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Variable binaries and variables in binaries in the Binary star DataBase

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Abstract The Binary star DataBase (BDB, *http://bdb.inasan.ru*) combines data from catalogs of binary and multiple stars of all observational types. There is a number of ways for variable stars to form or to be a part of binary or multiple systems. We describe how such stars are represented in the database.

Key words: astronomical data bases — stars: binaries: general — stars: variables: general

1 INTRODUCTION

Binary stars are very numerous, and binarity rate increases from $\sim 20\%$ for M-dwarfs up to $\approx 60\% - 70\%$ for A- and earlier spectral type stars (Duchêne & Kraus 2013). Also, in many cases (probably as often as 1/4, according to Tokovinin 2014) after thorough investigation, binaries prove to be multiples. Information on properties of the population of binary and multiple stars has significant influence on studies of stellar formation and of Galaxy evolution (Bate 2015; Kouwenhoven et al. 2009; Weidner et al. 2009; Malkov & Zinnecker 2001; Piskunov & Mal'Kov 1991). Binaries exhibit many astrophysical phenomena of extreme interest, such as novae, type I supernovae (SNe Ia), Wolf-Rayet stars, and X-ray and symbiotic binaries; later stages of evolution of close binaries involve formation of compact objects, such as neutron stars and black holes, including recently discovered events related to their merging (Abbott et al. 2017; Lipunov et al. 2017; Abbott et al. 2016; van den Heuvel & Lorimer 1996; Tutukov & Yungelson 1994, 1993). Moreover, gravitational interaction between components in binary and multiple stars allows us to directly determine physical characteristics of the system and its components, including dynamical mass. This provides calibration of a number of relations between observed and physical parameters applied to single stars (Kraus et al. 2015; Horch et al. 2015; Malkov 2007; Benedict et al. 2006; Malkov et al. 1997), and enables tests of models of stellar evolution (see, for instance, Higl & Weiss 2017; Stassun et al. 2014; Vos et al. 2012; Kovaleva 2002).

Binaries are observed by various methods resulting in separate datasets named *observational types* (Malkov et al. 2017) (e.g. eclipsing, visual, spectroscopic, etc.). A binary star belongs to a certain observational type according to what observational technique was used to observe its duplicity. One binary may belong to one, two or more observational types, as soon as they overlap in spaces of physical and observational parameters (Kovaleva 2015). Usually, catalogs and databases address one or a few selected observational types. Combining their information may be problematic because of a number of problems. This includes unsufficient or indefinite indentifiers, as well as non-homogeneous data which can characterize either a component, a pair or a system in total.

The purpose of the Binary star DataBase (BDB, *http://bdb.inasan.ru*) is to combine data from various catalogs and databases on binary and multiple stars, allowing a user to obtain complete information about a certain star, or about a set of binaries with pre-defined characteristics. This requires accurate cross-identification and establishment of proper relations between data and objects in binaries and multiples (Kovaleva et al. 2015b; Kaygorodov et al. 2012). The task is solved with an index catalog of binary and multiple stars, Identification List of Binaries (ILB, Malkov et al. 2016). This catalog implements a specially developed scheme based on three categories of object: System, Pair and Component (Kovaleva et al. 2015a).

The term "variable stars" refers to numerous and diverse sets of stars, having in common only photometric variability caused by a variety of astrophysical processes. If a binary star is observed as a variable, or a variable star is observed in a binary or multiple system, this often multiplies available astronomical information. BDB includes a number of catalogs having data on variable stars of different types, or focusing on variable binaries. In this paper, we discuss integration of these catalogs in BDB and related issues.

There are three types of relations between variables and binary (multiple) stars: (i) one or more components of a binary may vary its brightness by being a pulsator, a spotted star or an erupting star; (ii) the brightness of a pair may vary because of its orbital movement (e.g. eclipsing binaries); (iii) the binarity may cause physical variability (e.g. cataclysmic binaries). Though these types are not mutually exclusive (see a detailed discussion in Samus 2005), it is convenient to start discussing them separately. The primary catalog for all variable stars in BDB is the General Catalogue of Variable Stars (GCVS, Samus' et al. 2017), however there are also catalogs in BDB addressing different observational types separately.

