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GAMMA-RAY BURSTS WITHOUT MEASURED REDSHIFTS I: ENERGY ESTIMATE AND LAT BORESIGHT ANGLE DISTRIBUTION

Abstract. *Context.* With this short note we start a series of communications dedicated to the study of gamma-ray bursts (GRBs) without measured redshifts.

Aims. We make an attempt to estimate energy of GRBs without measured distances based on population of bursts with measured redshift.

Methods. We assume that there is indeed universal bimodal distribution on duration which is followed by all the events. Using data on best-fit spectral parameters from GBM GRB Catalog we calculate energy for each burst given mean redshift values for short/long distribution. Additionally, we cross-correlate GBM GRB Catalog with general GBM Trigger Catalog in order to retrieve information on LAT boresight angle at the moment of event detection.

Results. We obtained estimate energy for each burst and built a distribution plot which follows the idea of bimodal distribution. A scatter plot for LAT boresight angles of short GRBs was obtained.

Conclusions. The energy-based histogram follows a general pattern for short/long distribution having distinct peaks. On the other hand, LAT boresight angles for short events shows quite uniform distribution, and being an instrumental feature, therefore cannot implicitly point to some intrinsic mechanisms responsible for high-energy photons generation.

Keywords: gamma-ray burst; redshift; LAT boresight angle; data analysis.

1. Introduction.

There is essential quantitative information one can calculate knowing the distance to the astrophysical object. Among these values isotropic-equivalent energy is the starting point for inferences in any theoretical model. An estimate of injected energy is crucial information for numerical simulations, especially for modelling the most energetic phenomenon of the universe such as gamma-ray burst (GRB).

The *Fermi Gamma-Ray Space Observatory* (previously GLAST) has detected over two thousand* unique Gamma-Ray Burst (GRB) events during the first decade of operation [1]. Only ~10% of these bursts have measured redshifts therefore making possible a reliable physical interpretation of the processes onsite. Consequently the rest of GRBs do not offer the latter possibility in full though containing spectral information.

The statistics to the date of July 20th 2018 is the following (see **Table 1**): *Fermi*-GBM telescope detected 2367 gamma-ray bursts (100%) among which there are 398 short (16.8%) and 1969 long (83.2%) duration GRBs, both are with and without measured redshift values; out of this total number of bursts the *Fermi*-LAT telescope detected 169 bursts (7.1%) among which there are 14 short and 155 long duration GRBs, both are with and without measured redshift values [2].

* https://heasarc.gsfc.nasa.gov/W3Browse/fermi/fermigbrst.html

Table 1 - GRB detection statistics for all-sky *Fermi*-GBM (8 keV–40 MeV) and *Fermi*-LAT (20 MeV–100 GeV) since the beginning of operational era in July 2008. The first and the last rows correspond to the first [2] and the second [4] LAT catalogs. Percentages in parentheses are related to the total number of bursts by GBM. Numbers were retrieved from online *Fermi*-GBM Burst Catalog and *Fermi*-LAT Burst list.

End time	GBM	$T_{90} < 2$ s	$T_{90} > 2$ s	LAT	$T_{90} < 2$ s	$T_{90} > 2$ s
July 2011	733	122 (16.6%)	611 (83.4%)	35 (4.8%)	5	30
July 2018	2367	398 (16.8%)	1969 (83.2%)	169 (7.1%)	14	155

Within a decade of the *Fermi* operational era there were reported around 30 short GRBs with redshifts measured, among them there is only one GRB 090510 with both measured redshift and GeV photons detected [2]. This means a number of >350 short bursts does not have redshift and roughly same number without GeV photons were observed. As for the long bursts there are more than 200 events with known distances [3].

2. Methods.

In order to estimate energy for GRBs without redshift we take an average value of those short and long bursts with measured redshift. The *secure* median value for the redshift of short GRBs is around unity, while the median redshift value of long bursts is around two [5].

