

New Galactic High Mass X-ray Binaries discovered with INTEGRAL

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Abstract. I will review the main observational properties of the new Galactic High Mass X-ray Binaries (HMXBs) discovered by the *INTEGRAL* satellite in the hard energy range 17–100 keV. About 70% of the newly discovered HMXBs host OB supergiant companions and show peculiar properties with respect to classical HMXBs detected with previous missions: some of them display huge local absorptions, in excess of 10^{23} cm^{-2} (the so-called *obscured sources*), while others show fast transient X-ray emission, leading to the definition of a new sub-class of HMXBs, the so-called *Supergiant Fast X-ray Transients* (SFXTs). Their peculiar behavior is still poorly understood and represents a challenge to theory.

Keywords: X-ray binaries, X-ray sources, accretion and accretion disks, supergiants

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NEW GALACTIC HIGH MASS X-RAY BINARIES: THE ROLE OF INTEGRAL DISCOVERIES

Our view of the X-ray sky changed since the launch of the *International Gamma-Ray Astrophysics Laboratory* in October 2002 (*INTEGRAL*, [1]): 723 hard X-ray sources have been observed down to a sensitivity limit at mCrab level [2] in the energy band 17–100 keV, 30% of which are still unidentified.

Among all detected sources, 13% are High Mass X-ray Binaries (HMXBs). About 50 objects among the new sources discovered with *INTEGRAL* (*IGR* sources), have been classified as HMXBs. About 70% of them host supergiant donors (see also the *IGRs* on-line list at <http://irfu.cea.fr/Sap/IGR-Sources/>), almost tripling the number of known Galactic HMXBs with supergiant companions.

Among these new HMXBs, two peculiar behaviors have been recognized:

- the so-called *obscured sources*, which display huge amount of low energy absorption (well in excess of 10^{23} cm^{-2} , thought to be local because of its variability, and produced by the dense wind of the supergiant companion; [3, 4]);
- a new subclass of transients, the *Supergiant Fast X-ray Transients* (SFXTs; [5, 6]). Note that a high absorbing column density is *not* a characterizing property of SFXTs, although a few SFXTs show high and variable absorption.

The discovery of new types of supergiant HMXBs was somehow unexpected: indeed, before *INTEGRAL* discoveries, HMXBs hosting OB supergiants were known to exhibit persistent X-ray emission, driven by the accretion from the strong wind of the blue supergiant companions, mainly in narrow orbits.

They were thought to be easy to detect because of their luminous persistent emission ($\sim 10^{36} \text{ erg s}^{-1}$). The number of Galactic wind-fed HMXBs composed of pulsating neutron stars and OB supergiant companions was limited to a few sources (Vela X-1, 2S0114+650, GX301-2, 1E1145.1-6141, 4U1538-53, X1908+075, XTE J1855-026).

Then, after the launch of *INTEGRAL*, thanks to its sensitivity at hard X-rays and the monitoring strategy of the Galactic plane, several new HMXBs could be discovered and identified, either highly obscured or with fast transient X-ray emission with long duty cycles, very difficult to discover with previous missions.

Obscured sources: the prototype IGRJ 16318–4848

IGRJ16318–4848 is the first source discovered in 2003 by the IBIS/ISGRI detector on-board *INTEGRAL* [7]. The source displayed a variable hard X-ray emission on time scales of 1000 s, with an average flux of

$6 \times 10^{-11} \text{ erg cm}^{-2} \text{ s}^{-1}$ (20–50 keV).

XMM-Newton follow-up observations allowed to refine the position [8], and revealed an extremely absorbed X-ray spectrum, with an absorbing column density of $2 \times 10^{24} \text{ cm}^{-2}$, together with prominent iron K_α and K_β , and nichel K_α emission lines ([9], [10], [3], [11]), suggestive of the presence of a dense local envelope ([10], [12], [13]).

X-ray observations with *Suzaku* [14] confirmed the X-ray spectrum rich in iron and nichel emission lines and allowed a truly simultaneous broad band spectroscopy (1–60 keV). These authors confirmed the huge amount of absorption, but found a significantly harder X-ray spectrum, well described with a flat power law with a photon index of ~ 0.67 (assuming an absorbed exponentially cutoff power law, together with Gaussian emission lines).

