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X-Ray and Optical Followup of Gamma-Ray (up to TeV) Sources

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Abstract The imaging capabilities of the *INTEGRAL* and *HESS* observatories allow the study of hard X-ray and TeV sources with unprecedented positional accuracy. Here I review the multiwavelength followup studies which are currently being performed on the unidentified sources detected by these facilities in order to unveil their actual nature.

Key words: X-rays: general — gamma rays: observations — astrometry — techniques: spectroscopic — methods: observational

1 INTRODUCTION

The last years have witnessed a major advance in the study of hard X-ray and TeV emitting cosmic objects, particularly for what concerns the accuracy of their localization. This accomplishment was mainly achieved thanks to two observatories: the *INTEGRAL* satellite (Winkler et al. 2003) for hard X-ray sources and the *HESS* Čerenkov telescope array (Hinton 2004) for TeV objects. Both facilities are indeed capable to localize high-energy objects with a precision of a few arcminutes. This possibility allows reducing the area of the sky in which one should search for the counterpart of these objects at longer wavelengths in order to study their broadband spectrum and, eventually, to understand their actual nature.

This contribution thus aims at reviewing the current knowledge and results of this search for lower-energy counterparts (mainly at soft X-ray and optical frequencies) of these unidentified *INTEGRAL* and *HESS* sources.

2 THE SEARCH FOR COUNTERPARTS TO *INTEGRAL* SOURCES

This section may be considered as an update of my contribution at the proceedings of the Frascati Workshop held 2 years ago in Vulcano (Masetti 2006).

Recently, the largest survey performed with the IBIS instrument onboard *INTEGRAL* has been issued (Bird et al. 2007). It spans nearly 4 years of observations (from October 2002 to April 2006), for a total time of about 40 Ms. This resulted in a catalogue (Fig. 1) with an average sensitivity limit of $\sim$1m Crab (depending on the observing time spent on a given zone of the sky) in the 20–100 keV band and which contains 421 sources with positional accuracy spanning from 1 to 5 arcmin, depending on the source intensity. Of these, 147 (35%) are X-ray Binaries, 118 (28%) are Active Galactic Nuclei (AGNs), 23 (5%) are Cataclysmic Variables (CVs); among the remaining sources, 115 of them (about 27% of the total) have unidentified nature.

Besides this one, a number of other surveys were published recently; in particular, the one of Krivonos et al. (2007), of comparable depth with respect to that of Bird et al. (2007), detected 400 sources with a similar fraction of unidentified objects. In parallel, Bodaghee et al. (2007) collected all the available information on the sources detected by *INTEGRAL* during the first 4 years of operations, thus producing a catalogue of about 500 sources: again, the percentage of unclassified sources (26%) is similar to that found by Bird et al. (2007).

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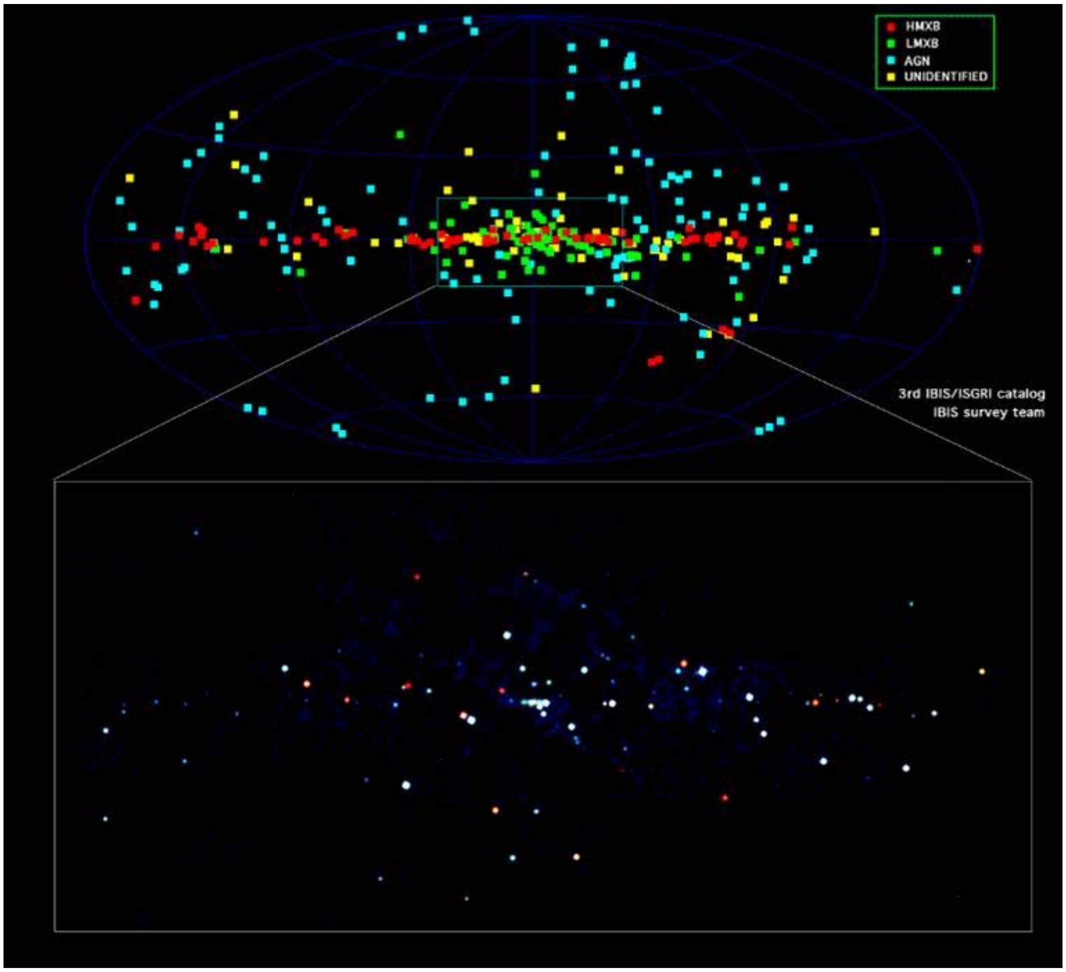

