A CCD Photometric Study of the W UMa Binary SW Lacertae

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Abstract Analysis of CCD data collected in *V*- and *R*-band over the last three months of 2005 has lead to a revised ephemeris and orbital period for SW Lac. A Roche-type model invoking a dark starspot on the cooler, more massive component has provided a theoretical fit of light curve data that largely accounts for the observed peak asymmetry and unequal successive maxima.

1. Introduction

The variability of SW Lacertae was first uncovered by Miss Ashall (Leavitt 1918) while examining photographic plates taken at the Harvard Observatory. In the intervening period, SW Lac has been observed in *U*, *V*, *B*, *R*, and *I* with full light curves published by no less than twenty investigators. Historically, SW Lac has also exhibited an inconstant orbital period which was discussed in some detail by Dugan and Wright (1939). A comprehensive record of photoelectric and CCD light curves for SW Lac has been published by Bookmyer (1965), Rucinski (1968), Faulkner and Bookmyer (1980), Stępień (1980), Mikołajewska and Mikołajewski (1981), Leung *et al.* (1984), Binnendijk (1984), Lafta and Grainger (1985), Eaton (1986), Niarchos (1987), Hrivnak and Goehring (1991), Lee *et al.* (1991), Zhang *et al.* (1992), and more recently by Rucinski *et al.* (2005). Common to the W UMa class of overcontact binaries, many light curves exhibit peak asymmetry visible as unequal heights of successive maxima, which some refer to as the O'Connell effect. This phenomenon has been frequently attributed to star spots. Binnendijk (1984) reproduced the asymmetrical shape of SW Lac light curves by invoking the geometrical and physical elements of a subluminous region on the more massive component. Since that time, Lee *et al.* (1991), Pribulla *et al.* (1999), Albayrak *et al.* (2004), and Gazeas *et al.* (2005) have all successfully fit light curves by applying cool starspot parameters to Roche-type models.SW Lacertae, comprising two stars each about the same mass as the Sun, has been variously assigned spectral types G3, G5, K0, G8, and most recently G5V (Rucinski *et al.* 2005). This system changes in visual magnitude from 8.6 to 9.4 with a period of 0.32072 day. SW Lac belongs to the W-type subclass of W UMa binaries, since the less massive (0.96 $M_\odot$) but hotter primary star is occulted by the more massive (1.14 $M_\odot$) but cooler secondary component during primary minimum (Binnendijk 1984). Our view of this system is not quite edge-on (orbital inclination ≈ 80°), so the eclipses are partial. SW Lac is also well suited for study by astronomy students and interested amateurs as this relatively bright variable is easily within the detection limits of a consumer-grade CCD camera coupled with a telescope of modest aperture. During the fall months, this system is favorably positioned since it passes near zenith for mid-latitude observers in the Northern Hemisphere.

2. Observations and data reduction

2.1. Astrometry

Images of SW Lac were matched against the standard star fields provided in MPO CANOPUS (V7.6.4.6, Minor Planet Observer 2003). The *MPO Star Catalog* (Minor Planet Observer 2003) is a mixture of the *Tycho 2* and *USNO A2.0* catalogues assembled using all *Tycho 2* stars brighter than magnitude 11, and *USNO A2.0* stars brighter than magnitude 15.3, also possessing a $B–R$ value in the range of 0.50 to 1.50.

2.2. Photometry

CCD photometric observations of SW Lac began on 01 October 2005 with the intent of generating light curves which could be used to: 1) potentially refine the orbital period, 2) calculate an updated ephemeris, and 3) further investigate the asymmetries regularly observed for this system. Equipment included a 0.2-m Celestron Nexstar 8 GPS (f/6.3 focal reducer) with an SBIG ST-402ME CCD camera mounted at the Cassegrain focus. The field of view produced by this configuration was 12.3 × 18.5 arcmin, corresponding to an image scale of 1.45 arcsec/pix. Imaging was carried out through a photometric V or R filter (Schüler 1.2") based upon the Johnson-Cousins Bessell design. Each unbinned exposure was captured over a 10-second (V) or 12-second (R) period with thermoelectric cooling regulated to maintain the CCD chip 20°C below the initial ambient temperature. These exposure times achieved acceptable sensitivity (~13.8 V mag. with S/N>100) for target and comparison stars alike. Barring clouds, a typical session which was centered around the tabulated minima listings provided at the AAVSO website for eclipsing binaries lasted from 2 to 4 hours, with images taken every 40–45 seconds. Clock time was updated via the Internet Time Server immediately prior to each session. Image acquisition (raw lights, darks, and flats) was performed using SBIG CCDSOFT 5, while calibration and registration were accomplished with AIP4WIN (V2.1.0, Berry and Burnell 2000). Aperture photometry was performed with MPO CANOPUS using at least three non-varying comparison stars ultimately to generate light curves for calculating ephemerides and orbital period. Instrumental readings were not reduced to standard magnitudes.

2.3. Light curve analyses

Light curve analysis was performed using the 2003 version of the Wilson-Devinney (WD) code (Wilson and Devinney 1971; Wilson 1979). Each model fit incorporated all individual observations assigned an equal weight of 1 and not binned to normal points.

Three-dimensional renderings showing the orbital progress of SW Lac and putative starspots were produced by BINARY MAKER 3.0 (Bradstreet and Steelman 2002). This JAVA-based, commercially available program employs Roche geometry to accurately compute light and radial velocity curves under manual interaction by the user. Used worldwide by professionals and amateurs alike, BINARY MAKER 3.0 provides a straightforward approach to solving eclipsing binary light curves. The synthetic light curves produced by the program are essentially identical to those produced by the Wilson-Devinney program but with a much friendlier user interface.

