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SPECTROSCOPIC ORBITS OF THE BINARY SYSTEMS
H.D. 128661, AR Cas, β Ari and H.D. 209813

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SPECTROSCOPIC ORBITS OF THE BINARY SYSTEMS H.D. 128661, AR Cas, β Ari and H.D. 209813

By Walter L. Gorza and John F. Heard

Abstract

From spectroscopic observations there have been obtained the orbital elements of two eclipsing binary systems (H.D. 128661, AR Cas) and two spectroscopic binaries (β Ari and H.D. 209813). For one system (H.D. 128661), no solution was previously available. The other systems are well known and were investigated for possible changes in their orbital elements. There seem to be no changes for AR Cas; a small change in the value of the longitude of periastron, ω, seems probable for β Ari; and there is some evidence of a change in the value of the semi-amplitude, K, for H.D. 209813.

Introduction

The spectrograms used during the present work were all obtained with the 12 Å/mm dispersion of the all-reflection grating spectrograph attached to the 74-inch telescope of the David Dunlap Observatory. The measurements were carried out on the Grant (AR Cas, β Ari and part of H.D. 128661) and Zeiss-Abbe (remaining plates for H.D. 128661 and H.D. 209813) comparators. Preliminary elements were derived by the use of a series of computed velocity-curves drawn by R. K. Young (except for β Ari, for which the Lehmann-Filhés method was used). Least-squares differential corrections were carried out on all the preliminary values by the use of a computer program written by D. Hube. The equation of condition derived by Lehmann-Filhés (1894) was used for all the systems, except for H.D. 209813 for which—its eccentricity, e, being so small—Sterne's (1941) method was used. The indicated errors are mean errors. The phases (given in the tables and used in the diagrams) are given in days relative to the finally adopted value for T, the time of periastron passage. Table IX (see page 110) shows the wavelengths used in obtaining the radial velocities for the four binary systems.

H.D. 128661

The variable radial velocity of this star ($\alpha = 14^h\ 33^m\!.1$, $\delta = +36°\ 22'$, $m_{ptg} = 6.97$, Sp. = A0) was first observed at the Simeis Observatory. Jackisch (1968) found that the star was probably an eclipsing variable with the minimum occurring at J.D. 2438906.455. Another minimum was observed by Harris (1969) to occur at J.D. 2440362.9070. Following the report by Jackisch, the star was placed on our observing program and altogether 52 spectrograms were obtained between February 8, 1969 and April 17, 1970.

By counting our radial velocity measures with the above-mentioned times of minima it was possible to obtain a very accurate period of 3.33284(2) days. The assumption was made that both minima are primary minima. This assumption seems to be justified inasmuch as only one component is visible on the spectrograms. The differential correction was carried out only on five elements, the period being held fixed. The observations are listed in Table I. Figure 1 (see page 102)

TABLE I

Radial-Velocity Observations of H.D. 128661

J.D. 2440000+	V_0 km/sec	Phase from Final T	O-C km/sec
260.827	−44.6	0.676	+0.9
268.950	+43.0	2.133	+2.7
269.938	−77.3	3.121	+2.7
270.928	−31.2	0.778	+0.1
271.896	+49.1	1.746	+1.8
273.932	−74.6	0.449	+1.3
274.853	+32.7	1.370	+0.8
282.842	−11.7	2.694	+4.3
283.815	−86.1	0.334	+2.4
284.778	+27.1	1.297	+0.6
285.763	+32.8	2.282	+2.0
290.784	−49.1	0.637	+1.8
296.712	−91.0	3.232	+0.9
307.860	+5.6	1.049	+2.8
317.811	+0.4	1.001	+3.1
323.882	−79.2	0.407	+1.7
325.618	+41.0	2.143	+1.2
331.735	+46.9	1.594	+3.4
341.647	+39.2	1.507	−0.7
346.732	−93.1	3.260	+1.0
353.593	−100.6	0.122	−0.2
364.699	+20.9	1.229	0.0
365.588	+41.9	2.118	+0.9
367.613	−26.6	0.811	+0.3
368.597	+48.4	1.795	+0.7
371.620	+36.4	1.485	−2.4
437.607	−28.4	0.815	−2.1
438.590	+46.8	1.798	−0.9
456.572	−78.0	3.116	+1.4
458.572	+46.4	1.783	−1.3
459.583	−31.8	2.794	−0.6
462.578	+14.8	2.456	+0.2
610.809	−44.6	0.709	−3.8
625.823	+19.3	2.392	−1.9
625.949	+7.5	2.518	0.0
629.917	−85.8	3.153	−1.9
640.822	−40.2	0.727	−1.8
641.899	+47.5	1.804	−0.3

