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The Intrinsically Bright Wolf-Rayet Stars of Type WN 7

I. The Binary HD 92740 and the Probable Single Star HD 93131 in Carina*

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Summary. Photographic coudé spectroscopy and narrow-band photoelectric photometry are used to investigate the nature of these two WN 7 stars—brightest of their kind in the sky. It is shown that HD 92740 is a single-line spectroscopic binary with a period of 80.35 days and a relatively large eccentricity 0.55. Its observed mass function combined with upper mass limits for the unseen secondary and lack of eclipses in the somewhat noisy light curve imply a mass ratio $M(WR)/M$(secondary) between 0.3 and 1.0. These values overlap with the directly observed ratio (0.2–0.4) in several known WR +OB binaries. The velocities of the relatively weak Balmer absorption lines (H 8–H 10) vary in phase with all remaining lines (emission and absorption) but with less than half their amplitude. This may imply that the Balmer lines of the fainter (late O-type or early B-type) secondary vary 180° out of phase with the dominant photospheric Balmer lines of the WR (and therefore Of-like) primary.

The constancy in velocity and light of HD 93131 within the observational precision leads to some restraints as a binary system. If HD 93131 is in fact a normal WR+OB binary, the inclination of the orbit must be $\lesssim 2°$; conversely, with the most probable inclination of $\sim 57°$, the secondary cannot have a mass more than $\sim 3\,M_\odot$. Such possibilities appear fairly improbable and we may conclude that HD 93131 is more likely to be a true single star. It too has Of-like Balmer absorption lines indicating that it may have evolved from a single massive Of star by a radiation pressure induced stellar wind.

Key words: Wolf-Rayet star — stellar mass loss — spectroscopic binary — individual stars: HD 92740, HD 93131

I. Introduction

Recent estimates of mass loss rates in massive Of stars (Hutchings, 1976; Barlow and Cohen, 1977) of the order of (5–10) $\cdot 10^{-6}\,M_\odot\,\mathrm{yr}^{-1}$ show that a significant fraction of mass can be lost by radiation pressure induced stellar winds during their lifetimes (several 10^6 yr) for initial masses $\gtrsim 30\,M_\odot$. Recent model calculations of the evolution of massive stars with mass loss by Chiosi et al. (1978) and de Loore et al. (1977) agree in showing that O stars of initial mass greater than $40\,M_\odot$ are capable of evolving via the Of stage into luminous Wolf-Rayet stars and never reach the luminous cool region of the HR diagram where massive red supergiants are completely lacking. Conti (1976) in a more empirical paper dealing with the relationship between Of and WR stars identified these evolved massive O stars with the single WN 7 (or possibly WN 8) stars with absolute luminosities ($M_V \sim -6^\mathrm{m}$ to -7^m) similar to their progenitors. All other single WR stars are about 2^m fainter than the WN 7/WN 8 group. Primary evidence for the above evolutionary scenario stems from two recently observed O-star binaries (BD +40° 4220, Bohannan and Conti, 1976; HDE 228766, Massey and Conti, 1977) for which orbital determinations imply that the Of-type secondaries in either case are undermassive for their (bright) luminosities and are possibly on the way to becoming WR stars of type WN 7. However, while de Loore et al. (1977) conclude that single stars of initial mass less than about $40\,M_\odot$ will not peal off enough mass to expose either directly or by mixing processes their He cores and therefore evolve into WR stars, Chiosi et al.'s (1978) models indicate that single stars of initial mass between 20–25 $M_\odot$ and 35–40 $M_\odot$ may evolve into the remaining types of less luminous WR stars. In either case, single stars below 20–25 $M_\odot$ cannot lose enough mass to become WR stars.

An apparently competing hypothesis to account for the presence of the overluminous WR components occurring in massive binary systems has been around for a long time (Pacziński, 1967; Kippenhahn, 1969) and

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* Based on observations collected at the European Southern Observatory, La Silla, Chile

