Period and light-curve study of the eclipsing contact binary SW Lac

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Abstract. New photoelectric U,B and V observations of the eclipsing contact binary SW Lac were taken in 1998 and nine new minima times were determined. The (O-C) diagram constructed using photographic and photoelectric minima times can be explained by a secular increase of the period combined with a light-time effect due to the presence of another two bodies in the system with orbital periods $P_3 = 23$ and $P_4 \approx 90$ years. The minimum masses of these bodies are $M_3 = 0.41 \pm 0.03$ $M_\odot$ and $M_4 = 1.47 \pm 0.03$ $M_\odot$. Photometric elements of the contact binary are given.

Key words: binaries – photometry

1. Introduction

The eclipsing binary SW Lac (BD +37°4717, HD 216598, $V_{max} = 8.51$, P $\approx$ 0.32072 days) was discovered by Miss Ashall (Leavitt, 1918) on plates taken at the Harvard Observatory. SW Lac is the most extreme representative of W-type W UMa stars and is well known for its variable light curve in the optical (Brownlee, 1957; Chou, 1963; Bookmyer, 1965; Lang & Vetešník, 1966; Rucinski, 1968 and others) and the near IR regions (Jameson & Akinci, 1979). The light curve exhibits 0.1-0.2 mag changes, suggesting the existence of spots on the surface of this contact binary.

The orbital period of SW Lac was found to be variable by Dugan & Wright (1939). Van't Veer (1972) explained period changes by "jumps" alternated with intervals of constant period. Panchatsaram & Abhyankar (1981) explained the (O-C) diagram of SW Lac by the presence of double sinusoids, interpreted as a light-time effect (LITE) in a quadruple system with the periods 19.67 and 70.25 years of the third and fourth component, respectively. On the other hand, Borkovits & Hegedüs (1996) could not find any LITE solution.

Wyse (1934) assigned spectral types G3p + G3p of the SW Lac components. Struve (1949, 1950) found a mass ratio m_1/m_2=1.17 determined from the radial velocity curves. The masses of the components were calculated as $m_1 \sin^3 i$ = 0.95 $M_\odot$ and $m_2 \sin^3 i$ = 0.81 $M_\odot$ (Batten et al., 1989). Zhang & Lu (1989) used the new radial velocity observations from 1984 and determined m_1/m_2 =

1.255±0.011. A joint solution of the velocity and light curves gave the parameters of the primary and secondary components as $M_1 = 0.96$ M$_\odot$, $R_1 = 1.00$ R$_\odot$ and $M_2 = 0.78$ M$_\odot$, $R_2 = 0.91$ R$_\odot$, respectively. Rucinski et al. (1984) found strong chromospherical and coronal activity of the system. Hendry & Mochnacki (1998) detected the late-type third component in the spectra of SW Lac.

The aim of our paper is to present additional minima times of SW Lac and to explain the long term changes of the orbital period.

2. New observations

The U,B and V photometry was performed over 9 nights from August to December 1998 at the Stará Lesná observatory of the Astronomical Institute of the Slovak Academy of Sciences. The 0.6 m Cassegrain telescope equipped with a single-channel pulse-counting photoelectric photometer (photomultiplier EMI 9789 QB) was used. For all observations a 10 second integration was chosen. BD +37°4715 (V = 9.07, B-V = 1.03, U-B = 0.66, sp. type G5) and BD +37°4711 (V = 8.6, sp. type K0) served as the comparison and check star, respectively. The comparison star was found to be stable within 0.01 mag. The standard international U,B,V magnitudes were obtained from instrumental u,b,v magnitudes using the following transformation:

$$\begin{aligned} \mathrm{V} &= \mathrm{v} - 0.1152(\mathrm{b} - \mathrm{v}) \\ \mathrm{B} - \mathrm{V} &= 1.1213(\mathrm{b} - \mathrm{v}) \\ \mathrm{U} - \mathrm{B} &= 1.0088(\mathrm{u} - \mathrm{b}) \end{aligned} \qquad (1)$$

For differential extinction correction we have used average seasonal extinction coefficients. Data reduction, the atmospheric extinction correction and transformation to the standard international system were carried out in the usual way. The total number of observations in each filter exceeded 660. U,B and V light curves are plotted in Fig. 1.

Our observations led to the determination of 7 primary a 2 secondary new minima times. We have calculated the times of minima separately for all three filters using the Kwee and Van Woerden's method, parabola fit, sliding integration method, tracing paper and "centre of mass" method which were described in detail by Ghedini (1982). The computer codes were kindly provided by Dr. R. Komžík (1999). The average times of minima found by these methods are given in Table 1.

3. Period changes of SW Lac

The (O-C) diagram of the system is quite complicated. The (O-C) residuals have not been satisfactory explained up to now. To analyse the period changes of SW Lac we have collected all available photoelectric minima times from literature (Table 2). Old photographic minima times were taken from Woodward (1952).