TABLE I—*continued*

J.D. 2440000+	V_0 km/sec	Phase from Final T	O-C km/sec
646.753	−99.7	3.325	−1.5
646.951	−100.4	0.190	−1.9
654.820	+32.0	1.393	−1.4
655.885	+12.4	2.458	−2.0
657.907	+12.1	1.147	−1.1
658.874	+39.9	2.114	−1.3
660.806	−42.0	0.714	−1.8
664.834	+32.3	1.409	−2.1
665.785	+22.7	2.360	−1.6
673.858	−77.5	0.434	+0.2
675.792	+20.8	2.368	−2.7
676.840	−103.0	0.083	−2.4
689.737	−62.7	2.982	−2.1
693.743	−89.2	0.322	+0.4

shows the individual observations and the adopted velocity curve. The mean error of a single observation was found to be ±1.8 km/sec. Table II lists the preliminary and the final values for the elements.

TABLE II

ORBITAL ELEMENTS OF H.D. 128661

Element		Preliminary	Final	
P	(days)	3.33284(2)	3.33284(2)	
T	(J.D.)	2440263.460	2440263.484	±0.003
ω	(°)	165	166.5	±0.3
e		0.15	0.137	±0.005
K	(km/sec)	75.3	74.2	±0.4
γ	(km/sec)	−15.9	−16.5	±0.3
a sin i	(10^6km)		3.37	±0.02
f(m)	⊙		0.137	±0.002

H.D. 221253 (AR Cas)

AR Cas ($\alpha = 23^h\ 25^m.4$, $\delta = +58°\ 00'$, $m_{ptg} = 4.89$, Sp. = B3 V) was first observed to be a spectroscopic binary by Frost and Adams (1903). Photoelectric observations, first by Stebbins (1921), and then by Huffer and Collins (1962), show a similar value for the longitude of periastron, ω, while spectroscopic observations first by Baker (1909), then by Luyten, Struve and Morgan (1939) and Petrie (1944, 1962), show a changing value for ω, which would indicate a rotation of the line of apsides (Petrie, 1944).

Following receipt of Circular No. 1 for the "AR Cassiopeiae Coordination Programme", 44 spectrograms were here obtained between August 14, 1968 and September 12, 1969. The period of the system

