Light curve analyses of eclipsing binary system ASAS 172533–1221.4

Agus T P Jatmiko¹, M Yusuf³, and M Putra¹,²

¹Bosscha Observatory, Institut Teknologi Bandung, Jl. Peneropongan Bintang, Lembang, Bandung, West Java, Indonesia
²Astronomy Study Program, Institut Teknologi Bandung, Jl. Ganesha No. 10 Bandung, West Java, Indonesia
E-mail: agustrionopj@alumni.itb.ac.id

Abstract. Using the data taken from our 0.36 m f/7.2 robotic telescope, we performed a very first light curve (LC) analyses of eclipsing binary ASAS 172533–1221.4, one of target stars which is part of program stars in our variable star survey project. The LC of this star was constructed by using LEMON, a semi–automatic photometric pipeline written in Python. We refined a Time of Minima (ToM, $T_0$) and variability period of this system, $P$ and updated its ephemerides as $HJD_{(min I)} = 2457200.255578 + 0.678861 \times \phi$. The LC modeling of the system was conducted with the PHOEBE (PHysics Of Eclipsing BinariE) software built on top of the widely used WD program. The assorted LC modeling solutions are shown as follows: mass ratio $q = 0.811 \pm 0.009$, inclination $i = 70.62 \pm 0.01^\circ$, temperature of primary and secondary component $T_1 = 5559.23 \pm 83.51 K$ and $T_2 = 3871.64 \pm 43.66 K$, respectively, and modified Kopal potentials which are a function of primary’s and secondary’s radii $\Omega_1 = 3.436 \pm 0.018$ and $\Omega_2 = \Omega_{cr} = 2.980$, respectively. It is concluded that ASAS 172533–1221.4 is found to be near–contact system with almost similar size between primary and secondary components, with its secondary component is already filling its Roche lobe.

1. Introduction

The All Sky Automated Survey (ASAS, [1]) project started in 1996 with the observations in the Southern Hemisphere aimed at classification and investigation about $10^7$ stars that show photometric variability in their light curves. The observations were carried out with the CCD cameras having 4K and 2K resolutions in the $V$ and $I$ filters at the stations located in Chile and Hawaii. The main scope of the survey was to form the ASAS Catalog of Variable Stars (ACVS).

Among those stars in ACVS, there are many of them which are still do not have a published physical and geometric parameters yet. We are trying to fill the gap by observing unpublished variable stars by using our new robotic telescope (Bosscha Robotic Telescope, BRT). BRT has 0.36 m f/7.2 telescope equipped with 4K × 4K CCD camera [2]. Our telescope system has a bigger aperture and camera resolution, in comparison with ASAS’, so aiming for better signal–to–noise ratio (S/N) and temporal resolution should not be a problem. This work also acts as benchmark model for our next works to develop the next generation robotic telescopes, which is part of Indonesia National Observatory Project in Amfoang, East Nusa Tenggara [3]. This new observatory is planned to do its first light in 2019.
2. Observation
The observations were conducted from June to August 2015. 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 hopefully 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 $S/N$ within allotted time; (3) They have a modest (but not too small) delta magnitude ($\Delta m > 0.15$) so we could easily recognize variability in target stars. With this criteria in mind, we managed to observe four target stars only, due to unstable weather during our observing time, by using differential photometry technique. BRT gives us a Field of View (FoV) of $\sim 42' \times 42'$ so it is sufficient to ensure that several comparison and check stars do fit into one frame along with target star. The target stars and their observation time are listed in table 1 below and the properties of the systems given by ACVS are shown in table 2.

In this work, we present a LC modeling and analyses of ASAS 172533–1221.4 which will be explained in details in the following section. We focused only on ASAS 172533–1221.4 because we do not have a good coverage of light curves for other listed stars due to weather problem. Analyzing those data will give us an unreliable conclusion about the systems.

Table 1. BRT Target Stars (June–August 2015).

| Observation Time | Target Stars |
|------------------|--------------|
| 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. Properties of the systems given by ACVS. Magnitudes are given in $V$ filter. $\alpha$ and $\delta$ are right ascension and declination of the systems.

| System              | $\alpha_{2000}$ (h m s) | $\delta_{2000}$ (d m s) | $P$ (days) | Magnitude |
|---------------------|-------------------------|--------------------------|------------|-----------|
| ASAS 172533–1221.4  | 17 25 33                | -12 21 24                | 0.678839   | 9.97      |
| ASAS 185542–0123.1  | 18 55 42                | -01 23 06                | 1.161599   | 10.15     |
| 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. LC 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. The LC construction for ASAS 172533–1221.4 was done by using LEMON, a semi–automatic photometric pipeline written in Python [4]. This code does plate solving automatically to the data and updates their file header. It also could boost $S/N$ by
combining multiple files into one 'mosaic' file. This step, even though it is optional, could make
determination of target star's magnitude easier, especially when dealing with data which have
low S/N. Next process is to obtain an instrumental magnitude for target star. We modify
LEMON code to automatically include 200 brightest stars in the image frame as a comparison
and check star, aside from target star itself. By default, LEMON will include all of stars which
it could find in a whole frame. In our case this code could detect more than 5000 stars in a
single frame. By modifying the core program, we cut down the need of extensive computing
power and time because LEMON only needs to process less stars compared to the unaltered code.
Another workaround to achieve the same goal is to provide a list–file which contains coordinates
of several stars which are being used as a comparison and check stars. We consider this method
was more tedious because we had to select manually the stars which we use for that purposes.
Last but not least, the next step is generating the LC itself.

