PUBLICATIONS OF
THE DAVID DUNLAP OBSERVATORY
UNIVERSITY OF TORONTO

VOLUME II NUMBER 8

SPECTROGRAPHIC ORBITS FOR THE ECLIPSING SYSTEMS V548 CYGNI, V805 AQUILAE AND V451 OPHIUCHI

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1962
TORONTO, CANADA

PRINTED AT
THE UNIVERSITY OF TORONTO PRESS

SPECTROGRAPHIC ORBITS FOR THE ECLIPSING SYSTEMS V548 CYGNI, V805 AQUILAE AND V451 OPHIUCHI

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Abstract

The orbital elements of these three eclipsing systems have already been published in an abstract by Heard and Morton (1956). These elements are unchanged in the present paper, but the observational data are here recorded in full, and the orbits are discussed in detail. Photometric elements are available for all three systems from the work of other authors. Thus, for the systems V805 Aql and V451 Oph, which are solved spectrographically for both stellar components, it has been possible to combine spectrographic and photometric results to obtain absolute values of diameters, masses and bolometric magnitudes.

V548 Cygni

This star, V548 Cygni, H.D. 189371, α (1900) 19^h $54^m.6$, δ (1900) $+54°32'$, m_{pg} 8.90–9.72, sp. A0, was once listed as an RR Lyrae variable (see I.A.U., 1951). The late Professor A. Colacevich observed it photoelectrically at Naples and recognized it as an Algol-type system with a period of about 1.8 days. Fresa (1956) has analysed the light curve resulting from the Naples observations and has determined elements of the photometric orbit.

During 1954 and 1955 thirty-six spectrograms of V548 Cyg were obtained here with dispersion 33 A./mm. The velocities from these were used to obtain the spectrographic orbit. The spectral lines are broad; on most of the plates only the hydrogen lines and λ3933 of Ca II and λ4481 of Mg II were measurable. Lines of the secondary spectrum were not seen with sufficient certainty for velocity measures.

The period reported by Fresa (1956), namely 1.805257 days, fitted our observations well and was accepted for our solution. The other elements were obtained first by the precomputed curves of R. K. Young, and then were corrected by a computer method of least squares reported by Heard and MacRae (1957). Table I lists the preliminary and final elements along with the mean errors; Table II lists the observed and computed velocities; figure 1 shows the velocity curve.

There is a contradiction between the value of ω (94°) derived here from the spectrographic data and the value, 316°, derived by Fresa

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TABLE I

ORBITAL ELEMENTS FOR V548 CYG

Element		Preliminary	Final	m.e.
Period	P	1.805257 days (Fresa)		
Eccentricity	e	0.10	0.11	± 0.03
Angle of periastron	ω	90°	94°	$\pm 17°$
Periastron passage	T	J.D. 2435336.356	J.D.2435336.383	± 0.084
Velocity of the system	γ	-22.5 km./sec.	-22.4 km./sec.	± 2.9
Semi-amplitude	K	68.5 km./sec.	66.7 km./sec.	± 1.9
$a \sin i$			1.65×10^6 km.	

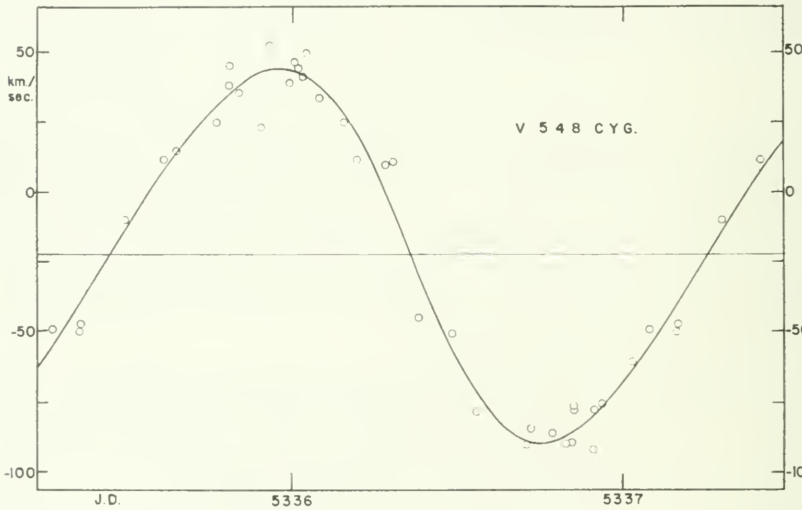

FIGURE 1.

