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BINARY STAR DATABASE: BINARIES DISCOVERED IN NON-OPTICAL BANDS

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Abstract. The Binary star Database (BDB) is the world's principal database of binary and multiple systems of all observational types. In particular, it should contain data on binaries discovered in non-optical bands, X-ray binaries (XRBs) and radio pulsars in binaries. The goal of the present study was to compile complete lists of such objects.

Due to the lack of a unified identification system for XRBs, we had to select them from five principal catalogues of X-ray sources. After cross-identification and positional cross-matching, a general catalogue of 373 XRBs was constructed for the first time. It contains coordinates, indication of photometric and spectroscopic binarity, and extensive cross-identification. In the preparation of the catalogue, a number of XRB classification disagreements were resolved, some catalogued identifiers and coordinates were corrected, and duplicated entries in the original catalogues were found.

We have also compiled a general list of 239 radio pulsars in binary systems. The list is supplied with indication of photometric, spectroscopic or X-ray binarity, and with cross-identification data.

Key words: binaries: close – X-rays: stars – pulsars: general – catalogs

1. INTRODUCTION

The Binary star DataBase (BDB, `http://bdb.inasan.ru`; Malkov et al. 2013; Kaygorodov et al. 2012) is the world's principal database of binary and multiple systems of all observational types. Information on the binaries is obtained from heterogeneous sources of data – astronomical catalogues and surveys. Organization of the information is based on careful cross-identification of the objects. BDB can be queried by star identifier, coordinates, and other parameters. Currently, BDB contains data on physical and positional parameters of 240,000 components of 110,000 stellar systems of multiplicity 2 to more than 20, belonging to various observational types: visual, spectroscopic, eclipsing, etc.

In particular, BDB should contain data on binaries discovered in non-optical bands. Among them are X-ray binaries and radio pulsars in binary systems. In this paper, we describe the main catalogues used to upload data on such binaries into BDB, discuss identification and cross-identification problems, and make an analysis of observational types of binaries.

X-ray and radio sources in binaries are discussed in Sections 2 and 3, respectively. In Section 4, we draw our conclusions.

2. X-RAY BINARIES

An X-ray binary (hereafter XRB) contains a white dwarf, neutron star, or black hole as the accretor and an optically visible donor. According to the donor mass, XRBs are subdivided into low-mass and high-mass subclasses (hereafter LMXBs and HMXBs, respectively).

2.1. Cross-identification process

A list of principal data sources for binaries of different types (particularly, for XRBs) to be included in BDB was presented in Malkov et al. (2011). One of the most representative catalogues of XRBs is the Catalogue of Highly Evolved Close Binary Stars (Cherepashchuk et al. 1996). Recently, however, some catalogues of XRBs were published or updated, therefore we have re-compiled a list of principal data sources on XRBs. The main modern XRB catalogues are presented in Table 1. It contains the catalogue reference together with the abbreviation used in this article, the type of XRB, and the number of objects of this type in the catalogue. At this stage, we do not consider the catalogues containing data on extragalactic XRBs only.

R14 contains, besides LMXBs, data on 1166 cataclysmic variables (CVs) and 500 related objects (detached binaries consisting of either a white dwarf or a white dwarf precursor primary and a low-mass secondary). K10 (all-sky catalogue) and K12 (Galactic equator only) contain, besides LMXBs and HMXBs, other hard X-ray sources (CVs, active galactic nuclei, etc.). Some catalogued sources in K10 and K12 are not classified.

One of the main problems in compilation of a general list of XRBs is the large variety of nomenclature systems used for XRB identification. For other types of binaries, this is not the case: eclipsing binaries are named according to the GCVS (Samus et al. 2013) notation, spectroscopic binaries have HD numbers, almost all visual binaries have WDS designations. Contrary, there is no unified identification system for XRBs, and more than twenty different nomenclature schemes are almost equally used for XRB designation: 1A, 1E, 1H, 1WGA, 1RXP, 2S, 3A, 4U, AX, EXO, GRO, GS, H, IGR, KS, OAO, RX, SAX, XTE, etc.

Our first step was to cross-match objects in K10 and K12. From these catalogues, we selected the sources with source types HMXB, HMXB? (the question mark indicates that the specified type is not firmly established), LMXB, LMXB?.

Table 1. Catalogues of X-ray binaries.

Catalogue	Abbr.	Type	N
Liu et al. 2006	L06	HMXBs	114
Liu et al. 2007	L07	LMXBs	187
Krivonos et al. 2010	K10	HMXBs	102
Ibid.		LMXBs	103
Krivonos et al. 2012	K12	HMXBs	82
Ibid.		LMXBs	108
Ritter and Kolb 2014	R14	LMXBs	105

Hereafter we consider HMXB? and LMXB? types to be HMXB and LMXB, respectively (see discussions of some particular systems below).

