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Statistical Properties of the Time Histories of Cosmic Gamma-Ray Bursts Detected by the BATSE Experiment of the Compton Gamma-Ray Observatory

Final Report

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Statistical Properties of the Time Histories of Cosmic Gamma-Ray Bursts Detected by the BATSE Experiment of the Compton Gamma-Ray Observatory

Final Report

The main scientific objectives of the project were the following activities:

(1) Calculation of average time history for different subsets of BATSE gamma-ray bursts.

(2) Comparison of averaged parameters and averaged time history for different BATSE GRBs sets (by Peak Flux, Hardness Ratio, etc.).

(3) Comparison of results obtained with BATSE data with those obtained with APEX experiment at PHOBOS mission.

(4) Use the results of (1)-(3) to compare current models of gamma-ray bursts sources.

To obtain these results, special statistical studies of 338 cosmic events of the Second BATSE Catalog have been done. The corresponding conclusions follows:

(1) The new method was developed by averaging time profiles of separate events when they are aligned around their principal peaks. This method was compared with other methods developed for similar analysis. An agreement was found in similar datasets used in these tests.

(2) Using the average time histories at different energy channels on 1024 ms time scale, the following features were found:

– The average time history of GRBs is non-symmetric: from the level of 0.25 of its maximum height, the rise front of the average curve of emissivity (ACE) lasts about 3 sec and back slop about 5 sec. The average Hardness Ratio has a broad maximum along the rise front of the ACE, then decreases along the back slope.

-- From the comparison of ACE obtained at different channels, we find that the averaged peaks of GRBs are broader at soft energies then at hard energies (softness/duration effect). Using the peak shape of discriminator No.3 as the standard, we find the best stretch factors K to fit the peaks in discriminators No.1 and No.2 , as the following low: $K(E) = (173 \{keV\}/E)^{0.23}$.

-- We find no evidence in this analysis for time-dilation in the ACE of weak events relative to bright events, when those sets of events are selected by the photon peak fluxes, as presented in the Second Catalog. The ACE at energies 50-300 keV for dataset of 143 bright events with F>1 ph/cm^{2}s and 179 weak events with F<1 ph/cm^{2}s correspond to similar curves. In the more conservative case with the gap between peak fluxes of bright and weak GRBs, the average curves have been shown to be similar as well.

-- We find the difference in average curves of Hardness Ratio for the sets of bright and dim events selected by the photon peak fluxes. Bright events have larger Hardness Ratio then weak ones not only averaged over time but at each point in the averaged time profile (effect of the brightness/hardness correlation).

(3) The comparison of results obtained with the BATSE data have been done with those obtained with the APEX/PHOBOS data. The perfect agreement is found between them.

(4) The following conclusions have been obtained for the theoretical models of GRBs:

-- Similarity between all outbursts and of all outbursting objects was found. This fact rules out all galactic models, which attribute GRBs to different populations of neutron stars. Another modern galactic model could also be rejected, which attributes all GRBs with the single class of neutron stars, but which are thought to emit two different types of strong and weak outbursts. On the other hand, the perfect similarity between average curves for bright and dim events makes the cosmological paradigm of GRBs quite unprobable also.

-- Average evolution of outbursting objects during a burst shows non-symmetrical rises and decay fronts on the average, the developing phases of GRBs before the maximum are shorter and harder then decaying phases after the maximum. The picture of outbursts is not time-reversible. Some sort of physical evolution of the outbursting object does occur during a burst, which leads to these features.

-- Theoretical models of GRBs agree with the brightness/hardness correlation of GRBs in two cases. In the first case, the model might explain the difference in brightness from different distances of sources, assuming that some evolution takes place. There is another possibility also, when the all range of brightness of GRBs is associated with the range of intrinsic luminosity of sources, which are at the same distance from the observer. Further study is necessary to resolve these possibilities, but all models with the standard candles could be ruled out due to brightness/hardness correlation of GRBs.

The main results of the project were reported in:
- 2nd Huntsville Symposium on Gamma Ray Bursts;
- 30th Scientific Assembly of COSPAR;
- 17th Texas Symposium on Relativistic Astrophysics.

The main results were presented in the following publications:

[1] Mitrofanov et al. 1994, In Proc. of "Gamma-Ray Bursts", AIP 307, p. 187.
[2] Mitrofanov et al. 1995, subm. to Astrophys. J.
[3] Mitrofanov et al. 1994, In Proc. of 30th Scientific Assembly of COSPAR, to be published.

STATISTICAL STUDY OF EVOLUTION OF GAMMA-RAY BURSTS DETECTED BY APEX/PHOBOS AND BATSE/COMPTON INSTRUMENTS

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ABSTRACT

The results of new method of statistical studying of APEX/PHOBOS and BATSE/COMPTON cosmic gamma-ray bursts (GRBs) are presented, which are based on the averaging of time profiles of separate events. Using time histories at different energy channels, the general features are found of averaged flux/spectrum evolution of GRBs. The comparison is done between flux/spectrum evolution of bright and dim events: while no differences were found between averaged curves of fluxes variability, the comparison of averaged evolution of their hardness ratios pointed out the effect of hardness/brightness correlation. The consequences of the statistical results are discussed for two principal alternatives: for the cosmological model of GRBs and for the models which associate them with the Galaxy.

INTRODUCTION

GRBs are known to have very random time histories [1]. Even assuming that sources are 'standard candles', one should suppose that some randomizing factors are acting during emission, providing very large changing between different events. The comparison of individual events hardly might resolve such systematic effects, as differences between averaged flux/spectrum variability.

