Research Article

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Parameterization of long-period eclipsing binaries

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Abstract: One of the important sources for independent determination of stellar masses is eclipsing binaries with components on the main sequence, and with observable spectral lines of both components. The parameters of such stars are used to construct the mass–luminosity relation for stars of high and intermediate masses. Among them, the type of long-period eclipsing binaries stands out, the parameters of which are currently not fully determined, which is associated with the difficulties caused by the need for long-term observations. In this article, we will review the currently available observational data for such objects and discuss the prospects for their use to determine stellar masses.

Keywords: stars, mass–luminosity relation, mass function – stars, binaries, spectroscopic – techniques, photometric, spectroscopic

1 Introduction

The mass of a star is one of the most important parameters that determine its evolution. However, for a single star, it is impossible to determine the mass directly, and

indirect methods are used to estimate the masses, and the subsequent transition to masses is carried out using the mass–luminosity relation (MLR). MLR is a fundamental law that is used in various fields of astrophysics. It is especially important for the construction of the initial mass function (IMF) from the luminosity function of stars. Independent stellar mass and luminosity determination is possible only for components of some observable types of binary systems. One of the types is orbital binaries (visual binaries with known orbital parameters and trigonometric parallax).

However, such systems have component masses less than $1.5 M_{\odot}$. Therefore, it is possible to construct an MLR using them only for small masses. For larger masses, a main source is detached main-sequence eclipsing binaries, with the spectrum lines of the two components (hereafter double-lined eclipsing binaries, DLEB). These stars are relatively massive ($M/M_{\odot} > 1.5$) and their parameters are utilized to construct the stellar MLR for intermediate and high masses.

However, we must be sure that in this case we get an MLR, which can really be legitimately used for single stars. The problem is that single young massive stars are fast rotators. And close eclipsing binaries with periods less than 15 days are almost all synchronized with orbital rotation, so they rotate more slowly. Accordingly, we cannot apply the MLR built for slow rotators for single rapidly rotating stars. Hence, it is necessary to look for other objects.

Such objects are long-period DLEB. They are mostly not yet synchronized and are fast rotators, that is, their evolutionary path must be similar to the evolution of single stars. But, unfortunately, the available observational data for this type of objects are too poor to draw definite conclusions about the effect on IMF. Therefore, we started a project to study long-period massive eclipsing binaries with the aim of constructing an MLR for stars of moderate and large masses (fast rotators) and further comparison with the “standard” MLR (for slow rotators). As a result of this pilot study, we plan to confirm that fast and slow rotators satisfy different MLRs that should be used for different purposes.

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2 The sample

To form a sample for our project, we have selected massive detached long-period eclipsing systems from the General Catalog of Variable Stars (Samus *et al.* (2018)) and the Catalog of Eclipsing Variables (Avvakumova *et al.* (2013), Avvakumova and Malkov (2014)). The selected systems satisfy the following criteria:

1. Detached eclipsing system;
2. Periods are between 15 days and 1 year;
3. Both components are on the main sequence;
4. Spectral classes are no later than F;
5. Apparent magnitudes are brighter of 13.0 in the V band.

Initially, 132 stars were selected, but after collecting and analyzing the available published data, the sample was reduced for various reasons, and at the moment it contains 45 stars. In the future, it will also be reduced and, if necessary, replenished with new objects. Table 1 presents the list of 22 stars from our sample in the Northern hemisphere. Almost all the stars are not brighter than 7^m magnitude, and their periods mostly lie between 20 and 40 days (Figure 1).

3 Data selection, observations, and analysis

3.1 Photometry

The first step of our work was to search and collect available photometric data on our stars from various surveys and databases. The list of resources we used is as follows:

- All Sky Automated Survey (ASAS),
- All Sky Automated Survey for SuperNovae (ASAS-SN),
- OMC-INTEGRAL database,
- SuperWASP Variable Stars database,
- Kepler Space Telescope archive,
- Transiting Exoplanet Survey Satellite mission,
- Database of the American Association of Variable Star Observers.

Then, based on these data, the light curves for all objects were constructed and analyzed in order, first, to carry out additional filtering of the sample by the shape of the curve (since it may become clear that the object is not an eclipsing system, but some other type of

