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Hard X-ray search for unidentified EGRET sources in the BAT survey archive

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The third EGRET catalogue includes a large number of unidentified sources. Some of these objects may represent a new class of yet undiscovered gamma-ray sources. Using a software tool developed for the Swift-BAT survey data analysis, the `BatImager`, highly efficient and independent from the tasks distributed by the Swift-BAT hardware team, we searched the archive of the first 39 months of Swift observations in the hard X-ray energy band, 14−150 keV, to find the counterparts of the unidentified EGRET sources, and then study their broad band emission properties. We found 23 associations, 20 of them already known in the literature and 3 newly proposed. A check of our set of associations with the revised EGRET catalogue [4] confirms only 15 of them, but gives 3 new associations, one with an EGRET source detected for the first time in the revised catalogue. We plan to investigate the proposed associations through exploitation of multi-wavelength archival data and follow-up observations.

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1. Introduction

Surveys are the most effective way to make important steps beyond the study of objects with known properties based on observations in other bands, because they allow to discover new classes of objects and astrophysical phenomena. They are also essential for population and evolution studies, that require the knowledge of complete samples of sources.

In the high energy gamma-rays, the most extended survey up to date has been performed between 1991 and 1995 by EGRET (Energetic Gamma Ray Experiment Telescope), the gamma-ray telescope on the Compton Gamma Ray Observatory (CGRO), sensitive in the energy range from 30 MeV to over 20 GeV. The third EGRET catalogue [11] includes 271 sources detected at energies $>$ 100 MeV, and $\sim$170 of them are still unidentified, lacking counterparts at lower wavelengths.

Surveys in the hard X-ray band (10$-$600 keV) have been poorly developed for decades since the most extended to date was conducted by the HEAO$-$A4 experiment in the late seventies [13]. Recently, two more all-sky surveys at hard X-ray energies (about 20$-$200 keV) have effectively been carried out: the INTEGRAL-IBIS survey [18, 3] and the *Swift*-BAT survey [10, 2]. The former, started in 2002, was initially devoted mostly to the Galactic plane scan, but has now reached a $>$ 70% coverage of the sky with an exposure of at least 10 ks. It provided the detection of more than 500 (mostly Galactic) sources in the 20$-$100 keV band. The latter, started in late 2004, had from the very beginning an almost uniform sky coverage because of the very large BAT field of view (FOV; $\sim$2 sr, partially coded, compared with the 0.02 sr IBIS FOV), and the almost-random pointing observation strategy related to the Gamma-ray burst chase which is the main purpose of the *Swift* mission. These characteristics make the *Swift*-BAT survey the natural complement to the INTEGRAL survey at high Galactic latitude.

The preliminary results of the first 3 months of the *Swift*-BAT survey data have been published by [14]. An extended analysis of 9 months of data has been performed by [17] and on 1/8th of the sky, by [1]. The largest published catalogue of BAT detected sources (presented in [17]) includes only 150 AGNs at high Galactic latitude (at more than 5 degrees from the Galactic Plane). We developed a dedicated software suite [15, 16], completely independent from the one developed by the Swift-BAT hardware team, to analyze BAT survey data, optimized for maximum speed and minimum CPU load in all-sky source detection, and run it over the first 39 months of *Swift*-BAT observations. We detected a total of 968 sources above the 4.8 σ significance limit. Through cross-correlation with the Simbad databases and published hard X-ray catalogues, and through analysis of field observations of soft X-ray instruments we obtained a catalogue of 748 identified sources, presented in [7, 12] and fully discussed in [6].

The main goal of this work is to identify potential hard X-rays counterparts of EGRET sources in the new BAT survey catalogue we produced, which is the most extended to date.

2. Results

We performed a cross correlation of the Third EGRET catalogue with our 39 months BAT survey catalogue, consisting of 748 identified sources. We accepted as possible counterpart of an EGRET source the nearest BAT source falling within the EGRET error radius, that we assumed given by θ_{95} in [11], i.e. the radius of the circle containing the same solid angle as the 95% confidence contour. We obtained 23 associations. The 23 images in Fig. 1 and Fig. 2 show the 3×2 deg^2 sky regions centred on these EGRET sources (red circles, with corresponding EGRET error radius) and their counterparts (green circles, with radius set to 5 arcmin for better visualization).

