Swift-BAT all-sky monitoring: transient phenomena with timescales from days to months

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Abstract

The Burst Alert Telescope on board of *Swift* is mainly devoted to the monitoring of a large fraction of the sky (50%-80% per day) for the occurrence of Gamma Ray Bursts. This provides the opportunity for a substantial gain of our knowledge of the Galactic and extragalactic sky in the hard X-ray domain. We have developed a code for the analysis of the survey data collected by the *Swift*-BAT telescope and produced two hard X-ray catalogues from the all-sky maps integrated over the first 39 and 54 months of *Swift*-BAT observations.

Here we present the method adopted for a systematic search for transient sources on the BAT survey data. We have applied this method to search for transient sources with characteristic timescales from a few days up to months on the data accumulated over 66 months of BAT survey, obtaining a list of 222 sources that were below the detection threshold in the all-sky map built integrating the entire observing period.

Key words: X-rays: catalogues — X-rays: surveys

1. Introduction

The Burst Alert Telescope (BAT; Barthelmy et al. 2005) on board of the *Swift* observatory (Gehrels et al. 2004) is a coded-aperture imaging camera operating in the 15–150 keV energy range, with a large field of view of 1.4 steradian (half coded) and a point spread function of 17 arcmin (full width half maximum). BAT operates as a hard X-ray monitor with the main goal of catching Gamma Ray Bursts and fast transient phenomena (with timescales up to several minutes), locating on board their position with an accuracy of 1 to 4 arc-minutes within 15 seconds. Thus, the telescope performs a continuous monitoring, collecting imaging and spectral information on a fraction of between 50% and 80% of the sky every day. As a byproduct of this monitoring, BAT has also allowed a substantial improvement in our knowledge of the hard X-ray sky: results obtained from the BAT survey data have been presented in several papers (see e.g. Markwardt et al. 2005, Ajello et al. 2008, Tueller et al. 2008, Tueller et al. 2010) that include the catalogues of the sources extracted from the analysis of different observing periods.

A code dedicated to the analysis of BAT survey data (batimager) was developed at the INAF-IASF Palermo. A detailed description of this code can be found in Segreto et al. (2010). This led to the production of the 39-month Palermo BAT Catalogue (Cusumano et al. 2010a) and of the 54-month Palermo BAT Catalogue (Cusumano et al. 2010b).

All the above mentioned catalogues, however, contain only sources that emerge over the noise on the all sky maps built integrating long observing periods. The drawback of this analysis is that some sources may result undetectable in these integrated all-sky maps because they could be active only during a small fraction of the survey time, while their average significance falls below the detection threshold when we integrate over the entire observing time. The search for slow transient phenomena (with timescales larger than days) requires the application of dedicated methodologies that favour the detection of transient signals.

In this paper we describe method and results of a systematic search for transient sources on timescales from a few days up to months performed over the first 66 months of BAT survey data.

2. Method

We have analyzed with the batimager code the survey data collected between November 2004 and May 2010,

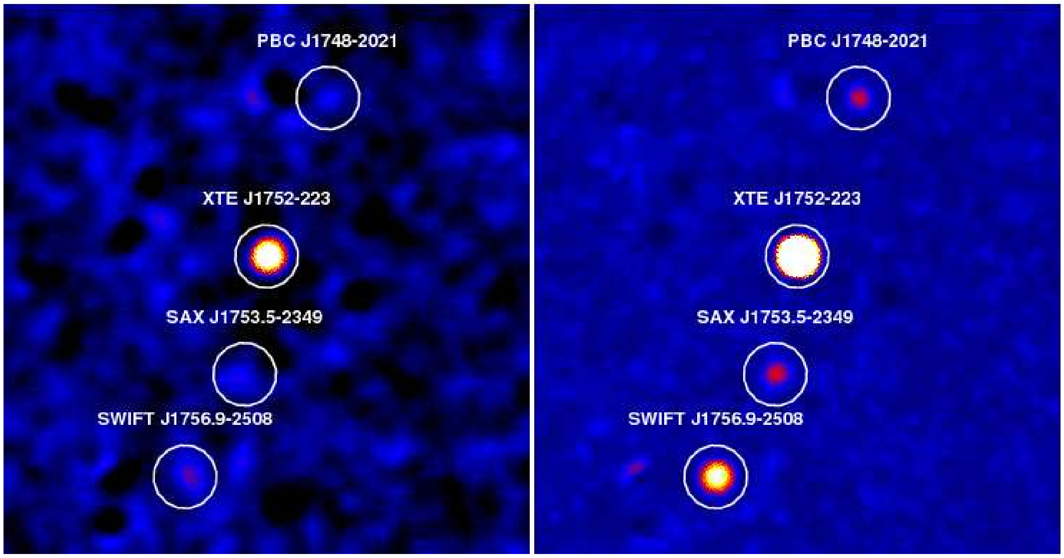

Fig. 1. **Left:** a sky region extracted from the 15–150 keV average significance map. **Right:** the same region as it appears in the "best significance" map obtained associating to each sky pixel the best signal-to-noise achievable summing over consecutive time bins.

