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The analysis of photometric light curves and the third body in the eclipsing binary system SW Lyn

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Abstract. An analysis of photometric light curves of SW Lyn and the up-to-date O-C diagram are presented. Both photometric light curve and O-C analyses prove the existence of a third companion, orbiting the eclipsing system SW Lyn with period $P = 2128^d$. Modeling of the light curves has been performed using the Wilson-Devinney code. It turned out that SW Lyn is in a semidetached configuration. Temperatures of primary and secondary components are 6700K and 4500K respectively, for the system mass ratio fixed at q=0.35. The photometric solution shows a significant influence of a third light.

Key words: binaries: eclipsing – stars: individual: SW Lyn

1. Introduction

SW Lyn (BD +42° 1811, HD 39771) is a short period binary system discovered by Hoffmeister (1949), and whose nature was established by Huth (1958). Complete light curves were obtained by Gleim (1967) and Vetešnik (1968). The spectroscopic observations throughout the orbital cycle were carried out by Vetešnik (1977). There are large discrepancies among the photometric solutions based on different series of observations, published by Gleim (1967), Vetešnik (1968), Wilson (1979) and Predolin et al. (1980). For example, Wilson classified SW Lyn as a semidetached system while Predolin et al. concluded that it is a contact system. These discrepancies may result from variation of the shape of the light curve reported by Vetešnik (1968). Based on his spectroscopical observations, Vetešnik (1977) found a surprisingly large eccentricity of the orbit (e=0.11) but this result was not confirmed by photometry.

We have analyzed the O-C diagram adding new data, which substantially enlarged the material previously available, to improve orbital parameters of the third body. Results are presented in the next section. We have also checked the existence of the third component by solution of the BV light curves, published by Gleim (1967). The procedure applied to solve the light curves and the comparison of results with and without a third light are described in Sect. 3.

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2. O-C diagram and period changes

The eccentricity mentioned above was an inspiration to construct the O-C diagram and search the evidence of apsidal motion. It was done by Mauder (1961), Landolt (1973), and Kim & Han (1993). The shape of the O-C curve did not confirm the assumption of an eccentric orbit, but it suggested the existence of a third body in the system.

The most recent study of the period changes of SW Lyn was made by Kreiner et al. (1997). Since that time twenty new photoelectric times of minima have been obtained at Skalnaté Pleso Observatory of the Astronomical Institute of the Slovak Academy of Sciences (SP) and Mt. Suhora Observatory of the Cracow Pedagogical University (MS). The minima are collected in Table 1. The O-C values were computed according to the elements:

$$M_{cal} = \text{JD } 2443975.3866 + 0.644065908 \text{ E}$$

The last two minima were observed without any filter. Fig. 1 shows the O-C diagram for all photoelectric minima. The dashed line represents the synthetic O-C curve for the triple system computed using the method of Moffat et al. (1983). The O-C values versus the phase of a third body are presented in Fig. 2. Figs. 1 and 2 are extended versions of Figs. 1 and 2 from the paper by Kreiner et al. (1997). Primary and secondary minima were marked by squares and asterisks, respectively. Recomputation of the third body orbit elements gives the following results:

$$P' = 2128 \pm 4 \text{ days} = 5.826 \text{ years}$$
$$e = 0.69 \pm 0.06$$
$$\omega = 197.4 \pm 3.5$$
$$M_0 = 2438746.3 \pm 18.5$$
$$C_0 = -0.0030 \pm 0.0008$$
$$C_2 = 0.0049 \pm 0.0005$$

They are in a good agreement with values published in the above mentioned paper of Kreiner et al.(1997).

