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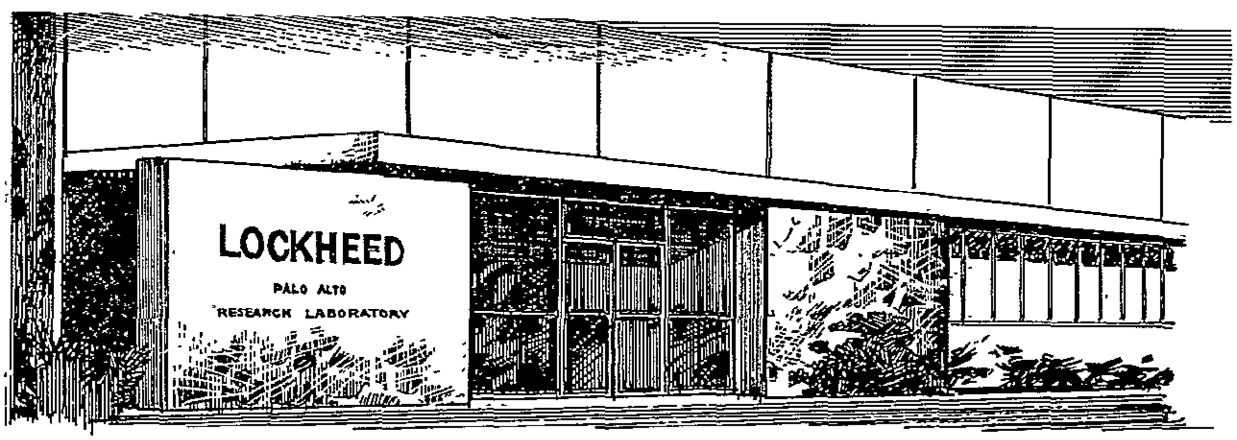
Research Contract Number NASW-2861

FINAL REPORT

ANALYSIS OF HIGH RESOLUTION SATELLITE DATA FOR COSMIC GAMMA RAY BURSTS

9 JUNE 1976

Prepared by:
W. L. Imhof
G. H. Nakano
J. B. Reagan



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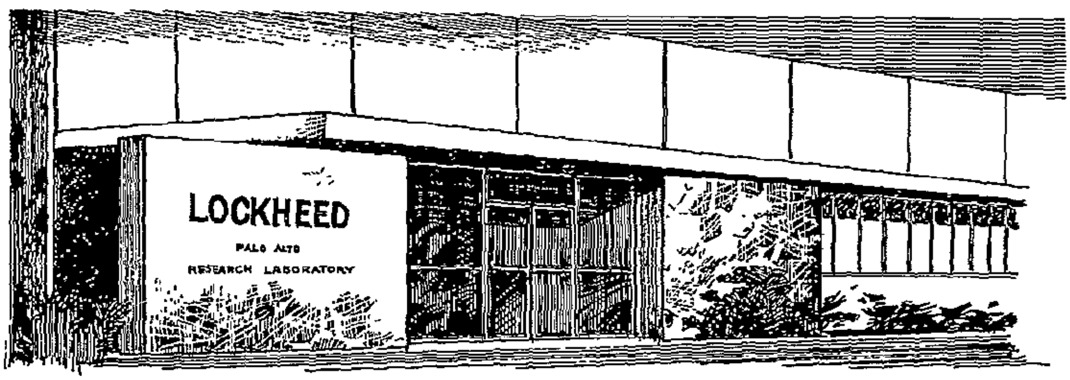

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ABSTRACT

This report summarizes the results of a preliminary survey for the occurrences of cosmic gamma ray bursts in a data set acquired with the Lockheed germanium spectrometer on the low altitude satellite 1972-076B. Since the recent discovery of cosmic gamma-ray bursts, only about 45 events have been reported with the Vela system. Detailed spectral measurements with fast time resolution have been performed for very few of these events, but the existing data indicate that intensity and energy spectrum variations on a fast time scale may be a common feature of gamma-ray bursts. With the Lockheed data two cosmic gamma ray bursts, originally identified with the Vela satellites, have been measured, analyzed and reported in the literature. The large body of high temporal resolution data available with the Lockheed experiment present the opportunity to search for previously undiscovered cosmic gamma-ray bursts, with particular sensitivity for events of short time duration. Under this preliminary study effort a survey of the germanium sensor data was performed to evaluate the potential value of undertaking a more complete survey and analysis.

From the preliminary survey several candidate bursts with durations ranging from ~ 0.032 to > 15 seconds have been found and are tabulated. These candidate events are presented and their frequency of occurrence/intensity distribution is compared with the $S^{-3/2}$ curve of confirmed events. The longer duration candidate events fall above the $S^{-3/2}$ curve of confirmed events, suggesting they are perhaps not all true cosmic gamma-ray bursts. The narrow duration candidates fall closely on the $S^{-3/2}$ curve. This may be fortuitous and some concern exists about the validity of such an intercomparison, since

at most, only a small fraction of those triggering the Vela system are of short (≤ 1 sec) duration. Such events may be part of a different class of bursts. The individual events have been subjected to various statistical analyses but to date none has been confirmed with the instrumentation on other satellites and/or balloons.

In addition to the foregoing candidate cosmic gamma-ray bursts the survey revealed several counting rate spikes, with durations comparable to confirmed gamma-ray bursts, which were shown to be of magnetospheric origin. Confirmation that energetic electrons were responsible for these bursts was achieved from analysis of all data from the complete payload of gamma-ray and energetic particle detectors on board the satellite. The analyses also revealed that the narrowness of the spikes was primarily spatial rather than temporal in character. One might therefore argue that this particular geomagnetic phenomenon should cause no problems for balloon-borne experiments which are relatively stationary in space. However, the occurrence of such structure in the electron environment over a wide range of latitudes and longitudes should serve as a cautionary warning that even with balloon borne experiments, when searching for temporal variations in the gamma ray intensities one should be careful about possible contributions from electrons and that use of energetic particle detectors should be made whenever possible.

Examples of the data and detailed analyses leading to the foregoing results and the list of candidate cosmic gamma ray bursts are presented. Based on this preliminary study we cannot make strong recommendations for further surveys unless additional events are found in other experiments or there is a new basis for further analyzing the present data.

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Section 1

INTRODUCTION

In the short time since the occurrence of short bursts of cosmic gamma radiation was first discovered by Klebesadel, Strong and Olson (1973), approximately 45 events have been observed by the Vela system. The observations have been confirmed with simultaneous measurements on board other satellites such as IMP-6 (Cline et al., 1973), OSO-7 (Wheaton et al., 1973), Apollo 16, (Metzger et al., 1974; Trombka et al., 1974), and 1972-076B (Imhof et al., 1974B, Nakano et al., 1974). Except for a single large burst in 1967 these events span a 5 year period, thus providing a frequency of occurrence of bursts above the Vela detectability threshold of about 9 per year. The very limited body of data available to date has yielded certain basic information such as typical spectral shapes and hence has provided some clues as to the origin of the gamma-ray bursts but many key questions remain unanswered. In particular, for an assessment of the overall importance of the bursts, it is very important to establish the frequency of occurrence of weak and short time duration bursts below the trigger threshold of the present Vela system.

Very recently the lower energy x-ray community has been excited about the discovery of soft x-ray bursts having time profiles similar to those of cosmic gamma-ray bursts. These appear to occur much more often than the more energetic gamma-ray bursts of interest here. For example, Mason et al. (1976) of Mullard Space Sciences Laboratory detected recurrent sequences of periodic pulses from an area of sky centered on $\alpha = 17^{h}27^{m}$, $\alpha = -33,^{0}5$. Pulses, in the energy range 2-7 keV, occurred every 17 seconds in pulse trains lasting between 1 and 3 minutes with individual pulses typically lasting for a few seconds. Grindlay and Gursky (1976) reported detection with the UHURU satellite of x-ray bursts on Norma. The burst decay time constants were both about 30 to 100 seconds. The burst spectrum was observed to harden significantly from $\sim$ 10 keV to $\geq$ 20 keV during the burst decay with no change in lower energy cutoff.

During 8-11 March 1976 the Ariel 5 scintillator detected 3 hard x-ray bursts in the range 50 to 200 keV, each lasting about 3 seconds (Coe et al., 1976). In comparison with the Vela type gamma ray bursts these were relatively weak, the energy per burst being $\geq 3 \times 10^{-7}$ erg/cm^2. These bursts correlated timewise with the soft bursts of Mason et al. but occurred after a time lag of between 12 seconds and 50 seconds.

Since there appear to be a variety of gamma-ray burst phenomena it is important to search for bursts over a wide range of energies and time durations. For a given class of events it is important to study the intensity distribution in order to learn more about the physical distributions of the sources and to establish the total rates of occurrence. If the sources are distributed uniformly throughout space then the number detectable above a given flux level would follow the well known relation $N(S) \alpha S^{-3/2}$. For sources confined to an infinite thin sheet, $N(S) \alpha S^{-1}$. Strong and Klebesadel (1974) have compared the Vela data with the various power law distributions. For weaker events they observe a break-away from the -3/2 power law which they point out may be related to threshold effects in the detector trigger logics or may be real. Recently, Herzo et al (1975) have observed a cosmic gamma-ray burst and two candidate events with a large scintillator flown on a balloon. These bursts, including the candidates, were found to be in agreement with the $S^{-3/2}$ law. In a coordinated set of two simultaneous balloon flights Schmidt et al (1976) have reported observing weak gamma-ray bursts.

Although cosmic gamma-ray bursts have been observed from several satellites and weak events have been measured the data available from all satellites to study gamma-ray bursts are severely limited and it may be several more years before satellite instrumentation based on our present knowledge of gamma-ray bursts can be put into operation. An expeditious (and economical) method of studying certain aspects of gamma-ray bursts, such as the intensity distributions, is to survey existing satellite data where acceptable measurements have already been performed. Although for the weaker events it is harder to confirm their validity with data taken on a single satellite, several options are available to establish the true occurrence of a gamma-ray burst.

When specific events are found in a given set of satellite data, measurements taken on other satellites at these times can be examined to provide coincident observations. Also if the experimental payload on a satellite contains more than one gamma-ray sensor and the data are sampled at a high repetition rate one has further tools for confirming the validity of an event with the data taken on that satellite alone. This is the case with the Lockheed germanium spectrometer experiment.

This report describes the results of a partial survey of a 6-month set of gamma-ray measurements performed in the first and to date only satellite flight of a germanium spectrometer. With this spectrometer two gamma-ray bursts first identified by the Vela system were observed. The data, however, had not been analyzed for cosmic gamma-ray bursts under the DARPA/ONR-sponsored program, which had other objectives. Under the present contract with NASA we have performed a preliminary survey of the Lockheed high resolution spectrometer data and found several candidate events which are described. In addition, some narrow counting rate spikes of magnetospheric origin have also been discovered and are discussed.

Section 2

STUDY PLAN

In this preliminary search for the occurrences of cosmic gamma-ray bursts we made primary use of the 6-month period of data when the germanium sensor was operating on orbit. Data taken since that period with the anticoincidence counters alone were analyzed when appropriate, such as at times of the launches by various scientific groups of balloons containing large area scintillation counters to search for gamma-ray bursts and at the times of any candidate events recorded on other satellites. The high bandwidth germanium spectrometer data were recorded during more than 1400 orbits of the satellite and are contained on about 3300 digital magnetic tapes. For maximum efficiency in searching for cosmic gamma-ray bursts we performed the following 3 tasks in parallel:

1. Processed on the UNIVAC 1110 computer part of a set of ~ 140 magnetic tapes containing the high resolution germanium spectrometer data from about 900 orbits in compressed form (15-second summation intervals as opposed to the 0.032 second intervals in the raw data). These compressed tapes were generated under another program with DARPA to analyze the data for other applications. They were, however, very useful in searching for cosmic gamma-ray bursts. The data taken at any times when the germanium spectrometer counting rates were significantly above the normal background levels were examined in more detail.

2. Surveyed with our small computer/ground station facility many of the high resolution digital tapes. Most of these tapes had previously never been surveyed for cosmic gamma-ray bursts. Strip plots of the counting rate profiles were generated and examined for narrow spikes. Interesting intervals were subjected to more detailed analyses.
3. Analyzed in detail data taken at times of candidate events found on other satellite and/or balloons by different experimental groups.

Section 3

SEARCH FOR TEMPORAL VARIATIONS WITH A ~ 15 SECOND SURVEY

In searching for temporal variations in the cosmic gamma-ray (> 50 keV) fluxes the data were surveyed in various time resolution intervals ranging from the basic x-ray counting rate sample period of 0.032 seconds up to the several minute time interval of a given satellite pass across the earth's equator. First we present the results of analyses of the data between 3 October 1972 and 29 April 1973 in 15-second increments during each of many 6.7 minute passes of the satellite. The latter intervals are each centered about the earth's magnetic equator which varies from $\sim 10^{\circ}$ north to $\sim 10^{\circ}$ south geodetic latitude. The data were taken from 569 orbits of the satellite during the time period 3 October 1972 through 29 April 1973. In order to minimize any variations introduced by the backgrounds the "down" counting rates have always been subtracted from the "up" rates on a spin for spin basis. Since the spin period was only 5 seconds the backgrounds other than external gamma-rays are nearly independent of view direction. The secondary neutral radiations, neutrons and gamma-rays, in the satellite arise in a complex manner from interactions of the incident energetic charged particles with the various materials on board, but any directional variations are expected to be minimal. Also counting rates from radioactivities induced in the sensor, the collimator and the satellite with half lives significantly longer than the satellite spin period of 5 seconds should, of course, not depend on the view direction. For an initial survey the up and down spin intervals were each taken to be 114.3° in width for the central viewing angles. These intervals were centered about zenith angles of 4° and 181°, respectively. During the upward spin interval the spectrometer did not view any part of the atmosphere whereas in the downward interval the atmosphere encompassed a large fraction, 0.865, of the solid angle with the sky encompassing the remaining fraction. For this survey all of the satellite passes across the equator were restricted to the longitude interval 5°E to 275°E to avoid the trapped radiation environment in the South Atlantic Anomaly.

The up-down counting rates, each averaged over a period of 405 seconds, are plotted in Figure 3-1 as a function of day number for the period 7 December 1972 through 29 April 1973. The local dayside and nightside data are plotted separately for comparison. An examination of the ~ 7 day counting rate averages, indicated by horizontal lines, reveals that the dayside x-ray intensities experienced a broad maximum in early January 1973. The sun was viewed during each of the upside scans but significant x-ray activity in the 20-30 keV range was not reported in the UCSD solar x-ray catalog from OSO 7 data or in the solar-geophysical data (Prompt Reports published by U. S. Department of Commerce) during the times of any of the satellite passes. The nightside fluxes, on the other hand were generally decreasing during this period after a maximum in December 1972.

The presentation in Figure 3-1 indicates the general nature of the raw data on an orbit to orbit basis. To study the directional variations the net up-down counting rates averaged over ~ 14 day intervals are plotted in Figure 3-2 as a function of the right ascensions of the nightside and dayside viewing directions, which differ by 10 hours. Except for two points taken in October 1972, when the threshold energy was ~ 40 keV, all of the data values are

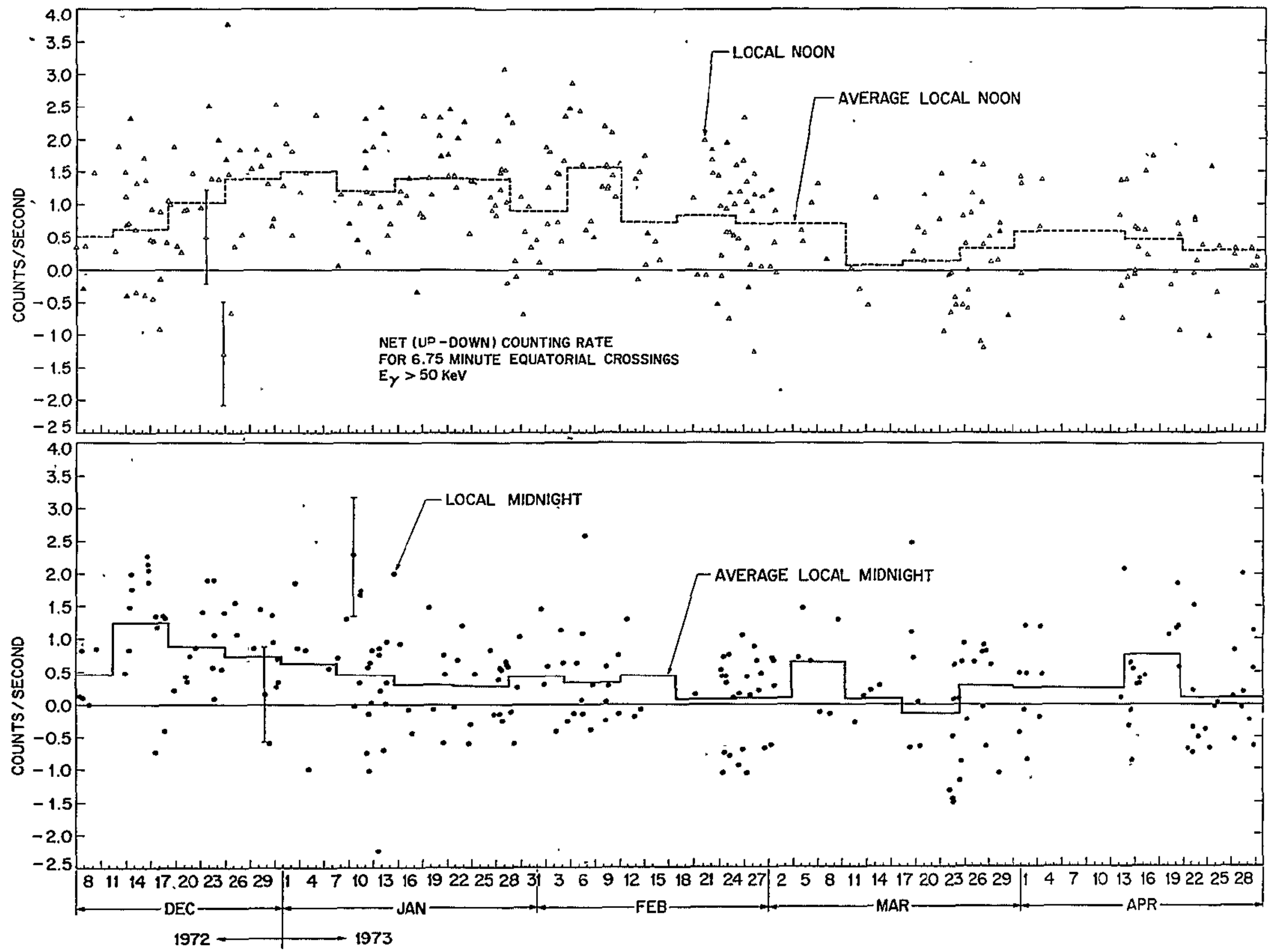

Figure 3-1. Net (up-down) counting rates for 6.75 minute equatorial crossings.

