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# Classification of eclipsing binaries: main results and problems

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A classification scheme including all major evolutionary types of eclipsing binaries is presented, and a procedure for classification of eclipsing variables based on their light curve parameters and spectral data is developed. The procedure is applied to a catalogue of eclipsing variables compiled by the authors. In this paper we discuss results of the determination of the eclipsing binaries evolutionary class, as well as some general problems concerning the classification.

*Keywords*: Binaries: eclipsing – catalogues

## 1 Introduction

Eclipsing binaries are very numerous and represent a source for an accurate determination of the fundamental properties of stars: masses, radii, temperatures and luminosities. To properly determine the physical parameters, information about the position on the HR diagram for both the primary and secondary is needed as it defines the evolutionary class of a given binary star. Various procedures had been provided for determination of the evolutionary classes of eclipsing binaries from their observational data (see Giuricin et al. 1983; Svechnikov et al. 1980). Most of the classification algorithms were based on a restricted number of systems of the known evolutionary class and are not used today for large sets of data.

Malkov et al. (2006) have compiled a catalogue of eclipsing variables CEV and later Malkov et al. (2007) have presented a classification procedure based on a set of observational data even if the set is incomplete.

A lot of new eclipsing variables have been discovered since then, new observational data were collected for a large number of eclipsing systems in such surveys as ASAS-3 (Pojmański 2002), NSVS (Woźniak et al. 2004) etc. Thus, the development of a new version of CEV becomes topical. It is briefly described in Section 2. Based on the

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data presented in the new release of catalogue, an update of the algorithm for the automatic classification of eclipsing variables is performed and presented in Section 3. Some problems of classification are reviewed in Section 4, and finally Section 5 contains our conclusions.

## 2 Catalogue of eclipsing variables

For the compilation of our catalogue we used GCVS and its textual remarks (Samus et al. 2009) as a main source. Additionally if it is possible we updated information about observational parameters. In this case we used:

- lists of Dvorak (2004), Hoogeveen (2005), Otero (2004), data from ASAS-3 survey (Pojmański 2002) and catalogue of Bulut and Demircan (2007) as sources of photometric data;
- catalogue of Kreiner (2004) to check the periods;
- lists of Liao and Qian (2010) and Lanza and Rodonò (1999) to collect data on period variability;
- catalogues of Pourbaix et al. (2004), Skiff (2010), Wright et al. (2003) and data from van der Hucht (2001) and Bilir et al. (2008) to update spectral classes;
- data from Karataş et al. (2004) and Strassmeier et al. (1993) to add information about chromospherical activity.

Observational parameters were updated for 1783 systems.

To develop the classification procedure, the evolutionary classes were included in the catalogue. We used original investigations and catalogues of physical parameters of binaries. The cited catalogues are listed in Avvakumova et al. (2013).

The data set used to train the classification algorithm contains 1427 classified eclipsing variables. The scheme of evolutionary classes is presented in Fig. 1. The description of each class can be found in Avvakumova et al. (2013).

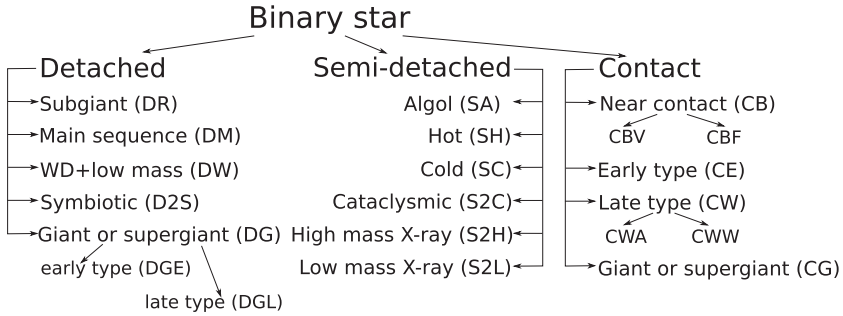



**Figure 1** The scheme of the evolutionary classes of binary stars.

## 3 Procedure for the classification of eclipsing binaries

Automatic classification of large lists of eclipsing variables is possible if some observational parameters are available. Usually the depth of the primary (always) and secondary (more rarely) minimum, orbital period and spectral type for at least more luminous component are known, so our algorithm operates with those values. For each evolutionary class we performed analysis of the distribution of eclipsing variables on the planes $A_1$ vs $A_2$, $A_1$ vs logP, logP vs $Sp_1$ and $Sp_1$ vs $Sp_2$ to determine the possible and limiting values for each observational parameter. Here $P$ is the orbital period, $A_1$ and $A_2$ is the depth of the primary and secondary minimum, $Sp_1$ and $Sp_2$ is the spectral type of the hotter and cooler component, respectively. Additionally we examined durations of the primary and secondary eclipses, variability of the period and chromospherical activity when known. Also the morphological type of the light curve (EA, EB or EW) was taken into account in our analysis. Using these parameters we constructed a set of classification rules for each evolutionary class displayed in Fig. 1.

