First light curve analysis of eclipsing binary system ASAS 185542–0123.1

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Abstract. A very first light curve (LC) analysis of eclipsing binary ASAS 185542–0123.1 is presented. This star is part of our binary star survey project at Bosscha Observatory and also plays an important role as a testing ground for our new robotic telescope. LC of this star was constructed by using LEMON, a semi-automatic photometric pipeline written in Python. We managed to refine orbital period of this system and its time of primary minimum, hence we could update its ephemeris as $\text{Min I(HJD)} = 2451964.551517 + 1.161607 \times E$. We also conducted a LC modeling with PHOEBE (PHysics Of Eclipsing BinariEs) software built on top of the widely used WD program. The photometry solutions are mass ratio $q = 0.309 \pm 0.026$, orbital inclination $i = 83.15 \pm 0.42^\circ$, ratio of effective temperatures $\frac{T_2}{T_1} = 0.972 \pm 0.008$, and surface potentials for primary and secondary component $\Omega_1 = 4.08 \pm 0.16$ and $\Omega_2 = 2.71 \pm 0.10$, respectively. In conclusion, this system is classified as detached eclipsing binary system which has almost similar temperatures between its primary and secondary component. From temperature solution estimation, we have preliminary conclusion that its primary and secondary component has a spectral type of G0/1V + G2/3V, respectively.

1. Introduction

Eclipsing binaries are a two–stars system with each component periodically covers its counterpart — partially or fully. This kind of objects are an important sources for studying structure and stellar evolution, also in determining the physical properties of stars in our own and neighboring galaxies. However, to obtain a complete solutions of each system component, it is necessary to combine LCs and radial velocity data.

The All Sky Automated Survey (ASAS)[1] is a project aiming to observe and investigate stars in Southern Hemisphere. One of those aims is to search for variability of their brightness. All data are compiled into one catalog namely ASAS Catalog of Variable Stars or ACVS.

In this work, we were observing and analyzing unpublished objects listed in ACVS. By using our newly developed Bosscha Robotic Telescope (BRT)[2], we aim to get a better data compared with ASAS data. BRT has 0.35 m f/7.2 CDK telescope combined with 4K × 2K CCD camera, hence our telescope is significantly bigger and has a better both spatial and temporal resolution than ASAS so our aim stated above is not too far fetched.
2. The Targets and Observation Time
As we failed to do variable stars observation in 2016 and 2017 due to a bad weather and maintenance of the telescope system, we mostly use the data taken in 2015 for this work. The observations were conducted from June to August 2015. By combining our telescope system configuration (the choice of telescope diameter, CCD camera, etc) and the allocated observing time for variable stars on BRT system, target stars were chosen with several criteria as follows: (1) They have a relatively short variability period (from several hours to couple of days) so we could cover one orbital period during a single night or several nights of observations; (2) They are relatively bright ($m_{\text{vis}} < 14$) in order to achieve good signal–to–noise ratio, $S/N$, within allotted time. This is mostly limited by the diameter of our telescope; (3) They have a modest — but not too small — amplitude of variations in magnitude ($\Delta m > 0.15$) so we could easily recognize variability in target stars. With this criteria in mind and due to lack of clear skies during observing season, we only managed to observe four target stars by using differential photometry technique. BRT gives us a Field of View (FoV) of $\sim 48' \times 32'$ so it was sufficient to ensure that several comparison and check stars did fall into one frame along with target stars. The target stars and their observation time are listed in table 1 below and the preliminary information about the stars are shown in table 2.

Table 1. BRT target stars during 2015 observing season (June–August 2015).

| Date of Observation | Target Stars ID |
|---------------------|-----------------|
| June 25, 2015       | ASAS 172533–1221.4, ASAS 185542–0123.1 |
| June 26, 2015       | ASAS 172533–1221.4, ASAS 185542–0123.1 |
| August 16, 2015     | ASAS 193943–1116.6, ASAS 185542–0123.1 |
| August 24, 2015     | ASAS 005328+2536.4 |
| August 28, 2015     | ASAS 172533–1221.4, ASAS 185542–0123.1 |
| August 29, 2015     | ASAS 172533–1221.4, ASAS 185542–0123.1 |
| August 31, 2015     | ASAS 172533–1221.4, ASAS 185542–0123.1 |

Table 2. Preliminary information of the target stars. Magnitudes are given in $V$ filter.