ACVS provides an estimation of variability period and $T_0$ of target star. We tried to fine–tune
these parameters by developing a Python code and apply it to the ACVS data. Our code for
period determination is based on Phase Dispersion Minimization (PDM) techniques [5] which is
easy and efficient to compute. The ACVS data contain grade C and D points that are mentioned
as ”not measured” and ”useless” in the header of the data files, therefore, we excluded these
points from our solutions. For $T_0$ determination, we took the estimated value taken from ACVS
as initial value and iterate it within PHOEBE. As result, we update the ephemerides of ASAS
172533–1221.4 as

$$HJD(min_I) = 2457200.25578 + 0.678861 \times \phi$$

where $HJD$ is Heliocentric Julian Day, and $\phi$ is normalized epoch of observation (or phase).

4. LC Modeling and Physical Parameters Determination
We were using PHOEBE [6] which is based on WD program [7] for data fitting to obtain physical
properties of the star. Complete solutions need spectroscopic data to be elaborated with
photometric data. This, however, is not covered in this work, therefore, physical properties of
the star are obtained solely based on LC modeling and are provided 'as is'. The most important
parameter for LC data fitting is mass ratio, $q$, which can be determined accurately only through
high resolution spectroscopic radial velocity measurements. In this case, we adopted value from
ACVS and consider it fixed until other parameters reach a certain degree of convergency, then
we iterate it as well. We also held period fixed during the whole iteration process.

Basically, we set mass ratio $q$, inclination $i$, temperature of primary and secondary
components $T_1$ and $T_2$, modified Kopal potentials for primary and secondary components, $\Omega_1, \Omega_2$,
and luminosity of primary component $L_1$ as free parameters. We took the initial values from
ACVS for these aforementioned parameters and iterate them within PHOEBE. In addition, since
the system was hypothesized to be semi–detached binary—according to a quick look into the LC
profile—the analyses were performed in the suitable mode of the PHOEBE software. Therefore,
$\Omega_2$ was set to the critical potential value of the first Lagrangian point, $\Omega_{cr}$. We also incorporate
the gravitational darkening coefficients $g_1, g_2$ which were derived from the values given by [8].
The results of physical properties determination are tabulated in table 3. The LC yielded by
solutions is presented in figure 1. We also present the geometric configuration of ASAS 172533–
1221.4 at $\phi = 0.25$ in figure 2. Reader should take a note that all uncertainties presented here
are a formal one, it means that . In order to determine whether the solutions are a global
minimum or not, one should apply a more sophisticated algorithm, such as Bayesian statistics,
e.g. Markov Chain Monte Carlo (MCMC), in particular. The next generation of PHOEBE, i.e.
PHOEBE2 will adopt this algorithm along with 'classical' algorithm which are already applied in
the current PHOEBE code [9].
Figure 1. The theoretical LC compared to observation data for ASAS 172533–1221.4. The dots are the observed data points, and the thick line is best fits of a LC model to data points.

Figure 2. The geometric configurations of ASAS 172533–1221.4 at $\phi = 0.25$.

Table 3. LC Solutions of ASAS 172533–1221.4.

| Parameter | Result from this work |
|-----------|-----------------------|
| $q$       | 0.811 ± 0.009         |
| $i$ (°)   | 70.62 ± 0.01          |
| $T_1$ (K) | 5559.23 ± 83.51       |
| $T_2$ (K) | 3871.64 ± 43.66       |
| $\Omega_1$| 3.436 ± 0.018         |
| $\Omega_2$| $\Omega_{cr} = 2.980$|
| $r_1(=\frac{1}{r_1})$| 0.291 ± 0.005         |
| $r_2(=\frac{1}{r_2})$| 0.277 ± 0.005         |
| $T_0$     | 2457200.255578        |
| $P$ (days)| 0.678861              |
5. Discussion and Concluding Remarks

We present the LC solutions of ASAS 172533–1221.4, one of binary system selected from ASAS database as part of variable stars observation campaign in Bosscha Observatory. The filling factor of the primary component \( f = \frac{r_1}{r_{L1}} \) of ASAS 172533–1221.4 was found to be 81% using the volume radius of the Roche lobe given by [10]:

\[
\frac{r_L}{r_1} = \frac{0.49q^2}{0.6q^2 + \ln(1 + q^2)}
\]

Therefore, the component is quite close to the Roche lobe which confirm our hypothesis. It is concluded that ASAS 172533–1221.4 is a near–contact (or semi–detached) system. Both components have almost a similar sizes with its secondary component is already filling its Roche Lobe. We also got a slightly higher \( q \) (i.e. 0.811 from this work, compared with \( q = 0.707 \) from ACVS). This indicates that the secondary component are more massive than previously thought. The more accurate \( q \) value should be obtained from spectroscopy observation which is not available in our data and should be put as a constant parameter in LC modeling and physical parameters determination process.

More data are always desirable to complete the gap, especially between \( \phi \approx 0.2 \) to \( \phi \approx 0.6 \) in our data. These data points will improve fitting accuracy and they will ensure that we get more reliable results. 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. Implementation of Bayesian statistics into data is highly recommended in order to ensure that the LC solutions are already at a global minimum.

References
[1] Pojmanski, G. 1997 AcA 47 467
[2] Yusuf, M. 2016 6thICMNS (in prep., ABS–279)
[3] Hidayat, T. et al. 2014 Experimental Astron. 37 85–108
[4] Terrón, V. and Fernández, M. 2011 Highlights of Spanish Astrophysics Conf. VI 755–761
[5] Stellingwerf, R.F. 1978 ApJ 224 953–960
[6] Prša, A. and Zwitter, T. 2005 ApJ 628 426–438
[7] Wilson, R. E. & Devinney, E. J. 1971 ApJ 166 605–619
[8] van Hamme, W. 1993 AJ 106 2096
[9] Prša, A. et al. 2016 http://arxiv.org/abs/1609.08135
[10] Eggleton, P.P. 1983 ApJ 268 368