The Direct Test of Cosmological Model for Cosmic Gamma-Ray Bursts Based on the Peak Alignment Averaging

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ABSTRACT

The cosmological origin of cosmic gamma-ray bursts is tested using the method of peak alignment for the averaging of time profiles. The test is applied to the basic cosmological model with standard sources, which postulates that difference between bright and dim bursts results from different cosmological red-shifts of their sources. The average emissivity curve (ACE_{bright}) of the group of bright BATSE bursts is approximated by a simple analytical function, which takes into account the effect of squeezing of the time pulses with increasing energy of photons. This function is used to build the model light curve for ACE_{dim} of dim BATSE bursts, which takes into account both the cosmological time-stretching of bursts light curves and the red-shifting of photons energies. Direct comparison between the model light curve and the ACE_{dim} of dim bursts is performed, which is based on the estimated probabilities of differences between ACEs of randomly selected groups of bursts. It shows no evidence for the predicted cosmological effects. The 3σ upper limit of the average red-shift z_{dim} of emitters of dim bursts is estimated to be as small, as ∼ 0.1 – 0.5, which is not consistent with values ∼ 1 predicted by the known cosmological models of gamma-ray bursts.

Subject headings: cosmology: theory-gamma rays: bursts
1. Introduction

The cosmological model of cosmic gamma-ray bursts is commonly accepted, as one of the most promising concept of the origin of gamma-ray bursts (GRBs). However, it has not been finally approved yet by the observational data. Two critical tests were suggested to verify the basic model with standard cosmological sources: dim bursts have to be time-stretched and red-shifted in comparison with bright events.

Gamma-ray bursts are known to have very different time histories, and one hardly could check the cosmological effects by direct comparison between particular events. These tests should be based on some averaged time-based and spectrum-based signatures, which represent the basic properties of GRBs. Several statistical tests have already been implemented to compare different groups of GRBs and to resolve the predicted cosmological effects. In the case of time-dilation, two scientific groups have checked the average emissivity curves (ACEs) derived from the peak alignment averaging of bright and dim bursts, and came to opposite conclusions: time-dilation of dim bursts was seen by one group (Norris et al. 1994a, 1994b, 1996; Bonnel et al. 1996) and it was not seen by another one (Mitrofanov et al., 1992a,b, 1994, 1996). Possible reasons for disagreement were discussed (Band 1994, Mitrofanov et al. 1996), and the tentative conclusion has been drawn that the claimed dilation of dim bursts was possibly resulted from some systematic in separation of bright and dim groups of events.

On the other hand, in the case of spectral red-shift, all groups involved have a consensus that bright GRBs have larger averaged spectral hardness than dim events. It was named, as the effect of hardness/intensity correlation (Mitrofanov et al. 1992b,c, 1994, 1996; Paciesas et al. 1993, Norris et al. 1994a,b). While this effect was originally seen for the average hardness ratio (defined as the ratio of counts at high and low energy channels), recently it was found also for the average peak energy $<E_p>$ of $\nu F_\nu$ energy spectra (Mallozzi et
The average peak energies $<E_p>$ of the integral spectra of photons were found to correlate with the photons peak fluxes $F_{\text{max}}^{(256)}$ at the 256 ms time scale. The effect of hardness/intensity correlation may be interpreted, as a result of cosmological red-shift of dim gamma-ray bursts in respect to bright events. The corresponding cosmological red-shift factor about 1.6-2.2 (Mallozzi et al. 1995) is consistent with original cosmological models based on the interpretations of log N - log F distribution (e.g. see Emslie and Horrack 1994).

Therefore, there is a discrepancy between different groups about time-dilation of dim GRBs in respect to bright bursts, but, on the other hand, there is an commonly accepted agreement between them for the hardness/intensity correlation.

Separate pulses of GRBs are known to squeeze with increasing energy of photons (Norris et al. 1986, Fenimore et al. 1995), and, therefore, the average curve of emissivity becomes narrower at higher energies (Mitrofanov et al. 1996). According to the cosmological model, when bright and dim bursts are detected at the same energy band in the observer frame of reference, their time profiles were actually emitted at less hard and more hard energy ranges at comoving frames of reference, respectively. Therefore, making a comparison of bright and dim bursts from sources with small and large red-shifts, one should suppose that the intrinsic squeezing of the light curves of dim bursts due to the increase of energy of the emitted photons could partially compensate their stretching due to the cosmological time-dilation.

This paper provides a test of the basic cosmological models of GRBs assuming them to be standard sources. It uses the average emissivity curves for groups of bright and dim bursts and takes into account the effects of cosmological time-stretching in the observer frame together with the internal energy dependent squeezing of bursts light curves in the comoving frames.
2. Analytic Approximation of the Average Curve of Emissivity for Group of Bright GRBs

The average curve of emissivity (ACE) of GRBs was introduced (Mitrofanov et al. 1994, 1996), as a general signature of bursts time variability. To build an ACE, all time histories of averaging bursts should be normalized by peak numbers of counts \( C_{max} \), then should be aligned at their peak bins \( t_{max} \) and then should be averaged at each of another bins. Comparison between the First, the Second and the Third BATSE Catalogs (Fishman et al. 1994, Meegan et al. 1994 and Meegan et al. 1995) has shown that ACE has rather stable shape: it has one peak profile with steep rise front and gentle back slope, and its width decreases with increasing energy of photons used for averaging (Mitrofanov et al. 1994, 1996).

