Characteristic for long GRBs with high energy component presence, which not required cosmological corrections

I V Arkhangelskaja
National Research Nuclear University MEPhI (Moscow Engineering Physics Institute), Kashirskoe highway 31, Moscow, 115409, Russia
E-mail: irene.belousova@usa.net

Abstract. Several thousands of gamma-ray bursts were observed by various experiments. During several GRBs very high-energy photons were detected both in space and ground-based experiments (up to some tens of GeV and up to some TeV, respectively). Usually 2 classes of bursts are considered: short and long GRBs separated by $t_{90}\sim2$ s. Because of several hundreds of GRBs located at high redshift, its sources’ origins nature concluding as cosmological. Therefore correction to cosmological dilation of GRBs $t_{90}$ should be considered during any analysis of bursts duration. Firstly very high-energy component was observed during GRB 970417a: 18 photons with energy ~650 GeV were registered by Milagrito within $t_{90}$ interval of this burst. Now several tens of GRBs reveal activity in energy bands up to some tens of GeV and up to some TeV accordingly data of space and ground-based experiments correspondingly. Unfortunately redshift is unknown approximately for half of GRBs with high energy component presence. Here we introduce new parameter $R_t$ is ratio of maximum energy photon arrival time to burst duration and it not required cosmological correction. At least 2 groups of long GRBs could be separated using parameter $R_t$: for 25% events highest energy gammas detected within $t_{90}$ interval, but for other 75% of bursts it registered more than 10 sec. later than one. Moreover, preliminary results of analysis allow concluding 2 subtypes of second group GRBs. For one $\gamma$-quantum with maximum energy arrived within $t_{90}$. For other such photon was registered later than $t_{90}$. Therefore, the results of preliminary analyses allow conclude long GRBs population inhomogeneity.

1. Introduction
GRBs observed since the end of 60th of previous century and now several thousands of events were listed in more than 20 catalogues as results of more than 40 satellites and ground experiments. During several GRBs very high-energy photons were detected both in space and ground-based experiments (up to some tens of GeV and up to some TeV, respectively). High energy (HE) GRB emission was firstly registered by the satellite experiments onboard the Compton Gamma Ray Observatory (CGRO) in time interval 1991-2000 [1]. Four experiments onboard CGRO: BATSE, OSSE, COMPTEL and EGRET [2] provided the widest energy range since of 10 keV up to more than 20 GeV. Spectra of most part of such bursts were well described by two components Band model [3]. But in some GRB spectra the new spectral components not corresponded to Band model was found up to 200 MeV, for example during GRB 941017 [19]. So, it was possible to introduce 2 spectral breaks in prompt emission of GRBs $E_1$ – between 2 components of Band model and $E_2$ – corresponds to HE component – see figure 1. Firstly confirmation of high energy afterglow was found during analysis of
data of GRB940217: $\gamma$-emission with energy more than 50 MeV was registered till 1.5 hours after start of burst, highest-observed energy of gamma was 18 GeV [5]. CGRO registered 15 GRB with E>120 MeV, but mostly no prompt emission E>200 MeV [6].

Firstly evidence of subTeV emission was observed during GRB 970417a: several photons with energies ~650 GeV were detected by Milagrito during this burst duration $t_{90}$ [20]. This fact allow to conclude a possibility of prompt emission with very high energy during GRBs.

Than GRBs high energy emission was observed in Russian experiment AVS-F onboard satellite COROPNAS-F in time period 2001-2005. 2 spectral breaks also observed in burst spectra and second break position registered in energy band $\sim$3–30 MeV – see figure 2 and [7].

![Figure 1](image1.png)  
**Figure 1.** The energy spectra of GRB941017: left straight line correspond to second component of Band model and right one represent approximations for HE part.

![Figure 2](image2.png)  
**Figure 2.** The summarized spectrum of GRB050525 has additional component in the high energy region ($E_{\text{break}}=2.4\pm0.1$ MeV).

2. Modern results of observations of high energy gamma-emission during GRBs

Next step of HE gamma-emission observed observation was start with launch of satellite experiments Fermi/LAT [8, 9] and AGILE/MCAL [10]. Also it followed by Cherenkov detectors MAGIC [11] and H.E.S.S. [12]. Now ~170 GRBs were registered by Fermi/LAT [13] and ~70 bursts observed by AGILE/MCAL [14]. But third spectral breaks should be introduced in very low energy band based on data of these experiments – see figure 3. And it is very interest fact that spectral indexes are similar in very low and in very high energy bands. So, very interesting question occur about extension of HE component to low energy region down to tens of keV.