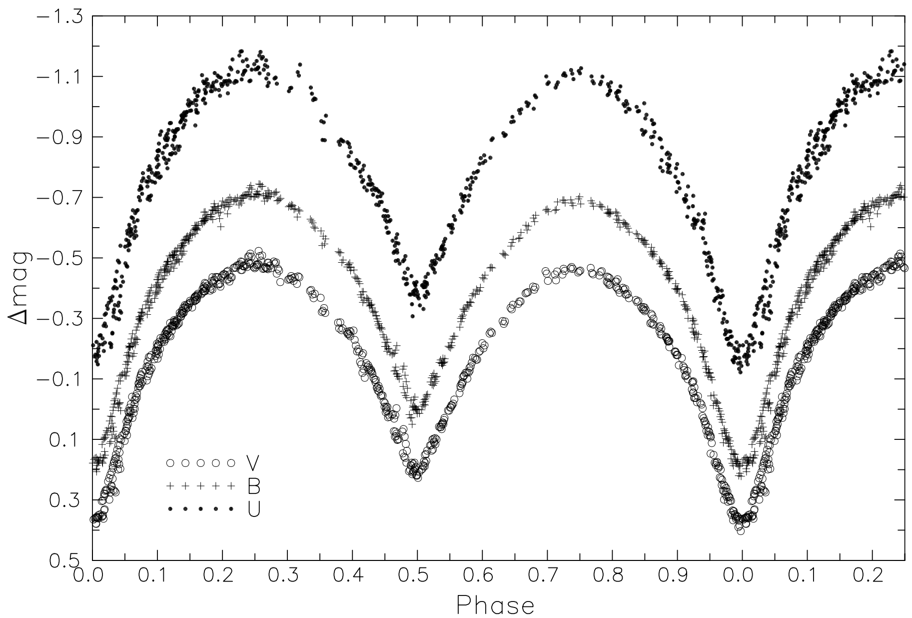

Figure 1. U,B and V light curves of SW Lac obtained in 1998 at the Stará Lesná Observatory

Table 1. New times of minimum light of SW Lac. Epochs were computed according to the ephemeris (2)

Epoch	U		B		V	
	JD_{hel} 2 400 000+	σ [days]	JD_{hel} 2 400 000+	σ [days]	JD_{hel} 2 400 000+	σ [days]
0.5	51056.45077	0.00009	51056.45060	0.00012	51056.45037	0.00012
32	51066.55250	0.00006	51066.55273	0.00014	51066.55258	0.00002
171.5	51111.29240	0.00020	51111.29290	0.00010	51111.29260	0.00020
209	51123.31688	0.00012	51123.31820	0.00005	51123.31778	0.00015
231	51130.37449	0.00001	51130.37453	0.00004	51130.37471	0.00007
262	51140.31637	0.00010	51140.31662	0.00006	51140.31787	0.00009
293	51150.25845	0.00009	51150.25922	0.00006	51150.25931	0.00009

We have used photographic minima times only prior to the first photoelectric observations of SW Lac published by Kwee (1958).

Several minima times show large deviations from the general trend. Some of them were found to be mistyped in the original papers and were corrected using published (O-C) residuals to given ephemerides. All corrected minima times are typed in italic in Table 2. Four minima times, that couldn't be corrected by this way as well as the minimum published by Fitch (1964) which we found in

Table 2. The times of photoelectric minima of SW Lac.

JD$_{hel}$	Fil.	Ref.	JD$_{hel}$	Fil.	Ref.	JD$_{hel}$	Fil.	Ref.
2 400 000+			2 400 000+			2 400 000+		
33923.5446		1	37173.7460		6	37887.5276		8
33928.5175		1	37191.7065		6	37890.4144		8
33931.4038		1	37192.8301	V	7	37897.4698		8
33993.3042		1	37192.8312	B	7	37903.4034		8
34271.3710		1	37194.7552	V	7	37916.7153		10
34600.5901		1	37194.7549	B	7	37919.7603		10
34637.7950		2	37194.9139	V	7	37926.6559		10
34658.8024		2	37194.9143	B	7	37926.8139		10
34660.7272		2	37201.6485	V	7	37929.7008		10
34663.7730		2	37201.6492	B	7	37929.8627		10
34664.5766		2	37201.6492	U	7	37940.6019		10
34664.7367		2	37202.7726	V	7	37941.4091		8
34665.6976		2	37202.7729	B	7	37959.3705		8
34665.8575		2	37202.7731	U	7	37961.2945		8
34666.8216		2	37220.5720		6	38235.5180		11
34667.7833		2	37220.7335		6	38670.4214		8
34668.7451		2	37225.5445		6	38670.4252		8
34680.6115		2	37225.7039		6	38708.2710		11
34681.5737		2	37233.5629		6	38709.3930		11
34681.7348		2	37258.5795		6	39039.4207		12
35036.6130		2	37262.5873		6	39040.3839		12
35037.5748		2	37556.6958		6	39041.3458		12
35037.7350		2	37572.5719		6	39041.5075		12
35040.6182		2	37572.7328		6	39059.4680		11
35055.5357		2	37573.6952		6	39393.1856		12
35055.6945		2	37577.7038		6	39393.3472		12
35057.6190		2	37578.6660		6	39443.3810		11
35374.4900		3	37611.7012		6	*40035.4449*		13
35379.4638		3	37614.5879		6	40110.4925		14
35390.3683		3	37615.5502		6	40128.4540		13
35390.5266		3	37619.5582		6	40202.2197		13
36037.5829		4	37845.5115		8	40373.4866		13
36045.4384		4	37846.4740		8	40419.3502		13
36045.6005		4	37869.4062		8	40441.4807		14
36046.4020		4	37871.4904		8	40467.4592		14
36046.5634		4	37875.3397		9	40497.2869		13
36048.4870		4	37875.4994		8	40515.2460		13
36048.6470		4	37876.3014		9	40542.3457		15
36049.4493		4	37876.4683		9	40836.4479		16
36049.6091		4	37877.4234		9	40842.3820		16
36050.4115		4	37878.3846		9	40843.5030		16
36050.5709		4	37879.3476		9	40848.4758		16
36461.4147		5	37879.5097		8	41167.4277		17
36462.3761		5	37879.6662		9	41172.4009		17
36463.3391		5	37881.2744		9	41172.4013		17
36480.3361		5	37881.4339		9	41192.7654		17
36843.3967		5	37883.3590		9	41192.9264		17
36844.3593		5	37885.4419		9	41249.3737		17
36847.4066		5	37886.4045		8	41583.4060		18
36848.3695		5	37887.3671		8	41598.3161	B	18

