Binary star database BDB: datasets and services

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Description of the Binary star DataBase (BDB, http://bdb.inasan.ru), the world's principal database of binary and multiple systems of all observational types, is presented in the paper. BDB contains data on physical and positional parameters of 100,000 components of 40,000 systems of multiplicity 2 to 20, belonging to various observational types: visual, spectroscopic, eclipsing, etc. Information on these types of binaries is obtained from heterogeneous sources of data – astronomical catalogues and surveys. Organization of the information is based on the careful cross-identification of the objects. BDB can be queried by star identifier, coordinates, and other parameters.

Keywords: binaries – databases

1 Introduction

Study of properties of binary stars is an extremely important problem of astrophysics and stellar astronomy. The components of a binary star have the same age and are assumed to be born at the same place and time (i.e., act as excellent tests of theoretical models of evolution and tests of chemical abundance). They are situated at the same distance and suffer the same interstellar extinction, which is useful for distance calibrations and study of interstellar reddening. The binary stars provide us with precise data on the absolute stellar masses and radii. Also, they give access to system characteristics (orbital parameters). Last but not least, binary stars are very numerous: at least half of the stars in galactic neighbourhood belong to double or multiple systems.

Construction of catalogues / databases of binary stars has a long history. Compilations of data on binary stars (catalogues and databases) have been published for visual, interferometric, eclipsing, spectroscopic and other types of systems. However,

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there is no database synthesizing the various categories. The Binary star DataBase (BDB) aims to fill this gap. It is worth noting that a comprehensive study of stellar populations should not be limited to a particular type of binary stars: e.g., to properly restore the star formation history, all types of binaries, from common proper motion pairs to close binaries with a degenerate component, should be analyzed. Also, a parameterization of components and orbits of binary stars can not be limited to a particular type of observational data. Properties of components of *eclipsing* binaries can be derived only if radial velocity light curves of the components are observed as well. To calculate mass of *visual* binary components, orbital parameters should be combined with photocentric orbit observational data and system parallax. Components of *spectroscopic* binary can be parameterized, only if the pair is astrometrically or interferometrically resolved.

BDB was constructed in Besançon Observatory (http://bdb.obs-besancon.fr). Initially it contained the CCDM and WDS1996 catalogues of visual binaries, a list of eclipsing binaries and three photometric (UBV, Stromgren, Geneva) catalogues (Oblak et al. 2004). In 2008 it was decided to move BDB to the Institute of Astronomy (Moscow), where the database was significantly reconstructed and renovated. Main BDB objectives and ideas of BDB management were discussed in Malkov et al. (2009), while discussion of some problems of BDB development was published in Skvortsov et al. (2013).

BDB architecture and data sources are described in Section 2. Binary star data from the planning space mission Gaia are also discussed there. Usage of the BDB is discussed in Section 3. Finally in Section 4 we give our conclusions.

2 BDB architecture and data

2.1 BDB scheme

BDB stores all the data from the original catalogues "as is", but some supplementary data is also generated, based on the catalogued content. This data is used mostly for search and cross-identification. There are several internal tables in the database, containing supplementary data: *component table*; *pair table*; *system table*; *ID table* (see Fig. 1).

Component table records contain information about components of pairs and systems: coordinates, magnitude and photometric band, spectral type, radial velocity, parallax, proper motion. A star can have more than one record in this table, if information about it is drawn from several catalogues. Some record fields can be empty, if there is no corresponding data in the catalogues.

Pair table contains data on pairs. Here *pair* is a specific pairing, usually pairs of single stars but sometimes higher order pairings within hierarchical systems. Each record in this table holds information about the pair: coordinates, parallax, proper motion, radial velocity, period. If the pair is a resolved binary, the record can also contain relative coordinates (θ and ρ) with epoch of observation, semi-major axis, inclination, eccentricity and other orbital elements. On the contrary, if the pair is an unresolved binary, the record can contain information on minimum and maximum magnitude, combined spectral type, etc. Also, each record in this table can refer

