

A RADIAL VELOCITY STUDY OF THREE WN STARS AND AN O3f STAR IN THE CARINA NEBULA

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ABSTRACT

An extensive collection of spectrograms obtained over a number of years provides the radial velocity data for these four stars. The WN star HD 92740 is shown to be a single-lined spectroscopic binary with an eccentric orbit and a period of about 80 days. The absorption and emission lines observed in this star vary *in phase*; some of the latter lines more truly represent the real motion of the star. The upper Balmer and He II absorption lines are formed in a region of the envelope/photosphere which is already moving outward with a velocity of some tens of kilometers per second. The two other WN stars, HD 93131 and HD 93162, and the O3f star HD 93129 appear to be single as their velocities show no discernible periodic motion although some random fluctuations are present. In the two WN stars the narrow emission lines appear to give the velocity of the star itself; the upper Balmer and He II absorption lines are formed in the moving envelope/photosphere. In HD 93129 the absorption and emission lines arise in a more or less stationary region of the star. The probable evolutionary status of these four stars is discussed.

Subject headings: stars: binaries — stars: Of-type — stars: Wolf-Rayet

I. INTRODUCTION

The four stars studied in this paper, HD 92740, HD 93129, HD 93131, and HD 93162, are all members of the very young Carina Nebula association. The association distance is based upon spectral classifications and the absolute magnitude calibration of other early-type stars (Walborn 1973*a, b*), so the absolute magnitudes are reasonably well determined. (They are subject to the possible uncertainty in the value of R , the ratio of total to selective extinction; and to the possibility that the main sequence of the very compact cluster Trumpler 14 could be subluminal, in which case HD 93129 would be somewhat less luminous.) The spectral types, colors, and magnitudes are listed in Table 1. Underhill (1967, 1968) has previously pointed out the intrinsic brightness of late WN stars and the similarity to Of and O-type supergiants. Walborn (1971, 1973*a*) has discussed the morphological properties of these three narrow line WN-A stars, and others, and their relationship to the O3 If* star HD 93129. Photographic reproductions of the individual spectra are given in Walborn (1974).

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Conti (1976) has called the three Carina Nebula WN stars "transition" cases because they share the following properties of Of stars which are not shared by most W-R stars studied up to the present time: relatively bright absolute magnitudes, hydrogen present in emission, and absorption present in the upper members of the Balmer series. These stars are probably evolved according to recent calculations of evolutionary tracks for massive stars with appreciable mass loss by a stellar wind. They may be either core-hydrogen-burning (de Loore, De Greve, and Lamers 1977), or core-helium-burning stars (Chiosi, Nasi, and Sreenivasan 1978).

Niemela (1973) has observed that the absorption and emission lines in HD 92740 vary in velocity and move *in phase*, indicating they are formed in the same object. Her preliminary radial-velocity study indicated a binary period of about 10 days, but we will demonstrate here that the correct period is about 80 days. We have carried out an extensive spectroscopic investigation of these objects because of their importance to the question of evolution of massive stars, and because of the possible relation between the WN-A stars and the very luminous O3f star HD 93129. A central question is that of the duplicity of the stars, in view of the statement often made in the literature that "all W-R stars are binaries" (e.g., Kuhl 1973).

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TABLE 1
OBSERVED PARAMETERS

STAR	SPECTRAL TYPES	MAGNITUDES			OTHER SPECTRAL TYPES
		V	$B - V$	M_v	
HD 92740.....	WN7-A (1)	6.40	+0.08	-6.5	WN7 (2)
HD 93129.....	O3 If* (1)	7.3	+0.22	-7.0	O3f (3)
HD 93131.....	WN6-A (1)	6.48	-0.05	-6.1	WN7 (2)
HD 93162.....	WN6-A (1)	8.10	+0.42	-5.9	WN7 (2)

REFERENCES.—(1) Walborn 1973*a*, 1974. (2) Smith 1968. (3) Conti and Leep 1974.

In § II, we shall discuss the spectroscopic data and present the radial velocity observations of the four stars. The new binary orbit of HD 92740 will be discussed in § III. The fact that the absorption and emission lines vary *in phase* enables us to be sure that we are dealing with the spectrum of only one object. Conclusions concerning the velocity gradients can be made since the emission and absorption lines give more or less the same velocity *amplitude* although with different *systemic* values. In § IV we discuss the velocities of the other three stars and indicate the confidence level to which we can choose between a single or binary nature. We also address the question of the velocity gradients in the envelopes of these stars, previously discussed by Niemela (1975). Given the example of HD 92740, the emission and absorption lines can be assumed to arise in the same object in each case. We shall show that there is quantitative similarity to at least a few Of stars in the derived velocity structure. A discussion of the significance of these results is presented in § V.

After the work reported in this paper was essentially completed, we received preprints from Drs. A. F. J. Moffat and W. Seggewiss concerning their spectroscopic investigations of the same WN stars (Moffat and Seggewiss, 1978; Moffat 1978). One of the major conclusions of this paper and theirs is the same, namely that HD 92740 is an 80 day spectroscopic binary, and the other two WN stars appear to be single. Some other results are different, and we shall discuss such differences where appropriate.

II. OBSERVATIONS

Although some spectroscopic data existed for all four stars in 1970 and 1971, a full-fledged attack on these objects was begun independently in 1974 by each of us. Extensive observations were obtained from then through 1977 when sufficient material appeared to have been collected. Although most of the spectroscopy was carried out at the Cerro Tololo Inter-American Observatory in Chile, a small portion was obtained at the Bosque Alegre Station of the Cordoba Observatory, in Argentina, by V. S. N. alone. Table 2 indicates the plate code giving the observatory, telescope, spectroscopic configuration, and dispersions utilized. Nearly all spectrograms were obtained in the blue region of the spectrum but a few were taken in the red. They were mostly on baked or unbaked Ila-O

plates, but several were on IIIa-J, 103a-F, 098-02, or 103a-O emulsions.

The spectral lines were measured on Grant single-coordinate machines, either at Kitt Peak National Observatory (P. S. C.), Cerro Tololo (N. R. W. and V. S. N.) or the La Plata Observatory (V. S. N.). The separate plates were usually measured by the individual observers who obtained them. The eight D plates (aside from the first) of HD 93129 were measured independently by P. S. C. and V. S. N. There was excellent agreement between the line velocities obtained by each measurer for this star, so it was felt that the measurement procedure itself does not contribute appreciably to the scatter in the data. Additionally, as will be seen by close inspection of the tables to follow, there were a few occasions when independent data were obtained the same night for each of the stars. Agreement between such plates is good.

As we have remarked previously, the spectra of all four stars contain both emission and absorption lines. The former are relatively more prominent in HD 92740 and HD 93131; the latter are relatively more prominent in HD 93129 and HD 93162. For all stars the $\lambda 4057$ N iv emission was reasonably strong and relatively "narrow" and could be measured with confidence on nearly every spectrogram. The lines that could be measured on each plate were otherwise an important function of the dispersion and spectrograph (some of the Cassegrain plates had a smaller wavelength range), the quality of the spectrogram, and probably real variations in the spectra.

Since individual line measures have uncertainties typically 20–30 km s⁻¹ per plate, it is important to average different lines wherever possible. We have taken two groups of lines for the averaging in each star. Group 1 lines are the "narrow" *emission* lines (e.g., $\lambda 4057$ N iv; $\lambda\lambda 4089, 4116$ Si iv) plus the N v

TABLE 2
SPECTROSCOPIC DATA

Plate Code	Observatory	Telescope	Spectrograph	Dispersions (Å mm ⁻¹)
A...	CTIO	0.9 m	Cass	42, 60, 124
C...	CTIO	1.5 m	Cass	39, 78
D...	CTIO	1.5 m	Coudé	9, 18
I....	Bosque Alegre	1.5 m	Cass	42

absorption at $\lambda\lambda 4603, 4619$. (The emission and absorption are treated separately in HD 92740.) Group 2 lines are the upper Balmer series and He II absorption lines. Each group has similar *mean* velocities for the individual lines in the three single stars, as we will justify more fully in § IV. The ubiquitous $\lambda 4057$ N IV is also considered separately, as is the very strong, "broad" emission at $\lambda 4686$ He II in HD 92740. In the averaging of line velocities and of plate velocities we have adopted equal weight for all plates, irrespective of the spectrogram and dispersion. In the final orbital solution for HD 92740 only, we have treated the coude plates (code D) with twice the weight of the others.