One source, IGR J17353-3257, was classified as HMXB? in K10 and later was confirmed to be an HMXB in K12. Five other sources, IGR J16358-4726, IGR J17353-3539, IGR J17407-2808, XTE J1901+014, and 4U 1954+319, were classified as HMXB or HMXB? in K10, but later were re-classified and listed as LMXB or LMXB? in K12. Hereafter, we assign for them the LMXB type.

Two sources, IGR J11187-5438 and IGR J17269-4737, are classified as just XRB in K10 (both sources are absent in K12). Coleiro et al. (2013) found IGR J11187-5438 to be most probably an LMXB, and Ozel et al. (2010) included IGR J17269-4737 in their list of LMXBs, so we refer to these two objects in the LMXB group.

As our analysis shows, 78 HMXBs and 95 LMXBs are included in both catalogues; however, sometimes the same objects have different identifiers in different catalogues. For instance, MXB 0656-072 in K12 and 2E 0655.8-0708 in K10 are the same object, but there is no indication of that in the Notes of both catalogues. Hence it was necessary to make a positional matching of the sources. One should note that the coordinates of an object, given in the two catalogues, slightly differ. To estimate the matching radius ($R_{\rm m}$), we used a set of XRBs having the same K10 and K12 identifiers. This training set allowed us to find an upper limit for the difference in the celestial coordinates used for cross-identification. It was found that $R_{\rm m}$ should not exceed 0.05 deg.

Altogether, K10 and K12 contain 93 HMXBs (11 of them are listed only in K10, and four of them are listed only in K12) and 121 LMXBs (13 of them are listed only in K10, and 13 of them are listed only in K12).

To compile the XRB cross-identification list, we used the Sesame name-resolver (Simbad database, CDS, Strasbourg). However, some identifications, listed in K10 and K12, could not be resolved through Sesame, and we used other sources found in the literature. Examples are X 0918-548 (correct identifier is 4U 0919-54) and RJ 0146.9+6121 (correct identifier is RX J0146.9+6121) Altogether, 44 K10 and K12 identifiers were corrected to resolve cross-identification problems. On the other hand, some names (for example, 4U 1556-605) or cross-identification (IGR J02403+6113 = V615 Cas), given in K10 and K12 catalogues, are absent in Simbad.

Our next step was to add objects from the L06/L07 catalogues. Again, to estimate $R_{\rm m}$, we used a set of 99 XRBs having the same K10+K12 and L06/L07 identifiers. The upper limit to $R_{\rm m}$ was also found to be 0.05 deg, like it was for the K10–K12 matching.

It was later found that the separation between two different sources listed in the L07 catalogue of LMHBs can be smaller than 0.05 deg. In particular, SLX 1744-299 and SLX 1744-300 are located at a distance of 0.046 deg from each other, and the separation between 1E 1742.8-2853 and 1E 1742.9-2852 is just 0.036 deg. This can be an indication that the two sources in each of these pairs are in fact a single one. Other three pairs of sources in L07 have a negligible separation between their members (given in parentheses): AX J1745.6-2901 and 1A 1742-289 (0.007 deg), CX-OGC J174540.0-290031 and 2E 1742.5-2858 (0.006 deg), CXO J212958.1+121002 and 4U 2129+12 (0.001 deg). The first two pairs are located in the direction of the Galactic center while the latter one is in M15. Hereafter, we consider each of these three pairs to represent a single source.

Matching the two lists, we also found six cases of discrepancy in HMXB/LMXB classification. To solve these problems, we attempted to find independent classification in the literature. IGR J16358-4726 and XTE J1901+014 (listed as LMXB in K10+K12, but included in the L06 catalogue of HMXBs) were discussed above, and we refer to these two objects in the LMXB group. XTE J1743-363 (an HMXB according to K10+K12 and LMXB according to L07) was studied in detail by Bozzo et al. (2013) and should be classified as an LMXB. According to Stiele & Yu (2014), IGR J17091-3624 (LMXB in K10+K12 and HMXB in L06) is also an LMXB. At last, GRS 1736-297 = RX J1739.4-2942 and 4U 1246-588 = 1A 1246-588 are mentioned in the K10+K12 list as LMXBs, but they are included in the L06 catalogue of HMXBs. As to the former source, Liu et al. (2007) clearly note that this object is no longer listed in the LMXB catalogue because of its HMXB properties. The latter source is listed in the Baumgartner et al. (2013) catalogue as an LMXB.

Some identifications, listed in L06 and L07, could not be resolved through Sesame, and we used other sources found in the literature. Altogether, two L06 and five L07 catalogued identifiers were corrected to resolve cross-identification problems.

