

# SPECTROGRAPHIC OBSERVATIONS OF THE ECLIPSING BINARIES RZ COMAE, V 502 OPHIUCHI, RV CORVI, AND BF VIRGINIS\*

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## ABSTRACT

Two systems of the W UMa type—RZ Com and V 502 Oph—show double lines which lead to mass ratios of  $a = 2.1$  and  $a = 2.5$ , respectively. The individual mass functions are: for RZ Com,  $m_1 \sin^3 i = 1.58 \odot$ ,  $m_2 \sin^3 i = 0.75 \odot$ ; for V 502 Oph,  $m_1 \sin^3 i = 1.22 \odot$ ,  $m_2 \sin^3 i = 0.49 \odot$ . The large values of  $a$  show that one or possibly both components of the W UMa systems depart from the mass-luminosity relation.

The other two systems—RV Crv and BF Vir—have single lines, and their mass functions are  $f(m) = 0.033 \odot$  and  $0.025 \odot$ , respectively. These mass functions are small, and they show that even for periods as short as 0.75 and 0.64 day, respectively, we encounter the same difficulty of reconciling the Algol-type binaries with the “normal” spectroscopic binaries as we encountered previously for systems of longer periods. The former have systematically much smaller values of  $K_1$  than do the ordinary spectroscopic binaries. This, in turn, leads to the conclusion that very often the fainter companions of the typical Algol systems depart appreciably from the mass-luminosity relation: they are either too luminous for their mass or not sufficiently massive for their luminosity.

Previous investigations of the velocity-curves of short-period eclipsing binaries had led to several interesting conclusions.<sup>1</sup> The four stars investigated in May and June, 1948, at the McDonald Observatory were chosen from N. L. Pierce's *Finding List of Eclipsing Variables*.<sup>2</sup> The first two stars, RZ Comae and V 502 Ophiuchi, are apparently systems of the W Ursae Majoris type. The other two, RV Corvi and BF Virginis, have earlier spectral types, slightly longer periods, and greatly different depths of minima. All the spectrograms were obtained on 103a-O film with the  $f/2$  Schmidt camera and two glass prisms in the standard Cassegrain spectrograph attached to the 82-inch reflector. The dispersion was 76 Å/mm at  $H\gamma$ ; the slit width was usually 0.10 mm and the length of the slit was 2.5 mm. The projected width of the slit on the film was usually 0.018 mm. RZ Comae is so faint and so red that it was sometimes necessary to increase the slit width to 0.15 or 0.20 mm.

Table 1 gives the observing program, together with the relevant data from Pierce's catalogue. Table 2 contains in the third and fourth columns the photometric elements given in Schneller's last catalogue and used for the computation of the phases. The fifth and sixth columns give for comparison the elements from the first edition of the new Kukarkin and Parenago (1948) catalogue, which arrived too late to be used in this study. Photometric orbits are available for only the first two stars. That of RZ Comae was obtained by S. Gaposchkin.<sup>3</sup> He found  $L_b = L_f = 0.50$ ;  $r_b = r_f = 0.34$ ;  $i = 81^\circ$ . The eclipse is partial, and the ratio of the surface brightnesses is 1.0. The photometric orbit of V 502 Ophiuchi was obtained by A. Nekrassova.<sup>4</sup> She found:  $L_b = 0.73$ ;  $L_f = 0.27$ ;  $r_b = 0.51$ ;  $r_f = 0.35$ ;  $i = 75^\circ$ . The ratio of the surface brightnesses is 1.4.

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<sup>1</sup> *Ap. J.*, **106**, 92, 1947; *Ann. d'ap.*, **11**, 117, 1948. D. M. Popper has independently reached similar conclusions for the W Ursae Majoris stars. (See his paper in this issue.)

<sup>2</sup> *Contr. Princeton U. Obs.*, No. 22, 1947.

<sup>3</sup> *Variable Stars* (“Harvard Monograph,” No. 5 [Cambridge: Harvard University Press, 1938]), p. 70.