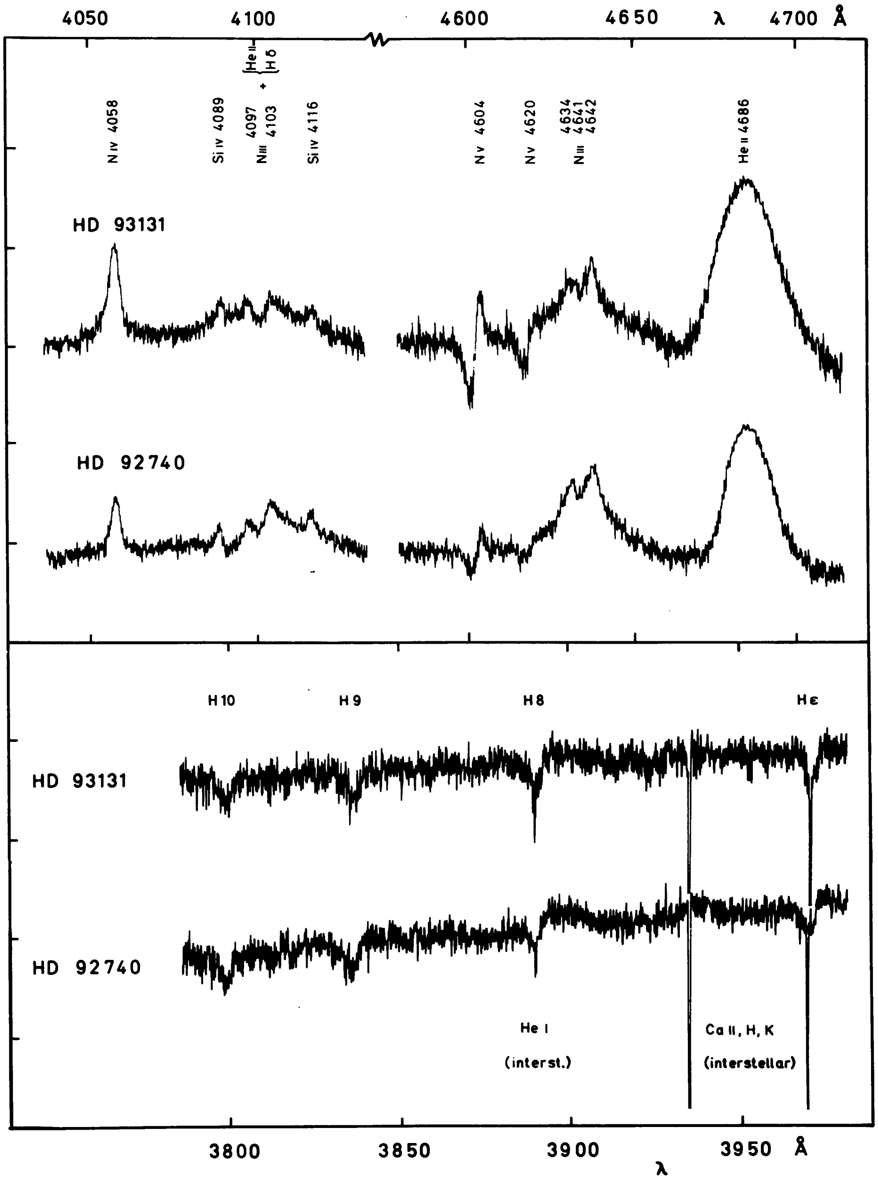


Fig. 1. Microphotometer tracings (relative transmission) of the spectra of HD 92740 and HD 93131 from coudé plates ESO-G 7263 and ESO-G 7267, respectively. The transmission of the continuum is nearly the same for both plates

extended more recently by de Loore et al. (1975). Mass transfer after central hydrogen exhaustion (case "*B*") from the originally more massive primary to the secondary star in a binary system is supposed to be capable of reducing the primary ($M \gtrsim 20\ M_\odot$) into a WR star. The basic assumption is that WR stars in binary systems represent He cores (with varying admixtures of leftover non-He rich layers), which remained after the more tenuous supergiant envelopes of their massive progenitors were dumped by Roche lobe overflow onto a secondary star. If the initial mass ratio is significantly greater than one, significant mass loss from the system as a whole becomes increasingly more likely (de Loore et al., 1975, van den Heuvel, 1976, and references therein; Thomas, 1977) but still does not impede the formation of the WR primary which would end up with a relatively low mass companion.