(1956) from the photometric data, although our value of e agrees with Fresa's value of 0.10. Regardless of the fact that neither Fresa's nor our value of ω is very precise, the contradiction is inherent in the forms of the light curve and the velocity curve; in the light curve the secondary eclipse follows the primary by appreciably more than half the period, which is consistent with a value of ω in the general neighbourhood of 360°, whereas the velocity curve is almost precisely the form given by an orbit of $\omega = 90°$.

If we compute the time of the minima from our spectrographic elements and then use Fresa's period (over about 600 cycles) to compare these with his, we get:

For primary minimum, Fresa: J.D. 2434298.393
ours: J.D. 2434298.342
For secondary minimum, Fresa: J.D. 2434299.373
ours: J.D. 2434299.240

TABLE II

Radial Velocity Observations of V548 Cyg

J.D.	V_o km./sec.	Phase from final T	V_c km./sec.	$V_o - V_c$ km./sec.
2434932.789	−51.0	0.784	−40.3	−10.7
933.813	−44.4	0.003	−28.5	−15.9
934.730	−10.2	0.920	−15.1	+ 4.9
935.778	−78.4	0.162	−69.3	− 9.1
936.815	+24.7	1.199	+30.3	− 5.6
937.768	−84.5	0.347	−89.5	+ 5.0
938.780	+52.4	1.359	+43.1	+ 9.3
939.785	−75.9	0.559	−76.6	+ 0.7
946.779	−90.2	0.332	−89.1	− 1.1
947.683	+38.1	1.236	+34.5	+ 3.6
949.710	+40.9	1.457	+42.2	− 1.3
950.762	−49.2	0.704	−54.7	+ 5.5
956.746	+35.8	1.272	+38.0	− 2.2
957.755	−76.1	0.476	−85.2	+ 9.1
958.694	+39.2	1.415	+43.6	− 4.4
960.671	+25.3	1.587	+27.4	− 2.1
961.674	−47.8	0.785	−40.3	− 7.5
968.644	−92.3	0.534	−79.6	−12.7
2435083.461	+11.6	1.619	+21.3	− 9.7
262.819	−89.9	0.452	−86.9	− 3.0
280.831	−85.9	0.411	−89.0	+ 3.1
291.788	−78.1	0.537	−79.2	+ 1.1
292.757	+33.4	1.506	+38.5	− 5.1
301.712	+46.5	1.434	+43.1	+ 3.4
302.735	−60.9	0.652	−63.3	+ 2.4
335.653	+14.7	1.075	+12.3	+ 2.4
338.658	−89.9	0.470	−85.7	− 4.2
339.652	+49.6	1.464	+41.8	+ 7.8

TABLE II—*Continued*

J.D.	V_o km./sec.	Phase from final T	V_c km./sec.	$V_o - V_c$ km./sec.
2435341.698	+ 9.6	1.705	+ 0.9	+ 8.7
343.711	−50.6	0.107	−56.9	+ 6.3
350.747	+11.3	1.727	− 5.0	+16.3
353.669	+11.5	1.039	+ 6.3	+ 5.2
355.767	+23.0	1.332	+42.1	−19.1
356.719	−77.8	0.478	−85.0	+ 7.2
357.682	+44.4	1.441	+42.9	+ 1.5
373.724	+45.1	1.236	+34.5	+10.6

V805 Aquilae

This star, V805 Aquilae, H.D. 177708, α (1900) $19^{h}00^{m}.7$, δ (1900) $-11°48'$, m_{pg} 7.81–8.48, sp. A2, was identified as an Algol-type eclipsing variable by Bakos (1950) who assigned to it a period of 1.20409 days.

From photoelectric observations made at Naples in 1952 Fresa (1954) has found that there are two unequal minima and that the period is twice that assigned by Bakos. Fresa analysed the light curve and determined the elements of the photometric orbit.

Between July 10, 1953 and August 16, 1955, twenty-nine spectrograms of V805 Aql were obtained here with dispersion 33 A./mm. It is these which have been used to obtain the spectrographic orbit reported here.

