Fermi-INTEGRAL: the odd skies

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on behalf of the Fermi Large Area Telescope Collaboration
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Summary: The analysis of the cross correlation between the *Fermi* LAT bright source list of objects emitting in the 100 MeV–100 GeV range and the 4th INTEGRAL/IBIS soft gamma-ray catalog, in the range 20–100 keV, shows that only around 16 objects are common to both skies.

Abstract

The most striking outcome of the analysis of the cross correlation between the *Fermi* LAT bright source list of objects emitting in the 100 MeV–100 GeV range and the 4th INTEGRAL/IBIS soft gamma-ray catalogs, in the range 20–100 keV is that only a small number of objects are common to both skies. This result,although in part expected due to the different physics driving the source emission in the two energy regimes, is also surprising in view of the large number of sources that populate the FERMI and INTEGRAL catalogues: 205 *Fermi* LAT sources and more than 720 sources detected by INTEGRAL. This marginal overlap is in spite of the breakthrough, in terms of sensitivity, achieved by *Fermi* at MeV–GeV energies and the sub-mCrab INTEGRAL sensitivity for both galactic and extragalactic sources.
The main result of the correlation is that set of sources seen at both energies comprises 14 *Fermi* LAT sources clearly detected in the fourth INTEGRAL/IBIS catalog. All of them have already been optically identified with active galactic nuclei (10) complemented by two isolated pulsars (Crab and Vela) and two high-mass X-ray binaries (LS I +61◦303 and LS 5039).
Furthermore two more possible associations have been found: one is 0FGL J1045.6-5937, possibly the counterpart at high energy of the massive colliding wind binary system Eta Carinae, discovered to be a soft gamma ray emitter by recent INTEGRAL observations and 0FGL J1746.0-2900 coincident with IGR J17459-2902, but still not identified with any known object at lower energy.

The *FERMI* LAT BSL cross correlated with the 4th IBIS Catalogue

Recently Ubertini et al., have cross-correlated the positions of the 205 *Fermi* LAT bright sources with the fourth IBIS catalog, following the Stephen et al. (2005, 2006) method. The starting assumption was that several of the sources detected by *Fermi* LAT were expected to generate soft gamma rays above 20-50 keV, i.e. where the imaging telescope IBIS on board Integral has sub mCrab sensitivity.
We took both catalogs and searched for the IBIS sources possibly coicident with LAT sources as a function of their distance.

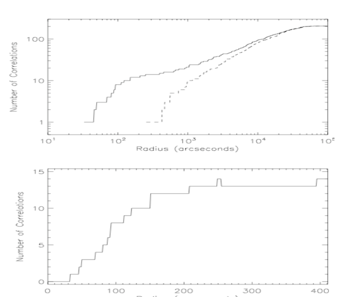

Figure 1. *Top: the number of IBIS sources associated with Fermi (solid line) and fake (dashed) objects. Bottom: the difference between the two upper curves revealing a correlation for a small number of sources.*

We have then generated a database of 205 false sources derived from the *Fermi* LAT catalog but with 'false' positions to be used as a control sample. The top panel in the Fig. 1 shows the number of IBIS sources associated with *Fermi* (solid line) and fake (dashed) objects. The bottom panel one shows the difference between the two upper curves revealing a correlation for a small number of sources. At about 4 arcmin the lower curve is leveling off indicating that there is a real correlation. Surprisingly enough, the total number of sources common to both catalogs is ~13–14. In comparison, at this distance only one source in the fake data set appears to be correlated. The 14 associations are listed in the Table.
The most likely chance correlation is 0FGL J1746.0-2900/IGR J17459-2902 found in the galactic center region, i.e., where a likelihood of an association by chance is very high due to INTEGRAL reaching the confusion limit and the presence of strong *Fermi* diffuse emission overlapping with compact sources.

