CrossMark

Applied Mathematics and Nonlinear Sciences 1(2) (2016) 321–334

Applied Mathematics and Nonlinear Sciences

http://journals.up4sciences.org

Period Variation Study and Light Curve Analysis of the Eclipsing Binary GSC 02013-00288

N.S. Awadalla[1], M.A. Hanna[1], M.N. Ismail[2], I.A. Hassan[2], M.A. Elkhamisy[1]†

1. National Research Institute of Astronomy and Geophysics, Dept. of Astronomy, Stellar Lab., Helwan, Cairo. EGYPT
2. Department of Astronomy, Faculty of Sciences of El Azhar University, Cairo. EGYPT

Submission Info

Communicated by E.I. Abouelmagd
Received 7th April 2016
Accepted 1st August 2016
Available online 1st August 2016

Abstract

We analyzed the first set of complete CCD light curves of the W UMa type eclipsing binary IK Boo in the BVRI bands by using the PHOEBE code and deduced its first photometric parameters with, mass ratio $q = 0.648$ and orbital inclination $i = 63^o$. We have applied a spotted model due to the light curves asymmetry. The system shows a distinct O'Connell effect. The best solution fit to the light curves suggested the influence of star spot(s) on both components. Such presence of star spot(s) is common among the RS CVn and W UMa chromospheric active late type stars.

We also present an analysis of mid–eclipse time measurements of IK Boo. The analysis indicates a period decrease rate dP/dt $= -1.68 \times 10^{-7}$d/yr, which can be interpreted in terms of mass transfer of rate $3.1 \times 10^{-7} \mathrm{M}_{\odot}/yr$, from the more massive to the less massive component.

Keywords: Put here your keywords
AMS 2010 codes: Put here the AMS 2010 codes of the paper.

1 Introduction

The star IK Boo (= GSC 02013-00288, mag_B=12.16, B-V=0.81, FONAC.Catalogue, Kislyuk+1999) was reported by Akerlof et al. [1] as a newly discovered eclipsing binary system. Unfiltered CCD light curve with SBIG ST-7 camera attached to the 0.15m starfire reflector in Wald, Switzerland, was obtained by Blättler during 6 nights between JD 2453382 (2005, Jan 12) and JD 2453517 (2005, May 27)(Figure 1). Blättler and Diethlem [3] reported the system to be an eclipsing W UMa type with a magnitude range 11.42-11.76 (<mag>=11.69).

†Corresponding author.
Email address: lkhmsy@yahoo.com

UP4 Sciences ISSN 2444-8656 doi:10.21042/AMNS.2016.2.00027

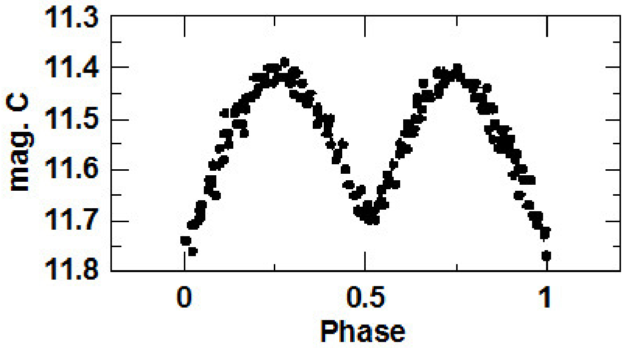

Fig. 1 The light curve of the binary IK Boo without filter given by Blättler in 2005.

Hanna and Awadalla [11] in a poster paper have presented the first set of complete light curves in BVRI filters observed photometrically during a clear night on 2013, May 1-2. They made a preliminary study for its period variations giving two new linear and quadratic ephemerides and deduced a decrease in the orbital period by a rate of -1.976×10^{-7} day/year.

The aim of this study is to analyze these light curves to determine the physical and geometrical elements for the system, to show any morphological variation due to star spot(s) activity found and to study the period variability of the system with some more details.

2 Observations

The observations of the W UMa eclipsing binary IK Boo were carried out through an EEV CCD 42-40 camera of multi-color BVRI standard Johnson filters attached to the Newtonian focus (F=4.0) of the 74-inch reflector telescope of the Kottamia observatory in Egypt, during a clear photoelectric night on 2013, May 1-2 i.e., HJD 2456414.0 (Hanna and Awadalla [11]). The exposure times, ranged from 20 s to 90 s, depend on the observing sky conditions and the filter used. The CCD camera has a format 2048 x 2048 pixels with a scale of $0''.308$ per pixel that was cooled by liquid nitrogen down to about -122 ^{o}C. The package of C-Muniwin, was used to reduce the CCD images.

The name and the coordinates of the variable star IK Boo (V), the comparison (C1), and the check (C2) stars are listed in Table 1, and their identification chart is shown in Figure 2. Also their magnitudes in different filters are presented in Table 2.

A total of 71 observations in B, 86 observations in V, 89 in R and 89 in I filters, were obtained and listed in Table 7, where Δ (BVRI) denote magnitude differences in the sense, variable minus comparison. The light curves in different filters with the calculated corresponding phases are plotted in Figure 3. The phases have been calculated from ephemeris given by Hanna and Awadalla [11].

3 Light curve analysis

The observed light curves of IK Boo indicate typical short period ($7^{h}.27$) W UMa eclipsing binary with narrow minima and broad maxima. To find the geometrical and physical parameters for the system, we proceed to solve the light curves simultaneously using the software PHOEBE (Prša and Zwitter [19]).

First, we have to determine the effective temperature of the primary star T_1, and the mass ratio q since there is no information about the mass ratio of the system in previous literature till now.

