PROCEEDINGS OF SCIENCE

The 4^{th} Palermo *Swift*-BAT catalogue: 7 years of survey of the hard X-ray sky

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The 4th Palermo Swift-BAT hard X-ray catalogue is obtained by analyzing data acquired in the first 7 years of the Swift mission. The survey covers 50% of the sky up to a 15-150 keV flux limit of 7.0×10^{-12} erg cm^{-2} s^{-1}. We used a source detection algorithm that optimizes the energy band and the time interval allowing to achieve the maximum signal to noise ratio for each pixel of the all-sky map. We obtain a list of $\sim$ 1700 source candidates with a negligible number of spurious detections. The identification of the source counterparts in softer energy bands is pursued both through the analysis of soft X-ray field observations and through the cross-correlation with source databases. The 4th Palermo Swift-BAT catalogue includes $\sim$ 20% of Galactic sources, $\sim$ 60% of extragalactic sources, $\sim$ 10% of sources with a counterpart at softer energies whose nature has not been determined yet while $\sim$ 10% still lack any associated counterpart.

"An INTEGRAL view of the high-energy sky (the first 10 years)" 9th INTEGRAL Workshop and celebration of the 10th anniversary of the launch,
October 15-19, 2012
Bibliotheque Nationale de France, Paris, France

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PoS(INTEGRAL 2012)095

1. Introduction

The Burst Alert Telescope (BAT; [1]) onboard the *Swift* observatory [2] is a coded-aperture imaging camera operating in the 15–150 keV energy range. The telescope is characterized by a large field of view (1.4 steradians half coded) and a moderate point spread function (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 and performing a continuous survey of the entire hard X-ray sky collecting imaging, timing and spectral information. BAT provides a coverage between 50% and 80% of the sky every day.

The analysis of BAT survey data produced several hard X-ray source catalogues (see e.g. [3], [4], [5], [6], [7]). Using a dedicated software [8] we have been producing the Palermo Swift-BAT Catalogue series (39-month [9], 54-month, [10], 66-month [11]). In this paper, we present the main properties of the the 4th Palermo *Swift*-BAT hard X-ray catalogue obtained from the analysis of the data relevant to the first 7 years of the *Swift* mission (December 2004 – November 2011).

2. Global survey properties

After 7 years of all-sky survey monitoring, BAT limiting flux has reached a few 10^{-12} erg cm^{-2} s^{-1}, depending on the sky direction. In Fig. 1 we show the map of the 5σ limiting flux of the 7-year BAT survey in the 15–150 keV band, projected in Galactic Aitoff coordinates.

The Galactic centre and the ecliptic plane are characterized by a relatively poorer sensitivity with the highest limiting flux of 1.8×10^{-11} erg cm^{-2} s^{-1}, while the lowest limiting flux (4.6×10^{-12} erg cm^{-2} s^{-1}) is achieved close to the ecliptic poles. This is due to the high contamination from intense Galactic sources and to the observing constraints on the *Swift* spacecraft.

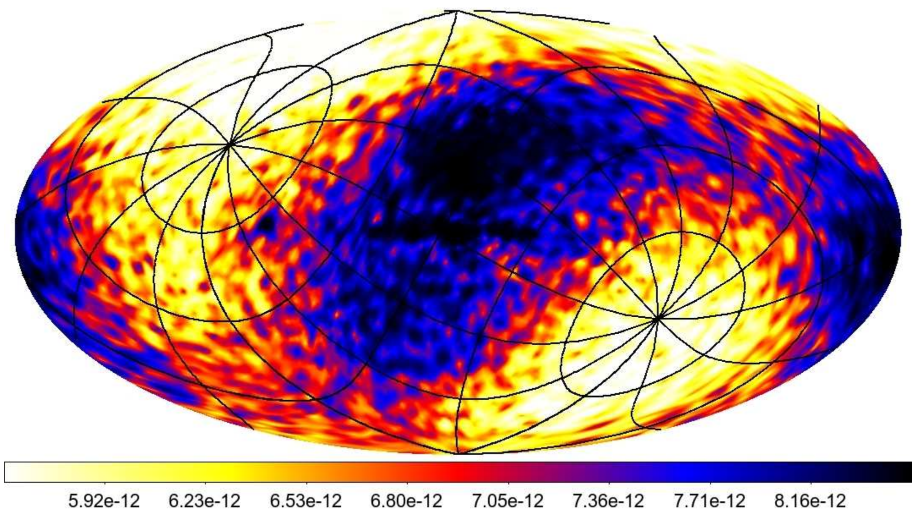

Figure 1: Map of the limiting flux of the 7-year BAT survey in the 15–150 keV band, projected in Galactic Aitoff coordinates, with the ecliptic coordinates grid superimposed. The color bar shows the flux scale in erg cm^{-2} s^{-1}.

