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Systematic time-resolved analysis of gamma-ray bursts detected by Fermi-GBM(*)

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Summary. — Here we present a systematic analysis of a subsample of bright GRBs detected by *Fermi*-GBM in the first two years of the mission, with particular focus on the temporal evolution of the parameters of the spectral models fitted to the data. The lightcurves are divided into time bins using the Bayesian Blocks method, whereas the time-resolved spectral analysis is done using the new dedicated Gamma-Ray Data Tools toolkit. For each bin, different spectral models are fitted to the data, and the best one is selected through appropriate statistical criteria. We illustrate the different analysis phases together with some preliminary results, such as the best model fractions. The aim of this work is to implement an automated pipeline for a systematic analysis of all GRBs detected by the GBM during the mission.

1. – Introduction

Gamma-Ray Bursts (GRBs) are extremely energetic transient emissions of gamma rays, characterized by extremely high luminosities (releases of 10^{51} to 10^{53} ergs in a few seconds). They are thought to be associated with the death of massive stars or the merger of compact objects in binary systems. GRB emission typically consists of a *prompt* phase in the keV-MeV energy range, lasting few seconds/minutes, followed by an *afterglow* phase, which can last up to several days and spans a much wider energy range, from radio to very high energies.

The *Fermi* Gamma-Ray Space Telescope, launched in 2008, was designed for the detection of electromagnetic radiation in the energy range from 8 keV up to more than

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300 GeV, allowing for the study of many different types of galactic and extragalactic sources. In particular, the Gamma-Ray Burst Monitor (GBM) [1] covers the energy range 8 keV - 40 MeV and has a very large field of view, which makes it the most prolific gamma-ray burst detector to date, with more than 4000 observed events so far.

Several publications are available dedicated to GRBs, from studies on single events to general catalogs. Regarding the latter category, the *Fermi*-GBM Collaboration has published 4 GRB catalogs that cover the first two, four, six and ten years [2-5]. The first two catalogs and the fourth are accompanied by spectral catalogs [6-8], which provide more detailed information on the spectral characteristics of nearly all GRBs. In addition, there is also a time-resolved spectral catalog [9] that analyzes 81 GRBs from the first four years of the mission.

This work is intended to develop an updated pipeline for systematic time-resolved analysis that may allow the study of a very large sample of GRBs over the entire mission lifetime. To do so, we have analyzed the GRBs detected in the first two years of the mission (2008-2010) using Python scripts, the dedicated *Gamma-ray Data Tools* (GDT) toolkit [10] and the Bayesian Blocks (BB) [11] algorithm for time binning.

2. – Methods

Between 11 July 2008 and 14 July 2010, a total of 496 GRBs have triggered GBM. Our analysis focuses on a subsample of bright GRBs that satisfy the following criteria:

- *Fluence* $f > 5 \cdot 10^{-6}$ erg cm^{-2} (in the 10-1000 keV energy band);
- *Peak photon flux* $F_p > 15$ photons cm^{-2} s^{-1} (in the 10-1000 keV energy band, in either 64 or 1024 ms binning timescales, depending on the duration of the event).

The 195 surviving events have been divided into bins using the Bayesian Blocks method on the data of the brightest NaI detector (*i.e.* the one with the most counts). In particular, we have used TTE (*Time Tagged Event*) data, which consist of individually digitized pulse height events from the GBM detectors during bursts (further details are available in [1]).

However, since for very short GRBs ($T_{90} < 0.3$ s) the output of the BB algorithm was not sufficiently meaningful, we have tried to fix the bin width at 16 ms (8 ms for 1 GRB with $T_{90} = 48$ ms).

All events with at least 3 bins for which the signal exceeds the 5σ significance over background (these bins will be referred to as *source* bins) have been selected for the spectral analysis. In this way, we have reduced the number of GRBs from 195 to 160. As an example of this procedure, fig. 1 shows the lightcurve of trigger 090618353 (GRB 090618), on which the BB output has been superimposed.

