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The Wolf-Rayet eclipsing binary HD 193576

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Abstract

Low dispersion spectra (75 Å/mm at 4300 Å) of HD 193576 have been utilized for radial velocity measures as well as line profile determinations of some of the emission lines. Using such measures for HeII 4686. the elements derived are, γ -axis = + 16.2 km/sec, K=282.8 km/sec, e=0.11, ω =163°. The velocity measures of NIV 4058 are combined with earlier measures of Munch to yield the following values : γ -axis (NIV 4058) = −41.5 km/sec, K = 302.6 km/sec, e = 0.09. ω = 130°, T_0 = 0.26, T = 0.62. The velocity measures of the absorption lines 4340 Å and 4100 Å that originate from the O component show much scatter. A combination of the K values of NIV 4058, Hα yield masses of the O and W stars as 23.3 and 8.2 solar masses respectively. If 4058 Å is used with the K value derived by Munch from measures of the higher members of the Balmer series these are 25.0 and 9.9 solar masses respectively.

Line profiles of 4058 Å, 4686 Å, 4861 Å from low dispersion spectra are discussed. A few coude spectrograms (10 Å/mm) of this star were obtained at primary and secondary minima and outside eclipse. The emission line NIV 3483 shows a violet absorption edge at primary minimum. Profiles of H9, H11 and H13 show clearly the increase in width at primary minimum caused by electron scattering. The intensities of the hydrogen lines are also found to increase slightly at this phase.

Introduction

The binary nature of HD 193576 (V444 Cygni) was discovered by Wilson (1939). Gaposchkin (1941) showed subsequently that the star is also an eclipsing variable. Precise light curves for this system have been obtained photo-electrically by the Krons (1950) and Hiltner (1949).

The most recent spectrographic orbit is by Munch (1950). Very soon after the discovery of the binary nature Wilson (1940) had shown that the 4686 Å line originating from the Wolf-Rayet component of this system experienced little eclipse when occulted by the O companion. Kuhi (1956) has recently scanned photo-electrically the spectrum of HD 193576 from 3400 Å to 11000 Å with a spectrum scanner used as a narrow band photometer. He finds that in the process of the eclipse of the Wolf-Rayet component by the O star, the lines of ionized He, NIII and NIV do not share in the eclipse but actually undergo a brightening. This behaviour is most conspicuously seen in 4686 Å. On the other hand, the line identified as CIV 5808 decreases in intensity as the Wolf-Rayet star is eclipsed by the O star. Apparently a similar behaviour is indicated in the case of the HeI line at 10830 Å. The interesting feature is that the CIV line goes into eclipse two hours before the neutral helium line does.

In this investigation we present new orbital parameters for the binary system from radial velocity data. We also present the line profiles for different lines at different phases.

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The observations

Twenty-eight spectra of this binary system were obtained in 1952 with the Mount Wilson 60-inch telescope and single prism spectrograph. The spectra have a dispersion of 75 Å/mm at 4340 Å and can be used to study the orbits of both componets. The phases of the observations have been computed from the epoch of primary minimum when the Wolf-Rayet star eclipses the O star. The elements provided by Kron and Gordon (1950) are

Phase zero=JD 2428771.379+4.21238E

The measures of radial velocity were of the emission line HeII 4686 and NIV 4058 along with the Balmer absorption lines 4861 Å, 4340 Å and 4101 Å. The accompanying table gives the velocity measures of this system.

