Iranian Journal of Astronomy and Astrophysics
Vol. 6, No. 2, Autumn 2019
©Available online at http://journals.du.ac.ir
DOI:10.22128/ijaa.2019.362.1067

Iranian Journal of Astronomy and Astrophysics

The Ground-Based Photometric Observation and Light Curve Analyses of Eclipsing Binary KIC 12418816

Mahdiyar Mousavi-Sadr*[1] · Hossein Ebadi[2]

[1] Department of Theoretical Physics and Astrophysics, Faculty of Physics, University of Tabriz, Tabriz, Iran;
RIAAM Observatory, Research Institute for Astronomy and Astrophysics of Maragha, University of Maragha, Maragha, Iran;
email: mahdiyar.mousavi@tabrizu.ac.ir

[2] Department of Theoretical Physics and Astrophysics, Faculty of Physics, University of Tabriz, Tabriz, Iran;
email:hosseinebadi@tabrizu.ac.ir

Abstract. Here, the photometric CCD observations in RIAAM observatory and light curve analyses of KIC 12418816 are presented. For comparison, the Kepler long cadence (LC) photometric data was studied. The analyses of the recorded light curve in R-band filter and Kepler LC photometric data were performed by PHOEBE software by using the last version of Wilson-Devinney code. Initially, the search of mass ratio ($q = \frac{m_2}{m_1}$) of the binary system was done with finding the minimum chi-square value (χ^2), which takes all sources of noise into account. By photometric modeling which was obtained from our observations, the mass ratio was calculated as 0.764 ± 0.006. The results were comparable with modeling extracted from Kepler LC data which was obtained 0.752 ± 0.002. Our observations showed that the effective temperature (T_{eff}) for primary and secondary stars were about 4421 ± 19 and 4412 ± 22 Kelvin, respectively. The similar results were obtained from Kepler LC data which were about 4463 ± 23 and 4419 ± 18 for primary and secondary stars, respectively. Our modeling demonstrated that we can introduce a spotted model with one spot on the primary component.

Keywords: Data reduction techniques, Photometry, Eclipsing Binary, Kepler data

1 Introduction

The study of eclipsing binaries is important for testing stellar structure and theories of stellar evolution; therefore, it is desirable to have as many accurate star parameters as possible[1]. Many studies have been done in this field. For example, Liu Xue-fu et al.[2] made photometric observations on the short-period Algol-type eclipsing binary with a period of 1.870052 days at McDonald Observatory. They used the Wilson-Devinney method to photometric solutions and determined the mass ratio and orbital inclination about 0.6871 ± 0.0354 and 74.42 ± 0.39, respectively. Davood Manzoori et al.[3] carried out photometric observations of Algol type binary star U Sagittae at Khajeh Nassir Addin observatory of Tabriz University (Iran) with a 40 cm Cassegrain telescope. Wilson-Devinney code was employed to analyze the light curves in order to determine the physical and orbital parameters like mass ratio and effective temperatures of components. Rahim Heidarnia et al.[4] analyzed the W UMa eclipsing binary OQ Dra which has an orbital period of 0.33967 days. They obtained an analysis of V-band CCD observations by using the 752582 pixels 16bit monochrome CCD camera attached to the 12-inches MeadeLX200 schmidt-cassegrian telescope at RIAAM observatory. For analyzing its light curves, they used Wilson-Devinney code. They discovered that OQ Dra has a mass ratio of $q = 0.55 \pm 0.01$ and introduced two spots on each component.

The Kepler space mission has provided an extended and almost uninterrupted data set for a variety of variable stars. The main purpose of the Kepler mission is to detect Earth-size planets in the habitable zone of solar-like stars, determine their frequency and identify their characteristics[5]. KIC 12418816 was identified for the first time in Kepler DR24 pipe processing and marked as "planetary candidates"; in the subsequent processing and analysis (DR25), it was identified again but with the recognition that it is eclipsing binary system[6]. This system was observed by the Kepler satellite in both the long-cadence (LC) and short-cadence (SC) modes. The Kepler long cadence light curves available for KIC 12418816 are from quarters 0 to 17 which cover 1443 days from 2009-05-02 to 2013-05-11. The only available short cadence data belongs to fourth quarter which covers 30 days of observation from 2010-02-18 to 2010-03-19. The terminology "quarter" refers to one quarter of Kepler space telescope's orbital period (372.5 days). So, one quarter is 93 days, except for the first the first and second quarters which cover 10 and 34 days of observations respectively. The long cadence and short cadence photometric data of KIC 12418816 are available in the Kepler archive. For the purpose of this study, we used only the LC data, which includes 57521 data points.