Section 2 discusses binary stars with variable components, Section 3 deals mainly with catalogs of eclipsing binaries and Section 4 contains information on catalogs of intrinsic binary variables. Section 5 discusses some issues relating to overlapping observational types and classes of variability, and Section 6 summarizes the results.

2 VARIABLE STARS IN BINARY AND MULTIPLE SYSTEMS IN BDB

In this section, we address cases when one or more components in a binary or multiple star system are intrinsic variables. The catalogs of such systems containing a few hundred stars were compiled by Baize (1962), Perova (1963) and Baize & Petit (1989). Regretfully, none of these catalogs is available in electronic form, so they can be used for referral but are not integrated in the BDB thus far. The data on 171 classical Cepheids in binary and multiple systems from the "Binary stars among Galactic classical Cepheids" database (Szabados 2003) have been integrated in BDB, and a special flag (in Observational Type field) was assigned to all stars from that dataset. For the other types of intrinsic variable stars in binaries, no special catalogs are available except the "Candidates for Binaries with an RR Lyrae Component" (Liška et al. 2016), which will not be integrated in BDB until the candidates are confirmed.

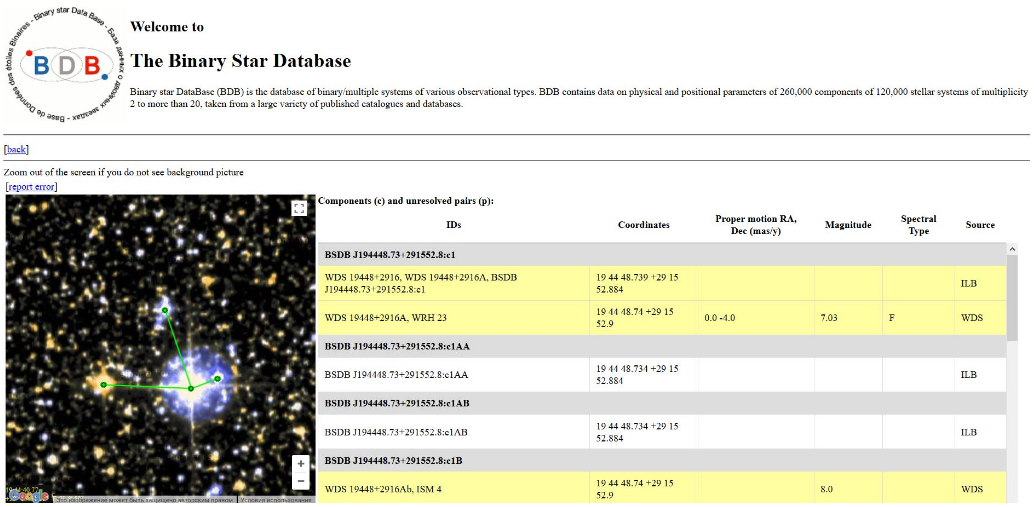
A catalog of UV Ceti type flare stars in binary systems was constructed by Tamazian & Malkov (2014). It contains information on 138 such binaries, and data on orbital elements are available for 31 of them.

Some major catalogs contain information on variable components of binaries in text files in the form of comments. In BDB, we work on reading data on properties of binaries from text files. The success strongly depends on whether authors use formal phrases to describe the structure of a system. We obtain part of the information on stellar types from text comments (Notes) that are part of the Washington Visual Double Star Catalog (WDS, Mason et al. 2016).