The orbital elements

The earlier spectrographic investigations of this system had assumed a circular orbit. We obtained a set of preliminary elements on the same basis from the velocity curve of 4686 Å. We next applied Sterne's method and determined the corrections necessary to the preliminary orbit. The orbital elements obtained from the 4686 Å velocity curve are

γ = +16.2 km/sec
K = 282.8 km/sec
e = 0.11
ω = 163°
T_o = 0.24
T = 0.69

In the case of NIV 4058 we combined our velocity measures with those of Munch (1950) in order to obtain a set of well defined orbital elements, using Sterne's method. The elements thus obtained are

γ = —41.5±6.2 km/sec
K = 302.6±9.3 km/sec
e = 0.09±.04

ω = 130°
T_o = 0.26
T = 0.62

The presence of a certain degree of eccentricity of the orbit has been speculated on for some time. The photo-electric measures of Kron and Gordon show that the secondary minima occur slightly earlier than the midpoint between the primary minima. The eccentricity derived spectroscopically is 0.09 and is of the right order of magnitude to explain the observation of Kron and Gordon. The systemic velocity derived from measures of 4058 Å is —42 km/sec as against +16 km/sec for 4686 Å, or a difference of 58 km/sec.

The velocity measures of HD 193576

Plate	J.D. of observation	Phase (in period)	Velocities in Km/Sec					
			4686e	4603e	4058e	4861a	4340a	4101a
32596 . . .	2434144.86	0.64	−183.6	−193.7	−311.8	..	+102.6	+112.3
32597a . . .	144.88	0.64	−248.3	−209.9	−323.1	−107.3	+130.3	+ 43.9
32597b . . .	144.91	0.65	−308.9	−236.4	−338.2	+ 77.2	+103.3	−151.6
32602 . . .	146.00	0.91	− 24.1	− 73.7	−191.2	..	+124.7	..
32631a . . .	170.76	0.79	−310.8	−229.8	−352.6	+158.6	+ 26.3	+168.2
32631b . . .	170.81	0.80	−270.1	−191.1	−313.7	+ 68.2	+ 96.5	−141.5
32634a . . .	171.77	0.03	+117.0	+ 67.0	− 28.0	..	− 17.1	+ 15.3
32636a . . .	171.95	0.08	+164.6	+ 86.0	+ 36.6	..	− 39.0	− 59.9
32636b . . .	171.98	0.08	+198.5	+176.7	+ 41.0	−120.6	− 49.8	+ 37.5
32642a . . .	173.88	0.53	+ 35.4	− 36.5	−115.0	− 60.3	+ 36.5	+ 37.4
32642b . . .	173.90	0.54	−121.0	+ 34.3	−201.5	− 60.3	− 6.6	− 28.5
32649a . . .	174.96	0.80	−318.7	−333.5	−319.0	−165.0	..	..
32649b . . .	175.00	0.80	−298.3	−308.3	−319.0	−113.5	+111.7	+198.5
32654b . . .	175.86	0.00	+ 69.1	+ 79.3	−106.6	+142.7	+ 74.1	+ 23.7
32654c . . .	175.90	0.01	+ 62.2	..	−102.3	..	+122.6	+ 32.4
32654d . . .	175.92	0.02	+ 69.0	+ 38.3	−132.6	+ 7.1	+ 90.2	..
32661a . . .	176.85	0.24	+259.4	+324.5	+359.0	..	− 28.6	− 88.7
32661b . . .	176.87	0.24	+259.3	+298.3	+248.1	−113.4	− 66.4	− 61.8
32669a . . .	177.96	0.50	+ 88.0	+ 85.2	−107.0	− 8.4	+ 30.4	− 3.8
32669b . . .	177.98	0.51	+ 27.7	+ 85.1	−128.8	− 1.0	− 34.5	+ 9.6
32681a . . .	194.71	0.47	+168.0	..	− 23.1	+ 27.0	− 22.4	+ 25.1
32683a . . .	194.87	0.51	− 43.1	− 59.7	− 88.3	−109.2	− 37.3	+ 83.2
32683c . . .	194.98	0.53	− 83.9	− 40.4	− 70.9	−139.3	+ 49.1	+ 20.3
32746b . . .	224.68	0.59	− 97.6	− 66.6	−255.5	+ 42.1	+ 63.8	