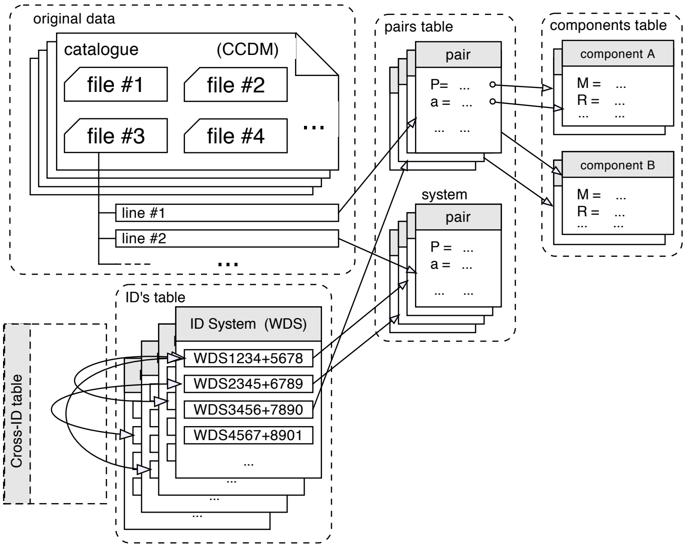

Figure 1 BDB scheme

up to two records in *component table*. If a pair contains a smaller order pairing (in hierarchical systems), then the record will refer to a primary component in the smaller order pairing. Some of the fields in this table duplicates fields from the *component table*, because in some cases we have no information about components of, for example, a spectroscopic binary.

System table does not contain specific information, it is only used to connect pairs of each system. Each record in this table can refer to one or more records in *pair table*.

All of the records in the tables has one or more references in *ID table*. *ID table* contains identifiers (ID's) of systems, pairs and components. Each ID can be referenced by one or more entities, because different catalogues can provide information about same pairs or components. Also, some additional references between ID's can be produced by cross-identification process.

Besides the data table BDB contains complementary information pages: contacts, introduction, log, list of references, list of included/linked catalogues and databases.

2.2 Data sources

The efficiency of a database strongly depends on the data, which are included into it. We have compiled a list of principal data sources for binaries of different types to be included in BDB (Malkov et al. 2011). A supplementary list of catalogues (published mainly in 2006-2010) to be integrated in BDB was presented in Kaygorodov et al. (2012). The catalogues are included "as is". The origin of information, presented as a result of a BDB query, is clearly indicated.

Beside the catalogues, BDB will provide links to external on-line data resources on binary stars of different observational types, particularly, to databases on visual and eclipsing binaries and to catalogues and databases on variable stars, including some types of binaries. BDB will also provide links to general purpose astronomical databases. A list of binary star data sources to be linked with BDB was also published by Kaygorodov et al. (2012).

Principal problems of information aggregation in a unique database were recently considered in (Skvortsov et al. 2013). Database structure, principles of data transformation from original catalogs' formats into the BDB format, as well as basic cross-identification methods for multi-source objects are also described there.

2.3 Gaia and binary stars

We plan to continue updating the list of binary data sources to be included in BDB, as well as the list of external links. One of the most promising sources of modern data on binary stars will be produced by european space mission Gaia.

Gaia is a space mission to chart a three-dimensional map of our Galaxy with the aim of revealing the composition, formation and evolution of the Galaxy. Gaia will provide unprecedented positional and radial velocity measurements with the accuracies needed to produce a stereoscopic and kinematic census of about one billion stars in our Galaxy and throughout the Local Group. Combined with astrophysical information for each star, provided by on-board multi-colour photometry, these data will have the precision necessary to quantify the early formation, and subsequent dynamical, chemical and star formation evolution of the Galaxy. Gaia will not resolve binaries with separations below $\sim$ 20 mas which today is routinely achieved from the ground by speckle interferometry. At this angular separation, only systems with nearly equal component magnitudes can be measured, but at the level of a few arcseconds, even very faint secondaries can be detected. For a distance-limited sample, the detection-efficiency for resolved binaries will thus be low at periods corresponding to 20-50 mas separations, but it will increase significantly for wider systems. The high-precision parallaxes and proper motions will also allow identifying the very widest binaries and studying their relation to common proper motion pairs and associations. Gaia is extremely sensitive to non-linear proper motions. A large fraction of all astrometric binaries with periods from 0.03-30 years will be immediately recognized by their poor fit to a standard single-star model. Most will be unresolved, with very unequal mass-ratios and/or magnitudes, but in many cases a photocentre orbit can be determined. The detection efficiency, as a function of period, shows a peak containing the astrometric binaries and a peak containing resolved binaries, and the gap between the two at about log P(y) = 2.5. The results of the simulations show that Gaia will detect a majority (59 per cent) of maybe 10 million binaries closer than 250 pc to the Sun. This fraction drops to 35 per cent out to 1000 pc.

