Sample of optically unidentified X-ray binaries in the Galactic bulge: constraints on the physical nature from infrared photometric surveys

Ivan Yu. Zolotukhin1,2* and Mikhail G. Revnivtsev3

1 CNRS, IRAP, 9 avenue du Colonel Roche, BP 44346, F-31028 Toulouse Cedex 4, France
2 Sternberg Astronomical Institute, Moscow State University, Universitetskij pr. 13, 119992 Moscow, Russia
3 Space Research Institute, Russian Academy of Sciences, Profsoyuznaya 84/32, 117997 Moscow, Russia

Accepted 2014 October 21. Received 2014 October 20; in original form 2013 August 19

ABSTRACT

We report on archival near-infrared and mid-infrared observations of seven persistent X-ray sources situated in the Galactic bulge, using data from the UK Infrared Telescope (UKIRT) Infrared Deep Sky Survey (UKIDSS), the Spitzer Galactic Legacy Infrared Mid-Plane Survey Extraordinaire (GLIMPSE) and the Wide-field Infrared Survey Explorer (WISE) all-sky survey. We were able to successfully identify or provide upper flux limits for the systems SAX J1747.0–2853, IGR J17464–2811, AX J1754.2–2754, IGR J17597–2201, IGR J18134–1636, IGR J18256–1035 and Ser X–1 and constrain the nature of these systems. In the case of IGR J17597–2201, we present arguments that the source accretes matter from the stellar wind rather than via Roche-lobe overflow of the secondary. We suggest that, at its X-ray luminosity of $10^{34}–35$ erg s$^{-1}$, we are probing the poorly known class of wind-fed low-mass X-ray binaries (LMXBs).

Key words: X-rays: binaries – X-rays: individual: AX J1754.2–2754 – X-rays: individual: IGR J17464–2811 – X-rays: individual: IGR J17597–2201 – X-rays: individual: Ser X–1 – infrared.

1 INTRODUCTION

X-ray surveys of the sky, performed over the last decade, have provided a lot of information about populations of sources in our Galaxy (see e.g. Grimm, Gilfanov & Sunyaev 2002; Gilfanov 2004; Sazonov et al. 2006). The hunt for complete samples of sources is motivated by the desire for better statistics to test theoretical predictions of binary system evolution, which in turn help to measure physical effects unreachable by any other methods.

Since our Galaxy has been well-studied in the X-ray bandpass (see e.g. the survey of the sky with the Uhuru satellite by Forman et al. 1978), a large fraction of the brightest sources was securely identified and many additional properties were catalogued (see e.g. Liu, van Paradijs & van den Heuvel 2007). Studies of these samples of known sources allow one to connect the intrinsic properties of the population with features of their observational appearance. For example, it was shown that the number of low-mass X-ray binaries (LMXBs) traces the stellar density (Grimm et al. 2002; Gilfanov 2004), while the number of high-mass X-ray binaries (HMXBs) in galaxies traces their total star formation rate (Grimm, Gilfanov & Sunyaev 2003; Ranalli, Comastri & Setti 2003); the spatial distribution of HMXBs and their correspondence with star formation regions makes it possible to constrain their natal kicks (Bodaghee et al. 2012; Coleiro & Chaty 2013); the distribution of LMXBs with luminosity demonstrates features corresponding to (1) the Eddington luminosity limit of neutron stars (Gilfanov 2004), (2) a change of donor stars in binaries (Revnivtsev et al. 2011), etc.

More recent X-ray surveys of the Galaxy have revealed fainter Galactic X-ray sources, which require optical identification. The typical sensitivity of the latest surveys is $\simeq 5 \times 10^{-12}$ erg s$^{-1}$ cm$^{-2}$ in the 17–60 keV energy range (see e.g. Krivonos et al. 2012), covering a large portion of the Galactic disc, which corresponds to luminosities $L_X \simeq 10^{33}–10^{35}$ erg s$^{-1}$ at distances 2–10 kpc.

This luminosity range has peculiarities. X-ray binaries with such luminosities, when mass transfer is expected to happen through Roche-lobe overflow of the secondary, cannot have stable mass transfer in their accretion discs, due to thermal instability (see e.g. Meyer & Meyer-Hofmeister 1981; Dubus et al. 1999; Lasota 2001), and thus should be transient unless they are extremely compact and have orbital periods less than approximately one hour. In the case of compact systems, they have hotter discs with temperatures above the threshold below which a disc becomes thermally unstable (Dubus, Hameury & Lasota 2001). On the other hand, sources might have such low luminosities if they accrete not through Roche-lobe overflow of the secondary but due to the capture of its stellar wind. Sources of the latter type are historically called symbiotic stars and they are known to be very rare (Masetti et al. 2007). Another peculiarity of this luminosity range is that, when material is accreting on to old neutron stars with a surface magnetic field of...
10^6 G at typical mass accretion rates, a so-called ‘propeller’ effect (Illarionov & Sunyaev 1975; Campana et al. 1995) is expected, which we suspect reduces the luminosity of the source to below our ability to detect. Therefore a systematic search for and identification of faint LMXB candidates, to assess their frequency, can give a key insight into the underlying accretion physics in these systems.

In this article, which continue our optical identification efforts started in Zolotukhin, Revnivtsev & Shakura (2010) and Zolotukhin & Revnivtsev (2011), we combine data from the UK Infrared Telescope (UKIRT) Infrared Deep Sky Survey (UKIDSS: Lawrence et al. 2007), Spitzer Galactic Legacy Infrared Mid-Plane Survey Extraordinaire (GLIMPSE: Benjamin et al. 2003; Churchwell et al. 2009) and Wide-field Infrared Survey Explorer (WISE) all-sky survey (Wright et al. 2010) for a set of assumed X-ray binaries, mainly LMXB candidates hosting neutron stars, present estimates of their near-infrared (NIR) brightness and use these to infer their underlying nature.

2 NIR DATA

In this study we used several NIR data collections, accessing them through available Virtual Observatory interfaces, such as the the TOPCAT tool (Taylor 2005) and the VizieR ConeSearch service for GLIMPSE and WISE all-sky catalogues and the WFCAM Science Archive\(^1\) for UKIDSS images. Out of several surveys comprising the UKIDSS, we used the Galactic Plane Survey and its Data Release 7 (UKIDSS GPS DR7) and in one case of Ser X−1 additionally Data Release 9.

