

THE WOLF-RAYET SPECTROSCOPIC BINARY HD 214419*

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Received February 18, 1944

ABSTRACT

The velocity-curve of this Wolf-Rayet spectroscopic binary was obtained from 50 spectrograms taken from November 5 to December 20, 1943. The curve for N iv 4058 leads to the following elements: $P = 1.6410$ days, $\gamma = -75$ km/sec, $K = 295$ km/sec, and $e = 0$ (assumed). The period was established with the help of 20 Ann Arbor spectrograms. Emission of He II in the Pickering series suggests a similar solution, except for a shift in the γ -axis to $+180$ km/sec and a small decrease in K . A phase difference is suggested by the velocity measurements, the He II emission leading N iv 4058 by 0.05 days. The intensity of the emission in this series varies appreciably during a cycle. The line He II 4686 gives a velocity-curve entirely different, leading to the following elements: $\gamma = +137$ km/sec, $K = 165$ km/sec, $e = 0.35$, $\omega = 0$, and $T =$ phase 0.41 day. It is suggested that the radial velocities of this emission line represent more than orbital motion. Variations in structure of He II 4686 are noted. Thus far no lines of the companion star have been detected. The star has been observed with a Fabry photometer attached to the 40-inch refractor of the Yerkes Observatory; and, from seven nights' observations, a variation of 0.20 mag. is established. The star is brightest when the Wolf-Rayet component is on the far side of the system. No evidence of an eclipse has been detected.

The Wolf-Rayet star, HD 214419,¹ was announced to be a spectroscopic binary from spectrograms obtained at Ann Arbor in 1941.² With the dispersion employed (150 Å/mm at $H\gamma$) at the time of this discovery, the existence of absorption lines, presumably belonging to the secondary star, could not be established with confidence. Furthermore, structural and intensity variations in He II 4686 were suspected, but the evidence was not conclusive. Consequently, in November, 1943, the star was placed on the observing program of the 82-inch reflector of the McDonald Observatory, and Struve obtained a series of 44 spectrograms (dispersion, 40 Å/mm at λ 3933) with the quartz Cassegrain spectrograph between November 5 and November 17, 1943. Six additional spectrograms were obtained by the author in December of the same year.

The Wolf-Rayet spectrum is of type WN6, with He I, He II, N III, N IV, and N V being responsible for nearly all the bands. No spectral features that can be attributed to the companion star have been observed. Some of the emission bands in the Wolf-Rayet star possess well-defined violet absorption edges, especially the Pickering series of He II and λ 4603 of N V, while other bands, for example, N IV 4058, are observed only in emission. The intensity of the emission in the Pickering series varies appreciably during a cycle, being strongest when the Wolf-Rayet is on the far side of the system. This strengthening of the emission appears to be accompanied by a weakening of the violet absorption edges. In contrast, the emission band N IV 4058 displays little variation in intensity. It is difficult to determine by visual inspection whether or not He II 4686 varies in intensity, since this band, by far the strongest in the photographic region, was usually overexposed, making estimates of intensities impossible. Plates XIII and XIV are reproductions of spectrograms of HD 214419 taken at different phases.

The results of the radial-velocity measurements are listed in Table 1, which records the results of the Ann Arbor spectrograms, and Table 2, which records the measurements of the McDonald spectrograms. Only He II 4686 was measured on the Ann Arbor plates,

* *Contributions from the McDonald Observatory, University of Texas*, No. 91.

¹ $\alpha = 22^h32^m9$, $\delta = +56^\circ23'$ (1900), ptm. mag., 8.92.

² Dean B. McLaughlin and W. A. Hiltner, *Pub. A.S.P.*, 53, 328, 1941.

their primary function being that of yielding a more accurate period for the system than was possible with the McDonald observations alone. Since there are large systematic differences between the velocities derived from various lines, the velocities of *N* IV 4058, *He* II 4686, and the mean of *He* II 4200, 4339, and 4541 of the Pickering series are recorded individually for the McDonald spectrograms. The phases are computed from the formula

$$JD = 2431037.82 + 1.6410E.$$

Zero phase corresponds to the time when the velocity-curve of the Wolf-Rayet star crosses from the negative to the positive side of the γ -axis as determined by *N* IV 4058.