In particular, 73 binary and multiple systems from this catalog are marked to contain pulsators like Cepheid or RR Lyr cases, though one should note that not necessarily all of these systems are physical (due to principles related to the way this catalog was constructed). On the contrary, information on intrinsic variability of the components of systems listed in the Multiple Star Catalog (MSC, Tokovinin 2018) and in The Ninth Catalogue of Spectroscopic Binary Orbits (SB9, Pourbaix et al. 2004) definitely refers to physical binaries. GCVS contains valuable information on variables having components in comments, though this information relates mainly to variable stars, and we do not use it in BDB so far. If a binary system is found in GCVS, we mark this system as one containing an intrinsic (pulsating, eruptive, spotted, etc.) variable, based on the GCVS variability type. However, the BDB information about different types of intrinsic variability is certainly very incomplete. We introduce "intrinsic variable inside" type only if a star has a GCVS identifier in some of the catalogs of binaries and GCVS provides information concerning relevant variability type.

Figures 1–4 below show the screenshots of (some part of) BDB representation for a remarkable multiple system BSDB J194448.73+291552.8:s including a classical Cepheid, SU Cyg. One of the components (BSDB J194448.73+291552.8:c1B) of the spectroscopic binary with an orbital period of $\sim$549 d, SBC9 1172 = BSDB J194448.73+291552.8:p1A-1B, is a Cepheid, while another component itself is a close spectroscopic binary, SBC9 2142 = BSDB J194448.73+291552.8:p1AA-p1Ab, having orbital period of $\sim$4.7 d. The wider pair can be resolved interferometrically. Three more distant visual components of yet unknown physical connection are situated at angular separations of $\sim 25''$, $\sim 71''$ and $\sim 75''$, respectively.

Combined with parallax $\varpi = 1.52 \pm 0.27$ mas (*Gaia* DR1 TGAS, Lindegren et al. 2016) or $\varpi = 1.1695 \pm 0.0516$ mas (*Gaia* DR2, Lindegren et al. 2018), this does not favor expectations of orbital motion. On the other hand, based on *Gaia* DR2 parallaxes for these remote components ($1.2351 \pm 0.0278, 1.9440 \pm 0.0246, 1.1280 \pm 0.0345$ mas), at least two of them are situated rather close to SU Cyg in space, and at least one of them, the one with $\varpi = 1.1280 \pm 0.0345$ mas, has similar proper motion. Anyway, the system is quite interesting and promis-


Welcome to

The Binary Star Database

Binary star DataBase (BDB) is the database of binary/multiple systems of various observational types. BDB contains data on physical and positional parameters of 260,000 components of 120,000 stellar systems of multiplicity 2 to more than 20, taken from a large variety of published catalogues and databases.

[back]

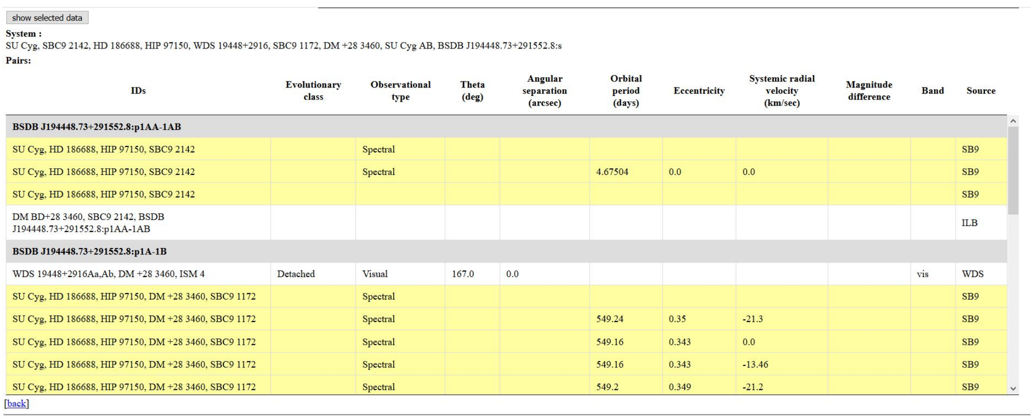
Zoom out of the screen if you do not see background picture

[report error]

Components (c) and unresolved pairs (p):

