AVERAGE COSMOLOGICAL INVARIANT PARAMETERS OF COSMIC GAMMA-RAY BURSTS

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ABSTRACT

Average cosmological invariant parameters (ACIPs) are calculated for six groups of BATSE cosmic gamma-ray bursts selected by their peak fluxes on the 1.024 s timescale. The ACIPs represent the average temporal and spectral properties of these events equally in the observer frame of reference and in the comoving frames of outbursting emitters. The parameters are determined separately for rise fronts and for back slopes of bursts, defined as the time profiles before and after the main peaks, respectively. The ACIPs for the rise fronts are found to be different for different intensity groups, while the ACIPs for the back slopes show no significant dependence on intensity. We conclude that emitters of bursts manifest standard average properties only during the back slopes of bursts.

Subject headings: gamma rays: bursts — methods: statistical

1. INTRODUCTION

The isotropy of gamma-ray bursts (GRBs) on the sky combined with the significant deviation of the log $N$/$\log P$ curve from a $-3/2$ power law (Meegan et al. 1992) gave the first clear evidence that sources of gamma-ray bursts are at cosmological distances, where the deficit of the observed number of dim events is a direct consequence of the non-Euclidean nature of the expanding universe (Paczynski 1986). Strong evidence in favor of the cosmological paradigm has recently been provided by the detection of redshifted spectral lines from the optical counterparts of GRBs 970508 (Metzger et al. 1997) and GRB 971214 (Kulkarni et al. 1998).

As soon as the cosmological paradigm became popular for GRBs, two effects were suggested to test it using the observational data of GRBs. The first one is the effect of cosmological redshift, which predicts that the energy of spectral features of dimmer bursts should be redshifted with respect to similar features of bright events. The second one is the complementary effect of cosmological time dilation, which predicts that light curves of dimmer bursts should be time stretched with respect to those of brighter events.

Since both effects are associated with the geometry of the expanding universe, we will refer to them as geometrical effects. The transformation factors are known to be

$$Y(z_{\text{br}}, z_{\text{dim}}) = (1 + z_{\text{dim}})/(1 + z_{\text{br}}),$$

where $z_{\text{br}}$ and $z_{\text{dim}}$ are the redshifts of emitters of bright and dim bursts, respectively.

If the brightest bursts are associated with the nearest objects and the dimmest bursts are related to the farthest emitters, their intensities could be used to determine distances to the corresponding emitters. In this case the cosmological effects should lead to a hardness-intensity correlation (due to the redshift) and a stretching-intensity anticorrelation (due to the time dilation).

However, GRBs are known to be very different from each other. In searching for the generic effects of hardness-intensity correlations and stretching-intensity anticorrelation between different intensity groups, one has to identify generic signatures among the divergence of properties of individual events to represent the properties of typical burst emission.

Using such signatures, the effects of hardness-intensity correlation and stretching-intensity anticorrelation have been studied by comparing groups of BATSE bursts with different brightnesses. The average peak energy $E_p$ of $\nu F_\nu$ spectra was found to show a hardness-intensity correlation consistent with cosmological redshift (Mallozzi et al. 1995), and there is evidence that the average emissivity curves of dimmer bursts are stretched relative to those of brighter bursts, although the results of different analyses are not entirely consistent (Norris et al. 1994, 1998; Mitrofanov et al. 1996, 1999). The possibility that the stretching of dimmer bursts might result from a selection effect has been considered, and it has been shown that it is not the case (Wijers & Paczynski 1994). On the other hand, it is also not clear that the results of redshift and time dilation studies agree with each other (Mitrofanov 1996).

On the other hand, the logically simple concept that burst intensities are "standard candles" may not be correct. It has been shown (Brainerd 1997) that the broad spread of observed intensities of bursts could result from a broad spread of intrinsic luminosities of emitters. Also, three bursts with measured redshifts of afterglowing optical emission have gamma-ray luminosities differing over a range of $\sim 20$ times. Despite the small sample size, these three events provide quite good evidence that GRBs are not standard candles. The correlations of burst hardness and duration with intensity could be related in this case to the intrinsic properties of sources rather than to geometrical effects of cosmological space (Mitrofanov et al. 1997a). Furthermore, one should take into account that the astronomical population of emitters could be quite different at close and distant cosmological distances. In this case the difference between brightness groups could reflect the intrinsic evolution of sources rather than cosmological effects.