<sup>4</sup> *Astr. Circ. Acad. Sci. Soviet Union*, No. 21, p. 8, 1943.

The radial velocities of the first and fourth stars were measured by Struve. Those of the second and third by Gratton. The results are listed in Table 4. The scatter of the measurements is large in all four cases, and the material warrants only the determination of circular orbits. These are listed in Table 5.

TABLE 1  
THE OBSERVING PROGRAM

No.	STAR	1950		PERIOD (DAYS)	MAGNITUDE			<i>D</i> (HOURS)	<i>d</i> (HOURS)	SP	REMARKS	NO. OF SPEC- TRO- GRAMS
		$\alpha$	$\delta$		<i>M</i>	<i>A</i> <sub>1</sub>	<i>A</i> <sub>2</sub>					
1.....	RZ Com	12 <sup>h</sup> 32 <sup>m</sup> 35 <sup>s</sup> *	+23° 37'	0.34	10.0	0.7	0.7	.....	.....	.....	Ellipticity	33
2.....	V 502 Oph	16 38 48	+ 0 36	.45	8.0	0.5	.4	.....	.....	.....	Ref., ellipt.	31
3.....	RV Crv	12 34 09	-19 18	.75	9.0	1.0	.6	.....	.....	F0	P?	26
4.....	BF Vir	13 45 18	- 0 20	0.64	9.5	0.5	0.1	4	0	A0	P? ellipt.	29

TABLE 2  
PHOTOMETRIC ELEMENTS

No.	Star	Epoch JD	Period (Days)	Epoch JD	Period (Days)
1.....	RZ Com	2425005.524	0.3385057	5005.522	0.33850534
2.....	V 502 Oph	28684.493	.453405	Same	0.453419
3.....	RV Crv	29703.284	.74728	Same	Same
4.....	BF Vir	28313.306	0.639599	Same	Same

TABLE 3  
LIST OF STAR LINES

Element	$\lambda$	No. of Star	Element	$\lambda$	No. of Star
<i>Ca</i> II.....	3933.67	3, 4	<i>Sr</i> II.....	4215.52	3
<i>Fe</i> I.....	4005.25	3	<i>Ca</i> I.....	4226.73	1, 2, 3, 4
<i>Fe</i> I.....	4045.82	1, 2, 3, 4	<i>Sc</i> II+ <i>Fe</i> I.....	4325.39	2, 3
<i>Fe</i> I.....	4063.60	1, 2, 4	<i>H</i> $\gamma$ .....	4340.47	1, 2, 3, 4
<i>Fe</i> I.....	4071.75	1, 2, 4	<i>Fe</i> II.....	4351.77	3
<i>Sr</i> II.....	4077.71	1, 2, 3, 4	<i>Fe</i> I.....	4383.55	3
<i>H</i> $\delta$ .....	4101.74	1, 2, 3, 4	<i>Mg</i> II.....	4481.23	3, 4
<i>Fe</i> II.....	4178.34	3			

The spectral type of RZ Comae is approximately K0. The lines are exceedingly diffuse, but two spectra can be clearly discerned at the elongations. The material is not suitable for a critical determination of the spectral types of the two components. If there is a difference, it is not large. However, there appears to be a fairly pronounced variation in the intensities of the two components at the elongations. This phenomenon resembles that previously seen in the case of YY Eridani<sup>1</sup> and AH Virginis.<sup>5</sup> In the case of RZ Comae this phenomenon produces a tendency of the violet-displaced components to appear relatively stronger than the red-displaced components. There is a suggestion that the relative intensities of the two components are not always precisely the same in dif-

<sup>5</sup> Y. C. Chang, *Ap. J.*, 107, 99, 1948.