IDs	Coordinates	Proper motion RA, Dec (mas/y)	Magnitude	Spectral Type	Source
BSDB J194448.73+291552.8:c1					
WDS 19448+2916, WDS 19448+2916A, BSDB J194448.73+291552.8:c1	19 44 48.739 +29 15 52.884				ILB
WDS 19448+2916A, WRH 23	19 44 48.74 +29 15 52.9	0.0 -4.0	7.03	F	WDS
BSDB J194448.73+291552.8:c1AA					
BSDB J194448.73+291552.8:c1AA	19 44 48.734 +29 15 52.884				ILB
BSDB J194448.73+291552.8:c1AB					
BSDB J194448.73+291552.8:c1AB	19 44 48.734 +29 15 52.884				ILB
BSDB J194448.73+291552.8:c1B					
WDS 19448+2916Ab, ISM 4	19 44 48.74 +29 15 52.9		8.0		WDS

Fig. 1 Result of request on "SU Cyg" in BDB. This multiple system includes a Cepheid. Yellow background indicates lines of text referring to the requester identifier, and other (*white*) lines provide information on other objects in the same system.


show selected data

System :

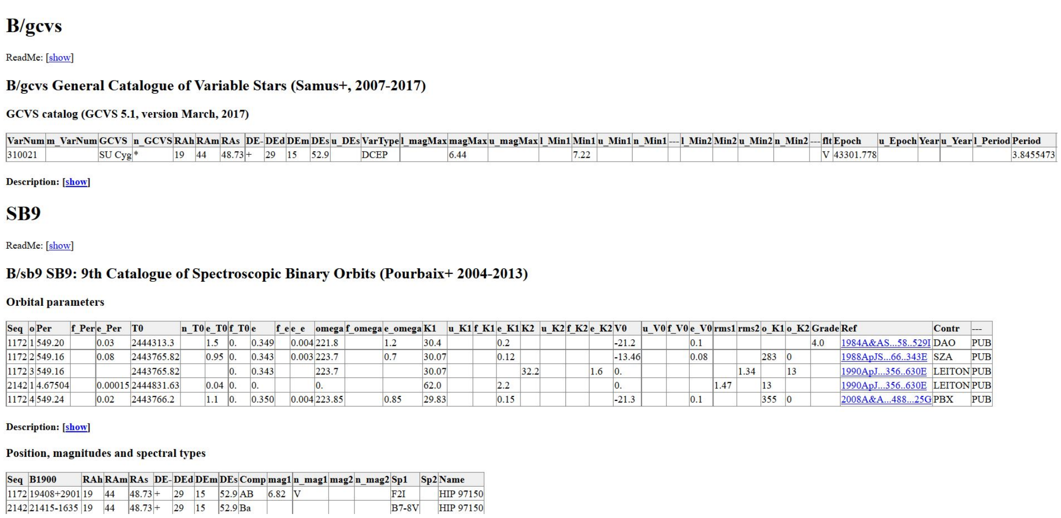
SU Cyg, SBC9 2142, HD 186688, HIP 97150, WDS 19448+2916, SBC9 1172, DM +28 3460, SU Cyg AB, BSDB J194448.73+291552.8:s

Pairs:

IDs	Evolutionary class	Observational type	Theta (deg)	Angular separation (arcsec)	Orbital period (days)	Eccentricity	Systemic radial velocity (km/sec)	Magnitude difference	Band	Source
BSDB J194448.73+291552.8:p1AA-1AB										
SU Cyg, HD 186688, HIP 97150, SBC9 2142		Spectral								SB9
SU Cyg, HD 186688, HIP 97150, SBC9 2142		Spectral			4.67504	0.0	0.0			SB9
SU Cyg, HD 186688, HIP 97150, SBC9 2142										SB9
DM BD+28 3460, SBC9 2142, BSDB J194448.73+291552.8:p1AA-1AB										ILB
BSDB J194448.73+291552.8:p1A-1B										
WDS 19448+2916Aa,Ab, DM +28 3460, ISM 4	Detached	Visual	167.0	0.0					vis	WDS
SU Cyg, HD 186688, HIP 97150, DM +28 3460, SBC9 1172		Spectral								SB9
SU Cyg, HD 186688, HIP 97150, DM +28 3460, SBC9 1172		Spectral			549.24	0.35	-21.3			SB9
SU Cyg, HD 186688, HIP 97150, DM +28 3460, SBC9 1172		Spectral			549.16	0.343	0.0			SB9
SU Cyg, HD 186688, HIP 97150, DM +28 3460, SBC9 1172		Spectral			549.16	0.343	-13.46			SB9
SU Cyg, HD 186688, HIP 97150, DM +28 3460, SBC9 1172		Spectral			549.2	0.349	-21.2			SB9

