OBSERVATIONS AND MODELS OF SOME NEGLECTED SOUTHERN ECLIPSING BINARIES*

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Abstract. Results of a photometric investigation of some photoelectrically neglected, southern eclipsing binaries, are presented for GW Car, X Car, and RS Sct. Light curve solutions obtained by the Wilson–Devinney and Wood synthetic light curve techniques are described.

1. Introduction

Photometric observations in the BVRI system were made of a selection of photoelectrically neglected, southern eclipsing binaries (Buckley, 1982). Of the six systems observed, reasonably complete light curves were derived for three; GW Carinae, X Carinae, and RS Scuti.

Attempts at determining parameters describing these binaries were made by solving light curves using the traditional approach of Russell and Merrill (1952). Results of these solutions were used to initialize parameters in the synthetic light curve codes of Wilson and Devinney (1971) and Wood (1971, 1972).

An overall consistent solution is presented for the early type (B1) short period system GW Carinae, as derived by both synthesis techniques. Preliminary solutions are also presented for X Car and RS Sct using the Wilson–Devinney program.

This paper summarises results obtained during an MSc thesis project at the University of Canterbury, New Zealand.

2. Observations

Observations were made using a cooled (−30 °C) RCA C31034A photomultiplier on a 61 cm Cassegrain reflector at Mount John University Observatory. Differential measurements were transformed into the standard Kron–Cousins BVRI system (Cousins, 1976). An individual observation consisted of the mean of three to five ten second integrations for each filter. Transformation coefficients were derived for most observing runs, while primary extinction was evaluated nightly. Two comparison stars for each program star gave a check against variations in the principal comparison star.

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3. Results

The reduced results in terms of H. J. D. vs differential magnitude are given in complete form elsewhere (Buckley, 1982, 1983). Reduced colors for the three complete systems were corrected for interstellar reddening. This was achieved using complementary photoelectric color indices found in the literature.

Times of minimum light were deduced for all the systems using the method of Kwee and van Woerden (1956). The O–C residuals were calculated using ephemerides from Kukarkin *et al.* (1969). These were used to determine periods based upon linear ephemerides and then to phase the observations. The results appear in Table I.

TABLE I

Times of minima and residuals

Star	T (Hel. JD–2440000)	Type	E	O–C (days)	P (days)
GW Car	4697.0326 ± 0.0002	I	12761	– 0.0402	1.128907 (9)
X Car	2785.1751	I	12865	– 0.0187	1.082629 (6)
	4343.0797 ± 0.0010	I	14304	– 0.0201	1.082629 (6)
	4612.116 ± 0.001	II	14552.5	– 0.0176	1.082629 (8)
RS Sct	4437.1674 ± 0.0010	I	29542	0.0370	0.664238 (3)
	4779.9125 ± 0.0005	I	30058	0.0368	0.664238 (4)

3.1. GW CARINAE

A photographic light curve was obtained and analysed by O'Connell (1956). His conclusion was that primary eclipse was a total occultation. He further surmised that the system may exhibit apsidal motion by virtue of a displaced secondary eclipse. Published photoelectric photometry includes *UBV* colors by Klare and Nekel (1977) and Garrison *et al.* (1983). Color indices in the $uvby\beta$ system have been published by Eggen (1978) for several phase angles, while Wolf's (1982) unpublished measurements are near both eclipses. Good agreement was achieved between results of this study and all other available data (Buckley, 1982, 1983). The values

$$(b-y)_0 = -0.120 \quad \text{and} \quad (B-V)_0 = -0.271$$

were derived using Eggen's (1978) color excesses. A B1 spectral type is consistent with these indices and this is in agreement with Garrison *et al.* (1977). An average primary effective temperature of

$$T_{\text{eff},1} = 25300 \pm 100 \text{ K}$$

was adopted from Bessell's (1979) calibration of T_{eff} vs $(b-y)_0$.

3.2. X CARINAE

Published work on X Car includes a determination of the system's parameters by Roberts (1905) from his observations. Sahade's (1952) spectroscopic analysis of rather blended lines resulted in estimates of the system's dimensions. Photoelectric color indices in the *uvbyβ* system have been obtained by Eggen (1978) and Wolf (1982).

Eggen and Wolf obtain a $(b - y)_0$ value of 0.020 and 0.026 respectively, implying a spectral type between A1 and A2. In this study a $(B - V)_0$ value of 0.06 ± 0.01 is derived using the same color excess as Eggen. This gives a somewhat later spectral type than A2.

