VARIATIONS IN VELOCITY AND SPECTRUM OF EIGHT N-TYPE LONG-PERIOD VARIABLE STARS

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ABSTRACT

Coudé spectrograms have been obtained of the following variables: R Leporis, UV Aurigae, T Cancri, V Hydrae, V Coronae Borealis, RR Herculis, V Ophiuchi, and U Cygni.

The absorption-line velocities depend upon lines of the *CN* molecule. Small variations have been found for all eight variables; these variations have the periods of the light-variations but phases 0.25 earlier.

If pulsation is assumed to explain the velocity variation, maximum diameter approximates the phase of minimum light; minimum diameter, the phase of maximum light. On such an assumption the average change in diameter of these variables may not exceed 3 per cent, i.e., less than the percentage change in the diameters of cepheid variables.

Emission Hα has been observed in the spectra of all these variables except T Cnc. The weighted mean velocity difference ($H\alpha$ − Abs.) from the seven variables is −20.3 km/sec compared with the best previous determination, −20.5 km/sec. No certain variation of velocity with phase is shown by $H\alpha$.

Spectral changes. Emission $H\alpha$ is present from $0.25P$ before to $0.25P$ after maximum light and disappears for the remaining phase interval. There is marked enhancement of absorption lines of *Na* I, *Sc* I, *La* I, and *Y* I and of the bands of *CaCl* near minimum light for R Lep, UV Aur, RR Her, and U Cyg.

UV Aur is the only known class N variable with the bright [*Ne* III] and [*O* III] lines which characterize gaseous nebulae and, as postmaximum features, the emission lines of *Si* I, *Fe* I, *In* I, and *Mg* I, which characterize long-period Me variables.

Radial velocities for 283 stars of spectral classes R and N have already been published.[1] A number of these stars are long-period variables about as regular as the well-known long-period Mira variables of spectral class Me. Although there was a considerable range of individual velocities for some of these long-period variables of class N, it was uncertain whether this variation meant more than errors of measurement with the dispersion used (largely 65 A/mm). Hence in the catalogue only mean velocities were given for such variables.

But now the very fast Eastman 103*a*-E emulsion permits spectrograms (20 A/mm) to be obtained of some of these variables at all phases of their light-changes. The higher accuracy of the velocities with this greater dispersion made it worth while to reobserve a few of the brighter variables. A well-exposed coudé spectrogram of a class N star with the 103*a*-E emulsion gives good density from λ 6100 to λ 6700. Frequently, the D lines also are well shown.

The eight long-period variables of class N used for this study are in Table 1. The columns for maximum and minimum magnitudes give the extreme values observed for each; as with Me variables, different maximum and minimum magnitudes may occur in different cycles.

Except for those of the two variables UV Aur and RR Her, the spectrograms have been referred to the epochs of current maxima, by means of photometric data kindly supplied by Professor Leon Campbell, of the Harvard College Observatory. UV Aur has received scant attention from variable-star observers in recent years. It was therefore necessary to assume the period best fitting the two series of observations by M. Luizet[2] and by W. Doberck.[3] The Julian day of maximum and the period for RR Her are from the *Katalog und Ephemeriden veränderlicher Sterne* for 1940.

[1] *Mt. W. Contr.*, No. 689; *Ap. J.*, **99**, 145, 1944.

[2] *A.N.*, **196**, 399, 1913.

[3] *J. des observateurs*, **7**, 85, 1924.

RADIAL VELOCITIES

ABSORPTION-LINE VELOCITIES

Certain atomic lines are fairly well seen in the spectra of some class N variables at all phases; other atomic lines may be strong at minimum and weak or absent at maximum light, but the details of the molecular absorption spectrum of *CN* are always prominent. Hence, for uniformity, it seemed best to base the radial velocities upon suitable lines chosen from the ever present spectrum of *CN*.

To this end, isolated lines of good quality were selected in the region from λ 6100 to λ 6700 on spectra of the carbon arc photographed with the same spectrograph as that used for the stars. The wave lengths of these lines were then derived by reference to an accompanying comparison spectrum of neon. Experience with these *CN* wave lengths led to the rejection of some lines that seemed to give erratic values of velocity from star to star. The remaining lines were retained after small systematic differences had been