Table 2. The times of photoelectric minima of SW Lac (continued).

JD$_{hel}$	Fil.	Ref.	JD$_{hel}$	Fil.	Ref.	JD$_{hel}$	Fil.	Ref.
2 400 000+			2 400 000+			2 400 000+		
41598.3154	V	18	45193.4020	V	35	46614.5122	U	45
41683.3055		18	45201.7407		36	46614.5161	V	45
41900.4293		19	45203.8264		36	46614.5204	B	45
42361.7776		20	45204.7892		36	46619.4859	U	45
42369.7962		20	45227.4186	V	37	46619.4864	B	45
42630.3750		21	45227.5634	V	37	46619.4866	V	45
42697.4039		21	45542.8279		38	46620.4476	U	45
42768.2821		22	45554.8542		38	46620.4479	V	45
43013.7890		23	45575.8630		38	46620.4483	B	45
43049.8700		23	45579.8695		38	46624.4591	V	45
43049.8707		20	45586.7678		38	46624.4594	B	45
43398.4899		24	45606.3293		39	46624.4596	U	45
43411.4804		25	45606.4918		39	46646.4273		46
43411.6343		25	45608.4174	BV	40	46669.3555	V	43
43459.7476		26	45609.3794	BV	40	46669.3565	B	43
43460.5490		26	45610.6588		38	46669.5154	B	43
43487.6504		26	45611.3038	BV	40	46669.5156	V	43
43488.6128		26	45611.4638	BV	40	46679.4569		46
43756.4151	V	27	45612.2660	BV	40	46689.3995	V	43
43780.14853	V	28	45612.4259	BV	40	46689.3999	B	43
43780.14892	B	28	45634.7124		38	46693.4089	V	43
43780.30895	V	28	45646.7412		38	46974.5235	B	45
43780.30905	B	28	45660.5327		38	46974.5238	V	45
43802.5987		29	45932.8239		41	46978.5313	B	45
44069.4412	V	27	45935.8710		41	46978.5316	V	45
44201.2550	b	30	45951.5860		41	47001.4612	B	45
44201.2556	v	30	46262.3633	V	42	47001.4612	V	45
44202.2174	b	30	46262.3636	B	42	47025.3535		48
44202.2177	v	30	46264.4467	V	42	47028.4022		48
44444.5211	b	31	46264.4470	B	42	47087.4116	V	48
44444.5213	v	31	46270.3797		42	47087.4123	B	48
44461.3592	v	30	46270.5404	B	42	47087.5707	V	48
44461.3600	b	30	46270.5408	V	42	47087.5721	B	48
44480.2822	b	30	46271.5028	B	42	47115.3153		48
44480.2823	v	30	46271.5030	V	42	47121.2456	V	45
44493.7540		32	46272.4655	V	42	47121.2459	B	45
44816.5570	b	31	46272.4656	B	42	47406.5285	V	49
44852.4784	b	31	46273.4268	V	42	47455.4368	V	49
44852.4793	v	31	46273.4271	B	42	47477.2456	V	50
44853.4400	b	31	46274.3887	B	42	47477.2463	B	50
44853.4414	v	31	46274.3891	V	42	47766.5308	BV	51
44854.4021	v	31	46288.5007	V	43	47769.4210	BV	51
44854.4045	b	31	46299.4058		44	47770.3841	V	52
44854.8834	V	33	46329.3932	B	43	47771.3440	BV	51
44856.8064	V	33	46329.3938	V	43	47771.5097	BV	51
44860.8188	V	33	46329.5541	BV	43	47775.3574	BV	51
44914.8574	V	33	46345.5903		41	47821.5405		53
44925.2840	V	34	46613.5475	V	45	47822.6617		53
45160.5296	V	35	46613.5476	B	45	47825.7092		53
45192.4399	V	35	46613.5483	U	45	47832.6037		54

Table 2. The times of photoelectric minima of SW Lac (continued). The last 5 minima were not used for further analysis

