Astron. Astrophys. 322, 778–784 (1997)

ASTRONOMY AND ASTROPHYSICS

Recent gamma-ray burst observations from the SROSS-C2 satellite

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Received 7 August 1995 / Accepted 18 November 1995

Abstract. An experiment to monitor celestial gamma ray bursts (GRBs) in the energy domain 20 keV–3 MeV was launched onboard the SROSS-C2 satellite on 4 May 1994. The experiment is currently operational in space and has recorded twelve candidate events as on 15 February 1995. Ten of these have been confirmed as genuine gamma ray bursts by their near-simultaneous detection by other GRB experiments in interplanetary space. The scientific objectives of the GRB payload on SROSS-C2, its in-flight performance and preliminary analysis of some of the candidate events are presented and discussed in this paper.

Key words: space vehicles – gamma rays: bursts

1. Introduction

Cosmic gamma ray bursts (GRBs), first reported by Klebesadel et al. (1973) remain an unsolved puzzle in high energy astrophysics, even twenty-two years after their discovery. These transient events may have durations ranging from a few milliseconds to several hundreds of seconds. Despite deep searches to identify their counterparts at other wavelength windows of the electromagnetic spectrum (such as radio, IR, optical and X-ray), the gamma ray burst sources have so far not been identified with any known population of objects in the universe. Because of this reason, the distances to the sources and the total energy involved in the emission process have not been established. Reviews on GRBs by Hurley (1988) and Higdon & Lingenfelter (1990) and conference proceedings edited by Fishman et al. (1994) provide a critical assessment of the available data and their interpretation.

Currently, the gamma ray burst monitoring network includes the Compton Gamma Ray Observatory (CGRO) in a near Earth orbit, the Granat satellite in a highly eccentric orbit around the Earth, the Ulysses spacecraft which is about 1.3 AU from the Sun (around March 1995) in a solar polar orbit, and the WIND spacecraft heading for placement at the first Lagrangian point of the Earth-Sun system. The Burst and Transient Source Experiment (BATSE) on CGRO has been detecting about one burst per day and has therefore recorded over a thousand bursts as of date. The most astounding result from BATSE data is that the angular distribution of GRB sources is found to be isotropic, with no concentration towards the galactic plane, or in directions of any nearby galaxy or clusters of galaxies (see Meegan et al. 1994). In addition the integral brightness distribution of these sources shows a depletion of weaker bursts with respect to the expected $-3/2$ power law. This would indicate that the spatial distribution of the sources, in addition to being isotropic, is also confined. These findings have important consequences to our understanding of the nature of GRB sources, their distances and energetics. They have led to extensions, revisions and/or new hypotheses of galactic, extragalactic and cosmological models.

CGRO and Granat have independent capabilities for localising bursts to an accuracy of few degrees. This accuracy is however too coarse to enable identification of the counterparts at other wavelengths. Better accuracies of source localisation can be obtained by the well known triangulation technique. In this method, arrival times of the event at four or more widely separated spacecrafts are used to constrain the location of the source in the celestial sphere. The larger the number of GRB detectors in space detecting the same burst and longer the distance (baseline) between detectors, the better the accuracy of source localisation by this method. Furthermore, for any detector (like BATSE) in near earth orbit, at any given time, nearly 34% of the sky is occulted by the earth and hence in order to have a complete sky coverage at all times, it is necessary to have more than one GRB instrument in near earth space. The GRB experiment flown onboard the Indian satellite SROSS-C2 is expected to fulfill this function.

The primary scientific objectives of the GRB experiment onboard SROSS-C2 are:

(i) monitor GRBs in the energy range 20 keV–3 MeV
(ii) determine the intensity variation with high time resolution (2 ms at the peak of the burst) and search for periodicities in the emitted radiation
(iii) determine the energy spectrum and its evolution during the burst
(iv) derive data on solar hard X-ray bursts and
(v) measure gamma ray background as a function of latitude and longitude in near earth space.

