OBSCURED HMXB UNVEILED BY INTEGRAL AND XMM-NEWTON

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ABSTRACT

During the first year in operation, INTEGRAL, the European Space Agency's γ-ray observatory, detected more than 28 new bright sources which emit the bulk of their emission above 10 keV. Follow-up observations of a subset of these sources in the X-ray band with XMM-Newton indicate that 80% of them are very strongly absorbed. More than half of these absorbed sources show pulsations with long periods ranging from 139 to 1300s, i.e., they are slow X-ray pulsars. The infrared counterparts are not strongly absorbed demonstrating that the absorbing matter is local to the sources. Many of these new sources are super-giant high-mass X-ray binaries (HMXB) in which the stellar wind of the companion star is accreted onto the compact object. The large local absorption in these new sources can be understood if the compact objects are buried deep in dense stellar winds. These new objects represent half of the population of wind-fed supergiant HMXB.

1. INTRODUCTION

The second catalogue of soft γ-ray sources detected by INTEGRAL (Bird et al, 2005) lists 209 objects detected with high significance. In the Milky-Way it lists 104 accreting binaries, 4 supernova remnant, 4 pulsars, 2 molecular clouds. The accreting binaries include 78 neutron star systems (31 HMXB, 47 LMXB) plus 2 candidates, 4 black-hole systems plus 10 candidates and 7 cataclysmic variables. The catalogue also contains 55 unidentified sources discovered by INTEGRAL (counterparts/source types have now been proposed for about 20% of them). Many of them are of galactic origin and clustered within a few degrees of the galactic plane.

Here, we present the results of INTEGRAL, XMM-Newton and infrared observations of 9 newly-discovered sources. These were selected among the new sources detected by INTEGRAL in the galactic plane during the first year of the mission. We demonstrate that 8 out of the 9 sources are intrinsically absorbed and that 7 of them are persistent X-ray emitters. Many systems appear to have super-giant companions. Since the X-ray properties of the other unknown systems are similar, we propose that a significant number of the unknown sources are likely to be OB supergiant systems - doubling the number of such systems known in the Galaxy.

2. SOURCE SAMPLE AND COUNTERPARTS

Among the sources detected by INTEGRAL during the first six months of the mission, 6 sources were selected for follow-up observation with XMM-Newton. We added to this sample 4 sources (2 are transients) for which TOO observations had been obtained. Results could be found in Bodaghee et al, 2005; Hill et al, 2005; Walter et al, 2005 and Zurita et al, 2005.

In all cases, bright X-ray sources have been detected in the ISGRI error circles, with 2-10keV fluxes of the order of $1 - 10 \times 10^{-11}$erg/s cm^2. One of them, IGR J17597-2201, is probably a LMXB system and will not be discussed any further.

Searching the 2MASS catalogue for near infrared counterparts in the XMM error circles provided a single candidate in most cases. Despite a K magnitude between 7 and 13, the counterparts are affected by interstellar extinction and are almost not detected in optical surveys. The analysis of the photometry provided upper limits to the source reddening that are comparable with the reddening derived from the galactic Hydrogen column densities in the direction of the sources. The spectral type could however not be determined from the photometry.

3. VARIABILITY

The INTEGRAL lightcurves of all sources do show variations. Excepting IGR J16465-4507, that was detected only once for a week, and IGR J17544-2619, that was

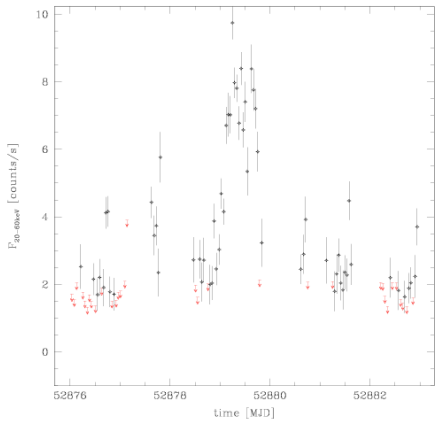


Figure 1. Short flare observed in IGR J17252-3616 by INTEGRAL.