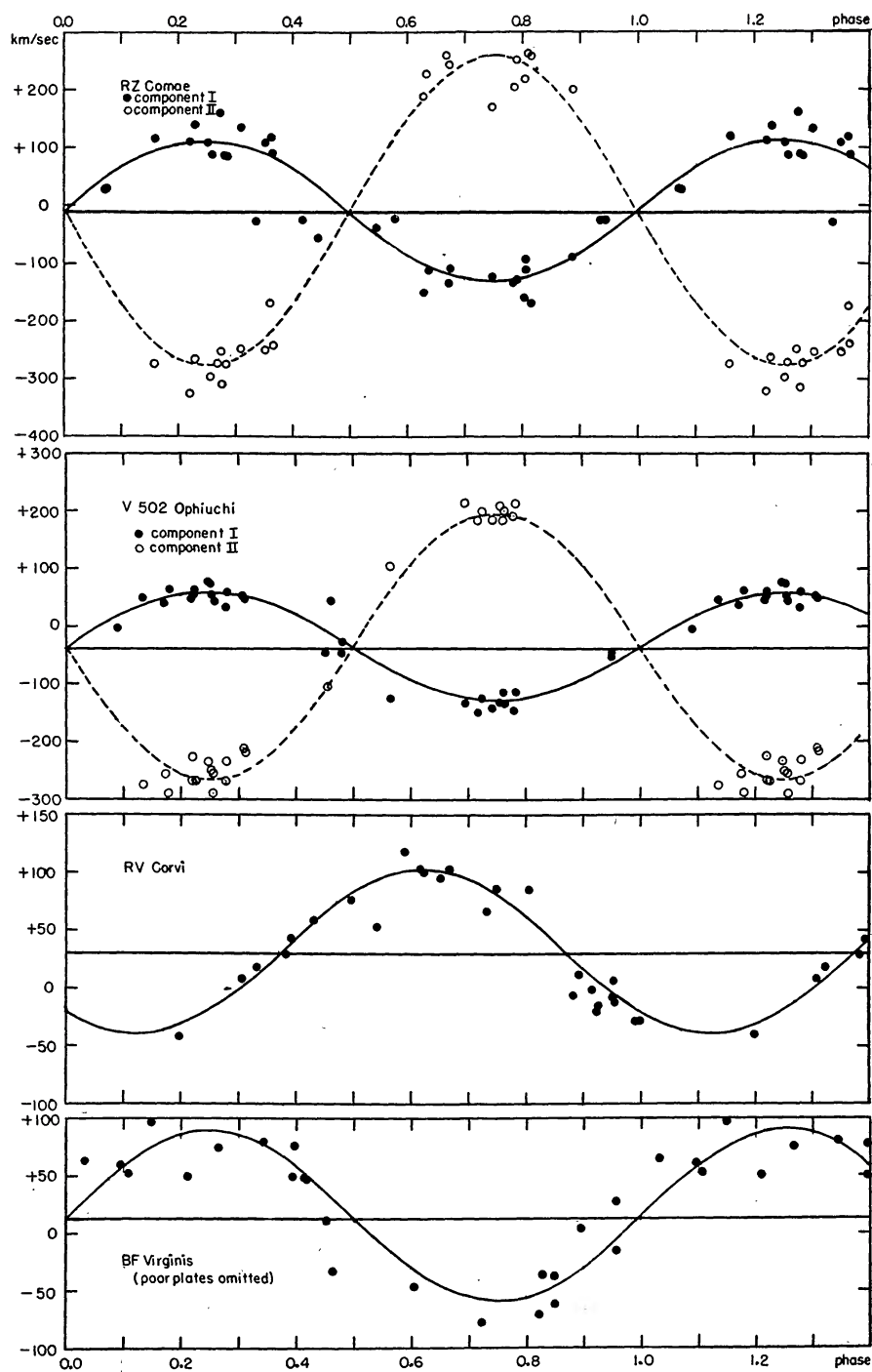


FIG. 1—Velocity-curves of four eclipsing binaries

TABLE 4  
RADIAL VELOCITIES  
RZ COMAE

PLATE	DATE (1948)	U.T.	PHASE		VELOCITIES (KM/SEC)	
			In Days	In Period	I	II
10846.....	May 2	3:05	0.273	0.806	-110	+222
10847.....	2	4:06	.316	.934	- 23	.....
10848.....	2	5:16	.025	.074	+ 28	.....
10849.....	2	6:43	.086	.254	+108	-298
10850P.....	2	8:16	.150	.443	- 58	.....
10862.....	5	2:50	.216	.638	-119	+231
10896.....	9	3:34	.185	.547	- 39	.....
10897.....	9	4:36	.228	.674	-115	+251
10904.....	10	2:54	.142	.419	- 29	.....
10926.....	12	2:58	.114	.337	- 26	.....
10940.....	14	2:51	.078	.230	+133	-262
10942.....	15	3:10	.075	.222	+114	-322
10943.....	15	4:20	.124	.366	+ 90	-239
10988.....	19	3:26	.024	.071	+ 29	.....
11004.....	25	3:25	.268	.792	-131	+249
11005.....	25	4:39	.320	.945	- 29	.....
11010.....	26	3:57	.276	.815	-169	+262
11021.....	27	4:57	.301	.889	- 87	+199
11048.....	29	3:55	.227	.671	-142	+266
11054P.....	30	3:56	.213	.629	-156	+188
11060.....	31	3:55	.196	.579	- 21	.....
11081.....	June 5	4:00	.123	.363	+120	-170
11094.....	7	4:40	.119	.352	+111	-250
11099.....	8	4:25	.093	.275	+163	-251
11110.....	9	4:51	.096	.284	+ 90	-270
11123.....	11	4:35	.054	.160	+117	-274
11150.....	16	3:24	.266	.786	-139	+204
11165.....	17	3:59	.274	.809	- 91	+266
11181.....	18	4:18	.272	.804	-156	+261
11199.....	19	4:13	.253	.747	-128	+172
11264.....	28	3:38	.088	.260	+ 88	-272
11270.....	29	4:07	.094	.278	+ 91	-309
11281.....	30	4:45	0.104	0.307	+134	-249

