Sample of LMXBs in the Galactic bulge – I. Optical and near-infrared constraints from the Virtual Observatory

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ABSTRACT

We report on the archival optical and near-infrared observations of six low-mass X-ray binaries situated in the Galactic bulge. We process several recent Chandra and XMM-Newton as well as Einstein data sets of binary systems suspected to be ultracompact, which give us arcsec-scale positional uncertainty estimates. We then undertake a comprehensive search in existing archives and other Virtual Observatory resources in order to discover unpublished optical/near-infrared data on these objects. We find and analyse data from European Southern Observatory Archive and UKIRT Infrared Deep Sky Survey on SLX 1735−269, 3A 1742−294, SLX 1744−299, SLX 1744−300, GX 3+1 and IGR J17505−2644 systems and publish their finding charts and optical flux constraints in this paper, as well as simple estimates of the physical parameters of these objects.

Key words: stars: individual: SLX 1735−269 – stars: individual: 3A 1742−294 – stars: individual: SLX 1744−299 – stars: individual: SLX 1744−300 – infrared: stars – X-rays: binaries.

1 INTRODUCTION

Low-mass X-ray binaries (LMXBs) are the most common astrophysical objects that host neutron stars and black holes. Galactic LMXBs were discovered at the dawn of X-ray astronomy (Giacconi et al. 1962) and now with the help of advanced orbital X-ray facilities such as Chandra or XMM-Newton they are being intensively studied in other galaxies as well (Fabbiano 1989; Primini, Forman & Jones 1993; Sarazin et al. 2003; Gilfanov 2004; Kim & Fabbiano 2004; Fabbiano et al. 2007). Apart from being hosts for exotic objects such as black holes and neutron stars, LMXBs attract a lot of attention as compact binaries. Indeed, understanding of their secular evolution can give us insights into the rate of events extremely important in astrophysics, such as (1) supernova Ia, standard cosmology candles, and (2) mergers of compact objects (such as white dwarf–white dwarf, neutron star–neutron star), which are crucial for our understanding of gravitational wave signals and construction of future gravitational wave detectors (Belczynski, Kalogera & Bulik 2002; Nelemans 2009).

Orbital periods of LMXBs evolve very slowly, making it challenging to observe their change (Burderi et al. 2009). However, it is clear that secular evolution of long-living LMXBs directly influences the overall statistical properties of their population, such as distribution over orbital periods or X-ray luminosities (Rappaport, Verbunt & Joss 1983; Kolb 1993; Howell, Nelson & Rappaport 2001). Therefore, by measuring the statistical properties of Galactic LMXBs, one can make important conclusions about the mechanisms of their long-term evolution. The ultimate sample for this purpose is the set of persistent sources, because it is for these sources that we can make an estimate of their time-averaged mass transfer rate with more or less confidence, which is almost absent in the case of transient objects. However, even in the case of persistent sources there might also be uncertainties connected with sources’ long time-scale variability (see e.g. Friedhorsky & Holt 1987; Gilfanov & Arefiev 2005; Maccarone et al. 2010).

In order to link the properties of binary systems with their statistical distributions, we need to measure the main parameters of LMXBs, such as orbital periods, type of donor star and others. These detailed studies are only possible for systems within our Galaxy. But even for these systems the studies have not yet completed in a systematic manner, although considerable efforts were invested in such projects (see e.g. Bandyopadhyay et al. 1999; Jonker et al. 2000; Wachter et al. 2005). Presently, the chance to know LMXB orbital parameters strongly increases if the binary system harbours a giant companion or if it is seen edge-on (and thus we observe periodic dips or eclipses of an X-ray source).

To continue our previous efforts in identifying X-ray binaries (Zolotukhin 2009; Zolotukhin, Revnivtsev & Shakura 2010), we undertake a systematic study of an unbiased sample of persistent LMXBs in an optical and near-infrared (NIR) spectral range. The sample of persistent LMXBs is taken from the deep survey of the Virtual Observatory.