Tables 3–6 give the Journal of Observations of HD 92740, HD 93129, HD 93131, and HD 93162, respectively. The letter preceding the plate code indicates the observer (C = P. S. C.; N = V. S. N.; W = N. R. W.). The second letter is the plate code from Table 2. The mean plate velocities for each group, the number of lines, and the standard deviations are given for each individual entry. The mean line velocities will be discussed in § IV.

Velocities of HD 92740 from the plates through D187 (but excluding I8387) have been reported previously (Niemela 1973). The values given in Table 3 are based on new measures of these spectrograms and are to be preferred over the older values.

III. THE ORBIT OF HD 92740

Although Niemela (1973) had reported a preliminary period of 10 days for this star, the velocities from the six-night coude run in 1975 late April (JD 2,442,528...) left no doubt that this result was not tenable. After considerably more data had been amassed, a period search by V. S. N. using her data and the coude plates up to 1977 February (i.e., before JD 2,443,200) revealed possible periods of about 46 and 80 days. The addition of the plates obtained subsequent to this date, and the velocities from the spectrograms of N. R. W., confirmed the latter period with its high eccentricity.

It is now understood how the initial erroneous period of 10 days was found: the first five spectrograms were (un)fortunately obtained just around periastron passage when the velocity changes in just a few days from negative to more positive values; the four subsequent spectrograms, except I7989, also came at the same phase. An incorrect short period was derived under the usual initial assumption of a circular orbit. A subsequent test by N. R. W. of possible periods for HD 92740 revealed that over 4 years of spectroscopic data were necessary to unambiguously define the correct value. For example, all of our extensive JD 2,442,000 material covers only the shallow descending branch of the 80 day velocity curve, while nearly all of the JD 2,443,000 observations lie on the steep ascending branch. Lafler-Kinman (1965) period searches of either subset fail to find the correct period with significant probability, but the latter subset yields a well-defined, nearly circular velocity curve with period 42.2 and high probability. Of course, a search

of both subsets combined finds the correct period and rules out any others.

We have derived orbital parameters from the data given in Table 3. The choice of which emission and absorption lines to average is predicated upon the results from the apparently single WN stars to be discussed in § IV, particularly with reference to HD 93131 which has a very similar spectrum. Orbital solutions were initially derived separately for the Group 1 and Group 2 lines using the program of Wolfe, Horak, and Storer (1967), subsequently modified by Paul Baker and Phillip Massey of the University of Colorado. The periods for the two sets of data were nearly identical (i.e., 80.34 and 80.36 days) from the formal least-squares criteria but they could not be made to converge to exactly the same value. Since this is clearly not physical we adopted a mean period of 80.35 days for both groups of lines as the formal solution. The orbital parameters with this period fixed are given in Table 7 for these two groups of lines, the mean of the absorption lines at $\lambda\lambda 4603, 4619$ N V and for the broad emission line $\lambda 4686$ of He II. The latter data were not expected to be as accurate as those for the group averages so the same period was assumed.

Comparing first the Group 1 and Group 2 lines, we see that they have similar e , ω , and T_0 (time of periastron passage). The "system" velocities, γ , differ significantly, as is to be expected from the outward velocity gradient in the envelope of this star. The γ velocity of the Group 1 lines agrees with that for the Carina Nebula association and that of the three single stars (cf. § IV); the Group 2 lines are violet displaced, as in Of stars (Conti, Garmany, and Hutchings 1977). The velocity semiamplitudes, K , differ by 15 km s^{-1} , an amount which is somewhat outside the formal probable errors, but which may not be significant.¹ The mean $O - C$ for the Group 1 and Group 2 lines are 11 and 20 km s^{-1} , respectively, in very nice agreement with the mean internal plate errors (s.d.) of 11.7 and 18.2 km s^{-1} .

Turning now to the solutions using the N V absorption and the He II emission line, we see that the former gives a γ similar to the Group 1 lines; hence they are formed at the same level in the stellar envelope (cf. § IV). The $\lambda 4686$ emission line has a significantly positive displaced systemic velocity, in agreement with the behavior of this line in other W-R binaries and single stars (cf. § IV) and in some Of stars. Although the e , ω , and T_0 appear to differ substantially from the Group 1 and Group 2 values, we believe this to be an artifact of deriving formal least-squares solutions from sets of data utilizing only one or two lines. These orbital parameters are particularly sensitive to measured velocities near periastron and, as we shall demonstrate shortly, there is considerable scattering near that phase.

¹ Moffat and Seggewiss (1978) found a K value for the emission lines of 70 km s^{-1} , in reasonable agreement with our comparable Group 1 lines. However, they find a K value of $\sim 30 \text{ km s}^{-1}$ for three Balmer lines, which is much smaller than our Group 2 lines. Although we are unable to account for this discrepancy, we note that we have a more extensive data base.

TABLE 3
HD 92740 JOURNAL OF OBSERVATIONS

Plate	JD 2440000 ⁺	Phase ϕ^*	Group 1 [†]			N IV $\lambda 4057$ km s ⁻¹	N V ABS. km s ⁻¹	Group 2 [†]			He II $\lambda 4686$ km s ⁻¹
			Mean km s ⁻¹	No.	S.D. km s ⁻¹			Mean km s ⁻¹	No.	S.D. km s ⁻¹	
NC1224	723.60	0.94	-70	6	14	-61	-92	-224	2	10	-5
NC1226	724.57	0.95	-94	6	9	-100	-149	-180	2	43	-2
NC1236	726.62	0.98	-86	7	2	-95	-130	-188	5	22	-23
NC1264	728.56	0.00	+9	6	23	-21	-38	-176	1		+41
NC1280	729.51	0.01	+62	6	15	+16	+12	-57	6	18	+124
NI7989	1079.48	0.37	+6	4	5	+16	-27	-148	4	33	+91
NA2021	1285.85	0.94	-107	4	10	-104	-202	-264	6	14	-28
ND159	1289.85	0.99	-68	6	7	-57	-72	-142	7	14	-11
NC2195	1290.87	0.00	-38	2	15	-23	-49	-127	4	24	+126
NC2204	1292.88	0.03	+32	2	4	+35	-18	-92	4	12	+166
NI8385	1462.50	0.14	+11	3	10	-10					
NI8386	1463.45	0.15	+30	7	9	+12		-114	8	8	
NI8387	1463.53	0.15	+36	6	20	+2		-97	5	28	
ND187	1491.50	0.50	-17	4	11						
NI8514	1666.75	0.68	-49	4	10	-42		-143	2	2	
NI8618	2025.80	0.15	+37	7	10	+32		-66	5	20	
NI8659	2091.78	0.97	-82	6	11	-71	-66	-192	7	13	-8
WA2901	2107.67	0.17	+25	3	8	+26		-115	3	13	
WA2904	2108.61	0.18	+22	3	1	+24		-122	3	24	
WA2906	2108.86	0.18	+28	4	8	+23		-99	3	8	
WD353	2112.90	0.23	+13	2	2	+15					
CD396	2121.75	0.34	-6	6	7	-15	-10	-92	3	24	+60
NI8678	2145.61	0.64	---			-9		-154	4	31	
NI8683	2146.50	0.65	-44	5	6	-28		-176	2	29	+11
NI8688	2147.53	0.66	-44	2	21		-164	-225	1		-13
NI8694	2148.50	0.68	-47	6	11	-68		-225	3	41	+11
NI8695	2148.58	0.68	-58	5	6	-65	-118	-153	1		+5
WA2988	2148.77	0.68	-55	3	10	-45		-124	2	24	
WA2993	2166.64	0.90	-91	4	10	-81		-151	4	28	
WA2997	2167.64	0.91	-76	4	11	-80		-196	3	36	
WA3001	2168.63	0.93	-80	4	13	-95		-166	4	23	
NI8772	2383.82	0.60	-44	3	11	-29		-202	3	24	
NI8775	2384.77	0.62	-21	2	19						
NI8781	2386.77	0.64	-11	3	26	-50		-194	6	24	
NI8786	2387.80	0.65	-29	5	11	-22		-167	6	27	
WA4093	2461.80	0.57	-46	4	12	-36		-134	2	6	
WA4096	2462.81	0.59	-40	4	17	-36		-113	3	21	
WA4098	2463.82	0.60	-37	3	2	-39		-140	2	11	
WA4101	2464.79	0.61	-49	4	16	-47		-97	5	20	
WA4103	2465.79	0.62	-65	4	15	-33		-180	1		
NA4106	2472.81	0.71	-82	4	16	-67		-154	5	22	
NA4107	2473.63	0.72	-60	4	17	-39		-181	4	12	
NA4108	2473.83	0.72	-64	3	10	-50		-178	5	15	
NA4110	2474.58	0.73	-82	3	21	-49		-174	3	10	
NA4112	2474.72	0.74	-74	3	43		-106	-220	3	27	
NA4114	2475.64	0.75	-68	6	8	-55	-119	-187	3	10	
NA4116	2475.71	0.75	-70	4	6	-59		-174	6	12	
NA4118	2476.66	0.76	-47	4	14	-23		-198	2	32	
NA4112	2477.68	0.77	-79	5	16	-65	-105	-214	9	12	+25
CD558	2528.65	0.41	-27	6	9	-41	+27	-158	6	16	+60
CD571	2530.52	0.43	-26	6	14	-23	-48	-152	5	26	+52
CD580	2531.58	0.44	-39	6	10	-18	-45	-148	6	18	+28
WA4262	2531.67	0.44	-22	4	16	-18		-93	5	15	
WA4265	2532.58	0.46	-10	4	13	-24		-136	2	21	
CD587	2532.66	0.46	-23	3	17	-25	-91	-129	6	18	+54
CD590	2533.59	0.47	-23	3	17	-25	-21	-165	7	16	+55
NA4423	2877.74	0.75	-64	6	14	-57	-56	-169	2	19	-12
NA4427	2878.62	0.76	-64	6	17	-46	-141	-183	4	12	-45
NA4433	2879.70	0.78	-69	7	14	-50	-108	-176	6	10	-16
NA4439	2880.68	0.79	-67	5	13	-67		-168	4	7	