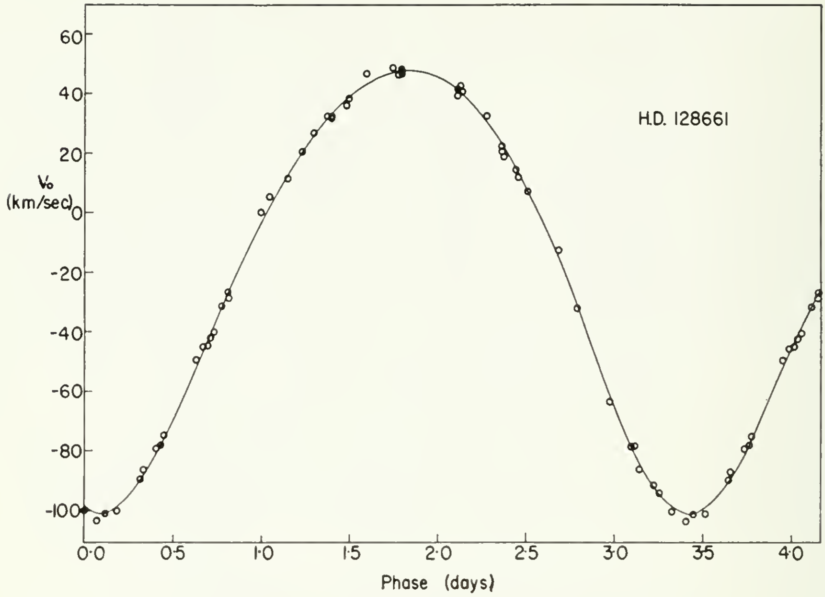

FIG. 1—Velocity Curve for the Eclipsing Binary H.D. 128661.

being known with great accuracy, it was held constant while the differential correction was carried out on the remaining five elements. The residuals were found to be reasonable except for those of three observations, which were made close to the time of the primary eclipse. It was easy to see that the radial velocities obtained at those points could have been influenced by the rotational velocity of the star itself (Batten, 1961), and accordingly they were removed. A new differential correction produced the final elements shown in Table IV. The observations are listed in Table III. Figure 2 shows the individual observations

TABLE III

RADIAL-VELOCITY OBSERVATIONS OF AR CAS

J.D. 2440000+	V_0 km/sec	Phase from Final T	O-C km/sec
82.730	−54.8	1.603	−2.8
83.716	−56.1	2.589	+0.3
84.590	−42.6	3.463	−2.7
95.773	−57.6	2.513	−0.5
98.706	+45.6	5.446	−3.4
100.825	−52.3	1.499	−2.9
102.925	−29.5	3.599	+6.4
103.710	−5.9	4.384	−0.5
104.849	+51.1	5.523	−0.5

TABLE III—*continued*

J.D. 2440000+	V_0 km/sec	Phase from Final T	O-C km/sec
106.827	−49.7	1.435	−2.2
107.731	−61.4	2.339	−3.3
108.693	−43.1	3.301	+1.1
111.812	+21.3	0.353	0.0
113.900	−53.4	2.441	+4.2
114.824	−46.7	3.365	−4.2
120.601	−52.6	3.076	−3.4
121.747	−11.7	4.222	+1.1
131.656	−56.2	1.998	+1.4
143.671	−57.5	1.881	−0.9
145.712	−32.3	3.922	−7.3
151.685	−27.9	3.828	+0.5
161.676	−54.5	1.687	−0.8
179.522	−41.5	1.334	+2.6
207.464	+29.6	5.010	+2.0
225.499	+18.8	4.846	+0.3
417.853	−50.7	3.078	−1.6
424.868	−20.9	4.027	+0.1
425.852	+29.5	5.011	+1.9
438.778	+52.2	5.804	−2.7
449.706	+5.8	4.599	+0.5
453.851	−50.4	2.678	+5.1
455.837	+8.5	4.664	−0.2
456.837	+60.3	5.664	+5.7
459.856	−52.3	2.617	+3.8
460.737	−36.1	3.498	+2.8
462.756	+49.2	5.517	−2.2
464.724	−45.2	1.418	+1.8
467.760	−1.7	4.454	+0.3
469.703	+24.1	0.331	+0.8
472.708	−44.8	3.336	−1.5
476.803	−44.4	1.365	+0.8
The following observations were not used to obtain the final solution.			
099.814	+8.1		
166.604	+13.8		
457.808	+18.8		

TABLE IV

ORBITAL ELEMENTS OF AR CAS

Element		Preliminary	Final	
P	(days	6.0663309	6.0663309	
T	(J.D.)	2440087.219	2440087.193	±0.013
ω	(°)	30	31.4	±0.8
e		0.22	0.245	±0.012
K	(km/sec)	56.5	56.7	±0.7
γ	(km/sec)	−10.3	−13.4	±0.5
a sin i	(10^6km)		4.59	±0.06
f(m)	⊙		0.095	±0.004

and the adopted velocity curve. The error of a single observation was found to be ±2.8 km/sec.

