COMMISSIONS 27 AND 42 OF THE IAU
INFORMATION BULLETIN ON VARIABLE STARS

Number 5285

Konkoly Observatory
Budapest
3 June 2002

HU ISSN 0374 – 0676

THE CONTACT BINARY GSC 3551-1708: LIGHT CURVE ANALYSIS

NELSON, ROBERT H.[1,5]; ROBB, RUSSELL M.[2,5]; KAISER, DAN H.[3]; BILLINGS, GARY B.[4]

[1] College of New Caledonia, 3330 - 22nd Avenue, Prince George, BC, Canada, V2N 1P8, e-mail: nelson@cnc.bc.ca

[2] Department of Physics and Astronomy, Univ. of Victoria, Victoria, BC, Canada, V8W 3P6, e-mail: robb@uvic.ca

[3] 2631 Washington Street, Columbus, IN 47201 USA, e-mail: dhkaiser@sprynet.com

[4] 2320 Cherokee Drive NW, Calgary, Alberta, Canada T2L 0X7, e-mail: obs681@telusplanet.net

[5] Guest User, Canadian Astronomy Data Centre, which is operated by the Dominion Astrophysical Observatory for the National Research Council of Canada's Herzberg Institute of Astrophysics

Searches for optical transients by the ROTSE project (Akerlof et al., 2000) have discovered, as a byproduct, many new variable stars. The catalogue of these systems (> 1700 in number) and individual light curve data are available (`http://www.umich.edu/~rotse/`).

The ROTSE variable star J192211.80+492831.7 (= GSC 3551-1708) was chosen for study at the Climenhaga Observatory at the University of Victoria because the ROTSE light curve suggested it was a contact binary.

The automatic telescope system at the University of Victoria has been fully described elsewhere (Robb and Greimel, 1999) as have the telescope and equipment of DHK and GWB (Billings, et al., 2001).

Given in Table 1 are the J2000.0 positions and V magnitudes of the observed stars taken from the Guide Star Catalogue (Jenkner, et al., 1990). Also tabulated are the mean differences and standard deviations (σ) both during a night and between nights. From this we can see that the comparison star was constant to approximately 5 millimagnitudes during the time period of our observations. While the standard deviations of GSC 3551-1748 seem large, our data do not prove the variations are intrinsic to the star.

Table 1. Positions and magnitudes

Star	GSC 3551-	RA 19^h	Dec $+49°$	V	ΔR	σ Between	σ During	ΔI	σ Between	σ During
V*	1708	22^m11^s	28′34″	11.1	0.177	0.076	var	0.313	0.073	var
C	1771	22^m21^s	26′06″	11.2	–	–	–	–	–	–
K1	1977	22^m09^s	24′15″	12.3	1.679	0.004	0.011	1.696	0.005	0.013
K2	1835	22^m05^s	24′28″	13.1	1.940	0.005	0.014	1.884	0.006	0.012
K3	1575	21^m57^s	27′47″	12.9	2.191	0.010	0.022	2.248	0.012	0.017
K4	2084	22^m03^s	25′55″	14.2	2.653	0.010	0.025	2.402	0.010	0.022
K5	1468	22^m13^s	27′30″	14.1	2.645	0.014	0.023	2.474	0.007	0.022
K6	1748	22^m34^s	27′16″	13.9	2.630	0.036	0.040	2.533	0.033	0.031

Over the period 2001 October 4-28, light curves in R_c and I_c were acquired by RMR which contained one distinct time of minimum (ToM) in R. In addition, DHK and GWB obtained ToM in V and unfiltered light, respectively. Using Period98 (Sperl, 1998) we searched our R data for periodicity and found the period 0.59208(6) days, in good agreement with the ROTSE period of 0.59205(5) days (where the figures in brackets are the uncertainties, in units of the last digit).

These periods and uncertainties allow us to include the ROTSE ToMs with our own to further refine the period. All the available times of minimum are listed in Table 2 together with the $O-C$ values from the best-fit ephemeris:

$$\text{Min. I} = \text{HJD } 2452186.90143 + 0\overset{\text{d}}{.}5921376 \times E.$$
$$\pm 0.00010 \pm 0.0000005$$

with all ToMs weighted equally.

Table 2. Observed minima of GSC 3551.1708

Source	Type	HJD 2400000+	Error (Days)	Epoch	$O-C$
ROTSE	I	51257.8370	na	−1569	−0.0006
ROTSE	I	51286.8520	na	−1520	−0.0003
ROTSE	I	51311.7230	na	−1478	0.0009
RR	I	52186.9007	0.0002	0	−0.0007
DHK	II	52189.5671	0.0001	4.5	0.0011
GWB	II	52307.9932	0.0002	204.5	−0.0004

The R (455 points) and I (272 points) light data are plotted in Figure 1. The data were analyzed by the Wilson-Devinney (WD) light curve analysis program (Wilson and Devinney, 1971; Wilson, 1990) on a computer running Windows, using a Windows interface program, WDWint.exe[1], written by RHN.

