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° magnitude, and their periods mostly lie between 20 and 40 days (Figure 1).

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 | 295.62208   | 31.23278     | A0            |
| 9 | IM Del   | 11.83  | 34.3333 | 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     | –             |

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-INTERGAL 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
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...
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 Kourovka 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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