building significance all-sky maps in three energy bands (15–30 keV, 15–70 keV, and 15–150 keV) and in time intervals of 15 days (hereafter called frame maps). As a first step, the set of frame maps, for each energy band, has been summed together to produce time integrated significance all-sky survey maps for the 66 month survey data. A blind search was then performed on each of the three maps with a S/N threshold of 4.8 standard deviations producing three lists of significance peaks. A final catalogue including about 1400 BAT source candidates was built merging the three lists. This catalogue includes mainly persistent hard X-ray sources plus a few transient sources whose intensity averaged over the 66 months results in a significance above the detection threshold. However, many other sources could remain below this detection threshold because their signal, emitted only during a shorter time interval, is drowned in the noise when averaged over 66 months.

In order to make these sources emerge we have built, for each energy band, a "best significance" all-sky map, assigning to each pixel the maximum significance value that could be obtained cumulating the signal of any subset of consecutive frame maps. As an example, for a source that has undergone a two months activity period, being switched off during the rest of the survey time, the "best significance" map reports the significance obtained integrating only over the frame maps covering these two months.

The statistical distribution of values in these maps is not gaussian and it could vary in different region of the sky mainly because of the non uniform exposure. In order to determine a significance threshold for source detection we have studied the "best significance" distribution in regions of 5 degrees radius randomly selected over the sky. We have then modeled them with an analytical function and computed the probability of observing an excess due to a noise fluctuation as a function of the detection threshold. We have thus verified that a detection threshold of 6 standard deviations in the "best significance" map results in a number of spurious detections much lower than 1.

A detection algorithm is then run on the three "best significance" maps adopting a threshold of 6 standard deviations. The lists of detections were then cleaned from the sources that were already detected in the 66 months integrated significance all-sky survey maps. Finally, a list of 222 sources was derived merging the three lists.

Figure 1 shows how a region on the Galactic plane appears both in the all-sky significance map and in the "best significance" map, with three sources (SWIFT J1756.9-2508, SAX J1753.5-2319, PBC J1748-2021) emerging in the latter while no signal was detected in the former map. Figure 2 shows the light curves (with a bin time of 15 days) and the transient nature of these sources, with the significance averaged over the 66 months (magenta line) and the significance achieved integrating along the "best significance" time interval (blue line).

3. Association strategy

To find the most likely counterpart to the sources detected in the "best significance" map, we applied two different strategies.