An example of such an analysis for detached systems with subgiants (denoted as DR in the catalogue, most of them belong to RS CVn systems) is shown in Fig. 2. Known DR systems are denoted with empty circles while filled circles correspond to eclipsing variables classified as DR with our algorithm.

As can be seen in the bottom panel of Fig. 2, the depths of the primary and secondary minima $A_1$ and $A_1$ do not exceed 1.3 mag and 0.4 mag, respectively. Two exceptions are RW UMa ($A_1$=1.56 mag) and TY Pyx ($A_2 > 0.6$ mag). The data for them are obsolete and the systems are in need of a further study.

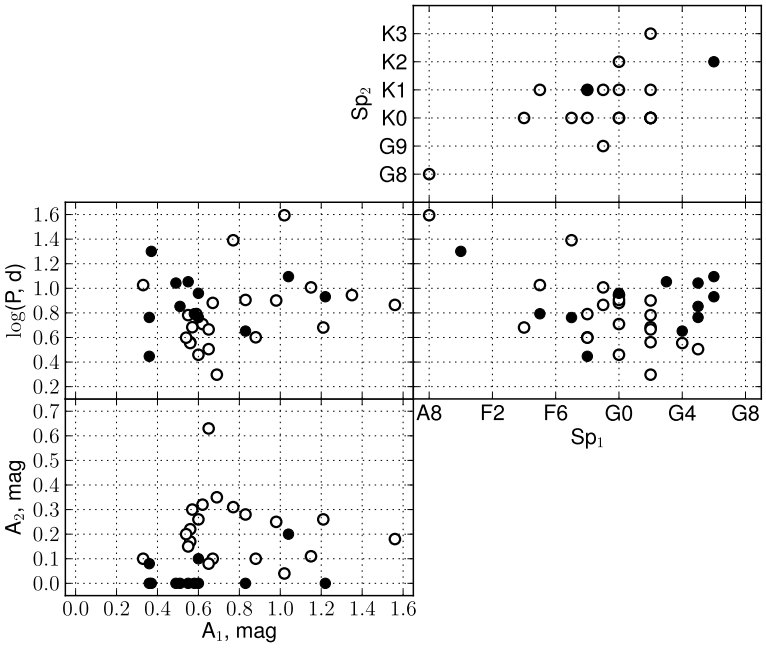



**Figure 2** Detached systems with subgiants. See discussion in the text.

Most of DR systems have periods shorter than 10 days (see the middle left panel of Fig. 2), except RZ Eri (logP=1.6) and AI Phe (logP=1.4). Both are long-period RS CVn systems. The lower period limit is about 1.5 days.

The relation between the period of DR systems and the spectral type of the hotter component is presented in the right middle panel of Fig. 2. The spectral type of the hotter component of most catalogued DR systems is within the range of F–G6. Only RZ Eri, with its spectral type of the hotter component A8–F0IV, does not satisfy this rule. We also found that secondary spectral types of such systems were between G8 and K3 (see top panel of Fig. 2). There is no DR systems with equal temperatures for both components in CEV; also at least one of the components is a subgiant.

Thus we concluded that the DR evolutionary class can be assigned to an eclipsing binary in the case when:

- The depth of the primary minimum does not exceed 1.56 mag and the depth of the secondary minimum does not exceed 0.35 mag;
- The orbital period is not shorter than 1.9 days and is not longer than 25.2 days;
- The spectral types of both components are late: the spectral type of the primary one lies in the range of A8–G6, while the spectral type of the secondary one is from G8 to K3, and the secondary spectra must be later than the primary at least by six spectral subclasses.

According to our analysis, all DR systems in CEV are chromospherically active stars exhibiting EA-type light curves (i.e., the light of the binary remains almost constant between eclipses). Those two additional conditions are also used for the classification.

The listed rules were applied to unclassified systems in CEV and new DR binaries were found. All of them are shown in Fig. 2 by filled circles. As can be seen, only for two of them a complete set of parameters ($A_1$, $A_2$, period and both spectra) is known. Other systems were classified successfully using an incomplete parameter set.

We applied the full set of rules for all evolutionary classes to 4748 unclassified systems of CEV. Using all parameters ($A_1$, $A_2$, period, both spectra) for 74% of systems the evolutionary class was determined. If the parameter set was incomplete the percentage of classified systems was lower.