We evaluated the fraction of expected spurious identifications due to spatial coincidence producing a set of 271 coordinate pairs by shifting the positions of the EGRET sources of 5 degrees in diagonal direction with respect to the Galactic reference system and cross correlating them with the BAT survey catalogue. We obtained 7 spurious associations.

In Table 1 we show all relevant information about the BAT fluxes and hardness ratios of the counterparts, when available. According to the Third EGRET catalogue, sources 12, 15, 16, 17, and 18 are unidentified. The associations here include two AGNs, two Galactic accreting binary systems, a cluster of galaxies, and an unidentified INTEGRAL source.

The association of source 15 (3EG J1639−4702) with IGR J16393−4643 has already been proposed in [5]. However this EGRET source has also been recently proposed for association with the Supernova remnant G338.3-0.0 detected by HESS [9].

The association of source 17 (3EG J1736−2908) with the active galactic nucleus GRS 1734−292 has already been discussed in [8].

The reliability of the association of source 18 (3EG J1746−2851) to the low mass X-ray binary 1E 1743.1−2852 is to be better investigated because the very same source has also been proposed for association with the cluster of massive stars, G0.12+0.017 [19].

Associations of source 12 (3EG J1424+3734) to the cluster of galaxies A1914 and of source 16 (3EG J1734−3232) to the unidentified INTEGRAL source IGR J17354−3255 are new.

Recently, Casandjian & Grenier (2008) produced a revised catalogue of point γ-ray sources detected by EGRET above 100 MeV, reprocessing the entire data set and using new Galactic interstellar emission models [4]. Their catalogue contains 188 sources, mostly corresponding to the identified sources in the Third EGRET catalogue. According to the revised positions and θ_{95} values of EGRET sources in the Casandjian & Grenier (2008) catalogue, the associations of sources 5, 10, 11, 16, 17, 20 and 22 would not be confirmed. Moreover, the EGRET source 3EG J1639−4702 (source 15) has no counterpart in the Casandjian & Grenier (2008) catalogue. A cross correlation of the Casandjian & Grenier (2008) catalogue with our 39 months BAT survey catalogue gives a total of 18 associations, 15 of them already listed in Table 1, plus the following:
3EG J0241+6103/EGR J0240+6112/GT 0236+610, 3EG J0533−6916/EGR J0537−6946/LMC X−1, and EGR J1642+3940/4C39.48, where the first two are associations well known in the literature and the last one refers to a new source with no counterpart in the Third EGRET catalogue. The number of expected spurious associations, evaluated with the same procedure used with the Third EGRET catalogue is of 5.

