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Search of Gamma-ray bursts detected by GBM alike to GRB 170817A

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Since the detection of Gravitational Waves (GW), a new window of multi-messenger astronomy was opened. The first GW event with an electromagnetic counterpart was GRB 170817A, an under luminous burst with properties of a short burst that was detected by Fermi-GBM, among other observatories. This burst revealed two different spectral components in the Fermi-GBM energy range, a short-lasting non-thermal pulse at early times followed by a soft thermal component. Previous studies have identified bursts based on these spectral and temporal features similar to the ones of GRB 170817A. In this work, we extend the search for short bursts alike GRB 170817A in the northern sky detected from 2018 to 2020. The initial search, based on temporal restrictions, gives 56 possible candidates. From these, only two bursts were consistent with the spectral behavior. Here we report the spectral features of those two objects.

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1. Introduction

Since 2017 with the detection by LIGO/VIRGO of a Gravitational Wave (GW) signal from a neutron star merger [1] followed by a gamma-ray burst (GRB 170817A) detected by the Fermi Gamma-ray Burst Monitor (GBM) [2] and by the INTErnational Gamma-ray Astrophysics Laboratory (INTEGRAL) [3], a new era in the multi-messenger astronomy started. Gamma-ray bursts (GRBs) are energetic sources that radiate isotropic-equivalent energy in the range of 10^{49} to 10^{55} erg. Their prompt emission is detected in the gamma-ray and X-ray energy bands followed by an afterglow phase, a long-lasting emission detected in different wavelengths fading in time. The most accepted scenario is the so-called fireball model [4, 5] that predicts non-thermal emission processes and the existence of a thermal-like component. These two components are predicted to be emitted simultaneously.

GRBs have been historically classified depending on their duration. Based on this criteria two types have been clearly differentiated, the long type bursts with a duration longer than 2 s and the short type of bursts with a duration shorter than 2 s [6]. These two groups seem to be related to two different kinds of progenitors: for long GRBs the proposed progenitor is a collapsar [7] meanwhile for short GRBs they are proposed to be compact objects binary mergers [8]. GRB 170817A was detected $\sim$ 1.7 s after the GW signal and was classified with a $\sim$ 72% of probability of being a short duration GRB [2] with atypical properties such as being an underluminous , by 3-4 orders of magnitud [9], and being a close burst with a reported redshift of z=0.01 [10]. This burst presented two different components, a nonthermal pulse at early times followed by a soft tail that is described with a thermal component.

The Fermi-GBM instrument, with a large Field of View (FOV) and capable of detect photons with energies between 8keV- 40 MeV, has significantly increased the study of GRBs. By detecting $\sim$ 235 bursts per year [11], Fermi-GBM constitutes a powerful instrument for GRBs spectral and temporal studies. Because of the importance that GRB 170817A has to multi-messenger astronomy, previous studies have searched for bursts with similar spectral and temporal properties [9, 12]. These studies may contribute to the identification of more bursts with GW counterparts by experiments with a high field of view, such as the HAWC gamma-ray observatory.

In this work, we continue with the search of bursts with similar properties to GRB 170817A using Fermi-GBM data. We make a search for bursts in the northern sky detected from the year 2018 to 2020. The text is organized in the following sections: in section 2 we present the methodology followed in this work and in section 3 we present the results and discussion of this work.

2. Methodology

The Fermi-GBM is the instrument on-board the Fermi observatory whose primary science objective is to make spectral and temporal analyses of GRBs [13]. After the first 10 years of observations (from July 12, 2008 to July 11, 2018) Fermi-GBM reported the detection of 2356 GRBs from which 17% and 83% have been reported as shorts and long bursts [9], respectively.

The Fermi-GBM instrument consists of 12 thallium activated sodium iodide (NaI(Tl)) and two bismuth germanate scintillators (BGO) to detect gamma-rays in the energy range between $\sim$8 keV up to $\sim$40 MeV. The NaI(Tl) detectors are the ones that determine the direction of the GRBs and measure the low-energy photons in the energy range between 8 keV to 1 MeV. The two BGO detectors are at opposite sides of the spacecraft and can measure photons with energies of ~200 keV to ~40 MeV. Fermi-GBM produces three types of data packets. The CTIME data have 8 energy channels and a nominal temporal resolution of 4.096 s. The CSPEC data have 128 energy channels and a nominal temporal resolution of 1.024 s. Finally, the CTTE data have 128 energy channels with a temporal resolution of 0.064 s. For more details about Fermi-GBM, visit to [13].