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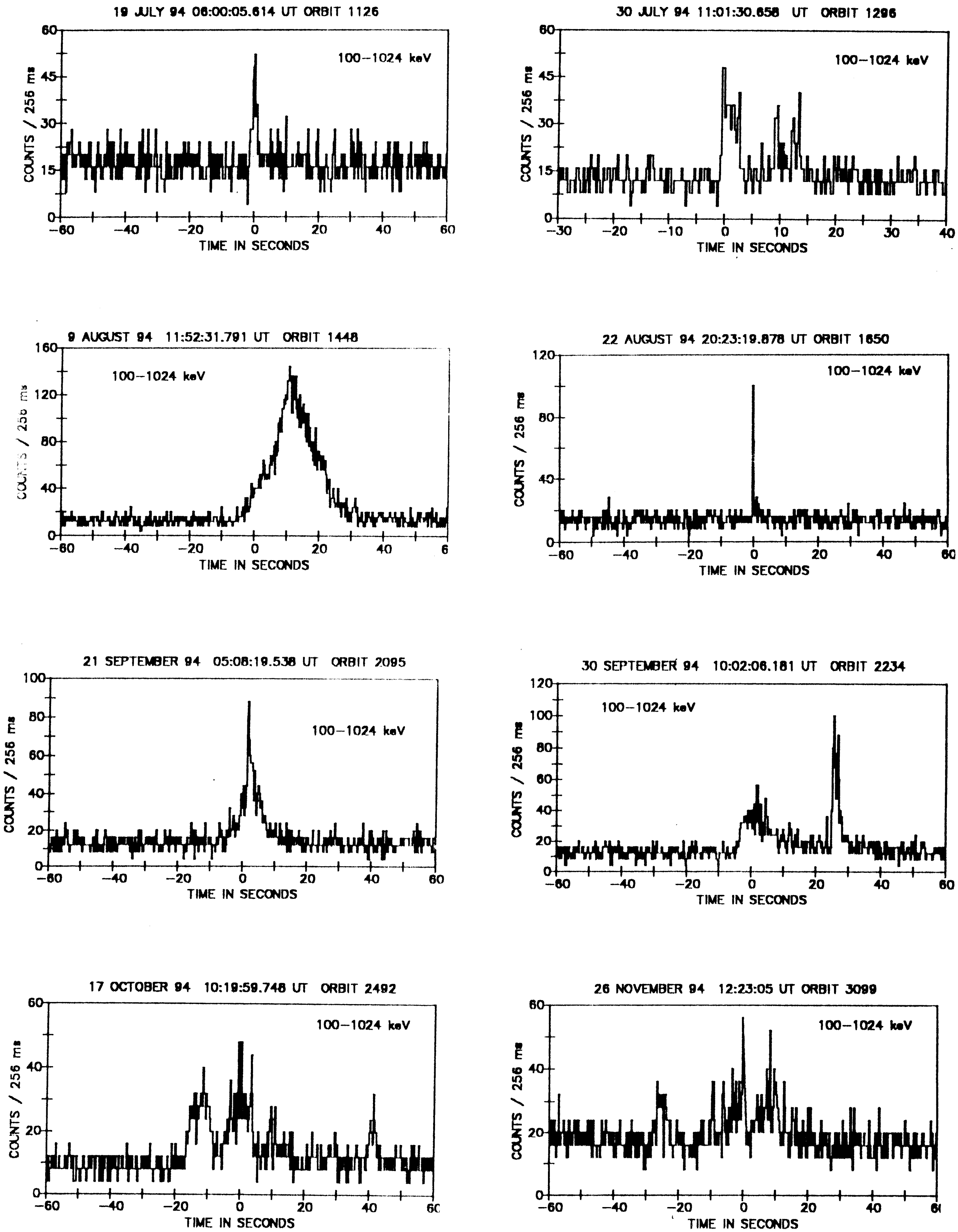
19 JULY 94 06:00:05.614 UT ORBIT 1126
100–1024 keV
COUNTS / 256 ms
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30 JULY 94 11:01:30.658 UT ORBIT 1296
100–1024 keV
COUNTS / 256 ms
TIME IN SECONDS
9 AUGUST 94 11:52:31.791 UT ORBIT 1448
100–1024 keV
TIME IN SECONDS
22 AUGUST 94 20:23:19.878 UT ORBIT 1650
100–1024 keV
COUNTS / 256 ms
TIME IN SECONDS
21 SEPTEMBER 94 05:08:19.538 UT ORBIT 2095
100–1024 keV
COUNTS / 256 ms
TIME IN SECONDS
30 SEPTEMBER 94 10:02:06.181 UT ORBIT 2234
100–1024 keV
COUNTS / 256 ms
TIME IN SECONDS
17 OCTOBER 94 10:19:59.746 UT ORBIT 2492
100–1024 keV
COUNTS / 256 ms
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26 NOVEMBER 94 12:23:05 UT ORBIT 3099
100–1024 keV
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Fig. 1a.