We employed our own processing technique for the UKIDSS imaging data instead of using available tabular data, in order to detect and measure fainter objects within X-ray positional uncertainties of our objects, which are not present in the public catalogue. We considered as potential NIR counterparts only sources situated within 1σ uncertainty of X-ray coordinates. We performed PSF photometry measurements of 2 arcmin by 2 arcmin cut-outs of UKIDSS science frames using IRAF DAOPHOT package. The calibration of instrumental magnitudes was achieved by comparing our 2 arcsec aperture magnitudes with UKIDSS catalogue magnitudes measured in the same aperture. We then applied constructed calibration to the PSF magnitudes and hence our photometry results are given in the intrinsic UKIDSS photometric system, i.e. the Vega system. Typically we were able to perform measurements on stars one magnitude fainter than those available in the catalogue. Upper limits of UKIDSS images were estimated using the magnitudes of the faintest stars detected at 3σ level above the background. Our astrometric calibration is based on the default UKIDSS astrometric solution embedded in UKIDSS image files. All our astrometric uncertainties include the systematic uncertainty of the UKIDSS system with respect to the International Celestial Reference Frame (ICRS). More details on our photometric and astrometric procedure are given in Zolotukhin & Revnivtsev (2011).

GLIMPSE data were taken from the official catalogue release, which we accessed through the Centre de Données astronomiques de Strasbourg (CDS) VizieR service. When dealing with GLIMPSE data, we took into account the astrometric uncertainty, which amounts to 0.3 arcsec for each coordinate. We accessed the WISE all-sky catalogue through the CDS VizieR service as well. The astrometric uncertainty of the WISE catalogue is known to be 0.4 arcsec for each coordinate. We list all photometric bands and surveys we used in Table 1.

In each field, we computed the chance superposition probability, which represents the probability of accidental background star coincidence with the X-ray 1σ positional uncertainty. It is used to quantify the local star density in the K-band image in the vicinity of objects and we calculate it as follows: \( P = A - \epsilon \), where \( A \) is the X-ray error-circle area and \( \epsilon \) is the average surface density of the sources we detected in a 2-arcmin field around the given position.

Using our NIR photometry, we plotted NIR colour–magnitude diagrams (CMDs) for all stars detected in our fields around X-ray coordinates to test if possible counterparts display similar colour properties as normal stars. For convenience, we represent such diagrams as 2D maps of star density in bins of colour–magnitude space. The absolute densities in the selected bins are not important and this is the reason why we do not give this scale. The purpose of CMDs is to compare the NIR colour of the majority of field stars with the colour of possible counterparts. As in this sample of X-ray sources we are looking in the direction of the Galactic bulge, a significant fraction of field stars belong to the bulge population of red giants and subgiants with similar colours residing at the same distance and subject to the same reddening. If a positional counterpart candidate exhibits the same colour as the majority of field stars, it is unlikely to be associated with the X-ray object. The nature of the NIR emission in X-ray sources differs from that in field stars and hence the NIR colours must be different too, unless interstellar reddening compensates for the exact difference, which is highly unlikely. We discuss individual CMDs in each object’s section separately.

| Survey | Band | λ (μm) | Δλ (μm) |
|--------|------|--------|---------|
| UKIDSS | J    | 1.25   | 0.079   |
| UKIDSS | H    | 1.63   | 0.146   |
| UKIDSS | K    | 2.20   | 0.177   |
| Spitzer | 3.6 μm | 3.53 | 0.37 |
| Spitzer | 4.5 μm | 4.47 | 0.50 |
| Spitzer | 5.8 μm | 5.68 | 0.693 |
| WISE | W1 | 3.38 | 0.34 |
| WISE | W2 | 4.63 | 0.525 |
| WISE | W3 | 12.33 | 3.228 |
| WISE | W4 | 22.25 | 1.973 |

1http://surveys.roe.ac.uk/wise/
estimates derived by these authors were based on the assumption that the reddening law has a shape described by Cardelli, Clayton & Mathis (1989), which is known to be inaccurate for some regions close to the Galactic Centre (Udalski 2003; Geminale & Popowski 2004).

Whenever SAX J1747.0—2853 was observed by sensitive X-ray instruments, it was seen to be above quiescence, with the faintest 2–10 keV flux of 1.9 × 10^{-11} erg cm^{-2}s^{-1} observed by Chandra (Wijnands, Miller & Wang 2002). This value is in agreement with more recent Swift observations (Campana, Chenevez & Kuulkers 2009) and corresponds to a luminosity of 2 × 10^{35} erg s^{-1}, which we accept as a persistent value. Werner et al. (2004) note that the binary must be close to the critical luminosity below which accretion on to the compact object changes from persistent to transient in nature.

We used UKIDSS Galactic Plane Survey Data Release 7 data, taken by the 3.8-m UKIRT telescope, to study the field of SAX J1747.0—2853 (see Table 2 for the observation log). We detected a single source 0.56 arcsec from the X-ray coordinates by Wijnands et al. (2002) within the formal 1σ X-ray positional uncertainty in $H$ and $K$ filters (see Fig. 1 for the image and Table 3 for positional information on this detection). However, this object is not visible in $J$ up to its limiting magnitude. We do not consider this source to be the counterpart of SAX J1747.0—2853, because of the significant coordinate mismatch and because its observed $H − K$ colour is similar to the majority of background stars in this field (see the leftmost panel in Fig. 2). Due to the different nature of the NIR emission, we expect the true counterpart to exhibit intrinsically different SED properties from field stars. As X-ray data show that SAX J1747.0—2853 resides inside the Galactic bulge, where most stars in the CMD come from, its true NIR counterpart must experience similar interstellar reddening, which cannot influence the intrinsic colour difference significantly, and hence the observed colours must be different. Therefore we think that the detected object is a chance projection of a bulge star on to our X-ray error circle.

We also inspected this field in the Spitzer data archive. The nearest object from the GLIMPSE catalogues is 2 arcsec away from the NIR counterpart position and hence is unlikely to be associated with SAX J1747.0—2853. The WISE catalogue does not contain sources within 2 arcsec radius centred at the X-ray position.

