Kodaikanal Obs. Bull. Ser. A (1977) 2, 89-94

THE WOLF-RAYET SPECTROSCOPIC BINARY HD 214419

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ABSTRACT

Velocity curves of the system HD 214419 are obtained for the N IV 4058 and He II 4686 emission lines from prismatic spectra taken in 1951 and 1952. The emission and absorption features experience several phase dependent changes that are described in detail. A common envelope model explains well the He II 4686 light and velocity changes. The system parameters are best derived from N IV 4058.

Key words : CQ Cephei—Wolf-Rayet star—velocity curve—spectral changes

1. Introduction

Mclaughlin and Hiltner (1941) announced the discovery of the binary nature of the star. This was followed soon after (Hiltner 1944) with the derivation of spectroscopic orbital parameters for the system. The eclipsing nature was demonstrated by Gaposchkin (1944) who found the minima of roughly equal depths and an amplitude of 0.3 magnitude. The star has the shortest period known for a Wolf-Rayet binary, and therefore presents several features not normally seen in other systems of its spectral class. Spectroscopically, the velocity curves derived from the emission lines of N IV 4058 and He II 4686 bear little resemblance to each other. The spectrum of the companion is invisible. Photoelectric photometry of CQ Cephei by Hiltner (1950) in the ultraviolet and yellow regions show the primary minimum, corresponding to the eclipse of the Wolf-Rayet component, to be narrower than the secondary. A marked asymmetry is seen in the light curve with the descending branch steeper than the ascending one. A most interesting finding relates to the monochromatic light curve of the system in the light of He II 4686. The emission light curve shows maxima at times of conjunction and minima at elongation. The descending branches of the curve are less steep than the ascending branches; the emission curve appears almost a mirror image of the continuum light curve. The system is thus one of considerable interest since it has many features not commonly seen even in other Wolf-Rayet binaries. Interpretation of these observational characteristics would undoubtedly improve our understanding of the Wolf-Rayet star.

The present study aims at a spectrographic study of the binary system and in particular the changes in profiles of lines at different orbital phases.

2. The Observations

All spectra were obtained in 1951 and 1952 with the single prism glass spectrograph on the Mount Wilson 60-inch reflector. The spectra have a dispersion of 76 Å mm^{-1} at Hγ and were 0.17 mm wide in the 1951 series and 0.47 mm wide in the 1952 series. All spectra were calibrated with a wedge slit spectrograph as well as a spot sensitometer. Exposure times were never greater than 75 minutes with a projected slit width of 20 microns on Eastman II a-O emulsion.

3. The Radial Velocities

The radial velocities were measured for several of the emission features and the violet absorption edges. No trace of the companion was seen on these spectra. It must, however, be realized that the glass prism allowed transmission in the UV to only about 3800 Å thus minimizing the chances of any possible detection of the higher members of the Balmer series. Unblended spectral features that can provide radial velocities of some degree of reliability are only the emission lines N IV 4058 and He II 4686. These velocities are given in Table 1. The phases are calculated on the basis of the photometric period and epoch of primary minimum as given by Hiltner (1950). A few additional spectra obtained with a grating spectrograph covering the wavelength region 4600-6600 at a dispersion of 66 Å mm^{-1} were generously provided by Dr. H. A. Abt. Measures of radial velocity of 4686 Å on these spectra have been included in Table 1. Normal places with weights depending on the number of observations included in each grouping have been made prior to solution of the orbit. These values form Table 2.

Table 1. Radial velocities of He II 4686 and N IV 4058.