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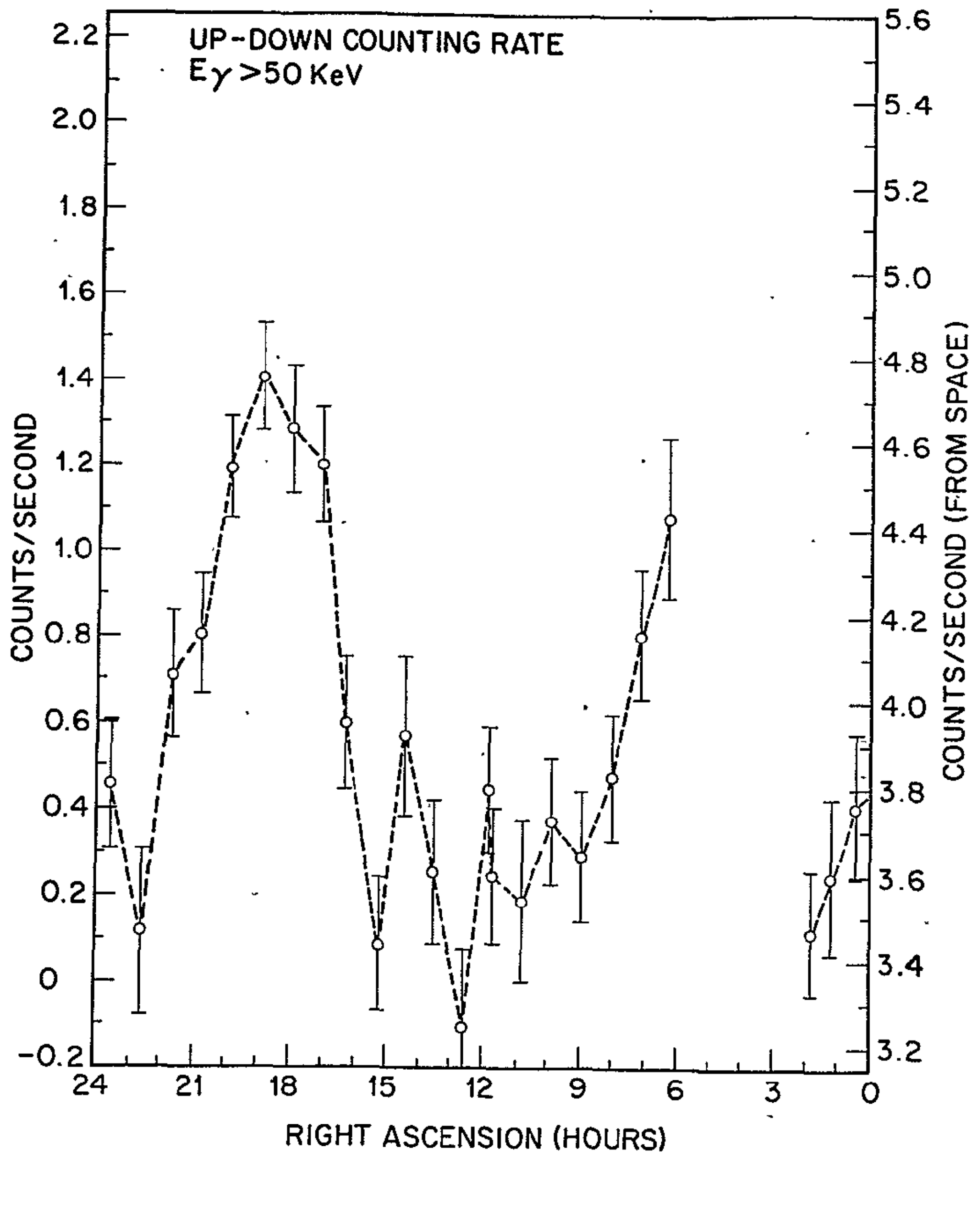

Figure 3-2. Net (up-down) counting rates averaged over ~ 14 day intervals plotted as a function of right ascension (hours). On the right hand scale the contribution to the counting rate from the atmosphere has been removed.

averages of the raw (> 50 keV) total up-down counting rates. The two October counting rates have been adjusted, on the basis of the measured spectra, to provide the rates above 50 keV for comparison with the rest of the measurements.

The data clearly indicate two pronounced maxima in the x-ray fluxes in the general longitude vicinity of the galactic center and anti-center at ~ 18 hours and ~ 6 hours, respectively. Due to the lack of coverage between 2 and 6 hours the direction of the latter maximum is not well defined. The location of the maximum near 18 hours R.A. is consistent with the known observations of significant hard x-ray fluxes from CYG x-1, CYG x-2, CYG x-3, and a source near the galactic center (Peterson, 1973; Ulmer, 1974). The maximum near 6 hour R.A. may be attributed entirely to the Crab Nebula.

Histograms are shown in Figure 3-3 of the average "up-down" counting rates measured during passes of the satellite across the earth's equator. These histograms are grouped into 5 dayside and 5 nightside time intervals, respectively. With each histogram Gaussian distributions are shown, based on the statistical accuracies of the individual points and the average up-down rates for that grouping. The summations of the chi-squared deviations from the Gaussian distributions are also shown. It is recognized that there are limitations to the validity of the chi-squared values when the statistical sampling in each intensity interval is small. Nonetheless these analyses do provide an important basis for investigating possible temporal variations in the x-ray intensities.

In Figure 3-3 the most pronounced deviations from a steady x-ray intensity are in the dayside histogram during the period 7 December 1972. Two of the

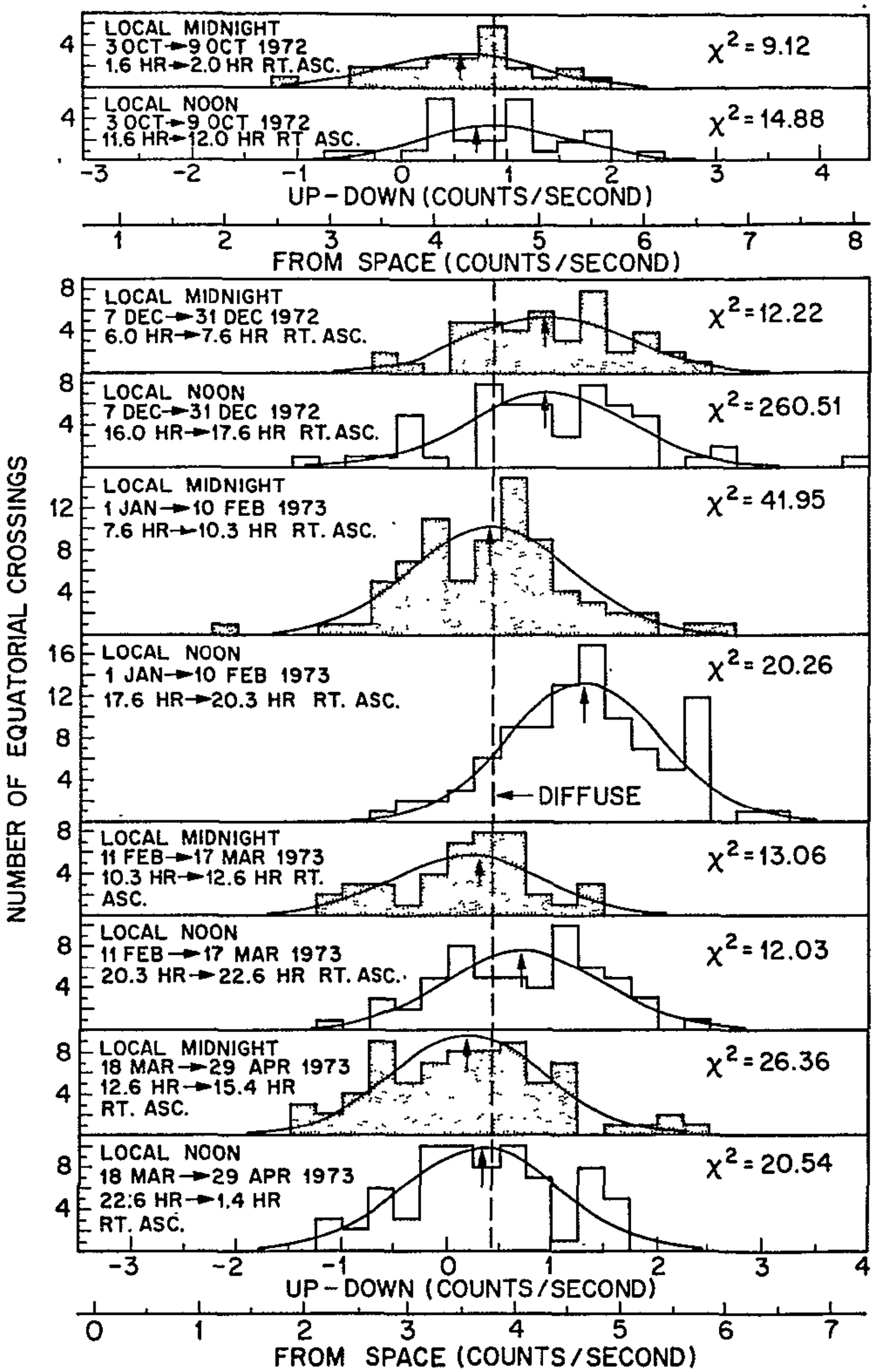

Figure 3-3. Histograms of the "up-down" counting rates measured during passes of the satellite across the earth's equator. The Gaussian distributions shown are based on the statistical accuracies of the individual points and the average up-down rates for that grouping.

passes with an average up-down counting rate in the 3.74-4.0 and 2.5 to 2.75 sec^{-1} interval occurred on 25 December and 23 December 1972, respectively, and are examined in more detail in Figure 3-4. Here are plotted the counting rates averaged over successive three 5-second spin intervals on each of several passes during the period 22-28 December 1972. During each pass the three horizontal lines indicate average rates during 405 second periods, the central ones being those spanning the magnetic equator. Elsewhere the analyses are restricted to the 405 second intervals spanning the equator. The up-down averages before and after the equatorial crossing are generally lower, consistent with the increased atmospheric gamma-ray rates at higher geomagnetic latitudes. The counting rate profiles during the "enhanced" passes are consistent with a higher average rate and do not indicate large single spin deviations.

From 189 passes at local midnight of the satellite across the geomagnetic equator 5103 15-second (3 satellite spin) intervals were obtained. During each pass of the satellite (containing 27 15-second intervals) the deviations of the 15-second counting rate periods from the mean value, averaged over 14-day intervals, were tabulated. A histogram of these deviations is presented in Figure 3-5 along with the values expected for a random distribution having measured mean values and standard deviations.

In Figure 3-5 one can see that the measured counting rates are generally consistent with a steady influx of gamma-rays, except in the upward viewing direction at very large deviations from the mean value where there are more cases than expected. Those local nighttime cases, along with a similar list for local daytime passes, with σ greater than 3 are tabulated in Table I.

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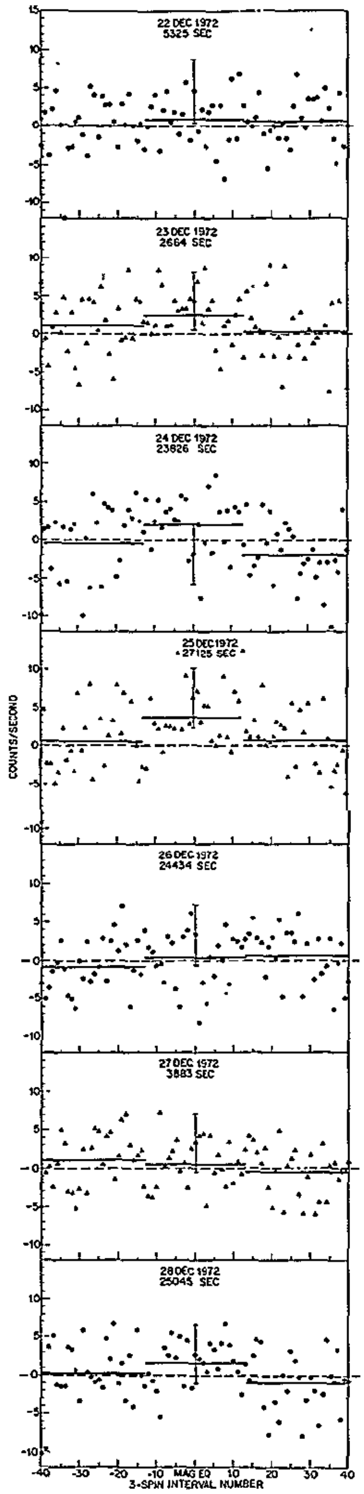

Figure 3-4. Net "up-down" counting rates averaged over successive three spin (~ 15 second) intervals on each of several satellite passes. The horizontal lines indicate average rates during 405 second periods.

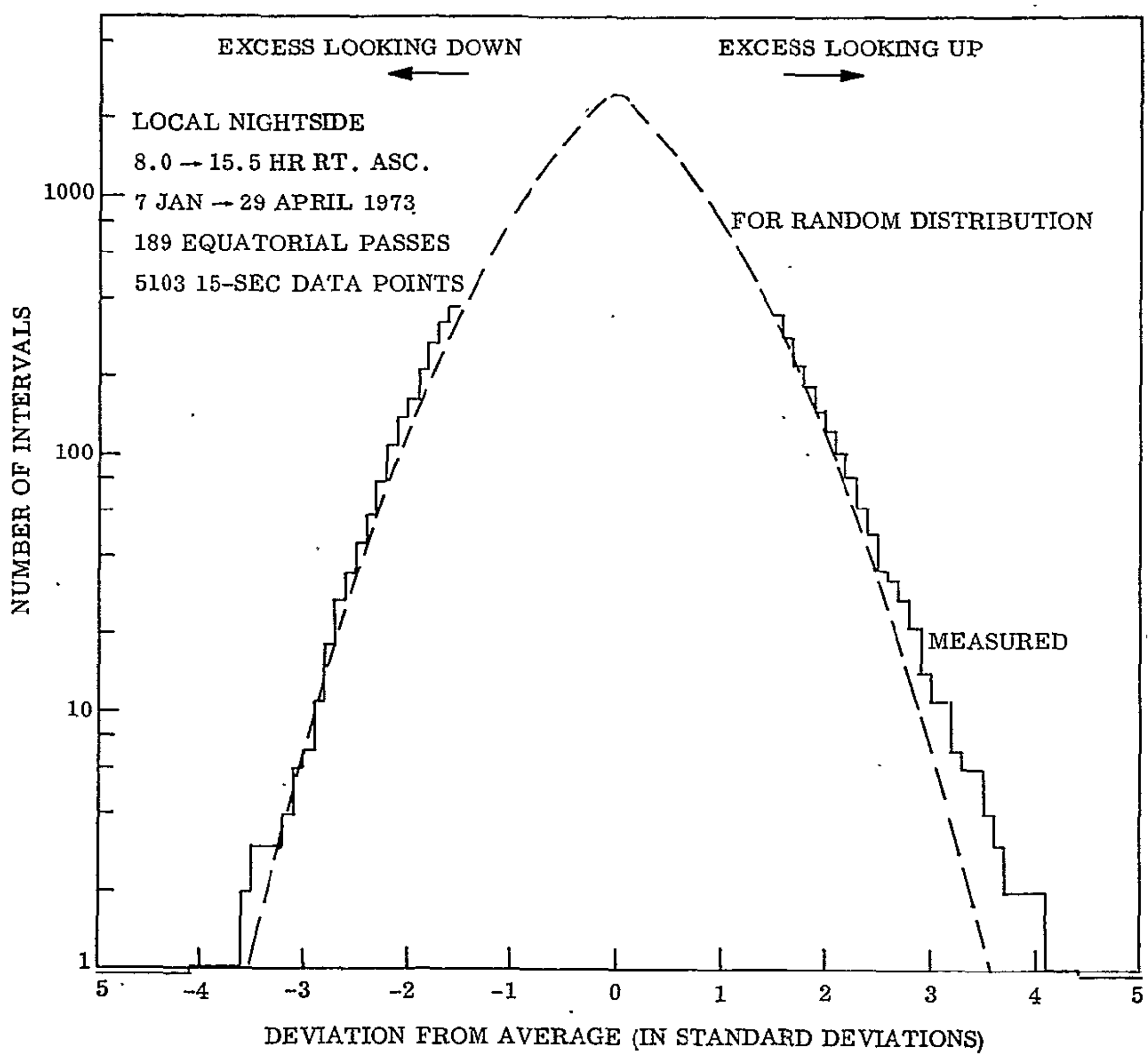

Figure 3-5. Histogram of the number of 15-second (3 satellite spin) intervals for which deviation from the mean value, in standard deviations, is greater than (for positive deviations) or less than (for negative deviations) a given value.

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TABLE I

Tabulation of Candidate 15 Second Intervals
with σ > 3 S.D.

Local Nighttime Events		Local Daytime Events	
Date	U.T. (Sec)	Date	U.T. (Sec)
30 December 1972	34573	12 December 1972	8281
27 January 1973	73427	1 January 1973	38194
2 February 1973	38994	29 January 1973	76756
13 February 1973	57464	1 February 1973	80606
25 February 1973	73158	5 February 1973	3971
1 March 1973	68300	12 March 1973	17476
18 March 1973	34536	27 March 1973	36928
18 March 1973	52628	22 April 1973	26819
1 April 1973	68597	25 April 1973	893
1 April 1973	74722	29 April 1973	25920
3 April 1973	57291		

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The IMP 7 records of Cline and Desai were examined for any events in time coincidence with those listed in Table I. From their list of "10 σ deviations" no coincidences were found, but that is perhaps not unexpected since the candidate events in Table I are relatively weak.