TABLE 1

EIGHT LONG-PERIOD VARIABLES OF CLASS N

Name	1900 R.A.	1900 Decl.	Mag. Max.	Mag. Min.	Spec.	Phase of Max. JD	Period	γ (Km/Sec)	γ from Mt. W. Contr., No. 689 (Km/Sec)	K (Km/Sec)
R Lep......	4^h55^m0	−14°57′4	5.5–8.4	8.0–10.7	N6e	2429908.4	447^d5	+ 32.4	+ 34	5.9
UV Aur*...	5 15.3	+32 24.7	7.9–...	..<10	Npe	2423336	395	− 5.6	− 3	7.0
T Cnc......	8 51.0	+20 13.9	7.6–9.2	9.1–10.5	N6	2431523	498.5	+ 6.2	+ 7	3.8
V Hya.....	10 46.8	−20 43.2	6.0–...	...−12.5	N6e	2430920.5	539	− 15.2	− 8	3.8
V CrB......	15 46.0	+39 52.5	6.8–9.1	9.9–12.4	N2e	2429823.5	361	−115.0	−115	5.7
RR Her....	16 1.5	+50 46.3	7.8–...	...− 8.8	Npe	2421508	238.8	− 37.2	− 37	5.8
V Oph......	16 21.2	−12 12.0	6.9–8.1	9.2–10.8	N3e	2429896	300.8	− 37.4	− 40	5.0
U Cyg.....	20 16.5	+47 34.7	6.1–9.0	8.9–12.2	Npe	2429963.7	480	+ 10.0	+ 13	9.0

* Primary of visual double star A.D.S. 3934. Secondary is distant 3″4; its magnitude is 11.6, spectrum A0. No changes in position angle or distance have been observed. Five spectrograms of the secondary give the radial velocity $+0.1 \pm 2.8$ km/sec.

smoothed out. The final test of the lines on this list is the accordance of their velocities with the velocities from atomic lines, when observable on the same plates. The mean of thirty-two differences is

$$\text{Vel. } (CN) - \text{Vel. (atomic)} = -1.3 \text{ km/sec ,}$$

which was deemed satisfactory accordance. The *CN* wave lengths were therefore adopted for velocity determinations of the class N stars whenever observed within their wave-length range with the dispersion of 20 A/mm.

The first and second columns of Table 2 list the *CN* lines, and the third column the atomic lines sometimes available. $H\alpha$, given among the latter, appears as an emission line at certain phases in many class N long-period variables.

Table 3 is the journal of observations, with phases expressed in decimals of the period. The absorption-line velocities in the fourth column and the velocities from bright $H\alpha$ in the fifth column (T Cnc has no bright $H\alpha$) are plotted for each variable in Figures 1 and 2, with filled circles and open circles, respectively. Values of $M - m$ from *Geschichte und Literatur des Lichtwechsels der veränderlichen Sterne* provide the vertical lines indicating the phases of light-minima in Figures 1 and 2.

The absorption-line velocities of all eight variables show variations in which the minimum velocity anticipates minimum light and the maximum velocity anticipates maximum light by roughly $0.25P$.

The ninth and eleventh columns of Table 1 are estimates of the systemic velocity and the semiamplitude of velocity variation. No solution has been made for spectroscopic binary elements, since it was very doubtful whether these would have any significance except as a formal way of describing the variation. The tenth column contains the velocities previously published in *Mt. W. Contr.*, No. 689.[1]

The intervals for the observations range from 3 cycles for T Cnc to 7.4 cycles for V Oph. Nevertheless, fairly consistent results for the variations are shown by throwing all the observations into single cycles. This does not, of course, rule out the possibility that inconsistencies may appear in abnormal cycles, as in a star like V Hya, for which Leon Campbell[4] finds an 18-year period in addition to the period of 539 days. Extra deep minima in the light-curve of V Hya were reached in 1889, 1908, 1925, and 1943. It is to be noted that the discordant velocities for V Hya are the first two in Table 3. The first (early in 1940) precedes and the second (early in 1944) follows the low light-minimum of 1943. The remaining radial velocities (1945–1947) are mutually consistent.

TABLE 2

ABSORPTION LINES FOR DETERMINATION OF RADIAL VELOCITY

CN	*CN*	Atomic
λ 6195.62	λ6438.03	λ 6102.72 *Ca* I
6201.08	78.71	03.64 *Li* I
04.95	6522.79	22.22 *Ca* I
18.05	36.99	41.72 *Ba* II
37.45	6692.89	43.20 *Zr* I
6310.48	97.76	62.17 *Ca* I
6408.15	6707.73 with *Li* I	6496.90 *Ba* II
10.52		6562.82 $H\alpha$
31.91		72.78 *Ca* I

If pulsation is assumed, the velocity-curves show a rough correspondence of maximum of light with minimum of diameter and minimum of light with maximum of diameter. The mean change in diameter for the eight stars is about 60,000,000 km. The percentage change in the diameter by the pulsation of such a variable is largely guesswork. However, a reasonable guess for the average diameter of one of these variables is of the order of 12 A.U. based upon a surface temperature of about 2150° K[5] and an absolute magnitude of about -2.[6] The average change in diameter of 60,000,000 km would, accordingly, be about 3 per cent of the diameter itself. This is less than the percentage change of diameter for pulsation in cepheid variables.

