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⑥ A Cosmic Gamma-Ray Burst on May 14, 1975.

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ABSTRACT

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A cosmic gamma-ray burst is reported that occurred at 29309.11 s UTC, May 14, 1975. The burst was detected at an atmospheric depth of 4 g/cm² residual atmosphere with the University of California double scatter gamma-ray telescope launched on a balloon from Palestine, Texas at 1150 UTC, May 13, 1975. The burst was observed both in the single scatter mode by the top liquid scintillator tank in anti-coincidence with the surrounding plastic scintillator and in the double scatter mode from which energy and directional information are obtained. The burst is 24 standard deviations (σ) above the background for single scatter events. The total gamma-ray flux in the burst, incident on the atmosphere with photon energy greater than 0.5 MeV, is 0.59 ± 0.15 photons/cm². The initial rise time to 90% of maximum is 0.015 ± 0.005 s and the duration is 0.11 s. Time structure down to the 5 ms resolution of the telescope is seen. The mean flux over this time period is 5.0 ± 1.3 photons/cm²-s and the maximum flux is 8.5 ± 2.1 photons/cm²-s. An integral energy distribution is obtained from the single scatter flux and the 8 double Compton scattered gamma-rays recorded during the 0.11 s. When fitted to a power law in energy $N(>E) = A\,E^{-\alpha}$, $A = 0.24 \pm 0.04$ and $\alpha = 1.3 \pm 0.2$. The total energy in the burst above 0.5 MeV is $2 \pm 0.5 \times 10^{-6}$ erg/cm². The direction of the source, with 90% confidence, is limited to a circle with radius of 25° and center at a R.A. of 248° and a declination of +22°. In the search for smaller bursts of more than 5σ above background, 2 additional candidates of 6.4 and 6.5σ were found. The number of bursts, including candidate bursts is in agreement with the integral distribution $S^{-1.5}$ where S is the total energy in the burst.

sq cm

+ or -

sq cm

sq cm

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1. INTRODUCTION

In this paper we describe a cosmic gamma-ray burst observed from a balloon with the University of California (UCR) double scatter telescope. Although gamma-ray bursts of about 100 s duration have previously been seen from single balloon observations (Kondo and Nagase, 1969; Kondo et al. 1970; Hirasima et al. 1970; Koga et al. 1974) this is the first observation of a short burst from a balloon with properties similar to bursts observed from satellites (e.g., Klebesadel et al. 1973; Strong et al. 1974; Cline et al. 1973; Cline and Desai, 1975b). This is the smallest yet reported and has a duration comparable to the shortest Vela satellite bursts. Evidence for small bursts from balloon measurements using time interval analysis was recently discussed by Cline and Desai (1975b).

The gamma-ray burst was detected on May 14, 1975 at 29309.11 s UTC during the night at an altitude of 4 g/cm^2 of residual atmosphere on a balloon launched from Palestine, Texas at 1150 UTC, May 13, 1975. The burst was detected in two modes of operation of the UCR double scatter gamma-ray and neutron telescope (Herzo et al. 1975, Zych et al. 1975). In the first mode the counting rate of the top liquid scintillator tank S1 of dimensions 100 cm x 100 cm x 12.5 cm is observed in anticoincidence with the plastic scintillator box of 0.6 cm thickness completely surrounding the tank. The number of counts in this neutral counter above a threshold of 0.5 MeV is telemetered every 5 ms. The burst was 24 σ above background in this mode.

In the second mode the energy and directional information about the incident gamma-rays are obtained from double Compton scattering. An event is recorded if the gamma-ray scatters in S1, continues on and scatters again in a second liquid scintillator tank S2, 100 cm x 100 cm x 20 cm, that is located 100 cm below S1 center to center. A separate anticoincidence box of plastic scintillator completely encloses S2. Each tank is divided into 28 cells and each cell is observed by a separate photomultiplier for better angular resolution. When a coincident neutral interaction occurs in S1 and S2, the pulse heights, time of flight between S1 and S2, identification of the cells registering the event and event arrival time are loaded into one event frame. The frames are telemetered at a rate of 200/s. Double scattered neutrons are also recorded in this mode and are distinguished from gamma-rays by their longer times of flight. The time of flight is also used to separate upward from downward moving gamma-rays so that celestial gamma-rays are clearly separated from earth albedo gamma-rays.