To determine the effective temperature, we used the observed colour index $(B-V)_o$ = 0.81 from FONAK

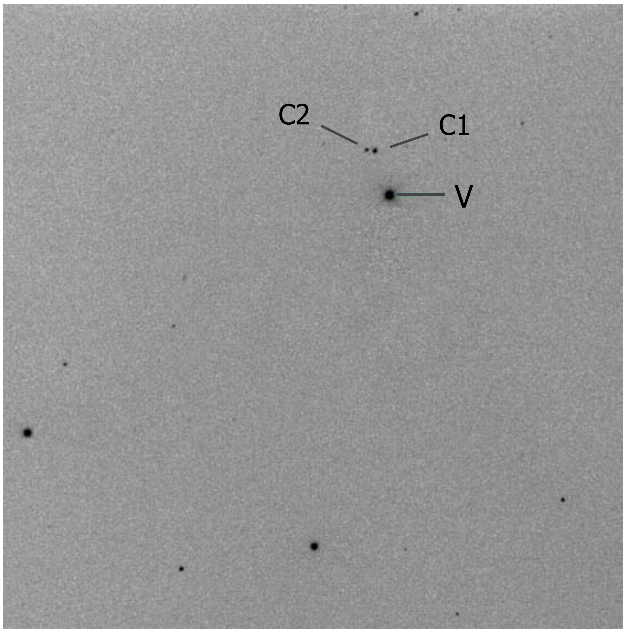

Fig. 2 One of the CCD images of IK Boo (V), obtained using the 74 inch Telescope of the Kottamia observatory in Egypt. $C1\&C2$ are the comparison and check stars, respectively. North is up and East is to the left.

Table 1 The coordinates of IK Boo and the comparison stars

	Star name	α_{2000}	δ_{2000}
V	IK Boo	$14^h\ 08^m\ 46^s.270$ [1]	$+29^\circ\ 29'\ 07''.00$ [1]
C1	N13323112930	$14^h\ 08^m\ 47^s.985$ [2]	$+29^\circ\ 29'\ 51''.77$ [2]
C2	N13323112929	$14^h\ 08^m\ 47^s.480$ [2]	$+29^\circ\ 29'\ 50''.95$ [2]

[1] 2MASS Catalogue, (Cutri [5]): yCat 2246C.
[2] GSC 2.2 catalogue (STScI, 2001).

catalogue (Kislyuk, 1999) and the colour excess $E(B-V) = 0.016$ from the All Sky Imaging Survey AIS (Bianchi et al. [2]). Hence, the intrinsic colour index equals 0.794. Then, using tables of Cox [4] for the main sequence stars, a surface temperature 5190K was obtained for the primary component of IK Boo.

To determine the mass ratio q we have applied an extensive q-search procedure. We searched for solutions with mass ratios from 0.1 to 1.7. The relation between the resulted sum $\sum$ of the weight square deviation $(O-C)^2$ and q is shown in Figure 4. The q-search of PHOEBE converged and resulted acceptable photometric solution for a contact configuration at about $q_{ph} \simeq 0.657$.

Second, by using van Hamme's [27] tables, the corresponding bolometric coefficient x_1 and x_2 were interpolated and found. Also, by following Lucy [17] and Rucinski [26], the gravity darkening exponent $g_1 = g_2 = 0.32$ and the bolometric albedo $A_1 = A_2 = 0.5$ were assumed for both components with a convective envelope. With the assumed initial parameters we continued the programme process, by using the "over contact mode" based on the shape of the light curves, till the solution converged. Finally, the solution with the standard errors obtained is tabulated for each filter in Table 3. The theoretical light curves are computed with the obtained parameters and plotted in Figure 3 as solid lines.

Table 2 The magnitude of IK Boo and the comparison stars in different filters

	Star name	mag.V	mag.B	mag.R	mag.I	mag.J	mag.H	mag.K
V	IK Boo	11.42 – 11.76[1]	12.37[1]	10.78[2]	10.69[2]	10.222[3]	09.864[3]	09.805[3]
C1	N13323112930	15.82[2]	15.61[2]	15.03[2]	-	14.967[3]	14.646[3]	14.525[3]
C2	N13323112929	14.82[2]	14.96[2]	14.01[2]	-	12.990[3]	12.400[3]	12.284[3]

[1] The Tycho catalogue (Hog+ 2000), [15].
[2] NOMAD Catalogue (Zacharias+2005), [28].
[3] 2MASS Catalogue, (Cutri 2003), [5].

Table 3 The light curve fit parameters by PHOEBE for GSC 4405-00129

Parameter	Filter B		Filter V		Filter R		Filter I	
T_1 (K)	5190		5190		5190		5190	
T_2 (K)	5000($\pm$189)		5000($\pm$128)		5000($\pm$128)		5000($\pm$261)	
Surface potential (Ω)	3.20($\pm$0.05)		3.20($\pm$0.04)		3.20($\pm$0.04)		3.20($\pm$0.05)	
Mass ratio ($q_{ph} = M_2/M_1$)	0.648($\pm$0.025)		0.673($\pm$0.029)		0.660($\pm$0.027)		0.648($\pm$0.279)	
Inclination (i)	63.2($\pm$1.3)		61.9($\pm$1.7)		62.0($\pm$0.7)		63.2($\pm$0.7)	
Albedo (A_2), (A_2)	0.50($\pm$0.13)		0.50($\pm$0.13)		0.50($\pm$0.13)		0.50($\pm$0.13)	
Gravity darkening Coef. (g)	0.32$\pm$(0.04)		0.32$\pm$(0.04)		0.32$\pm$(0.04)		0.32$\pm$(0.04)	
$l_1 = L_1/(L_1+L_2)$	0.668($\pm$0.0)		0.702($\pm$0.057)		0.738($\pm$0.023)		0.676($\pm$0.016)	
$l_2 = L_2/(L_1+L_2)$	0.332($\pm$0.0)		0.298($\pm$0.057)		0.262($\pm$0.064)		0.324($\pm$0.016)	
x_1	0.863($\pm$0.046)		0.654($\pm$0.023)		0.437($\pm$0.037)		0.284($\pm$0.052)	
x_2	0.833($\pm$0.047)		0.781($\pm$0.130)		0.625($\pm$0.130)		0.465($\pm$0.196)	
Fill-out Factor f	-0.003		-0.003		-0.003		-0.003	
Spots	Pri.	Sec.	Pri.	Sec.	Pri.	Sec.	Pri.	Sec.
Latitude (^{o})	80	75	90	80	90	75	60	50
Longitude (^{o})	110	120	110	110	110	140	110	80
Radius (^{o})	7	4	5	4	5	5	4	5.5
T	0.6	0.8	0.7	1.2	1.0	1.5	0.8	1.5

