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# The Palermo *Swift*-BAT Hard X-ray Catalogue

## Results after 39 months of sky survey

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**Abstract.** The BAT telescope onboard the Swift satellite is performing the deepest and most complete hard (15–150 keV) X-ray survey to date.
In order to exploit the BAT survey data we developed a software based on a FFT algorithm that performs data reduction, background subtraction, mosaicking and source detection. We have analyzed the BAT hard X-ray survey data of the first 39 months of the *Swift* mission. The survey covers 90% of the sky down to a flux limit of $2.5 \times 10^{-11}$ erg cm$^{-2}$ s$^{-1}$ and 50% of the sky down to a flux limit of $1.8 \times 10^{-11}$ erg cm$^{-2}$ s$^{-1}$ in the 14–150 keV band. We derived a catalogue of 754 identified sources, of which ~ 69% are extragalactic, ~ 27% are Galactic objects, ~ 4% are already known X-ray or gamma ray emitters whose nature has not been determined yet.

**Key words.** X-rays: general - Catalogs - Surveys

## 1. Introduction

The Burst Alert Telescope (BAT; Barthelmy et al. 2005) is one of the three instruments on board the *Swift* observatory (Gehrels et al. 2004). The telescope, operating in the 14–150 keV energy range, is mainly devoted to the monitoring of a large fraction of the sky for the occurrence of Gamma Ray Bursts (GRBs). While waiting for new GRBs, BAT continuously collects spectral and imaging information, covering a fraction between 50% and 80% of the sky every day. This provides the opportunity for a substantial gain of our knowledge of the Galactic and extragalactic sky in the hard X–ray domain and for an increase of the sample of objects which contribute to the luminosity in this energy range.

The first results of the BAT survey have been presented in Markwardt et al. (2005); Ajello et al. (2008a,b); Tueller et al. (2008, 2009). The latter presents a catalogue of sources detected in the first 22 months of BAT survey data, identifying 487 sources.

We developed a dedicated software (Segreto et al. 2009), independent from the one developed by the Swift-BAT team[1]. This software, suitable to perform data reduction, mosaicking and source detection on the BAT survey data, was applied to the first 39 months of the Swift mission. We present the results of this analysis and the first Palermo *Swift*-BAT hard X-ray catalogue.

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[1] http://heasarc.gsfc.nasa.gov/docs/swift/analysis/

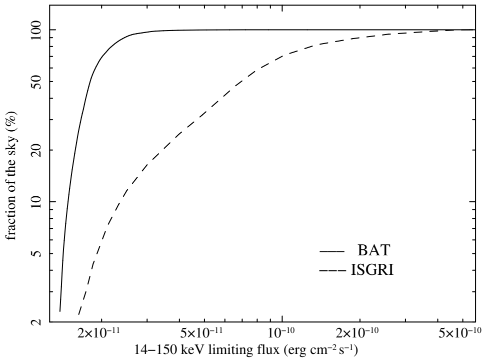


**Fig. 1.** Fraction of the sky covered by the *Swift*-BAT and INTEGRAL-ISGRI surveys vs. limiting flux.

### *1.1. Sky coverage and limiting flux*

Figure 1 shows the 39 months BAT sky coverage, defined as the fraction of the sky covered by the survey as a function of the detection limiting flux. The limiting flux for a given sky direction is calculated by multiplying the local image noise by a fixed detection threshold of 5 standard deviations. In the same figure the BAT sky coverage is compared with that of INTEGRAL/ISGRI after 44 months of observation (Krivonos et al. 2007). The large BAT field of view, the large geometrical area together with the Swift pointing distribution, covering the sky randomly and uniformly according to the appearance of GRBs, has allowed the achievement of an unprecedented sensitive and quite uniform sky coverage. The 39 months BAT survey covers 90% of the sky down to a flux limit of $2.5 \times 10^{-11}$ erg cm$^{-2}$ s$^{-1}$(1.1 mCrab), and 50% of the sky down to $1.8 \times 10^{-11}$ erg cm$^{-2}$ s$^{-1}$(0.8 mCrab).

Figure 2 shows the limiting flux map in galactic Aitoff projection, with the ecliptic coordinates grid superimposed. The minimum detection limiting flux is not fully uniform on the sky: the Galactic center and the ecliptic plane are characterized by a worse sensitivity due to high contamination from intense Galactic sources and to the observing constraints of the *Swift* spacecraft. The highest flux sensitivity is achieved near the ecliptic poles where a detection flux limit of about $1.1 \times 10^{-11}$erg cm$^{-2}$ s$^{-1}$ is reached ($\sim$ 0.5 mCrab).