SAX J1747.0—2853 was reported to exhibit outbursts lasting ~60 d, with a recurrence time of 185 d (Brandt et al. 2007), stabilizing at approximately the persistent flux level during the intervening period. In particular, it was known to be active in 2006 February (Chenevez et al. 2006) and 2006 September (Wijnands et al. 2006), so we assume it to be in quasi-quiescence during our NIR observations.

In the absence of counterpart detection, we are only able to give the upper limit for the SAX J1747.0—2853 NIR brightness as the detection limit of the UKIDSS images used (see Table 2). This implies a lower limit on the SAX J1747.0—2853 absolute magnitude of $M_K > 1.0$. In this case, if the secondary fills its Roche lobe, the empirical relation of Revnivtsev, Zolotukhin & Meshcheryakov (2012) predicts an upper limit on the orbital period $P \lesssim 50$ h.

### 3.2 IGR J17464—2811

Faint accreting neutron star binary IGR J17464—2811 (aka XMMU J174716.1—281048) was discovered by XMM–Newton (Sidoli & Mereghetti 2003). In 2005, INTEGRAL observed a type-I X-ray burst from this source, which allowed the distance and luminosity of the system to be estimated as $d \lesssim 3$ kpc Del Santo et al. (2007) and $L_X = 10^{34} \text{erg s}^{-1}$. According to Marshall et al. (2006), the line-of-sight extinction for this distance is $A_K \simeq 0.5$ mag. X-ray spectra from this source also demonstrate a high level of interstellar extinction, $N_H \sim 6–9 \times 10^{22} \text{cm}^{-2}$ (Del Santo et al. 2007), which can be translated into $A_V$ and $A_K$ using the relations from Predelli & Schmitt (1995), suggesting $A_K \sim 3–5$. Discrepancy between X-ray extinction values and Marshall et al. (2006) values at 3 kpc distance may be explained by invoking local absorption material.

### Table 2. Observation log for the UKIDSS data used in this study.

| Field       | Obs. start UTC | Filter | Exp. time (s) | Seeing (arcsec) | Mag. limit Vega mag. |
|-------------|----------------|--------|---------------|-----------------|----------------------|
| SAX J1747.0—2853 | 2006-07-18 09:04:42 | J | 10 | 0.9 | 20.0 |
|             | 2006-07-18 09:12:48 | H | 10 | 0.8 | 19.9 |
|             | 2006-07-18 09:20:50 | K | 5 | 1.0 | 17.8 |
| IGR J17464—2811 | 2006-07-18 09:06:35 | J | 10 | 0.9 | 20.0 |
|             | 2006-07-18 09:14:40 | H | 10 | 0.9 | 18.7 |
|             | 2006-07-18 09:22:01 | K | 5 | 0.9 | 17.5 |
| AX J1754.2—2754 | 2007-05-03 12:51:07 | J | 10 | 0.8 | 19.7 |
|             | 2007-05-03 12:58:53 | H | 10 | 0.9 | 18.7 |
|             | 2007-05-03 13:04:41 | K | 5 | 0.9 | 18.0 |
| IGR J17597—2201 | 2006-07-26 08:06:33 | J | 10 | 1.0 | 20.0 |
|             | 2006-07-26 08:14:39 | H | 10 | 1.0 | 19.2 |
|             | 2006-07-26 08:22:08 | K | 5 | 1.1 | 18.1 |
| IGR J18134—1636 | 2006-07-23 10:38:22 | J | 10 | 1.0 | 20.0 |
|             | 2006-07-23 10:46:27 | H | 10 | 1.0 | 19.0 |
|             | 2006-07-23 10:54:39 | K | 5 | 0.9 | 18.0 |
| IGR J18256—1035 | 2006-06-04 11:54:58 | J | 10 | 0.8 | 20.4 |
|             | 2006-06-04 12:03:27 | H | 10 | 0.8 | 19.5 |
|             | 2006-06-04 12:11:56 | K | 5 | 0.7 | 18.4 |
| Ser X—1     | 2007-05-17 13:54:17 | K | 5 | 0.7 | 18.8 |
|             | 2010-05-12 13:23:23 | J | 10 | 0.8 | 20.4 |
|             | 2010-05-12 13:30:52 | H | 10 | 0.8 | 19.5 |
|             | 2010-05-12 13:36:28 | K | 5 | 0.8 | 18.7 |
Figure 1. NIR images of the studied X-ray source fields from UKIDSS GPS DR7, with Chandra 1σ positional uncertainties overplotted as larger circles in the centre. Possible counterparts are marked with smaller circles and discussed in the text. In the case of Ser X−1, its optical counterpart was already known. The solid point in the Ser X−1 field represents the known optical counterpart position (usually denoted as DSe), whereas empty points with labels denote nearby objects DN and DSw as per Wachter (1997).
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Table 3. X-ray and NIR positional information on the sources analysed in this study. For each source (except Ser X—1, for which the optical counterpart was already known), we give X-ray coordinates, their 1σ uncertainties and the literature reference for the X-ray position. Probabilities of a chance background star superposition are given with respect to the K-filter image and computed with the formula discussed in Section 2. The designation column contains the names of possible counterparts as they are discussed in the text. The star symbol denotes the suggested counterpart; other variants mean that we were not able to suggest a counterpart. Positional errors determined for possible NIR counterparts in this work are radii of 1σ coordinate uncertainties in arcsec with respect to ICRS. The last column contains the separation between NIR and X-ray positions.

