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Fermi GBM transient searches with ADWO

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Abstract. We present the method called Automatized Detector Weight Optimization (ADWO). This method searches for non-triggered, short-duration transients in the data-set of the Fermi's Gamma-ray Burst Monitor. The data of all available detectors and energy channels are combined. Therefore, ADWO is ideal to search for electromagnetic counterparts of gravitational wave events. We present the successful identification of all short-duration gamma-ray bursts, as well as that of the possible electromagnetic counterparts of gravitational wave transients GW150914 and LVT151012.

Key words: gravitational waves – gamma rays bursts: general

1. Introduction

On September 14, 2015 at 09:50:45.391 UTC the Advanced Laser Interferometer Gravitational-Wave Observatory (LIGO) observed the first transient gravitational-wave (GW) signal GW150914 (Abbott et al., 2016e). The signal originates from the merger of a binary black hole (Abbott et al., 2016a). Observations with the *Fermi* Gamma-ray Space Telescope's Gamma-ray Burst Monitor (GBM) (Carson, 2007; Meegan et al., 2009), custom pipeline looking for prompt gamma-ray counterparts in GBM (Blackburn et al., 2015; Kelley et al., 2013), optimized for LIGO GW candidate events found a weak transient source(Connaughton et al., 2016) 0.4 s after the GW event, with a false probability of 0.0022.

Similar searches were unsuccessful with the *Fermi* LAT (Ackermann et al., 2016), as well as during the partial Swift follow-up (Evans et al., 2016). The INTEGRAL observation of the event was unsuccesful too (Savchenko et al., 2016). Despite these unsuccesful detections, the GBM's signal is interesting enough to investigate the electromagnetic (EM) counterparts of GW detections, such as short-duration gamma-ray bursts (SGRBs). Perna et al. (2016) proposed a model in which a double black hole merger produces a SGRB. In this model, two low-metalicity massive stars are orbiting around each other (de Mink et al., 2009; Marchant et al., 2016; Mandel & de Mink, 2016) with synchronized rotations because of the tight orbit. Their rotational periods are very short (a few days), and these stars evolve homogeneously as the fast rotation prevents them to expand (Szécsi et al., 2015). Assuming that one of the supernova explosions leaves a disk behind, a relativistic jet will be launched during the black holes' merger Perna et al. (2016).

There are two more LIGO observations worth to explore. On 12/10/2015 at 09:54:43.555 UTC LVT151012 was observed as the second GW candidate transient (Abbott et al., 2016c,b), with a false alarm probability of 0.02, considered to be not low enough to confidently claim this event as a real signal. On 26/12/2015 at 03:38:53.647 UTC the third GW transient event, GW121226 was observed, with a significance greater than 5 σ (Abbott et al., 2016d).

2. The Automatized Detector Weight Optimization (ADWO) method

The *Fermi* GBM includes 12 Sodium Iodide (NaI(Tl)) and two Bismuth Germanate (BGO) scintillation detectors (Meegan et al., 2009). The NaI(Tl) detectors measure the spectrum from 8 keV to $\sim$ 1 MeV, while the BGO detectors are sensitive from $\sim$ 200 keV to $\sim$ 40 MeV. To calculate the significance of an event, the spectral model should be multiplied by the detector response matrix (DRM) and binned to get the photon events. These counts will be compared to the counts and the background noise observed by the detectors. The DRM describes the effective detection area as the function of the incoming photon energy, angular dependence, detector non-linearity and scattering. Without directional information this method cannot be used as the DRM exhibits a strong angular dependence. Although the direction is unknown the time interval where the possible EM trigger could happen is given. To analyze the multi-detector multi-channel continuous data the simplest method would be to sum all the detectors and channels. Clearly this way is not optimal since non-illuminated detectors and noisy energy channels should be taken into account only with low weights.

The Automatized Detector Weight Optimization (ADWO) method (Bagoly et al., 2016) solves this problem by assigning different normalized and positive weights to different energy channels (e_i) and detectors (d_j). The signal is $S(t) = \sum_{i,j} e_i d_j C_{ij}(t)$, where $C_{ij}(t)$ denotes the background subtracted lightcurve in the jth detector's ith energy channel. ADWO maximizes the Signal's Peak (maximum of $S(t)$ within the search interval) over the Background's Peak (maximum of $S(t)$ outside the search interval). The Signal's Peak over the Background's Peak (SPBPR) is one of the most important statistical parameters in our analysis. ADWO provides not only maximum value of SPBPR, but also the best weights and the exact time of the event. ADWO's Matlab/Octave source code is freely available[1].