The last step was to add to our list LMXBs from R14. Comparison of coordinates for a list of 26 LMXBs having the same (K10+K12+L06/L07) and R14 identifiers shows that the maximum $R_{\rm m}$ can be set at 0.015 deg. The reason for such a small $R_{\rm m}$ is the following: the coordinates from the former list are mostly taken from the K12 catalogue whose epoch is closer to that of R14 than to epochs of other lists.

It was found in the cross-matching process that SAX J1819.3-2525 = V4641 Sgr was included both in the L06-HMXB and R14-LMXB catalogues. Morningstar et al. (2014) confirmed V4641 Sgr to be an HMXB. We also found that AX J1824.5-2451 (L07) was located in only 0.02 deg from PSR J1824-2452 (R14). AX J1824.5-2451 is a poorly studied LMXB in M28, with positional accuracy of only about 1 arcmin. Probably these two sources are in fact a single one, and hereafter we consider this pair to represent a single source.

26 identifiers from R14 were not resolved with Sesame, and we have found alternative names browsing the literature and/or making a coordinate matching with Simbad objects. In the case of J1538-5542, the R14 identifier and coordinates do not correspond to original values, published by Kennea et al. (2007) for AX J1538.3-5541. Also, incorrect coordinates are given in R14 for J1753-0127 (SWIFT J1753.5-0127).

Table 2. X-ray binaries, members of multiple systems.

HD	ADS	IDS	WDS
5394	782 AB		J00567+6043AB
24534	2859 A	03491+3045 A	J03554+3103AB
63666		07449−5305 A	J07474−5320A
109857		12328−7449 AB	J12392−7522AB
112091		12487−5638 B	J12546−5711B
141926		15465−5502 AB	J15544−5520AB

2.2. Compiled list of XRBs

Our final list contains 373 XRBs, of which 137 binary systems are HMXBs and 236 systems are LMXBs. The list is available in electronic form only, at the CDS via anonymous ftp to `cdsarc.u-strasbg.fr` or using the VizieR catalogue access tool at `http://vizier.u-strasbg.fr/viz-bin/VizieR`.

The format of the list is the following: (1) Principal Simbad name; (2) Alternative name, taken from an original catalogue; (3–7) Serial number of the corresponding entry in the original catalogues K10, K12, L06, L07, R14 respectively; (8) H or L stands for HMXRs or LMXBs, respectively; (9–10) Indication of eclipsing (E) and spectroscopic (1 or 2 for SB1 and SB2) binarity; (11) J2000 coordinates from Simbad; (12) IGR name; (13) HD number; (14) Hip number; (15) GCVS name; (16) SBC9 number; (17) DM identifier.

The DM identification numbers for stars in the Bonner Durchmusterung (BD), Cordoba Durchmusterung (CD), and Cape Photographic Durchmusterung (CPD) are given following the HD convention. When the zone of the DM number is between +90 degrees and –22 degrees, the BD number is used. When the zone of the DM number is between –23 degrees and –51 degrees, the CD number is used. When the zone of the DM number is between –52 degrees and –90 degrees, the CPD number is used.

For some of the sources, Simbad coordinates are rather approximate and are given in the HHMMSS+DDMM.m or even HHMM.m+DDMM format. However, as our comparison shows, the original catalogues do not provide more precise coordinates.

We did not intend to include all of the catalogued data into our final list. In particular, we provide neither X-ray fluxes (in different original catalogues they are presented in different energy ranges) nor photometric information and orbital parameters (only some of the catalogues considered include these data). However, we provide references to the original catalogues and Simbad, where the data can be easily found.

Identifiers were added from Simbad and from the original catalogues (some of the latter ones are absent in Simbad). In some cases (e.g., QU TrA = 4U 1543-62), two distinct objects in Simbad were found to represent a single source. Note that not every system indicated here as an eclipsing or spectroscopic binary has respectively a GCVS or an SBC9 name.

Six XRBs were found to be members of wider binary/multiple systems. Their ADS/IDS/WDS identifiers are presented in Table 2.

Table 3. Radio pulsars in binaries of other observational types.

PSR name	Other name	Observational type
PSR J0823+0159	SBC9 511	single-lined spectroscopic binary
PSR J1023+0038	AY Sex	low mass X-ray binary
PSR J1302–6350	CPD–63 2495	high mass X-ray binary
PSR J1824–2452I	IGR J18245–2452	low mass X-ray binary
PSR J1915+1606	SBC9 1137	single-lined spectroscopic binary
PSR J1959+2048	QX Sge	eclipsing binary
PSR J2051–0827	LY Aqr	eclipsing binary
PSR J2305+4707	SBC9 1421	single-lined spectroscopic binary

3. RADIO PULSARS IN BINARIES

In this section, we consider binary systems containing a radio pulsar and a companion star (in at least one case, that of the double pulsar PSR J0737-3039, the companion neutron star is another pulsar as well). To compile a general list of such objects, we have selected 239 binary radio pulsars from the ATNF Pulsar Catalogue (Manchester et al. 2005, hereafter ATNFPC), v. 1.51, 2014/11/13. All of them have PSR names; however, not all of these names/objects are known to Simbad.