TABLE 3—*Continued*

Plate	2440000 ⁺	Phase ϕ^*	Group 1 [†]			N IV $\lambda 4057$ km s ⁻¹	N V ABS. km s ⁻¹	Group 2 [†]			He II $\lambda 4686$ km s ⁻¹
			Mean km s ⁻¹	No.	S.D. km s ⁻¹			Mean km s ⁻¹	No.	S.D. km s ⁻¹	
NA4442	2881.60	0.80	-74	7	12	-59	-113	-198	5	17	-2
CD710	2882.52	0.81	-90	6	14	-98	-104	-167	5	23	-15
NA4449	2882.60	0.81	-68	4	16	-52		-206	6	10	
ND715	2883.50	0.82	-84	6	17	-87	-64	-213	4	30	-17
CD718	2884.55	0.84	-88	5	13	-95	-65	-207	6	12	-20
CD722	2887.53	0.87	-97	5	15	-111	-88	-215	4	20	-28
CD727	2888.54	0.89	-107	5	17		-72	-229	4	24	-14
CD733	2889.52	0.90	-122	7	7	-116	-114	-243	7	23	-41
CD739	2890.55	0.91	-99	7	8	-100	-128	-173	7	20	-37
NA4506	3135.79	0.96	-73	6	15	-68	-163	-233	3	37	-67
NA4511	3136.84	0.98	-47	5	12	-17		-142	2	3	-14
NA4515	3137.79	0.99	-52	7	7	-33	-93	-153	8	19	-6
NA4519	3138.81	0.00	-22	7	11	-24	-38	-175	7	10	+38
NA4523	3139.81	0.01	+14	7	6	+5	-36	-127	9	10	
NC4742	3141.85	0.04	+46	7	7	+29	+20	-94	7	16	+117
NC4746	3142.70	0.05	+43	7	6	+51	-17	-132	6	7	+112
NC4747	3142.76	0.05	+38	7	7	+39	+16	-95	6	15	+117
NC4755	3143.83	0.06	+58	7	9	+48	+24	-84	8	7	+143
NC4760	3144.85	0.08	+41	7	8	+33	+30	-102	7	4	+113
NA4528	3145.79	0.09	+47	7	8	+41	+8	-123	3	28	+129
NA4532	3146.82	0.10	+66	7	17	+45	+66	-75	9	13	
NA4536	3147.82	0.11	+79	7	21	+42	+102	-87	10	14	
NC4799	3200.80	0.77	-48	7	5	-64	-116	-203	5	9	+24
NC4803	3201.67	0.78	-63	7	7	-66	-86	-206	7	10	+15
NC4810	3202.67	0.79	-77	7	4	-79	-98	-217	7	10	+15
NC4821	3203.69	0.81	-47	7	16	-37	-111	-206	3	46	-22
CD905	3204.76	0.82	-106	5	10		-61	-188	5	22	+11
CD917	3206.76	0.85	-89	8	7		-61	-191	6	19	+4
CD928	3208.68	0.87	-104	7	9		-74	-167	3	8	-23
NC4839	3212.59	0.92	-118	7	11	-103	-105	-268	7	15	-30
NC4843	3213.55	0.93	-109	7	16	-106	-133	-280	8	15	-39
NC4845	3214.55	0.94	-95	7	10	-97	-133	-248	6	13	-25
CD931	3235.53	0.20	+12	6	10	-1	+26	-136	6	20	+92
CD935	3236.54	0.21	+11	6	7	+2	+14	-101	7	15	+89
CD943	3238.47	0.24	-7	4	10	-3	+30	-110	4	21	+78
CD947	3239.50	0.25	-6	5	8	-10	+38	-125	6	9	+85
CD951	3240.53	0.27	+8	5	6	-5	+37	-138	4	14	+84
Means					11.69(96)				18.2(90)		
					±0.6				±0.95		

*Phase based on elements of Table 7.

[†]Group 1 lines: narrow emission $\lambda\lambda 4089, 4116$ Si IV; $\lambda 4057$ N IV; $\lambda\lambda 4097, 4379, 4634, 4640-42$ N III.Group 2 lines: absorption, Balmer series H11 to H8; $\lambda\lambda 3923, 4025, 4200, 4541$ He II.

From the preceding discussion it is reasonable to assume that all observed lines originate in the W-R star, although at different levels in the stellar envelope as evidenced by the different system velocities. (We shall return to the possible difference in the velocity amplitude between the Group 1 and Group 2 lines presently.) We adopt the Group 1 solution as representing the orbital motion of the primary W-R star since it has the smallest $O - C$ and mean internal plate errors and a γ velocity similar to that of the Carina Nebula association. We then plot all the velocities separately (with very slight phase shifts to account for the T_0 differences). Figure 1 shows the

narrow emission lines of Group 1. Figure 2 shows the absorption lines of Group 2. Figure 3 shows the N v absorption lines at $\lambda\lambda 4603, 4619$; and Figure 4 the $\lambda 4686$ He II emission line. The solid curve in each figure represents the Group 1 solution with different γ (only) as shown in Table 7. The agreement with this assumption is very good for the Group 2 lines, the N v absorption lines, and the He II emission line. For the Group 2 lines the dotted curve in Figure 2 is a formal solution using the least squares criteria alone.

Taken at face value, this difference between the two solutions could be interpreted as an effect of blending of the secondary star lines with the absorption lines of