3. Results and discussion

3.1. Astrometry

The position determined for SW Lac was R.A. (2000.0) $22^h\ 53^m\ 41\overset{s}{.}71$, Dec. (2000.0) +37° 56' 18.4" based upon the reference coordinates in the *MPO Star Catalog* and agrees within 0.213 arcsec of either computed position generated from the SIMBAD website (ICRS 2000.0 coordinates: 22:53:41.6575 +37:56:18.613).

3.2. Ensemble photometry

Every attempt was made to ensure that comparison stars were themselves not variable at least over the observation time span. This was verified prior to accepting data from each session. On any night, at least three of the following five stars from the *Tycho2* catalog were used for differential measurements: TYC3215-01406-1, TYC3215-00906-1, TYC3215-01586-1, TYC3215-01978-1, and TYC3215-01288-1. Average (CAvg) instrumental magnitude (Imag) readings for comparison stars captured in quick succession ($n=7$) within two minutes typically exhibited less than ±1% variability in V or R. Over each viewing session lasting as long as four hours, CAvg variability in Imag from all comparison stars was within 2% in V or 3% in R. The airmass for all observations over the entire campaign ranged from 1.00 to 1.97. Plotting the difference in magnitude over time for SW Lac against the averaged magnitude for all comparisons yielded a narrow range of values with no obvious trend. A representative example is shown for a data set in V collected on 06 October 2005 (Figure 1). Collectively, CAvg in V or R did not exhibit a pattern that would otherwise suggest variability beyond experimental error.

3.3. Folded light curve and ephemeris

A total of 997 individual photometric readings in V and 897 in R were combined to produce light curves that spanned ten weeks of observation. These included seven times of minima (ToM) which were captured during nine viewing sessions between 01 October 2005 and 17 December 2005. The Fourier analysis routine in MPO CANOPUS provided a period solution for the entire dataset. The time of minimum for the latest primary epoch was estimated by CANOPUS using the Hertzsprung method as detailed by Henden and Kaitchuck (1990); the linear ephemeris equation (1) was initially determined to be:

$$\begin{aligned}\text{Min. I (hel.)} &= 2453721.5959 + 0.32072\,\text{E} \\ &\quad \pm 0.0001 \pm 0.00001\end{aligned} \tag{1}$$

This orbital period based upon a limited set of data compares very favorably with values reported from a number of contemporary investigations, including those by Pribulla *et al.* (1999), Derekas *et al.* (2002), Albayrak *et al.* (2004), and Gazeas *et al.* (2005). The times of minimum for all epochs were then separately estimated by MINIMA (V24d, Nelson 2005) using the simple mean from a suite of six different methods including parabolic fit, tracing paper, bisecting chords, Kwee and van Woerden (1956), Fourier Fit, and sliding integrations (Ghedini 1981). These seven new minima (Table 1) along with previously published ToM values were used to calculate residual values (Table 2) based upon the reference epoch from Pribulla *et al.* (1999) defined by the ephemeris (2):

$$\text{Min. I (hel.)} = 2451056.2900 + 0.32071532\ \text{E} \tag{2}$$

Due to the curvilinear nature of the O–C residuals observed over the last four years, two separate regression analyses were performed. A revised ephemeris equation (3) based upon a linear least squares fit (Figure 2) of near term $(\text{O–C})_1$ data from 12 August 2003 to 17 December 2005 was calculated:

$$\begin{aligned}\text{Min. I (hel.)} &= 2451056.2674 + 0.32071813\,\text{E} \\ &\quad \pm 0.0007 \pm 0.00000011\end{aligned} \tag{3}$$

Recalculated residuals $(\text{O–C})_L$ from this linear regression are provided in Table 2 and illustrated in Figure 3. The types (I or II) for six minima were corrected from those reported in the literature; they are annotated in Table 2. In addition, both ToM values from Cook *et al.* (2005) were considered outliers and not included in the regression analyses. It should also be noted that due to the continuing change in orbital period, updated linear elements for SW Lac may only be valid for a relatively short time after 2005.

Expanding the analysis to include O–C data from 2001 clearly revealed a parabolic relationship (Figure 4) between daily residuals $(\text{O–C})_1$ and time (cycle number) that is well fit ($r^2 > 0.937$) by a quadratic expression (4):

$$\text{O–C} = a + bE + cE^2 \tag{4}$$

where:

$$\begin{aligned} a &= 0.47789244\ \text{E–02} \quad \pm 0.08716284\ \text{E–02} \\ b &= -0.5304045\ \text{E–05} \quad \pm 0.03323842\ \text{E–05} \\ c &= 5.87329202\ \text{E–10} \quad \pm 0.29761014\ \text{E–10} \end{aligned}$$

This least-squares fit solution leads to the following quadratic ephemeris (5):

$$\begin{array}{rcl} \text{Min. I (hel.)} & = & 2451056.2948 + 0.3207100\,\text{E} + 5.9 \times 10^{-10}\ \text{E}^2 \\ & & \pm\ 0.0009 \pm\ 0.0000003\ \ \pm\ \ 3 \times 10^{-10} \end{array} \tag{5}$$

The parabolic fit of these data indicate a continuing change in orbital period which has been frequently reported for SW Lac. Recalculated residuals $(\text{O–C})_Q$ resulting from this quadratic regression are listed in Table 2 and plotted in Figure 5. Since late 2001 an orbital period rate of increase can be defined by the equation (6) below:

$$\begin{array}{l} \text{dP/dt} = 2\,(5.87 \times 10^{-10})\,(1/0.3207100)\,(86400)\,(365.25) = 0.1156\ \text{sec/yr} \\ \hfill \pm\ 0.0059 \end{array} \tag{6}$$

Should the quadratic rather than the linear ephemeris prove to be more representative in its behavior, then the parabolic O–C curve would suggest that the orbital period increase may be associated with material transfer from the less massive to the more massive component.

