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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 \( M_\text{D} \geq 10 \, M_\odot \); in LMXBs \( M_\text{D} \lesssim 1 \, M_\odot \). 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 (SXR Bs). 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, SXR Bs 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
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).

<table>
<thead>
<tr>
<th>Source</th>
<th>Date</th>
<th>Instrument</th>
<th>Exposure time (s)</th>
<th>Counts</th>
<th>RA(J2000)</th>
<th>Dec.(J2000)</th>
<th>WAVDETECT error on RA, Dec.(arcsec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IGR J16194-2810</td>
<td>2008 Jan. 18</td>
<td>HRC-I</td>
<td>1129</td>
<td>1075</td>
<td>$10^5.19^m.33^s.30$</td>
<td>$-28^i.07^m.40^s.30$</td>
<td>0.018, 0.014</td>
</tr>
<tr>
<td>IGR J16293-4603</td>
<td>2008 Jan. 24</td>
<td>ACIS-I</td>
<td>1135</td>
<td>237</td>
<td>$10^5.19^m.29^s.86$</td>
<td>$-46^i.02^m.50^s.94$</td>
<td>0.072, 0.068</td>
</tr>
<tr>
<td>IGR J16479-4514</td>
<td>2007 Oct. 24</td>
<td>HRC-I</td>
<td>1174</td>
<td>44</td>
<td>$10^5.48^m.06^s.58$</td>
<td>$-45^i.12^m.06^s.74$</td>
<td>0.061, 0.061</td>
</tr>
<tr>
<td>IGR J16500-3307</td>
<td>2007 Sep. 29</td>
<td>HRC-I</td>
<td>1150</td>
<td>198</td>
<td>$10^5.49^m.55^s.65$</td>
<td>$-33^i.07^m.02^s.28$</td>
<td>0.032, 0.029</td>
</tr>
<tr>
<td>XTE J1716–389</td>
<td>2008 Sep. 23</td>
<td>ACIS-I</td>
<td>1141</td>
<td>12</td>
<td>$10^5.13^m.56^s.42$</td>
<td>$+38^i.51^m.54^s.13$</td>
<td>0.227, 0.256</td>
</tr>
<tr>
<td>XTE J1743–363</td>
<td>2009 Feb. 08</td>
<td>HRC-I</td>
<td>1172</td>
<td>11</td>
<td>$10^5.43^m.01^s.31$</td>
<td>$-36^i.22^m.22^s.00$</td>
<td>0.14, 0.043</td>
</tr>
<tr>
<td>IGR J17597–220</td>
<td>2007 Oct. 23</td>
<td>HRC-I</td>
<td>1160</td>
<td>227</td>
<td>$10^5.59^m.45^s.52$</td>
<td>$-22^i.01^m.09^s.17$</td>
<td>0.022, 0.022</td>
</tr>
<tr>
<td>IGR J18490-0000</td>
<td>2008 Feb. 16</td>
<td>HRC-I</td>
<td>1174</td>
<td>22</td>
<td>$10^5.49^m.01^s.59$</td>
<td>$-00^i.01^m.17^s.73$</td>
<td>0.0432, 0.061</td>
</tr>
<tr>
<td>IGR J19308+0530</td>
<td>2007 Jul. 30</td>
<td>HRC-I</td>
<td>1129</td>
<td>26</td>
<td>$10^5.30^m.50^s.77$</td>
<td>$+05^i.30^m.58^s.09$</td>
<td>0.061, 0.072</td>
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Table 2. Known X-ray positions

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<td>XTE J1710–281</td>
<td>$17^h.16^m.13^s$</td>
<td>$-28^i.07^m.51^s$</td>
<td>1&quot;</td>
<td>XMM-Newton a</td>
</tr>
<tr>
<td>IGR J17254–3257</td>
<td>$17^h.25^m.25^s$</td>
<td>$-32^i.57^m.15^s$</td>
<td>2&quot;</td>
<td>XMM-Newton b</td>
</tr>
</tbody>
</table>


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 uncertainty on the localisation on the image (see Section 2).

Table 1 shows the known X-ray positions.

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<td>2&quot;</td>
<td>XMM-Newton b</td>
</tr>
</tbody>
</table>

Table 2 presents 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 instrument1) 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 WAVEDETECT using the tool DMEXTEND. We estimated the background in an annulus centered on the WAVEDETECT 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 Imamura 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 0.07 to 0.17 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.
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° 10′±33.4′, Dec.=−28° 07′±0′.2′.