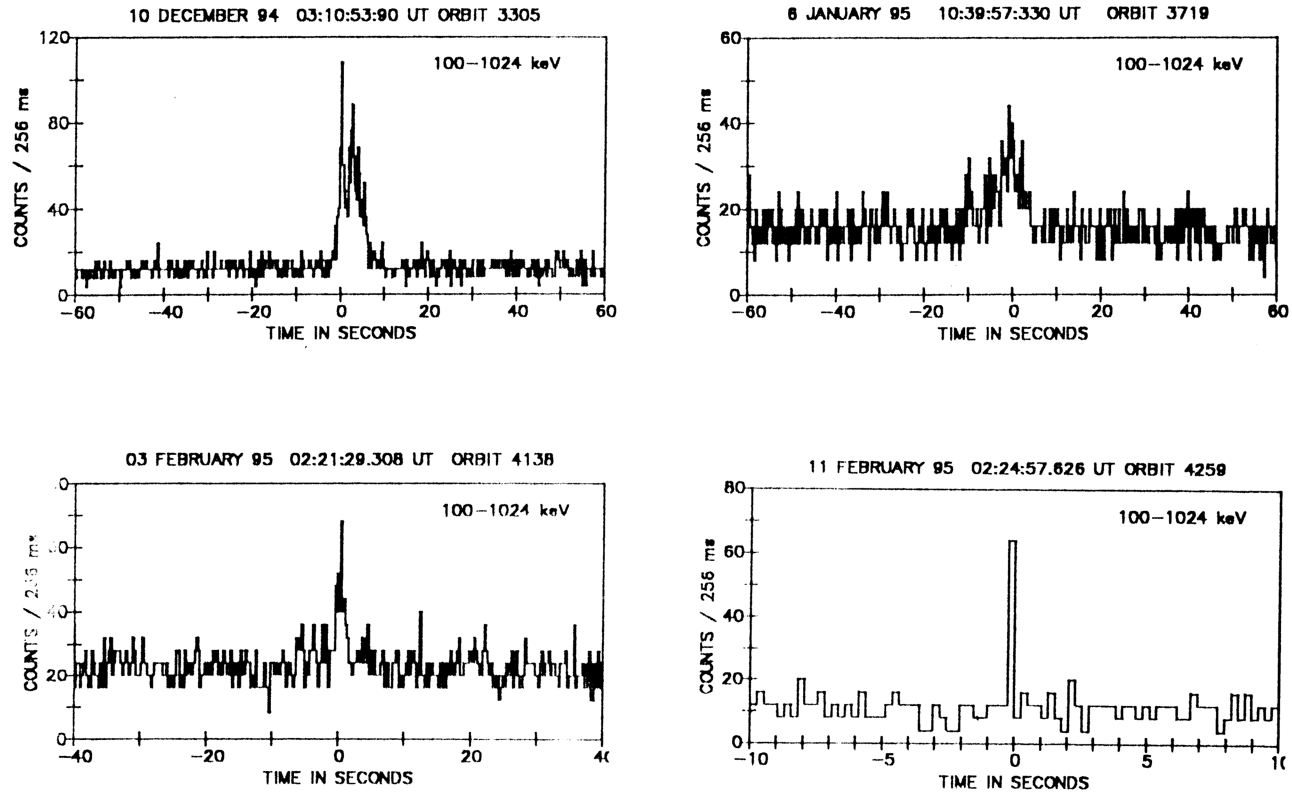

Fig. 1a and b. Mosaic of the time histories of SROSS-C2 GRB candidate events plotted in the energy range 100–1024 keV. (The profiles are very similar in the lower energy band of 20–100 keV and hence not displayed.) Note that the ordinate of GRB 950211 alone is in counts per 8 ms

Highlights of the instrumentation used and some early results obtained upto 15 Feb 1995 are presented in this paper.

2. The SROSS-C2 GRB payload

The Stretched Rohini Satellite Series-C2 (SROSS- C2) carrying the GRB payload was launched on 4 May 1994 using the Indian Augmented Satellite Launch Vehicle (ASLV-D4). The spin stabilised SROSS-C2 satellite is presently operating in a 420 $\times$ 620 km orbit with an inclination of 46°.