Fig. 1 *Upper image*: distribution on the sky of three of the main soft gamma-ray source populations (HMXBs, LMXBs and AGNs) observed in the third *INTEGRAL*/IBIS survey catalogue (Bird et al. 2007). Besides, around one out of four of the sources seen by *INTEGRAL* are unidentified, and their distribution is also shown. *Lower image*: false colour image of the central region of our Galaxy. This is a composite image based on all-sky IBIS/ISGRI maps in three energy windows between 17 and 100 keV and represents the true X-ray 'colours' of the sources. Red sources are dominated by emission below 30 keV, while blue sources have harder spectra, emitting strongly above 40 keV (Credit: IBIS Survey Team; *INTEGRAL* Picture of the Month of February 2007).

As already widely discussed in the past, the *INTEGRAL* unprecedented capabilities of localizing hard X-ray sources, together with the positional cross-correlation with catalogues at longer wavelengths (especially the ones of soft X-ray satellites), allows a further reduction of the error box to few arcseconds or less. Indeed, Stephen et al. (2006) demonstrated that, when a soft X-ray source is found within the IBIS error box, it is most likely the counterpart of the *INTEGRAL* object. This technique allows pinpointing the putative optical and near-infrared (NIR) counterparts of the *INTEGRAL* sources, on which spectroscopy can be performed to ascertain the actual nature of the high-energy emitting object.

This approach was first applied, for a newly-discovered *INTEGRAL* source, IGR J16138−4848, by Filliatre & Chaty (2004): thanks to the arcsec-sized X-ray position afforded with *XMM-Newton*, they could identify the nature of this source as a heavily absorbed High-Mass X-ray Binary (HMXB) hosting a supergiant B[e] star.

Motivated by this, on July 2004 our group started a program for the systematic identification of *INTEGRAL* sources of unknown nature through optical spectroscopic observations of putative optical candidates pinpointed through the use of soft X-ray observations of *INTEGRAL* error boxes performed with *ROSAT*, *Chandra*, *XMM-Newton* or *Swift*. This program, performed at northern (Loiano, Asiago) and southern (ESO, SAAO, CTIO) telescopes, allowed us to identify 40 objects, of which 23 are nearby AGNs (with redshift between 0.013 and 0.084: among them we found 11 Seyfert 1 galaxies, 11 Seyfert 2 galaxies, and 1 BL Lac), 10 are HMRBs and 7 are CVs (Masetti et al. 2004, 2006a,b,c,d).

Using cross-correlations with available catalogues of variable or emission-line stars, we could also identify 3 more *INTEGRAL* sources (1 transient HMXB and 2 Symbiotic stars: see Leyder et al. 2007 and Masetti et al. 2005, 2006e,f). These three identifications were confirmed by X-ray observations made with *Swift* (Tueller et al. 2005a,b; Kennea & Campana 2006).

Since the second part of 2006 this observational campaign was continued at Loiano, Asiago, CTIO, CASLEO and SAAO observatories, and more observations were collected at CTIO and ESO in June 2007. Besides, we retrieved archival spectra of putative optical counterparts from the 6dF (Jones et al. 2004) and SDSS (Adelman-McCarthy et al. 2006) surveys. Preliminary results (Masetti et al. 2006g,h, 2007a,b) from these observations showed that, of 15 newly identified objects, 13 are AGNs (with $0.006 < z < 0.230$: among them, 4 Seyfert 1s and 9 Seyfert 2s) and 2 are Low-Mass X-ray Binaries (LMXBs) or reddened CVs.

In particular, the most recent (April-May 2007) observations performed at SAAO showed that (i) the galaxy associated with IGR J16024−6107 is at z=0.011 and its emission line ratios place it at the border between Seyfert 2 AGNs and starbursts/HII galaxies; (ii) IGR J14298−6715 is a Galactic emission-line object, most likely a LMXB or a CV; (iii) IGR J19405−3015 is a Seyfert 1.2 galaxy at z=0.052.

The need for high-precision localizations (at the arcsecond level or better) assumes fundamental importance when we are dealing with crowded optical fields, for instance in the case of searches along the Galactic Plane. In this sense the case of the transient X-ray source IGR J17497−2821 is paradigmatic: the *Swift*/XRT position, with an error radius of $5''$, contains more than 20 NIR sources, and only the precise localization (better than $1''$) afforded by *Chandra* allowed determining the actual counterpart of this X-ray source (Torres et al. 2006; Paizis et al. 2007).

Because of the paramount importance of exploring the *INTEGRAL* error circle of the unidentified sources with soft X-ray satellites allowing arcsecond-sized precision on the object position, we started a collaboration with the *Swift* team to get short (∼5 ks) exposures on the error boxes of *INTEGRAL* sources lacking soft X-ray pointings or with soft X-ray positions with radius of tens of arseconds and containing several optical sources. This was done in order to get a position as much precise as possible for these unidentified high-energy sources.

This collaboration has proven very fruitful, and the preliminary results are more than encouraging. Among them, the XRT observations of the *INTEGRAL* source IGR J16194−2810 allowed us to spot the soft X-ray counterpart and to see that it behaves as an X-ray binary under both the spectroscopic and temporal profiles. These X-ray pointings also permitted us to pinpoint the optical counterpart (Fig. 2, left panel): optical spectroscopy revealed that it is a 'normal' red giant of spectral type M2 III, with no emission features (Fig. 2, right panel). All this joint multiwavelength information allowed us to prove that this *INTEGRAL* source is a Symbiotic X-ray Binary (SyXB; see Masetti et al. 2007c for details), i.e. a LMXB composed of a compact object (likely a neutron star) accreting from the wind of a red giant. We stress that this object is remarkable in the sense that SyXBs are very rare LMXBs: IGR J16194−2810 is just the fifth case known to date. The other four known cases are GX 1+4 (Chakrabarty & Roche 1997), 4U 1700+24 (Garcia et al. 1983; Masetti et al. 2002, 2006i), 4U 1954+31 (Masetti et al. 2006i, 2007d) and Sct X-1 (Kaplan et al. 2007).