For the present analysis the DISCLA data were used from the large area BATSE detectors (LADs) with 1024 ms time resolution on three discriminator channels, number 1 (25-50 keV), number 2 (50-100 keV) and number 3 (100-300 keV). Two basic intensity groups of BATSE GRBs were selected from the Third BATSE Catalog (3B) (Meegan et al. 1995): 296 bright bursts with \( F_{max}^{(1024)} > 1 \) photons cm\(^{-2}\) s\(^{-1}\) and 332 dim events with \( F_{max}^{(1024)} < 1 \) photons cm\(^{-2}\) s\(^{-1}\). Only bursts with \( t_{90} > 1.0 \)s were taken into account for consideration.

The group of bright bursts is used as the reference sample to find the analytical approximation of \( \text{ACE}_{bright} \) at different discriminator channels (Figure 1). The function

\[
f_{bright}^{(i)}(t) = \left( \frac{t_{0}^{(i)}}{t_{0}^{(i)} + |t - t_{max}|} \right)^{a_{RF}^{(i)}} \qquad (1)
\]

approximates \( \text{ACE}_{bright}^{(i)} \) profiles at each discriminator channel \( i = 1, 2, 3 \) with different power indexes \( a_{RF}^{(i)} \) at the rise front (RF) \( t < t_{max} \) and \( a_{BS}^{(i)} \) at the back slope (BS) \( t > t_{max} \).
respectively. Instead of three different functions (1) for each of three channels, a single function \( f_{\text{bright}}(t, E) \) could be implemented, which approximates the shape of \( \text{ACE}_{\text{bright}} \) at different energies \( E \), which correspond to these channels

\[
f_{\text{bright}}(t, E) = \left( \frac{t_{\text{bright}}(E)}{t_{\text{bright}}(E) + |t - t_{\text{max}}|} \right)^{a_{\text{RF}}(E) a_{\text{BS}}(E)},
\]

where the functions

\[
t_{\text{bright}}(E) = t_{\text{bright}}^{(0)} \cdot (E/173 \text{ keV})^{\alpha_1}
\]

\[
a_{\text{RF}}(E) = a_{\text{RF}}^{(0)} \cdot (E/173 \text{ keV})^{\alpha_2}
\]

\[
a_{\text{BS}}(E) = a_{\text{BS}}^{(0)} \cdot (E/173 \text{ keV})^{\alpha_3}
\]

represent the change of \( \text{ACE}_{\text{bright}} \) shape with energy. A difference between three observed \( \text{ACE}_{\text{bright}}^{i} \) profiles (Figure 1) and the model approximation (2) could be evaluated using the function

\[
S_{\text{bright}} = \sum_i \sum_j \frac{(\text{ACE}_{\text{bright}}^{(i,j)} - f_{\text{bright}}(t_j, E_i))^2}{\sigma^2(\text{ACE}_{\text{bright}}^{(i,j)})}
\]

where \( E_i \) corresponds to mean energies at three discriminator channels \( i = 1, 2, 3 \) and \( t_j \) corresponds to the time bins of ACE curves from \( j = -19 \) up to \( j = +19 \). Errors of observed ACE profiles were estimated from the sample variance.

The parameters of approximation \( t_{\text{bright}}^{(0)} = 1.80_{-0.28}^{+0.33} \) s, \( a_{\text{RF}}^{(0)} = 1.31_{-0.12}^{+0.13} \), \( a_{\text{BS}}^{(0)} = 1.10_{-0.09}^{+0.10} \), \( \alpha_1 = -0.10 \pm 0.16 \), \( \alpha_2 = 0.06 \pm 0.09 \) and \( \alpha_3 = 0.11 \pm 0.08 \) were estimated from the best fitting of all three \( \text{ACE}_{\text{bright}}^{(i)} \) profiles at channels \( i = 1, 2, 3 \). This fitting leads to the minimum \( S_{\text{bright}}^{(\text{min})} \) of Exp.(6), which corresponds to rather small value of the Pearson criterion: reduced \( \chi^2 = 0.66 \) for 108 degrees of freedom. Therefore, one might conclude that
Exp. (2) gives a rather good approximation of the observed $ACE_{bright}$ profiles for the basic group of bright bursts at a broad energy range from 25 up to 300 keV. On the other hand, rather small values of the reduced $\chi^2$ points out that the errors of $ACE_{bright}$ was probably overestimated by the sample variance algorithm, or there were some correlation between them.

However, the Pearson criterion allows to determine the confidence region for the estimated parameters of the fitting function (2). According to Lampton et al. (1976), the confidence region for the significance level $\lambda$ could be determined by the 5-dimensional contour $S_{countur}$ in the 6-dimensional parameter space, which is given by the equation

$$S_{countur} = S_{bright}^{(min)} + \chi^2_6(\lambda), \quad (7)$$

where $\chi^2_6(\lambda)$ represents the value of $\chi^2$ distribution for significance $\lambda$ for 6 degrees of freedom. Errors $\pm 1\sigma$ for each of six parameters, as presented above, were estimated from the condition that Exp. (6) for $S_{bright}$ becomes equal to $S_{countur}$ when the parameter goes up and down from the best fitting value, while another five parameters are used as free parameters for minimization. Therefore, each of these 12 points could be interpreted as $\pm \sigma$ deviations from the minimum point along the axes of corresponding parameter inside a 5-dimensional contour $S_{countur}$.

