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Chandra localisation and optical/NIR follow-up of Galactic X-ray sources

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ABSTRACT

We investigate a sample of eleven Galactic X-ray sources recently discovered with *INTEGRAL* or *RXTE* with the goal of identifying their optical and/or near-infrared (NIR) counterpart. For this purpose new *Chandra* positions of nine objects are presented together with follow-up observations of all the targets in the optical and NIR. For the four sources IGR J16194−2810, IGR J16479−4514, IGR J16500−3307 and IGR J19308+0530, the *Chandra* position confirms an existing association with an optical/NIR object, while for two sources (XTE J1716−389 and IGR J18490−0000) it rules out previously proposed counterparts indicating new ones. In the case of IGR J17597−220, a counterpart is selected out of the several possibilities proposed in the literature and we present the first association with an optical/NIR source for IGR J16293−4603 and XTE J1743−363. Moreover, optical/NIR observations are reported for XTE J1710−281 and IGR J17254−3257: we investigate the counterpart to the X-ray sources based on their XMM-*Newton* positions. We discuss the nature of each system considering its optical/NIR and X-ray properties.

Key words: X-rays: binaries - infrared: stars - binaries:symbiotic - binaries: eclipsing

1 INTRODUCTION

X-ray binaries (XRBs) are binary systems where a compact object, either a black hole (BH), a neutron star (NS) or a white dwarf (WD) accretes matter from a stellar companion (the donor or secondary star). In case the compact object is a WD, the XRB is called a cataclysmic variable (CV). In these systems, gravitational potential energy is extracted from the matter falling onto the compact object via the accretion process, producing the observed X-ray luminosity. XRBs represent a large fraction of X-ray sources in our Galaxy (see Psaltis 2006 for a review).

The majority of XRBs accreting onto a NS or BH can be grouped in two classes, defined by the mass of the secondary star: high mass X-ray binaries (HMXBs) and low mass X-ray binaries (LMXBs). In HMXBs the mass of the donor is $M_D \gtrsim 10\ M_\odot$; in LMXBs $M_D \lesssim 1\ M_\odot$. A few intermediate mass XRBs (IMXBs) are also known (see Charles & Coe (2003) for a review).

HMXBs are further divided into Be-XRBs and supergiant X-ray binaries (SXRBs). Be-XRBs are characterized by a Be-star companion and typically have eccentric orbits: the compact object accretes in major outbursts near the periastron, when it passes through the circumstellar disk of the Be-star. On the other hand, SXRBs host an early type O/B supergiant companion and are 'traditionally' found to be persistent X-ray sources. However, recent observations by the International Gamma-ray Astrophysics Laboratory (*INTEGRAL*) have revealed a class of fast X-ray transient sources spending most of their time at a quiescent level, that have sporadic outbursts lasting a few minutes to hours. The class was named "supergiant fast X-ray transients" after follow-up optical and near-infrared (NIR) spectroscopic observations of a number of systems revealed supergiant secondary stars (Negueruela et al. 2006). The physical origin of the fast X-ray outbursts is not yet understood (for different models see in't Zand 2005, Sidoli et al. 2007, Bozzo et al. 2008, Ducci et al. 2010). The *INTEGRAL* satellite also discovered a population of XRBs characterized by a large amount of absorption local to the source (Lutovinov et al. 2005) as the accreting compact object is immersed in the dense stellar wind of a massive companion star. The NIR

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Table 1. *Chandra* observations. Source counts and positions are given in the table. The positional uncertainty is 0.6 arcsec on all the positions (see Section 2).

Source	Date	Instrument	Exposure time (s)	Counts	RA(J2000)	Dec.(J2000)	WAVDETECT error on RA, Dec.(arcsec)
IGR J16194−2810	2008 Jan. 18	*HRC-I*	1129	1075	$16^h19^m33\overset{s}{.}30$	$-28°07'40\overset{''}{.}30$	0.018, 0.014
IGR J16293−4603	2008 Jan. 24	*ACIS-I*	1135	237	$16^h29^m12\overset{s}{.}86$	$-46°02'50\overset{''}{.}94$	0.072, 0.068
IGR J16479−4514	2007 Oct. 24	*HRC-I*	1174	44	$16^h48^m06\overset{s}{.}58$	$-45°12'06\overset{''}{.}74$	0.061, 0.061
IGR J16500−3307	2007 Sep. 29	*HRC-I*	1150	198	$16^h49^m55\overset{s}{.}65$	$-33°07'02\overset{''}{.}28$	0.032, 0.029
XTE J1716−389	2008 Sep. 23	*ACIS-I*	1141	12	$17^h15^m56\overset{s}{.}42$	$-38°51'54\overset{''}{.}13$	0.227, 0.256
XTE J1743−363	2009 Feb. 08	*HRC-I*	1172	11	$17^h43^m01\overset{s}{.}31$	$-36°22'22\overset{''}{.}00$	0.14, 0.043
IGR J17597−220	2007 Oct. 23	*HRC-I*	1180	227	$17^h59^m45\overset{s}{.}52$	$-22°01'39\overset{''}{.}17$	0.022, 0.022
IGR J18490−0000	2008 Feb. 16	*HRC-I*	1174	22	$18^h49^m01\overset{s}{.}59$	$-00°01'17\overset{''}{.}73$	0.0432, 0.061
IGR J19308+0530	2007 Jul. 30	*HRC-I*	1129	26	$19^h30^m50\overset{s}{.}77$	$+05°30'58\overset{''}{.}09$	0.061, 0.072

Table 2. Known X-ray positions

Source	RA(J2000)	Dec.(J2000)	Uncertainty (1σ)	Instrument
XTE J1710−281	$17^h10^m13\overset{s}{.}$	$-28°07'51\overset{''}{.}$	$1''$	XMM-*Newton* [a]
IGR J17254−3257	$17^h25^m25\overset{s}{.}$	$-32°57'15\overset{''}{.}$	$2''$	XMM-*Newton* [b]

[a] Watson et al. 2008. [b] Chenevez et al. 2007.

counterparts identified for a number of sources are all consistent with supergiant stars. It has been suggested that all the obscured HMXBs are hosting supergiant companions (Walter et al. 2006).

LMXBs are traditionally divided into NS and BH binaries. Surface phenomena occurring on the accreting object, like thermonuclear X-ray bursts or the detection of a pulsating signal are evidence for the presence of a NS. Nevertheless, in the absence of such phenomena no definitive conclusion can be drawn about the nature of the compact object from X-ray observations alone (see Psaltis 2006 for a review). Dynamical constraints on the mass of the compact object are required in order to confidently distinguish a NS from a BH. These can be obtained via orbital phase-resolved spectroscopy of the optical or NIR counterpart to the X-ray source (van Paradijs & McClintock 1995a).

Two sub-classes of LMXBs also exist that are characterised by peculiar companion stars: ultra compact X-ray binaries (UCXBs) and symbiotic X-ray binaries (SyXBs). The signature of UCXBs is an orbital period of ~ 1 hour or less. This implies that the orbital separation is very small and the donor must be hydrogen poor to fit in its Roche lobe (in't Zand et al. 2007). SyXBs are defined by the presence of an M-type giant companion. Those systems are rare, as the giant phase does not last long, and are characterised by a lack of accretion signatures in the optical spectra, since the accretion disk is out-shined by the companion star unless the X-ray luminosity is particularly high (Masetti et al. 2007 and references therein).

Since the classification is based on the mass of the companion and/or of the compact object, the identification of counterparts of XRBs in optical or NIR is important. In this article we present a search for the optical/NIR counterpart of a sample of 11 Galactic sources, recently discovered with *INTEGRAL* or with the Rossi X-ray Timing Explorer (*RXTE*). A classification has been proposed in the literature for all but one of the sources (IGR J16293-4603) on the basis of the X-ray behaviour alone or the spectrum of an optical/NIR candidate counterpart. Nevertheless, none of the proposed counterpart identifications are conclusive due to the lack of an accurate X-ray position. For the 9 sources listed in Table 1 we obtained *Chandra* observations, with the main goal of determining an accurate X-ray position. Thanks to the high spatial resolution of *Chandra* we could verify previously proposed candidate counterparts and investigate sources for which no counterpart was known. For the two sources listed in Table 2 we do not have *Chandra* data. We have searched for their optical/NIR counterparts referring to previous XMM-*Newton* observations.

This paper is structured as follows: sections 2 and 3 present the observations and the data reduction procedures. In section 4 we provide a short introduction for each source followed by the results from our analysis. All the coordinates reported in the text and tables are referred to epoch J2000.

2 X-RAY DATA: REDUCTION AND ANALYSIS

We observed the sources in Table 1 with *Chandra*, using the High Resolution Camera (*HRC-I*) and the Advanced CCD Imaging Spectrometer (*ACIS-I*). We have reprocessed and analysed the data using the CIAO 4.0.1 software developed by the *Chandra* X-ray Centre. All data have been used in our analysis, as background flaring is very weak or absent. We localized X-ray sources on each observation with the tool WAVDETECT from the total energy range of *HRC-I* and *ACIS-I*. The uncertainty on the localisation on the image as given by WAVDETECT (Table 1) is negligible with respect to the *Chandra* boresight uncertainty of 0.6 arcsec (90 per cent confidence, slightly dependent on the instrument[1]) for all the sources but the weakest, XTE J1716−389 and XTE

[1] http://cxc.harvard.edu/cal/ASPECT/celmon/

J1743−363. Although the centroiding uncertainty for those targets is of the same order of magnitude as the boresight uncertainty, the latter still dominates the overall X-ray positional accuracy. Therefore we adopt a 90 per cent confidence uncertainty of 0.6 arcsec on the X-ray position of all the sources. We extracted the source counts in a 40-pixel radius around the position from WAVDETECT using the tool DMEXTRACT. We estimated the background in an annulus centered on the WAVDETECT position, with an inner and outer radius of 70 and 200 pixels. We considered all the counts from *HRC*, while we select the counts in the 0.3 − 7 keV energy band for *ACIS* observations. The net, background subtracted counts for each source are given in Table 1.