The narrow band indices were adopted for determining temperatures. Eggen's (1978) $(c_1)_0$ value of 1.052 was used in Relyea and Kurucz's (1978) $(c_1)_0$ vs $(b - y)_0$ color-color diagram to estimate both temperature and gravity. These indices apply to primary eclipse and, hence, the secondary component by definition. However, the indices are all essentially equal for both eclipses in this system where the components are of similar temperatures. Bessell's (1979) calibration gave a slightly hotter temperature. The values were,

T_{eff}: 9100 ± 100 K log$g$: 4.1 + 0.1 dex Relya and Kurucz ,

T_{eff}: 9300 ± 100 K Bessell .

Eclipse times are presented in Table I together with Kvíz's (1983) time of minimum.

3.3. RS Scuti

Two visual light curves exist for RS Sct, an early one by Ichinoe (1915) and another by Tsesevich (1954). Numerous visual and photographic times of minima dating back to 1909 have been made. Piotrowski's (1936, 1949) compilation resulted in his conclusion that the scatter in the O–C values was larger than that which could be attributed to observational error. Kwee (1958) found that no linear ephemeris fitted the observations well.

In Table I the times of minima for RS Sct derived in this study are used to calculate the O–C values and, hence, revise the linear period. The initial ephemeris is again taken from Kukarkin *et al.* (1969). Piotrowski's (1936, 1949) compilation of timings were combined with timings found in IBVS publications and Koch's (1982) compilation to produce a residual plot against epoch. This diagram clearly shows what appears to be a non-linear secular change in period. Furthermore, there is a good deal of scatter, which a to a varying degree must be associated with systematic errors in visual timings.

The $(B - V)_0$, $(V - R)_0$, and $(V - I)_0$ color indices derived in this study were analysed together with Wolf's (1982) unpublished *ubvyβ* colors. The β-index at secondary eclipse indicates an F-type star is implied for the primary, as is reported in Wood *et al.* (1980). A recently obtained spectrum of RS Sct gave calcium H and K and hydrogen line strengths appropriate to an F4 to F5 star (Wolf, 1982).

Reddening in $(b - y)$ and $(B - V)$ was calculated using the method prescribed in Crawford and Barnes (1974) for A–F stars. The following dereddened indices were derived $(b - y)_0 = 0.245$, $(B - V)_0 = 0.386$, $(c_1)_0 = 0.569$. Hence, the temperature and gravities were estimated in the same manner as X Car, giving

$T_{\text{eff, 1}}$: 6900 ± 100 K log$g$: 4.0 + 0.1 Relyea and Kurucz ,

$T_{\text{eff, 1}}$: 6840 ± 80 K Bessell .

4. Synthetic Light Curve Solutions

Both the synthesis programs of Wilson and Devinney (1971) and Wood (1971, 1972, 1978) were used for solving light curves of GW Car. Lack of time precluded a similar analysis of X Car and RS Sct with both codes. Only the Wilson–Devinney (W–D) code was used on these systems. The choice of the synthesis techniques was dictated, in part, by reasons of expediency and utility.

Descriptions of the two models and solutions procedures will not be given here as they are adequately covered in the literature.

Initialization of parameters was achieved using results from Russell–Merrill analyses (Buckley, 1982, 1983).

4.1. GW CARINAE

Simultaneous solutions of the *B*, *V*, and *R* light curves were searched for using modes of detachment from contact, semi-detached to detached in the W–D code. The chief variable parameter set, used in the differential corrector, was inclination (i), secondary polar temperature (T_2), normalized gravitational surface potentials (Ω), mass ratio (q), and luminosities ($L_{1,2}$).

Runs in all modes resulted in the secondary becoming semi-detached and, hence, further work was conducted in this mode. After initial convergence, some second-order parameters; limb darkening ($x_{1,2}$) and primary albedo (A_1), were added to the variable set. Improvements to the solution resulted, and this is presented in Table II. Investigation of asynchronous rotation, by systematically changing the ratio of angular velocities (F), did not improve the solution.

Following the derivation of the W–D solution, Wood's (1972, 1978) program WINK was used to find solutions to the *B* and *V* light curves. The variable parameter set was taken as i, T_2, ratio of radii (k_v), unperturbed radius of primary (r_1), q, and the scaling factor m_{quad}. Other parameters were initialized from the W–D solution or theoretical values. Since WINK requires gravities for interpolation in the model atmosphere grid, a mass estimate for the system was made from Eggen's (1978) *uvbyβ* photometry of $15 M_\odot$. This was used with the W–D mass ratio to give radii using Kepler's law, and thence gravities.

Both the W–D and WINK solutions show good consistency. The latter solutions are detached, whereas the W–D solution gives the smaller cooler secondary as filling its Roche-lobe. The WINK solution for *V*, however, is very close to this model and a 0.06 decrease in q would bring the secondary in contact with its inner critical potential surface.

4.2. X CARINAE

The W–D solution for the *B* and *V* light curves was performed in a similar manner to the GW Car analysis. A detached model resulted with a mass ratio of unity, consistent with Sahade's (1952) estimate.