TABLE 4
HD 93129 JOURNAL OF OBSERVATIONS

Plate	JD 2440000+	Group 1*			N IV			Group 2*		
		Mean km s ⁻¹	No.	S.D. km s ⁻¹	λ4057 km s ⁻¹	Mean km s ⁻¹	No.	Mean km s ⁻¹	No.	S.D. km s ⁻¹
NA2015	1284.85	-44	3	4	-37	-34	9	-34	9	7
NA2032	1287.85	-8	3	10	-16	-25	4	-25	4	16
NC2194	1290.81	-2	3	8	-2	+2	8	+2	8	8
NC2198	1291.80	-12	3	12	-29	-4	8	-4	8	8
NC2203	1292.87	-36	3	5	-9	-15	9	-15	9	9
NI8502	1664.77	-70	1	--	-70	-65	3	-65	3	12
NI8509	1665.74	+2	1	--	+2	-23	7	-23	7	11
NI8515	1666.81	-25	3	4	-20	-30	6	-30	6	10
WA2901	2107.75	-10	1	--	-10	-1	5	-1	5	9
WA2904	2108.69	-31	1	--	-31	-22	5	-22	5	5
WA2906	2108.89	-15	1	--	-15	-22	4	-22	4	20
WD349	2111.71	-19	1	--	-18	-21	4	-21	4	4
CD358	2114.70	-16	3	3	-22	-28	9	-28	9	4
CD362	2115.71	-46	3	7	-36	-43	10	-43	10	4
CD368	2116.79	-32	3	17	-9	-32	8	-32	8	7
CD373	2117.80	-16	2	5	-21	-28	10	-28	10	6
CD378	2118.69	-33	3	13	-9	-33	9	-33	9	5
CD382	2119.67	-34	3	19	-11	-32	10	-32	10	5
CD388	2120.63	-49	3	18	-22	-35	9	-35	9	5
CD395	2121.65	-37	3	17	-13	-33	10	-33	10	4
WA2988	2148.75	+2	1	--	+2	+1	4	+1	4	9
NI8679	2145.70	-7	3	16	+12	-2	9	-2	9	8
NI8684	2146.59	-3	3	12	+3	+7	10	+7	10	6
NI8689	2147.62	-1	3	1	-3	-12	9	-12	9	7
WA2993	2166.62	-12	1	--	-12	-13	5	-13	5	3
WA2996	2167.62	-19	1	--	-19	-24	5	-24	5	6
WA3001	2168.62	-8	1	--	-8	-5	8	-5	8	6
WA4093	2461.77	-39	1	--	-39	-17	5	-17	5	10
WA4095	2462.71	-21	1	--	-21	-10	6	-10	6	10
WA4098	2463.80	-33	1	--	-33	-17	5	-17	5	8
WA4100	2464.69	-3	1	--	-3	-17	5	-17	5	4
WA4103	2465.77	-2	1	--	-2	+11	5	+11	5	10
WA4106	2472.83	-11	3	12	-21	-26	8	-26	8	9
NA4109	2473.86	-1	2	6	-6	-25	7	-25	7	10
NA4111	2474.75	+13	2	43	+19	-23	5	-23	5	15
NA4112	2474.75	+13	1	--	---	-1	4	-1	4	12
NA4116	2475.74	-18	1	--	-18	-21	10	-21	10	4
NA4119	2476.71	-9	3	13	-15	-6	11	-6	11	9
NA4122	2477.70	-37	3	18	-9	-18	8	-18	8	7
CD550	2527.65	-42	2	20	-23	-42	8	-42	8	7
CD556	2528.53	-8	3	8	-23	-22	8	-22	8	7
CD571	2530.48	-34	3	14	-38	-31	8	-31	8	7
CD579	2531.50	-5	3	14	-29	-26	8	-26	8	4
WA4262	2531.59	-37	3	18	+7	-27	4	-27	4	6
CD586	2532.58	+16	1	--	+16	-13	6	-13	6	6
CD590	2533.36	-30	3	11	-27	-35	9	-35	9	7
NA4423	2877.66	+10	5	6	+12	+9	10	+9	10	7
NA4432	2879.66	-13	5	9	-15	-20	9	-20	9	7
NA4439	2880.62	+11	3	10	-8	-21	5	-21	5	11
NA4442	2881.59	-37	3	19	-16	-6	7	-6	7	10
NA4449	2882.61	+10	1	--	+10	-44	9	-44	9	9
CD710	2882.55	-4	3	16	-35	-28	9	-28	9	6
CD718	2884.63	-18	3	11	-38	-8	7	-8	7	7
CD722	2887.58	-8	3	13	-27	-9	8	-9	8	8
CD727	2888.58	-10	3	8	-21	-39	7	-39	7	11
CD733	2889.56	-14	2	4	-18	-35	9	-35	9	9
NA4506	3135.84	-26	3	23	-15	-17	6	-17	6	8
NA4514	3137.76	+8	5	13	+12	-1	9	-1	9	10
NA4518	3138.77	-9	4	12	-12	-19	8	-19	8	11
NA4523	3139.79	+19	4	11	-5	-4	10	-4	10	9
NC4747	3142.73	-20	5	5	-20	-18	9	-18	9	6
NC4760	3144.84	-28	5	4	-17	-10	9	-10	9	9
NA4528	3145.80	-12	4	20	-4	-26	5	-26	5	14
NA4532	3146.84	-33	4	9	-11	+1	10	+1	10	6
NA4535	3147.77	+14	3	16	-17	-7	10	-7	10	11
NC4803	3201.69	-21	5	5	-18	+5	9	+5	9	8
NC4810	3202.68	-23	5	3	-22	-16	7	-16	7	8
NC4821	3203.73	43	4	13	-21	-45	1	-45	1	--
CD932	3235.57	-9	3	12	-33	-8	8	-8	8	7

*Group 1 lines: narrow emission λ4089, 4116 Si IV; λ4057 N IV; and

absorption λ4603, 4619 N V.

Group 2 lines: absorption, Balmer series H11 to Hγ; and λλ3923, 4025, 4200, 4541 He II.

TABLE 5
HD 93131 JOURNAL OF OBSERVATIONS

Plate	JD 2440000+	Group 1*			Group 2*		
		Mean km s ⁻¹	No.	S.D. km s ⁻¹	Mean km s ⁻¹	No.	S.D. km s ⁻¹
NC1224	723.61	-23	7	6	-137	3	8
NC1227	724.68	-65	8	14	-165	5	15
NC1248	727.50	-30	8	16	-176	4	25
NC1264	728.55	-50	7	17	-155	7	22
NC1280	729.55	-37	6	11	-130	7	15
NI7990	1079.50	-39	7	18	-172	5	34
ND159	1289.81	-42	8	14	-146	7	9
ND191	1484.46	-38	4	27	---	---	---
WA2901	2107.68	-27	4	15	-69	3	23
WA2904	2108.62	-34	4	9	-81	3	4
WA2906	2108.87	-33	4	4	-100	4	21
WD349	2111.76	-22	2	6	-64	3	31
CD357	2114.58	+2	6	6	-120	7	12
CD369	2116.83	-45	6	7	-123	7	22
CD373	2117.82	-39	7	8	-130	4	20
CD377	2118.65	-42	8	8	-145	7	20
CD381	2119.60	-41	6	9	-143	7	13
CD387	2120.52	-35	6	8	-129	6	23
CD394	2121.52	-49	7	9	-128	7	23
WA2988	2148.78	-36	7	11	-61	3	23
WA2993	2166.65	-55	4	17	-99	4	12
WA2997	2167.65	-15	4	6	-135	3	29
WA3001	2168.64	-41	4	5	-14	3	16
WA4093	2461.82	-31	4	6	-107	3	11
WA4096	2462.82	-40	4	16	-70	2	29
WA4098	2463.83	-38	3	21	-96	5	9
WA4101	2464.81	-37	3	17	-97	5	16
WA4103	2465.81	-22	3	2	-131	4	31
NA4106	2472.85	-52	3	13	-98	9	9
NA4107	2473.65	-23	3	11	-138	4	16
NA4108	2473.84	-40	3	24	-123	5	15
NA4110	2474.59	---	---	---	-116	5	37
NA4112	2474.77	-40	3	24	-123	3	8
NA4114	2475.65	-25	7	11	-151	3	11
NA4116	2475.76	-34	3	12	-109	7	16
NA4119	2476.68	-35	4	29	-185	2	51
NA4122	2477.71	-55	6	6	-134	10	10
CD549	2527.59	-44	2	5	-203	4	18
CD557	2528.59	-29	5	8	-103	8	20
CD571	2530.50	-49	5	5	-119	6	28

Plate	JD 2440000+	Group 1*			Group 2*		
		Mean km s ⁻¹	No.	S.D. km s ⁻¹	Mean km s ⁻¹	No.	S.D. km s ⁻¹
CD580	2531.60	-52	7	7	-44	4	14
WA4262	2531.68	-28	3	14	-35	3	17
WA4265	2532.62	-22	3	14	-37	3	28
CD586	2532.63	-51	5	15	-31	4	21
CD590	2533.61	-50	6	16	-48	6	3
NA4428	2878.63	-46	5	21	-38	6	18
NA4431	2879.59	-56	8	16	-20	6	22
NA4432	2879.60	-37	9	11	-13	7	15
NA4433	2879.69	-37	8	12	-12	6	19
NA4439	2880.63	-9	5	9	-2	4	1
NA4442	2881.60	-36	9	7	-33	5	9
CD710	2882.53	-43	7	8	-35	8	16
NA4449	2882.71	-31	4	11	-30	5	15
CD718	2884.58	-46	7	7	-57	8	16
CD722	2887.55	-62	7	10	-57	6	11
CD727	2888.55	-55	8	5	-53	5	15
CD733	2889.54	-48	5	8	-45	7	20
CD739	2890.56	-61	5	8	-55	7	14
NA4506	3135.83	-77	7	22	-22	6	7
NA4510	3136.83	-57	5	24	-9	8	31
NA4515	3137.81	-36	9	10	-37	10	14
NA4519	3138.79	-44	9	5	-32	8	8
NA4523	3139.82	-38	8	16	-33	9	8
NC4742	3141.87	-35	8	10	-30	7	23
NC4747	3142.86	-38	9	7	-37	8	5
NC4755	3143.77	-44	9	11	-29	10	5
NC4760	3144.86	-46	9	9	-49	8	14
NA4529	3145.84	-62	7	16	-43	3	24
NA4532	3146.80	-30	7	12	-24	9	9
NA4536	3147.81	-15	6	4	-22	8	6
NC4803	3201.76	-36	9	10	-30	8	7
NC4810	3202.69	-55	9	9	-38	8	12
NC4821	3203.74	-55	7	15	-51	---	---
CD931	3235.54	-40	7	6	-44	7	7
CD943	3238.51	-43	5	11	-48	7	7
CD947	3239.52	-37	5	7	-40	6	11
CD951	3240.55	-37	5	9	-40	8	11

*Group 1 lines: narrow emission $\lambda\lambda 4089, 4116$ Si IV; $\lambda 4057$ N IV; $\lambda\lambda 4097,$

4379, 4634, 4640-42 N III and absorption $\lambda\lambda 4603, 4619$ N V.