The direction and energy of the incident gamma-ray are not uniquely defined because part of the energy can be carried away by the scattered gamma-ray in S2. In order to take account of this, on the average, the electron energy deposit in S2 is multiplied by a correction factor f(E). The resulting distributions are sufficiently narrow that the uncertainty in energy is only about 20%. The incident gamma-ray direction can be determined to a cone whose axis is the direction of the scattered gamma-ray and whose opening angle is twice the scattering angle in S1. The uncertainty is about 10°. The maximum digitized event rate in the double scatter mode is 1 event/5 ms determined by the telemetry frame rate. In addition the number of true and accidental coincidences between S1 and S2 are recorded and telemetered every 5 ms. The digitized double scatter gamma-ray rate is corrected for the frame dead time to obtain the true gamma-ray rate. In the double scatter mode each event gives an energy and cone direction for the incident gamma-ray. From the overlap of the cones the direction of the source may be found.

2. RESULTS

The counting rate at and near the time of the burst, in the single scattering mode, as a function of time in intervals of 5 ms is given in Figure 1. From it, a burst rise time of 0.015 ± 0.005 s and a burst duration of 0.11 s are obtained. It appears from this figure that significant variations are occurring in time intervals comparable to our time resolution of 5 ms. These variations appear to be the shortest yet observed in bursts, considerably shorter than the 60 ms "microbursts" observed by Imhof et al. (1975) with a time resolution of 32 ms and likely shorter than the ≤ 16 ms durations suggested by the Vela satellite results (Strong et al. 1974) and the 10-15 ms fluctuations suggested by the Apollo 16 burst (Metzger et al. 1974). This short time infers a maximum source dimension of 1500 km. The 0.11 s duration is also comparable to the shortest Vela bursts that consist of single 0.1 s spikes (Strong et al. 1974).

Using a total of 670 burst counts above background, the detector area of 10^4 cm^2, an efficiency of 0.19, and a transmission by the 2.3 g/cm^2 of the detector and gondola material above the S1 scintillator and by the 4 g/cm^2 overlying atmosphere of 0.63, we find a total burst flux of 0.59 ± 0.15 photons/cm^2 with energies greater than 0.5 MeV, incident on the atmosphere. The flux averaged over the 0.11 s of burst time is 5.0 ± 1.3 photons/cm^2-s with energies greater than 0.5 MeV and the maximum flux during the burst is 8.5 ± 2.1 photons/cm^2-s.

A comparison of the true (zero dead time) double scattering and accidental (delayed coincidence) rates with the single rate is shown in Figure 1. These rates represent both neutron and gamma-ray interactions in S1 and S2.

The observed number of accidental counts during the burst agrees with the number calculated. The lack of any large increase in the accidental counting rate during the burst is evidence that the burst double scattering rate increase was caused entirely by time-correlated interactions in S1 and S2 and not by an extraordinarily large increase in the counting rate of S2. It appears that the double scatter counting rate approaches background during the latter half of the burst as measured by the S1 counting rate. This could mean that the burst energy distribution softened with time as has also been observed by Wheaton _et_ _al_. (1973) for each of the main pulses in the May 14, 1972 burst and by Imhof _et_ _al_. (1975) for the December 14, 1972 burst.

In the Compton double scatter mode, the average burst counting rate during the 0.11 s is 280 ± 100 counts/s, 12 ± 4 times the background rate of 22.5 counts/s. Because of the limitation in the telemetry frame event rate of 1 event/5 ms, during the burst of 0.11 s, a maximum of 22 gamma-rays could be recorded if every frame contained a good gamma-ray burst event. Actually 8 gamma-rays were recorded that satisfied our gamma-ray event criteria. No neutrons were observed during the 0.11 s burst time.