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Galaxy, performed by the INTEGRAL observatory in an energy range of 17–60 keV (Krivonos et al. 2007; Revnivtsev et al. 2008), which is free from all complications, caused by the interstellar absorption in the Galactic disc. As the optical and NIR emission of the LMXBs is mainly caused by reprocessing of their X-ray flux in the extended accretion disc [see e.g. van Paradijs & McClintock (1994)]; however, at longer wavelengths there might be a considerable contribution from the jet – see e.g. Homan et al. (2005); Russell, Fender & Jonker (2007); Migliari et al. (2010) for comparison of the NIR brightness of sources with their X-ray luminosity], this will allow us to make at least an estimate of the size of the accretion disc and therefore the binary system orbital parameters. In this work, we study sources in the direction of the Galactic Centre; most of them very likely reside in the Galactic bulge (see e.g. discussion in Revnivtsev et al. 2008). This gives an additional advantage over some arbitrarily chosen set of LMXBs to adopt a canonical distance of 8 kpc in the case of a missing distance estimate for a source.

As the first step of this study, we perform a dedicated search of the unpublished optical and NIR data publicly available for the sources of our interest in observational archives and other resources of the Virtual Observatory (VO). In order to facilitate possible follow-up studies, we publish immediate observational results for a subset of them, leaving other sources with deep enough data existing in the VO and thorough theoretical interpretation for the future.

2 DATA

2.1 X-ray

The sample of LMXBs, which we study, is taken from the INTEGRAL all-sky survey (Krivonos et al. 2007). We have limited ourselves to sources in the Galactic bulge region, which are known to be neither active galactic nuclei nor high-mass X-ray binaries (Revnivtsev et al. 2008). Accurate astrometric positions of a subsample of these sources were extracted either from archival Chandra observations or from dedicated Chandra observations, performed in 2009 (PI M. Revnivtsev). In all but one analysed Chandra observations, the astrometric accuracy of the position of the sources is provided by direct imaging. The position of sources was determined with the WAVDETECT task of CIAO 4.2 package and has a 90 per cent confidence level. The position of the source GX 3+1 is measured from observation, taken in the continuous-clocking mode of Chandra (observation ID 2745); therefore, essentially only one coordinate of the source position is measured with high accuracy. The position of this source was additionally constrained by archival Einstein/High Resolution Imager (HRI) imaging observation.

2.2 Optical and NIR

We have checked two well-known data collections, European Southern Observatory (ESO) Archive\(^1\) and WFCAM Science Archive,\(^2\) for the optical/NIR imaging data on the sources of our interest. Following the principal differences between these data sources, we employed slightly different processing sequences.

In spite of the difficulties with the calibration data that frequently accompanied proper ESO Archive data sets’ reduction, we accurately retrieved them and reduced raw data (both science and Landolt standard frames) to the science-ready form using generic routines from IRAF CCDPROC package. Then we performed point spread function (PSF) photometry measurements of science frames and aperture photometry of the standards fields using IRAF DAOPHOT package, thus transforming instrumental magnitudes to the standard (Vega) system.

WFPCAM Science Archive was used to retrieve publicly available science-ready JHK imaging data of the Galactic Plane Survey (GPS), which is a part of UKIRT InfraRed Deep Sky Survey (UKIDSS; Lawrence et al. 2007), Data Release 3 (DR3). All frames were binned 2 × 2, obtaining a 0.4 arcsec pixel\(^{-1}\) scale to get rid of evident CCD artefacts. In order to ensure the search for NIR counterparts with the maximum sensitivity, we decided to employ the same photometry procedures for all UKIDSS fields, as we did for ESO data. Calibration dependencies in this case were constructed comparing our 2-arcsec aperture measurements with UKIDSS JHK magnitudes measured in this aperture (\(^*\)AperMag3 in terms of UKIDSS data columns), thus transforming our instrumental magnitudes to the intrinsic UKIDSS magnitude system, i.e. to the Vega system as for the ESO data.

In cases where we mention upper limits, they were estimated using magnitudes of the faintest stars detected at a 3\(\sigma\) level above the background by our algorithm. For ESO data that frequently come without astrometric calibration, we performed our own calibration procedure using the SCAMP routine (Bertin 2006). For UKIDSS data we used an in-place WCS solution considering it to be precise at a 100-mas level for each coordinate with respect to the Two-Micron All-Sky Survey (2MASS) astrometry system (see e.g. Deacon et al. 2009), which itself is known to be accurate at the 100-mas level in the International Celestial Reference System reference frame (Skrutskie et al. 2006). Our astrometric uncertainty thus includes not only our coordinates’ error estimate, but also the uncertainty of the reference system we used in each specific case. For the reasons of interoperability with X-ray observations, by astrometric uncertainty we usually mean the radius of a positional error circle unless otherwise specified.