## V 502 OPHIUCHI

PLATE	DATE (1948)	U.T.	PHASE		VELOCITIES (KM/SEC)	
			In Days	In Period	I	II
10918.....	May 11	5:37	0.116	0.256	+ 43	-290
10929P.....	12	5:34	.207	.457	+ 41	-101
10930P.....	12	5:47	.216	.476	- 47	.....
10947.....	15	6:44	.082	.181	+ 62	-290
10962.....	16	5:19	.116	.256	+ 53	-256
10963.....	16	5:36	.127	.280	+ 60	-232
10964.....	16	5:56	.141	.311	+ 49	-216
10971.....	17	5:12	.204	.450	- 47	.....
10972.....	17	5:32	.218	.481	- 27	.....
10979.....	18	6:20	.345	.761	-114	+188
10990.....	19	6:10	0.431	0.951	- 44	.....

TABLE 4—Continued  
V 502 OPHIUCHI—(Continued)

PLATE	DATE (1948)	U.T.	PHASE		VELOCITIES (KM/SEC)	
			In Days	In Period	I	II
11006P.....	May 25	5: 39	0.061	0.135	+ 49	-273
11007P.....	25	6: 03	.078	.172	+ 39	-255
11022.....	27	5: 50	.256	.565	-125	+102
11036P.....	28	5: 47	.347	.765	-131	+202
11050.....	29	5: 32	.430	.948	- 50	.....
11055P.....	30	4: 51	.041	.090	- 2	.....
11061P.....	31	4: 40	.126	.278	+ 31	-269
11062.....	31	4: 58	.139	.307	+ 53	-211
11072.....	June 3	3: 10	.343	.756	-132	+212
11073.....	3	3: 27	.355	.783	-111	+214
11082.....	5	3: 43	.099	.218	+ 49	-225
11130.....	12	11: 22	.325	.717	-151	+185
11131.....	12	4: 38	.336	.741	-144	+185
11140.....	15	3: 07	.100	.221	+ 54	-268
11141.....	15	3: 24	.112	.247	+ 79	-233
11166.....	17	4: 44	.353	.779	-148	+192
11207.....	22	3: 32	.315	.695	-132	+216
11208.....	22	3: 50	.328	.723	-125	+200
11223.....	24	4: 48	.101	.223	+ 61	-270
11224.....	24	5: 06	0.114	0.251	+ 75	-249