On the other hand, the averaged flux/spectrum variably has the physical sense, which represents the general properties of outbursting sources and basic features of bursts mechanisms. The future theory of GRBs, as the single phenomenon, has to explain the averaged flux/spectrum variability. Moreover, at the present level of knowledge of GRBs, some differences might be expected in the flux/spectrum variability of bright and dim events. There are lot of new or revisited models of GRBs, which deal with some of these effects: e.g. the model of two types of outbursts from close galactic neutron stars [2], or the model with two outbursting populations [3], or the cosmological model with necessary predictions of time stretch and frequency shift [4].

Those general observational features hardly can be found in the study of particular GRBs, but they might be found in the special averaging of the data available. And, provided some of them would be found, the origin of GRBs could become clear, because particular effects are associated with specific models. Therefore, special statistical analysis of the total set of available GRBs is now very actual.

Together with new models, new methods of statistical analysis have been proposed to resolve the origin of GRBs. In particular, the methods of averaging of time histories have been developed [5-9]. Another known methods were based on the wavelet analysis of GRBs, which provide the averaged activity curves for different sets of selected events [10 - 12]. The separation of GRBs into two different classes of variability has been proposed [13]. This studying interferes with the method of estimation of time duration of GRBs [14], which permits to resolve two possible classes of GRBs with different averaged duration, namely smaller and larger of 2 seconds [15]. One might conclude that some 'new statistics' of GRBs are appearing now, which represent the general features of flux/spectrum variability.

This paper presents the results of the particular method of 'new statistics' of GRBs, which is based on the averaging of events aligned around their principal peaks. The studying focuses on the general features of flux/spectrum variability and gives the way of simple comparison between bright and dim events.

THE AVERAGING OF FLUX/SPECTRUM VARIABILITY OF GRBS

To resolve real general features of flux/spectrum variability of different GRBs, one needs to develop method, which excludes as much as possible the influence of their different brightness and their individual time histories. The methods have been developed [5-9], which respond to this demands. They include the following procedures:

1) For averaging of all selected GRBs, a spectral range should be selected, where their time histories will be averaged. It is possible, that different spectral ranges could be used for alignment of time histories, and for averaging of aligned events.

2) A unique time scale should be selected with time bins, which ensures acceptable signal to noise ratio at principal peaks of all time histories, even for dimmest events. Bins at selected time scale have to correspond to the actual exposures of each events in the selected energy range.

3) Along time history of each burst, rise front, back slope and the unique time bin t_{max} of primary peak should be selected. At the primary peak the maximal number of counts C_{max} should be determined. After that, normalization of time history should be done, when actual counts C_i at all time bins t_i are replaced by dimensionless values $f_i=C_i/C_{max}$.

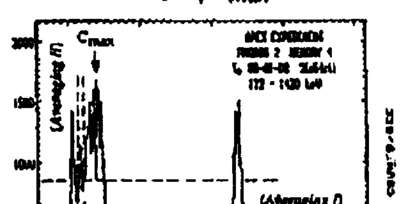

Figure 1. Two kinds of averaging of flux/spectrum variability of GRBs: (I) and (II) - *Averaging I and II.*

4) The first method of averaging of time histories (*Averaging I*) provides the joint statistical study of time intervals with increasing and decreasing counting rate at time intervals of particular events, which have the similar dimensionless fluxes. For selected intervals of relative flux F, the averaged durations $t_{RF,BS}(F)$ of all time bins are obtained with corresponding fluxes for *rise fronts (RF)* and *back slopes (BS)*, separately, for all contributing GRBs (Fig. 1). The values of $t_{RF}(F_i)$ and $t_{BS}(F_i)$ represent the averaged curve of flux variations for selected set of GRBs. The errors of estimations of those time intervals represents the errors of used relative fluxes of particular events.

5) For another procedure of the averaging, all normalized time histories should be aligned around the same time bin, placing their peaks t_{max} at the single bin t_0. For time bins t_i of common time scale before and after t_0, the values of normalized fluxes f_i are averaged over the selected set of bursts. The second procedure of averaging (*Averaging II*) builds the dimensionless value F_i along the time scale, equals to the sum of f_i of each contributing events, divided by their number for this time bin (Fig. 1). The values F_i along time scale t_i represent the *averaged curve of emissivity (ACE)* for selected set of GRBs. The error of

each value F_i is associated with statistical errors of measured numbers of counts C_i. These errors represent the uncertainty of ACE, which is resulted from the uncertainties of particular measurements, which is much smaller for bright bursts then for dim events.

6) Estimation of the *hardness ratio* (HR) of detected counts is the most simple way to study the evolution of energy spectra along time histories of GRBs. For the *Averaging I*, the mean values of hardness ratio could be estimated for each separate time intervals $t_{RF,BS}(F_i)$. They represent the *averaged HR for selected interval of relative fluxes* at rise fronts and back slopes, respectively. The *averaged curve of HR (ACHR)* could be created along the time scale of the *Averaging II*, as the ratio of corresponding hard and soft ACE, averaged around aligned peaks at the integral spectral range.

AVERAGED FLUX/SPECTRUM VARIABILITY OF GRBS

Study of APEX/PHOBOS data

The Russian-French experiment APEX on the interplanetary spacecraft PHOBOS-2 detected 62 GRBs during 8 months of flight from July 1988 till March 1889. The instrument used a 10 x 10 cm CsI(Tl) scintillator to measure time profiles in the broad energy interval 120-1420 keV and energy spectra in 108 channels from 65 to 9000 keV. The totality of 48 APEX/GRBs with good telemetried data have been loaded to the APEX data base for further statistical study [5-7]. For the averaging, the APEX/GRBs are divided into subsets corresponding to the 2 sub-sets of 19 bright and 29 dim events with V/V_{max} at sub ranges of ($0.0 < V/V_{max} < 0.3$) and ($0.3 < V/V_{max} < 1.0$), respectively.