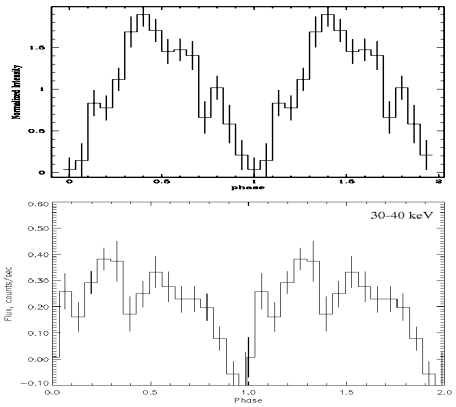


Figure 2. INTEGRAL orbital folded lightcurve of IGR J17252-3616 (top) and of IGR J18027-2016 (bottom).

detected flaring at three occasions separated by 165 ± 3 days, all sources could be detected in the different INTEGRAL visibility periods and could therefore be considered as persistent.

In all persistent sources, the X-ray fluxes detected by XMM-Newton matched the average hard X-ray fluxes accumulated by INTEGRAL over long time scales within a factor of two, excepting for IGR J16479-4514 for which the X-ray flux was found fainter by a factor of 20. As this source features strong flares (Sguera et al, 2005) XMM-Newton probably observed the source in quiessence.

Among the persistent sources, flaring activity has been observed on time scales of hours in six sources (IGR J16318-4848, IGR J16320-4751, IGR J16393-4641, IGR J16418-4532, IGR J16479-4514, IGR J17252-3616) with variability amplitude from 4 to 50. Such flares (figure 1 for an example) could be compared with the ones observed in fast transient (for a review see Negueruela, this volume) that typically varies by a factor of 100. In one persistent source, IGR J18027-2016 no flaring activity has been observed.

Long (139-1300s) pulse periods have been detected in all persistent sources excepting in IGR J16318-4848 (in which the pulse fraction cannot be higher than 10%) and in IGR J16479-4514 for which the XMM data were not of enough quality.

Estimates for the orbital period are available for two systems thanks to the detection of eclipses (figure 2):

- IGR J17252-3616: P_{spin}=413.85s; P_{orb} =9.741d; f(M)=15$M_\odot$; a$\times$sin(i) = 111 lt-s; eclipse duration = 1.26d; flares by factor of 50; $N_H = 2 - 10 \times 10^{23}\mathrm{cm}^{-2}$ (Zurita et al, 2005; Corbet et al, 2005)
- IGR J18027-2016: P_{spin}=139.612 s; P_{orb}=4.5696d; f(M)=16$M_\odot$; a$\times$sin(i) = 68 lt-s; eclipse duration = 0.9d; absence of large scale variability (Hill et al, 2005; Auguello et al, 2003).

Both sources appear to be located in the part of the super giant wind accretors of the Corbet diagram. The large mass functions derived from the X-ray data and the optical/infrared spectra, with few lines, confirmed the early type stellar companions. The wide and probably asymmetric eclipse profiles are similar to ones observed in Vela X-1 (Feldmeier, 1996).

The two eclipsing systems, the identification of the counterpart of IGR J16318-4848 with an sgB[e] star (Filliatre and Chaty, 2004) and the discovery of long spin periods in 3 persistent sources (that are therefore unlikely to be Be systems with short orbital period) suggest that all the persistent sources are supergiant HMXB systems and most of them wind-fed when they feature long spin periods.

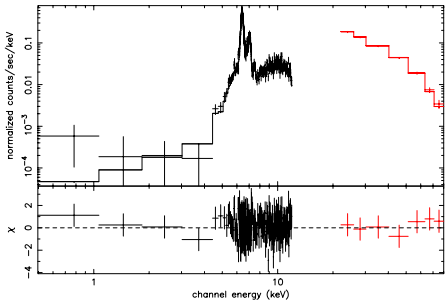
The two transient sources of our sample (IGR J16465-4507 and IGR J17544-2619) have also been identified with supergiant systems (Smith, 2004; Negueruela, this volume).

The fraction of eclipsing systems among the observed sources is consistent with short orbital periods around supergiant stars.