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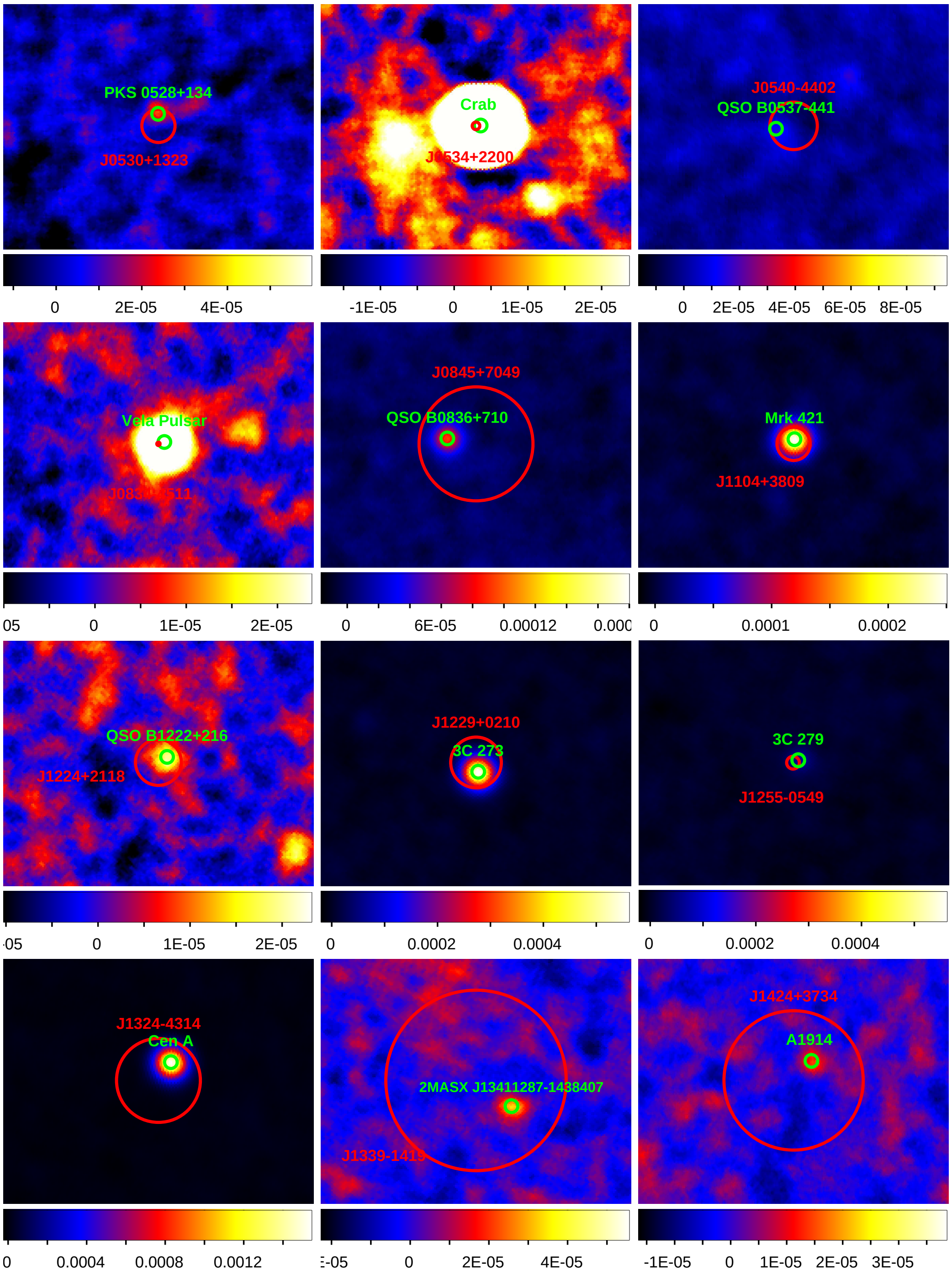

Figure 1: The 3×2 deg^2 images above show the locations of the first 12 EGRET sources with counterparts in the 39 months BAT survey catalogue listed in in Table 1. They are extracted from the BAT survey map in intensity units (counts s^{-1} pixel^{-1}). Red circles represent the EGRET sources with corresponding EGRET error box as radius and green circles their BAT counterparts with 5 arcmin radius.