Actually, these 12 points in the six-dimensional parameter space correspond to 12 fitting models (2) of the $ACE_{bright}^i$ curves. Were taken all together, they would present the $\pm 1\sigma$ corridor of analytical approximations around the best fitting model, which leads to $S_{bright} = S_{bright}^{(min)}$. The boundary curves of this corridor are presented at Figure 1. One might see that all these models provide rather good approximation of all three $ACE_{bright}^i$ profiles measured at three energy discriminitors.
3. Comparison between the average emissivity curves for different groups of bursts

Particular gamma-ray bursts are known to have very different time histories and energy spectra. Therefore, ACE curves could be different for particular groups of bursts randomly selected from the total data base. Groups with $N_{\text{rep}}$ bursts could be defined, as representative samples, provided the differences between their ACEs would be comparable with the errors from the sample variance for each group. For smaller groups with $N < N_{\text{rep}}$ a difference between ACE curves could be significantly larger than it would be expected from the sample variance. Therefore, the comparison of ACE of different groups has to take into account the actual distribution of differences between ACEs profiles due to a random choice of contributing bursts.

Nobody knows how large is the representative sample of time histories of GRBs, but it seems from the comparison of ACE curves for 1B, 2B and 3B databases that $N_{\text{rep}}$ could be about the presently available number of bursts $\sim 10^3$ (Mitrofanov et al. 1997). As it was found there, the Pearson criterion provides a rather sensitive test to measure a difference between ACEs for any two groups of bursts, namely groups I and II, at any discriminator channel $i$:

$$
S_{I-II}^{(i)} = \sum_j \frac{(ACE_{(I)}^{(i,j)} - ACE_{(II)}^{(i,j)})^2}{\sigma^2(ACE_{(I)}^{(i,j)}) + \sigma^2(ACE_{(II)}^{(i,j)})}
$$

The magnitude $S_{I-II}^{(i)}$ was used to compare ACEs profiles for randomly selected groups of events. It was found that groups with $N$ increasing from $\sim 30$ up to $\sim 300$ become more and more representative with respect to the full set. In particular, the probability distribution $P_{300}$ of $S_{I-II}^{(2)}$ at discriminator $i = 2$ was obtained from $10^5$ random choices of two groups with $N=303$ among the total 3B set of 638 BATSE bursts (Figure 2). This
distribution does not depend significantly on the intensity of selected bursts, because the main contribution into $S_{(I-II)}$ comes from the actual difference of their time histories.

Thus, Exp. (8) could be used for direct comparison between ACE profiles of groups of bright and dim bursts, and the significance of a physical difference $S$ between them could be estimated as the probability of obtaining $S$ greater than $S_{(I-II)}$ according to the distribution $P_{300}(S_{(I-II)})$ provided by the Monte Carlo random choice test (Figure 2). This probability distribution will be used below to compare the analytical model based on the ACE$_{\text{bright}}$ of bright bursts and the actual ACE$_{\text{dim}}$ measured for the group of dim events.

4. Direct cosmological Test Based on the Analytic Approximation of the Average Curve of Emissivity

The simplest test of cosmological model of GRBs could be based on the standard candle assumption, which means that everywhere at cosmological distances all sources have the same properties in their comoving frame. This basic version of the cosmological model assumes that all groups of bursts, provided would be averaged in comoving frames, should have the same ACEs. Therefore, any difference between ACEs of bright and dim bursts measured in the observer frame should point out on the cosmological effects.

Let us assume that the emitters of bright and dim bursts have average red shifts $z_{\text{bright}}$ and $z_{\text{dim}}$, respectively. If two standard sources at $z_{\text{bright}}$ and $z_{\text{dim}}$ emit bright and dim bursts with photons energy $E_0$ and variability time scale $\tau_0$, they would be detected in the observer frame at energies $E_{\text{bright}} = E_0/(1 + z_{\text{bright}})$ and $E_{\text{dim}} = E_0/(1 + z_{\text{dim}})$ and with variability at time scales $\tau_{\text{bright}} = \tau_0(1 + z_{\text{bright}})$ and $\tau_{\text{dim}} = \tau_0(1 + z_{\text{dim}})$, respectively. The so-called stretching factor could be introduced
\begin{equation}
Y(z_{\text{bright}}, z_{\text{dim}}) = \frac{1 + z_{\text{dim}}}{1 + z_{\text{bright}}},
\end{equation}

which equals to the ratio of energies of photons \(E_{\text{bright}}/E_{\text{dim}}\) and/or to the ratio of variability time scales \(\tau_{\text{dim}}/\tau_{\text{bright}}\) at the observer frame of reference, provided they were the same in comoving frames.