## 4 Discussion

We presented a new version of the catalogue of eclipsing variables and the classification algorithm for the determination of evolutionary classes of eclipsing binaries based on their observable parameters such as the depth of the minima, the period and the spectra. The efficiency of our procedure can reach 74% in the case when a complete parameter set is given for a system. However, several problems arose:

1. A multiple-valued classification occurs in some cases;
2. Obsolete or unconfirmed values of observational parameters can obstruct the classification;
3. Contradictory values of parameters can lead to uncertain classification;
4. Extreme and unusual systems sometimes can not be classified.

### *4.1 Multiple-valued classification*

Multiple-valued classification is possible when a parameter list is incomplete or/and the limits for observational parameters of several classes are close to one another.

In Fig. 3 we give an example of a possible multiple-valued classification. Distribution of the systems of two classes SH and DR is shown on planes $A_1$ vs $A_2$ (bottom panel), $A_1$ vs logP (top left panel) and logP vs $Sp_1$ (top right panel).

As can be seen in Fig. 3 (bottom panel) the depth of the primary minimum $A_1$ for both semi-detached hot SH systems and detached systems with subgiants DR is in the same interval from 0. to $\sim 1.5$ mag. Moreover, about half of all SH systems have the same depth of the secondary minimum as DR systems do. The orbital periods of both DR and SH systems (see left top panel of Fig. 3) are also in the same range. Systems that can be classified with our procedure both as SH and as DR, based on their $A_1$, $A_2$ and logP values, are shown by filled circles in the bottom and top left panels of Fig. 3. The location of SH and DR systems on the plane logP vs $Sp_1$ is also shown. It is obvious that the spectral type of the primary (hotter) must be given to distinguish SH and DR systems. So we could not successfully classify systems which are shown with filled circles while their spectra are unknown. In some cases however the evolutionary class which is determined by our procedure remains uncertain even when the parameter set is complete. In such a case we calculated the membership probability for each class that can be assigned to the system during the classification.

For a given system the membership probability for the class $N$ is the ratio of classified systems of class $N$ to the total number of classified systems in the vicinity of a system in the parameter space. As the size of this parameter space, we used $3\sigma$

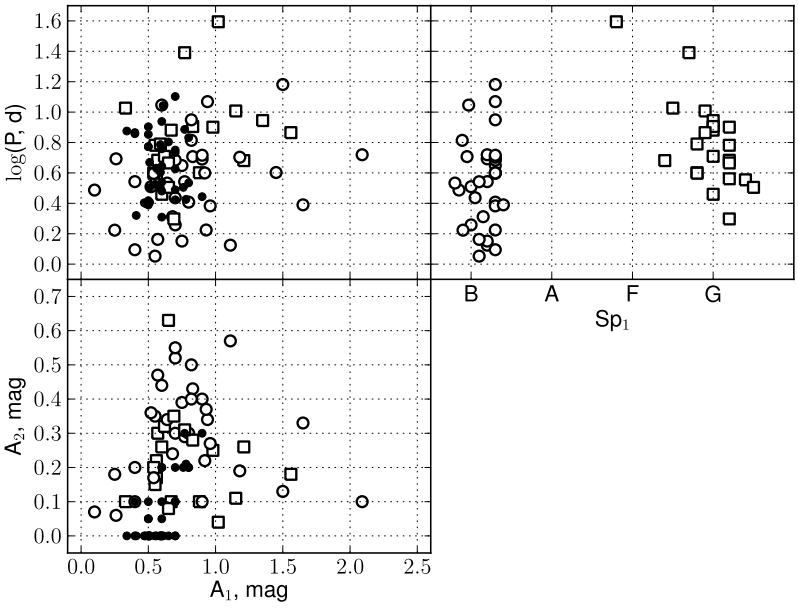



**Figure 3** Classified hot semi-detached systems (empty circles), detached systems with subgiants (empty squares) and systems which are candidates to both classes (filled circles).

estimates for each observational value. In the case of a multiple classification a star was considered to be classified successfully if the membership probability for one of the possible evolutionary classes was larger than 0.5.

### *4.2 Unconfirmed observational data*

The problem that we can refer to as "lack of observations" is an old photographic data about the amplitudes of the primary and secondary minima for many eclipsing variables. One of such a system RW UMa was mentioned earlier (see Fig. 2). RW UMa were classified as DR by Popper (1990) and values of $A_2$, period and spectra are typical for other DR binaries. But the value of the depth of the primary minima is equal to $1.56^m$ and is larger than the typical values for other DR. It may be assumed that new photometric observations will help us to determine the new value of $A_1$ and it will be lower than 1.2 mag.

Altogether, we found 238 systems in CEV, whose parameters are too unusual for any of the evolutionary classes that can be recognized by our algorithm. In the majority of the cases such parameters are based on photographic (probably, outdated) photometry, and we could not find confirmation (or refutation) of that data in the literature. Consequently, new observations and further investigations are required for these systems.