Group 2 lines: absorption, Balmer lines H11 to H6; $\lambda\lambda 3923, 4025, 4200,$

4541 He II.

TABLE 6
HD 93162 JOURNAL OF OBSERVATIONS

Plate	JD 2440000+	Group 1*			N IV $\lambda 4057$ km s ⁻¹	Group 2*		
		Mean km s ⁻¹	No.	S.D. km s ⁻¹		Mean km s ⁻¹	No.	S.D. km s ⁻¹
NC1224	723.64	-64	3	14	-41	-72	2	21
NC1264	728.54	-116	2	26	-90	-87	7	15
NC1280	729.54	-12	5	11	-3	-37	8	13
NC2194	1290.80	-5	4	24	0	-34	10	11
NC2203	1292.80	-34	4	13	-5	-52	10	16
WA2901	2107.72	-17	1	--	-17	-54	5	9
WA2904	2108.65	-8	1	--	-8	-59	5	14
CD368	2116.76	-33	5	14	-29	-73	8	10
CD373	2117.76	-43	2	20	-24	-90	6	8
CD376	2118.62	-22	4	7	-26	-80	8	11
CD387	2120.59	-23	4	6	+7	-68	7	13
CD394	2121.58	+4	3	19	-35	-69	8	15
WD402	2143.66	-23	1	--	-23	-60	6	16
WA2988	2148.71	-18	1	--	-18	-50	3	17
WA2992	2166.57	-26	1	--	-26	-52	5	10
WA2996	2167.57	-8	1	--	-8	-21	5	9
WA3000	2168.57	-36	3	1	-38	-37	5	18
WA4093	2461.72	-36	2	23	-60	-60	4	26
WA4096	2462.77	-55	1	--	-55	-59	6	22
WA4098	2463.74	-47	1	--	-47	-37	3	8
WA4101	2464.75	-40	1	--	-40	-56	4	19
WA4103	2465.72	-30	1	--	-30	-35	4	13
NA4106	2472.87	---			+4	-93	3	30
NA4108	2473.77	-23	3	6	-22	-78	5	18
NA4111	2474.66	-21	3	29	-3	-87	4	31
NA4116	2475.79	+17	3	24	-31	-84	8	22
NA4123	2477.75	-83	4	12	-46	-84	9	17
CD558	2528.62	-44	3	7	-30	-85	7	9
CD580	2531.55	-16	4	14	-6	-70	7	10
WA4262	2531.63	+6	1	--	+6	-36	6	8
NA4423	2877.70	-50	5	12	-44	-52	7	16
NA4432	2879.63	-33	6	18	-52	-49	7	29
NA4439	2880.70	-23	2	20	-44	-130	2	59
NA4442	2881.58	-31	6	26	-21	-69	6	21
CD711	2882.59	-53	5	13	-50	-47	9	15
NA4449	2882.67	-33	1	--	-33	-105	7	13
CD722	2887.64	-34	4	7	-55	-102	6	13
CD727	2888.62	-63	3	8	-48	-75	7	11
NA4510	3136.80	-16	3	6	-8	-90	8	23
NA4514	3137.73	-32	3	10	-15	-48	10	15
NA4518	3138.76	-36	4	13	-4	-65	9	12
NA4522	3139.77	-17	3	18	-11	-70	10	16
NC4741	3141.84	-60	3	20	-19	-62	6	16
NC4748	3142.85	-31	7	9	-18	-65	6	19
NC4745	3143.80	-17	7	12	-21	-53	9	15
NC4759	3144.81	-12	7	15	-12	-82	8	13
NA4529	3145.79	---			---	---		
NA4531	3146.77	-30	5	13	-5	-61	10	17
NA4536	3147.79	-24	4	36	+35	-30	9	14
NC4803	3201.73	-30	7	5	-17	-56	8	10
NC4808	3202.65	-22	7	8	-19	-80	8	12
NC4821	3203.71	-39	7	15	-25	-96	4	11
CD936	3236.59	-46	4	14	-57	-42	6	8

*Group 1 lines: narrow emission $\lambda\lambda 4089, 4116$ Si IV; $\lambda 4057$ N IV; $\lambda\lambda 4634, 4640-42$ N III; and absorption $\lambda\lambda 4603, 4619$ N V.

Group 2 lines: absorption, Balmer lines H11 to H γ ; $\lambda\lambda 4025, 4200, 4541$ He II.

TABLE 7
FORMAL ORBITAL SOLUTION HD 92740
($P = 80.35$ days adopted)

Element	Group 1 (Emission)	Group 2 (Absorption)	N v (Absorption)	$\lambda 4686$ (Emission)
γ (km s $^{-1}$).....	-28 $\pm$ 1	-150 $\pm$ 2	-38 $\pm$ 3	+43 $\pm$ 2
K (km s $^{-1}$).....	77 $\pm$ 2	62 $\pm$ 3	82 $\pm$ 7	88 $\pm$ 3
e	0.64 $\pm$ 0.01	0.62 $\pm$ 0.03	0.45 $\pm$ 0.05	0.72 $\pm$ 0.02
ω	275° $\pm$ 3°	258° $\pm$ 6°	296° $\pm$ 9°	276° $\pm$ 3°
T_0 (2,440,000+).....	728.3 $\pm$ 0.2	726.8 $\pm$ 0.5	732.7 $\pm$ 1.3	728.3 $\pm$ 0.2
Mean $O - C$ (km s $^{-1}$).....	11	20	26	15

NOTE.—Adopting Group 1 solution $f(m) = 1.75$: Group 2: $\gamma = -158$ km s $^{-1}$; N v: $\gamma = -30$ km s $^{-1}$; $\lambda 4686$: $\gamma = +45$ km s $^{-1}$.

the primary.² The effect of the purported secondary spectrum would be a blending of absorption lines over all phases, possibly somewhat more importantly at periastron. This would imply that the γ velocity for the secondary star is necessarily also as violet-displaced from the Carina Nebula association velocity as are all the Group 2 lines. Since we believe that the violet displacement indicates an outflow of material from the WN star, the secondary would have a wind of equal magnitude. This appears highly unlikely. The difference between the two curves shown in Figure 2 is therefore probably not due to a blend from the secondary star. It may indicate some random fluctuations in the line profiles or may not be statistically significant.

On a few of the spectrograms, however, extra absorption dips were noted significantly redward or violet-displaced from several Balmer or He II lines. These were not seen on most spectrograms and their interpretation is not certain as they are at the limit of visibility. There is some basis for interpreting these dips as absorption lines due to the secondary since the velocity phasing is consistent with that interpretation.

² Moffat and Seggewiss attribute the large difference between their velocity amplitudes of the emission and absorption lines to the secondary star, which contributes only to the absorption spectrum.

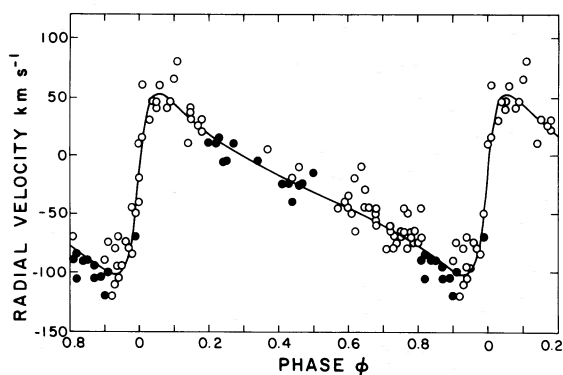


FIG. 1.—Mean radial velocities of the Group 1 (emission) lines for HD 92740, adopting the orbital parameters of Table 7 (solid line). In this figure and the next three, the filled circles are the coude plates; the open circles, the Cassegrain spectrograms.

