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SROSS C-2 Detections of Gamma Ray Bursts and the SGR 1627-41

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Abstract. The GRB monitor (GRBM) on board the Indian SROSS C-2 satellite has detected 53 classical gamma ray bursts since its launch in May, 1994 till its re-entry in July, 2001. For a subset of 26 events, locations were obtained from simultaneous observations by other gamma-ray detectors in space. The sky distribution of these 26 SROSS C-2 bursts is consistent with isotropy. The distribution of event durations shows evidence for bimodality. There is an evidence for a moderate hardness ratio-intensity (HIC) correlation in the data. The SROSS C-2 GRBM has also detected three episodes of emission from the SGR 1627-41.

Key words. Gamma Ray Bursts—SGRs.

1. Introduction

The primary focus of gamma-ray burst research in the 80s and early 90s was to determine the sky distribution of the GRBs along with source localisations of sufficient accuracy (less than one arc minute) to permit observations at other frequencies. Given the poor angular resolutions of gamma-ray burst detectors and wide field-of-view, the objective was to obtain as many independent gamma-ray detections as possible, using many widely-spaced observing platforms in space. Such near-simultaneous observations of events with accurate arrival times permit event triangulation leading to a significantly smaller error box on the sky. After the discovery of X-ray afterglows from GRBs by the Italian-Dutch BeppoSax satellite in 1997 that provided accurate source positions and follow-up optical spectroscopy by large optical telescopes such as the 10-m KECK telescope, the extreme distances to these objects (billions of light years) and hence the enormous luminosity in gamma rays was convincingly demonstrated.

It is in the pre-1997 context that experiments to monitor gamma ray bursts were placed onboard the Stretched Rohini Series Satellites (SROSS). The most successful of these was onboard the SROSS C-2 satellite launched on May 4th, 1994 (Kasturirangan *et al.* 1997). The primary goals of this experiment included:

- detection of GRBs in the 20 keV to 3 MeV energy range,
- determination of intensity variation with high time-resolution (2 ms during the peak),
- providing arrival time information, and
- deriving the energy distribution of the GRB photons.

The GRB detector on SROSS C-2 has detected 56 events in total, the latest being GRB010611 at 79568.2 UT on June 11th, 2001 before the mission ended with an atmospheric re-entry in July, 2001.

2. Instrument capabilities

The details of the instrument are described elsewhere (Kasturirangan *et al.* 1997). The SROSS C-2 GRB monitor consists of a single CsI(Na) crystal (76 mm in diameter, 12.7 mm thick) viewed by a 76 mm diameter photomultiplier tube. The pulse height spectra (107 channels) are available between 20 keV and 3 MeV with varying energy resolution—the best being 4 keV per channel. The GRB time-histories are recorded between -65.536 sec and 204.8 sec of the GRB trigger, the integration time being 256 ms for the two broadband energy channels, viz., channel 1 (20–100 keV) and channel 2 (100–1024 keV). In addition, high resolution (2 ms) GRB time-history is available during T0-1.024 sec to T0+1.024 sec and with a slightly worse time resolution (16 ms) during T0+1.024 sec to T0+8 sec in the 20–1024 keV channel (channel 1 plus channel 2). The GRB time-history is also recorded in the 1.024-3 MeV channel (channel 3) during T0-2.048 sec to T0+204.8 sec. The integration time for the channel 3 data is 512 ms. The pre-trigger data are obtained using a circulating memory. A maximum of seven events may be stored on board before the next read-out. The SROSS C-2 GRB trigger is generated by the SROSS C-2 on board software if the detector counting rate exceeds either of two preset thresholds- the integration times for these being 256 ms and 1024 ms respectively. The detector has no anti-coincidence shield and hence has a relatively large background and large number of false (charged particle induced) triggers are recorded. Also, the duty cycle of the experiment is low due to earth occultation, passage through SAA and high latitude regions.

The GRB event trigger times are derived from the satellite house-keeping telemetry clock which is based on a 128 kHz crystal oscillator. This clock has a drift rate of 274 ± 44 ms (one sigma) per day. This on board clock is calibrated (usually once a day) using a ground-based atomic clock.

3. Data analysis

Candidate events were selected purely on the basis of their temporal characteristics, viz. their short durations, fast variability and the nature of the background before and after the trigger from a very large number ($\sim 10,000$) of triggers. After careful selection, the event parameters and their errors are determined using the temporal and spectral data.