The satellite data acquired after 29 April 1973 have not been routinely surveyed for gamma ray bursts under the present effort except at times when coordinated operations with balloon launches were performed. However, two candidate events were found in the course of processing the data for another program. These events have been investigated under the present effort. The counting rate data at the times of the two bursts are shown in Figure 3-6 and 3-7. Unlike many of the candidate events just discussed there is little question of the statistical significance of either, especially the one on 19 June 1974. The possibility of the events being associated with a magnetospheric phenomenon such as the precipitation of energetic electrons from the radiation belts has been investigated. None of the several energetic particle detectors in the payload showed any response at the times of the peaks in the anticoincidence counters, thus setting a rather low upper limit on the maximum possible fluxes of precipitating electrons. Furthermore in contrast with electron precipitation events, which are occasionally observed and are discussed in Section 7, these bursts in June 1974 occurred at much lower latitudes. The bursts which we have been able to identify as being of magnetospheric origin occurred in the invariant latitude interval 58° to 61°, whereas the 18 and 19 June 1974 bursts were at 28.7° and 23.0°, respectively. So we conclude that the two events in June 1974 are probably of extraterrestrial origin, but the possibilities that the counting rate enhancements were due to energetic electrons cannot be definitively rejected.

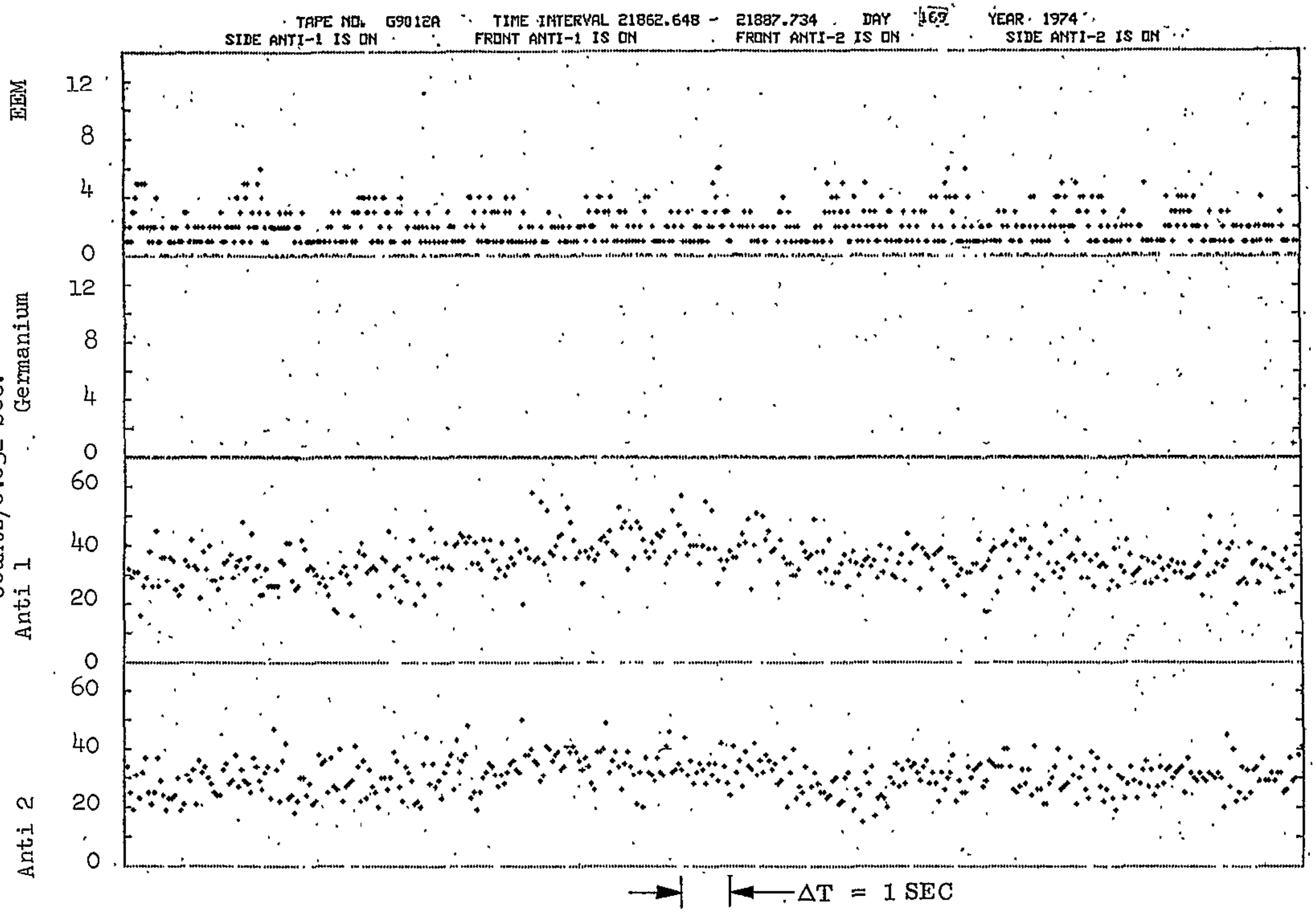

Figure 3-6 Single frame counts for a selected interval.

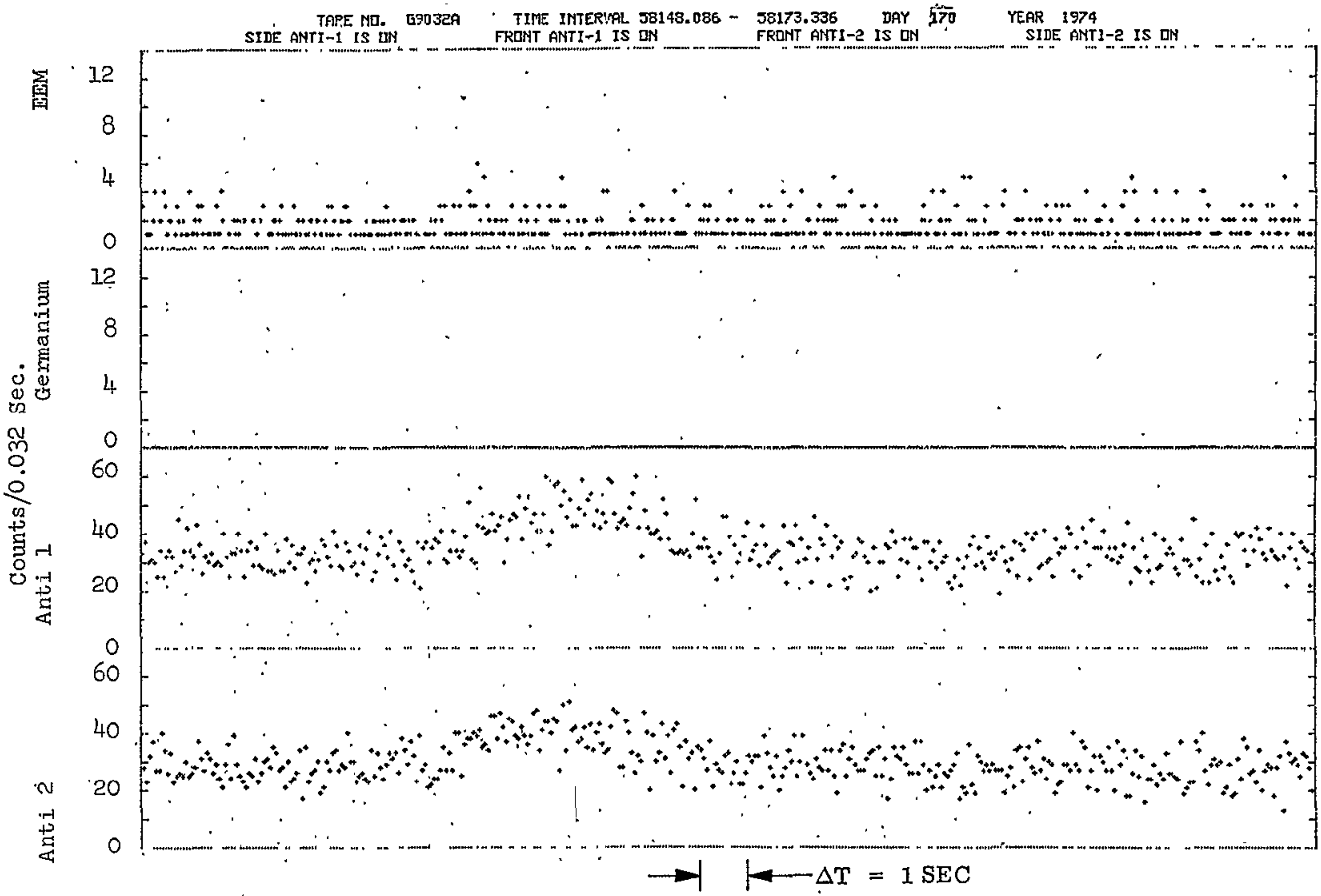

Figure 3-7 Single frame counts for a selected interval.

Section 4

SEARCH FOR TEMPORAL VARIATIONS WITH A ~ 0.032 SEC SURVEY

An extensive search for narrow cosmic gamma ray bursts was conducted by surveying strip plots of the counting rate data taken on the 1972-076B satellite at low latitudes. These plots had been produced in the course of generating compressed magnetic tapes of the data for other purposes. The compressed tapes had been produced with ~ 15 second time resolution but in the strip plots the pen could respond to single 0.032 second frames. Visual surveys can therefore provide a very efficient means of identifying narrow spikes in the counting rate profiles. Separate plots were generated for the germanium spectrometer and for each of the large anticoincidence counters. The plots had been generated under various averaging intervals, but of prime interest for the present investigation were the plots in which the second highest counting rate frame (of 0.032 second duration) was plotted. Selection of the second highest value was chosen to eliminate response to noise appearing in a single frame, but it thereby restricted the identification of gamma ray bursts to those lasting for at least a portion of two 0.032 second intervals within 0.256 seconds.

From the initial survey of the strip plots a list of possible events was generated and subsequently subjected to more careful examination. The latter amounted to listing the counts in each 0.032 second frame around the interval of interest and also plotting the counting rates on a 0.032 second frame to frame basis. Examples of these plots are shown in Figures 4-1 through 4- 8.

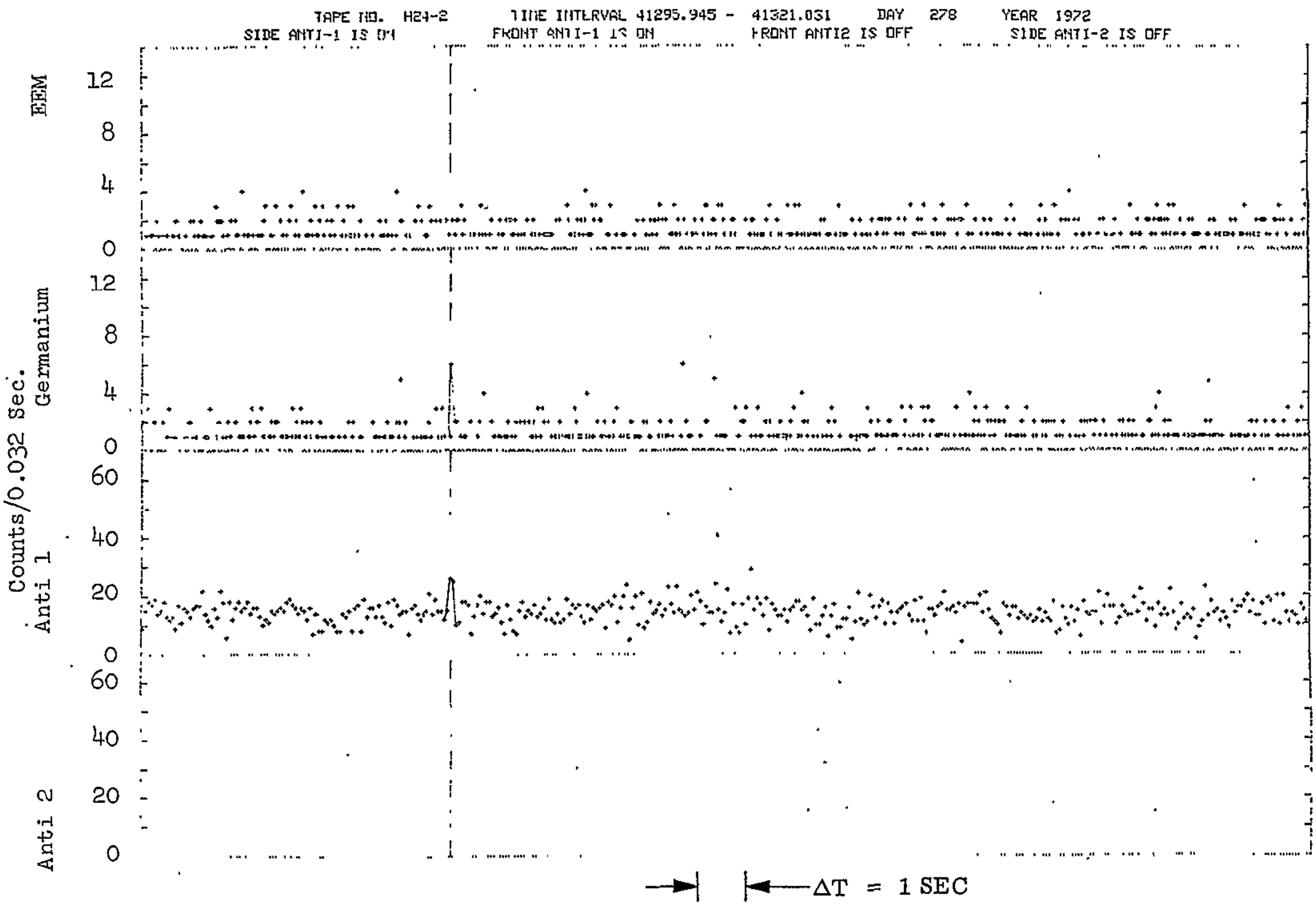

Figure 4-1 Single frame counts for a selected interval.

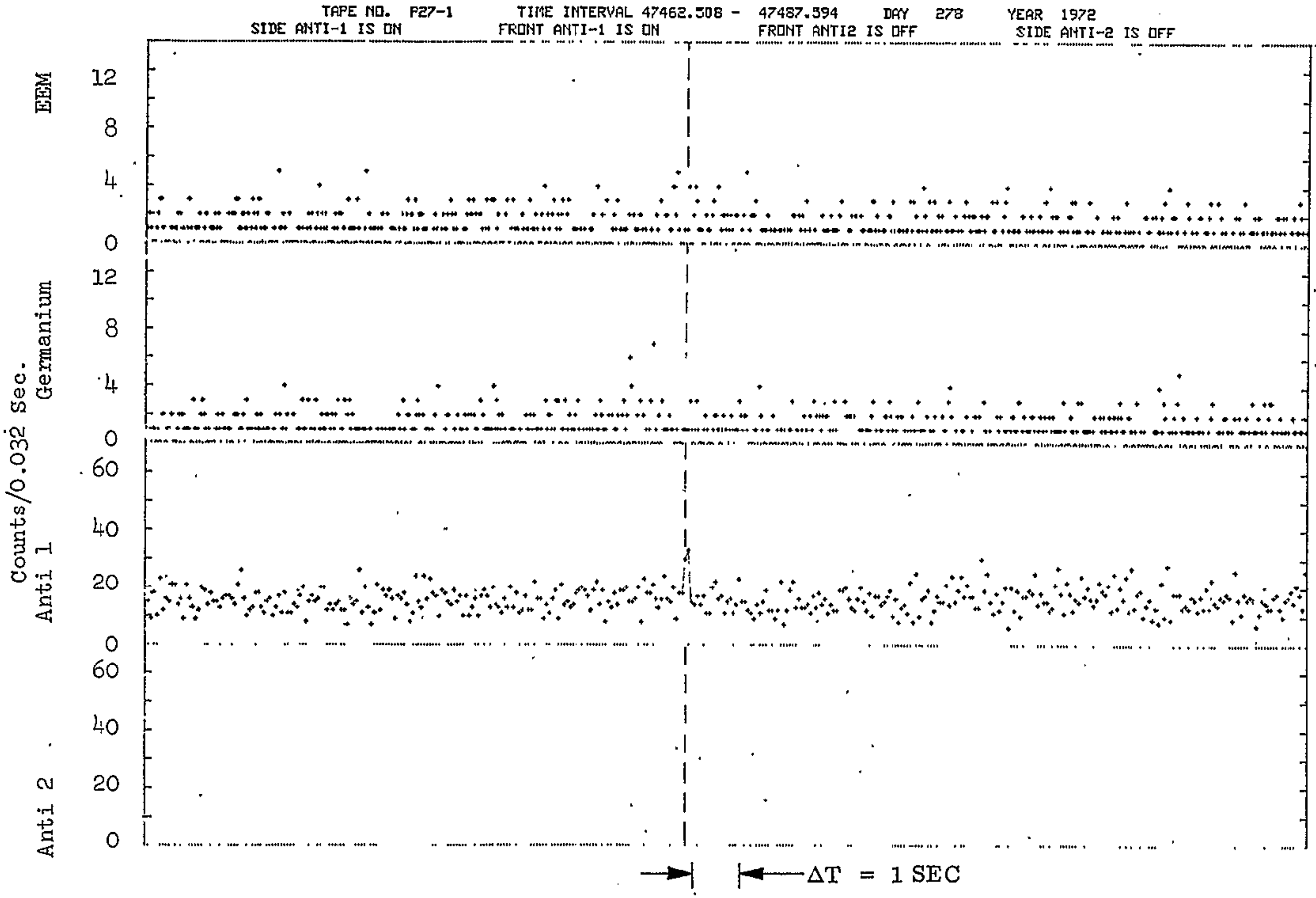

Figure 4-2 Single frame counts for a selected interval.