JD_{hel}	Fil.	Ref.	JD_{hel}	Fil.	Ref.	JD_{hel}	Fil.	Ref.
2 400 000+			2 400 000+			2 400 000+		
47832.7646		54	48887.4511	UBV	51	51056.4504	V	64
47836.7733		54	49242.3249	UBV	51	51056.4506	B	64
47849.4427		55	49242.4838	UBV	51	51056.4508	U	64
47850.5649		53	49589.4973	B	58	51066.5525	U	64
47854.5747		53	49589.4989	V	58	51066.5526	V	64
47860.5080		53	49594.4674	V	58	51066.5527	B	64
48087.4166	B	55	49594.4696	B	58	51111.2924	U	64
48087.4172	V	55	49597.5156	B	58	51111.2926	V	64
48092.5473	V	56	49597.5159	V	58	51111.2929	B	64
48158.2975	BV	51	49928.4976		59	51123.3169	U	64
48158.4553	BV	51	49929.4567		59	51123.3178	V	64
48159.4169	BV	51	49975.3209	UBV	51	51123.3182	B	64
48179.4636	B	55	49975.4803	UBV	51	51130.3745	B	64
48179.4636	V	55	50010.2777	BV	51	51130.3745	U	64
48179.6213	V	55	50013.4845		59	51130.3747	V	64
48179.6230	B	55	50013.6449		59	51140.3164	V	64
48504.3532	BV	51	50340.4558	V	60	51140.3166	B	64
48504.5116	BV	51	50647.3785	UBV	61	51140.3179	U	64
48505.3102	BV	51	50649.3023	BV	61	51150.2585	U	64
48505.4746	V	51	50649.4673	UBV	61	51150.2592	B	64
48537.3889	BV	51	50694.3642		62	51150.2593	V	64
48833.0909	V	57	50700.2965		62	34519.9300	V	65
48833.0917	B	57	50961.5180	V	63	42723.8271		20
48834.2127	V	57	50986.5360	V	63	42724.7881		20
48834.2130	B	57	51017.4840	V	63	42738.7390		20
48887.2921	UBV	51	51035.4430		62	46707.4465		47

Observers: 1 - Kwee (1958), 2 - Brownlee (1957), 3 - Hinderer (1960), 4 - Broglia (1962), 5 - Widorn (1962), 6 - Bookmyer (1965), 7 - Muthsam & Rakos (1974), 8 - Lang & Vetešník (1966), 9 - Kalchaev et al. (1968), 10 - Chou (1963), 11 - Pohl (1967), 12 - Rucinski (1968), 13 - Kizilirmak & Pohl (1970), 14 - Semeniuk (1971), 15 - Muthsam (1972), 16 - Pohl & Kizilirmak (1971), 17 - Pohl & Kizilirmak (1972), 18 - Pohl & Kizilirmak (1974), 19 - Baldinelli (1973), 20 - Skillman (1977), 21 - Kizilirmak & Pohl (1976), 22 - Baldinelli & Ghedini (1976), 23 - Kalish (1976), 24 - Ebersberger et al. (1978), 25 - Faulkner et al. (1979), 26 - Faulkner & Bookmyer (1978), 27 - Pohl & Gülmen (1981), 28 - Leung et al. (1984), 29 - Faulkner & Bookmyer (1980), 30 - Aslam et al. (1981), 31 - Hopp et al. (1982), 32 - Faulkner & Kaitchuck (1983), 33 - Margrave (1982), 34 - Pohl et al. (1982), 35 - Pohl et al. (1983), 36 - Margrave (1983), 37 - BAV-M 36, 38 - Faulkner et al. (1984), 39 - BAV-M 38, 40 - Niarchos (1985), 41 - Faulkner (1986), 42 - Evren et al. (1985), 43 - Pohl et al. (1987), 44 - BBSAG-78, 45 - Essam et al. (1992), 46 - BAV-M 46, 47 - BAAVSS 67, 48 - BAV-M 50, 49 - Ogloza (1995), 50 - BAV-M 52, 51 - Müyesseroğlu et al. (1996), 52 - Wunder et al. (1992), 53 - Mullis & Faulkner (1991), 54 - Pena et al. (1993), 55 - BAV-M 59, 56 - BAAVSS 91, 57 - Zhang et al. (1992), 58 - Demircan et al. (1994), 59 - Agerer & Hübscher (1996), 60 - BAAVSS 62, 61 - Selam et al. (1999), 62 - Kiss et al. (1999), 63 - Borkovits & Bíró (1998), 64 - present work, 65 - Fitch (1964) literature after the submission of our paper were omitted in further analysis. These five minima are listed at the end of Table 2. The total number of all photoelectric minima times used for our analysis is 373. The higher accuracy of the photoelectric minima times in comparison with the photographic ones were evaluated by five times larger weightings in calculations.

