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Classification of close binary systems by Svechnikov

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The paper presents the historical overview of classification schemes of eclipsing variable stars with the foreground of advantages of the classification scheme by Svechnikov being widely appreciated for Close Binary Systems due to simplicity of classification criteria and brevity.

Keywords: Stars: eclipsing variables, close binary systems, classification scheme, classification criteria, card catalogue

1 From the history of the discovery of stellar variability

Ancient astronomers were likely quick-witted about stellar variability. One may suppose that the names of some stars indicate to this. For example βPer also known as *Algol* that in Arabic means *"devil's winking eye"*. Today we know that all stars may be considered as variables because during the evolution the luminosity of any star changes. A thing of importance is the phenomenon if the light changes are strictly periodic. This question deserves special attention and gives reasons to the necessity of a classification scheme which could distinguish variable objects by mechanisms of variability.

In the Soviet Union, work on the systematization and cataloging of variable stars was initiated in 1930s. It resulted in the publication of the first version of the General Catalogue of Variable Stars edited by Kukarkin and Parenago in 1948 where the information about **10930** variables was compiled.

The nature of variable stars is rich and includes among others such types as *classical cepheids*, short-periodic variables of *RR Lyrae* type, long-periodic variable giants of *Mira Ceti* type, *eruptive* variables, *explosive*, and *nova*-like variables.

The special place in this series is occupied by eclipsing variable stars. This is the class of close binaries, the orbital plane of which is so close to sight axis of an observer that makes eclipses of one component by another favorable for registration. Since 1669 when Montanari discovered the variability of *Algol* it remained an enigma for more than a hundred years. For the first time the eclipse mechanism was proposed by John Goodricke in 1783 to explain light curves obtained by him for *Algol*.

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Photometric solution of light curve gives us information about the relative parameters of stars and their orbital characteristics. In combination with spectroscopic data on radial velocity curves it allows us to consider eclipsing close binaries as most valuable and important objects in astrophysics. These data proved to be useful for studies of the stellar interior the understanding of which brings up more complex problems inseparably linked with stellar evolution and multiformity of close binaries. That is why classification of eclipsing variable stars is quite necessary.

2 First classifications of Eclipsing Variable Stars

The scheme by Payne-Gaposchkin and Gaposchkin (1938) became the first classification scheme capable of identifying the evolutionary status of eclipsing binaries. It was solely based on the analysis of light curves. The morphological variety of all known light curves was reduced to only three classes:

1. **EA** – *Algol*-type eclipsing variables;
2. **EB** – β *Lyrae*-type eclipsing variables;
3. **EW** – *W Ursae Majoris*-type eclipsing variables.

This scheme interpreted all multiformity of eclipsing variables as a variation of tidal deformation of components and their surface brightness ratio. The scheme did not concern the physical properties of stars and its main imperfection is shape dependence of the light-curve upon observation wavelength.

The next scheme proposed by Krat (1944) had unquestionable advantages in its completeness and took into account the physical characteristics of stars. Based on component spectral types the scheme allowed segregating binaries into the following groups: **A** (O–B9); **B** (B0–A9); **C** (*Algol-type*); **D** (A0–F9); **E** (G–M); **F** (*subdwarfs*); **G** (*supergiants*).

A serious drawback of this scheme was the fusion of stationary and non-stationary systems in one class.

The classification scheme by Plaut (1953) separated all known binaries into three classes: both components belong to Main Sequence (MS); only one component belongs to MS; both components do not belong to MS (*W UMa* systems are implied). It is obvious that the second class of the classification by Plaut can not distinguish secondary status. It may be equally supergiant, giant, dwarf, and subdwarf.

Another classification of binaries was performed by Kopal (1955) using a purely geometric criterion derived from the analysis of Roche lobes filling degree by each component which allowed dividing all binaries also into three classes: *detached*; *semi-detached*; *contact*.