A total of 1799 intervals have been fitted with the 4 spectral models traditionally included in all GBM catalogs: power-law (PL), Comptonized (COMP), Band function (BAND) [12] and smoothly-broken power law (SBPL) [13]. The fits are labeled GOOD if the errors on the model parameters lie below the following thresholds:

- $\sigma_\alpha < 0.8$;
- $\sigma_\beta < 1.0$;
- $\sigma_Q/Q < 0.4$ where $Q = A, E_{peak}, E_{break}$.

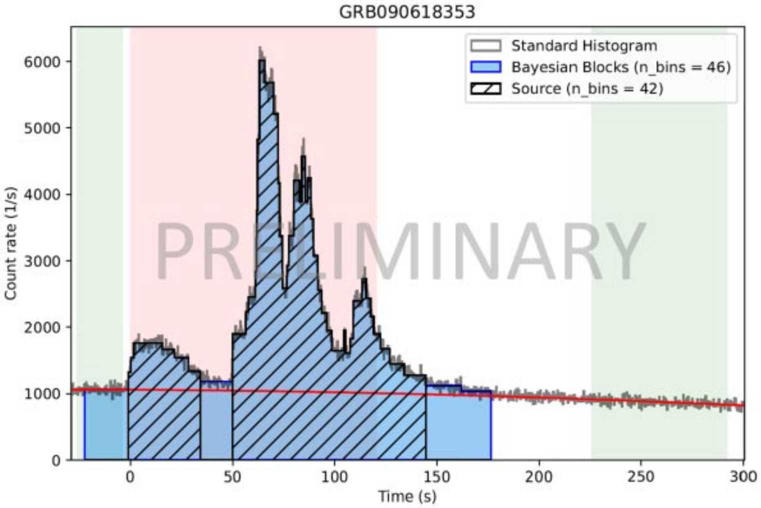

Fig. 1. – Lightcurve of trigger 090618353 with traditional binning (grey line) and Bayesian blocks binning (blue histogram). The bins highlighted with black diagonal lines are the *source* bins, the red line represents the background fit (performed with a second-order polynomial), while the red and green boxes show the T_{90} interval and the background intervals respectively.

At this stage, for each interval the BEST fitting model has been selected among all the GOOD ones, according to the value of the test statistics PSTAT (Poissonian signal with known background). However, since models with less free parameters should be preferred in case of similar values of test statistics, we subtract $\Delta_{CRIT} = 11.83$ to $\mathrm{PSTAT}_{\mathrm{COMP}}$ and $\Delta_{CRIT} = 20.41$ to $\mathrm{PSTAT}_{\mathrm{PL}}$ (these values are the same as used in [9]).

3. – Results and discussion

Table I shows the BEST model fit fractions. The COMP model is the most frequent one by a large margin, and PL also has a considerable number of occurrences. On the other hand, models with more free parameters (BAND, SBPL) are strongly disfavoured. This may be a hint that the Δ_{CRIT} values used to compare the models, which have been derived by simulating GRBs in the context of time-integrated spectral analysis [7], are inadequate in the case of time-resolved analysis.

Table I. – *BEST model fit fractions.*

MODEL	N	Percentage
BAND	15	0.9%
COMP	1219	69.5%
PL	429	28.0%
SBPL	28	1.6%
TOTAL	1754	100.0%

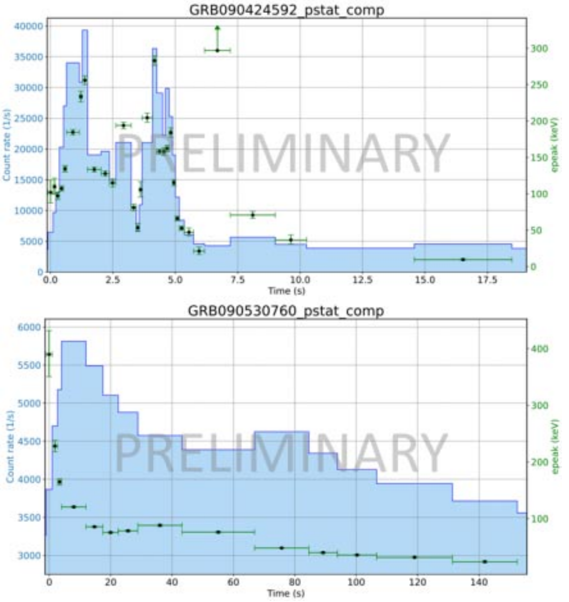

Fig. 2. – Lightcurves of triggers 090424592 (top) and 090530760 (bottom), binned using the Bayesian Blocks method. The black points with green error bars represent the E_{peak} values from COMP fits (scale on the right, in green) in each *source* interval.