EMISSION $H\alpha$ VELOCITIES

The velocities from $H\alpha$ plotted in Figures 1 and 2 are algebraically less than the absorption-line velocities, but they are not sufficiently accurate to settle whether their variation parallels the variation for the absorption-line velocities. In deriving the mean value of the difference between the velocity from emission $H\alpha$ and that from the absorption lines (Table 4), no distinction for phase has been made. The mean value of this difference for

[4] *Pop. Astr.*, **51**, 400, 1943.

[5] Nicholson and Pettit, *Mt. W. Contr.*, No. 369; *Ap. J.*, **68**, 91, 1928.

[6] R. E. Wilson, *Mt. W. Contr.*, No. 618; *Ap. J.*, **90**, 492, 1939; Sanford, *Mt. W. Contr.*, No. 689; *Ap. J.*, **99**, 365, 1944.

TABLE 3

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Plate Ce	JD	Phase	Radial Velocity Absorption (Km/Sec)	Radial Velocity Emission $H\alpha$ (Km/Sec)
		R Leporis		
2674	2430308	0.895	+36.0	....
2692	0325	.950	+35.3	+12.6
2853	0624	.600	+35.6	....
2885	0658	.677	+36.7	+ 4.6
2949	0773	.935	....	+18.7
3208	0988	.414	+29.0	....
3238	1010	.463	+30.7	....
3240	1010	.463	+30.1	....
3263	1038	.525	+34.2	....
3321	1063	.581	+35.2	....
3346	1101	.666	+36.1	+ 7.8
3392	1132	.735	+39.4	+13.5
3584	1365	.256	+23.1	....
3617	1393	.319	+23.2	....
3622	1394	.321	+23.2	....
3675	1454	.455	+28.1	....
3734	1539	.638	+38.1	....
3981	1717	.042	+30.6	+ 8.1
4086	1806	.242	+28.5	+ 9.8
4160	1865	.374	+30.4	....
4589	2224	.176	+23.2	....
4625	2258	0.252	+23.2	....
		UV Aurigae		
3207	2430988	0.364	−11.5	....
3232	1009	.417	−10.4	....
3268	1039	.493	− 6.9	....
3320	1073	.580	− 2.5	....
3347	1102	.652	− 1.4	....
3393	1132	.730	+ 0.5	−23.1
3413	1194	.885	+ 1.8	−26.9
3519	1300	.154	−10.3	−21.0
3583	1365	.319	−10.3	....
3624	1393	.390	− 9.7	....
3682	1456	.549	− 5.3	....
3867	1655	.053	−18.4	−35.6
3980	1717	.210	−15.3	....
4020	1748	.288	−13.4	....
4082	1805	.432	−10.5	....
4391	2070	.104	−13.0	−25.5
4856	2433	.023	− 7.3	−28.3
4872	2456	.081	−12.1	−20.7
4970	2515	0.230	−12.5	....