3. Light curve modeling

The observations of SW Lyn we used, were made by Gleim (1967) in the B and V filters. The latest version of the Wilson-Devinney (W-D) code, available to us, (Wilson & Devinney

Table 1. New times of minima of SW Lyn

No	J.D.Hel. 2450000+	error	band	epoch	O-C	obs.
1	49.5677	±.0005	U	9431	-0.0045	SP
2	49.5686	±.0008	B	9431	-0.0036	SP
3	49.5694	±.0006	V	9431	-0.0028	SP
4	80.4851	±.0009	U	9479	-0.0022	SP
5	80.4856	±.0007	B	9479	-0.0017	SP
6	80.4869	±.0007	V	9479	-0.0004	SP
7	160.3501	±.0003	B	9603	-0.0014	SP
8	160.3502	±.0003	V	9603	-0.0013	SP
9	160.3504	±.0007	U	9603	-0.0011	SP
10	196.4171	±.0008	U	9659	-0.0021	SP
11	196.4172	±.0011	V	9659	-0.0020	SP
12	196.4174	±.0007	B	9659	-0.0018	SP
13	411.5410:	±.0015	V	9993	0.0038	MS
14	457.5878	±.0005	V	10064.5	-0.0001	SP
15	457.5905	±.0006	B	10064.5	0.0026	SP
16	465.6399	±.0003	U	10077	0.0012	SP
17	465.6406	±.0001	V	10077	0.0019	SP
18	465.6409	±.0002	B	10077	0.0022	SP
19	753.5418	±.0003	-	10524	0.0056	MS
20	841.4566	±.0010	-	10660.5	0.0054	MS

1971, Wilson 1993) was used along with the Monte Carlo method as the search procedure (Price 1976, Zola et al. 1997). From all individual points we have calculated 80 normal ones in each filter, and these, normal light curves were solved simultaneously in B and V. Each normal point has been assigned an error, calculated as the standard deviation σ, from all individual observations this point contains. The eccentricity was set to 0.0, following Wilson's (1979) suggestion and lack of evidence for any eccentricity from the O-C diagram. The primary component's temperature was estimated from its spectral type to 6700K (F2V, Vetešnik 1977), with the calibration published by Popper (1981). Additionally, we assumed that A_1=$A_2 = 0.50$ and g_1=$g_2 = 0.32$. The limb darkening coefficients were taken from the Al-Naimiy (1978) tables for each wavelength and according to components' temperatures. Other parameters were adjusted in as wide as possible ranges, listed in Table 2.

Two models have been considered: (I) - it was assumed that there is no third light in the system, and (II), for which, the third light was included into the list of free parameters. The searching procedure was stopped when the difference between the smallest and the largest χ^2 values of elements in the search array was less than 1 percent. Initially, we allowed the mass ratio q to be a free parameters. However, the solutions has converged at too large q values (0.5 and 0.6 for models I and II, respectively), implying non-physical values for masses of the components. To solve this problem, we re-determined K_1 using the radial velocity curve published by Vetešnik (1977) and obtained K_1=80 km/s assuming a circular orbit. Thus the new mass funtion value is f(m_2)=0.034. The mass of a main sequence star of F2 spectral type should be in the range 1.28-1.72 M_{Sun} (Harmanec 1988). Making use of the new value for the