| Target Stars        | $\alpha_{2000}$ | $\delta_{2000}$ | $P$ (days) | Mag  | Notes                      |
|---------------------|-----------------|-----------------|------------|------|----------------------------|
| ASAS 185542–0123.1  | 18 55 42        | -01 23 06       | 1.161599   | 10.15| target of this work        |
| ASAS 172533–1221.4  | 17 25 33        | -12 21 24       | 0.678839   | 9.97 | see [3]                    |
| ASAS 193943–1116.6  | 19 39 43        | -11 16 36       | 1.925659   | 11.02|                            |
| ASAS 005328+2536.4  | 00 53 28        | +25 36 24       | 0.345571   | 10.80|                            |
3. Light Curve Construction and Period Analysis

We applied a standard data reduction technique, i.e. bias, dark and flat correction in order to obtain a noise–free data by using Image Reduction and Analysis Facility (IRAF) software[4]. Next step was obtaining an instrumental magnitudes by applying aperture photometry technique through LEMON, a semi–automatic photometric pipeline written in Python [5]. Prior to this, LEMON did a couple things: (1) plate solved the data by comparing x–y coordinates of the stars in the frame with its internal database and convert them into a proper coordinates. This step also updated their file header; (2) It combined multiple files into one (called ‘mosaic file’ in LEMON) in order to boost S/N. This step is optional, but recommended to do on barely measurable data (S/N ∼ 10). In instrumental magnitude determination process, we modified LEMON code to automatically included 200 brightest stars in the image frame as a comparison and check stars — aside from target star itself — instead of including all stars in the frame for instrumental magnitude calculation. By doing so, less stars were processed and this lead to lesser needs for extensive computing power and time. We also could provide a list–file which contains coordinates of several stars which were being used as a comparison and check stars. We had to select manually the stars which we used for that purposes so we abandoned this method because it was tedious to do so. After we did all of steps mentioned above, we could finally construct the LC of this system.

We were developing a simple Python code based on Phase Dispersion Minimization (PDM) techniques [6] to fine–tune variability period value of this system. We chose to apply this step on data from ASAS database because they cover almost a full phase coverage, to ensure easier fitting process and its reliability. We sorted the data and only took data flagged as grade A to maximize data quality. One parameter which also important was Time of Minima, \( T_0 \). We adopted \( T_0 \) value from ACVS and used it as initial value and then iterated it within PHOEBE.

We updated the ephemeris of ASAS 185542–0123.1 as

\[
\text{min I(HJD)} = 2451964.551517 + 1.161607 \times E
\]

where HJD is Heliocentric Julian Day, and \( E \) is a cycle count.

4. Light Curve Modeling and Parameters Determination

A complete solutions need spectroscopic data to be elaborated with photometric data. In this work, we were using PHOEBE [7] which is based on WD program [8] on our photometric data taken with BRT to obtain physical properties of the star. Mass ratio or \( q \) plays an important role in LC data fitting. This parameter could be determined accurately through high resolution spectroscopic radial velocity data, hence we adopted \( q \) value from ACVS as initial value and iterated it within PHOEBE. Parameter which we held it fixed during a whole iteration is variability period of the target star (see prior section for details).

As in our previous work, we set mass ratio \( q \), inclination \( i \), temperature of primary and secondary components \( T_1 \) and \( T_2 \), and modified Kopal potentials for primary and secondary components, \( \Omega_1, \Omega_2 \) as free parameters. Reader should take a note that in order to obtain a temperature value of each component, \( T_1 \) and \( T_2 \), we need at least two LCs in different passbands, e.g. in \( B \) and \( V \). In this work we only could get ratio of effective temperatures, i.e. \( \frac{T_2}{T_1} \). We adopted color of this object from Tycho–2 catalog[9], which is \( B–V = 0.61 \), to help us estimating initial value of \( T_1 \). Then, we used empirical relation between color \( B–V \) and temperature \( T \) given by [10] to estimate \( T_1 \) and then iterated it throughout the whole iteration process.

\[
T = 4600 \left( \frac{1}{0.92(B–V) + 1.7} + \frac{1}{0.92(B–V) + 0.62} \right)
\]

Preliminary values of other parameters were taken from ACVS and we treated them as initial input for PHOEBE. In addition, we incorporated the gravitational darkening coefficients \( g_1, g_2 \)
which were derived from the values given by [11]. The results of physical properties solely determined from our photometric data are tabulated in table 3. We plot the LC model yielded by solutions, along with BRT and ASAS data, for ease of presentation only, in figure 1 (their LCs were normalized into 1.0 in $\phi = 0.25$ and 0.75). We also present the geometric configuration of ASAS 185542–0123.1 for $\phi = 0.25$ as a mesh plot in figure 2.