Therefore, to test the cosmological paradigm it is necessary to separate in the data the geometrical effects due to

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cosmological expansion of the universe from the physical effects due to the intrinsic luminosity-based correlation of emitters and the astronomical effects due to the evolution of sources over the different redshifts.

2. DOUBLE-PEAK ENERGY AS A BURST SPECTRAL PARAMETER

To compare the average temporal and spectral signatures of GRBs with different brightness, six intensity groups, each consisting of ~100 bursts, were selected by their peak fluxes $F_{\text{max}}$ on the 1024 ms timescale in the 3B BATSE Catalog (Meegan et al. 1996), as shown in Table 1.

The time profile of each burst has a well-defined moment $t_{\text{max}}$ when the observed flux reaches a maximum, $F_{\text{max}}$. One might postulate that peaks are associated with some particular physical transition, when the average rising trend of intensity before the peak is converted into the decaying tail after that. The procedure of peak alignment has the physical effect of combining all bursts together at the same stage of the emission process. On the other hand, the $vF_{\nu}$ energy spectrum of burst emission usually has a well-defined peak energy $E_{p}$, but $E_{p}$ typically varies with time during a burst. One could, however, introduce a single-valued spectral parameter for each burst, which is the peak energy $E_{p,\text{max}}$ of the spectrum at the time of peak photon flux $F_{\text{max}}$. We will refer to $E_{p,\text{max}}$ as the double-peak energy, which corresponds to photons with the largest spectral density of emission.

We evaluated the double-peak energy $E_{p,\text{max}}$ for each BATSE burst using the CONT data, which has a time resolution of 2048 ms (Anfinnov et al. 1998). The distributions of these energies for the reference group and for the dimmest intensity group are shown in Figure 1. The observed distributions for these groups might be compared with K-S test provided that the reference group is shifted leftward to match the curves for the dimmer groups. The lowest K-S probability is equal to 0.3 for the comparison between the reference group and the dimmest intensity group when they are shifted to the same mean. The present data allow us to measure with statistical significance these shifts, but do not reveal any difference in the shapes. We might assume that there is a universal lognormal law for all these distributions, which can be parameterized using a set of redshifting factors $Y^{(i)}$, defined by shifting the lognormal distribution for the brightest reference group ($i = 1$) to provide the best fit for the corresponding distributions of the dimmer intensity groups ($i = 2$–6).

Table 1 shows the best-fitting shift factors and the lognormal average values $E^{(i)} = \langle E_{p,\text{max}}^{(i)} \rangle$ for our selected intensity groups. The differences between them show the effect of the hardness-intensity correlation of GRBs. Basically, the ratios between the average double-peak energies for different brightness groups $E^{(1)}/E^{(6)}$ are very close to the best-fitting shifting factors $Y^{(6)}$. The difference of the average peak fluxes between the 100 brightest and 100 dimmest bursts is a factor of ~43, while the corresponding lognormal average values of the double peak energy differ by a factor of ~3 (Table 1).

3. EQUIVALENT TIME WIDTH AS A BURST TEMPORAL PARAMETER

A robust temporal parameter for bursts is very difficult to define. Bursts have a variety of light curves, and for many of them the light curves are very complex. The evaluation of a duration-type parameter depends on the sensitivity of the instrument, its energy range, and its time resolution. The best known parameters $t_{50}$ and $t_{90}$, attribute definite durations to any individual burst, but there are several statistical biases that could affect the results when statistical studies are performed using them.

Below we suggest another duration-type parameter that could be associated with a group of bursts. It was defined using the average emissivity curves (ACE; Mitrofanov et al. 1998). The time profile of each burst has a well-defined moment $t_{\text{max}}$ when the observed flux reaches a maximum, $F_{\text{max}}$. One might postulate that peaks are associated with some particular physical transition, when the average rising trend of intensity before the peak is converted into the decaying tail after that. The procedure of peak alignment has the physical effect of combining all bursts together at the same stage of the emission process. On the other hand, the $vF_{\nu}$ energy spectrum of burst emission usually has a well-defined peak energy $E_{p}$, but $E_{p}$ typically varies with time during a burst. One could, however, introduce a single-valued spectral parameter for each burst, which is the peak energy $E_{p,\text{max}}$ of the spectrum at the time of peak photon flux $F_{\text{max}}$. We will refer to $E_{p,\text{max}}$ as the double-peak energy, which corresponds to photons with the largest spectral density of emission.