3 OPTICAL AND NIR DATA: REDUCTION AND ANALYSIS

We performed optical and/or NIR imaging of the field of each X-ray source in our sample from various Chilean sites, with the following instruments:

- the ESO Multi Mode Instrument (*EMMI*) at the 3.5 m New Technology Telescope on La Silla
- the Low Dispersion Survey Spectrograph (*LDSS3*), the Persson's Auxiliary Nasmyth Infrared Camera (*PANIC*) and the Inamori Magellan Areal Camera and Spectrograph (*IMACS*) at the 6.5 m Magellan telescopes Clay and Baade on Las Campanas
- the *MOSAIC II* imager at the 4 m Blanco telescope on Cerro Tololo.

Table 3 reports the pixel scale and the field of view (FOV) of each instrument, together with the binning we employed. A journal of the observations is presented in Table 4. All optical observations include a short (10-15 s) exposure image for the astrometry, where bright stars do not saturate, and several deeper exposures to observe faint objects. We observed four of the sources in the K_s band using the PANIC camera. The observations consisted of five point dither patterns with a 5s or 15s exposure repeated three times at each offset position. Table 4 gives the total time expended on source.

Optical images have been reduced for photometry with standard routines running within MIDAS or IRAF, corrected for the bias and flat-fielded. The *PANIC* NIR data were reduced through the *PANIC* software: the raw frames were first dark subtracted and flat-fielded. Normalized flat-fields were made by combining twilight flat field frames scaled by their mode. Next, a sky image was built by masking out stars from each set of dithered frames and was subtracted from the set of target frames. Finally, a mosaic image was built by combining and averaging the sky-subtracted images.

The DAOPHOT II package (Stetson 1987), running inside MIDAS, was used to determine instrumental magnitudes through a Point Spread Function (PSF) fitting technique. The aperture correction was measured from aperture photometry on bright and isolated stars. Unless we detect the counterpart to an X-ray source only on deep images, we preferably perform photometry on the short-exposure astrometric images, which have the advantage of being less crowded than deeper ones.

The last column in Table 4 lists the fields employed for photometric calibration. The *PANIC* K_s-band images have been calibrated with respect to K band magnitudes of 2MASS stars in the field. An accurate calibration for the LDSS3 observations of XTE J1716−389 and IGR J17597−220 is not possible since the observing night was not photometric. Nevertheless we provide indicative magnitudes by calibrating the images with the zero point from a previous *LDSS3* observing run in November 2007, correcting for the different air mass.

For the astrometry, we compared the position of the stars against entries from the second USNO CCD Astrograph Catalogue (UCAC2, Zacharias et al. 2004) or from the Two Micron All Sky Survey (2MASS). The positional accuracy of UCAC2 varies between 0.02 arcsec (for stars with magnitude $R < 14$) and 0.07 arcsec ($14 < R < 16$); that of 2MASS is ∼0.1 arcsec (for stars with magnitude $K < 14$). UCAC2 positions were preferably adopted, unless less than 5 stars from that catalogue overlap with stars in the field. In this case we compared with the more rich but less precise 2MASS catalogue. An astrometric solution was computed by fitting for the reference point position, the scale and the position angle, considering all the stars that are not saturated and appear stellar and unblended. We obtain solutions with root-mean-square (rms) residuals ranging from 0.05 to 0.1 arcsec when 2MASS is used, and from 0.05 to 0.07 arcsec in case UCAC2 is used. The uncertainty on the position of a star due to centroiding is negligible with respect to that of the astrometry. Once astrometrically calibrated, short-exposure images have been adopted as secondary catalogues for the calibration of the longer-exposure images (see Table 4), obtaining rms residuals negligible with respect to those of the 'primary' solution against the standard catalogues. We adopted as the accuracy on our stellar positions the quadratic sum of the residuals of the 'primary' astrometry and the accuracy of the catalogue employed (although the latter could be a systematic error) : the resulting positional accuracy is ranging from 0.07 to 0.13 arcsec (1σ) on both right ascension (RA) and declination (Dec.). In order to identify the optical/NIR counterpart of the X-ray sources in our sample, we plotted the 90 per cent confidence error circle around *Chandra* or XMM-*Newton* positions on optical/NIR charts, taking into account the positional error due to our astrometry. For all the *Chandra* targets we searched for a counterpart inside an overall 90 per cent confidence radius of ∼0.7 arcsec, resulting from the combination of the 0.6 arcsec accuracy of *Chandra* positions with the accuracy of our astrometry. The contribution of the astrometric error to the XMM-*Newton* positional error (see Table 2) is negligible.

When the candidate counterpart is not saturated, we compute the probability that it falls inside the *Chandra* error circle by chance as the number of stars of brightness equal to or larger than that of the counterpart (considering the error on the photometry), divided by the area of the field and multiplied by the area covered by the *Chandra* error circle. For stars that saturate even in a 10-15 seconds image we do not compute a probability, since their magnitude cannot be reliably determined.

Table 3. Properties of the instruments employed for optical/NIR observations.

Instrument	Pixel scale (arcsec)	Binning	Field of view (arcmin)
EMMI	0.166	2×2	9.1×9.9
IMACS	0.111	2×2	15.4×15.4
LDSS3	0.189	1×1	Diameter=8.3
MOSAIC	0.27	1×1	36×36
PANIC	0.127	1×1	2×2

Table 4. Journal of the optical/NIR observations.

Source	Date	Instrument(s)	Filter(s)	Exposures	Seeing (arcsec)	Photometric calibration
IGR J16194−2810	2006 Jun. 24	*MOSAIC II*	*r'*	1×10s +5×300s	1.6	PG1323-086
	2006 Aug. 03	*PANIC*	K_s	1×75s	0.5	2MASS
IGR J16293−4603	2008 Jun. 24	*LDSS3*	*g', r', i'*	3×180s (*r'*)+1×180s (*g'*,*i'*)	1.1	SDSS(1)(s82)
IGR J16479−4514	2006 Jun. 24	*MOSAIC II*	*i'*	1×10s +5×300s	1.6	PG1323-086
IGR J16500−3307	2006 Jun. 24	*MOSAIC II*	*r'*	1×10s +5×300s	1.6	PG1323-086
	2006 Aug. 03	*PANIC*	K_s	1×75s	0.7	2MASS
XTE J1710−281	2005 May 07	*IMACS*	*I*	2×10s +2×300s	0.9	Landolt109-954
XTE J1716−389	2009 May 07	*LDSS3*	*i'*	2×10s+4×300s	0.75	non-photometric(2)
IGR J17254−3257	2006 Aug. 03	*PANIC*	K_s	1×75s	0.8	2MASS
XTE J1743−363	2007 Jun. 22	*EMMI*	*I*	1×30s +1×600s	1.7	non-photometric
IGR J17597−220	2009 May. 07	*LDSS3*	*i'*	2×10s +4×300s	0.75	non-photometric(2)
	2007 Jun. 22	*EMMI*	*I*	1×20s +2×600s	1.7	non-photometric
IGR J18490−0000	2006 Jun. 25	*MOSAIC II*	*i'*	1×10s +5×300s	1.1	PG1323-086
	2009 Jul. 16	*PANIC*	K_s	1×450s	0.8	2MASS
IGR J19308+0530	2006 Jun. 22	*MOSAIC II*	*r'*	1×10s +5×300s	1.1	PG1323-086

(1) SDSS=Sloan Digital Sky Survey (2) see text (Section 3)

4 INDIVIDUAL SOURCES

4.1 IGR J16194-2810: a SyXB

IGR J16194−2810 was discovered by *INTEGRAL/IBIS* (Bird et al. 2006; Bassani et al. 2006) and soon identified as the ROSAT object 1RXS J161933.0-280736 (Stephen et al. 2006). Based on its *Swift/XRT* and *ROSAT* position, Masetti et al. (2007) associated the source with the bright object USNO-A2.0 U0600_20227091. The optical spectrum presented by the authors indicates an M2 III star, thus IGR J16194−2810 was classified as a SyXB (Masetti et al. 2007).

We observed the field with *Chandra/HRC-I* for ∼ 1.1 ks on 2008 Jan. 18, detecting a single, bright source (1075 counts) inside the *ROSAT* and *Swift* error circles at RA= $16^{\rm h}\ 19^{\rm m}\ 33\overset{\rm s}{.}42$, Dec.= $-28^\circ\ 07'\ 40\overset{''}{.}3$.