We included in this list contact and semi-detached systems, exhibiting evidence of orbital eccentricity (which is strange for such close systems), notably when the phase of the secondary minimum differs from 0.5 or durations of primary and secondary eclipses are not equal.

The list also contains systems with an unconfirmed value of orbital period, under suspicion that it can be twice longer or shorter.

### *4.3 Contradictory classification*

One of the results of our classification is that some systems turned out to belong to two or more classes, because their observed parameters (periods, spectra, depths of minima, etc.) are inconsistent with one another. All such systems were checked with the literature. For a lot of them we found contradictory classifications. The complete list includes 39 such systems, two examples are given below.

**BL Tel**

BL Tel ($A_1 = 2.32$ mag, $A_2 = 0.10$ mag, $P = 778.3$ days, F5Iab/b+M) is classified as a detached system with late-type supergiant DGL, but its observable depth of the primary minimum is larger than the typical value ($A_1 < 1.5$ mag) for other DGL systems. Based on its values of $A_1$, $A_2$ and spectrum, the system can be also classified with our procedure as a semi-detached algol SA, however its period is longer than the possible maximum value for the SA class ($P_{max} \approx 45$ days). The large value of $A_1$ may be caused by out-of-eclipse light variation. The hotter F supergiant is a pulsating variable, the amplitude of its intrinsic light variation is $0.1 - 0.2$ mag (see e.g. van Genderen 1982). But according to Zsoldos (1994) the depth of the primary minimum varies from year to year and it is not likely that this is caused by the variability of F-type primary alone. The color curves are symmetric too. To explain the variability

of color indexes van Genderen (1983) supposed a cold asymmetric gas stream, but we did not find any confirmation of semi-detached configuration. We assume that new investigations (especially spectral observations) are needed to confirm or reject the semi-detached configuration.

**PW Pup**

PW Pup ($A_1 = 0.65$ mag, $A_2 = 0.30$ mag, P = 158. days, B8:+F2epIab) is another unclassified system in our catalogue. Its long period is suitable for a detached system with late-type supergiant DGL only, but its $A_2$ is larger than the upper limit ($A_2^{max} = 0.2$ mag) for this class. Also the spectral type of the secondary is earlier than the typical spectra of other DGL systems (from G to M). Bopp et al. (1991) pointed out that PW Pup is an interacting system with $H_\alpha$ emission in spectra, thus, an accretion process is possible. According to Eggen (1983) the system is close to contact, but its period is much greater than any type of contact and close to contact system may have.

### *4.4 Extreme and unusual systems*

We also compiled a list of systems which have unusual values of parameters and stay at extreme or rare stages of evolution. These systems do not belong to any of the classes that we use. Some of these binaries may be used as prototypes for new classes or/and may serve as excellent tests of stellar evolution theories. We found 52 such systems. Some examples are presented below.

**V718 Per**

V718 Per is an unclassified system with a very long period (up to 1716 days according to VSX). Such a long period points to a detached system with late-type supergiant, but the spectral type of V718 Per is G9IV–V (Grinin et al. 2008). Based on the comprehensive analysis of photometric and spectroscopic data, Grinin et al. (2008) concluded that V718 Per is a pre-MS post-T Tau single star, and eclipses are caused by large variable amounts of circumstellar dust. Thus, we deleted this system from our catalogue.

**$\upsilon$ Sgr**

$\upsilon$ Sgr is an unclassified system with a long period P = 137.94 days which is suitable for a detached system with the late-type component. However, both the primary and secondary of $\upsilon$ Sgr are early-type stars. According to Netolický et al. (2009), the system is the brightest member of the type of extremely hydrogen-deficient stars (HdB). These stars are a rather rare class of evolved binary systems that are in the second phase of mass transfer where the primary ended the core-helium burning phase. The dusty circumstellar disk was also registered.

## 5 Conclusions

We performed a comprehensive analysis of the observational parameters of eclipsing variables of the recently compiled CEV catalogue (Avvakumova et al. 2013). We

studied the distribution of systems of different evolutionary classes (see Fig. 1) in the parameter space and extracted the set of classification rules to determine the evolutionary class of eclipsing binaries depending on the parameters of their light curves and spectra.

The developed algorithm was applied to 4748 unclassified systems of the CEV catalogue. Our procedure allows us to classify up to 74% of eclipsing variables with the full set of parameters.

We found systems that can not be recognized by the procedure during the training of our algorithm and classification. We compiled lists of problem stars and discussed several examples of such binaries. Further observations and investigations are needed for the majority of them. Some of those binaries represent rare and extreme evolutionary states.

The list of classified systems and lists of problem stars are available upon request.

Our procedure can be applied to the data from ground- and space-based missions.

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