The Table 1 [6] represents the comparison between the mean durations $t_{RF,BS}$ for the interval of relative fluxes [0.35 - 1.0] at rise fronts and back slopes, respectively (1/2 of the duration of peak intervals f_{max}=1 1/2 are included into RF and BS). For relative fluxes greater then 0.35 one could be sure that all the events considered, the total number of counts contained in the broad channel 300-1000 keV would exceed the level of 3 sigma od background fluctuations. The Table 1 also gives the averaged valus of HR, defined as HR=F(300-1000 keV)/F(100-300 keV) corresponding to the intervals of relative fluxes [0.35 - 0.70] at RF and BS. To estimate HR, summation has been done of all contributing particular energy spectra, which have been normalized to ensure the equal contributions of all selected events.

TABLE 1 *Averaging I* [6] for intervals of similar relative fluxes at rise fronts and back slopes of APEX/PHOBOS GRBs.

Selected set of GRBs	Rise front, (RF)	Back slope, (BS)
Set of bright events $0.0 < V/V_{max} < 0.3$	t_{RF} (0.35-1.0) = 6.2±0.8 s	t_{BS} (0.35-1.0) = 3.6±0.9 s
	HR_{RF}(0.35-0.70)=0.40±0.01	HR_{BS}(0.35-0.70)=0.31±0.01
Set of dim events $0.3 < V/V_{max} < 1.0$	t_{RF} (0.35-1.0) = 3.1±0.9 s	t_{BS} (0.35-1.0) = 3.6±1.0 s
	HR_{RF}(0.35-0.70)=0.25±0.03	HR_{BS}(0.35-0.70)=0.24±0.2

From the Table 1 one might conclude the difference between averaged RFs and BSs of bright GRBs and their symmetry for dim events, and the difference between t_{RF} and HR_{RF} of bright and dim events.

Another studying of flux/spectrum variability of APEX/PHOBOS GRBs using the procedure of the *Averaging II* permits to see the general properties of the evolution along the bursts. The averaged curves of flux/spectrum evolution for bright and dim sub-sets of GRBs are presented at the Figure 2. Both ACE curves have one peak shape with smooth back slopes. Those back slopes are very similar for bright and dim events. Applied statistical criteria do not show any significant differences between them [5,6]. The difference at the rising parts of ACEs, with curve for bright sub-set going higher then one for dim events, is probably caused by the selection effect: For weak events the triggering happens earlier for steep rise fronts then for gently sloping ones, therefore dim events might be in a deficit before the maximum.

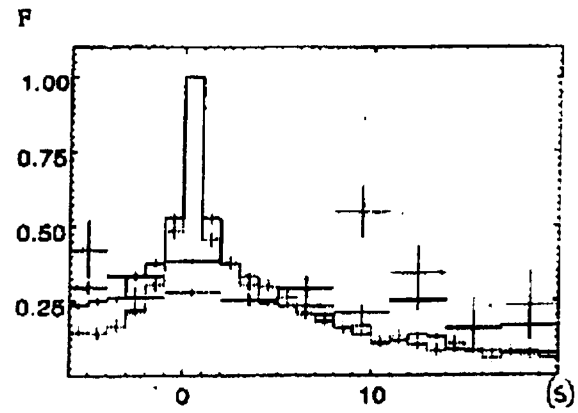

Figure 2. *Averaging II* [7]: ACE (thin lines) and ACHR (thick lines) for bright set $0.0<V/V_{max}<0.3$ (solid line, 19 events) and dim set $0.3<V/V_{max}<1.0$ (dotted line, 29 events) for APEX/PHOBOS GRBs..

On the other hand, after the maximum, there is no influence of the triggering at all, and shapes of ACE curves represent the real cases. At the Table 2 the results of the *Averaging II* are presented for sets of bright and dim APEX/GRBs, which compare the averaged fluxes and HR along the ACE curve.

TABLE 2 *Averaging II* [7] along time curves of APEX/PHOBOS GRBs

Selected set of GRBs	1 s before t_{max}	Bin at t_{max}	1 s after t_{max}
Set of bright events $0.0 < V/V_{max} < 0.3$	F=0.53±0.01	F=1.0 by definition	F=0.53±0.02
	HR=0.37±0.02	HR=0.45±0.01	HR=0.29±0.02
Dim events with $0.3 < V/V_{max} < 1.0$	F=0.49±0.03	F=1.0 by definition	F=0.46±0.02
	HR=0.27±0.03	HR=0.25±0.03	HR=0.30±0.02

While no difference is seen between ACE curves for bright and dim events, the hardness at fronts and peaks of bright GRBs is much higher. However, the APEX/PHOBOS experiment have provided very limited sets of GRBs, and much better statistics of BATSE/COMPTON is necessary for statistical studying of averaged flux/spectrum variability with higher significance.

Study of BATSE/COMPTON data

For statistical analysis of flux/spectrum variability of BATSE/COMPTON GRBs, 260 events have been used [8,9] of the First BATSE Catalog [14]. The events have been excluded with short time duration $t_{90}<1$ sec, and other ones with missed data; the total number of excluded events was 52. The used set of 208 BATSE GRBs corresponds to data recorded from April 19, 1991 till March 5, 1992. For each event of 260 GRBs from [14], the data file has been used of measurements of Large Area Detectors (LAD) with time resolution of 1.024 s in four discriminator channels No.1(25-50 keV), No.2(50-100 keV), No.3(100-300 keV) and No.4(>300 keV). To create the time history of an event, data has been taken from LAD, which had the largest counting rate. From the time profile of the continues measurements, those time bins have been selected for time history of an event, which correspond to intervals of ±max(t_{90}, 20 s) around the moment of burst triggering t_{trig}. Measurements outside those intervals have been used to interpolate and substract background during an event.