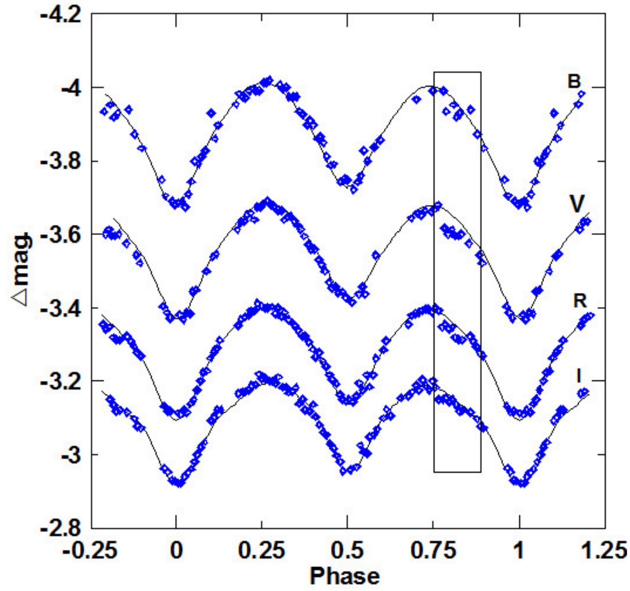

Fig. 3 The best match between the synthetic light curves and the observed light curves of binary IK Boo. The rectangle shows a hump like distortion in all the LCs.

4 Light curve study

The fill-out factors of both components $f_1 = f_2 \simeq -0.003$, as obtained and listed in Table 3, imply that IK Boo is a contact binary system according to Lucy and Wilson [18]. The Roche lobe configuration of IK Boo is illustrated in Figure 5.

Rucinski [23] has discussed the properties of W UMa-type systems in terms of their division into A- and W-types. He reported that for q nearer to the upper limit of the range $0.145 < q < 0.88$, later spectral type G-K, for shallow envelopes Roche lobe configuration denoted by the fill-out factor f and for high colour index $B-V \geq 0.54$; the system can be classified as W-type contact binary system. For IK Boo, the results show a q value $\simeq 0.65$, late spectral type K0 + K1.5 (corresponding to the obtained low temperatures $T_1 = 5190, T_2 = 5000K$), the Roche geometry configuration (Figure 5) where the fill out factor $f = -0.003$, and the colour index $B-V = 0.796 > 0.54$. Hence, one can deduce that IK Boo is likely to be of W-type W UMa system.

To follow the light curve variation for IK Boo, we measured the light curve levels at maxima and minima directly from Figure 3. Table 4 shows the magnitude difference between both maxima $D_{max.}$ (O'Connell effect) and both minima $D_{min.}$; and the depths of the primary (A_p) and secondary (A_s) minima for the observed light curves in all bands (BVRI). Table 4 and Figure 3 show that the primary and secondary minima are deeper (A_p&A_s) in short wavelength and decreased with increasing the wave length, while the depth difference in minima is larger in V-band.

Some of interesting in all light curves of IK Boo is the existence of a hump like distortion waves between phase 0.75 and 0.90 (Figure 3). This phenomenon displays when the primary goes free from the secondary and it has been recorded for the RS CVn binary systems as flare-like episodes (Zeilik, et al., [29]).

5 Period variation study

The first light elements was obtained by Blättler and Diethelm [3] by performing a linear regression to 10 times of minima obtained from ROTSE1 data. Later, Hanna and Awadalla [11] collected all the available time of minima together with their observed minima times and deduced two linear and quadratic ephemerides

Table 4 Magnitude differences and minima depthes of IK Boo

Filter	$D_{max.}$ $max_p - max_s$	$D_{min.}$ $min_p - min_s$	A_p $min_p - max_p$	A_s $min_s - max_p$
B= 445 nm	-0.03	0.04	0.34	0.30
V= 550 nm	-0.02	0.05	0.32	0.26
R= 560 nm	-0.01	0.03	0.30	0.26
I= 800 nm	-0.01	0.03	0.28	0.25

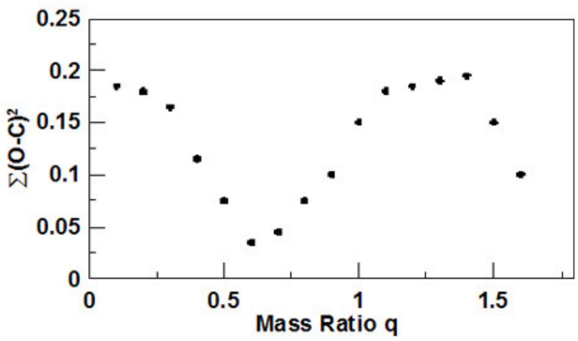

Fig. 4 Relation between $\sum$ and q.

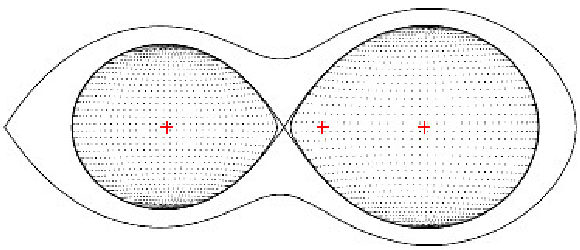

Fig. 5 Roche lobe configuration of IK Boo.

by constructing the O-C diagram. They have deduced a decrease in the orbital period of IK Boo by a rate dP/dt= -1.979×10^{-7} day/year. In this section we aimed to re-visit the period variation study of this system in some more details.

In order to study the period variation of IK Boo, we used all the minima times used in Hanna and Awadalla [11] together with two new minima observed recently by Hübscher and Lehmann [14]. They are all listed in Table 5.