In Figure 5 we show the very tentative results. The values are based on more than one “line” in most cases, but the uncertainty is of the order of 50 km s $^{-1}$ at least. With the omission of the two entries at very large positive values, the mean velocity for the other lines is close to the velocity of the association, inducing us to present this figure. If these dips are real, and correctly interpreted as belonging to the secondary star, then its velocity semiamplitude is ~ 170 km s $^{-1}$. In this case, given the parameters of Table 7, the mass ratio is ~ 2 with the W-R star being the more massive. In addition, the $m \sin^3 i$ of the W-R star is of the order of $40 M_{\odot}$. Although this is well outside the mass range normally associated with W-R stars, it is not impossible as a value for these bright “transition” objects (cf. de Loore, De Greve, and Lamers 1977; Chiosi, Nasi, and Sreenivasan 1978).

We must stress, however, that this result is highly tentative and must be confirmed before it can be accepted. Higher signal-to-noise spectrograms will be necessary. It should be noted that Moffat and Seggewiss (1978) did not observe these “dips,” nor are they observed on all our spectrograms taken when the velocity of the WN star is most displaced from the

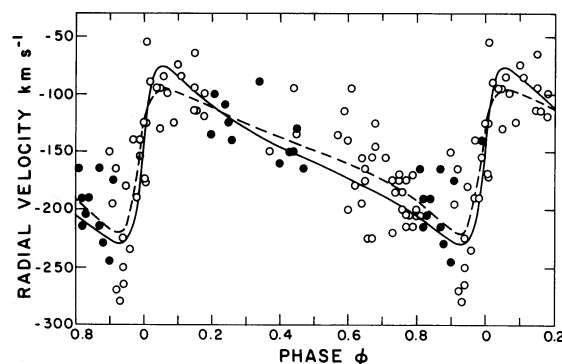


FIG. 2.—Mean radial velocities of the Group 2 (absorption) lines for HD 92740, adopting the orbital parameters of Table 7 (dashed line) or the same velocity curve as shown in Fig. 1 (solid line), but with a γ of -158 km s $^{-1}$. There is only a slight difference between the two curves which may not be physically significant. The difference cannot be due to the presence of a blend from the secondary star; see text.

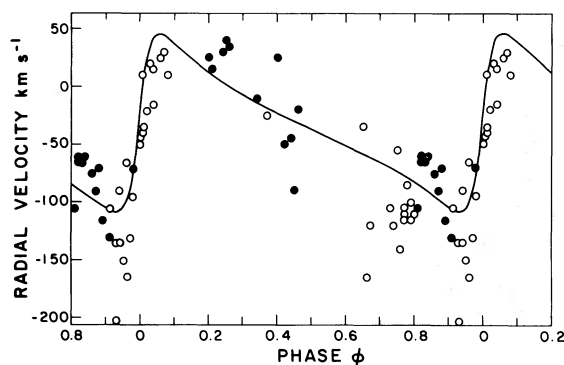


FIG. 3.—Mean radial velocities of the $\lambda\lambda 4603, 4619$ N v absorption lines for HD 92740, adopting the same velocity curve as shown in Fig. 1 (solid line) but with a γ of -30 km s^{-1} .

mean value. Our coude plates do not provide complete phase coverage.

IV. VELOCITIES OF HD 93129, HD 93131, AND HD 93162

a) Search for Periodicities

Careful study of the various velocity data sets of these three stars as listed previously in Tables 4–6 occasionally suggested short-term periodic behavior. Invariably, however, consistency could not be maintained over longer intervals. Period search routines using the Lafler and Kinman (1965) procedure on the Groups 1 and 2 and $\lambda 4057$ N iv lines also failed to turn up any convincing periodic velocity variation for any star. In particular, the $\lambda 4057$ velocities for all three stars were exhaustively searched for periodicities in the range 0.5–300 days. No suggestions whatever of periodicities were found for HD 93129 A or HD 93131. For HD 93162 a systematic trend consistent with a period of about 20^{d} did appear in the 13 velocities of JD 2,442,400/500; the curve is not consistent with the full data set, although curiously it appears to “fill in” preferentially toward negative velocities, with the 20 day curve persisting as an

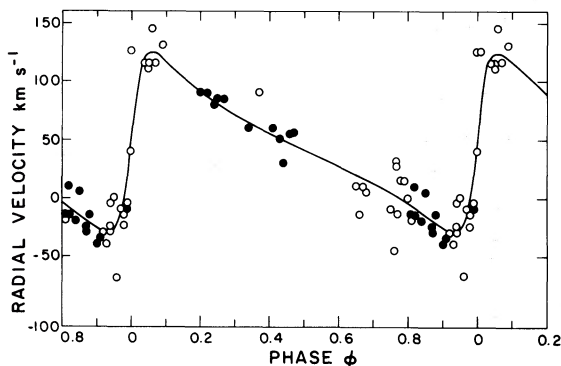


FIG. 4.—Radial velocities of the $\lambda 4686$ He II emission line for HD 92740, adopting the same velocity curve as shown in Fig. 1 (solid line) but with a γ of $+45 \text{ km s}^{-1}$.

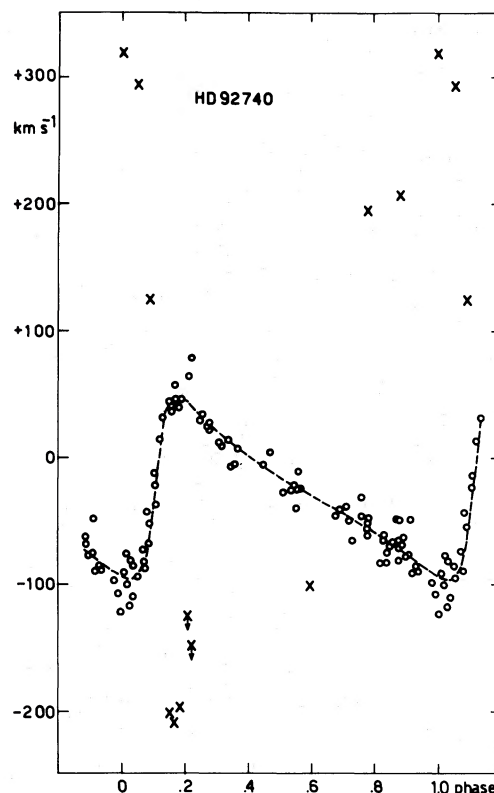


FIG. 5.—Radial velocities of several absorption lines marginally detected on a few spectrograms of HD 92740 (crosses). The open circles and dashed curve duplicate the information in Fig. 1. These absorption lines may be due to the secondary star but this interpretation is highly tentative; see text.

“envelope.” It is perhaps worth noting that the scatter is significantly greater in the $\lambda 4057$ velocities of HD 93129 A and HD 93162 than in those of HD 93131 and (about the velocity curve) of HD 92740. The latter two stars have the stronger envelope characteristics; perhaps the more extensive envelopes are more stable.

Histograms showing the distribution of the individual velocities of the Group 1 and 2 lines were constructed—Figures 6 and 7. These typically had Gaussian shapes, indicating that the scatter in the individual velocities was random (the histograms for the binary HD 92740 were distinctly non-Gaussian, as expected). The Group 2 (absorption line) histogram for HD 93129 was narrower than the Group 1 (emission line) histogram; the reverse situation was found for HD 93131. Both Group 1 and Group 2 line histograms had similar widths in HD 93162. This is completely consistent with the appearance of the spectra (§ II) as the absorption lines dominate in HD 93129 and the emission lines dominate in HD 93131; the velocities of the relatively stronger lines are better determined in each case. From each of the narrower histograms we estimate upper limits to a periodic velocity variation that could be detected as follows: HD 93129, $\pm 20 \text{ km s}^{-1}$; HD 93131, $\pm 15 \text{ km s}^{-1}$; HD 93162, $\pm 30 \text{ km s}^{-1}$. If these stars are, in fact,