Phase	Radial Velocity in km s^{-1}	
	He II 4686	N IV 4058
0.024	+ 40	− 134
0.024	+ 46	—
0.028	+ 172	− 88
0.036	+ 104	− 106
0.081	+ 93	− 242
0.091	+ 118	− 173
0.143	+ 86	− 284
0.159	+ 100	− 280
0.174	+ 70	− 307
0.223	+ 16	− 350
0.226	+ 127	− 369
0.283	+ 9	− 355
0.284	+ 93	− 356
0.324	− 79	—
0.354	+ 36	− 381
0.365	+ 93	− 342
0.372	+ 1	—
0.381	− 82	—
0.400	+ 60	—
0.415	− 32	− 368
0.433	+ 89	− 351
0.446	− 39	—
0.460	− 48	− 343
0.502	+ 11	− 325
0.533	+ 23	− 290
0.551	+ 17	− 343
0.560	+ 28	—
0.576	− 1	− 273
0.593	− 93	− 290
0.622	− 2	—
0.668	+ 50	− 251
0.700	+ 28	—
0.708	− 8	− 179
0.711	—	− 166
0.738	+ 23	− 138
0.768	− 9	—
0.773	+ 35	—
0.782	—	− 138
0.802	+ 12	− 56
0.811	+ 118	− 60
0.840	+ 72	—
0.854	+ 144	—
0.868	+ 76	+ 22
0.890	+ 57	+ 44
0.931	+ 141	+ 100
0.962	+ 152	+ 161
0.994	+ 201	—
0.995	+ 216	+ 148
0.996	+ 194	—
1.032	+ 233	+ 239
1.059	—	+ 199
1.062	+ 194	—
1.099	+ 308	+ 217
1.101	+ 257	+ 269
1.109	+ 282	+ 176
1.126	—	+ 203
1.127	+ 276	—
1.164	+ 308	+ 225
1.166	+ 371	+ 194
1.206	+ 242	—
1.220	+ 349	+ 269
1.247	+ 314	—
1.272	—	+ 190
1.284	+ 246	+ 266
1.316	+ 414	—
1.321	+ 161	+ 203
1.328	+ 223	+ 229
1.386	+ 203	+ 166
1.441	+ 175	+ 165
1.449	+ 161	+ 207
1.480	+ 171	+ 134
1.501	+ 100	+ 87
1.508	+ 137	—
1.517	+ 198	+ 60
1.542	+ 169	+ 14
1.549	+ 117	+ 66
1.568	+ 107	+ 35
1.570	+ 163	—
1.601	+ 206	— 26
1.614	+ 114	+ 5
1.623	+ 62	—

Preliminary elements from the velocity curve of N IV 4058 were determined by the Lehman-Filhes method. They are given below.

γ = −61.6 km s^{-1}

K = 295.0 km s^{-1}

e = 0.0

T_o = 1.235 days.