The *Averaing I* study of the BATSE/COMPTON GRBs corresponds to much better statistics, then in the case of the APEX data. The first results of this analysis [8,9] are presented below.

The *averaged curve of emissivity* ACE(2+3) curve for the full set of BATSE GRBs [14] is shown at Figure 3 for discriminator channels No.(2+3) at the energy range of 50-300 keV. The curve has one-peak structure with non-symmetrical *front* (F) and *decay* (D), which have widths above the level of 0.1 equal to

$$T_{F,D} = \Big(1 + \sum_{\text{for } f_i^{(F,D)} > 0.1} f_i^{(F,D)} \Big) \cdot 1.024 \text{ s} \qquad (1)$$

The total width of peak above the level of 0.1 equals to $T_P = T_F + T_D$. Corresponding values of widths are presented in the Table 3. It is evident from this data that averaged front of ACE is much shorter then decay. To illustrate non-symmetry of the peak, the time-reversal decay is shown at the front side (Fig.3).

TABLE 3. *Averaging II* [9]: Widths of fronts, decays and total peak of ABC above the level of 0.1 for full set of BATSE GRBs [14] (sum of discriminators No.(2+3) at energies 50-300 keV)

Selected set of GRBs	T_F (s)	T_D (s)	T_P (s)
Full set of 208 events	2.36±0.02	3.83±0.02	6.19±0.03
81 bright events with flux >1ph/cm^{2}s	2.65±0.01	3.82±0.01	6.47±0.01
127 dim events with flux <1ph/cm^{2}s	2.11±0.02	3.78±0.03	5.89±0.04

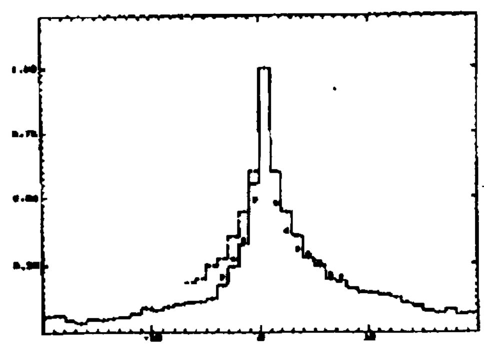

Figure 3. The ACE(2+3) curve for full set of BATSE GRBs [14] for discriminators No.(2+3) at range 50-300 keV [8,9]. The time-reversal decay of the main peak is shown with dash line.

Time histories at discriminations No.1-No.3 could be used separately to build corresponding ACE's. The estimations of widths of fronts, decays and total widths of ACE's peaks at discriminators No.1-No.3 are presented in the Table 4. From the comparison of ACE curves obtained at different channels, one might conclude that averaged peaks of GRBs are broader at soft energies then at hard energies. Using the peak shape at the discriminator No.1, as the fitting model, one might find its best stretches to fit two other peaks at discriminator No.2 and discriminator No.3. The corresponding stretch coefficients K(2,3) are presented in Table 4. Using those values of K, one might interpolate the stretch/energy dependence within the range from 25 up to 300 keV, as the following:

$$K(E) = \left({}^{170\,keV}/_{E} \right)^{a} \qquad (2)$$

with the best fitting values of parameter a equals to 0.24±0.03 for reduced chi^2=0.5.

TABLE 4 *Averaging II* [9]: Widths of fronts, decays and total peaks of AEC above the level of 0.1 for discriminators No.1, No.2 and No.3 for full set of BATSE GRBs [14]

	Discr. No.1	Discr. No.2	Discr. No.3
T_R(s)	3.07±0.03	2.52±0.02	2.02±0.02
T_D(s)	4.76±0.04	4.01±0.02	3.10±0.02
T_P(s)	7.83±0.05	6.53±0.03	5.12±0.03
K	1.43±0.08	1.27±0.05	1.0 by definition.

The ACE curves for BATSE GRBs could be compared with similar averaged curves previously obtained for GRBs detected by APEX experiment. Data of 48 APEX GRBs at the energy range of 100-1000 keV could be compared with ACE for 205 BATSE events for the discriminator No.(2+3) (Fig. 3). Good agreement between averaged curves of APEX and BATSE events shows that they represent real physical evolution of emissivity GRBs and faintly depend on type of instruments used.

The fact that AEC depend on the energy means that some kind of spectrum evolution should take place along the averaged light curve. This evolution could be resolved from the comparison of the averaged values of Hardness Ratio (HR) for different bins along ACE. To estimate averaged HR, discriminator channels No.(2+3) could be used to align the primary peaks, and averaging should be done based on this alignment of time histories at channels No.2 and No.3. The ratio of corresponding curves for #3 and #2 provides the *averaged curve of hardness ratio* variability (ACHR) (Fig. 4).

The time profile of ACHR shows the broad maximum at the front of ACE curve during about 10 seconds before the main peak. After the peak, the averaged hardness ratio decreases with the decreasing averaged flux along the decay. The broad maximum of hardness ratio at the rise front of averaged peak of ACE means that usually peaks at higher energies take place before peaks at medium and low energies. This conclusion, based on the present statistical analysis of BATSE GRBs, confirms the pervious observations of many particular GRBs, when peaks of hardness ratio have been found at fronts of peaks [10].