It can be seen that the value for ω here obtained (that is, $\omega = 31^\circ\!.4$) and the identical result obtained by Petrie in 1958 (Batten, 1968), together with the two photoelectric solutions by Stebbins ($\omega = 37^\circ\!.25$), and by Huffer and Collins ($\omega = 34^\circ \pm 5^\circ$), seem to rule out the suggestion that there is a rotation in the line of apsides. If, nonetheless, small variations in the value of ω are real, then, the suggestion by Batten (1960, 1961) that a third body may be present in the system would explain these variations and the variations that Batten found in the value of V_0, the systemic velocity.

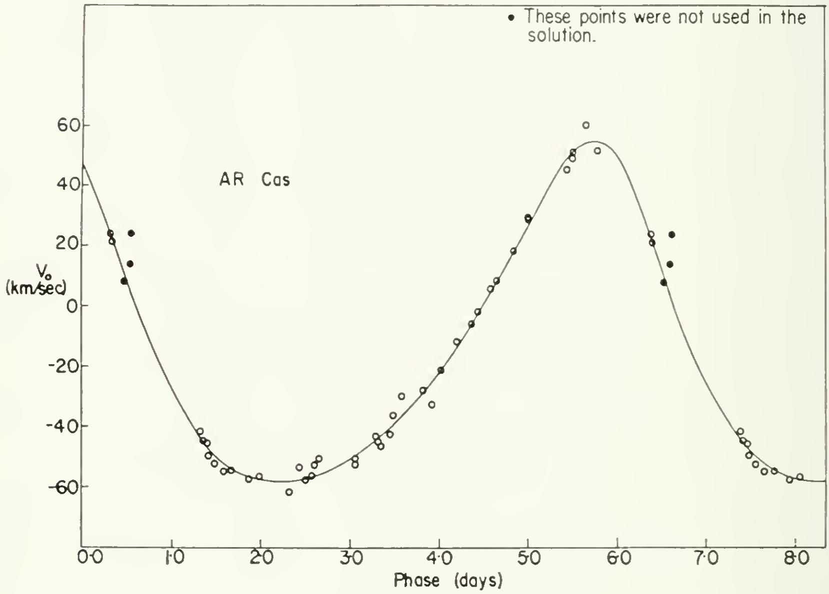

FIG. 2—Velocity Curve for the Eclipsing Binary AR Cas.

H.D. 11636 (β Ari)

The first spectroscopic orbital solution to this star ($\alpha_{1900} = 01^h\ 49^m\!.1$, $\delta = +20^\circ\ 19'$, $m_{ptg} = 2.86$, Sp. = A5) was obtained by Ludendorff (1907), and another by Petrie (1938). Because of the unusually large orbital eccentricity, Dommanget suggested that this may be an excellent system in which to observe the "periastron effect".

Following receipt of a list of binary stars in need of spectroscopic observation from Commissions 30 and 42 of the I.A.U., the star was placed on our observing program and 44 plates were obtained between August 31, 1968 and June 11, 1970. (On two occasions three plates were obtained very close together in time and were combined into normal places.) Since the period of the system is so very close to an integral number of days, no observations can be made at the present time, of the maximum point in the velocity curve from observatories in North America. This point now crosses the meridian during daylight, and it will be the end of the century before it will again cross the meridian at a time when observations can be made, as it was at the time of Petrie's observations. For this reason our preliminary elements were obtained with the help of some of Petrie's observations near the maximum point of the velocity curve. The least-squares differential correction, however, was carried out only on our own observations. The value for the period (as given by Petrie) was held constant. The observations are listed in Table V, while Table VI gives the preliminary and the final elements. Figure 3 shows the individual observations and the adopted velocity curve. The error of a single observation was found to be ±2.3 km/sec.