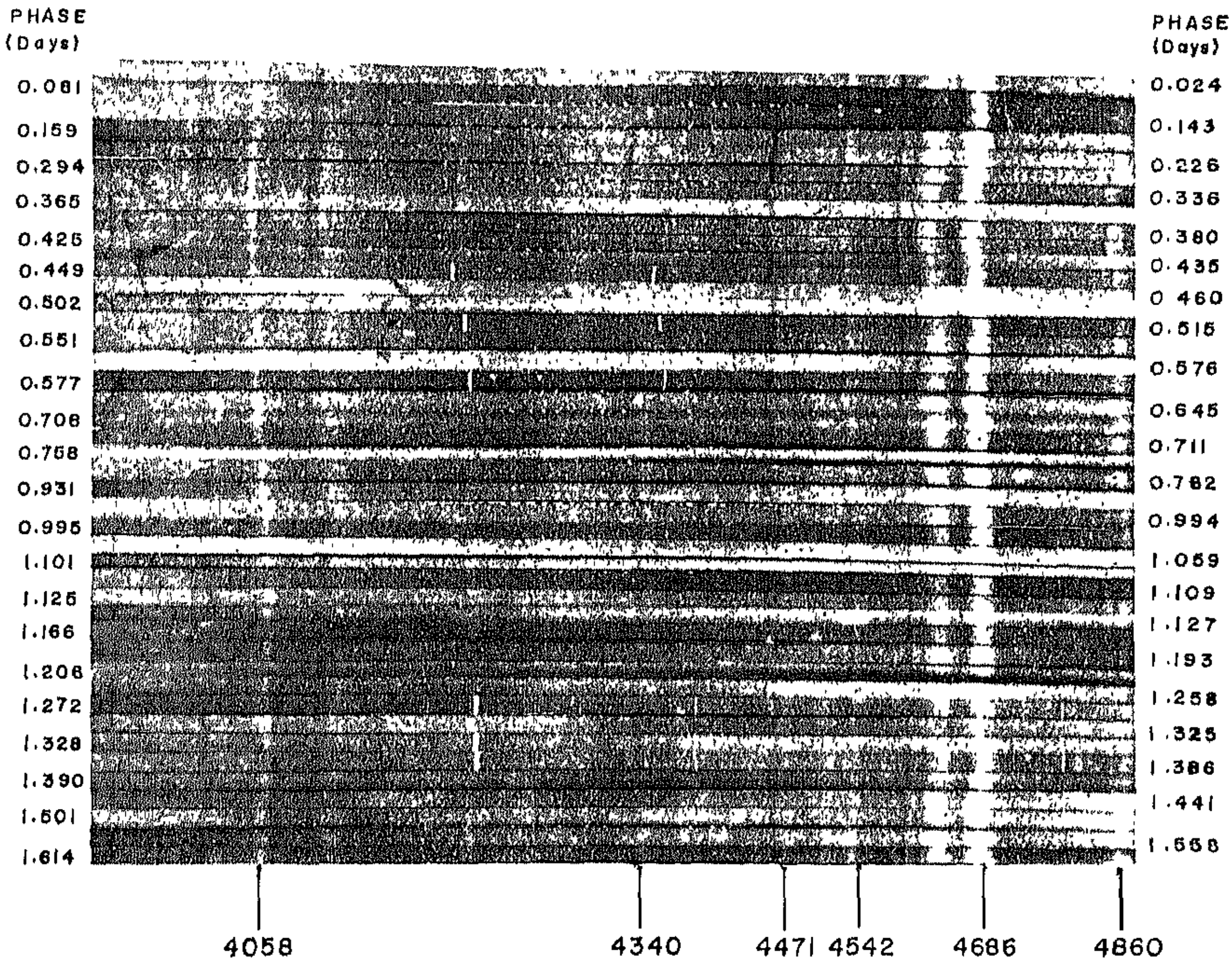

Fig. 1. Spectra of CQ Cephei obtained in 1951

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PLATE 14

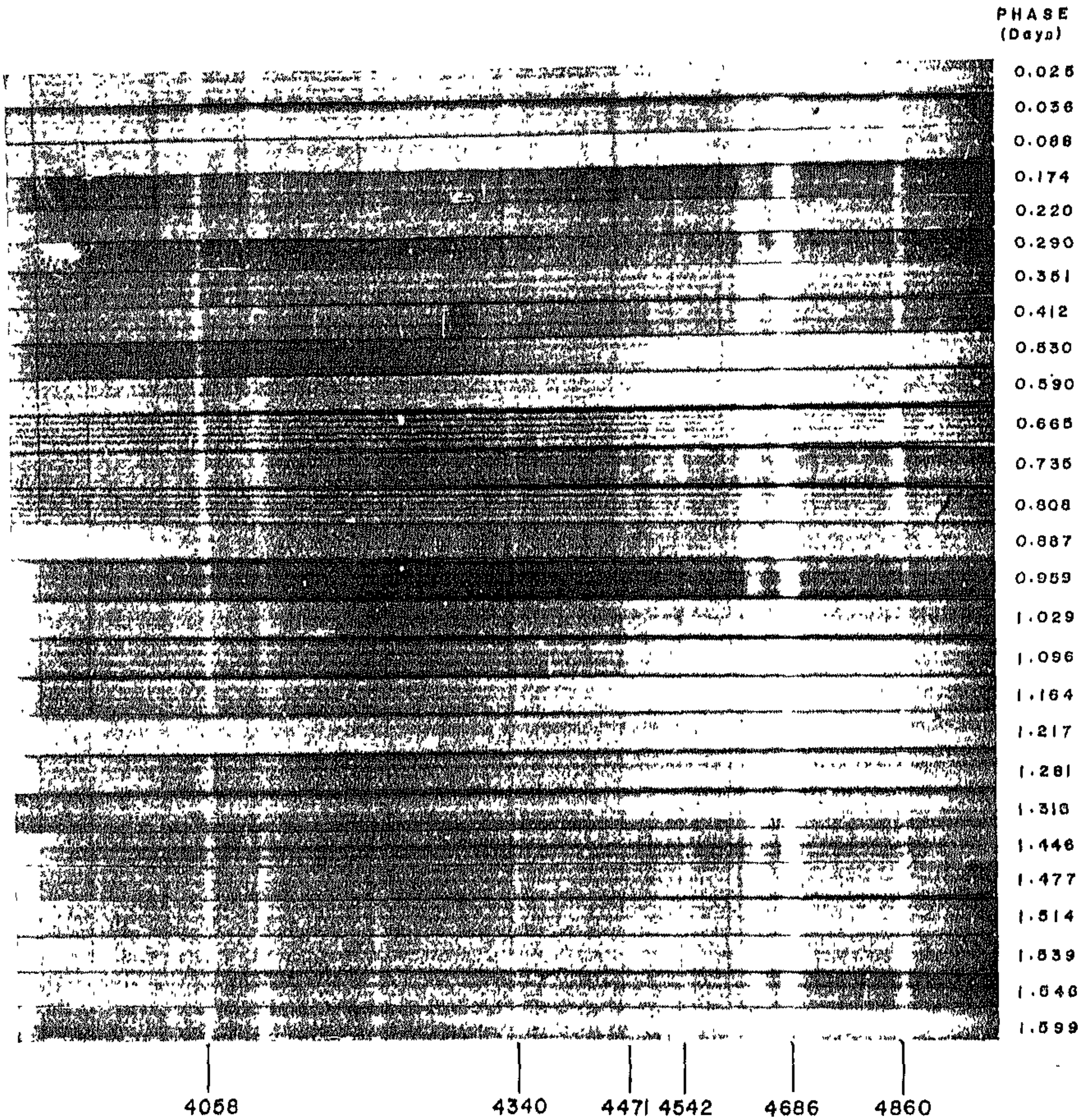

Fig. 2. Blue spectra of CQ Cephei taken in 1952

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The value employed for the period is 1.6413 days. A least squares solution following Sternes method gives the definitive elements with probable errors as follows :

γ		-60.8 km s^{-1} $\pm$ 3.7 km s^{-1}
K	=	312.7 km s^{-1} $\pm$ 5.4 km s^{-1}
e		0.035 $\pm$ .016
ω		96.7° $\pm$ 26.4°
T		0.010 days $\pm$ 0.13 days
a sin i	=	7.1 x 10^{6} km
f (m)	=	5.2 ⊙