Figure 1 is a plot of our measured velocities of the two emission lines 4686 Å and 4058 Å as well as the velocities derived from the absorption lines. These absorption line velocities show a certain degree of scatter and indicate a range in location of the γ-axis. This originates presumably by contamination caused by the emission lines that are present in the spectrum of the Wolf-Rayet component. We have used separately the velocity measures of 4340 Å and 4101 Å to determine the orbit of the O star. A least squares solution was made to obtain corrections to initial values for K as well as γ. The values obtained are the following :

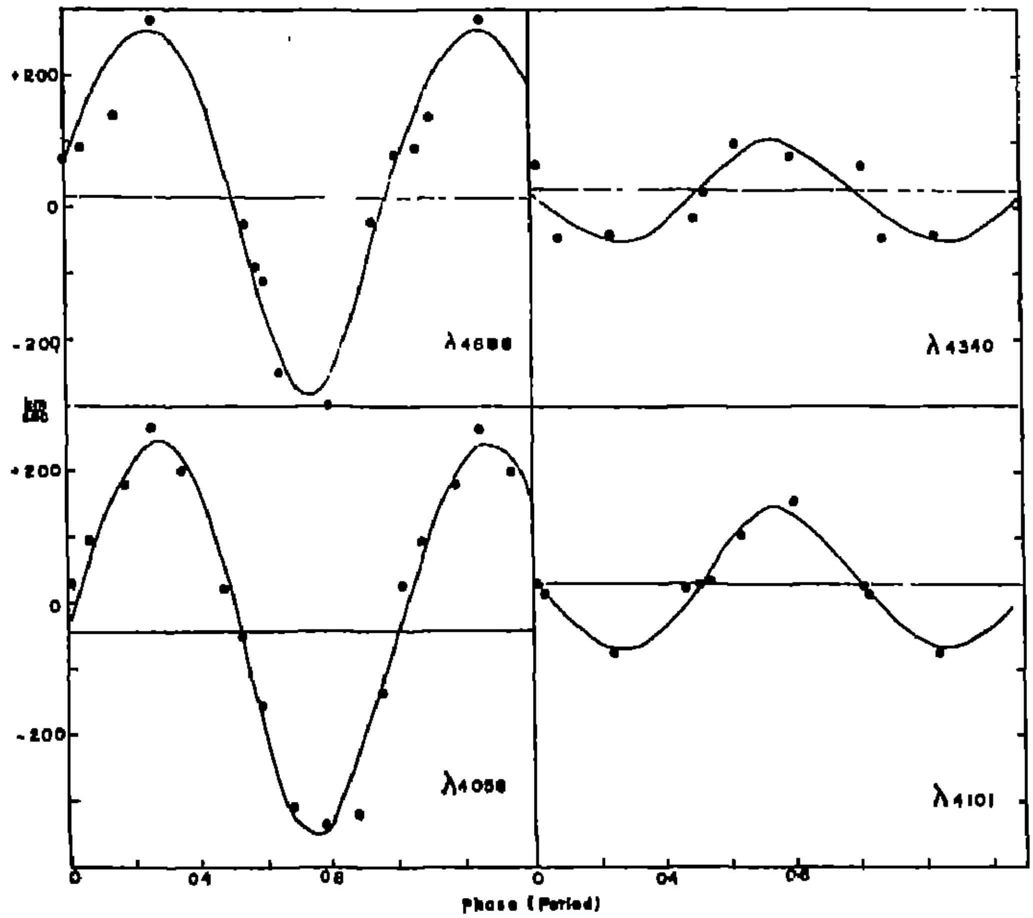

Figure 1.—The Radial velocity curve of HD 193576

	Hγ	Hδ
γ-axis (km/sec)	+22.1	+32.2±6.7
K (km/sec)	76.9	106.0±11.7

The large discrepancy between the values of K of the two velocity curves indicates that either one or both are affected seriously by emission from the Wolf-Rayet component. Since the value of K is very important in the determination of the masses of the components, it is doubtful if our values of K from the absorption lines at 4340 Å and 4101 Å would add to the reliability of a mass determination. In this respect, measures of the higher members of the Balmer series, as carried out by Munch, would have been more useful. In the calculation of the values of $m_O \sin^3 i$ and $m_W \sin^3 i$ we, therefore, use in addition to our values of K for the O component those obtained by Munch. The values of $m_0 \sin^3 i$ obtained are the following :