In particular, PSR names for five pulsars: PSR J0605+37, PSR J1142+0119, PSR J1227-4853, PSR J1312+0051, PSR J1630+37 are not included in Simbad. We have identified them with Simbad objects via original publications (Ray et al. 2012; Roy et al. 2014).

For PSR J1405-4656, a closest counterpart in Simbad is PSR J1406-4656. Simbad provides very approximate coordinates for PSR J1406-4656, with a precision of only 1 arcmin. Within this accuracy, PSR J1405-4656 (with positional precision of 0.01 arcsec, see Bates et al. 2015) and PSR J1406-4656 obviously represent a single object.

We failed to find Simbad's counterpart for PSR J1653-2054, which also has a relatively high (0.1 arcsec) positional accuracy (Bates et al. 2015). Other three pulsars, which also are not included in Simbad, reside in "pulsar-rich" globular clusters (the clusters with large number of known pulsars to date), namely, PSR J1824-2452K and PSR J1824-2452L (Freire 2012; Bogdanov et al. 2011) in M28, and PSR J1748-2446ai in Terzan 5 (Freire 2012).

The format of our final list of radio pulsars in binaries is the following: (1) PSR name taken from the ATNFPC; (2) Principal Simbad name, if the object is included in Simbad; (3) Alternative PSR name, taken from the ATNFPC or Simbad; (4) J2000 coordinates from the ATNFPC (Simbad coordinates are of the same or lower precision). Note that for three objects (PSR J1017-7156, PSR J1741+1351, and PSR J2033+1734), the ATNFPC coordinates differ from those in Simbad by more than 2 arcmin.

The list is available in electronic form only at the CDS via anonymous ftp to `cdsarc.u-strasbg.fr` or via `http://vizier.u-strasbg.fr/viz-bin/VizieR`.

It has been found that eight objects from the list of radio pulsars in binaries were also detected as binaries of other observational types (eclipsing, spectroscopic, X-ray binaries). They are listed in Table 3. For these objects, a combined analysis is possible for the parameterization of the components.

4. CONCLUSIONS

Our main goal was to compile lists of binaries detected in non-optical bands and to include them in the Binary star Database (BDB), the world's principal database of binary and multiple systems of all observational types.

We present a general catalogue of 373 (137 HMXBs and 236 LMXBs) X-ray binaries (XRBs), constructed for the first time. It contains objects from five principal XRB catalogues and lists their coordinates, indication of photometric and spectroscopic confirmation of binarity, references to the original catalogues and identifiers in IGR, HD, Hip, GCVS, SB9, DM, and Simbad.

To compile the catalogue, objects in the principal XRB catalogues were cross-identified using the Sesame (Simbad database, CDS) name resolver. However, dozens of objects, included in different catalogues under different names, were not resolved by Sesame. For some of them, necessary information was found in the literature, but for others, a positional cross-matching was applied. It was found, in particular, that the matching radius does not exceed 0.05 deg and is as small as 0.02 deg when cross-matching two catalogues with close observational epochs.

HMXB/LMXB classification collisions were found and resolved for nine systems, using recent observational results in the literature. Also, we have noted that there are the cases of two different objects in the LMXB catalogue of Liu et al. (2007), having relatively small positional separation, that may represent in fact a single source. We have found three such pairs beyond doubt (with separation less than 0.008 deg) and two doubtful cases (with separation in the range 0.036–0.046 deg).

We have also compiled a general list of 239 radio pulsars in binary systems, selecting them from the ATNF Pulsar Catalogue (Manchester et al. 2005) . We have supplied the list with indication of photometric, spectroscopic, or X-ray binarity and with cross-identification, taken from Simbad. Cross-matching of the objects with Simbad was done through their PSR names or data from original publications. Four objects were not found in Simbad.

The general XRB and radio pulsar cross-identification lists are available in electronic form only, at the CDS via anonymous ftp to `cdsarc.u-strasbg.fr` or via `http://vizier.u-strasbg.fr/viz-bin/VizieR`.

The catalogues of X-ray and radio sources in binaries are to be included in BDB. To make a cross-identification with binaries of other observational types, BSDB (internal BDB) identifications, described by Kovaleva et al. (2015), are assigned to all objects.

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