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### Table 1: Characteristics of Six Selected Intensity Groups

| Intensity Group | Peak Flux ($\gamma$ cm$^{-2}$ s$^{-1}$) | Average Peak Flux ($\gamma$ cm$^{-2}$ s$^{-1}$) | $\langle E_{p}\rangle$ (keV) | $Y^{(1)}$ | $t_{50}$ (s) | $t_{90}$ (s) |
|----------------|--------------------------------------|-----------------------------------------------|----------------------------|----------|------------|------------|
| 1 .................. | >3.8 | 14.2 ± 1.4 | 293 ± 23 | 1.0 | 4.1 ± 0.5 | 4.6 ± 0.6 |
| 2 .................. | 1.6–3.8 | 2.4 ± 0.3 | 235 ± 21 | 1.22 ± 0.12 | 4.7 ± 0.6 | 7.3 ± 0.9 |
| 3 .................. | 0.95–1.6 | 1.2 ± 0.1 | 160 ± 12 | 1.82 ± 0.35 | 4.9 ± 0.6 | 8.8 ± 1.1 |
| 4 .................. | 0.62–0.95 | 0.77 ± 0.08 | 134 ± 14 | 2.07 ± 0.20 | 4.6 ± 0.6 | 8.0 ± 1.0 |
| 5 .................. | 0.43–0.62 | 0.51 ± 0.05 | 116 ± 12 | 2.58 ± 0.23 | 5.3 ± 0.7 | 10.2 ± 1.3 |
| 6 .................. | <0.43 | 0.33 ± 0.03 | 97 ± 10 | 2.92 ± 0.10 | 4.5 ± 0.6 | 12.4 ± 1.6 |
The ACE is known to be a quite robust signature for any large group of bursts. This ACE profile represents the slow component of burst variability, which can be interpreted as the general envelope of individual light curves. By its nature, the ACE averages over the faster variability, leaving only the signature of slow clocks, so in computing the ACE of BATSE GRBs we can use the DISCLA and CONT data, which have 1024 and 2048 ms time resolution, respectively. The ACE intermixes individual events with all their particular time profiles and represents them by one profile, which is a single asymmetric peak with steeper rise front and flatter back slope. Therefore, for each intensity group $i$ the ACE profile can be used to estimate the average duration of rise fronts and back slopes for averaged events.

Although the BATSE data set is large, the variety of burst time profiles is such that we must consider its effect on the variance among finite samples. We have found by direct comparison of ACE profiles for different samples of BATSE bursts that they were much more distinct than would be expected from the errors of sample variance for individual samples. This means that a random sample of bursts for individual groups does not ensure the well-weighted contribution of events with all kinds of profiles. To study the random choice statistics of bursts, a special Monte Carlo simulation was performed using the total set of 603 bursts in the 3B Catalog with durations $t_{00} > 2$ s (Mitrofanov et al. 1999; Litvak et al. 1998). Indeed, the distributions of stretching coefficients $Y$ due to statistics of random choice were found to be much broader than expected from the sample variance predicted by normal statistics. From the simulations, the $1 \sigma$ deviation around a nonstretched value $Y \sim 1$ for a sample of $N$ bursts was found to be

$$\frac{\delta Y}{Y} = 0.13 \frac{100}{\sqrt{N}}. \quad (2)$$

This value can be used as an estimate of the error in stretching factors between ACEs for any two groups of $N$ bursts. The present size of our selected intensity groups (Table 1) allows us to resolve stretching at $\sim 3 \sigma$ significance between them provided the effect is larger than $\sim 1.41$ (Mitrofanov et al. 1999; Litvak et al. 1998).

There is a simple analytic form that provides a very good fit to the ACE profile $\Phi(t)$ for time intervals of 20–50 s around the maximum:

$$\Phi(t) = \left( \frac{t_0}{t_0 + |t - t_{\text{max}}|} \right)^a, \quad (3)$$

where the exponent $a$ has different values $a_{\text{RF}}$ and $a_{\text{BS}}$ for the rise front (RF) and back slope (BS), respectively. This law allows us to take into account the energy dependence of ACEs (Mitrofanov et al. 1997b) by interpolating in energy between the parameters $a_{\text{RF}}$, $a_{\text{BS}}$, and $t_0$ measured for ACEs in three BATSE discriminator channels (25–50 keV, 50–100 keV and 100–300 keV). It also allows us to use a time-efficient procedure to estimate the relative time-stretching factor between ACE profiles for any two samples with different intensity (Mitrofanov et al. 1999).