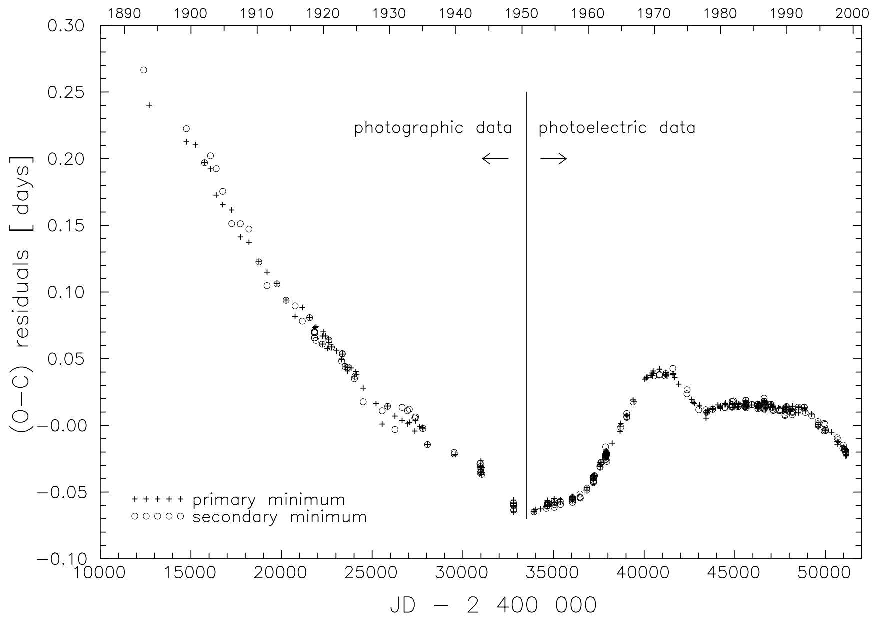

Figure 2. The (O-C) diagram for SW Lac constructed using the linear ephemeris (1)

We have evaluated the possibility set forth by Bookmyer (1965) that the secondary minima do not occur in phase 0.50. We have used only consecutive photoelectric minima (46 such occurrences) for this analysis. The time displacements of the secondary minima with respect to the phase 0.5 reach ±0.006 days (the errors in determination of the minima are usually smaller than 0.001 days). The displacements occur equally probably in both senses. As we did not find any significant periodicity in these data, we interpret them as a result of variable migrating spots positioned on one or both component. Since the average displacement is -0.0003 ± 0.0003 days, we have neglected this effect in further analysis.

A weighted linear regression applied to all minima times led to the ephemeris:

$$\begin{array}{rl} \text{Min I} = \text{JD}_{\text{hel}}\ 2\,451\,056.3073 & +\ 0.32071991\ \times E, \\ \pm 26 & \qquad \pm 7 \end{array} \qquad (2)$$

The (O-C) residuals from this ephemeris are plotted in Fig. 2. The ephemeris suitable for near-future forecast of minima times was obtained by fitting of the recent photoelectric minima times (since July, 1992):

Table 3. The light-time effect solutions and corresponding ephemerides of the binary system for a circular and elliptical orbit. T_{super} and T_{infer} are the times of the superior and inferior conjunction of the third (fourth) body, respectively.

Element		3^{rd} body	σ	4^{th} body	σ
P	[days]	8465	57	33000	–
e		0.600	0.059	0.703	0.014
ω	[°]	206.3	5.5	22.6	1.1
T_0	[JD]	2 425 264	194	2 439 260	97
a sin i	[AU]	1.988	0.101	12.55	0.16
$f(m_3)$	[$M_\odot$]	0.0146	0.0024	0.2421	0.0093
T_{super}	[JD]	2 424 229	318	2 440 204	120
T_{infer}	[JD]	2 425 617	289	2 436 709	195

Quadratic ephemeris			σ
JD_0	[JD]	2 451 056.2995	0.0016
P_{binary}	[days]	0.32072121	0.00000007
Q	[days]	$2.660\ 10^{-11}$	$0.065\ 10^{-11}$
$\sum$(O-C)^2	[days^2]	0.024237	

$$\text{Min I} = \text{JD}_{\text{hel}}\ 2\,451\,056.2900 \underset{\pm 2}{} + 0.32071532 \underset{\pm 7}{} \times E, \tag{3}$$

This ephemeris was used for the light-curve analysis of our observations.

As mentioned in the introduction, Panchatsaram & Abhyankar (1981) tried to explain the (O-C) diagram of SW Lac by the presence of double sinusoids, interpreted as a LITE in a quadruple system. In their simple approach they fixed the ephemeris of the eclipsing binary. In our analysis we have assumed that the minima times follow a quadratic ephemeris and are deviated due to LITE caused by two another bodies, so they can be computed as follows:

$$\begin{aligned} \text{Min I} &= JD_0 + P \times E + Q \times E^2 + \\ &\frac{a_{12}\cdot \sin i_3}{c}\left[\frac{1-e_3^2}{1+e_3\cos\nu_3}\sin(\nu_3+\omega_3)+e_3\sin\omega_3\right] + \\ &\frac{a_{123}\cdot \sin i_4}{c}\left[\frac{1-e_4^2}{1+e_4\cos\nu_4}\sin(\nu_4+\omega_4)+e_4\sin\omega_4\right], \end{aligned} \tag{4}$$

where a_{12} sin i_3 is the projected semi-major axis, e_3 is the eccentricity, ω_3 is the longitude of the periastron, ν is the true anomaly of the binary orbit around the centre of the mass of the triple system. A similar designation was used for the fourth body. $JD_0 + P \cdot E + Q \cdot E^2$ is the quadratic ephemeris of the minima in an eclipsing binary and c is the velocity of the light.