3 OBSERVATIONS AND RESULTS

3.1 SLX 1735–269

SLX 1735–269 was previously studied by Wilson et al. (2003), who obtained with Chandra its X-ray position at thearcsecond accuracy level and first attempted to detect its NIR counterpart using dedicated observations at UKIRT. No source was found in the J band down to the limiting magnitude of 19.4.

In this work, we analysed \(R\) and \(I\) filter data on SLX 1735–269 available in ESO Archive under programme ID 67.D-0116(A). The data set contained 900-s exposures for every filter taken on 2001 May 28 between 08:22 and 08:58 UT with the ESO Multi-Mode Instrument (EMMI) detector attached to the ESO 3.6-m New Technology Telescope (NTT). The single source is clearly visible inside the Chandra error box by Wilson et al. (2003) in the \(R\) image (see Fig. 1) and is at the 3\(\sigma\) level in \(I\). We estimated the brightness of this positional candidate as \(R = 21.31 \pm 0.12, I = 20.10 \pm 0.07\). The astrometric solution was obtained in the 2MASS reference frame and had 0.15-arcsec calibration uncertainty (see Table 1). Note, however, that due to the shape of the measured source we cannot rule out its double nature, and this may have influenced our coordinates and magnitude estimate.

The X-ray bursting behaviour of SLX 1735–269 was extensively analysed in Molkov et al. (2005) who confirmed previous estimates of its distance as 8.5 kpc. This, together with extinction for this

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1 http://archive.eso.org
2 http://surveys.roe.ac.uk/wsa/

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line of sight taken from Marshall et al. (2006) \((A_V \simeq 0.5 \text{ mag})\) and normal extinction law as in Cardelli, Clayton & Mathis (1989), gives us upper limits (due to the uncertain nature of position-based identification) on absolute magnitudes in \(R\) and \(I\) for this system: 
\[ M_R \gtrsim 3.4 \text{ mag and } M_I \gtrsim 3.4 \text{ mag}. \]

### 3.2 3A 1742–294

3A 1742–294 (sometimes also referred to as 1A 1742–294 or 2E 1742.92929) is a persistent X-ray binary which exhibits Type-I X-ray bursts. The first optical finding chart of this source was presented in Jernigan et al. (1978), though X-ray positional uncertainty at that time did not allow us to make unambiguous conclusions. Wijnands et al. (2006) determined with Chandra its X-ray position accurate to the arcsecond level, but very little efforts were invested in a study of this error box in the optical/NIR domain.

We analysed the field around 3A 1742–294 using UKIDSS GPS DR3 images obtained by the 3.8-m UKIRT telescope on 2006 July 18 at 09:30 with 10-s integration time (filter \(J\)), at 09:38 with 10-s integration time (filter \(H\)) and at 09:45 with 5-s integration time (filter \(K\)). We did not detect any source well within the X-ray coordinates’ uncertainty by Wijnands et al. (2006) (see Fig. 2), and therefore we publish only the upper limit on the X-ray flux of 3A 1742–294 (see Table 1). However, we note that to the south-east immediately close to the formal error circle from Chandra there is a blended object with two components; either of them may turn out to be a counterpart. Our PSF photometry procedure cannot resolve them, whereas single detection lies outside of the X-ray error region.

### Table 1.

Summary of the optical/NIR constraints, positional estimates and orbital period constraints of the sources analysed in this study. Magnitudes (either positional candidates or upper limits) are given in the Vega system. Positional errors determined for possible counterparts in this work are radii of coordinate uncertainties in arcseconds with respect to International Celestial Reference Frame. Sources of positional uncertainties are indicated in the footnotes. Probabilities of an accidental background star superposition are given for the reddest filter in the case of an upper limit, or the reddest filter, where detection is available (see the text). Absolute magnitudes are calculated for the reddest available filter using extinction from Marshall et al. (2006) and distance estimates from the literature (see the text); we consider all them being upper limits due to the uncertain nature of position-based identification. Upper limits on orbital periods are estimated in hours using the van Paradijs & McClintock (1994) relation and X-ray luminosities taken from the references, indicated in the footnotes.