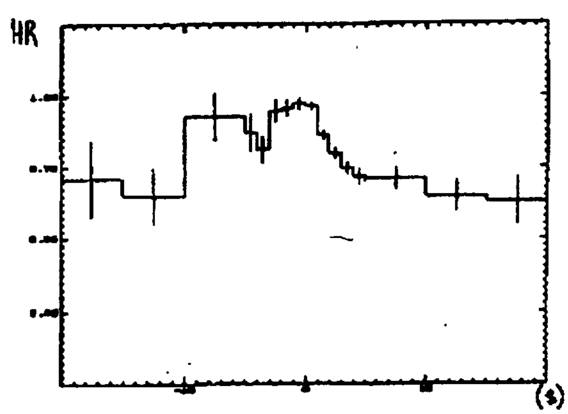

Figure 4. The averaged curve of hardness ratio (ACHR) [8,9] for full set of BATSE GRBs [14], with hardness ratio defined as (100-300 keV)/(50-100 keV) [8,9].

To compare bright and dim BATSE GRBs, two sub-sets have been formed from the First Catalog database: As bright and dim GRBs, those sub-sets of events have been selected, which have $F > 1$ ph/cm^{2}s and $F < 1$ph/cm^{2}s, respectively. Taking into account that the time scale for averaging has resolution of 1,024 s, only those GRBs have been used for comparison, which have duration $t_{90} > 1$ s. There were two sub-sets of 81 bright and 127 dim BATSE GRBs, which have been used to compare the averaged flux/spectrum variability.

For the sets of bright and dim GRBs, the ACEs curves for discriminator channels No.(2+3) are presented in Figure 5. Both curves have one-peak profiles, and no significant difference is evident between them. The width of rise fronts of ACE peak of bright events is slightly longer then the similar width of dim events, but both back slopes have very similar duration (Table 3).

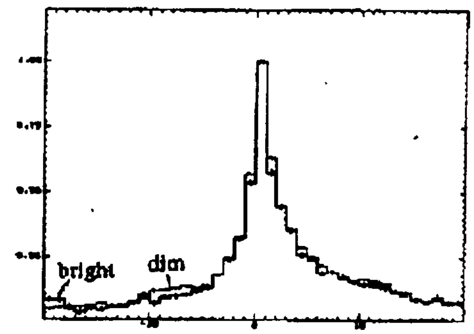

Figure 5. ACE curves [8,9] for sets of bright and dim BATSE GRBs [14] for discriminators No.(2+3) at enery range 50-300 keV.

The ACE curves of bright and dim sub-sets could be compared more accurately by the using of central peak for ACE of bright sub-set, as a stretching fitting model for central peak for ACE of dim events. Taking into account only those time bins of main peaks, where ACE curve lies above the level of F> 0.1, the best fit of $ACE^{(dim)}$ corresponds to the narrowing factor K=0.97 ± 0.05 of $ACE^{(bright)}$ with reduced chi^2=2.80.

Thus, from the comparison of bright and dim sub-sets of BATSE GRBs, the conclusion should be drawn that there is no statistically significant difference between them in the averaged emissivity curves. All proposed methods of comparison do not show that ACE for dim set is broader then ACE for bright set. Moreover, there is even some evidence that it is narrower then ACE for bright events.

Another comparison could be done between sub-sets of bright and dim BATSE GRBs, which is associated with their mean hardness ratios. Two ACHR curves were calculated for two selected sub-sets of bright and dim events (Figure 6). Those two curves have similar shapes with broad maxima at fronts and peaks

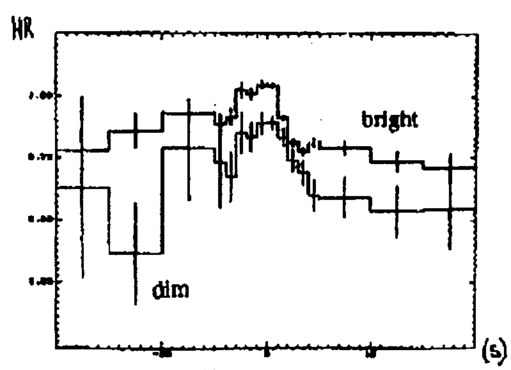

Figure 6. Two ACHR curves [8,9] for sub-sets of bright and dim BATSE GRBs [14], with hardness ratio defined as (100-300 keV)/(50-100 keV) [8,9].

of ACE. The most important finding of this comparison is the difference of the levels of those two curves: along the full all time scale the curve $ACHR^{(bright)}$ goes well above the curve $ACHR^{(dim)}$. The difference between ACHRs curves for bright and dim events could be interpreted, as the evidence for the effect of brightness/hardness correlation of BATSE GRBs.

CONCLUSIONS

The main results of the statistical studying of flux/spectrum variability are the following:

i) Bright events have longer and harder averaged rise fronts then back slopes. Dim events have more symmetrical averaged rise fronts and back slopes, both in the averaged duration and in the hardness ratio (*Averaging I* of APEX/PHOBOS GRBs [5,6]).

ii) Averaged rise fronts are longer and harder for bright events than for dim events. Averaged back slopes of bright and dim events have similar time duration and hardness ratio (*Averaging I* of APEX/PHOBOS GRBs [5,6]).

iii) Averaged curves of emissivity for both bright and dim events are very similar, especially at their decays. Averaged curve for HR of bright events goes higher then for dim events (*Averaging II* of APEX/PHOBOS GRBs [7] and BATSE/COMPTON GRBs [8,9]).