The folded light curves (Figure 6a) comprising all observations in *V* and *R*, show that both minima are separated by ~0.5 phase, which is consistent with a circular orbit. Also evident is peak asymmetry characterized by unequal successive maxima (Max II > Max I), which historically had been the most common observation (Jeong *et al.* 1994) up to and including the 1989 light curve published by Peña *et al.* (1993). More recently, the full light curves produced by Pribulla *et al.* (1999), Derekas *et al.* (2002), Albayrak *et al.* (2004), and Gazeas *et al.* (2005) have reversed this trend such that Max I > Max II has been more frequently observed. A plausible explanation for this seasonal variability would likely involve the changing presence of starspots on one or more binary components and is further explored in section 3.4.

3.4. Light curve analyses

In first quadrature (0.25P) we get a broadside view (Figure 6b) of both stars in which the total output of light is at a maximum (Max I). Thereafter, the more massive but cooler of the two stars is occulted by the primary at 0.5P, where the secondary minimum (Min II) is observed. Greater light is observed at Max II (0.75P) compared to Max I, and, finally, as the most massive star orbits in front of the hotter component at 0.0P, the primary and deeper minimum (Min I) is observed. The asymmetry in the maxima was more obvious in *V*-band, however, since some photometric readings in each color were separated by as long as 10 weeks, it is possible this indicates a temporal change rather than a true color dependent difference. On the other hand, the ratio of sunspot umbral to photospheric intensity is known to decrease at shorter wavelengths (Allen 1973). The temperature distribution in sunspot umbrae favors longer wavelengths such that the relative monochromatic intensity is nearly 1.5-fold higher at the nominal bandpass midpoint of *R* (700 nm) compared to *V* (550 nm) filters (Rozhavskii 1976). Assuming that sunspots are representative, then the photometric contrast for cool starspots in W UMa systems comprising solar-like stars might be greater in *V* than in *R*.

The rather significant asymmetry in flux at Max I and Max II strongly suggested a starspot solution for the SW Lac light curves reported herein. Dark spot models, embodied in the theory of magnetic dynamos born in the convective zone of rapidly rotating stars, were invoked over forty-five years ago by Binnendijk (1960) to address the light curve perturbations observed in AH Vir. Mullan (1975) further proposed that with W-type systems the probability of a starspot on the more massive component was greater due to the thicker convection envelope resulting from transfer of energy from the primary to the secondary component. Not unexpectedly, given the temporal nature of starspots, the exact solutions for SW Lac light curves that have been reported for over a decade did not result in an acceptable fit of these most recent photometric observations. A strategy to build a starspot model was consequently based on the assumption that the asymmetric maxima observed for SW Lac this season arise from one of two possibilities: 1) dark starspot(s) on either component facing the observer to decrease the depth of Max I, or 2) hot starspot(s) on either star responsible for an increase in flux during Max II.

For overcontact binary systems of this type, light curve solutions employ WD mode 3 with synchronous rotation and circular orbits. Since SW Lac has a convective envelope ($T_{eff} < 7500$K), values for bolometric albedo (0.5) and gravity darkening exponents (0.32) were based on theoretical considerations reported by Rucinski (1969) and Lucy (1967), respectively. Logarithmic limb darkening coefficients for both stars were interpolated according to van Hamme (1993). The mean effective temperature of star 1 (the star eclipsed at primary minimum) was set equal to 5413K, based on the Tycho $B–V = 0.75$ and the temperature calibration of Flower (1996). Initial attempts to obtain a light curve solution involved adjustment of parameters for the mean effective temperature of the secondary (T_2), orbital inclination (i), mass ratio (q), bandpass-specific luminosity of the primary (L_1), and common envelope surface potential (Ω), as well as the size, location, and relative temperature of putative starspot(s). Once an approximate fit was obtained, differential corrections were applied simultaneously to photometric data in both filters. To alleviate strong correlations, especially among the starspot parameters, the *Method of Multiple Subsets* (Wilson and Biermann 1976) was used. The subsets consisted of the non-spot parameters, the spot co-latitude and temperature factor, and the spot longitude and radius.

Results from the simultaneous solution of both photometric data sets (*V* and *R*) are provided in Table 3. Standard errors for the present study are as calculated by WD. A comparison to the five most recently obtained (1998–2003) geometrical and physical elements of SW Lac following optimized curve fitting using a Roche-type model with a starspot reveals significant differences in starspot location and size. Each light curve solution (Figure 7) from late-2005 features a common dark starspot on the surface of the more massive star which becomes fully exposed as the system approaches Max I (Figure 6b). The residual sum of squares fit [$\Sigma(O–C)^2$] for the *R*-band data is improved (0.105271) over that observed in *V*-band (0.268330) and is most likely attributed to the greater variability detected around Max I and Max II.

4. Conclusions

CCD visual (*V*) and red (*R*) filter photometric observations have led to the construction of light curves which were used to: 1) revise the orbital period for SW Lac, 2) calculate an updated ephemeris and, 3) further investigate the peak asymmetries regularly observed for this system. A parabolic relationship between O–C residuals and cycle number has been derived which suggests a period increase over at least the past four years. Light curve analysis using the Wilson-Devinney program and incorporating a dark starspot on the cooler, more massive component has provided a theoretical fit of light curve data that largely accounts for the observed peak asymmetry and unequal successive maxima.

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Table 1. Light curve minima of SW Lac.

Observed Time of Minimum (HJD-2400000.0)	*UT Date*	*Color*	*No. of Observations*	*Type of Minimum*
53644.6230 ±0.0002	01 Oct 05	*V*	214	II
53645.5852 ±0.0003	02 Oct 05	*V*	246	II
53649.5956 ±0.0001	06 Oct 05	*V*	204	I
53677.6563 ±0.0002	03 Nov 05	*V*	153	II
53692.5713 ±0.0001	18 Nov 05	*V*	180	I
53717.5872 ±0.0001	13 Dec 05	*R*	266	I
53721.5959 ±0.0001	17 Dec 05	*R*	218	II

Table 2. Recalculated residuals following linear and quadratic fit of $(O–C)_1$ and times of minima (03 September 2001–17 December 2005) data for SW Lac.

