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ASTRONOMICAL DATA RESOURCES FOR BINARY AND MULTIPLE STARS

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Abstract. Binary stars form a significant part of stellar population. They are registered and observed by a number of methods. This is the reason for variety of present-day resources of astronomical data dealing with binaries and multiples. The review of observational types of binary stars and of basic data resources for them is presented. The properties of stars within these types and possible relationships between them are discussed. The Binary star DataBase, BDB (http://bdb.inasan.ru), is presented as the resource joining data for all observational types of binaries. The problem of correct cross-identification of objects within binary and multiple stars is being solved in the frame of the Identification List of Binaries (ILB).

Key words: astronomical catalogues and databases – binaries

1. INTRODUCTION

Different authors not always agree in their estimates of the fraction of binaries and multiples in various stellar populations (for instance, selecting from recent papers, binarity/multiplicity fraction is estimated to be about 62% in the Taurus-Auriga star-forming region, Daemgen at al. 2015; 21% to 27% for Galactic M-dwarfs, Janson et al. 2014; 69% for solar-neighborhood A-stars, de Rosa et al. 2014). Observational binarity rate depends on the primary's spectral type (see discussion in Kouwenhoven et al. 2009), and, evidently, this observational trend is not purely due to selection effects, as the correlation between mass and binary fraction is also predicted by the hydrodynamical/sink particle simulations (Bate 2012). van Haaften et al. (2013) provide a numerical estimate for the binarity fraction – mass dependence: $B(M) = 1/2 + 1/4 \times \log(M/M_{\odot})$. Anyway, it seems obvious that the share of binaries and multiples in the stellar population is at the very least considerable.

As for the cataloguing, the catalogues of binaries represent this population relatively poorly due to specifics of observations of this type of stars. Moreover, there is a number of methods to register stellar binarity, and every method usually produces its own list of stars – observational type of binaries. It often happens that binaries of different observational types are observed by different teams with different purposes, and even designated by different identifiers. As we discuss only the catalogues treating binarity (or multiplicity) of stars, it happens that for every observational type one may rather easily point out several (usually one to three) catalogues that we call the basic ones. We are not attempting to downplay significance of other catalogues, but the basic catalogues contain a major part of data on investigated binaries of any given type. Very often, the basic catalogues contain data compilations.

Until recently, there was no general list of binaries of all observational types (Malkov et al. 2009), and the researcher willing to gather all observational data for a certain binary had to undertake a search through various catalogues. Even cross-identifications for objects in binaries and especially in multiples and proper linking of identifiers with data was often problematic. Talking about objects in binary and multiple stars, we will keep to the scheme "system – pair – component", where a component is a single star, a pair is a couple of objects (each of them may be a component or a pair) observed together, and a system is a set of pairs designated by the same stellar identifier (a binary system evidently contains just one pair).

In Section 2, the main observational types of binary stars are described, along with their basic data sources. Section 3 deals with characteristics of binaries of various observational types in the space of observational and physical parameters. Section 4 describes how the data on binary and multiple stars of all observational types are joint in the Binary star DataBase, BDB (`http://bdb.inasan.ru`).

2. OBSERVATIONAL TYPES OF BINARIES AND BASIC CATALOGUES

A number of binaries are detected with astrometric methods. The most common among them is the observational type of *visual* binaries. There are more than 110,000 binary and multiple systems containing pairs of this type. The majority of them are just pairs of the components observed separately via the optical telescope, with their position angle and angular separation measured. This observational type contains a certain share of non-physical double stars.

The wide pairs with the components united by similar proper motions are called *common proper motion* (CPM) binaries. There are about 9000 of such binaries, and they represent a part of the set of wide visual binaries. These pairs are evidently physically bound, so this dataset is less contaminated by optical pairs than wide visual pairs in general. However, it is also likely that the majority of these pairs were born together but are not gravitationally bound anymore, just traveling in space side by side.

The absolute majority of observational data on these two observational types of stars are contained in three catalogues. These are the Washington Double Star Catalogue (WDS, Mason et al. 2014), the Catalogue of Components of Double and Multiple Stars (CCDM, Dommanget & Nys 2002), and the Tycho Double Star Catalogue (TDSC, Fabricius et al. 2002). Recently, the objects in these three catalogues were cross-matched, resulting in the most complete list of visual binaries, named, by first letters of the three abbreviations, WCT (Isaeva et al. 2015; Kovaleva et al. 2015a). The WCT has proved that the three basic catalogues of visual binaries contain data about some more than 130,000 visual pairs in more than 110,000 binary and multiple systems (about 1500 pairs from CCDM are added to the largest catalog, WDS). The data available for pairs in these catalogues are position angles and angular separations. For the CPM binaries, there are specific catalogues (Luyten 1987; Greaves 2004; Gavras et al. 2010) but their data are mainly included in the WDS.