NIR and optical images, collected with *Magellan/PANIC* in K_s band on 2006 Aug. 3 and with *Blanco/MOSAIC II* in *r'* band on 2006 Jun. 24, reveal a bright source overlapping with the *Chandra* error circle. The source is not saturated only in the 10s-long exposure with *MOSAIC II* shown in Figure 4. It falls on the border of the 90 per cent *Chandra* error circle, at RA= $16^{\rm h}\ 19^{\rm m}\ 33\overset{\rm s}{.}346$, Dec.= $-28^\circ\ 07'\ 39\overset{''}{.}92$ (±0.08 arcsec on both coordinates). Comparing our finding charts with those in Masetti et al. (2007) we identify this object with the candidate counterpart proposed by the authors. The position reported in the USNO-A2.0 catalogue from observations performed in 1979 is in agreement with our measurements if the strong proper motion of the source is taken into account ($1.3\ \pm\ 4.7$ mars yr^{-1} in RA and $-20.2\ \pm\ 4.7$ mars yr^{-1} in Dec., from UCAC2). The magnitudes of the object from USNO-A2.0 in the R and B bands is $R = 11$ and $B = 13.2$. We found the source also in UCAC2 and in 2MASS, where the following magnitude are reported: $J = 8.268\ \pm\ 0.029$, $H = 7.333\ \pm\ 0.044$ and $K = 6.984\ \pm 0.016$. We measure an apparent magnitude $r' = 10.98\ \pm\ 0.04$ in *r'* band. The probability that such a bright star falls by chance in the Chandra error-circle is $\sim 2 \times 10^{-7}$. Based on its position and proper motion we confirm the red giant USNO-A2.0 U0600_20227091/2MASS 16193334-2807397 (first proposed by Masetti et al. 2007) as the optical and NIR counterpart to IGR J16194−2810 and the classification of the source as a SyXB.

We investigated the high proper motion of the source by calculating its peculiar velocity, i.e. the velocity with respect to the local standard of rest. The distance d can be estimated by comparing the apparent magnitude we measure in the *r'* band with the typical R-band absolute magnitude of an M2 III star ($M_R \sim -2$, Cox 2000), accounting for extinction. We obtain the extinction coefficient in the R band from that in the V band following the optical extinction laws in Cardelli et al. (1989). The standard value of the extinction-law parameter R_V for the diffuse interstellar medium is assumed ($R_V = 3.1$). We derived A_V from the hydrogen column density N_H in accordance with Güver & Özel (2009). With $N_H = (0.16 \pm 0.08) \times 10^{22}$ cm^{-2} from Masetti et al. (2007), the distance is $d = 3.0 \pm 0.2$ kpc, in agreement with the upper limit estimated by those au-

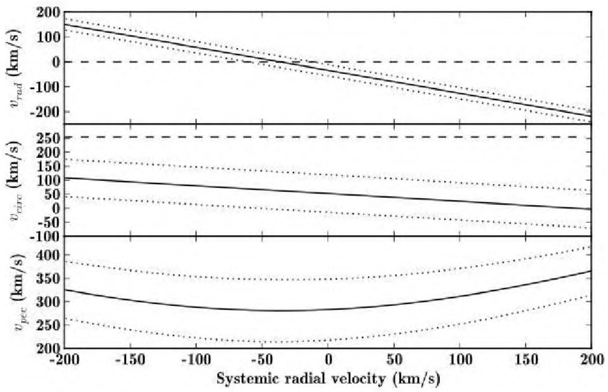

Figure 1. From top to bottom, modelled Galactocentric radial velocity and circular velocity and peculiar velocity of IGR J16194−2810 against systemic radial velocity: the solid line in each case shows the best fitting values while the dotted lines show the uncertainty. The dashed lines show the expected values for Galactocentric radial and circular velocities for an object participating in the Galactic rotation. The minimum peculiar velocity is 280±66 km s^{-1}, corresponding to a systemic radial velocity of −35 km s^{-1}.

thors. While the systemic radial velocity, γ, is unknown, we can use the measured proper motion and source distance to derive the three-dimensional space velocity components as a function of γ. Using the transformations of Johnson & Soderblom (1987) and the standard solar motion of Dehnen & Binney (1998) we derive the space velocity components and compare with those predicted by the Galactic rotation parameters of Reid et al. (2009) (but note McMillan & Binney 2009), obtaining the peculiar velocity as a function of γ (Figure 1) under the asumption that the object participates in the Galactic rotation. We find a minimum peculiar velocity of 280±66 km s^{-1}, at $\gamma = -35$ km s^{-1}. This limit on the peculiar velocity is high, indicating that either the binary is a halo object or that it has received a kick. The latter possibility is more natural in the case of a NS/BH accretor.

4.2 IGR J16293-4603: a new LMXB (possibly SyXB)

The source IGR J16293−4603 was discovered in 2008 combining *INTEGRAL IBIS/ISGRI* data collected over the period from 2003 Mar. 2 to 2006 Feb. 24. The discovery is reported in Kuiper et al. (2008), together with a *Chandra* localisation and preliminary results regarding the optical counterpart of the source: in this paper we report the conclusive results of that analysis.

We observed the field of IGR J16293−4603 with *Chandra/ACIS-I* for $\sim$ 1.1 ks on 2008 Jan. 24, detecting a single source (237 counts) inside the *IBIS/ISGRI* error circle, at RA= 16^h 29^m $12\overset{s}{.}86$, Dec.= -28° $02'$ $50\overset{''}{.}94$.

Optical images have been acquired with *Magellan/LDSS3* on 2008 Jun. 24 in the *g', r'* and *i'* bands. An object is visible in all the observed bands inside the 90 per cent *Chandra* error circle (see Figure 5) at RA= 16^h 29^m $12\overset{s}{.}885$, Dec.= -46° $02'$ $50\overset{''}{.}55$ (± 0.1 arcsec on both coordinates). After absolute photometric calibration, we measure the following magnitudes: $g' = 23.35 \pm 0.07$, $r' = 20.67 \pm 0.04$ and $i' = 19.12 \pm 0.07$. In order to constrain the intrinsic colour index $(r' - i')_0$ for the counterpart to IGR J16293−4603, we derived the extinction coefficients in the *g', r'* and *i'* bands as we did for IGR J16194−2810, obtaining the extinction coefficient in the *V* band, A_V from the hydrogen column density N_H. With $N_H = (0.7 \pm 0.5) \times 10^{22}$ cm^{-2}, as measured in Kuiper et al. (2008) from the fitting of *Chandra-ACIS* spectra in the 0.3-7 keV range, we obtain $A_V = 3 \pm 2$ and $(r' - i')_0 = 0.9 \pm 0.4$. If the counterpart we observe has no flux contribution from an accretion disk, this colour index indicates a main sequence star of K or early M spectral type or a giant (Cox 2000). If we are observing a combination of the optical light emitted by the disc and by the companion star, the latter is even redder than $(r' - i')_0 = 0.9 \pm 0.4$, since the disk is bluer than a K-type star (van Paradijs & McClintock 1995b). Therefore, IGR J16293−4603 is most likely not a HMXB. Single stars have been observed in hard X-rays only during flares (Osten et al. 2007): the fact that IGR J16293−4603 was discovered by combining multiple *INTEGRAL* observations suggests that the X-rays are not due to a single active star. Thus, IGR J16293−4603 is most likely an LMXB or a CV. Moreover, Figure 2 shows the colour-magnitude diagram of the source field, where the apparent magnitude of the stars in *g'* band is plotted versus the $(r' - i')$ colour index: the counterpart to IGR J16293−4603 lies on the Giant Branch of the diagram, suggesting the system has a giant companion. For $N_H \sim 0.7 \times 10^{22}$, the source has the $(r' - i')_0$ of a K5-M0 giant. This value of N_H is in the middle of the range allowed by *Chandra* measurements and corresponds to the Galactic value from Dickey & Lockman (1990). For extreme values of the N_H within the error of *INTEGRAL* measurements, the companion could also be a G5-M2 giant (N_H respectively lower or higher than the Galactic value). The typical absolute magnitude in R band of an M2 giant is $M_R \sim -1.94$; that of a G5 is $M_R \sim 0.2$ (Cox 2000). Comparing these values with the magnitude we observe in the *r'*-band and assuming the appropriate column density in the two cases, we can estimate the distance d to the source: $d \sim 28$ kpc if the donor is an *M2-III* type and $d \sim 45$ kpc if the donor is a *G5-III* type. The X-ray flux from our *Chandra* observations is 4×10^{-12} erg s^{-1} cm^{-2} in the band 0.3-7 keV, assuming a simple power-law spectrum with photon index γ =1.0 (Kuiper et al. 2008). This results in a luminosity of $\sim 4 \times 10^{35}$ erg s^{-1} at 28 kpc and $\sim 2 \times 10^{36}$ erg s^{-1} at 45 kpc. Intermediate luminosities and distances are obtained for a K-type companion. All the possibilities lead to an X-ray source that is too bright for a CV, but consistent with an LMXB (although in the case of a G secondary star the source would be located very far in the halo). We conclude that IGR J16293−4603 is an LMXB, probably with a giant companion of spectral type K, M or, less likely, a G. Since the donor can also be an M-type giant, we also indicate IGR J16293−4603 as a candidate SyXB.