| Design. RA (J2000) | Dec. (J2000) | Pos. err. | Probability | Magnitude | Abs. mag. | Period |
|-------------------|-------------|-----------|-------------|-----------|-----------|--------|
| SLX 1735–269      |             |           |             | R = 21.31 ± 0.12; I = 20.10 ± 0.07 | \(M_I \gtrsim 3.4\) | \(\lesssim 2.6^b\) |
| src A 17:38:17.11 | −26:59:39.1 | 0.2^e     | 0.07        |           |           |        |
| 3A 1742–294       |             |           |             | J > 19.9; H > 18.6; K > 17.9 | \(M_K \gtrsim 2.0\) | \(\lesssim 28^d\) |
| src A 17:46:05.20 | −29:30:53.3 | 1.3^c     | 0.55        |           |           |        |
| SLX 1744–299      |             |           |             | I = 23.37 ± 0.28; J > 19.9; H > 18.7; K > 18.0 | \(M_I \gtrsim 2.2\) | \(\lesssim 24^e\) |
| src A 17:47:25.89 | −30:00:01.6 | 0.4^e     | 0.17        |           |           |        |
| SLX 1744–300      |             |           |             | I > 23.4; J > 19.8; H > 18.8; K > 18.0 | \(M_K \gtrsim 1.9\) | \(\lesssim 65^e\) |
| src A 17:47:26.01 | −30:02:41.8 | 0.7^f     | 0.17        |           |           |        |
| src B 17:47:56.06 | −26:33:48.9 | 0.2^e     | 0.55        | J = 16.43 ± 0.11; H = 15.42 ± 0.09; K = 14.87 ± 0.13 | \(M_K \gtrsim 0.2\) | \(\lesssim 14^g\) |
| src A 17:50:39.48 | −26:44:36.3 | 0.3^g     | 0.13        | J > 20.3; H > 19.3; K = 18.5 ± 0.4 | \(M_K \gtrsim 2.2\) | \(\lesssim 390^h\) |

\(^a\) From optical/NIR observations, this study.
\(^b\) Using \(L_X\) (0.5–100 keV) from Molkov et al. (2005) transformed to 2–10 keV by means of the relation from Revnivtsev et al. (2008).
\(^c\) From Wijnands et al. (2006).
\(^d\) Using \(L_X\) (2–10 keV) from Wijnands et al. (2006).
\(^e\) Using \(L_X\) (2–10 keV) from Sidoli et al. (1999).
\(^f\) From X-ray observations, this study.
\(^g\) Assuming \(L_X\) from Galloway et al. (2008), all comes from 2–10 keV (Revnivtsev et al. 2008).
\(^h\) Using \(L_X\) (17–60 keV) from Revnivtsev et al. (2008) transformed to 2–10 keV by means of the relation from the same paper.
Galloway et al. (2008) estimated the distance to 3A 1742−294 from its photometric radius expansion X-ray bursts as 5.8, ..., 7.5 kpc. Adopting \( d = 6 \) kpc and corresponding \( M_K \approx 2.0 \) mag from Marshall et al. (2006), our upper limit can be translated to 3A 1742−294 absolute magnitude constraint: \( M_K \gtrsim 2.0 \) mag.

### 3.3 SLX 1744−299

The source SLX 1744−299 is the southern source of the close pair SLX 1744−299/300 (~2.5 arcmin angular separation), discovered in the Galactic Centre region by Spartan1 experiment (Kawai et al. 1988) and resolved into two sources by the Spacelab X-ray telescope (Skinner et al. 1987, 1990), MIR-KVANT-TTM and GRANAT/ART- P telescopes (Siuniaev et al. 1991). Both sources are known to be X-ray bursters (Skinner et al. 1990; Siuniae et al. 1991).

The position of the source was determined with the help of Chandra imaging, performed during observation IDs 2834 (ACIS-I imaging, 2002 October 23) and 9106 (HRC-I imaging, 2008 February 7). The source, being very bright for ACIS-I capacity, suffers from strong pile-up, which creates a hole around the source position. We have used interception of this area with the readout streak, clearly visible on the image as the estimate of the centroid of the source position: RA = 17:47:25.88, Dec. = −30:00:02.0 (J2000). Absence of a large number of X-ray sources, available for cross-matching with existing optical or IR images, does not allow us to improve the accuracy of the astrometry; therefore, we anticipate that the uncertainty of the position here is mainly determined by the Chandra aspect solution and equals to ~0.6 arcsec. The second Chandra observation of the source was performed with HRC-I and does not suffer from pile-up. We have determined the position of the source with the help of the WAVDETECT task of CIAO 4.0 package. As the source in this observation is relatively far from the optical axis of the telescope (~3 arcmin), the accuracy of its localization is worse than usual. According to the study by Alexander et al. (2003), the accuracy of the Chandra localization of sources at these offsets is about ~0.4 arcsec if the references of X-ray and optical images match. In the absence of cross-match between our images and the optical reference frame, we added 0.6 arcsec quadratically to the resulting uncertainty radius, thus obtaining an accuracy of ~0.7 arcsec.