IGRJ16318–4848 is optically associated with a sgB[e] star, with a highly uncertain distance (0.9–6.2 kpc), implying an X-ray luminosity in the range between $1.3 \times 10^{35} \text{ erg s}^{-1}$ and $6.2 \times 10^{36} \text{ erg s}^{-1}$ (2–10 keV). If it is located in the Norma Arm, it lies at a distance of about 4.8 kpc [15]. The optical to MIR spectral energy distribution suggests the presence of a mid-infrared excess above the stellar spectrum, indicative of dust. This findings, together with the high absorption, imply dust and dense cool gas enshrouding the whole binary system ([16], [17]).

The B[e]-phenomenon is peculiar of very different kinds of stars (from supergiants to pre-main sequence stars) and is characterized by spectra with a near infrared excess (attributed to emission from warm dust) and by forbidden emission lines (e.g. Fe II) [18]. In particular, B[e] supergiants (sgB[e], [19, 18]) are thought to be in an evolutionary stage intermediate between OB supergiant and Wolf Rayet star [20]. Their properties have been explained in terms of a two component stellar wind, with the presence of a circumstellar outflowing disk wind [19].

After IGRJ16318–4848, *INTEGRAL* discovered other similar sources displaying high local absorption at soft X-rays (larger than 10^{23} cm^{-2}) associated with blue supergiant companions. Thus, IGRJ16318–4848 became the prototype of the so-called *obscured* HMXBs, being the first and most extreme example of this sub-class of massive X-ray binaries (e.g. [13, 21]). It is also one of the rare examples of HMXB with a companion showing the B[e] phenomenon [20].

Supergiant Fast X-ray Transients

Supergiant Fast X-ray Transients (SFXTs) are a sub-class of massive X-ray binaries recognized mainly thanks to *INTEGRAL* discoveries [5, 6].

SFXTs are characterized by transient and fast X-ray emission (composed by short and bright flares, with a duration of a few hours, as observed with *INTEGRAL*, [5], [6]) and by the association with OB supergiant companions (e.g. [22], [23], [24], [16], [25]). These two main properties have led to the identification of a new class of 9 members to date (together with several other SFXTs candidates, with fast transient X-ray emission, but still unknown counterparts). Optical/IR spectroscopy allowed the determination of the source distance, implying an X-ray luminosity at the flare peak of 10^{36} – $10^{37} \text{ erg s}^{-1}$.

INTEGRAL is able to observe the brightest flares, with no persistent emission outside flaring activity. More sensitive instruments allow to better investigate the properties of SFXTs when they are not undergoing an outburst.

The quiescence, characterized by a very soft (likely thermal) spectrum, has been rarely observed in SFXTs. It is at a luminosity level of $\sim 10^{32} \text{ erg s}^{-1}$, as observed in IGR J17544–2619 with *Chandra* [26]. In literature, the term “quiescence” is often used with different meanings, sometimes simply to indicate the X-ray emission when the source is not undergoing a bright outburst (“out-of-outburst” emission), whereas we mean here a specific source state at $10^{32} \text{ erg s}^{-1}$, where no accretion onto the compact object is present and the spectrum is very soft and thermal [26]. This quiescent luminosity implies a very high dynamic range (ratio between the peak luminosity and the luminosity during quiescence) of 4–5 orders of magnitude.

Observations with *XMM-Newton* caught a few SFXTs in a very low level of emission ($L_X \sim 10^{32} \text{ erg s}^{-1}$), showing a hard 0.5–10 keV spectrum and faint very short flares, suggestive of some level of accretion onto the compact object [27, 28].

The presence of a very low level of accretion is also suggested by our recent observation of the SFXT IGR J08408–4503 with *Suzaku* [29] performed in December 2009, which caught the source in an initial low intensity state at $4 \times 10^{32} \text{ erg s}^{-1}$ (0.5–10 keV), during the first 120 ks. Then, the source showed two long (lasting about 45 ks each) and faint flares. The spectrum of both the pre-flare and flare emission resulted in a hard X-ray emission, well fitted by a double component spectrum, with a soft thermal plasma model ($kT \sim 0.2$ – 0.3 keV) together with a power law (photon index ~ 2), differently absorbed. The long faint flares are probably produced by the direct accretion of large structures in the supergiant wind (similar to corotating interaction regions, [30]), with an estimated thickness of 10^{12} cm [29].