Time of Minimum	*Type*	*Cycle Number*	$(O–C)^a_1$	$(O–C)_{Lin}$	$(O–C)_{Quad}$	*Reference (cited in notes)*
52156.3371	I	3430	–0.0064476	0.0065301	0.00005648	IBVS 5341
52188.4083	I	3530	–0.0067796	0.0059170	–0.00015390	IBVS 5300
52190.3326	I	3536	–0.0067715	0.0059082	–0.00013889	IBVS 5255
52190.3329	I	3536	–0.0064715	0.0062082	0.00016111	IBVS 5255
52190.3331	I	3536	–0.0062715	0.0064082	0.00036111	IBVS 5255
52190.4932	II	3536.5	–0.0065292	0.0061491	0.00010402	IBVS 5255
52190.4936	II	3536.5	–0.0061292	0.0065491	0.00050402	IBVS 5255
52190.4937	II	3536.5	–0.0060292	0.0066491	0.00060402	IBVS 5255
52191.4550	II	3539.5	–0.0068751	0.0057947	–0.00023849	IBVS 5341
52195.3037	II	3551.5	–0.0067590	0.0058771	–0.00010866	IBVS 5255
52195.3040	II	3551.5	–0.0064590	0.0061771	0.00019134	IBVS 5255
52195.3043	II	3551.5	–0.0061590	0.0064771	0.00049134	IBVS 5255
52195.3055	II	3551.5	–0.0049590	0.0076771	0.00169134	IBVS 5300
52195.4636	I	3552	–0.0072166	0.0054181	–0.00056576	IBVS 5255
52195.4637	I	3552	–0.0071166	0.0055181	–0.00046576	IBVS 5255

(Table 2 continued on following pages)

Table 2. Recalculated residuals following linear and quadratic fit of $(O–C)_1$ and times of minima (03 September 2001–17 December 2005) data for SW Lac, continued.

Time of Minimum	*Type*	*Cycle Number*	$(O–C)^a_1$	$(O–C)_{Lin}$	$(O–C)_{Quad}$	*Reference (cited in notes)*
52195.4641	I	3552	–0.0067166	0.0059181	–0.00006576	IBVS 5300
52195.4651	I	3552	–0.0057166	0.0069181	0.00093424	IBVS 5255
52196.2653	II	3554.5	–0.0073049	0.0053227	–0.00065123	IBVS 5255
52196.2660	II	3554.5	–0.0066049	0.0060227	0.00004877	IBVS 5255
52196.2662	II	3554.5	–0.0064049	0.0062227	0.00024877	IBVS 5255
52196.4255	I	3555	–0.0074626	0.0051637	–0.00080833	IBVS 5255
52196.4266	I	3555	–0.0063626	0.0062637	0.00029167	IBVS 5255
52197.2274	II	3557.5	–0.0073509	0.0052683	–0.00069381	IBVS 5255
52197.2279	II	3557.5	–0.0068509	0.0057683	–0.00019381	IBVS 5255
52197.2280	II	3557.5	–0.0067509	0.0058683	–0.00009381	IBVS 5255
52197.3869	I	3558	–0.0082086	0.0044093	–0.00155091	IBVS 5255
52197.3880	I	3558	–0.0071086	0.0055093	–0.00045091	IBVS 5255
52197.3885	I	3558	–0.0066086	0.0060093	0.00004909	IBVS 5255
52450.4316	I	4347	–0.0078960	0.0025034	–0.00071669	IBVS 5300
52503.5114	II	4512.5	–0.0064815	0.0034526	0.00071450	IBVS 5407
52505.4351	II	4518.5	–0.0070734	0.0028438	0.00012257	IBVS 5341
52517.4617	I	4556	–0.0072979	0.0025139	–0.00010289	IBVS 5407
52518.4240	I	4559	–0.0071439	0.0026595	0.00005100	IBVS 5434
52538.3082	I	4621	–0.0072937	0.0023353	–0.00010427	IBVS 5407
52538.4700	II	4621.5	–0.0058514	0.0037763	0.00133801	IBVS 5407
52566.3717	II	4708.5	–0.0063842	0.0029988	0.00078988	Albayrak *et al.*
52566.3720	II	4708.5	–0.0060842	0.0032988	0.00108988	Albayrak *et al.*
52566.5301	I	4709	–0.0083419	0.0010398	–0.00116789	Albayrak *et al.*
52566.5303	I	4709	–0.0081419	0.0012398	–0.00096789	Albayrak *et al.*
52584.4911	I	4765	–0.0073998	0.0018244	–0.00024039	IBVS 5484
52607.5828	I	4837	–0.0072028	0.0018189	–0.00006759	IBVS 5371
52863.5142	I	5635	–0.0066282	0.0001499	–0.00016843	IBVS 5471
52883.3986	I	5697	–0.0065780	0.0000257	–0.00020206	IBVS 5592
52903.2835	I	5759	–0.0060279	0.0004015	0.00025978	IBVS 5623
52903.6037	I	5760	–0.0065432	–0.0001166	–0.00025700	IBVS 5623
52904.4061	II	5762.5	–0.0059315	0.0004881	0.00035104	IBVS 5623
52904.5657	I	5763	–0.0066892	–0.0002710	–0.00040735	IBVS 5623
52905.3675	II	5765.5	–0.0066775	–0.0002663	–0.00039932	Albayrak *et al.*
52905.3681	II[b]	5765.5	–0.0060775	0.0003337	0.00020068	IBVS 5668
52905.3683	II	5765.5	–0.0058775	0.0005337	0.00040068	Albayrak *et al.*
52905.5278	I	5766	–0.0067351	–0.0003254	–0.00045771	Albayrak *et al.*
52905.5279	I	5766	–0.0066351	–0.0002254	–0.00035771	Albayrak *et al.*

(Table 2 continued on following page)

Table 2. Recalculated residuals following linear and quadratic fit of $(O–C)_1$ and times of minima (03 September 2001–17 December 2005) data for SW Lac, continued.