To test the basic cosmological model, the analytical approximation \(f_{\text{bright}}(t, E)\) (Exp. (2)) should be transformed into the model function \(f_{\text{dim}}(t, E)\) according to cosmological red-shifting and time-stretching transformations, which has to represent the measured \(\text{ACE}_{\text{dim}}\) profiles for the group of dim bursts. According to the assumption of standard candles one should postulate

\begin{equation}
\begin{aligned}
    f_{\text{dim}}(t, E) &= f_{\text{bright}}\left(\frac{t}{Y}, E \cdot Y\right), \\
\end{aligned}
\end{equation}

Using the Exp. (2), one might represent Exp. (9), as the following

\begin{equation}
\begin{aligned}
    f_{\text{dim}}(t, E; Y) &= \left(\frac{Y \cdot t_{\text{bright}}(Y \cdot E)}{Y \cdot t_{\text{bright}}(Y \cdot E) + |t - t_{\text{max}}|}\right)^{a_{RF}(Y \cdot E) \cdot a_{BS}(Y \cdot E)}, \\
\end{aligned}
\end{equation}

which could be used either as a function of one stretching parameter \(Y\), or as a function of two red-shifts \(z_{\text{bright}}\) and \(z_{\text{dim}}\).

Figure 3 presents \(\text{ACE}_{\text{dim}}^{(i)}\) profiles for the basic group of 332 dim bursts from the 3B database with \(F_{\text{max}}^{(1024)} < 1 \text{ photons } \text{cm}^{-2} \text{ s}^{-1}\) observed at three energy discriminators with numbers \(i = 1, 2, 3\). Expression (11) provides a trial function for the \(\text{ACE}_{\text{dim}}^{(i)}\) profiles with the factor \(Y\), as a free parameter. To compare the model with observations, the function \(S_{\text{dim}}\) could be used similar to \(S_{\text{bright}}\) (6). Table 1 presents the best fitting values \(Y^*\) for each of the three \(\text{ACE}_{\text{dim}}^{(i)}\) profiles fitted separately, and one more value for the joint fit of all
three curves together. The errors of $Y^*$ correspond to the range of the best fitting values of $Y$ for the 12 different models (11) based on the initial model (2) with ±σ deviations of its six parameters (see Section 2).

The values of minima $S^{(\text{min})}_{\text{dim}}$ for the best fitting parameters $Y^*$ are rather large, and according to the Pearson criterion, the model of equation (11) does not agree with the observed $\text{ACE}^{(i)}_{\text{dim}}$ profiles for discriminators $i = 1, 3$ and $(1 + 2 + 3)$. Only in the case of discriminator $i = 2$ the model (11) with $Y^* = 0.85-0.87$ formally agrees with the $\text{ACE}^{(2)}_{\text{dim}}$ profile. Moreover, instead of the expected stretching, all the best fitting factors $Y^*$ (Table 1) correspond to squeezing of $\text{ACE}^{(i)}_{\text{dim}}$ profiles with respect to the analytic approximation of $\text{ACE}^{(i)}_{\text{bright}}$ for bright bursts (Exp. (2)).

However, the classical Pearson criterion based on the $\chi^2$-distribution could not be applied in this case, because it does not take into account the actual distribution of differences $S_{\text{(I-II)}}$ between ACEs profiles due to a random selection of contributing events. A more accurate test of the basic cosmological model is done below, which takes into account the probability distribution of $S_{\text{(I-II)}}$ resulting from the random sampling of BATSE bursts (see Section 3). This test has to provide the upper limits of $z_{\text{dim}}$ for the basic cosmological model with standard sources, which could be deduced from the observed profiles of $\text{ACE}_{\text{bright}}$ and $\text{ACE}_{\text{dim}}$.

According to this model, a group of bursts with fluxes $\sim F$ corresponds to a definite red-shift $\sim z$. While in the Euclidean space there is a flux dilution law $\sim R^{-2}$, which establishes the well-known flux/distance relation for standard sources, the non-Euclidean dilution of fluxes from cosmological emitters is influenced by the effects of photon energy red-shifting and light curve time-stretching.

While each burst has a particular energy spectrum, the average spectral distribution could be obtained for any selected group of bursts as well as ACEs were obtained for their
time histories. According to Band et al. (1993), the energy spectra of BATSE bursts $\phi(E)$ could be described by the law

$$\phi(E) = A \cdot \left(\frac{E}{100 \text{ keV}}\right)^\alpha \cdot e^{-\frac{E}{E_{\text{peak}}}}$$  \hspace{1cm} (12)

if

$$E < (\alpha - \beta) \cdot \frac{E_{\text{peak}}}{(2 + \alpha)}$$  \hspace{1cm} (13)

$$\phi(E) = A \cdot ((\alpha - \beta) \cdot \frac{E_{\text{peak}}}{100 \text{ keV}(2 + \alpha)})^{(\alpha - \beta)} \cdot e^{E_{\text{peak}}/100 \text{ keV}} \cdot (\beta - \alpha)\beta$$  \hspace{1cm} (14)

if

$$E > (\alpha - \beta) \cdot \frac{E_{\text{peak}}}{(2 + \alpha)}$$  \hspace{1cm} (15)

where all energies are normalized by 100 keV. The BATSE database includes the spectral data at 2048 ms time scale, which could be used to find the average spectral parameters at peak time intervals. For the group of bright BATSE bursts, the average spectral parameters at the peaks are $<\alpha> = -0.618$, $<E_{\text{peak}}> = 329$ keV and $<\beta> = -3.18$ (Mitrofanov et al. 1997).