For most part of GRBs sources’ origins nature is cosmological – see redshift corresponding columns in catalogues, for example, [13, 14, 15]. Therefore correction to cosmological dilatation of GRBs duration should be consider because of real cosmological sources time properties should be investigated only taking into account its redshift. Typically short and long GRBs classes considered using the results of burst duration distribution analysis. GRBs duration characterized by $t_{90}$ and $t_{50}$ accordingly to BATSE data analysis [16]. These parameters are the intervals for 90% and 50% of burst statistics accumulation (i.e. durations where the integrated burst’s counts raise from 5% to 95% and for 25% to 75% respectively). Short GRBs are defined to have durations $t_{90}$ of $<2$s accordingly to BATSE data analysis [16], but after correction to cosmological dilatation several long events could interpreted as short in this classification. For example, $t_{90}$ of long GRB160625B is 2.8 sec, $z$~1.4 and after correction it became $t_{90z}$ ~1.2 sec which correspond to burst of short class. Also the same values for GRB110731A are $t_{90}$~7.3 sec, $z$~2.83, $t_{90z}$~1.2 sec as relate to short class burst again.

LAT GRBs distribution on burst duration $t_{90}$ and cosmologically corrected $t_{90z}$ is presented in figure 3. Of course, several correlations exist between burst duration and $t_{90z}$, but it is impossible to
draw any conclusions without information on the distance to the burst. Thus, bursts duration distributions should be analyzed always taking into account the cosmological correction.

**Figure 3.** LAT GRBs distribution on burst duration $t_{90}$ and cosmologically corrected $t_{90,z}$.

**Figure 4.** This LAT GRBs distribution on burst duration and maximum registered energy (open circles). Black circles shows events with known redshift and open triangles represent these burst duration $t_{90}$ with cosmological correction and most part of bursts after this were shifted in dashed region with $2 \, \text{s} < t_{90} < 30$.

**Figure 5.** The LAT bursts distribution on high energy episode duration and $t_{90}$.

**Figure 6.** The distribution of LAT GRBs on $R_t$ and $t_{90}$.

LAT GRBs distribution on burst duration and maximum registered energy is shown at figure 4. It is seen that after correction to cosmological dilation most part of GRBs were shifted in time interval with $t_{90}$ from 2 to 30 sec. Unfortunately only several tens of LAT GRBs has information both about redshifts and $t_{90}$. The bursts distribution on high energy episode duration and $t_{90}$ is presented at figure 5. It is possible to conclude 2 long GRBs subgroup existence separated by limit where maximum energy photon arrival time is equal to event $t_{90}$.

For next analysis we introduce new value $R_t$ is ratio of maximum energy photon arrival time to burst duration and this value not required cosmological correction. The distribution of LAT GRBs on
Rt and \( t_{90} \) is shown at figure 6. The investigation results conclude 2 long GRBs subgroup existence separated by limit where maximum energy photon arrival time is equal to event \( t_{90} \). During events of the first subtype high energy emission duration interval is smaller than \( t_{90} \). Second subtype characterized longer period of high energy emission than \( t_{90} \).

**Figure 7.** The examples of concrete GRBs illustrate new characteristic Rt using in burst classification: a) Type 1 example of event, b) Type 2a example of GRB.

**Figure 8.** The example of type 2b event illustrate new characteristic Rt using in burst classification.

But second subtype bursts divided to 2 subgroups. For first gamma-quantum with maximum energy arrived within \( t_{90} \). For other such photon was registered later than \( t_{90} \). The examples of concrete GRBs illustrate new characteristic Rt using in burst classification is presented at figures 7 and 8.

No sufficient correlations registered between maximum energy of gammas during prompt emission and burst redshift. The highest energy of photons was registered by LAT during GRB 130427 and it
was ~94 GeV [17]. Unfortunately, only 3 bursts were registered in subTeV region during Fermi operation: GRB 190114C, GRB 180720B and GRB 160821B [18, 19, 20]. Now GRB high energy gamma-emission was observed both during short and long bursts, but photons in the band E>0.1 TeV usually are observed only during long GRBs (now only one short GRB appear such emission). Long GRBs with subTeV emission has characteristics the same than 2b type and 1 type accordingly to preliminary results of analysis. As 2b type events we can consider GRB 190114C during which MAGIC start registration of about 50 s after the trigger and detected photons with E > 300 GeV for the first 20 min from this burst with a significance higher than 20σ [18]. GRB190114C is near long burst (z = 0.4245 and t0~120 s in low energy band [21, 22]).

Also GRB180720B reveals similar properties: H.E.S.S. began observation of this burst at about 10 h after the burst trigger and detected 100–440 GeV photons at such late time interval [19]. GRB 180720B is near long burst (z = 0.6535 and t0 ~150 s in low energy band [23, 24]). We can consider GRB 190829A as 1 type event: prompt emission during 190829A was detected by H.E.S.S. to in subTeV band. It is very near long burst z = 0.0785 +/- 0.005 [25].

But one short GRB reveals high energy afterglow: during GRB 160821B MAGIC detected subTeV photons up to 10’s after burst trigger [20]. GRB160821B is near (z =0.16 short burst with HE afterglow: in low energy band t0= 0.48 ± 0.07 sec in energy region 15-350 keV [26] and t0~1 s in energy range 50-300 keV [27].