We use the *Fermi* GBM continuous time-tagged event (CTTE) data, grouped by the CTIME energy channels 4.4, 12, 27, 50, 100, 290, 540, 980 and 2000 keV (denoted with $e_1 \dots e_8$, resp.), smoothed by a 64 ms moving average window. We use only the upper 6 energy channels, since we look for spectrally hard events and want to reduce the low energy noise. For the background determination one should take the detailed satellite positional information into account (e.g. Szécsi et al. (2013)). However, here we are only looking for short transients or SGRBs, hence a 6th order polynomial background fit was subtracted in the $\approx (-200, 500)$ s region around the possible trigger, similarly to Connaughton et al. (2016).

3. Transient search results

We analyzed the short GRB150522B gamma-ray burst. Full CTTE data of the $(-137, 476)$s interval relative to the trigger was analyzed. ADWO obtained SPBPR=3.12 (Fig. 1). We've generated 10^4 Monte-Carlo (MC) simulations to determine the significance: there was no case with SPBPR above 3.12, therefore the false alarm rate is below 2×10^{-5} Hz, with a corresponding false alarm probability $< 2.8 \times 10^{-5}$.

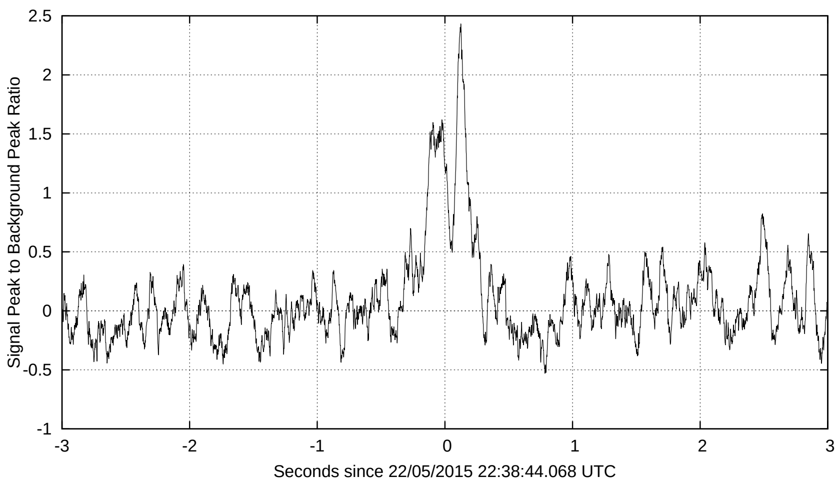

Figure 1. ADWO light curve of GRB150522B in the 27-2000 keV range.

[1] `https://github.com/zbagoly/ADWO`

We also applied the ADWO method on the *Fermi* CTTE data, around the GW150914 event. The 6 s long signal window was analyzed in the $(-195, 495)$s full interval (relative to the GW trigger). ADWO obtained SPBPR=1.911, 474 ms after the GW event (Fig. 2). The 10^4 MC simulations produced 86 cases with bigger SPBPR, thus the false alarm rate is ≈ 0.0014 Hz, and the false alarm probability is ≈ 0.0075.

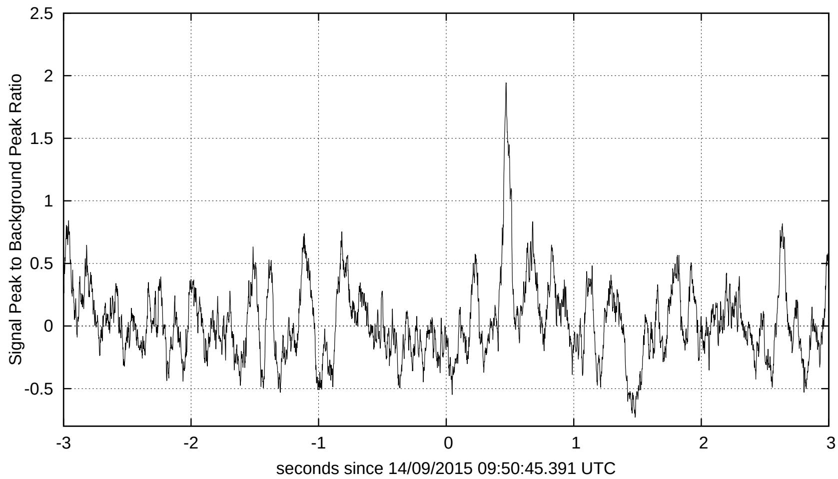

Figure 2. ADWO light curve of GW150914 in the 27-2000 keV range.

We analyzed the GBM CTTE data of LVT151012, covering the $(-195, 495)$ s window around the trigger. ADWO produced a SPBPR=1.805, 652 ms after the GW event (Fig. 3). 10^4 MC simulations were performed to determine the significance. 308 cases had bigger SPBPR than 1.805, giving the false alarm rate of ≈ 0.0051 Hz and the false alarm probability of ≈ 0.037. Cross-check with the lightning detections made by WWLLN (Rodger et al., 2009) produced no TGF candidates within 500 km of the spacecraft position.