Figure 2 shows two examples of lightcurves binned using the Bayesian Blocks method, on top of which the values of E_{peak} of the COMP fits in each *source* interval are plotted (black points with green error bars). Both plots are particularly relevant since they highlight two possible behaviors of E_{peak} as a function of time (which is also found in [9]):

- event 090424592 is an example of *intensity tracking*, in which the E_{peak} values vary according to the shape of the lightcurve;
- event 090530760, instead, is an example of *hard-to-soft* trend, *i.e.*, E_{peak} decreases with time.

Lastly, fig. 3 shows the preliminary distribution of the BEST fitting parameters α, β and E_{peak}. Also these distributions are in agreement with what is found in [9]. In particular, the α total distribution, dominated by the COMP entries, is distributed around $\alpha_{mean} = -1.0 \pm 0.6$, whereas the PL values are typically distributed around lower values (~ -1.7). The β values (which can only be defined and estimated for BAND and SBPL) are gathered around the physical limit -2, with $\beta_{mean} = -2.4 \pm 0.6$. Finally, the mean value of $\log_{10}(E_{peak}/\mathrm{keV})$ is $\log_{10}(326.3) \pm 0.9$. The distribution is dominated by COMP entries, but the values of BAND and SBPL are distributed in the same range.

4. – Conclusions and future perspectives

In conclusion, this new automated pipeline has been successfully tested for a subsample of GRBs from the first two years of the *Fermi* mission, and the final results are compatible with [9].

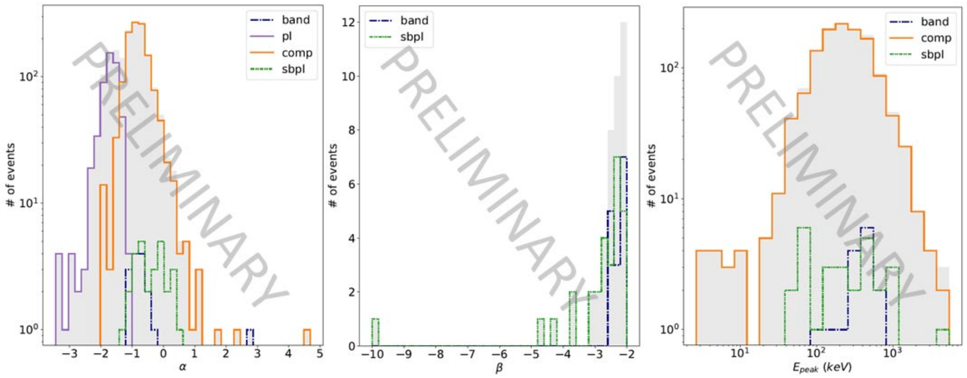

Fig. 3. – Distributions of BEST fit parameters α, β and E_{peak} (from left to right). The colors and linestyles of each model are reported in the legend, while the light grey histogram is the total distribution of all BEST models.

However, the pipeline is not yet fully developed and has undergone several modifications and improvements in recent months. These include:

- the extension of the initial sample to 6 years (until July 2014);
- new thresholds on parameter errors;
- the implementation of the Bayesian Information Criterion (BIC) [14], a useful parameter for model selection which also penalizes complexity (*i.e.*, higher number of free parameters).

These are very useful steps for the realization of an updated time-resolved catalog which covers the entire mission lifetime, uses the best possible selection criteria, and provides new results and insights on the GRB properties in the energy range of the prompt emission.

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