Both primary and secondary spectra are visible, the primary considerably the stronger. In the primary spectrum many lines are measurable, but in the secondary the lines are so weak that only the few strongest of them could be measured near the phases of extreme velocities.

Fresa's period of 2.408230 days fitted our observations well; no attempt was made to improve it. From the velocity curve for the primary, preliminary elements were obtained by the use of R. K. Young's precomputed curves, and then least-squares corrections to five elements were obtained by a computer method of Heard and MacRae (1957).

As for the secondary component, the velocities were used only for the purpose of determining the value of K_2 by least squares, the other elements being regarded as fixed by the solution for the primary.

The preliminary and final elements are listed in Table III, the velocity curves are shown in figure 2, and the observed and calculated

TABLE III

Orbital Elements for V805 Aql

Element	Preliminary	Final	m.e.
Period	P 2.408230 days (Fresa)		
Eccentricity	e 0	0.018	±0.009
Angle of periastron	ω	37°±31°	
Periastron passage	T	J.D.2434959.513	±0.2
Velocity of the system	γ −39 km./sec.	−39.6	±0.7
Semi-amplitude, primary	K_1 107 km./sec.	106.2	±0.9
" " secondary	K_2 127 km./sec.	130.5	±5.7
$a_1 \sin i$, primary		3.5×10^6 km.	
$a_2 \sin i$, secondary		4.32×10^6 km.	

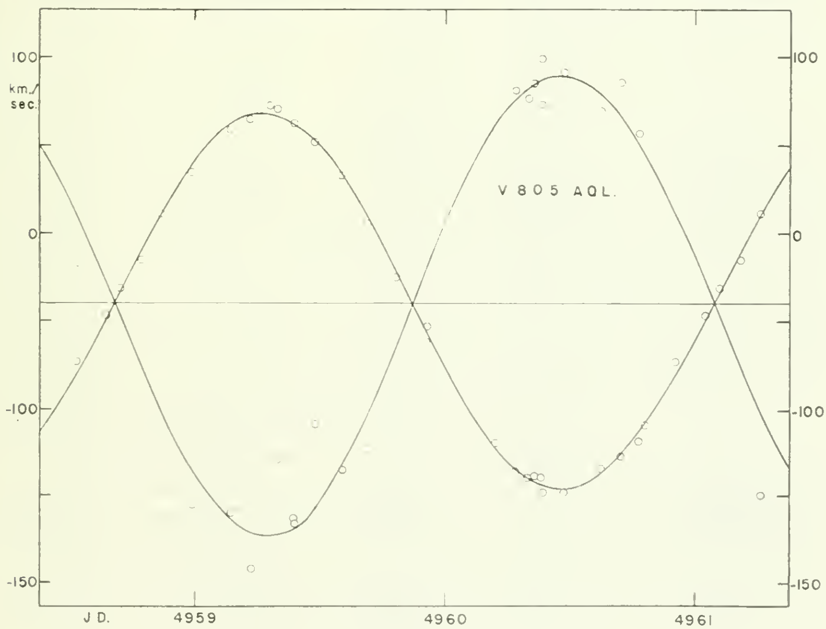

Figure 2.

velocities are listed in Table IV (in which the velocity of the primary component is always listed first).

When we compute the expected time of eclipses from the spectrographic orbit and compare them with Fresa's observed times (using his period), we find no significant discordance.