TABLE 1
RADIAL VELOCITIES OF HD 214419, ANN ARBOR

Plate	Date	Phase	Vel. in Km/Sec <i>He</i> II 4686	Plate	Date	Phase	Vel. in Km/Sec <i>He</i> II 4686
X 15738....	1941 Sept. 21.164	0.319	+229	X 16093....	1942 July 20.350	0.561	+224
X 15752....	23.172	0.686	+ 56	X 16102....	21.300	1.511	+ 14
X 15820....	Oct. 26.229	0.923	+ 47	X 16105....	23.394	0.323	+341
X 15825....	28.233	1.286	- 44	X 16107....	24.365	1.294	+ 1
X 15826....	29.175	0.587	+152	X 16158....	Aug. 20.376	0.408	+377
X 15840....	Nov. 4.158	0.006	+138	X 16166....	21.337	1.369	+ 11
X 15899....	25.143	1.299	+ 15	X 16212....	Oct. 10.275	0.436	+196
X 15914....	27.154	0.028	+184	X 16219....	11.222	1.383	+ 52
X 15935....	29.140	0.373	+302	X 16229....	12.253	0.773	+ 77
X 15948....	1941 Dec. 19.040	0.581	+195	X 16233....	13.237	0.116	+156
X 16089....	1942 July 19.390	1.242	- 77				

A period of 1.6410 days was determined with the help of the Ann Arbor spectrograms. The individual observations of *N* IV 4058, the means of *He* II 4200, 4339, and 4541, and *He* II 4686 are plotted in Figures 1, 2, and 3, respectively. The plot of *N* IV 4058 shows a well-defined velocity-curve with an eccentricity near zero. Assuming $e = 0$, a graphical solution yields the following elements:

$$P = 1.6410 \text{ days}, \quad e = 0.0 \text{ (assumed)},$$

$$\gamma = -75 \text{ km/sec}, \quad a \sin i = 6.66 \times 10^6,$$

$$K = 295 \text{ km/sec}, \quad \frac{m_2^3 \sin^3 i}{(m_1 + m_2)^2} = 4.38.$$

The representation of the observations of *N* IV 4058 by the above solution is shown by the continuous curve in Figure 1. The resulting mass function is large, indicating that the system is very massive.

The *He* II lines of the Pickering series have marked absorption edges. The center of the absorption, as well as the emission, was measured whenever possible; and mean of the three lines most frequently measured in this series are plotted in Figure 2. The filled circles indicate emission, and the open circles represent measurements of the absorption edges. The line λ 4339 was included in the mean, since it is evident from comparing individual plots of this line and *He* II 4200 and 4541 that *H* γ contributes insignificantly, although emission to the violet of the absorption may infrequently be present. This emission is probably similar to that observed by O. C. Wilson in HD 193576.³ The