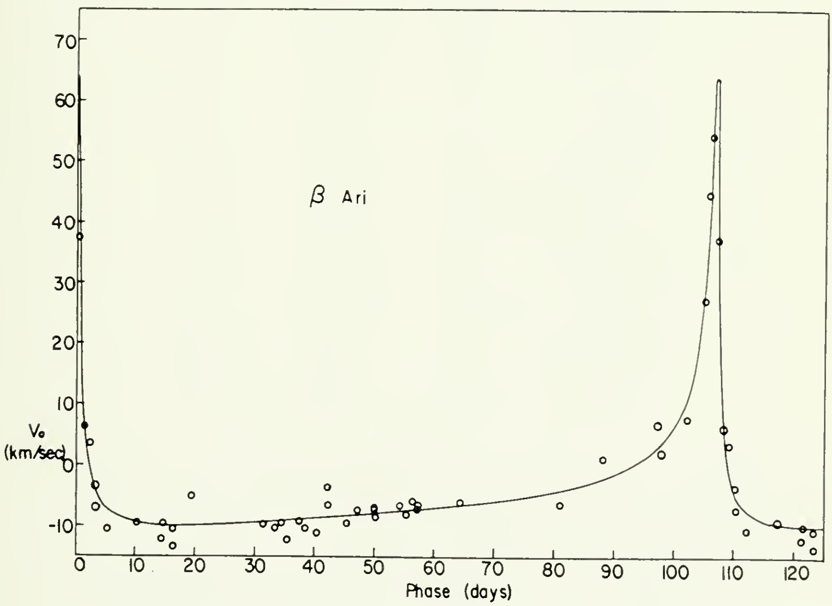

Fig. 3—Velocity Curve for the Spectroscopic Binary β Ari.

The value for ω obtained by Ludendorff is 21°88, that by Petrie 24°17 and the present one 20°01. Leaving aside Ludendorff's solution (only two lines at the most could be measured on each plate), and if the

TABLE V
RADIAL-VELOCITY OBSERVATIONS OF β ARI

J.D. 2440000+	V_0 km/sec	Phase from Final T	O-C km/sec
99.789	+27.6	105.385	−2.2
106.844	−10.6	5.443	−3.1
120.807	−4.8	19.406	+5.0
143.692	−3.4	42.291	+5.1
151.698	−8.6	50.297	−0.7
158.723	−7.0	57.322	+0.2
199.574	+2.3	98.173	−1.6
207.451	+45.1	106.050	+2.5
223.038	−9.4	14.639	+0.4
258.499	−7.1	50.100	+0.8
417.863	+8.0	102.467	−3.3
421.856	+54.6	106.460	−0.6
425.867	−6.9	3.474	−2.3
432.840	−9.3	10.447	+0.2
436.889	−12.1	14.496	−2.3
438.790	−10.5	16.397	−0.7
438.890	−13.3	16.497	−3.5
453.866	−9.7	31.473	−0.4
455.849	−10.6	33.456	−1.4
456.877	−9.5	34.484	−0.4
457.818	−12.2	35.425	−3.2
459.867	−9.2	37.474	−0.3
460.831	−10.4	38.438	−1.6
462.871	−10.9	40.478	−2.2
464.744	−6.5	42.351	+2.0
467.872	−9.5	45.479	−1.2
469.724	−7.3	47.331	+0.8
472.763	−7.2	50.370	+0.7
476.813	−6.5	54.420	+1.0
477.832	−7.9	55.439	−0.5
478.863	−5.6	56.470	+1.7
479.862	−6.5	57.469	+0.7
486.817	−6.1	64.424	+0.4
503.633	−6.3	81.240	−2.5
510.672	+1.5	88.279	+3.4
733.855	+7.1	97.467	+3.9
743.839	+37.4	0.454	0.0
744.839	+6.4	1.454	−0.9
745.849	+3.7	2.464	+4.8
746.851	−3.5	3.466	+1.1

TABLE VI
ORBITAL ELEMENTS OF β ARI

Element		Preliminary	Final	
P	(days)	106.9973	106.9973	
T	(J.D.)	2440208.286	2440208.398	±0.033
ω	(°)	25.5	20.0	±1.3
e		0.89	0.896	±0.003
K	(km/sec)	38.1	37.1	±0.9
γ	(km/sec)	−3.8	−4.0	±0.4
a sin i	(10^6km)		24.3	±0.7
f(m)	$\odot$		0.050	±0.004

criterion is used that only variations that exceed three times their probable error are real (Batten, 1968) then, since the mean error is $\pm 1\overset{\circ}{.}28$ (i.e. a probable error of $\pm 0\overset{\circ}{.}86$), it would appear that the variation in the value of ω—41°6 in 32 years—though small, may be real.