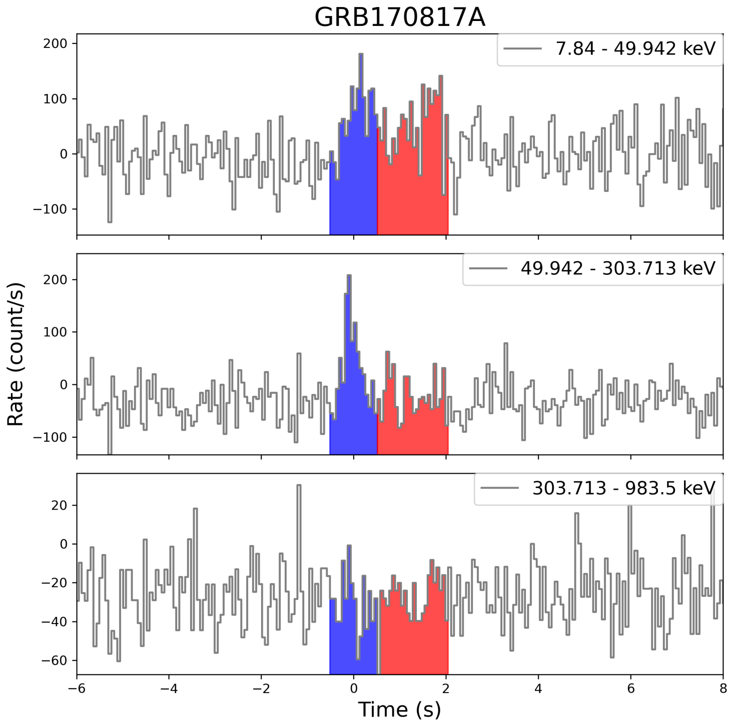

Figure 1: Composed light curve for GRB 170817A as observed by Fermi-GBM with 3 NaI(Tl) detectors in 3 different energy bands: 8-50 keV, 50-300 keV, and 300-1000 keV (from top to bottom). The non-thermal pulse is indicated in blue, and the thermal soft component is in red.

To select GRBs with similar properties to GRB 170817A, we follow the manual procedure presented in [14], a study performed using data from the 10-year GBM burst catalog. We extend the analysis to bursts in the northern hemisphere, detected from July 2018 to October 2020.

We inspect the light curves of the bursts in three different energy bands, 8-50 keV, 50-300 keV, and 300-1000 keV by combining CTTE and CTIME data from three of the NaI(Tl) detectors, generating a combined light curve, as shown in figures 1 and 2. Then, we perform a Bayesian block analysis in these three energy bands followed by a manual selection. A notorious change in the morphology of the light curves in distinct energy bands is observed, which could be an indicator that different emission mechanisms may be present, consistent with previous works that suggested the presence of different spectral components in the prompt phase [15, 16]. It can be seen that two notorious episodes in the light curves are apparent. One is a luminous peak that is present at the initial time of the bursts, that highlights in the energy range of 50 to 300 keV, and that is better described by a nonthermal function (Comptonized). The second episode is a weak tail observable after the initial peak. This tail highlights in the energy range from 8 to 50 keV and is better fitted with a thermal (Black Body) function. These two episodes can be seen in figures 1 and 2 for GRB 170817A and for the other two bursts (GRB 190717C and GRB 200626A) respectively.

After identifying the two episodes from the light curves, we perform the spectral analysis of the candidates using the RMFIT[1] package version 4.3.2. The background subtraction was made by modeling the count rate, before and after the burst, with a polynomial function. We perform fits using different photon models: Comptonized (Compt), Black Body (BB), and Power-Law (PL) function. The best-fit spectral parameters are determined by optimizing the Castor C-statistic, a likelihood technique that converges to a χ^2 when there are enough counts in specific data.