| Source       | X-ray position J2000 | Pos. err. (arcsec) | Ref. | Prob. | Design. | NIR position J2000 | Pos. err. (arcsec) | Sep. (arcsec) |
|--------------|----------------------|--------------------|------|-------|---------|-------------------|-------------------|--------------|
| SAX J1747.0–2853 | 17:47:02.60–28:52:58.9 | 0.6                | [1]  | 0.21  | –       | 17:47:02.642–28:52:58.97 | 0.2 | 0.56       |
| IGR J17464–2811 | 17:47:16.15–28:10:48.0 | 0.6                | [2]  | 0.18  | Src A  | 17:47:16.195–28:10:47.62 | 0.2 | 0.75       |
| AX J1754.2–2754 | 17:54:14.49–27:54:35.8 | 0.6                | [2]  | 0.20  | –       | 17:54:14.553–27:54:36.15 | 0.2 | 0.89       |
| IGR J17597–2201 | 17:59:45.52–22:01:39.2 | 0.6                | [3]  | 0.11  | *       | 17:59:45.522–22:01:39.31 | 0.2 | 0.18       |
| IGR J18134–1636 | 18:13:28.03–16:35:48.5 | 0.6                | [4]  | 0.12  | *       | 18:13:28.059–16:35:48.39 | 0.15 | 0.42       |
| IGR J18256–1035 | 18:25:43.83–10:35:01.9 | 0.6                | [5]  | 0.19  | *       | 18:25:43.836–10:35:02.09 | 0.2 | 0.20       |
| Ser X—1       | –                    | –                  | –    | –     | –       | 18:39:57.543+05:02:09.61 | 0.2 | –          |

Notes: [1] From Wijnands et al. (2002).  
[2] This study.  
[3] From Ratti et al. (2010).  
[4] From Tomsick et al. (2009).  
[5] From Tomsick et al. (2008).

We studied the field of IGR J17464–2811 using UKIDSS GPS DR7 JHK data (see Table 2). Two objects were detected in the vicinity of the X-ray error circle, source A (0.7 arcsec away from its centre) and source B (0.8 arcsec away), both of which have a similar colour H – K ≃ 1.6. No sources are visible inside the 1σ X-ray error circle after subtracting the modelled PSF of sources A and B, so we cannot claim a positional identification. See Fig. 1 for the K band field image and Table 3 for positional information on these two detections.

We analysed the brightest and closest visible object, source A, in order to test its association with the X-ray source. The Spitzer archive contains a single source, G000.8344+00.0834, which coincides with source A within the coordinate uncertainties, so we consider it to be the same object. Source B has no counterpart in the GLIMPSE data. The WISE catalogue does not contain sources within 2 arcsec radius from the X-ray position. Hence we were able to construct a five-band SED of source A and fit it with the stellar atmosphere models of Castelli & Kurucz (2004) with extinction, obtaining best-fitting values of the free parameters \( T_{\text{eff}} = 3800 \pm 200 \) K and \( A_V = 2.6 \pm 0.1 \), with reduced \( \chi^2 = 0.12 \).

We also tried to fit a Rayleigh–Jeans law with extinction to the observed SED of source A:

\[
F_\nu = \frac{R^2}{D^2} \times \frac{2\pi \nu^2}{c^2} k T \times 10^{-0.4A_V},
\]

where \( F_\nu \) is the observed flux density in erg cm\(^{-2}\) s\(^{-1}\) Hz\(^{-1}\), \( \nu \) the frequency in Hz, \( c \) the speed of light, \( k \) the Boltzmann constant, \( T \) the effective temperature of a blackbody emitter in K, \( R \) its radius in cm, \( D \) the distance in cm and \( A_V \) the line-of-sight extinction at a given frequency, defined by the Cardelli et al. (1989) law with a single parameter \( A_V \), the extinction in the optical V band. By fitting this function to the observed SED, we obtain two parameters: a normalization factor comprising a combination of \( T \), \( R \) and \( D \) and line-of-sight extinction \( A_V \). For convenience, we express the latter as the extinction in the K band \( A_K \), given that \( A_K/A_V = 0.11 \) (Cardelli et al. 1989).

The Rayleigh–Jeans law describes the SED of source A with worse statistics than stellar atmosphere models, namely reduced \( \chi^2 = 3.2 \). Both extinction-corrected and observed fluxes are shown in Fig. 3.

Figure 2. NIR colour–magnitude diagrams of 4 arcmin star fields in the vicinities of the studied X-ray sources represented as 2D histograms. Star symbols denote proposed (as in the cases of IGR J17597–2201, IGR J18134–1636, IGR J18256–1035) or unlikely (cases of SAX J1747.0–2853, IGR J17464–2811) counterparts. See the text for details on each source.
Figure 3. Flux versus frequency plot of source A from the vicinity of the IGR J17464−2811 X-ray error circle. The upper set of points is flux-corrected for the best-fitting value of Galactic extinction $A_K = 2.6$; the lower set of points is the observed flux not corrected for extinction. GLIMPSE and UKIDSS data are shown. For compactness, photometric errors and bandwidths are displayed for observed flux values only, but correspondingly apply to the extinction-corrected data points too. Similarly, band labels apply to both sets of points.

Whereas such extinction is intuitively very large, in the Marshall et al. (2006) 3D extinction catalogue this region is shown to be one of the most obscured in the Galaxy, reaching our inferred values at a distance of only 8 kpc. Large reddening values in this direction are also immediately clear (from Fig. 2), because the red giant branch in the CMD is shifted redwards to $J-K \approx 4-5$ (note that source A resides within this branch).

On the basis of the observed SED of source A being well represented by a simple cold stellar atmosphere and its position on the CMD consistent with the red giant branch, we conclude that source A is a background red giant, not associated with IGR J17464−2811. Source B is also unlikely to be a counterpart of IGR J17464−2811, because its $JHK$ colours are very similar to those of source A and hence it is likely to be a background object as well. Therefore, we are unable to associate any existing UKIDSS or GLIMPSE source with IGR J17464−2811 and only provide an upper limit of its NIR magnitude derived from the detection limit of our $JHK$ images (see Table 2). Deeper observations are required to identify the source in the NIR.

Adopting $A_K = 0.5$ and a source distance of 3 kpc from Del Santo et al. (2007), from the detection limit of the image in the $K$ band, $m_{lim} = 17.5$, we impose a lower limit on the NIR absolute magnitude of the binary system $M_K \gtrsim 4.6$. Then, substituting an estimated persistent X-ray luminosity value of $L_X = 10^{34}$ erg s$^{-1}$ in the period–magnitude relation for persistent LMXBs (Revnivtsev et al. 2012), we give an upper limit on the orbital period of IGR J17464−2811 (see Table 4).