Maximum amount of data have been used in order to calculate an accurate detector background. This is done by removing the BURST portion in the GRB time history, since quite often the real burst is of very short duration. The GRB duration (T_{90}) is calculated using an algorithm that detects the onset and disappearance of the burst precisely by successively higher time integration of the burst signal and when a consistent value for this parameter is achieved. For the peak hardness ratio calculation, a similar approach is used. The minimum S/N ratio in both channel 1 and channel 2 has to be equal to or greater than 5. The peak hardness ratio is defined as the hardness ratio when the signal peaks in the 2nd (triggering) channel (100–1024 keV). The GRB fluences in the three energy channels are calculated using successive spectral and temporal integration. Several systematic errors including the variable drift of the on board clock have been taken into account to arrive at accurate (few ms uncertainty) trigger times for several GRBs.

4. Results

4.1 *Timing accuracy*

The SROSS C-2 on board clock has a large drift rate which is also highly variable. However, for a few GRB events it has become possible to correct for all the systematic and random errors and finally arrive at accurate (a few ms uncertainty) absolute event trigger times. Cross-correlations of these SROSS C-2 GRB time-histories with their corresponding BATSE and BeppoSax time-histories (K. Hurley, pvt. comm.) have given the following results:

Table 1.

GRB Name	SROSS C-2 trigger time and its uncertainty (3σ)secs (UT)	Time lag (secs)
981226	38758.844 ± 0.014	0.037 ± 0.074
990323	62914.103 ± 0.008	-0.002 ± 0.044
990424	11489.819 ± 0.018	-0.034 ± 0.350
010427	67390.912 ± 0.012	0.059 ± 0.174

The first three event time-histories were cross-correlated with their corresponding BATSE time-histories and the last one with its corresponding BeppoSax time-history. The maximum expected time lag between a SROSS C-2 event and the corresponding BATSE event is $\sim$ 45 ms. The absolute time inaccuracy for the second and third events are respectively -4 ms and -36 ms. The large uncertainties in the time lag is due to the poor S/N ratio of these events.

4.2 *Sky distribution*

The locations of 26 classical GRBs (22 of these were obtained from the BATSE 4B and BATSE current catalogs for SROSS C-2 GRBs that have near simultaneous BATSE triggers, 2 were obtained from GCN 763 and GCN 853 (Hurley *et al.* 2000) and another 2 also determined by the 3rd IPN (K. Hurley, pvt. comm.)) are plotted in galactic coordinates (Fig. 1). The distribution is consistent with isotropy.

4.3 *The T_{90} (duration) distribution: The 'tip of the iceberg effect'*

T_{90} is a measure of the duration of a GRB (the time interval during which the burst integrated counts increases from 5 % to 95 % of the total counts). The T_{90} distribution for 49 GRBs is shown in Fig. 2(a). Our data are consistent with the bimodality reported earlier (Kouveliotou *et al.* 1993). Since the SROSS C-2 GRB monitor does not possess any anti-coincidence shield, the detector background is much higher compared to a GRB detector that has an anti-coincidence shield. This essentially implies that the S/N ratio of a detected burst is much smaller than what it would be for a detector having an anti-coincidence shield. Due to this reason, our T_{90} values are systematically lower than the corresponding BATSE T_{90} values. Hence the well known dip (Kouveliotou *et al.* 1993) near 2 secs is shifted in our case to 0.4 seconds in the T_{90} axis.

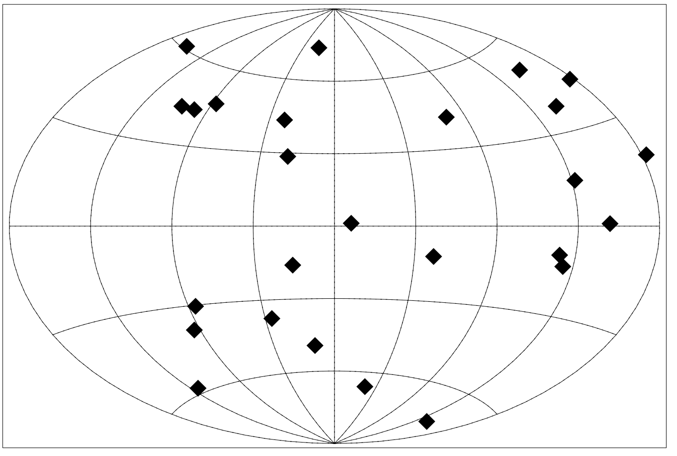

Figure 1. Sky distribution (Galactic coordinates) of 26 SROSS C-2 classical GRB events.