To obtain the optimal elements of the LITE orbits including error estimates, we have used the differential corrections method. As a first approximation of

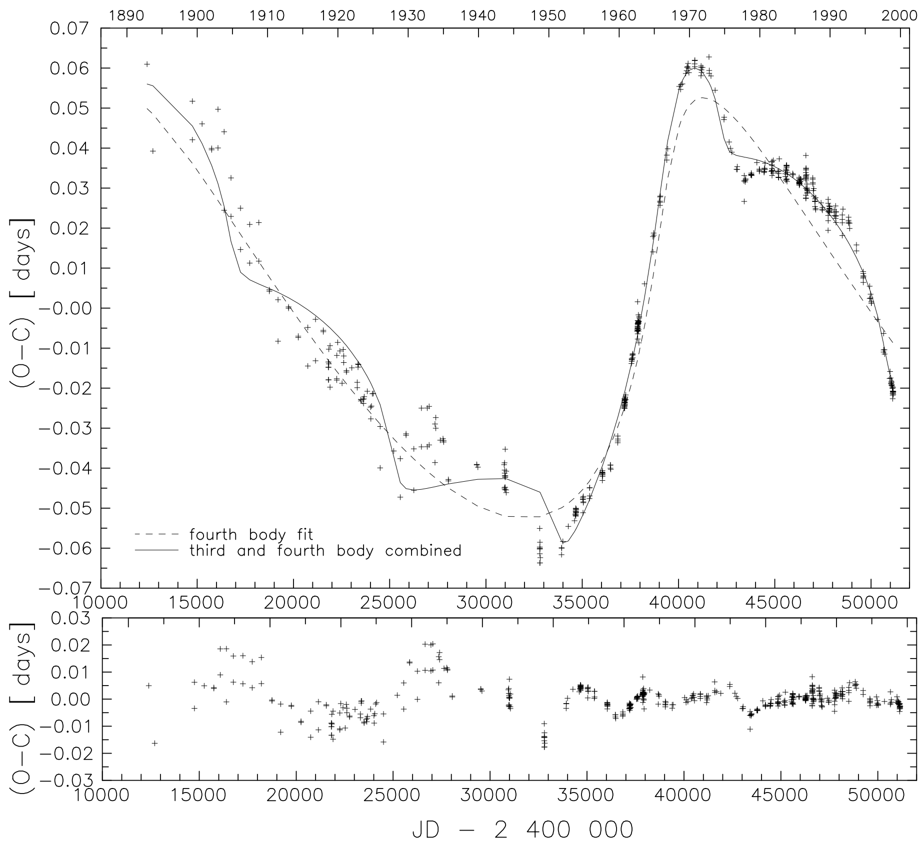

Figure 3. The fit of the (O-C) residuals from quadratic ephemeris (Table 3) by the third and fourth bodies LITE (top) and residuals from this combined fit (bottom)

the elements we have taken the orbital periods determined by Panchatsaram & Abhyankar (1981) and the ephemeris obtained by weighted quadratic regression of all minima. We have tried to fit all 13 parameters. Due to a strong correlation between some parameters of the third and fourth body, differential corrections did not converge. As the period of the fourth body (on longer period orbit) was found to affect the fit only negligibly, we have fixed this parameter at several reasonable values. The differential corrections converged for periods larger than 27 000 days. The sum of squares of residuals decreased slowly with increasing P_4. The upper limit of P_4 was set to 39 000 (the time interval of observations). The orbital solutions, however, did not change much for periods in the above range.

The resulting orbital parameters for $\mathrm{P}_4 = 33\,000$ days (middle of the interval of reasonable periods) are given in Table 3. The corresponding fit of the (O-C) residuals from the optimal quadratic ephemeris is displayed in Fig. 3.

The masses of the components of the contact binary SW Lac (accepted from Zhang & Lu, 1989) as well as the mass functions given in Table 3 give the minimum masses of the third and fourth component as 0.41±0.03 $M_{\odot}$ and 1.47±0.03 $M_{\odot}$, respectively. The faint spectral lines detected by Hendry & Mochnacki (1998) probably belong to the third component. If it is the main-sequence object its luminosity ($L \approx M^{3.45}$) is about 25 times lower than that of the eclipsing pair. Thee high mass of the fourth component posses a real problem. The main-sequence object of this mass would significantly affect the observed light curve of the system. However, the third light is not detected. If the observed changes are interpreted as LITE, the fourth component has to be a compact or multiple object. Another possible explanation of the (O-C) diagram is a combination of the LITE in a shorter period orbit caused by the third body (detected spectroscopically) with sudden period changes caused by the internal activity of the contact binary.

Nevertheless, photoelectric minima times are generally well explained by a continuous period increase combined with the LITE caused by the third and fourth body. The old photographic minima contain little information about the third body and determine only the long-term orbit well. The residuals from the fit exhibit quasi-periodic behaviour, suggesting the presence of further effects affected observed minima times. Fourier analysis of the residuals from the fit, in the range of periods 100 - 20000 days, provided different periodicities for photographic and photoelectric data, except the period 406±2 days, which is present in both sets of data. If this period is caused by LITE, the variations of the systemic velocity of SW Lac are expected as in the case of AW UMa (Pribulla et al. 1999). There are not enough spectroscopic data to test this hypothesis. The quasi-periodic variability in residuals could also be explained by the action of the Applegate's mechanism due to magnetic activity in the system. Such changes of period must correlate (or anticorrelate) with the total brightness of the binary. Such a study would require a detailed analysis of the historical data and is out of the scope of the present paper. We should note that Rucinski (1968) found light-curve changes of SW Lac on a time-scale of a few years reminiscent of magnetic cycle variations.

