THE ASTROPHYSICAL JOURNAL, 182:L85–L88, 1973 June 1

OBSERVATIONS OF GAMMA-RAY BURSTS OF COSMIC ORIGIN

RAY W. KLEBESADEL, IAN B. STRONG, AND ROY A. OLSON

University of California, Los Alamos Scientific Laboratory, Los Alamos, New Mexico
Received 1973 March 16; revised 1973 April 2

ABSTRACT

Sixteen short bursts of photons in the energy range 0.2–1.5 MeV have been observed between 1969 July and 1972 July using widely separated spacecraft. Burst durations ranged from less than 0.1 s to ~30 s, and time-integrated flux densities from ~10^{-5} ergs cm^{-2} to ~2×10^{-4} ergs cm^{-2} in the energy range given. Significant time structure within bursts was observed. Directional information eliminates the Earth and Sun as sources.

Subject headings: gamma rays — X-rays — variable stars

I. INTRODUCTION

On several occasions in the past we have searched the records of data from early *Vela* spacecraft for indications of gamma-ray fluxes near the times of appearance of supernovae. These searches proved uniformly fruitless. Specific predictions of gamma-ray emission during the initial stages of the development of supernovae have since been made by Colgate (1968). Also, more recent Vela spacecraft are equipped with much improved instrumentation. This encouraged a more general search, not restricted to specific time periods. The search covered data acquired with almost continuous coverage between 1969 July and 1972 July, yielding records of 16 gamma-ray bursts distributed throughout that period. Search criteria and some characteristics of the bursts are given below.

II. INSTRUMENTATION

The observations were made by detectors on the four *Vela* spacecraft, *Vela 5A, 5B, 6A,* and *6B,* which are arranged almost equally spaced in a circular orbit with a geocentric radius of ~1.2×10^5 km.

On each spacecraft six 10 cm^3 CsI scintillation counters are so distributed as to achieve a nearly isotropic sensitivity. Individual detectors respond to energy depositions of 0.2–1.0 MeV for *Vela 5* spacecraft and 0.3–1.5 MeV for *Vela 6* spacecraft, with a detection efficiency ranging between 17 and 50 percent. The scintillators are shielded against direct penetration by electrons below ~0.75 MeV and protons below ~20 MeV. A high-Z shield attenuates photons with energy below that of the counting threshold. No active anticoincidence shielding is provided.

Normalized output pulses from the six detectors are summed into the counting and logics circuitry. Logical sensing of a rapid, statistically significant rise in count rate initiates the recording of discrete counts in a series of quasi-logarithmically increasing time intervals. This capability provides continuous coverage in time which, coupled with isotropic response, is unique in observatonal astronomy. A time measurement is also associated with each record.

The data accumulations include a background component due to cosmic particles and their secondary effects. The observed background rate, which is a function of the energy threshold, is ~150 counts per second for the *Vela 5* spacecraft and ~20 counts per second for the *Vela 6* spacecraft.

III. OBSERVATIONS

Since these detectors are susceptible to stimulation by energetic particles, the following evidence is offered in support of the interpretation that the signals reported here are due to fluxes of photons within the quoted energy range. Other Vela detectors with high sensitivity to energetic charged particles and neutrons recorded no deviation from the steady counting rate induced by cosmic particle fluxes at the time of any of the observed bursts. It has been noted, furthermore, that the detailed time structure of each burst is reproduced at all spacecraft recording the event, even though the radiation must, in most cases, have traversed an appreciable portion of the geomagnetic field. Simple calculations show that electron energies of many GeV and proton energies of many MeV would be required to produce this degree of rigidity, and fluxes of such particles would create observable effects in the other instruments on the spacecraft. Additionally, no difference in the time of arrival of the stimulating signals at two different spacecraft has been found which exceeds 0.8 s, the maximum transit time for light, even though the search allowed a deviation from simultaneity as great as 4 s.