This technique takes advantage only of the source position, disregarding the uncertainty associated with the source error box.
To use this extra information and retrieve possibly lost associations, another procedure has been applied. This technique compares the distance between LAT and IBIS sources with the quadratic sum of their corresponding error radii (of course after re-normalisation of the *Fermi* 95% and IBIS 90% quoted error radii). Sources are assumed to be potentially correlated when their separation is less than 2.15σ, corresponding to 90% for a two-dimensional normal distribution.
The first result of this second procedure is to confirm the previous 14 correlations. Furthermore, we can now recover two more sources, listed at the end of the Table: the first is 1ES 0033+59.5 which appears in both the IBIS and *Fermi* catalogs and so is assumed to be a correct association, while the second corresponds to Eta Carinae/0FGL J1045.6-5937, listed in the *Fermi* LAT bright source catalog as unidentified. For all the remaining 189 *Fermi* LAT sources for which no IBIS counterpart was found, the 2σ upper limit in the energy band 20–40 keV was calculated and these are reported in Ubertini et al., 2009.

Results

The result of the spatial correlation between the Fermi LAT BSL and IBIS 4th catalogue is shown in the following table

Table 1: Spatial correlation between Fermi LAT and IBIS sources.[1]

Fermi (0FGL)	RA (deg)	Dec (deg)	IBIS RA (deg)	IBIS Dec (deg)	distance (arcmin)	$\frac{distance}{\sqrt{FermiR^2_{1\sigma}+IbisR^2_{1\sigma}}}$	ID source
J1229.1+0202	187.287	2.045	187.279	2.049	0.533	0.258	3C 273
J1325.4-4303	201.353	-43.062	201.363	-43.021	2.5	0.332	Cen A
J1653.9+3946	253.492	39.767	253.488	39.753	0.85	0.410	Mkn 501
J2202.4+4217	330.662	42.299	330.677	42.293	2.01	0.481	BL Lac
J2254.0+1609	343.502	16.151	343.489	16.149	0.75	0.558	3C 454.3
J0240.3+6113	40.093	61.225	40.119	61.240	1.16	0.562	LS I+616 303
J0320.0+4131	50.000	41.524	49.967	41.532	1.55	0.645	NGC 1275
J1256.1-0547	194.034	-5.8	194.044	-5.770	1.88	0.827	3C 279
J1104.5+3811	166.137	38.187	166.119	38.207	1.46	1.067	Mkn 421
J1833.4-2106	278.37	21.103	278.415	-21.063	3.46	1.180	PKS 1830-211
J0534.6+2201	83.653	22.022	83.629	22.017	1.36	1.190	Crab
J1826.3-1451	276.595	-14.86	276.525	-14.847	4.13	1.406	LS 5039
J0835.4-4510	128.865	-45.17	128.831	-45.179	1.53	1.437	Vela Pulsar
J1746.0-2900	266.506	-29.005	266.485	-29.043	2.51	1.472	IGR J17459-2902
J0036.7+5951	9.177	59.854	8.964	59.83	6.56	1.802	1ES 0033+59.5
J1045.6-5937	161.409	-59.631	161.206	-59.704	7.5	2.073	Eta Carinae

The Fermi sources firmly detected by IBIS comprise the 10 optically identified AGNs, the two isolated pulsars Crab and Vela and 2 HMXB, while there are a further two possible associations with unidentified Fermi sources: 0FGL J1746.0-2900/IGR J17459-2902 and 0FGL J1045.6-5937/Eta Carinae.

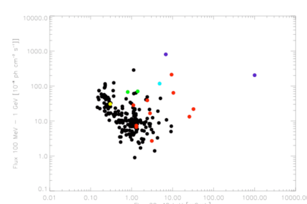

Figure 2. *Gamma-ray flux (100 MeV - 1 GeV) of each Fermi source as a function of the corresponding 20--40 keV IBIS flux. The coloured points refer to the IBIS detections, specifically red points are blazars, dark blu are pulsars, green are HMXBs, yellow is Eta Carinae and finally light blu is IGR J17459-2902. The black points refer to IBIS non detection (2 sigma upper limit)*

The two bright radio galaxies NGC1275 and Cen A are the only Seyfert objects detected by INTEGRAL (Bassani, et al., 2009, Beckmann, et al., 2009) present in the Fermi catalog.