Table 2. Table of normal places

He II 4686

No.	Mean phase (days)	Mean Velocity km s^{-1}	Weight	Residuals (O-C) Preliminary	Final
1	0 004	+ 106	7	+ 19	+ 3
2	0.119	+ 99	4	+ 48	+ 31
3	0.208	+ 71	3	+ 40	+ 24
4	0,340	+ 10	7	− 2	− 13
5	0 431	+ 6	5	+ 3	− 4
6	0.553	3	6	− 9	− 8
7	0.675	+ 17	4	− 6	+ 3
8	0.776	+ 36	5	− 16	− 4
9	0.863	+ 87	4	− 10	+ 7
10	0.985	+ 190	6	− 3	+ 7
11	1.100	+ 283	5	− 29	− 10
12	1 201	+ 317	5	− 2	+ 18
13	1.312	+ 269	4	− 10	+ 3
14	1.425	+ 176	3	− 19	− 20
15	1.528	+ 143	8	+ 5	+ 6
		N IV 4058			
1	0.004	− 73	5	− 11	+ 19
2	0.119	− 250	4	− 63	− 21
3	0.208	− 339	3	− 70	− 27
4	0.327	− 368	4	− 14	+ 12
5	0.436	364	3	+ 2	+ 12
6	0 551	− 304	5	+ 11	+ 2
7	0 696	− 195	3	+ 6	− 21
8	0.783	− 98	4	+ 14	− 19
9	0.879	− 33	2	+ 34	+ 5
10	0.960	+ 162	4	+ 69	+ 34
11	1.099	+ 211	5	+ 17	− 4
12	1.183	+ 229	3	+ 2	− 17
13	1.301	+ 222	4	− 2	− 17
14	1.425	+ 176	3	+ 17	+ 13
15	1.525	+ 69	6	0	+ 10

Elements derived from the velocity curve of He II 4686 on the assumption that the radial velocity variation is indicative of orbital motion are as follows :

γ	=	+117.5 kms^{-1}
K	=	148.2 kms^{-1}
e	=	0.309
ω	=	323°
a sin i	=	3.2 x 10^{6} km
f (m)	=	0.48 ⊙

The 4058 Å velocity curve gives a value of eccentricity of orbit that is close to zero. The light curve of Hiltner also indicates an eccentricity that is zero. One can therefore assume with some certainty that the N IV velocity curve represents the orbital motion of the Wolf-Rayet star.

4. Phase Dependent Changes in the Spectrum

Lindsey Smith (1968) has classified the spectrum of HD 214419 as WN7 + O7 while Hiltner and Schild (1966) consider it to be WN7-A on their classification scheme of stars that have relatively narrow lines, strong continua and with absorption lines characteristic of O-B stars. The emission line contrast is low in this star signifying the contribution to the continuum by the companion. Figures 1 and 2 show the spectral changes with phase in the years 1951 and 1952. Perhaps the most striking feature in these spectra is the presence of violet edges for lines of the Pickering series. These are present at almost all phases, but are most intense immediately following primary and secondary minima. An alteration in intensity between 4860 Å, 4542 Å, 4340 Å and 4200 Å indicates the significant Balmer contribution to the Pickering violet edges. The interesting feature is that their velocity curve follows that of the Wolf-Rayet component.

We show in Figure 3 a set of profiles of the emission feature He II 4860, reduced to the intensity of the continuum and which is obtained from the well-widened spectra of 1952. At phases 0.735 days and 0.808 days when the Wolf-Rayet star is nearest to the observer, we notice a peak intensity of 1.4 and emission wings of width round 39 Å. At phases close to primary minimum the profile becomes sharper and more intense, with wings having values similar to that at secondary minimum. The overall intensity of the line experiences a sharp decrease thereafter having its lowest value near phase 0.41 days; recovery to normalcy in intensity is rapid thereafter until secondary minimum. For phases that follow, especially between values 0.887 and 1.123 the profile is double peaked and the line decreases in intensity. It partially recovers the shape and intensity value it had at secondary minimum before it becomes sharply peaked and more intense near the phase of primary minimum. The contours also show an extension of the wings between phases 0.887 and 1.123 when a value of nearly 48Å is attained.

The serrated structure seen in He II 4860 appears to be the result of the violet edge moving into the emission line profile. The amplitude of the violet edge values with phase for this line is 510 km. The value is smaller than that seen for N IV 4058 and supports the view that the region which produces the absorption has dynamical properties different from that which gives rise to the N IV 4058 line.