2.4 Identification/designation problems

Another problem to be solved is an identification problem: right data should be linked with right components. It includes a development of a unique and consistent system for component designations and a solution of problem of component identifications in different catalogues (cross-identification problem).

For internal use we develop a consistent scheme for the designation of multiple objects. The scheme should meet the following requirements:

- Designation stable with respect to new distant components.
- Designation stable with respect to new components of resolved binaries.
- A particular name always represents one object only.
- A particular object is always represented by one name only.
- Compatibility with existent nomenclatures, if possible.

According to these requirements, a unique BDB-identifier should be constructed for each object. All original identifiers of that object, met in the published sources, will be associated with that BDB-identifier, including false identifiers, which will be marked properly. False identifiers are recognized by the following procedure: if an object, according to data from two different sources, has different identifiers in the same catalogue (i.e., different HD names) then all attempts to assign them common identifiers are ignored.

We have developed a tool for detection and correction of inconsistencies in identifiers for binaries of all observational types. It sometimes leads to correction of published data, which we make in collaboration with authors of original catalogues.

2.4.1 On cross-identification of visual binaries

The most numerous type of binaries is visual binary and multiple systems. Data on visual systems are published mostly in WDS (Mason et al. 2001) and CCDM (Dommanget and Nys 2002) catalogues. We have recently made a cross-identification of objects in WDS, CCDM and other important source of visual binary data, TDSC (Fabricius et al. 2002), compiling thereby a largest list of visual binaries.

Cross-identification process was made in three stages. In the first stage, the cross-identification data, provided by the catalogues, are analyzed. In the second stage, all the components that have similar values of their parameters are detected, and cross-identification data are produced for them in a semi-manual manner. In the last stage, the cross-identification data for pairs are produced, based on cross-identification of the components. The final list will also be included in BDB.

2.4.2 On identifiers of X-ray binaries

All visual binaries have WDS/CCDM identifiers, eclipsing binaries have GCVS names (except of eclipsing systems, discovered in large photometric surveys like ASAS-3 and MACHO), SBC9 identifiers are common for spectroscopic binaries. Contrary to those types of binaries, there is no unique system for identification of X-ray binaries. For the majority of X-ray systems only one identifier is well known (like SS 433), and nobody knows other identifiers for such stars. However, there is a number of stars, for which at least two identifiers are equally used (e.g. Her X-1 = HZ Her).

In BDB we use Integral (IGR) identifier as a principal name for X-ray binaries, as more than 95% of them have IGR identifier. We will probably use an alternative name for search of X-ray binaries and we will use the Sesame name resolver.

2.4.3 On primary component designation in different types of binaries

Every binary/multiple system contains one and only one primary component. However, various approaches to binary star study specify different ways of selection of a primary among other components.

In theoretical studies a **more massive** component is usually declared to be a primary component. Sometimes, to properly make calculations of stellar evolution the components, primary and secondary components should keep their marks even if a mass exchange occurs in the system. So, from this point of view, one uses the term "primary component" for **initially more massive** star. According to this scheme, e.g., the white dwarf Sirius B is the primary component in their pair with Sirius A.

Note however the following curious approach, mentioned by Lipunov (1986): in classical mechanics a **less massive** component can be considered as the primary. Indeed, from the law of conservation of momentum ($m_1v_1 = m_2v_2$) it follows that kinetic energy and orbital angular momentum of the less massive component are larger than corresponding entities of the more massive component: $m_1v_1^2/2 < m_2v_2^2/2$ and $m_1v_1r_1 < m_2v_2r_2$. Here m_i, v_i, r_i are mass, velocity of orbital motion, radius vector of i-th component, respectively. Circular orbits are assumed for simplicity.

Another approach is applied for visual binaries. For the majority of known visual binaries components, one observes only their magnitudes. That is why it is customary to consider a **brighter** star as the primary component. A similar notation is adopted for spectroscopic binaries, where an observer deals with integrated light of components. Being about 3^m fainter than primary component, secondary component does not contribute to the integrated light.

