Photometric Analysis of the Solar Type, Totally Eclipsing, Southern, Near Critical Contact Binary, CW Sculptoris

Ronald G. Samec
Cody L. Norris
Astronomy Group, Department of Natural Science, Emmanuel College, 181 Springs Street, P.O. Box 129, Franklin Springs, GA 30639; ronaldsamec@gmail.com; s.cln@ec.edu

Bob L. Hill
Astronomy Program, Department of Chemistry and Physics, Bob Jones University, 1700 Wade Hampton Boulevard, Greenville, SC 29614

Walter Van Hamme
Physics Department, Florida International University, 11200 SW 8th Street, Miami, FL 33199

Danny R. Faulkner
Johnson Observatory, 1414 Bur Oak Court, Hebron, KY 41048

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Abstract CW Sculptoris is a solar type ($T_1 \sim 5750$ K) eclipsing binary. It was observed in October and November 2014 at Cerro Tololo InterAmerican Observatory in remote mode with the 0.6-m SARA South reflector. Three times of minimum light were calculated from our present observations, one secondary and two primary eclipses. In addition, six observations at minima were determined from archived All Sky Automated Survey Data. An increasing period was determined from all available times of minimum light with a $1.14 \pm 0.16 \times 10^{-10} \times E^2$ quadratic term. A BVR_cI_c simultaneous Wilson-Devinney Program solution reveals that the system has a mass ratio of ~0.44, and a component temperature difference of ~200 K. The Roche Lobe fill-out is only 3%. This may indicate that the system has recently come into contact. The inclination is ~84°. An eclipse duration of 19.5 minutes was determined for the primary eclipse.

1. Introduction

This paper represents the first precision and multicolor photometric study of CW Sculptoris, an interesting EW Southern, solar-type eclipsing binary.

2. History and observations

The variable, GSC 7517 0234, was observed by the All Sky Automated Survey (ASAS 232801-3359.8.; Pojmański 2002). In "Reports on New Discoveries" (Otero *et al.* 2004; http://www.astrouw.edu.pl/~gp/asas), it was designated as an EW binary, with magnitude range 12.13–12.87 (V) with the following ephemeris:

$$JD = 2452940.676 + 0.385588\,d \quad (1)$$

The ASAS data are plotted in Figure 1, phased with the period above. Six "times of low light" were determined from the ASAS plots by taking points of low light near the primary and secondary minima:

HJD Min I = 2452177.603, 2452466.793, 2454404.752,
HJD Min II = 2453647.652, 2454669.843, 2455101.701.

The variable was included in the "Automated Variable Star Classification" using *The Northern Sky Variability Survey* and classified as an EW type (Hoffman *et al.* 2009).

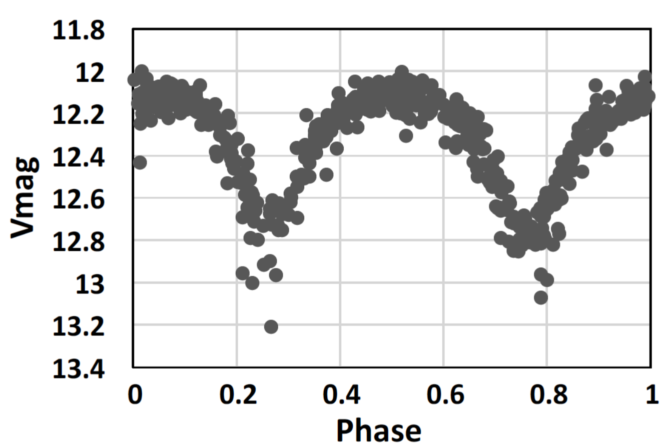

Figure 1. CW Scl phase plot from ASAS data (Pojmański 2002).

CW Scl was included in the "80th Name List of Variable Stars" (Kazarovets *et al.* 2013).

This system was observed as a part of our student/professional collaborative studies of interacting binaries from data taken from SARA observations. The observations were taken by Samec, Faulkner, Hill, and Van Hamme. Reduction and analyses were mostly done by Samec and Norris. The Observations were taken with the Southeastern Association for Research in Astronomy (SARA South) telescope at Cerro Tololo InterAmerican Observatory (CTIO) in remote mode. The 0.6-meter F/11 reflector was used on four nights, 9, 10, 19 October, and 15 November 2014 with the ARC Camera

Table 1. Information on the stars used in this study.

Star	*Name*	*R.A. (2000)* h m s	*Dec. (2000)* ° ′ ″	*V*	*J–K*
V	SW Scl 3UC113-502395 GSC 07517-00234	23 28 01.095	–33 59 51.75[1,2]	12.28	0.40
C	GSC 7517 0304 3UC112-498808	23 27 47.540	–34 05 51.67[1]	13.26	0.46
K (Check)	GSC 7517 0049 3UC112-498812	23 27 56.625	–34 02 19.52[1]	13.24	0.32

[1] UCAC3 (USNO 2012). [2] USNO CCD Astrograph Catalog (Zacharias et al. 2012).