The profiles of He II 4686 demonstrate principally the intensity changes shown by Hiltner's monochromatic light curve. The profiles are narrow at primary minimum and more rounded and less intense at secondary minimum. Figure 4 shows the sequence of changes with phase It is apparent that there is an additional contribution of He II 4686 emission, besides the normal aspect of the Wolf-Rayet star, that sharpens the profile and enhances the intensity in the line. Changes in the appearance of N IV 4058 can be seen in Figure 5. The half-widths seem to be greater at primary minimum than at phase 0.81 days. Noteworthy is the fact that the profiles are symmetric at all phases.

The intensities near primary minimum also seem enhanced when compared to the values seen at phases of conjunction, though the line is most intense at secondary minimum when the Wolf-Rayet star is closest to the observer. It should be noted that no continuum corrections have been made. The spectra show N IV 4058 to be free of absorption effects In fact, it seems to be the only line in the visible region of the spectrum which is free of contamination and which can provide reasonable dynamical orbits for binary systems that have Wolf-Rayet stars of the nitrogen sequence as a component.

A double violet edge for the emission line complex at 4100Å occasionally merges to form a single broad feature in the phase interval 0.88 to 1.3 days. The separation of the two absorption lines corresponds to the difference in wavelength between the two N III lines 4097.31Å and 4103.37Å. The velocities calculated on the assumption that these are due to N III, have values that are consistent with the displacements of violet absorption components of 4200 Å, 4471 Å and 4542 Å.

Temporal changes of a sporadic nature on a time scale covering many cycles seem to be an aspect of this interesting system. The He I 4471 violet edge in the 1951 spectra shows up, in the phase interval 0.9 to 1.3 days, a second component with an almost constant velocity of flow. The violet edge normally associated with this line has a curve of velocity variation similar in phase to that of the Wolf-Rayet star. The second component existed in 1951 for well over a month. It was invisible in the spectra taken in 1952. Between phases 0.08 and 0.3 days there is usually an intensification of the violet absorption. This can be interpreted as due to the superposition of the component of constant outflow and the component which shares the velocity curve of the Wolf-Rayet star. Such intensification is also seen in the 1952 spectra, though it is possible that the two absorption components had widths large enough to prevent resolution into two separately visible components. Studies at higher dispersion of the absorption profile of 4471 Å will undoubtedly contribute to a better understanding of the spectrum.

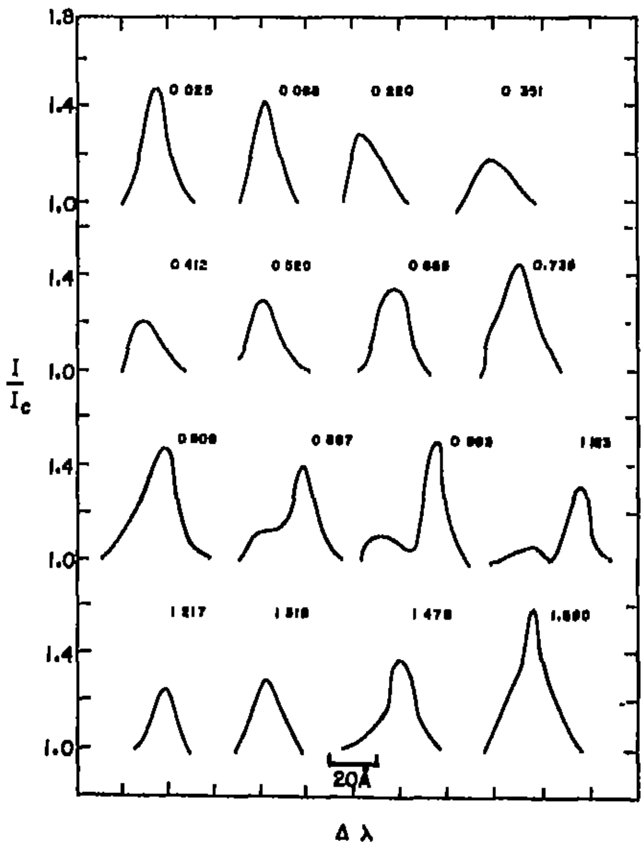

Fig. 3. Line profiles of He II 4860 in CQ Cephei

The changes witnessed with phase in the line profiles and apparent intensities are not duplicated