Emission line		Absorption line		
		Hγ	Hδ	Munch H8, H9, H10
HeII 4686	$m_O \sin^3 i$	15.7	18.4	19.7
	$m_W \sin^3 i$	4.3	6.9	8.4
NIV 4058	$m_O \sin^3 i$	18.8	21.8	23.3
	$m_W \sin^3 i$	4.8	7.7	9.3

A value of mass determined from the velocity curve of HeII 4686 is questionable since this line in a close binary system is liable to have complications by virtue of gas streaming near the inner Lagrangian point. We are, therefore, limited to using 4058 Å and the absorption lines, preferably the higher members of the Balmer series.

There are very few mass determinations of the O stars available in the literature. Using a value of $i = 78°$ derived by Kron and Gordon (1950) as well as the values of $m_O \sin^3 i$ and $m_W \sin^3 i$ determined from a combination of 4058 Å and Hδ we get the masses of the O and W components as 23.3 and 8.2 solar masses respectively. If we use the combination of 4058 and Munch's value of K from the higher members of the Balmer series these become 25.0 and 9.9 solar masses respectively.

The line profiles

It is well known that the Wolf-Rayet spectrum of 193576 shows very striking changes in the line contours of its various emission lines at various phases. A study of these contours help us in building a picture of the binary system as a whole. Figure 2 depicts the variations experienced at various phases by NIV 4058, HeII 4686 and HeII 4860, as measured from low dispersion spectra. In the case of HeII 4686, we find that at the conjunctions a narrow hump appears at about the peak of the profile and this hump which is on the red side at phases close to the primary minimum, moves over to the violet side at phases close to the secondary minimum when the Wolf-Rayet star is eclipsed. This variation in HeII 4686 was first pointed out by Wilson in 1942. In general, the overall widths of the lines are essentially the same. But in the vicinity of the conjunctions, the second hump caused by the superposed narrow emission seems to be primarily responsible for the changes in the profile. Sahade has shown (1958) that this narrow emission originates at the inner Lagrangian point and the observations reported here substantiate his point of view.

The profile of HeII 4860 essentially portrays the variations in location of the Hβ absorption line of the O star and the consequent effects that it has on the appearance of the overall structure. However, the total emission width seems to be greater near secondary minimum than it is at primary minimum. The profile at phase 0.02P has the absorption component on the violet side caused by an approaching O star but the narrowness of the overall emission cannot just be explained by a heavy mutilation of the emission line by the Hβ profile of the O star. It, therefore, seems that the emission line itself has a difference in width near about primary and secondary minimum, or in other words the emission line is narrower when the Wolf-Rayet star is closest to the observer than it is when it is farthest away.

The profiles of 4058 Å are also displayed in Figure 2. We have given six of these profiles to indicate the fact that no serious changes in the structure have been observed during the period when these plates were obtained. Hence, we can adopt the values obtained from the radial velocity measures of this line with a good degree of confidence. However, a few minor changes in the appearance of the profile need further mention. The profile close to primary minimum is fairly sharp peaked, differing from that near secondary minimum.