The gamma ray burst experiment on SROSS-C2 consists of a Cs I(Na) scintillation crystal with a diameter of 76 mm and thickness of 12.5 mm, optically coupled to a 76 mm diameter EMI 9758NA photomultiplier tube. An RCA 1802 microprocessor based electronics system controls, stores, and processes the output from the detector. The payload is designed to operate in either calibration/background mapping mode or in burst detection mode.

The data recorded in background mode consists of spectral data over the energy band 20 keV–3 MeV and is integrated for 102.4 s each. The number of consecutive spectra recorded is commandable from 2 to 96. Total duration of data collection can therefore span anywhere between 3 min to 2.7 hours. This enables the study of the radiation background in the detector for the SROSS-C2 orbit, as a function of satellite position – i.e., in terms of latitude, longitude and altitude. The experiment was initially set in background mode and an attempt was made to collect the background data spanning the complete latitude–longitude range.

After the initial background mapping the instrument was set to burst detection mode. The detection of a gamma ray burst is based on the 0.1–1 MeV counting rate exceeding a preset threshold value. Based on initial background measurement the threshold is set through command, to well over 6σ times the equatorial radiation background level. We have onboard two thresholds for comparing the count rate at every 256 ms and at every second. The two thresholds will not always have a ratio of 1:4. This is done in order to take into account statistical variation for different integration times and also to detect bursts of differing rise times. Whenever the incident count rate in the energy band 0.1–1 MeV from the detector exceeds either of the preset thresholds, an event trigger is detected, processed and stored. The time at which an event trigger occurs is stored as the time of burst, To.

Temporal data for the ensuing 204 s is stored with varying time resolutions of 2 ms from the time of burst To to To+1s, 16 ms from To+1s to To+8s and 256 ms from To+8s to To+204 s. In addition a circulating memory stores 2 ms resolution data for a duration of 1 second and 256 ms resolution data for a duration of 65 s prior to the burst. Spectra are stored every 0.512 s over the energy range 20 keV–3 MeV with varying energy resolution, the best being 4 keV/channel in the range 20–128 keV. The present experiment is an improved version of the GRB payload flown successfully on the SROSS-C satellite (see Marar et al. 1994 for details). The most important improvements are as follows:

1. An enhanced memory feature was designed in order to improve the duty cycle of the experiment in SROSS-C2 as compared to that of SROSS-C where only one burst data could be stored between two consecutive readouts. In the present experiment, after completion of processing of one event trigger, the instrument starts the burst search again. Onboard memory consists of two banks each capable of storing 7 triggers. After one bank is filled, the data is readout and the instrument is reinitialised with the second memory bank. This enables us to again readout the earlier data in the first memory bank in case of any link errors, without sacrificing the duty cycle of the burst search process. Data can however be readout during any visible pass even if the particular memory bank in which it is recorded is not completely full (i.e., if less than 7 bursts are stored). This new feature has resulted in an increase of effective ON-time from 40% in SROSS-C payload to 70% in the present experiment

2. The second improvement over the earlier SROSS-C experiment is related to the measurement of background spectra at the end of a burst event. In order to achieve this two spectra each integrated for 8 seconds are stored from 188 s to 204 s after the recording of event trigger.

An onboard Cd^{109} radioactive source (88 keV) serves the purpose of energy calibration in orbit. Spectral measurements in orbit indicate that the gain change of the instrument in space is less than 5% as compared to the calibration done on ground.

3. Observations and results

3.1. Background measurements

The background mode operations were carried out for a period of 10 days starting from 12 May 1994 upto 22 May 1994 in order to ascertain the variation of counting rate with latitude, longitude and altitude. The background measurements were repeated in orbit 999/1000 (10 July 1994) and in orbits 3493/3494 (22 Dec 1994). Count rates measured at nearly same locations in different orbits are very consistent. The average counting rate in the 0.1–1 MeV and 1–3 MeV energy bands are $\sim 45 \pm 5$ c/s and $\sim 14 \pm 3$ c/s within $\pm 25°$ of the equator. The onboard trigger thresholds were set based on the above measurements after some initial trials. The present value of the 256 ms threshold is 52 counts, and the 1024 ms threshold is 144 counts.