The energy of the incident gamma-ray is taken to be

$$E_\gamma = E_{e1} + f(E)\, E_{e2}$$

where E_{e1} is the recoil electron energy in S1 and E_{e2} is the recoil electron energy in S2. The f(E) values were estimated from Monte Carlo calculations and along with our best estimates of the energies of the double scattered gamma-rays are given in Table 1. Likewise the gamma-ray scattering angles are estimated from

Table 1. Double Scattered Gamma-Rays.

Gamma-Ray	E_{e1} (MeV)	E_{e2} (MeV)	f(E)	E_{γ} (MeV)	θ (deg)
1	1.34	0.60	1.55	2.3	48
2	0.88	2.34	1.23	3.8	16
3	3.22	0.99	1.38	4.6	45
4	1.37	0.60	1.55	2.3	48
5	1.07	1.39	1.28	2.9	27
6	0.91	0.78	1.47	2.1	37
7	0.91	16.2	1.18	20.	3
8	1.09	2.11	1.23	3.8	22

$$\cos\theta = 1 - m_e c^2 \left(\frac{1}{f(E)E_{e2}} - \frac{1}{E_{e1} + f(E)E_{e2}} \right)$$

where m_e is the electron rest mass and c is the velocity of light. The values of the calculated scattering angles are also given in Table 1.

An estimate of the direction in the sky of the source of the burst is obtained from the overlap of the scattering cone circles transformed to right ascension and declination. In order to sharpen the source direction capability and enhance the rejection of the atmospheric background that is maximum in the horizontal plane, only those gamma-rays with scattering angles $<30^{\circ}$ are used. This reduces the number of gamma-rays from 8 to 4. The direction of the source, with 90% confidence, is then limited to a circle of radius of 25° and center at a R.A. of 248° and a declination of $+22^{\circ}$. For stronger bursts, the circle radius can be reduced significantly, to a few degrees.

With the points from single scatters at 0.5 MeV and the 8 double scatter events it is possible to give the estimate of the integral energy distribution of the burst gamma-rays shown in Figure 2. When the data are fitted by least squares to an integral power law distribution $N(>E) = A\,E^{-\alpha}$ we find $A = 0.24 \pm 0.04$ and $\alpha = 1.3 \pm 0.2$ where E is in MeV. This is in agreement with an α of 1.5 proposed by Cline and Desai (1975a).

A search was made of 24 hours of single scatter data with 0.1 s resolution print-outs for smaller bursts that were at least 5 σ above background. The only two candidates found are 6.4 and 6.5 σ above background and are given in Figure 3 with 20 ms resolution, along with the 24 σ burst. The smaller candidate events show similar rise times, variations and durations as the larger burst but have much poorer statistics. The candidate at 47779.3 s UTC was observed while the double scatter telescope was in a mode measuring both upward and downward moving gamma-rays and neutrons. As a consequence, most of the telemetry was filled with upward moving gamma-rays and the downward moving double scattered gamma-rays were not above background. The candidate at 25057.1 s UTC, however, was observed when the telescope was telemetering downward moving gamma-rays and neutrons, only, and the double scattered gamma-ray count rate increased by a factor of 3 ± 1 during the burst. The five gamma-rays, 3 with scattering angles $\leq 35^\circ$, limit the direction of the source, with 90% confidence, to a circle with a radius of 35° and center at a R.A. of 200° and a declination of $+10^\circ$.

In order to evaluate the total energy in the burst consistent with earlier papers (Strong et al. 1974; Cline and Desai 1975b), we use our integral energy distribution $N(>E) = 0.24\ E^{-1.3}$ photons/cm^2 from 0.50 MeV to infinity, $N(>E) = 16\ e^{-(E/0.15)}$ from 0.15 to 0.50 MeV and add 25% for the fraction of the total energy that lies below the Vela threshold of 0.15 MeV. We find 4, 1 and 1×10^{-6} erg/cm^2 for the burst and 2 candidate bursts, respectively.