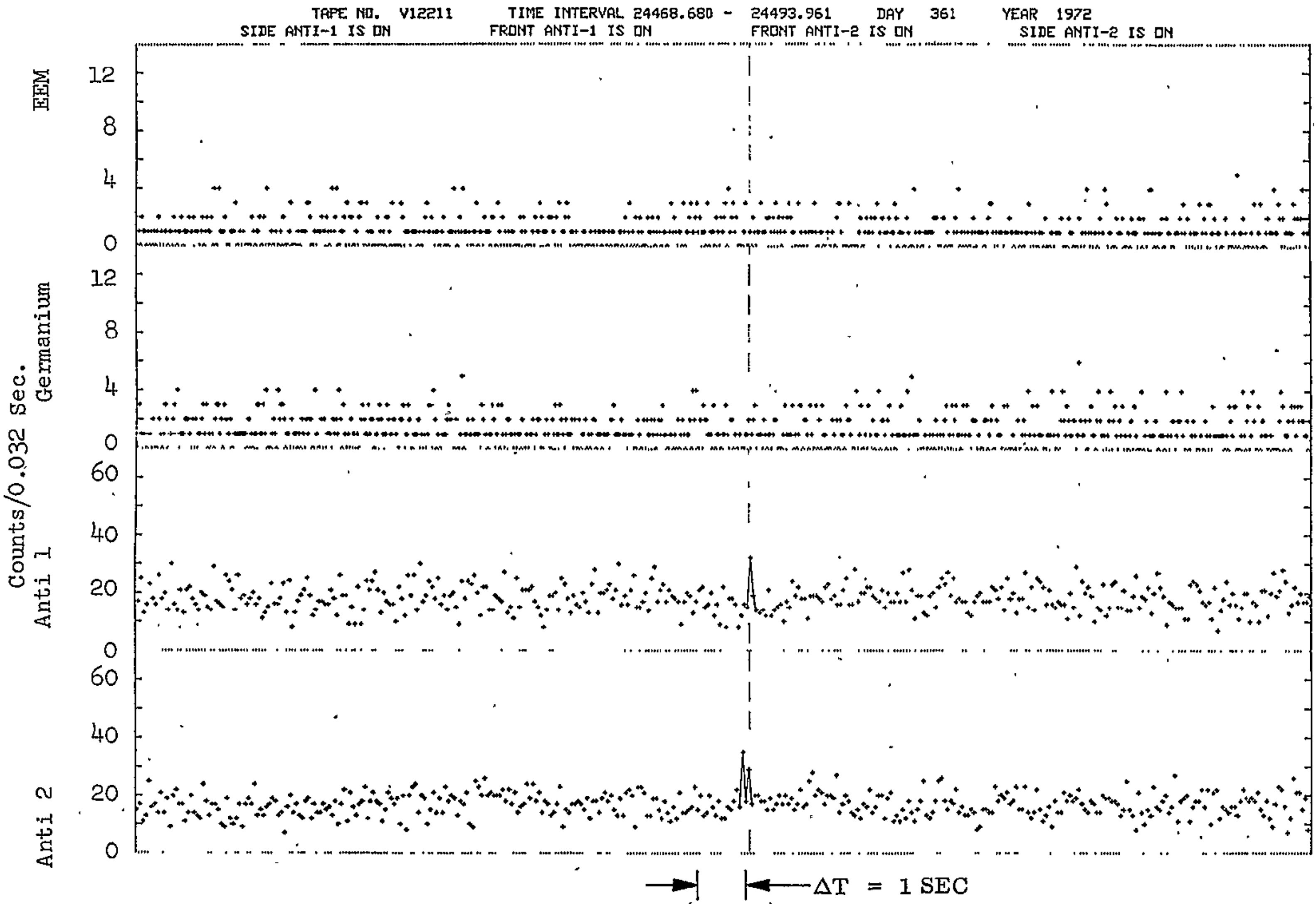

Figure 4-3 Single frame counts for a selected interval.

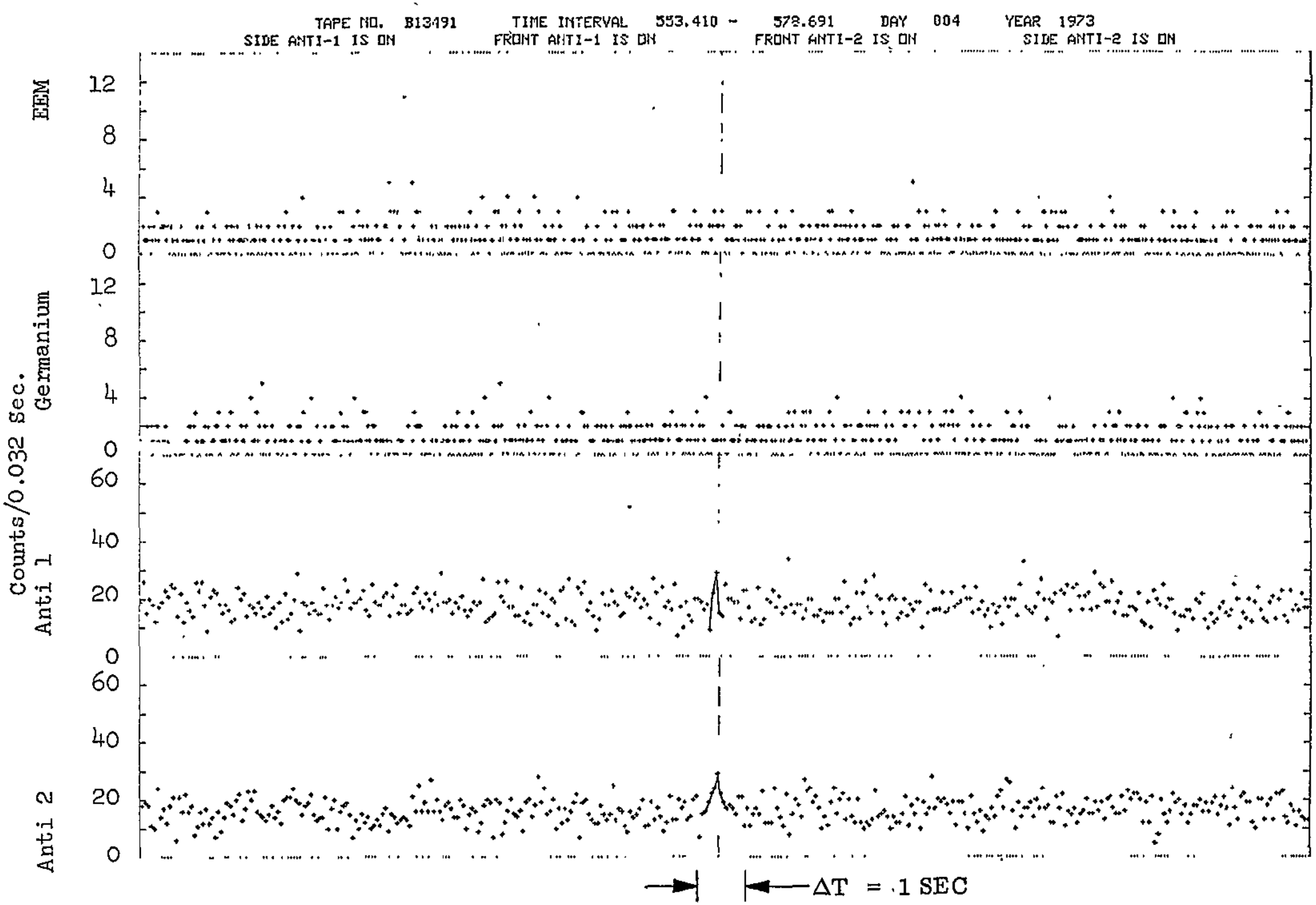

Figure 4-4 Single frame counts for a selected interval.

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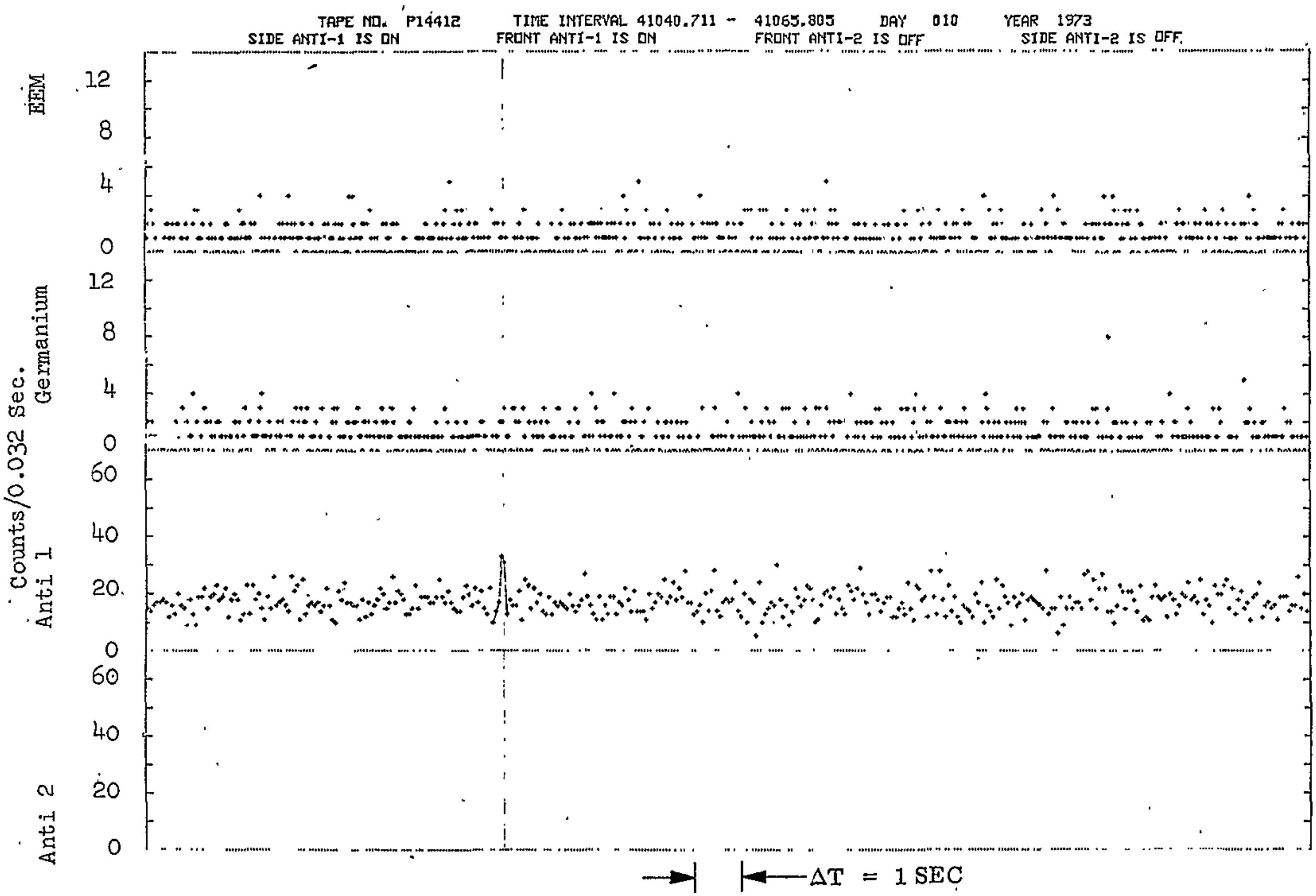

Figure 4-5 Single frame counts for a selected interval.

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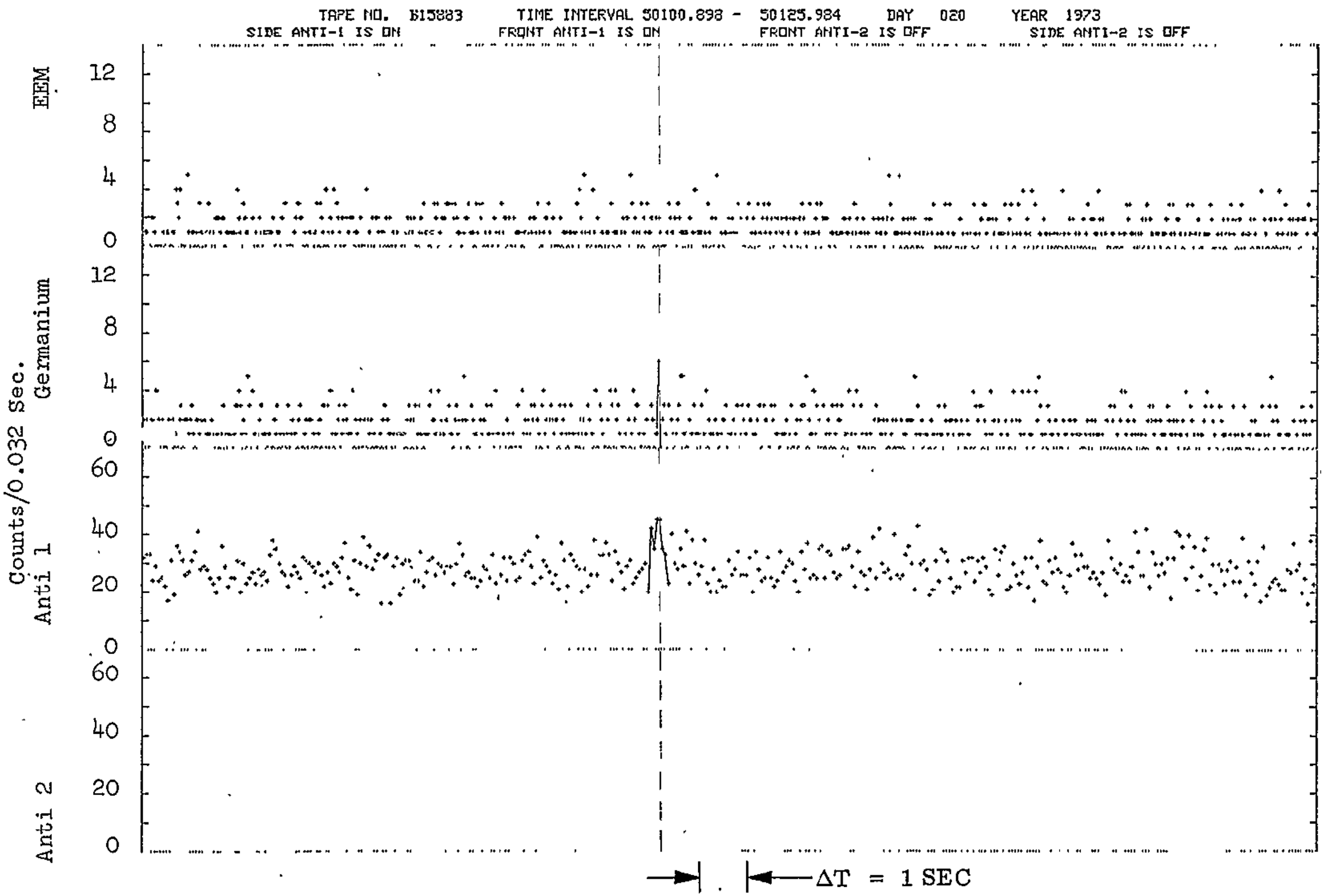

Figure 4-6 Single frame counts for a selected interval.

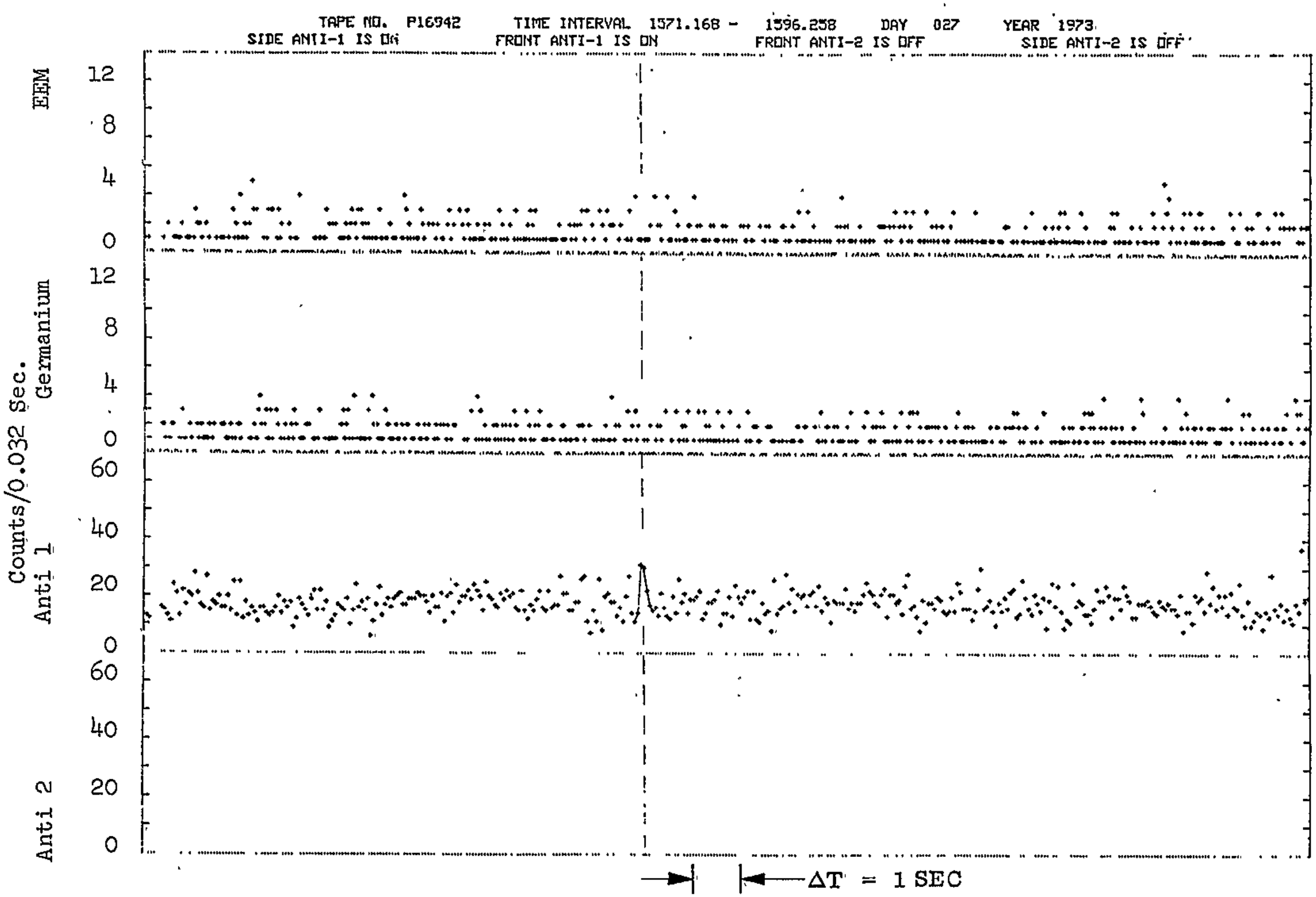

Figure 4-7 Single frame counts for a selected interval.