But the first class integrated the binaries belonging to MS with binaries of *AR Lac* type, components of which are subgiants, even if they are detached and with detached binaries consisting of MS-star and subgiant. It is also true for the second class, containing *classic algols* together with short-periodic semi-detached systems of *R CMa* type. The third class mixes up contact binaries of *W UMa* type with contact systems of early spectral types. So, the small number of introduced classes may be considered as the main reason of the non-popularity of these classification schemes.

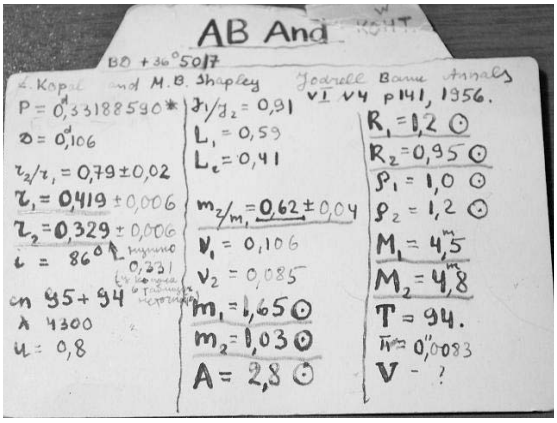


Figure 1 *AB And* as an example of a *CW* system from the card catalogue by Svechnikov.

Another problem of former classifications is their unhandiness and incapability of selecting criteria to guarantee the homogeneity within a class. Here one may recollect the classification by Sahade (1960) foreseen the class of binaries with pre-Main Sequence components without observational support.

In late 1960s, a new attempt to construct a more complete classification, that would be free of drawbacks of former schemes and would keep their advantages, was made by Svechnikov and his colleagues (Svechnikov, Istomin, Grehova (1980)).

3 Card catalogue by Svechnikov

The basis of any classification scheme are observational data. Therefore one has to start from data collection, selection, and systematization. It was Mariy Anatolievich Svechnikov who commenced the work in 1962. Information collected for each eclipsing variable star was carded including the designation of the star, its relative and absolute orbital elements, astrophysical parameters if known as well as authors' names and reference to the original paper (Fig. 1 (taken from M.A. Svechnikov's home archive)).

By 1969 the number of eclipsing variables compiled in the card catalogue was already **474**.

The most informative systems are eclipsing variables with known spectroscopic data allowing direct calculation of all astrophysical parameters of components from the solution of radial velocity curve or by means of some indirect method to evaluate the mass ratio of components and other stellar parameters. Systems not supported by spectroscopic observations have a lower priority but in those cases when the photometric value of mass ratio and spectral type of at least one of the components (usually more massive) are known one may roughly calculate the astrophysical parameters.

By 1969 the number of eclipsing variables with the known orbital elements and astrophysical parameters in the card catalogue by Svechnikov was **197**. Namely these systems served as a basis for the systematization of close binary systems in accordance with the generality of their geometric and physical properties.

4 Criteria of new classification of close binary systems

To make the classification scheme capable of distinguishing between close binaries on evolutionary status it is necessary that the classification criteria were fitted to evolutionary signs. During the evolution the size of components and their mutual orbit change. At some moment the components of close binary systems begin to interact actively via exchange of mass. Changes in geometrical characteristics of components are reflected by Roche lobes fill-out degree. This criterion has already been used by Kopal (1955) but proved to be insufficient for complete classification. Since mass exchange is an important process in binary evolution, Svechnikov decided to keep Kopal's criterion in the new classification scheme.

As is known, the components of close binaries fill in their Roche lobes not once during the evolution, therefore an additional criterion specifying the current state of each component is required. Such identification was performed using the Hertzsprung–Russell diagram (HR) for systems with known astrophysical parameters, i.e., for **197** systems from the card catalogue.