## RV CORVI

PLATE	DATE (1948)	U.T.	PHASE		VELOCITIES (KM/SEC)
			In Days	In Period	
10852.....	May 4	2: 55	0.405	0.542	+ 53
10853P.....	4	3: 47	.441	.590	+117
10854.....	4	4: 23	.466	.624	+100
10855P.....	4	5: 10	.498	.666	+103
10863.....	5	3: 42	.690	.923	- 20
10864.....	5	4: 11	.710	.950	- 7
10889.....	8	2: 42	.660	.883	- 6
10890.....	8	3: 16	.683	.914	- 1
10891.....	8	3: 58	.712	.953	- 11
10892.....	8	4: 46	.746	.998	- 28
10914P.....	11	2: 38	.668	.894	+ 12
10915.....	11	3: 11	.691	.925	- 15
10927.....	12	3: 59	.229	.306	+ 9
10959.....	16	3: 14	.462	.618	+104
10960.....	16	3: 47	.485	.649	+ 95
10968.....	17	3: 10	.712	.953	+ 7
10969.....	17	3: 51	.740	.990	- 28
10976P.....	18	3: 45	.241	.322	+ 18
11074.....	June 3	4: 01	.559	.748	+ 86
11095.....	7	5: 37	.143	.191	- 41
11097.....	8	3: 00	.286	.383	+ 29
11121.....	11	2: 54	.293	.392	+ 43
11128.....	12	2: 57	.548	.733	+ 66
11164.....	17	3: 06	.323	.432	+ 58
11221P.....	24	3: 12	.601	.804	+ 85
11269.....	29	3: 14	0.372	0.498	+ 77

TABLE 4—Continued

## BF VIRGINIS

PLATE	DATE (1948)	U.T.	PHASE		VELOCITIES (KM/SEC)
			In Days	In Period	
10865.....	May 5	5:04	0.061	0.095	+ 60
10866.....	5	5:51	.094	.147	+ 97
10893.....	8	5:37	.525	.821	- 71
10898.....	9	5:46	.252	.394	+ 50
10905.....	10	4:01	.539	.843	- 37
10906.....	10	4:48	.572	.894	+ 4
10907.....	10	5:42	.610	.954	+ 28
10916P.....	11	4:02	.261	.408	- 24
10917.....	11	4:52	.296	.463	- 32
10928.....	12	4:57	.020	.031	+ 65
10941P.....	14	4:47	.094	.147	+ 66
10961.....	16	4:40	.170	.266	+ 75
10970.....	17	4:36	.529	.827	- 36
10977.....	18	4:42	.254	.397	+ 77
10978.....	18	5:34	.290	.453	+ 11
10989.....	19	5:16	.637	.996	+ 35
11049.....	29	4:52	.387	.605	- 46
11075.....	June 3	4:47	.267	.417	+ 47
11080P.....	4	3:23	.569	.890	- 78
11086.....	6	4:46	.069	.108	+ 52
11109P.....	9	3:21	.451	.705	- 30
11122.....	11	3:37	.543	.849	- 61
11129.....	12	3:40	.266	.416	+ 49
11133.....	13	3:17	.611	.955	- 15
11137P.....	14	4:17	.372	.582	- 53
11151.....	16	4:26	.461	.721	- 77
11198.....	19	3:23	.219	.342	+ 80
11222.....	24	4:09	.134	.210	+ 50
11280P.....	30	3:34	0.354	0.553	+ 4