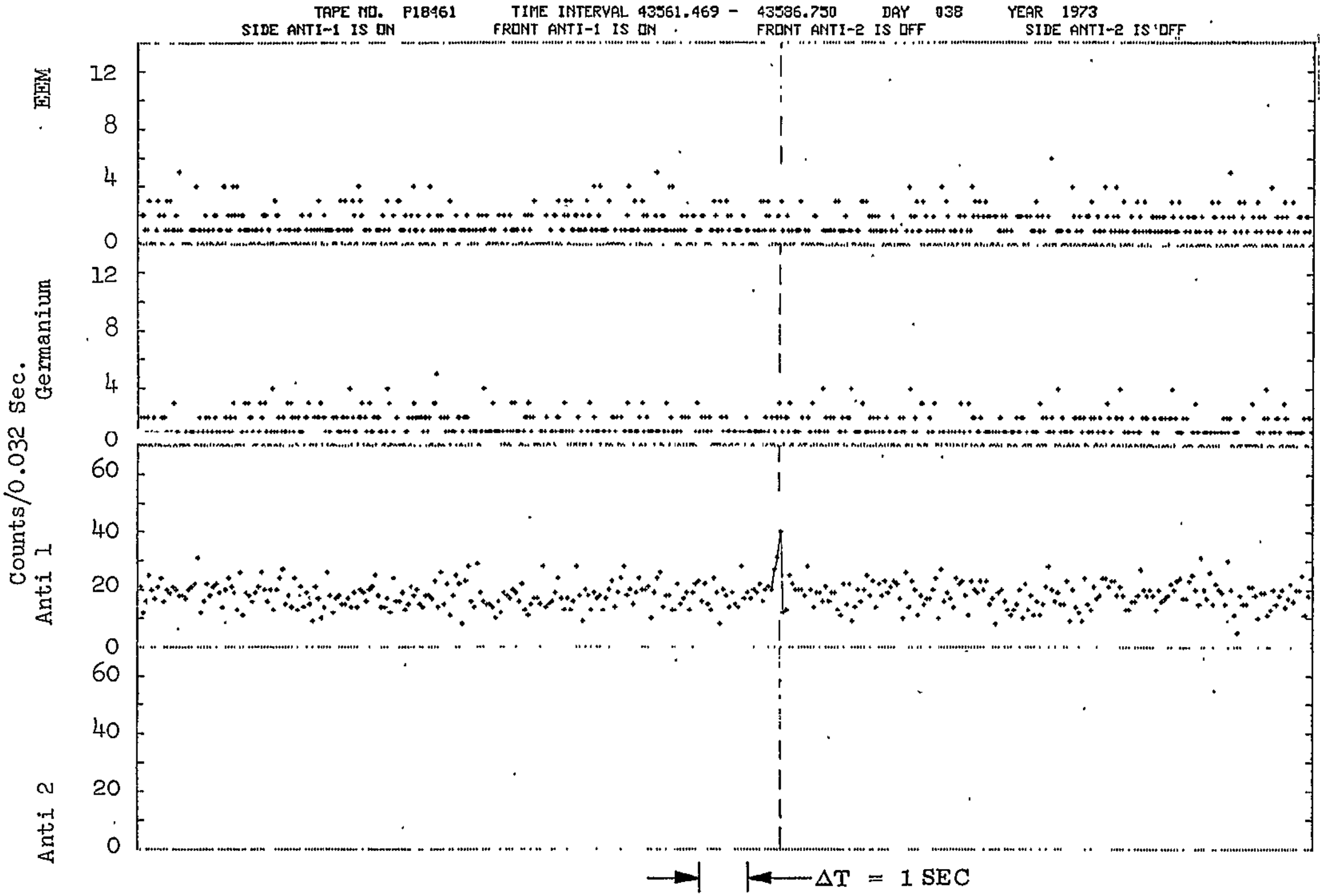

Figure 4-8 Single frame counts for a selected interval.

For comparison equivalent plots of two confirmed cosmic gamma ray bursts are included in Figures 4-9 and 4-10. With the plots and listings a more careful selection of candidate events was made in which an added importance was assigned to those spikes with response in more than one sensor. Possible noise contributions were evaluated by examining the outputs of other data points in the telemetry format. A list of candidate events in which there appear to be no noise contributions and which otherwise look promising is provided in Table II.

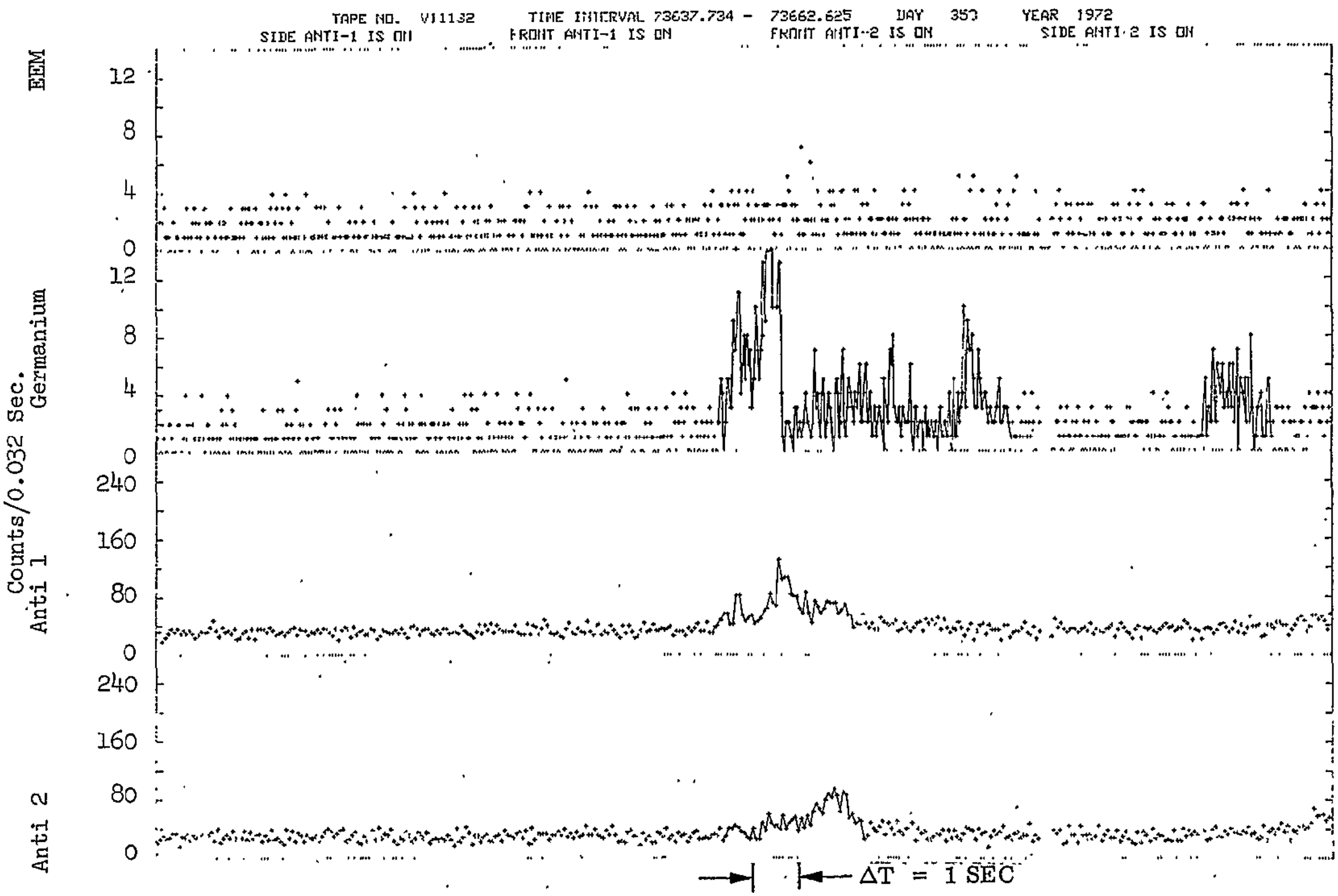

Figure 4-9 Single frame counts for a selected interval.

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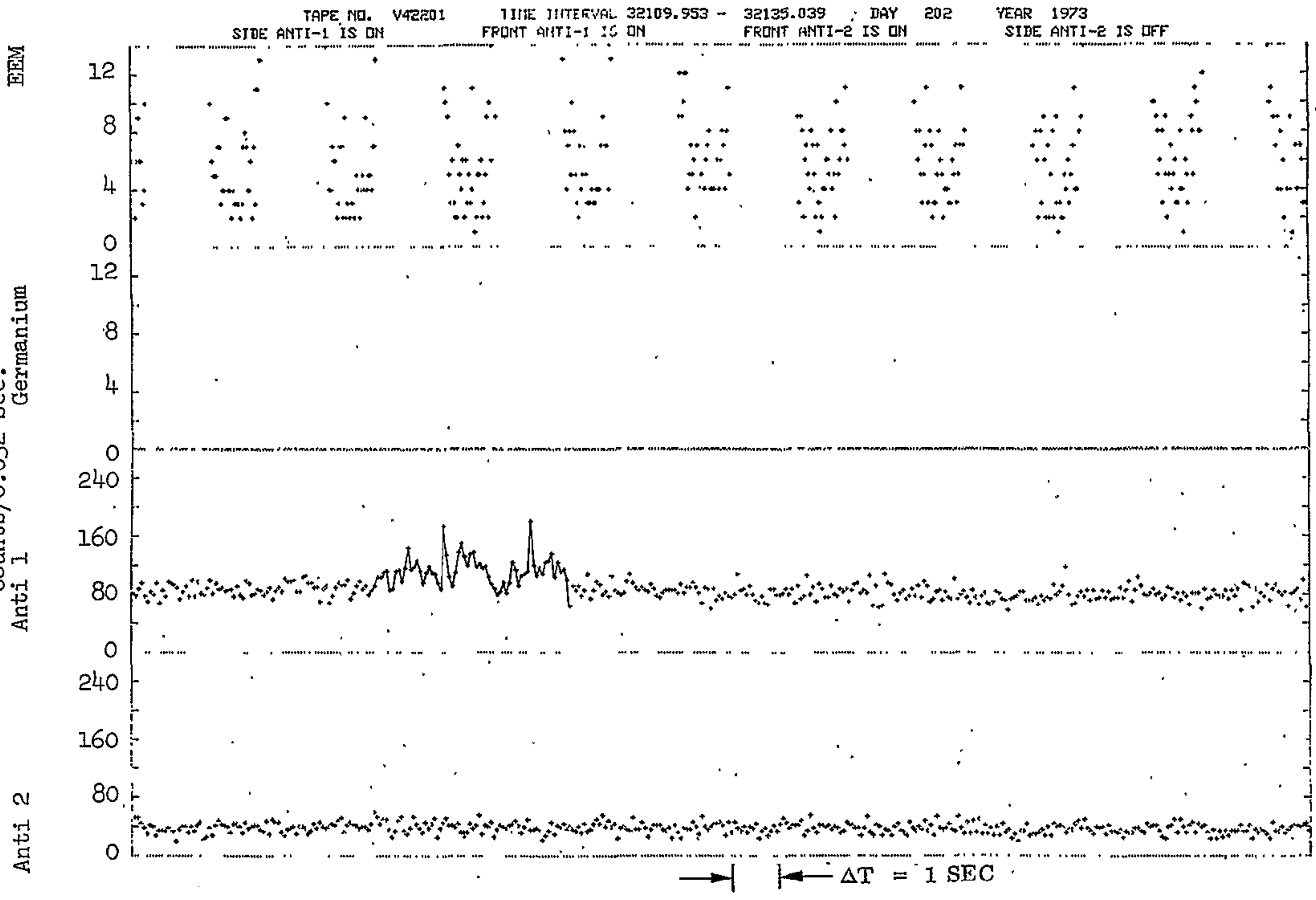

Figure 4-10 Single frame counts for a selected interval.

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Table II

List of Candidate Events
from ~ 0.032 Sec of Survey

Date	Universal Time (Sec)
October 4, 1972	41302
October 4, 1972	47474
December 26, 1972	24481
January 4, 1973	565
January 10, 1973	41048
January 20, 1973	50111
January 27, 1973	1581
February 7, 1973	43575

Section 5

SPIKES OF MAGNETOSPHERIC ORIGIN

From our survey of approximately 1400 orbits of satellite data taken during the period 2 October 1972 to 2 May 1973 several mid-latitude passes were found with pronounced narrow spikes in the anticoincidence counter, but also with concurrent spikes in the high energy electron fluxes, as measured with three different electron spectrometers on board the same satellite. Since the time durations of the typical spikes as seen from a moving satellite were similar to the durations of cosmic gamma ray bursts we felt it was important to investigate their characteristics in more detail. It should be noted, however, that with a complete array of energetic particle detectors on the same satellite it was always possible to test for the presence of electrons during any candidate events. The sensitivity of the particle detectors was relatively high, but for very weak spikes in the anticoincidence counters some ambiguities still remained.

One of the more pronounced spikes that we have observed is shown in Figure 5-1. Here the counting rates measured in the various sensors are plotted as a function of time. Each of the data points represents the counts accumulated over a period of 0.032 second. The counting rate in the electron spectrometer, EEM, is read out once every 32 millisecond whereas the counts occurring in each of the two anticoincidence shields are accumulated during alternate 32 millisecond intervals and those in the electron mode of the

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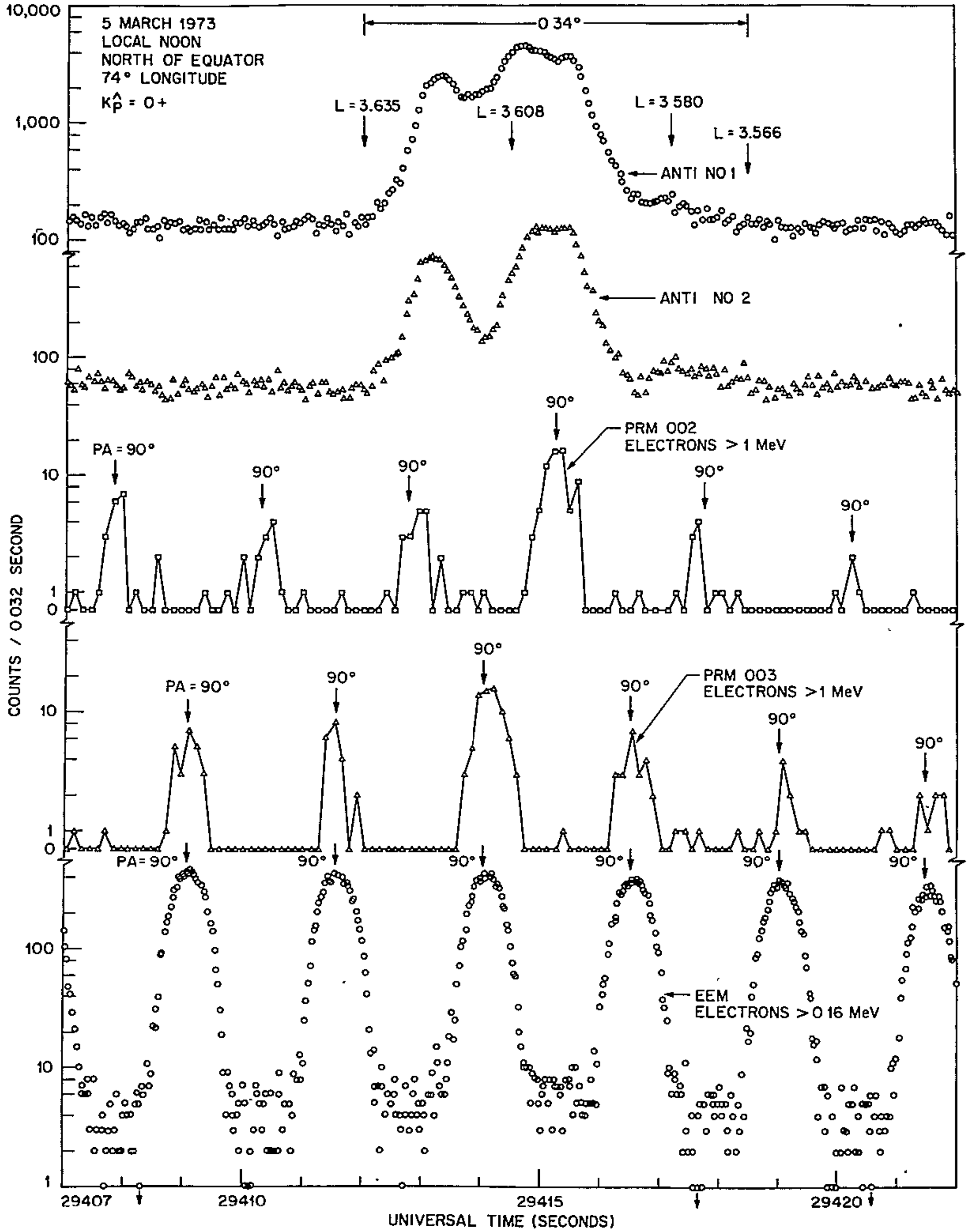

Figure 5-1. Counts accumulated in 0.032 sec. intervals during a pronounced spike in the anticoincidence counter on 5 March 1973. The times for orientation of the collimated detectors at 90° pitch angle are indicated.

electron spectrometers, PRM 002 and PRM 003, are sampled only during every fourth 32 millisecond interval. The times for orientation of the collimated detectors at 90^{o} pitch angle are indicated. The pitch angle distributions reveal that the spike is comprised of locally trapped particles, which are quasi-trapped since the minimum longitude trace altitude, h_{min}, is below sea level. The anticoincidence counters have a more omnidirectional response. The differences in the counting rate profiles of the two anticoincidence counters may be attributed to the fact that only the front portion of unit #2 was on at the time whereas both sections of the first unit were in operation.

Several salient features of the data in Figure 5-1 are to be noted. During the spike the counting rate enhancements are most pronounced in the anticoincidence counters ($E_{el} \geqslant 4$ MeV), less so in the PRM's ($E_{el} \geqslant 1$ MeV), and are not evident in the total counting rate of the EEM with its threshold energy at 0.16 MeV. Therefore, the spikes result primarily from the precipatation of relativistic electrons. There is some indication in the anticoincidence counters of a weak shoulder on the lower latitude edge of the spike at $L \approx 3.58$. The full extent of the spike, including the shoulder, is less than 0.34^{o} in invariant latitude.