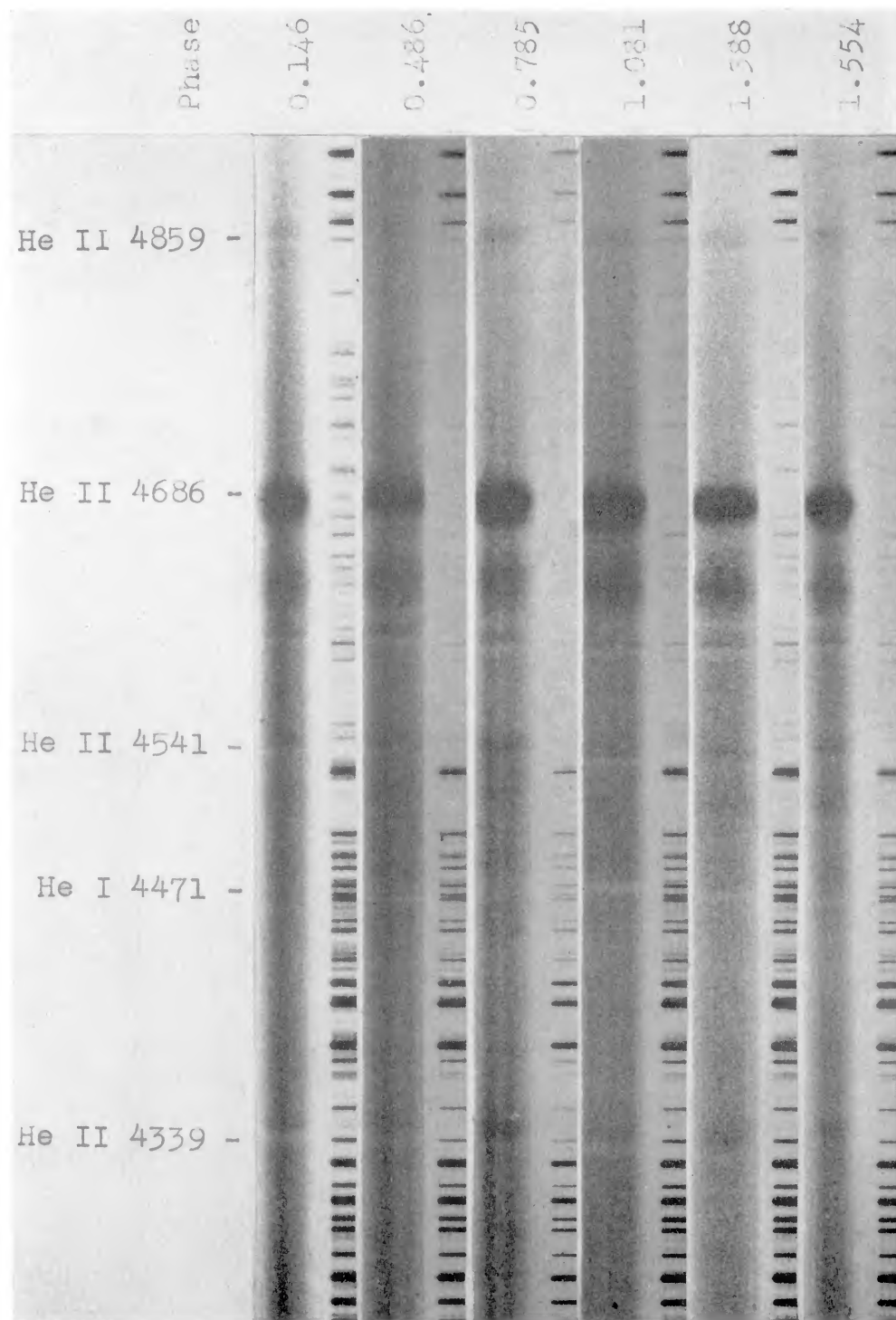
³ *Ap. J.*, 95, 404, 1942.