TABLE IV

RADIAL VELOCITY OBSERVATIONS OF V805 AQL

J.D.	V_o km./sec.	Phase from final T	V_c km./sec.	$V_o - V_c$ km./sec.
2434567.661	−119.0	0.690	−122.5	+ 3.5
568.722	+ 11.3	1.751	+ 9.8	+ 1.5
	−148.7		−100.3	−48.4
934.692	− 15.0	1.670	− 11.0	− 4.0
935.720	− 24.7	0.290	− 23.8	− 0.9
937.716	+ 62.3	2.286	+ 62.6	− 0.3
	−165.1		−166.4	+ 1.3
938.656	−138.9	0.817	−138.6	− 0.3
	+ 76.5		+ 82.1	− 5.6
939.709	+ 34.3	1.870	+ 36.3	− 2.0
	−154.4		−133.1	−21.3
946.649	− 30.8	1.586	− 33.5	+ 2.7
949.657	+ 72.6	2.186	+ 67.9	+ 4.7
950.653	−135.4	0.773	−134.4	− 1.0
	+ 81.0		+ 76.6	+ 4.4
958.634	− 46.9	1.530	− 48.6	+ 1.7
960.625	−133.0	1.112	−135.1	+ 2.1
	+ 70.3		+ 77.6	− 7.3
961.622	+ 65.0	2.109	+ 66.7	− 1.7
	−190.8		−170.4	−20.4
967.608	−138.2	0.871	−142.5	+ 4.3
	+ 99.2		+ 86.6	+12.6
971.619	+ 33.7	0.065	+ 33.8	− 0.1
	−133.7		−129.8	− 3.9
981.598	− 61.5	0.411	− 57.9	− 3.6
982.594	− 72.6	1.407	− 80.4	+ 7.8
2435006.531	−118.3	1.262	−112.4	− 5.9
	+ 57.1		+ 49.9	+ 7.2
261.828	−108.2	1.287	−107.5	− 0.7
262.762	+ 70.8	2.221	+ 67.1	+ 3.7
	−131.7		−170.6	+38.9

TABLE IV—*Continued*

J.D.	V_o km./sec.	Phase from final T	V_c km./sec.	$V_o - V_c$ km./sec.
2435279.765	+ 52.0	2.366	+ 53.2	− 1.2
	−108.1		−153.6	+45.5
280.770	−146.6	0.963	−144.2	− 2.4
	+ 90.5		+ 88.8	+ 1.7
291.729	+ 62.3	2.289	+ 62.5	− 0.2
	−162.2		−165.0	+ 2.8
292.692	−137.8	0.844	−140.3	+ 2.5
	+ 85.3		+ 84.1	+ 1.2
301.650	+ 7.1	0.169	+ 9.2	− 2.1
	−123.0		− 99.6	−23.4
302.675	−126.6	1.194	−124.1	− 2.5
	+ 85.5		+ 64.3	+21.2
321.624	−146.6	0.877	−142.7	− 3.9
	+ 73.2		+ 87.1	−13.9
327.593	+ 59.2	2.029	+ 60.8	− 1.6
	−157.9		−162.9	+ 5.0
335.610	− 52.6	0.414	− 58.8	+ 6.2

V451 Ophiuchi

The star V451 Ophiuchi, H.D. 170470, α (1900) $18^{h}24^{m}.5$, δ (1900) $+10°49'$, m_{pg} 7.86–8.46, sp. A0, was identified as an Algol-type eclipsing variable by Hoffmeister (1935). Colacevich (1953) studied the light variations in detail and determined photometric elements. At that time, on the basis of five radial velocities for 1936, 1939 and 1940 which were supplied to him by one of us (J. F. H.), he determined the amplitudes of the velocity variations of both components, and combined these with his photometric data to determine the dimensions, mass and absolute magnitudes of the stars.

Between 1952 and 1955, thirty-nine additional radial-velocity observations of this star were made here. The original five observations had been made with a dispersion of 66 A./mm.; most of the additional ones were made with 33 A./mm. dispersion and were much superior in quality. Of these higher dispersion spectrograms, twenty-three were selected on which double lines were clearly seen. These form the basis of the spectrographic orbit here reported.

All lines in the spectrum of both components are much broadened, so that only the stronger lines (those of hydrogen, λ3933 of Ca II and λ4481 of MgII) could be measured, and only at phases near the maxima of velocity could the double lines be resolved. The result is that the velocity curves are not distinguishable from sine curves; therefore the orbital eccentricity was taken as zero. (Colacevich, 1953, obtained $e = 0.025$ from the photometric orbit.) Furthermore, the velocity observations over the whole 16 years of our observations were well satisfied by Colacevich's period of 2.1965962 days; therefore the period was not included in our solution. Likewise Colacevich's epoch of primary eclipse, J.D. 2434165.499, was consistent with our velocity observations, and we assumed the corresponding epoch of the ascending node of the brighter component, namely J.D. 2434164.950 (or J.D. 2434237.438 as brought forward to the time of our observations). Therefore our least-squares solution was made for three unknowns only, namely the velocity of the system and the two semi-amplitudes of velocity. Table V gives preliminary and final elements so derived.