3.3 AX J1754.2−2754

The source AX J1754.2−2754 was discovered in a survey of the Galactic Centre (GC) region by the Advanced Satellite for Cosmology and Astrophysics (ASCA; Sakano et al. 2002). Long-term observations of the GC region with the INTEGRAL observatory revealed the source at approximately the same flux level (Krivonos et al. 2007). The average source flux is about $10^{-11}$ erg s$^{-1}$ cm$^{-2}$. In 2005, a type-I X-ray burst was detected from the source, which allowed Chelovekov & Grebenev (2007) to identify it as a neutron star. The distance to the source was estimated to be $\approx 7-10$ kpc (for different atmosphere models).

The source was observed with Chandra on 2008 July 15, which allowed us to determine its astrometric position (see Table 3). Additional refinement of the astrometry is not possible, due to the lack of field stars visible on both X-ray and NIR/optical images.

We examined the field of AX J1754.2−2754 in UKIDSS GPS DR7 data. The $JHK$ images contain no positional counterpart within the 1σ X-ray error circle (see Fig. 1); the nearest object is 0.89 arcsec away (see Table 3). This allows us to put only an upper limit on brightness of the NIR counterpart, $M_K > 2.8$. We note that the observing night was of a moderate quality, so the actual limiting magnitude is worse than typical for UKIDSS data sets (see Table 2). The only nearby source in the GLIMPSE catalogue is 1.9 arcsec away from the X-ray coordinates, so is unlikely to be associated with AX J1754.2−2754, given the Spitzer positional uncertainty of 0.3 arcsec in each coordinate. The WISE catalogue does not contain sources within 2 arcsec radius centred at the X-ray position.

Assuming that the secondary star fills its Roche lobe, then the upper limit on the NIR brightness can be used to constrain the orbital period of AX J1754.2−2754. Adopting $L_X \approx 10^{34}$ erg s$^{-1}$ and the appropriate scaling relation from Revnivtsev et al. (2012), we obtain $P \approx 9$ h. In fact, the persistent nature of the source allows us to put tighter constraints on the orbital period of the system. Adopting the boundary of the persistent luminosity from Dubus et al. (2001) and Revnivtsev et al. (2011), $L_X/10^{37} \lesssim 0.025 R_1^{-4} \cdot M_1$, we can obtain $P \lesssim 0.5$ h. Allowing the presence of some systematic uncertainties of the adopted transient–persistent–line boundary, we can conservatively assume that $P \lesssim 2$ h.

3.4 IGR J17597−2201

IGR J17597−2201 (also sometimes referred to as XTE J1759−220) is a LMXB hosting a neutron star, as suggested by the presence of X-ray bursts (Markwardt & Swank 2003) and a high/slow spectral state spectrum typical for neutron star binaries (lutovinov et al. 2005). Markwardt & Swank (2003) reported 20 per cent dips with a typical duration of $\approx 5$ min, which authors interpret as an evidence for a 1–3 h orbital period; however, it is highly unconstrained. This X-ray binary demonstrates long-term variations of its flux (see e.g. its light curve on the web)$^2$, which makes the transient/persistent classification of the source unclear.

Chaty et al. (2008) tried to look for a NIR counterpart of IGR J17597−2201 using the 4-arcsec $XMM$–Newton error circle available at that time and identified six possible candidates in their $JHK$ data obtained with the European Southern Observatory (ESO) New Technology Telescope (NTT). Ratti et al. (2010) later observed a much smaller Chandra error circle in the $J$ filter and suggested Candidate 1 of Chaty et al. (2008) to be the actual positional counterpart, without, however, giving reliable photometry due to bad weather conditions during observations.

We inspected UKIDSS GPS DR7 images in the field of IGR J17597−2201 (see the observation log in Table 2). There is a single bright source visible inside the Chandra error circle (see Fig. 1), consistent with the position of Candidate 1 from Chaty et al. (2008) as well as with their photometry. We consider it to be the positional counterpart of IGR J17597−2201 and give its photometric

$^2$http://asd.gsfc.nasa.gov/Craig.Markwardt/galscan/html/XTE_J1759-220.html by C. Markwardt or http://hea.iki.rssi.ru/integral/survey/source.php?srcid=086 by R. Krivonos

2811 (see Table 2) and only provide an upper limit of its NIR magnitude derived from the detection limit of our $JHK$ images (see Table 2). Deeper observations are required to identify the source in the NIR.

Adopting $A_K = 0.5$ and a source distance of 3 kpc from Del Santo et al. (2007), from the detection limit of the image in the $K$ band, $m_{lim} = 17.5$, we impose a lower limit on the NIR absolute magnitude of the binary system $M_K \gtrsim 4.6$. Then, substituting an estimated persistent X-ray luminosity value of $L_X = 10^{34}$ erg s$^{-1}$ in the period–magnitude relation for persistent LMXBs (Revnivtsev et al. 2012), we give an upper limit on the orbital period of IGR J17464−2811 (see Table 4).
parameters in Table 4. We note that, as expected, the counterpart is redder than most of the stars in its vicinity (see the third panel from the left in Fig. 2).

The GLIMPSE catalogue contains single source G007.5695+00.7703, detected at 3.6 and 4.5 µm within 1σ X-ray positional uncertainty, which we consider to be the same object. Though the catalogue does not include the source at longer wavelengths, it is clearly visible in the 5.8-µm image, so we were able to perform PSF photometry and obtain the source’s magnitude at 5.8 µm and an upper limit at 8.0 µm (see Table 4). The WISE catalogue does not contain sources within 2 arcsec radius centred at the X-ray position.

We fitted a Rayleigh–Jeans law with extinction to the observed SED of the source as described in Section 3.2, in order to test whether the observed data are compatible with a typical stellar SED approximation. For this source, we obtained the value of line-of-sight extinction $A_K = 1.77 \pm 0.07$; the fit had reduced $\chi^2 = 2.8$. We consider this fit quality satisfactory, given the unknown systematic differences between the two surveys used and the multi-epoch nature of the data for a potentially variable source.

Overall extinction-corrected and observed fluxes of IGR J17597−2201 are presented in Fig. 4. In this study, we adopt the value of extinction $A_K \simeq 2.65$ mag calculated from X-ray data by Chaty et al. (2008), though we note that our best-fitting value is slightly smaller.