We have constructed the O-C diagram as seen in the Figure 7 by using the light elements of Blättler and Diethelm [3]. Then, by using the linear and quadratic least squares methods, we obtained the following new linear and quadratic ephemerides:

$$HJD(MinI) = 2453382^d.62805 + 0^d.303117067E, \tag{1}$$

with standard deviation (SD) =0.0025 day, correlation coefficient (r)=0.9609, and residual sum of squares =

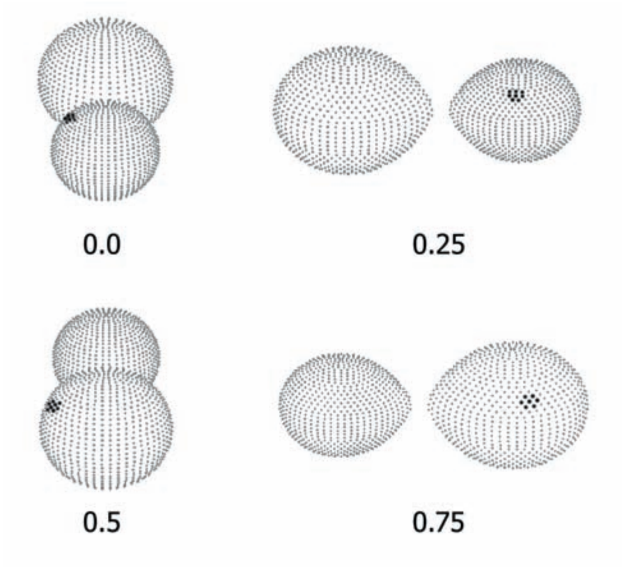

Fig. 6 A schematic spots modelling for IK Boo.

1.68×10^{-4}; and

$$HJD(MinI) = 2453382^{d}.62741 + 0^{d}.303118999 \cdot E - 6.96 \times 10^{-11} E^{2}, \tag{2}$$

with SD=0.0025 day, r=0.9636, and residual sum of squares = 1.57×10^{-4} associated with the period decrease rate $\mathrm{d}P/\mathrm{dt} = -1.39 \times 10^{-10}$d/cycle$(= -1.68 \times 10^{-7}$d/yr). Such period decrease rate is usually interpreted to be due to a transfer of matter from the more massive to the less massive component.

If the period decrease is caused by conservative mass transfer, then one can calculate the mass transfer between the binary components. On using the formula derived by Kreiner & Ziolkowski [16]:

$$\frac{\mathrm{d}M}{\mathrm{dt}} = \frac{M_t \cdot q}{3P(q^2-1)} \cdot \frac{\mathrm{d}P}{\mathrm{dt}}, \tag{3}$$

where, $M_t = M_1 + M_2$ and $q = M_2/M_1$, and by adopting the value 0.91 $M_\odot$ for M_1 by using Harmanec's [12] table for main sequence stars where $T_1 = 5190$ K, consequently M_2= 0.59 $M_\odot$, where $q_{ph} = 0.648$ (Table 3). Hence, we have obtained the rate of mass transfer dP/dt (= 3.1×10^{-7} $M_\odot$/yr) from the more massive to the less massive star.

Eliminating the effect of mass transfer which is represented by the parabolic term of equation 2, we obtain the $(O-C)_2$ residual plot (Figure 8), which shows a significant orbital period variation. The dashed curve on Figure 8 represents the 4^{th} order polynomial fit to all the data (without the last two points since they have a severe upward bind) with SD = 0.002 and r = 0.612. We have performed such polynomial fit just to show the sine like variation which is usually interpreted to be due to the presence of a third body orbiting the binary or the effect of magnetic activity cycling as a result of star spot(s) activity. However, at present we cannot able to distinguish between the two possibilities due to that, the data available represents only one cycle. One cycle cannot confirm the third body hypothesis without either spectroscopic evidence or a presence of another cycle equals in duration to the first cycle. Strictly periodic sine variation behavior concerning the $O-C$ diagram shape is an essential property to prove the LITE due to the presence of a third body. Hence, More photoelectric and spectroscopic observations are indeed required to decide among the two possibilities that causing the sine variation.

The present $(O-C)_2$ values in Figure 8, considering all the data, clearly suggest a non-continuous variation. Following Qian's [20] method, three clear jumps have taken place in the period of IK Boo within a time interval of about 9 years between the middle of Jan 12, 2005 (or JD = 2453382.6234) and the end of Mar 31, 2014 (or

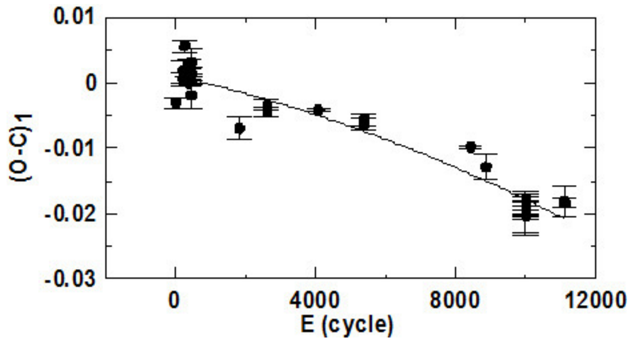

Fig. 7 O-C diagram of IK Boo. Error bars due to minima times determination.

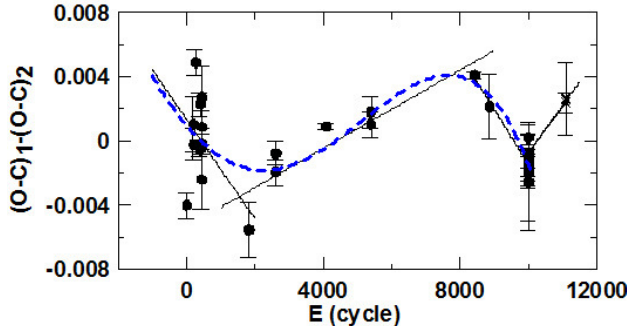

Fig. 8 Residuals of IK Boo from the quadratic ephemeris and their description by four linear ephemerides. The solid curve represents the 4^{th} order polynomial fit with SD=0.002 and r = 0.632.