Thus, *Roche lobes fill-out degree* and *the location of the components on the HR diagram* were chosen by Svechnikov as *principal criteria* of the new classification (Svechnikov (1969)). As a result of performed classification of **197** close binary systems nine classes homogenous in their properties were revealed (Table 1). Already established terminological concepts were used for input classes of close binaries, for example, "systems with detached components", "semi-detached", "contact binaries of early-spectrum types".

The results of the classification were published in the "Catalogue of orbital elements, mass, and luminosities of Close Binary Systems"(Svechnikov (1969)), including information about **197** systems and their classification signs.

5 Simple criteria of the classification of eclipsing variables

For statistical investigations much larger data volumes are needed. But in catalogues as a rule only the most general observational data are collected. For instance, in the third edition of the General Catalogue of Variable Stars (**GCVS III**) and in three supplements to it (Kukarkin, Kholopov et al., (1969–1976)) for eclipsing variable stars one can find information about the type of light curve (*EA, EB, EW*), orbital period, P, and primary minimum depth, A_1. But information about the depth difference of minima, ΔA, is rare as well as spectral type of primary component. Naturally the question arises whether relying only on raw observational data one may construct exactly the same classification of eclipsing variable stars as was performed on the basis of astrophysical parameters analysis of star components. Search for new simplest criteria following from direct observations became an attempt to answer the question.

The card catalogue by Mariy Svechnikov proved to be very useful. For **367** of **474** close eclipsing binaries information about photometric elements including the mass ratio and in the most cases primary spectral type, Sp_1, was available. Using methods of approximate estimations one could derive absolute elements of the orbit and astrophysical parameters of stars (masses and radii). Analysis in the framework

Table 1 The classification scheme for close binary systems by Svechnikov.

Class abbreviation	Class full name	Class definition
DMS	**D***etached on* **M***ain* **S***equence*	Both components are on the Main Sequence (MS) and do not fill in their own Roche lobes.
SD	**S***emi-***D***etached*	A more massive component is a MS-star not filling its own Roche lobe and the secondary component is a subgiant close in-sizes to Roche lobe.
DS	**D***etached with* **S***ubgiant*	A more massive component is a MS-star not filling its own Roche lobe and the secondary component is a subgiant far out in-sizes of its Roche lobe.
S-G	**S***upergiant-***G***iant*	Systems in which at least one component is late spectral type supergiant or giant.
S-D	**S***ubdwarf-***D***warf*	Systems in which at least one component is in far advanced evolution stage being hot subdwarf, white dwarf or compact non-classic objects as neutron star (**NS**), Black Hole (**BH**). *Wolf–Rayet* stars are also here.
DW	**D***etached similar to* **W** *UMa, or short-periodic RS CVn*	Components are far from Roche lobe sizes but their orbital periods are much shorter than those of **DMS** systems with the same masses. Chromospheric activity signs are discovered.
CW	**C***ontact of* **W** *UMa type*	Contact systems of late spectral types (later than $F0$) are often embedded in common envelope. Components of such systems are in active phase of mass exchange and loss. Photometric wave is characteristic for these systems. Resonance doublet of $MgII$ 2802$\dot{A}$ and L_α serve as indicators to magnetic and chromospheric activity.
CE	**C***ontact* **E***arly*	Contact systems of early spectral types (earlier than $F0$).
AR	**AR** *Lac* type or *RS CVn* type	Both components are detached subgiants. Such systems show coronal eruptions similar to solar flares, the periodicity of which is explained in the framework of the cyclic spot activity model.

of theoretical stellar evolutionary models allowed reliably sorting out these systems into classes. The distribution of stars in classes was as follows: DMS – 77; SD – 43; DS – 21; CW – 47; CE – 48; S-G – 20; AR – 6; SW – 5.

It is important to emphasize that this distribution was obtained relying on known astrophysical data. But what if one would not have these data excepting raw observational data A_1, ΔA, P, Sp_1. Would the systems form exactly the same "islets" of clustering in the space of these four parameters?