References
Abdo, A.; et al. 2009, ApJS, 183, 46.
Ajello M; et al. 2009, ApJ,.699, 603.
Bassani, L.; et al. 2009, MNRAS, 395, L1.
Beckman, V.; et al. 2009, A&A, in press (arXiv: 0907.0654)
Bird, A.J., et al. 2009, ApJS in press (arXiv: 0910.1704)
De Rosa, A.; et al. 2008, MNRAS, 338, L54
De Rosa, A.; et al. 2009, in preparation
Maraschi L. & Tavecchio, F. 2003, ApJ, 593, 667
Stephen, J. B.; et al. 2005, A&A, 432L, 49
Stephen, J. B.; et al. 2006, A&A, 445, 869
Tavani, M.; et al. 2009, ApJ, 698L, 142
Ubertini, P.; et al., 2009, ApJ Letters in press (arXiv: 0910.1738)

Discussion

The gamma-ray flux (100 MeV - 1 GeV) of each catalogued LAT source as a function of the IBIS flux in the 20-40 keV range is shown in Fig. 2. With the exception of ETA Carinae, no LAT objects have been detected by IBIS at a flux below 1 mCrab despite the fact that a large fraction of the IBIS sky has a detection limit well below this value and is well populated with hard X-ray sources.

The FSRQ 4C04.42 has been detected the first time in hard-X rays with INTEGRAL. This source is particularly bright among the INTEGRAL Blazars and a detailed broadband study (INTEGRAL/XMM, De Rosa et al. 2008) has shown possible evidence of Bulk Compton motion in the SED (Celotti et al. 2007). A preliminary analysis of LAT data has revealed the gamma ray emission of this source to be as shown in Fig. 3 together with a non-simultaneous data set collected over a wide energy band.

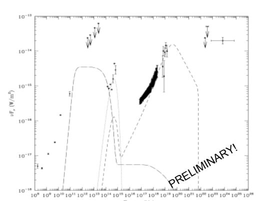

Figure 3. *Non simultaneous SED of the bright FSRQ 4C04.42*

The majority of the associations reported in Table 1 refer to blazars, mainly detected by IBIS in flaring state, or in deep studies with long devoted exposures or because they are bright objects over the entire gamma-ray band (see Fig.3). IBIS sees both types of blazars,Flat Spectrum Radio Quasars (FSRQ) and BL Lac type objects. In the widely adopted scenario of blazars, the Spectral Energy Distribution (SED) has a double peaked structure, with the low frequency hump (the synchrotron component) peaking anywhere from Infrared to X-rays and the high frequency hump (the inverse Compton component EC) extending up to GeV or even TeV gamma-rays (Maraschi and Tavecchio, 2003).

The average GeV spectra of BL Lac objects are significantly harder (Γ=1.99+-0.22) than the spectra of FSRQs (Γ =2.4+-0.17). The opposite spectral trend is found in the hard X-ray energy range, as demonstrated through INTEGRAL/IBIS (De Rosa et al. 2009) and Swift/BAT (Ajello et al. 2009) analysis. This different behaviour is probably due to the fact that Fermi and IBIS/BAT are observing different parts of the SED in the different blazar populations: Fermi is monitoring the ascending part of the EC component in BL Lac and its descending part in FSRQ while IBIS/BAT are monitoring the decreasing part of the Synchrotron component in BL Lac and the increasing EC in the FSRQ (see sketch in Fig. 4).

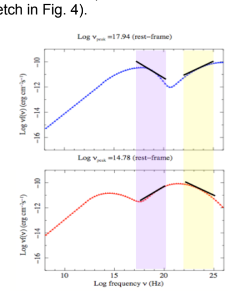

Figure 4. *A sketch of the SED of Blazars: BL Lac in the top panel and FSRQ in the bottom panel. Different energy range are monitoring different part of the emission depending on the type of source.*