TABLE V

ORBITAL ELEMENTS FOR V451 OPH

Element	Preliminary	Final	m.e.
Period	P 2.1965962 days (Colacevich)		
Eccentricity	e 0		
Epoch of ascending node of primary component	J.D.2434237.438		
Velocity of the system	γ −15.0 km./sec.	−14.7 km./sec.	±2.0
Semi-amplitude, primary	K_1 120 km./sec.	121.1 km./sec.	±3.3
" " secondary	K_2 145 km./sec.	145.7 km./sec.	±3.3
$a_1 \sin i$, primary		3.66×10^6 km.	
$a_2 \sin i$, secondary		4.40×10^6 km.	

In a later section we give the values for the dimensions, masses and absolute magnitudes of the component stars as derived from a combination of the photometric and spectrographic elements. These are more accurate than those given by Colacevich (1953) who used very rough values of K_1 and K_2 derived, as stated above, from only five of our early observations.

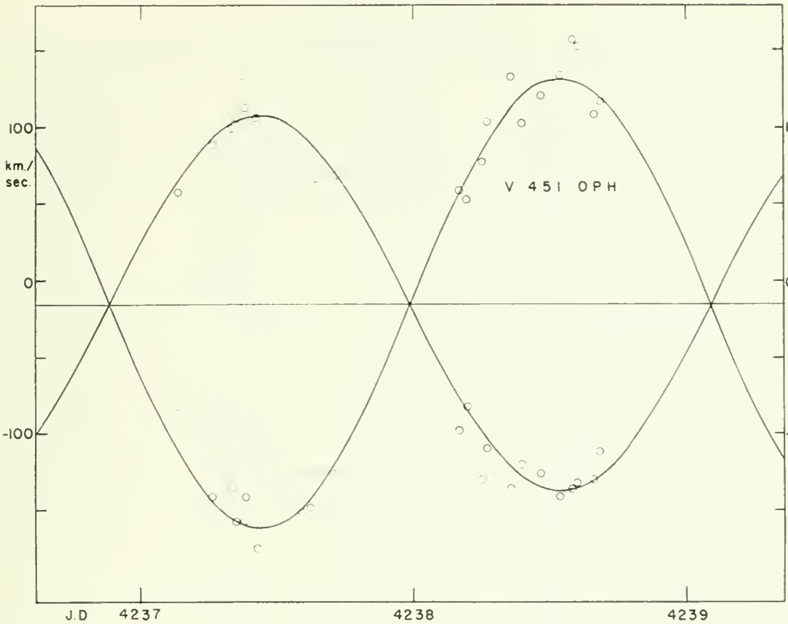

FIGURE 3.

Figure 3 shows the velocity curves, and Table VI lists the observed and computed velocities, the primary component being listed first in each case.

TABLE VI

RADIAL VELOCITY OBSERVATIONS OF V451 OPH

J.D.	V_o km./sec.	Phase from final T	V_c km./sec.	$V_o - V_c$ km./sec.
2434237.640	+ 65.9	1.850	+ 86.6	−20.7
	−124.0		−136.6	+12.6
238.678	−109.8	0.691	−126.0	+16.2
	+116.2		+119.2	− 3.0
242.647	−128.1	0.267	− 98.5	−29.6
	+ 77.4		+ 86.1	− 8.7
248.696	+ 68.4	1.923	+ 70.6	− 2.2
	−124.1		−117.4	− 6.7
249.640	−128.2	0.670	−128.6	+ 0.4
	+107.7		+122.4	−14.7