4.3 IGR J16479-4514: an eclipsing SFXT

IGR J16479−4514 was discovered with the *IBIS/ISGRI* detector on board the *INTEGRAL* observatory on 2003 Aug. 8-9 (Molkov et al. 2003) and observed several times by the same satellite during the following years (Sguera et al. 2005; Markwardt & Krimm 2006). It

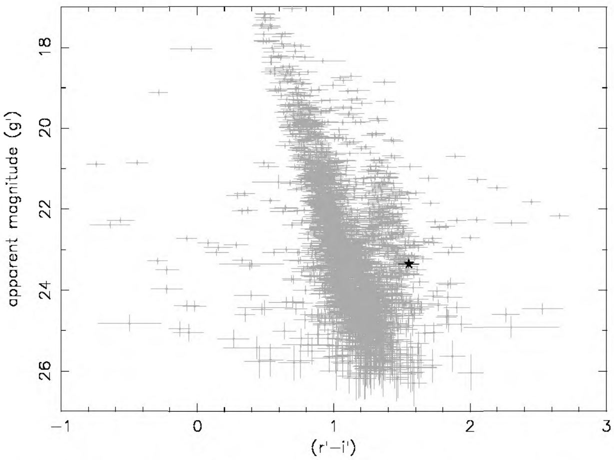

Figure 2. Colour-magnitude diagram of the field of IGR J16293−4603, observed with LDSS3. The apparent magnitude of the stars in *g'* band is plotted versus the $(r' - i')$ colour index. The counterpart to IGR J16293−4603 is indicated by the black star.

has been regularly monitored with *Swift* from October 2007 to October 2008 (Sguera et al. 2008; Romano et al. 2008 and Romano et al. 2009) and observed with XMM-*Newton* in 2008 (Bozzo et al. 2008). The X-ray behaviour of the source is typical of SFXTs, characterized by short outbursts that have been observed with both *INTEGRAL* and *Swift* (Kennea et al. 2005; Sguera et al. 2006; Walter & Zurita Heras 2007; Sidoli et al. 2009). Evidence of possible X-ray eclipses is presented in Bozzo et al. (2008) on the basis of XMM-*Newton* observations and has been recently confirmed by Romano et al. (2009) from the analysis of *Swift/BAT* data. The orbital period obtained from the eclipses is $\sim$ 3.3 days, short compared to other SFXTs. Moreover, the luminosity of IGR J16479−4514 is $\sim 10^{34}$ erg s^{-1} in quiescence. This is the typical luminosity of the fainter persistent SXRBs and two orders of magnitude higher than typical for SFXTs. This suggests that IGR J16479−4514 is persistently accreting at a low level, in agreement with its short orbital period. Due to its quiescent luminosity level, compatible with 'canonical' SXRBs, combined with the short outbursts typical of SFXTs, IGR J16479−4514 has been proposed as the missing link between the two classes (i.e. Jain et al. 2009).

The 2MASS star J16480656-4512068 has been proposed as a possible counterpart to IGR J16479−4514 by Kennea et al. (2005) and Walter et al. (2006). NIR spectra of that object are presented in Chaty et al. (2008) and Nespoli et al. (2008), indicating an O/B supergiant. This is supported by the SED in Rahoui et al. (2008). In particular, Nespoli et al. (2008) classify the source as a spectral type O9.5 Iab. A second, fainter candidate counterpart is also indicated in Chaty et al. (2008) in K band, inside the 4 arcsec XMM-*Newton* error circle.

In order to select the actual counterpart to IGR J16479−4514, we observed the field with *Chandra/HRC-I* for $\sim$ 1.2 ks on 2007 Oct. 24. A single source (44 counts) is detected in the XMM-*Newton* error circle, at coordinates RA= $16^{\rm h}\ 48^{\rm m}\ 06\overset{\rm s}{.}6$, Dec.= $-45^\circ\ 12'\ 06\overset{''}{.}7$

Follow-up observations, performed with *Blanco/MOSAIC II* in the *i'* band on 2006 June 24, revealed no candidate counterpart inside the *Chandra* 90 per cent confidence error circle , down to a limiting magnitude of $i' \sim 23$. We detect the object labelled *2* in Chaty et al. (2008) at RA= $16^{\rm h}\ 48^{\rm m}\ 06\overset{\rm s}{.}56$, Dec.= $-45^\circ\ 12'\ 08\overset{''}{.}1$ ($\pm$ 0.1 arcsec on both coordinates) inside the XMM-*Newton* error circle but outside the *Chandra* one (see Figure 6). We can exclude that source as a counterpart to IGR J16479-4514. We do not detect the candidate counterpart labeled *1* in Chaty et al. (2008) in *i'* band, but this is not surprising on the basis of its NIR spectrum. In order to verify its association with IGR J16479−4514 we compared its coordinates from 2MASS with our *Chandra* position, finding a separation of 0.2 arcsec ($< 1\sigma$). Based on its position, we confirm the object 2MASS J16480656-4512068 (indicated in Kennea et al. 2005) as the counterpart of the hard X-ray source IGR J16479−4514. The magnitudes from 2MASS are $J = 12.95 \pm 0.03$, $H = 10.825 \pm 0.02$, $K = 9.80 \pm 0.02$.

Figure 3 shows a comparison between the intrinsic NIR colours $(J-H)_0$ and $(H-K)_0$ of the counterpart to IGR J16479−4514 and the same colours for typical stars of luminosity class I, III and V and spectral type from O9 to M7 (from Tokunaga 2000). The intrinsic NIR colours for the counterpart are obtained from the 2MASS magnitudes for different values of A_V. The comparison is constructed as follows: we assume $(H-K)_0$ as for the tabulated spectral types and calculate the A_V that is required to obtain such an intrinsic colour from the observed $(H-K)$ (A_V related to A_J, A_H and A_K as for IGR J16194−2810, with the typical central wavelength of 2MASS filters from Skrutskie et al. 2006). With this A_V, $(J-H)_0$ is derived from the observed $(J-H)$. We accounted for the difference in the photometric system employed by Tokunaga (2000) and the 2MASS J,H,K[2]. Interestingly, the possible combinations of $(J-H)_0$ and $(H-K)_0$ obtained for IGR J16479−4514 seem not to agree with the spectral classification as a O9.5 Iab. The NIR colours point instead toward a late type red giant, or a spectral type not included in the comparison such as a supergiant earlier than O9. The comparison method has been tested by obtaining the NIR colours for objects with a known spectral type: we tested all the sources classified in Nespoli et al. (2008) (IGR J16465-4507, AX J1841.0-0536, 4U 1907+09, IGR J19140+0951), with IGRJ 17544-2619 and XTEJ17391-3021 (Negueruela et al. 2006), IGRJ16207-5129 (Negueruela & Schurch 2007), HD 306414 (Negueruela et al. 2005) and with the sources IGR J16194−2810 and IGR J19308+0530 included in this paper (see section 4.1 and 4.11). The agreement is good for all the systems but the O8 Ia type XTEJ17391-3021, which is offset by $\sim$ 0.1 mag from to the closest spectral type in our reference table, an O9 I object. The test source 4U 1907+09 has the same spectral type (O9.5 Iab) as IGR J16479−4514 and indeed its NIR colours are fully consistent with the spectral classification, while those of IGR J16479−4514 are not. This discrepancy is difficult to explain. There is no indication that the 2MASS photometry is subject to additional uncertainties and it seems unlikely that the spectra are compatible with that of a late-type giant. We conclude that the coun-

[2] following the transformations at http://www.astro.caltech.edu/~jmc/2mass/v3/transformations/

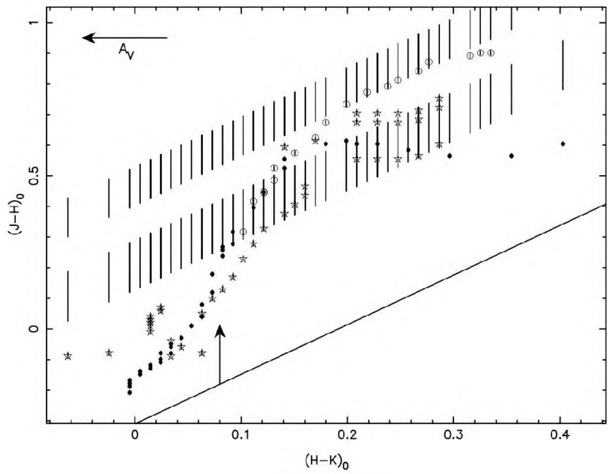

Figure 3. Possible $(J-H)_0$, $(H-K)_0$ combinations allowed by the 2MASS J, H and K magnitudes of the sources IGR J16479−4514 (top hatched area), XTE J1716−389 (lower limit to $(J-H)_0$ indicated by the solid line and arrow) and XTE J1743−363 (bottom hatched area), for different values of the absorption (A_V increasing from right to left). For comparison, the symbols indicate the couples $(J-H)_0$, $(H-K)_0$ for stars of different spectral type (O9 to M7) and luminosity class (I,III and V) (from Tokunaga 2000): dots represent main sequence stars, empty circles are red giants and stars are supergiants.

terpart to IGR J16479−4514 is peculiar in the NIR region of the spectrum.

4.4 IGR J16500-3307: an Intermediate Polar

IGR J16500−3307 was discovered by *INTEGRAL* (Bird et al. 2006) and has been associated with the *ROSAT* bright object 1 RXS J164955-330713 (Voges et al. 1999). It has been also observed by *Swift* (Masetti et al. 2008).