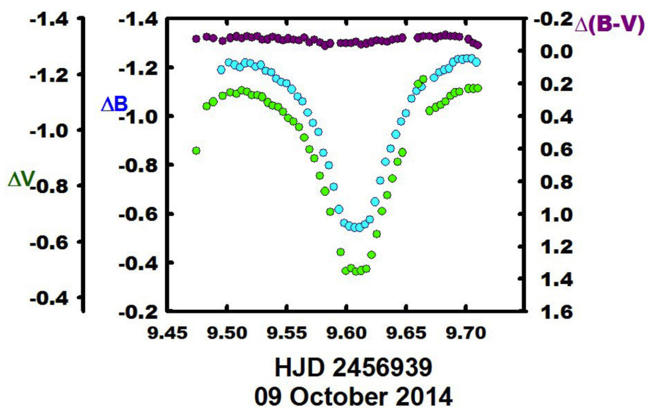

Figure 2a. CW Scl. B,V delta magnitudes and color curves taken on 9 October 2014.

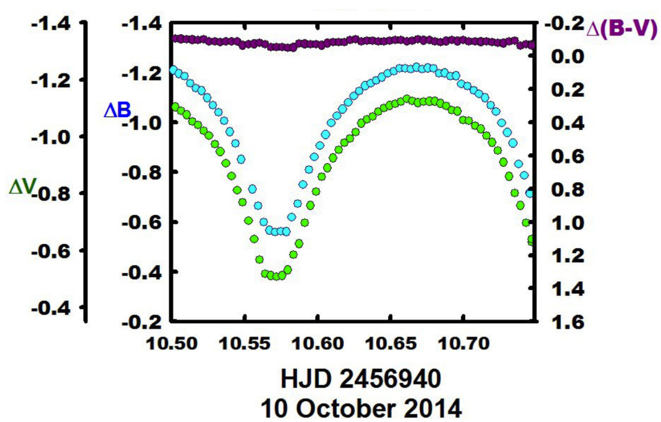

Figure 2b. CW Scl. B,V delta magnitudes and color curves taken on 10 October 2014.

cooled to –110 C using BVR_cI_c Johnson/Cousins standard filters. Figures 2a and 2b give sample nightly curves in B, V delta magnitude and color magnitudes as a function of phase plots in the sense of V–C from 2014, October 9 and 10, respectively.

3. Positions and finding chart

The finding chart, given here for future observers, is shown as Figure 3. The coordinates and magnitudes of the variable star, comparison star, and check star are given in Table 1. The C–K values stayed constant throughout the observing run with a nightly precision of V = 6–7 mmag. Exposure times varied from 100–120s in B, 50–75s in V, and 40–60s in R_c and I_c.

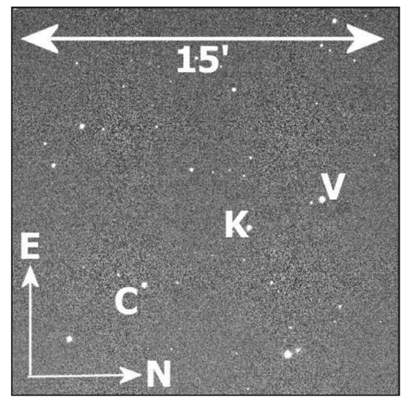

Figure 3. CW Scl finding chart. Variable (V), Comparison (C), and Check (K).

4. Period study

Three times of minimum light were calculated from our present observations, one secondary, and two primary eclipses:

HJD Min I = 2456939.60799 ± 0.0002,
2456976.62450 ± 0.0002
HJD Min II = 2456940.57227 ± 0.0006.

In addition, six observations at minima were determined from archived All Sky Automated Survey data:

HJD Min I = 2452177.603, 2452466.793, 2454404.752,
HJD Min II = 2453647.652, 2454669.843, 2455101.701.

The following linear and quadratic ephemerides were determined from all available times of minimum light:

$$\text{JD Hel Min I} = 2456976.6241 \pm 0.0005\ \text{d} + 0.38558774 \pm 0.00000008 \times E \quad (2)$$

$$\text{JD Hel Min I} = 2456976.6246 \pm 0.0003\ \text{d} + 0.38558897 \pm 0.0002 \times E + 0.000000000114 \pm 0.000000000016 \times E2. \quad (3)$$

The O–C curve shown in Figure 4 is a smoothly increasing quadratic over the course of 13.3 years and nearly 13,000 orbits. The table of O–C residuals, both linear and quadratic calculations, are given in Table 2. In a conservative scenario, the period is increasing so the mass ratio is becoming more disparate, where the more massive component is the gainer. According to the light curve solution the more massive component is presently 2.6 times that of the less massive one. The ephemeris yields a $\dot{P} = 3.03 \times 10^{-8}$ d / yr or a mass exchange rate of

$$\frac{dM}{dt} = \frac{\dot{P} M_1 M_2}{3P (M_1 - M_2)} = \frac{1.75 \times 10^{-8} M_\odot}{d.} \qquad (4)$$

It is commonly thought that the more massive component steadily absorbs the secondary during normal evolution. However, this short interval of increasing period in a solar type binary may be overcome by a secular period decrease due to magnetic braking. Alternatively, the curve seen in the O-C diagram may be a part of a sinusoidal oscillation due to a third body. More timings over a decade or more are needed to determine the actual nature of the current period change.

5. Light curves and temperature determination

The light curves were phased using Equation 2. These are given as Figures 5a and 5b. A table of light curve characteristics averaged at quadratures is given in Table 3. Photometry from the 2MASS All-Sky Catalog of Point Sources (2MASS; Skrutskie *et al.* 2006) gives J–K = 0.40. This is G5V, T ~ 5750 K (Cox 2000).

