PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A
MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

Do $\gamma $-ray Bursts Contain $\gamma $-rays of Energies above 1 GeV?

P. N. Bhat, N. V. Gopalakrishnan, S. K. Gupta, P. V. Ramana Murthy, B. V. Sreekantan and S. C. Tonwar

Phil. Trans. R. Soc. Lond. A 1981 **301**, 659-660
doi: 10.1098/rsta.1981.0147

Phil. Trans. R. Soc. Lond. A **301**, 659–660 (1981)
Printed in Great Britain

Do γ-ray bursts contain γ-rays of energies above 1 GeV?

By P. N. Bhat, N. V. Gopalakrishnan, S. K. Gupta, P. V. Ramana Murthy, B. V. Sreekantan and S. C. Tonwar
Tata Institute of Fundamental Research, Homi Bhabha Road, Bombay 400005, *India*

A ground-based experiment to detect gamma-ray bursts (g.r.b.) at gigaelectronvolt energies is being made at a depth of 800 g cm^{-2} in the atmosphere at Ootacamund, India. During the 1.2 years of operation of the experiment, the various satellite-borne experiments have reported observing tens of g.r.b. at megaelectronvolt energies. Of these, the source locations and times of occurrence for five g.r.b. were such that they were potentially observable in our experiment, had they contained γ-rays at gigaelectronvolt energies. None was seen. The details of the experiment and the implications of the result are presented.

Observations on gamma-ray bursts (g.r.b.) have so far been confined to γ-rays with energies of less than a few megaelectronvolts (see, for example, Klebesadel *et al.* (1973), Klebesadel & Strong (1976), Cline & Desai (1976) and Hurley (1980)). While theoretically there is as yet no consensus on their origin, the experimental question of whether there are γ-rays of gigaelectronvolt energies in g.r.b. remains unanswered; for the g.r.b. detectors in the past were not equipped to measure such high energies.

Gamma-rays incident on the top of the atmosphere initiate electromagnetic cascades in the atmosphere producing many low energy γ-rays which can penetrate to mountain altitudes with a non-negligible probability. Monte-Carlo simulations by Tonwar (1980, private communication) reveal that, for example, a 5 GeV photon incident on top of the atmosphere would yield about 0.02 photons of energy above 1 MeV at mountain altitudes. An intense burst of 5 GeV γ-rays of order 10 m^{-2} at the top of the atmosphere would, therefore, result in a corresponding burst of low energy (*ca.* 1 MeV) γ-rays at mountain altitudes with densities of order 1 m^{-2}. Detection of a burst of megaelectronvolt γ-rays at mountain altitudes then implies the incidence of a g.r.b. with gigaelectronvolt energies on the top of the atmosphere. Based on this approach we have designed a ground-based experiment to detect g.r.b. at gigaelectronvolt energies and operated it for 1.2 years at Ootacamund, India (800 g cm^{-2} deep in the atmosphere). Details of the experiment have been published elsewhere (Gopalakrishnan *et al.* 1980). Briefly, it consists of four liquid scintillators (each 1 m^2 × 20 cm deep) located at the four corners of a rectangle of side 11 m. Electronics circuitry is so adjusted as to make the output of each scintillator correspond most probably to the incidence and interaction of a low energy γ-ray. The outputs from the four scintillators are put in coincidence. The coincidence-resolving time, which was varied during the experiment, was either 10 μs or 100 μs. If a burst (micropulse) of γ-rays of gigaelectronvolt energies is incident on the top of the atmosphere, it would lead to a fourfold coincidence between the four scintillators. The background coincidences are due to weak cosmic-ray air showers in which low energy γ-rays outnumber the electrons. The coincidence rate was either 3 h^{-1} (when τ = 10 μs) or 64 h^{-1} (τ = 100 μs). If the coincidences occur in a rapid sequence with inter-event intervals of less than 10 or 100 ms, then this would be the signature of a g.r.b. with gigaelectronvolt energies; for the probability of the average counting rate fluctuating to produce the rapid sequence of events is negligible. We did not observe even a single case in which three or more fourfold coincidences occurred in a rapid sequence.