If we now turn to analyze the sample of *INTEGRAL* objects in the three IBIS surveys (see Fig. 3, from Bird et al. 2007) and we consider their breakdown into the various classes, we can see the following when we pass from the 1$^{\rm st}$ to the 3$^{\rm rd}$ survey catalogue:

- a large increase of AGN detections;
- a substantial increase of CV detections;

- the percentage of unidentified sources keeps nearly constant (22%, 27% and 27% in the three catalogues, respectively);
- a decrease in the detection rate of LMXBs.

The first item is reasonably explained by the fact that *INTEGRAL* allows the exploration of the region around the Galactic Plane (the so-called 'Zone of Avoidance' for extragalactic studies) at hard X-rays, which can easily penetrate the dust layers of this part of the sky bringing information on what lies behind it.

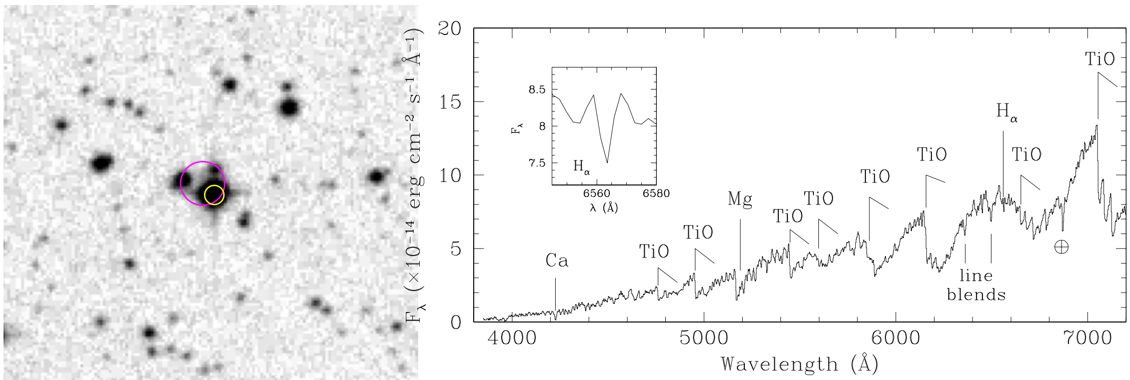

Fig. 2 *Left panel*: optical image of the field of IGR J16194−2810 with the *Swift*/XRT (smaller circle, 3″.5 radius) and the *ROSAT*/PSPC (larger circle, 8″ radius) X-ray positions superimposed. The only star positionally consistent with the XRT error circle is the brighter one at the centre of the image. In the figure, North is at top and East is to the left. The field size is ∼2′.5×2′.5. *Right panel*: optical spectrum of the counterpart of IGR J16194−2810 obtained with the 1.9-meter Radcliffe telescope of SAAO (South Africa). The spectrum is typical of a star of type M2 III. The inset shows a close-up of the spectrum around the H_α region. See Masetti et al. (2007c) for details.

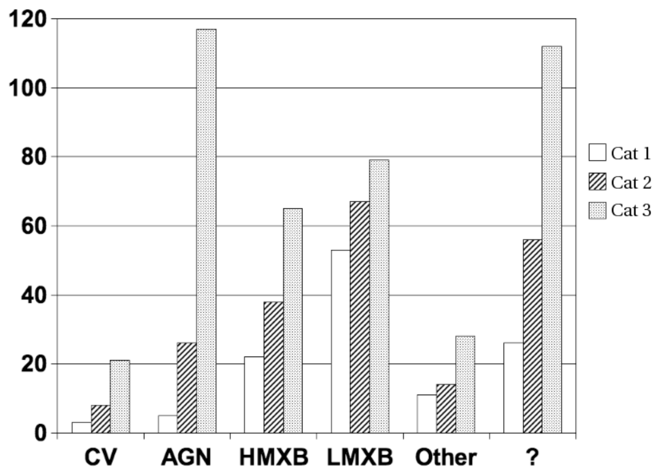

Fig. 3 Histogram reporting the numbers of sources in the first, second, and third IBIS/ISGRI catalogs, classified by type; the question mark indicates the unidentified objects (from Bird et al. 2007).

According to Bodaghee et al. (2007), the last item is explained by the fact that LMXBs are intrinsically less obscured than HMXBs and AGNs, and were therefore easier to detect with previous satellites. Besides, the unprecedented localization capabilities of *INTEGRAL* in the energy range above 20 keV and its high sensitivity in this band are two further reasons which allow this satellite to detect many more (obscured) HMXBs than LMXBs.

The detection of a non-negligible fraction (about 5% of the 3 rd *INTEGRAL* survey sources, and ∼10% of the optical identifications achieved up to now) of CVs is instead surprising, as they were not expected to substantially emit in the hard X-ray band. As a matter of facts, it is found that most of these are magnetic CVs (intermediate polars or polars: Barlow et al. 2006; Masetti et al. 2006d), which may indeed show hard X-ray tails (e.g., de Martino et al. 2004).

Besides all this, *INTEGRAL* allowed the detection of a new class of heavily absorbed Galactic HMXBs (see the contribution by S. Chaty to these proceedings).