ADWO was applied for the GW151226 event's GBM CTTE data, in the $(-195, 495)$ s window around the trigger. ADWO produced a relatively low peak with SPBPR=1.321, 1950 ms before the signal. This SPBPR value is so low that it cannot be considered as a real signal (Fig. 4).

It is known that GBM observed several untriggered EM events, e.g. Gruber & Fermi/GBM Collaboration (2012) estimates ≈ 1.6 untriggered SGRB/month in the *Fermi* observations. They even produce an untriggered GRB list on the *Fermi* webpage, as an output of the offline (ground based) processing pipeline (Siellez et al., 2016; Briggs et al., 2016). In Figs. 5-6 the results of the ADWO searches are shown for two such cases. Both of the ADWO light curves show a clear transient after the trigger.

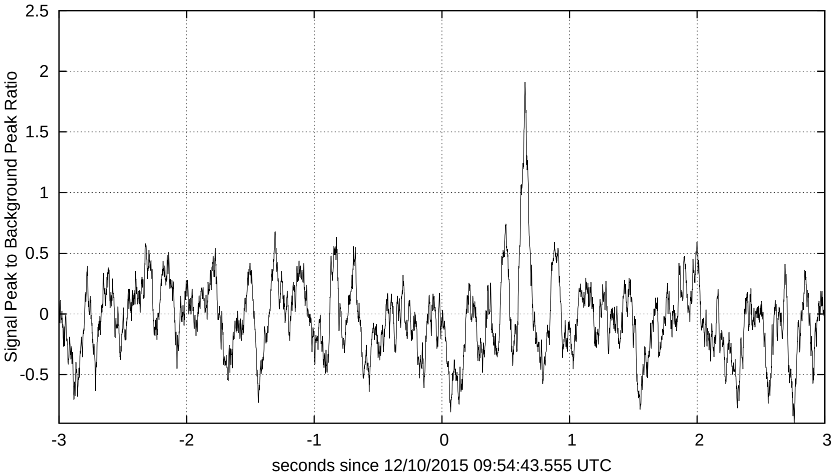

Figure 3. ADWO light curve of LVT151012 in the 27-2000 keV range.

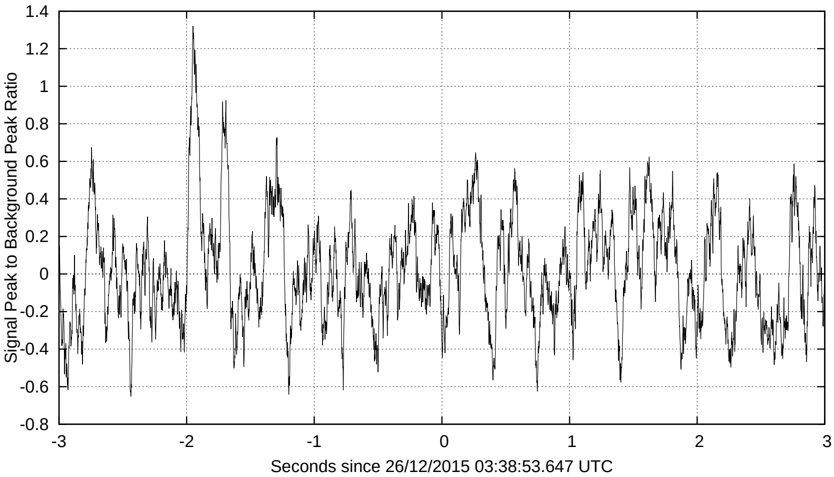

Figure 4. ADWO light curve of GW151226 in the 27-2000 keV range.

4. Discussion

We've analyzed *Fermi*'s all triggered GRBs with $T_{90} < 10$s. On Fig. 7 sum of the $27 - 290$ keV weights (softness) and the SPBPR values are shown with events having SPBPR below 6. Furthermore, we repeated the ADWO on 61.4 ks CTTE GBM observation on 15/09/2015. 10235×6 s long signal window slices were analyzed, and the corresponding sum of the $27 - 290$ keV weights and