The distance to this binary system was estimated by Lutovinov et al. (2005) to be around 5–10 kpc, based on the assumption that the luminosity at which the neutron-star-accreting binaries typically change their spectral state/spectral hardness is universal. Adopting this distance, one can estimate the absolute brightness of the binary to be $M_K \simeq -2.2$ to $-3.1$. Such bright NIR counterparts are typical for long-period LMXBs with high X-ray luminosities (see e.g. Revnivtsev et al. 2011, 2012). Assuming the X-ray luminosity of the binary during the analysed NIR observations was $5 \times 10^{35}$ erg s$^{-1}$ and that the secondary star fills its Roche lobe, we can estimate the binary system period following the approach of Revnivtsev et al. (2012) to obtain $P \simeq 800$–2000 h. Such a large orbital period is highly improbable for a system with low persistent X-ray luminosity. On the contrary, if the system is transient, then the observed NIR brightness should be attributable to the secondary star. In this case, the secondary star should be a giant. Therefore the only way under the assumptions above for such a system to produce X-ray emission is accretion of the stellar wind from a giant secondary on to a compact object, a neutron star in the case of IGR J17597−2201. Systems like this are called symbiotic X-ray binaries (SyXB) and they are known to be rare (Masetti et al. 2007), despite the theoretical predictions from population synthesis (Lü et al.

### Table 4. Summary of the NIR and MIR photometry or upper limits and orbital period constraints of the sources analysed in this study. Magnitudes (either positional candidates or upper limits) are given in the Vega system as observed with no extinction correction applied. Magnitude errors are 1σ uncertainties. AbsOLUTE magnitudes $M_K$ are calculated for the $K$ filter using extinction $A_K$ from Marshall et al. (2006) or the indicated references and distance estimates from the literature (see text). Orbital periods of LMXBs are estimated in hours using Revnivtsev et al. (2012)’s relation and X-ray luminosities necessary for that are taken from the references, as discussed in the text.

| Source          | Type   | Observed magnitudes (Vega mag) | Extinction $A_K$ | Abs. mag. $M_K$ (Vega mag) | Period (h) |
|-----------------|--------|-------------------------------|-----------------|---------------------------|------------|
| SAX J1747.0−2853 | NS LMXB | $J > 20.2; H > 19.0; K > 17.8$ | 2.4$^a$ | $\gtrsim 1.0$ | $\lesssim 50$ |
| IGR J17464−2811  | NS LMXB | $J > 20.0; H > 18.7; K > 17.5$ | 0.5$^a$ | $\gtrsim 0.6$ | $\lesssim 4$ |
| AX J1754.2−2754  | NS LMXB | $J > 18.7; H > 18.7; K > 18.0$ | 0.9$^a$ | $\gtrsim 2.2$ | $\lesssim 2$ |
| IGR J17597−2201  | SyXB   | $J = 16.58 \pm 0.07; H = 14.87 \pm 0.11; K = 13.89 \pm 0.11$ | 2.6$^b\dagger$ | $\simeq 2.2$ | $\ldots - 3.1$ |
| IGR J18134−1636  | AGN    | $J > 20.0; H = 16.03 \pm 0.15; K = 14.59 \pm 0.18$ | $\simeq 1.9^c$ | $\ldots - 2$ | $\ldots - 2$ |
| IGR J18256−1035  | HMXB   | $J = 16.88 \pm 0.15; H = 16.16 \pm 0.16; K = 15.63 \pm 0.15$ | 0.3$^a$ | $\gtrsim 2.1$ | $\gtrsim 7.0$ |

Notes: $^a$From Marshall et al. (2006).
$^b$From Chaty et al. (2008).
$^c$From Rayleigh–Jeans law fitting, this study.

![Figure 4. Flux versus frequency plot for the IGR J17597−2201 counterpart in the near-infrared. The upper set of points is flux-corrected for Galactic extinction such that flux distribution matches best Rayleigh–Jeans law; the lower set of points is the observed flux uncorrected for extinction. GLIMPSE and UKIDSS data are shown. For compactness, photometric errors and bandwidths are displayed for observed flux values only, but correspondingly apply to the extinction-corrected data points too. Similarly, band labels apply to both sets of points.](https://academic.oup.com/mnras/article-abstract/446/3/2418/2892043)
This wind accretion cannot provide high mass accretion rates and thus limits the X-ray luminosity at the level of $10^{34} - 35$ erg s$^{-1}$. It is only recently that we started to sample these luminosities with X-ray observations at the typical Galactic distance scale of a few kpc and started to discover new possible SyXBs (e.g. Revnivtsev et al. 2013). It is hence natural to expect more SyXB to be discovered in the coming years. We think that the IGR J17597$-$2201 binary system is likely another example of the emerging class of symbiotic X-ray binaries in our Galaxy. Spectroscopic follow-up observations are required for definitive conclusions on the nature of IGR J17597$-$2201 to be drawn.

3.5 IGR J18134$-$1636

IGR J18134$-$1636 was discovered by INTEGRAL (Bird et al. 2006; Krivonos et al. 2007). Its accurate astrometric position was determined from Chandra observations (Tomsick et al. 2009). The energy spectrum of the source is highly absorbed, with $N_{H} \cong (4-17) \times 10^{22}$ cm$^{-2}$.

We studied NIR data for this source in UKIDSS DR7 (see Table 2) and report that a single object is visible in $H$- and $K$-band images inside the X-ray positional uncertainty, whereas it is not present in the $J$-band exposure (see the $K$-band image in Fig. 1). Based on NIR coordinates from UKIDSS data, we also identify this NIR counterpart with the object denoted as G013.8877$+$00.5968 in the GLIMPSE catalogue, where it is detected in all four bands. The separation between these two catalogued sources is 0.3 arcsec. Furthermore, the source is present in the WISE (Wright et al. 2010) all-sky catalogue at a nominal distance of 0.6 arcsec from the centre of the $X$-ray coordinates. Since it exhibits similar fluxes as in Spitzer data and given the 0.4 arcsec uncertainty in the WISE position of each coordinate, we consider it to be the same object.