TABLE VI—*Continued*

J.D.	V_o km./sec.	Phase from final T	V_c km./sec.	$V_o - V_c$ km./sec.
2434251.641	−124.7	0.475	−133.1	+ 8.4
	+120.1		+127.7	− 7.6
252.638	+ 88.3	1.472	+ 92.0	− 3.7
	−140.4		−143.0	+ 2.6
543.681	−134.6	0.367	−119.7	−14.9
	+131.8		+111.7	+20.1
622.599	− 81.1	0.208	− 84.0	+ 2.9
	+ 53.0		+ 68.6	−15.6
623.681	+ 57.1	1.290	+ 48.4	+ 8 7
	− 81.8		− 90.7	+ 8.9
639.593	+ 75.3	1.826	+ 90.9	−15.6
	−146.8		−141.8	− 5.0
663.514	+132.6	1.584	+104.4	+28.2
	−155.9		−158.0	+ 2.1
664.525	−118.0	0.399	−124.8	+ 6.8
	+102.5		+117.8	−15.3
666.500	− 95.9	0.177	− 73.6	−22.3
	+ 58.3		+ 56.1	+ 2.2
685.487	+111.7	1.591	+104.8	+ 6.9
	−139.7		−158.5	+18.8
2435245.824	+ 72.7	1.796	+ 95.6	−22.9
	−150.3		−147.4	− 2.9
246.818	−134.1	0.594	−134.8	+ 0 7
	+157.0		+129.8	+27.2
269.748	+105.3	1.558	+102.5	+ 2.8
	−155.3		−155.7	+ 0.4
279 719	−139.4	0.546	−135.8	− 3.6
	+133.5		+131.0	+ 2.5
280.710	+ 98.4	1.537	+100.4	− 2.4
	−134.2		−153.2	+19.0
292.632	−107.6	0.279	−101.4	− 6.2
	+103.4		+ 89.6	+13.8
301.748	−130.2	0.609	−134.3	+ 4 1
	+152.5		+129.2	+23.3
302.776	+105.8	1.637	+106.4	− 0.6
	−174.7		−160 3	−14.4

Masses and Luminosities of V805 Aql and V451 Oph

When a binary system has been solved both photometrically and as a double-line spectrographic binary a rich harvest of information about the separate components becomes available, i.e.,

(*a*) the inclination, i, being known from the photometric solution, the orbital semi-axes, a_1 and a_2, may be determined from the spectrographic values of $a_1 \sin i$ and $a_2 \sin i$;

(*b*) thus, in turn, the sum of the masses may be computed, and, from the mass ratio, the individual masses;

(*c*) the stellar radii being known (in terms of the total orbital semi-axis, $a_1 + a_2$) from the photometric solution, and $a_1 + a_2$ being known from the spectrographic solutions, the stellar radii may be computed in absolute units;

(*d*) if the spectral type of the brighter component is known (and thus an effective temperature may be assigned) and if the ratio of the luminosities of the two components is known from the photometric solution, then it is possible, by an application of the Stefan-Boltzmann theorem, to compute values of the effective temperature (and thus spectral type) of the fainter component, and to assign the bolometric absolute magnitudes of both components.

For the two of these systems which show double lines, namely V805 Aql and V451 Oph, we have used our results along with those of the photometric solutions to obtain the data referred to above. These are given in Table VII in which the subscripts 1 and 2 refer to the brighter and fainter components respectively, and the symbols have the following meanings: m is the mass of the star; r is the radius;

TABLE VII

Physical Data for the Component Stars

	V805 Aql	V451 Oph
m_1	1.85 ⊙	2.38 ⊙
m_2	1.50 ⊙	1.98 ⊙
r_1	2.16 ⊙	2.51 ⊙
r_2	1.84 ⊙	2.01 ⊙
$sp._1$ (obs.)	A2	A0
T_{e_1}	9800°K	10700°K
$sp._2$ (comp.)	A7	A2
T_{e_2}	8000°K	9800°K
$M_{bol\ 1}$	+0.6	−0.1
$M_{bol\ 2}$	+1.8	+0.8
M_1	+1.2	+0.5
M_2	+2.2	+1.3

sp. is the spectral type, observed for the brighter component, computed for the fainter; T_e is the effective temperature either appropriate to the observed type or computed from the Stefan-Boltzmann theorem in the manner described by Plaut (1953); M_{bol} is the bolometric absolute magnitude computed in the manner of Plaut (1953); M is the "reduced" bolometric magnitude given by $M = M_{bol} + 2 \log (T_e/5200)$ which has been used by Petrie (1950) and Plaut (1953) in their discussions of the mass-luminosity relation.

When plotted on either Petrie's (1950) or Plaut's (1953) mass-luminosity diagram, the four values of mass and reduced bolometric magnitude lie close to the median of the points.

Acknowledgements

We wish to thank Dr. A. Fresa of the Osservatorio di Capodimonte, Naples, Italy, for helpful correspondence and discussions relating to the photometric solutions of these stars. We had also been indebted to the late Professor A. Colacevich for similar kindness.

This investigation was supported in part by a grant from the National Research Council, Ottawa.

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