The general appearance of the light curve suggested a contact binary; hence Mode 3, synchronous rotation ($F_1 = F_2 = 1.0$), and a circular orbit (e=0.0) were used. Since the maximum at phase 0.75 was some two percent dimmer than the maximum at phase 0.25, a spot solution was sought from the start. The Tycho catalogue (ESA, 1997) gave a colour index of $B-V = 0.38$ magnitudes and, assuming that interstellar reddening is negligible, this gives a spectral type of approximately F4 (Allen, 1973) and accordingly, a temperature $T_1 = 6820$ K was used (Flower 1996). Stellar masses and radii, taken to be main sequence values for an F4 star (Allen 1973), were used to calculate log g. Limb darkening values were found from van Hamme's tables (van Hamme, 1993), interpolated by Dirk Terrell's program (`http://www.boulder.swri.edu/~terrell/ld/`). The square root form for the limb darkening law was selected because of the assertion (van Hamme, 1993) that this is preferred over the logarithmic law for red and infrared wavelengths; it also gave lower residuals. Central wavelengths were assumed to be 6530 and 7890Å for R and I, respectively (Bessell, 1979). The light data were all assigned equal weights of 1.0.

Light curve synthesis (with a grid size integer of $N_1 = N_2 = 30$) was used to obtain a reasonable fit; the parameters adjusted were i, T_2, Ω_1, q, L_1 as well as the location, size and relative temperature of the spot(s). After that, differential corrections (with the same grid size) was applied on both R and I data simultaneously, using the method of multiple subsets (Wilson and Bierman, 1976); subsets used were (i, T_2, q), (i, T_2, Ω_1), (i, Ω_1, L_1), (Spot Longitude, Spot Radius, i), and (Spot Longitude, Spot Temperature Factor, i).

[1]This program speeds the WD modelling process greatly; it writes the input files for light curve synthesis (LC) and differential corrections (DC), runs the compiled WD code from the interface, and automatically displays output data in convenient tables and graphs. It is available to all who wish it at RHN's e-mail address above.

Because a star of spectral type F4 can be radiative at the surface, initial runs were made using the radiative mode; however this required two spots on star 2 and never reached a satisfactory solution. Once convective mode was selected, it was not necessary to cycle more than once or twice through the subsets; convergence was achieved in about a dozen runs. These initial runs assumed the stars radiated as black bodies, but later runs used the atmosphere option of WD which uses the Carbon and Gingerich atmospheres (Carbon and Gingerich, 1969).

A series of runs was attempted with a spot on star 1, but convergence could not be attained. Two spots on star 1 yielded some success, but this avenue was not followed nor was a solution involving a hot spot. A single spot on star 2 worked well.

Solutions obtained using the R and I light curves are displayed in Table 3. Note that the quoted errors are formal errors indicated by the WD software and the actual uncertainties may be larger. Synthetic light curves, produced by LC, are shown in Figure 1 (Upper: R band; lower: I band shifted down 0.2).