We tried to determine the source’s extinction with the same method we used above for other sources and note that the data cannot be fitted with a Rayleigh–Jeans law in a physically meaningful range of extinction. This implies the presence of significant emission excess at MIR wavelengths discrepant from the blackbody radiation, akin to the obscured supergiant X-ray binary IGR J16318$-$4848 (Chaty & Rahoui 2012), which is also known to possess significant local absorption. However, IGR J18134$-$1636 shows 2–3 times larger MIR/NIR flux ratio (see Fig. 5). We think that this MIR excess feature and distance constraint $d = (L_{X}/10^{35})^{1/2} \times 17$ kpc make it unlikely that IGR J18134$-$1636 is an HMXB, but further observations (e.g. infrared spectroscopy) are required to test this idea.

GLIMPSE source G013.8877$+$00.5968 was also classified as a young stellar object (YSO) candidate by Robitaille et al. (2008) based on its intrinsically red mid-infrared colour. In the NIR, the source is indeed redder than most stars in its vicinity (see the second panel from the right in Fig. 2). To check the YSO classification, we performed photometry fitting using an online YSO SED fitting tool (Robitaille et al. 2007) on the UKIDSS, Spitzer and WISE data sets and managed to achieve a fit with a reduced $\chi^2 = 10.6$ for one of the models from the grid described by a distance $d \cong 600$ pc and an interstellar extinction $A_K \cong 3.2$. While this model may seem unfavourable based on the fit statistics, we suspect that data errors are somewhat underestimated, because they come from different instruments or, maybe more importantly, from different epochs. The potential variability of the candidate definitely adds scatter to non-simultaneous photometric measurements. To get an idea of what the possible uncertainties are, we can compare the fluxes of the candidate between nearby GLIMPSE 3.6- and 4.5-$\mu$m bands and WISE bands W1 and W2 correspondingly (see Table 4). They should match each other within the uncertainties, but in fact we see that there is a difference of a factor of 2 in the sum of the formal uncertainty values. Whatever the reason for this, e.g. systematic photometric errors between the surveys or the variability of the source, such a mismatch hints that our $\chi^2$ value may be overestimated. We therefore think that, in principle, the infrared SED of IGR J18134$-$1636 can be described by YSO models and the observed X-ray flux does not contradict the hypothesis of a YSO emitting at $L_X \cong 10^{35}$ erg s$^{-1}$, which is not unreasonable for these sources. However, we discard the hypothesis of a YSO nature for IGR J18134$-$1636 based on its X-ray spectral properties: a hard photon index $\Gamma \cong 1.4$ as per Tomsick et al. (2009), which is atypical for an X-ray emitting YSO, and the requirement of excessive extinction to account for the observed infrared SED. Total Galactic extinction in the direction of the source is estimated to be $A_K = 2.4$ (Schlegel, Finkbeiner & Davis 1998), 2.0 (Schlafly & Finkbeiner 2011) and 1.9 at 15 kpc (Marshall et al. 2006), much smaller than the best-fitting value obtained.

The hard photon index of IGR J18134$-$1636 hints at its probable active galactic nucleus (AGN) nature, as these are known to have similar photon indices (see e.g. Lin, Webb & Barret 2012). To test this hypothesis, we performed 11-band NIR-to-MIR SED fitting with a set of 25 galaxy and AGN templates from the Spitzer Wide-area InfraRed Extragalactic survey (SWIRE) library (Polletta et al. 2007) using foreground extinction and redshift as free parameters. We obtained a best-fitting reduced $\chi^2 = 7.3$ using the heavily obscured broad absorption line quasar Mrk 231 template seen through $A_K = 1.7$ mag Galactic extinction. Fit degeneracy does not allow us to constrain its redshift, but it is likely to be less than 0.05. Though the fit statistics do not look very convincing, we again note that our formal photometry errors may be underestimated. This AGN template nevertheless matches our data better than other models we checked (stellar atmospheres, Rayleigh–Jeans, YSOs and all other SWIRE library models). Moreover, the value of foreground extinction obtained is in line with the total Galactic extinction in...
the IGR J18134—1636 direction and the heavily obscured nature of the best template chosen agrees well with X-ray data showing significant intrinsic absorption of the source. Therefore we suggest IGR J18134—1636 to be an obscured AGN seen through the disc of our Galaxy.

3.6 IGR J18256—1035

The source was discovered by INTEGRAL (Bird et al. 2006; Krivonos et al. 2007). Its astrometric position was refined later by Landi et al. (2007) using data from the Swift observatory and the most accurate position was obtained with the help of Chandra observations by Tomsick et al. (2008), who estimated the 0.3–10 keV flux to be $2.9 \times 10^{-12}$ erg cm$^{-2}$ s$^{-1}$.

We performed an analysis of the IGR J18256—1035 field in the UKIDSS GPS DR7 data (see observation log in Table 2). A single object is visible in these JHK images inside the Chandra positional uncertainty (see Fig. 1) and we propose it as the NIR counterpart of this binary. The GLIMPSE catalogue contains an object G020.5947+00.8120 detected in a single 3.6-μm band and separated from the centre of the X-ray position by only 0.5 arcsec. Though formally it may be a counterpart as well, we think, however, that due to the lower angular resolution of the Spitzer IRAC detector compared with UKIRT, this GLIMPSE object is a blend of three sources clearly visible in the K band in Fig. 1 around the X-ray coordinate uncertainty and hence its photometric measurements cannot be used together with the UKIDSS ones. The visually elongated shape of the GLIMPSE object supports this idea as well. Moreover, if we consider the four-band SED (JHK and 3.6 μm), it cannot be described by a reasonably smooth NIR emission model that fits JHK data, as the 3.6-μm band flux is 1.5 mag brighter than simple JHK extrapolation to 3.6 μm. The WISE catalogue does not contain sources within a 2 arcsec radius centred at the X-ray position.

The source’s X-ray spectra are strongly absorbed along the line of sight. In the work of Tomsick et al. (2008), the absorption column was determined to be $3.1 \times 10^{22}$ cm$^{-2}$ for a power-law energy spectrum with photon index $\Gamma = 0.1$. At the same time, the X-ray spectrum presented by Tomsick et al. (2008) hints at a steeper photon index. If this is the case, the absorbing column value will likely be a bit larger.