We used this value for the primary component in our light curve solution. The curve is of 0.8% to 1.0% precision in BVR_cI_c. The amplitudes of the light curves are 0.6–0.7 in magnitude from I_c to B. The O'Connell effect (magnitude difference in the maxima), classically thought of as an indicator of spot activity, is only 0.005–0.020 magnitude in all filters, and the Wilson-Devinney program (WD; Wilson and Devinney 1971) needed no spots to solve the light curves. But night-to-night variations are occurring as seen in the light curves. The difference between the primary and secondary minima is only 0.03–0.04 magnitude, indicating a high degree of physical and thermal contact. The WD solution indicates that the system is of W-type (the more massive star is cooler), but night-to-night variations show that the minima may be essentially equal. We believe that rapidly varying spots are inducing this complication. The indications are that this is an active contact binary.

6. Synthetic light curve solution

The B,V,R_c, and I_c curves were carefully pre-modeled with BINARY MAKER 3.0 (Bradstreet and Steelman 2002) fits in all filter bands. The parameters were then averaged and input into a four-color simultaneous light curve calculation using the Wilson code (Wilson and Devinney 1971; Wilson 1990, 1994, 2001, 2004; Van Hamme and Wilson 1998; Van Hamme and Wilson 2003). These fits were all contact binaries, so the solution was computed in Mode 3 (the contact mode). Circular and gravitationally locked orbits are assumed. Convective parameters, g = 0.32, (Lucy 1967), A = 0.5 (Ruciński 1969), were used. Since the eclipses were total, no q-search was needed to have fair results (Terrell and Wilson 2005). However, the referee wisely noted since there had been no previous determinations or observations that one should be conducted. Because of the total eclipse we ran a limited q-search from 0.2 to 1.0. It is shown in Figure 6. The mass ratio minimized at q ~ 0.44. Opening up the q-value along with all the other parameters, we determined a final solution. Third light was also tested, but only yielded both low order, positive and negative values, so it was abandoned. A geometrical representation of the system is given in Figures 7a, b, c, and d at quadratures so that the reader may visualize the configuration and relative size of the stars as compared to the orbit. The synthetic light curve solution is given in Table 4. The normalized curves overlaid by our light curve solutions are shown as Figures 8a and 8b.

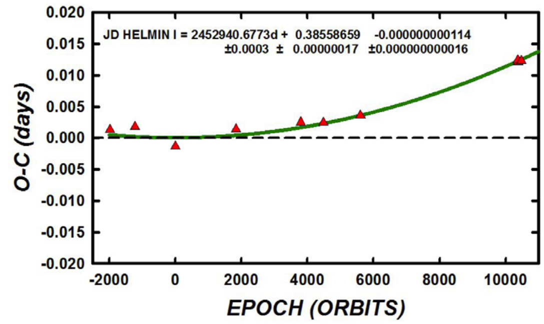

Figure 4. CW Scl. Quadratic O–C residuals from the period study.

7. Conclusion

CW Scl is a moderate period, P = 0. 38558897 (8) d W UMa eclipsing binary. The thirteen-year orbital study reveals an increasing quadratic ephemeris, which indicates that the binary's mass ratio is steadily becoming more extreme. 2MASS photometry gives a temperature for the primary component of ~ 5750 K for this G5V type variable. The Wilson-Devinney Program solution gives a mass ratio of ~ 0.4, and a component temperature difference of ~ 200 K. The system is probably magnetically active and the curve's night-to-night variation is on the order of V ~ 0.05 magnitude, as easily seen in the eclipse curve. The Roche Lobe fill-out is only 3% for this near critical contact binary. The inclination is 84° so that it is totally eclipsing, with an eclipse duration of ~19.5 minutes. The W UMa binary is of W-type (the less massive component is slightly hotter). This is the usual case for shallow contact binaries. It is thought to be due to the prevalence of spots on the larger component.

Further eclipse timings are need to affirm the orbital evolution found here. We finally note that radial velocity curves are needed to obtain absolute (not relative) system parameters.

8. Acknowledgements

We wish to thank the Southeastern Association for Research in Astronomy for allocation of observing time, and the Department of Natural Science, Emmanuel College for encouraging us to continue this undergraduate research.

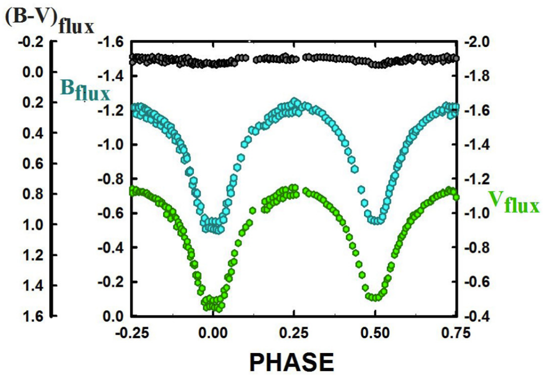

Figure 5a. CW Scl. B,V delta magnitude and color magnitudes vs. phase plots in the sense of V–C.

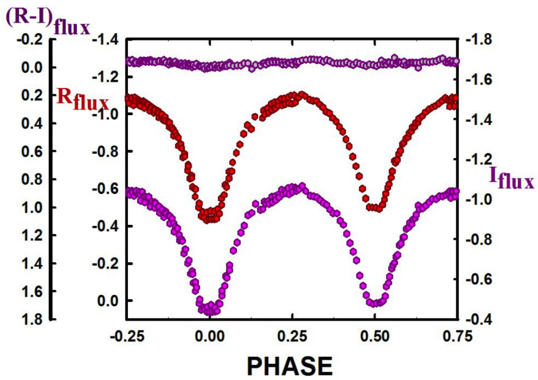

Figure 5b. CW Scl. R_c,Ic delta magnitude and color magnitudes vs. phase plots in the sense of V–C.

