Intermediate GRBs observed by various satellite experiments

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Abstract. Firstly GRB duration distribution was analyzed on data of BATSE experiment onboard the Compton Gamma Ray Observatory (CGRO) operated from April 1991 until to June 2000. Usually two GRBs groups separated in duration distribution: short and long. These types of events are classified due to analysis of duration of interval where integrated counts from the GRB raising from 5% to 95% (t_{90}). The value $t_{90} \sim 2$s is used as boundary between short and long events. However, in 1999 third burst subgroup (intermediate GRBs) was found due to GRBs duration and duration-hardness distributions analysis of 4B current BATSE catalogue (recently available as 5B one) in time interval of 0.8 s $\leq t_{90} \leq$ 50 s. Since CGRO operation has finished, two satellite experiments GRBs catalogues BAT/Swift and GBM/Fermi contain the amount of bursts comparable with 4B current BATSE catalogue and it is sufficient for duration distribution precision investigation. The results of these distributions analysis are discussed. It allows concluding the appearance of intermediate GRB subgroup on data of three experiments: BATSE/CGRO, BAT/Swift and GBM/Fermi.

1. GRBs registration in experiments BATSE/CGRO, BAT/Swift and GBM/Fermi

Gamma-ray bursts observations since 1967 [1] up to now contains several thousands of events listed in more than 30 catalogues – see, for example, [2-4]. GRBs properties vary in extremely large intervals. For instance, fluence (registered near the Earth) lies in the range 10^{-8} –10^{-3} erg/(cm^2×s) and bursts duration varies in the interval 10^{-2} –10^{3} s.

GRBs duration distribution was firstly analyzed using data of BATSE [5] (Burst and Transient Source Experiment) onboard the Compton Gamma Ray Observatory (CGRO). CGRO [6] was launched on April 5, 1991 and finished its functioning on June 4, 2000. BATSE registered events time profiles in four energy bands: 25 - 50 keV, 50 - 100 keV, 100 – 300 keV and > 300 keV. Two detector types were used for γ-emission registration - large area detectors (LAD) provide event temporal profile registration and spectroscopy detectors SD supply spectral analysis. The comparison of BATSE instrument characteristics with ones of presently operate BAT/Swift and GBM/Fermi experiments is presented in table 1.

Accordingly to BATSE data analysis, gamma-ray burst duration characterised by two parameters [5]: t_{90} and t_{50} are the times of accumulation for 90% and 50% of burst statistics (i.e. duration of intervals where the integrated counts from the GRB raise from 5% to 95% and for 25% to 75% correspondingly). Additional criterion of burst spectrum description was hardness H_{32}, introduced using this experiment data analysis results. It was defined as the ratio of fluence in third and second BATSE energy channels. The GRBs duration distribution analysis had shown the existence of two bursts classes: long (t_{90} more than 2 s) and short (t_{90} less than 2 s) [7]. Five GRBs catalogues were made due BATSE data analysis – see table 2.

GBM (Gamma-ray Burst Monitor – see, for example, [8]) installed onboard the Fermi Gamma-Ray Space Telescope [9], formerly GLAST was launched on June 11, 2008 and operates up to now. GBM includes 12 NaI based low-energy detectors for burst temporal profile registration and two high-energy ones made on BGO provide event spectra accumulation. Characteristics of NaI and BGO detectors of GBM instrument are similar to ones of BATSE LAD and SD combination but cover a wider energy range despite of they have smaller collection area – see table 1. Four GRB catalogues are published based on GBM data analysis – its specifications are listed in table 2.

Table 1. The comparison of detectors characteristics for BATSE/CGRO, BAT/Swift and GBM/Fermi experiments.