The USNO A2-0 object U0525-24170526 has been proposed as a possible optical counterpart to IGR J16500−3307 based on the X-ray position from *INTEGRAL* and *Swift/XRT*. An optical spectrum of this source is presented in Masetti et al. (2008) and is compatible with IGR J16500−3307 being an intermediate polar (IP) CV. The source is included in the study of hard X-ray detected magnetic CVs by Scaringi et al. (2010).

We observed the source with *Chandra* for $\sim$ 1.2 ks on 2007 Sept. 29, detecting a single source (198 counts) compatible with the *INTEGRAL*, *Swift* and *ROSAT* positions, at RA= 16^{h} 49^{m} $55\overset{s}{.}7$, Dec.= -33° $07'$ $02\overset{''}{.}3$.

Follow-up observations, performed with *Blanco/MOSAIC II* in the *r'* band on 2006 Jun. 24 and with *Magellan/PANIC* in the K_s band on 2006 Aug. 3, show a bright source inside the *Chandra* error circle (see Figure 7), at RA= 16^{h} 49^{m} $55\overset{s}{.}633$, Dec.= -33° $07'$ $02\overset{''}{.}13$ ($\pm$ 0.09 arcsec on both coordinates). This position corresponds to the previously proposed counterpart from Masetti et al. (2008). The star is also reported in 2MASS as 16495564-3307020, with magnitude $J = 14.409 \pm 0.039$, $H = 13.969 \pm 0.044$ and $K = 13.712 \pm 0.049$. After absolute photometric calibration, we measure a magnitude $K_s = 13.64 \pm 0.04$ with *PANIC* and $r' = 15.94 \pm 0.04$ with *MOSAIC II*. The probability that a star with that brightness falls by chance in the *Chandra* error circle is very low ($\sim 3 \times 10^{-7}$ in *PANIC* observations). Based on its position, we confirm the object USNO A2-0 U0525-24170526/2MASS 16495564-3307020 (first proposed by Masetti et al. 2008) as the counterpart of the X-ray source IGR J16500-3307.

4.5 XTE 1710-281: an eclipsing LMXB

XTE J1710−281 was serendipitously discovered in 1998 by *RXTE/PCA* and associated with the *ROSAT* source 1RXS J171012.3-280754 (Markwardt et al. 1998). The source was detected by *INTEGRAL/IBIS* (Revnivtsev et al. 2004) and recently by XMM-*Newton* (Watson et al. 2008; Younes et al. 2009). Complete X-ray eclipses and dips have been detected in the *RXTE/PCA* light curves, indicating an orbital period of $\sim$ 3.28 hours. Thermonuclear type I X-ray bursts indicate the object is a NS and strongly suggest that the system is an LMXB (Lewin et al. 1995). The distance d has been constrained from type I X-ray bursts: Markwardt et al. (2001) indicate $d = 15 - 20$ kpc, while Galloway et al. (2008) obtain $d = 12 - 16$ kpc.

XTE J1710−281 is reported in the second XMM-*Newton* serendipitous source catalog (Watson et al. 2008) at RA= 17^{h} 10^{m} $12\overset{s}{.}532$, Dec.= -28° $07'$ $50\overset{''}{.}95$, with an accuracy of 1 arcsec at 1σ on both coordinates. Taking advantage of this recent position we performed a search for the counterpart in I band, observing on 2006 Aug. 3 with *Magellan/IMACS*. We detect one object inside the 90 per cent confidence radius around the XMM-*Newton* position (see Figure 8) at RA= 17^{h} 10^{m} $12\overset{s}{.}6$, Dec.= -28° $07'$ $51\overset{''}{.}0$ ($\pm$ 0.1 arcsec on both coordinates). Its magnitude in I band is $I = 19.7 \pm 0.1$. The probability that this source falls by chance inside the XMM-*Newton* error circle is 2.3×10^{-4}. Since the distance of the source has been constrained, we can infer an upper and lower limit to the absolute magnitude M_I of that candidate counterpart in I band. We derive the absolute extinction coefficient in the I band similarly to what we did for IGR J16293−4603 (see Section 4.2), assuming the N_H obtained by Younes et al. (2009) from XMM-*Newton* spectra. Considering a distance 12 kpc $< d <$ 20 kpc (see above), the I band absolute magnitude of the counterpart to XTE J1710−281 is in between $M_I \sim 3.43$ and $M_I \sim 2.32$. This is in agreement with what is expected if we are observing the disk of an high inclination LMXB (van Paradijs & McClintock 1995a) and supports the association with XTE 1710-281.

4.6 XTE J1716-389: an obscured HMXB system

XTE J1716−389 was discovered by *RXTE* between 1996 and 1997 (Remillard 1999) and corresponds to the source KS1716-389 (Cornelisse et al. 2006) detected two years before the launch of *RXTE* itself by the *TMM/COMIS* telescope on board the *Mir-Kvant* module (Aleksandrovich et al. 1995) . It is also reported in the *EXOSAT* Slew survey catalogue (Reynolds et al. 1999) as EXO J1715557.7-385 and is associated with the *ROSAT* source 1RXH J171556.7-385150. It has been observed with *ASCA* and detected in hard X-rays by *INTEGRAL* (Bird et al. 2006).

Extensively monitored by *RXTE*, the system has shown a highly-variable persistent emission (Wen et al. 1999; Cornelisse et al. 2006). It presents dips with a duration of $\sim$ 30 days and a recurrence period of $\sim$ 100 days, associated with sudden increases in the absorption column density N_H. Even outside the dipping phase the N_H is high ($\sim 10^{23}$ cm^{-2}) compared to the Galactic value towards the source ($\sim 2\times10^{22}$ cm^{-2}), indicating that the system is absorbed locally. The source presents remarkable similarities with the class of obscured HMXBs (Wen et al. 1999; Walter et al. 2006). The $\sim$ 100-day recurrence of the dips is likely not associated with the system orbital period, but with a super-orbital periodicity (Wen et al. 1999) as has been observed in many HMXBs with a supergiant companion.

Stephen et al. (2005) present a search for an optical/NIR counterpart to XTE J1716−389 based on its *ROSAT* position. They indicate a candidate counterpart in optical, also reported in 2MASS and a few NIR sources inside the *ROSAT/HRI* error circle.

We observed XTE J1716−389 with *Chandra/ACIS* for $\sim$ 1.1 ks on 2008 Sep. 23 detecting one faint source (12 counts in a $0.3-7$ keV energy band) compatible with the *ROSAT* pointing from Stephen et al. (2005), at coordinates RA= $17^{\rm h}\ 15^{\rm m}\ 56\overset{\rm s}{.}42$, Dec.= $-38^{\circ}\ 51'\ 54\overset{''}{.}127$. This position excludes the optical counterpart proposed in Stephen et al. (2005), being $\sim$ 4.5 arcsec (more than 10σ) far away from it.

Follow-up optical observations in *i'* band were performed on 2009 May 7 with *Magellan/LDSS3*, showing a very faint source inside the 90 per cent confidence *Chandra* error circle, at RA= $17^{\rm h}\ 15^{\rm m}\ 56\overset{\rm s}{.}457$, Dec.= $-38^{\circ}\ 51'\ 53\overset{''}{.}9$ ±0.1 arcsec on both coordinates (see Figure 9). The probability that the source falls by chance in the *Chandra* error-circle is $\sim 3\times10^{-4}$. The object is reported in the 2MASS catalogue, with magnitude $H = 13.569 \pm 0.09$, $K = 12.579 \pm 0.059$. A limit to the magnitude in J band is also reported, the object being fainter than $J = 15.058$. We observed the source in a non photometric night: we obtain an estimate of the I-band magnitude $I \sim 22.7$ by calibrating our *LDSS3* observation with the zero-point from a previous observing run (see Section 3). As for IGR J16479−4514 (see last paragraph in Section 4.3), the possible combinations of $(J-H)_0$ and $(H-K)_0$ allowed by the 2MASS observed colours $(J-H)$ (lower limit) and $(H-K)$ are shown in Figure 3. The colours are compatible with a star of any class, but only for an A_V ranging between $\sim$ 8 and $\sim$ 17. Those are acceptable values for a HMXB, where the companion star can be highly obscured in the optical due to its own wind ($A_V \sim 9-15$, i.e., for the five systems investigated in Torrejón et al. 2010). On the other hand, a main sequence star or a red giant are unlikely since the high A_V requires a dense stellar wind to be justified. An even higher A_V (~ 45) corresponds to the N_H obtained from the X-rays observations (see above). This indicates that there is absorption in the surroundings of the compact object, not affecting the companion star. We conclude that the source 2MASS 17155645-3851537 is most likely a massive self-absorbed star: this supports its positional association with XTE J1716−389 and the classification of the latter as an obscured HMXB.

4.7 IGR J17254-3257: a candidate UCXB

IGR J17254−3257 was discovered by *INTEGRAL* in 2003 (Walter et al. 2004) and reported in various catalogues of *INTEGRAL/IBIS* sources (i.e. Bird et al. 2004). It is also a *ROSAT* source (1RXS J172525.5-325717), it has been continuously detected by *RXTE/PCA* at very low count-rate since 1999 (Stephen et al. 2005) and was also observed with XMM-*Newton* (Chenevez et al. 2007) and *Swift* (Cusumano 2009).