3.2. Burst observations

Event triggers may be caused by genuine gamma ray bursts or they may be false triggers caused due to charged particles which satisfy the onboard threshold criteria.

False triggering is a common phenomemon encountered in all GRB detectors. Further, in our experiment, due to the absence of an anticoincidence shield, there exists no means of differentiating between charged particles and gamma ray events as long as the total energy deposited in the crystal lies between

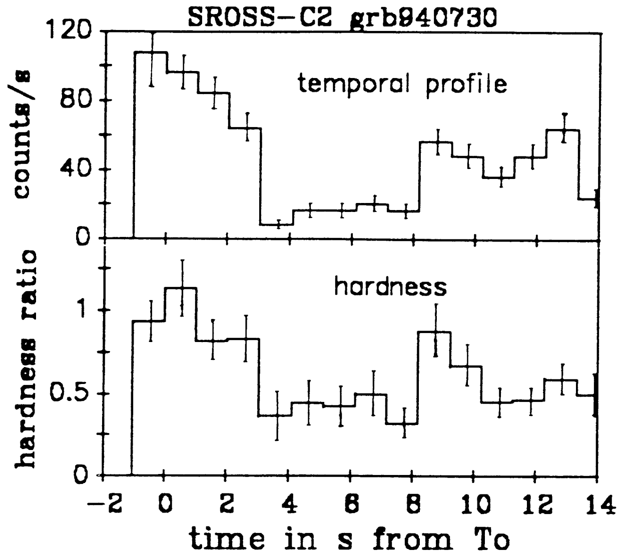

Fig. 2. A plot of the evolution of hardness ratio of the event GRB940730 as a function of time. Top panel is an intensity profile for background subtracted counts in the energy range 100–1024 keV and bottom panel is the hardness plot for the ratio of counts in the band 100–1024 keV to that in the 20–100 keV

20 keV to 1024 keV. The inclination of the SROSS-C2 orbit being 46°, the GRB instrument will pass through some of the high latitude charged particle concentrations leading to false triggering. Based on the background data, the onboard thresholds have been optimised so as to keep the false triggering to a minimum and also to maximise the sensitivity to the detection of genuine gamma ray bursts.

We have used the following criteria to filter out a majority of the charged particle false triggers. A particle event is expected to have count rates increasing in a few tens of seconds leading to saturation. On the other hand, a GRB event will have typical rise times ranging from a few milliseconds to a few seconds with durations anywhere between a fraction of a second to a few hundred seconds, more typically tens of seconds. For inclusion as a candidate GRB event, we also demand that the preburst background rates be stable and consistent with the rates encountered at latitudes less than $\pm 30°$ of the equator and that the post-burst counting rates do return to the background levels. In this way, it is generally easy to reject a majority of the non-genuine events. The hard energy spectra of celestial GRBs and the expected limits on the fluences of the events can also be used for further filtering of candidate events.

Based on the above criteria we list in Table 1, twelve candidate events detected upto 15 February 1995, out of a total of 993 triggers.

Figures 1a and 1b give a mosaic of the temporal profiles of all these events in the energy band 100–1024 keV at a time resolution of 256 ms except GRB950211 which is plotted with an 8 ms resolution. The table gives the date and time in UT of the event trigger, and the latitude, longitude and altitude of the satellite at the time of detection of the event. In addition it provides for each of the events, the total duration of the event, peak count rate

Table 1. SROSS-C2 GRB candidates

Event date	Time (UT)	Satellite location			Peak count rate[a]	Duration of burst	Fluence[b]	Remarks[c]
		Lat	Long	Alt.				
	(h m s)	(°)	(°)	(km)	(c/s)	(s)	(erg cm^{-2} $\times 10^{-6}$)	
GRB 940719	06 00 06	34.2	−127.7	487	250	7	4.54	U
GRB 940730	11 01 31	27.8	−21.7	608	296	15	6.1	U,B[d]
GRB 940809	11 52 31	21.5	−105	517	2335	42	300	—
GRB 940822	20 23 20	39.8	148.6	547	310	0.45	—	U
GRB 940921	05 08 19	6.6	73.0	618	660	25	42	U
GRB 940930	10 02 06	22.8	93.1	500	545	40	48	U
GRB 941017	10 20 00	19.4	−153.7	501	375	63	44	U
GRB 941126	12 23 05	46.0	−10.1	512	390	52	58	U,B,W
GRB 941210	03 10 54	−2.7	141.7	469	540	14	19	U
GRB 950106	10 39 57	44.9	143.4	510	337	23	16	—
GRB 950203	02 21 29	46.1	83.1	507	465	15	20.4	U
GRB 950211	02 24 58	−3.4	121.6	441	226	0.128	—	U