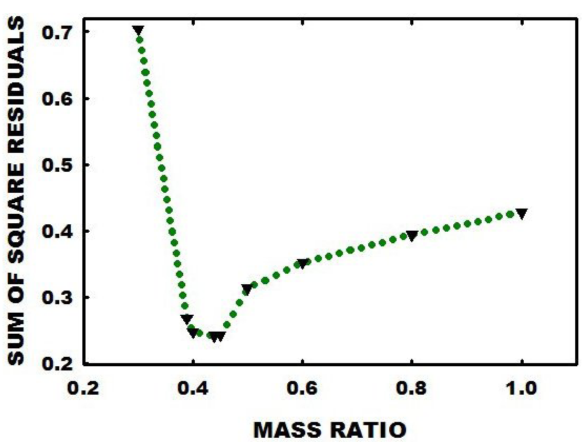

Figure 6. Q-search for CW Scl. The search minimizes at q ~ 0.44.

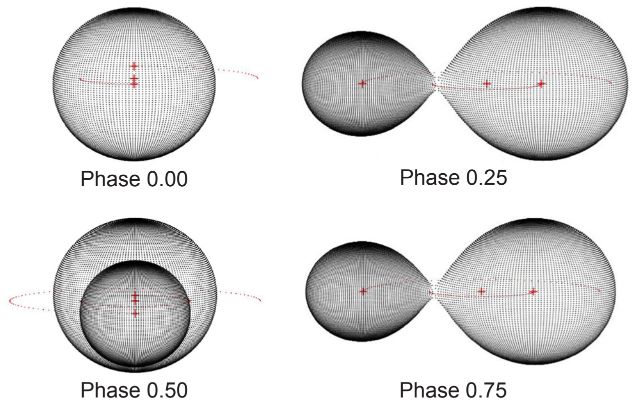

Figure 7. a: Roche Lobe surfaces from our BVRI solution, phase 0.00 (the primary eclipse). b: Roche Lobe surfaces from our BVRI solution, phase 0.25. c: Roche Lobe surfaces from our BVRI solution, phase 0.50. d: Roche Lobe surfaces from our BVRI solution, phase 0.75.

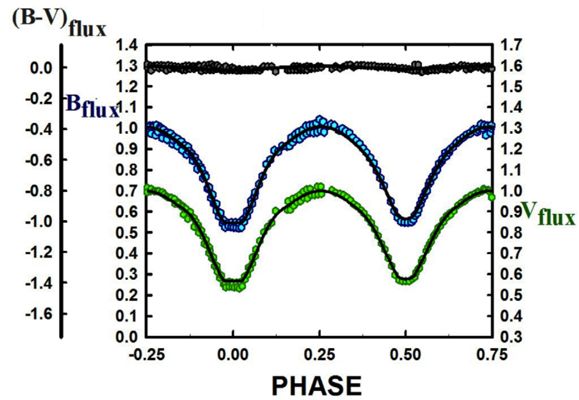

Figure 8a. B,V synthetic light curve solutions overlaying the normalized flux curves.

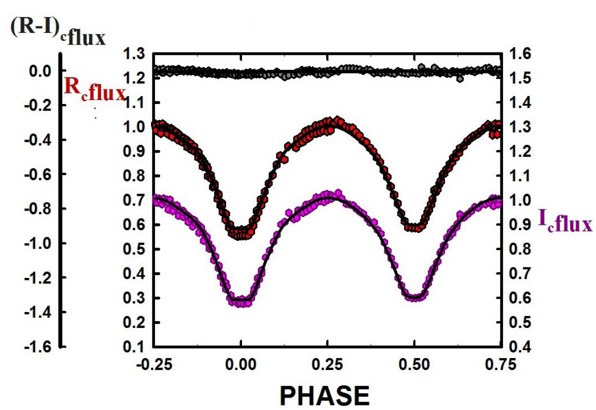

Figure 8b. Rc,Ic synthetic light curve solutions overlaying the normalized flux curves.

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Table 2. CW Scl observations ΔB, ΔV, ΔR, and ΔI, variable minus comparison star (Epoch 2400000+).