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° 19′±33.3′, Dec.=−28° 07′±39.9′ (±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 ± 4.7 marsyr−1 in RA and −20.2 ± 4.7 marsyr−1 in Dec., from UCAC2). The magnitudes of the object from USNO-A2.0 in the R and B bands are $R = 11$ and $B = 13.2$. We found the source also in UCAC2 and in 2MASS, where the following magnitude are reported: $J = 8.268 ± 0.029$, $H = 7.333 ± 0.044$ and $K = 6.984 ± 0.016$. We measure an apparent magnitude $r' = 10.98 ± 0.04$ in $r'$ band. The probability that such a bright star falls by chance in the Chandra error-circle is ~ $2 \times 10^{-7}$. 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 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 $N_H = (0.16±0.08) \times 10^{22}$ cm$^{-2}$ from Masetti et al. (2007), the distance is $d = 3.0±0.2$ kpc, in agreement with the upper limit estimated by those authors.
The systemic radial velocity, $\gamma$, is unknown, but we can use the measured proper motion and source distance to derive the three-dimensional space velocity components as a function of $\gamma$. 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 $\gamma$ (Figure 1) under the assumption that the object participates in the Galactic rotation. We find a minimum peculiar velocity of 280±66 km s$^{-1}$, corresponding to a systemic radial velocity of $\gamma = -35$ km s$^{-1}$.

**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$=16^h 29^m 12.86$, Dec.$=-28^\circ 02^\prime 50.94$.

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$=16^h 29^m 12.885$, Dec.$=-46^\circ 02^\prime 50.55$ (± 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 $A_V = 3.2 \pm 2$ 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 $(r'-i')$ 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 (1999). 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 $4 \times 10^{32}$ erg s$^{-1}$ cm$^{-2}$ in the band 0.3-7 keV, assuming a simple power-law spectrum with photon index $\gamma = 1.0$ (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
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 (Kennel 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 ~ 3.3 days, short compared to other SFXTs. Moreover, the luminosity of IGR J16479−4514 is ~ 10^{38} \text{ 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 ~ 1.2 ks on 2007 Oct. 24. A single source (44 counts) is detected in the XMM-Newton error circle, at coordinates RA= 16^h 48^m 06^s 6, Dec. = −45° 12′ 06″ 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’ ~ 23. We detect the object labelled 2 in Chaty et al. (2008) at RA = 16^h 48^m 06^s 56, Dec. = −45° 12′ 08″ 1 (± 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 (< 1σ). 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 ± 0.03, H = 10.82 ± 0.02, K = 9.80 ± 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_I, 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 IGR J17544−2619 and XTE J17391−3021 (Negueruela et al. 2006), IGR J16207−5129 (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 XTE J17391−3021, which is offset by ~ 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-

\[ \text{Figure 2. Colour-magnitude diagram of the field of IGR J16293−4603, observed with LDSS3. The apparent magnitude of the stars in g' band is plotted versus the (r'−i') colour index. The counterpart to IGR J16293−4603 is indicated by the black star.} \]
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 U0525-24170526/2MASS 16495564-3307020 (first proposed by Masetti et al. 2008) as the counterpart of the X-ray source IGR J16500-3307.

4.5 XTE J1710-281: 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 ∼ 3.28 hours. Thermomolecular type I X-ray bursts indicate the object is a NS and strongly suggest that the system is an LMXB (Levin 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° 10′ 12.32, Dec. = −28° 07′ 50.795, 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° 10′ 12.6, Dec. = −28° 07′ 51.0 (± 0.1 arcsec on both coordinates). Its magnitude in I band is I = 19.7 ± 0.1. The probability that this source falls by chance inside the XMM-Newton error circle is 2.3 x 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_M 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 ~ 3.43 and M_I ~ 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 Sloan survey catalogue (Reynolds et al. 1999) as EXO J1715557.7-385 and it 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 ~30 days and a recurrence period of ~100 days, associated with sudden increases in the absorption column density $N_H$. Even outside the dipping phase the $N_H$ is high ($\sim 10^{33}$ cm$^{-2}$) compared to the Galactic value towards the source ($\sim 2 \times 10^{22}$ 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 ~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 ~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$^h$ 15$^m$ 56$^s$.42, Dec= −38° 51′ 54″.127. This position excludes the optical counterpart proposed in Stephen et al. (2005), being ~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$^h$ 15$^m$ 56$^s$.457, Dec= −38° 51′ 54″.9 ±0.1 arcsec on both coordinates (see Figure 9). The probability that the source falls by chance in the Chandra error-circle is ~3 × 10$^{-4}$. 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).

For IGR J17254−3257, we obtained 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.

### 4.7 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, int’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.

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 ∼1.2 ks detecting one faint source (11 counts) compatible with the INTEGRAL position (from Bird et al. 2006) at coordinates RA= 17h 43m 01s 73, Dec. = −36° 22′ 22′′.0.

Optical images in the J band, collected with EMMI on 2007 June 22, show a bright star lying inside the Chandra error circle (see Figure 11) at RA= 17h 43m 01s 324, Dec. = −30° 22′ 22′′.2 (±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 ± 0.024, H = 8.305 ± 0.034, K = 7.624 ± 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 also Section 4.6). As for IGR J16479−4514 and XTE J1716−389, figure 3 shows the combination of (J−H) and (H−K) allowed by the observed 2MASS colours, for different values of the absorption. The colours are compatible with a type G0−6 III (Av between 8 and 9) or G/K I (Av between 6 and 9) and do not exclude a supergiant of spectral type earlier than O9 (see last paragraph in section 4.3) if Av > 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 Av.