TABLE 3—*Continued*

Plate Ce	JD	Phase	Radial Velocity: Absorption (Km/Sec)	Radial Velocity: Emission $H\alpha$ (Km/Sec)
		T Cancri		
2962	2430804	0P558	+ 8.4	....
3684	1456	.866	+ 6.6	....
3716	1484	.921	+ 7.1	....
3735	1539	.032	+ 9.1	....
3750	1572	.098	+ 7.6	....
3800	1604	.163	+ 3.3	....
3817	1622	.199	+ 2.4	....
4027	1751	.458	+ 8.6	....
4083	1805	.565	+ 6.1	....
4112	1831	.618	+ 8.3	....
4158	1864	.685	+10.0	....
4187	1895	.745	+ 8.8	....
4220	1927	.810	+ 9.6	....
4273	1956	.870	+ 5.1	....
4539	2195	.348	+ 4.6	....
4595	2227	.413	+ 5.4	....
4621	2257	.474	+ 5.9	....
4668	2308	0.576	+ 7.6	....
		V Hydrae		
2274	2429687	0.712	− 2.6	....
3352	2431103	.339	−12.6	....
3681	1455	.993	−15.4	−43.3
3710	1483	.044	−18.3	−44.1
3751	1572	.209	−17.6	....
4163	1865	.752	−12.0	−27.4
4188	1895	.810	−10.2	−33.6
4212	1925	.865	−14.2	−38.2
4267	1954	.917	−16.0	−45.0
4540	2195	.365	−18.6	....
4622	2257	.480	−17.2	....
4659	2306	.571	−16.6	....
4708	2342	0.638	−13.6	....
		V Coronae Borealis		
2012	2429386	0.790	−112.3	−136.8
3105	2430924	.041	−114.1	−129.0
3204	0988	.218	−118.3	−134.8
3398	1134	.622	−110.6	....
3415	1195	.790	−107.2	−137.1
3429	1230	.887	−110.5	−133.3
3489	1278	.019	−118.8	−138.0
3515	1300	.080	−118.9	−131.8
3541	1334	.174	−123.8	−133.8
3581	1365	.259	−122.9	−138.8
3752	1572	.831	−109.0	−141.0
3832	1625	.978	−110.6	−129.7
3863	1655	0.061	−115.7	−136.1

TABLE 3—*Continued*

Plate Ce	JD	Phase	Radial Velocity: Absorption (Km/Sec)	Radial Velocity: Emission $H\alpha$ (Km/Sec)
		RR Herculis		
3155	2430955	0ᵖ595	−31.3	−47.6
4196	1897	.505	−33.2	−67.6
4221	1927	.630	−32.2	−49.3
4272	1956	.750	−35.6	−52.5
4284	1983	.860	−37.3	−51.6
4344	2023	.033	−40.2	−62.4
4660	2306	.218	−43.5	...
4709	2342	0.368	−40.6	...
		V Ophiuchi		
2039	2429418	0.411	−44.3	...
2968	2430806	.025	−36.2	−54.8
3002	0832	.112	−40.6	−58.8
3042	0866	.225	−41.5	−57.6
3062	0889	.302	−42.1	−61.5
3102	0923	.414	−41.0	...
3492	1279	.597	−36.3	...
3516	1300	.667	−36.2	−62.7
3542	1335	.783	−34.8	−59.0
3578	1363	.875	−30.6	−52.8
3833	1625	.748	−31.8	−57.5
3862	1655	0.848	−35.7	−50.5
		U Cygni		
2438	2429918	0.676	+17.5	+ 0.8
2809	2430539	.970	+ 2.3	− 9.0
2855	0625	.150	+ 0.8	...
2889	0659	.221	+ 1.2	...
3050	0869	.658	+18.5	− 6.2
3063	0889	.700	+19.5	− 8.7
3104	0923	.770	+19.5	− 5.4
3157	0955	.837	+17.9	− 8.6
3234	1010	.951	+ 7.0	− 7.4
3260	1038	.011	+ 0.7	− 8.4
3319	1073	.084	+ 2.4	− 9.8
3427	1229	.408	+ 5.2	...
3430	1230	.411	+ 9.3	...
3451	1249	.450	+ 8.6	...
3485	1277	.509	+11.7	...
3517	1300	.556	+16.4	...
3540	1333	.625	+20.1	− 2.2
3579	1363	.688	+17.2	− 5.3
3830	1624	.232	+ 5.5	−11.6
3869	1656	.298	+ 6.0	...
3969	1716	.422	+12.6	...
3983	1718	.427	+12.9	...
4859	2433	0.918	+ 9.7	− 8.1