H.D. 209813

Four plates of this star ($\alpha = 22^h\,01^m0$, $\delta = +46°\,45'$, $m_v = 6.52$, Sp. = KO III) taken at this Observatory in 1935–37 showed it to be a spectroscopic binary, and from 39 plates taken in 1945–46 the late Miss Ruth Northcott (1947) computed an orbit using a period of 24.431 days derived with the help of the first four plates. The 1945–46 plates were from the prism spectrograph with dispersion of 33 Å/mm. On six of her plates which were strong in the violet region Miss Northcott was able to see H and K lines in emission and to measure the velocities; they appeared to follow the velocities from the absorption lines.

Blanco and Catalano (1968) observed a slight variability of the light of H.D. 209813 to which they at first assigned a period of 25.98 days. Not being aware that the star had been studied as a spectroscopic binary, they suggested that the star was probably a Cepheid variable. Fernie, Hube and Schmidt (1968) of this Observatory replied that there were reasons to doubt the Cepheid explanation, and that the light variations should be re-examined relative to Miss Northcott's period to see if an explanation could be found in terms of an eclipsing system. At the same time we put the star on our spectroscopic observing program for a second orbit determination.

From a combination of our 30 1968–70 observations (which are listed in Table VII) and Miss Northcott's 1945–46 observations we have improved the period to 24.4284 days. We then solved for the remaining elements which are shown in Table VIII. Also in this table are listed the results of a new solution for Miss Northcott's observations which uses the improved period. Figure 4 shows our observations and the velocity curve representing our elements.

A comparison of the new elements from the 1945–46 observations and the elements from the 1968–70 observations calls for the following comments. In view of the smallness of the eccentricity the differences in the values of e and ω are not regarded as necessarily significant. The difference in γ, the systemic velocity, finds an easy explanation in the fact that different spectrographs were used. The difference of 1.5 km/sec in the value of K, the semi-amplitude, may be significant; it is about three times the mean error of either determination, and on a plot of the two sets of observations it was quite apparent. If it is indeed real it is tempting to think of an explanation in terms of mass transfer

TABLE VII

RADIAL VELOCITIES AND *H* AND *K* EMISSION WIDTHS

J.D. 2400000+	V_{abs} km/sec	Phase from Final T Days	O-C km/sec	V_{em}	Em. Width km/sec
39999.974	−60.1	7.231	−3.1	—	—
40099.719	−47.6	9.263	+0.4	−48.4	68
40100.786	−41.4	10.330	−0.9	−49.7	—
40103.663	−16.2	13.207	−0.5	−14.4	70
40104.630	−7.6	14.174	0.0	−8.5	63
40107.835	+10.2	17.379	+0.4	+10.1	60
40112.717	−2.6	22.260	+1.9	0.0	67
40120.651	−57.8	5.766	+0.2	−60.7	59
40125.773	−36.8	10.888	−0.8	—	—
40133.664	+13.1	18.779	+2.2	+10.9	61
40140.688	−32.4	1.375	+2.3	−36.2	67
40143.588	−56.2	4.275	−2.2	−58.7	—
40151.647	−23.6	12.334	−0.2	−23.5	62
40161.647	−2.4	22.334	+2.7	−6.4	66
40179.579	+3.1	15.838	−0.6	+0.8	64
40424.809	+6.8	16.784	−1.2	+6.2	62
40459.784	−49.2	2.902	−2.8	−46.2	65
40486.762	−57.1	5.451	+0.5	−58.1	—
40779.822	−55.6	5.370	+1.8	−63.4	—
40794.653	+8.2	20.211	+0.7	+14.0	—
40800.783	−39.4	1.903	−0.3	−40.9	68
40804.799	−57.0	5.919	+1.1	−57.7	75
40820.774	−5.8	21.894	−3.9	+3.6	57
40866.724	+9.2	18.987	−1.5	+13.1	—
40869.513	−0.7	21.776	+0.4	+9.6	69
40878.644	−57.1	6.479	+1.0	−54.0	64
40879.692	−55.2	7.527	+1.0	−57.5	68
40883.679	−27.8	11.514	+2.8	−31.3	57
40895.481	−13.4	23.315	−0.4	−11.2	73
40896.600	−23.4	0.007	−0.6	−20.5	70

