Astrophys Space Sci (2007) 309: 5–9
DOI 10.1007/s10509-007-9477-9

ORIGINAL ARTICLE

New INTEGRAL sources and TeV emission

Roland Walter

Received: 7 July 2006 / Accepted: 1 November 2006 / Published online: 12 April 2007

Abstract INTEGRAL is operational since more than three years and producing high quality data that allows to detect fainter new hard X-ray sources. The new sources, identified until now, are mostly active galactic nuclei and absorbed or transient high mass X-ray binaries. TeV emission could be expected from the new high mass X-ray binaries accreting dense clumps of stellar wind. INTEGRAL sources with TeV counterparts are discussed.

Keywords X- and gamma-ray telescopes and instrumentation · X-rays: binaries · Pulsars · Mass loss and stellar winds

PACS 95.55.Ka · 97.80.Jp · 97.60.Gb · 97.10.Me

1 Introduction

Since the beginning of 2003, the international gamma-ray astrophysics laboratory (INTEGRAL) is surveying the sky at hard X-rays and gamma-rays, with a particular emphasis on the plane and central regions of the Galaxy. The two main scientific instruments consist of the imager (IBIS) (Ubertini et al. 2003) and of the spectrometer SPI (Vedrenne et al. 2003), providing respectively sub-arcmin source positioning and keV spectral resolution in a band ranging from 17 keV to few MeV. Both instruments use coded-masks for the imaging. Substantial monitoring capabilities are also provided in the X-rays (3–35 keV) and in the optical V band by the JEM-X (Lund et al. 2003) and OMC (Mas-Hesse et al. 2003) instruments.

About 75% of the INTEGRAL observing program is driven by selected open time observation proposals and target of opportunity observations. The remaining of the observing time is devoted to the so-called core program, that mostly consists of regular scans of the galactic plane and central regions. During the two first years in operation many transient and new sources were detected. With an average of one IAU circular or Astronomer's Telegram issued per week following INTEGRAL observations (Courvoisier et al. 2003), one of the goal of the INTEGRAL core program namely to monitor the hard X-ray sky is fully met.

Multiplexing large field of view images obtained for many short pointings allows to obtain Msec effective exposure times and sub mCrab sensitivity in many areas of the sky. Below 100 keV, the IBIS spatial resolution is a key feature to resolve the numerous point sources of hard X-ray emission detected in particular within the Galactic bulge and spiral arms.

2 Source detection and identification

All sky mosaic images have been constructed using all public INTEGRAL/IBIS data obtained from the beginning of the mission up to April 2005 (Fig. 2). Source candidates have been extracted and filtered according to source significance, available exposure time and source shape to minimize the number of false detection. Transient sources that were active on a short time scale are usually not significant

Based on observations with INTEGRAL, an ESA project with instruments and science data centre funded by ESA member states (especially the PI countries: Denmark, France, Germany, Italy, Switzerland, Spain), Czech Republic and Poland, and with the participation of Russia and the USA.

R. Walter (✉)
Observatoire de Genève, INTEGRAL Science Data Centre,
Chemin d'Ecogia 16, 1290, Versoix, Switzerland
e-mail: Roland.Walter@obs.unige.ch

enough to appear in average mosaic images and need to be considered separately.

The number of source candidates detected above 25 keV amounts to about 375. Among them not more than 30 false detections are expected. For comparison, above 20 keV, HEAO-1 and SIGMA detected 70 sources down to 14 mCrab and respectively 15 galactic sources to a sensitivity of 30 mCrab.

Many detections correspond to sources known before INTEGRAL. Identification of a fraction of the new candidates has been obtained by improving the source position from arcmin to arcsec scales through the search for radio/soft X-ray counterparts in existing archives (Stephen et al. 2006) or through specific high resolution X-ray observations (Walter et al. 2006b). Optical/infrared spectroscopy of counterpart candidates have then been obtained (Masetti et al. 2006).

About 70 out of 200 new hard X-ray sources have already been identified (Fig. 1). 40% of them are high-mass X-ray binaries (HMXB), 40% are active galactic nuclei (AGN) and the remaining are distributed as follow: 3 low-mass X-ray binaries (LMXB), 4 X-ray novae, 6 cataclismic variables, 2 symbiotic stars, 1 msec pulsar and a few counterparts of TeV sources (see Sect. 6 for more details).