One thing should be noted, all uncertainties generated by PHOEBE are a formal one, so we have to use a more sophisticated algorithm e.g. Markhov Chain Monte Carlo (MCMC) to ensure a global solutions. PHOEBE 2.x[12] — still in beta release — will adopt this algorithm as well as the algorithm which being used in PHOEBE legacy code.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure1.pdf}
\caption{The theoretical LC compared to observation data for ASAS 185542–0123.1. The filled grey circle symbol represent data taken from ASAS database; \times symbol represent BRT data; and the red line is best fits of a LC model to BRT data points.}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure2.pdf}
\caption{The geometric configurations of ASAS 185542–0123.1 at $\phi = 0.25$.}
\end{figure}
Table 3. LC Solutions of ASAS 185542–0123.1.

| Parameter | Result from this work |
|-----------|-----------------------|
| $q_0$     | 0.309 ± 0.026         |
| $i$ (°)   | 83.15 ± 0.42          |
| $\frac{T_2}{T_1}$ | 0.972 ± 0.008 |
| $\Omega_1$ | 4.08 ± 0.16        |
| $\Omega_2$ | 2.71 ± 0.10         |
| $T_0$     | 2451964.551517 ± 0.001222 |
| $P$ (days)| 1.161607 ± 0.000135   |

5. Discussion and Concluding Remarks
We present the LC solutions of ASAS 185542–0123.1, one of target stars selected from ASAS database as part of variable stars observation campaign at Bosscha Observatory during 2015 observing season. From LC solutions and geometric configuration, we concluded that this system is considered a detached binaries which their components have an almost similar temperatures. We also found that the spectral and luminosity classification of this system are differ from the one listed in Michigan Catalogue of HD Stars Vol. 5[13]. As we mentioned earlier, accurate determination of temperatures needs at least two LCs in different passbands, so to give us a preliminary insight regarding classification of the system, we use $T_1$ and ratio $\frac{T_2}{T_1}$ to estimate $T_2$. By comparing $T_1$ and $T_2$ from this work with list of intrinsic color and adopted effective temperature given in [14], we classified this system as G0/1V + G2/3V for primary and secondary component, respectively, instead of F0/3V as listed in [13] for both components. We should check this further by obtaining more data in different passbands.

Mass ratio $q$ value from this work is slightly lower than listed in ACVS (i.e. $q = 0.309$, compared with $q = 0.354$ from ACVS) but they are quite in agreement to each other up to a fraction of tenth. One should get spectroscopic data for accurate determination of $q$, which was not available in this work.

In order to improve fitting accuracy and getting more reliable results, one should add more data points with sufficiently good S/N (preferably S/N ~ 20 or more) and cover two or more period cycles. Spectroscopic data, i.e. radial velocity measurements, surely will improve the LC solutions, especially on determining $q$ value which is crucial to LC modeling in order to get absolute parameters of the system. For code development, implementing a more sophisticated algorithm as mentioned in previous section is a must to obtain absolute parameter solutions.

References
[1] Pojmanski, G. 1997 AcA 47 467
[2] Yusuf, M. 2016 6thICMNS (Abstract ID: ABS–279)
[3] Jatmiko, A. T. P. 2016 6th ICMNS (Abstract ID: ABS–293)
[4] http://iraf.noao.edu
[5] Terrón, V. & Fernández, M. 2011 Highlights of Spanish Astrophysics Conf. VI 755–761
[6] Stellingwerf, R.F. 1978 ApJ 224 953–960
[7] Prša, A. & Zwitter, T. 2005 ApJ 628 426–438
[8] Wilson, R. E. & Devinney, E. J. 1971 ApJ 166 605–619
[9] Hog, E. et al. 2000 A&A 355 27–30
[10] Ballesteros, F. J. 2012 EPL Vol. 97 No. 3
[11] van Hamme, W. 1993 AJ 106 2096
[12] Prša, A. et al. 2016 http://arxiv.org/abs/1609.08135
[13] Honk, N. & Swift, C. 1999 MSS 5 0
[14] Pecaut, M. J. & Mamajek, E. E. 2013 ApJS 208 9