Thus, the synergy among *INTEGRAL*, soft X-ray satellites like *Swift*, and optical spectroscopy is allowing the discovery of new classes of sources, of new members of rare classes of objects, or of unexpected features from known types of objects. It is thus planned to extend this very effective approach of following up the error boxes of unidentified *INTEGRAL* sources at soft X-rays through the use of the X-ray satellite *XMM-Newton*, in order to get more high-precision positions in the near future.

To conclude this Section, I would like to mention the web page by Jerome Rodriguez which contains an updated list of detected *INTEGRAL* sources:
http://isdcul3.unige.ch/˜rodrigue/html/igrsources.html .

I also report here that, as a service to the community, I am maintaining a web archive with the main properties of the *INTEGRAL* sources identified through optical or NIR spectroscopy. This archive can be found at the URL:
http://www.iasfbo.inaf.it/IGR/main.html.

3 UNIDENTIFIED *HESS* SOURCES AND THEIR MULTIWAVELENGTH FOLLOWUP

Recently, the *HESS* team reported the discovery of 14 previously unknown TeV gamma-ray sources (Aharonian et al. 2006); some of these detections have subsequently been confirmed by deeper *HESS* observations or by pointings made with the *MAGIC* Čerenkov telescope.

The common properties of these sources are the following: (i) they are positioned along the Galactic Plane; (ii) many of them appear to be extended; (iii) their energy spectra are generally hard, with an average photon index $\Gamma \sim 2.3$.

Some of them were readily identified as SuperNova Remnants (SNRs) or Pulsar Wind Nebulae (PWNe) through positional coincidence; however, many still lack counterparts at longer wavelengths, and hence a clear identification of their nature. Aharonian et al. (2006) also put forward the hypothesis that those of them lacking longer-wavelength counterpart may be classified as ‘dark particle accelerators’, i.e. a new class of sources which are relatively bright at TeV energies and much fainter in the other bands of the electromagnetic spectrum. Nonetheless, other types of sources can emit TeV photons, such as SNRs, pulsars and PWNe, microquasars (or, more generally, X-ray binaries), and background AGNs.

Given the great importance of these accurate detections and the potential discovery of a new class of sources, the search of counterparts at other wavebands was soon initiated by several groups around the world.

The first step in this search was to find positional agreement between the various *HESS* sources and the object in catalogues at other wavelengths, mostly in the soft X-ray and radio bands. In parallel, followup programs at longer wavelengths were started, mostly with the use of X-ray satellites, such as *Chandra*, *XMM-Newton*, *Swift* and *INTEGRAL* itself.

After this, and once a possible longer-wavelength counterpart was found, the second step in this work was the search of a viable gamma-ray emission mechanism explaining the multiwaveband observations from the putative counterpart. Next, the third step was to provide a consistent multi-wavelength picture. Additionally, in the cases in which the source is extended, a further analysis involved the study of the morphological match among the appearance of the source itself at various wavelengths.

In what follows I will report the main results of this multiwavelength search for the counterpart of these *HESS* sources at other wavelengths, and I will focus on the most interesting cases.

HESS J1614−518. The *Swift*/XRT followup observations on this source detected 6 faint X-ray objects (with 2–10 keV flux less than 5×10^{-13} erg cm^{-2} s^{-1}) within or close to the *HESS* error box (Fig. 4, left panel; Landi et al. 2006, 2007a). Optical followup on five of these sources showed that they are Galactic stars (Landi et al. 2007a); moreover, the open cluster C1609−517, at a distance of 1 kpc and with age 40 Myr (Piatti et al. 2000) lies positionally close to the XRT source No. 1 and to the centre of the *HESS* error ellipse. It is possible that at least some of the stars detected in X-rays by *Swift* are part of this cluster. The recent discovery of the unidentified TeV gamma-ray sources in the vicinity of open clusters Cyg OB2 with *HEGRA* (Aharonian et al. 2002) and Cen OB1 with *HESS* (Aharonian et al. 2005a) have renewed the interest in young open clusters as possible sites for the acceleration of cosmic rays and for the emission of TeV gamma-rays; it is thus suggested by Landi et al. (2007a) that the open cluster C1609−517 is possibly the counterpart of HESS J1614-518.

HESS J1616−508. According to Matsumoto et al. (2006), *Suzaku* observations suggest that this source is a Dark Particle Accelerator, as no X-ray source was detected within the TeV error circle. The brightest high-energy source in the field is PSR J1617−5055, a young X-ray pulsar already proposed to emit TeV gamma-rays (Torii et al. 1998). *INTEGRAL*, *BeppoSAX* and *XMM-Newton* observations (Landi et al. 2007b) support this hypothesis, indicating it as the possible counterpart of the *HESS* TeV source. Indeed, according to Landi et al. (2007b), 1.2% of the spin down luminosity of this pulsar is sufficient to power the TeV flux seen by *HESS*. However, PSR J1617−5055 lies slightly outside the *HESS* error box. In its followup observations, *Swift* detected 2 X-ray sources within or close to the *HESS* error circle, but they are unlikely counterparts of HESS J1616−508: one is soft and is probably a star, the other is possibly an artifact, (Landi et al. 2007b). These authors suggest that an asymmetric PWN powered by PSR J1617−5055 is the counterpart of HESS J1616−508; this would explain why the pulsar is not exactly within the *HESS* error box.