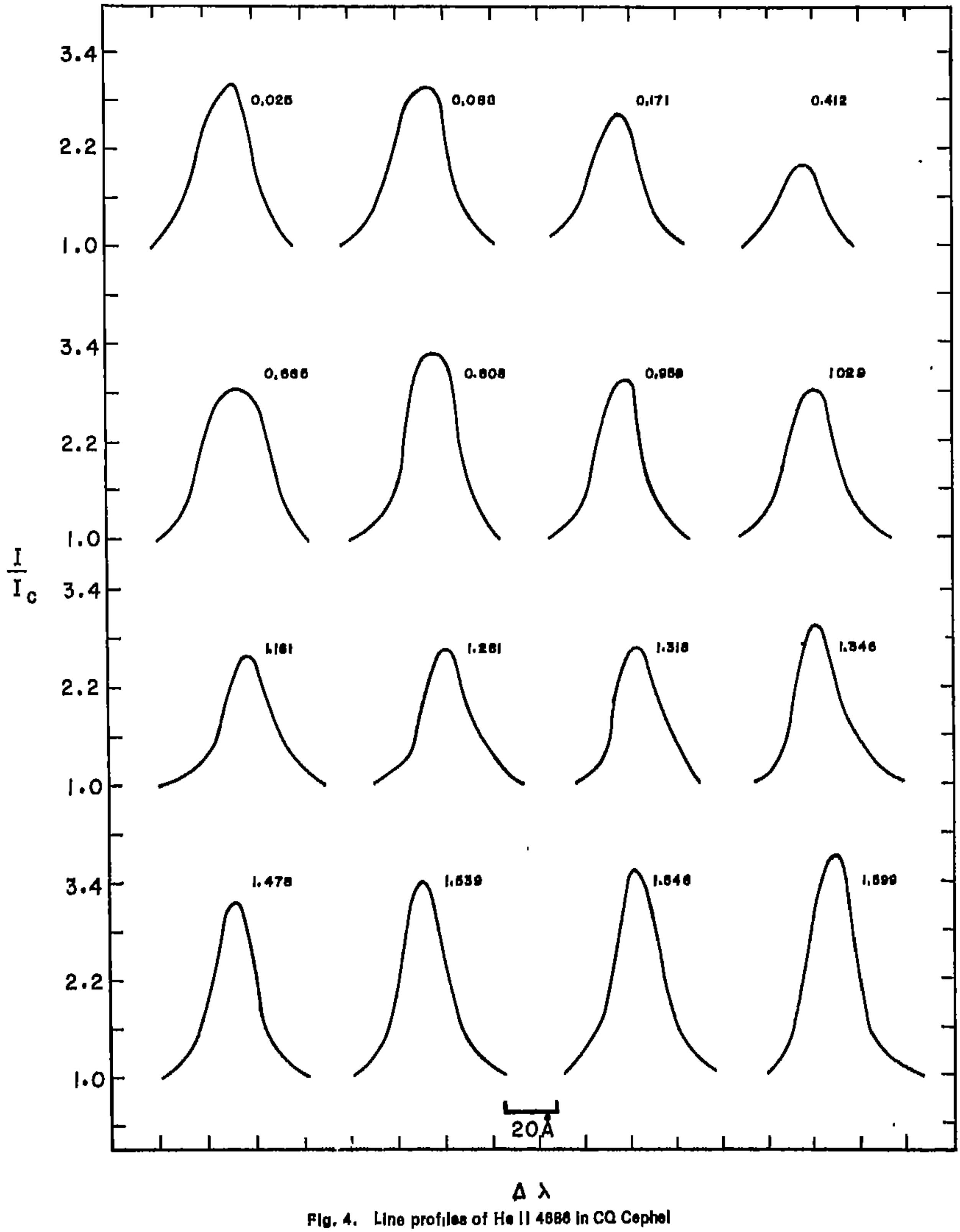

Fig. 4. Line profiles of He II 4686 in CQ Cephei

in any other Wolf-Rayet system, thus making HD 214419 a unique system. A common envelope, tically thin in He II 4686, and which is around the two stars (Bappu, 1951; Bappu and Sinvhal, 1955) explains the variation in He II 4686 intensity. The other He II lines in emission also appear to come from this envelope since the behaviour of He II 5411 has been shown by Bappu and Sinvhal (1959) to be similar to that of 4686Å. The companion star is thus hot enough to have radiation characteristics that lead to the production of the ionized helium lines in the large scale gas flow around the two stars which we call the common envelope. The derived mass function from N IV 4058 is consistent with a value of 15 solar masses for the companion. The kinematics of this flow lead to a velocity contribution to the overall emission of He II 4686 so as to produce a velocity curve that is quite different in appearance from what it would have been, if He II 4686 originated only from the Wolf-Rayet star. It seems reasonable to conclude that N IV 4058 is the only line in the visible region which portrays the velocity of the Wolf-Rayet star in the system. In