Time of Minimum	*Type*	*Cycle Number*	$(O–C)^{a}_{1}$	$(O–C)_{Lin}$	$(O–C)_{Quad}$	*Reference (cited in notes)*
52909.5377	II	5778.5	–0.0057766	0.0005980	0.00048233	IBVS 5471
52912.2629	I	5787	–0.0066568	–0.0003062	–0.00041054	IBVS 5471
52912.4243	II	5787.5	–0.0056145	0.0007348	0.00063105	IBVS 5471
52916.2725	II	5799.5	–0.0059983	0.0003172	0.00022920	Albayrak *et al.*
52916.2729	II	5799.5	–0.0055983	0.0007172	0.00062920	Albayrak *et al.*
52916.4320	I	5800	–0.0068560	–0.0005419	–0.00062922	Albayrak *et al.*
52916.4324	I	5800	–0.0064560	–0.0001419	–0.00022922	Albayrak *et al.*
52919.3187	I	5809	–0.0065939	–0.0003050	–0.00038073	IBVS 5579
52919.4798	II	5809.5	–0.0058515	0.0004359	0.00036085	IBVS 5579
52939.5243	I[b]	5872	–0.0060590	0.0000527	0.00005605	IBVS 5643
52958.4473	I	5931	–0.0052629	0.0006829	0.00075611	IBVS 5588
53244.5265	I	6823	–0.0041284	–0.0006905	–0.00005992	IBVS 5588
53250.4596	II[b]	6841.5	–0.0042618	–0.0008760	–0.00024368	IBVS 5657
53280.4472	I	6935	–0.0035442	–0.0004213	0.00021328	IBVS 5649
53290.3892	I	6966	–0.0037191	–0.0006834	–0.00005031	IBVS 5649
53298.4072	I	6991	–0.0036021	–0.0006367	–0.00000564	IBVS 5649
53303.3777	II[b]	7006.5	–0.0041896	–0.0012677	–0.00063832	IBVS 5657
53322.3002	II	7065.5	–0.0038935	–0.0011375	–0.00051689	IBVS 5649
53552.8936	II[b]	7784.5	–0.0048085	–0.0040741	–0.00388936	IBVS 5636[c]
53553.8554	II[b]	7793.5	–0.0560464	–0.0553373	–0.05516185	IBVS 5636[c]
53644.6230	II	8070.5	0.0000099	–0.0000598	–0.00021719	Present study
53645.5852	II	8073.5	0.0000640	–0.0000142	–0.00017568	Present study
53649.5956	I	8086	0.0015225	0.0014092	0.00123049	Present study
53677.6563	II	8173.5	–0.0003680	–0.0007273	–0.00103151	Present study
53692.5713	I	8220	0.0013696	0.0008796	0.00050503	Present study
53717.5872	I	8298	0.0014746	0.0007653	0.00026707	Present study
53721.5959	II	8310.5	0.0012331	0.0004886	–0.00003006	Present study

a. $(O–C)_1$ *determined from the reference ephemeris equation (2). b. Minimum type corrected from original citation. c. Outlier values not included in regression analyses. Reference citations: Albayrak* et al. *(2004); IBVS 5255, Derekas* et al. *(2002); IBVS 5300, Albayrak* et al. *(2002); IBVS 5341, Pribulla* et al. *(2002); IBVS 5371, Nelson (2003); IBVS 5407, Tanriverdi* et al. *(2003); IBVS 5434, Borkovits* et al. *(2003); IBVS 5471, Selam* et al. *(2003); IBVS 5484, Agerer and Hübscher (2003); IBVS 5579, Borkovits* et al. *(2004); IBVS 5588, Aksu* et al. *(2005); IBVS 5592, Krajci (2005); IBVS 5623, Dróżdz and Ogloza (2005); IBVS 5636, Cook* et al. *(2005); IBVS 5643, Hübscher (2005); IBVS 5649, Albayrak* et al. *(2005); IBVS 5657, Hübscher* et al. *(2005); IBVS 5668, Pribulla* et al. *(2005).*

Table 3. A comparison of recent geometrical and physical elements of SW Lacertae obtained following optimized curve fitting using a starspot model.

Parameter	*Present Study Value (S.E.)*	*Pribulla* et al. (1999)	*Albayrak* et al. *(2004)*			*Gazeas* et al. *(2005)*
Year of Observation	2005	1998	2001	2002	2003	2003
T_1	5413K	6200K	5630K	5630K	5630K	5800K
T_2	5186K (5)	5834K	5347K	5348K	5345K	5515K
$L_{1V}/(L_{1V}+L_{2V})$	0.4892	0.5340	0.530	0.540	0.548	0.5836
$L_{1R}/(L_{1R}+L_{2R})$	0.4781					0.4960
$q\ (m_2/m_1)$	1.37	1.255	1.255	1.255	1.255	1.270
$A_{1,2}$	0.5	0.5	0.5	0.5	0.5	0.5
$g_{1,2}$	0.32	0.32	0.08	0.08	0.08	0.32
$x_{1V}\ ,\ y_{1V}$	0.782, 0.187	0.63	0.6261	0.6260	0.6264	0.67
$x_{2V}\ ,\ y_{1V}$	0.792, 0.147	0.61				
$x_{1R}\ ,\ y_{1V}$	0.714, 0.220					
$x_{2R}\ ,\ y_{1V}$	0.727, 0.192					
$\Omega_{1,2}$	4.151 (0.003)	3.9325	3.9801	3.9796	3.9795	3.977
i	79.21° (0.09)	80.32°	79.85°	79.85°	79.85°	79.8°
f (% overcontact)	31.45	39.3	30.86	30.95	30.96	30
r_1 (pole)	0.3499					0.3595
r_1 (side)	0.3698					0.3990
r_1 (back)	0.4149					0.3809
r_2 (pole)	0.4020					0.4253
r_2 (side)	0.4282					0.4281
r_2 (back)	0.4680					0.4679
$A_{S1}=T_{S1}/T_1$					0.89	
Θ_{S1} (co-latitude)					26.4°	
ϕ_{S1} (longitude)					87.8°	
r_{S1} (angular radius)					30.5°	
$A_{S2}=T_{S2}/T_2$	0.879 (0.002)		0.84	0.85	0.87	0.72
Θ_{S2} (co-latitude)	79.4° (0.45)	90°	48.3°	45.4°	61.9°	107°
ϕ_{S2} (longitude)	51.87° (1.72)	270°	278.9°	294.3°	263.6°	279°
r_{S2} (angular radius)	20.18° (0.29)	25°	31.8°	44.4°	46.9°	17°