JD = 2456747.5323). Between these jumps, the period is assumed to have undergone a steady decrease. Similar systems, such as Y Psc, BO Mon, Z Per, and UU And have been studied by Qian [21,22], AT Peg by Hanna [9], BB Peg by Hanna and Awadalla [10]. Using the least squares method, a linear function in each portion is used to obtain the best fit to the $(O-C)_2$ values:

$$(O-C)_2 = \Delta T + \Delta P \times E; \tag{4}$$

the values ΔT and ΔP in each portion are listed in Table 6. The period at any cycle E has been computed with the following equation:

$$P_{Re}(E) = P_{Eph} + \Delta P + \frac{dP}{dE} \times E; \tag{5}$$

results are shown in Figure 9, where we have plotted the difference between the real period $P_{Re}(E)$ and the ephemeris period P_{Eph} ($0^d.303117067$) - in units of 10^{-6} day- as a function of time.

6 Conclusion

1. From the study of the color indices we can conclude that the system is of late spectral type (K0+K1.5).

2. The system was found to have mass ratio $q = 0.648$ approaching the upper limit of the range $0.145 < q < 0.88$ which is a W-type property, (note, $q < 0.54$ for A-type, Rucinski, [23]). In addition, the shapes of the light curves appear to have a moderate activity (seen between phase 0.75 and 0.9 of Figure 3).

Table 5 Time of Minima

HJD (Min. I) (+2400000)	Error	Filter	E	$(O-C)_1$	$(O-C)_2$	Ref.
53382.62340	0.0008	C	0	-0.0030	0.0010	[1]
53445.37260	0.0010	C	207	0.0006	-0.0008	[1]
53445.52540	0.0017	C	207.5	0.0018	-0.0008	[1]
53463.41320	0.0008	C	266.5	0.0056	-0.0007	[1]
53502.35840	0.0004	C	395	0.0000	-0.0005	[1]
53502.51280	0.0007	C	395.5	0.0028	-0.0005	[1]
53515.39060	0.0019	C	438	-0.0019	-0.0005	[1]
53515.54440	0.0006	C	438.5	0.0003	-0.0005	[1]
53517.36600	0.0019	C	444.5	0.0032	-0.0005	[1]
53517.51570	0.0011	C	445	0.0013	-0.0005	[1]
53936.41790	0.0017	R	1827	-0.0069	-0.0014	[2]
54174.36990	0.0007	C	2612	-0.0033	-0.0026	[2]
54174.52030	0.0008	C	2612.5	-0.0045	-0.0026	[2]
54619.80250	0.0002	R	4081.5	-0.0041	-0.0050	[3]
55015.37130	0.0010	C	5386.5	-0.0056	-0.0074	[4]
55015.52210	0.0008	C	5387	-0.0064	-0.0074	[4]
55937.00040	0.0002	C	8427	-0.0098	-0.0139	[5]
56069.46040	0.0020	I	8864	-0.0128	-0.0155	[6]
56414.40227	0.0030	B	10002	-0.0204	-0.0178	[7]
56414.40278	0.0030	V	10002	-0.0199	-0.0178	[7]
56414.40288	0.0026	R	10002	-0.0198	-0.0178	[7]
56414.40333	0.0024	I	10002	-0.0193	-0.0178	[7]
56414.55457	0.0031	B	10002.5	-0.0196	-0.0178	[7]
56414.55517	0.0029	V	10002.5	-0.0190	-0.0178	[7]
56414.55656	0.0025	R	10002.5	-0.0176	-0.0178	[7]
56414.55567	0.0026	I	10002.5	-0.0185	-0.0178	[7]
56747.38050	0.0006	-I	11100.5	-0.0184	-0.0208	[8]
56747.53230	0.0023	-I	11101	-0.0181	-0.0208	[8]

Ref.: Diethelm [6], Diethelm [7], Nelson [24], Diethelm [8], Nelson [25], Hübscher and Lehmann [13], Hanna and Awadalla [11], Hübscher and Lehmann (2015) [14].

Table 6 Four linear fit sections, intervals, and the rates of change of the period of IK Boo

	t_o to t_1 E_1	t_1 to t_2 E_2	t_2 to t_3 E_3	t_3 to t_4 E_4
Interval (in Cycles)	0.0 to 1827	1827.0 to 8427.0	8427.5 to 10002.5	10002.5 to 11101
Interval (in JD:2400000+)	53382.62340 to 53936.41790	53936.41790 to 55937.00040	55937.00040 to 56414.55567	56414.55567 to 56747.5323
Epoch	53382.6287	53382.6211	53382.6560	53382.5923
Period (days)	0.3031159	0.3031206	0.3031182	0.3031219
SD, Stand. Div.,	0.0028	0.0014	0.0018	0.0002
r Corr. Coef.	0.4864	0.8797	0.5627	0.9979
Res. sum of sq.($\times 10^{-5}$)	6.96	0.829	2.93	0.003
ΔT (day)	0.0023	-0.0053	0.0296	-0.0341
ΔP (day) $\times 10^{-6}$	-3.092	1.558	-0.820	2.919
$\Delta P/P$ ($\times 10^{-5}$)	-1.021	0.514	-0.271	0.963
$\Delta P/\Delta E$ (d/cycle) ($\times 10^{-9}$)	-1.693	0.236	-0.521	2.657

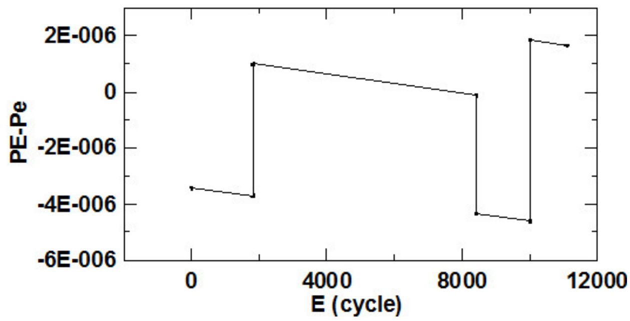

Fig. 9 Variations in the orbital period of IK Boo. Three jumps in the period are clearly visible.

