In this Letter we present the result of the cross correlation between the fourth INTEGRAL/IBIS soft gamma-ray catalog, in the range 20–100 keV, and the Fermi LAT bright source list of objects emitting in the 100 MeV–100 GeV range. The main result is that only a minuscule part of the more than 720 sources detected by INTEGRAL and the population of 205 Fermi LAT sources are detected in both spectral regimes. This is in spite of the mCrab INTEGRAL sensitivity for both galactic and extragalactic sources and the breakthrough, in terms of sensitivity, achieved by Fermi at MeV–GeV energies. The majority of the 14 Fermi LAT sources clearly detected in the fourth INTEGRAL/IBIS catalog are optically identified 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). 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. For the remaining 189 Fermi LAT sources no INTEGRAL counterpart was found and we report the 2σ upper limit in the energy band 20–40 keV.

Key words: gamma rays: observations
Online-only material: machine-readable table

1. INTRODUCTION

In the last few years, our knowledge of the soft gamma-ray sky ($E > 20$ keV) has greatly improved thanks to the observations performed by the imager IBIS (Ubertini et al. 2003) onboard INTEGRAL (Winkler et al. 2003) and by the BAT telescope (Barthelmy et al. 2005) onboard Swift (Gehrels et al. 2004). In particular, IBIS is surveying the 20–100 keV sky with a sensitivity better than a mCrab and a point source location accuracy of the order of a few arcmin. The fourth IBIS catalog has been just released, listing 723 soft gamma-ray sources (Bird et al. 2009). It represents an extension both in exposure and sky coverage with respect to the previous catalog (Bird et al. 2007). The IBIS soft gamma-ray sky is surprisingly dynamic and diverse, with many different types of objects such as active galactic nuclei (AGNs), galactic X-ray binaries, cataclysmic variables (CVs), and also newly discovered classes of sources such as supergiant fast X-ray transients (SFXTs; Sguera et al. 2005, 2006) and highly absorbed supergiant high mass X-ray binaries (Walter et al. 2006).

Recently, INTEGRAL and Swift have been joined in operation by the Fermi gamma-ray satellite launched in 2008 June, providing a coverage of the sky over 10 orders of magnitude in energy, from keV to GeV. Onboard this satellite, the Large Area Telescope (LAT; Atwood et al. 2009) is an imaging high-energy gamma-ray telescope (20 MeV–300 GeV) which provides, with respect to its predecessor EGRET, superior angular resolution, sensitivity, field of view, and observing efficiency. These improved capabilities have allowed a catalog of 205 highly significant detections (>10σ) after three months of an all sky survey (Abdo et al. 2009b). Many Fermi LAT sources have been identified as AGNs (121) and pulsars (30), but interestingly there are also two high-mass X-ray binaries (HMXBs) while the remaining objects have no obvious counterparts. To identify those sources IBIS is particularly suited since it provides a hard X/soft gamma-ray point source location accuracy of the order of an arcmin as well as information close to the MeV band.

2. CROSS CORRELATING THE FOURTH IBIS CATALOG AND THE FERMI LAT BRIGHT SOURCE LIST

Many of the detected Fermi LAT sources are expected to emit around 20 keV, i.e., in the IBIS regime. With the aim of investigating such a link, we have cross-correlated the positions of the 205 Fermi LAT bright sources with the fourth IBIS catalog. Specifically, following Stephen et al. (2005, 2006), we took both catalogs and calculated the number of LAT sources which could be considered to be coincident with IBIS sources as a function of distance. As a control, we then created another database of 205 false sources derived from the Fermi LAT catalog but with positions mirrored in both galactic longitude and latitude. The top panel of Figure 1 shows the number of coincidences for both the real and false data sets while the bottom panel illustrates the difference between the two. The leveling off of the lower curve in Figure 1 at a distance of about 13–14 sources common to both catalogs. In comparison, at this distance only one source in the fake data set appears to be correlated. Therefore, the 14 associations are listed in Table 1 (the first 14 sources in the list). 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.

In applying this technique, we only employ the positions of the sources, and not the errors on these positions and therefore sources which have relatively large error boxes could become
use of this extra information and retrieve these associations “lost” in the chance association distribution. In order to make use of this extra information and retrieve these associations we have applied another procedure in which we compare the distance between IBIS and LAT sources with the quadratic sum of their corresponding error radii. We first convert the Fermi 95% and IBIS 90% quoted error radii to the equivalent 1σ values, which were then added in quadrature. This value is then compared with the distance between the Fermi and IBIS catalog positions and 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 result of this second procedure is to reaffirm the 14 associations found using the first method and to recuperate two more sources (the last two rows in Table 1). 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.

