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Comprehensive list of semi-detached double-lined eclipsing binaries with Gaia DR2 data

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Semi-detached eclipsing systems play an important role in our understanding of stellar properties. In the present study, we have cross-matched a previously compiled comprehensive list of SD double-lined eclipsing binaries, containing 119 systems, with Gaia DR2, and analyze the result. A special analysis is conducted for systems with controversial data on parallaxes. It is shown that Gaia DR2 effective temperatures should be used with caution, as they do not describe hot SD systems well. We have also compiled an empirical relation between the temperature of the accretor and the donor.

Keywords: Binaries: close – binaries: eclipsing – stars: evolution – stars: fundamental parameters

1 Introduction

Eclipsing binaries provide a unique opportunity to derive the basic properties of detached and interacting binaries. With precise mass, radius, and temperature estimates, they offer an exceptional opportunity to test theoretical stellar models. Semi-detached (SD, a term introduced into astronomical literature by Kopal (1955)) binaries are systems where one of the components is generally considered to be Roche lobe filling and transferring mass to its companion. If a binary star happens to orbit in a plane along our line of sight, its components will eclipse and transit each other. However, such a binary would not be detected if its orbit inclinations were less than $\sim 70^\circ$. Such "pole-on" binaries look like single stars. The frequency of SD binaries among the stars observed as single is estimated in Malkov (2016).

Semi-detached binaries are very numerous. The catalogue of eclipsing variables (CEV, Avvakumova and Malkov (2014), `http://www.inasan.ru/~malkov/CEV/`), the world principal database of eclipsing binary systems with available classification, contains 2207 semi-detached systems. For 481 of them, the evolutionary class is available from the literature, and a further 1726 systems are classified according to the procedure described in Malkov et al. (2007) and developed in Malkov et al.

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(2011). However, the stellar parameters (mass m, radius R, effective temperature $T_{\rm eff}$, luminosity L) can be determined for only part of them, as only a small fraction of the eclipsing binaries have been spectroscopically followed to determine their physical properties. We have recently compiled a most comprehensive list of 119 semi-detached double-lined eclipsing binaries (SD DLEB), containing orbital parameters and physical parameters of components (Malkov 2020). The goal of this work is to cross-match our SD DLEB with Gaia DR2 (Gaia Collaboration et al. 2018) and analyze the resulting list.

2 Analysis of Gaia DR2 data for SD DLEB

We have made a cross-match of 119 SD DLEB catalogued in Malkov (2020) with Gaia DR2 (Gaia Collaboration et al. 2018) using the Gaia archive*.

Note that besides the parallax value ϖ the Gaia archive provides also the so-called target parallax (hereafter ϖ_{tg}), which is the result of cross-identification of Simbad objects with Gaia DR2 made in CDS. For six stars (GG Cas, QS Aql, δ Pic, V Pup, AB Per, λ Tau), ϖ values differ from ϖ_{tg} values. The data catalogued in Malkov (2020) allows us to undo this uncertainty. For these six stars, we have made a parallax estimation, based on visual magnitude of the systems and bolometric luminosities of the components (with disregard of interstellar extinction). Our analysis shows that for QS Aql and V Pup ϖ demonstrates a more reliable value than ϖ_{tg}, while for AB Per and λ Tau the ϖ_{tg} value is more preferable. The parallax difference for δ Pic is too small (ϖ=1.97 mas, ϖ_{tg}=2.51 mas), to make a definite conclusion. Finally, parallax of GG Cas ($\varpi = -2.54$ mas, ϖ_{tg}=0) remains uncertain (our rough estimation is about 0.5 mas).

The cross-match of SD DLEB with Gaia DR2 provides us, besides reliable parallaxes and Gaia photometry, with effective temperature (hereafter, Gaia DR2 $T_{\rm eff}$ or $T_{\rm eff}(G)$). Those Gaia DR2 $T_{\rm eff}$ values can be compared with $T_{\rm eff}$ of accretors and donors, derived from light and radial velocity curve solutions.

First, analyzing $T_{\rm eff}$ of accretors and donors (Fig. 1), we should note that for cool SD DLEB

$$T_{\rm eff}({\rm acc}) < 12900 \text{ K} \tag{1}$$

the "temperature–temperature" relation can be satisfactory approximated by

$$T_{\rm eff}({\rm acc}) - T_{\rm eff}({\rm don}) = 0.9 \times T_{\rm eff}({\rm acc}) - 4000 \text{ K} \quad [std.dev. = 500]. \tag{2}$$

About two-thirds of all known SD DLEB satisfy the condition (1), so the equation (2) can be useful for parameterization of components of SD binaries, i.e., for an estimate of the temperature of the donor from the accretor. Note that the vast majority of the cool SD DLEB belong to the low-massive systems and demonstrate a small mass difference of components (see Fig. 2). Apparently they represent a group of SD binaries that have recently experienced mass inversion of their components and are in the slow mass exchange stage.