ΔB	HJD 2456930+	ΔB	HJD 2456930+	ΔB	HJD 2456930+	ΔB	HJD 2456930+	ΔB	HJD 2456930+
–1.187	9.4950	–1.001	9.6455	–1.138	10.5169	–1.201	10.6523	–1.059	46.5727
–1.205	9.5014	–1.029	9.6498	–1.121	10.5208	–1.226	10.6562	–1.023	46.5797
–1.217	9.5065	–1.084	9.6542	–1.095	10.5246	–1.221	10.6601	–0.971	46.5848
–1.206	9.5108	–1.076	9.6585	–1.071	10.5285	–1.219	10.6639	–0.910	46.5908
–1.215	9.5152	–1.108	9.6628	–1.040	10.5323	–1.220	10.6678	–0.837	46.5959
–1.213	9.5195	–1.156	9.6732	–1.007	10.5362	–1.218	10.6717	–0.765	46.6002
–1.188	9.5239	–1.173	9.6775	–0.959	10.5400	–1.219	10.6756	–0.721	46.6031
–1.204	9.5282	–1.187	9.6817	–0.910	10.5439	–1.221	10.6794	–0.661	46.6060
–1.181	9.5325	–1.196	9.6856	–0.856	10.5477	–1.212	10.6833	–0.612	46.6089
–1.174	9.5368	–1.218	9.6894	–0.737	10.5555	–1.199	10.6871	–0.545	46.6130
–1.143	9.5412	–1.221	9.6933	–0.659	10.5593	–1.184	10.6910	–0.508	46.6159
–1.143	9.5455	–1.223	9.6971	–0.598	10.5632	–1.178	10.6949	–0.518	46.6196
–1.128	9.5498	–1.232	9.7010	–0.563	10.5670	–1.161	10.6987	–0.512	46.6224
–1.112	9.5541	–1.251	9.7048	–0.556	10.5709	–1.150	10.7026	–0.507	46.6254
–1.079	9.5589	–1.239	9.7087	–0.555	10.5748	–1.135	10.7070	–0.504	46.6283
–1.046	9.5632	–0.580	9.8098	–0.560	10.5787	–1.114	10.7108	–0.500	46.6312
–1.017	9.5675	–0.637	9.8137	–0.617	10.5825	–1.103	10.7147	–0.507	46.6340
–0.982	9.5718	–0.715	9.8175	–0.670	10.5864	–1.066	10.7186	–0.562	46.6370
–0.934	9.5764	–0.778	9.8214	–0.748	10.5902	–1.043	10.7224	–0.611	46.6399
–0.848	9.5807	–0.820	9.8245	–0.808	10.5941	–1.006	10.7263	–0.663	46.6428
–0.790	9.5850	–0.884	9.8284	–0.867	10.5979	–0.968	10.7301	–0.717	46.6457
–0.717	9.5893	–0.922	9.8322	–0.913	10.6018	–0.918	10.7340	–0.776	46.6486
–0.640	9.5937	–0.967	9.8361	–0.958	10.6056	–0.843	10.7378	–1.108	46.6846
–0.571	9.5980	–1.018	9.8413	–1.003	10.6095	–0.787	10.7417	–1.110	46.6875
–0.549	9.6023	–1.070	9.8451	–1.034	10.6134	–0.712	10.7456	–1.130	46.6910
–0.553	9.6067	–1.072	9.8490	–1.050	10.6172	–1.169	46.5215	–1.148	46.6949
–0.552	9.6110	–1.216	10.4847	–1.087	10.6211	–1.182	46.5266	–1.148	46.6989
–0.550	9.6153	–1.226	10.4886	–1.103	10.6250	–1.178	46.5330	–1.165	46.7028
–0.583	9.6196	–1.220	10.4924	–1.126	10.6288	–1.169	46.5381	–1.178	46.7067
–0.656	9.6239	–1.196	10.4976	–1.143	10.6327	–1.154	46.5456	–1.185	46.7106
–0.743	9.6282	–1.203	10.5015	–1.157	10.6366	–1.146	46.5507	–1.182	46.7146
–0.806	9.6326	–1.191	10.5053	–1.172	10.6404	–1.122	46.5568	–1.186	46.7185
–0.867	9.6369	–1.180	10.5092	–1.180	10.6443	–1.111	46.5620	–1.194	46.7224
–0.923	9.6412	–1.156	10.5130	–1.197	10.6482	–1.085	46.5676	–1.186	46.7263

Table continued on following pages

Table 2. CW Scl observations ΔB, ΔV, ΔR, and ΔI, variable minus comparison star (Epoch 2400000+), cont.