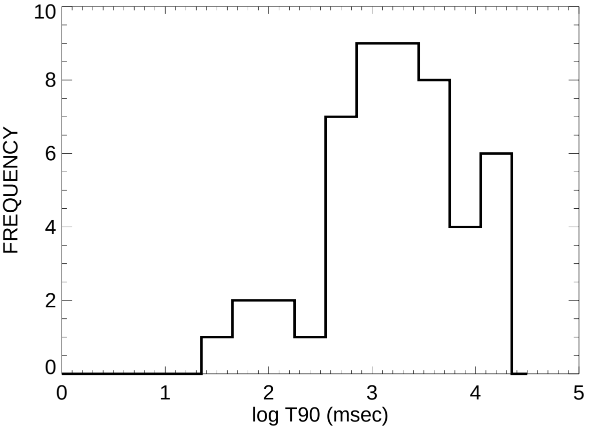

Figure 2(a). Duration distribution of 49 SROSS C-2 classical GRBs.

4.4 *The hardness ratio distribution*

The hardness ratio is defined as the ratio of detected counts in the 100–1024 keV energy band to that in the 20–100 keV energy band. The distribution of this parameter for 48 events observed by the SROSS C-2 GRBM is shown in Fig. 2(b). For the sake of comparison, the hardness ratio (similarly defined) distribution for the subset of 22 SROSS C-2 GRBs are shown (dotted histogram) that have near simultaneous BATSE events. The dotted histogram is normalised to have total number of events equal to 48. The hardness ratio distribution for the complete sample is essentially similar to that of the events that have common BATSE triggers. The calculated hardness ratios contain some systematic errors since for quite a few events the direction of arrival is not known.

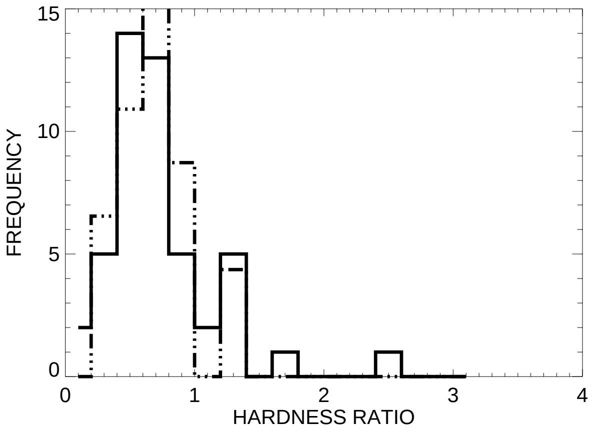

Figure 2(b). Hardness Ratio distribution of 48 SROSS C-2 GRBs (solid histogram). Hardness ratio distribution for 22 SROSS C-2 events having common BATSE triggers are also shown (dotted histogram, normalised to the same total number = 48).

4.5 *Correlations*

We have also studied correlations between different sets of parameters. The peak hardness ratio shows a moderate correlation (correlation coefficient 0.54, chance probability = 0.0028) with the peak counts in the channel two (100–1024 keV, triggering channel).

4.6 *SGR1627-41*

The SROSS C-2 GRBM has detected three episodes of emission from the SGR1627-41 on 18th June, 1998 at 6151.616 secs (UT) and at 14662.081 secs (UT) and also on 7th April, 2000 at 37496.804 secs (UT). These trigger times have small systematic errors. The durations of these outbursts from the SGR were respectively 970 ± 8 ms, 260 ± 8 ms and 1.6 ± 0.066 secs. Based on the known distance of SGR1627-41 (11 kpc) we derive the following values for the intrinsic luminosities of the source in gamma rays (assuming isotropic emission).

The peak luminosities (0.512 s) in the 20–150 keV band as observed by the SROSS C-2 GRBM for the three episodes are $6.3E39$, $2.2E40$ and $3.7E40$ ergs s^{-1} respectively. The peak luminosities (energy greater than 25 keV, $0.064s$) for 57 events observed by BATSE between 17th and 18th June, 2000 range between $1.0E39$ and $1.0E42$ ergs s^{-1} (Woods *et al.* 1999). Actually our luminosities are underestimated by factors that might be as large as twenty because of loss of signal due to the saturation of counters. Furthermore, the larger SROSS C-2 integration time ($0.512s$) compared to that of BATSE ($0.064s$) results in reduced estimates for the luminosities derived from our observations. Taking all these into consideration the luminosities derived by us agree very well with that derived by the BATSE experiment.