HESS J1632−478 and HESS J1634−472. These two sources are quite close to each other (they are separated by about 45′) and are positionally consistent with the X-ray binaries 4U 1630−47, IGR J16358−4726 and IGR J16320−4751: HESS J1634−472 with the former two, and HESS J1632−478 with the latter one. However, in this region of the sky (the Norma Arm region) there is a high concentration of sources, so the probability of chance coincidence can be high. This said, if we consider HESS J1632−478, *XMM-Newton* archival data show that there are actually two more (unidentified) X-ray sources, besides IGR J16320−4751, within the TeV error ellipse: AX J163252−4746, at a 0.2–12 keV flux of 5×10^{-12} erg cm^{-2} s^{-1}, and a still unnamed source with a 0.2–12 keV flux of 1.5×10^{-12} erg cm^{-2} s^{-1}. Thus, a deeper multiwavelength effort is needed to shed light on the actual nature of HESS J1632−478 and on its connection with any of these three sources detected with *XMM-Newton*. One should also note that HESS J1632−478 and HESS J1634−472 are extended and persistent, while all of the X-ray objects mentioned above are pointlike objects; moreover, 4U 1630−47 and IGR J16358−4726 are transients. So one can, at the very least, state that none of these two latter X-ray objects is the likely counterpart of the source HESS J1634−472.

HESS J1640−465. This *HESS* source is positionally associated with the broken shell SNR 338.3–0.0 (Fig. 4, right panel), detected in X-rays by *ASCA* as AX J1640−4632 (Sugizaki et al. 2001). This X-ray source is well detected also by *Swift*/XRT at the centre of the *HESS* error circle, with spectrum and flux compatible with those measured with *ASCA* (Landi et al. 2006). Again according to these authors, the chance positional probability of finding a soft X-ray source with the flux of AX J164042−4632 (7.2×10^{-13} erg cm^{-2} s^{-1} in the 2–10 keV band) in the *HESS* error box is as low as 1%, suggesting that the two sources are the same. This evidence suggests that HESS J1640−465 is a SNR, although the lack of evident diffuse emission, together with the central location of the X-ray source within the SNR, do not allow one to rule out that this is actually a PWN. Recent *XMM-Newton* data (Funk et al. 2007) show extended emission from the *ASCA* source, and strengthen the SNR interpretation for the TeV emission observed by *HESS*. However, the *XMM-Newton* position of the source is not consistent with that of XRT. Moreover, in the *XMM-Newton* error circle one can find two optical sources, with magnitudes $R\sim$15.4 and $R\sim$17, respectively, whereas the XRT error box does not contain any optical or NIR object. Thus, optical spectroscopy of the sources within the *XMM-Newton* error circle is desirable to shed light on this positional mismatch and on their association with the X-ray and TeV emissions.

HESS J1804−216. This source was observed with several soft X-ray satellites. *Swift*/XRT detected 3 objects within the TeV error circle of this object: two are likely stars, and the third is close to a radio complex

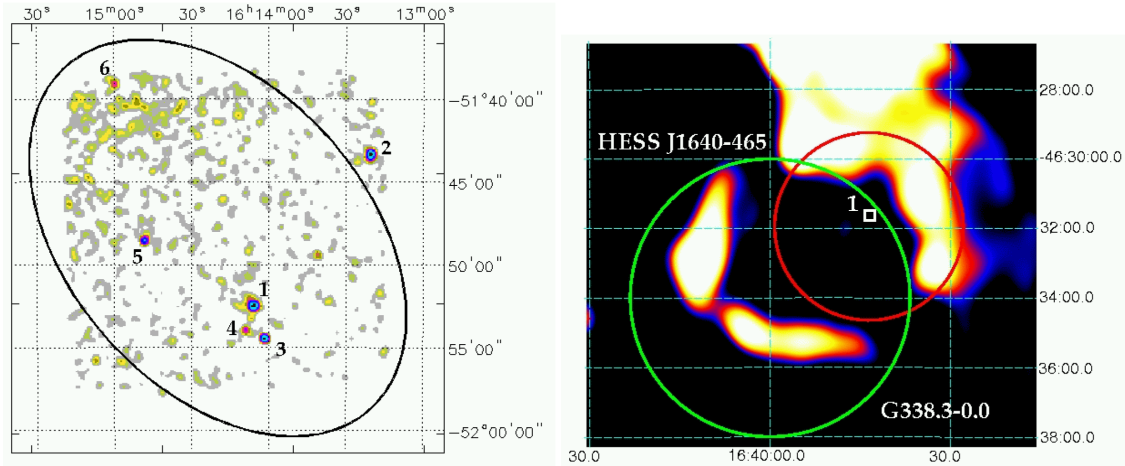

Fig. 4 *Left panel*: XRT 0.3–10 keV image of the region surrounding HESS J1614−518. The ellipse (with axes of size 28′ and 18′) represents the extension of the TeV source. For details see Landi et al. (2006, 2007a). *Right panel*: radio image at 843 MHz of the region surrounding HESS J1640−465. The larger circle (green, 4′ radius) describes the position and extension of SNR G338.3−0.0 as given in Green (2004). The smaller circle (red, 2.′5 radius) represents instead the extension of the TeV source. The position of the XRT Source 1 is given by a box. For details see Landi et al. (2006).

of unknown origin (Landi et al. 2006). Subsequent observations by *Suzaku* detected 2 non-variable objects (S1 and S2, the latter coinciding with the third *Swift* source mentioned above), with hard and absorbed X-ray spectra (Bamba et al. 2007). More recently, observations with *Chandra* (Kargaltsev et al. 2007) showed that source S2 is compact, while S1 is extended. No reliable optical/NIR counterpart was found for both sources (Kargaltsev et al. 2007). All these observations still do not allow to understand what these two X-ray objects are, as well as what their connection (if any) with the TeV source is. Thus, the study of their X-ray variability is needed to shed light on their nature.

HESS J1813−178. Ubertini et al. (2005) reported on a followup on this TeV source made with *INTEGRAL* and using *ASCA* archival data (Fig. 5, left panel). They found that the spectrum of the X-ray source positionally consistent with the TeV emission is modeled with an absorbed power law with photon index $\Gamma \sim 1.8$, and hypothesized that this source is a PWN able to emit TeV photons. Radio data acquired with the VLA confirmed that the shell-type SNR G12.82−0.02 is positionally coincident with HESS J1813−178 (Brogan et al. 2005). More recently, *Chandra* data suggest the presence of a young X-ray pulsar within the SNR (Helfand et al. 2007). Therefore, this SNR/PWN is the likely counterpart of the *HESS* source.

