Spot Activity of AK Her Binary Star

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Abstract

In this investigation B and V filters light curves of the AK Her are presented. Their light curves notice O'Connell effect phenomenon in which the level of the primary maxima peaks being higher than that of the secondary ones or contrarily in both filters. Photometric solutions were carried out by using the latest version (2003) of the W-D program; the present light curves are analyzed. The spot model has been applied to fit the asymmetric light curves in order to explain the O'Connell effect. The explanation of the O'Connell effect by spot model of AK Her binary carried out for the first time by cool spot on the primary component and the spot parameters of such system have been determined. It has been observed that by changing only the spot parameters, the model light curves can fit the observed light curves. This indicates that the variation of the spot location, size and its temperature is the main reason for changing the shape of light curves. The spot effect has been calculated to compare how much the light curve is distorted by the star spot; also the spot area has been calculated. It is found that the system is over-contact of A-subtype. From our data analysis, the fundamental orbital, physical and geometrical parameters were determined, and the absolute parameters have been determined.

Keywords: eclipsing binaries; stars: star-spots: light curve; magnetic field.

Introduction

The variability of the W Ursae Majoris type system AK Herculis (HD 155937, B & V mag. 9.01, 8.51) has been discovered in (1917). AK Her is a visual binary, with the third component (ADS 10408B). It is the brighter component of the visual double star ADS 10408. The fainter component is 4 magnitude fainter than the variable at the maximum light [1,2]. Classified as A subtype W UMa system with and spectral type F2+F6 [3]. The system shows W UMa type light curve with obvious O'Connell effect (0.017 mag in B, 0.028 mag in V) with period of rotation of 0.42152207 days [4]. The plot of an image close up field map of the AK Her with the surrounding has been shown in Fig.(1) which has been taken from STSCI[5].

Photometry observations of AK Her in the B and V bands were carried out in 1973 at Kitt Peak National Observatory [6]. The light curves of the system are shown in Fig.(2).The system AK Herculis exhibits variable light curve and obvious O'Connell effect as well as unequal depth of both eclipses.

Photometric Analysis of AKHer

Photometric solutions were obtained by means of the latest version of the Wilson-Devinney program W-D (2003)[7], which includes the ability to adjust spot parameters. All the observations are used to compute the solutions. Initial starting values were determined from the previously published light-curve solutions. The adopted parameters in the solutions are as follows: a temperature of 6400 K for star 1 (the star eclipsed at primary minimum), values of the limb-darkening coefficient (x_1,x_2=0.38 for V band and 0.49 for B band), values of the gravity-darkening coefficient (g_1,g_2=0.81); values of the albedo (A_1, A_2=2.02) [6]. The adjustable parameters employed were: the orbital inclination (i), the mass ratio (q), the mean temperature of star2 (T_2) the potentials of the components (Ω_1 and Ω_2) and the monochromatic luminosity of Star 1 (L_1). The fit of the computed light curves in B an V bands is marked with solid lines in Fig.(3a) and Fig.(4a) respectively. The photometric parameters are listed in Table (1), where ''star1 '' indicates a more massive component, and ''star2 '' is of lesser mass. The obvious distortions in the observed light curves appear as shown in Fig.(3) and Fig.(4) clearly, which seem to be due to the surface in homogeneities of the components. Unequal quadrature light level, namely, the O'Connell effect, is known in many eclipsing binaries, and several suggestions have been made to explain this effect by various authors. All of former authors attributed the photometric distortion waves to be only caused mainly by mass transfer between the two components, from the primary to the secondary which causes an oscillation of the secondary as well as a pulsation of the common envelope [2]. In fact, their solutions could not fit the observations well. In order to reveal the true nature of the surface brightness distribution on AK Her, for analyzing the asymmetric light curves, deformed by the presence of active spotted areas on the components, that have been used. The presence of spotted areas (dark or bright) enables one to explain the asymmetry and the depression on the light curves of active AK Her. Recently the magnetic activity has successfully explained the light variation of the fast rotating late-type stars. The magnetic activity causes photospheric spots. W UMa type binaries are known as active binaries that have magnetic activity. There is presented observational evidences for magnetic activities on close binary stars which explain the distorted asymmetric light curves [8].