*https://gea.esac.esa.int/archive/

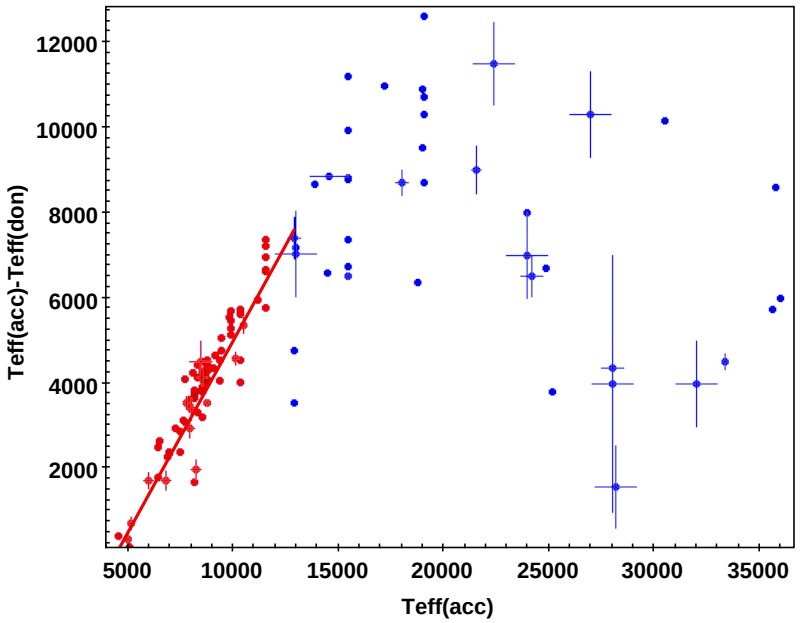


Figure 1 Effective temperatures of SD DLEB. "$T_{\rm eff}$ difference of components – accretor $T_{\rm eff}$" plot. The equation $T_{\rm eff}({\rm acc}) - T_{\rm eff}({\rm don}) = 0.9 \times T_{\rm eff}({\rm acc}) - 4000$ K (red line) is a satisfactory approximation for cool ($T_{\rm eff}({\rm acc}) < 12900$ K) systems (red circles). Observational errors are given when available.

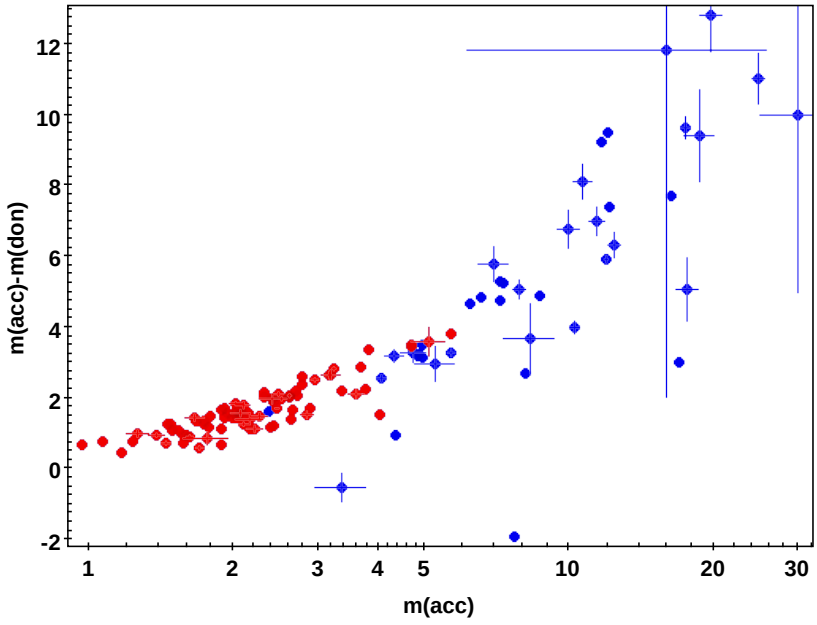


Figure 2 Masses of SD DLEB. "$m/m_\odot$ difference of components – accretor $m/m_\odot$" plot. Symbols are as in Fig. 1. Note a logarithmic scale for X-axis.