HESS J1825−137. The X-ray observations performed with *INTEGRAL* (A. Malizia, priv. comm.) and *XMM-Newton* (Gaensler et al. 2003) allow associating this *HESS* source with the PWN of the X-ray pulsar PSR B1823−13. Actually, as in the case of HESS J1616−508, the pulsar is slightly outside the TeV error ellipse; however, the X-ray emitting nebula associated with the pulsar falls within the *HESS* error box. This supports the fact that the PWN powered by PSR B1823−13 is responsible for the TeV emission from HESS J1825−137.

HESS J1834−087. The positional coincidence of this TeV source with the central hot spot of the broken shell SNR G23.3−0.3 (Fig. 5, right panel) suggested an association between the two sources. *Swift*/XRT found only one source inside the TeV error box, at a 2–10 keV band flux of 2.6×10^{-13} erg cm^{-2} s^{-1}, implying a chance positional probability of about 40% (Landi et al. 2006). Thus, the two sources are probably not associated. It should be however noted that a reddened object (with magnitudes $R \sim 18$ and $K \sim 13$) is found at the border of the XRT error circle. So, albeit this TeV source may be associated with a SNR, more multiwavelength followup observations are needed to confirm this connection and to understand whether the emission is rather produced by a PWN.

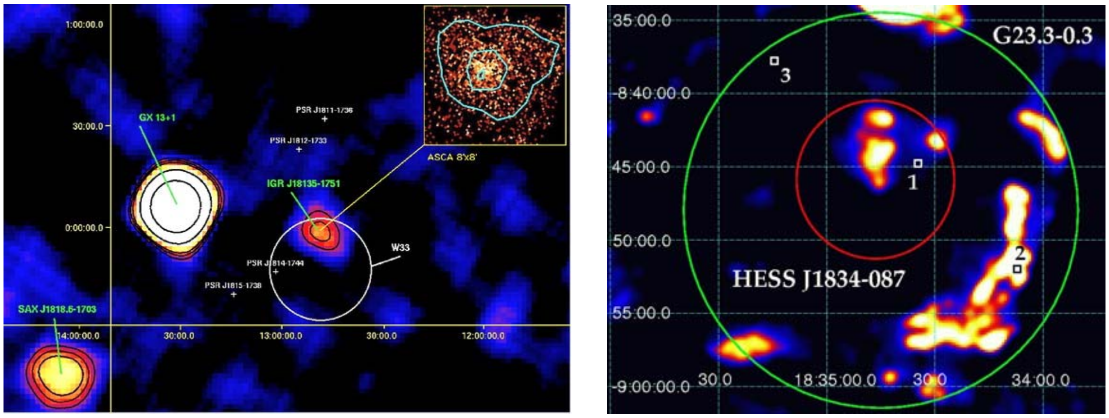

Fig. 5 *Left panel*: IBIS/ISGRI 20–40 keV image showing the location of HESS J1813−178 and its surroundings. The extension of the TeV source is contained within the contour of the *INTEGRAL* source IGR J18135−1751. Also shown are the location of SNR W33 (G12.82−0.02) and of the 4 nearest radio pulsars. The extension (15′ radius) of W33 is also indicated by the white circle. The *ASCA* image at the *HESS* position is shown as an inset on the top right side of the figure; the box covers an 8′×8′ region centered on the *ASCA* source position. Coordinates are displayed in the Galactic system. For details see Ubertini et al. (2005). *Right panel*: radio image at 20 cm of the region surrounding HESS J1834−087. The larger circle (green, 13′ radius) describes the position and extension of SNR G23.3−0.3 as given in Green (2004). The smaller circle (red, 3′ radius) represents instead the extension of the TeV source. The positions of the XRT sources are given by boxes. For details see Landi et al. (2006).

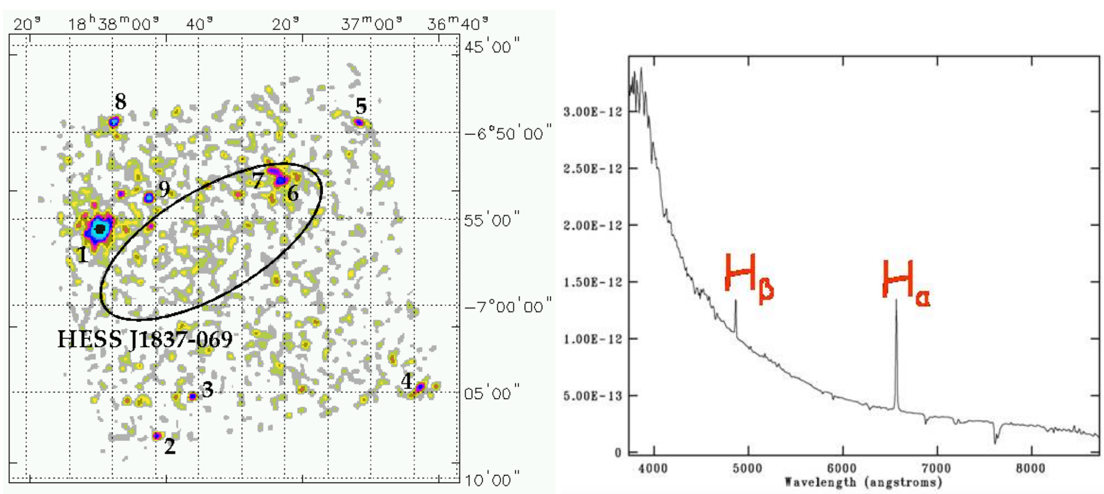

Fig. 6 *Left panel*: XRT 0.3–10 keV image of the region surrounding HESS J1837−069. The ellipse (with axes of size 14′ and 6′) represents the extension of the TeV source. For details see Landi et al. (2006). *Right panel*: optical spectrum of the emission-line star HD 259440 acquired in Loiano on April 2007. Balmer H_α and H_β emissions, superimposed on a very blue continuum, are apparent. On the y-axis, the fluxes are expressed in erg cm^{-2} s^{-1} Å^{-1}.