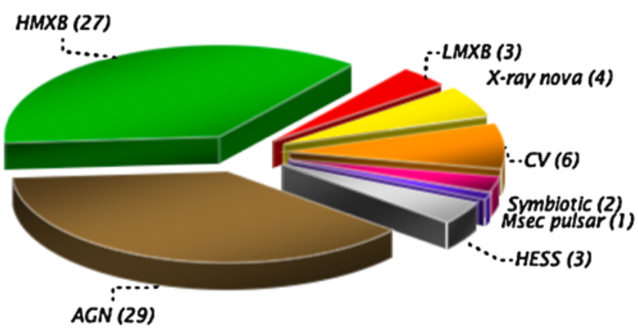

Fig. 1 Identification of the new INTEGRAL sources

Study of the new INTEGRAL detected sources provided several unexpected results:

- 25% of the Active Galactic Nuclei detected by INTEGRAL are new detections. Those sources are not particularly absorbed but located behind the galactic plane (Bassani et al. 2006).
- 50% of the HMXB are new absorbed or transient systems (Walter et al. 2006b).
- Anomalous X-ray pulsars have very hard spectra in the soft gamma-rays, signature of magnetar emission (Kuiper et al. 2006).
- Hard X-ray counterparts of several unidentified HESS sources (Ubertini et al. 2005; Malizia et al. 2005).

The distribution of INTEGRAL sources on the sky is as expected with Active Galactic Nuclei following the exposure map, HMXB tracing the galactic plane, the Gould belt and the two Magellanic Clouds and finally LMXB tracing older stellar population and in particular the bulge of the Galaxy.

3 High-mass X-ray binaries

A number of new bright persistent sources have been detected by INTEGRAL above 20 keV in the galactic plane. Such sources were either unknown before INTEGRAL or weakly detected in previous X-ray surveys. Follow-up observations of a subset of those sources with XMM-Newton

Fig. 2 High resolution image of the inner galaxy above 25 keV by INTEGRAL/IBIS (the image covers $100^\circ \times 60^\circ$)

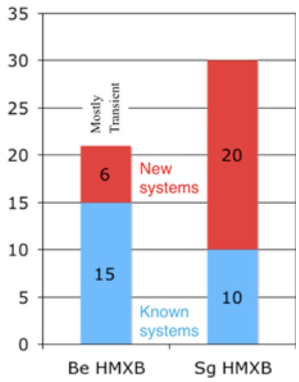

Fig. 3 Known and new Be and super-giant HMXB systems (*left* and *right column* respectively) detected by INTEGRAL

revealed that 80% of those new persistent sources are highly absorbed. Most of them are accreting pulsars in HMXB systems with long (100–1300 sec) spin periods characteristic of wind accretion. The orbital periods and infrared spectra indicate the presence of massive companions, most likely super-giant stars (Walter et al. 2006b).

A family of fast hard X-ray transients, discovered by INTEGRAL, flaring on few hours time scales (Sguera et al. 2006), have also been associated with super-giant companion stars (Negueruela et al. 2006).

Among the HMXB detected by INTEGRAL 25 were known previously and 26 are new systems. Because of their transient and long period nature only 15 Be systems have been detected out of the hundred known systems and 6 new ones have been discovered. The 10 wind accreting super-giant persistent systems previously known in the Galaxy have been detected by INTEGRAL. In addition 20 new supergiant systems have been discovered, increasing the number of those systems by a factor of 3. 13 of them are obscured and persistent and 7 are fast transients.

The distribution of HMXB detected by INTEGRAL along the galactic plane peaks in the Norma and Scutum/Sagittarius inner spiral arms regions. The sources are on average slightly brighter and more scattered along the galactic plane in the Sagittarius region as expected if the Norma region sources are located further out from the Sun. This suggests that the bulk of the observed HMXB population is located in the outer parts of the inner arms at a distance of the order of 5 kpc from the Galactic Center.

4 Dense and clumpy stellar winds

In contrast with the new persistent HMXB discovered by INTEGRAL the previously known systems are most of the time not strongly absorbed and bright in the X-ray band. As their average X-ray luminosity is not exceptional, the new sources detected by INTEGRAL are very likely characterized by peculiar wind geometrical configuration (e.g. dense equatorial disks or accretion wakes).