The procedure to build the ACE includes the selection of the highest peak of each burst $C_{\text{max}}$ in count space and the normalization of time profiles by the $C_{\text{max}}$ value. Therefore, the ACE is sensitive to a bias resulting from the domination of positive fluctuations in the selected peaks. As a result of this bias, the ACE profile is systematically lower in both wings; i.e., the measured value is narrower than the true value. The bias is stronger for dimmer bursts, where the influence of positive fluctuations is larger. To take this into account, our reference group $i$ (the brightest one) was transformed into an artificial reference group by Monte Carlo noisification, having the same event profiles but with dimmer peak fluxes. When the reference group $i$ was dimmed down to the level of the dimmest group 6, the noise-produced ACE was found to be different than the original ACE by a factor of $\sim 0.8$ (i.e., narrower; see Mitrofanov et al. 1999).

To estimate the average equivalent time width for the brightest reference group $i$, the observed ACE profiles in three energy ranges $j = 1$ (25–50 keV), $j = 2$ (50–100 keV), and $j = 3$ (100–300 keV) were used as they are. The bias due to positive fluctuations is assumed to have no influence on this group. Using the $ACE^{(1,j)}$ profiles, we calculated average equivalent widths in each of three energy channels $j$ as

$$\tau_{\text{RF,BS}}^{i(1,j)} = \int dt \Phi_{\text{RF,BS}}^{i(1,j)}(t) \quad (4)$$

for the rise front and back slope, respectively. The values of $\tau^{(1,j)}$ were then interpolated over the broad energy range 25–300 keV, and the equivalent width was determined at the double-peak energy $E^{(1)} = 293$ keV. The values of $\tau^{(1,j)}(E^{(1)})$ for rise front and back slope are the temporal parameters $\tau_{\text{RF,BS}}^{i(1,j)}$ for the reference group 1 (Table 1). Physically, $\tau$ represents the average duration of emission either over the rise or over the decay at the spectral range around the double-peak energy $E_{p,\text{max}}$.

$\text{ACE}^{i,j}$ profiles for dimmer groups ($i = 2–6$) can be used similarly to estimate temporal parameters, provided that they are corrected for the noise-produced narrowing of ACEs. For a given intensity group $i$, an artificial reference group $i'$ was created from the events of the reference group 1 by Monte Carlo noisification, in which the reference bursts are reduced in intensity to the fluxes of group $i$ and noise added corresponding to the noise level of group $i$. The artificial reference group $i'$ therefore represents the original group 1, but takes into account the noise-produced effects. Therefore, to evaluate the noise-corrected average stretching between the testing group $i$ and the reference group 1 for energy channel $j$, we measured the stretching factors $Y_{i,j}^{(0)}$ between the $\text{ACE}^{i,j}$ of the actual dim group $i$ and the $\text{ACE}^{i,j}$ of the artificial reference group $i'$. We calculated $Y_{i,j}^{(0)}$ separately for rise fronts and back slopes for intensity groups $i = 2–6$ in three energy ranges $j = 1–3$. Using these factors, the parameters of equivalent width of $\text{ACE}^{i,j}$ could be defined for the energy channels $j$ as

$$\tau_{\text{RF,BS}}^{i,j} = \tau_{\text{RF,BS}}^{i,j(1)} Y_{i,j}^{(0)}. \quad (5)$$

These values are corrected for the noise-produced narrowing of ACEs because they are determined from the stretching factors between the testing dim groups and the corresponding artificially noisified reference groups. The single-value temporal parameters $\tau^{(0)}(E^{(0)}) = \tau^{(0)}$ were interpolated between the values $\tau_{\text{RF,BS}}^{i,j}$ for three discriminator channels $j = 1–3$ at the double-peak energies $E^{(0)}_{p,\text{max}}$. The parameters $\tau^{(0)}$ are presented in Table 1 for rise fronts and back slopes of bursts. Their errors are estimated from the choice statistics for stretching factors $Y_{i,j}^{(0)}$. The rise front equivalent widths $\tau_{\text{RF}}^{(0)}$ do not show a correlation with burst intensity. On the other hand, the back slope equivalent...
The average double-peak energy $E_{\text{p,max}}^{(i)}$ and the equivalent time width $t_\text{RF}^{(i)}$ at the double-peak energy are very useful parameters for testing the cosmological paradigm. Indeed, the energy-dimension parameters $E_{\text{p,max}}^{(i)}$ represent *spectral signatures* that have the same physical sense for all bright, medium, and dim groups of bursts. The time-dimension parameters $t_\text{RF}^{(i)}$ represent *temporal signatures* that are also well defined for all groups of bursts.