HESS J1837−069. This source is positionally associated with the SNR G25.5+0.0 complex, detected in X-rays by *ASCA* (Bamba et al. 2003), *BeppoSAX* and *INTEGRAL* (Malizia et al. 2005). Observations made with *Swift*/XRT detected 9 sources in or around the *HESS* error ellipse for this source (Fig. 6, left panel; Landi et al. 2006). Of these, only two (at 2–10 keV fluxes of 4×10^{-13} erg cm^{-2} s^{-1}

and 2×10^{-13} erg cm^{-2} s^{-1}) are within this ellipse, while the brightest one (with 2–10 flux of 1.1×10^{-11} erg cm^{-2} s^{-1}) lies slightly outside it. This latter source is associated with a very reddened optical object (with magnitudes $R \sim$ 17.5 and $K \sim$ 10.5), while the other two sources have no optical counterpart but are associated with relatively bright NIR objects (both have $K \sim$ 13). Thus, further observations, especially at optical and NIR wavebands, are needed to understand the nature of these X-ray sources and to see whether one of them is associated to the TeV emitter.

HESS J0632+058. Although this TeV source is not in the sample of Aharonian et al. (2006) – indeed, it was dicovered later (Aharonian et al. 2007) – I included it in this review because it is located as well along the Galactic Plane and it has a similar spectral shape at TeV energies when compared to the sources of the aforementioned sample. HESS J0632+058 lies close to the rim of the Monoceros SNR, and its position suggests an association with a faint *ROSAT* soft X-ray source, with an unidentified EGRET high-energy source, and/or with the early-type, emission-line star HD 259440 (Aharonian et al. 2007). Recent optical spectroscopy of this star, acquired in Loiano on April 2007 (Fig. 6, right panel), indeed shows Balmer H $_\alpha$ and H_β emissions superimposed on a very blue continuum. If the optical and the TeV source are associated, this object may be a gamma-ray microquasar similar to the HMXBs LS 5039 (Aharonian et al. 2005b) and Cyg X-1 (e.g., Romero et al. 2002). However, accurate pointed X-ray and radio observations are needed to confirm (or disprove) this hypothesis.

To conclude this Section, I would like to stress the following: as *INTEGRAL* preferentially detects PWNe rather than SNRs (L. Bassani, priv. comm.; Bird et al. 2007), one may suggest that the *HESS* sources detected with *INTEGRAL*, i.e. HESS J1616−508, HESS J1813−178 and HESS J1837−069, and which are likely associated with the residual of a Supernova explosion, are possibly PWNe.

Of course, a long work of multiwavelength followup still needs to be done to conclusively determine the nature of these TeV sources; however, the present evidence seems to suggest that many of them are possibly connected with the aftermath of Galactic Supernovae, or with HMXBs showing collimated emission (i.e. microquasars).

4 CONCLUSIONS

In summary, the *INTEGRAL* and *HESS* observatories allowed opening wide two major windows of the electromagnetic spectrum on our Galaxy and beyond; their data, complemented with multiwavelength spectroscopic and imaging followup from radio to X-rays, are fundamental for the identification and the study of the high-energy sources newly discovered by these facilities. And, as more and more hard X-ray and TeV data are accumulated, we can get an increasingly better insight on the single sources emitting at such high energies, as well as on their classes.

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References

Adelman-McCarthy J., Agueros M.A., Allam S.S. et al., 2006, ApJS, 162, 38
Aharonian F., Akhperjanian A., Beilicke M. et al., 2002, A&A, 393, L37
Aharonian F., Akhperjanian A.G., Aye K.-M. et al., 2005a, A&A, 439, 1013
Aharonian F., Akhperjanian A.G., Aye K.-M. et al., 2005b, Science, 309, 746
Aharonian F., Akhperjanian A.G., Bazer-Bachi A.R. et al., 2006, ApJ, 636, 777
Aharonian F., Akhperjanian A.G., Bazer-Bachi A.R. et al., 2007, A&A, 469, L1
Bamba A., Ueno M., Koyama K., Yamauchi S., 2003, ApJ, 589, 253
Bamba A., Koyama K., Hiraga J.S. et al., 2007, PASJ, 59S, 209
Barlow E.J., Knigge C., Bird A.J. et al., 2006, MNRAS, 372, 224
Bird A.J., Malizia A., Bazzano A. et al., 2007, ApJS, 170, 175
Bodaghee A., Courvoisier T.J.-L., Rodriguez J. et al., 2007, A&A, 467, 585
Brogan C.L., Gaensler B.M., Gelfand J.D. et al., 2005, ApJ, 629, L105
Chakrabatry D., Roche P., 1997, ApJ, 489, 254