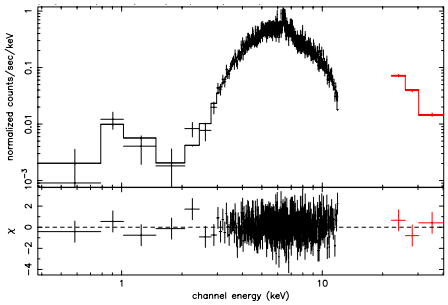
4. SPECTRAL ANALYSIS

The detection of new bright persistent hard X-ray sources has been a surprise as they have remained almost unnoticed in previous X-ray galactic surveys. This suggested highly absorbed sources, which has been confirmed by the source spectra, obtained with XMM-Newton, featuring absorbing column densities, ranging from 10^{23} to 2×10^{24} cm^{-2} (Walter et al, 2005 – see figure 3 for example spectra).

The weak detection of several sources at low energy by the X-ray monitor on board INTEGRAL or by ASCA/BeppoSAX indeed suggest that the absorption is persistent (Walter et al., 2004). So far this has been con-



(a) IGR J16318-4848



(b) IGR J16393-4641

Figure 3. ISGRI (>20 keV) and EPIC (<15 keV) source count spectra with best fit model predictions and residuals.

firmed in the few sources observed several times in the X-ray band (Rodriguez, 2005; Kuulkers, pers comm.).

The continuum emission of all sources could be fitted with an absorbed power-law featuring a high energy cut-off or by a comptonization model that are typical for accreting pulsars.

When the absorbing column densities are large enough, a soft X-ray excess below 1 keV could be detected in all cases excepting in IGR J16318-4848. In supergiant HMXB systems, such excesses are expected to originate from the photoionized sphere surrounding the neutron star.

The strong fluorescence lines, together with the continuum spectral shape, point towards a transmission geometry in which the compact sources are embedded within a dense envelope of cold matter. The strength of the Fe Kα lines, when compared to the unabsorbed continua are related to the absorbing column densities as expected for a spherical geometry (figure 4).

When detected well enough, the Fe Kα line energy provided a lower limit on the distance separating the X-ray source and the matter in which fluorescence takes place. Depending on the object, this lower limit is as large as the expected or measured orbital radii.

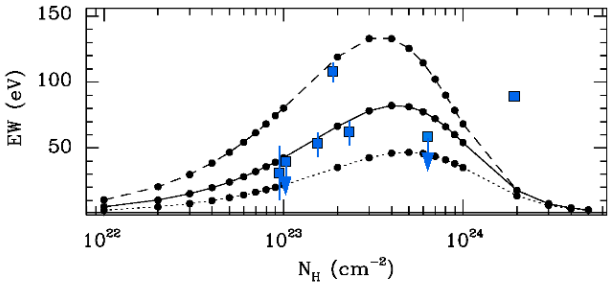


Figure 4. The observed Fe Kα equivalent width calculated with reference to the unabsorbed continuum (and corrected for the peculiar Iron abundances when needed) plotted against the absorbing column density (squares). The curves show the prediction of a spherical distribution of matter around the X-ray source for different Iron abundances (from Matt, 2002). The square at the extreme right is IGR J16318-4848.

5. IGR J16318-4848

IGR J16318-4848 features an excess of absorption along the line of sight when compared with the strength of the Fe Kα line (figure 4). This excess of absorption could explain the absence of a soft X-ray excess in that source if the excess of absorbing material is located at a distance larger than the orbital radius. This material could be the cold and dense equatorial wind that is often assumed to explain the numerous emission lines observed in B[e] stars. This scenario however requires that the thickness of that wind component is large as eclipses have not been observed in this system. An alternate possibility is that the accretion is Roche lobe dominated and that the excess absorption is related to an accretion disk.