	BATSE [5]	**GBM [8]**	**BAT[10]**
Trigger formation threshold	~0.2 phot./cm^2/s	0.61 phot./cm^2/s	~4×10^{-2} phot./cm^2/s
	Large Area Detectors	Low-Energy Detectors	
Detector type	NaI	NaI	CdZnTe
Detectors amount	8	12	array of 4x4 mm^2 elements (256 modules of 128 elements/module)
Effective area	2025 cm^2	126 cm^2	5200 cm^2
thickness	1.27 cm	1.27 cm	2 mm
Energy band	20 keV - 2 MeV	8 keV to 2 MeV	15.0 - 150 keV
	Spectroscopy Detectors	High-Energy Detectors	
Detector type	NaI	BGO	
Detectors amount	8	2	
Effective area	126 cm^2	126 cm^2	
thickness	7.62 cm	12.7 cm	
Energy band	15 keV - 10 MeV	150 keV -40 MeV	

The Burst Alert Telescope (BAT) [10] is a highly sensitive coded aperture imaging instrument designed to provide GRBs observations with large field of view (1.4 steradian half coded) and 4-arcmin positions definition – see table 1. The energy range of registered photons is 15-150 keV for imaging mode and up to 500 keV with a non-coded response. It was installed onboard Swift satellite launched in November 2004 [10]. Three GRB catalogues are published due to BAT data analysis – see table 2.

The subgroup of intermediate GRBs was first found in 1999 [11] during 4B current BATSE catalogue analysis at 99% confidence level taking into account duration and duration-hardness distributions. Lately this catalogue was published as 5B one [12].

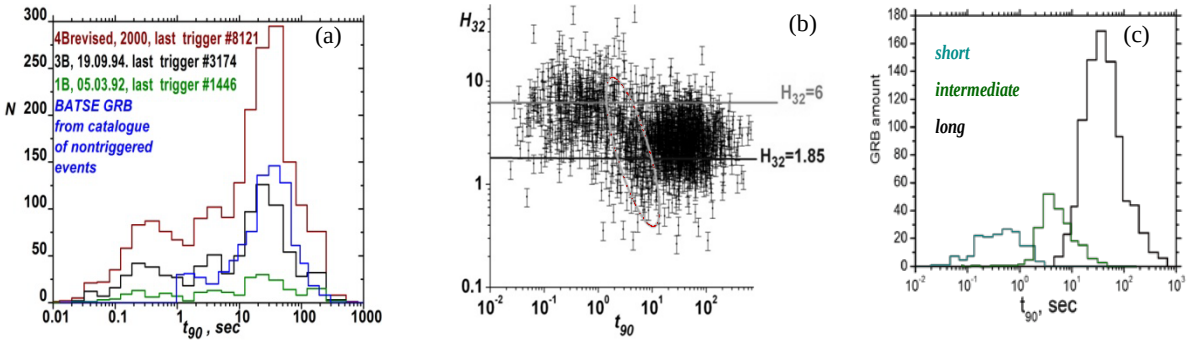

Figure 1. Intermediate GRBs subgroup appearance on BATSE data: (a) in duration distributions for 1B, 3B - 4B revised catalogues and its absence in non-triggered event catalogue; (b) in distribution on hardness and duration for 4B revised catalogue; (c) in duration distributions obtained after using mentioned in table 3 criteria.

Table 2. Integral amount of GRBs with defined t_{90} observed in experiments BATSE/CGRO, BAT/Swift and GBM/Fermi.