de Martino D., Matt G., Belloni T., Haberl F., Mukai K., 2004, A&A, 415, 1009
Filliatre P., Chaty S., 2004, ApJ, 616, 469
Funk S., Hinton J.A., Pühlhofer G. et al., 2007, ApJ, 662, 517
Gaensler B.M., Schulz N.S., Kaspi V.M., Pivovaroff M.J., Becker W.E., 2003, ApJ, 588, 441
Garcia M.R., Baliunas S.L., Doxsey R. et al., 1983, ApJ, 267, 291
Green D.A., 2004, BASI, 32, 335
Helfand D.J., Gotthelf E.V., Halpern J.P. et al., 2007, ApJ, in press [arXiv:0705.0065]
Hinton J., 2004, New Astron. Rev., 48, 331
Jones D.H., Saunders W., Colless M. et al., 2004, MNRAS, 355, 747
Kaplan D.L., Levine A.M., Chakrabarty D. et al., 2007, ApJ, 661, 437
Kargaltsev O., Pavlov G.G., Garmire G.P., 2007, ApJ, submitted [astro-ph/0701069]
Kennea J.A., Campana S., 2006, ATel 818
Krivonos R., Revnivtsev M., Lutovinov A. et al., 2007, A&A, submitted [astro-ph/0701836]
Landi R., Bassani L., Malizia A. et al., 2006, ApJ, 651, 190
Landi R., Masetti N., Bassani L. et al., 2007a, ATel 1047
Landi R., De Rosa A., Dean A.J. et al., 2007b, MNRAS, in press [arXiv:0707.0832]
Leyder J.-C., Walter R., Lazos M., Masetti N., Produit N., 2007, A&A, 465, L35
Malizia A., Bassani L., Stephen J.B. et al., 2005, ApJ, 630, L157
Masetti N., 2006, Chin. J. Astron. Astrophys. (ChJAA), 6S1, 143
Masetti N., Dal Fiume D., Cusumano G. et al., 2002, A&A, 382, 104
Masetti N., Palazzi E., Bassani L., Malizia A., Stephen J.B., 2004, A&A, 426, L41
Masetti N., Bassani L., Bird A.J., Bazzano A., 2005, ATel 528
Masetti N., Mason E., Bassani L. et al., 2006a, A&A, 448, 547
Masetti N., Pretorius M.L., Palazzi E. et al., 2006b, A&A, 449, 1139
Masetti N., Bassani L., Bazzano A. et al., 2006c, A&A, 455, 11
Masetti N., Morelli L., Palazzi E. et al., 2006d, A&A, 459, 21
Masetti N., Bassani L., Bazzano A. et al., 2006e, ATel 815
Masetti N., Bassani L., Dean A.J., Ubertini P., Walter R., 2006f, ATel 715
Masetti N., Bassani L., Malizia A., Bird A.J., Ubertini P., 2006g, ATel 941
Masetti N., Malizia A., Dean A.J., Bazzano A., Walter R., 2006h, ATel 957
Masetti N., Orlandini M., Palazzi E., Amati L., Frontera F., 2006i, A&A, 453, 295
Masetti N., Morelli L., Cellone S.A. et al., 2007a, ATel 1033
Masetti N., Cellone S.A., Landi R. et al., 2007b, ATel 1034
Masetti N., Landi R., Pretorius M.L. et al., 2007c, A&A, 470, 331
Masetti N., Rigon E., Maiorano E. et al., 2007d, A&A, 464, 277
Matsumoto H., Ueno M., Bamba A. et al., 2007, PASJ, 59S, 199
Paizis A., Nowak M.A., Chaty S. et al., 2007, ApJ, 657, L109
Piatti A.E., Clariá J.J., Bica E., 2000, A&A, 360, 529
Romero G.E., Kaufman Bernadó M.M., Mirabel I.F., 2002, A&A, 393, L61
Stephen J.B., Bassani, Malizia A. et al., 2006, A&A, 445, 869
Sugizaki M., Mitsuda K., Kaneda H. et al., 2001, ApJS, 134, 77
Torres M.A.P., Steeghs D., Jonker P.G., Burns C.R., Freedman W.L., 2006, ATel 909
Torii K., Kinugasa K., Toneri T. et al., 1998, ApJ, 404, L207
Tueller J., Barthelmy S., Burrows D. et al., 2005a, ATel 669
Tueller J., Gehrels N., Mushotzky R.F. et al., 2005b, ATel 591
Ubertini P., Bassani L., Malizia A. et al., 2005, ApJ, 629, L109
Winkler C., Courvoisier T.J.-L., Di Cocco G. et al., 2003, A&A, 411, L1

DISCUSSION

SYLVAIN CHATY: In your sample of optically identified *INTEGRAL* sources, which is the percentage of Be HMXBs compared to that of HMXBs hosting a blue supergiant? Do you have information on the absorption towards these sources?

NICOLA MASETTI: The HMXBs with supergiant companion are at least 4 out of the 11 in our sample. However they may be more, as in some cases we could not firmly identify the luminosity class of the companion star. Concerning the absorption, we find that 6 cases out of 11 are heavily reddened; however, as they lie along the Galactic Plane, the observed reddening may be interstellar and not local to the system.

SYLVAIN CHATY's comment: we acquired a NIR spectrum of IGR J16320−4751, which you possibly associate with the *HESS* source HESS J1632−478, and it appears to be a HMXB hosting a blue supergiant star.

ARNON DAR: Can you give the linear size of the *HESS* error box radius if placed at the distance of the Galactic Center?

NICOLA MASETTI: assuming a (typical) radius of $3'$ one gets a linear size of about 7 pc. This of course means that we cannot discount the possibility that some of the X-ray counterparts proposed for the HESS sources are chance coincidences, as already stressed by Landi et al. (2006).

STEFANO COVINO: Which is the percentage of intrinsically obscured AGNs in your sample?

NICOLA MASETTI: Up to now we found that, out of the 36 objects that we identified as AGNs, 20 are Seyfert 2 galaxies. This would mean that 56% of these objects are intrinsically absorbed. However this percentage can be lowered if, among these cases, 'genuine' Seyfert 2s, i.e. without intrinsic nuclear absorption, are found (see the contribution of T. Boller to these proceedings).

FILIPPO FRONTERA: Is it possible, on the basis of the *INTEGRAL*/IBIS X-ray spectra alone, to establish the nature of a given source?

NICOLA MASETTI: The *INTEGRAL* spectra can of course give hints on the nature of the unidentified sources, but only optical or NIR followup spectroscopy can definitely pinpoint their actual nature.