Thus, if single WR stars and WR components in binaries, both of which have comparable spectral characteristics, represent the same phenomenon, we appear to have two mechanisms to explain them. However, the empirical mass loss rates as well as the theoretical evolutionary models with mass loss are still plagued by large uncertainties and it may be possible that all WR stars are binaries in which basically only one mechanism (mass transfer) is operative in producing WR stars. For this to be the case one would have to prove without doubt that all WR stars were formed in, and are still probably components of binary systems. The fact that at least 50% (or even ~70% of a complete sample, Kuhi, 1973) of WR stars are spectroscopic binaries is highly suggestive but by no means conclusive. The other 50% (or ~30%), which appear spectroscopically to be single could still be high mass-ratio binaries in which the spec-

Table 1. Journal of coudé observations of HD 92740 (period $P = 80^{\mathrm{d}}.35$)

Plate	JD(Hel)- 2440000	Phase	Radial Velocities (km s^{-1}) Hydrogen (1)	Helium (2)	(3)	(4)	(5)	Nitrogen (6)	(7)	(8)	(9)	Silicon (10)
G 931	676.747	0.3721	- 89	+ 84	+215	+278	-118	+10	+ 4	+199	- 21	0
G 932	676.789	.3726	-118	82	229	283	-110	- 8	8	191	- 34	+ 7
G 7261	2819.657	.0418	- 99	93	201	309	- 84	+28	33	228	+ 4	19
G 7263	2820.836	.0565	- 93	114	196	338	-107	41	32	231	12	15
G 7264	2821.701	.0672	- 86	117	201	-	- 69	49	38	224	38	30
G 7266	2822.737	0.0801	-119	+117	+215	+328	- 68	+44	+46	+244	+33	+23
G 7269	2823.814	.0935	-121	132	219	332	- 78	49	49	244	18	26
G 7270	2824.605	.1034	-137	120	232	309	-115	61	40	224	28	33
G 7274	2825.638	.1162	-115	113	189	316	- 84	47	38	229	44	18
G 7278	2826.788	.1305	-109	119	179	325	-101	46	36	240	17	21
G 7281	2827.753	0.1425	-	+108	+200	+306	-115	+36	+30	+224	+ 9	+26
G 7285	2828.786	.1554	-112	127	169	316	-112	36	29	219	19	26
G 8175	3199.832	.7733	-137	13	132	192	-148	-60	-68	125	-79	-62
G 8183	3200.831	.7954	-160	6	107	194	-166	-55	-64	125	-90	-79
G 8189	3201.612	.7954	-163	26	132	226	-200	-51	-77	127	-93	-88
G 8200	3202.650	0.8105	-185	+15	+154	+216	-234	-57	- 76	+102	- 97	- 78
G 8211	3203.825	.8230	-128	24	150	-	-227	-69	- 78	124	- 94	- 83
G 8218	3204.578	.8323	-143	- 7	134	180	-234	-69	- 92	114	-109	- 91
G 8236	3205.910	.8499	-168	-35	106	150	-237	-64	-103	109	-105	- 96
G 8244	3206.824	.8603	-177	-22	86	164	-183	-88	- 81	98	-108	-121
G 8251	3207.603	0.8700	-	-16	+103	+147	-157	-85	- 88	+119	-124	-103
G 8267	3208.623	.8827	-159	-25	-	147	-193	-80	- 86	103	- 95	- 93
G 8277	3209.634	.8953	-158	-28	74	158	-237	-91	- 84	100	-110	-132
G 8292	3210.621	.9075	-152	-23	-	162	-216	-96	- 95	121	-112	-129
G 8311	3211.848	.9228	-135	-35	77	151	-194	-95	- 99	96	-115	-107
Center-of-mass-velocity γ			-132	+54	+157	+244	-151	-17	- 23	+170	- 46	- 40
Mean error			± 10	± 3	± 10	± 10	± 10	± 2	± 2	± 2	± 3	± 2
Semi amplitude K			30	70	70^{-}	90	70	70^{-}	70	70	70	70^{-}

(1) Mean of Balmer absorption lines H8, H9, H10
(2) He II emission λ4685.682
(3) He II emission λ4541.59
(4) He II emission, mean of λ4338.67 (+ Hγ) and λ4859.323 (+ Hβ)
(5) He II absorption, mean of λ4199.83 and λ4541.59
(6) N III emission, mean of λλ4641.16, 4634.16, 4103.37, 4097.31
(7) N IV emission λ4057.759
(8) N V emission λ4603.73
(9) N V absorption, mean of λ4603.73 and λ4619.98
(10) Si IV emission, mean of λ4088.854 and λ4116.097

trum of the secondary is completely drowned out by the overluminous WR primary. Low amplitude, periodic radial velocity variations of the broad, often asymmetric emission lines of the WR stars are difficult to measure with precision but no other method remains without actually resolving (e.g. interferometrically) the second star. Indeed, if all WR stars are binaries, one would be obliged to favour the mechanism of mass transfer for the formation of WR stars. If on the other hand, the final fraction of binaries remains about 50%, similar to the frequency of binaries among massive stars (e.g. Jaschek and Gomez, 1970), the single star wind loss mechanism would have to be considered instrumental in forming WR stars whether single or in binaries.