3. Conclusion
Several thousands of gamma-ray bursts were observed by various experiments. During several GRBs very high-energy photons were detected both in space and ground-based experiments (up to some tens of GeV and up to some TeV, respectively). For example, GRB 190114C was detected by Fermi and MAGIC in very wide band up to subTeV energies. Now GRB high energy γ-emission was observed both during short and long bursts, but photons in the band E>0.1TeV usually are observed only during long GRBs (now only one short GRB appear such emission).

GRBs mostly located at cosmological distances and cosmological correction should be used in duration investigation. But here we introduce new value Rt as ratio of maximum energy photon arrival time to burst duration in low energy band and it not required cosmological correction. At least 2 groups of long GRBs could be separated using parameter Rt: for 25% events highest energy gammas detected within t0 interval, but for other 75% of bursts it registered more than 10 seconds later than one. Moreover, preliminary results of analysis allow concluding three types of GRBs with high energy emission registration without dependence of burst duration value. During events of first subtype high energy emission duration interval smaller than t0. Second subtype characterized longer period of high energy emission than t0. But second subtype bursts divided to 2 subgroups: a) γ-quantum with maximum energy arrived within t0, b) such photon was registered later than t0. Long GRBs with subTeV emission has characteristics the same than 2b type (for example, GRB190114C and GRB180720B) or 1 type (for instance, 190829A) on preliminary results of analysis.

Therefore, results of preliminary analyses allow conclude long GRBs population inhomogeneity.

Acknowledgments
Authors thank for the support from National Research Nuclear University MEPhI in the framework of the Russian Academic Excellence Project (contract No. 02.a03.21.0005, 27.08.2013).

References
[1] Schneid E J, Bertsch D L and Fichtel C E 1991 *AIP Conf. Proc.* 265 38
[2] Bunner A 1989 *Proc. CGRO Science Workshop* 12.7
[3] Band D *et al.*, 1993 *Astrophys. J.* 413 281
[4] Hamburg R, Veres P, Meegan C, Burns E, Connaughton V, Goldstein A, Kocevski D and Roberts O J 2019 *GCN CIRCULAR NO. 23707*
[5] Baring M G 1997 *Gamma-Ray Bursts Above 1 GeV Preprint* astro-ph/9711256
[6] Kaneko Y, González M, Preece R D, Dingus B L and Briggs M S 2008 Astrophys. J. 677 1128
[7] Arkhangel'skaja I V, Arkhangel'skiy A I, Gilyanenko A S, Kotov Yu D and Kuznetsov S N 2008 Proc. of the MG11 Meeting on General Relativity (Berlin) (World Scientific Publishing Co. Pte. Ltd.) 1968

[8] Atkins R et al. 2007 Astrophys. J. 583 824
[9] Ackermann M et al. 2014 Astrophys. J. 787 15
[10] Labanti C, Marisaldi M, Fuschino F, Galli M, Argan A, Bulgarelli A, Di Cocco G, Gianotti F, Tavani M and Trifoglio M 2009 Nucl. Instrum. Methods Phys. Res. A 598 470

[11] Aliu E et al. 2009 Astroparticle Physics 30 (6) 293
[12] Reimer O 2009 Bull. Am. Astron. Soc 41 508
[13] URL https://fermi.gsfc.nasa.gov/ssc/observations/types/grbs/lat_grbs/
[14] URL https://vizier.u-strasbg.fr/viz-bin/cat/J/A+A/553/A33
[15] URL https://swift.gsfc.nasa.gov/archive/ground_table/
[16] Kouveliotou C 1995 Ann. N.Y. Acad. Sci. 759 411
[17] Zhu S, Racusin J, Kocevski D, McEnery J, Longo F, Chiang J and Vianello G 2013 GCN CIRCULAR NO 14471
[18] Mirzoyan R 2019 ATel 12390
[19] Ruiz-Velasco E L 2019 URL https://indicocta-observatory.org/event/1946/timetable/#all
[20] Palatiello M, Noda K, Inoue S, Colin P, Moretti E and Longo F 2017 Proc of the 7th International Fermi Symposium (Garmisch-Partenkirchen) (Sissa Medialab) 84
[21] Krimm H A, Barthelmy S D, Cummings J R, Gropp J D, Lien A Y, Markwardt C B, Palmer D M, Sakamoto T, Stamatikos M and Ukwatta T N 2019 GCN CIRCULAR NO 23724
[22] Hamburg R, Veres P, Meegan C, Burns E, Connaughton V, Goldstein A, Kocevski D and Roberts O J 2019 GCN CIRCULAR NO 23707
[23] Siegel M H et al. 2018 GCN CIRCULAR NO 22973
[24] Robertsand OJ and Meegan C 2018 GCN CIRCULAR NO 22981
[25] de Naurois OJ and Meegan C 2018 GCN CIRCULAR NO 22981
[26] Palmer D M et al. 2016 GCN CIRCULAR NO 19844
[27] Stanbro M and Meegan C 2016 GCN CIRCULAR NO 19843