To answer the question it was necessary to study projections of star distribution onto 2D planes defined by any two of four variables. The treatment of the projections was carried out by means of cluster analysis and resulted in the formulation of reliable segregation criteria.

6 $A_1 - \Delta A$ criterion

The first criterion of class segregation was derived from the analysis of the distribution of close binary systems with respect to primary minimum depth, A_1. It was found that the overwhelming majority of *SD* and *DS* systems have $A_1 > 0.^m8$. It is explained by eclipse character in primary minimum, when low luminosity secondary component (subgiant large in size) occults primary component entirely. Only in cases of low inclination of orbital plane to the plane of the sky (inclination i is noticeably less than 90°) the value of A_1 proved to be small. It also concerns *DMS* class with large brightness ratio hereupon the eclipse in the primary minimum looks shallow.

The analysis of mistakes and "admixture" in preliminary classification shows that the segregation would be more trustworthy if one uses the secondary criterion – ΔA. For 92.6% of *SD* and *DS* class binaries differences of minima depths are greater than $0.^m6$ while for *DMS* and *CE* classes $\Delta A < 0.^m6$. As for *CW* class the values of ΔA are less than $0.^m3$.

But even for *SD* and *DS* binaries with $A_1 < 0.^m8$ and $\Delta A < 0.^m6$ their segregation from other classes may be performed surely if one analyzes dual criterion $A_1 - \Delta A$. For systems of *SD* and *DS* classes values of A_1 and ΔA are almost equal and as seen from Fig. 2 (Svechnikov (1985)) systems of these classes are located close to bisector while systems of other classes show a noticeable digression from it.

7 $P - Sp_1$ criterion

The study of orbital period distributions of close eclipsing binaries of different classes shows that systems of *SD* and *DS* classes may be easily sorted out by the criterion $P = 8^d$. For all *SD* class systems their orbital periods are shorter than 8^d and for 90% of *DS* class systems their periods are longer than 8^d. The criterion does work for other classes:

- *CW* class systems have periods less than $0.^d5$
- periods of *CE* class binaries are within the range from $0.^d5$ to $1.^d58$
- *DMS* class binaries have periods longer than $1.^d58$ but shorter than 20^d
- *S-G* class systems have periods longer than 20^d for 95% of the class and longer than 100^d for 70% of the class. This criterion in combination with small values of A_1 and ΔA allows us to easily segregate these systems from *DS* class.

The remaining ambiguity in the classification may be eliminated by the application of a fourth criterion which was derived from the analysis of spectral type (Sp_1) distribution of primaries. This is the most important criterion because it allows us to reveal such hard-to-detect classes as *DW, AR* and *S-D* which were *"washed off"* in A_1, ΔA, and P projections.

For example, orbital periods of *DW* class are projected on the same interval as *CE* class while primary spectral types are different: Sp_1 later than *F*0 for *DW* and *CW* classes but earlier than *F*0 for *CE* class. The segregation of *DW* class from *CW* class is performed by *P*-criterion: orbital periods of *DW* class systems lie in the range from $0.^d5$ to $1.^d2$ while for *CW* systems orbital periods are strictly smaller than $0.^d5$.