TABLE II

Photometric solutions

	RS Sct	X Car	GW Car			
W-D solutions					WINK	
	BVR	*BV*	*BVR*		*B*	*V*
i	87°.32 ± 0.56	87°.60 ± 0.21	89°.93 ± 0.47	i	88°.16 ± 0.46	90°.0 ± 1.4
k	0.788	0.951	0.852	k_v	0.846 ± 0.004	0.877 + 0.009
r_1	0.381	0.370	0.392	r_1	0.389 ± 0.002	0.392 + 0.002
$T_1(p)$	7000 ± 150 K	9500 ± 100 K	26470 ± 100 K	$T_1(e)$	25300 ± 100 K	25300 ± 100 K
$T_2(p)$	4749 ± 260 K	9500 ± 100 K	21160 ± 170 K	$T_2(e)$	20240 ± 100 K	20230 ± 100 K
Ω_1	3.501 ± 0.011	3.820 ± 0.011	3.214 ± 0.010	$L_1(t)$	0.779	0.767
Ω_2	3.734 ± 0.019	3.944 ± 0.014	3.0101	$L_2(t)$	0.221	0.233
q	0.774 ± 0.007	1.000 ± 0.005	0.571 ± 0.008	$L_1(a)$	0.691	0.661
g_1	1.0	1.0	1.0	$L_2(a)$	0.309	0.339
g_2	0.61 ± 0.44	1.0	1.0	q	0.812	0.722
A_1	1.0	1.0	0.6 ± 0.2	a	0.4280	0.4280
A_2	0.5	1.0	1.0	b	0.4000	0.4033
r_1				c	0.3793	0.3831
Pole	0.3605	0.3476	0.3732	a	0.3555	0.3792
Side	0.3768	0.3639	0.3898	b	0.3342	0.3503
Back	0.4005	0.3910	0.4092	c	0.3213	0.3367
Point	0.4323	0.4349	0.4329	u_1	0.319	0.354
r_2				u_2	0.304	0.330
Pole	0.2887	0.3338	0.3101	β_1	0.25	0.25
Side	0.2970	0.3474	0.3237	β_2	0.25	0.25
Back	0.3120	0.3692	0.3563	w_1	0.6 ± 0.2	0.6 ± 0.2
Point	0.3228	0.3984	0.4236	w_2	1.00	1.00
$L_1(B)$	0.933	0.517	0.689	rms	$0^m.0079$	$0^m.0077$
$L_1(V)$	0.896	0.519	0.677	ε	0.01%	0.01%
$L_1(R)$	0.874	–	0.676			
$x_1(B)$	0.76	0.49	0.319 ± 0.001			
$x_1(V)$	0.60	0.49	0.354 ± 0.033			
$x_1(R)$	0.49	–	0.449 ± 0.030			
$x_2(B)$	0.86	0.49	0.304 ± 0.120			
$x_2(V)$	0.70	0.49	0.330 ± 0.093			
$x_2(R)$	0.60	–	0.443 ± 0.115			
Σ Res^2	0.085	0.032	0.017			

Note: The second-order parameters (x, g, A and u, β, w) without errors are theoretical values from Grygar *et al.* (1972), Von Zeipel (1924), and Rucinski (1969).
t = total, a = apparent, p = polar, e = equatorial.

4.3. RS SCUTI

A simultaneous solution of B, V, and R light curves resulted in a detached configuration.

5. Conclusions

The good agreement between GW Car's solutions is encouraging. Clearly the lack of any spectroscopic evidence severely limits how far we can go in building a model. If the radii of the components are well determined, then a limit can be put on the mass ratio, namely

$0.57 < q < 1.15$. Main-Sequence configurations are admitted by both WINK solutions, within uncertainties. For the W–D solution, though, the secondary would appear to be some three times more luminous than a Main-Sequence object. An assumption in this argument is that the primary obeys the upper Main-Sequence mass-luminosity relation. An iterative procedure calculating the radius from Kepler's law and mass from the luminosity resulted in a primary mass of $9 \pm 1 M_{\odot}$.

If the semi-detached interpretation is correct, then GW Car may join the group of hot semi-detached binaries where the secondary is semi-detached. Similar systems include SX Aur (Chambliss and Leung, 1979) and V Pup (Popper, 1980).

The solutions for RS Sct and X Car are not as yet considered complete. Solutions are likely to be improved and recent work using both WINK and W–D on RS Sct indicates a tendency towards a semi-detached model.

Spectroscopic work is clearly a high priority for these systems. Garrison *et al.* (1977) reports GW Car as a double lined spectroscopic binary, and therefore appears ripe for an independent determination of its dimensions.

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