## 2. BAT survey results

We have produced all-sky maps of the first 39 months of the BAT survey data archive, from 2004 December to the end of 2008 February in three energy bands: 14–150 keV, 14–70 keV, 14–30 keV. A source detection in the 3 all-sky maps was performed by searching for local excesses in the significance map greater than 4.8 standard deviations. Such a threshold represents the optimal value that maximizes the number of detectable sources, maintaining at the same time an acceptable number of spurious detections: taking into account the total number of pixels in the all sky map, the PSF and the Gaussian distribution of the noise, we expect $\sim$20 spurious detections above our threshold due to statistical fluctuations.

The resulting detection catalogues (one for each of the three energy bands) have been cross-corraleted (nearest match within the BAT error circle) in a single catalogue. We obtain a final number of 970 source candidates above our threshold in at least one of the three energy bands. The identification of these source candidates has been carried on through cross correlation with X-ray and optical catalogues and soft X-ray field observations. This allowed for the identification of the counterparts of $\sim$ 750 BAT sources and for the compilation of the largest hard X-ray catalogue to date.

The catalogue is composed of $\sim$ 65% of extragalactic objects, $\sim$ 25% of Galactic sources and $\sim$ 10% of known X-ray or Gamma-ray sources whose nature is yet to be determined (Table 1). Figure 3 shows the distribution of all the sources in our catalogue, colour-coded according to the object class, and size coded according to their measured flux (averaged over 39 months). We have compared this distribution with the third ISGRI catalogue Bird et al. (2007). The results are plotted in Figure 4. Our BAT survey catalogue shows a dramatic improvement (more than a factor three) in the number of extragalactic sources, both in the nearby Universe (normal galaxie, LINERS) and at larger distances (Seyfert galaxies, QSOs, blazars). We find also

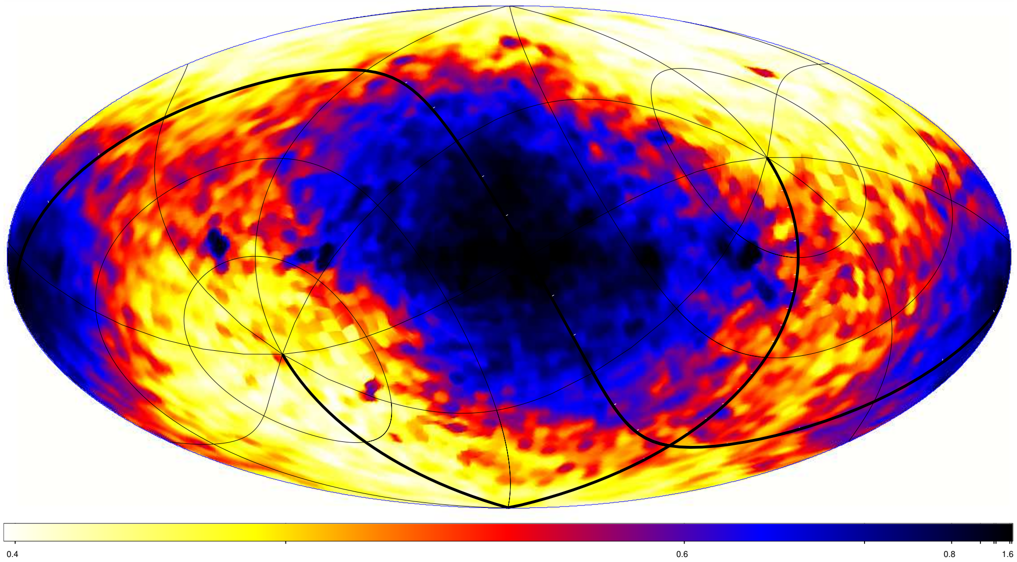


**Fig. 2.** Map of the limiting flux (in mCrab) of the 39-months BAT-survey data in the 14–150 keV band, projected in Galactic coordinates, with the ecliptic coordinates grid superimposed (the thick lines represents the ecliptica axes). The scale on the colorbar is in mCrab.