In Figure 5-2 are shown representative examples of the spikes as measured in anticoincidence counter #1. To facilitate intercomparisons of the latitude profiles the counting rate versus time profiles are all lined up at the geomagnetic shell $L = 4.0$ and are all plotted with latitude increasing toward the right. All of the plots have the same time increment scale, indicated at the bottom. The lines are best-fit curves drawn through 0.32 second averages of the counting rates. Some of the important parameters associated

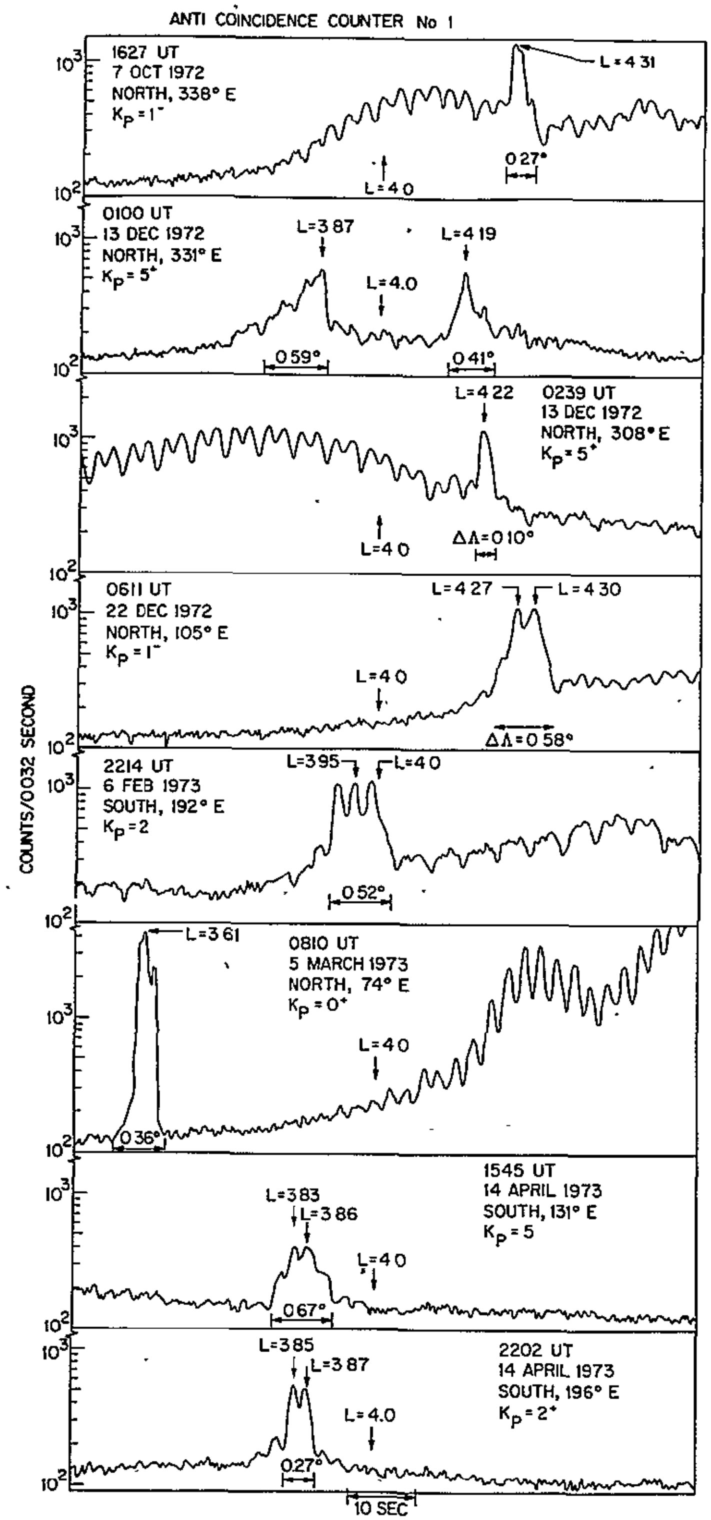

Figure 5-2. Representative examples of spikes in anticoincidence counter #1 that are caused by locally trapped electrons.

with each pass are indicated, including the longitude at L = 4.0 and whether the data were taken in the northern or southern hemisphere. On some of the passes, when the electron rates are significantly above background, a spin modulation (5 second period) in the counting rate is evident. This reflects some directionality in the response of the anticoincidence counters.

The spikes in Figure 5-2 display a variety of intensities and latitude widths. In some of the more pronounced peaks the enhancements in counting rate are about an order of magnitude. Some spikes are as narrow as ~ 2 seconds in time or ~ 0.1 degrees invariant latitude whereas others extend over intervals exceeding 10 seconds or 0.5 degrees.

The narrowness of many of the "geomagnetic" spikes encountered from a polar orbiting satellite appears to be primarily spatial rather than temporal in character. One might thereby argue that this particular geomagnetic phenomenon should cause no problems for balloon-borne experiments which are relatively stationary in space. However, the occurrence of such structure in the electron environment over a wide range of latitudes and longitudes should serve as a cautionary warning that even with balloon borne experiments, when searching for temporal variations in the gamma-ray intensities one should be careful about possible contributions from electrons.

Section 6

COORDINATED OPERATIONS TO SEARCH FOR COSMIC GAMMA-RAY BURSTS

The LPARL gamma-ray spectroscopy payload on the 1972-076B satellite was turned on for high coverage during the flight time of a balloon payload by the University of California at Riverside group under the direction of Professor R. S. White. The satellite coverage during 13-15 May 1975 was arranged to emphasize the times when the satellite was on the same hemisphere of the world as the balloon since at those times the probability of both instruments seeing a given gamma-ray burst is much greater. During this time Herzo et al (1975) reported measuring a cosmic gamma-ray burst that occurred at 29309.11s UTC on May 14, 1975. The burst, which was 24 standard deviations above the background, had a duration time of 0.11 second and a total energy above 0.5 MeV of $2 \pm 0.5 \times 10^{-6}$ erg/cm^2. Unfortunately, at this time the satellite was not in operation.

In the balloon data obtained by the White group they made a search for smaller bursts and found two additional candidates of 6.4 and 6.5 σ above background. However, as with the main event at 29309.11s the LPARL satellite payload was not acquiring data at this time.

Operation of the LPARL satellite payload was also coordinated with a dual balloon flight by the GSFC group of Cline et al on 9-11 May 1975. Many hours of data were acquired on the balloons and with the satellite payload. It is our understanding (private communication) that analysis of the balloon data has been delayed by difficulties relating to the on board clocks.

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Whenever the times of any candidate events recorded by Cline et al become available to us a search can be made for enhanced responses in the LPARL anticoincidence counters.

Section 7

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

In summary, from the high resolution gamma ray spectroscopy data acquired with the LPARL payload on the satellite 1972-076B a preliminary survey has been conducted for the occurrences of short time duration bursts. The time resolution employed in this survey has varied from the basic instrument resolution of ~ 0.032 second to time averages of ~ 15 seconds. From this preliminary survey a number of candidate cosmic gamma ray bursts have been found and are listed in Tables I and II. Several of these have shown responses in more than one sensor in the payload, but a positive confirmation of any of these by other satellite observations is yet to be established.

For the individual candidate bursts in which there is no confirmation from other experiments it is of interest to consider the intensity distribution on a statistical basis. The counting rates during the candidate events are all at large variations from the statistical mean, but the deviations are not so large as to preclude the possibility that many of them are statistical in nature. So to further assess the significance of these points their intensities and rates of occurrence have been compared with those of confirmed events. When the candidate events of long (~ 1 to ~ 100 seconds) duration are placed on the plot of events/day versus burst size, shown in Figure 7-1, they tend to fall above the $S^{-3/2}$ curve of confirmed events, suggesting they are perhaps not all true cosmic gamma-ray bursts. On the other hand, the short duration (~ 0.01 to ~ 1 second) events fall closely on the $S^{-3/2}$ curve. In each case the exact positions of the points depend on the precise criteria used for

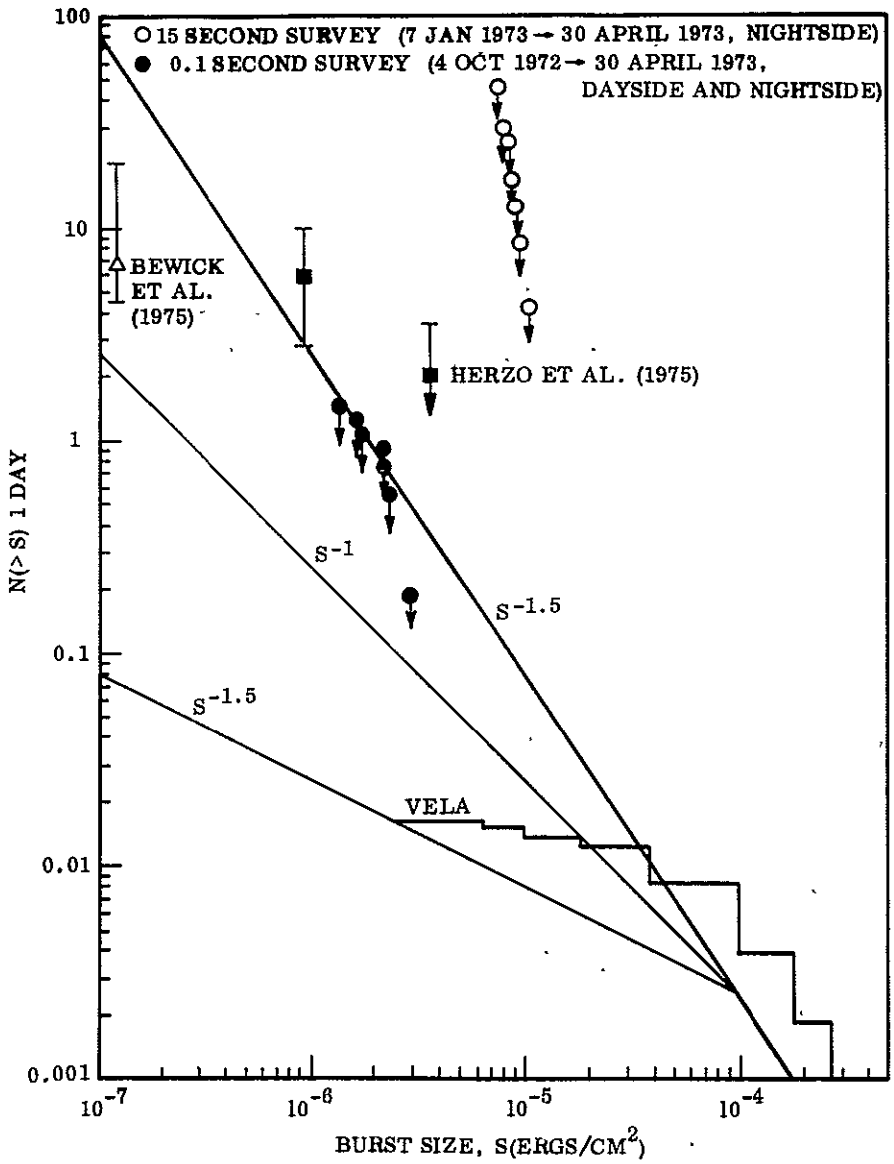

Figure 7-1. The number of bursts per unit time with total energy greater than S versus S. The curves are taken from Herzo et al (1975) which includes results from the Vela satellites. The points labelled Herzo et al (1975) are taken from a burst and two candidate events measured with a large area plastic scintillator on a balloon. The Bewick et al (1975) point represents the results of three balloon-borne searches for small cosmic gamma ray bursts with a large plastic scintillator.

selecting candidate events and on a careful assessment of the sensitivity to the range of background levels and to burst time durations. Questions arise, for example as to whether events of widely differing time duration should be plotted together as one distribution or separately as different classes of events. The Vela data suggest that a small fraction of the cosmic gamma-ray bursts may be considerably shorter in duration than average. Until more extensive data are available one can only speculate on the possibilities of different "populations" of bursts. But in the meantime caution should be exercised in intercomparing spikes of widely varying durations.

An important finding of this study effort has been the discovery of narrow spikes of magnetospheric origin. The time durations of these spikes as seen from a moving satellite were similar to the duration of cosmic gamma-ray bursts so they were investigated in detail by studying the outputs as a function of orientation of all of the gamma-ray and energy particle detectors on board the satellite. The narrowness of many of the "geomagnetic" spikes encountered from a polar orbiting satellite appears to be primarily spatial rather than temporal in character, but clearly even in a balloon-borne experiment one should be alert to the possible effects from energetic electrons.

It should be emphasized that the results presented here are based on only a preliminary and partial survey of the data. The magnitude of the effort undertaken was approximately only one third of that required to accomplish a complete study. The absence of any positive event findings may merely reflect the preliminary nature of the survey. Further analyses of the data may reveal new discoveries, but based on the present results we cannot make strong recommendations for further surveys unless additional events are found in other experiments or there is a new basis for further analyzing the present data.

Section 8

ACKNOWLEDGMENTS

The gamma-ray spectroscopy data used in this investigation were acquired under a DARPA/ONR sponsored program, contract N00014-69-C-0372. We acknowledge the very important support and guidance provided by Dr. R. G. Johnson in the design and conduction of the original experiment and in the analysis of the data. In the pursuit of the present NASA contract special thanks are extended to Dr. J. R. Kilner and Ms. S. N. Spencer for their invaluable contribution to the data analysis.

Section 9

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Appendix A

DESCRIPTION OF THE GERMANIUM SPECTROMETER SATELLITE EXPERIMENT

The primary data of concern here were taken during a 6 month period in 1972-1973 with a cooled 50 cm^3 Ge(Li) spectrometer placed on the low altitude polar orbiting satellite 1972-076B. In addition, the anti-coincidence counter surrounding the germanium spectrometer is still in operation and these data from 2 October 1972 until the present time have been used when appropriate. This represents the first time a high resolution germanium spectrometer has been operated in space on a satellite. A schematic diagram of this instrument is shown in Figure A1-1. The vehicle was launched on 2 October 1972 into a sun synchronous noon-midnight orbit (inclination is 98.4°) with a perigee of 736 km and an apogee of 761 km. The satellite is spin stabilized at a rotation period of approximately 5 seconds with the spin axis perpendicular to the satellite velocity vector. Cooling was achieved with a solid CO_2 cryogen system. The instrument was collimated to $\pm 45^{\circ}$ with a high-density (predominately tungsten) shield and plastic scintillator anticoincidence counter and was oriented at 105° to the spin axis of the satellite. The collimator was $\sim$ 20 cm long and thus provided a relatively sharp cutoff angle. The germanium spectrometer performed for a period spanning 7 months, initially with a resolution of $\sim$ 3.5 keV (full width at half maximum) at all energies. After 10 days it underwent a serious degradation in gain and energy resolution, but after a few weeks it made a rather remarkable recovery and performed for over 5 months with a resolution of $\sim$ 10 keV at 60 keV and $\sim$ 50 keV at 511 keV. The remainder of the satellite payload, including two large area plastic

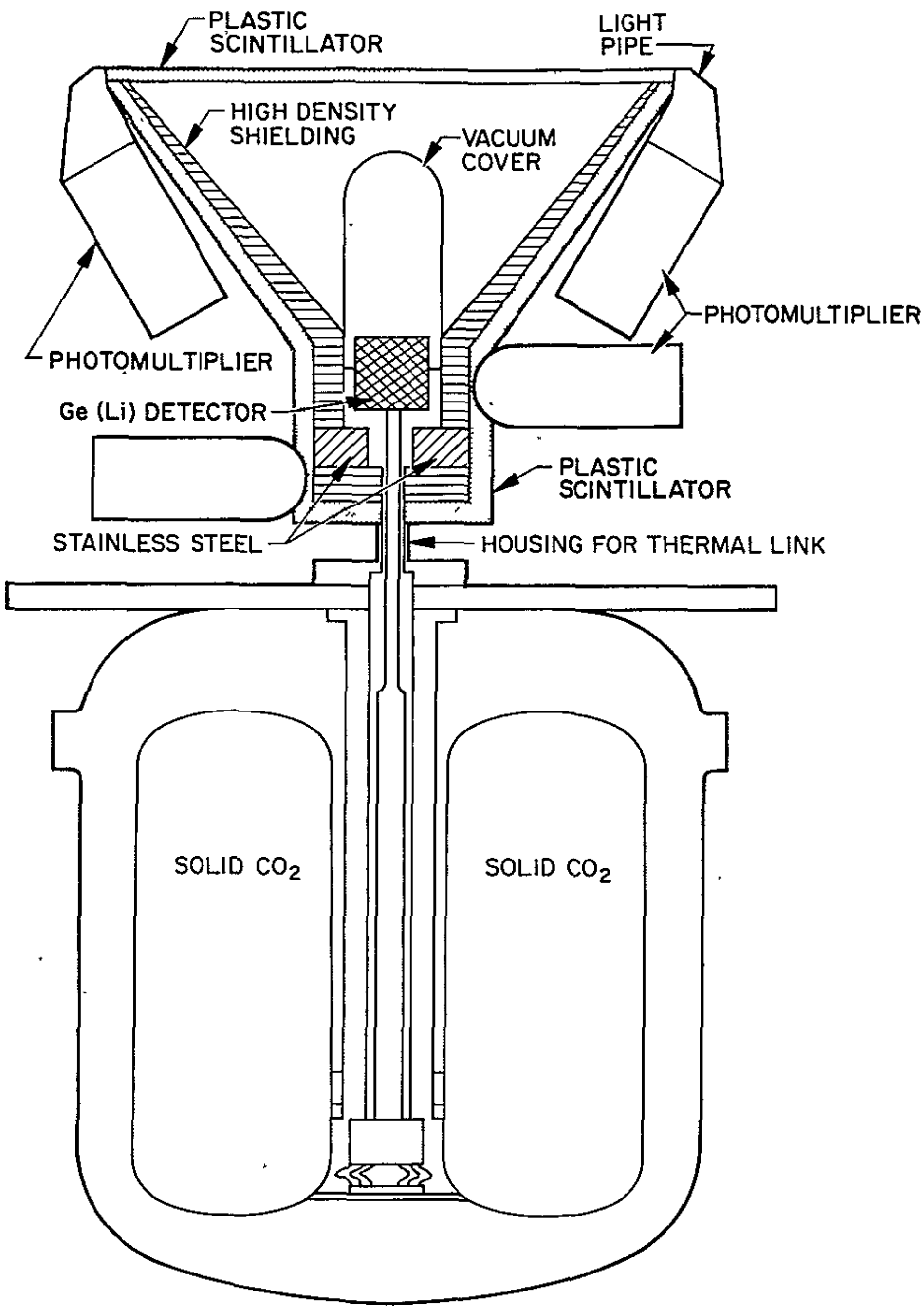

Figure A1-1. Schematic diagram of the high resolution germanium spectrometer.

scintillator anticoincidence counters are still operating normally.