In the single scatter mode, almost 2π solid angle of the celestial sphere was under observation at all times. Our two points for the number of bursts $N(>S)$ per unit time with total energy in the burst greater than S are plotted in Figure 4 along with data from Cline and Desai (1975b) which include results from the Vela satellites (Strong et al. 1974), the SAS-B satellite, the IMP-7 satellite and their balloon flight of 5 May 1974 (Cline and Desai 1975b). Both the point for our burst and for our burst plus candidate bursts, with large uncertainties, are consistent with the line $S^{-1.5}$ for sources distributed uniformly in space.

The data presented here are strong evidence that we have observed one and possibly three cosmic gamma-ray bursts.

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FIGURE CAPTIONS

Figure 1. Count rates versus time during the burst at 29309.11 UTC, May 14, 1975. The count rates were telemetered every 5 ms. The top graph is the single scatter neutral count rate ($\overline{A1}S1$). The error bars are standard deviations of the counting statistics. The middle graph gives the double-scattered neutral count rate ($\overline{A1}S1\overline{A2}S2$). The bottom graph gives the chance coincidence background count rate obtained from delayed coincidences of S2 with S1. Each dot on the middle graph represents a telemetered double-scattered gamma-ray event for which pulse height, time of flight and cell identification were telemetered at a maximum rate of 1 event every 5 ms.

Figure 2. Integral gamma-ray energy distribution for the burst. The point at 0.5 MeV is obtained from the single scatters and the points at higher energies from double scatters. The straight line is a least squares fit to the data.

Figure 3. Neutral count rates in S1 ($\overline{A1}S1$) for the two candidate bursts starting at 25057.1 and 47779.4 UTC, respectively, and for the burst starting at 29309.1 UTC. The data are combined in 20 ms intervals.

Figure 4. The number of bursts per unit time with total energy greater than S versus S. The data are taken from Cline and Desai (1975b) which include results from the Vela satellites (Strong *et al*. 1974), the SAS-B satellite, the IMP-7 satellite and their balloon flight of 5 May 1974 (Cline and Desai 1975b).