In the program these active regions are approximated by circular spots, described by the temperature contrast of the spot with respect to the surrounding photosphere ($As = Ts/T_*$), by the angular radius of the spot (γ) and by the longitude (θ) and latitude (φ) of the spot centre. the latitude of a star spot centre in degree measured from 0 degrees at the north pole to 180 degrees at the south pole, the longitude of a star centre in degree measured counter-clockwise from the line of star centers from 0 to 360 deg, the angular radius of a star spot in degrees, this angle is the one subtended by the spot radius at the centre of the star, and the temperature factor of the spot, that specifies the local spot temperature compared to the local temperature one would have without the spot, a value larger or smaller than unity corresponds to the spot being hotter than or cooler than the unspotted surface, respectively. For AK Her, the observed distortion, with the secondary maximum being fainter than the primary maximum, may result from a cool or hot region on either component. It is assumed that the spot is on star 1 or star 2, and we tested several groups of dark spots or hot spots. While a convergent solution with the hot spot could not be found, the best fit to the observed light curves was found with a dark spot on the primary (more massive) star. The fit of the computed light curves corresponding to the dark spot on the secondary is shown by the solid lines in Fig.(3b) an Fig.(4b) in B and V bands respectively. The solution with the dark spot (co-latitude (φ), longitude (θ), angular radius (γ), all in degrees, and the temperature factor ($As = Ts/T_*$)) is also listed in Table (1), and the comparison of the two solutions (with and without spot) are illustrated in Fig.(3c) and Fig.(4c). By changing only the spot parameters, the model light curves could fit to the observed light curves, this indicates that the variation of the spot location and size is the main reason for changing the shape of light curves. The spots assumption gives a good description of the asymmetry of the light curves of the present binary system. The spot area has been calculated for all systems as a fraction of the hemispheric areas of the star by the following equation [9].

$S_{spot}=1-\cos\gamma(\circ)$ spot......................................(1)

In order to compare how much the light curve of each system is distorted by the star spots on the surface of the components, the star spot effect has been defined by the following equation [10].

$SE=(\acute{\iota}-\iota)/\iota$...(2)

Where ί is computed light after the wave-like distortion is removed and ι is computed light, which fits to the observation with spot, ί and ι have been reduced by the W-D light curve program. The spot effect has been calculated for V and B; the results are tabulated in Table (2).

Three-dimensional models of AK Her binary star are shown in Fig. (5), and from this figure the spot region appear in a red region on a binary surface. Fig.(6) shows calculated Roche Geometries, with the surface potentials of the stars, its shows the degree of filling factor. Each model was created using Binary Maker 3.0 [11].

Absolute Parameters

The most of our knowledge of absolute parameters of stars beyond our Sun has been derived from the study of binary star system, and most especially of individual eclipsing photometric. A mathematical analysis of the light curves enables us not only to determine the physical and geometrical elements of selected binary system but also to find their absolute parameters. In order to calculate the absolute parameters of the binary system the following formulae has been used [12,13].

$A^3 = 74.5\ P^2\ (M_1 + M_2)$ ....(3)

$(M_2/M_\Theta) = q\ (M_1/M_\Theta)$ ....(4)

$R_1 = A\ r_1\ ,\ R_2 = A\ r_2$ ....(5)

$L_1 = R_1^2 T_1^4\ ,\ L_2 = R_2^2 T_2^4$ ....(6)

$\rho_{1,2}/\rho_\Theta = (0.01344 M_{1,2})/[(M_1+M_2)P^2\ r^3_{1,2}]$ .....(7)

Where equation (3) is Third Kepler's law, A is the separation between the two components expressed in solar radii, P is the orbital period in days, M_1 and M_2 are the masses of the components in solar mass. Equation (4) is the relation between mass for the primary component to the secondary one, q is the mass ratio. Equation (5) is the relation between absolute R_1 and R_2, and relative r_1 and r_2 radii of the components. The relative radii have been taken equal to the geometrical mean of the polar, side, and back radii, that were computed in this work for all selected binaries with (W-D) program.