We analysed I filter data on SLX 1744−299 available in ESO Archive under programme ID 079.D-0385(C). The data set contained six 600-s exposures taken on 2007 June 23 between 06:27 and 07:36 UT with the EMMI detector attached to the ESO 3.6-m NTT telescope. First three exposures were centred at SLX 1744−299, whereas the remaining ones at SLX 1744−300, though X-ray positions for both sources are visible on all frames as there is only 2.7 arcmin between them, and they fall well within the EMMI single field of view. Observing conditions became slightly worse in the second half of the data set, so we summed only the first three of them, obtaining 1800 s of the total integration time. The single source is clearly visible inside the Chandra error box in the co-added image (see the left-hand panel of Fig. 3), though we note the source to be sharp, somewhat untypical for this image. At the same time it is marginally detected at individual exposures, so we cannot immediately consider it as an artefact, especially after careful inspection of all the calibration frames we used, since they contain nothing that can influence the source’s profile in an observed way. The PSF photometry of these data yields \( I = 23.37 \pm 0.28 \) for this positional candidate. The astrometric solution was achieved to 0.2-arcsec precision in the GSC 2.2 reference frame, which is known to be precise up to the 170-mas level on both coordinates (see e.g. Fienga & Andrei 2004).

This field is also present in the UKIDSS GPS DR3 survey (see the right-hand panel of Fig. 3). Frames taken by the 3.8-m UKIRT telescope on 2006 July 20 between 09:16 and 09:30 UT (10-s exposure for J and H and 5 s for K) show nothing remarkable in the error box, closely packed between neighbouring objects in the dense field, so we consider this as an upper limit estimate (see Table 1).

At the canonical distance of 8 kpc using the same extinction treatment as above, we estimate \( M_I \gtrsim 2.2 \) for SLX 1744−299.

### 3.4 SLX 1744−300

The source is the northern source of the pair of X-ray bursters SLX 1744−299/300.

The position of the source was determined with the help of Chandra observation ID 9106 (HRC-I imaging). During this observation the source was quite far from the optical axis of the telescope (~5.4 arcmin), where its PSF, and thus the accuracy of the localization, is significantly worse. We have determined the position of the source with the help of the WAVDETECT task of CIAO 4.0 package. The centroid of the source position was determined to be RA = 17:47:26.02, Dec. = −30:02:41.8 (J2000) with the estimated accuracy of 0.7 arcsec.

For SLX 1744−300 we used exactly the same data sets in both ESO and UKIDSS archives, as for SLX 1744−299. We do not detect any source up to 3σ limiting magnitude of \( I = 23.4 \) (see the left-hand panel of Fig. 4) in ESO data. The UKIDSS data set also contains nothing remarkable in the error box [though an object RA = 17:47:25.97, Dec. = −30:02:41.1 (J2000) is detected 0.3 arcsec away from its boundary in H and K images: \( H = 17.90 \pm 0.14; K = 16.75 \pm 0.14 \)], and we hence publish only upper limits in Table 1.

At the canonical distance of 8 kpc using the same extinction treatment as above, we are able to pose the following constraint on SLX 1744−300 absolute magnitude: \( M_K \gtrsim 1.9 \).

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3.5 GX 3+1

GX 3+1 is an LMXB which is known to emit X-ray bursts, ranging from normal ones (see e.g. Chenevez et al. 2006, and references therein) to the superburst (Kuulkers et al. 2002). Among many bursts detected, only one showed the evidence of photospheric radius expansion and hence was used to estimate the source distance as $d \sim 4.5$ kpc (Kuulkers & van der Klis 2000) for a hydrogen-rich neutron star atmosphere. However, analysis of thermonuclear bursts from GX 3+1 by den Hartog et al. (2003) suggests He-rich fuel and hence somewhat a larger value of $d = 6.1 \pm 0.1$ kpc, which we adopt below. First, the GX 3+1 NIR counterpart search was undertaken by Naylor, Charles & Longmore (1991). They reported a single source within Einstein and the intersection of GX 3+1 lunar occultation error boxes (see below).