While the spectroscopic technique of searching for low-amplitude radial velocity variations is difficult, it may not be impossible with spectra of sufficiently high resolution and appropriate means of analysis of the Doppler shifts. This appears most important for the WN 7 subset of WR stars for which the process of formation by single star mass loss is most credible. We use as a working definition of a WN 7 star those objects so classified (with or without OB-type companion) in the comprehensive list of Smith (1968a). Since this catalogue is complete only to $v = 12^{\mathrm{m}}$ we restrict our selection to those seven WN 7 stars brighter than this limit. Three of these stars are located in the northern sky and have already been proven to be binaries, although HDE 228766 mentioned above has been reclassified by Massey and Conti (1977) as O 7.5 (supergiant?) + O 5.5f instead of WN 7 + O 6 (Smith, 1968a). Apparently the WN 7 and O 5.5f classes refer to the same component. Despite the

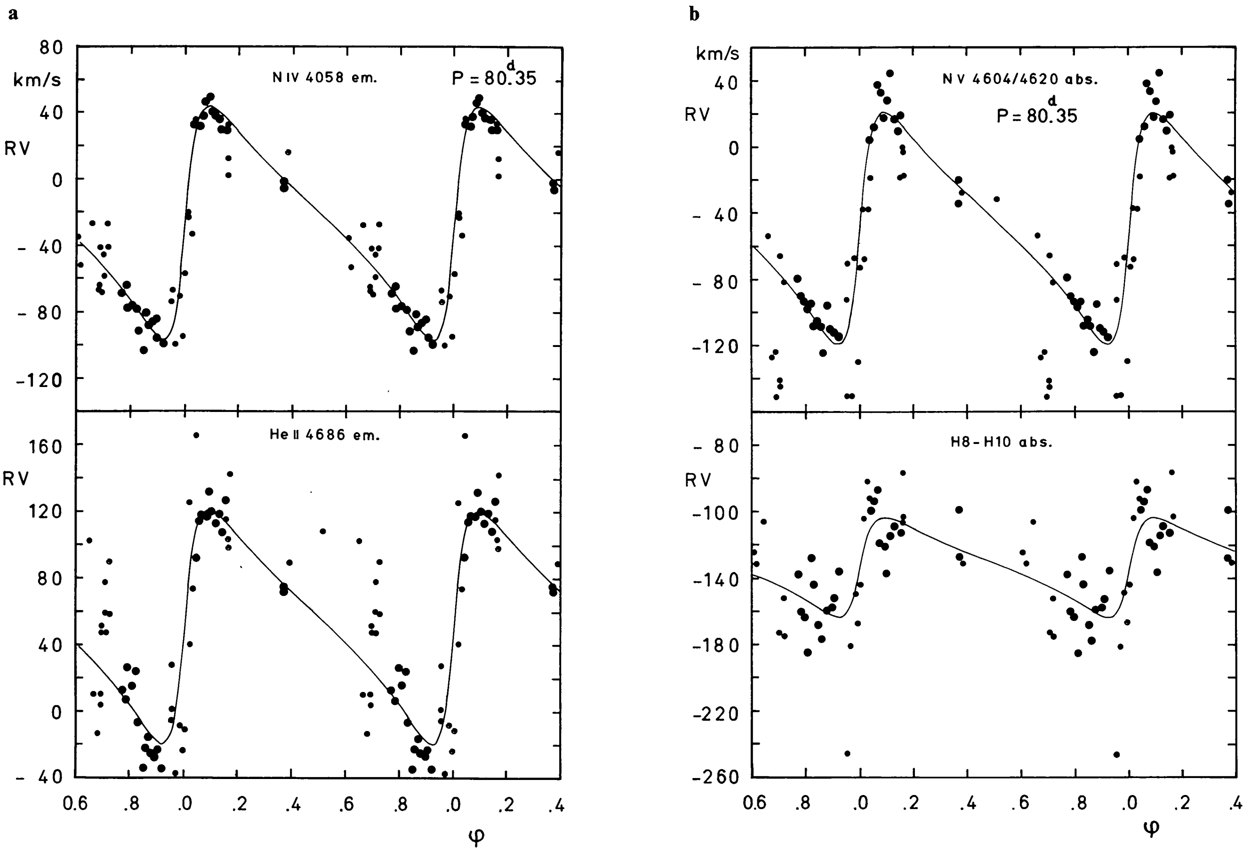
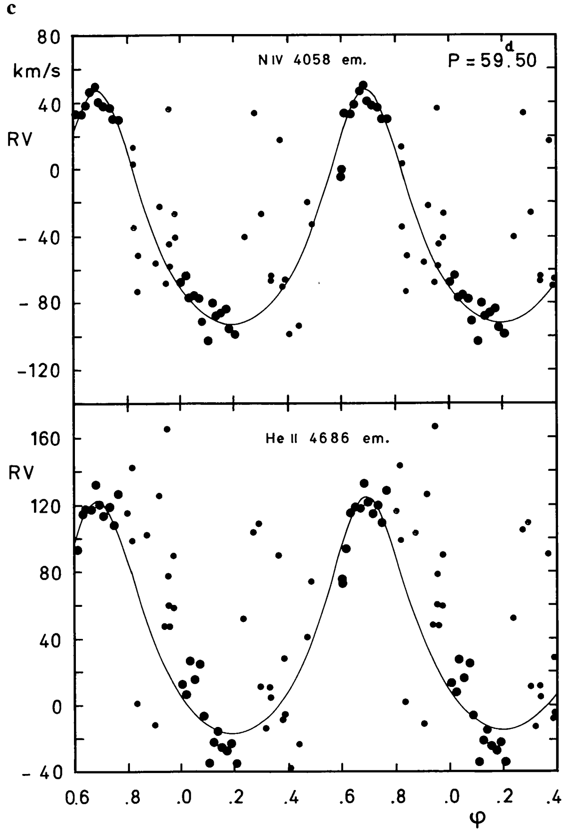