Equation (6) is the Stefan-Boltzman law, L_1 and L_2 are bolometric luminosities expressed in solar units, T_1 and T_2 are the effective temperatures in units of solar effective temperature. Equation (7) is the mean densities of the components in solar units. The absolute parameters of the system were evaluated and compared them with literature are presented in Table. (3).

Discussion and Conclusions

A large O’Connell effect, difference in the observed light levels outside of eclipse, of the AK Her are present. In this research light curves were analyzed by using the (2003) version Wilson-Devinney program to investigate O’Connell effect via spot activity. A possible explanation is the presence of large spotted areas on a star, giving rise to an asymmetric surface distribution of light relative to the line of sight. The system show intrinsic irregularities in their photometry. Two different solutions were carried out, one assuming the presence of spot and the other without spot model. After both solutions were completed, it was found that the spot model better fit the observed light curve. This indicates that the presence of spots (dark or hot) enables to explain the asymmetry and depressions on the light curves of active close binary. The solution based on the minimization of the sum of the squares of residuals $\sum W(O\text{-}C)^2$ between the real observations and the simulated ones generated in a close binary model, the accuracy of the results depends on the value of predicted sum of residuals which is based on corrections to the selected parameters, lesser it is more accurate, therefore there is a good evidence of presence spots on a binary stars, because its value are smaller in the case spot model than the case without spot. There is subtle error in the parameters; however, the solution closely fits the observed light curve and supports the inclusion of at least one spot, the physical and geometrical parameters of such system has been determined. The spot effect has been calculated to compare how much the light curve for each system is distorted by the star spot; also the spot area has been calculated, and the absolute parameters has been derived. The present solution agrees or nearly comes close to the solutions of the other researcher. Observations of AK Her indicated an over-contact, W UMa , A-type system, in this system no one solved the O’Connell effect according to spot model, the star spot model have been applied, after several solution we found that there is a cool spot on a primary component, which is consistent with the O’Connell effect observed in the system’s light curve. The presence of a possible hot spot on the components can be discarded, the solution closely fits the observed light curve, the analysis of the light curves also indicate that the system is very close to just fitting their inner Roche lobe. From the present study of AK Her conclude that the system is a A-type contact binary with a degree of over contact of $f=(\Omega in-\Omega_{1,2})/(\Omega in-\Omega\ out)=8.41\%$. Therefore, according to this criterion, the system is an over contact one, with two stars overfilling their respective Roche lobes. AK Her is very interesting as it is peculiar binary system. It exhibits rapid light variation, especially at the regions near the two maxima and the tow minima, the light curves of the system show a short period.

Fig.(1) Close up field map of AK Her from STSCI [5].