We extracted astrometric position of the source from observations of Chandra (observation ID 2745, 2002 April 9) and Einstein/HRI (observations 1979 March 23 and 1980 March 28). The Chandra observation was performed in continuous-clocking mode, which precludes the determination of accurate source position along one coordinate (the long size of the ellipse of the Chandra localization in Fig. 5 is arbitrary, because the position was determined only along another axis). However, combining results from Einstein/HRI [best-fitting position RA = 17:47:56.11, Dec. = –26:33:48.8 (J2000), localization accuracy of ~2 arcsec] and Chandra data sets, we can slightly improve the accuracy of the localization to the level of a $0.5 \times 2$ arcsec$^2$ box (see Fig. 5).

We examined this combined Chandra and Einstein error box in UKIDSS GPS DR3 (see Fig. 5). Due to its relatively large area, we detect two sources falling within its limits. It is impossible to choose...
among them at this stage: either a more compact X-ray error box or phase-resolved NIR photometry is needed. Source A in this work most likely corresponds to source 311 from Naylor et al. (1991). The results on GX 3+1 presented in Table 1 were inferred from exposures taken on 2007 May 3 between 13:47 and 14:02 UT with usual survey integration times.

To estimate GX 3+1 absolute magnitude, we took the brightest of the two positional candidates thus making our estimate an upper limit of the absolute brightness at the distance determined by den Hartog et al. (2003): $M_K \gtrsim 0.2$.

3.6 IGR J17505−2644

The source IGR J17505−2644 is one of the faintest persistent sources in the Galactic bulge region, discovered by INTEGRAL (Krivonos et al. 2007). It was tentatively classified as an LMXB by Revnivtsev et al. (2008).

The source was observed on 2009 August 5 by Chandra as part of a special programme, dedicated to measurements of astrometric positions of LMXBs (and LMXB candidates) in the Galactic bulge. A single relatively bright source was detected within the source localization circle, obtained by INTEGRAL. The position of the X-ray source was measured by Chandra: RA=17:50:39.49, Dec.=−26:44:36.1 (J2000), with 0.6-arcsec accuracy mainly determined by the Chandra aspect solution precision, rather than the statistical accuracy of the measurements.

We studied the X-ray error circle of IGR J17505−2644 in UKIDSS GPS DR3 (see Fig. 6) in the data obtained under better than average observing conditions (with a seeing of ~0.7 arcsec) on 2007 May 3 between 13:49 and 14:03 UT. We were not able to detect any source within the X-ray coordinates’ uncertainty in J and H filters, but we marginally detected a faint source in the K band. We did not succeed in fitting its profile with a PSF due its low brightness, so we publish here its aperture photometry measurement and the astrometric position determined by simple centroids. Upper limits in J and H bands are significantly better than those from the usual UKIDSS data sets because of the particularly good weather conditions.

Detection of a possible counterpart in the K band allows us to make an estimate of IGR J17505−2644 absolute magnitude as $M_K \gtrsim 2.2$.

4 SUMMARY

We have made a systematic search in ESO and WFCAM science archives for photometric images of the areas around positions of six LMXBs in the Galactic bulge region. In all but two cases, we have detected faint optical/NIR sources with brightness in the range of 15–23 mag within arcsecond-scale X-ray error boxes and obtained upper limits on optical/NIR brightness for the rest. We note that positional-based identification is always uncertain, and one should take our detections with caution; they, however, still carry important information about upper limits on an optical brightness of a real counterpart. Our main results are summarized in Table 1. To quantify local star density in the vicinity of objects, we calculate the simple probability of accidental background star coincidence with an error box: $P = S_{\text{err}} \times \rho$, where $S_{\text{err}}$ is an error box area and $\rho$ is an average surface density of the sources we detected in a 2-arcmin field around the given position. Hence, as the total probability of chance star coincidence across all error boxes is 1.64 and we detected five possible counterparts of four objects, we conclude that two or three of these objects may have true counterparts.

Assuming intrinsic colours of LMXBs with non-evolved companions as $(V − K)_0 \sim 0$ (see e.g. Hertz & Grindlay 1984) and somewhat arbitrarily, but conservative $(V − R)_0 \sim 0$ and $(V − I)_0 \sim 0$, we estimated upper limits on the orbital periods of the systems under study, presented in the last column of Table 1. We used simple scaling relations, proposed for optical emission, dominated by illumination with their central X-ray emission (van Paradijs & McClintock 1994), adopting Eddington luminosity from Kuulkers et al. (2003). Under these assumptions, we find that (at least) one of the binary systems studied is quite compact, with an implied orbital period less than 3 h. We plan to make more accurate estimates of their orbital parameters in our future works.
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