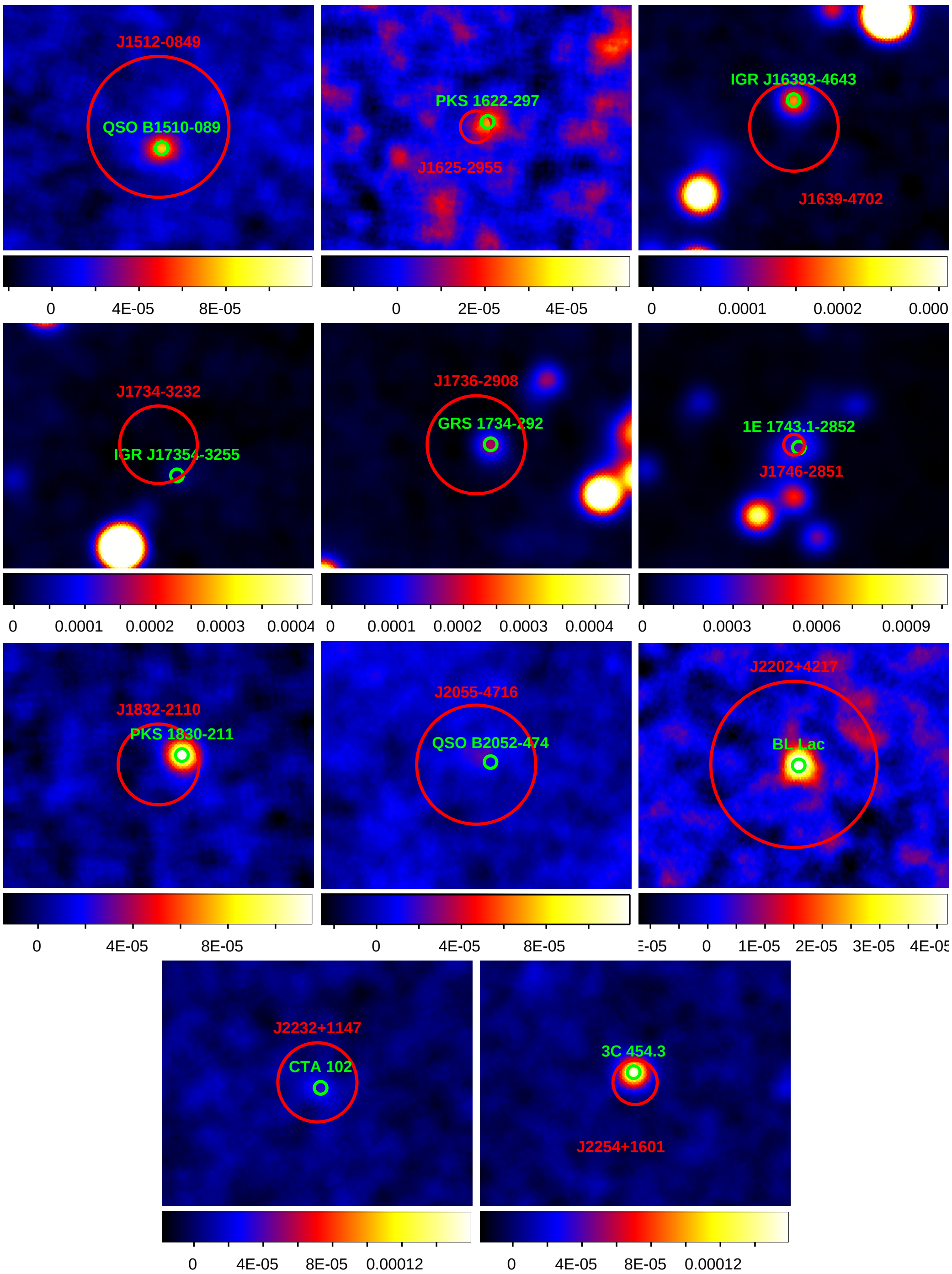

Figure 2: Same as Fig. 1 for EGRET sources with counterparts 13–23 in Table 1.

Table 1: Counterparts for EGRET sources in the BAT survey.