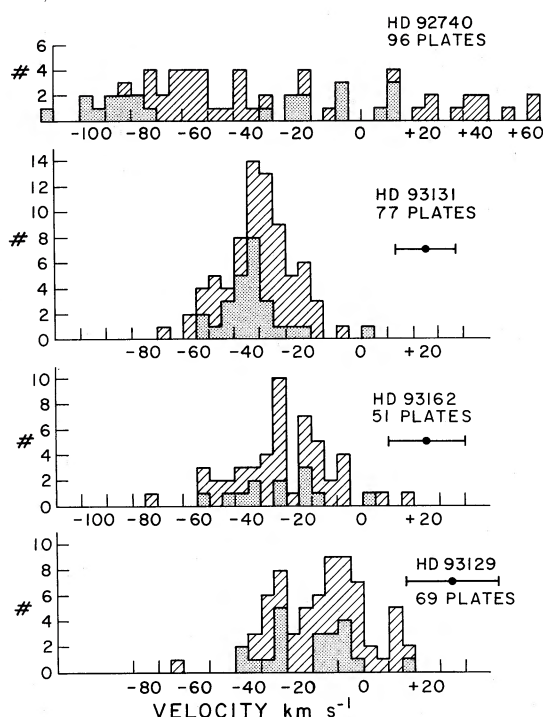


FIG. 6.—Emission line (Group 1) velocity histograms, in 5 km s^{-1} intervals, for the four stars discussed in this paper. The distribution is Gaussian for the three single stars, but non-Gaussian, as expected, for the binary HD 92740. Gray areas, the coudé plates; crosshatched regions, the Cassegrain spectrograms.

binaries, then the velocity variations must lie inside these very conservatively determined values; or possibly, in the case of HD 93162, be masked by variable envelope motions.

A question of whether or not a star or a group of stars has a binary nature can never be answered *conclusively* in the negative, but there comes a point at which it is necessary to call a halt and analyze what observations are available. Our extensive data base for these three objects, extending over 4 years of observation, and independently that of Moffat and Seggewiss (1978) and Moffat (1978), show no conclusive evidence for binary behavior. Although it is possible that perhaps one of these stars is a binary with a low velocity amplitude due to a small inclination, it appears to be unlikely (unless we are very unlucky) for two or three of them. If one were to assume that *both* W-R stars were binaries (not more widely separated than HD 92740), the inclinations would have to be uncomfortably small, particularly for appreciably shorter periods. One certainly must begin to be suspicious of statements that "all W-R stars are binaries" when very careful study fails to confirm this hypothesis for most stars.

Since the Group 1 and 2 velocities are observed to follow Gaussian distributions, we are confident that straight averages of the *individual* lines for each star will give physically meaningful results. The resultant average line velocities for HD 93129, HD 93131, and

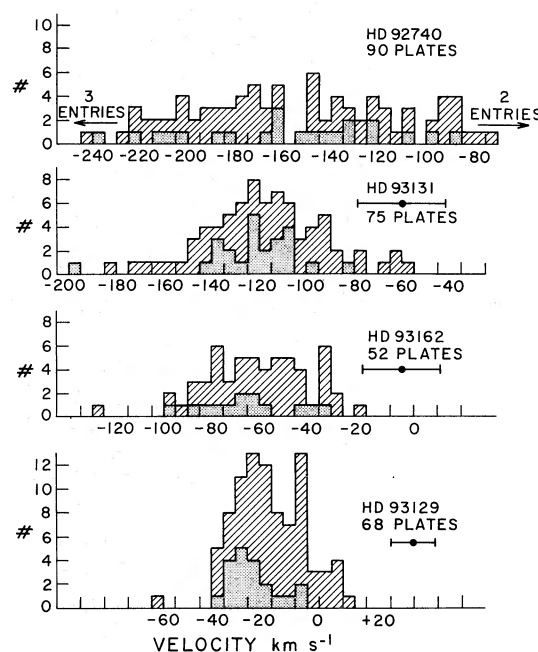


FIG. 7.—Absorption line (Group 2) velocity histogram, in 5 km s^{-1} intervals, for the four stars discussed in this paper. The distribution is Gaussian for the three single stars, but non-Gaussian, as expected, for the binary HD 92740. Gray areas, the coudé plates; crosshatched regions, the Cassegrain spectrograms.

HD 93162 are contained in Tables 8–10, respectively. We have included lines other than those included in Groups 1 and 2, such as the broad emission at $\lambda 4686$

TABLE 8
HD 93129 INDIVIDUAL LINE VELOCITIES

Line	Mean (km s^{-1})	No.	s.d. (km s^{-1})
Balmer absorption:			
H11.....	-20.2	42	3.8
H10.....	-25.8	47	4.0
H9.....	-13.0	58	3.0
H8.....	-12.3	56	2.2
H ϵ	-24.0	35	3.9
H δ	-24.5	67	2.8
H γ	-37.3	52	2.7
He II absorption			
$\lambda 3923$	-7.0	8	13.0
$\lambda 4025$	+4.2	37	5.0
$\lambda 4200$	-10.6	50	3.7
$\lambda 4541$	-7.7	47	3.4
N V absorption:			
$\lambda 4603$	-26.3	44	4.3
$\lambda 4619$	-14.3	41	4.5
Narrow emission:			
N IV $\lambda 4057$	-15.1	68	1.9
Si IV $\lambda 4089$	+2.6	23	4.9
Si IV $\lambda 4116$	-16.4	15	7.6
Broad emission:			
He II $\lambda 4686$	+213	33	16
N V $\lambda 4603$	+243	12	13
N V $\lambda 4619$	+253	3	1
Nebular absorption:			
He I $\lambda 3889$	-31.3	45	1.0

Group 2
-17.5(WTD)

Group 1
-11.9(WTD)

TABLE 9
HD 93131 INDIVIDUAL LINE VELOCITIES

Line	Mean (km s ⁻¹)	No.	s.d. (km s ⁻¹)	
Balmer absorption:				
H11.....	-110.2	32	6.5	Group 2 -122.1(WTD)
H10.....	-92.6	45	4.9	
H9.....	-108.4	61	6.1	
H8.....	-112.0	58	6.6	
Hε.....	-135.0	28	5.8	
Hδ.....	-129.5	49	3.5	
He II absorption:				
λ3923.....	-137.5	18	13.9	Group 1 -34.4(WTD)
λ4025.....	-114.3	32	6.2	
λ4200.....	-141.1	55	6.7	
λ4541.....	-146.5	54	5.6	
N V absorption:				
λ4603.....	-49.7	44	4.9	Group 1 -34.4(WTD)
λ4619.....	-52.7	48	4.5	
Narrow emission:				
N III λ4097.....	-47.0	45	4.6	Group 1 -34.4(WTD)
N III λ4379.....	-13.9	34	5.1	
N III λ4634.....	-21.1	26	5.0	
N III λ4640-42...	-50.6	48	3.6	
N IV λ4057.....	-34.0	74	1.6	
Si IV λ4089.....	-19.3	72	2.6	
Si IV λ4116.....	-49.8	53	3.2	
P Cyg absorption:				
Hγ.....	-242	51	7.5	Group 1 -34.4(WTD)
Hβ.....	-320	9	20.0	
N IV λ3478.....	-344	22	9.4	
N IV λ3483-85*..	-181	21	3.7	
P Cyg emission:				
Hδ.....	+169	32	6.8	Group 1 -34.4(WTD)
Hγ.....	+208	47	5.5	
Hβ.....	+134	13	10.2	
N IV λ3478†.....	+42	23	3.4	
N IV λ3483-85...†	+151	22	3.8	
N V λ4603.....	+198	49	3.1	
Broad emission:				
He II λ4686.....	+69	47	4.6	

* Distorted by λ3478 N IV emission.

† Distorted by λ3483-85 N IV absorption.