3. The two spots were found on both components (Table 6, and Figure 6). The presence of star spots reveals the magnetic activity that characterizing the chromospheric activity in late W UMa and RS CVn stars.

4. The schematic picture of the Roche lobe (Figure 5) showed moderate outer convective zone with common radiative envelope for both components which is a property of W-type W UMa systems (Rucinski, [23]).

5. The study of the O-C diagram of IK Boo showed a long term orbital period modulation decrease of rate dP/dt $= -1.68 \times 10^{-7}$d/yr, that can be interpreted to be due to mass transfer from the more to the less massive component.

6. The light curves solution showed presence of star spots on both components. Such magnetic activity is recommended to be the reason of the sine-like variation seen in the $(O-C)_2$ diagram (Figure 8). However, one cannot dismiss a probable detection of a third body orbiting the system, which can be proved by a periodic behaviour of the O-C diagram. The presence of a third body has to be supported by more observed minima time of mid-eclipse, and/or spectroscopic observations.

Spectroscopic observations for the binary system IK Boo are strongly recommended in order to determine its physical parameters and to verify the obtained photometric results. Also, observing more minima times are needed to re-study the period variability in order to decide among, is the alternating change in its period cyclic or periodic?

References

[1] Akerlof, C., Amrose, S. Balsano, R. Bloch, J. et al.: (2000), ROTSE All-Sky Surveys for Variable Stars. I. Test Fields, Astronomical Journal 119, 1901. doi 10.1086/301321
[2] Bianchi, L., Herald, J., Efremova, B., Girardi, L., Zabot, A., Marigo, P., Conti, A., Shiao, B.: (2011), GALEX catalogs of UV sources: statistical properties and sample science applications: hot white dwarfs in the Milky Way, Astrophysics and Space Science 335, 161. doi 10.1007/s10509-010-0581-x
[3] Blättler, E. and Diethelm, R.: (2006), Observations of Variables , Infomation Bulltine of Vaiable Stars, No. 5699.
[4] Cox, A.N.: (2002), Book Review: Allen's astrophysical quantities. - 4th ed.; New York: Springer. doi 10.1007/978-1-4612-1186-0
[5] Cutri, R.M., Skrutskie, M.F., van Dyk, S., Beichman, C.A., Carpenter, J. M., Chester, T., Cambresy, L., Evans, T., Fowler, J., Gizis, J., and 15 coauthors: (2003), "VizieR Online Data Catalog: 2MASS All-Sky Catalog of Point Sources (Cutri+2003)", yCat., 2246, 0.
[6] Diethelm, R.: (2006), 165. List of Timings of Minima Eclipsing Binaries by BBSAG Observers, Information Bulletin of Variable Stars Stars, No. 5713.
[7] Diethelm, R.: (2007), 166. List of Timings of Minima Eclipsing Binaries by BBSAG Observers, Information Bulletin of Variable Stars, No. 5781.
[8] Diethelm, R.: (2010), 166. Timings of Minima of Eclipsing Binaries, Information Bulletin of Variable Stars, No. 5920.
[9] Hanna, M.A. (2012): Orbital period changes and possible stellar wind mass loss in the algol-type binary system AT Pegasi, Journal of Astronomy and Geophysics, 1, 87. doi 10.1016/j.nrjag.2012.12.003
[10] Hanna, M.A. and Awadalla, N.S.: (2011), Orbital period variation and morphological light curve studies for the W UMa binary BB Pegasi, Journal of Korean Astronomical Society, 44 , 97. doi 10.5303/JKAS.2011.44.3.97
[11] Hanna, M.A. and Awadalla, N.S.: (2014), New CCD photoelectric observations of the contact binary GSC 02013-00288, Contributions of the Astronomical Observatory Skalnaté Pleso, 43, 440.
[12] Harmanec, P.: (1988), Stellar masses and radii based on modern binary data, BAICz, 39, 329.
[13] Hübscher, J. and Lehmann, P.B.: (2013), BAV-Results of Observations - Photoelectric Minima of Selected Eclipsing Binaries and Maxima of Pulsating Stars, Information Bulletin of Variable Stars, No. 6070.
[14] Hübscher, J. and Lehmann, P.B.: (2015), BAV-Results of Observations - Photoelectric Minima of Selected Eclipsing Binaries and Maxima of Pulsating Stars, Information Bulletin of Variable Stars, No. 6149.
[15] Hog, E., Fabricius, C., Makarov, V. V., Urban, S., Corbin, T., Wycoff, G., Bastian, U., Schwekendiek, P., Wicenec, A.: (2000), The Tycho-2 catalogue of the 2.5 million brightest stars, Astronomy and Astrophysics 355, 27.
[16] Kreiner, J.M. and Ziolkowski, J.: (1978), Period changes and evolutionary status of 18 Algol-Type Systems, Acta Astronomica 28, 497.
[17] Lucy, L.B.: (1967), Gravity-Darkening for Stars with Convective Envelopes, Zeitschrift für Astrophysik, 65, 89.
[18] Lucy, L.B. and Wilson: (1979), Observational tests of theories of contact binaries, Astrophysical Journal 231, 502.
[19] Prša, A. and Zwitter, T.: (2005), A Computational Guide to Physics of Eclipsing Binaries. I. Demonstrations and Perspectives, Astrophysical Journal 628, 426. doi 10.1086/430591
[20] Qian, S., Orbital period changes and possible mass and angular momentum loss in two Algol-type binaries: RW Coronae Borealis and TU Herculis.: (2000a), Astronomical Jounal 119, 901. doi 10.1086/301412
[21] Qian, S., Possible Mass and Angular Momentum Loss in Algol-Type Binaries. II. TT Delphini, BO Monocerotis, and Y Piscium: (2000c), Astronomical Jounal 119, 3064. doi 10.1086/301412
[22] Qian, S., Possible Mass and Angular Momentum Loss in Algol-Type Binaries. IV. UU Andromedae and Z Persei: (2001b), Astronomical Jounal 122, 1561. doi 10.1086/322179
[23] Rucinski, S.M.: (1973), The Photometric Proximity Effects in Close Binary Systems. VI. The Exact Solution for the Source Function in Monodirectional Illumination of the Grey Atmosphere, Acta Astronomica 23, 301.
[24] Nelson, R.H.: (2009), CCD Minima for Selected Eclipsing Binaries in 2008, Information Bulletin of Variable Stars, No. 5875.
[25] Nelson, R.H.: (2013), CCD Minima for Selected Eclipsing Binaries in 2012, Information Bulletin of Variable Stars, No. 6050.
[26] Rucinski, S.M.: (1974), Binaries. II. A- and W-type Systems. The W UMa-type Systems as Contact, Acta Astronomica 24, 119.