KIC 12418816 was listed in the USNO-A2.0 catalogue for the first time in the literature[7]. The B-band and R-band magnitudes were calculated as 13.9 and 12.6, respectively. Watson et al. classified this system as eclipsing Algol binary without third object and calculated its period as 1.521925 days[8]. Coughlin et al. calculated the parameters of this binary for the first time. The system's light curve amplitude was determined as 0.581 magnitude and orbital inclination as 87.12. They calculated the effective temperatures of the system as 4603 K and 4563 K for the primary and secondary component, respectively[9]. Armstrong et al. computed the temperature as 4909 ± 352 K for the primary component and 4796 ± 545 K for the secondary component, based on spectral energy distribution fitting[10]. More recently, Dal and Ozdarcan presented photometric and spectroscopic analyzing of the KIC 12418816 system and found that it is composed of two very similar and young main-sequence stars. They found masses and radii of the components of $0.88 \pm 0.06 M_{\odot}$ and $0.85 \pm 0.02 R_{\odot}$ for the primary and $0.84 \pm 0.05 M_{\odot}$ and $0.84 \pm 0.02 R_{\odot}$ for the secondary. The most interesting and important result which they arrived through this research is that this system exhibits strong star spot and flare activity[11]. Since the magnetic activity of a star is dynamic phenomena, so it is required to observe the system frequently during the time. Similar to the sun as typical star, the magnetic activity may change and the size of the star spots evolve and migrate through star disc. Although there are some works in the literature devoted to this system and some of them are mentioned here, the ground-based observation of this system can be comprehensive and meaningful. Specially, the magnetic activity is very important in modelling the interior and atmosphere of the star and deeply understanding the physics of the system and interacting behavior of the system. So, still in these days that there are a lot nice and accurate data related to binaries through space missions specially Kepler, it is a necessary need to ground-based observations. In this concern, we are going to observe and analyze the same system through small telescope but with modified optics. In addition for comparison, we present the Kepler LC data and their analyzing too.

In this paper, we present the photometric study and light curve analysis of eclipsing binary KIC 12418816 recorded from our observations and Kepler LC data. The extracted results from these two data series were compared with together. This paper is organized as follows: In Section 2, we introduced the employed instruments, and the steps of recording and processing data in RIAAM observatory. In Section 3, the light curve modeling of stars

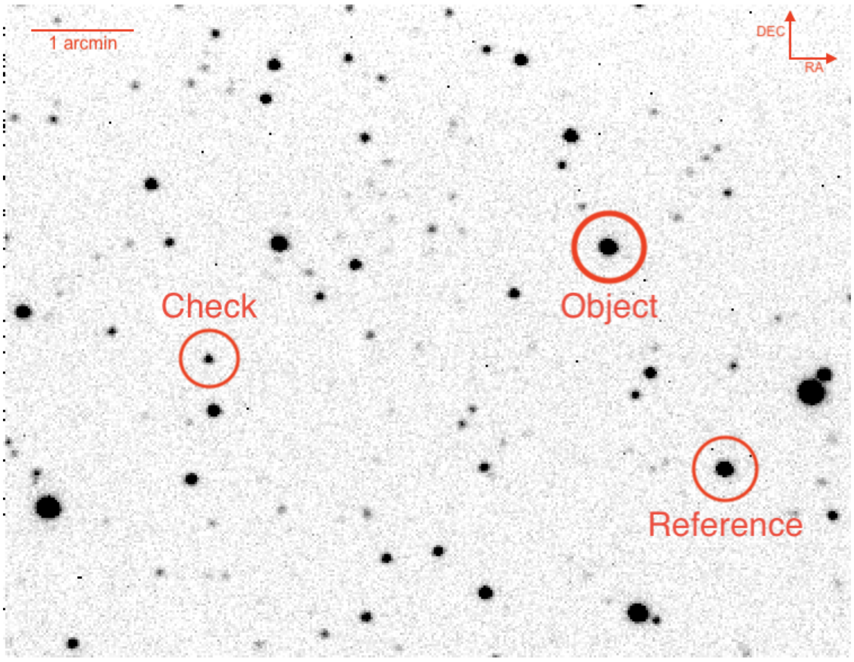

Figure 1: KIC 12418816, reference and check star in the field of view of the telescope.

were explained. The main results were discussed in Section 4.