PLATE XIII



THE SPECTRUM OF HD 214419

PLATE XIV



THE SPECTRUM OF HD 214419

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TABLE 2
RADIAL VELOCITIES OF HD 214419, McDONALD OBSERVATORY

PLATE	DATE	PHASE	RADIAL VELOCITY IN KM/SEC			
			λ 4058	λ 4686	He II _A	He II _E
CQ 2524.....	1943 Nov. 5.092	0.695	+113	+153	- 62	+289
2527.....	5.262	0.865	-128	+ 73	-362	+131
2533.....	6.053	0.015	- 69	+ 64	- 99	+294
2552.....	7.094	1.056	-364	+ 24	-446	- 62
2562.....	8.127	0.448	+210	+300	- 59	
2583.....	9.102	1.423	-288	- 24	-424	- 69
2584.....	9.140	1.461	-278	+ 3	-365	+ 84
2589.....	9.233	1.554	-184	+ 19	-411	+204
2593.....	9.324	0.004	- 80	+ 95		
2608.....	10.105	0.785	+ 14	+122	-226	+175
2611.....	10.181	0.861	-132	+113	-386	+120
2614.....	10.255	0.935	-233	+ 81	-386	+ 33
2617.....	10.330	1.010	-292	+ 59	-437	- 43
2629.....	11.147	0.186	+134	+219	- 96	+416
2633.....	11.233	0.272	+190	+309	- 94	+456
2637.....	11.333	0.372	+255	+354	- 14	+452
2641.....	12.042	1.081	-334	+ 28	-427	- 6
2642.....	12.064	1.103	-342	+ 23	-428	+ 48
2643.....	12.085	1.124	-337	+ 70	-460	- 23
2644.....	12.110	1.149	-360	+ 79	-480	- 82
2645.....	12.128	1.167	-370	+ 77	-484	- 35
2646.....	12.149	1.188	-367	+ 85	-509	- 83
2647.....	12.170	1.209	-328	+ 72	-518	- 66
2648.....	12.191	1.230	-357	+ 63	-495	- 85
2652.....	12.243	1.282	-360	+ 45	-517	-131
2653.....	12.264	1.303	-376	+ 58	-482	-108
2657.....	12.316	1.355	-367	+ 67	-424	- 64
2658.....	12.338	1.377	-321	+ 67	-545	- 35
2659.....	12.366	1.405	-298	+ 10	-500	- 23
2667.....	13.031	0.429	+207	+345	- 90	+442
2668.....	13.057	0.455	+200	+340	- 90	+413
2669.....	13.088	0.486	+174	+322	- 64	+474
2670.....	13.114	0.512	+206	+309	- 64	+470
2671.....	13.135	0.533	+180	+277	- 11	+396
2674.....	13.185	0.583	+141	+290	- 10	+361
2675.....	13.215	0.613	+141	+232	- 38	+332
2676.....	13.255	0.653	+153	+228	- 72	+293
2686.....	14.038	1.436	-237	+ 32	-420	+ 19
2697.....	15.036	0.793	- 32	+ 67	-273	+185
2698.....	15.062	0.819	- 52	+ 67	-365	+ 95
2700.....	16.030	0.146	+ 86	+187	- 55	+ 84
2701.....	16.062	0.178	+118	+187	- 88	+400
2711.....	17.033	1.149	-361	+ 72	-445	- 28
2712.....	17.061	1.177	-370	+ 80	-475	- 44
2724.....	Dec. 19.088	0.384	+210	+370	- 8	
2725.....	19.156	0.452	+226	+352	- 83	+460
2726.....	19.194	0.490	+226	+330	-108	+434
2728.....	20.047	1.343	-363	+ 30	-534	+ 38
2729.....	20.092	1.388	-304	- 23	-494	- 78
2730.....	20.146	1.442	-263	+ 55	-506	+ 32

The velocity-curve of $He\ II\ 4686$ should be regarded with suspicion, since it is the only line that shows such a variation in velocity. In addition to $N\ IV\ 4058$ and $He\ II$ of the Pickering series, $He\ I\ 4471$ also indicates an eccentricity near zero, although the amplitude may be smaller than that for $N\ IV\ 4058$, probably similar to that for the Pickering $He\ II$ absorption edges. The measures are not sufficiently accurate and numerous to be conclusive and, hence, were not included in Table 2 along with the other measured velocities. An argument of equal weight that the velocity-curve of $He\ II\ 4686$ does not represent orbital motion alone is that this line is subject to appreciable variations in structure during a cycle. From phases 0.0–0.8 the band usually appears symmetrical with infrequent indication of shading to the red; but from phases 0.8–1.6 the band is normally shaded to the violet. The measures represented in Figure 3 refer to the "center of gravity." Structural variations were also observed on the Ann Arbor spectrograms.

The lines of $He\ I$ are present in this Wolf-Rayet star both in emission and in absorption. The emission is always very weak and never of sufficient intensity to measure with accuracy. The absorptions of $\lambda\lambda\ 4471, 4026$, and 3889 were measured when possible. The last two are probably blended with $He\ II$. Although the measures were usually very uncertain because of weakness of the lines and varying intensity, they do prove conclusively that the $He\ I$ absorption normally present belongs to the Wolf-Rayet.

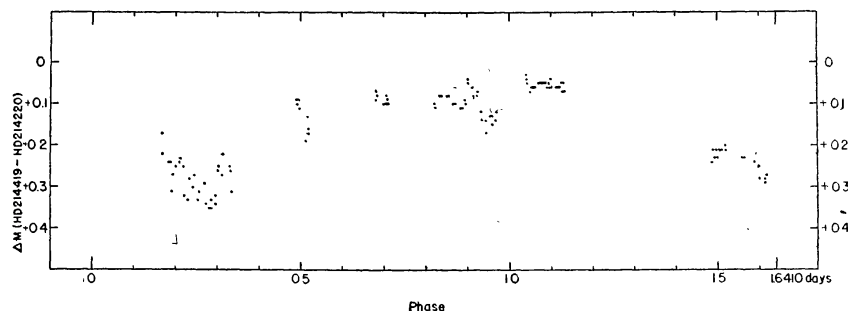


FIG. 4.—Photometric measures of HD 214419. Dots represent individual observations. The Wolf-Rayet star is brightest when it is on the far side of the system.