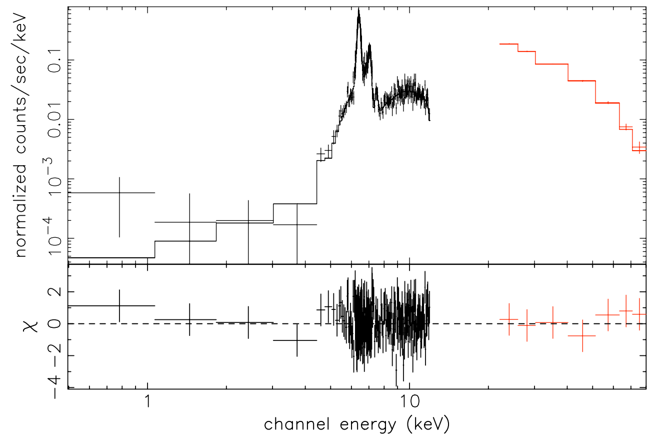

Fig. 4 X-ray spectrum of IGR J16318-4848 as observed by XMM-Newton and INTEGRAL. The strongly attenuated continuum at soft X-rays indicate an absorption column density as large as 2×10^{24} cm^{-2}. The region emitting the fluorescence Fe and Ni lines is much less absorbed

INTEGRAL observations indicate that the new absorbed systems form the majority of the active super-giant HMXB detected so far. The fluorescence lines are particularly striking in those objects (Fig. 4). Together with the continuum spectral shape they point towards a transmission geometry in which the compact sources are embedded within a dense envelope of cold matter. A likely model is one in which the compact object orbits its companion within a dense stellar wind component. This model is confirmed by the eclipses (Hill et al. 2005; Zurita et al. 2006) and the evidences for variation of the absorbing column densities that have been found in few of those sources (Rodriguez et al. 2006). Fast flaring activities also indicate inhomogeneities in the accreted wind (Walter 2006a).

Fast transient super-giant HMXB are characterized by short flares lasting a few hours and separated by many weeks. These flares are likely the signature of the interaction between the orbiting compact source and highly inhomogeneous stellar winds made of very dense clumps (Leyder et al. 2007). The timing characteristics of those flares allows to measure the physical characteristics of those clumps.

The main difference between transparent, obscured and fast transient super-giant HMXB systems is probably related to the structure of the stellar wind. The clumpness of the wind could increase from transparent to obscured and even further to fast transient systems. Hard X-ray variability studies provide a direct way to probe the stellar wind characteristics (clumpness, density) and constrain clumpy stellar wind models (Leyder et al. 2007). This complements studies based on high resolution spectroscopy (Oskinova et al. 2006).

Table 1 TeV sources with possible INTEGRAL counterparts

Source	Type	Remarks
HESS J1745-290	SNR	The peak of the hard X-ray emission detected close to the galactic center by INTEGRAL is located 1 arcmin from Sgr A*. It very probably corresponds to the hard energy tail of the X-ray diffuse emission observed within 6 arcmin of the galactic center. That hard X-ray emission could be interpreted as synchrotron emission associated with the inverse Compton TeV emission detected by HESS (Neronov et al. 2005)
Crab	PWN	The INTEGRAL detection is completely dominated by the pulsar emission
HESS J1514-591	PWN	INTEGRAL is detecting the associated pulsar PSR B1509-58. The pulsar is too bright to allow for the detection of the jet-like PWN observed by Chandra and HESS
HESS J1837-069	?	The nature of this source is still unclear. As the INTEGRAL PSF is larger than the TeV extension measured by HESS, it is currently not possible to tell if the INTEGRAL point-like source is a counterpart of the TeV emission (Malizia et al. 2005)
HESS J1813-178	SNR	The point-like INTEGRAL source is compatible with the almost point-like HESS source (Ubertini et al. 2005)
HESS J1420-607	PWN/SNR	An excess of emission is observed by INTEGRAL at a slight offset from the TeV source. The INTEGRAL position coincides with the soft X-ray source RXS J141935.3-604523 located about 4 arcmin at the west of the X-ray source PSR J1420-6048 located close to the center of the TeV emission. The INTEGRAL/RXS and the HESS/ASCA sources coincide with two different wings of the Kookaburra SNR
HESS J1616-508	PWN/SNR	A clear and elongated excess of hard X-ray emission is detected by INTEGRAL at the position of the TeV source. Both are offset from PSR J1617-5055 and close to the SNRs G332.4-0.4 and G332.4+0.1
LS 5039	HMXB	An excess of emission is observed by INTEGRAL at the position of LS 5039. The significance is however too low for a formal detection
PSR B1259-63	HMXB+PWN	The INTEGRAL and X-ray variability of PSR B1259-63 are compared to the HESS observations in this volume by Neronov et al. (2006)
LSI +61 303	HMXB+PWN	The TeV, INTEGRAL, X-ray and radio variability of LSI +61 303 are compared and discussed in Chernyakova et al. (2006)
HESS J1632-478	?	IGR J16320-4751 is an obscured HMXB featuring bright flares (Rodriguez et al. 2006) probably related with inhomogeneous stellar winds. As such it could emit TeV (Sect. 5). However the HESS source seems extended, ruling out the association