a. Subscripts 1 and 2 correspond to the star being eclipsed at primary and secondary minimum, respectively.

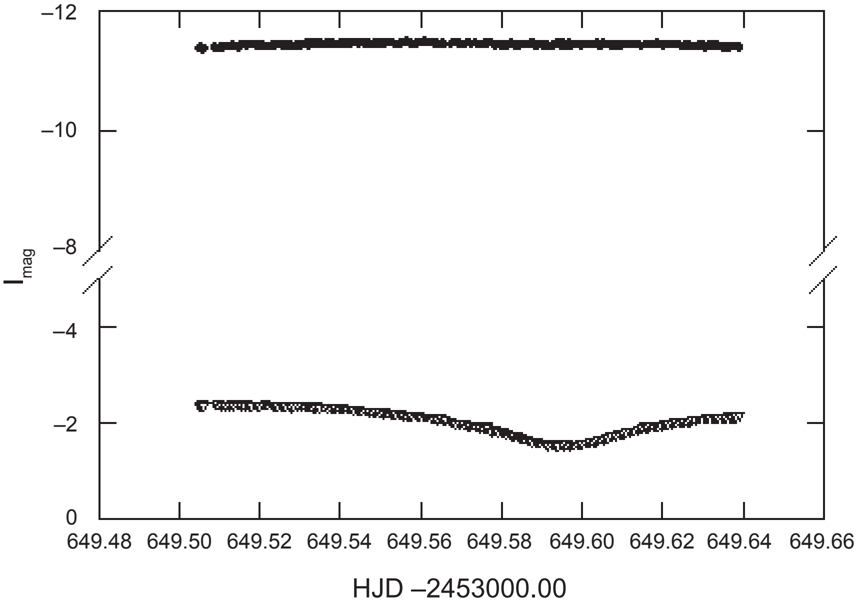


Figure 1. Magnitude (y-axis) plotted against HJD (x-axis) for SW Lac and the mean instrumental magnitude (C_{Avg}) of four comparison stars in *V*. Discontinuities in data arise from the sporadic appearance of clouds.

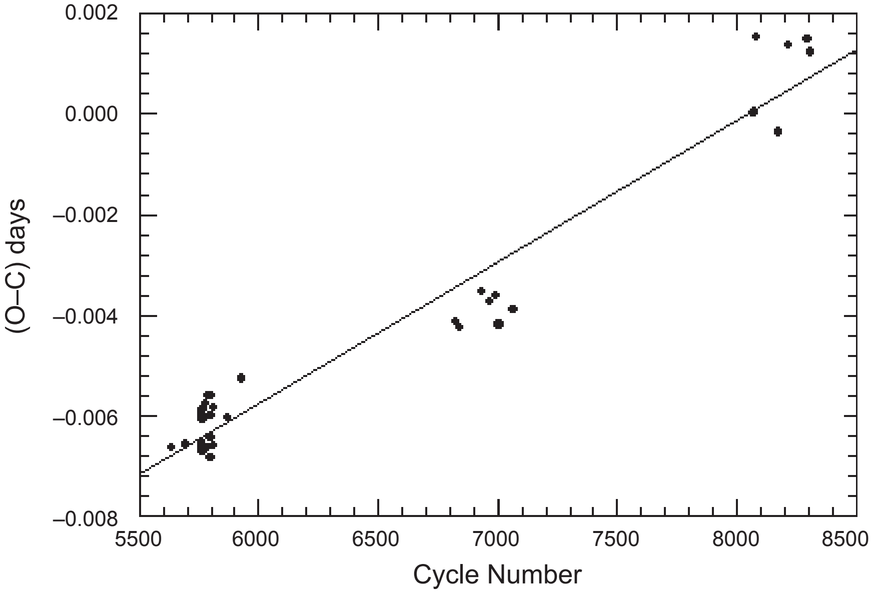


Figure 2. Linear least squares fit of residuals $(O–C)_1$ plotted against time (cycle number) of minima for SW Lac observed between 12 Aug 2003 and 17 Dec 2005.