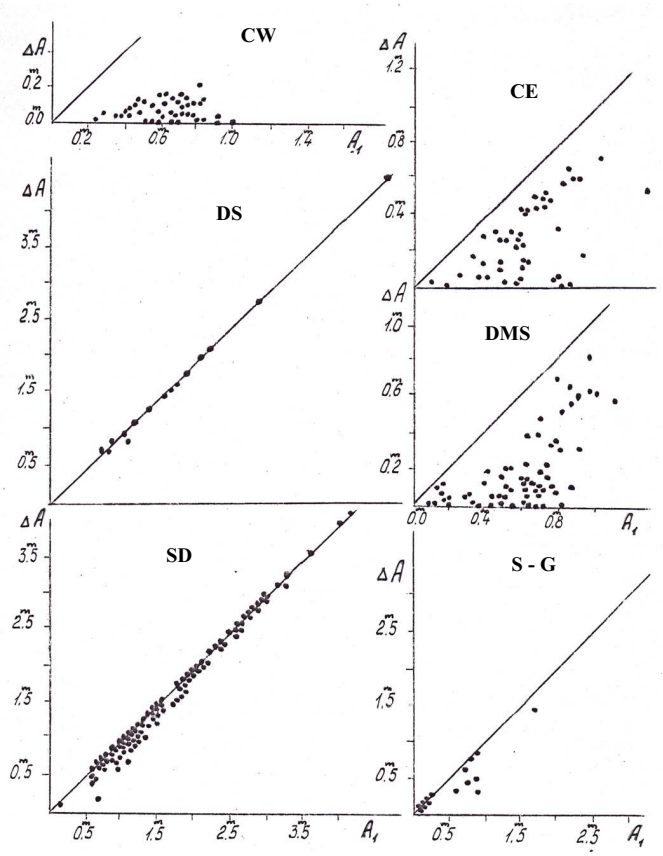


Figure 2 Classification diagram $A_1 - \Delta A$.

Systems of *AR* class have F–K spectral types for both components which are subgiants of **IV**–**V** luminosity classes. Classes of luminosity for primary components of *S-G* systems correspond to **I**–**II** or to late **III** and this is important for 5% of *S-G* systems with periods shorter than 20^d like *DMS* class systems but the luminosity class of the latest is **V**. Spectral types of *SD* and *DS* systems are earlier than *G*0.

For a more reliable separation of *CE* systems from short-periodic *DMS* systems the use of dual criterion diagram P–Sp_1 again proved to be effective as seen from Fig. 3 (Svechnikov (1985)). The diagram reflects a remarkable fact that components of *CE* systems have always filled Roche lobes at any value of mass ratio, q, while primaries of *DMS* systems having a mass ratio close to unity rarely fill in their Roche lobes more than 70%.

Figure 3 illustrates the way of sorting out different class systems, boundaries of which are well-outlined by solid and dashed lines reflecting the dependence $Sp_1(P)$ for *DMS* systems with $q = 1$ and $q = 0.75$, correspondingly. In both cases the primary component fills in its Roche lobe only by three quarters. This diagram also allows us to separate systems of *DW* and *CE* classes which are projected on the same range of orbital period.

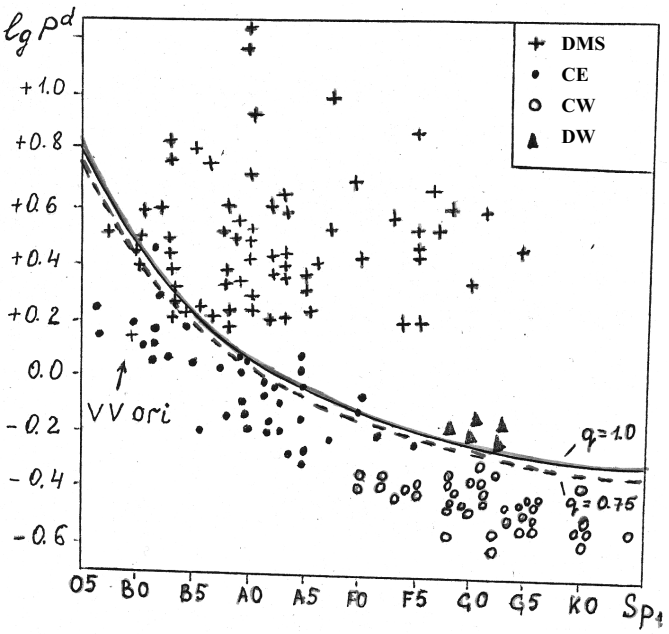


Figure 3 Classification diagram P–Sp_1.