According to the concept of standard sources, one could use the average spectra of bright bursts $\phi^{(\text{bright})}(E)$, as a standard distribution of photons for all emitters. Therefore, one might derive a universal relation between the observed photon fluxes $F$ and red-shifts $z$ of corresponding emitters. For two basic groups of 296 bright and 332 dim bursts with average peak fluxes $<F_{\text{max}}^{(\text{bright})}> = 6.15 \pm 0.35$ photons cm$^{-2}$ s$^{-1}$ and $<F_{\text{max}}^{(\text{dim})}> = 0.53 \pm 0.03$ photons cm$^{-2}$ s$^{-1}$, respectively, this relation corresponds to the ratio

$$\frac{<F_{\text{max}}^{(\text{bright})}>}{<F_{\text{max}}^{(\text{dim})}>} = \frac{\int_{E_1}^{E_2} \phi^{(\text{bright})}[E(1 + z_{\text{br}})]dE \cdot R^2(z_{\text{dim}})}{\int_{E_1}^{E_2} \phi^{(\text{bright})}[E(1 + z_{\text{dim}})]dE \cdot R^2(z_{\text{br}})}$$  \hspace{1cm} (16)

where
\[ R = \frac{c}{(1 + z)q_0^2 H_0} \cdot [q_0 z + (1 - q_0)(1 - \sqrt{1 + 2zq_0})] \]  \hspace{1cm} (17)

is cosmological distance to a source, \( H_0 \) is the Hubble constant and \( q_0 \) represent the type of cosmological geometry. The geometry of the Universe with critical density is tested below with \( q_0 = \sigma_0 = 0.5 \). The peak flux (photons cm\(^{-2}\) s\(^{-1}\)) was calculated in the 50-300kev energy range according to 3B Catalog database.

Using the average values \( \langle F_{\text{max}}^{(\text{bright})} \rangle \) and \( \langle F_{\text{max}}^{(\text{dim})} \rangle \) and the average spectral law \( \phi^{(\text{bright})}(E) \), Exp. (16) could be transformed into the relationship between two cosmological parameters: an average red-shift \( z_{\text{dim}} \) of emitters of dim bursts and an average stretching factor \( Y \) between dim and bright bursts. Therefore, the \( z_{\text{dim}} \) value could be implemented into the model function (11) \( f_{\text{dim}}(t, E; z_{\text{dim}}) \), as a free parameter, to check the consistency between the basic cosmological model and observed ACE\( ^{(i)}_{\text{dim}} \) curves for dim bursts.

To do this, one has to put the \( z_{\text{dim}} \) value into the model function \( f_{\text{dim}}(t, E; z_{\text{dim}}) \) and to calculate the difference (6) between the model and the ACE\( ^{(2)}_{\text{dim}} \) profile at the energy discriminator channel \( i = 2 \). The estimated value \( S_{\text{dim}}(z_{\text{dim}}) \) could be corresponded to the probability \( P_{300}(S_{(I-II)}) \) (Figure 2) to find the difference \( S_{(I-II)} \) equal to this value. The integrated probability

\[ P_{300}(z_{\text{dim}}) = \int_{S_{\text{dim}}(z_{\text{dim}})}^{\infty} P_{300}(S_{(I-II)})dS_{(I-II)} \]  \hspace{1cm} (18)

could be interpreted, as the probability that cosmological model with \( z_{\text{dim}} \) is consistent with observed ACE\( _{\text{dim}} \) profile. Changing \( z_{\text{dim}} \), one might create this way the probability function \( P_{300}(z_{\text{dim}}) \) (Figure 4).

To take into account errors in the parameters of the basic analytical model of \( f_{\text{bright}}(t, E) \), the main theoretical model (11) was used together with 12 additional models
with $\pm \sigma$ deviations from the best fitting parameters $(3)$. They compose the $1\sigma$ corridor of models around the medium curve which corresponds to the best one (see Figure 4).

It was found that the probability $P(z_{\text{dim}})$ decreases with increasing $z_{\text{dim}}$ becoming as small as the level $\sim 3 \cdot 10^{-3}$ of $3\sigma$ fluctuations at $z_{\text{dim}} = 0.07 - 0.09$ (Figure 3). Therefore, one might consider the value $\sim 0.1$, as the $3\sigma$ upper limit for average red-shift of emitters of the basic group of 332 dim bursts with $F_{\text{max}}^{(1024)} < 1$ photons cm$^{-2}$ s$^{-1}$.

Two groups of bright and dim bursts are used for this estimation which been separated by the peak flux $F_{\text{max}}^{(1024)} = 1$ photons cm$^{-2}$ s$^{-1}$. In this case one has the largest possible number of events in each sample, $\sim 300$, with the ratio of corresponding average peak fluxes of two samples $\sim 12$. However, one might suspect that selected sample of $\sim 300$ bright bursts might contain a large deal of bursts at cosmological distances, and, as such, a time dilation between bright and dim samples could be difficult to resolve.