ΔV	HJD 2456930+	ΔV	HJD 2456930+	ΔV	HJD 2456930+	ΔV	HJD 2456930+	ΔV	HJD 2456930+
–1.084	9.4830	–0.766	9.6339	–1.040	10.5181	–1.087	10.6416	–0.921	46.5813
–1.101	9.4884	–0.826	9.6383	–1.020	10.5220	–1.100	10.6455	–0.885	46.5864
–1.121	9.4962	–0.886	9.6426	–1.002	10.5258	–1.108	10.6494	–0.809	46.5923
–1.135	9.5028	–0.919	9.6469	–0.973	10.5297	–1.114	10.6535	–0.744	46.5974
–1.130	9.5079	–0.944	9.6512	–0.946	10.5335	–1.122	10.6574	–0.704	46.6010
–1.141	9.5122	–1.014	9.6555	–0.906	10.5374	–1.131	10.6613	–0.639	46.6039
–1.136	9.5166	–1.068	9.6694	–0.860	10.5412	–1.124	10.6651	–0.595	46.6068
–1.125	9.5209	–1.081	9.6746	–0.810	10.5451	–1.118	10.6690	–0.541	46.6097
–1.125	9.5252	–1.090	9.6789	–0.769	10.5489	–1.122	10.6729	–0.481	46.6139
–1.118	9.5296	–1.102	9.6829	–0.703	10.5528	–1.123	10.6768	–0.450	46.6167
–1.098	9.5339	–1.121	9.6868	–0.640	10.5567	–1.123	10.6806	–0.458	46.6204
–1.087	9.5382	–1.133	9.6906	–0.567	10.5605	–1.116	10.6845	–0.459	46.6233
–1.082	9.5426	–1.137	9.6945	–0.518	10.5644	–1.106	10.6883	–0.451	46.6262
–1.064	9.5469	–1.148	9.7022	–0.511	10.5682	–1.092	10.6922	–0.451	46.6291
–1.043	9.5512	–1.148	9.7060	–0.508	10.5721	–1.088	10.6961	–0.442	46.6320
–1.030	9.5555	–0.543	9.8110	–0.511	10.5760	–1.057	10.6999	–0.464	46.6349
–1.009	9.5602	–0.615	9.8149	–0.531	10.5799	–1.054	10.7038	–0.522	46.6379
–0.973	9.5645	–0.678	9.8187	–0.585	10.5837	–1.037	10.7082	–0.567	46.6408
–0.931	9.5689	–0.779	9.8257	–0.623	10.5876	–1.026	10.7121	–0.618	46.6436
–0.897	9.5732	–0.824	9.8296	–0.697	10.5914	–1.003	10.7159	–0.660	46.6465
–0.835	9.5777	–0.869	9.8334	–0.757	10.5953	–0.979	10.7198	–0.718	46.6494
–0.780	9.5821	–0.913	9.8373	–0.806	10.5991	–0.951	10.7236	–1.022	46.6855
–0.707	9.5864	–0.958	9.8425	–0.858	10.6030	–0.909	10.7275	–1.021	46.6884
–0.562	9.5951	–0.986	9.8463	–0.889	10.6068	–0.859	10.7313	–1.044	46.6921
–0.495	9.5994	–1.001	9.8502	–0.924	10.6107	–0.801	10.7352	–1.062	46.6961
–0.504	9.6037	–1.129	10.4898	–0.952	10.6146	–0.757	10.7390	–1.068	46.7000
–0.493	9.6080	–1.115	10.4936	–0.978	10.6184	–0.697	10.7429	–1.087	46.7039
–0.496	9.6123	–1.110	10.4988	–0.993	10.6223	–0.629	10.7468	–1.085	46.7078
–0.502	9.6167	–1.103	10.5027	–1.014	10.6262	–0.640	10.7468	–1.104	46.7117
–0.552	9.6210	–1.090	10.5065	–1.046	10.6301	–1.092	46.5282	–1.103	46.7157
–0.627	9.6253	–1.076	10.5104	–1.059	10.6339	–0.994	46.5692	–1.105	46.7196
–0.708	9.6296	–1.053	10.5142	–1.069	10.6378	–0.969	46.5743	–1.108	46.7236

ΔR	HJD 2456930+	ΔR	HJD 2456930+	ΔR	HJD 2456930+	ΔR	HJD 2456930+	ΔR	HJD 2456930+
–1.075	9.4996	–0.692	9.6306	–1.088	10.4829	–0.785	10.6000	–0.959	10.7168
–1.077	9.5045	–0.741	9.6349	–1.105	10.4868	–0.839	10.6039	–0.929	10.7206
–1.085	9.5089	–0.791	9.6392	–1.096	10.4907	–0.867	10.6077	–0.902	10.7245
–1.080	9.5132	–0.837	9.6435	–1.076	10.4958	–0.896	10.6116	–0.873	10.7283
–1.086	9.5175	–0.893	9.6479	–1.072	10.4997	–0.929	10.6154	–0.817	10.7322
–1.072	9.5219	–0.940	9.6522	–1.070	10.5035	–0.952	10.6193	–0.773	10.7360
–1.069	9.5262	–0.919	9.6565	–1.052	10.5074	–0.976	10.6232	–0.721	10.7399
–1.068	9.5305	–0.986	9.6608	–1.036	10.5113	–0.988	10.6271	–0.670	10.7438
–1.056	9.5348	–1.019	9.6712	–1.013	10.5151	–1.009	10.6309	–0.599	10.7477
–1.042	9.5392	–1.031	9.6755	–1.005	10.5190	–1.024	10.6348	–1.040	46.5191
–1.027	9.5435	–1.055	9.6798	–0.979	10.5228	–1.035	10.6386	–1.042	46.5242
–1.015	9.5478	–1.063	9.6838	–0.961	10.5267	–1.044	10.6425	–1.060	46.5305
–0.988	9.5522	–1.065	9.6876	–0.931	10.5305	–1.056	10.6464	–1.047	46.5357
–0.963	9.5569	–1.081	9.6915	–0.906	10.5344	–1.071	10.6506	–1.045	46.5432
–0.954	9.5612	–1.083	9.6953	–0.865	10.5383	–1.085	10.6544	–1.032	46.5483
–0.917	9.5655	–1.089	9.6992	–0.827	10.5421	–1.074	10.6583	–1.019	46.5544
–0.886	9.5698	–1.099	9.7031	–0.771	10.5460	–1.088	10.6621	–1.006	46.5595
–0.838	9.5744	–1.100	9.7069	–0.721	10.5498	–1.086	10.6660	–0.982	46.5652
–0.787	9.5787	–1.090	9.7108	–0.667	10.5537	–1.088	10.6699	–0.969	46.5703
–0.729	9.5830	–0.543	9.8119	–0.601	10.5575	–1.083	10.6738	–0.932	46.5773
–0.657	9.5874	–0.607	9.8157	–0.547	10.5614	–1.089	10.6777	–0.885	46.5824
–0.598	9.5917	–0.660	9.8196	–0.501	10.5652	–1.076	10.6815	–0.831	46.5883
–0.522	9.5960	–0.750	9.8233	–0.500	10.5691	–1.067	10.6854	–0.769	46.5935
–0.476	9.6003	–0.755	9.8266	–0.498	10.5730	–1.062	10.6892	–0.698	46.5988
–0.473	9.6047	–0.803	9.8304	–0.493	10.5769	–1.051	10.6931	–0.655	46.6017
–0.482	9.6090	–0.846	9.8343	–0.514	10.5807	–1.035	10.6969	–0.610	46.6046
–0.478	9.6133	–0.877	9.8395	–0.573	10.5846	–1.022	10.7008	–0.558	46.6075
–0.491	9.6176	–0.908	9.8433	–0.625	10.5884	–1.005	10.7052	–0.500	46.6116
–0.549	9.6219	–0.932	9.8472	–0.694	10.5923	–0.999	10.7091	–0.455	46.6145
–0.620	9.6263	–0.954	9.8510	–0.739	10.5962	–0.985	10.7129	–0.445	46.6182