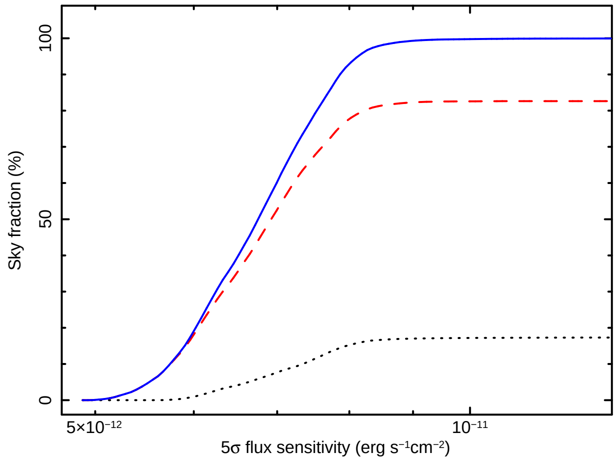

Figure 2: Fraction of the sky (black dotted line: $|b| < 10°$, red dashed line: $|b| > 10°$, blue solid line: entire sky) covered by the BAT survey as a function of the 15–150 keV detection limiting flux for a detection threshold of 5 standard deviations.

In Fig. 2 we show the fraction of the sky covered by the 7-year BAT survey as a function of the detection limiting flux in the 15–150 keV skymap for Galactic ($|b| < 10°$) and extragalactic ($|b| > 10°$) regions. As it can be seen from the plot the survey covers 50% of the sky to a flux limit of 7.15×10^{-12} erg cm^{-2} s^{-1} and 6.72×10^{-12} erg cm^{-2} s^{-1}for $|b| < 10°$ and $|b| > 10°$, respectively.

3. Detection strategy

We built all-sky survey maps in three separated energy bands (15–30 keV, 30–70 keV and 70–150 keV) mosaicking all the sky images extracted from the BAT survey data. A source detection algorithm was run on each of these skymaps and on any combination forming contiguous energy intervals to extract significance excesses above a threshold of 4.8 standard deviations. The use of 7-year integrated maps is efficient to extract sources characterized by persistent emission or transient sources with a large fluence. Weak and/or short transient sources may escape detection because their significance, averaged over seven years, is lower the detection threshold. To detect these sources we produced all-sky maps integrating the survey data in 15-day time intervals, and built a best significance map, assigning to each sky pixel the maximum significance that can be obtained cumulating the signal in any combination of consecutive 15-day maps. The source detection algorithm was run on this map with a detection threshold of 6 standard deviations. Thresholds were set in order to obtain a negligible number of possible spurious detections. The resulting catalogue includes $\sim$ 1700 hard X-ray sources with an expected number of spurious detections of 1-2%.

4. Association strategy

Since the source localization improves with the S/N (while the error radius associated to it

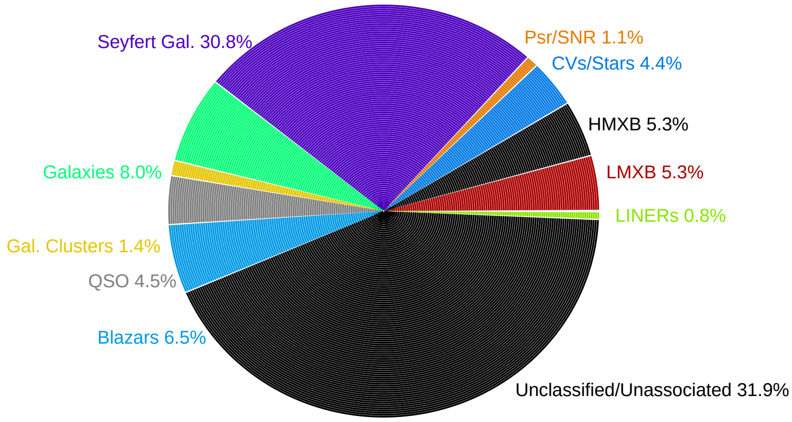

Figure 3: Detailed distribution of the catalogue sources among different classes of cosmic sources.

becomes smaller), for all sources we have optimized their position deriving it from the best significance map.

In order to identify the nature of the detected sources, we have searched for possible counterparts in other energy bands. Our main strategy consists in using soft X-ray observations whose field of view covers the position of the BAT sources, and in searching sources inside the BAT error box. We have used mainly Swift-XRT follow-up observations requested by us, or archival observations of previous soft X-ray satellites. The identification of the soft X-ray counterparts was pursued using the much smaller soft X-ray error box to search on the SIMBAD and NED archives.

The BAT sources without a counterpart in soft X-ray field observations were cross-correlated with a list of possible counterparts obtained merging appropriate catalogues (high and low mass X-ray binaries, cataclysmic variables, supernova remnants and pulsars, Seyfert galaxies, unclassified AGNs, interacting galaxies, LINERs, and γ-ray sources from the SIMBAD database as of January 2010; the *Roma*-BZCAT [12]; the ROSAT All-Sky Survey (RASS) Bright Sources Catalogue [13]).

After the application of the association procedures, $\sim$ 90% of BAT sources have an associated counterpart; $\sim$ 60% of them are extragalactic, $\sim$ 20% are Galactic and $\sim$ 10% are soft X-ray emitters whose nature has not been determined yet. The detailed distribution among different classes of cosmic sources is shown in Figure 3.

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