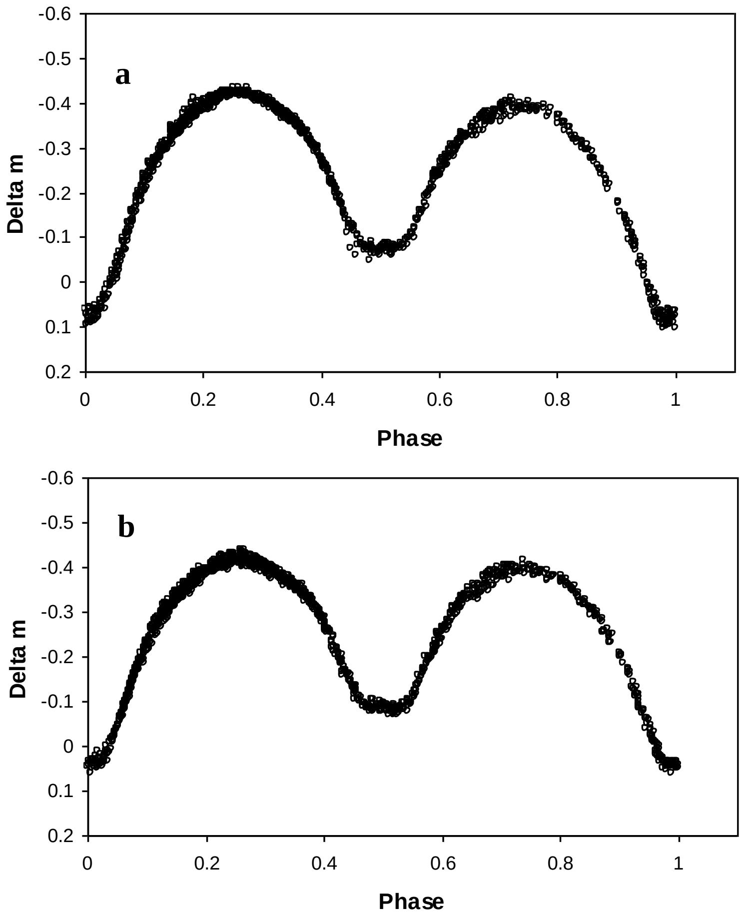


Fig.(2) Observed light curve of AK Her. Where, (a) B-filter, (b) V-filter.