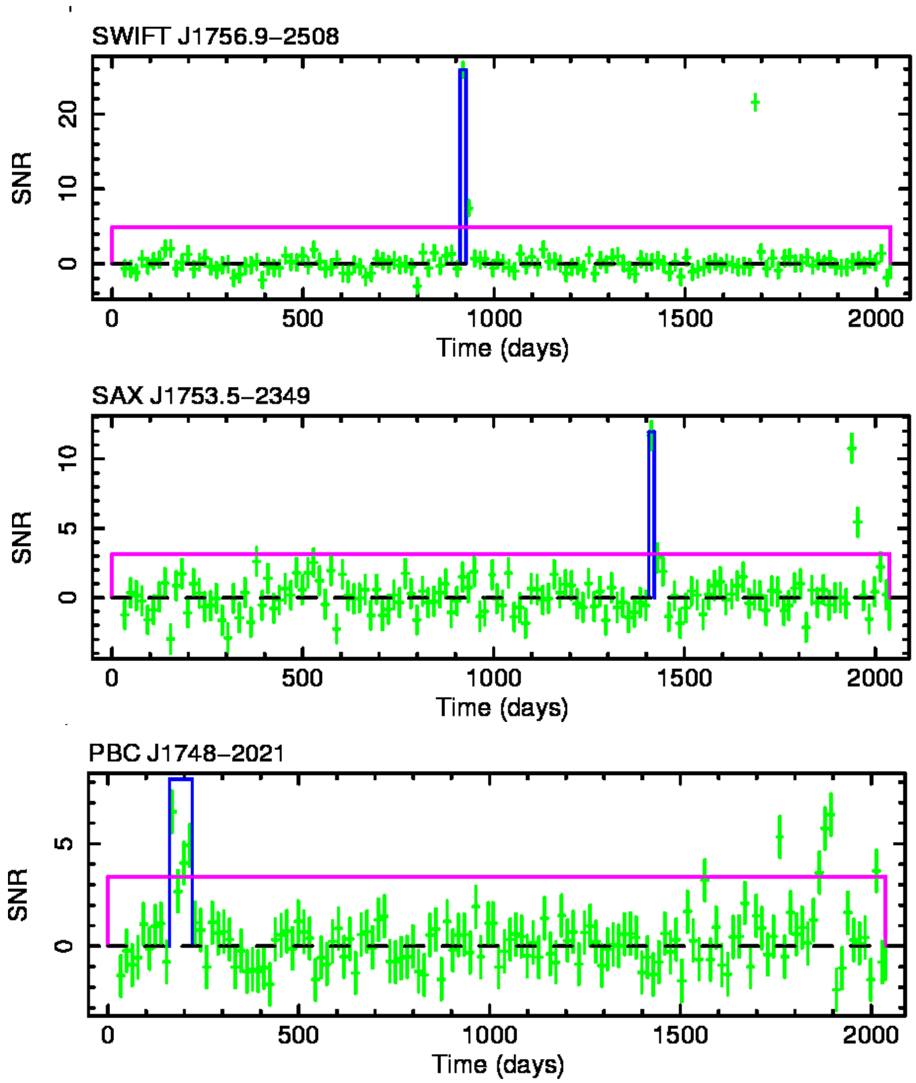

Fig. 2. Significance light curves of the three transient sources shown in Fig. 1. The magenta line is the significance level averaged over the 66 months of survey; the blue line shows the "best significance" and the interval where this is achieved.

3.1. Follow-up observations.

We analyzed soft X-ray archival observations whose field of view covers the position of the sources. First, we use the huge data set of *Swift*-XRT observations, many of which were performed to provide the counterpart of sources listed in the BAT catalogues. When the BAT position of a source was not covered by any XRT observation, we searched for pointed archival observations with other X-ray instruments (Beppo-SAX, ASCA, Newton-XMM, Chandra, ROSAT). In each soft X-ray image, we searched for sources within a 6 arcmin radius error circle. Then, the identification of the likely soft X-ray counterpart was done by searching in the SIMBAD[1] and NED[2] databases within the soft X-ray error box.

*1 http://simbad.u-strasbg.fr/simbad/
*2 http://nedwww.ipac.caltech.edu/

3.2. Catalogue match.

To find an association for the sources not associated with the follow-up method, we compiled a list of possible counterparts merging several catalogues and source lists:

- high and low mass X-ray binaries, cataclysmic variables, Seyfert galaxies, unclassified AGNs and γ-ray sources, whose lists were extracted from the SIMBAD database on January 2010;

- the *Roma*-BZCAT (Massaro et al. 2008), a list of Blazars based on multifrequency surveys and on an extensive review of the literature;

- the ROSAT All Sky Survey (RASS) Bright source

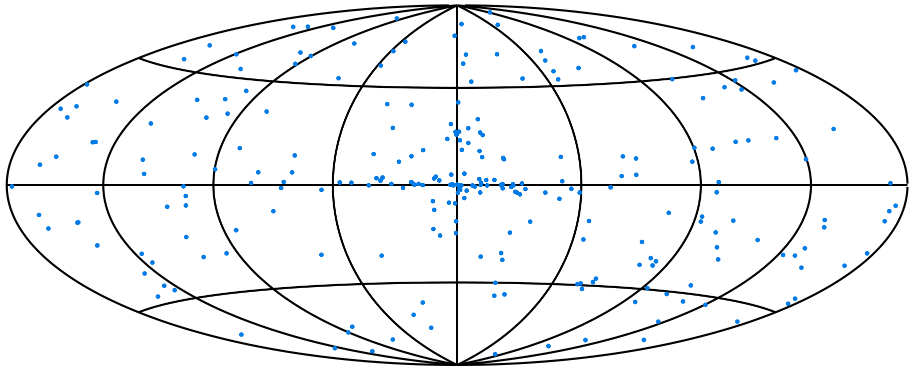

Fig. 3. Map (in Galactic coordinates) of the sources detected in the "best significance" all-sky map.

catalogue (Voges et al 1999).

Then we performed a cross correlation of the BAT position with the positions of the sources in this list with an association radius of 6.8 arcmin (Cusumano et al. 2010b).
The two methods led to the association of 66 out of the 222 BAT excesses: 24 are Galactic, 20 are extragalactic and 22 are X-ray sources whose nature has not been determined yet. Within the last group, 14 sources have a Galactic latitude lower than 5 degrees.

4. Conclusion

We have analyzed the first 66 months of BAT survey data and applied a procedure that allows to reveal slow transient phenomena with a characteristic timescale higher than 15 days. The procedure is based on a "best significance" all-sky map, where the value assigned to each sky pixel is the maximum significance that can be obtained cumulating the signal of subset of consecutive frame maps with a time granularity of 15 days.

We found 222 excesses above a detection threshold of 6 sigmas. These sources remain undetectable on the all-sky map obtained integrating the whole observing period. Figure 3 shows the distribution of these source on the sky. A crowding of sources is observed along the Galactic plane. A soft X-ray counterpart was associated to 66 out of 222 sources. A *Swift*-XRT follow-up campaign will be requested to determine the nature of the remaining sources.

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