During the period of our observations, a large number of g.r.b. were detected at megaelectronvolt energies by satellite-borne detectors (see, for example, Hurley 1980 and Mazets & Golenetskii 1979), for some of which the source directions, besides the time of occurrence, are available. The source directions and event times for six of these are such that they were potentially detectable by us, should the γ-ray spectrum extend to gigaelectronvolt energies. Some details of the six low-energy g.r.b. are given in table 1. As seen from the table, our experiment was off on one occasion and on for the remaining five. We did not, however, record any of them even within a time window of ± 20 minutes around the reported times. The sensitivity of our experiment in terms of energy flux of g.r.b. is *ca.* 3×10^{-4} erg† cm^{-2} in the form of γ-rays with energies above 1 GeV. The sensitivity in terms of energy flux of g.r.b. integrated over the entire γ-ray energy spectrum depends obviously on the spectral index; for example, detection of g.r.b. with three or more coincidences in our system implies that the energy flux in the g.r.b. at $E_\gamma \geqslant 100$ keV is greater than 1.3×10^{-3}, 3.0×10^{-2} and 8.5×10^{-2} erg cm^{-2} for a spectral index in the differential γ-ray spectrum of -2.2, -2.5 and -2.6 respectively.

Table 1

serial no.	date	event time (U.T.C.) h	min	s	right ascension h	min	declination deg	reference
1	29 Oct. 1977	11	41	21	22	02	+17	Hurley (1980)
2	14 Sep. 1978	11	42	46	16	40	−3.1	Mazets & Golenetskii (1979)
3	24 Nov. 1978†	03	53	51	12	00	+20.9	Mazets & Golenetskii (1979)
4	1 Jan. 1979	00	07	20	11	52	+20.5	Mazets & Golenetskii (1979)
5	25 Mar. 1979	01	58	14	19	01	+14.5	Mazets & Golenetskii (1979)
6	2 Apr. 1979	01	27	07	19	27	−7.3	Mazets & Golenetskii (1979)

† Our experiment was off at this time.

We conclude from our observations that either

(*a*) there are no γ-rays at gigaelectronvolt energies in the γ-ray bursts detected at megaelectronvolt energies, or

(*b*) if the gigaelectronvolt γ-rays are indeed present, the micro-pulsations (10–100 μs in duration) needed for their detection are absent, or

(*c*) if the gigaelectronvolt γ-rays and micropulsations do both exist in γ-ray bursts, the differential energy spectrum must be steeper than $E^{-2.5}$ in the range $0.1 \leqslant E_\gamma \leqslant 5$ GeV.

It is a pleasure to thank Messrs A. R. Apte, J. A. Joshi, S. Ramani and S. Y. Tandale for their technical help.

References (Bhat *et al.*)

Cline, T. L. & Desai, U. D. 1976 *Astrophys. Space Sci.* **42**, 17.

Gopalakrishnan, N. V., Gupta, S. K., Ramana Murthy, P. V. & Tonwar, S. C. 1980 *Nucl. Instrum. Meth.* **175**, 555–559.

Hurley, K. 1980 *Non-solar gamma-rays.* Also (Cospar Symp.) *Adv. Space Explor.* **7**, 123–139.

Klebesadel, R. W., Strong, I. B. & Olson, R. A. 1973 *Astrophys. J.* **182**, L 85.

Klebesadel, R. W. & Strong, I. B. 1976 *Astrophys. Space Sci.* **42**, 3.

Mazets, E. P. & Golenetskii, S. V. 1979 A. F. Ioffe Physico-Technical Institute (Acad. Sci. U.S.S.R.) Preprint no. 632.

---

† 1 erg = 10^{-7} J.