Formally speaking, this statement is not correct: in accordance with the basic cosmological model, the increase of $z_{\text{bright}}$ value for the bright group results to more and more pronounced cosmological stretching of bursts from the dim sample, provided the ratio of their average peak fluxes is fixed. Indeed, the Exp. (16) points out that for a given ratio of peak fluxes $<F_{\text{max}}^{(\text{bright})}> / <F_{\text{max}}^{(\text{dim})}>$ an increase of $z_{\text{bright}}$ from the value 0 leads to increase of stretching factor $Y(z_{\text{bright}}, z_{\text{dim}})$. Thus, for the ratio $<F_{\text{max}}^{(\text{bright})}> / <F_{\text{max}}^{(\text{dim})}> = 11.6$ one might find $Y = 1.2, 1.6$ and 1.8 and $z_{\text{dim}} = 0.3, 1.1$ and 1.7 for $z_{\text{bright}} = 0.1, 0.3$ and 0.5, respectively.

The found $3\sigma$ upper limit $z_{\text{dim}} \sim 0.08$ corresponds to the stretching factor $Y \sim 1.05$ and $z_{\text{bright}} = 0.03$. One might conclude that the basic cosmological model with $\sim 300$ standard emitters of bright and dim bursts is consistent with the observed ACE$_{\text{bright}}$ and ACE$_{\text{dim}}$ curves, provided their red-shifts are $z_{\text{bright}} < 0.03$ and $z_{\text{dim}} < 0.1$, respectively.
However, even taking into account the argument above, one could apply the proposed redshifting technique to perform a more conservative comparison between two samples of bright and dim bursts, which could be selected by a more stringent criterion based on the slope of $\log N - \log F$ distribution, and which would be truly isolated one from another by the sample of intermediate events in between.

Let us select two samples of 102 brightest bursts with $F_{\text{max}}^{\text{brightest}} > 4.0$ photons cm$^{-2}$ s$^{-1}$ and 100 dimmest events with $F_{\text{max}}^{\text{dimmest}} < 0.41$ photons cm$^{-2}$ s$^{-1}$. The brightest sample corresponds to the -3/2 part of the $\log N - \log F$ distribution (see 3B catalog, Meegan et al. 1995). There is about $\sim 400$ bursts with medium peak fluxes in between the brightest and the dimmest samples, and the ratio of the average peak fluxes $<F_{\text{max}}^{\text{brightest}}>/ <F_{\text{max}}^{\text{dimmest}}>$ = 49.8 is as large as possible to imply the largest cosmological stretching between them.

For the new sample of the brightest 102 bursts the analytical approximation (2) corresponds to the best fitting parameters, which all agree quite well with the estimated $\pm 1\sigma$ corridor with the basic sample of 296 bright bursts. The best fitting parameters for the ACE$^{\text{brightest}}$ curve are $t^{(0)}_{\text{brightest}} = 1.88$ s, $\tilde{a}_{RF}^{(0)} = 1.37$, $\tilde{a}_{BS}^{(0)} = 1.26$, $\tilde{\alpha}_1 = -0.25$, $\tilde{\alpha}_2 = 0.065$ and $\tilde{\alpha}_3 = 0.075$. Similarly to (11), these new parameters could be used to build the trial function $f_{\text{dimmest}}(t, E; Y(z_{\text{brightest}}, z_{\text{dimmest}}))$ (11) to fit the ACE$^{\text{dimmest}}$ curve of the sample of 100 dimmest bursts.

The best fitting values of $Y^{**}$ equal 1.01, 0.80 and 0.88 for ACE$^{(i)}_{\text{dimmest}}$ at the three energy discriminators with numbers $i = 1, 2$ and 3, respectively. The corresponding values of reduced $\chi^2$ are 2.95, 3.20 and 1.90, respectively. Therefore, the best fitting stretching factors $Y^{**}$ between the samples of the dimmest and the brightest bursts do not manifest any stretching. These values are similar to the best fitting factors between the basic samples of $\sim 300$ bright and dim bursts, and they all are consistent with the absence of any
However, to find the upper limit of the stretching factors between the two samples of brightest and dimmest events, one has to compare the trial model $f_{\text{dimmest}}(t, E; z_{\text{dimmest}})$ (Exp. 11) with the ACE$_{\text{dimmest}}$ curve taking into account the sampling statistics of two groups. The probability distribution $P_{100}(S(t-II))$ has to be used for the two sets of $\sim 100$ events (see Section 3). According to Mitrofanov et al. (1997), the distribution of $P_{100}(S(t-II))$ will have the same shape as the distribution $P_{300}(S(t-II))$ for sets with $\sim 300$ events. Therefore, the value of $S(t-II)$ for the 3$\sigma$ limit will be about the same. However, because of smaller statistics, for samples with $\sim 100$ events the function (8) has denominator in $\sim 3$ times larger than for samples with $\sim 300$ events, and therefore, the difference between two ACEs profiles allowed by 3$\sigma$ limit could be in $\sim 1.7$ times larger.