Table 1: List of stars in our sample – northern sky

#	Name	V(mag)	P(day)	RA (2000.0)	DEC (2000.0)	Type
1	SY And	10.70	34.9085	3.31833	43.71139	A0 + K1
2	CD And	9.90	34.4434	21.61833	44.35695	F8
3	V436 Per	5.49	25.9359	27.99708	55.14750	B1.5V
4	AN Cam	10.40	20.9986	61.49000	76.88667	F8
5	V454 Aur	7.74	27.0270	95.51292	34.59750	F8
6	TU Lyn	11.40	38.9461	97.76125	61.24139	F0:
7	alf CrB	2.21	17.3599	233.67208	26.71472	B9.5IV + G5V
8	V541 Cyg	10.20	15.3378	295.62250	31.32778	A0
9	IM Del	11.83	34.3383	305.62500	18.56500	—
10	MP Del	7.56	21.3387	307.11083	11.72083	Am
11	V1326 Cyg	11.30	16.6817	308.62750	54.21028	B7
12	OT And	7.32	20.8529	350.00500	41.75500	—
13	V409 Cyg	13.30	37.7260	317.75958	49.70111	—
14	V698 Cyg	12.20	97.7732	299.9725	36.27778	A7IV
15	V1156 Cyg	13.50	44.5647	297.65458	29.35472	—
16	EU Gem	13.70	52.2665	99.925	17.19222	—
17	V340 Lac	11.80	19.9433	333.18542	54.18583	A8
18	CR Per	12.40	22.6810	32.4675	57.90917	—
19	V355 Her	13.20	17.0000	276.8375	13.16917	—
20	V413 And	7.61	50.1150	358.51667	39.28250	A7V + G0III
21	V733 Per	11.89	77.5300	52.95208	36.21250	—
22	LX Gem	13.36	145.1000	100.02083	15.11111	—

Figure 1: Distribution of our sample by the period and magnitude.

variable, for example); second, in order to understand the quality of existed photometry.

Two of light curves are shown in Figure 2. It is seen that the curves have a flat continuum between the minima, and the minima themselves are narrow and deep. That is, they belong to standard eclipsing systems suitable for our further studies. But if you look at the area of the minima closer, it becomes clear that there are only a few observation points, and the shape of the minima is not spelled out in sufficient detail. This situation is typical for many stars and most surveys, and this suggests that we need to obtain more accurate photometry and carry out additional observations.

Another example of an unsuitable light curve is shown in Figure 3. It is built using photometric data for HU Per binary system, which was subsequently excluded from the sample. Its curve is not flat, but has a kind of “waves” between the minima. This can be explained by the fact that one of the objects in the system has a higher temperature (and, accordingly, the luminosities of objects differ greatly), by some atmospheric effects, etc. It suggests that an object with that shape of a light curve is not suitable for our work, and, thus, it became one of the criteria for additional filtering of the sample.

During the last 2 years we took photometric observations at the Las Cumbres Observatory (LCO) telescope network. It consists of 13 1 m and 10 40 cm robotic telescopes with remote access located at seven observational sites around the world. In addition, starting from this year we began to receive photometric data with the 60 cm telescope of Caucasian Mountain Observatory and with 1 m Zeiss telescope of Simeiz observatory (INASAN). Additionally, we plan to carry out photometric observations with small robotic telescopes of the Special Astrophysical Observatory (hereafter

Figure 2: Light curve for (a) V1326 Cyg and (b) SY And based on ASAS-SN data converted to the period. There are only a few points indicating the shape of the primary and secondary minima.

Figure 3: Light curve for HU Per based on ASAS-SN data converted to the period.

SAO RAN), telescopes of the Terskol Observatory of INASAN and two 1 m telescopes of the South African Astrophysical Observatory.

3.2 Spectroscopy

We observe stars of the southern sky with the 11 m SALT telescope using a high-resolution échelle spectrograph there. These spectral observations started about 5 years ago and more than 200 spectra were taken and parameters of some binary systems were obtained. Detailed description and our first results of this work were presented in the studies of Kniazev (2020) and Kniazev *et al.* (2020).

Since the work with the northern sky sample began much later, we can describe our current observational plans mainly. Currently, we receive spectra with HERMES spectrograph on the Canary Mercator 1.2 m telescope. And we are planning to carry out spectral observations at the Kourouva Astronomical Observatory, at SAO RAN, at the Terskol Observatory using the MAESTRO high-resolution spectrograph and also at the Simeiz Observatory, where a spectrograph has recently appeared. In addition, we include the Caucasian Mountain Observatory in this list, despite the fact that the spectrograph has not yet been installed at the observatory, since our tasks involve long-term observations.

4 Conclusion

We are continuing our project on study of long-period eclipsing binaries, expanding it to the northern part of the sky. The new sample of 22 northern binary systems was described here for which we plan to carry out photometric and spectroscopic observations. Thus, at the moment we can talk about such intermediate results of our work:

1. Over 5 years of spectral observations at SALT, we obtained more than 200 échelle spectra for 43 stars (some of these stars were subsequently excluded from the sample based on the results of spectral analysis).
2. We have collected and analyzed photometric data from most of the available databases and surveys.

3. For 32 stars from our sample, we conduct observations and obtain photometry at the LCO.
4. At this year, we received the first observational data for our project from KGO and Simeiz Observatory.

Furthermore, for some southern objects all the necessary spectral and photometric data have already been obtained and their analysis and parameterization have begun.

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