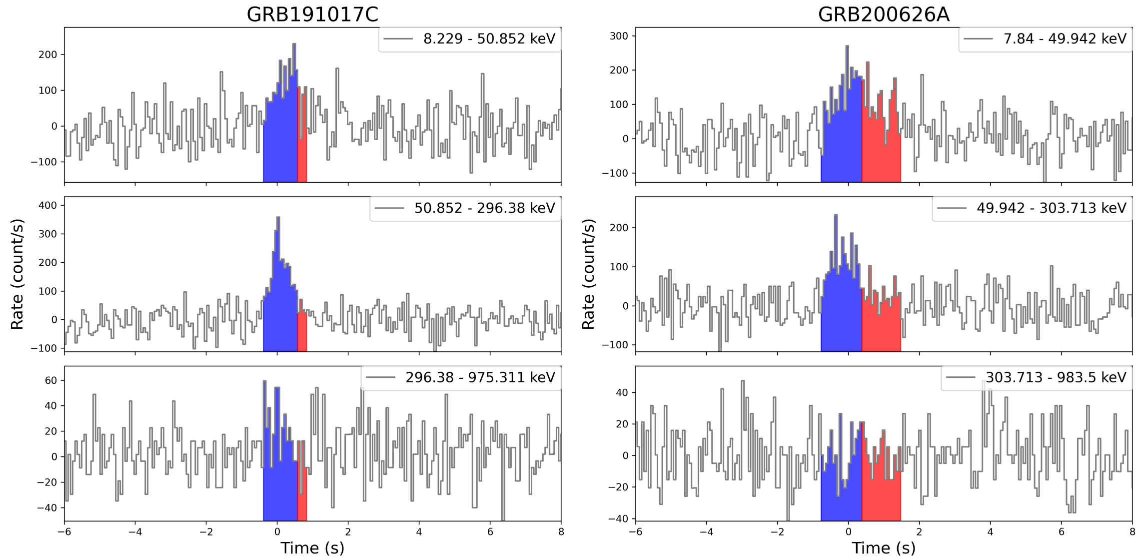

Figure 2: Composed light curves for GRB 191017C and GRB 200626A are shown. The nonthermal pulse is indicated in blue and the thermal soft component in red.

3. Results and discussion

The first selection criterion was that the burst had a T_{90} less than 5 s. Applying this cut, we identify 124 bursts, 55 of them occurred in the northern hemisphere. To this sample of 55 bursts, we perform the Bayesian block analysis followed by the manual selection proposed by [14] and summarized in the previous section. With this method, 13 possible candidates are identified. We perform spectral fitting to the episodes differentiated from the light curves and determine which function fits them better based on the C-stat value. The fitting parameters are reported in table 1. We can see that the initial episode is better described with a Compt function when compared to a Black Body (BB) or Power Law (PL) function, in agreement with the reported by [14].

From all the bursts in the northern hemisphere in the two years of data considered in this work, only two bursts have observational and spectral similarities to GRB 170817A. These bursts and their spectral properties are listed in table 1. The Fermi-GBM collaboration reported GRB 191017C as a

[1]https://fermi.gsfc.nasa.gov/ssc/data/analysis/rmfit/

Table 1: Spectral properties for the bursts that present similar features compared to GRB 170817A are fiven. The parameters obtained for GRB 170817A are in agreement with the ones reported by [9].

GRB	time (s)	Model	Epeak (keV)	Index	kT	C-stat/DOF
GRB 170817A	-0.512:0.512	Compt	181.7 ±85.6	-0.84 ± 0.4		256.76/253
	0.512:2.048	BB			9.69 ± 1.16	320.74/254
GRB 191017C	-0.32:0.64	Compt	484.6 ± 214	-0.93 ± 0.17		263.91/253
	-0.32:0.64	BB			34.97 ± 2.02	320.39/256
	-0.32:0.64	PL		-1.27 ± 0.05		270.86/254
	0.64:0.896	Compt	79.04 ± 42.3	-0.55 ± 1.33		290.76/253
	0.64:0.896	BB		17.06 ± 3.64		291.41/254
	0.64:0.896	PL		-1.74 ± 0.28		292.39/254
GRB 200626A	-0.768:0.384	Compt	455.9 ± 33.7	-0.81 ± 0.05		31038/247
	-0.768:0.384	BB			32.61 ± 0.2	34996/248
	-0.768:0.384	PL		-2.03 ± 0.02		40106/248
	0.384:1.472	Compt	300 ± 18.7	-0.5 ± 0.08		56991/247
	0.384:1.472	BB			29.25 ± 0.17	50934/248
	0.384:1.472	PL		-2 ± 0.02		51958/248

likely short GRB located at RA=134.6^o and Dec=15.3^o in J200 coordinates [17]. The T_{90} reported for this burst is 3.136 s and it was detected at 22:58:20 UT on the 17th of October 2019.

GRB 200626A is also reported as a likely short GRB located at RA=87.35^o and Dec=16.13^o in J200 coordinates [18]. With T_{90} = 3.52s, this burst was detected at 02:31:31 UT on the 26th of June 2020.

This search contributes to the prospect of detection of short GRBs by observatories in the northern hemisphere as counterparts of a GW event similar to GRB 170817A during the LIGO/Virgo observing time.

Acknowledgments

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