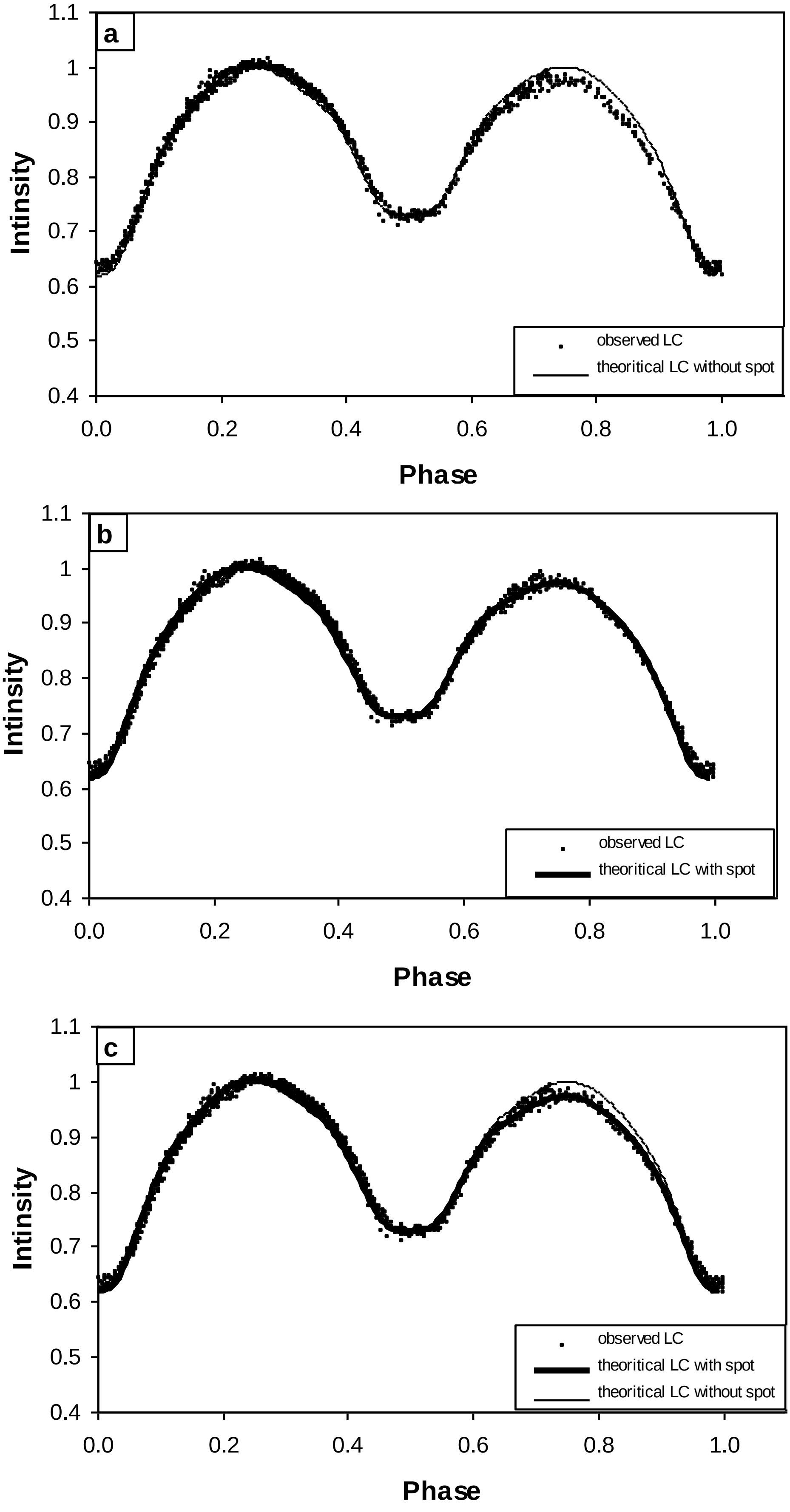


Fig.(3) The light curves of eclipsing binary AK Her. Points represent the observations of B bands and the solid lines are the theoretical LC, where, (a)- LC without spot sol. (b)- LC with spot sol. (c)- Compare (a and b).