5 Do neutron stars accreting dense stellar wind clumps emit TeV?

The possible detection of HMXB in the TeV range in the 80's (see Protheroe 1986 for a review) led to the idea that protons trapped in the outer and closed regions of a neutron star magnetosphere could be accelerated up to $\gamma \approx 10^8$ by multiple scattering of Alfvén waves close to the accretion column (Katz and Smith 1988). Protons could be accelerated to high energies only if the synchrotron loss time is larger than the travel time needed to bounce back often enough to gain energy. Within milli-seconds, when the giro-radius becomes larger than the magnetospheric region, the high energy protons escape the system. For the highest energies this occurs close to the Alfvén radius $R_A \approx 10^8$ cm. The luminosity of the high energy proton leaving the system was estimated as the total energy trapped over the escape time and could reach 10^{36} erg/s (Smith et al. 1992).

Significant γ-ray production will take place if the high energy protons interact with dense enough accreted material outside of the Alfvén radius. The size of the stellar wind clumps assumed to be responsible for the hard X-ray flares observed in fast transient super-giant HMXB could be estimated as 10^{10} cm from the duration of the flares. At $\sim 10^9$ cm from the neutron star, the pulsar magnetic field will be of the same order than the companion stellar wind magnetic field (i.e. $\sim 100G$ (Donati et al. 2006)) such that Bohm diffusion could take place. The diffusion time scale $t_d \approx 150\text{ s} \times (R/10^{10}\text{ cm})^2 \times (1\text{ TeV}/E) \times (B/100G)$ becomes larger than the proton interaction timescale $t_p = 470\text{ s} \times (10^{23}\text{ cm}^{-2}/N_H) \times (R/10^{10}\text{ cm})$ if

$$N_H \geq 5 \times 10^{23}\text{ cm}^{-2} \times (E/1\text{ TeV}) \times (100G/B) \times (10^{10}\text{ cm}/R)$$

We conclude that HMXB accreting dense stellar wind clump could be transient TeV sources if the column density is large enough. This applies to dense clumps in fast transient HMXB and to persistent obscured HMXB if the accretion wakes are dense enough. The strength of the TeV emission also depends on the magnetic strength and structure in the stellar wind. As column densities larger than 10^{23} cm^{-2} have been observed in specific objects during flares, one could expect to observe TeV flares from fast transient supergiant HMXB on a timescale of a few hours and possibly in persistent highly absorbed systems as well.

6 INTEGRAL counterparts of TeV sources

Several of the sources detected by HESS and MAGIC in the galactic plane do have counterparts detected by INTEGRAL (see Table 1) including some of the unidentified HESS sources. In the case of point-like and variable TeV sources the correspondence between the TeV and INTEGRAL sources is almost sure. For extended sources the situation is more delicate as HESS and INTEGRAL may see different particle acceleration sites emitted in different regions of the same supernova remnant (SNR) or by a pulsar and/or its pulsar wind nebula (PWN). Clearly more spatial resolution and sensitivity are needed from the hard X-rays to the TeV range to allow precise mapping of particle acceleration sites in the Galaxy.

Currently none of the obscured or fast X-ray transient HMXB discovered by INTEGRAL has been detected in the TeV (with the possible exception of IGR J16320-478), however one must note that TeV emission is expected only during the accretion of dense clumps which happens only when the source is active at hard X-rays, i.e. for a small fraction of the time.

References

Bassani, L., et al.: INTEGRAL IBIS extragalactic survey: active galactic nuclei selected at 20–100 keV. Astrophys. J. **636**, L65 (2006)

Chernyakova, M., et al.: XMM-Newton observations of PSR B1259-63 near the 2004 periastron passage. Mon. Not. Roy. Astron. Soc. **367**, 1201 (2006)

Courvoisier, T., et al.: The INTEGRAL science data centre (ISDC). Astron. Astrophys. **411**, L53 (2003)

Donati, J.-F., et al.: The surprising magnetic topology of tau Sco: fossil remnant or dynamo output? Mon. Not. Roy. Astron. Soc. **370**, 629 (2006)

Katz, J.A., Smith, I.A.: Particle acceleration in accreting magnetospheres. Astrophys. J. **326**, 733 (1988)