8 An approbation of classification scheme on GCVS III

The found classification criteria for eclipsing variable stars are presented in Fig. 4 (Svechnikov (1985)) in a form of classification scales to make analysis of general observational data – A_1, ΔA, P, Sp_1 – easier and more convenient.

The next step was to estimate the reliability of performed classification. For this purpose three "verifiers" (Svechnikov, Istomin, Grehova (1980)) independently reclassified the same **367** eclipsing binaries from the card catalogue by Svechnikov, based only on the data about A_1, ΔA, P, Sp_1 which were taken from the **GCVS III** (Kukarkin, Kholopov et al. (1969–1976)). Results of the reclassification were then compared with the results of physical classification derived from the analysis of astrophysical parameters of star components and their localization on the HR diagram. It appeared that for **326** of **367** close binaries (almost 90%) the results of both classifications coincide.

The percentage of "admixtures" and "loss" is determined by the incompleteness of information on A_1, ΔA, P, Sp_1. For example, the absence of information on Sp_1 may lead to erroneous classification of DW class systems, which are identified as CE class systems. The same concerns short-periodic DMS systems with $P < 1.^d58$ which cannot be recognized by the classification scheme without the knowledge of Sp_1 and, as a consequence, are "admixed" with the CE class.

Taking into consideration the fact that information about Sp_1 was known only for **345** of **367** close binaries from the card catalogue by Svechnikov, it was decided to repeat the classification for these **345** systems having all four classification parameters.