Fixing the redshift at unity (short) and two (long) values we calculate E_{iso} given a spectral model. For every GRB its Flnc_Best_Fitting_Model parameter from GBM catalog indicates the model best fitting the data for a spectrum accumulated over T_{90} duration of the burst [1]. The models used to fit each spectrum are: simple power law (plaw or PL), cutoff power law (comp or CPL), smoothly broken power law (SBPL) and Band function. Depending on model we will have various parameters to consider. The best-fit model is automatically selected by comparison of the values of the likelihood-based Castor C-Statistic (C-STAT). The C-STAT is a modified log-likelihood statistic based on Cash statistic, see [6], and it is used for fitting a model to data set through minimization. The isotropic energy equation has the form:

$$E_{iso} = \frac{4\pi d_L^2}{1+z} S(E_1, E_2, z), \tag{1}$$

where d_L is the luminosity distance and $S(E_1, E_2, z)$ is the fluence accumulated between minimum E_1 and maximum E_2 energy. It is defined by following expression:

$$S(E_1, E_2, z) = T_{90} \int_{E_1/(1+z)}^{E_2/(1+z)} EN(E)dE. \tag{2}$$

Here *N(E)* defines the best-fit model of the prompt phase spectrum and the integration is done over GBM working energy band. Since GRBs are the cosmological objects then above mentioned luminosity distance will be defined, assuming a flat universe ΛCDM model with Ω_Λ=0.692, Ω_M=0.308, H_0=67.8 km s^{-1} Mpc^{-1} and c=2.998e+10 cm s^{-1}, by following equation [7]:

$$d_L(z, \Omega_\Lambda, \Omega_M) = (1+z)\frac{c}{H_0}\int_0^z \frac{dz'}{\sqrt{\Omega_M(1+z')^3+\Omega_\Lambda}}. \tag{3}$$

As can be seen the redshift stays as only unknown parameter. The calculated values of $E_{iso}^{z=1}$ and $E_{iso}^{z=2}$ are shown on **Figure 1** and listed in **Table 2** of the next section.

Another issue to consider for future studies is a boresight angle of the LAT instrument at the moment of GBM trigger. This angle defines the sensitivity of LAT and simply represents itself a viewing angle outside of which no observation is possible. Given orientation coordinates two instruments can calculate mutual directions and when burst location defined by GBM the LAT normal angle is calculated with respect to that pointing and stored in GBM Trigger Catalog. We scan throughout (in order of priority) the *Fermi LAT Second GRB Catalog*,[†] the *Fermi GBM Trigger Catalog*[‡] and GCN archive[§] looking for the LAT boresight angle with regard to the best location of every burst.

[†] https://heasarc.gsfc.nasa.gov/W3Browse/all/fermilgrb.html
[‡] https://heasarc.gsfc.nasa.gov/W3Browse/fermi/fermigtrig.html
[§] https://gcn.gsfc.nasa.gov/

3. Results. We obtained estimate energy for each burst and built a distribution plot which follows the idea of bimodal distribution.

Table 2 lists all short GRBs observed within a decade of GBM operation and columns indicate: burst full name, duration (in seconds), rest-frame spectral peak energy calculated at z=1.0 (in keV), isotropic-equivalent energy calculated at z=1.0 (in erg, rest-frame by definition), and LAT boresight angle at the GBM trigger (in degrees). Although not listed here, a similar table is obtained for long (T_{90} >2 s) duration GRBs, and both tables in full are available upon request.

Table 2 - List of 398 short (T_{90} <2 s) GRBs within August 2008–July 2018 detected by *Fermi*-GBM with estimated isotropic-equivalent energy E_{iso} when given z=1.0 as an average redshift for short bursts. Since the table is large in size we show here only the first and the last three rows. Full table is available upon request

GRB name	T_{90} (s)	$E_{peak}^{z=1}$ (keV)	$E_{iso}^{z=1}$ (erg)	θ (degrees)
080723913	0.192	641.679	6.70615e+50	—
080725541	0.96	2965.18	4.87635e+51	—
080802386	0.576	1244.78	4.81246e+51	—
...	...	...	...	...
180703949	1.536	273.749	4.60329e+52	32
180715741	1.664	1121.59	8.24943e+51	79
180715755	0.704	1804.56	8.58977e+51	75

We built an energy-based histogram for two populations of 1800 long and 363 short GRBs on figure 1. The median values are 2.16e+51 erg (short) and 4.61e+52 erg (long), and two distinct peaks are easily observed.

Regarding the LAT boresight angles there are 363 short GRBs with known θ at the trigger (for 35S-GRB there is no angle information, see table 3), of which 210 bursts were detected at θ <75 degrees, number of 6 short GRBs were triggered at θ =75 degrees and events in amount of 147 were detected at θ >75 degrees.

Table 3 - Distribution of short GRBs with regard to LAT boresight angle.