A much smaller but very interesting observational class of astrometrically detected binaries is comprised by *orbital* binaries. Such pairs demonstrate orbital motion and, with some additional data, make one of the few classes of stars allowing dynamical determination of their masses. There are somewhat more than 3000 of such systems. Basic catalogues of orbital binaries are the Sixth Catalog of Orbits of Visual Binary Stars, ORB6 (Hartkopf et al. 2014a) and Catalog of Orbits and Ephemerides of Visual Double Stars, OARMAC (Docobo et al. 2013). These catalogues contain orbital parameters for the pairs. The recently compiled list of Orbits of visual binaries and dynamical masses (Malkov et al. 2012) comprises the best orbits from these two catalogues.

Astrometric binaries are detected because the primary component demonstrates orbital motion, while the secondary remains unseen. There are about 200 astrometric binaries listed in the CCDM and about 4500 of such systems registered by Hipparcos (Makarov & Kaplan 2005); no specific pair parameters are available for these binaries, though.

There is a set of methods that permit distinguishing binary stars not detected astrometrically. Various interferometric techniques provide the largest observational class of non-astrometric binaries – *interferometric* binaries. There are at least about 60,000 of resolved pairs with measured position angle and angular separation, included in the Fourth Catalog of Interferometric Measurements of Binary Stars, INT4 (Hartkopf et al. 2014b).

Spectroscopic binaries are much smaller in number but very promising for investigators, allowing them to estimate at least some or, in certain cases, many physical characteristics, including masses. The basic catalogue, The Ninth Catalogue of Spectroscopic Binary Orbits, SB9 (Pourbaix et al. 2004–2014) contains the orbital parameters and velocity amplitudes of the components for 3300 spectroscopic binaries.

The star may be discovered as a binary by photometric methods as well. First of all, let us mention *eclipsing* binaries. Their number grows rather quickly due to by-product discoveries in the course of microlensing and exoplanet surveys (Prşa et al. 2011; Pawlak et al. 2013; Paczynski et al. 2006) so that, by now, the number of pairs registered as eclipsing stars exceeds 20,000. However, the newly discovered eclipsing binaries usually remain registered but unobserved during some time, while the General Catalogue of Variable Stars GCVS (Samus et al. 2013), though not being specifically a catalogue of binaries, does contain basic information on more than 7200 eclipsing pairs. The GCVS eclipsing binaries were supplied with additional data in the Catalogue of Eclipsing Variables, CEV2 (Avvakumova et al. 2013). For these pairs, the light curve parameters, orbital period, and morphological type are available. These stars permit to determine relative physical parameters of their components.

Cataclysmic binaries, variable stars that exhibit sudden outbursts, make another observational type discovered photometrically. There are about 2000 such pairs known, and except the GCVS, an investigator can refer to the catalogues by Ritter & Kolb (RK, 2014) and by Downes et al. (2006). The data on these pairs are not uniform but usually contain some information about the orbit (period, inclination constraints), morphological type of the variable, relative parameters of the components.

There are other types of binaries discovered photometrically. For all of them, the GCVS can be considered a basic catalogue. It contains data on more than 200 *spotted*, more than 100 *ellipsoidal* and seven *reflecting* binaries.

Table 1. Some observational and physical parameters of binaries depending on observational type.

Observational type		No. of pairs	Periods	Separations ($''$)	Semimajor axis (AU)
CPM		9000+	>1000 yr	10–1000	
Visual	Vis	130 000+	1–1000+ yr	1–1000	10–1 000 000
Astrometric	Ast	4500+	<100 yr	n/a	<0.001–100
Orbital	Orb	3000+	<100 yr	0.1–25	<0.001–100
Eclipsing	Ecl	20 000+	0.05 d – 10 yr		0.1–1000
Interferometric	Int	60 000+		<0.00025–1000	<0.001–100
Spectroscopic	Sp	3000+	0.05 d – 5 yr	n/a	<5

There are several observational types of binaries registered beyond the optical wavelengths. Among them, let us mention *X-ray binaries*, about 300 of which are known at present. Basic data for this observational type are available from the RK catalogue, Catalog of Galactic Low-Mass X-Ray Binaries, LMXBs (Liu et al. 2007), and Catalog of Galactic High-Mass X-Ray Binaries, HMXBs (Liu et al. 2006). There are also pairs discovered from variations of their gamma-ray flux, *gamma-ray binaries*, though the total number of proved and suspected pairs of this observational type is so far less than ten (Marcote et al. 2015; Corbet et al. 2013). More than 200 pairs are observed as binaries in the radio range (Malkov et al. 2015a) thanks to flux variations of one of the components that is a radio pulsar (*radio pulsars in binaries*). There is the only case of double pulsar known (PSR J0737-3039). A basic source of data on this observational type is the ATNF Pulsar Catalog (Manchester et al. 2005).