2 Observations and data reduction

We have made photometric observations for five nights between September 19, 2016 and October 4, 2016 at the RIAAM observatory. We employed a 12-inch Meade LX200 Schmidt-Cassegrain telescope controlled by the StarryNight software and a QHY6 monochrome CCD which has a quantum efficiency of about 65% to 550 nm. The CCD was controlled by MaxImDL v5.24. It uses the 80% power of the CCD cooling fan to keep the temperature at -15°C. We have also used a small chip CCD DMK 31AU03 mounted on a 70 mm guide-scope to keep the stars in their position in the field of view using the PHD Guiding software. We have taken more than 1000 light frames in the R-band Johnson filter. To increase the signal-to-noise (SNR) in recording data, we selected binning 2×2 pixels with long period of exposure time about 80s. Data reduction procedures were done by MaxImDL v5.24 to remove noise. We took 60 frames of dark, bias and flat during 5:00 am - 6:00 am and they were combined using the median method. The calibration of light frames was done through the use of master dark, master bias and master flat frames. The stars (object, reference, and check) were displaced in Fig. 1. The properties of stars were given in Table 1. The apparent magnitudes of object star were calculated using $magnitude_{obj} = magnitude_{ref} - 2.5log(flux_{obj}/flux_{ref})$ and applying deviation of check star's magnitudes. Finally, the observed light curve was displaced in Fig. 2.

Table 1: Object, reference and check star.

	Star	RA	DEC	B Mag
Obj	KIC 12418816	19h 45m 46.062s	$+51^\circ\ 13'\ 27.56''$	12.262
Ref	N2HR000446	19h 45m 53.66s	$+51^\circ\ 15'\ 24.35''$	12.467
Chk	N2HR047823	19h 45m 22.48s	$+51^\circ\ 14'\ 38.92''$	14.81

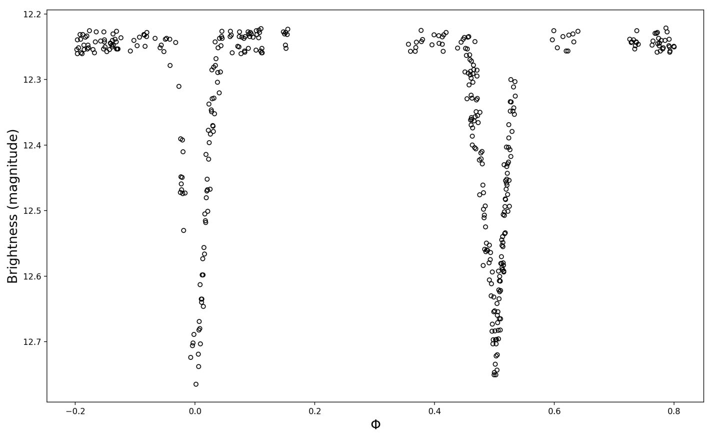

Figure 2: Observed light curve of KIC 12418816 in R-band filter.