The first evidence of the effect of brighness/hardness correlation (see (ii) and (iii)) has been found using the APEX experiment data, when two averaged energy distributions have been compared, which summarized particular energy spectra measured at peaks of strong and weak detected events [17]. Later, when the method of averaging with peaks alignment has been developed, the presence of brightness/hardness correlation has been demonstrated for APEX events more clearly [5-7]. Independently, the effect of brightness/hardness correlation has been resolved in the limited set of the first 126 BATSE GRBs [18]. Finally, the studying of the set of 205 GRBs from the First Catalog of BATSE had shown the presence of hardness/brightness correlation [8,9]. Using another set of bright and dim BATSE GRBs, larger spectral hardness was found for bright events in comparison with dim bursts [19].

Cosmology Model

Developed method of statistical studying of time/energy evolution of GRBs permits to compare bright and dim events according to the predictions of cosmological model. To explain observed value of averaged $<V/V_{max}>$ for the first 118 BATSE events, the cosmological model has been developed [20], which works with sources of GRBs, as standard candles. For the best fit of the observational data, the model corresponds to a red shift about unity for a most distant objects, but the factor of 2 is possible for other marginally acceptable fits.

Assuming the validity of this model, the following testing procedure could be used based on the method proposed. The sub-set of brightest events is selected, which corresponds to the most close sources with the smallest red-shift, one might take those 38 events, which have $0<V/V_{max}<0.05$. According to the cosmological model [20], their mean red-shifts could be estimated, as $z_{br}=0.11$, 0.29 and 0.50 for low z fit, best z fit and high z fit, respectively. On the other hand, to select the most distant observable sources with the largest red-shift, one might use the comparable number of 42 dim events with V/V_{max} from the interval $0.6<V/V_{max}<1.0$. According to the cosmological model, for those dim events one estimates $z_{dim}=1.24$, 1.36 and 1.70 for low z fit, best z fit and high z fit, respectively.

According to the cosmological model [20] and the width/energy dependence (2) (see Table 4), the theoretical evaluations have been done of the total stretch factor, which provides the best fit of ACE of dimmest events at discriminator No.2 by the ACE for brightest events at discriminator No.3. Those factors were estimated, as 1.42 for low z fit, 1.53 for best z fit and 1.83 for high z fit [9]. On the other hand, the best fitting value of the stretch factor [9] equals to 1.04 ± 0.1, which is far away from the theoretical predictions. So, the averaged AEC curve for brightest events does not differ so significantly from the AEC curve for dimmest events [8,9], as it could be expected according to the cosmological model [20].

Galactic Models

The averaged emissivity curves AEC are very similar for sub-sets of bright and dim events. This fact does not agree with models, which attribute GRBs to different populations of galactic neutron stars (e.g. [3, 21]). These classes are thought to belong to the close vicinity of galactic disk and to the extended galactic halo. Close sources might be responsible for dim events only, because more distant outbursts from those population, which would dominate at low galactic latitudes, are not observable. On the contrary, distant neutron stars in the halo might be attributed to bright GRBs. Talking into account the ratio of bright and dim events ~10^2 - 10^3, and the difference in their distances ~10^3, one might deduce the difference of internal radiated energy by those two classes ~10^8 - 10^9. Such a large difference in the radiated energy points out, that outbursting activities of those two classes have very different physical nature.

Another modern galactic model attributes all GRBs with the single class of neutron stars in galactic disk, but which are thought to emit two different types of strong and weak outbursts [2]. Close members of this population are thought to be visible either through events of the strong class, observed as bright GRBs, or through events of weak class, observed as dim GRBs. More distant part of the population is thought to be detectable through events of the strong class only, observed as medium GRBs. Therefore, for the model [2], performed statistical comparison of bright and dim events corresponds to the comparison of two different classes of outbursts from the close stars, i.e. classes of strong and weak events.

Therefore, taking into account the similarity of ACE's for bright and dim sets, the model with different populations of GRBs sources does not seem to be very probable, as well as the model of single population of sources with different classes of outbursts.

While the perfect similarity has been found between the averaged emissivity curves of bright and dim sub-sets of GRBs, as the evidence for the homogeneity of radiating objects, the difference in the averaged hardnesses has also been seen between those two sub-sets, which points out on some intrinsic difference between emitters of bright and dim events.

The model of extended galactic halo population (e.g. see [22]) agrees with the brightness/hardness correlation of GRBs in two cases. In the first case, the model explains the difference in brightness by different distances of sources within the halo, assuming some evolution of *non-standard* sources along the run away path from the center region to the periphery (e.g. see [23, 24]). For those models, the main difference between brightness of GRBs in ~10^4 times is attributed mainly to the broad spread of their distances 3-300 kpc. The change of sources could be resulted from some sort of evolution of outgoing neutron stars during ~300 (v_o/1000 km/s) Myrs. In this case the effect of brightness/hardness correlation might correspond to some physical correlation between inverse distance and hardness of gamma-rays.

There is another way to implement the idea of *non-standard* sources into the model of extended galactic halo, when the all range of brightness of GRBs is associated with the range of intrinsic luminosity of sources about ~10^4 times, which all are at the comparable distances ~30-300 kpc from the observer. The reason is unknown for the absence of GRBs from the inner regions of the halo, and neutron stars have to preserve the ability to radiate GRBs during all maximal age of ~10^4 Myrs. In this case the effect of brightness/hardness correlation might be associated with some intrinsic correlation of radiated power with hardness.