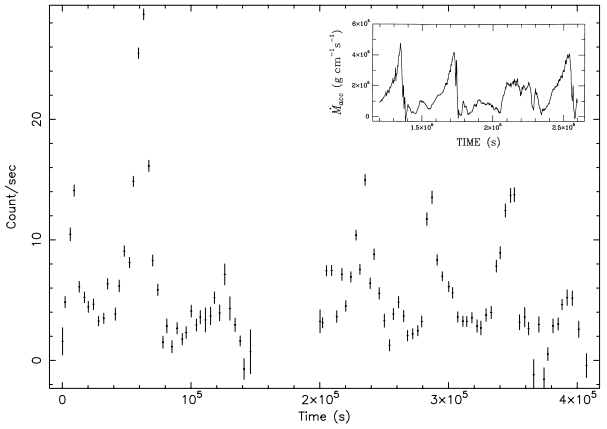


Figure 5. Flaring activity observed in IGR J16318-4848 by INTEGRAL (22-60keV ISGRI lightcurve). Inset: mass accretion rate variability driven by accretion wake oscillations (from Blondin et al, 1990).

As IGR J16318-4848 is the brightest of all the new persistent sources detected by INTEGRAL, its long term variability could be studied in more detail. The source shows constant variability on time scales of several hours. Dur-

ing peculiar periods it features sequences of flares with a characteristic time scale of 15-16 hours (figure 5), much too short to be an orbital period.

The observed sequences of flares do match very well the time-scale and variability amplitude predicted from accretion wake oscillations in the stellar wind of supergiant HMXB systems (Blondin et al, 1990). In that model the sign of the spin of the accreting flow changes regularly driving bursts of mass accretion (inset of figure 5). If this interpretation is correct, IGR J16318-4848 is a wind-fed system.

The possibility that accretion wakes or clumps in the stellar wind disruption zones around the compact sources are responsible for part of the flaring activity observed in the other sources and even possibly in the fast transient systems is worth considering.

6. GALACTIC DISTRIBUTION

INTEGRAL detected an overabundance of new HMXB candidates in the Norma arm tangent region (Walter, 2004). Figure 6 displays the distribution of all HMXB detected by INTEGRAL with galactic longitude, including the newly detected sources for which a strong indication for a high-mass system exists. The open histogram shows the same distribution including all unidentified sources that are within 2 degrees of the galactic plane. The two distributions are corrected for the effective exposure using a logN-logS slope of -0.7.

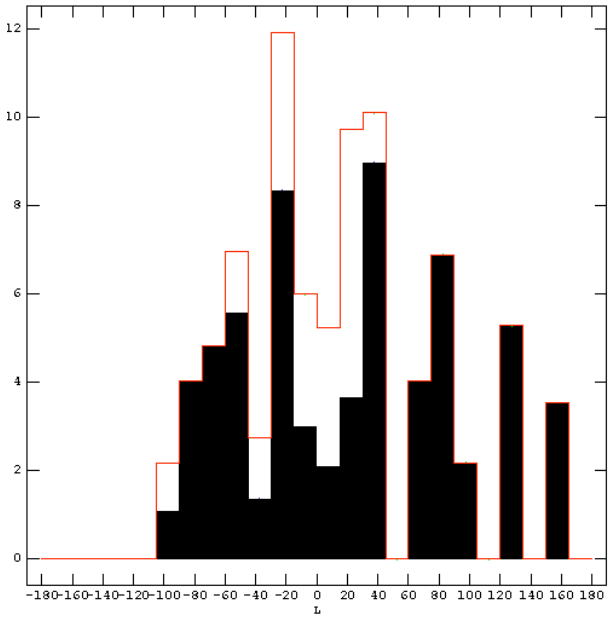


Figure 6. Distribution of HMXB (including candidates) detected by INTEGRAL. The open histogram includes all unidentified sources within 2 degrees from the galactic plane.

The galactic distribution of HMXB detected by INTEGRAL peaks within the inner arms of the galaxy and traces the region with the highest stellar formation rate of massive stars within the galaxy. This distribution is consistent with the identification of a good fraction of the unidentified INTEGRAL sources with HMXB systems.

7. CONCLUSIONS

A large fraction of the new obscured galactic sources detected by INTEGRAL share the properties of wind-fed supergiant HMXB. However the typical column densities that have been observed is of the order of 3×10^{23}cm^{-2} which is significantly higher than what is expected in usual wind fed supergiant system outside of eclipses (Blondin, 1994). As the orbital radii, when available, are not peculiarly small, this points towards low luminosity systems, buried in rather dense stellar winds.

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