The germanium spectrometer provided fast-time resolution capability which can be of great value in searching for narrow and weak gamma-ray bursts. The importance of this instrumentation feature was clearly demonstrated during the early time portions of the 18 December 1972 gamma-ray burst, as illustrated in Section 3. With the use of an on-board tape recorder nearly complete worldwide measurements were achieved. After launch on 2 October 1972 until the cryogen depleted in May 1973 the orbit operations plans of the satellite was such that data coverage was achieved approximately 50 percent of the time.

Individual addresses from the 4096 channel pulse height analyzer associated with the germanium spectrometer are recorded at a maximum rate of 1625/second, and the total counting rates are sampled once every 32 millisecond interval, depending on the mode of operation. When analyzing the data, spectra can be accumulated over any desired time intervals. In particular, the short-time sample periods can be optimized for the measurements of microbursts and the analysis can be restricted to selected view directions so as to provide a clear viewing geometry for spectral measurements. Examples of energy spectra accumulated during time intervals as short as 0.096 seconds and as long as 1.28 seconds for the gamma-ray burst of 18 December 1972 are shown in Section 3. In addition, the surrounding anticoincidence counter, which contains approximately 3.4 kilograms of plastic scintillator responds to gamma-rays. Counts in this counter are accumulated and recorded during alternate 32 millisecond time intervals.

Examples of spectra accumulated over longer time periods are shown in

Figure A1-2. To illustrate the varieties of background spectra encountered, data taken near the magnetic equator and over the polar caps with the spectrometer in two different look directions are shown. For this presentation the channels in the original 4096 channel spectra have been grouped by fours.

Other examples of energy spectra taken at a number of geomagnetic latitudes are shown in Figure A1-3. In the top section is shown a typical spectrum associated with electrons precipitating into the atmosphere. At the time the bremsstrahlung spectrum in Figure A1-3 was taken the satellite was over the South Pole of the earth and no radiation belt particles were in the immediate vicinity. When the gamma-ray spectra are compared with the electron spectra measured with an electron detector on the same satellite (at a time when the satellite passes directly through the environment of the precipitating electrons) the shapes are consistent with the bremsstrahlung calculations of Berger and Seltzer (Imhof et al., 1974A). The bremsstrahlung spectrum produced by trapped electrons when the satellite is actually in the outer radiation belt is often harder in shape than that associated with precipitating electrons. However, even the hardest bremsstrahlung spectra do not present a serious background for observations above a few hundred keV. Nonetheless, when searching for cosmic gamma-ray bursts we confined the primary analyses to regions where bremsstrahlung is not a problem, as in the low latitude data shown in the bottom section. The satellite spends a large portion of its time in these regions away from the South Atlantic Anomaly so a sizeable quantity of low background data were available for surveys.

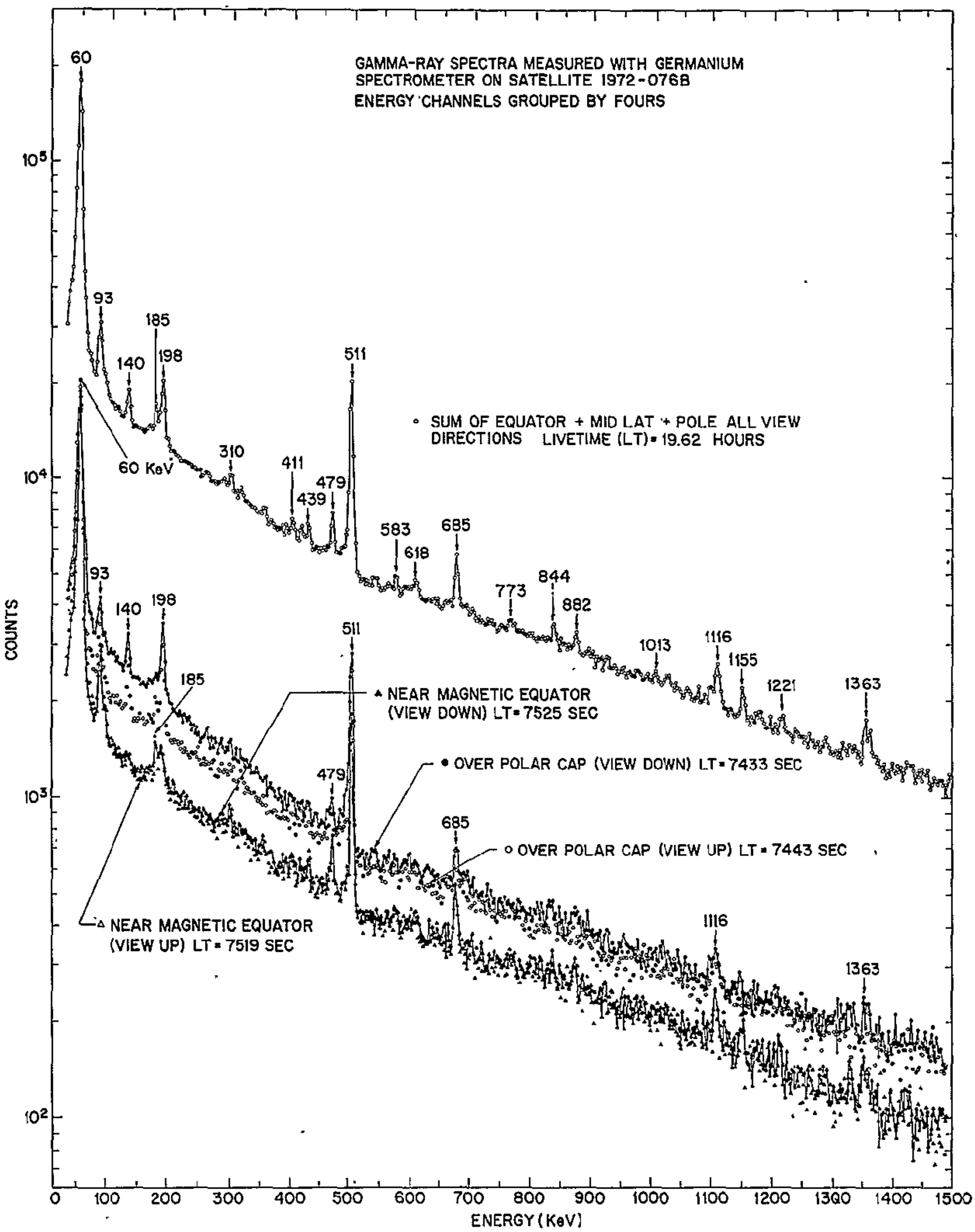

Figure A1-2. Pulse height spectra measured in the germanium sensor at various positions and view directions, as indicated. The original 4096 channels have been grouped by four. The accumulation livetimes are indicated.

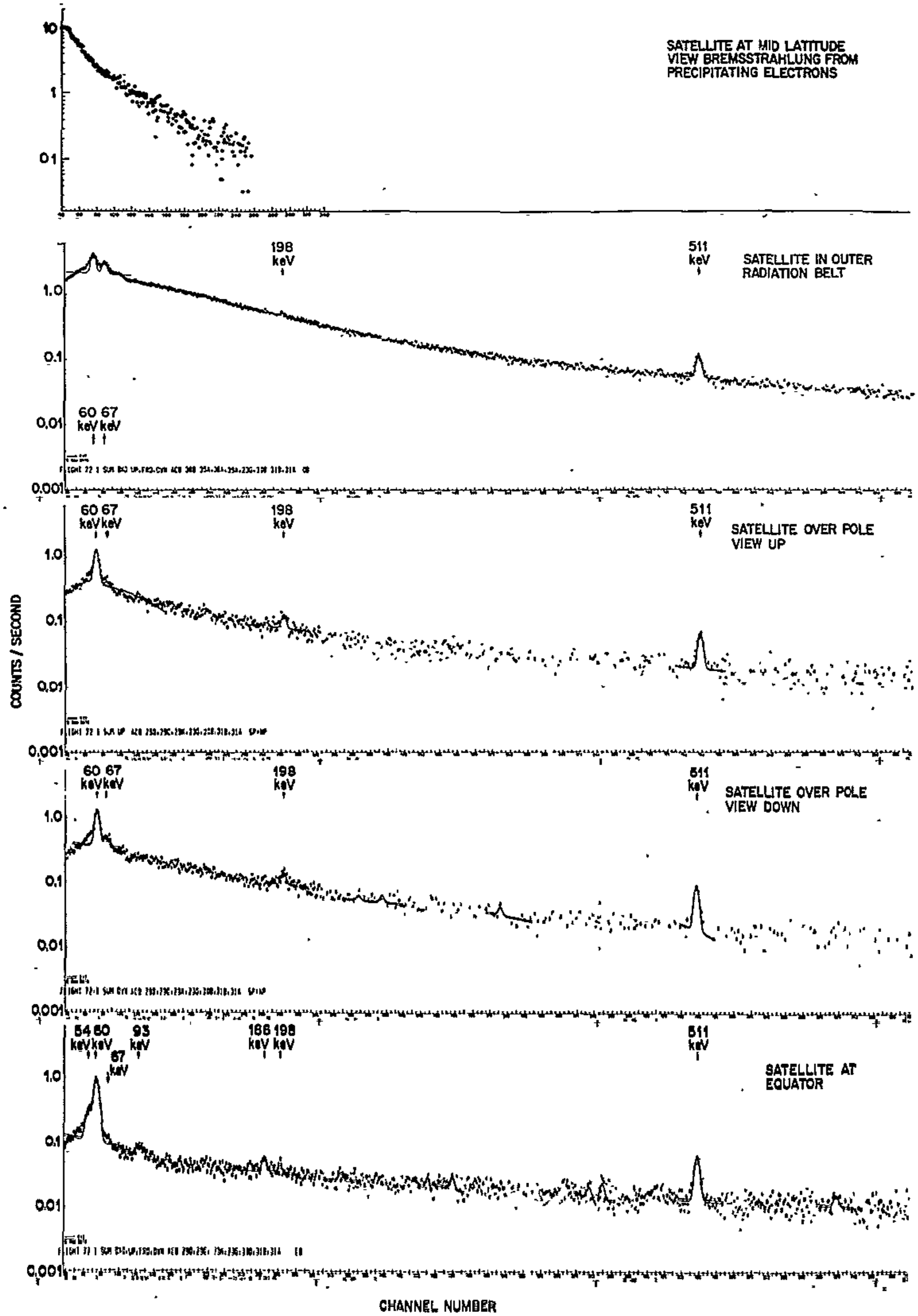

Figure A1-3. Examples of energy spectra taken at various geographic positions.

Appendix B

DESCRIPTIONS OF GAMMA-RAY BURSTS MEASURED WITH THE GERMANIUM SPECTROMETER SYSTEM

Two cosmic gamma-ray bursts, originally identified with the Vela satellites, have been measured with the germanium spectrometer system (i.e., central detector and anticoincidence counters). The results of these measurements have been published elsewhere (Imhof et al., 1974A; Nakano et al., 1974; Imhof et al., 1975), but for convenience a brief summary is given here.

A. The 18 December 1972 Cosmic Gamma-Ray Burst

A cosmic gamma-ray burst was triggered on the Vela satellites at a universal time of 73658.75 seconds on 18 December 1972. At this time the germanium spectrometer on board the polar orbiting satellite was functioning and data were being recorded. Fortunately, the satellite was located in an excellent position (39.2°N and 44.1°E) for observing the burst with no interference from the radiation belts. Beginning at a time of approximately 73657.5 seconds the anticoincidence counter surrounding the gamma-ray spectrometer experienced a significant increase in counting rate, and at 73657.8 seconds the germanium spectrometer underwent a rather sharp increase in rate. These data are shown in Figure B2-1. The time scale for the low altitude satellite data has an absolute accuracy of $\pm$ 50 milliseconds. The counting rate in the germanium spectrometer remained significantly above background until $\sim$ 73658.75 seconds, at which time the source was occulted by the collimator, as substantiated by the continued high response of the more omnidirectional anticoincidence

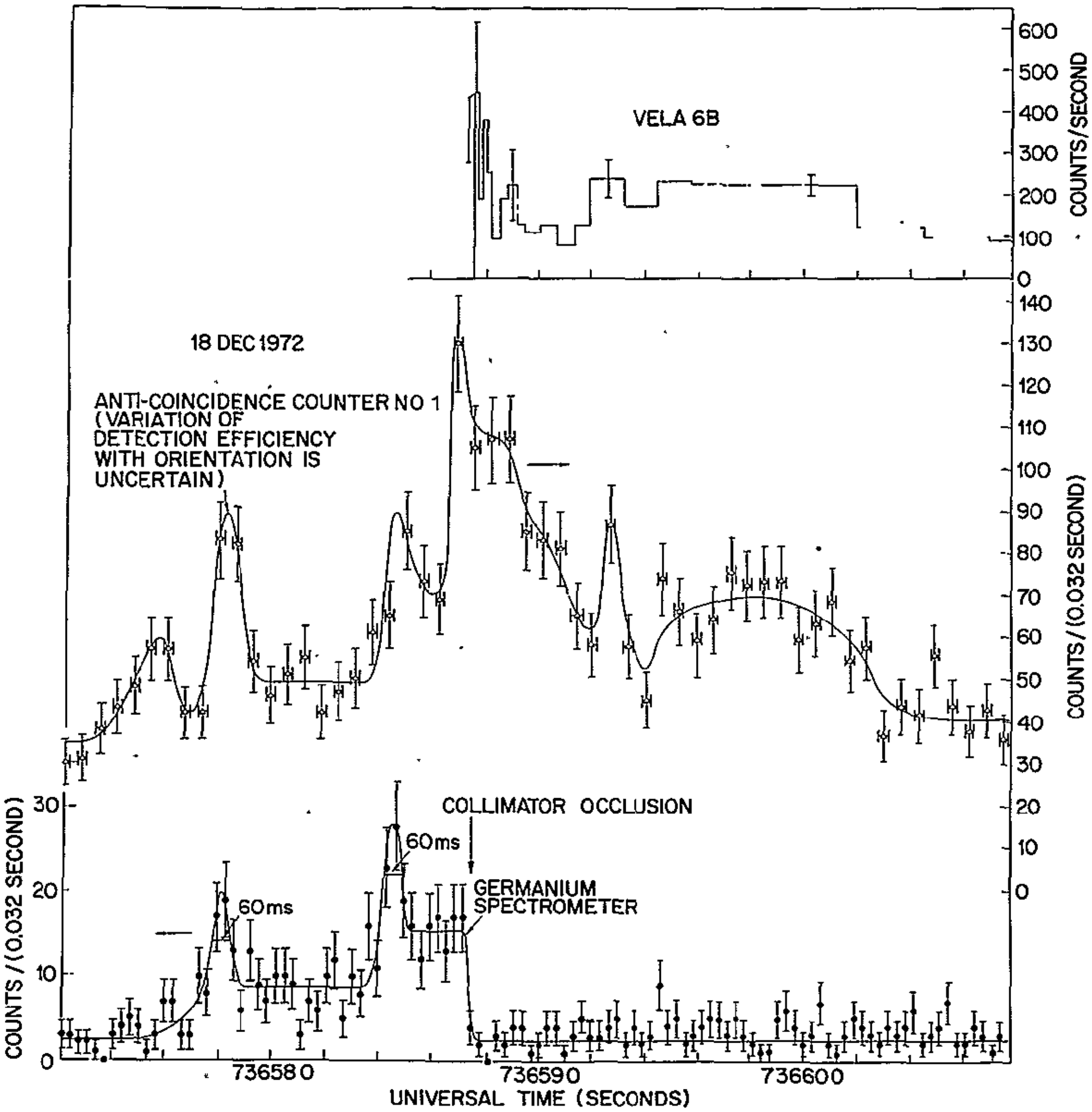

Figure B2-1. Plot of counting rates in the germanium spectrometer, the anticoincidence counter surrounding the germanium sensor, and the Vela 6B detector as a function of Universal Time for the cosmic gamma ray burst on 18 December 1972 (from Imhof et al., 1974B).

scintillator. The latter sensor experienced a maximum response at ~ 73658.7 seconds, which is consistent, within the overall timing accuracies, with the time of the Vela trigger at 73658.75 seconds. The direction of the source, as determined from the times of arrival at two Vela satellites and from occultation by the germanium collimator, requires the nearly simultaneous arrival time of the gamma-rays at the low-altitude vehicle and at the Vela 6B satellite. A preliminary location of the source direction has been determined to be 70° to 120° right ascension and 0° to $+20^{\circ}$ declination. From further analysis the size of the error box may be reduced.

Since the threshold energy levels for the anticoincidence counter varied with position and because the viewing geometry was quite complex, data from the anticoincidence counter have not been used for quantitative time profile studies. On the other hand, the collimation for the germanium spectrometer provided an excellent geometry for measuring spectra during the approximately 1 second on each of three spins when the spectrometer was viewing the source. The period of observation with the spectrometer was terminated at 73671 seconds by the scheduled shutdown of the flight tape recorder.

Certain outstanding features in the counting rate profiles of Figure B2-1 are to be noted. Two narrow bursts with trailers (i.e., higher intensities after the peaks than before) are evident in the germanium spectrometer data. These microbursts are also seen in the counting rate profiles of the anticoincidence counter along with two more which are also evidenced by the Vela response and the indication of an earlier one before the source was in the field of view of the germanium spectrometer. These five microbursts occur within 1.8 seconds. Since the anticoincidence counter was sampled only during alternate 32 millisecond intervals, the shape of the time profile is not as well defined as with the germanium spectrometer. Curves have been drawn through both sets of data to aid the eye, but the lines are not intended to represent quantitative fits to the time profile. The labeled widths (60 milliseconds) are approximate, but the data clearly indicate widths of that magnitude which correspond to source regions of less than about 1.8×10^9cm. In view of the relatively low counting rates, rise and decay times are not accurately defined. The germanium spectrometer data are consistent within the statistical variations with the trailers after each of the microbursts being flat in time, but other shapes may also be compatible with the observations.