Total S-GRBs	θ<75 degrees	θ=75 degrees	θ>75 degrees	no θ
398	210	6	147	35

A scatter plot for LAT boresight angles of short GRBs was obtained on figure 2. Labeled red points indicate S-GRBs from the Second LAT Catalog [2]. Note that a large offset of S-GRB 170127067 still had high-energy emission at late repointing. The histogram shows the same distribution stacked in 30 bins.

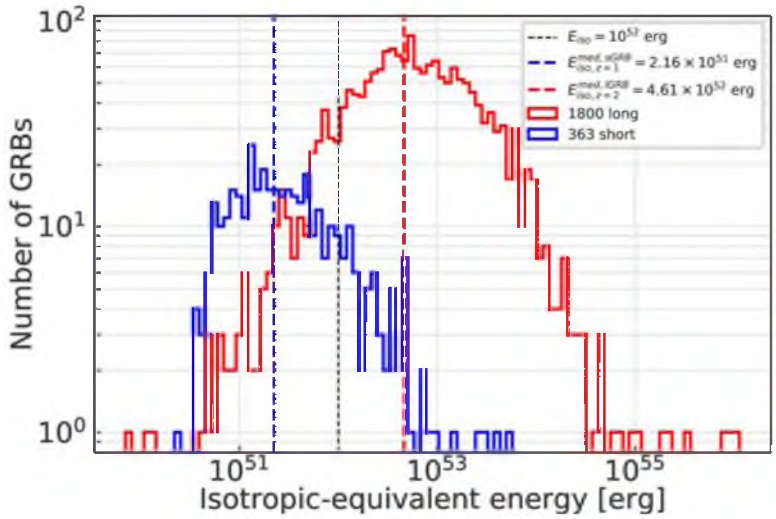

Figure 1 - Histogram of isotropic-equivalent energy for 363 short and 1800 long GRBs for a decade of *Fermi* mission. The values of energy are calculated by assuming average redshifts for short (z=1.0, solid blue) and long (z=2.0, solid red) bursts. Dashed black line indicates E_{iso}=1e52 erg energy. Dashed blue and red lines indicate median energy values

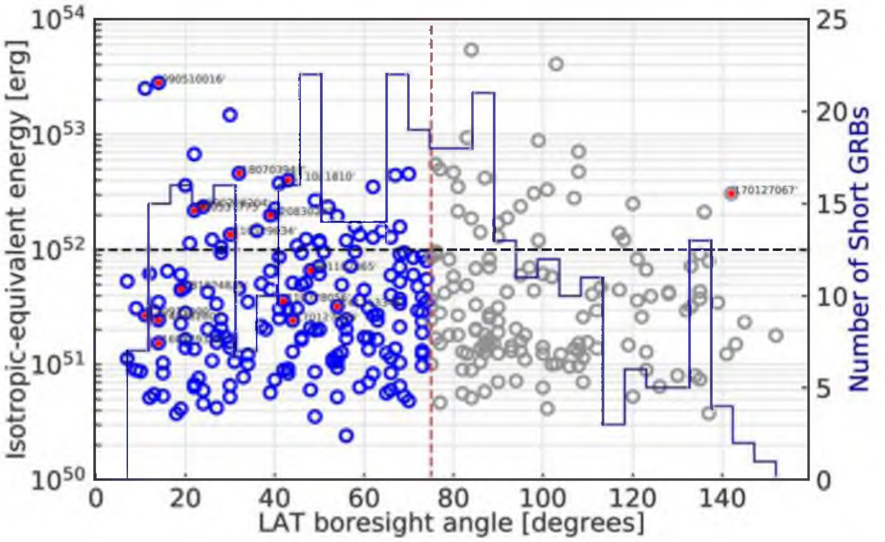

Figure 2 - Distribution of 363 short GRBs by LAT boresight angle and isotropic-equivalent energy calculated under assumption of common z=1. Vertical dashed lines indicates θ =75 degrees threshold angle for LAT instrument, horizontal dashed line indicates E_{iso}=1e52 erg energy

4. Discussion. The energy-based histogram follows a general pattern for short/long distribution having distinct peaks. These two populations when put on E_{peak}-E_{iso} plane stays in accordance with spectral energy correlation for short [9] and long [10] GRBs. The prospect of further detailed study is possible due to the presence of redshift measured bursts [Aimuratov et al. (2020) in *Proceedings of the Fifteenth Marcel Grossmann Meeting*, submitted].