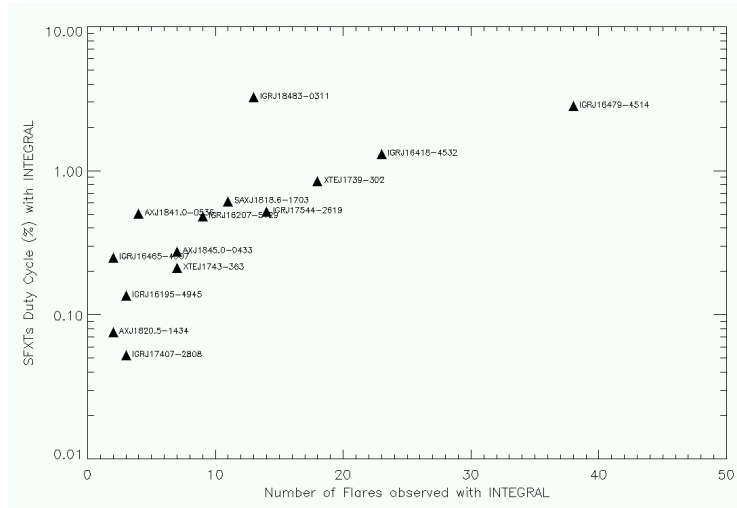


FIGURE 1. *INTEGRAL* results on SFXTs: duty cycles (percentage of time spent in bright flares with respect to the total observing time with *INTEGRAL* of the source position) calculated from data reported by [31]. The sources are both confirmed and candidate SFXTs observed during the survey of the central region of our Galaxy (see [31] for details).

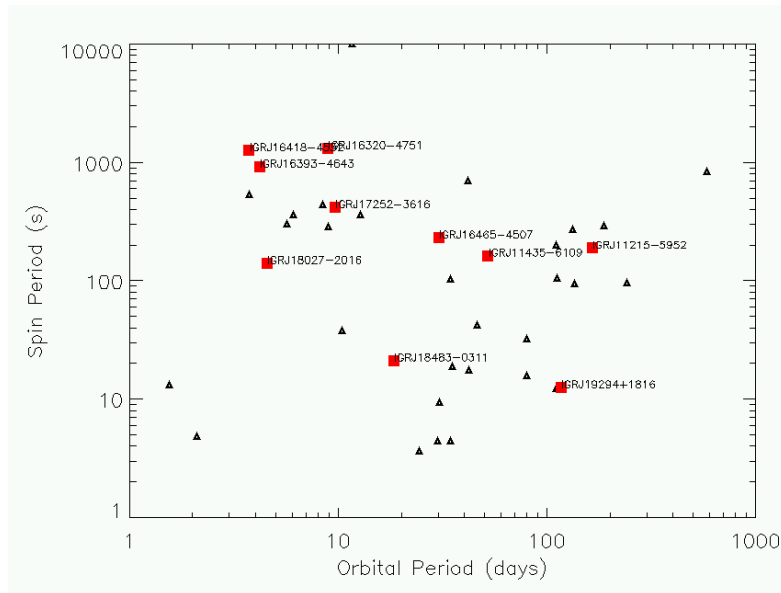


FIGURE 2. New Galactic X-ray binaries discovered by *INTEGRAL* (red squares and source names) in the Corbet diagram of spin period versus orbital period. The solid triangles indicate previously known Galactic HMXBs and Be/X-ray transients. Note that almost all the new Galactic IGRs reported here are HMXBs hosting supergiant companions, except IGR J16393-4643 (likely a Symbiotic system) and IGR J11435-6109 (Be star). The nature of the donor star in IGR J19294+1816 (main sequence Be or OB supergiant) is still unclear [32].

A monitoring with Swift/XRT of 4 members of the class, spanning about two years of observations (starting in October 2006, [33, 34]), demonstrated that the quiescence is a rare state for these transients. Indeed, most of their lifetime is spent in an intermediate state of emission in the range between 10^{33} and 10^{34} erg s $^{-1}$ (0.3–10 keV), with a hard spectrum (well described by a hard power law with photon index of $\sim 1-2$ or hot black body with temperature kT $\sim 1-2$ keV) and high level of flux variability. The spectral hardness and the highly variable X-ray intensity indicate that the sources are in accretion even outside the bright outbursts.