In a behavior thus far unpredictable, the three $He\ I$ lines mentioned previously, or $He\ I\ 3889$ alone, may show a relatively sharp component strongly displaced toward the violet (see Pl. XV). For example, on November 8.127, 1943, phase 0.448, a sharp absorption line of $He\ I\ 3889$ ($2^3S - 3^3P^0$), displaced by -1100 km/sec, was observed to be moderately strong, although only the component belonging to the Wolf-Rayet star was present at $\lambda\ 4026$ ($2^3P^0 - 5^3D$) and $\lambda\ 4471$ ($2^3P^0 - 4^3D$). This line has not been previously or later observed with certainty. However, all the spectrograms taken on November 13, from phases 0.429–0.653, show a strong, violet-displaced, relatively sharp absorption line of $He\ I\ 4471, 4026$, and 3889 , in addition to the Wolf-Rayet component. The violet displacement corresponds to -800 km/sec for all three lines. The wave lengths of this component remained constant within the errors of measurements, although the velocity of the Wolf-Rayet star changed from -220 km/sec to -100 km/sec during the interval of the observations. Only one plate was obtained on November 14 (phase 1.436), but the violet component of $\lambda\ 3889$ was still strongly present at the same displacement and was probably sharper than on the previous night, while only the Wolf-Rayet components of $\lambda\ 4026$ and $\lambda\ 4471$ were present. No trace of the violet component of $\lambda\ 3889$ was observed on November 15 (phase 0.793 and 0.819) or on subsequent nights. This behavior strongly suggests that the system is subject to erratic ejection of material of such velocities that we have an enormous change in dilution in an interval of only twenty-four hours.

continuous curve in Figure 2 represents the solution for N iv 4058, and the dashed curve is the same except for a shift in the γ -axis from -75 km/sec to $+180$ km/sec. The latter satisfies the observations except that, in addition to a small decrease in the semi-amplitude, an appreciable difference in phase between N iv and He II is suggested, the difference amounting to approximately 0.05 days. The explanation for this phenomenon is not clear. The observations do not indicate whether or not a similar shift in phase exists for the violet-absorption edges of the emission bands. It does not seem possible to explain the phase difference in terms of a transit time effect discussed by O. C. Wilson⁴ in connection with HD 193576, unless we assume a stratification in which N iv is at a much higher level than He II, since the band widths are similar to a first approximation. The violet-absorption edges are undoubtedly responsible for the shift in the γ -axis of 255 km/sec.

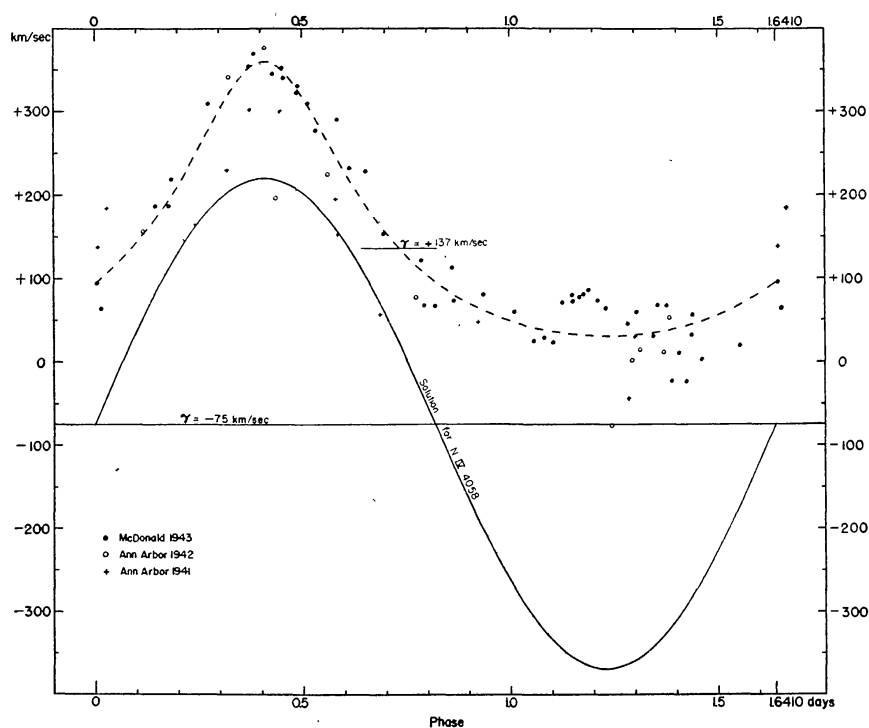


FIG. 3.—Observed velocity-curve of HD 214419 from He II 4686. The filled circles represent McDonald observations in 1943; open circles, 1942 Ann Arbor observations; and crosses, 1941 Ann Arbor observations. The continuous curve is the solution for N iv 4058, and the dashed curve is the solution for He II 4686.