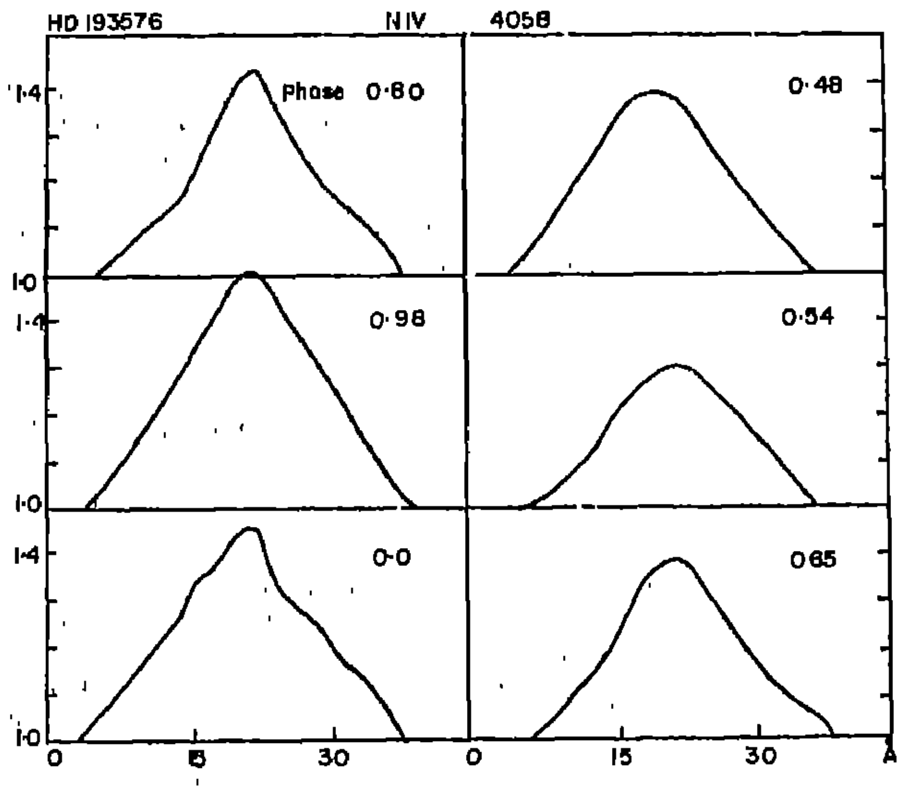

Figure 2 (a).—Profiles of NIV 4058 in the spectrum of HD 193576 at various phases.