3 Light curve modeling

We analyzed the RIAAM observations taken at R-band light curve of KIC 12418816 using the PHOEBE (physics of eclipsing binaries) package that is based on the Wilson-Devinney (WD) code[12, 13]. To model the observed light curve, we used the range of values between 0.1 to 1.5 by steps 0.1 for the mass ratio (q) to select the optimal value for q when the obtained curve from model fitted to the observed curve has the minimum error. The optimal value of the synthetic model was obtained at 0.764 ± 0.006. Using PHOEBE calculation, the inclination value (I) for binary system was obtained to be 86.1 ± 0.7. Using J-H color index from set of identifications, measurements and bibliography for astronomical data (SIMBAD) astronomical database (10.873-10.400) and also V-R index (V magnitude from guide star catalog-2 (GSC2) and observed R magnitude), the star's spectral type was estimated to be K2V. So the effective temperature must be between 4400 and 4700. The results of modelings presented that the suitable temperature for primary (T_{eff1}) and secondary (T_{eff2}) stars would be about 4421 ± 19 and 4412 ± 22 K respectively. We used the logarithmic law for the limb darkening according to van Hamme (1993) and Al-Naimiy (1978) for an effective temperature of $T < 9000K$[14, 15]. The limb darkening coefficient values of x_1=0.62358 and x_2=0.62275 (where x_1 and x_2 represent the ratio of the brightness at the edge to the central brightness of the primary and secondary star, respectively) were given in catalogue provided by van Hamme and Lucy[14, 16]. For $T_{eff} < 7500K$, the values of the gravity-darkening coefficient g_1=g_2=0.32[16] (where g_1 and g_2 represent the ratio of the brightness at the equator to the polar brightness of the primary and secondary star, respectively) and the bolometric albedo a_1=a_2=0.5[17] were assigned for stars with convective envelopes. We had some time intervals which would not completely conformed with given model. So, we added one cool spot on the primary star to get the optimal fit. The colatitude, longitude, radius and $\frac{T_{spot}}{T_{sur}}$ of the primary star KIC 12418816 obtained from model corresponding with our observed light curve are equal to 34, 87, 6, 0.6, respectively, where T_{sur} is the temperature of the surface. With many iterations, the best values were obtained as shown in Table 2. Figure 3 shows the unspotted and spotted model light curves. The geometric appearance of the system was drawn for the phase -0.25 which is shown in Fig. 4.

We studied Kepler long cadence data, too. The LC data of Kepler show that the target has variability besides its eclipses. To ignore their effects in the modeling process of the light curve, we modeled all available LC data after the phase binning in 5 minutes (Kepler's light curve after the phase binning is shown in Fig. 5). Table 3 presents available information for the target from the Kepler eclipsing binary (EB) catalog[18, 19, 20]. The analysis of the Kepler light curves were carried out in similar way; $q = 0.752 \pm 0.002$ for the mass ratio and $I = 86.5 \pm 0.3$ for the inclination value were determined. J-H and V-R (R magnitude from SIMBAD) color indexes were used to estimate the star's spectral type equal to K2V and by using PHOEBE calculation, the best values for temperatures were obtained as $T_{eff1} = 4463 \pm 23$ K and $T_{eff2} = 4419 \pm 18$ K. After setting the initial values, we tried to find the best fit of the complete light curves and obtain the most accurate model. We had some unfitted regions in our model. So, we added one cool spot on the primary star (with colatitude, longitude, radius and $\frac{T_{spot}}{T_{sur}}$ are equal to 41, 83, 7.8, 0.7, respectively) to get the best fit. Finally, the best values were obtained as shown in Table 4. Figure 6 also shows the model light curves. The geometric appearance of the system was drawn for the phase -0.25 and is shown in Fig. 7.

Table 2: Physical and geometrical parameters of KIC 12418816 obtained from our observed data.

Parameter	Model value	Error
Period [day]	1.521870	0.0000046
Omega1	3.3554	0.0005
Omega2	2.9222	0.0004
q	0.764	0.006
Inclination [degree angle]	86.1	0.7
Limb darkening(linear)	x1=0.62358 x2=0.62275	
Limb darkening(non-linear)	y1=0.16378 y2=0.16434	
Gravity darkening	g1=0.32	
	g2=0.32	
Teff1 [K]	4421	19
Teff2 [K]	4412	22
epoch [HJD]	2454954.741222	0.0053
log(g)1	4.61	0.02
log(g)2	4.60	0.02
a1	0.5	
a2	0.5	
r1	0.1377(0.89959$R_\odot$)	0.00074
r2	0.1224(0.79964$R_\odot$)	0.00043
L1	0.561669	0.015
L2	0.438331	0.018

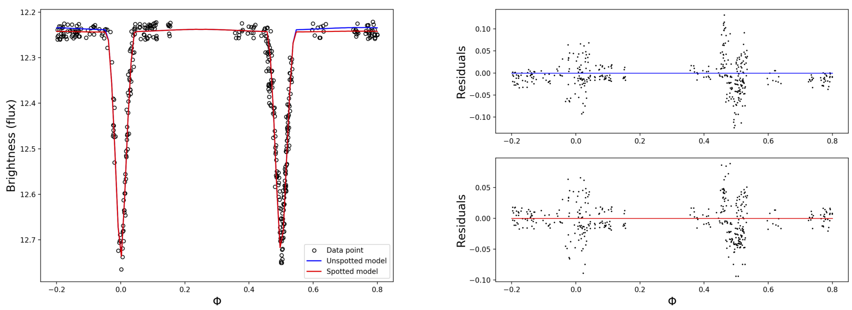

Figure 3: Left panel shows the KIC 12418816 observed light curve and two right panels show the corresponding residuals from the unspotted (blue line) and spotted (red line) models subtracted data for all phases (including eclipses).