Table 7 BVRI-Observations of IK Boo

HJD. (+2450000)	ΔB	HJD. (+2450000)	ΔV	HJD. (+2400000)	ΔR	HJD. (+2450000)	ΔI
6414.30566	-4.02437	6414.30666	-3.64348	6414.30407	-3.35437	6414.30457	-3.17065
6414.30866	-4.00268	6414.31257	-3.65419	6414.30728	-3.37802	6414.30777	-3.17864
6414.31160	-3.96709	6414.31552	-3.65237	6414.31020	-3.38707	6414.31069	-3.20317
6414.32347	-4.01359	6414.31843	-3.66495	6414.31317	-3.38786	6414.31368	-3.18568
6414.32640	-3.99298	6414.32442	-3.66115	6414.31611	-3.39329	6414.31659	-3.21114
6414.33537	-3.99183	6414.32736	-3.66618	6414.31904	-3.39744	6414.31951	-3.19473
6414.33832	-3.93605	6414.33032	-3.67598	6414.32205	-3.39774	6414.32252	-3.17867
6414.34428	-3.95282	6414.33334	-3.63581	6414.32502	-3.38880	6414.32551	-3.19801
6414.34723	-3.91849	6414.33632	-3.61634	6414.32796	-3.40047	6414.32845	-3.19543
6414.35021	-3.93183	6414.33928	-3.59945	6414.33095	-3.39098	6414.33145	-3.16099
6414.35986	-3.93855	6414.34228	-3.61216	6414.33394	-3.34611	6414.33448	-3.15799
6414.36581	-3.87267	6414.34525	-3.59620	6414.33691	-3.35521	6414.33741	-3.16171
6414.37177	-3.83452	6414.34821	-3.59440	6414.33990	-3.34370	6414.34037	-3.15892
6414.38969	-3.74906	6414.35118	-3.59982	6414.34287	-3.34502	6414.34336	-3.16052
6414.39263	-3.70469	6414.35785	-3.57566	6414.34584	-3.32106	6414.34633	-3.13863
6414.39843	-3.68975	6414.36677	-3.54375	6414.34882	-3.31500	6414.34929	-3.12770
6414.40134	-3.68329	6414.36972	-3.52042	6414.35178	-3.31286	6414.35227	-3.12886
6414.40422	-3.68512	6414.38528	-3.43963	6414.35846	-3.29993	6414.35894	-3.09889
6414.40718	-3.68969	6414.39061	-3.40603	6414.36146	-3.30848	6414.36196	-3.10811
6414.41015	-3.67348	6414.39355	-3.38488	6414.36443	-3.29425	6414.36491	-3.10956
6414.41310	-3.70936	6414.39647	-3.37200	6414.36738	-3.27644	6414.36786	-3.07826
6414.41602	-3.74467	6414.39936	-3.35017	6414.37034	-3.26982	6414.37082	-3.07792
6414.41890	-3.79969	6414.40517	-3.38035	6414.39122	-3.13334	6414.39170	-2.95536
6414.42182	-3.79328	6414.40810	-3.36956	6414.39414	-3.11726	6414.39462	-2.96251
6414.42475	-3.81160	6414.41108	-3.38878	6414.39706	-3.11711	6414.39753	-2.93136
6414.42765	-3.82808	6414.41405	-3.38428	6414.39994	-3.10736	6414.40044	-2.92693
6414.43344	-3.93091	6414.41696	-3.44406	6414.40286	-3.11168	6414.40333	-2.92091
6414.43640	-3.86038	6414.41985	-3.45141	6414.40576	-3.10990	6414.40624	-2.93063
6414.43932	-3.89629	6414.42275	-3.46115	6414.40872	-3.12317	6414.40919	-2.94535
6414.45500	-3.95317	6414.42567	-3.48664	6414.41169	-3.11540	6414.41218	-2.95074
6414.45802	-3.98208	6414.42859	-3.49959	6414.41464	-3.13684	6414.41512	-2.95194
6414.46108	-3.97359	6414.43148	-3.50941	6414.41755	-3.15000	6414.41801	-2.98455
6414.46404	-3.97184	6414.43437	-3.53880	6414.42045	-3.17722	6414.42093	-2.99608
6414.46694	-3.99016	6414.43733	-3.54508	6414.42333	-3.20088	6414.42385	-3.02218
6414.46988	-3.99485	6414.44029	-3.56637	6414.42625	-3.22437	6414.42677	-3.03106
6414.47281	-3.99293	6414.45078	-3.59509	6414.42918	-3.22879	6414.42966	-3.06942
6414.47575	-3.99235	6414.45206	-3.61690	6414.43208	-3.26235	6414.43255	-3.06939
6414.47882	-4.01102	6414.45596	-3.61215	6414.43498	-3.27926	6414.43545	-3.10065
6414.48179	-4.01246	6414.45897	-3.63415	6414.43792	-3.29056	6414.43840	-3.11625
6414.48479	-4.01953	6414.46201	-3.63551	6414.44088	-3.30604	6414.44140	-3.12359
6414.48773	-4.03093	6414.46498	-3.65469	6414.45657	-3.35315	6414.45705	-3.15426
6414.49068	-4.02132	6414.46789	-3.65648	6414.45959	-3.36862	6414.46009	-3.16861
6414.49359	-4.00925	6414.47083	-3.63990	6414.46265	-3.37594	6414.46313	-3.16521
6414.49657	-3.99700	6414.47375	-3.67385	6414.46557	-3.37822	6414.46606	-3.18349