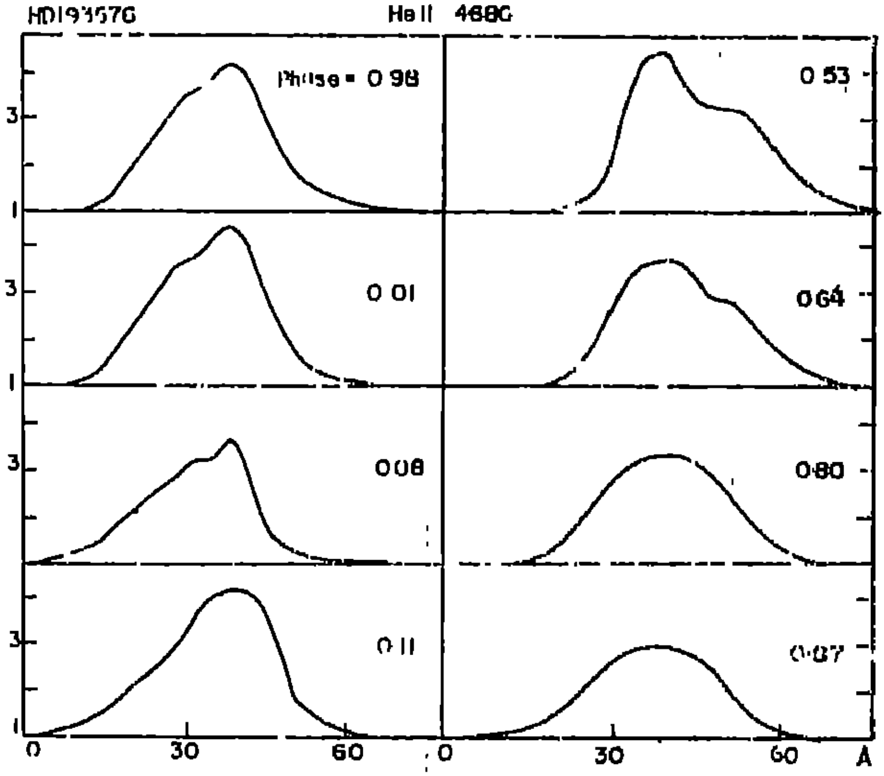

Figure 2 (b) Profiles of He II 4686 in the spectrum of HD 193576 at various phases.

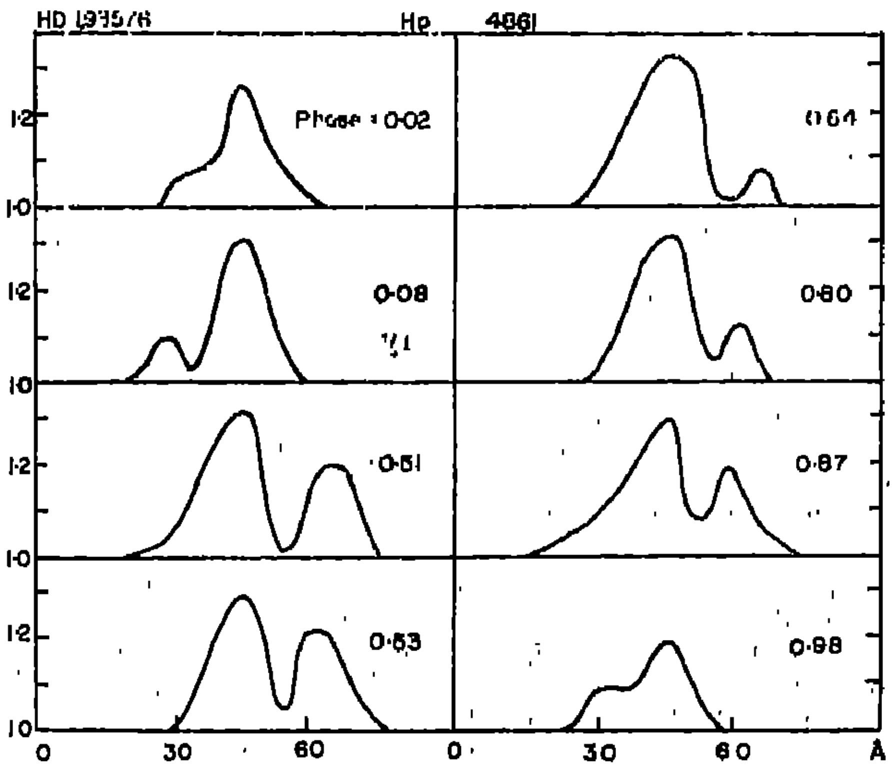

Figure 2 (c).—Profiles of H β 4861 in the spectrum of HD 193576 at various phases.

High dispersion spectra obtained at phases 0.02, 0.48, 0.71 and 0.95P are available, for the study with better resolution, of some of these characteristic changes. These spectra obtained at 10 Å/mm with the 100-inch coude spectrograph extend into the ultra-violet to about 3300 Å. In fact these plates at selected phases, more especially at conjunctions, were exposed to study the profiles of the higher members of the Balmer series and how these have been affected by the electron scattering envelope around the Wolf-Rayet star.