On the other hand, LAT boresight angles for short events shows quite uniform distribution, and being an instrumental feature, therefore, it cannot implicitly point to some intrinsic mechanisms responsible for high-energy photons generation. An outlier GRB 170127C detected ~300 s after GBM trigger [8] is one of the clear examples for prolonged GeV emission of still unknown nature. This implies

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ҚЫЗЫЛ ЫҒЫСУЫ ӨЛШЕНБЕГЕН ГАММА-СӘУЛЕЛЕНУ ЖАРҚЫЛДАРЫ I: ЭНЕРГИЯНЫ БАҒАЛАУ ЖӘНЕ LAT КӨРУ БҰРЫШТАРЫНЫҢ ҮЛЕСТІРІМІ

Аннотация. *Мәнмәтіні.* Осы қысқаша хабарламамен біз қызыл ығысуы өлшенбеген гамма-сәулелену жарқылдарына (ГСЖ) арналған зерттеулер туралы мақалалар сериясын бастаймыз.

Мақсаты. Біз қызыл ығысуы өлшенген жарқылдар жиынтығына сүйеніп, қашықтығы өлшенбеген ГСЖ популяциясының энергия өлшемін бағалауға әрекет жасаймыз.

Әдісі. Біз барлық оқиғалар расында әмбебап бимодалдық үлестіріміне сай болады деп негіздейміз. GBM GRB каталогындағы әр оқиғаға ең жақсы сәйкес келетін спектрлік параметрлер туралы мәліметтерді және қызыл ығысуы өлшенген қысқа/ұзақ уақытты оқиғалар үшін берілген орташа мәндерді қолдана отырып, біз энергияны есептейміз. Сонымен қатар біз оқиғаларды анықтаған сәтте LAT инструментінің көру бұрышы туралы ақпарат алу үшін GBM GRB каталогын GRB Trigger Catalog жалпы каталогымен өзара салыстырамыз.

Нәтижелері. Біз әр ГСЖ-ның энергиясын есептеп алдық және нәтижесінде бимодалды үлестірім идеясына сәйкес келетін алаңын алдық. Қысқа уақытты оқиғалардың LAT көру бұрыштары үшін шашырау сюжеті алынды.

Қорытындысы. Энергияға негізделген гистограмма нақты шыңдары барын көрсете отырып, қысқа/ұзақ уақытты оқиғалардың үлестіріміне сай жалпы үлгісін ұстанады. Екінші жағынан, қысқа оқиғаларға арналған

LAT көру бұрыштары біркелкі таралуды көрсетеді және инструменталды сипат болып табылады, сондықтан жогары энергиялы фотондардыц пайда болуына жауап беретін кейбір ішкі механизмдерді нақты көрсете алмайды.

Түйін сөздер: гамма-сәулелену жарқылы; қызыл ыгысуы; LAT көру бұрышы; деректерді талдау.

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ГАММА-ВСПЛЕСКИ БЕЗ ИЗМЕРЕННЫХ КРАСНЫХ СМЕЩЕНИЙ I: ОЦЕНКА ЭНЕРГИЙ И РАСПРЕДЕЛЕНИЕ УГЛОВ ПРИЦЕЛИВАНИЯ LAT

Аннотация. *Контекст.* С этой короткой заметки мы начинаем серию сообщений, посвященных изучению гамма-всплесков (ГВ) без измеренных красных смещений.

Цели. Мы предпринимаем попытку оценить энергию ГВ без измеренных расстояний на основе совокупности всплесков с измеренным красным смещением.

Методы. Мы предполагаем, что, действительно, существует универсальное бимодальное распределение по продолжительности, которому следуют все события. Используя данные о спектральных параметрах из каталога GBM GRB для наиболее подходящих моделей, мы вычисляем изотропную энергию для каждого всплеска, учитывая средние значения красного смещения для распределения коротких/длинных событий. Кроме того, мы производим взаимную корреляцию каталога GBM GRB с общим каталогом GBM Trigger Catalog для получения информации об угле прицеливания LAT в момент обнаружения события.

Результаты. Мы получили оценку энергии для каждого всплеска и построили график распределения, который следует идее бимодального распределения. Получен график распределения углов прицеливания LAT для коротких GRB.

Заключения. Гистограмма по энергиям ГВ следует общей схеме распределения по коротким/длинным событиям, показывая два отчетливых пика. С другой стороны, углы прицеливания LAT для коротких ГВ показывают довольно равномерное распределение, и, являясь инструментальной особенностью, не могут неявно указывать на какие-либо внутренние механизмы, ответственные за образование фотонов высоких энергий.

Ключевые слова: гамма-всплеск; красное смещение; угол прицеливания LAT; анализ данных.

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