We have found that these parameters vary significantly among the different intensity groups. However, the differences between them could be caused either by the purely *geometrical* transformations of redshift and time dilation in the expanding universe or by a *physical* variation among the outbursting sources in the comoving frames. These two parameters cannot by themselves be used to perform a model-independent test of the cosmological paradigm of GRBs. One must either postulate some intrinsic properties of emitters and then resolve the cosmological transformations of observed GRBs or postulate the geometrical effects of time dilation and energy redshift and then deconvolve properties of observed bursts into the intrinsic properties of emitters.

As an alternative, we wish to find a special observational parameter for any selected sample of gamma-ray bursts that does not depend on the geometrical effects of the universe extension, and which we call an *average cosmological invariant parameter* (ACIP; Mitrofanov et al. 1998). Let us assume that some brightness group $i$ corresponds to emitters with redshifts around some average value $z_\text{avg}^{(i)}$ and the corresponding equivalent width and double-peak energy equal to $w_\text{RF}^{(i)}$ and $E^{(i)}_{\text{p,max}}$ in the comoving frame, respectively. Then, since a time-dimensional average parameter is increased by a factor $1 + z_\text{avg}^{(i)}$, giving $t_\text{RF}^{(i)} = t_\text{RF}^{(i)}(1 + z_\text{avg}^{(i)})$ in the observer’s frame, and an energy-dimensional average parameter is reduced by a factor $(1 + z_\text{avg}^{(i)})^{-1}$, giving $E^{(i)}_{\text{p,max}} = E^{(i)}_{\text{p,max}}(1 + z_\text{avg}^{(i)})^{-1}$ in the observer’s frame, the product $\Pi^{(i)}$ of time-dimensional and energy-dimensional average parameters for the group is an invariant because the redshift factors cancel each other:

$$\Pi^{(i)} = t_\text{RF}^{(i)}E^{(i)}_{\text{p,max}} = t_\text{RF}^{(i)}E^{(i)}_{\text{p,max}}.$$

Therefore, any difference between values of $\Pi$ for two different samples of bursts has to be attributed to a real physical difference between their emitters.

**5. RESULTS FROM A COMPARISON OF ACIPs FOR DIFFERENT INTENSITY GROUPS**

The average durations of rise fronts and back slopes are known to have different behaviors for bursts with the different intensity. We calculated $\Pi$ as defined in equation (6) for the same six brightness groups as in Table 1, separately for time signatures $\tau_\text{RF}$ and $\tau_\text{BS}$. The results are presented in Table 2 and Figures 2 and 3.

One can consider emitters of GRBs as standard candles with respect to the property described by the ACIP if the values are independent of brightness. This model can be rejected for the rise fronts of bursts: the assumption of a constant $\Pi_\text{RF}$ in our analysis has a negligibly small prob-

![Fig. 2.](image-url) The dependence of ACIP\textsubscript{RF} on $\langle F_{\text{max}} \rangle$. The best linear fit (solid curve) has a nonzero slope.

![Fig. 3.](image-url) The dependence of ACIP\textsubscript{BS} on $\langle F_{\text{max}} \rangle$. The best linear fit (solid curve) has a slope consistent with zero.

