solar Cosmic Ray Event," EOS Trans. AGU, Vol. 51, 409, 1970.

5. Masley, A. J., and P. R. Satterblom, "A Discussion of the 2 November 1969 Solar Cosmic Ray Event," presented at American Astronomical Society Solar Physics Meeting, Huntsville, Ala., Nov. 1970.

6. Masley, A. J., and P. R. Satterblom, "Observations During 2 November 1969 Solar Cosmic Ray Events," EOS Trans, AGU, Vol. 51, 799, 1970.

7. Satterblom, P. R., and A. J. Masley, "The 25 September 1969 Solar Cosmic Ray Event," EOS Trans. AGU, Vol. 51, 799, 1970.

8. Masley, A. J., J. W. McDonough, and P. R. Satterblom, "Solar Cosmic Ray Observations During 1969," Antarctic J. of the U.S., 5, 172, 1970.

9. Masley, A. J., P. R. Satterblom, E. D. Stone, and J. A. Lockwood, "Geomagnetic Storm of 1969 November -- Storm Morphology," paper presented at 52nd Annual AGU Meeting, Washington, D. C., April 12-16, 1971.

10. Masley, A. J., and W. P. Olson, "Calculations of Charged Particle Access Into Polar Regions," EOS Trans. AGU, 52, 315, 1971. In preparation, to be submitted to Journal of Geophysical Research.

11. Masley, A. J., and P. R. Satterblom, "Observations During the 2 November 1969 Solar Cosmic Ray Event," paper presented at COSPAR Symposium on the November 1969 Solar Particle Event, AFCRL, Bedford, Massachusetts, June 16-18, 1971.

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13. Masley, A. J., W. P. Olson, and K. A. Pfitzer, "Calculations of Charged Particle Entry Into Polar Regions," Conf. Papers, 12th Intl. Conf. on Cosmic Rays, Hobart, Australia, 2, 824, 1971.

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23. Masley, A. J., P. R. Satterblom, and M. B. Baker, "Solar Cosmic Ray Investigations During 1971," Antarctic Journal, VII, 161, 1972.

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M. B. Baker, scientific analysis

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