The observations of He II 4686 are plotted in Figure 3. The 1941 and 1942 Ann Arbor observations are included with the more numerous 1943 McDonald measures. Again the continuous curve is the solution for N iv 4058. Obviously, it is impossible to adjust the N iv 4058 solution to satisfy both N iv 4058 and He II 4686. A rough graphical solution for He II 4686 alone yields the following elements

$$\begin{aligned}
 P &= 1.6410, & \omega &= 0 \\
 \gamma &= +137 \text{ km/sec}, & T &= \text{Phase } 0.41 \text{ days}, \\
 K &= 165 \text{ km/sec}, & a \sin i &= 2.06 \times 10^6. \\
 e &= 0.35, & \frac{m_2^3 \sin^3 i}{(m_1 + m_2)^2} &= 0.130.
 \end{aligned}$$

This solution is represented by the dashed curve in Figure 2.

⁴ *Ibid.*, pp. 409–417.

THE SPECTRUM OF NOVA PUPPIS 1942*

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Received February 19, 1944

ABSTRACT

The development of the spectrum of Nova Puppis 1942 is described on the basis of a series of spectrograms obtained at the McDonald Observatory between November, 1942, and May, 1943.

Attaining a maximum brightness of magnitude² $+0.4$ on November 12.0, Nova Puppis³ 1942 became the fourth brightest nova of the last three hundred years. Its light-curve,⁴ while rather peculiarly its own, resembles in some respects the light-curve⁴ of Nova T Coronae Borealis 1866. Both of these novae are noteworthy for their rapid decline in brightness after maximum. McLaughlin's "mean relative Δt " unit,⁵ the time in days required for the nova to decline through 3.0 magnitudes after maximum light, is, for N Puppis, 6.5 days, for N T Coronae Borealis 1866, 6.0 days.⁶ These are the smallest mean relative Δt units recorded. For comparison with other fast novae of the twentieth century, the mean relative Δt unit of N Aquilae⁵ 1918 is 7.0 days, of N Lacertae⁵ 1936, 8.5 days. For slow novae this unit has a different order of magnitude. For N Herculis 1934⁵ the unit is 93 days, for N Pictoris 1925,⁵ 150 days.

Perhaps the most unusual feature in the light-curve of N Puppis is its remarkable pre-maximum rise. Harvard plates⁷ having a limiting magnitude of 17 fail to show the star in the prenova stage. An independent search of the Franklin-Adams chart on which the nova should appear (April 19, 1912) was made by Pettit.⁸ No star was found in the position of the nova, which, in 1912, was therefore fainter than magnitude 14.5, the plate limit. This remarkable rise of 17 magnitudes is considerably greater than the rough average of 11 magnitudes⁹ for fast novae and puts the star within the range of the supernovae. The spectrum of N Puppis, however, bears no relationship to the spectra of the supernovae.

Humason and Sanford,¹⁰ using the velocity determined from the interstellar lines, find, by the method of McLaughlin,¹¹ $M_{\max} = -11$, a very high value for galactic novae. If $M_{\max} = -11$, the M of the star in the prenova stage was roughly $+6$. M for N Aquilae 1918 in the prenova stage was, according to Wyse,¹² $+3.9$. Interstellar absorption, the effect of which should be small, is not included in the estimate of M for N Aquilae.

* *Contributions from the McDonald Observatory, University of Texas, No. 93.*

¹ National Research Fellow, 1942-1943. The author left the Yerkes Observatory before this work was completed to engage in war research.

² Mean values are from: (1) L. Campbell, *Pop. Astr.*, **51**, 226, 1943, and unpublished material kindly furnished by Mr. Campbell; (2) E. Pettit, *Pub. A.S.P.*, **55**, 14, 1943; (3) G. P. Kuiper, *Ap. J.*, **97**, 443, 1943; and (4) W. W. Morgan, material kindly furnished in advance of publication.