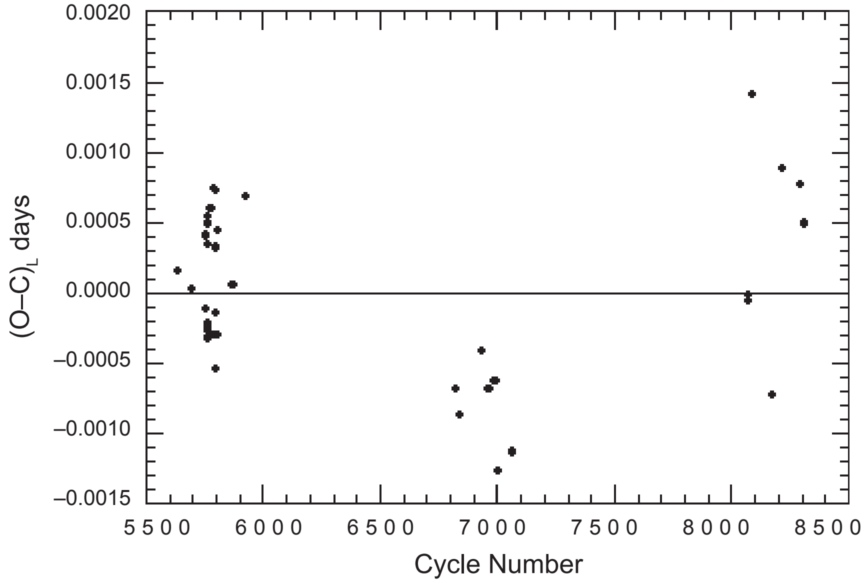


Figure 3. Recalculated residuals following linear fit of $(O–C)_1$ and times of minima (12 Aug 2003–17 Dec 2005) data for SW Lac.

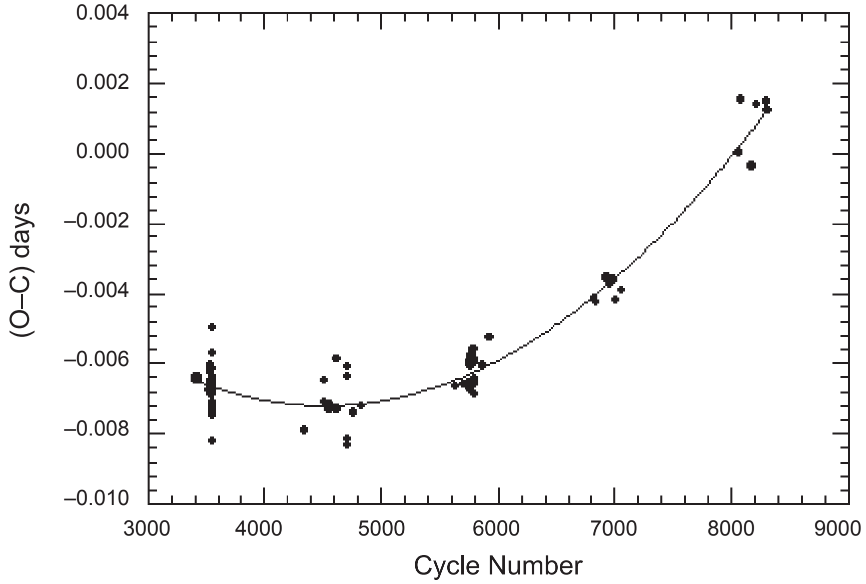


Figure 4. Quadratic least squares fit of residuals $(O–C)_1$ plotted against time (cycle number) of minima for SW Lac observed between 03 Sept 2001 and 17 Dec 2005.

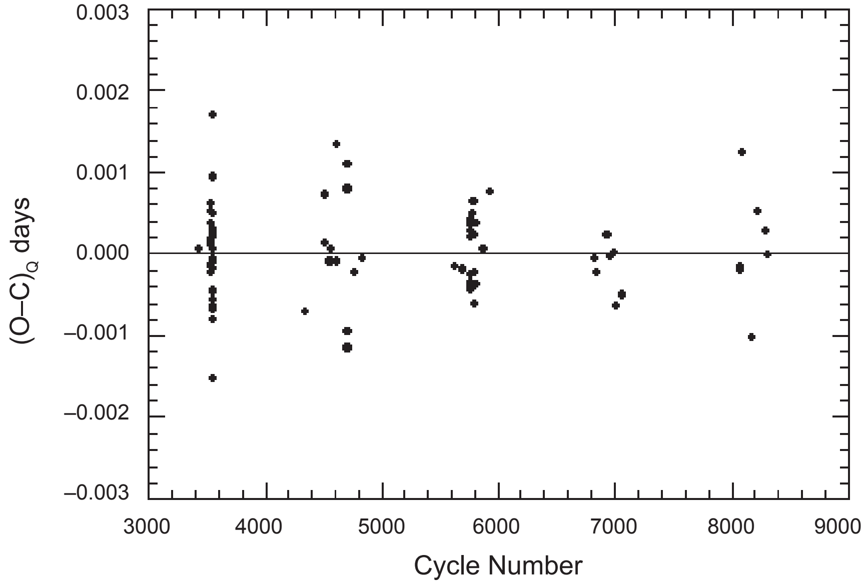


Figure 5. Recalculated residuals following quadratic fit of $(O–C)_1$ and times of minima (03 Sept 2001–17 Dec 2005) data for SW Lac.