**TABLE 2**

| Intensity Group | $\Pi_{\text{RF}}$ (keV s) | $\Pi_{\text{BS}}$ (keV s) |
|----------------|--------------------------|--------------------------|
| 1              | $1196 \pm 174$           | $1350 \pm 205$           |
| 2              | $1107 \pm 172$           | $1716 \pm 271$           |
| 3              | $784 \pm 113$            | $1402 \pm 211$           |
| 4              | $616 \pm 103$            | $1072 \pm 179$           |
| 5              | $613 \pm 103$            | $1183 \pm 194$           |
| 6              | $438 \pm 74$             | $1203 \pm 199$           |
ability (<0.001). Indeed, $\Pi_{\text{RF}}$ decreases with decreasing average fluxes $\langle F_{\text{max}} \rangle$ as

$$\Pi_{\text{RF}} = 1196 \left( \frac{\langle F_{\text{max}} \rangle}{14.2} \right)^{0.22 \pm 0.03},$$

(7)

where $\langle F_{\text{max}} \rangle$ is in units of $\gamma \text{ cm}^{-2} \text{ s}^{-1}$ and $\Pi_{\text{RF}}$ is in units of keV s. Therefore $\Pi_{\text{RF}}$ cannot be used as a standard candle (Fig. 2). Of course, there may be a concern that the dimmest group suffers from incompleteness, since it is closest to the trigger threshold where slow-rising events can be missed (Kommers et al. 1997). If we exclude the dimmest group from the fit in Figure 2, the fitted power-law index in equation (7) does not change dramatically: $0.18 \pm 0.03$. In this case, the probability that the data are consistent with a constant is still very small (0.003).

On the other hand, the values of $\Pi_{\text{BS}}$ are consistent with a constant value (Fig. 3). Quantitatively, we find that

$$\Pi_{\text{BS}} = 1350 \left( \frac{\langle F_{\text{max}} \rangle}{14.2} \right)^{0.03 \pm 0.03},$$

(8)

where the units are the same as in equation (7). During the back slopes, the differences between average $E^{0}$ and average $\tau_{0}$ (Table 1) for different intensity groups $i = 1-6$ effectively compensate each other when they form such a product as $\Pi_{\text{BS}}$. Since the two are physically different parameters of emitters, we conclude that their brightness dependencies have predominantly a geometrical origin; i.e., they are due to the geometrical transformations of time and energy in the expanding universe.

Comparing the values of $\langle E_{p} \rangle$ and $\tau_{\text{BS}}$ for the 100 brightest bursts (group 1, with peak fluxes greater than $3.8 \gamma \text{ cm}^{-2} \text{ s}^{-1}$) with those for the 100 dimmest bursts (group 6, with peak fluxes less than $0.43 \gamma \text{ cm}^{-2} \text{ s}^{-1}$), we find that the factor of cosmological transformation between emitters of these groups, for both time dilation and redshift, is about 3 (Table 1). For this factor the value of $z_{\text{dim}}$ for emitters of dimmest bursts is about 2, provided the brightest bursts correspond to $z_{\text{br}} \ll 1$. Recently it has been suggested that $z_{\text{br}} > 1$, based on measurements of the spectra of bright burst (Dezalay et al. 1998), and as a consequence of the idea that GRB sources should follow the history of star formation (Wijers 1998; Chen, Yang, & Nemiroff 1998). In this case, the group of dimmest bursts would have an average redshift factor $z_{\text{dim}} \sim 3(1 + z_{\text{br}}) - 1$ as large as $\sim 5$. While the outbursting sources are effectively standard candles along the back slopes, they are not standard along the rise fronts of bursts. If the bursts have a cosmological origin, observations of dim and bright bursts correspond in local time to the younger and older universe, respectively. The variation of $\Pi_{\text{RF}}$ with intensity (Table 2) is associated with a difference of average duration $\tau_{\text{RF}}$ in the comoving frames of reference, because the values of $E_{p,\text{max}}$ are the same for both $\Pi_{\text{BS}}$ and $\Pi_{\text{RF}}$. In the comoving frames the bursts in the recent universe have an average rise time $\sim 3$ times shorter than the average rise time of bursts in the early universe.

The difference in rise time between emitters of bright and dim bursts could be the result of differences in the interaction of the outbursting source with the surrounding medium. Emitters of dimmer bursts could have interacted in a medium with higher density, or with a harder background emission, or with a stronger average magnetic field, or with a difference of some other global parameter of the universe. On the other hand, during the back slope there is no difference between bursts from close and distant cosmological distances. The tails of bursts are thought to represent a self-determined internal process, which has some internal timescale associated either with some inertia or with a time constant of some decay, or with some other process, and which does not depend on the external condition of the surrounding medium. A future cosmological model has to take into account these differences between processes of emission during the rising phases of bursts and their decays, which is apparently intrinsic to the comoving reference frames.

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