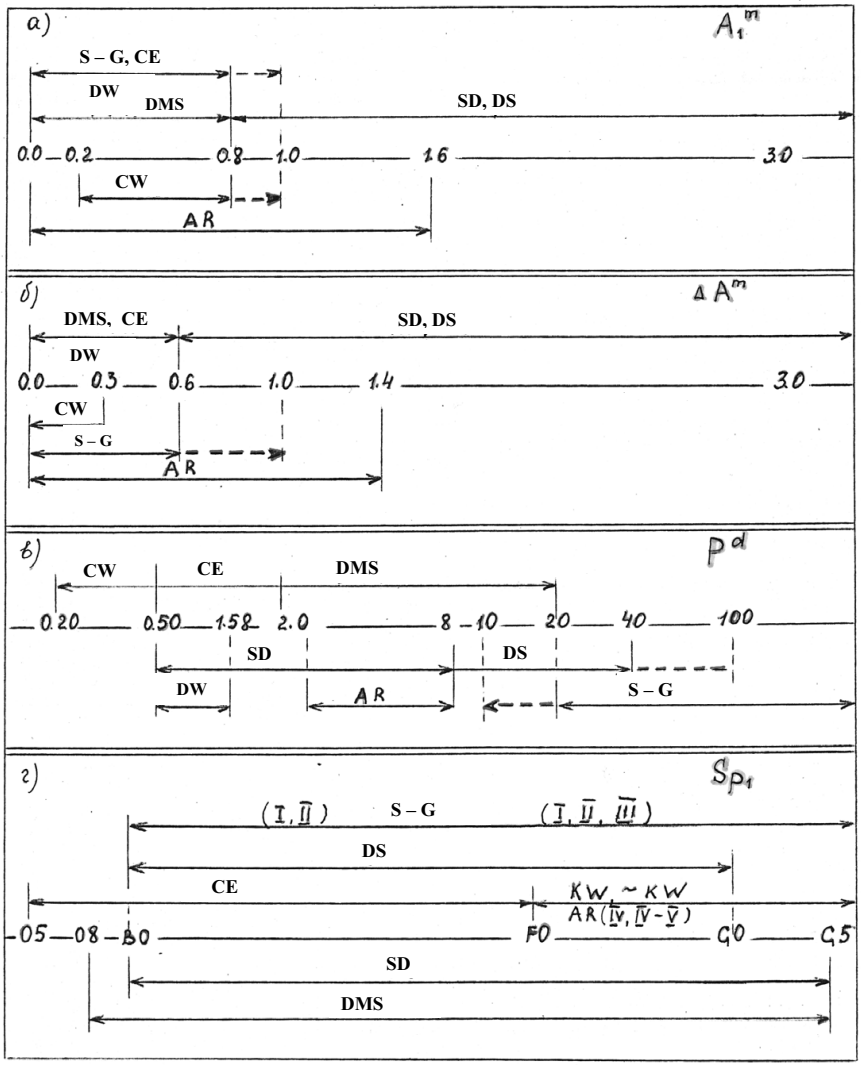


Figure 4 Scales of simple criteria for Close Binary System classification.

Repeated classification has shown a larger share of correctly classified systems (96%) justifying the conclusion about the importance of primary spectral type knowledge that allows sorting out AR and DW classes reliably.

Relying on obtained comparison results the conclusion about practical applicability of simple criteria for the classification of eclipsing variable systems was made. Being approximate the classification is of great interest to statistical study of close binaries and to the study of their evolution. This conclusion was immediately tested on **GCVS III** data containing **4704** eclipsing variable stars designated as E- *"eclipse"* (Kukarkin, Kholopov et al. (1969–1976)).

For many of these systems the data about minima depth difference, ΔA, could not be found. For **581** eclipsing variable stars information about the orbital period was absent and such systems were immediately excluded from the sample. Primary spectral type, Sp_1, was known for a limited number of systems – **1285**. They were considered as the *"golden fund"* for extensive testing of the four-parameter classification scheme. For the majority of systems from **GCVS III** (Kukarkin, Kholopov et al. (1969–1976)) the data about Sp_1 were not given and therefore two- or three-parameter classification was performed.

Saving the symbols adopted in **GCVS III** for the designation of data reliability degree the results were as follow:

- 58% is the share of reliably classified systems
- 17% is the share of classified systems with a slight degree of confidence
- 13% is the share of classified systems with a high degree of uncertainty
- 12% is the share of non-classified systems.

9 Perspectives of new classifications for close binaries

Application of the proposed classification scheme to eclipsing variables with known A_1, ΔA,P, Sp_1 from the **GCVS III** (Kukarkin, Kholopov et al. (1969–1976)) resulted in the publication of classification results in the next edition of the **GCVS IV** released in 1985 under the editorship of Kholopov (Kholopov et al. (1985)).

Today, when the completeness of the **GCVS** is close to 10^5 (Samus et al. (2009)) that is at the edge of capabilities to support the catalogue data by man, it is just the time to start thinking of an innovative concept of the new generation of catalogues planned to be issued upon completion of currently operated and to be launched missions such as *INTEGRAL*, *COROT*, *KEPLER*, *GAIA*, *SIM*. It is very likely that future catalogues will be deprived of a *"human face"*. They will be fully automated and robotic systems fitted to electronic data storage.

The comprehension of huge volumes of data is impossible without the development of systematization methods and classification schemes. Today the search for new general classification of variable stars including close binary systems continues. The classification scheme by Svechnikov was developed for only those binaries the components of which are in the phase of first mass exchange. But it is far from the end of the evolution of close binary systems.

A broad range of modern observational data allows us to distinguish between the nuances in transitional evolutionary stages of degenerate stellar objects, accompanied by the formation of ring nebulas, accretion disks, rings, and jets. Proper to these structures flashes and explosions are well separated in the energy range that may be considered as the classification criterion for late evolutionary stages of close binaries. The guarantee of the classification correctness is the preservation of its structure on larger volume statistics. Newly discovered classes are to be embedded in the basic classification according to the principle of hierarchical nesting.

There is no doubt that the scheme by Svechnikov will be naturally integrated in the new classification, despite the surprises that will definitely be presented by new space missions.

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