principle, one may therefore, on the basis of some assumption, utilize the departure of the 4686Å velocity curve from that of 4058Å to gauge the kinematic characteristics of the envelope. To do so, one would firstly need to obtain a photoelectrically derived monochromatic light curve of N IV 4058 to see the difference between it and Hiltner's 4686Å light curve. The violet edges of the Balmer and Pickering series also originate in this common envelope, perhaps mostly in the region between the two stars.

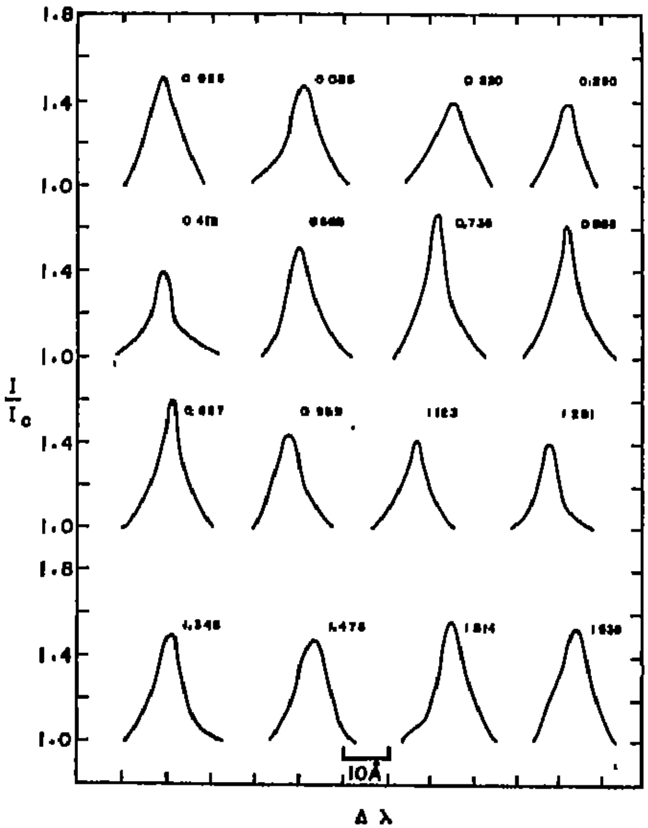

Fig. 5. Line contours of N IV 4058 in CQ Cephei.

The conclusion seems inescapable that future additional effort in this area, most likely to lead to a better understanding of the role of Wolf-Rayet stars in close binary systems, would be monochromatic emission line photometry, especially of eclipsing systems with periods less than four days. It will also be necessary to discover hitherto unknown binary system by extending a search for these to fainter limits.

Acknowledgment

We are indebted to Mr. V. Natarajan for help in the computations. The observations reported herein were obtained at the Hale Observatories in 1951 and 1952.

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