Based on the spectrum of the SGR derived by the BATSE group (Woods *et al.* 1999), we estimate a hardness ratio (as would be seen by the SROSS C-2 GRBM)

Table 2(a).

Episode	Peak flux (20-100) keV	(photons $cm^{-2}s^{-1}$) (100–150) keV	Fluence (20–100) keV	(ergs cm^{-2}) (100–150) keV
1	4.87	0.17	$0.36E-6$	$0.45E-7$
2	22.19	0.05	$0.20E-5$	$0.58E-7$
3	34.46	0.86	$0.33E-5$	$0.26E-6$

Table 2(b).

Episode	Peak luminosity (20–100) keV	(ergs s^{-1}) (100–150) keV	Integrated luminosity (20–100) keV	(ergs) (100–150) keV
1	$5.8E39$	$5.0E38$	$0.52E40$	$0.65E39$
2	$2.2E40$	$1.5E38$	$2.8E40$	$8.3E38$
3	$3.5E40$	$0.24E40$	$4.7E40$	$3.8E39$

to be 0.076 which also agrees well with the hardness ratios observed by the SROSS C-2 detector.

The 000407 event (episode 3 listed in Tables 2a and 2b) was not confirmed by any other spacecraft (K. Hurley, E. Mazets, pvt. comm.). The high time-resolution data resembles very much the flare from the SGR 1627-41 on 29th June, 1998 (BATSE trigger no. 6887) (Woods *et al.* 1999). The event time history has two peaks (T_{90} duration being 1.6 ± 0.066 sec). Also, during this trigger SGR 1627-41 makes the minimum space angle with the view axis of the GRBM (49.6 degrees) whereas the other known SGRs make much larger angles. From the data it is evident that the spectral hardness of the SGR emission decreases significantly (from 0.12 to 0.03) from the first episode to the second episode that has occurred only a few hours later. On the contrary, after nearly 22 months we notice that the photon spectrum has a spectral hardness that is intermediate (0.08) of the first two episodes. Fast Fourier Transforms of the high resolution (2 ms) data for the first two burst episodes of this SGR is consistent with the statistical noise in the data.

4.7 *Unconfirmed events*

The characteristics of five events are listed in Table 3. These were not confirmed by any other spacecrafts but their characteristics suggest that they are either GRBs or other high energy transients (e.g. hard X-ray transients).

Table 3.

Event name	Trigger time (TJD:sec)	Hardness ratio	Duration T_{90}(sec)
950106	9723:38397.586	0.86 ± 0.26	8.1 ± 0.11
980612	10976:74694.711	0.60 ± 0.12	0.97 ± 0.06
990119	11197:255.591	1.0 ± 0.28	0.011 ± 0.001
000131	11574:36286.907	0.73 ± 0.10	0.97 ± 0.02
010108	11917:10824.533	0.32 ± 0.05	1.6 ± 0.06

(TJD=JD-2440000.5).

5. Discussion and conclusion

Even though the clock used in our detector is not very accurate, it has become possible to arrive at accurate (few ms uncertainty) GRB trigger times for some events by applying corrections for several systematic errors including the highly variable drift of the clock. The accuracy of the derived trigger times have been established by cross-correlating SROSS C-2 event time histories with that of other spacecrafts.

The sky distribution of SROSS C-2 classical GRBs is consistent with isotropy.

Because of relatively larger detector background (absence of anti-coincidence shield), the SROSS C-2 T_{90} values for GRBs are systematically less than that of corresponding BATSE events. Hence the well-known dip in the 2 seconds region (Hurley *et al.* 2000) is shifted towards lower values (0.4 secs) in the T_{90} axis. The hardness ratio distribution of the SROSS C-2 global sample of GRBs agrees very well with that of those events having common BATSE triggers.

Also, we report detection of three flares from SGR 1627-41. The third flare has not been convincingly detected by any other spacecraft.

Finally, we may conclude that from this experiment many of the important results (derived from other satellites) on GRBs are verified using an independent sample of data though statistics are quite low because of limited sensitivity of the detector and limited duty cycle of this experiment.

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