A count-rate record is generated only in response to a rapid rise in count rate to a level significantly above background. The frequency with which individual records are generated is relatively high for *Vela 5* spacecraft. Modifications to *Vela 6* detectors reduced this frequency, at some cost in sensitivity, to an insignificant level. Only 47 such records have been generated by both *Vela 6* spacecraft over a 2-year period, 22 of which are responses, in coincidence, to the bursts reported here. Present processing requires that at least two spacecraft record the burst with a deviation from simultaneity of 4 s or less. Sixteen events have been observed to meet these criteria, two of which were recorded by all four spacecraft. Absence of consistent response from all four spacecraft can be attributed in most cases to an inappropriate mode of operation or to marginal signal levels.

These bursts display a wide variety of characteristics. Time durations range from less than a second to about 30 s. Some count-rate records have a number of clearly resolved peaks while others do not appear to display any significant structure. The time-integrated flux density in the measured energy interval ranges from the minimum identifiable level of $\sim 10^{-5}$ ergs cm^{-2} to more than 2×10^{-4} ergs cm^{-2}. Instantaneous flux densities have exceeded 4×10^{-4} ergs cm^{-2} s^{-1}. An indication of the spectral distribution of the incident flux may be derived from the ratio of the response in the two energy intervals in those cases where both *Vela 5* and *Vela 6* spacecraft recorded the burst.

Allowing for differing energy thresholds and statistical fluctuations, the integrated flux for a particular event is independent of the recording spacecraft. Differences in the time of arrival of the signals at the various spacecraft imply that the spacecraft are not equidistant from any given source. Inverse-square law considerations thereby place the sources at a distance of at least 10 orbit diameters, or several million kilometers.

Arrival-time differences have been derived approximately in all cases, and fairly accurate (± 0.05 s) for a number of cases. For a two-spacecraft coincidence the transit delay defines a circle on the celestial sphere on which the source position must lie. For three spacecraft we can define intersecting circles, whose points of intersection represent the source position and its mirror image in the orbital plane of the spacecraft, a presently unresolved ambiguity. Nevertheless, it has been possible by this technique to rule out the sun as a source. Also, in none of the 16 cases was there found any close correlation with any recorded indications of solar activity.

One event has been observed which almost certainly was associated with a solar outburst. It differs distinctly from the 16 bursts reported here, and will be described in detail at a later date.

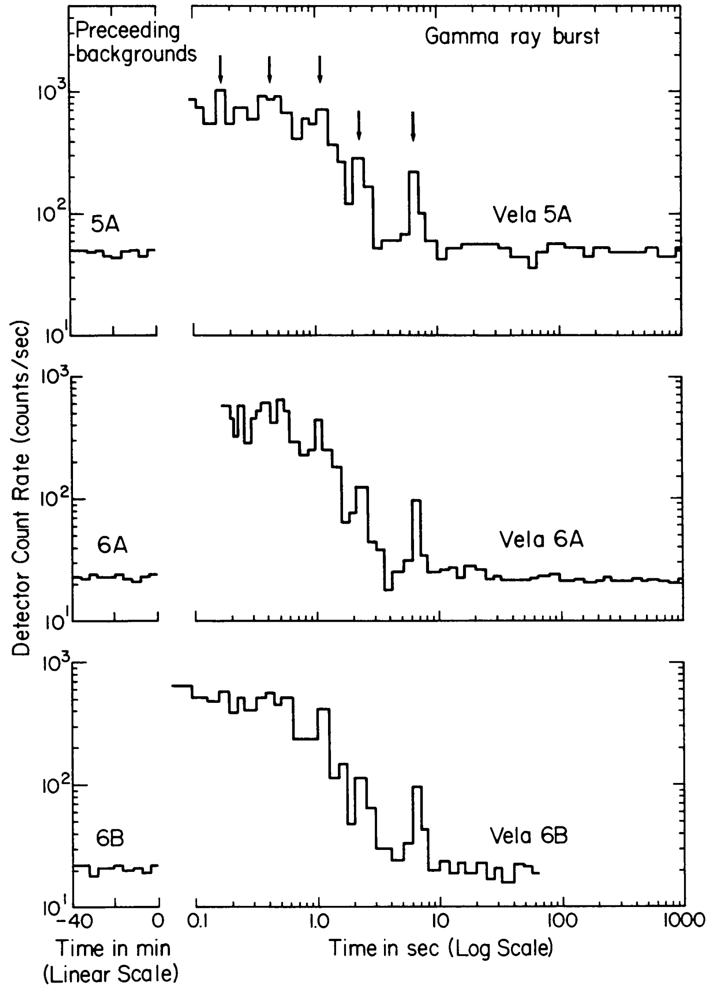

FIG. 1.—Count rate as a function of time for the gamma-ray burst of 1970 August 22 as recorded at three Vela spacecraft. Arrows indicate some of the common structure. Background count rates immediately preceding the burst are also shown. *Vela 5A* count rates have been reduced by 100 counts per second (a major fraction of the background) to emphasize structure.