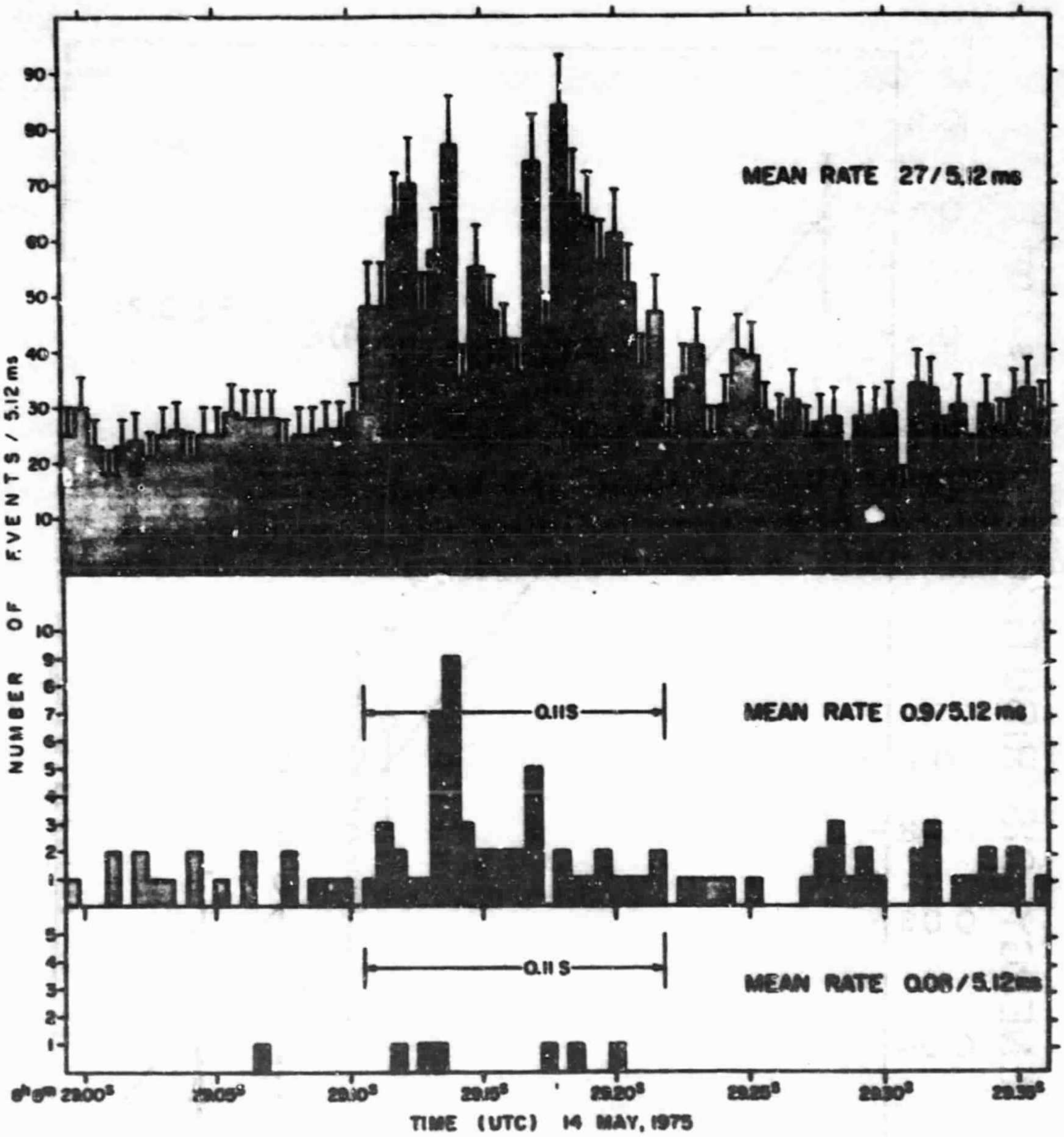