Kuiper, L., et al.: Discovery of luminous pulsed hard X-ray emission from anomalous X-ray pulsars 1RXS J1708-4009, 4U 0142+61, and 1E 2259+586 by INTEGRAL and RXTE. Astrophys. J. **645**, 556 (2006)

Leyder, J.-C., et al.: Hard X-ray flares in IGR J084084503 unveil clumpy stellar winds. Astron. Astrophys. (2007, in press)

Lund, N., et al.: JEM-X: The X-ray monitor aboard INTEGRAL. Astron. Astrophys. **411**, L231 (2003)

Hill, A., et al.: The 1–50 keV spectral and timing analysis of IGR J18027-2016: an eclipsing, high mass X-ray binary. Astron. Astrophys. **439**, 255 (2005)

Johnson, P.: Rapid stochastic acceleration of protons to energies above 100 TeV in the accretion column of Hercules X-1. Astropart. Phys. **3**, 53 (1995)

Malizia, A., et al.: The INTEGRAL/IBIS source AX J1838.0-0655: a soft X-Ray-to-TeV gamma-ray broadband emitter. Astrophys. J. **630**, L157 (2005)

Mas-Hesse, M., et al.: OMC: an optical monitoring camera for INTEGRAL. Instrument description and performance. Astron. Astrophys. **411**, L261 (2003)

Masetti, N., et al.: Unveiling the nature of INTEGRAL objects through optical spectroscopy. IV. A study of six new hard X-ray sources. Astron. Astrophys. **455**, 11 (2006)

Negueruela, I., et al.: Supergiant fast X-ray transients: a new class of high mass X-ray binaries unveiled by INTEGRAL. In: Wilson, A. (ed.) The X-ray Universe 2005. ESA SP-604, vol. 1, p. 165. Noordwijk (2006)

Neronov, A., et al.: Hard X-ray diffuse emission from the Galactic Center seen by INTEGRAL. astro-ph/0506437 (2005)

Neronov, A., et al.: Radio to TeV gamma-ray emission from PSR B1259-63. Astrophys. Space Sci. doi:10.1007/s10509-007-9454-3 (2007)

Protheroe, R.: Gamma-ray astronomy at the highest energies. Proc. Astron. Soc. Aust. **6**, 280 (1986)

Oskinova, L., et al.: High-resolution X-ray spectroscopy of bright O-type stars. Mon. Not. Roy. Astron. Soc. **372**, 313 (2006)

Rodriguez, J., et al.: INTEGRAL and XMM-Newton observations of the X-ray pulsar IGR J16320-4751/AX J1631.9-4752. Mon. Not. Roy. Astron. Soc. **366**, 274 (2006)

Sguera, V., et al.: Unveiling supergiant fast X-ray transient sources with INTEGRAL. Astrophys. J. **646**, 452 (2006)

Smith, I.A., et al.: Proton acceleration in neutron star magnetospheres. Astrophys. J. **388**, 148 (1992)

Stephen, J., et al.: Using the ROSAT catalogues to find counterparts for the second IBIS/ISGRI survey sources. Astron. Astrophys. **445**, 869 (2006)

Ubertini, P., et al.: IBIS: the imager on-board INTEGRAL. Astron. Astrophys. **411**, L131 (2003)

Ubertini, P., et al.: INTEGRAL IGR J18135-1751 = HESS J1813-178: a new cosmic high-energy accelerator from keV to TeV energies. Astrophys. J. **629**, L109 (2005)

Vedrenne, G., et al.: SPI: the spectrometer aboard INTEGRAL. Astron. Astrophys. **411**, L63 (2003)

Walter, R., et al.: IGR J16318-4848 & Co., a new population of hidden high-mass X-ray binaries in the Norma Arm of the Galaxy. In: Battrick, B. (ed.) The INTEGRAL Universe. ESA SP-552, p. 417. Noordwijk (2004)

Walter, R.: XMM-Newton and INTEGRAL observations of new absorbed supergiant high-mass X-ray binaries. In: Wilson, A. (ed.) The X-ray Universe 2005. ESA SP-604, vol. 1, p. 161. Noordwijk (2006)

Walter, R., et al.: XMM-Newton and INTEGRAL observations of new absorbed supergiant high-mass X-ray binaries. Astron. Astrophys. **453**, 133 (2006)

Zurita, J., et al.: IGR J17252-3616: an accreting pulsar observed by INTEGRAL and XMM-Newton. Astron. Astrophys. **448**, 261 (2006)