³ α (1943.0), $8^{\text{h}}09^{\text{m}}6$; δ (1943.0), $-35^{\circ}11'$.

⁶ McLaughlin, *Pop. Astr.*, **47**, 539, 1939.

⁴ Campbell, *loc. cit.*

⁷ *Sky and Telescope*, **2**, 2, 1943.

⁵ *Ap. J.*, **95**, 432, 1942.

⁸ *Op. cit.*, p. 19.

⁹ McLaughlin, *op. cit.*, p. 545. McLaughlin's value has been rounded off to the nearest whole magnitude.

¹⁰ *Pub. A.S.P.*, **54**, 256, 1942.

¹¹ *Ap. J.*, **93**, 417, 1942.

¹² *Pub. Lick Obs.*, **14**, 93, 1940.

PLATE XV



THE SPECTRUM OF HD 214419 ON FOUR CONSECUTIVE NIGHTS

Note the presence of a relatively sharp violet component of *He* I 3889 and 4026 on 1943 Nov. 13, and that on 1943 Nov. 14 only the component of *He* I 3889 is present and at the same displacement. The two sharp lines are interstellar *Ca* II.

Since the amplitude of the velocity-curve is large, HD 214419 was observed for possible light-variations. It is not listed as a known variable. Figure 4 is a plot of the observations thus far obtained on seven nights with a Fabry photometer⁵ attached to the 40-inch refractor of the Yerkes Observatory. The dates of the observations and the mean for the night are listed in Table 3. The stars HD 214220 of spectral type A3 and HD 214259 of type A0 were used for comparison stars, the latter serving primarily as a check on the former. These comparison stars were selected because of their proximity to HD 214419, their distances being 11' and 31', respectively, and because they are of nearly the same magnitude as the Wolf-Rayet star. The exposure time on Eastman II-0 emulsion was 90 seconds, and exposures of the comparison stars were made at frequent intervals, about every 20 minutes. The plates were calibrated with a tube sensitometer and measured with a Hartmann microphotometer. Although no eclipse is evident, the observations strongly suggest that a variation of approximately 0.20 mag. exists. The variation thus far observed is such that it can be explained qualitatively by a "reflection effect" on the Wolf-Rayet component. It may be recalled that *He II* emission of the Pickering series is much stronger when the Wolf-Rayet star is on the far side of the system.

TABLE 3
PHOTOMETRIC MEASURES OF HD 214419

Date	Phase	ΔM (HD 214419-HD 214220)
1943 Dec. 30.144.....	1.594	+0.25
Dec. 31.093.....	0.902	.10
1944 Jan. 1.084.....	0.252	.28
Jan. 13.015.....	0.696	.09
Jan. 15.046.....	1.086	.06
Jan. 21.029.....	0.505	.13
Jan. 22.026.....	1.502	+0.22

(Since the preparation of this paper, Dr. Gaposchkin has kindly informed the author of his unpublished photometric observations of HD 214419. The light-curve, according to Dr. Gaposchkin, is of the β Lyrae type, with the two minima of nearly equal depth, approximately 0.35 mag., and with one minimum asymmetrical. Since the contribution by the companion star to the total light is appreciable, it is remarkable that no spectral features of the companion have been observed. A finer-grained and higher-contrast emulsion than Eastman 103a-0 employed in this investigation may possibly reveal some spectral information concerning the companion star. Dr. Gaposchkin published a remark concerning the light-variability of HD 214419 [BD+56°2818] and other Wolf-Rayet stars in *Pub. A.A.S.*, 10, 250, 1942.)

I wish to express my appreciation to Dr. O. Struve for obtaining nearly all the McDonald spectrograms used in this investigation and for many helpful discussions. I also wish to thank Dr. W. Carl Rufus, acting director of the Observatory of the University of Michigan, for lending the Ann Arbor spectrograms to the author, and to Dr. W. W. Morgan and Dr. G. Van Biesbroeck for generously relinquishing observing time with the 40-inch refractor so that photometric observations might be obtained. Miss G. Peterson kindly reduced a large number of the spectrograms and prepared the figures for publication.

⁵ For details concerning this instrument see O. Struve and C. T. Elvey, *Ap. J.*, 83, 167, 1936.