A burst observed on 1970 August 22 is presented as an example. Figure 1 shows the count rate as a function of time. Each plot is presented in two parts. On the left, on a linear time scale, are plotted 10 measurements of count rate made at 4-minute intervals for the time immediately preceding the burst. These establish a background count rate. The record of the burst is plotted on the right on a logarithmic time scale. All the *Vela 5A* data have had a uniform 100 counts per second (a major fraction of the background) subtracted before plotting in order to facilitate comparison of time structure.

The initial part of the burst (extending to ~4 s) has an integrated flux density of $\sim 8 \times 10^{-5}$ ergs cm^{-2} in the range 0.2–1.0 MeV, and $\sim 6 \times 10^{-5}$ ergs cm^{-2} in the range 0.3–1.5 MeV. Within these 4 s there appears structure common to the records of all three spacecraft. Although the exact statistical significance of this structure has not yet been firmly established, it has been used to adjust these three records in time, relative to the initiation of the recordings. Exclusion of the Sun as the source, based on directional resolution, is unaffected by this correction.

In addition to the initial structure, all three records show a distinct peak centered around 6.5 s. For each record this peak is statistically significant to about 6 standard deviations. It represents integrated flux densities of 10^{-5} ergs cm^{-2} and 4×10^{-6} ergs cm^{-2} in the lower and higher energy ranges, respectively. The spectrum is clearly softer than that of the initial part of the burst.

IV. DISCUSSION

A search was made for reports of a nova or supernova within a reasonable time ($\sim$ several weeks) of each gamma-ray burst. No reported novae were related in time or direction to any of the bursts. Only two reported supernovae reached maximum apparent magnitude within a few days of an observed burst. In both cases, however, reports of prediscovery observations were later made which preceded the gamma-ray burst by at least several days. In addition, the source positions derived from preliminary timing data are inconsistent with the locations of the supernovae.

The lack of correlation between gamma-ray bursts and reported supernovae does not conclusively argue against such an association, since it is possible that there are supernovae, not necessarily bright in the optical region ("theoreticians' supernovae"), whose rate of occurrence may exceed those which are optically visible (see, e.g., Thorne 1969). A source at a distance of 1 Mpc would need to emit $\sim 10^{46}$ ergs in the form of electromagnetic radiation between 0.2 and 1.5 MeV in order to produce the level of response observed here. Since this represents only a small fraction ($< 10^{-3}$) of the energy usually associated with supernovae, the energy observed is not inconsistent with a supernova as a source.

The authors wish to acknowledge the interest shown in the past by Edward Teller, Stirling Colgate, and A. G. W. Cameron who have on a number of occasions encouraged us to look for bursts of energetic photons.

We also wish to thank J. H. Coon and all of our colleagues in the Space Science Group at Los Alamos who have helped with this work. The detector electronics were the responsibility of the Space Electronics section at Los Alamos, under the direction of J. P. Glore. Logics were developed by the Satellite Systems Division at Sandia Laboratories; in particular we wish to mention R. E. Spalding, G. J. Dodrill, and J. G. Mitchell.

This research was performed as part of the Vela Satellite Program, which is jointly sponsored by the U.S. Department of Defense and the U.S. Atomic Energy Commission. The program is managed by the U.S. Air Force, and satellite operation activities are under the jurisdiction of the Air Force Satellite Control Facility, Sunnyvale, California.

REFERENCES

Colgate, S. A. 1968, *Canadian J. Phys.*, **46**, S476.

Thorne, K. S. 1969, in *Supernovae and Their Remnants*, ed. Peter J. Brancazio and A. G. W. Cameron (New York: Gordon & Breach).