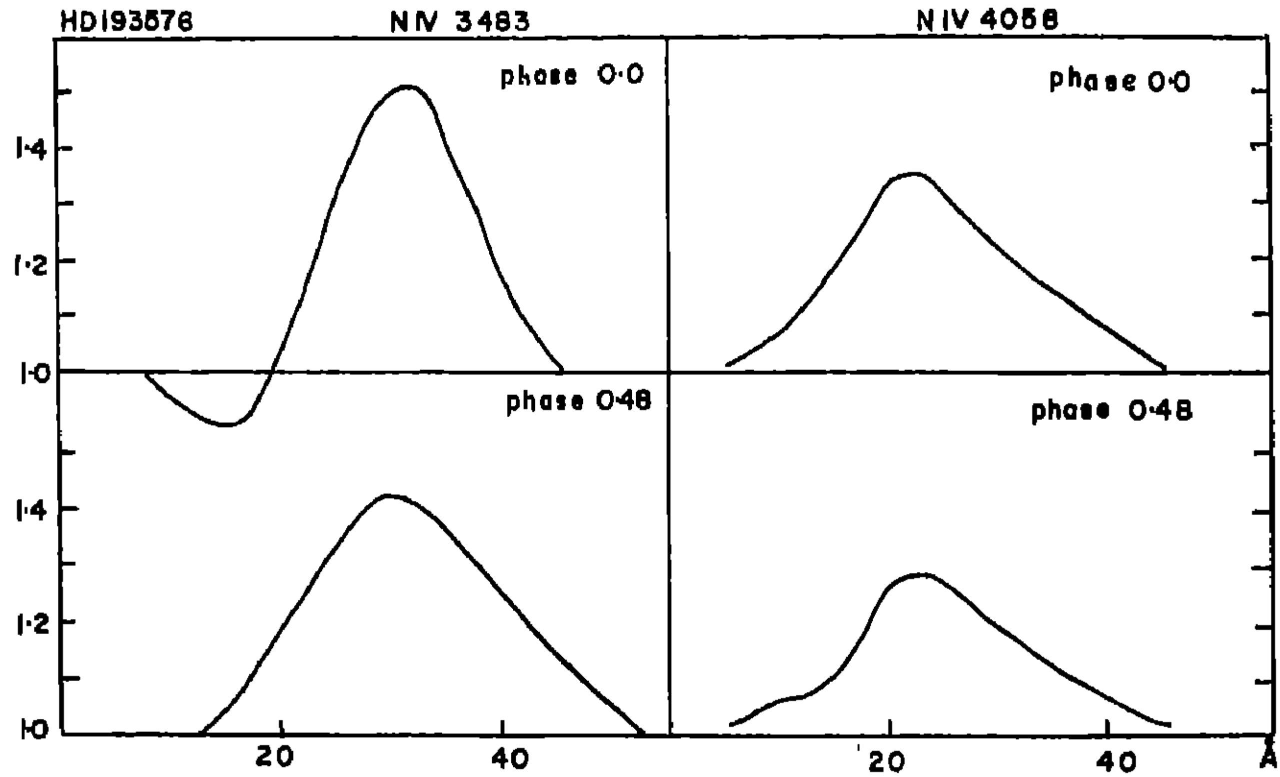

Figure 3—Profiles of NIV 3483 and NIV 4058 in the spectrum of HD 193576 at primary and secondary minimum.

In Figure 3, the profiles of the NIV multiplet $3s^3S$—$3p^1P$ at 3479 Å, 3483 Å and 3485 Å can be seen at primary minimum and secondary minimum alongside the profiles at corresponding phase of the $3p^1P$—$3d^1D$ multiplet at 4058 Å. The kinematic conditions in the Wolf-Rayet envelope are such as to broaden the individual transitions of the triplet considerably, so that we see them unresolved separately. The main characteristic of interest is the presence of a violet absorption edge displaced with respect to the centre of the emission at 3482 Å by 1160 km/sec. This feature is seen only at primary minimum when the Wolf-Rayet star eclipses the O component. The surprising fact is that, at this phase, the Wolf-Rayet spectrum should have the normal characteristics of a WN5 star. The appearance of a violet absorption edge for NIV 3483 is not seen on any of the high dispersion spectra of HD 192163, HD 191765 or HD 193077. It, therefore, seems to be a characteristic stimulated by the component of the binary system. The multiplet $3p^1P$—$3d^1D$ at 4058 Å does not show the absorption feature.