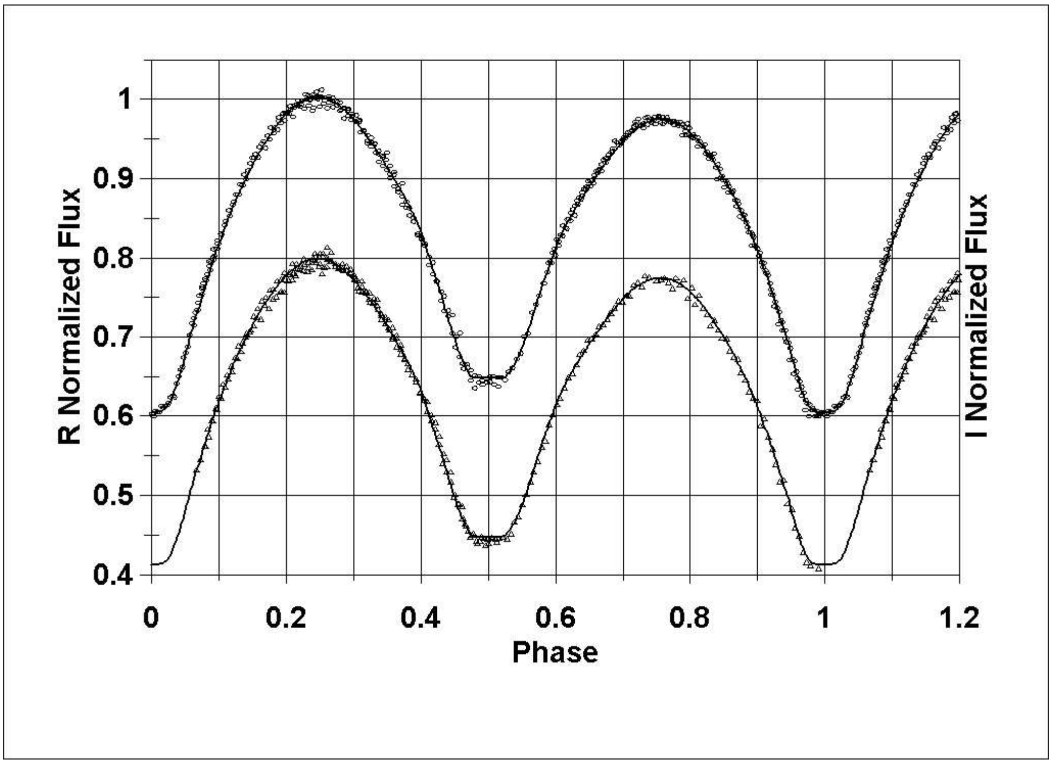

Figure 1. Phased R and I light data.

Table 3. Solution parameters

Quantity	Result	Error	Quantity	Result	Error
e	0.00	assumed	$\Omega_1 = \Omega_2$	2.390	0.004
$F_1 = F_2$	1.00	assumed	$q = M_2/M_1$	0.306	0.002
$g_1 = g_2$	0.32	assumed	$L_1/(L_1 + L_2)(R)$	0.753	0.001
$A_1 = A_2$	0.50	assumed	$L_1/(L_1 + L_2)(I)$	0.753	0.001
$x_1 = x_2$ (bol)	0.109	assumed	Spot Lat°	90	assumed
$y_1 = y_2$ (bol)	0.615	assumed	Spot Long°	280	11
$x_1 = x_2(R)$	-0.004	assumed	Spot Radius°	22	4
$y_1 = y_2(R)$	0.724	assumed	Sp Temp factor	0.71	0.07
$x_1 = x_2(I)$	-0.056	assumed	r_1 (pole)	0.473	0.001
$y_1 = y_2(I)$	0.688	assumed	r_1 (side)	0.514	0.002
ϕ	0.0007	0.0003	r_1 (back)	0.546	0.002
i°	81.8	0.2	r_2 (pole)	0.283	0.002
T_1 (K)	6820	assumed	r_2 (side)	0.298	0.003
T_2 (K)	6615	20	r_2 (back)	0.351	0.006

Inspection of the light curves reveals a flat-bottom at secondary minimum, indicating that this is an A-type W UMa system (Duerbeck, 1996), consistent with the assumed spectral type F4V. This system is reminiscent of V728 Herculis (Nelson, et al., 1995), but it has a lower mass ratio and different inclination. V728 Her is undergoing a steady period increase (Nelson, 1999), which means that mass is being transferred from star 2 to star 1 (thereby lowering the mass ratio). It would be prudent to monitor the period behavior of this system to see if it will have the same fate as V728 Her.

It is a pleasure for RHN to acknowledge the help that Dirk Terrell has provided in answering many questions, clearing up points in the WD modelling process, and reviewing the manuscript. Thanks to Peter Guilbault for translating the manuscript into Latex.

References:

Akerlof, C., et al., 2000, *AJ*, **119**, 1901
Allen, C.W., 1973, *Astrophysical Quantities*, (Univ. of London Press)
Bessell, M.S., 1979, *PASP*, **91**, 589
Billings, G. et al., 2001, *IBVS*, 5029
Carbon, D.F. and Gingerich, O. 1969 in *Theory and Observation of Normal Stellar Atmospheres*, ed. O. Gingerich, Cambridge, MA, MIT U. Press, p.377
Duerbeck, H.W., 1996, *Light Curves of Variable Stars, a Pictorial Atlas*, Cambridge
ESA, 1997, *The Hipparcos and Tycho Catalogues*, ESA, SP-1200
Flower, P., 1996, *ApJ*, **469**, 355
Jenkner, H., Lasker B., Sturch C., McLean B., Shara M., Russell, J., 1990, *AJ*, **99**, 2082
Nelson, R.H., et al., 1995, *AJ*, **110**, 2400
Nelson, R.H., 1999, *JAAVSO*, Vol. **27**, 26
Robb, R.M. and Greimel, R. 1999, *Asp. Conf.*, **189**, 198
Sperl M, 1998, Master's Thesis, Institut für Astronomie, Universität Wien
van Hamme, 1993, *AJ*, **106**, 2096
Wilson, R.E., and Devinney, E.J., 1971, *ApJ*, **166**, 605
Wilson, R.E. and Bierman, P. 1976, *A&A*, **48**, 349
Wilson, R.E., 1990, *ApJ*, **356**, 613