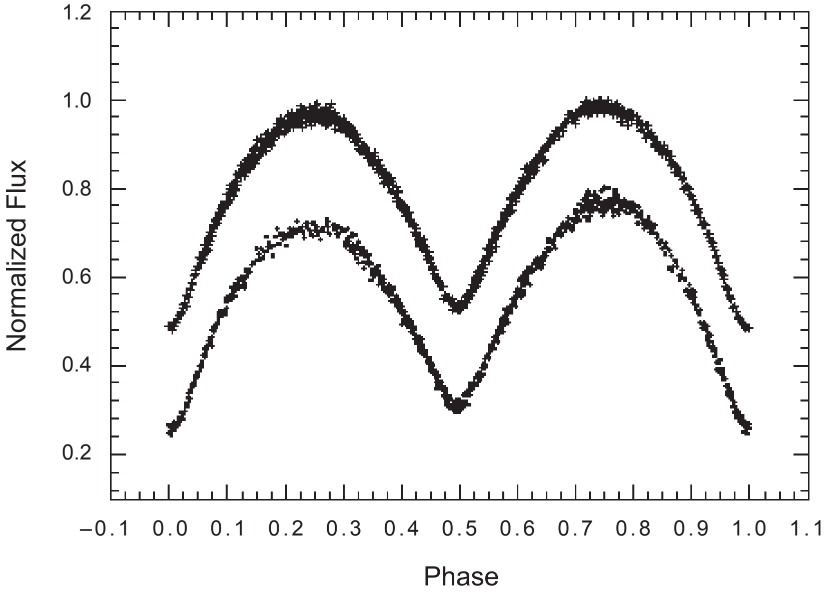
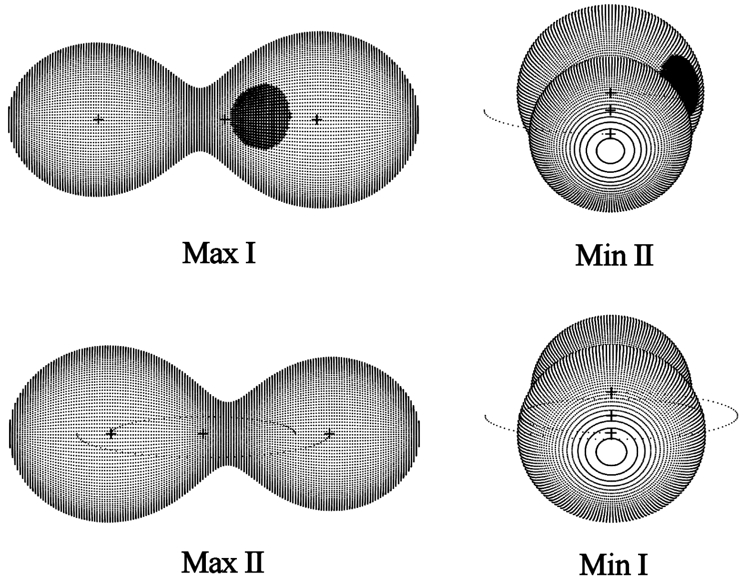


Figure 6a. Folded CCD light curves for SW Lacertae captured in *V*- (Oct–Nov 2005, lower plot) and *R*-band (Dec 2005, upper plot). Curves are offset for clarity.

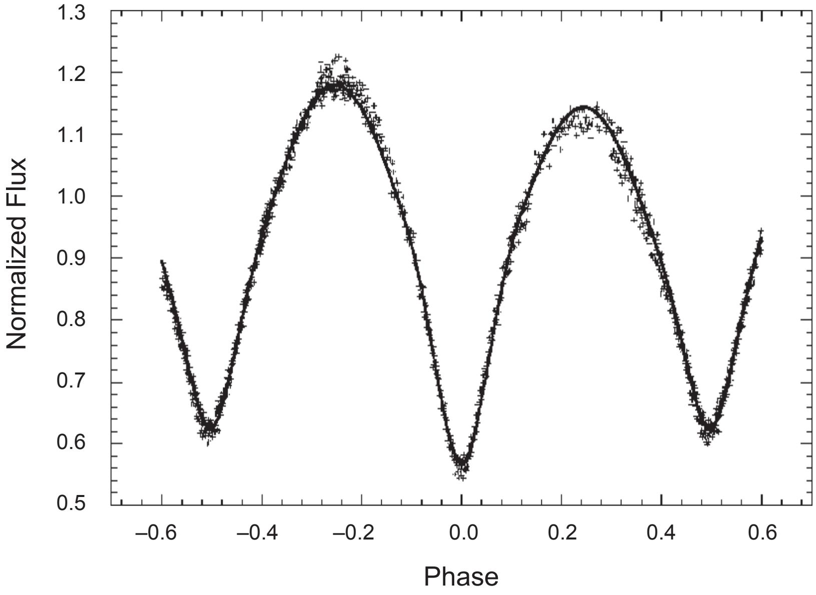

Max I

Min II

Max II

Min I

Figure 6b. 3-D Rendering of SW Lac binary star system, with dark starspot location from Max I (0.25P) to Min I (0.0P). The primary, smaller component is hotter (5413K) than the cooler (5186K) more massive star.



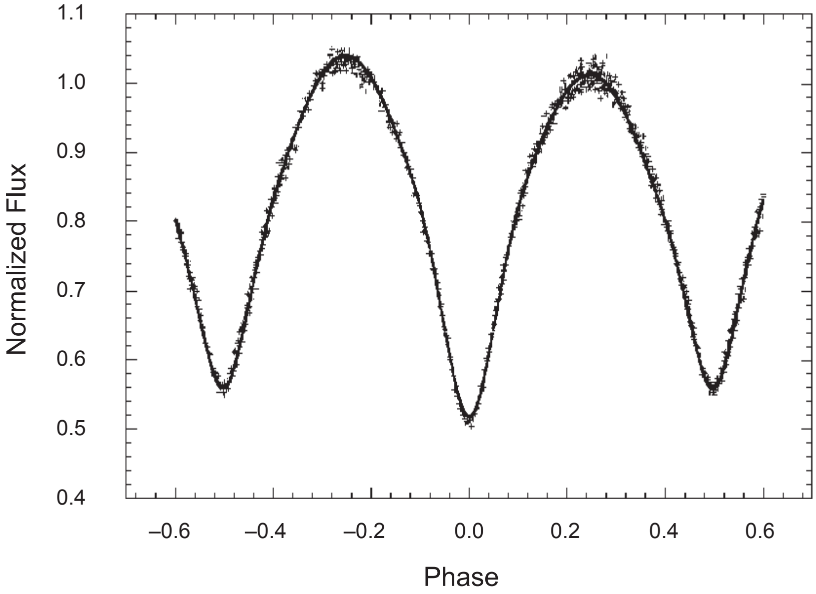


Figure 7. Spotted WD simulation of 2005 light curves for SW Lac superimposed with CCD observations in *V*-band (top) and *R*-band (bottom).