[a] The contribution due to onboard calibration source which is 50c/s is subtracted from the peak count rate.
[b] The fluence for the shortest bursts are not listed as the estimates are not reliable due to spectral duration exceeding the burst duration.
[c] Confirmed by U-Ulysses, B-BATSE, W-Wind (K. Hurley , private communication).
[d] Confirmed by B - BATSE (G.Fishman, private communication). GB 940730 was not a trigger on BATSE since the trigger logic was disabled to avoid false triggering during passage through the Australian coast. It was however detected in the continuous 1 s low resolution data stream.

in the energy range 20–1024 keV, fluence in the energy range 20–330 keV and the status on confirmation of the event by its detection by other spacecrafts in the interplanetary network. In order to confirm an event as a genuine GRB event, its time of occurrence, temporal profile, duration, normalised count rates and hardness as measured on different satellites have to match with one another. With the estimated 3σ sensitivity for detection of bursts with fluence greater than 5×10^{-6} erg cm^{-2}, we expect to detect about 18 celestial bursts per year. The observed event rate using our experiment for 8 months of observing time is therefore consistent with the above estimate.

We note that out of a total of 12 listed events, two have durations less than 1 s. Kouveliotou et al. (1994) have found that the GRBs observed using BATSE follow a bimodal distribution of durations, consisting of short events less than 2 s with hard spectra, and long events having durations greater than 2 s with softer spectra. The short events form about 26% of the total BATSE data base. It may be noted that our observation of two short events out of 12 events indicates that the trend of bimodal distribution in our small data is not inconsistent with BATSE database. Amongst the long duration bursts a majority display multiple peaks and one of the events (GRB941126) detected by SROSS-C2, CGRO, Ulysses and WIND spacecrafts has a complex temporal structure.

An important characteristic of GRB events is that the spectrum generally evolves with time with a tendency towards softening of the spectrum in the later phase of the burst as compared to the initial phase. This evolution can also be studied by measuring the variation of hardness ratio of counts in the energy range 100–1000 keV as compared to that in the range 20–100 keV. We therefore attempted to study the variation of hardness ratio in the burst GRB940730 which was also detected by BATSE and Ulysses. Figure 2 shows the temporal profile of the event in the energy range 100–1024 keV (top panel) and the evolution of the hardness ratio (bottom panel), both plotted with a time resolution of 1 s. It shows that the intensity and spectral hardness are correlated. This relation, a feature of many GRBs, was first noticed by Mazets et al. (1983). It can be seen from Fig. 2 that the hardness ratio of the first pulse is higher than that of the second pulse indicative of the first pulse having a harder spectrum. In order to verify this we computed the energy loss spectrum of this event using the onboard spectral data. Figure 3 shows the spectra in the range 35–300 keV for the first and second pulses. A power law fit to the two data sets shows that the energy power law index of the spectrum varies from -1.48 ± 0.1 to -2.36 ± 0.1 clearly indicating that the spectrum has softened as the burst progressed. In other words, the change in hardness ratio in the second pulse as compared to that of the first pulse is not an effect of absorption of continuum photons of energy less than 100 keV but is due to spectral softening. These results are consistent with similar observations made from BATSE data (Bhat et al. 1994; Norris 1986).

The trigger GRB940809 is a long duration symmetric event lasting 42 s. The Ulysses spacecraft detected a rate increase in their instrument eventhough not a trigger. The event has a high peak count rate but most of the photons are in the low energy range of 20–100 keV. The hardness ratio is constant (0.25) over the complete duration of the event. This trigger is unlikely to be a genuine GRB event but it could well be a short solar burst.