Perhaps up to a quarter of binary stars may be *multiples* (Tokovinin 2014). Multiple systems may be hierarchical (stable) or non-hierarchical (stellar groups). For the non-hierarchical multiples, their number being about 8000, the WDS catalogue may serve as the basic data source, while the Multiple Star Catalogue, MSC, by Tokovinin (2010) contains the most complete list of orbital parameters and other data for pairs in physical multiple systems.

3. OBSERVATIONAL TYPES OF BINARIES IN THE SPACE OF PARAMETERS

It was already mentioned that binary stars, catalogued according to their method of detection, may look as separate sets. However, they represent different parts of the same binary population, and though they may be separate observationally, physically these observational types can and do interfere.

Table 1 contains data on some observational and physical characteristics of the most populated observational types of binaries. Note that there are possible ways of interference between certain observational types. The interference can be of different kind: the star can pass from one observational type to another, for instance, from astrometric to visual binaries (like Sirius did once), or from CPM to orbital binaries; on the other hand, a star may belong to several observational types simultaneously (e.g., may be observed as a spectroscopic and eclipsing binary at the same time). In Fig. 1, possible simultaneous interferences between the main observational classes of binaries are plotted in a symbolic way. The size of the ellipses does not correspond to the population of each observational type but was selected to properly illustrate possible connections between the types.

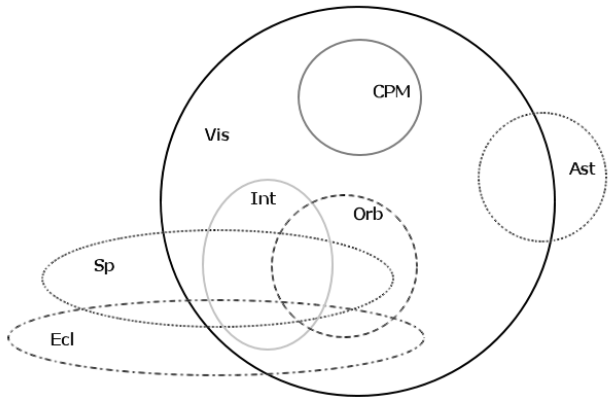

Fig. 1. Possible interference between major observational classes of binary stars.

4. JOINING DATA ON BINARIES OF ALL OBSERVATIONAL TYPES: THE BINARY STAR DATABASE, BDB

A comprehensive study of stellar populations should not be limited to a certain observational type of binary stars. Thus, to properly restore the star formation history, one needs to analyze data on binaries of all types, from CPM stars to evolved close binary variables. Similarly, if a star is observed using different techniques, it is often very useful to join the data from various sources in order to obtain certain parameters. For example, masses of the components of a spectroscopic binary can be determined if the pair is astrometrically or interferometrically resolved.

The purpose of creating the Binary star DataBase, BDB (available at `http://bdb.inasan.ru`), was to join data on physical and positional parameters of all catalogued binary and multiple stars belonging to various observational types (Kaygorodov et al. 2012; Malkov et al. 2013; Kovaleva et al. 2015b). Information on these types of binaries is obtained from heterogeneous sources of data – astronomical catalogues and surveys. At present, BDB contains data on about 240,000 components of 110,000 systems of multiplicity 2 and more, which can be queried by object name, coordinates, and various criteria. The data from the basic catalogues of all major observational types of binaries are uploaded to the database. Minor catalogues data are being added in the course of time; however, the used concept of basic catalogues for different observational types allowed us to cover almost all catalogued binary and multiple stars by now. We expect that, in the course of uploading minor catalogues, the amount of data per object rather than the number of objects in the database will increase.

To provide quick and effective cross-identification, as well as proper linking between data and objects in the binary and multiple stars in the frame of BDB, we are compiling and implementing the general catalogue of identifications of binaries, named Identification List of Binaries, ILB (Malkov et al. 2015b). The ILB should include unique identifications for all systems, pairs, and components inserted in the BDB up to date, as well as leave such possibility open for the coming binary lists/catalogues/surveys.

Thus, the data from basic astronomical data sources for binary and multiple stars of all observational types are available for search and analysis via the BDB.

In the course of its development, the database should become a tool for convenient access and work with all catalogued data for binary and multiple stars of all types.

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