TABLE 5

## ELEMENTS OF CIRCULAR SPECTROGRAPHIC ORBITS

No.	Star	Period (Days)	$V$ (Km/Sec)	$K_1$ (Km/Sec)	$K_2$ (Km/Sec)	$T_1$ (Min. Vel.)	$f(m)$ ○	$m_1$ ○	$m_2$ ○	$a_1 \sin i$ (Km)	$m_1/m_2$
1.....	RZ Com	0.34	-12	130	270	0.75 P	0.078	1.58	0.75	$0.61 \times 10^6$	2.1
2.....	V 502 Oph	.45	-37	95	235	.75 P	.040	1.22	0.49	$.59 \times 10^6$	2.5
3.....	RV Crv	.75	+30	75	.....	.12 P	.033	.....	.....	$.77 \times 10^6$	.....
4.....	BF Vir	0.64	+13	72	.....	0.70 P	0.025	.....	.....	$0.63 \times 10^6$	.....

ferent cycles, even though the phases within the cycle may be identically the same. The possibility of such a variation was suspected in the course of the observations, but there was no time to secure additional material to study it adequately. From the velocity-curve it will be seen that the more massive component is being eclipsed during the secondary minimum. Since in the case of this star the depths of the minima are very nearly the same, this is, of course, not physically significant. It is, however, important to know that the mass ratio of the two components is  $\alpha = 2.1$ . As in the cases of all other known

velocity-curves of W Ursae Majoris systems, this large ratio of the masses is incompatible with the mass-luminosity relation, because we know from the photometric orbits and from the appearance of double lines that the luminosities of the two components must be roughly the same, so that their masses cannot differ very greatly.

V 502 Ophiuchi has double lines which are appreciably broadened by rotation but are easier to measure than the lines of RZ Comae. The brighter star, which is in front at phase 0.0, is a G2 dwarf of class V: the fainter, which is in front at phase 0.5, is an F9 dwarf of class V. The hydrogen lines are quite strong but probably not unusually so for these spectral types. The velocity-curve resembles strikingly those of other stars of the W Ursae Majoris class. The more massive component is eclipsed at the secondary minimum; hence it is consistent with the photometric data that its spectral type should be later than that of the less massive component. The mass ratio  $\alpha = 2.5$  is unusually large even among the W Ursae Majoris systems. Although in this system one component is always stronger than the other, the difference between the luminosities of the two stars is not nearly sufficient to account for the large mass ratio if the mass-luminosity relation is to be used.

The spectrum of RV Corvi is F0. There are no appreciable variations in spectral type with phase. The velocity-curve shows a pronounced shift in phase from that computed with the elements of Table 2. A small correction in the period would suffice to produce the desired shift, which amounts to about 0.13 day. The spectrum of only one component is visible, and it is this component which undergoes eclipse at the phase nearest to zero.

The spectral type of BF Virginis is approximately A2. The  $H$  lines and  $Ca$  II are very strong.  $Ca$  I,  $Mg$  II 4481, and  $Fe$  I are fairly pronounced, but the lines of  $Fe$  II are very weak. The star is thus a representative of the group of relatively not very luminous A-type stars similar to those found in all other short-period systems of type A. The spectrum of only one component is visible. It is important to note that this component undergoes eclipse not at primary minimum, whose depth is 0.5 mag., but at secondary minimum, whose depth is only 0.1 mag. This phenomenon might tend to connect BF Virginis with the W Ursae Majoris systems, in which the same anomaly occurs whenever there is a measurable difference in the two photometric minima. The mass function of BF Virginis is small, as is that of RV Corvi. It is probable that there is no blending with the spectrum of the fainter component, so that we may conclude that the unusual tendency of the eclipsing variables to have small mass functions persists even among binary systems of periods of the order of  $\frac{2}{3}$  of a day.<sup>6</sup> The consequences of this tendency have been discussed elsewhere.<sup>7</sup> The representation of the observations would be improved by assuming a slightly shorter period.

<sup>6</sup> *Ap. J.*, **104**, 281, 1946.

<sup>7</sup> O. Struve, *Ann. d'ap.* **11**, 117, 1948.