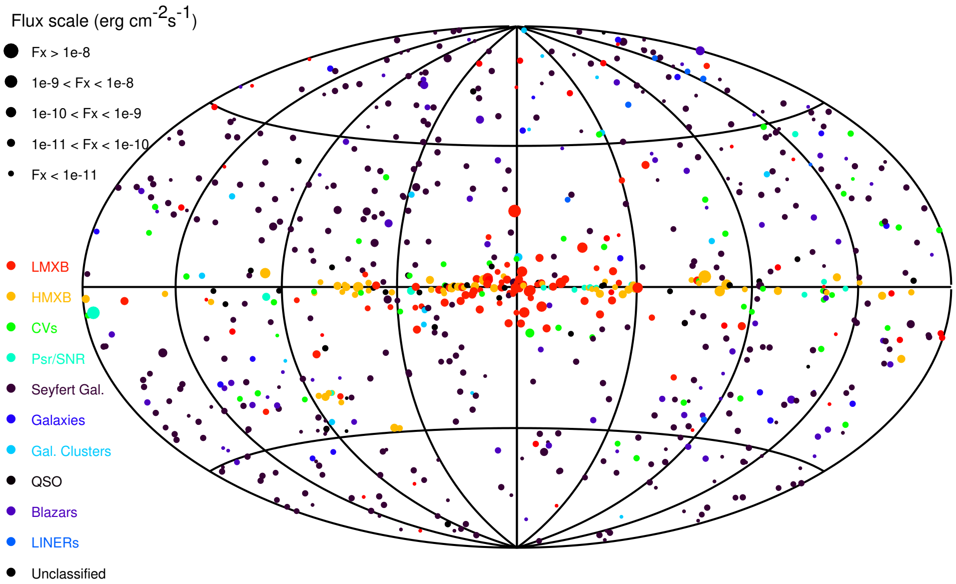


**Fig. 3.** Sky distribution of the sources detected in the BAT survey data. The size of the symbol is proportional to the 14–150 keV flux while different colours refer to different object classes.

**Table 1.** Classification of the known sources detected in the BAT survey. *Other types* includes all sources that have a catalogued counterpart but have not been classified yet.

| Class | # of sources | % in the Catalog |
|---|---|---|
| LXB | 76 | 10.1% |
| HXB | 64 | 8.5% |
| Pulsars | 10 | 1.3% |
| SN/SNR | 5 | 0.7% |
| Cataclysmic variables | 46 | 6.1% |
| Stars | 5 | 0.7% |
| Molecolar Cloud | 1 | 0.1% |
| Galactic (total) | 207 | 27.5% |
| Seyfert 1 galaxies | 235 | 31.2% |
| Seyfert 2 galaxies | 131 | 17.4% |
| LINERs | 7 | 0.9% |
| QSO | 14 | 1.8% |
| Blazars | 71 | 9.4% |
| Galaxy clusters | 18 | 2.4% |
| Normal galaxies | 27 | 3.6% |
| Unclassified AGN | 16 | 2.1% |
| Extragalactic (total) | 519 | 68.8% |
| Other types | 28 | 3.7% |

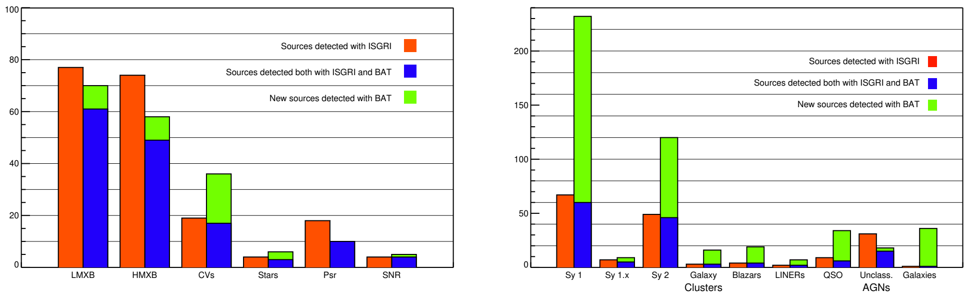


**Fig. 4.** Comparison between the sources in our catalogue and those reported in the third ISGRI catalogue Bird et al. (2007). Top: Galactic sources. Bottom: Extragalactic sources.

a large increase (of a factor two) in the number of hard X-ray detected cataclysmic variables.

We also detected ∼ 200 source candidates for which we have not any association yet. These candidates are uniformly distributed across the sky and we expect them to be mostly extragalactic objects. A follow-up campaign with *Swift*-XRT is in progress to reveal their soft counterparts.

## 3. DISCUSSION

**Filippo Frontera:** What do you mean with ”identification” of the sources discovered in your catalogue?

**Giancarlo Cusumano:** We have searched for sources in the Swift-XRT archival observations covering the sky position of the BAT source candidates. A source detected inside a 6.3 arcmin error circle was associated with the BAT excess if its count rate was above rate threshold. In the few cases where more than one source was within the BAT error circle, we selected the hardest one. The number of expected spurious identifications we evaluated collecting a large sample of XRT observations of GRB fields, using only late follow-ups (where the GRB afterglow has faded) with the same exposure time distribution as the XRT pointings of the BAT sources. We searched for sources that satisfied the same threshold conditions (excluding any GRB residual afterglow) within a 6.3 arcmin error circle centered at the nominal pointing position in each of these fields. This analysis resulted in a negligeable number of expected spurious assosiations (∼1%). A similar analysis was also performed using observations with other X-ray instruments (XMM-Newton, Chandra, BeppoSAX).

**Jurgen Knoedlseder:** Your Log N Log S looks steep since it turns up at low fluxes.

**Giancarlo Cusumano:** The Log N Log S has been derived using the Telescope sky coverage that suffers from systematics at low fluxes. This systematics propagates on the Log N Log S.

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