The source’s JHK SED can be fitted with the Rayleigh–Jeans law with extinction, which results in $A_K = 1.0$ (reduced $\chi^2 = 1.3$). Using the Marshall et al. (2006) 3D Galactic extinction model, $A_K = 1.0$ corresponds to distances larger than 10 kpc for the given sky position. The total value of Galactic extinction in this direction in Schlegel et al. (1998) is smaller than in Marshall et al. (2006), $A_K = 1.1$ (compare with $A_K = 0.9$ in Schlafly & Finkbeiner 2011). High photoabsorption and strong extinction along the line of sight to the source (compared with the total Galactic value) can be taken as an indication that the distance to the source is greater than $\approx 5$–10 kpc.

At the same time, if we consider the LMXB accretion-disc model of Revnivtsev et al. (2012), such a combination of X-ray flux, observed K-band magnitude and a realistic range of extinction yields orbital periods between 200 and 1000 h and excessive values of (unreddened) $J - K > 4$ colour within a plausible distance. We interpret this as an argument against the LMXB nature of this source. For $A_K \leq 1.0$ and observed colour $J - K = 1.25$, the object must be intrinsically blue, like e.g. a star of spectral class B having unreddened $(J - K)_0 = -0.25$.

Based on the observed source’s colour and extinction-related reasons above, we suggest it is an HMXB. The absolute magnitude of a B giant, $M_K \approx -2$ (Pickles 1998), would imply a distance of about 20 kpc and a height of 300 pc above the Galactic plane, which seems excessive for this type of object (Lutovinov et al. 2013). On the other hand, we note that IGR J18256—1035 is situated only 50 arcmin away from the nearest star-forming complex 20.7–0.1 in the Russeil (2003) catalogue, which may agree with the correlation between HMXBs and the distribution of OB star-forming complexes (Bodaghee et al. 2012; Coleiro & Chaty 2013). The kinematic distances to 20.7–0.1 (11.8 kpc) and to the second nearest complex 21.0+0.0 (14.0 kpc), approximately 55 arcmin away, may be used as indicative for IGR J18256—1035 if it is fainter than a BII star.

We stress that, without additional data, it is not possible to rule out a chance superposition of a nearby B star, inactive in X-rays, that outshines the (fainter) LMXB.

3.7 Ser X—1

Ser X—1 was discovered using rocket experiments by Bowyer et al. (1965). Detection of type-I X-ray bursts from the source established that the binary harbours a neutron star (Swank et al. 1976; Li et al. 1977). The source distance was estimated to be 9.5–12.7 kpc (Jonker & Nelemans 2004). Its average luminosity is about $5 \times 10^{36}$ erg s$^{-1}$ (Masetti et al. 2004).

It has long been thought that the optical counterpart of Ser X—1 is an MM Ser variable. However, it turned out to be a close superposition of several objects. First, Thorstensen, Bowyer & Charles (1980) found that the previously identified counterpart contains two components, unrelated north DN and true variable south DS, separated by 2.1 arcsec. Later, Wachter (1997), using PSF fitting, showed that the southern component of the blend DS in turn contains two optical objects, eastern DSe and western DSw, separated around 1 arcsec. Wachter (1997) was not able to measure photometry of DSe reliably, but proposed it to be the true counterpart of Ser X—1 based on its bluer colour. Later, Hynes et al. (2004) carried out high-quality spectral observations of the DSe and DSw blend and confirmed that DSe is the true LMXB, based on its spectral features.

The field of Ser X—1 was twice observed by UKIDSS (see Table 2), during the first epoch in the K band only (included in DR7 and later) and during the second epoch in all three JHK filters (available starting from the DR9 release). Both nights had excellent seeing conditions. We reliably detect and resolve all the close objects previously known to compose MM Ser, including the true counterpart DSe (see Fig. 1), and we list its first NIR photometry estimates in Table 4. Two K-band magnitudes favour a slight variability of the source, though the confidence is not so certain.

We also note that the dereddened colour of Ser X—1 $J - K = -0.1$ matches well the value $J - K \approx 0.0$ expected for this system from Revnivtsev et al. (2012)’s irradiated accretion disc model in X-ray binaries with Roche-lobe overflow.

The GLIMPSE catalogue does not contain any sources within 2 arcsec of the optical position of Ser X—1.

4 SUMMARY

We studied data of three infrared surveys, UKIDSS, GLIMPSE and WISE, around the positions of seven X-ray sources. All but two were previously unidentified in the optical and had no certain type identification. In four cases, we were able to detect their positional counterparts in arcsec-scale X-ray error circles and in three cases we determined an upper limit for the source’s brightness. Based on this multiband photometric information, we suggest that one source from our set is a rare symbiotic X-ray binary, four are LMXBs (one of them, Ser X—1, is well-studied, but had no NIR photom-
eternity before), one is an HMXB and one is a tentative AGN. For one of the LMXBs, AX J1754.2−2754, which was not detected directly, we give a 2 h upper limit on its orbital period estimated using Revnivtsev et al. (2012)’s relation for the NIR luminosity of an illuminated accretion disc powered through Roche-lobe overflow. Our main results are summarized in Table 3, which gives the positional information, and in Table 4, which gives details of the photometry, suggested types, absolute magnitudes and orbital periods of counterparts.

ACKNOWLEDGEMENTS
This research has made use of the VizieR catalogue access tool, CDS, Strasbourg, France. The authors made use of the website ‘INTEGRAL sources’ of Jerome Rodriguez (http://irfu.cea.fr/Sap/IGR-Sources/). This publication makes use of data products from the Wide-field Infrared Survey Explorer, which is a joint project of the University of California, Los Angeles, and the Jet Propulsion Laboratory/California Institute of Technology, funded by the National Aeronautics and Space Administration. This work is based in part on observations made with the Spitzer Space Telescope, which is operated by the Jet Propulsion Laboratory, California Institute of Technology under a contract with NASA. The authors are grateful to Mark Burke for suggesting a number of improvements and to an anonymous referee, whose comments helped to improve significantly the contents and presentation of the manuscript. IZ was supported by the Russian Foundation for Basic Research grant 12-02-00186. MR was supported by the RFBR grant 13-02-00741. This paper has been typeset from a TeX file prepared by the author.