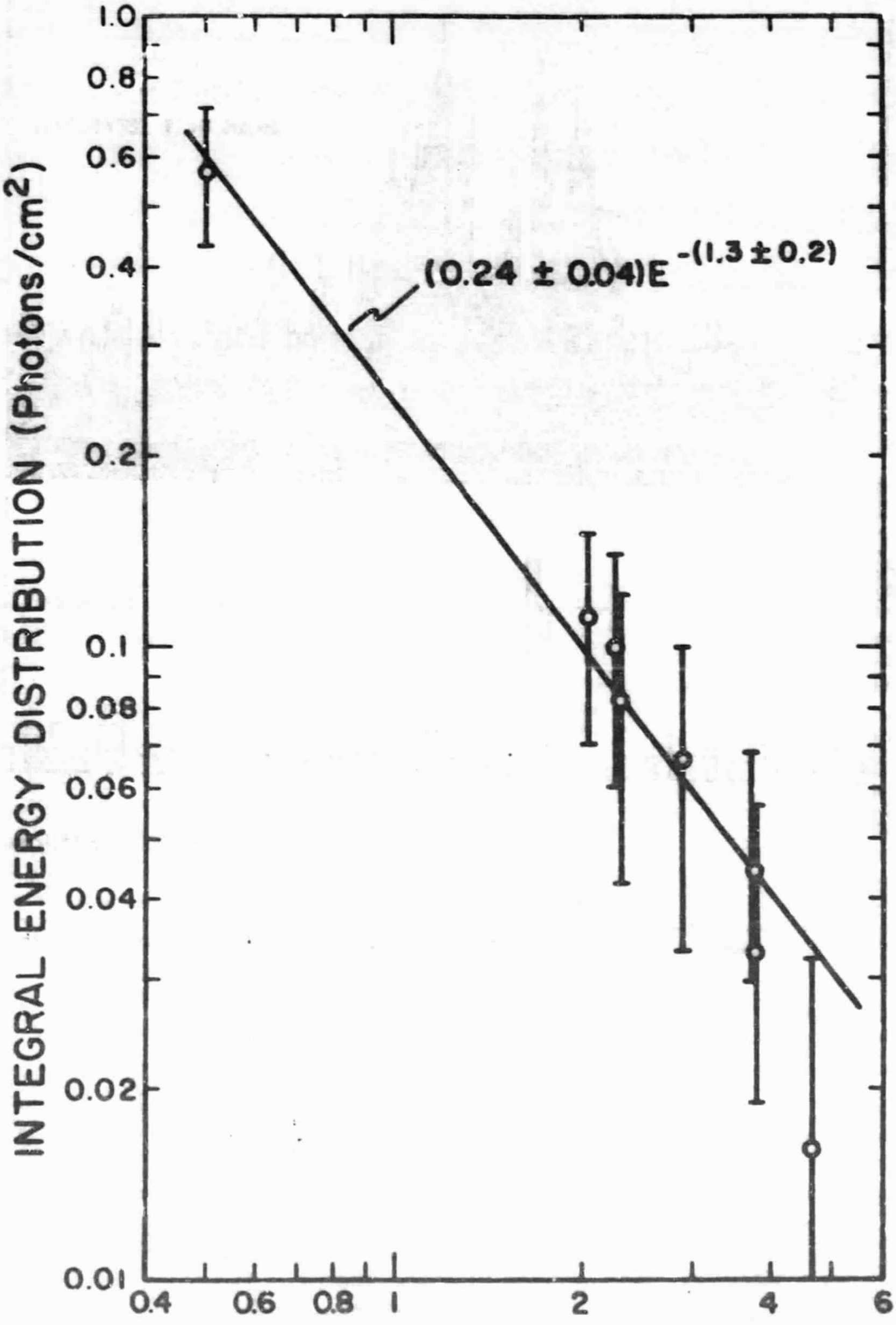