Table continued on next page

Table 2. CW Scl observations ΔB, ΔV, ΔR, and ΔI, variable minus comparison star (Epoch 2400000+), cont.

Δ*R*	*HJD* 2456930+	Δ*R*	*HJD* 2456930+	Δ*R*	*HJD* 2456930+	Δ*R*	*HJD* 2456930+	Δ*R*	*HJD* 2456930+
–0.430	46.6211	–0.466	46.6357	–0.694	46.6503	–1.029	46.7009	–1.055	46.7206
–0.436	46.6240	–0.513	46.6386	–0.979	46.6861	–1.044	46.7048	–1.061	46.7245
–0.438	46.6269	–0.567	46.6414	–0.999	46.6891	–1.046	46.7087		
–0.438	46.6298	–0.609	46.6443	–1.007	46.6931	–1.052	46.7127		
–0.441	46.6327	–0.655	46.6472	–1.020	46.6970	–1.059	46.7166		

Δ*I*	*HJD* 2456930+	Δ*I*	*HJD* 2456930+	Δ*I*	*HJD* 2456930+	Δ*I*	*HJD* 2456930+	Δ*I*	*HJD* 2456930+
–1.033	9.5003	–0.921	9.6529	–0.949	10.5197	–1.023	10.6551	–0.879	46.5783
–1.041	9.5053	–0.933	9.6573	–0.931	10.5235	–1.041	10.6590	–0.839	46.5834
–1.040	9.5096	–0.978	9.6616	–0.930	10.5274	–1.039	10.6628	–0.795	46.5893
–1.030	9.5139	–0.989	9.6720	–0.894	10.5313	–1.041	10.6667	–0.730	46.5945
–1.034	9.5183	–0.991	9.6763	–0.873	10.5351	–1.044	10.6706	–0.681	46.5994
–1.042	9.5226	–1.014	9.6806	–0.829	10.5390	–1.042	10.6745	–0.629	46.6023
–1.027	9.5270	–1.017	9.6845	–0.783	10.5428	–1.035	10.6784	–0.583	46.6052
–1.017	9.5313	–1.025	9.6883	–0.739	10.5467	–1.037	10.6822	–0.542	46.6081
–1.007	9.5356	–1.048	9.6922	–0.696	10.5505	–1.038	10.6861	–0.481	46.6122
–0.990	9.5400	–1.044	9.6960	–0.619	10.5544	–1.012	10.6899	–0.447	46.6151
–0.986	9.5443	–1.056	9.6999	–0.568	10.5582	–1.013	10.6938	–0.451	46.6188
–0.966	9.5486	–1.062	9.7038	–0.522	10.5621	–0.990	10.6976	–0.437	46.6216
–0.946	9.5529	–1.058	9.7076	–0.486	10.5659	–0.980	10.7015	–0.438	46.6246
–0.928	9.5576	–0.485	9.8087	–0.477	10.5698	–0.965	10.7059	–0.437	46.6275
–0.915	9.5620	–0.516	9.8126	–0.480	10.5737	–0.951	10.7098	–0.441	46.6304
–0.879	9.5663	–0.583	9.8164	–0.484	10.5776	–0.941	10.7136	–0.442	46.6332
–0.856	9.5706	–0.654	9.8203	–0.493	10.5814	–0.920	10.7175	–0.479	46.6362
–0.801	9.5751	–0.683	9.8234	–0.566	10.5853	–0.905	10.7213	–0.518	46.6391
–0.750	9.5795	–0.722	9.8273	–0.615	10.5892	–0.865	10.7252	–0.568	46.6420
–0.694	9.5838	–0.780	9.8311	–0.671	10.5930	–0.823	10.7290	–0.608	46.6449
–0.628	9.5881	–0.811	9.8350	–0.714	10.5969	–0.792	10.7329	–0.646	46.6478
–0.559	9.5925	–0.860	9.8402	–0.771	10.6007	–0.751	10.7367	–0.947	46.6838
–0.500	9.5968	–0.876	9.8440	–0.810	10.6046	–0.696	10.7406	–0.952	46.6867
–0.460	9.6011	–0.908	9.8479	–0.852	10.6084	–0.641	10.7445	–0.981	46.6899
–0.462	9.6054	–0.969	9.8517	–0.883	10.6123	–0.587	10.7484	–0.977	46.6939
–0.472	9.6098	–1.055	10.4811	–0.900	10.6161	–1.008	46.5201	–0.986	46.6978
–0.460	9.6141	–1.051	10.4837	–0.924	10.6201	–1.015	46.5252	–0.996	46.7017
–0.480	9.6184	–1.067	10.4875	–0.949	10.6239	–1.024	46.5315	–1.009	46.7056
–0.544	9.6227	–1.041	10.4914	–0.956	10.6278	–1.017	46.5367	–1.026	46.7096
–0.617	9.6270	–1.019	10.4965	–0.970	10.6316	–0.993	46.5442	–1.032	46.7135
–0.670	9.6313	–1.015	10.5004	–0.985	10.6355	–0.986	46.5493	–1.027	46.7174
–0.745	9.6357	–1.011	10.5043	–1.003	10.6393	–0.964	46.5554	–1.037	46.7214
–0.784	9.6400	–0.996	10.5081	–1.002	10.6432	–0.959	46.5605	–1.043	46.7253
–0.833	9.6443	–0.982	10.5120	–1.015	10.6471	–0.934	46.5662		
–0.869	9.6486	–0.972	10.5158	–1.016	10.6513	–0.912	46.5713		