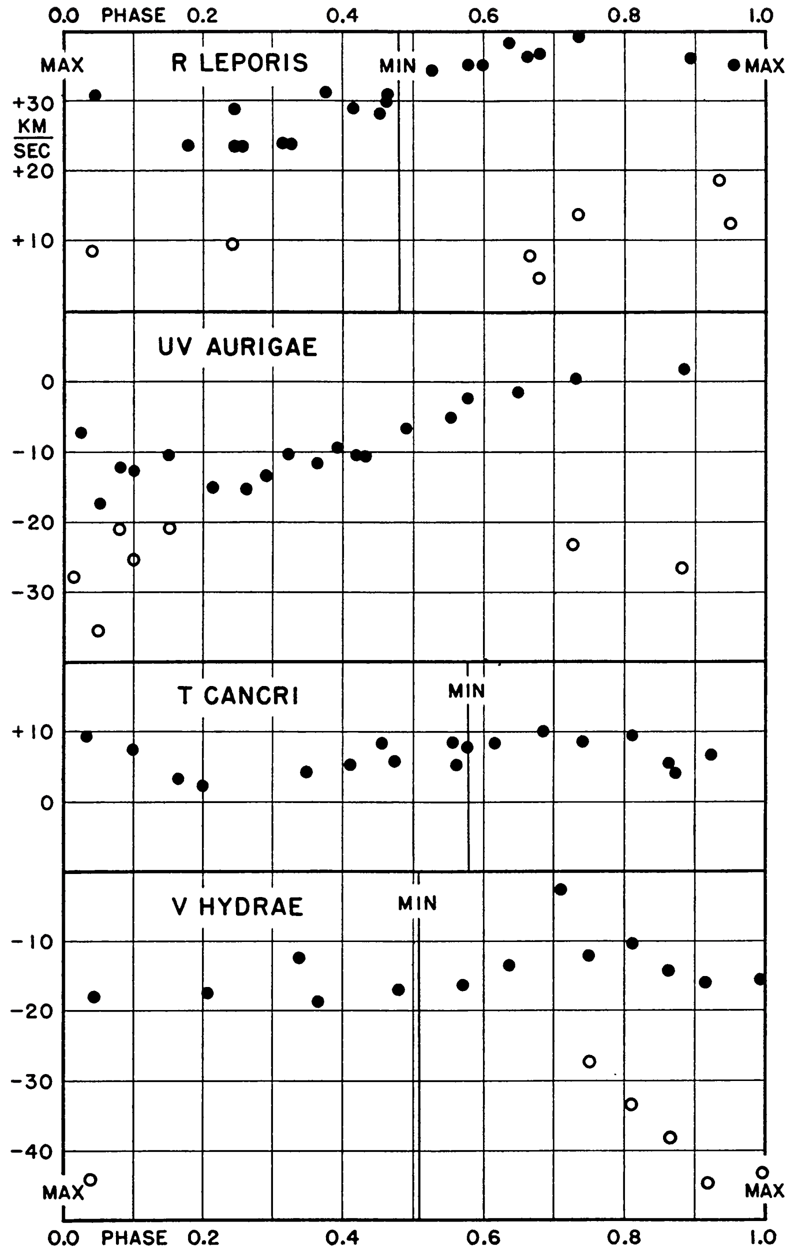

FIG. 1.—Velocities for the first four variables of Table 3 plotted with phases derived from the epoch of maximum light and the period as in Table 1. Solid circles are absorption-line velocities; open circles, emission $H\alpha$ velocities.