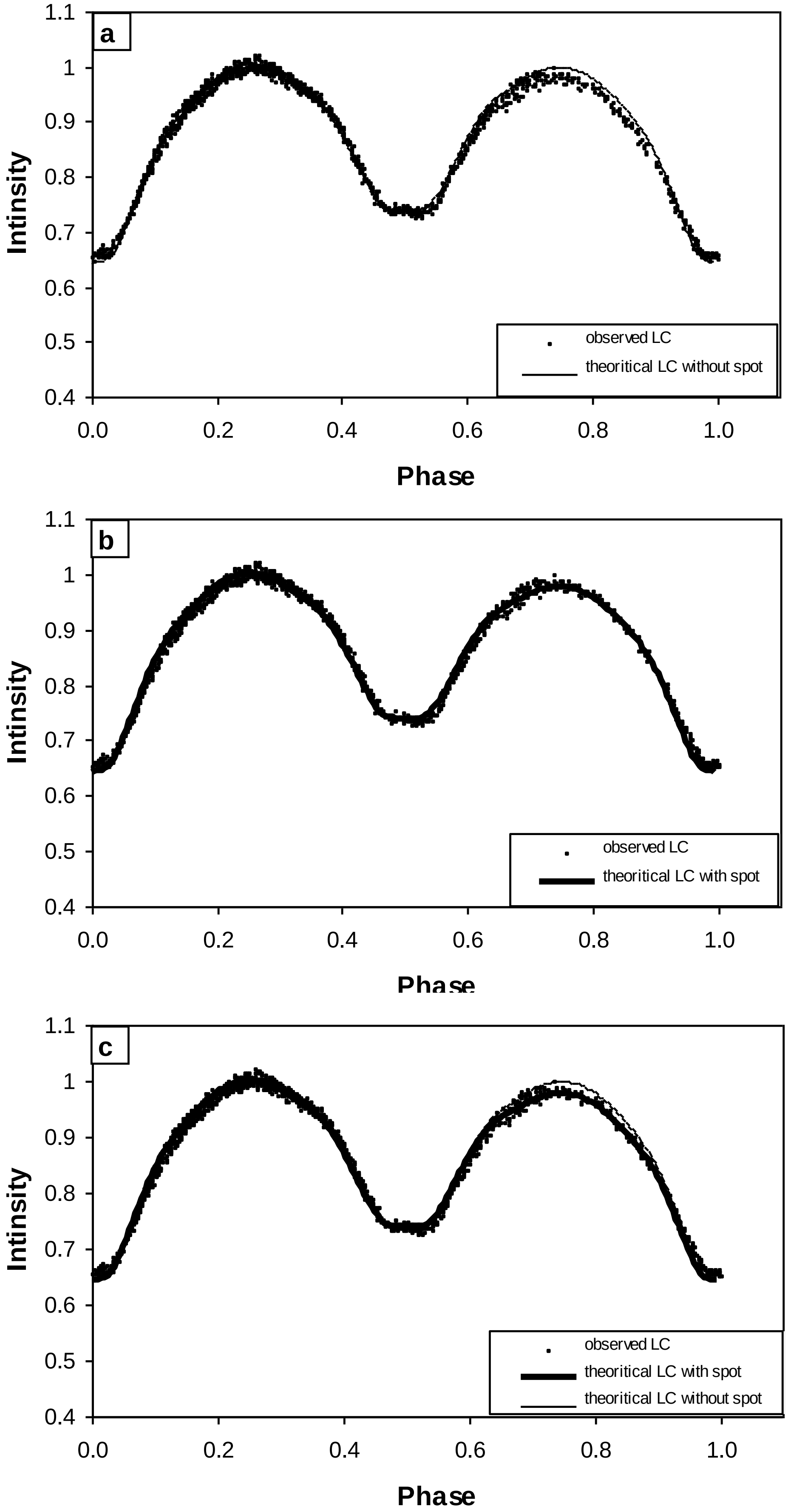
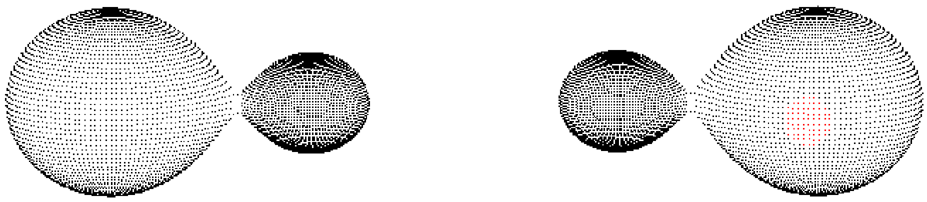


Fig.(4) The light curves of eclipsing binary AK Her. Points represent the observations of V bands and the solid lines are the theoretical LC, where, (a)- LC without spot sol. (b)- LC with spot sol. (c)- Compare (a and b).

Table (1)
Geometrical and physical elements of AK Her in B and V filters obtained from optimal curve fitted in Fig.(3) and Fig. (4).