TABLE VIII

ORBITAL ELEMENTS OF H.D. 209813

Element		Preliminary	Final	Northcott's (re-computed)
P	(days)	24ᵈ4284	24.4284 ± 0.0005	24.4284 ± 0.0005
T	(J.D.)		2440017.170 ± 0.054	J.D. 2431661.692 ± 0.070
ω	(°)	0	89 ±15	73 ± 6
e		0	0.009 ± 0.003	0.026 ± 0.003
K	(km/sec)	35.3	34.6 ± 0.4	33.1 ± 0.6
γ	(km/sec)	−24.2	−23.6 ± 0.3	−22.2 ± 0.4
a sin i	(10^6km)		11.6 ± 0.2	11.1 ± 0.2
f(m)	$\odot$		0.105 ± 0.005	0.092 ± 0.005

The mean error of the period is estimated.

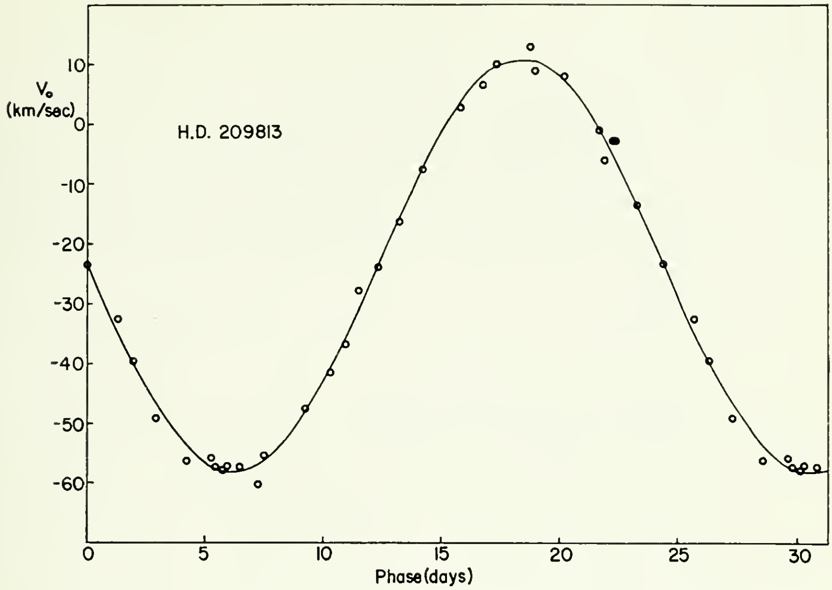

FIG. 4—Velocity Curve for the Spectroscopic Binary H.D. 209813.

between the components. Although it is difficult to belive that sufficient mass could be transferred in 24 years to affect the mass ratio by an observable amount, it may be that the elements are affected by a process of gas streaming which for this star changes its pattern with time. The idea that motion of this star's atmosphere plays a role in the measured radial velocities is suggested by the fact that a few of our residuals (O–C in Table VII) are larger than 2.5 km/sec. Such large residuals we have never encountered in our measures of spectrograms of standard-velocity stars with the 12 Å/mm spectrograph. Also the mean error of a single observation for H.D. 209813 is ± 1.6 km/sec compared with ± 1.1 km/sec for measures of standard-velocity stars.