[back]

Fig. 2 Result of request on "SU Cyg" in BDB, which lists identifiers and part of the data on pairs. The "Show selected data" button in the upper part of the figure (just below the visualization figure on the real screen) leads to lines of original data from the catalogs for objects displayed on the yellow background.


B/gcvs

ReadMe: [show]

B/gcvs General Catalogue of Variable Stars (Samus+, 2007-2017)

GCVS catalog (GCVS 5.1, version March, 2017)

VarNum	m_VarNum	GCVS	n_GCVS	RAh	RAm	RAs	DE-	DEd	DEm	DEs	u_DEs	VarType	l_magMax	magMax	u_magMax	l_Min1	Min1	u_Min1	n_Min1	---	l_Min2	Min2	u_Min2	n_Min2	---	flt	Epoch	u_Epoch	Year	u_Year	l_Period	Period
310021		SU Cyg	*	19	44	48.73	+	29	15	52.9		DCEP		6.44			7.22									V	43301.778					3.8455473

Description: [show]

SB9

ReadMe: [show]

B/sb9 SB9: 9th Catalogue of Spectroscopic Binary Orbits (Pourbaix+ 2004-2013)

Orbital parameters

Seq	o	Per	f_Per	e_Per	T0	n_T0	e_T0	f_T0	e	f_e	e_e	omega	f_omega	e_omega	K1	u_K1	f_K1	e_K1	K2	u_K2	f_K2	e_K2	V0	u_V0	f_V0	e_V0	rms1	rms2	o_K1	o_K2	Grade	Ref	Contr	---
1172	1	549.20		0.03	2444313.3		1.5	0.	0.349		0.004	221.8		1.2	30.4			0.2					-21.2			0.1					4.0	1984A&AS...58..529I	DAO	PUB
1172	2	549.16		0.08	2443765.82		0.95	0.	0.343		0.003	223.7		0.7	30.07			0.12					-13.46			0.08			283	0		1988ApJS...66..343E	SZA	PUB
1172	3	549.16			2443765.82			0.	0.343			223.7			30.07				32.2			1.6	0.					1.34		13		1990ApJ...356..630E	LEITON	PUB
2142	1	4.67504		0.00015	2444831.63		0.04	0.	0.			0.			62.0			2.2					0.				1.47		13			1990ApJ...356..630E	LEITON	PUB
1172	4	549.24		0.02	2443766.2		1.1	0.	0.350		0.004	223.85		0.85	29.83			0.15					-21.3			0.1			355	0		2008A&A...488...25G	PBX	PUB

Description: [show]

Position, magnitudes and spectral types

Seq	B1900	RAh	RAm	RAs	DE-	DEd	DEm	DEs	Comp	mag1	n_mag1	mag2	n_mag2	Sp1	Sp2	Name
1172	19408+2901	19	44	48.73	+	29	15	52.9	AB	6.82	V			F2I		HIP 97150
2142	21415-1635	19	44	48.73	+	29	15	52.9	Ba					B7-8V		HIP 97150

Fig. 3 One part of the result from a request on "SU Cyg" in BDB, second level (after the "Show selected data" button is pressed). Original data are from catalogs.