A type I X-ray burst detected on 2004 Feb. 17 (Brandt et al. 2006) indicated that the system is an LMXB hosting a NS. Moreover, a long thermonuclear burst lasting about 15 minutes was observed on 2006 October 1, placing IGR J17254−3257 in the small group of XRBs showing bursts very different in duration (Chenevez et al. 2007 and references therein). Based on the persistent behaviour of the source at a low accretion rate, in't Zand et al. (2007) proposed IGR J17254−3257 as a candidate UCXB. An upper limit to the distance of 14.5 kpc has been estimated from the bursts (Chenevez et al. 2007).

Zolotukhin (2009) reported two possible optical counterparts to IGR J17254−3257 that are compatible with the XMM-*Newton* position.

We observed the field of IGRJ17254-3257 with *Magellan/PANIC* on 2006 Aug. 03 in K_s band: in addiction to the two sources indicated by Zolotukhin (2009) (see Figure 10), 11 further object are resolved by our PSF photometry within the XMM-*Newton* error circle.

Considering a maximum distance to the source of 14.5 kpc and with the N_H from Chenevez et al. (2007), we can set a limit to the absolute magnitude M_K of the candidates, similarly to what we did for XTE J1710−281 (see Section 4.5). In order to reduce the number of possible counterparts we compared those magnitudes with that of the UCXB 4U 0614+09, for which the case for an ultracompact nature is strong (Nelemans et al. 2004; Shahbaz et al. 2008). For 4U 0614+09, $d = 3.2$ kpc (Kuulkers et al. 2009), $K = 17.1$ and $A_V = 1.41$ (Russell et al. 2007), thus $M_K = 4.46$. This is consistent with what expected for an UCXB (van Paradijs & McClintock 1995a). The first candidate from Zolotukhin (2009) should be very close by ($d = 0.6$ kpc) in order to have a similar $M_K \sim 4$: this is unlikely because IGR J17254−3257 would than be the nearest XRB known and its X-ray luminosity during X-ray bursts would be anomalously low. Beside that, unfortunately the comparison does not provide any constraint to further reduce the number of candidates in the XMM-*Newton* error circle. A localization of the X-ray source with *Chandra* is necessary to identify the actual counterpart.

4.8 XTE J1743-363: a candidate SFXT

XTE J1743−363 was discovered with *RXTE* in 1999 (Markwardt et al. 1999). The system has been detected by *INTEGRAL/IBIS* several times in 2004 at diverse flux levels (Revnivtsev et al. 2004; Grebenev & Sunyaev 2004). It also showed a few-hour long outburst, because of which XTE J1743−363 is considered a candidate SFXT (Sguera et al. 2006). No search for an optical or NIR counterpart is reported in the literature.

We observed XTE J1743−363 with *Chandra/HRC* on

2008 Feb. 8 for $\sim$ 1.2 ks detecting one faint source (11 counts) compatible with the *INTEGRAL* position (from Bird et al. 2006) at coordinates RA= $17^{\rm h}$ $43^{\rm m}$ $01\overset{\rm s}{.}3$, Dec.= $-36°$ $22'$ $22\overset{''}{.}0$.

Optical images in the I band, collected with *EMMI* on 2007 June 22, show a bright star lying inside the *Chandra* error circle (see Figure 11) at RA= $17^{\rm h}$ $43^{\rm m}$ $01\overset{\rm s}{.}324$, Dec.= $-36°$ $22'$ $22\overset{''}{.}2$ ($\pm$0.1 arcsec on both coordinates). The position of the source is coincident within the error with the object 2MASS 17430133-3622221, for which the following magnitudes are reported in the catalogue: J = 9.616 $\pm$ 0.024, H = 8.305 $\pm$ 0.034, K = 7.624 $\pm$ 0.026. We cannot report a magnitude in I band since the field was observed in a non-photometric night.

Given the classification as a SFXT, the companion star in XTE J1743−363 is expected to be a supergiant, locally absorbed in the NIR due to its own wind (see Section 1 and 4.6). As for IGR J16479−4514 and XTE J1716−389, figure 3 shows the combination of $(J-H)_0$ and $(H-K)_0$ allowed by the observed 2MASS colours, for different values of the absorption. The colours are compatible with a type G0-6 III (A_V beween 8 and 9) or G/K I (A_V between 6 and 9) and do not exclude a supergiant of spectral type earlier than O9 (see last paragraph in section 4.3) if $A_V > 12$. As in the case of XTE J1716−389, a main sequence or giant star are allowed by the colours, but unlikely due to the high A_V.

Based on its position we conclude that the object 2MASS 17155645-3851537 is most likely the NIR counterpart to XTE J1716−389. The NIR colours of the counterpart are consistent with a late type supergiant and do not exclude an early O I type. This is consistent with the classification of the X-ray source as a SFXT and supports the counterpart association.

4.9 IGR J17597-220: a dipping LMXB

IGR J17597−220 was first detected in 2001 by *RXTE/PCA* (Markwardt & Swank 2003) but it was reported for the first time in 2003 (Lutovinov et al. 2003) as a new *INTEGRAL* source. For that reason it is usually indicated as either IGR J17597−220 or XTE J1759-220. Type I X-ray bursts from the source have been observed by *INTEGRAL/JEM-X*, identifying the compact object as a NS (Brandt et al. 2007) and the system as a probable LMXB. IGR J17597−220 has also shown dips of ~30 per cent with a duration of $\sim$ 5 minutes, from which Markwardt & Swank (2003) suggested an orbital period of 1-3 hours.

XMM-*Newton* observations localised the source with a 4 arcsec accuracy (Walter et al. 2006). Chaty et al. (2008) identified 6 candidate counterparts consistent with the XMM-*Newton* position on NIR observations in J, H and K_s bands. We detect a single *Chandra/HRC* source (227 counts) inside the XMM-*Newton* error circle, at RA= $17^{\rm h}$ $59^{\rm m}$ $45\overset{\rm s}{.}52$, Dec.= $-22°$ $01'$ $39\overset{''}{.}17$, during a $\sim$ 1.2 ks-long observation performed on 2007 Oct. 23.

Follow-up observations in I band were performed with *NTT/EMMI* on 2006 June 22 and with *Magellan/LDSS3* in *i'* band on 2009 May 7. A single, faint source lies inside the *Chandra* error circle in both bands, at RA= $17^{\rm h}$ $59^{\rm m}$ $45\overset{\rm s}{.}525$, Dec.= $-22°$ $01'$ $39\overset{''}{.}25$ ($\pm$0.1 arcsec on both coordinates). The detection is evident in the 300 s-long *LDSS3* images (see Figure 12), while it is less significant in the 600 s-long *EMMI* one. We consider the detection with *EMMI* as real due to its positional coincidence with that of the source in *LDSS3*. The observing nights with both instruments were not photometric: we obtain an estimate of the I-band magnitude $I \sim 22.4$ by calibrating our *LDSS3* observation with the zero-point from a previous observing run (see Section 3). The probability that our candidate counterpart falls by chance inside the *Chandra* error circle is $\sim 1 \times 10^{-4}$ and $\sim 8 \times 10^{-4}$ for *LDSS3* and *EMMI* respectively (photometry on a smaller field for *EMMI*). Its position matches that of the Candidate 1 in Chaty et al. (2008) that we establish as the very likely optical/NIR counterpart of IGR J17597−220.

4.10 IGR J18490-0000: a Pulsar Wind Nebula

A Pulsar Wind Nebula (PWN) is a nebula powered by the interaction of the highly relativistic particle wind formed in the magnetosphere of a pulsar with the surrounding material. IGR J18490−0000 was discovered by *INTEGRAL* in the spring of 2003, during a survey of the Sagittarius arm tangent region of the Galaxy (Molkov et al. 2004). In the soft X-rays the source is composed of a point-like source surrounded by an extended nebula (Terrier et al. 2008). Its morphology and spectral properties at X-rays are reminiscent of a PWN, although pulsations have not been detected so far (Mattana et al. 2009). The association of IGR J18490−0000 with a PWN was further strenghtened by the discovery of a TeV counterpart with the High Energy Stereoscopic System *HESS* (Terrier et al. 2008).

Swift/XRT observations are presented in Rodriguez et al. (2008): based on the *Swift* position, the object 2MASS 18490182-0001190 has been proposed as a possible NIR counterpart (Rodriguez et al. 2008).

A ~1.2 ks-long *Chandra/HRC* observation of the field, obtained on 2008 Feb. 16, shows a single source (22 counts) inside the *Swift* error circle, at RA= $18^{\rm h}$ $49^{\rm m}$ $01\overset{\rm s}{.}59$, Dec.= $-00°$ $01'$ $17\overset{''}{.}73$, whose morphology is compatible with an extended nebula. Those coordinates exclude the association of IGR J18490−0000 with the candidate counterpart proposed by Rodriguez et al. (2008), which is located at ~3.8 arcsec (over 9σ) from the *Chandra* position.

We observed the field of IGR J18490−0000 with *Blanco/MOSAIC II* on 2006 June 25 in *i'* band and did not detect any optical counterpart. Nevertheless, giving the low number of sources that we observe in the field and comparing the *i'* band images with 2MASS infrared ones, we consider it likely that a dark cloud is located between us and the source, obscuring the counterpart. Further observations in the K_s band, performed on 2009 Jul. 16 with *Magellan/PANIC*, revealed a faint candidate counterpart on the edge of the 90 per cent *Chandra* error circle (Figure 13) at RA= $18^{\rm h}$ $49^{\rm m}$ $01\overset{\rm s}{.}563$, Dec.= $-00°$ $01'$ $17\overset{''}{.}35$ ($\pm$ 0.1 arcsec on both coordinates). After absolute photometric calibration, we measure a magnitude of $K_s = 16.4 \pm 0.1$.