NUMBER OF EVENTS / 5.12 ms
90
80
70
60
50
40
30
20
10
MEAN RATE 27/5.12 ms
10
9
8
7
6
5
4
3
2
1
0.11S
MEAN RATE 0.9/5.12 ms
5
4
3
2
1
0.11 S
MEAN RATE 0.08/5.12ms
6h5m 29.00s
29.05s
29.10s
29.15s
29.20s
29.25s
29.30s
29.35s
TIME (UTC) 14 MAY, 1975

Figure 1



1.0
0.8
0.6
0.4
0.2
0.1
0.08
0.06
0.04
0.02
0.01
INTEGRAL ENERGY DISTRIBUTION (Photons/cm^2)
(0.24 ± 0.04)E$^{-(1.3 \pm 0.2)}$
0.4
0.6
0.8
1
2
4
6
GAMMA-RAY ENERGY (MeV)

Figure 2

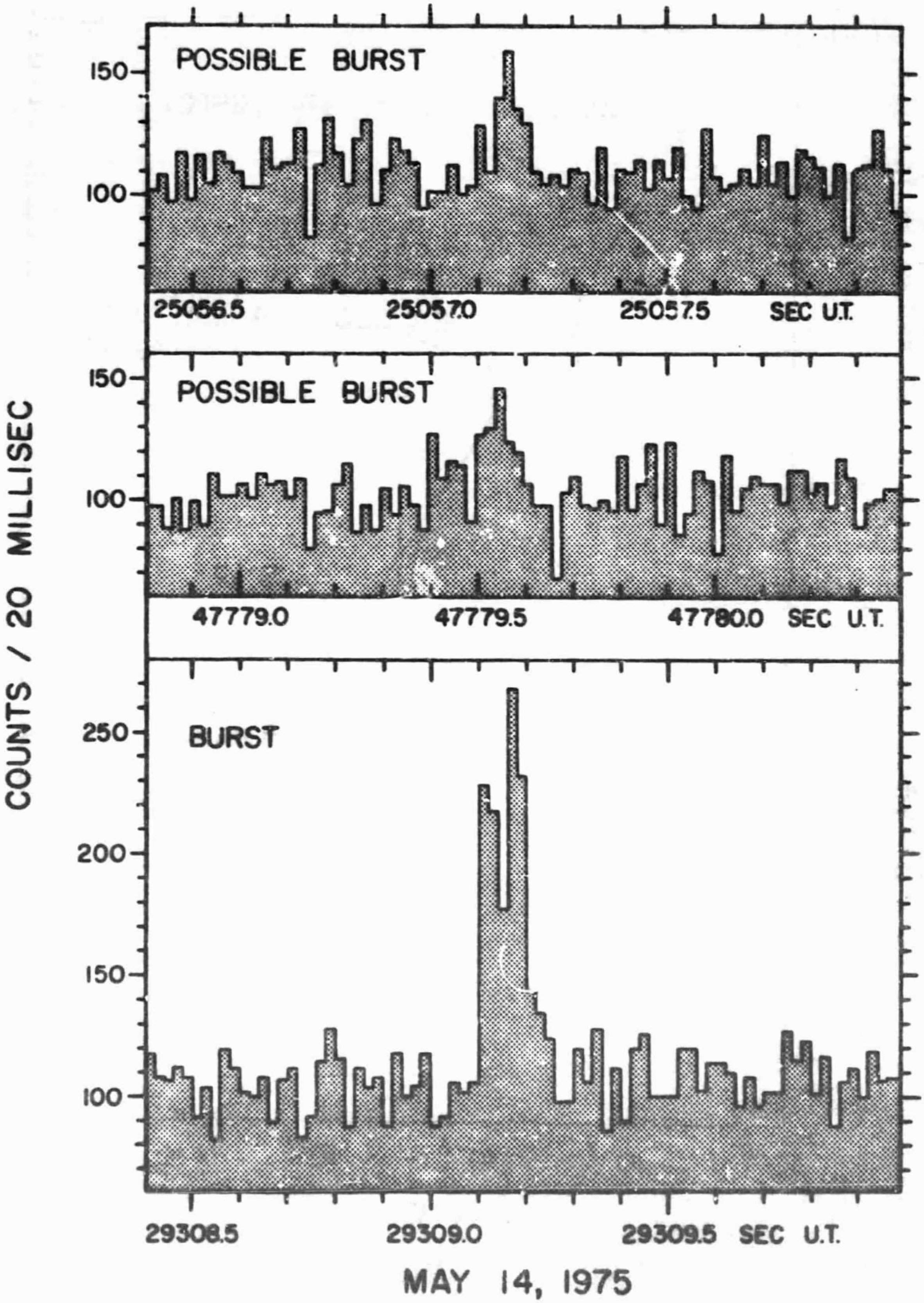