B/wds The Washington Visual Double Star Catalog (Mason+ 2001-2014)

The Washington Double Star Catalog (main part)

WDS	Disc	Comp	Obs1	Obs2	Nobs	pa1	pa2	sep1	sep2	mag1	mag2	SpType	pmRA1	pmDE1	pmRA2	pmDE2	DM	Notes	n_RAh	RAh	RAm	RAs	DE-	DEd	DEm	DEs
19448+2916	ISM 4	Aa,Ab	1949	1988	4	119	167	0.1	0.0	7.0	8.0	F2Iab	+000	-003			+28 3460	N		19	44	48.74	+	29	15	52.9
19448+2916	WRH 23	AE	1895	2006	9	290	288	24.4	24.8	7.03	10.54	F2I	+000	-004	-001	-002		N		19	44	48.74	+	29	15	52.9
19448+2916	WRH 23	AF	1895	2006	8	18	18	71.4	70.9	7.03	10.88	F2I	+000	-004	+007	-009		N		19	44	48.74	+	29	15	52.9
19448+2916	WRH 23	AG	1895	2006	8	88	87	75.9	75.9	7.03	10.21	F2I	+000	-004	+003	-005		N		19	44	48.74	+	29	15	52.9

Description: [show]

The Washington Double Star Catalog (notes)

WDS	Disc	Text	RefCode
19448+2916	ISM 4	The Cepheid SU Cyg. This is also known as WRH 23Aa,Ab. The Wilson	
19448+2916	ISM 4	component were previously assigned to 19372+2920, but this was a	
19448+2916	ISM 4	position error on Wilson's part leading to the the pairs not being	WRH1950a
19448+2916	ISM 4	confirmed for many years. The wider components of Wilson will retain	
19448+2916	ISM 4	their historical, AE, AF, and AG component identifiers. The closer	
19448+2916	ISM 4	Aa,Ab pair will remain ISM 4. The problem was noted by Cliff	
19448+2916	ISM 4	Ashcraft and the correct system found by James Daley.	

Description: [show]

II/235

ReadMe: [show]

II/235 The Photometric Magnitude Difference Catalog (Worley+ 2001)

Delta-M Catalog

RAh	RAdm	DE-	DEd	DEm	DiscName	Comp	dm	o_dm	r_dm	Meth	Notes
19	448	+	29	16	ISM 4		1.0	1	Ism1992	E	550

Fig. 4 Another part of the result from a request on "SU Cyg" in BDB, second level (after the "Show selected data" button is pressed). Original data are from catalogs (not all catalogs are represented).

ing, thanks to an admirable combination of multiplicity and variability.

3 ECLIPSING BINARY CATALOGS

Eclipsing binaries form the most populated observational type of binaries, and hundreds of thousands of such stars have already been discovered in our Galaxy and in the Magellanic Clouds. The increase in the number of known eclipsing binaries during recent decades is thanks to projects searching for brightness variability (ASAS, Paczyński et al. 2006) due, in particular, to gravitational microlensing or exoplanet transit (OGLE, Soszyński et al. 2016; *Kepler*, Kirk et al. 2016). Numerous eclipsing binaries discovered in the course of such projects cannot, as a rule, be individually investigated and classified. In the meantime, the recent version of GCVS (Samus' et al. 2017) includes more than 10 000 eclipsing variables having sufficiently complete data.

Eclipsing binaries can be very different both morphologically and physically. There is a number of catalogs devoted to some subclasses of these stars in BDB. Compared to other observational types of stars, catalogs devoted to reliably classified eclipsing binaries contain more physical information on the systems and components. In particular, a large volume of physical data was obtained by Prof. M. A. Svechnikov and his colleagues in their investigation of lightcurves of eclipsing variable stars (Perevozkina & Svechnikov 2004; Surkova & Svechnikov 2004; Dryomova et al. 2005; Svechnikov & Bessonova 1984; Bondarenko & Perevozkina 1996; Polushina 2011; Svechnikov & Kuznetsova 2004).

