A search for Terrestrial Gamma-ray Flashes in the BeppoSAX Gamma-Ray Burst Monitor data archive

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Up to now, Terrestrial Gamma-ray Flashes (TGFs) have been observed by several spacecraft devoted to astrophysics, such as CGRO, RHESSI, AGILE and Fermi. The Italian/Dutch satellite BeppoSAX (1996-2002) was one of the most important missions in the field of high-energy astrophysics: its payload housed the Gamma-Ray Burst Monitor (GRBM), a segmented detector that could, in principle, have observed TGFs as well. Motivated by this possibility, we carried out for the first time a systematic quest of possibly observed TGFs throughout the BeppoSAX GRBM data archive. Our search ended up with a sample of 12 TGF candidates. Among these events, we also found a peculiar candidate, whose features may represenent the signature of a mirrored electron TGF.

1. Introduction

Terrestrial Gamma-ray Flashes (TGFs) are brief (<ms) and intense gamma-ray (few÷tens MeV) emissions coming from the lowest part of the terrestrial stratosphere (~15 km a.s.l.), strictly correlated with thunderstorms. Unexpectedly discovered in the early '90s by the Burst And Transient Source Experiment (BATSE) on-board the Compton Gamma-Ray Observatory (CGRO) [1], TGFs have been further investigated by several satellites devoted to high-energy astrophysics like RHESSI [3], AGILE [4] and the Fermi Space Telescope [5].

2. The BeppoSAX Gamma-Ray Burst Monitor

The Satellite for X-ray Astronomy (BeppoSAX) was a project of the Italian Space Agency (ASI), with participation of the Netherlands Agency for Aerospace Programs (NIVR), operational from 1996 to 2002. On its payload, BeppoSAX housed the Gamma-Ray Burst Monitor (GRBM), a segmented detector with four independent 1136 cm^2 wide CsI(Na) scintillator units [2] (Fig. 1).

GRBM data are available in two energy channels: the GRBM band (40÷700 keV) and the AC band (>100 keV). The first kind of data is acquired whenever an excess of counts over the background rate is detected, in at least two units out of four, with a 7.8 ms time resolution. The second kind of data is continuously acquired with a 1 s time resolution.

From simulations we found out that a TGF with a typical 0.1 ph/cm^2 fluence would release about 1÷11 counts within a single 7.8 ms temporal bin, into a single detector unit, that are just few counts above the typical background rate of 6÷7 cts/bin.

From an accurate overview of the GRBM main technical characteristics, three major drawbacks concerning TGF detection, are pointed out: such issues represent basic limitations to our analysis. First, the integration times upon which the on-board trigger condition is set turn out to be too long to be sensitive to TGFs: as simulations show that typical TGFs would not release a large amount of counts in the detector, we expect that these events would not trigger the GRBM. Hence, possibly detected TGFs should be searched into the available data acquired at random times. Second, the GRBM time resolution (7.8 ms) is not optimized for TGF studies: counts due to TGFs would be integrated all within a single time bin, not providing information about the time profile of the burst. Third, data acquired in the AC band have a too rough time resolution (1 s) to be suitable for TGF analysis and the only useful data are those acquired in the GRBM band. The absence of more than one useful energy channel prevents us from performing spectral studies.

3. The search algorithm

Due to the GRBM coarse time resolution, TGF light curves would appear just as simple spikes above the background rate. In this perspective, statistical fluctuations of the background and high-energy charged particles could mimic the expected light curve of a TGF: a discrimination against these sources of fake spikes is necessary. Such a discrimination is performed by selecting the spikes exceeding a certain settable threshold level in

at least three units out of four: this ensures that the detected spikes are not caused by either statistical fluctuations (within a certain confidence level, depending on the threshold value), or by high-energy charged particles crossing the detector slabs. Thresholds are chosen in order to select spikes simultaneously observed in three (or four) units, with a global probability to be statistical fluctuations within a 5σ (or 4σ) confidence level. We label as $n\sigma_k$ the different selection criteria, with confidence level *k* and a number of units *n* in which the spike is observed. The $4\sigma_3$ and the $5\sigma_4$ selection criteria therefore represent the loosest and the tightest selection criterion, respectively.

Before starting our search, we estimated the expected number of TGFs detected by our selection criteria, during the whole mission lifetime. We took in consideration the actual exposure time of the BeppoSAX GRBM (~24 days), the geographic region spanned by the spacecraft (within a ±3.9° inclination orbit) and the minimum detectable threshold for the different selection criteria. We obtained that the $4\sigma_3$ criterion would allow us to find throughout the data archive <10 TGFs, while the $5\sigma_4$ criterion would allow us to find <4 TGFs, in six years activity.

4. Results

As expected, the $4\sigma_3$ selection criterion produced the largest sample, consisting in 12 TGF candidates (Fig. 1). Among them, 5 events satisfy also the $5\sigma_4$ selection criterion.

The evaluation of the payload configuration with respect to Earth at the time each candidate took place shows that, for all 12 candidates, at least one GRBM unit was directly pointing towards the Earth (within ±30° from the nadir). Moreover, the TGF candidate sample exhibits an evident clustering over the continental regions, reflecting the common behavior of a genuine TGF geographic distribution.

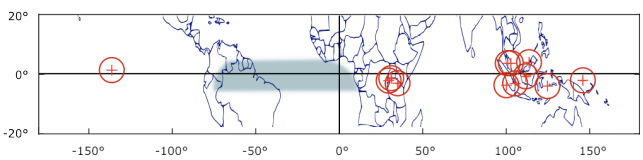

Fig. 1: Geographic distribution of the 12 TGF candidates satisfying the $4\sigma_3$ selection criterion

Among the $5\sigma_4$ events, TGF candidate 000308, occurring over central Africa, exhibits a peculiar double-peaked time profile: the first brighter pulse is compatible with a sky incoming direction and the second fainter pulse is compatible with a terrestrial incoming direction. The pulses are (46±4) ms apart. The second pulse is available with both 7.8 ms and 0.5 ms time resolution and exhibits a rather long duration (4÷5 ms) and an asymmetric time profile (Fig. 2), differently from typical TGFs.

Given the temporal and directional features of this event, we suggest this could be the signature of a mirrored electron TGF [6].

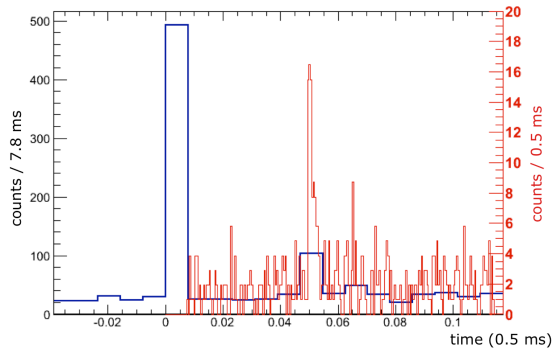

Fig. 2: Light curve of TGF candidate 000308, with 7.8 ms (blue) and 0.5 ms (red) time resolutions

5. Conclusions

Motivated by the possibility that the BeppoSAX GRBM did observe TGFs, we developed a search algorithm to look for events throughout its data archive. However, the low time resolution and the absence of useful spectral data severely hampered this search: the 12 TGF candidates selected by our algorithm cannot be solidly confirmed as TGFs. Nevertheless, such events are consistent with some typical properties of TGFs, as the geographic distribution and the terrestrial incoming direction. Moreover, the number of candidates we ended up with is totally consistent with the expected number of TGFs that would be detected by the GRBM in six years activity.

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