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THE AVERAGE TEMPORAL PROFILE OF BATSE GAMMA-RAY BURSTS: COMPARISON BETWEEN STRONG AND WEAK EVENTS

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ABSTRACT

First results are presented from the analysis of 260 BATSE gamma-ray bursts (GRBs)[1] using a method[2,3] whereby all events are synchronized and averaged around the bins which are the brightest time intervals of each of them. For the averaged time history, a difference is found between the rise front and the back slope, and good evidence is found for the presence of hard-to-soft spectral evolution. We compare sub-sets of "strong" and "weak" events and find no evidence for time dilation in weak GRBs, as would be expected in cosmological GRB models. On the other hand, for the strong events the averaged hardness ratio is found to be larger than for the weak GRBs.

1. INTRODUCTION

As discussed in many contributions to this Workshop, our present knowledge of GRBs is full of apparent contradictions. One of these is the contradiction between the perfect isotropy of GRBs on the sky[4,5], which corresponds to a very homogeneous angular distribution, and the value of $\langle V/V_{max} \rangle \approx 0.32$[4,5], which indicates that GRBs have a non-homogeneous radial distribution in Euclidean space. To resolve this contradiction one might suppose, for instance, that GRBs are generated in the Extended Galactic Corona[6], or that they belong to a cosmological population with redshift $z \approx 1$[7]. A definite decision between cosmological and non-cosmological models would be a crucial step in understanding the origin of GRBs.

The method of averaging time histories of cosmic GRBs around the brightest time interval was developed for analysis of events detected in the APEX experiment of the PHOBOS Mission[2]. A set of 48 events was divided into two subsets of "strong" and "weak" events, and their averaged time histories were directly compared. While differences were found in the rising parts, the back slopes were identical within statistics. The differences in the rising parts could result from a systematic difference in triggering moments for strong and weak GRBs. On the other hand, the similarity of back slopes indicated that there is no cosmological stretch of weak events with respect to strong GRBs.

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II. AVERAGE TIME HISTORY AND HARDNESS RATIO

The data from the BATSE instrument on the Compton Gamma Ray Observatory provide an excellent opportunity to study the averaged time histories of GRBs, in particular to compare subsets of strong and weak events, with much better statistics. We present herein preliminary results of this comparison.

A total of 260 GRBs from the first BATSE Catalog[1] have been studied so far. For each event we used the DISCLA count rate time histories (four broad energy channels with a time resolution of 1 s) from the large area detector which had the highest peak count rate. Those are independent of the instrument trigger, so that one has for every event a continuous time history containing both pre-burst and post-burst background. We defined each burst interval as extending from $T_0 - \Delta T$ to $T_0 + \Delta t$, where T_0 is the burst trigger time and $\Delta T = \max(T_{90}, 20\ s)$, where T_{90} is a measure of burst duration[1]. Background during the burst interval was interpolated using the measurements before and after this interval, and the difference between the measured actual counts and the interpolated background curve constituted the burst time history.

The results we report are derived from two broad discriminator channels #2 (50–100 keV) and #3 (100–300 keV). For each GRB time history we determined the brightest time bin where the maximal number of counts was recorded in the sum of channels #2 and #3. The time histories (with statistical uncertainties) in the separate channels were then normalized to the count rate in the brightest bin. The result is a standardised set of GRB time histories, with time resolution of 1.024 s and maximum magnitude equal to 1.

With this data type, all events with duration shorter than 1 s are unresolved, their time histories falling within one or two bins, depending on their phase with respect to the instrument clock. At this stage, all events with $T_{90} < 1$ s were therefore excluded from the analysis. In the next analysis phase, we plan to use data with a time resolution of 64 ms, allowing use of the shorter events.

The averaged time history in the sum of discriminator channels #2 and #3 (50–300 keV) is presented in Figure 1 for 205 GRBs with $T_{90} > 1$ s from the first BATSE catalog[1]. Besides the short bursts, 0 other events from the Catalog could not be used due to data gaps. The omission of these events should not bias the final result: the set of 205 GRBs fully represent the continuous observation period of BATSE from 19 April 1991 to 5 March 1992[1]. The time scale of all figures corresponds to numbers of 1.024 s bins before and after the brightest one, which we defined as zero. Within the time interval from bin -15 to bin 20, the total number of contributing events (i.e., with significant count rate above background) is more that 90% of the total number in the averaged set. The mean duration of the averaged time profile at the level of 0.25 of its maximum height is about 7–9 s, which corresponds to 2–3 s of rise front and 4–5 s of back slope (with uncertainties of about 1 s). The difference between the averaged rise front and back slope is illustrated by the dashed curve in Fig. 1, which shows the time-reversal of the averaged light curve.

GRBs are known to have broader peaks of time histories at low energies relative to high energies. In Fig. 2 we compare the averaged time history of the full set of BATSE GRBs in discriminator channel #2 aligned around the brightest bin in channel #2 with the averaged time history in channel #3 aligned around the brightest time bin in channel #3. It is easily seen that the softer energy channel indeed has a broader peak in its averaged time history.

The averaged time history of BATSE GRBs may be compared with that for APEX GRBs, which was obtained previously by the same method[3]. The dots in Fig. 2 represent the averaged time history of 48 APEX GRBs in the broad energy channel 100–1000 keV. The two data sets agree quite well in spite of the instrumental differences between APEX and BATSE.

A comparison of "color" of GRBs along the averaged time history has been done by separate averaging of their profiles for discriminator channels #2 and #3, aligned with respect to the brightest bins for the sum of those two channels. The average time profile of the hardness ratio (HR), defined as the ratio of counts in 100–300 keV to the counts in 50–100 keV, is shown in Fig. 3. The HR has a maximum around 0.9 during the time interval from -9 to 0, during which the averaged time history rises to its maximum from the level of 0.1. Before the rise front, i.e., within time interval from −16 to -10, the averaged HR is about 0.7. After the maximum, HR decreases with the averaged flux to the value at the beginning of the rise front. Thus, we conclude that HR is a maximum during the rise front.