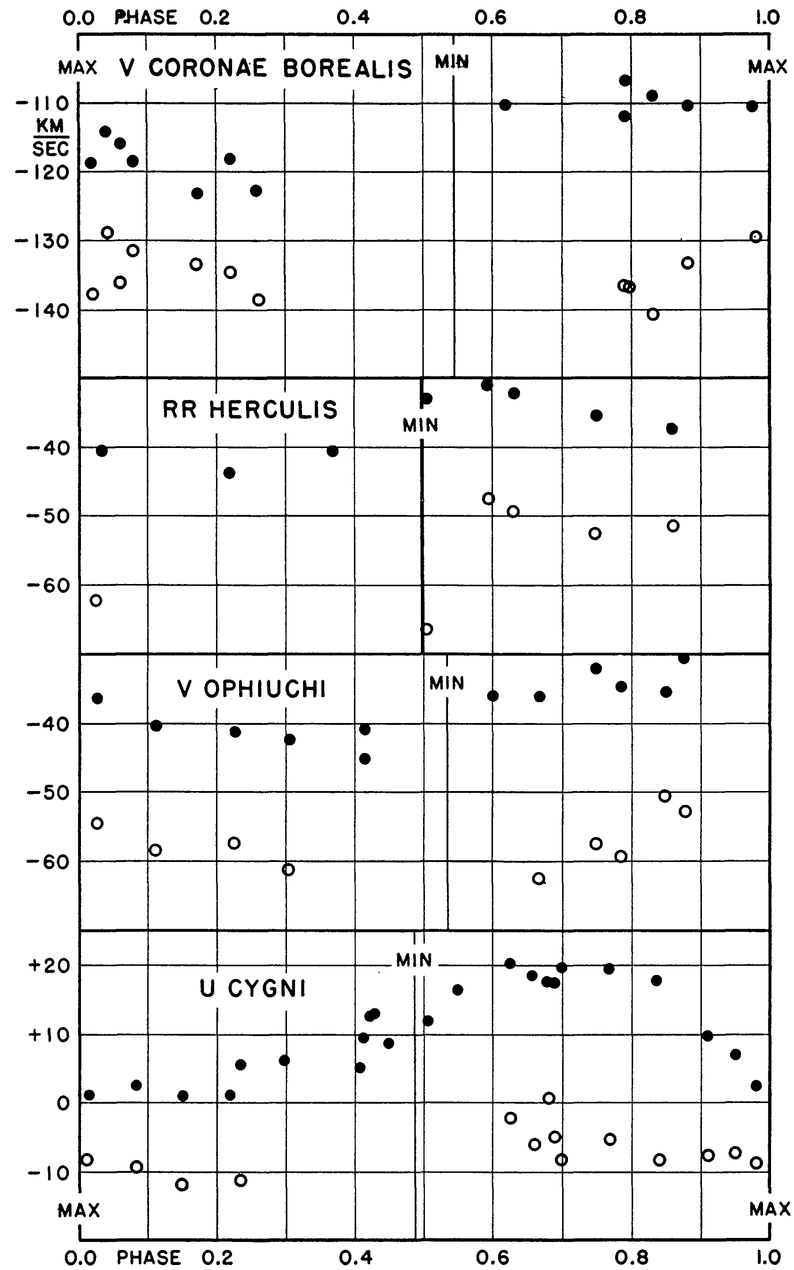

FIG. 2.—Velocities for the last four variables of Table 3 plotted with phases derived from the epoch of maximum light and the period as in Table 1. Solid circles are absorption-line velocities; open circles, emission $H\alpha$ velocities.

all the stars, weighted according to the number of separate determinations for each, is −20.3 km/sec, agreeing with the value (−20.5 km/sec) derived previously in *Mt. W. Contr.*, No. 689.[1]

SPECTRAL CHANGES

ABSORPTION LINES

The spectra of T Cnc, V Hya, V CrB, and V Oph in passing from maximum to minimum light show no conspicuous changes in the absorption lines in the part of the visible region that is used. The spectra of R Lep, UV Aur, RR Her, and U Cyg show, however, considerable enhancement of the lines of *Na* I, *Sc* I, *Y* I, and *La* I at minimum as compared with maximum light. The 0, 0 band of *CaCl*, λ 6185, also strengthens at light-minimum as compared to light-maximum, especially in U Cyg.

TABLE 4

DIFFERENCES ($H\alpha$ VELOCITIES *minus* ABSORPTION-LINE VELOCITIES)

	Km/Sec		Km/Sec
R Lep	−25.0	RR Her	−20.2
UV Aur	−18.0	V Oph	−19.5
V Hya	−24.2	U Cyg	−19.0
V CrB	−18.9		
		Weighted Mean	−20.3

EMISSION LINES

Emission $H\alpha$ occurs in the spectra of all the stars except T Cnc. It is strongest at maximum light, being visible from phase −0.25*P* to +0.25*P*. Limited observations of other *H* emission lines in these variables indicate that they are probably present at the same phases as emission $H\alpha$. The Balmer decrement is rapid.

A spectrogram of U Cyg, Ce 4859, September 5, 1947, phase 70 days, has the triplet lines of *Ca* II λλ 8498.018, 8542.089, and 8662.140 in absorption with shortward emission borders, while another spectrum, Ce 5742, July 10, 1949, at phase −216 days has only the absorption components. Emission $H\alpha$ is present on the first spectrogram but not on the second. Nothing is known about the *Ca* II triplet emission lines for any of the other stars here concerned.

The only emission lines regularly observed in long-period variables of spectral class N are those of *H* and of *Ca* II (in U Cyg). In UV Aur, however, there also appear the lines of [*Ne* III] and [*O* III], characteristic of gaseous nebulae, and lines of *Si* I, *Fe* I, *In* I, and *Mg* I as in long-period Me variables. This unusual array of bright lines in the spectrum of UV Aur has already been described.[7] The mean velocity from all measurable [*Ne* III] and [*O* III] lines is −4.7 km/sec; and from the *Fe* I lines (λ 4202 and λ 4308), −5.7 km/sec. Both these velocities agree well with the systemic velocity −5.6 km/sec for the absorption lines (Table 2). In Me stars, however, the velocities from emission lines of *Fe* I, like those from emission lines of *H*, are algebraically less than the velocities from the absorption lines.

[7] *Pub. A.S.P.*, **61**, 261, 1949.