ID	Name	RA (deg)	Dec (deg)	θ_{95}[a] (deg)	Alt. Name	Type[b]	$\sigma_{14-150\,\mathrm{keV}}$	$\mathrm{Flux}_{14-150\,\mathrm{keV}}$ (10^{-11} erg cm^{-2} s^{-1})	Hardness ($\mathrm{rate}_{30-150\,\mathrm{keV}}/\mathrm{rate}_{14-30\,\mathrm{keV}}$)
1	3EG J0530+1323	082.74	+13.38	0.210	PKS 0528+134	QSO	4.66	1.53 ± 0.33	–
2	3EG J0534+2200	083.57	+22.01	0.048	Crab	Psr	4670.65	2111.51 ± 0.45	0.80016 ± 0.0002
3	3EG J0540−4402	085.02	−44.05	0.300	QSO B0537-441	BLL	4.72	0.78 ± 0.19	–
4	3EG J0834−4511	128.73	−45.20	0.021	Vela Pulsar	Psr	48.50	12.20 ± 0.25	0.94 ± 0.03
5	3EG J0845+7049	131.46	+70.83	0.720	QSO B0836+710	QSO	23.06	4.42 ± 0.19	1.40 ± 0.12
6	3EG J1104+3809	166.10	+38.15	0.210	Mrk 421	BLL	62.78	11.41 ± 0.18	0.42 ± 0.01
7	3EG J1224+2118	186.11	+21.31	0.290	QSO B1222+216	QSO	5.27	0.97 ± 0.18	–
8	3EG J1229+0210	187.25	+02.17	0.320	3C 273	QSO	105.20	26.86 ± 0.26	1.18 ± 0.02
9	3EG J1255−0549	193.98	−05.82	0.080	3C 279	QSO	10.41	2.66 ± 0.26	0.82 ± 0.13
10	3EG J1324−4314	201.15	−43.25	0.530	Cen A	Sy2	219.76	75.59 ± 0.34	1.03 ± 0.01
11	3EG J1339−1419	204.84	−14.32	1.140	2MASX J13411287-1438407	Sy1	6.58	1.75 ± 0.27	–
12[c]	3EG J1424+3734	216.22	+37.58	0.880	A1914	ClG	5.09	0.40 ± 0.08	–
13	3EG J1512−0849	228.17	−08.83	0.890	QSO B1510-089	QSO	10.75	3.26 ± 0.30	1.51 ± 0.30
14	3EG J1625−2955	246.36	−29.92	0.200	PKS 1622-297	QSO	4.65	1.73 ± 0.39	–
15	3EG J1639−4702	249.78	−47.04	0.560	IGR J16393-4643	HXB	19.71	9.48 ± 0.48	0.12 ± 0.01
16	3EG J1734−3232	263.56	−32.55	0.490	IGR J17354-3255	gam	5.69	2.98 ± 0.54	0.39 ± 0.10
17	3EG J1736−2908	264.16	−29.14	0.620	GRS 1734-292	Sy1	16.82	9.08 ± 0.54	0.81 ± 0.08
18	3EG J1746−2851	266.51	−28.86	0.130	1E 1743.1-2852	LXB	28.51	15.38 ± 0.54	0.43 ± 0.02
19	3EG J1832−2110	278.10	−21.18	0.510	PKS 1830-211	QSO	11.40	5.35 ± 0.48	1.48 ± 0.27
20	3EG J2055−4716	313.80	−47.28	0.760	QSO B2052-474	QSO	5.00	1.43 ± 0.29	–
21	3EG J2202+4217	330.60	+42.29	1.050	Bl Lac	BLL	7.39	1.86 ± 0.25	0.90 ± 0.19
22	3EG J2232+1147	338.11	+11.80	0.500	CTA 102	QSO	7.91	1.86 ± 0.23	1.14 ± 0.26
23	3EG J2254+1601	343.51	+16.02	0.280	3C 454.3	QSO	32.32	7.70 ± 0.24	1.44 ± 0.08

[a] According to [11] θ_{95} represents the radius of the circle containing the same solid angle as the 95% confidence contour.

[b] Source type according to Simbad database nomenclature.

[c] The source is not detected over the 14−150 keV band. Values from the 14−30 keV band are used for detection significance and flux.

3. Summary

We cross correlated the Third EGRET catalogue with the 39 months BAT survey catalogue [6, 7, 12] to look for possible hard X-ray counterparts of unidentified EGRET sources. We obtained 23 possible associations, 20 of them already known and 3 newly proposed. A cross correlation of the BAT catalogue with the revised EGRET catalogue [4] confirms only 15 of our associations, but gives 3 new associations, one of them with an EGRET source detected for the first time in the revised catalogue. The reliability of all the proposed associations must be carefully investigated. To this aim we plan to make use of data in other bands of the electromagnetic spectrum, either already existing in the literature or in the archives, or to be obtained in future observations.

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