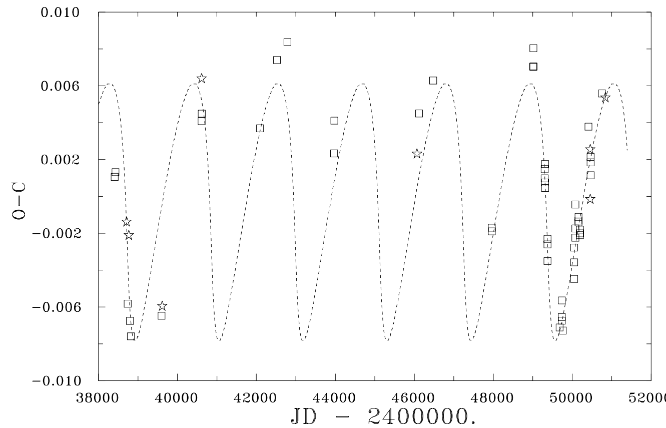

Fig. 1. The O-C diagram of SW Lyn

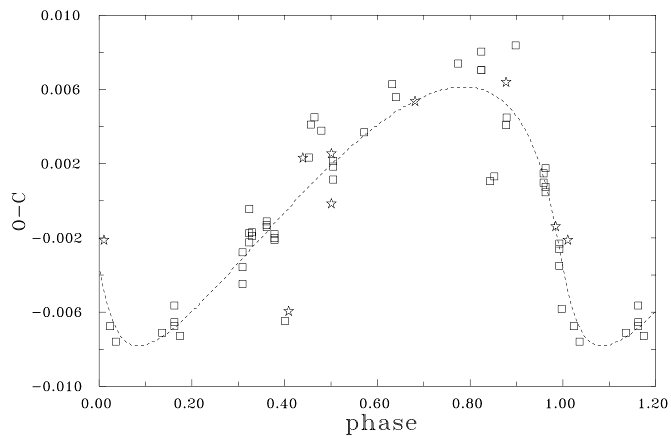

Fig. 2. O-C values versus the phase of a third body orbit

mass function, we could estimate the most probable range for the system mass ratio: q between 0.33 and 0.37. In further computations we fixed q=0.35 and restarted the Monte Carlo search. Again, we stopped computation when the above mentioned criterion was fullfilled. Finally, the stability of derived solutions was checked by switching to the original, Wilson's DC searching procedure, and setting the input parameters to the values derived from the Monte Carlo search. The cross-section of the search array in q-Ω plane is shown in Fig. 3. We obtained detached configuration for model I and semidetached for model II. For both models the secondary star is closer to the Roche potential (continuous line shown in Fig. 3).

Table 2 contains the values of parameters for the best fits. The errors listed in this table are standard deviation for every parameter adjusted, calculated for all elements in the final search array. Observations (squares) and the theoretical light curves corresponding to the model without a third light (dashed line) and one with a third light (continuous line) are displayed in Figs. 4 and 5.

4. Conclusions

We have added twenty new observations of primary and secondary eclipses of SW Lyn. Analysis of the most recent O-C

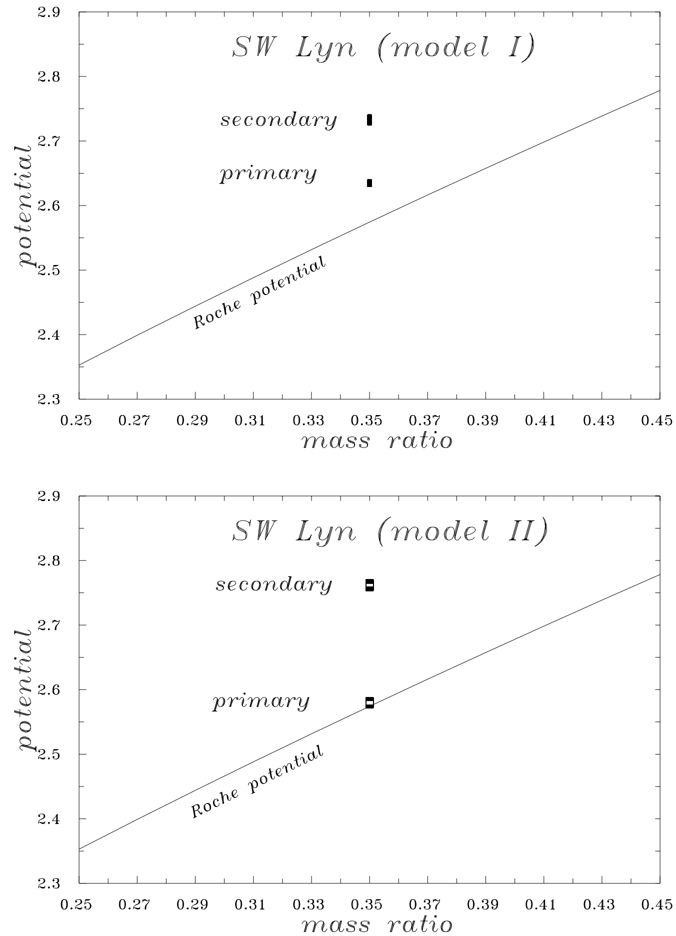

Fig. 3. The cross-section of the search array in the $q - \Omega$ plane.