Energy spectra of the photons emitted during the gamma-ray burst are presented in Figure B2-2 for six different short accumulation periods. The raw channels are grouped into 16.5 keV bins at low energies, 55-keV bins at intermediate energies, and 110-keV bins at high energies to improve statistics. The raw spectra have been corrected for the intrinsic efficiency of the germanium sensor and for transmission through the 2.81g cm^{-2} of plastic and aluminum at the collimator entrance. Corrections have not been made for the contributions to the counter in lower-energy channels from the Compton distributions. However, calculations performed for various representative exponential and power law spectra showed that the changes in e-fold energy were no greater than 15 keV, or the changes in spectral index were no greater than 0.21. The energy spectra can be fitted nearly as well, within the limited statistics, with an exponential shape as with a power law. From the OSO-7 and IMP-6 measurements it has generally been found that the energy

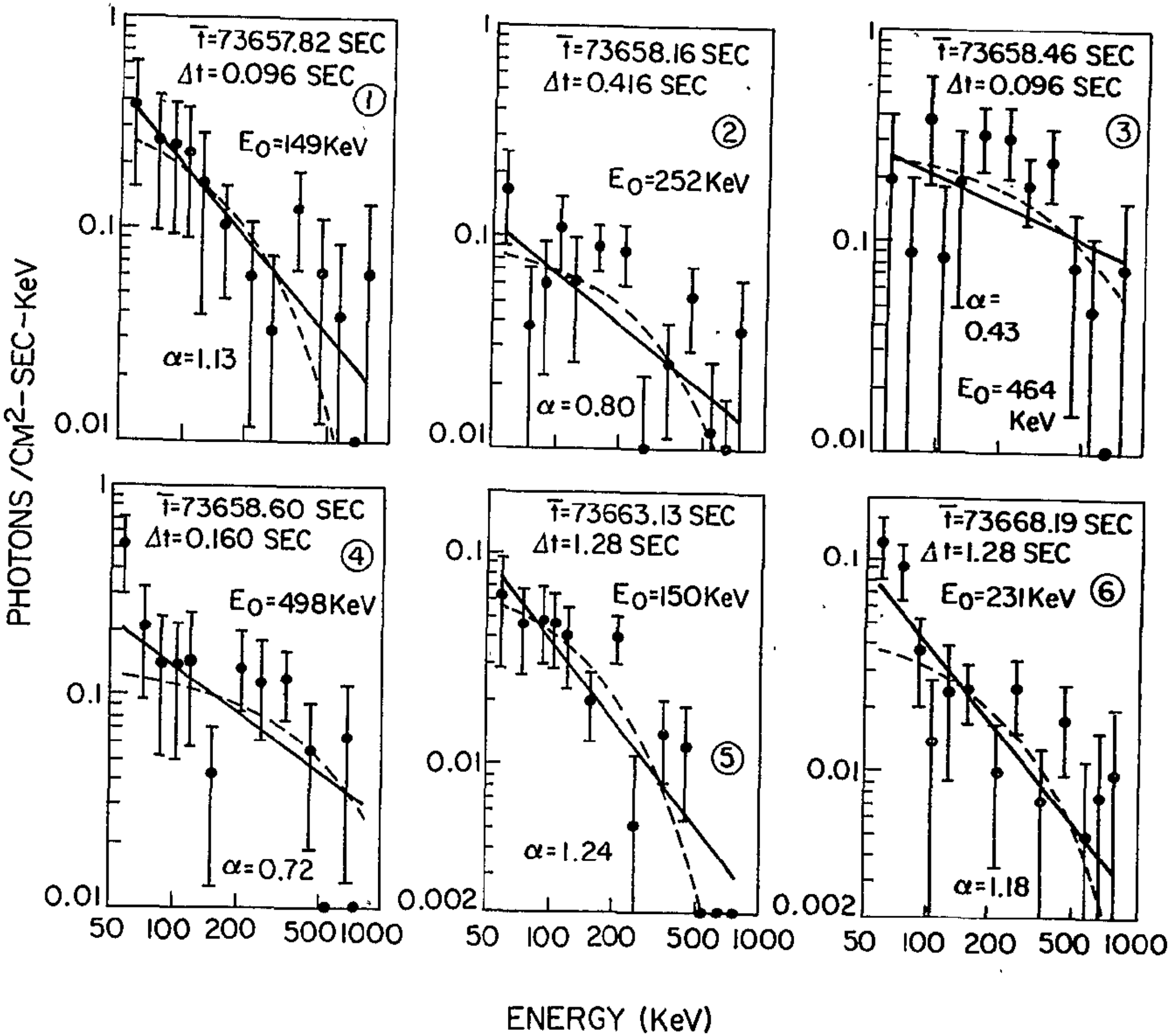

Figure B2-2. Spectra for six different accumulative periods during the 18 December 1972 burst. The least-squares-fit power law and exponential curves are also shown (from Imhof et al., 1974B).

spectra fit a power law below 100 keV and an exponential shape above that energy. But because the dividing line does not appear to be definitive, the spectra have been fitted to both power law and exponential functions.

The on-board data handling and telemetry systems were designed with a high bandwidth to provide spectral measurements with a fast time resolution. When analyzing the data the spectra can be accumulated for arbitrary time intervals, depending upon the statistics desired and the times of interest. This flexibility can be of great value for studying phenomena with pronounced and varied time structure as in the case of the 18 December 1972 cosmic gamma-ray burst. The fast-time resolution measurements are also important for restricting the spectral analyses to times when the viewing geometry is optimum. All spectra used in the analyses were taken only at times when the collimator provided a direct view of the source. Least-squares spectral fits for a selected grouping of the data during the 18 December 1972 event are shown in Figure B2-3. Here each of the narrow microbursts are treated as separate entities and the time periods before and afterwards are divided into sub intervals. Some time intervals when the total counting rates were close to background are not included in the analysis periods. The data have been subjected to least squares fits for exponential, power law and blackbody shapes. For the exponential fits e-fold values are presented, labelled as E_o. The exponents for the power law fits are given and for the blackbody fits the temperatures are presented in units of keV.

For each of the three spectral shapes the spectrum hardens (or the blackbody temperature increases) with time during the precursor to the Vela trigger. The spectra measured after the main burst are comparable to

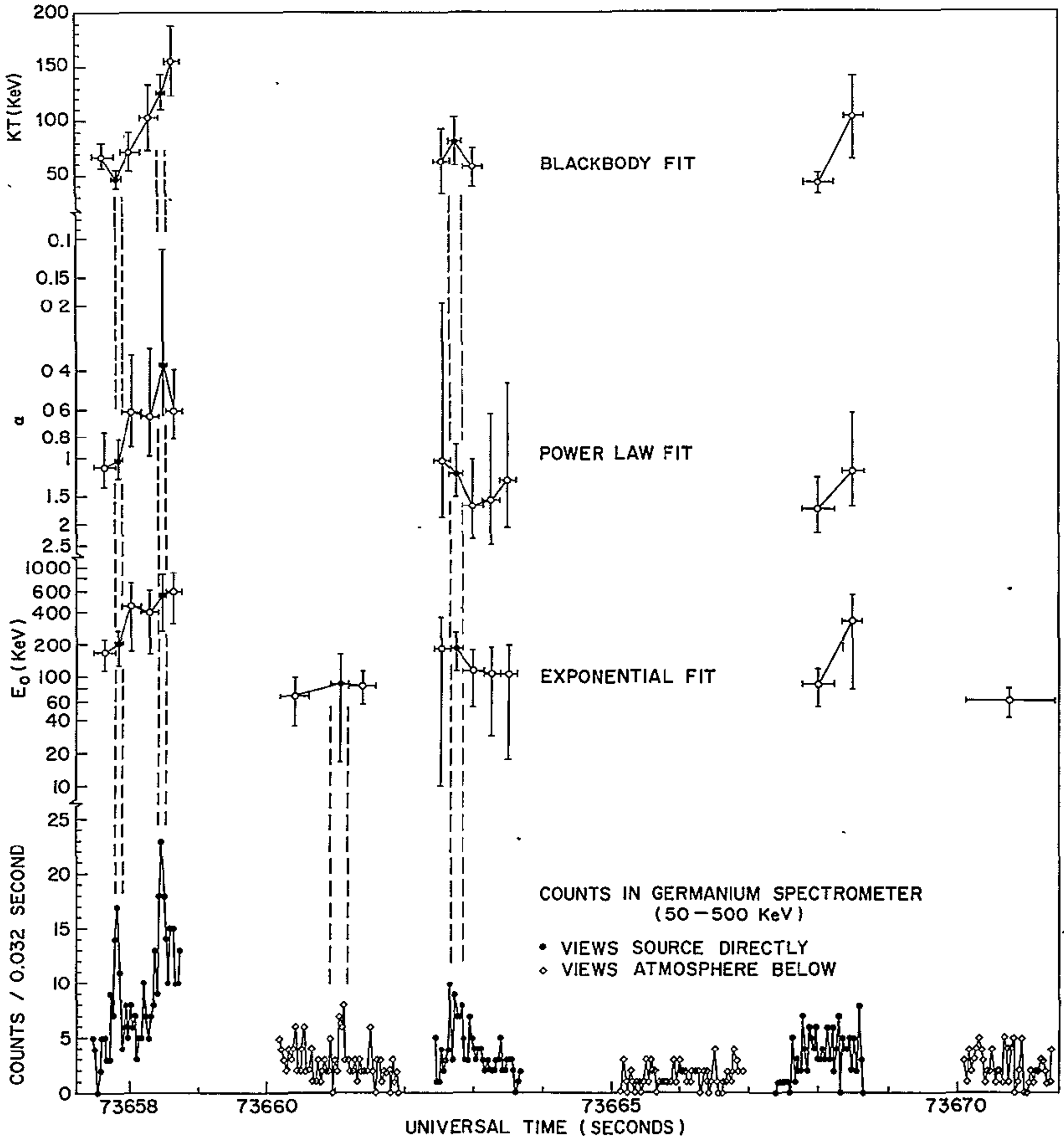

Figure B2-3. Plot of least squares spectral fits to the germanium spectrometer data taken during the 18 December 1972 gamma-ray burst. The counting rates in the energy range 50-500 keV in the germanium sensor are also plotted. The time intervals encompassing three separate intensity spikes are indicated by dotted lines.

those observed $\sim$ 1 second prior to the Vela trigger but are significantly softer than those observed just prior to the main burst. Another obvious feature in Figure B2-3 is the lack of correlation of any spectral changes with the occurrences of the microbursts. It would appear that the additional gamma-ray fluxes associated with the microbursts have nearly the same spectra as the fluxes just prior to or subsequent to the microburst. This finding may have important implications for any proposed models and also indicates that it may not be possible to enhance the presence of any spikes by performing measurements at different gamma-ray energies.

The shapes and temporal variations of the energy spectra associated with a gamma-ray burst should provide strong clues as to the physical mechanisms responsible. For example, the presence of a blackbody spectrum might favor the neutron star formation model of Ramaty and Cohen (1974) in which blackbody temperatures with duration times of $\sim$ 0.1 second are predicted. A blackbody spectral shape is consistent with the data during the early portions of the event, but is not obviously preferred over an exponential or power law form. It should again be noted, however, that at the beginning of the event the spectrum shows a generally increasing hardness (or the blackbody temperature increases). This provides evidence for increasing energy states in the system near the beginning of the event.

The possible presence of lines in gamma-ray spectra is very important for evaluating certain theoretical models. Their presence might provide strong evidence for the occurrence of certain nuclear reactions during an event. In order to detect gamma-ray lines with a high sensitivity, good energy resolution should be used, thus favoring the use of a cooled-germanium spectrometer.

However, at the time of the 18 December 1972 event the resolution of the germanium spectrometer on the 1972-076B satellite had degraded to ~ 10 keV at 60 keV and to ~ 50 keV at 511 keV. Such resolutions are comparable to those observable with a good scintillation spectrometer, so these data do not offer the advantage of high energy resolution. The fast time resolution does present the opportunity of detecting gamma-ray lines present only during portions of an event. However, the data have not revealed the presence of lines, but the large statistical errors prevent setting stringent limits on their intensities.

B. The Event of 21 July 1973

A gamma-ray burst on 21 July 1973 triggered the Vela 5A satellite at 32113.34 seconds U.T., the Vela 6B satellite at 32115.25 seconds, and the Vela 6A satellite at 32116.03 seconds. This gamma-ray burst was also measured in one of the large area plastic scintillators on the Lockheed experiment, providing fast time measurements of the intensity profile on this event. However, it was not observed in the germanium sensor since its cryogen supply had depleted two months earlier.

During the 21 July 1973 event the background rates were higher than during the 18 December 1972 event because the satellite was at a higher magnetic latitude at the time of the burst. However, the satellite was fortunately not within the radiation belts as evidenced by the lack of response in the energetic particle detectors. Furthermore, considering the very close time coincidence with the Vela measurements, it is clear that the anticoincidence counter was responding to the cosmic gamma-ray burst.

The counting rates for the 21 July 1973 event measured in the anticoincidence counter in spectrometer #1 and in three of the Vela sensors are shown in Figure B2-4. The starting times of the response in each of the Vela sensors have been corrected to represent arrival times of the gamma-rays at the low altitude satellite. The fluxes near the beginning were too low to trigger either the Vela 6A or 6B satellites and were barely above the background level of the anticoincidence counter on the low altitude satellite. The large side section of the plastic scintillator on the other germanium spectrometer was not turned on at the time so data are presented for only one anticoincidence counter. The plotted counts are those accumulated during alternate 32 millisecond intervals. The data clearly demonstrate the frequent occurrence of narrow microbursts. Several pronounced spikes, with peak intensities many standard deviations above the background, occurred during later portions of the 21 July 1973 event. In fact, the fast-time structure was more pronounced during this event than during the 18 December 1972 gamma-ray burst.

The cosmic ray background counting rates in the plastic scintillator have been subtracted from the total counting rates. The backgrounds used for this purpose were obtained from the counting rates measured before and after the event and were taken to vary linearly with time. Intercomparisons between the plastic scintillator counting rates, which are regularly sampled with a 32-millisecond time resolution, and the various Vela sensors, each of which triggered at a different time and with a progressively increasing time resolution, are complicated by the differing sample times and intervals. Nonetheless, the counting rate profiles from the different sensors are all consistent with each other and many features of the time structure are substantiated by the simultaneous response of more than one instrument.

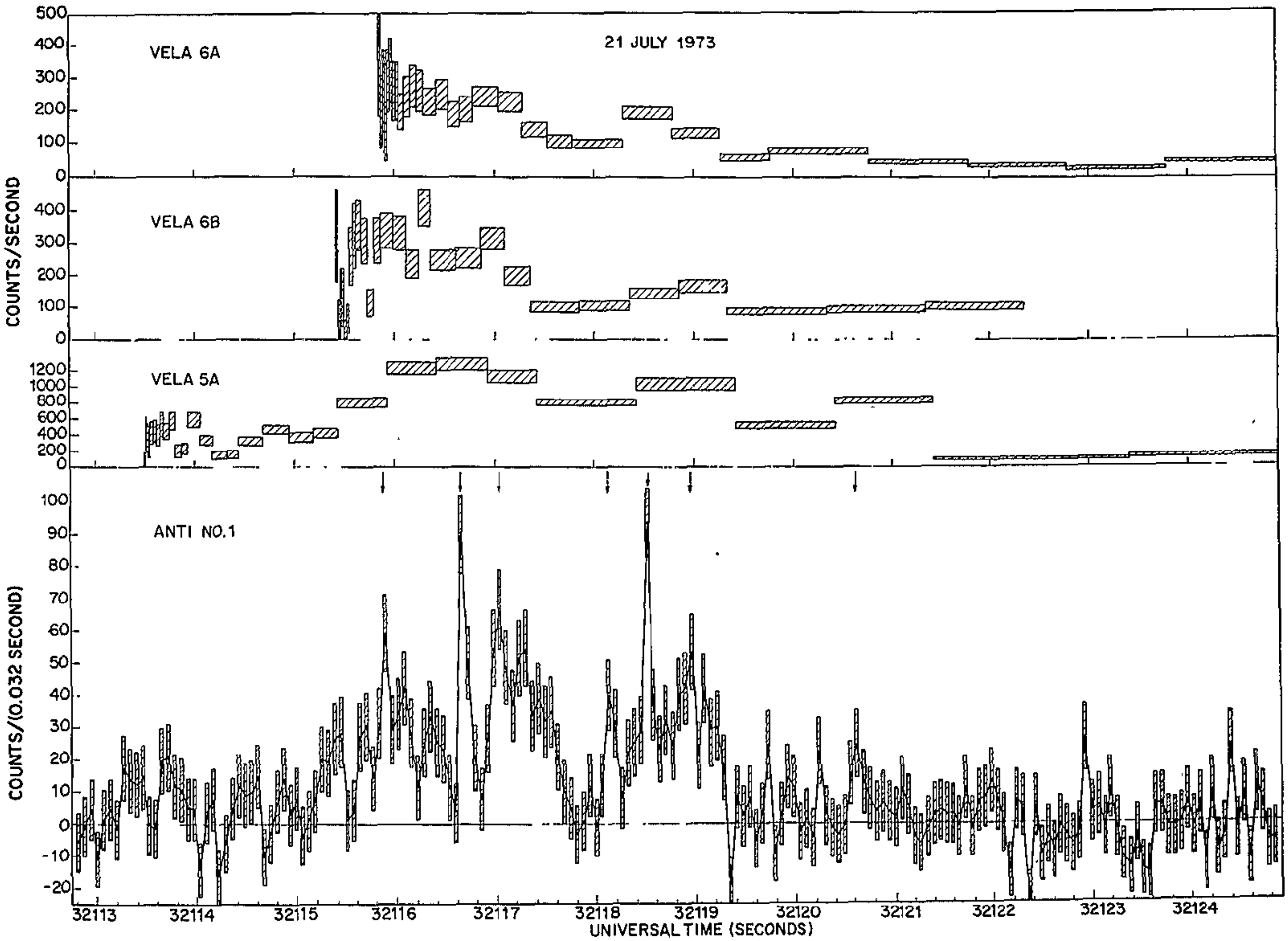

Figure B2-4. Plot of counting rates in the anticoincidence counter in spectrometer #1 on the satellite 1972-076B and in the Vela 5A, 6A and 6B sensors as a function of time for the 21 July 1973 gamma-ray burst (from Imhof et al., 1975).