He II, the P Cygni emission at λλ4603, 4619 N V, and the absorption and emission sometimes present in several Balmer lines and at λλ3478, 3483-3485 N IV. Generally speaking, the broad emission lines have positive velocities with respect to the narrow emission lines, whereas the lower Balmer series and the N IV absorption lines are more highly blueshifted.

b) Velocity Gradients

These results may be applied to an investigation of the velocity gradients in these stars. The velocity of the Carina Nebula association of which these three stars are members is not too well established, but the O stars in this association as listed by Conti, Leep, and Lorre (1977), have values between +5 and -25 km s⁻¹. In Figure 8 we plot the Groups 1 and 2 line velocities on the same graph. (A preliminary version of this figure based upon coude plates has been published by Conti 1978.) The first point to make is that all the line velocities for HD 93129 lie near that of the association, although Hγ is somewhat violet-shifted. In this star then, all of the plotted lines are formed at about

TABLE 10
HD 93162 INDIVIDUAL LINE VELOCITIES

Line	Mean (km s ⁻¹)	No.	s.d. (km s ⁻¹)	
Balmer absorption:				
H11.....	-65.4	29	6.1	Group 2 -62.3(WTD)
H10.....	-41.7	35	5.0	
H9.....	-53.3	39	5.4	
H8.....	-41.4	47	5.3	
Hε.....	-63.4	21	4.6	
Hδ.....	-80.8	51	3.8	
Hγ.....	-129.7	35	7.2	Group 2 -62.3(WTD)
He II absorption:				
λ4025.....	-42.2	26	7.7	
λ4200.....	-54.0	32	8.2	
λ4541.....	-48.6	31	7.0	
N V absorption:				
λ4603.....	-57.3	34	7.6	Group 1 -25.4(WTD)
λ4619.....	-36.6	30	6.9	
Narrow emission:				
N III λ4634.....	-8.8	8	7.6	Group 1 -25.4(WTD)
N III λ4640-42...	-38.6	14	7.6	
N IV λ4057.....	-24.7	52	3.0	
Si IV λ4089.....	-14.7	24	6.9	
Si IV λ4116.....	-26.5	17	2.0	
Broad emission:				
He II λ4686.....	+85.6	28	8.2	
N V λ4603.....	+218.1	19	10.5	

the same level in the stellar photosphere/envelope. By contrast, in the two WN stars the narrow emission lines and N V absorption lines *alone* are at or near this velocity. For both these stars, however, the Balmer absorption lines are violet-shifted with respect to the emission-line velocity and the value for the Carina Nebula association. Furthermore, a Balmer progression is present (Niemela 1975) quantitatively similar to that reported for two Of stars by Hutchings (1968). The He II absorption lines in HD 93162 are displaced similarly to the upper Balmer series; in HD 93131 they are more violet-shifted. From the He II and the Balmer measurements it is seen that the outflow is greater in HD 93131 than in HD 93162, exactly consistent with the emission line *strengths* (Walborn 1974). One could imagine either that the outflow velocity is higher in HD 93131 than in HD 93162 while the envelope densities are similar, or that the densities are higher in the former star while the wind velocities are similar. In either case, a higher mass-loss rate would be inferred for HD 93131.

c) Envelope Structure and Line Formation

The velocities also show that the emission lines are formed closer to the star than the absorption lines, if the flow is accelerated outward. However, the N V absorption, which corresponds to a much higher ionization state than either the Balmer series or the He II lines, is formed at the same lower level as the narrow emission lines.

The result that absorption lines without accompanying P Cygni emission can be found in an outwardly moving portion of a stellar photosphere was pointed out by Niemela (1975), for the class of Of stars by

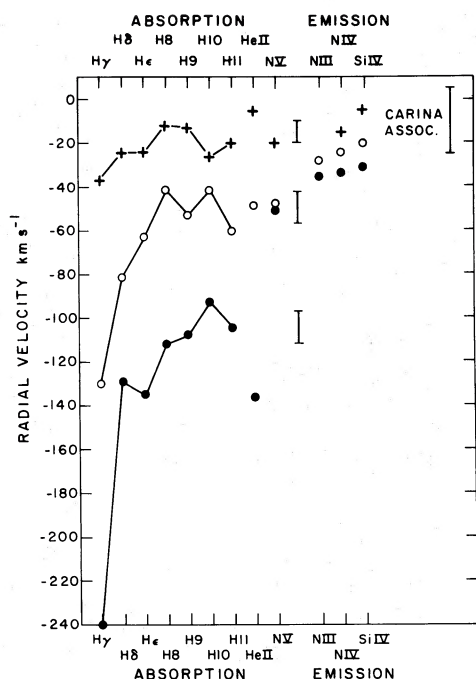


FIG. 8.—Velocity gradients for the three single stars discussed in this paper: plus signs, HD 93129; open circles, HD 93162; filled circles, HD 93131. In all stars the narrow emission lines, and the N v absorption, have velocities of the order of, or slightly more negative than, the Carina Nebula association. These values represent closely the motion of the star itself. The absorption lines of the Balmer series and He II are formed in an outwardly moving region of the photosphere in the two WN stars; the greater velocity is seen in HD 93131.

Conti, Leep, and Lorre (1977), and further elaborated for two Of cluster members by Conti, Garmany, and Hutchings (1977). The behavior of the Balmer series and He II lines in these WN stars is exactly similar. Figure 8 can be taken as confirmatory evidence of our choice of orbital solution for HD 92740 (Table 7): the Group 1 lines are formed closest to the star itself. The Group 2 absorption lines are formed in a region of the photosphere/envelope which is already moving outward. The N v absorption lines are formed in a low level similar to the narrow emission lines. Furthermore, the “system” velocity for the Group 1 lines, and N v absorption, is similar to that of the Carina Nebula association.

Not shown in Figure 8 is the velocity of the broad emission line at $\lambda 4686$ He II, or the emission-line components of the lower Balmer series and N IV $\lambda\lambda 3478, 3483-3485$. These features are all substantially redward displaced. Figures showing the velocity gradients in these lines, and others, have been presented elsewhere (Niemela 1978). Redward-displaced emission can be understood as an effect of line scattering in a stellar envelope with an outward velocity gradient—the Auer-Van Blerkom effect (Mihalas 1974). This emission-line redshift has long been known in other W-R binaries (e.g., Kuhi 1973), and in several Of binaries (Mihalas 1974; Massey and Conti 1977). Since this same effect is now observed in presumably

single stars, it clearly must be due to the envelope of the star itself, and not be an effect of binary interaction. In the wide binary HD 92740 (§ III) the $\lambda 4686$ line has essentially the same velocity amplitude as the narrow emission lines (although with more positive system velocity, of course), and it follows the motion of the primary star. In close binaries, however, measurement of $\lambda 4686$ alone to determine the orbital parameters of the W-R star might lead to difficulties.

H β absorption as measured in HD 93131 is even more violet-displaced than the higher series members. In this star, H β and H γ show P Cygni emission, consistent with our inference that the lowest Balmer series lines are formed farthest from the star, where the outflow velocity is higher. In this region also the N IV lines at $\lambda\lambda 3478, 3483-3495$ are formed. The behavior of these broad (triplet) lines is to be contrasted with the formation level of the narrow (singlet) N IV line at $\lambda 4057$. The line source function of the two N IV multiplets is clearly very different, and the emission process is probably not the same.³

V. DISCUSSION/CONCLUSIONS

Two important conclusions may be reached on the basis of the results described in the preceding sections.

1. The radial velocities are consistent with the existence of a physical connection, perhaps evolutionary, between the O3 If and the WN-A stars, as previously discussed on morphological grounds by Walborn (1971, 1973a, 1974). If, on the contrary, the WN-A stars had all turned out to be mass-transfer binaries while HD 93129 A was apparently single, then a clear physical distinction would have been made. The fact that no definite evidence for a binary nature can be found for two of the WN-A stars, while the one definite binary has a long period and shows essentially a single-star spectrum (i.e., its binary nature may well be merely incidental), admits the possibility that HD 93129 A could become a similar WN-A star.

2. Evidently, a binary nature is not a necessary condition for a late type Population I WN star, and very massive single stars can develop into these kinds of objects. It should be noted that the O3 stars with which the Carina Nebula WN-A's are associated may have very large masses (Conti and Burnichon 1975). Also, Seggewiss and Moffat (1978) found no definite evidence for a binary nature of the morphologically related (Walborn 1973a, 1974) WN7-A star HD 151932 in Scorpius OB1, also associated with very massive OB stars. It is possible that there may be two

³ The isoelectronic series lines in C III, namely $\lambda\lambda 4648, 4650-4651$ (triplet) and $\lambda 5696$ (singlet), are generally not found in the same O and Of type stars, suggesting the formation mechanisms are different (Conti 1973). Cardona (1978) has found that the $\lambda 5696$ line can be in emission in a plane-parallel O type star. An extended envelope is probably also not necessary for $\lambda 4057$ emission, although no detailed line calculations are yet available. From the morphological behavior of N IV $\lambda 4057$ and C III $\lambda 5696$ in O type spectra, it has been suspected for some time that they are susceptible to emission processes which are primarily a function of temperature and gravity rather than of envelope extent (Underhill 1967; Walborn, unpublished), as is the case for N III $\lambda\lambda 4634-4640-4642$ (Mihalas, Hummer, and Conti 1972).

kinds of Population I WN stars: interacting binaries and very massive single stars, which arrive at their advanced evolutionary state by different paths: mass transfer or stellar wind mass loss, respectively (Conti 1976).

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