Extrapolation of this approach to other types of binaries is not always correct: visually **brighter** primary component can become fainter than the other component **in another spectral range**. Moreover, in some cases (e.g., in X-rays) a circumstellar disc is the brightest agent in the system.

As to photometric (eclipsing) binaries, here a primary maximum on the light curve corresponds to an eclipse of a **hotter** star, so the latter one is considered as the primary component of the system. Designation of a **larger** star as the primary component can be also found in literature. Concluding this section we should add that sometimes astronomers use subscripts 1 and 2, or gainer (accretor) and loser (donor) terms instead of the primary and the secondary.

In BDB we take the considerations listed above into account when cross-identifying components, if the binary system is observed with two or more different techniques.

3 Query capabilities

Designing BDB we take into account and rely on experience of well-known and widely used astronomical databases such as SIMBAD, VizieR and others. However, some of the catalogues incorporated in BDB are not included in VizieR. Also, we will provide links to other binary star databases from BDB. We use CDS service Sesame (see below), however, we have found a number of component cross-identification problems occurring in SIMBAD and original catalogues, and with our software we will be able to find and solve such problems automatically.

BDB can be accessed interactively at http://bdb.inasan.ru via a web-interface. BDB data can be queried using two methods: *by identifier* and *by parameters*.

3.1 Query by identifier

Query by identifier allows user to select object, using an identifier from the following list: **Name/Bayer/Flamsteed**, **HD**, **HIP**, **GCVS**, **DM**, **CCDM**, **WDS**, **ADS**, **IDS**, **SBC9**, **IGR**. While typing the ID, interactive hint is displayed, allowing user to write only a part of the identifier for searching. The identifiers are resolved with BDB ID table. User is also allowed to choose **Misc** (Miscellaneous) from the list and type another stellar identifier. CDS service Sesame is used to resolve miscellaneous identifiers. After submitting the form, the main result page is displayed. This page visualizes the queried system and lists identifiers for all involved systems, pairs and components.

The image contains graphical representation of all found and listed objects. Components of visual binaries are represented by circles, close (spectroscopic, eclipsing) pairs are shown as circles with two dots (components). Clicking circles on the image or entity names in the list, one can select/deselect them for displaying and further analysis.

When one, more or all objects are marked, one can also select one or more catalogues for further analysis and press the *Next* button. The resulting page contains fundamental parameters of the selected entities listed in the selected catalogues.

A query by identifier can also be realized in batch mode. User should prepare a list of identifiers and submit to BDB.

3.2 Query by parameters

Query by parameters allows user to compile a list of binaries, satisfying one or more conditions. One can make a query by *parameters of systems* (e.g., coordinates (cone search) or parallax), *parameters of pairs* (e.g., period or angular separation) and *parameters of components* (e.g., mass or spectral type).

A query can also be made by *evolutionary type* (currently we distinguish detached, semi-detached and contact binaries) and *observation type* of pair. The following list of observation types is suggested: common proper motion, visual, interferometric, orbital (visual or interferometric binary with known orbital elements), astrometric (discovered in residuals to visual or interferometric orbit), occultation, spectroscopic (including SB1 and SB2), spectral (pairs with composite, markedly contrasting spectra, they include symbiotic stars), eclipsing, elliptical, reflecting, spotted, cataclysmic, X-ray and radiopulsars. Detected optical pairs are also included in BDB and marked correspondingly.

Query by evolutionary type, observational type and spectral type allows user to select value from the proposed list. For all other parameters user should specify range limits. Query by parameters brings to a list of queried systems, satisfying the selected criteria.

4 Conclusions

The Binary star database (BDB) unites most of available catalogued data on all types of binary and multiple stars. Current version of BDB contains astrometric, photometric, spectroscopic and other data on some 40,000 systems, which can be queried by object name, coordinates and various criteria. BDB will also provide links to corresponding external on-line services.

BDB can serve as a database for deriving and combination of empirical data for all types of binary/multiple systems, for determination of stellar and orbital parameters and construction of fundamental relations between them throughout the entire stellar mass and orbital separation ranges, for study of star formation history of binary and single stars and for the preparation of future observing programs concerning various types of binaries.

The list of binary data sources to be included in BDB, as well as the list of external links is being updated. Result of a query will be listed in generally used formats HTML, ASCII, XML (VOTable). A BDB mirror in Besançon Observatory will be established.

BDB is available at http://bdb.inasan.ru

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