We notice from Table 1 that most of the events detected by SROSS-C2 are confirmed by Ulysses spacecraft. This is because the Ulysses spacecraft is placed in a solar polar orbit with a per-

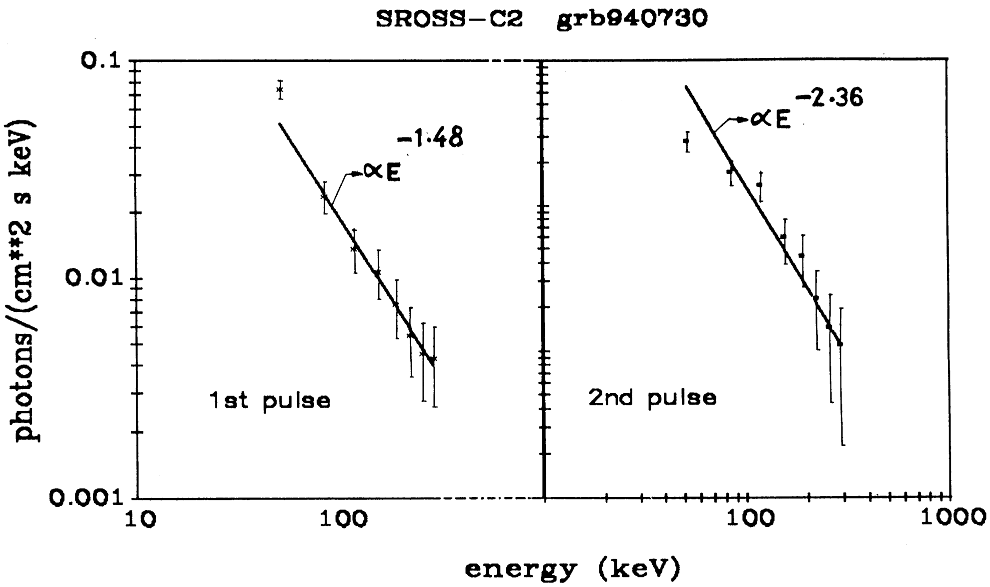

Fig. 3. Energy loss spectra of the first and second pulses of GRB940730, showing softening of the spectrum as the burst progressed

ihelion of 1.3 AU and hence no significant portion of the sky is occulted by any planetary body near it. For satellites like CGRO and SROSS-C2 which are in a low earth orbit, earth occultation of sky and loss of observation time due to passages through high latitudes, SAA etc are inevitable. Eventhough CGRO has an omnidirectional response, nearly 34% of the sky is occulted by the earth at any given instant and about 15% data loss occurs in observation time due to high latitude/SAA passages. The corresponding numbers for SROSS-C2 satellite are 34% and 30% respectively. Thus non-detection of SROSS-C2 events by CGRO and confirmation of most of the SROSS-C2 events by Ulysses are to be expected. The timing of events detected by SROSS-C2 can therefore be used for triangulation for localisation of GRB sources along with timing from Ulysses, particularly for events not detected by BATSE. Since triangulation calculations require data on satellite ephemeris, its orbit etc., we are in the process of co-ordinating with various groups for this purpose. We therefore expect that in future the GRB experiment on SROSS-C2 with a predicted mission life of about 5 years will contribute significantly towards the localisation of several interesting and unique events in future.

4. Conclusions

The GRB payload on the SROSS-C2 satellite has been functioning very satisfactorily, and its performance in orbit conforms to the design specifications. As of 15 February 1995, we have listed 12 candidate events, of which 10 have been confirmed as genuine GRBs by their detection by other satellites in interplanetary space. We therefore have confidence in our ability to isolate most of the genuine events from the vast ocean of false triggers.

(a) The number of genuine events detected so far is consistent with the estimated sensitivity of the instrument.

(b) The observed events have a variety of temporal profiles exhibiting varying degrees of complexities.

(c) A bimodal distribution of event durations is already beginning to emerge in our albeit small data base.

(d) We observe variation in hardness ratio and a spectral softening in the energy range 35–300 keV for the event GRB940730. This event was also detected by both BATSE and Ulysses.

With SROSS-C2 expected to remain in orbit for about 5 years, the GRB experiment can now join the interplanetary network of GRB detectors for triangulation and localisation of several events. We therefore hope that this experiment may also play an important role in solving the GRB puzzle in the not-too- distant future.

Acknowledgements. The authors wish to express their sincere gratitude to Dr Kevin Hurley, Principal Investigator, Ulysses GRB experiment for his continued support in communicating to us confirmation of SROSS-C2 GRB candidates by other spacecraft experiments. They also thank Dr TMK Marar for his many contributions and the referee for his extremely useful suggestions for the paper. Thanks are due to Ms Padma for secretarial assistance in the preparation of this paper.

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