Table 7 *Continued ...BVRI-Observations of IK Boo*

HJD. (+2450000)	ΔB	HJD. (+2450000)	ΔV	HJD. (+2400000)	ΔR	HJD. (+2450000)	ΔI
6414.49951	-4.00102	6414.47670	-3.67419	6414.46847	-3.39283	6414.46899	-3.18361
6414.50250	-3.97494	6414.47978	-3.69023	6414.47144	-3.38820	6414.47192	-3.19292
6414.50553	-3.97492	6414.48278	-3.69096	6414.47435	-3.40975	6414.47485	-3.22558
6414.50846	-3.97438	6414.48574	-3.68139	6414.47735	-3.40449	6414.47782	-3.19679
6414.51142	-3.93653	6414.48869	-3.67834	6414.48038	-3.39648	6414.48087	-3.20110
6414.51438	-3.92664	6414.49162	-3.66740	6414.48337	-3.39940	6414.48388	-3.19757
6414.51778	-3.89895	6414.49455	-3.66660	6414.48634	-3.40047	6414.48683	-3.19487
6414.52075	-3.91008	6414.49751	-3.63948	6414.48928	-3.38499	6414.48978	-3.18485
6414.52368	-3.89689	6414.50047	-3.64840	6414.49222	-3.40091	6414.49270	-3.19890
6414.52666	-3.86159	6414.50345	-3.64957	6414.49517	-3.37656	6414.49567	-3.17769
6414.52966	-3.86647	6414.50648	-3.63621	6414.49812	-3.38720	6414.49861	-3.17667
6414.53269	-3.84928	6414.50944	-3.62274	6414.50108	-3.36690	6414.50155	-3.16169
6414.53578	-3.81341	6414.51238	-3.61398	6414.50409	-3.36006	6414.50457	-3.14524
6414.53881	-3.78881	6414.51532	-3.59513	6414.50707	-3.35208	6414.50757	-3.14997
6414.54182	-3.79060	6414.51873	-3.56983	6414.51005	-3.33744	6414.51052	-3.13050
6414.54771	-3.74313	6414.52169	-3.55700	6414.51299	-3.32362	6414.51347	-3.15082
6414.55067	-3.75169	6414.52463	-3.55548	6414.51593	-3.32372	6414.51642	-3.12454
6414.55363	-3.74839	6414.52760	-3.52624	6414.51934	-3.30017	6414.51985	-3.09640
6414.55657	-3.69175	6414.53061	-3.51531	6414.52230	-3.28860	6414.52279	-3.09629
6414.55953	-3.72178	6414.53363	-3.49757	6414.52524	-3.27041	6414.52575	-3.09083
6414.56258	-3.74201	6414.53672	-3.47249	6414.52824	-3.27677	6414.52872	-3.08256
6414.56561	-3.75830	6414.53977	-3.45351	6414.53124	-3.25651	6414.53174	-3.04411
6414.56858	-3.82962	6414.54278	-3.45826	6414.53428	-3.23939	6414.53477	-3.02405
6414.57150	-3.80046	6414.54573	-3.44013	6414.53736	-3.21856	6414.53785	-3.03043
6414.57743	-3.83625	6414.54866	-3.44010	6414.54041	-3.19800	6414.54088	-2.99843
6414.58323	-3.85780	6414.55161	-3.42833	6414.54337	-3.19318	6414.54385	-2.98659
6414.59233	-3.88628	6414.55457	-3.41750	6414.54633	-3.16064	6414.54681	-2.94536
		6414.55755	-3.41686	6414.54926	-3.15239	6414.54977	-2.96036
		6414.56046	-3.42375	6414.55221	-3.14553	6414.55273	-2.96942
		6414.56352	-3.44078	6414.55517	-3.14976	6414.55567	-2.98336
		6414.56656	-3.45854	6414.55814	-3.14249	6414.55863	-2.94095
		6414.56953	-3.43661	6414.56110	-3.15709	6414.56161	-2.95867
		6414.57247	-3.48379	6414.56416	-3.18986	6414.56463	-3.02289
		6414.57542	-3.48103	6414.56716	-3.17518	6414.56766	-3.00127
		6414.57840	-3.54157	6414.57013	-3.21859	6414.57061	-2.99313
		6414.58418	-3.56333	6414.57307	-3.18574	6414.57355	-3.02348
		6414.58715	-3.59460	6414.57603	-3.21754	6414.57653	-3.04310
		6414.59019	-3.62027	6414.57900	-3.26195	6414.57951	-3.06134
		6414.59328	-3.59783	6414.58478	-3.28646	6414.58527	-3.07382
		6414.59633	-3.61881	6414.58778	-3.30990	6414.58826	-3.11400
		6414.59935	-3.59469	6414.59086	-3.30683	6414.59135	-3.11844
		6414.60233	-3.67044	6414.59390	-3.35342	6414.59439	-3.12964
				6414.59697	-3.34156	6414.59745	-3.14733
				6414.59995	-3.37410	6414.60045	-3.11837
				6414.60292	-3.30471	6414.60341	-3.07985

[27] van Hamme, W. (1993), New Llimb-darkening Coefficients for Modeling Binary Star Light Curves, Astronomical Journal 106, 2096. doi 10.1086/116788
[28] Zacharias, N., Monet, D.G., Levine, S.E., Urban, S.E., Gaume, R., Wycoff, G.L.: (2004), "The Naval Observatory Merged Astrometric Dataset (NOMAD)", American Astronomical Society Meeting 205, 4815.
[29] Zeilik, M., Elston, R., and Henson, G.: (1983), The short-period eclipsing system XY UMa - 1982 UBV light curves and a flare-like event, Astronomical Jounal 88, 532. doi 10.1086/113339