Similarly to the basic case of two samples of $\sim 300$ bursts, the new samples of $\sim 100$ brightest and dimmest events are compared by the proposed technique, when for selected values of $z_{\text{dimmest}}$ the probability $P_{100}(z_{\text{dimmest}})$ is estimated (see (18)) to get the found difference between the model profile $f_{\text{dimmest}}(t, E; z_{\text{dimmest}})$ and the observed ACE$_{\text{dimmest}}$ curve at the third energy discriminator channel. The corresponding probability function $P_{100}(z_{\text{dimmest}})$ is presented at the Figure 5. The 3$\sigma$ upper limit of the $z_{\text{dimmest}}$ value is 0.46.

Thus, when two samples of the brightest and the dimmest bursts with $\sim 100$ events are compared, no significant increase is found for the best fitting stretching factors in comparison with the case of two basic samples of $\sim 300$ bright and dim bursts. At both cases one does not see any evidence for stretching effect at all. Using the sampling statistics of bursts, the 3$\sigma$ upper limits are estimated of $z_{\text{dim}}$ for $\sim 300$ dim bursts and of $z_{\text{dimmest}}$ for $\sim 100$ dimmest events, which equal $\sim 0.1$ and $\sim 0.5$, respectively. One could suspect that the larger upper limit in the second case results from the smaller sampling statistics of groups of $\sim 100$ bursts, and it hardly provides more evidence for cosmological stretching in cosmological stretching.
comparison with the basic case of groups of $\sim 300$ events.

However, formally speaking, one has to conclude that the basic cosmological models with standard candles are still allowed for gamma-ray bursts provided they correspond to the $3\sigma$ upper limit $z_{\text{dim}} < 0.1$ for the group of dim bursts with $F_{\text{max}}^{(\text{dim})} < 1.0$ photons cm$^{-2}$ s$^{-1}$ or to the upper limit $z_{\text{dimmest}} < 0.5$ for the group of the dimmest bursts with $F_{\text{max}}^{(\text{dimmest})} < 0.41$ photons cm$^{-2}$ s$^{-1}$. These limits resulted from the different sampling statistics of these groups, and further observations of bursts will allow either to decrease these limits, or to resolve the time-stretching effect of dim gamma-ray bursts with respect to bright ones.

Two different average photon spectra with power laws $\alpha = 1$ and $\alpha = 2$ were used for the test of the basic samples also. At the plane $P_{300}(z_{\text{dim}})$ versus $z_{\text{dim}}$ these models correspond to upper and lower lines around the main curve, which was found for the average energy spectra (Figure 6). Therefore, the shape of the photon energy spectra does not affect significantly the upper limit of $z_{\text{dim}}$. The upper limits of $z_{\text{dim}}$ could be estimated also for different parameters of cosmological geometry. Two curves for chance probability $P_{300}(z_{\text{dim}})$ were derived for two different sets of cosmological parameters (Figure 7): $q_0 = \sigma_0 = 0.1$ (open Universe) and $q_0 = \sigma_0 = 1.0$ (closed Universe). One might see that these cases of the Universe geometry lead to $3\sigma$ upper limits $z_{\text{dim}} \sim 0.08$ about the same as the case of flat expanding Universe ($q_0 = \sigma_0 = 0.1$).

5. Discussion and Conclusions

So, the performed comparison of the ACE profiles for groups of bright and dim bursts does not allow $z_{\text{dim}}$ larger than $\sim 0.1 - 0.5$ for the basic cosmological model with standard sources. Moreover, the $ACE - based$ limit of red-shift of dim bursts agrees with
non-cosmological models of GRBs in the flat Euclidean space.

There are two well-known estimations of the red-shifts of emitters of GRBs according to cosmological models. The first one is based on the average parameter $<V/V_{\text{max}}>=0.33 \pm 0.01$ for 3B data base (Meegan et al. 1995). One should expect to have $<V/V_{\text{max}}>=0.50$ for homogeneous distribution of standard sources in the Euclidean space. On the other hand, the observed parameter $<V/V_{\text{max}}>$ is consistent with the non-Euclidean geometry of expanding Universe. For distant emitters of dim bursts the $\text{geometry - based}$ upper limit of red-shift was estimated about 0.5-2.0 (Wickramasinghe et al. 1993). Taking into account the coupling between the spectral shape and the temporal profiles of bursts, Fenimore and Bloom (1995) have obtained much larger upper limit $\sim 2-6$.

Another estimation of cosmological limit of the red-shift was based on the effect of hardness/intensity correlation of GRBs. The average peak of $\nu F_{\nu}$ spectra of dim bursts was found to be much softer than the average peak of bright bursts (Mallozzi et al. 1995). The corresponding ratio between peak energies of dim and bright bursts leads to the $\text{spectra - based}$ upper limit of red-shift, which was estimated about $\sim 1$.

There is an agreement, at least qualitative, between $\text{geometry - based}$ and $\text{spectra - based}$ upper limits of red-shifts of distant emitters of GRBs. These estimations result to $z_{\text{dim}} \sim 1$ or even much larger. On the other hand, the $ACE - based$ upper limit of $z_{\text{dim}} \sim 0.1 - 0.5$ does not agree with either the $\text{geometry - based}$ or the $\text{spectra - based}$ limits. Therefore, the basic model of GRBs with standard cosmological sources is not with all available constraints. This is the main conclusion of the present paper.