An important property is their spectral similarity with accreting X-ray pulsars: the broad-band spectrum (0.5–100

TABLE 1. List of Supergiant Fast X-ray Transients

Source	Orbital Period (d)	Spin Period (s)	References
IGRJ 08408–4503	35 (?)	-	P_{orb} : [40]
IGRJ 11215–5952	164.6	186.78 ± 0.3	P_{orb} : [35, 46]; P_{spin} : [47, 45]
IGRJ 16465–4507	30.243 ± 0.035	228 ± 6	P_{orb} : [48, 49]; P_{spin} : [50]
IGRJ 16479–4514	3.3194 ± 0.0010	-	P_{orb} : [51]
XTE J1739–302	51.47 ± 0.02	-	P_{orb} : [52]
IGRJ 17544–2619	4.926 ± 0.001	-	P_{orb} : [53]
SAXJ 1818.6–1703	30.0 ± 0.1	-	P_{orb} : [54, 55]
AX J1841.0–0536	-	4.7394 ± 0.0008	P_{spin} : [56]
IGR J18483–0311	18.55 ± 0.03	21.0526 ± 0.0005	P_{orb} : [57]; P_{spin} : [58]

keV) during bright flares is well fitted by an absorbed hard power law (photon index ~ 1) with a high energy cutoff at ~ 10 – 30 keV, or with Comptonized emission [35, 36, 37, 38, 39, 40]. The absorbing column density is often variable [41], indicating that it is local and close to the X-ray source.

The SFXTs outbursts last a few days ([42, 43, 44]), as demonstrated for the first time by an X-ray monitoring of an outburst of the SFXT IGRJ 11215–5952 in February 2007 ([42, 45]) and later confirmed during the *Swift*/XRT monitoring of other 4 SFXTs during their outbursts [41]. Each outburst is actually composed by an enhanced average X-ray emission together with several bright flares lasting a few hours ([42, 44]).

Source duty cycles are small, although highly variable from source to source: during the *Swift*/XRT monitoring, the time spent in bright outburst is 3%–5% in 3 SFXTs, [34], while with *INTEGRAL* it is much smaller (see Fig. 1). The figure has been obtained from data reported by [31] and includes both confirmed and candidate SFXTs after seven years of *INTEGRAL* operations.

A few SFXTs are X-ray pulsars (see Table 1 and Fig. 2), thus demonstrating that the compact object is a neutron star, while in the other sources a black hole cannot be excluded, although the spectral similarity to accreting pulsars is suggestive of a neutron star. The SFXTs spin periods are in the range from 4.7 s to 228 s. The orbital periods are also very different, between 3.3 days and 165 days (Table 1). Most of them have been determined from the modulation of the X-ray light curve, while in the case of IGRJ 11215–5952 [35] it has been derived from the periodically recurrent outbursts. The orbital period of ~ 35 days in IGRJ 08408–4503 (Table 1) has been suggested by [40] based on the duration of the flares, which is thought to be linked to the orbital separation, in the framework of the new wind accretion model of [59]. Thus, it needs to be confirmed by timing analysis.

Interestingly, a few of the newly discovered HMXBs hosting supergiants lie in the region typical of Be/X-ray transients (IGRJ 11215–5952, IGR J19294+1816, IGRJ 18483–0311) in the Corbet diagram (Fig. 2), probably suggesting a possible evolutionary link with these transients (see, e.g., [60] and Chaty 2010, these proceedings).

The mystery of SFXTs

SFXTs are massive binaries where the X-ray emission is thought to be produced by the direct accretion of the supergiant wind onto the compact object, although the possible formation of transient accretion disks have been suggested [31]. On the other hand, the wind accretion alone cannot explain a so different behavior in two sub-classes of HMXBs (SFXTs vs persistent HMXBs with supergiant donors) where the donor star, the compact object (neutron star), the orbital parameters seem to be very similar. SFXTs like IGRJ 16479–4514 [51] and IGRJ 17544–2619 [54, 55] are in narrow orbits, even narrower than several persistent HMXBs, thus ruling out the hypothesis of wide eccentric orbits [61] as the main property which makes the difference between these SFXTs and persistent HMXBs containing supergiants.

Different mechanisms have been proposed to explain SFXTs (see [62] for a review): accretion from clumpy winds, where the SFXTs flares are produced by the sudden accretion of a dense clump [26, 63] in a binary system with a wide and possibly eccentric orbit [61]; accretion from aspherical winds (with a preferential plane for the outflowing wind), where the flares are triggered by the neutron star passage inside this outflow [45]; centrifugal or magnetic barriers which halt the accretion onto the neutron star for most of the time [64, 65]. Each these mechanisms can hardly explain the behavior of *all* SFXTs, whose link with persistent HMXBs remain unclear. It is also possible that

different mechanisms are at work together in a single SFXT, or, alternatively, that SFXTs is a non-homogeneous class. Thus, despite the large amount of observational data, there are still several open issues that need to be addressed: the accretion mechanism, the link between different kinds of HMXBs, the SFXTs evolutionary path and formation history.

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