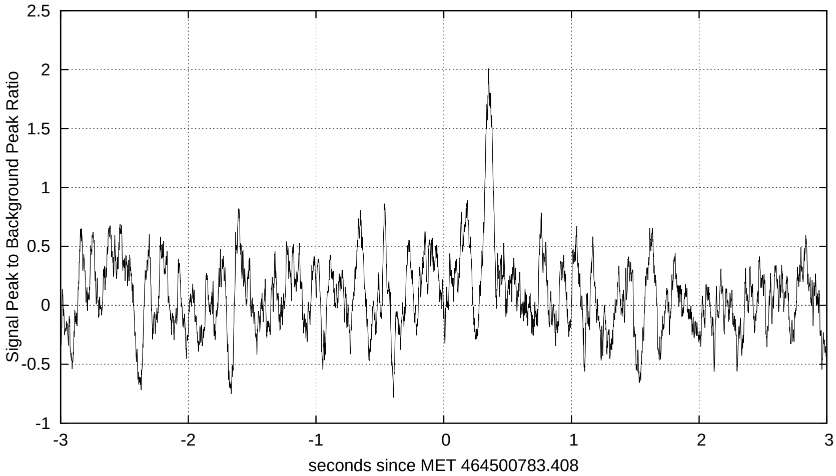

Figure 5. ADWO light curve of the untriggered GRB150921153 in the 27-2000 keV range.

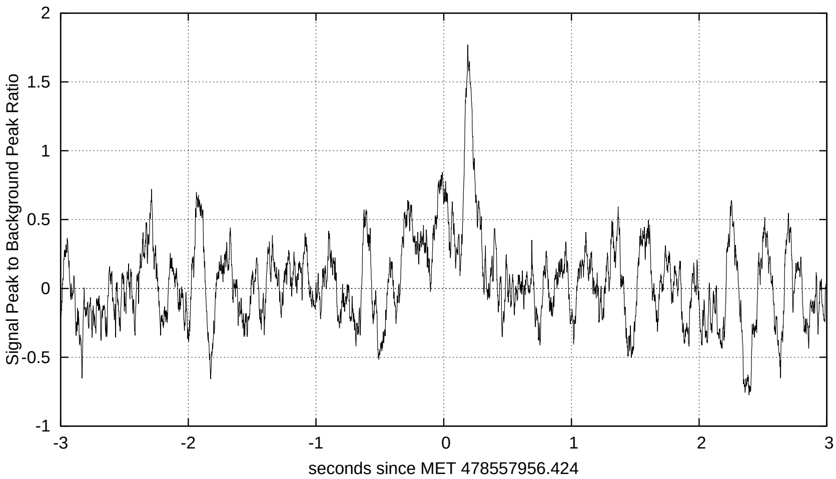

Figure 6. ADWO light curve of the untriggered GRB160301788 in the 27-2000 keV range.

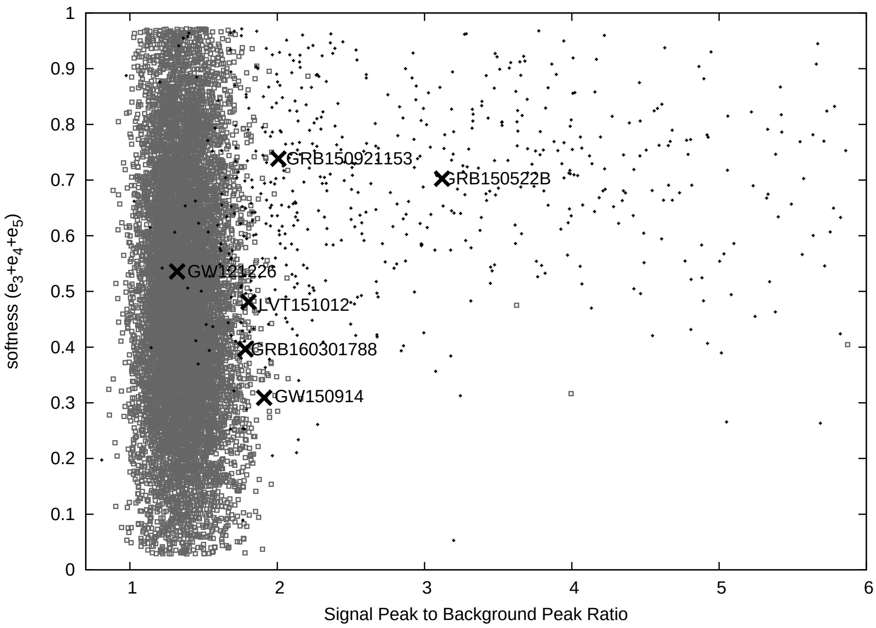

Figure 7. Signal Peak to Background Peak Ratio and the sum of the $27 - 290$ keV weights for the 61.4ks GBM data background (grey open squares) and for the $T_{90} \leq 10$ s *Fermi* SGRBs (small crosses). All transients mentioned in the article are also shown.

SPBPR values are also plotted on Fig. 7.

It is interesting that all transient mentioned above are within the SGRBs' distribution, and also one can see that several GBM background observations produce a strong SPBPR signal. Both effects will be investigated in a forthcoming paper.

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