Parameter	***B-filter***		***V-filter***	
	Spot Sol.	***Un spot sol.***	***Spot Sol.***	***Un spot sol.***
i(˚)	81.23 (±0.31)	81.23 (±0.42)	81.23 (±0.25)	81.23 (±0.31)
x_1=x_2	0.49	0.49	0.38	0.38
g_1=g_2	0.81	0.81	0.81	0.81
A_1=A_2	2.02	2.02	2.02	2.02
Ω1= Ω2	2.351 (±0.0029)	2.351 (±0.0039)	2.351 (±0.0024)	2.351 (±0.0028)
Ωin	2.3645	2.3645	2.3645	2.3645
Ωout	2.2040	2.2040	2.2040	2.2040
f_1= f_2 (%)	8.41	8.41	8.41	8.41
T_1(k)	6400	6400	6400	6400
T_2(k)	5394 (±9)	5394 (±12)	5394 (±7)	5394 (±9)
q	0.255 (±0.0011)	0.255 (±0.0016)	0.255 (±0.00094)	0.255 (±0.0011)
$L_1/(L_1+L_2)$	0.8989 (±0.014)	0.8989 (±0.019)	0.88149 (±0.011)	0.88149 (±0.013)
r_1(pole)	0.471617 (±0.0006)	0.471617 (±0.0009)	0.471617 (±0.0005)	0.471617 (±0.0006)
r_1(side)	0.510048 (±0.0009)	0.510048 (±0.0012)	0.510048 (±0.0007)	0.510048 (±0.0009)
r_1(back)	0.535117 (±0.0012)	0.535117 (±0.0016)	0.535117 (±0.0010)	0.535117 (±0.0012)
r_2(pole)	0.252728 (±0.0012)	0.252728 (±0.0017)	0.252728 (±0.0010)	0.252728 (±0.0012)
r_2(side)	0.263445 (±0.0015)	0.263445 (±0.0020)	0.263445 (±0.0012)	0.263445 (±0.0014)
r_2(back)	0.298645 (±0.0028)	0.298645 (±0.0038)	0.298645 (±0.0023)	0.298645 (±0.0027)
$φ(∘)_1$	93	- -	93	- -
$θ(∘)_1$	85	- -	85	- -
$γ (∘)_1$	14	- -	14	- -
$(Ts/T_*)_1$*	0.88	- -	0.88	- -
L3	0.022	0.022	0.044	0.044
$\sum W(O\text{-}C)^2$	0.098	0.1861	0.094	0.13

Notes:
i: orbit inclination in degrees; x_1,x_2:limb darkening coefficient of the primary and secondary components; g_1,g_2: gravity darken exponent of the components; A_1,A_2: bolometric albedo of the primary and secondary component; Ω1, Ω2: surface potential of the components; Ωin: inner potential; Ωout : outer potential; f_1, f_2: filling coefficients of the components; T_1,T_2: effective temperature of the components; q: mass ratio of the components(m_2/m_1); $L_1/(L_1+L_2)$: fractional luminosity of the primary component; r_1,r_2:relative radii of both components; φ(∘): Co latitude in degree; θ(∘):longitude in degree; γ (∘): spot radius in degree; Ts/T_*: temp. factor; L3: third light; $\sum W(O\text{-}C)^2$: final sum of squares of residuals between observed(LCO) and synthetic(LCC) light curves.



Phase = 0.25 *Phase = 0.75*

Fig.(5) AK Her at phase 0.25 and 0.75, the larger star represent primary component while smaller star represent secondary component , the red region represent the area of the spot on the stars which is caused the asymmetry of the light curve, it has been produced with Binary Maker 3.0 [11].

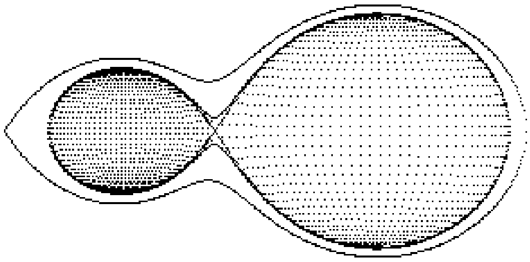


Fig.(6) Three dimension surface out lines of AK Her, produced with Binary Maker 3.0[11].

Table (2)
The parameters of the spot for AK Her binary system.

Star	***Position***	***φ(◦)***	***θ(◦)***	***γ (◦)***	***Ts/T****	***Spot area (%)***	***SE_B***	***SE_V***
AK Her	Pr.	93	85	14	0.88	1.48	0.009	0.007

Table (3)
The comparison between absolute parameters of the present work with the literature.

Star	***$R_1/R_Θ$***	***$R_2/R_Θ$***	***$L_1/L_Θ$***	***$L_2/L_Θ$***	***$M_1/M_Θ$***	***$M_2/M_Θ$***	***$ρ_1/ρ_Θ$***	***$ρ_2/ρ_Θ$***	***Reff.***
AK Her	1.657	0.82	4.07	0.788	1.993	0.464	--	--	Brancewicz (1980}
	1.6139	0.867	3.8613	0.5622	1.9577	0.4992	0.4663	0.7670	Present work

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