Table 3: Parameters of KIC 12418816 from the Kepler EB catalog.

Parameter	Period [day]	Kmag	Teff [K]	Pdepth	Sdepth	Pwidth	Swidth
Value	1.5218703	12.4020	4583	0.3581	0.3319	0.0623	0.0625

Figure 4: The geometric view of KIC 12418816 system at phase -0.25 (obtained from our observed data).

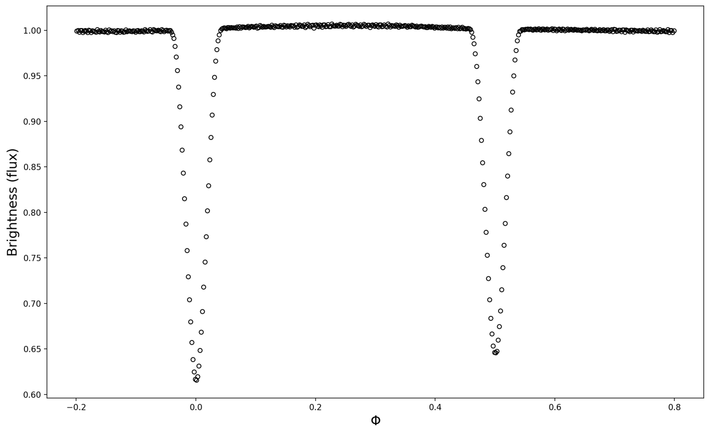

Figure 5: Kepler phase binned light curve of KIC 12418816.

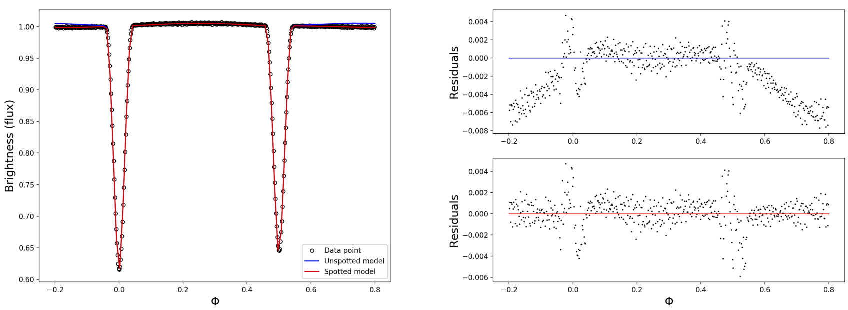

Figure 6: Left panel shows the KIC 12418816 Kepler light curve and two right panels show the corresponding residuals from the unspotted (blue line) and spotted (red line) models subtracted data for all phases (including eclipses).

Table 4: Physical and geometrical parameters of KIC 12418816 obtained from Kepler data.

Parameter	Model value	Error
Period [day]	1.521870	
Omega1	3.3341	0.0004
Omega2	2.9069	0.0003
q	0.752	0.002
Inclination [degree angle]	86.5	0.3
Limb darkening(linear)	x1=0.62539 x2=0.62326	
Limb darkening(non-linear)	y1=0.16202 y2=0.16438	
Gravity darkening	g1=0.32	
	g2=0.32	
Teff1 [K]	4463	23
Teff2 [K]	4419	18
epoch [HJD]	2454954.747937	0.0004
log(g)1	4.70	0.02
log(g)2	4.64	0.02
a1	0.5	
a2	0.5	
r1	$0.1243(0.81205R_{\odot})$	0.00051
r2	$0.1162(0.75913R_{\odot})$	0.00067
L1	0.548107	0.012
L2	0.451893	0.013

Figure 7: The geometric view of KIC 12418816 system at phase -0.25 (obtained from Kepler data).