The Catalogue of Eclipsing Variables (CEV, Avvakumova et al. 2013; Malkov et al. 2006) contains the most complete data on eclipsing variables of known morphological types. It combines data from GCVS tables and text remarks with data from other bibliographic sources and observations, using an author's original scheme of lightcurve processing to determine the physical type of a binary and its characteristics.

The gap between a number of discovered eclipsing binaries and possibilities for individual investigation of every star to obtain its physical characteristics make automatization of lightcurves classification extremely advantageous (see, for instance, Modak et al. 2018; Armstrong et al. 2016; Avvakumova & Malkov 2014; Malkov et al. 2008). It is expected that as one of the results of the *Gaia* mission, several million eclipsing binaries will be discovered (Süveges et al. 2017; Kochoska et al. 2017).

So far, extensive lists of recently discovered eclipsing binaries were not included into BDB, due both to their underclassification and low probability that they may intersect with any other catalogs. However, recent progress in automated classification of lightcurves, systematic investigations of eclipsing binaries discovered in large surveys with different techniques (Soszyński et al. 2016; Kozłowski et al. 2016; Parihar et al. 2009), objects observed in more than one survey (Drake et al. 2014; Muraveva et al. 2014; Schaffenroth et al. 2013), and many objects of interest among these eclipsing binaries (see, e.g., eclipsing binaries with a Cepheid component, Pilecki et al. 2016; Udalski et al. 2015; spectroscopically resolved eclipsing binaries Maceroni & Montalbán 2004;

Kozłowski et al. 2016) motivate us to start preparing for integration of extensive lists of eclipsing binary stars, discovered in surveys, into the ILB.

4 CATALOGS OF INTRINSIC BINARY VARIABLE STARS

In GCVS, there is a number of classes of physically variable stars with variability caused by their binarity. Let us name them intrinsic binary variable stars.

Currently about 2000 cataclysmic variable stars are known. In addition to GCVS, two main (overlapping) catalogs for this observational type are those by Ritter & Kolb (2011) (which was regularly updated until 2016) and by Downes et al. (2005). The data on these binaries are highly non-uniform, but usually include orbital characteristics (period, inclination limitations), morphological type of a variable and relative characteristics of the components.

Some binaries demonstrate variability out of the optical range. In BDB, there are data on about 300 X-ray binaries (partly included in the already mentioned catalog by Ritter & Kolb 2011). Other data sources for these objects are the Catalogue of Galactic Low-Mass X-Ray Binaries (LMXB, Liu et al. 2007), and Catalog of Galactic High-Mass X-Ray Binaries (HMXB, Liu et al. 2006). In addition, there are more than 200 radio pulsars discovered in binary systems. These objects were identified with optical sources for their integration into ILB and, therefore, into the database (Malkov et al. 2015).

We do not yet include data on the classes of binaries discovered at the stage when they actually cease being binary, like SNe Ia and gravitational wave binaries.

There is a group of variable binaries for which brightness varies with stellar or orbital rotation. Simultaneously, this variability critically depends also on their binarity: these are ellipsoidal, reflecting and spotted binaries (Samus 2005). GCVS is the main source of data for these stars in BDB.

5 CONCLUSIONS

Variable stars with different physical and observational natures are represented in BDB by data from a number of catalogs. As part of binary or multiple systems, intrinsic variable stars can provide more interesting data than single ones. Intrinsic binary variable stars are among the most popular astrophysical laboratories. Eclipsing binary stars form the most populated and rapidly increasing class of variable binaries. Only a smaller, well-studied part of them from the GCVS catalog is presented in BDB thus far. These stars allow determination of astrophysical data if their physical nature is properly classified. Automated classification of lightcurves of eclipsing binaries is an important challenge at present and in the near future.

When this paper was almost completed, the Second Data Release of the *Gaia* mission (Gaia Collaboration et al. 2016) had just been published. Although, contrary to earlier plans, this data release does not include catalogs of non-single stars, it contains extensive new information on variable stars. We work on BDB and its index catalog, ILB, to compile data from present and forthcoming large catalogs to benefit investigations of binary stars, including variable binaries and variables in binaries.

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