Based on its position we conclude that the 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 SFXT 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 ∼5 minutes, from which Markwardt & Swank (2003) suggested an orbital period of 1-3 hours.

XMM-Newton observations localized 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 Ks bands. We detect a single Chandra/HRC source (227 counts) inside the XMM-Newton error circle, at RA= 17h 59m 00s 752, Dec. = −22° 01′ 39′′.17, during a ∼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= 17h 59m 00s 752, Dec. = −22° 01′ 39′′.25 (±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 ∼ 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 ∼1 × 10−4 and ∼8 × 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 first strengthened by the discovery of a TeV counterpart with the High Energy Stereoscopic System HESS (Terrier et al. 2008).

Swift/XRT observations are presented in Rodríguez et al. (2008): based on the Swift position, the object 2MASS 18490182-0001190 has been proposed as a possible NIR counterpart (Rodríguez 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= 18h 49m 01s 59, Dec. = −00° 01′ 17′′.73, whose morphology is compatible with an extended nebula. Those coordinates exclude the association of IGR J18490−0000 with the candidate counterpart proposed by Rodríguez 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 Ks 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 = 18h 49m 01s 563, Dec. = −00° 01′ 17′′.35 (± 0.1 arcsec on both coordinates). After absolute photometric calibration, we measure a magnitude of KS = 16.4 ± 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 (∼1.6 × 10−5). We encourage spectroscopic obser-
vations 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 ~ 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 ~ 4 x 10^{31} ergs^{-1} at 1 kpc. The corresponding luminosity in the 0.5-10 keV range is ~ 4 x 10^{33} ergs^{-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 ~ 10^{33} ergs^{-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 ~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 = 19h 30m 50s.77, Dec. = 05° 30' 58.09.

We searched for an optical counterpart with Blanco/MOSAIC H 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 ± 0.6 mas yr^{-1} in RA and -10.5±0.5 mas yr^{-1} in Dec. (from UCAC3). The magnitudes reported in 2MASS are \( J = 9.617 ± 0.032 \) (poor photometry) \( H = 9.245 ± 0.023 \) and \( K = 9.130 ± 0.023 \). 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 (although 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 an 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.

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<tr>
<td>XTE J1710—281 SyXB</td>
<td>M2 III[1][a]</td>
<td>confirmed</td>
<td>16h 29m 33s 46s M2MASS -28° 07' 39s 74s M2MASS</td>
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<td>IGR J16194—2810 SyXB</td>
<td></td>
<td>yes: K, M or G (unlikely) III</td>
<td>16h 29m 12s 9s M2MASS -46° 02' 50s 58' M2MASS</td>
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<tr>
<td>IGR J16238—4603 LMXB</td>
<td></td>
<td>confirmed</td>
<td>16h 29m 48s 56s M2MASS -45° 12' 06s 52s M2MASS</td>
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<tr>
<td>IGR J16479—4514 SFXT</td>
<td>O/B I star[b]</td>
<td>confirmed</td>
<td>16h 49m 55s 64s M2MASS -33° 07' 02s 15s M2MASS</td>
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<tr>
<td>XTE J1716—389</td>
<td>dwarf nova[c]</td>
<td>confirmed</td>
<td>17h 15m 56s 49s M2MASS -38° 51' 58s 72s M2MASS</td>
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<td>XTE J1743—363</td>
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<td>2MASS J17155645-3851537</td>
<td>17h 43m 01s 34s M2MASS -36° 22' 22s M2MASS</td>
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<tr>
<td>IGR J17507—220</td>
<td>6 NIR candidates[c]</td>
<td>Select candidate 1 (see text)</td>
<td>17h 59m 45s 5s ±0.1''</td>
<td>22° 01' 39s 6s ±0.1''</td>
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<tr>
<td>IGR J18490—0000 PWN</td>
<td>in[d]: excluded</td>
<td>yes/tentative</td>
<td>18h 49m 07s 55s ±0.1''</td>
<td>-09° 01' 17s 20s ±0.1''</td>
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<tr>
<td>IGR J19308+0530 L/IMXB</td>
<td>F8 star[e][g]</td>
<td>confirmed</td>
<td>19h 30m 50s 76s 2MASS +05° 30' 58' 2MASS</td>
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XMM-Newton

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<tr>
<td>XTE J1710—281 NS LMXB (eclipsing)</td>
<td>none</td>
<td>yes</td>
<td>17h 10m 12s ±0.1''</td>
<td>-28° 07' 51s ±0.1''.</td>
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<tr>
<td>IGR J17254—3257 UCXB</td>
<td></td>
<td>12 candidates (see text)</td>
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[a]: New classification
[b]: Optical/NIR spectrum reported in the literature.
[c]: 2MASS J16480654-4512068; Kennea et al. (2005): Walter et al. 2006; Chaty et al. (2008).
[d]: USNO A2-0 U0525-24170526:Masetti et al. (2008).
[e]: Stephen et al. (2005), also indicates the presence of several further NIR objects. (f): Chaty et al. (2008). (g) 2MASS J18490182-0001190: Rodríguez 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 Ks 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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