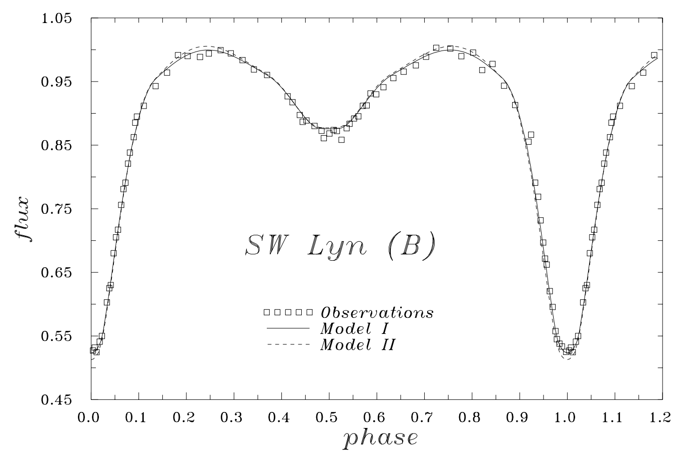

Fig. 4. Observed and theoretical light curves of SW Lyn in the B filter

Table 2. Parameters derived from the Wilson-Devinney model

	$l_3 = 0$	$l_3 \neq 0$	Search range
config.	d	s-d	
phase shift	-0.0006 (1)	0.0003 (1)	-0.002-0.002
i	83°.6 (1)	86°.4 (1)	70°.0-90°.0
$g_1 = g_2$	*0.32	*0.32	
$A_1 = A_2$	*0.50	*0.50	
T_1	*6700K	*6700K	
T_2	4390K (25)	4520K (15)	3000-6000K
q	*0.35	*0.35	
Ω_1	2.733 (30)	2.762 (11)	1.6-5.0
Ω_2	2.635 (15)	2.580 (10)	1.6-5.0
L_1 (B)	12.06 (1)	10.47 (2)	3-13
L_1 (V)	11.70 (1)	11.13 (2)	3-13
L_2 (B)	*0.46	*0.56	
L_2 (V)	*0.60	*0.78	
l_3 (B)	*0.0	0.112 (2)	0.0-0.5
l_3 (V)	*0.0	0.035 (2)	0.0-0.5
χ^2 (weighted)	10.876	4.064	

* - not adjusted

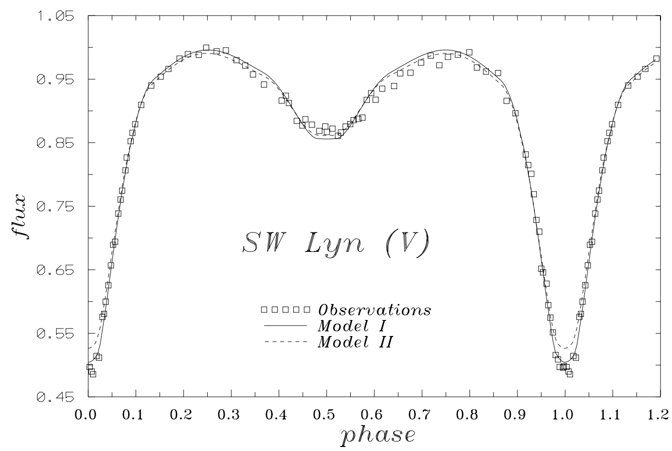

Fig. 5. Observed and theoretical light curves of SW Lyn in the V filter

diagram confirms that SW Lyn is a triple system. However, the orbital parameters of the third body haven't been changed significantly in comparison to those published by Kreiner et al. (1997).

The BV light curves were solved with the W-D code. We have considered two models: one without a third light in the system and the other including a third light in the list of free parameters. It turned out that the latter model fits much better with observations (χ^2 (weighted) = 4.064 versus 10.876 for the former one). Improvements are particularly well visible in the primary minimum (see Figs. 4 and 5) which was too deep in the B filter and too shallow in the V filter for the model without a third light.

We derived a detached configuration for SW Lyn when a third light parameter was set to zero and a semidetached when the third light was allowed to be adjusted. It was shown by Zola (1998) that detached geometry likely can be obtained if a third light is not included in the list of free parameters but it is present. For both models the secondary component is close to or in its Roche lobe. This star must be distorted which could be another argument in favor of a circular orbit of this system. The reported light curve variations can be explained either by a gas stream between components or some other activity of one or both stars.

It is not possible to determine the mass ratio of SW Lyn from the BV data published by Gleim (1967). The best fit which can be obtained to this data, indicate mass ratio to be about 0.50 and 0.60 for model I and II, respectively. However, such mass ratio values would imply non-physical masses of components.

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