Figure 2 shows its 95% error circle (∼7.4 arcmin radius) superimposed on the IBIS 18–60 keV significance mosaic with an exposure of ∼2.3 Ms. The clear IBIS detection (∼5.5σ) is Eta Carinae, located right on the border of the LAT error circle. It is worth pointing out that the AGILE gamma-ray satellite detected an MeV source (1AGL J1043-5931, 95% error radius of 0.68) consistent with the position of Eta Carinae (Tavani et al. 2009). For all the remaining 189 Fermi LAT sources for which no IBIS counterpart was found, we calculated the 2σ upper limit in the energy band 20–40 keV, and these are listed in Table 2.

3. DISCUSSION

The Fermi sources firmly detected by IBIS comprise the 10 optically identified AGNs complemented by the two isolated pulsars Crab and Vela and 2 HMXB, while there are a further two possible associations with unidentified Fermi sources. This can be interpreted as an indication that the acceleration processes dominating in the high-energy range are only partially efficient in the soft gamma ray regime. Vice versa, the well-populated INTEGRAL sky, comprising 13% LMXB, 13% HMXB,
Figure 2. IBIS 18–60 KeV significance map (~2.3 Ms exposure time) superimposed on the Fermi LAT error circle of the unidentified source 0FGL J1045.6-5937. It is evident a clear IBIS detection at ~5.5σ. The optical position of Eta Carinae is marked by a black cross point.

Table 2

| Fermi (0FGL) | Upper limit 20–40 keV (mCrab) | Fermi (0FGL) | Upper limit 20–40 keV (mCrab) | Fermi (0FGL) | Upper limit 20–40 keV (mCrab) | Fermi (0FGL) | Upper limit 20–40 keV (mCrab) |
|---------------|-------------------------------|---------------|-------------------------------|---------------|-------------------------------|---------------|-------------------------------|
| J0007.4+7303  | 0.3084                        | J0643.4+5042  | 2.3834                        | J1331.7–0506  | 0.5776                        | J1834.4–0841  | 0.2302                        |
| J0017.4-0503  | 2.3976                        | J0700.0–6611  | 0.5454                        | J1333.3+5058  | 0.6076                        | J1836.1–0727  | 0.2332                        |

Note. a The first (and odd) column(s) list the Fermi LAT bright sources emitting in the 100 MeV–100 GeV range (Abdo et al. 2009a); the second (and even) column(s) report the Integral/IBIS 2σ upper limit in the energy band 20–40 keV. The IBIS fluxes are in milliCrab = $7.6 \times 10^{-12}$ erg cm$^{-2}$s in the 20–40 KeV range.

(The this table is available in its entirety in a machine-readable form in the online journal. A portion is shown here for guidance regarding its form and content.)

35% AGN, 10% pulsar, supernova remnant (SNR) and CV, and 29% unknown emitter, is barely detectable at MeV energies, in spite of the unprecedented sensitivity of Fermi. Figure 3 shows the gamma-ray flux (100 MeV–1 GeV) of each cataloged LAT source as a function of the IBIS flux in the 20–40 keV range. First of all, we note that no LAT sources (except for the peculiar object ETA Carinae) 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 (typically about 0.1 mCrab) and is well populated with hard X-ray sources. This indicates that the typical LAT source is either very strong or very weak in the IBIS energy range providing important information on the spectral energy distribution (SED) of these objects. Further, only a couple of the Seyfert 1 and 2 detected by INTEGRAL (Bassani et al. 2009; Beckmann et al. 2009; Molina et al. 2009) are present in the Fermi catalog, i.e., the two bright radio galaxies NGC1275 and Cen A. In contrast to blazars, most radio galaxies have large inclination angles and hence their emission is not significantly amplified due to Doppler beaming; however, if the jet has velocity gradients (Georganopoulos & Kazanas 2003; Ghisellini et al. 2005; Lenain et al. 2008), then it is possible to produce bright gamma-ray emission via the IC process where one component sees the (beamed) radiation produced by the other, and this enhances the IC emission of all components in the jet.

Figure 3. Gamma-ray flux (100 MeV–1 GeV) of each Fermi source as a function of the corresponding 20–40 keV IBIS flux. The colored points refer to the IBIS detections, specifically red points are blazars, dark blue are pulsars, green are HMXBs, yellow is Eta Carinae and finally light blue is IGR J17459-2902. The black points refer to IBIS non detection (2σ upper limit).