We have been able to study the Ca II emission lines better than could Miss Northcott from her prism spectrograms. The velocities which we obtained from measures of H and K emission lines are listed in Table VII; the overall mean value of V_{abs}—V_{em} is -0.2 km/sec. Also we have measured the widths of the emission lines, the mean widths being listed in Table VII. The overall mean width is 65 km/sec. This gives for the star an absolute magnitude of $M_v = +0.8$ according to the correlation of Wilson and Bappu (1957). Neither the widths nor the differences between the H- and K- and the absorption-line velocities seem to correlate with the orbital period or any period near 24 days, and, in fact, we believe that the widths are constant and that the velocity differences between emission and absorption lines are zero.

To return to the question of the light variability of H.D. 209813, Blanco and Catalano (1970) in the light of new observations have revised their period from 25.98 days to 25.3 days, but they state that their photometric observations are not at all satisfied by the orbital period, and that there are changes in the light curves of 1967 and 1968 and also apparent fluctuations in the period. For these and other reasons they reject the suggestion that the light variations are associated with eclipses.

A model to explain the light variability and its period remains to be

TABLE IX

List of Wave-Lengths used in the Determination of the Radial Velocity for:

H.D. 128661		AR Cas		β Ari		H.D. 209813	
Fe I	3820.428	H16	3703.855	H16	3703.855	Mn I	4034.490
Fe I	3825.884	H15	3711.973	H15	3711.973	Mn I	4035.728
Fe I	3859.913	H14	3721.940	H14	3721.940	Mn I	4041.361
Fe I	3865.526	H13	3743.370	H13	3734.370	Mn I	4055.543
Fe I	3920.260	H12	3750.154	H12	3750.154	Gd II	4078.444
Fe I	3922.914	H11	3770.632	H11	3770.632	Fe I	4156.803
Fe I	3927.922	H10	3797.900	H10	3797.900	Fe I	4174.917
Fe I	3930.299	He I	3819.606	Fe I	3820.428	Fe I	4187.044
Ca II	3933.664	H9	3835.386	H9	3835.386	Co I	4190.712
Al I	3944.009	H8	3889.051	Si II	3856.021	Fe I	4199.970
Sr II	4077.714	Hϵ	3970.075	H8	3889.051	Fe I	4202.031
Si II	4130.876	He I	4009.270	Ca II	3933.664	Fe I	4210.352
Fe I	4181.758	He I	4026.140	Sr II	4077.714	Fe I	4219.364
Fe I	4202.031	Hδ	4101.738	Hδ	4101.738	Fe I	4233.608
Sr II	4215.524	He I	4143.759	Sr II	4215.524	Fe I	4238.816
Fe I	4250.125	Hγ	4340.466	Hγ	4340.466	Fe I	4239.847
Fe I	4271.764	He I	4387.928	Mg II	4481.228	Fe I	4245.258
Fe I	4383.547	He I	4471.477	S II	4549.550	Fe I	4271.764
Fe I	4404.752	Hβ	4861.332	Hβ	4861.332	Fe I	4325.765
Ti II	4468.493					Cr I	4359.631
Ti II	4501.449					Fe I	4375.932
Fe II	4508.283					Fe I	4383.547
Fe II	4515.337					Fe I	4389.244
Ba II	4554.926					Gd II	4390.953
Ti II	4571.971					Fe I	4442.343
Fe II	4583.829					Fe I	4447.722
Fe II	4629.323					Fe I	4459.121
						Fe I	4466.554
						Fe I	4476.021
						V I	4496.864
						Cr I	4526.466
						Cr I	4527.339
						Fe I	4528.619
						Co I	4533.985
						Ba II	4554.033
						Cr I	4565.512
						Fe I	4602.944
						Fe I	4934.023

found. Probably a discussion in terms of gas streaming within the geometry of the Lagrangian surfaces would be illuminating in this regard. Meanwhile it seems clear that H.D. 209813 belongs to a group of spectroscopic binaries which all show greatly enhanced H and K emission (Hiltner 1947; Gratton 1950; Abt, Dukes, and Weaver 1969). Whether or not these other systems show light variability of the type seen in H.D. 209813 is important in determining a general model for their behaviour, and such an investigation is currently being carried out by Mr. William Herbst at this Observatory.

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