The object does not look extended as one would expect for a PWN: our PSF fitting indicates a point-like source, which looks partially blended with a nearby star (Figure 13). The two sources are resolved by the PSF fitting. This suggests that the object is a foreground star, although its positional coincidence with IGR J18490−0000 within the accuracy of *Chandra* has a low probability of being due to chance ($\sim 1.6 \times 10^{-5}$). We encourage spectroscopic observations of the source in order to investigate its association with IGR J18490-0000.

4.11 IGR J19308+0530: an L/IMXB with an F8 companion

IGR J19308+0530 was discovered by *INTEGRAL* (Bird et al. 2006) and observed by *Swift* in X-rays and in the UV band 170-650 nm (Rodriguez et al. 2008).

Based on the *Swift* position, Rodriguez et al. (2008) identify the star TYC 486-295-1/2MASS J19305075+0530582 as a possible counterpart. This object is classified as an F8 star in the survey by McCuskey (1949). Based on the typical parameters of an F8 star, Rodriguez et al. (2008) suggest IGR J19308+0530 is a L/IMXB in quiescence or a CV at a distance of $\sim$ 1 kpc or lower. Fitting the *Swift* spectrum with a black body of temperature kT =0.2 keV the authors obtained a 2-10 keV luminosity of $\sim 4 \times 10^{31}$ erg s^{-1} at 1 kpc. The corresponding luminosity in the 0.5-10 keV range is $\sim 4 \times 10^{33}$ erg s^{-1}. The spectrum is very soft, suggesting IGR J19308+0530 is most likely not a CV (Pooley & Hut 2006) but an L/IMXB hosting a NS or a BH in quiescence. This suggestion is strengthened by the fact that the spectra of NS/BH LMXBs in quiescence at a 0.5-10 keV luminosity level of $\sim 10^{33}$ erg s^{-1} are expected to be dominated by the soft black-body component, as found by Jonker et al. (2004) and updated in Jonker (2008).

In a $\sim$1.1 ks-long *Chandra/HRC* observation on 2007 Jul. 30, we detected a single source (26 counts) inside the *Swift* error circle, at RA= $19^{\rm h}$ $30^{\rm m}$ $50\overset{\rm s}{.}77$, Dec.= 05° $30'$ $58\overset{''}{.}09$.

We searched for an optical counterpart with *Blanco/MOSAIC II* in r band, on 2006 Jun. 22: the *Chandra* error circle includes a very bright star that is saturated even in the 10 s-long image (Figure 14). Its position is compatible with the position of the previously proposed F8-type counterpart as reported in the Tycho catalogue, in 2MASS, in the LF Survey catalogue and also in UCAC 2 and 3, if the motion of the source since the epoch of each catalogue to that of our observations in 2006 is taken into account. The object has a proper motion of -2.9 $\pm$ 0.6 mars yr^{-1} in RA and -10.5$\pm$0.5 mars yr^{-1} in Dec. (from UCAC3). The magnitudes reported in 2MASS are $J = 9.617 \pm 0.032$ (poor photometry) $H = 9.245 \pm 0.023$ and $K = 9.130 \pm 0.023$. The intrinsic NIR colours (obtained with the method used for IGR J16479−4514, XTE J1716−389 and XTE J1743−363) are consistent with the spectral classification. Moreover, the Supplement-1 to the Tycho-2 catalogue reports $B_T = 11.706$ and $V_T = 10.915$. We confirm the association of IGR J19308+0530 with the F8 star TYC 486-295-1/2MASS J19305075+0530582 (first proposed by Rodriguez et al. 2008) and we suggest the source is most likely an L/IMXB in quiescence.

5 CONCLUSION

We have investigated a sample of 11 Galactic X-ray sources recently discovered by *INTEGRAL* or *RXTE*. For 9 of those, we presented a refined position from *Chandra* observations (Table 1), localising the targets with a positional accuracy of 0.6 arcsec at a 90 per cent confidence level. Thanks to the accurate X-ray position, we have detected a counterpart for all the sources we observed with *Chandra*: the previously proposed counterparts to IGR J16194−2810, IGR J16500−3307, IGR J19308+0530 and IGR J16479−4514 are confirmed by our observations, supporting their classification as, respectively, a SyXB, a CV, an L/IMXB and a SFXT (altough we evidenced some peculiarity in the NIR colours of the latter). The counterpart to the obscured source XTE J1716−389 is consistent with it being a HMXB. The NIR colours of the counterpart to the SFXT candidate XTE J1743−363 indicate indeed a supergiant companion. A point-like NIR source is located at the position of the PWN IGR J18490−0000, although its morphology suggests a foreground star despite its positional coincidence with the nebula. The photometry of the counterpart to the unclassified source IGR J16293−4603 indicates it is an LMXB with a giant companion star, possibly a SyXB.

We also presented optical/NIR observations of the two LMXBs XTE J1710−281 and IGR J17254−3257, searching for a counterpart based on their XMM-*Newton* position. We detected only one source compatible with the position of XTE J1710−281, whose magnitude is consistent with what is expected for an LMXB. This supports its association with the X-ray source. Twelve NIR candidates are consistent with IGR J17254−3257: a *Chandra* position of the source is necessary to select the counterpart. Table 5 summarizes the results of our counterpart search in comparison with previous results.

Table 5. Results of our optical/NIR counterpart search. The upper part of the table lists sources that we observed with *Chandra*. For the last two sources we obtained XMM-*Newton* positions from the literature. Candidate counterparts previously proposed are discarded or confirmed based on the *Chandra* position (see text). The coordinates of the counterparts in the table are from 2MASS when available, from our astrometry elsewhere.

Source	Classification	Counterparts in literature	New counterpart	RA(J2000)	Dec.(J2000)
Chandra					
IGR J16194−2810	SyXB	M2 III$^{\dagger(a)}$	*confirmed*	$16^{h}\ 19^{m}\ 33^{s}.348^{2MASS}$	$-28^{\circ}\ 07'\ 39''.74^{2MASS}$
IGR J16293−4603	LMXB[1]	none	yes: K, M or G (unlikely) III	$16^{h}\ 29^{m}\ 12^{s}.9 \pm 0''.1$	$-46^{\circ}\ 02'\ 50''.58 \pm 0''.1$
IGR J16479−4514	SFXT (eclipsing)	O/B I star$^{\dagger(b)}$	*confirmed*	$16^{h}\ 48^{m}\ 06^{s}.56^{2MASS}$	$-45^{\circ}\ 12'\ 06''.8^{2MASS}$
IGR J16500−3307	CV	dwarf nova$^{\dagger(c)}$	*confirmed*	$16^{h}\ 49^{m}\ 55^{s}.64^{2MASS}$	$-33^{\circ}\ 07'\ 02''.1^{2MASS}$
XTE J1716−389	obscured HMXB	in $^{(d)}$: *excluded*	2MASS J17155645-3851537	$17^{h}\ 15^{m}\ 56^{s}.46^{2MASS}$	$-38^{\circ}\ 51'\ 53''.7^{2MASS}$
XTE J1743−363	SFXT	none	2MASS J17430133-3622221	$17^{h}\ 43^{m}\ 01^{s}.34^{2MASS}$	$-36^{\circ}\ 22'\ 22''.2^{2MASS}$
IGR J17597−220	NS LMXB (dipper)	6 NIR candidates$^{(e)}$	Select candidate 1 (see text)	$17^{h}\ 59^{m}\ 45^{s}.5 \pm 0.1''$	$22^{\circ}\ 01'\ 39''.6 \pm 0.1''$
IGR J18490−0000	PWN	in$^{(f)}$: *excluded*	yes/tentative	$18^{h}\ 49^{m}\ 01^{s}.553 \pm 0.1''$	$-00^{\circ}\ 01'\ 17''.20 \pm 0.1''$
IGR J19308+0530	L/IMXB[1]	F8 star$^{\dagger(g)}$	*confirmed*	$19^{h}\ 30^{m}\ 50^{s}.76^{2MASS}$	$+05^{\circ}\ 30'\ 58''.3^{2MASS}$
XMM-*Newton*					
XTE J1710−281	NS LMXB (eclipsing)	none	yes	$17^{h}\ 10^{m}\ 12^{s}.6 \pm 0.1''$	$-28^{\circ}\ 07'\ 51''.0 \pm 0.1''$
IGR J17254−3257	UCXB	none	12 candidates (see text)	-	-

[1]: New classification
†: Optical/NIR spectrum reported in the literature.
$^{(a)}$ USNO-A2.0 U0600_20227091: Masetti et al. (2007). $^{(b)}$ 2MASS J16480656-4512068; Kennea et al. (2005); Walter et al. 2006; Chaty et al. (2008). $^{(c)}$ USNO A2-0 U0525-24170526:Masetti et al. (2008). $^{(d)}$ Stephen et al. (2005), also indicates the presence of several further NIR objects. $^{(e)}$ Chaty et al. (2008). $^{(f)}$ 2MASS J18490182-0001190: Rodriguez et al. (2008)

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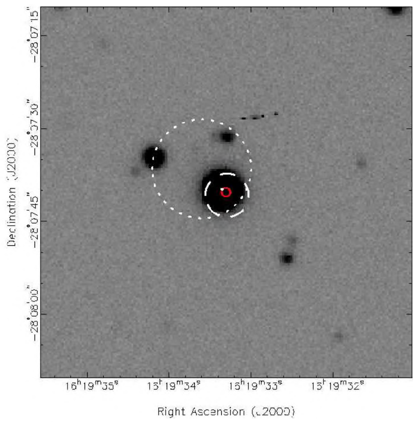

Figure 4. IGR J16194−2810: *MOSAIC II*, 300 s in the *r'* band. The red error circle indicates the *Chandra* position. The small-dashed error circle is that of *ROSAT*, the large-dashed one is *Swift*.