III. COMPARISON BETWEEN STRONG AND WEAK EVENTS

The total set of GRBs may be sub-divided into "strong" and "weak" events. We first consider a simple separation, where strong and weak events are associated with $V/V_{max} < 0.34$ and > 0.34, respectively (for the set of BATSE GRBs $\langle V/V_{max}\rangle = 0.34 \pm 0.02$[1]). The averaged time histories of 112 strong and 79 weak events thus defined are shown in Fig. 4 by bold and thin lines, respectively. No statistically significant difference is seen between the two profiles.

In cosmological models the time dilation stretch factor between the strong and weak event profiles should be $\sim (1 + \langle z_w\rangle)/(1 + \langle z_s\rangle)$, where $\langle z_w\rangle$ and $\langle z_s\rangle$ are the average redshifts of the weak and strong events, respectively. Strictly speaking, the above comparisons are compromised in a cosmological model by the redshift of photons from higher to lower energies. Because of the redshift, the profile of weak bursts in the observed energy channel corresponds to higher rest energies than the profile of strong bursts. Since the bursts are intrinsically narrower at higher energies (Fig. 2), this effect could wipe out any time dilation which might be present.

In order to compensate for this effect, we compared the averaged time history of 38 "very strong" events ($V/V_{max} < 0.05$) in 100–300 keV and the averaged time history of 42 "very weak" events ($V/V_{max} > 0.60$) in 50–100 keV. The results (Fig. 5) again show no evidence for systematic stretching of the very weak events relative to the very strong events. For comparison, we also show in Fig. 5 the stretched profile expected from cosmological models which acceptably fit the BATSE number/intensity distribution[7]. Here we assumed $\langle V/V_{max}\rangle \approx .026$ for the very strong events and $\langle V/V_{max}\rangle \approx .8$ for the very weak events, from which Fig. 2 of Ref. 7 predicts stretch factors of 22–67%. Fig. 5 represents a conservative test since the rest energies of the weak events are on the average lower than those of the strong events for these values of $\langle z\rangle$. Thus, the redshift in energy of photons cannot account for the absence of time dilation.

On the other hand, the averaged HR time profiles show a difference between strong and weak subsets (Fig. 6). Both profiles have rather similar shapes with a flat maximum along the rising part of the averaged time histories and a decrease just after the brightest time bin, but the averaged values of HR for strong events are larger than the corresponding averaged values for weak events. A similar correlation between intensity and hardness was found previously for

APEX GRBs[7]. This result also confirms and extends the correlation found previously for BATSE GRBs[8].

IV. CONCLUSIONS

1) The averaged time history of GRBs is non-symmetric: from the level of 0.25 of its maximum height the rise front lasts about 2–3 s and back slope about 4-5 s. The averaged HR profile has a broad maximum along the rise front of the averaged time history, and decreases along its back slope.
2) We find no evidence in this analysis for time-dilation in the averaged time histories of "weak" GRBs relative to "strong" events. If we assume a cosmological scenario, the redshift of narrower temporal structure from higher to lower energies is insufficient to account for the absence of a time dilation effect,
3) We find evidence for differences between strong and weak GRBs in the averaged hardness ratio: strong events have larger HR then weak ones not only averaged over time but also at each point in the averaged time profile. In the absence of a cosmological interpretation, we must then consider the similarities of the HR profiles to indicate their association with the same unique class of radiating objects, but with some important difference between them which leads to a hardness/intensity correlation.

Further analysis is essential to compare the sensitivity of this method with that of other analyses which have been shown to support a cosmological interpretation[9]. We will continue to investigate these issues further with various refinements to our analysis, including a larger sample of bursts, use of data with finer time resolution, and use of data in other energy ranges.

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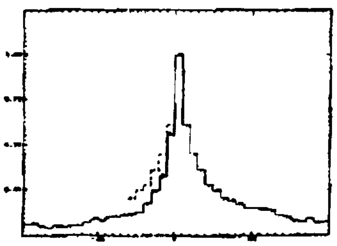

Fig. 1—Flux versus time.

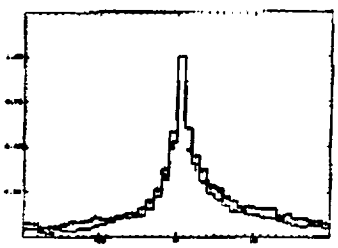

Fig. 2—Flux versus time. Bold line: 50–100 keV. Thin line: 100—300 keV. Dots represent APEX data.

Fig. 3—Hardness ratio versus time.

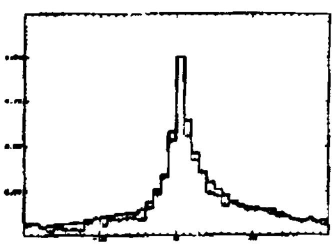

Fig. 4—Flux versus time. Bold line correspond to "strong" events. Thin line corresponds to "weak" events.

Fig. 5—Flux versus time. Bold line correspond to "very strong" events with inner ends stretched by 22% and outer ends stretched by 67%. Thin line corresponds to "very weak" events.

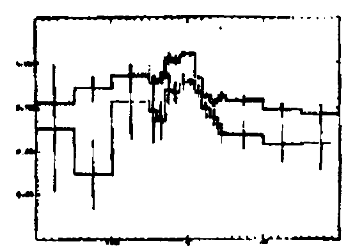

Fig. 6—Hardness ratio versus time. Bold line correspond to "strong" events. Thin line corresponds to "weak" events.