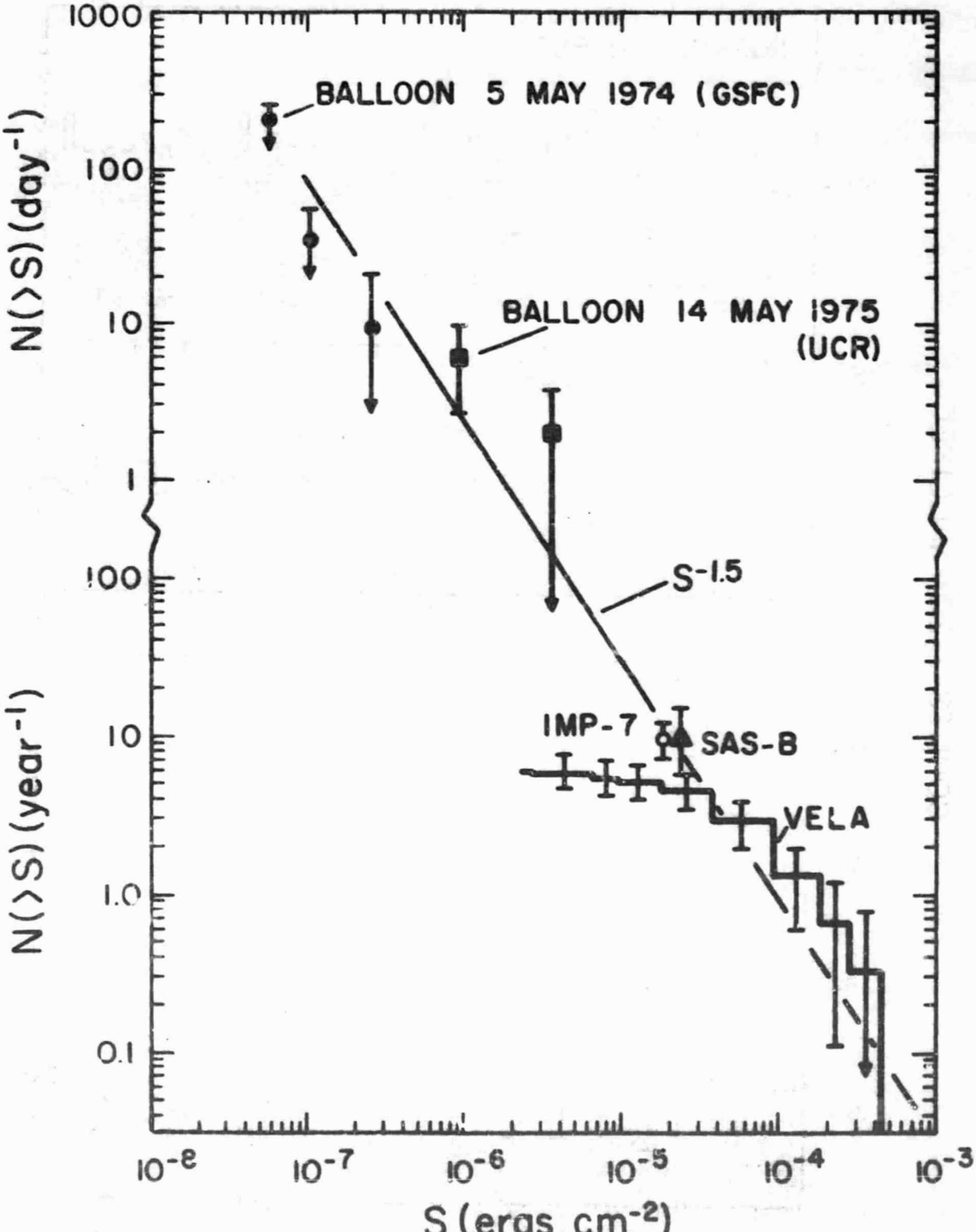

COUNTS / 20 MILLISEC
POSSIBLE BURST
150
100
25056.5
25057.0
25057.5
SEC U.T.
POSSIBLE BURST
150
100
47779.0
47779.5
47780.0
SEC U.T.
BURST
250
200
150
100
29308.5
29309.0
29309.5
SEC U.T.
MAY 14, 1975

Figure 3



BALLOON 5 MAY 1974 (GSFC)
BALLOON 14 MAY 1975 (UCR)
$S^{-1.5}$
IMP-7
SAS-B
VELA
1000
100
10
1
100
10
1.0
0.1
$N(>S)\ (\mathrm{day}^{-1})$
$N(>S)\ (\mathrm{year}^{-1})$
10^{-8}
10^{-7}
10^{-6}
10^{-5}
10^{-4}
10^{-3}
$S\ (\mathrm{ergs\ cm}^{-2})$

Figure 4