Developing a cosmological model of GRBs, one should postulate some kind of $z$-dependent property(ies) of outbursting sources which could ensure the consistency. Generally speaking, $z$-dependence could be attributed to different properties of bursts sources, such as outbursts rate density, bursts luminosity, average energy spectra and
average light curves. There is a reasonable consistency between geometry-based and spectra-based limits of red-shifts of dim bursts emitters. Therefore, one might not suggest any intrinsic $z$-dependence either for the outbursts rate density, or for the energy spectra of the emitted gamma-rays, because they would both lead to consistent limits of $z$ for the model with standard sources. On the other hand, to make the agreement between them and the $ACE$-based limit, one could postulate some sort of intrinsic evolution of outbursting sources which leads to intrinsic squeezing of their light curves with increasing red-shifts. There are physical conditions in local cosmological space which vary with $z$: the local density of matter, the local temperature of microwave background, etc., but at the present time no one knows how much these conditions could actually influence on bursts’ light curves, if they could at all. Obviously, $a$ priori there is no physical reason to propose this kind of evolution, and it could be considered as a pure phenomenological speculation.

In addition to $ACE$-based test, the time-dilation tests should also be done with another time-based parameters of bright and dim GRBs, such as pulse width, interpulse duration, etc. Comparison of distinct time-based signatures for different intensity groups of bursts would allow to distinguish the basic effect of cosmological time-stretching and energy red-shifting, which should be identical for all time-energy signatures, from another effects resulted from $z$-dependent evolution, which should be different for each of temporal parameters. The cosmological paradigm of GRBs could be finally approved at these tests, and new knowledge would be obtained about intrinsic properties of close and distant GRBs sources in the co-moving reference frames. This studies will be done elsewhere.

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Table 1. Best fitting factors $Y^*$ for $\text{ACE}^{(i)}_{\text{dim}}$

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<th>Energy range, keV</th>
<th>Best fit</th>
<th>Reduced $\chi^2$</th>
<th>$P(&gt; \chi^2)$</th>
<th>DOF</th>
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<td>25-50</td>
<td>0.81±0.02</td>
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<tr>
<td>25-300</td>
<td>0.84±0.02</td>
<td>2.0</td>
<td>&lt; 10$^{-6}$</td>
<td>113</td>
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REFERENCES


This manuscript was prepared with the AAS L\TeX macros v4.0.
Fig. 1.— At the left line three viewgraphs for $\text{ACE}_{\text{bright}}$ profiles are presented for three discriminator channels number $i = 1, 2, 3$. The best fitting approximation profiles (2) are shown for each ACE. At the bottom viewgraph ($i = 3$) the model for $i = 1$ is shown (dash line) to demonstrate the energy dependence of ACE. At the right line three zooms of corresponding ACEs are presented to show the quality of approximations and the boundaries of $\pm \sigma$ corridor of models around the best ones.

Fig. 2.— The probability distribution of $S^{(2)}$ values divided by number of ACE bins (38) for energy discriminator $i = 2$. It is provided by $10^5$ random choices of two groups of 303 bursts among the total set of 3B database. The value corresponding to $3\sigma$ standard deviation is shown by dotted-dashed line. One sees that sampling statistics allows much larger difference between two sets of bursts than it could be expected from the sample variance for each of them.

Fig. 3.— $\text{ACE}^{(i)}_{\text{dim}}$ profiles for 332 dim bursts with $F_{\text{max}}^{(1024)} < 1$ photons cm$^{-2}$ s$^{-1}$. The best fitting models (11) of ACEs at each discriminator channel are shown by solid lines.

Fig. 4.— The estimated probability $P_{300}(z_{\text{dim}})$ of consistency is shown between the model curve (11) based on the $\text{ACE}_{\text{bright}}$ profiles and the standard cosmological model and the observed $\text{ACE}_{\text{dim}}$ profile at the second ($i = 2$) discriminator channel. The dashed region represents the probabilities for $\pm \sigma$ corridor of models around the best one. The dotted-dashed line shows the probability level of standard $3\sigma$ fluctuations.

Fig. 5.— The estimated probability $P_{100}(z_{\text{dim}})$ of consistency is shown between the model curve (11) based on the $\text{ACE}_{\text{brightest}}$ profiles and the standard cosmological model and the observed $\text{ACE}_{\text{dimnest}}$ profile at the third ($i = 3$) discriminator channel. The dotted-dashed line shows the probability level of standard $3\sigma$ fluctuations.

Fig. 6.— The same probability $P_{300}(z_{\text{dim}})$ is shown as at the Figure 4 (solid line) together
with two another estimations based on the energy spectra with power law: dashed and dotted lines correspond to $\alpha = 1$ and $\alpha = 2$, respectively.

Fig. 7.— The same probability $P_{300}(z_{dim})$ is shown as at the Figure 4 (solid line) together with two estimations corresponded to another models of Universe: dashed and dotted lines correspond to $q_0 = 0.1$ and $q_0 = 1.0$, respectively.