4 Conclusion

We employed known and accurate methods and software to analyze our data and Kepler one. This system was firstly identified as "planetary candidate" with the orbital period of 0.760935268 days in Kepler DR24 pipe processing. Our findings show that this system is a binary system with similar stars with the orbital period of 1.5218703 days. By analyzing the light curves in R-band filter, we determined mass and radii ratio as 0.764 and 0.889, respectively. The proper calculations were done by Kepler data and the results are presented in Table 4. V-R color index estimated the stellar spectral type as K2V for both components. R-band magnitude is calculated as 12.262 which is in agreement with the results reported by Devor [21]. Full set of parameters for the system are presented in Table 2 and Table 4. Our analysis shows that the system exhibits star spot at the primary component surface. The parameters of the star spot is presented through the context. Dal and Ozdarcan showed through spectroscopic and photometric data that this system is magnetically active and star spots and flares are presented in binary components[11]. Magnetic activity is dynamic phenomena and observing and analyzing the system after 5.5 years says that star spots may change through components. But the interesting and important result is that the system keep magnetic activity during the time. In magnetically active stars, it is necessary to observe the star during time steps to model the interiors and atmosphere of the stars which is affected deeply related to magnetic activity. Solar magnetic activity as typical star has been studied for three decades or more, but still new observations have new and useful findings.

References

[1] Kallrath, J., Milone, E. F., & Wilson, R. 2009, Eclipsing binary stars: modeling and analysis, Springer.

[2] Xue-fu, L., Zhi-an, L., Leung, K., & Hui-song, T. 1990, ChJAA, 14, 167.

[3] Manzoori, D., Jassur, D. M., & Kermani, M. H. 2006, Ap&SS, 302, 145.

[4] Heidarnia, R., Ebadi, H., & Rooydargard, H. 2016, NEW ASTRON, 49, 28.

[5] Kasting, J. F., Whitmire, D. P., & Reynolds, R. T. 1993, ICARUS, 101, 108.

[6] Morton, T. D., Bryson, S. T., Coughlin, J. L., Rowe, J. F., Ravichandran, G., Petigura, E. A., Haas, M. R., & Batalha, N. M. 2016, ApJ, 822, 86.

[7] Monet, D. 1998, Bulletin of the American Astronomical Society.

[8] Watson, C., Henden, A., & Price, A. 2006, Sciences 25th Annual Symposium on Telescope Sciences.

[9] Coughlin, J. L., Lopez-Morales, M., Harrison, T. E., Ule, N., & Hoffman, D. I. 2011, AJ, 141, 78.

[10] Armstrong, D. J., Gomez Maqueo Chew, Y., Faedi, F., and Pollacco, D. 2013, MNRAS, 437, 3473.

[11] Dal, H. A. & Ozdarcan, O. 2018, MNRAS, 474, 326.

[12] Prsa, A. & Zwitter, T. 2005, ApJ, 628, 426.

[13] Wilson, R. E. & Devinney, E. J. 1971, ApJ, 166, 605.

[14] Van Hamme, W. 1993, AJ, 106, 2096.

[15] Al-Naimiy, H. M. 1978, Ap&SS, 59, 3.

[16] Lucy, L. B. 1967, Z. Astrophys., 65, 89.

[17] Rucinski, S. 1969, ACTA ASTRONOM., 19, 245.

[18] Prsa, A., Batalha, N., Slawson, R. W., Doyle, L. R., Welsh, W. F., Orosz, J. A., Seager, S., Rucker, M., Mjaseth, K., Engle, S. G., et al. 2011, AJ, 141, 83.

[19] Slawson, R. W., Prsa, A., Welsh, W. F., Orosz, J. A., Rucker, M., Batalha, N., Doyle, L. R., Engle, S. G., Conroy, K., Coughlin, J., et al. 2011, AJ, 142, 160.

[20] Kirk, B., Conroy, K., Prsa, A., Abdul-Masih, M., Kochoska, A., MatijeviC, G., Hambleton, K., Barclay, T., Bloemen, S., Boyajian, T., et al. 2016, AJ, 151, 68.

[21] Devor, J., Charbonneau, D., ODonovan, F. T., Mandushev, G., & Torres, G. 2008, AJ, 135, 850.