Table 3. Period Study Results, CW Scl.

No.	HJD 2400000+	Cycle	Linear Residual	Quadratic Residual	Weight	References
1	52177.6	–12446.0	0.0037	0.0009	0.3	ASAS 23801–3359.8 (ASAS 3)
2	52466.79	–11696.0	0.0034	0.0016	0.3	ASAS 23801–3359.8 (ASAS 3)
3	53647.65	–8633.5	–0.0005	0.0011	0.3	ASAS 23801–3359.8 (ASAS 3)
4	54404.75	–6670.0	–0.0017	0.0009	0.3	ASAS 23801–3359.8 (ASAS 3)
5	54669.84	–5982.5	–0.0025	0.0002	0.3	ASAS 23801–3359.8 (ASAS 3)
6	55101.7	–4862.5	–0.0027	0.0000	0.3	ASAS 23801–3359.8 (ASAS 3)
7	52940.68	–10467.0	–0.0012	–0.0013	1	Otero *et al.* 2004
8	56939.61	–96.0	0.0003	–0.0001	1	Present Observations
9	56940.57	–93.5	0.0006	0.0002	1	Present Observations
10	56976.62	0.0	0.0004	–0.0001	1	Present Observations

Table 4. Light curve characteristics.

Filter	Phase	Magnitude Min. I	Phase	Magnitude Max. II
	0.0		0.25	
B		–0.526 ± 0.023		–1.204 ± 0.024
V		–0.466 ± 0.024		–1.123 ± 0.022
R		–0.458 ± 0.008		–1.076 ± 0.019
I		–0.451 ± 0.013		–1.034 ± 0.010
Filter	*Phase*	*Magnitude Min. II*	*Phase*	*Magnitude Max. I*
	0.50		0.75	
B		–0.557 ± 0.002		–1.216 ± 0.019
V		–0.511 ± 0.002		–1.127 ± 0.015
R		–0.498 ± 0.003		–1.085 ± 0.018
I		–0.482 ± 0.018		–1.053 ± 0.010
Filter		*Min. I – Max. I*		*Min. I – Min. II*
B		0.69 ± 0.048		0.031 ± 0.026
V		0.66 ± 0.046		0.045 ± 0.025
R		0.63 ± 0.027		0.040 ± 0.011
I		0.60 ± 0.023		0.030 ± 0.031
Filter		*Max. II – Max. I*		
B		0.012 ± 0.044		
V		0.004 ± 0.037		
R		0.009 ± 0.037		
I		0.019 ± 0.020		

Table 5. CW Scl Light curve solution.

Parameters	Values
λB, λV, λR, λI (nm)	440, 550, 640, 790
xbol1,2 , ybol1,2	0.647 0.647 0.176 0.176
$x_{1I,2I}$, $y_{1I,2I}$	0.590 0.590 0.260 0.260
$x_{1R,2R}$, $y_{1R,2R}$	0.674 0.674 0.269 0.269
$x_{1V,2V}$, $y_{1V,2V}$	0.745 0.745 0.256 0.256
$x_{1B,2B}$, $y_{1B,2B}$	0.829 0.829 0.185 0.185
g_1 , g_2	0.32, 0.32
A_1 , A_2	0.5, 0.5
Inclination (°)	84.2 ± 0.3
T_1, T_2 (K)	5750, 5968 ± 9
Ω_1, Ω_2	2.749 ± 0.005
Pshift	0.5
q (m_2 / m_1)	0.439 ± 0.004
Fill-out (%)	3 ± 1
$L_1 / (L_1 + L_2)_I$	0.655 ± 0.002
$L_1 / (L_1 + L_2)_R$	0.651 ± 0.002
$L_1 / (L_1 + L_2)_V$	0.645 ± 0.002
$L_1 / (L_1 + L_2)_B$	0.631 ± 0.002
HJD_o (days)	2456976.6241 ± 0.00015
Period (days)	0.385578 ± 0.000002
r_1, r_2 (pole)	0.426 ± 0.001, 0.291 ± 0.002
r_1, r_2 (side)	0.454 ± 0.002, 0.304 ± 0.002
r_1, r_2 (back)	0.482 ± 0.002, 0.337 ± 0.004

Errors are from WD *full set standard deviations (formal errors). The temperature, T_1 is fixed from the 2MASS determination and may carry a 200–250 K error.*