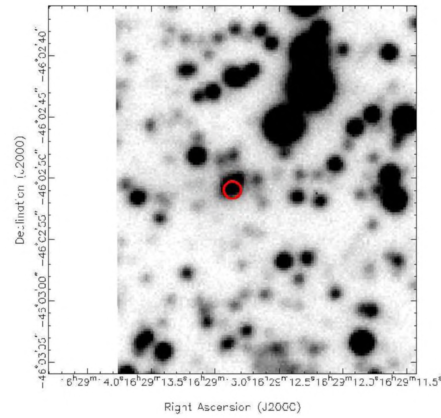

Figure 5. IGR J16293−4603: *LDSS3*, 180 s in the *i'* band. The error circle indicates the *Chandra* position.

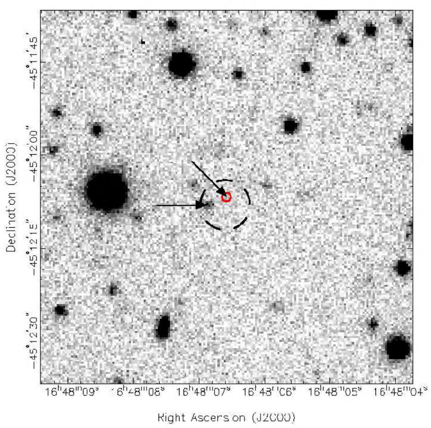

Figure 6. IGR J16479−4514, *MOSAIC II*, 300 s in the *i'* band. Red error circle: *Chandra* position. Dashed error circle: XMM-*Newton*. The arrows indicate the position of the candidate counterparts 1 and 2 in Chaty et al. (2008).

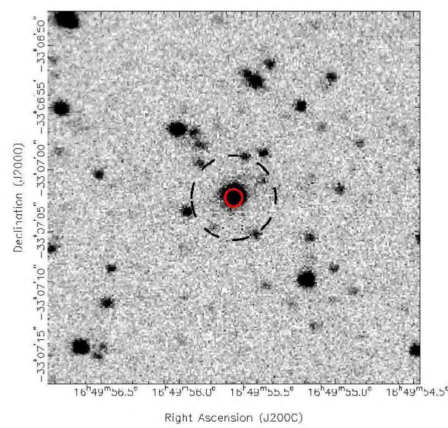

Figure 7. IGR J16500−3307, *PANIC*, 75 s in the K_s band. Red error circle: *Chandra* position. Dashed error circle: *Swift*.

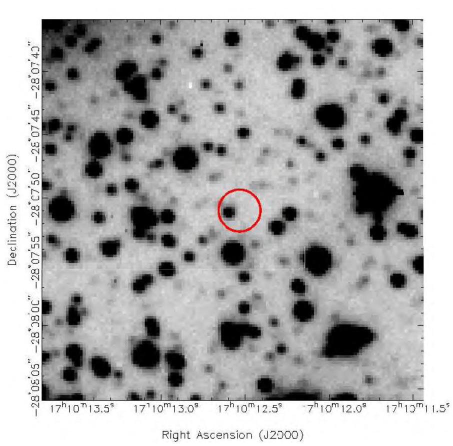

Figure 8. XTE J1710−281, *IMACS*, 300 s in the *I* band. Red error circle: XMM-*Newton* position.

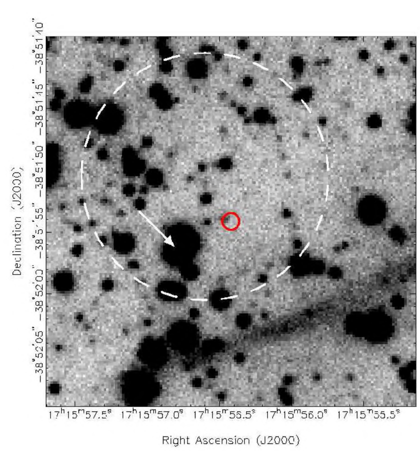

Figure 9. XTE J1716−389, *LDSS3*, 300 s in the *i'* band. Red error circle: *Chandra* position. Dashed error circle: *ROSAT*. The arrow indicates the position of the candidate counterpart proposed in Stephen et al. (2005), which the *Chandra* position rules out. There is one candidate counterpart in the *Chandra* error circle.

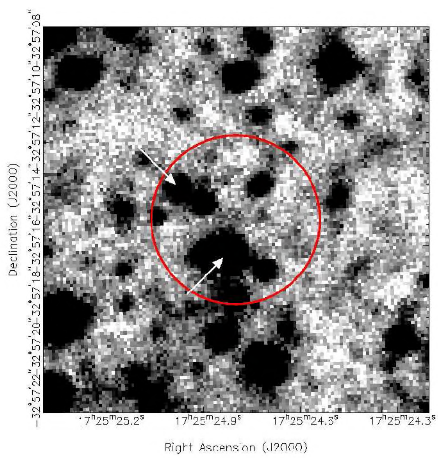

Figure 10. IGR J17254−3257: *PANIC*, 15 s in the K_s band. Red error circle: XMM-*Newton* position. The arrows indicate the position of the two candidate counterparts in Zolotukhin (2009) (first and second from bottom to top).

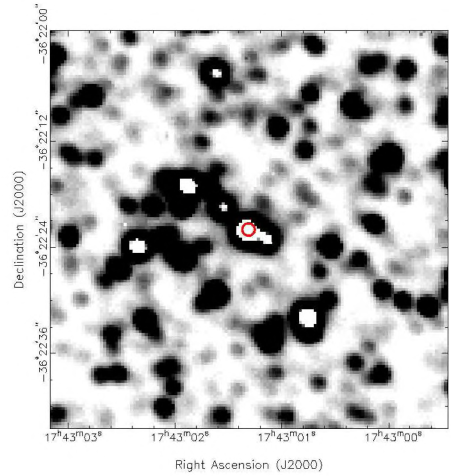

Figure 11. XTE J1743−363: *EMMI*, 600 s in the *I* band. Red error circle: *Chandra* position.

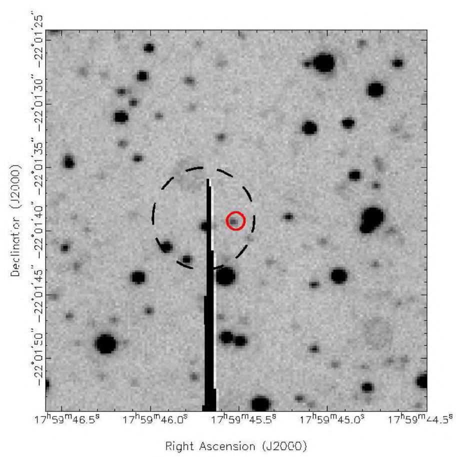

Figure 12. IGR J17597−220: *LDSS3*, 300 s in the *i'* band. Red error circle: *Chandra* position. Dashed error circle: XMM-*Newton*

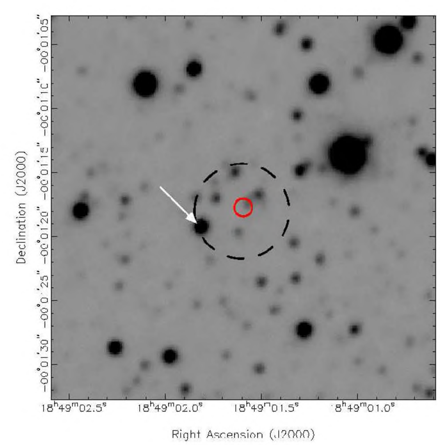

Figure 13. IGR J18490−0000: *PANIC*, 15 s in the K_s band. Red error circle: *Chandra* position. Dashed error circle: *Swift*. The arrow indicates the candidate counterpart from Rodriguez et al. (2008)

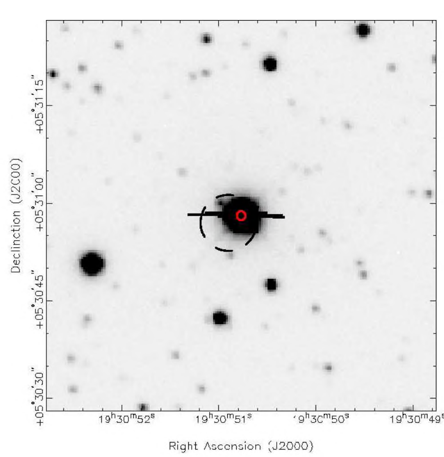

Figure 14. IGR J19308+0530: *MOSAIC II*, 10 s in the *I* band. Red error circle: *Chandra* position. Dashed error circle: *Swift*

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