4. Light-curve analysis

The observed light curves (Fig. 1) are quite asymmetric - max I (at phase 0.25) is about 0.02 mag brighter than max II (at phase 0.75). The descending branch of the secondary minimum in the U light is fainter than the ascending one. The overall variations of the light curve, however, were only about 0.01 mag over the whole interval of observations.

All our U,B and V observations were used to compute 50 normal points (listed in Table 4) in each passband using the method of running parabolae. The numbers of points coming into one normal point were used as weights.

Since phases 0.31 - 0.35 in the U filter were covered only poorly, two normal points (at phases 0.32 and 0.34) were omitted from the light curve-analysis.

The W&D (Wilson & Devinney, 1971) code was employed to determine the photometric elements of the system. As the first approximation we have used the photometric elements computed by Djurašević & Erkapić (1997). Mode 3, appropriate for contact configuration, was used. Black-body radiation and the cosine law for the limb darkening of both components was assumed. Limb-darkening coefficients of both components were fixed at theoretical values (Grygar et al., 1972) because of their small influence on the light curve. We have adopted the same gravity darkening coefficient and bolometric albedo for both components (see e.g. Rucinski, 1973).

We solved the U,B and V light curves simultaneously. The luminosity of the secondary component was not minimized - it was computed automatically after every program run.

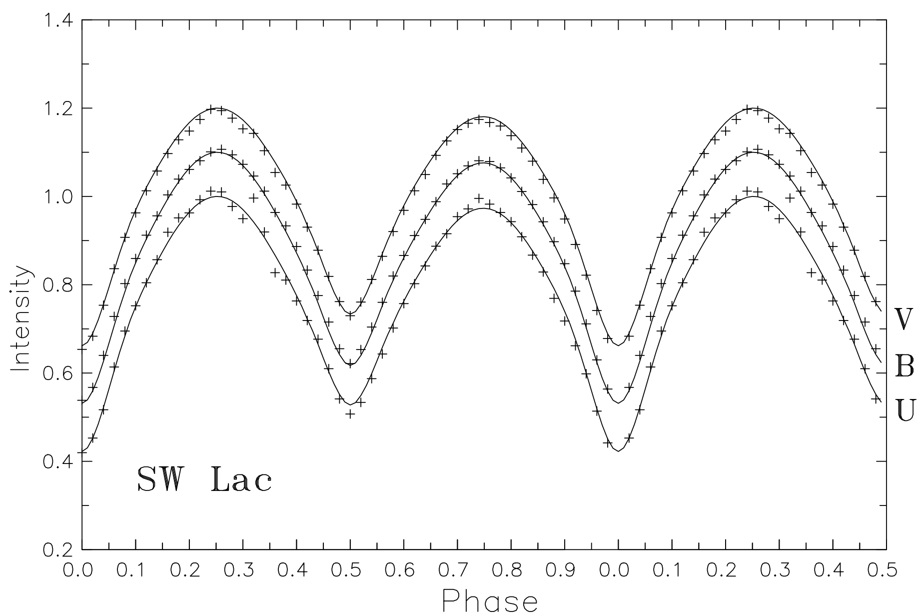

Figure 4. Normal points of SW Lac and their best fits

The differential correction code was run until the corrections to the input parameters were lower than their errors. The computed curves exhibited a slight differences in the brightness of the maxima (Max I being brighter). Therefore, we have tried to improve the fit by introducing of a spot. Observed differences in the brightness of maxima could be explained by the presence of a dark spot in the middle of the facing hemisphere of either component visible at phase 0.75. The radius r_s and temperature factor $A_s = T_{spot}/T_{1,2}$ are correlated. For $r_s =$

Table 4. Normal points of SW Lac

Phase	U	n	B	n	V	n
0.00	-0.177	65	0.186	70	0.368	73
0.02	-0.260	68	0.116	72	0.299	73
0.04	-0.403	78	-0.041	79	0.152	77
0.06	-0.590	80	-0.205	80	0.001	77
0.08	-0.725	78	-0.327	75	-0.114	74
0.10	-0.811	76	-0.411	75	-0.196	76
0.12	-0.884	78	-0.484	76	-0.265	76
0.14	-0.952	73	-0.541	74	-0.323	73
0.16	-1.028	64	-0.600	66	-0.372	64
0.18	-1.066	54	-0.642	57	-0.409	55
0.20	-1.079	48	-0.667	49	-0.432	48
0.22	-1.112	39	-0.689	42	-0.462	43
0.24	-1.133	40	-0.711	43	-0.487	44
0.26	-1.131	32	-0.717	43	-0.484	43
0.28	-1.095	24	-0.704	34	-0.465	33
0.30	-1.064	11	-0.680	21	-0.438	21
0.32	-1.116	11	-0.650	15	-0.426	15
0.34	-1.029	13	-0.610	14	-0.380	14
0.36	-0.914	15	-0.551	15	-0.319	15
0.38	-0.892	21	-0.512	22	-0.282	22
0.40	-0.827	32	-0.449	32	-0.224	34
0.42	-0.762	43	-0.373	44	-0.149	45
0.44	-0.696	52	-0.284	52	-0.068	54
0.46	-0.583	50	-0.183	50	0.031	50
0.48	-0.454	55	-0.071	53	0.136	54
0.50	-0.383	57	-0.003	52	0.200	51
0.52	-0.438	57	-0.067	52	0.138	51
0.54	-0.542	47	-0.163	43	0.043	43
0.56	-0.641	39	-0.259	38	-0.046	38
0.58	-0.736	32	-0.353	32	-0.134	32
0.60	-0.818	24	-0.421	24	-0.204	23
0.62	-0.881	16	-0.483	16	-0.265	16
0.64	-0.934	14	-0.531	14	-0.313	14
0.66	-0.990	15	-0.581	15	-0.367	15
0.68	-1.024	12	-0.629	12	-0.406	12
0.70	-1.069	13	-0.656	13	-0.436	13
0.72	-1.089	13	-0.676	14	-0.452	14
0.74	-1.115	14	-0.689	14	-0.462	14
0.76	-1.101	12	-0.687	12	-0.454	12
0.78	-1.080	20	-0.671	20	-0.445	20
0.80	-1.056	25	-0.645	25	-0.420	25
0.82	-1.016	28	-0.609	28	-0.387	30
0.84	-0.965	26	-0.573	25	-0.351	25
0.86	-0.916	33	-0.524	33	-0.299	33
0.88	-0.835	34	-0.464	35	-0.243	33
0.90	-0.760	42	-0.394	42	-0.176	42
0.92	-0.672	43	-0.300	43	-0.089	43
0.94	-0.562	57	-0.176	54	0.026	52
0.96	-0.397	62	-0.020	61	0.176	60
0.98	-0.233	66	0.124	67	0.311	67