Experiment, energy band	**year (catalogue)**	**GRBs amount**
BATSE/CGRO	1991	192
20 keV-2.0 MeV	1B, 05.03.92 [5]	219
	1992	383
	2B, 09.03.93 [15]	436
	1993	629
	3B, 19.09.94 [16]	835
	1994	890
	1995	1082
	4B, 29.08.96 [12]	1235
	1996	1300
	1997	1544
	1998	1735
	1999	1955
	2000 4B revised	2049
	4B current (5B), last 2014 [13-14]	2056
BAT/Swift	2004	9
15.0 - 150 keV	2005	95
	2006	197
	The first SWIFT BAT Gamma-Ray Burst Catalog 4.09.2007	222
	2007	280
	2008	381
	2009	465
	2010	538
	The second SWIFT BAT Gamma-Ray Burst Catalog [17], 19.07.2011	458
	2011	613
	2012	698
	9 years Swift BAT Gamma-Ray Burst Catalogue [18] 01.10.2013	753
	2013	781
	2014	925
	2015	960
	November 2016 current catalogue [20]	1096
	September 2016 The Third Swift BAT GRB Catalogue [19]	1047
GBM/Fermi	2008	123
~8 keV ÷ ~ 30 MeV	2009	372
	2010	611
	2011	827
	The Fermi GBM Gamma-Ray Burst catalog: the first two years 01.03.2012 [21]	488
	2012	1046
	2013	1278
	The Second Fermi GBM Gamma-Ray Burst catalog: the first four years 06.01.2014 [22]	949
	2014	1520
	2015	1757
	April 2016 The Third Fermi GBM GRB Catalog: The First Six Years [23]	1405
	November 2016 current catalogue Fermi/GBM [24]	1916

Following parameters for three GRB classes were obtained [11] – see table 3. Figure 1 presents this subgroup appearance in BATSE data. The data analysis have shown the existence of intermediate

GRB subgroup more intensive than short and long events (such bursts were absent in catalogue of faint bursts separated by ground analysis [25, 26] and had intensity lower than one sufficient for onboard trigger).

Table 3. Separation criteria for short, intermediate and long GRBs accordingly duration and duration-hardness distributions analysis of 4B revised BATSE catalogue data.

GRB subgroup	t_{90} parameters	$\langle t_{90} \rangle$	Hardness limitations
short	$t_{90} < 3$ sec	0.5 sec	$H_{32} > 6.00$
intermediate	0.8 sec $< t_{90} <$ 50 sec	≈ 3 sec	
long	$t_{90} > 5$ sec	≈ 30 sec	$H_{32} < 1.85$

2. GRBs duration distributions and intermediate GRBs subgroup for BAT/Swift and GBM/Fermi databases

Now GBM/Fermi GRBs catalogue contains ~ 1900 events and BAT/Swift one enclose ~ 1000 bursts. However GRBs sources' origins nature is cosmological – see redshift corresponding columns in [17 – 20] and [23, 24]. Therefore correction to cosmological dilation of GRBs duration should be consider because of real cosmological sources time properties should be investigated only taking into account its redshift.

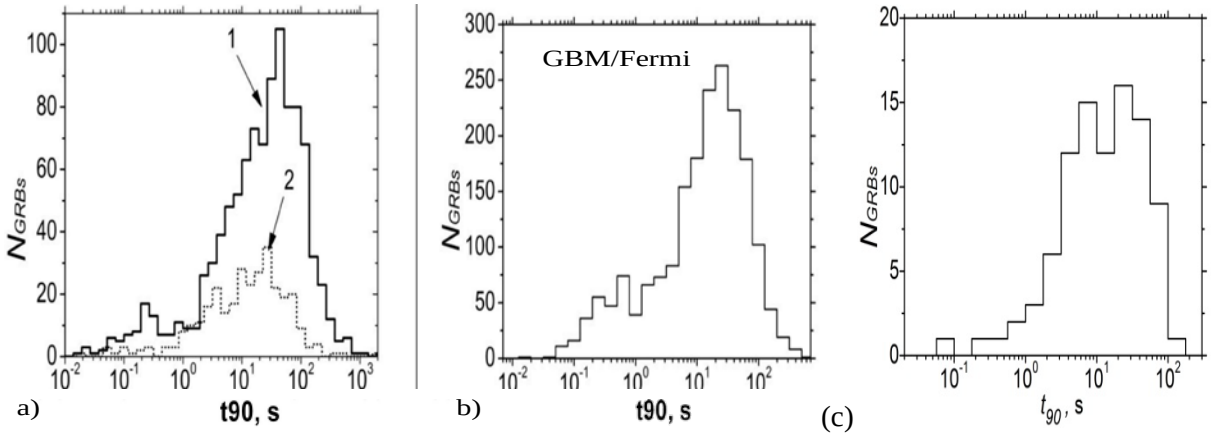

Figure 2. Duration distributions for GRB: from BAT catalogue (a) without (1) and with (2) correction to cosmological dilation and from GBM one (without (b) and with redshift taking into account (c)).