The majority of the associations reported in Table 1 refer to blazars, mainly detected by IBIS during TOO observations, hence in flaring, or in deep studies with long devoted exposures.
or because they are bright objects over the entire gamma-ray band (see Figure 3). Their detection in the IBIS band is therefore not unexpected and suggests that the number of blazars common to both gamma-ray regimes will increase as the INTEGRAL and Fermi catalogs expand. Interestingly, IBIS also sees both types of blazars, i.e., flat spectrum radio quasars (FSRQ) and BL Lac type objects. In the widely adopted scenario of blazars, a single population of high-energy electrons in a relativistic jet radiates from the radio/FIR to the UV/soft X-rays by the synchrotron process and at higher frequencies by inverse Compton scattering of soft photons present either in the jet (synchrotron self-Compton [SSC] model), in the surrounding material (external Compton [EC] model), or in both (Ghisellini et al. 1998 and references therein). Therefore, a strong signature of the Blazar nature of a source is a double peaked structure in the SED, with the synchrotron component peaking anywhere from infrared to X-rays and the inverse Compton extending up to GeV or even TeV gamma-rays (Maraschi & Tavecchio 2003; Brambilla et al. 2006).

The analysis of the gamma-ray properties of Fermi blazars (Abdo et al. 2009a) have revealed that the average GeV spectra of BL Lac objects are significantly harder ($\Gamma \sim 1.99 \pm 0.22$) than the spectra of FSRQs ($\Gamma \sim 2.40 \pm 0.17$). This is probably due to Fermi observing different parts of the Compton bump in the different blazar populations: the ascending part in BL Lac and the descending part in FSRQ. A similar analysis can be performed with IBIS detected blazars despite the poor statistics. The class of BL Lac objects seen by IBIS, including BL Lac, Mkn501, and Mkn421, are weak emitters in soft gamma-rays (Maraschi & Tavecchio 2003; Sambruna et al. 2006).

For all the Fermi detected blazars, the spectral indices are usually steeper than 2 (Guetta et al. 2004; Lichti et al. 2004). BL Lac, Mkn501, and Mkn421, are weak emitters in soft gamma-rays (Maraschi & Tavecchio 2003; Sambruna et al. 2006). The analysis of the spectral shapes of BL Lac objects are significantly harder ($\Gamma \sim 1.99 \pm 0.22$) than the spectra of FSRQs ($\Gamma \sim 2.40 \pm 0.17$). This is probably due to Fermi observing different parts of the Compton bump in the different blazar populations: the ascending part in BL Lac and the descending part in FSRQ. A similar analysis can be performed with IBIS detected blazars despite the poor statistics. The class of BL Lac objects seen by IBIS, including BL Lac, Mkn501, and Mkn421, are weak emitters in soft gamma-rays when not flaring and have 20–100 keV spectral indices usually steeper than 2 (Guetta et al. 2004; Lichti et al. 2008). Conversely, the FSRQ, including 3C454.3, PKS1830-211, 3C273, and 3C279 are characterized by harder spectra, though more easily detectable by IBIS in the 20–100 keV range even if in the quiescent state (De Rosa et al. 2005; Vercellone et al. 2008; Iafrate et al. 2009; Chernyakova et al. 2007). Their sustained emission in this energy range is due to IC plus EC from the Crab with a luminosity peak at around 100 keV, all the remaining gamma-ray pulsars show a dominating emission at energies higher than 10 MeV.

Of particular interest are the IBIS detections of the two Fermi HMXBs LS 5309 and LS I +61 303. It has been suggested that these are both microquasars although another scenario is that they host young non-accreting pulsars and are powered by the interaction between the pulsars’ relativistic wind and the wind from the massive stellar companion (Dubus 2006). Both these HMXBs are those with the most exposure (apart from the Crab) at TeV energies, and now also in the MeV/GeV regime. The measurements indicate that the emission mechanisms active in these two energy ranges are not correlated (Abdo et al. 2009c; Holder et al. 2009). INTEGRAL has detected several (10–15) BHC/microquasar candidates, but it is necessary that Fermi detects more of these sources in order to be able to disentangle the emission mechanisms active at high energies and at soft gamma-rays in these objects.

4. CONCLUSIONS

From our analysis it appears that MeV/GeV Fermi sources are not commonly associated with IBIS sources in the range 20–100 keV. The handful of objects common to both surveys comprise so far mainly FSRQ and BL Lac, with no XRB apart from the two microquasars. Equally absent are the AXP which are strong emitters in the keV–MeV range with a total energy rising in $\nu F_\nu$ and no cutoff detected up to a few hundreds of keV (Kuiper & Hersmen 2009), implying some kind of switch-off mechanism in the MeV regime. Similarly, SGR and Magnetars, detected even in quiescence mode by IBIS (Rea et al. 2009) and among the brightest sources when flaring (Kouveliotou et al. 1999; Gotz et al. 2006; Israel et al. 2008), are not detected so far by Fermi/LAT.

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