25° we get $A_s = 0.95$. A similar fit can be accomplished by the positioning of a hot spot in the middle of the hemispheres visible at phase 0.25.

The normal points and the best fits are depicted in Fig. 4. The photometric elements and their probable errors are given in Table 5. The 3D surfaces corresponding to the best fit with this spot, plotted by Binary Maker 2.0 (Bradstreet, 1993), are depicted in Fig. 5. Further improvement of the fit can be done by introducing a second spot. Since determination of the spot parameters is not unique (Djurašević & Erkapić, 1997) we have not tried to find such a solution.

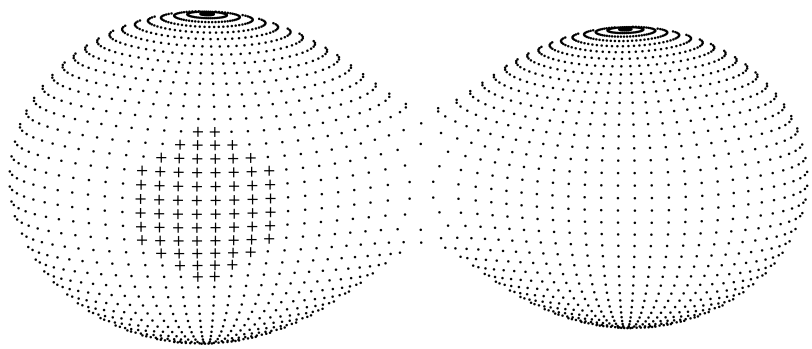

Figure 5. The 3D model of SW Lac in the phase 0.75

We have also checked the possibility (proposed in Section 3) that the light curve is affected by the presence of the third light. However, the third light was found to be negligible. This could be caused by the positive correlation of the third light with the inclination. On the other hand, reliable determination of the small third light expected for this system ($L_3 \approx 0.05$) is influenced by the presence of spots.

The geometric elements $i = 80.23°$, fill-out $= 0.39$, obtained from our observations are close to that determined by Leung et al. (1984). On the other hand, Djurašević & Erkapić found the components to be just in contact.

5. Discussion and conclusions

The detailed analysis of the (O-C) diagram of the system has revealed the presence of two possible bodies on $P_3 = 23$ and $P_4 \approx 90$ years orbits. In spite of their masses $M_3 = 0.41$ $M_\odot$ and $M_4 = 1.47$ $M_\odot$, the light curve analysis has shown that their contribution to the light curve is negligible. Detected continuous period increase could be caused by the mass transfer from the lesser to the more massive component. A mass transfer rate of $2.32\ 10^{-7}$ $M_\odot.y^{-1}$ is necessary to explain the period increase.

Table 5. Photometric elements and their probable errors σ (i - inclination; $q = m_2/m_1$ - mass ratio; Ω - surface potential; T_1, T_2 - polar temperatures; L_1, L_2 - luminosities of the components, u_1, u_2 - limb darkening coefficients, g - gravity darkening coefficient). $\sum w(O-C)^2$ is weighted sum of squares of residuals for all four light curves. Parameters not adjusted in the solution are denoted by a superscript "a".

Element			σ
i [°]		80.23	0.17
q		1.255^a	–
Ω		3.9325	0.0060
Fill-out		0.393	0.011
T_1 [K]		6200^a	–
T_2 [K]		5834	9
g		0.32^a	
u_1	V	0.63^a	–
	B	0.75^a	–
	U	0.77^a	–
u_2	V	0.61^a	–
	B	0.74^a	–
	U	0.86^a	–
L_1	V	0.5181	0.0012
	B	0.5340	0.0011
	U	0.5520	0.0009
L_2	V	0.4819	0.0012
	B	0.4660	0.0011
	U	0.4480	0.0009
$\sum w(O-C)^2$		0.2968	–

Since our quadruple model is based only on the study of period changes it needs to be proved by further spectroscopic observations.

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