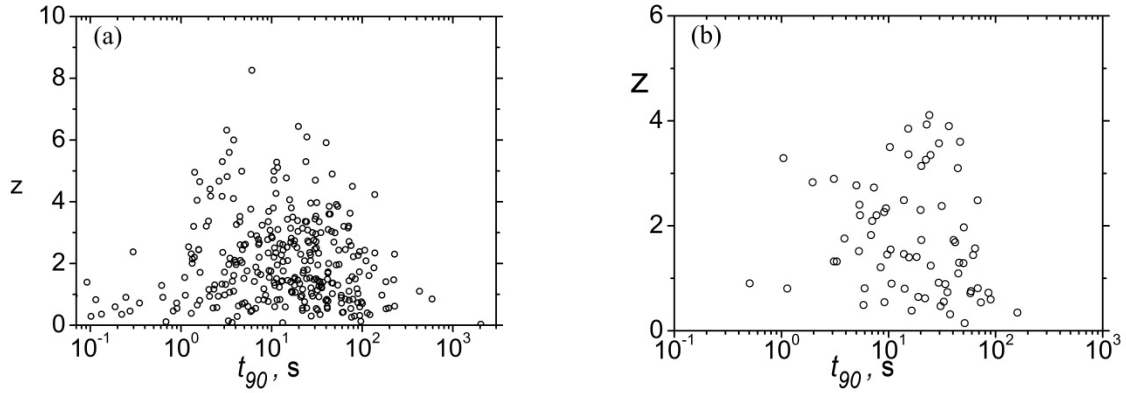

Figure 3. GRBs distributions on redshift and duration for BAT/Swift (a) and GBM/Fermi (b) current catalogues.

Unfortunately the volumes of subsets of GRBs with known redshift are limited ~300 and ~100 events for BAT/Swift and GBM/Fermi catalogues correspondingly. In spite of this, the intermediate GRBs subgroup appears in the region of ~1 s < t_{90} < ~10 s for both BAT/Swift and GBM/Fermi catalogues events distributions on duration especially after taking into account cosmological dilation – see figure 2. Also this subtype existence shows in intervals of t_{90} from 1 to 10 s at GRBs distributions on redshift and duration presented at figure 3. But detailed analysis required subsets volumes extension for concretisation of GRBs subgroups content like at figure 1c.

3. Conclusion

The first detailed GRB catalogue was obtained as a result of BATSE experiment [5] onboard the Compton Gamma Ray Observatory (CGRO) [6]. Data analysis of this catalogue has shown two GRBs subgroups presence on duration distribution: short and long [5]. The value of $t_{90} \sim 2$s is used as boundary between short and long events [7].

However in 1999 third burst subgroup [11] (intermediate GRBs) was found due GRBs duration and duration-hardness distributions analysis of 4B current BATSE catalogue (recently available as 5B one) [12, 13] in duration interval of $0.8\ \text{s} \leq t_{90} \leq 50$ s with $\langle t_{90} \rangle \approx 3$ sec. Taking into account duration-hardness distributions analysis the following criteria were obtained for short ($t_{90} < 3$ sec, $\langle t_{90} \rangle \approx 0.5$ sec , $H_{32} > 6.00$) and long ($t_{90} > 5$ sec, $\langle t_{90} \rangle \approx 30$ sec, $H_{32} < 1.85$) GRBs. Later intermediate GRBs subgroup was widely discussed - see, for example, [27, 28].

After end of CGRO operation, two satellite experiments GRBs catalogues BAT/Swift and GBM/Fermi contain amount of bursts comparable with 4B current BATSE catalogue one and it is sufficient for duration distribution precision investigation. The results of these distributions analysis allow concluding the appearance of intermediate GRB subgroup on data of three experiments: BATSE/CGRO, BAT/Swift and GBM/Fermi.

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