The higher members of the Balmer series that originate in the atmosphere of the O star are widened at primary minimum when the O star shines through the electron scattering envelope of the Wolf-Rayet star. This property was first observed by Munch. Figure 4 indicates the differences in profile for H9, H11

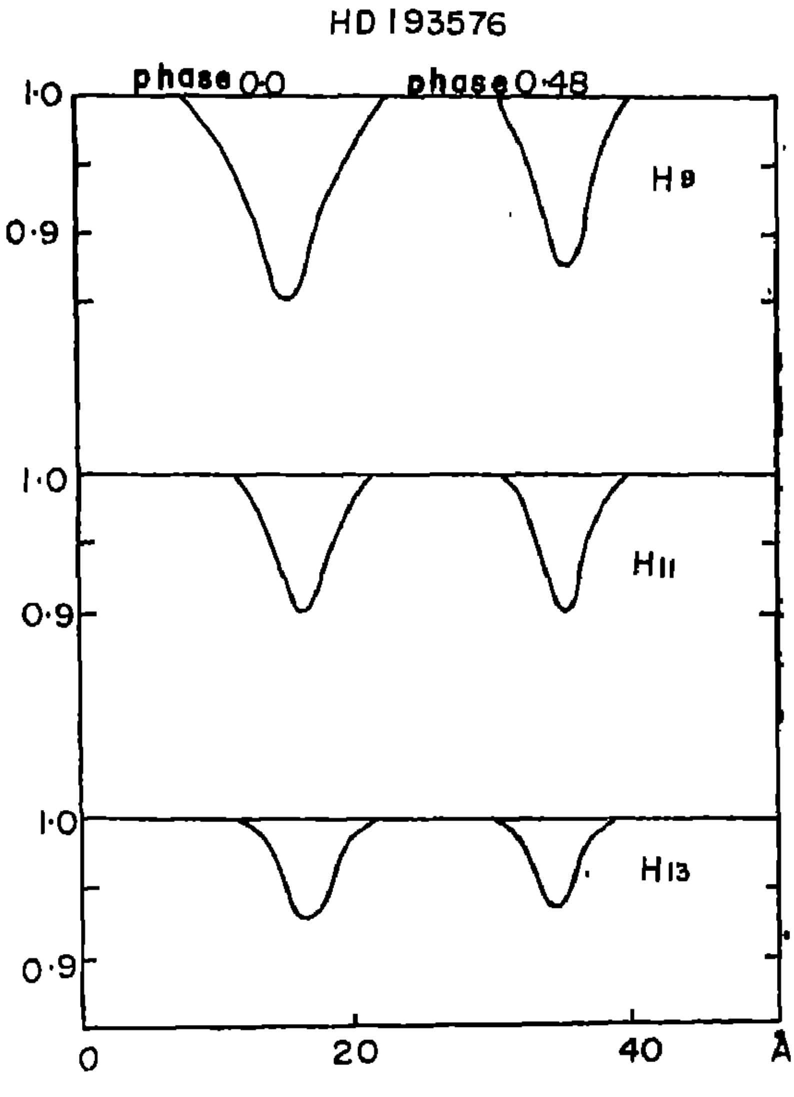

Figure 4—Profiles of H_9, H_{11} and H_{13} in the spectrum of HD 193576 at primary and secondary minimum.

and H13 for the two phases representing primary and secondary minima. The increase in widths is obvious, confirming our speculations regarding the electron scattering envelope. However, the intensities of the hydrogen lines increase by a small amount at this phase. More quantitative information would be necessary before we consider this as definite evidence of enhanced hydrogen absorption in the Wolf-Rayet atmosphere.

The observations reported herein were obtained by one of us (MKVB) during the tenure of a Carnegie Fellowship at the Mount Wilson and Palomar Observatories.

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