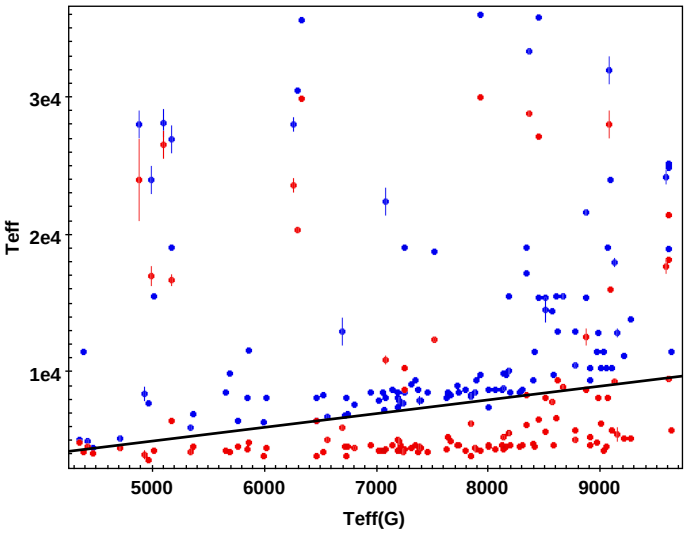


Figure 3 Effective temperatures of SD DLEB. $T_{\rm eff}$ of accretors (blue circles) and donors (red circles) vs. Gaia DR $T_{\rm eff}$. Observational errors are given when available. The one-to-one relation is shown as a solid black line, for reference.

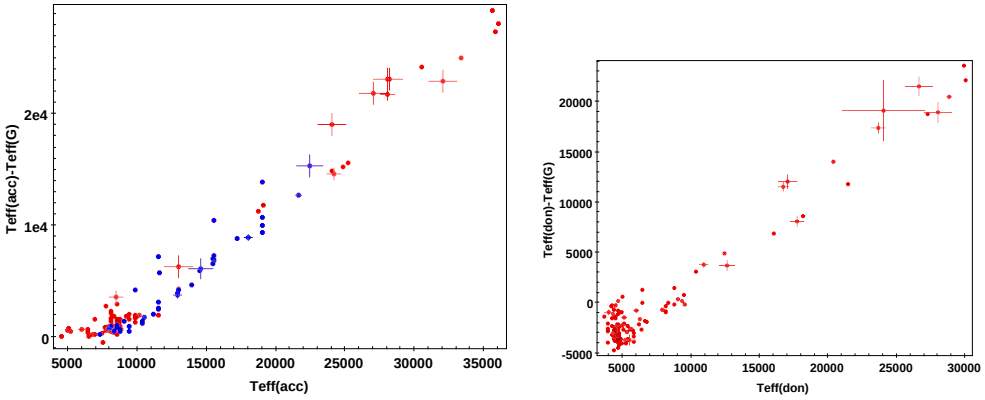


Figure 4 Comparison of $T_{\rm eff}$(acc) (left panel) and $T_{\rm eff}$(don) (right panel) with Gaia DR2 $T_{\rm eff}$. Observational errors are given when available. Blue circles are accretors in SD SLEB systems with large luminosity difference ($\log L_{\rm bol}$(acc) $-$ $\log L_{\rm bol}$(don) > 1).

A comparison of Gaia DR2 data with the catalogued (Malkov 2020) temperatures demonstrates (Fig. 3) that Gaia DR2 $T_{\rm eff}$ corresponds neither to $T_{\rm eff}$ (acc) nor $T_{\rm eff}$ (don). However, one can see (Fig. 4) that there is a clear correlation between the difference in temperature and the temperature of the system. The hotter the system, the larger the difference of Gaia DR2 $T_{\rm eff}$ from the catalogued values, both for accretors and donors. This is true even for systems in which the luminosity of the accretor *far* exceeds the luminosity of the donor ($\log L_{\rm bol}$(acc) $-$ $\log L_{\rm bol}$(don) > 1, blue circles in Fig. 4).

3 Conclusions

We present the results and analysis of cross-match of the most comprehensive list of semi-detached double-lined eclipsing binaries (SD DLEB) with Gaia DR2. We have analyzed six systems with controversial data on parallaxes. We have shown that effective temperature values, determined by Gaia for SD DLEB, are not correct for systems with $T_{\rm eff}(\rm acc) > 10000$ K, and the detection error increases with the system temperature rise. We have also found an empirical relation between the temperature of the accretor and the donor. The SD DLEB list with Gaia DR2 data is available upon request and will be uploaded to the VizieR database.

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