Fig. 2a—c. Sample radial velocity curves of HD 92740. Large dots represent present observations, small dots those of Niemelä (1974). The curves are computed from the parameters in Table 2. **a** Period $P=80^{d}.35$, N IV λ 4058 and He II λ 4686 emission. **b** Period $P=80^{d}.35$, N V λλ 4604, 4620 and H 8 to H 10 absorption. **c** Period $P=59^{d}.50$, N IV λ 4058 and He II λ 4686 emission



difficulty often encountered in differentiating Of and WN 7 (or WN 8) spectra we retain the list of Smith for the sake of consistancy.

This paper is the first in a series to investigate, with the aid mainly of coudé spectroscopy and narrow-band photoelectric photometry or spectrophotometry, the two brightest (apparently single) WN 7 stars in the sky: HD 92740 and HD 93131, both located in the Great Carina Nebula. Later papers will deal with the remaining southern WN 7 stars HD 93162 (a fainter star, WN 7+O 7, in Carina) and HD 151932 (WN 7) in the OB association Sco OB 1. While as yet no detailed spectroscopic search for duplicity has been made for HD 93131, Niemelä (1973, 1974) has found evidence for a 10.025 day period in the radial velocity curve of HD 92740, based on 31 plates of moderate dispersion ranging mainly from 40 to 120 Å mm^{-1}. From inspection of Skylab ultraviolet observations of both stars, Henize et al. (1975) have suggested that both stars probably have O–B 1 I companions.

The similarity of their optical spectra is illustrated in Figure 1. Both stars show the Balmer lines H 7–H 10

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Table 2. Orbital parameters from the radial velocity data for HD 92740

Element		Best solution		Second best	
Period	days	80.35	±0.10	59.50	±0.05
JD(Hel) for passage of WR component in front		2440727.2	±1.0	2440729.0	±0.7
ω		265°	±5°	0°	±10°
e		0.55	±0.05	0.25	±0.07
K (N IV λ4058)	km s^{-1}	70		70	

Table 3. Filters used for the narrow-band photometry

Filter	$\lambda_{\rm peak}$	Half-width	Purpose
	Å	Å	
F_1	3635	70	blue continuum
F_2	4680	130	strongest emission complex
F_3	5170	190	yellow continuum

clearly in absorption. From the emission line strengths it appears that HD 93131 may be of slightly earlier (hotter) type (e.g. N V/N III stronger in HD 93131).

II. HD 92740

a) Spectroscopic Data

A total of 25 plates was available with a dispersion of 12 Å mm^{-1}, all obtained at the coudé focus of the ESO 152 cm telescope on La Silla, Chile. A journal of observations is presented in Table 1. The first two plates (IIa-O) from 1970 were kindly loaned to us by Maitzen. The remaining plates were obtained in 1976 (IIa-D) and 1977 (IIa-O baked) by the present authors. The best quality radial velocity data were judged to be those of two lines: the moderate strength, symmetric emission line N IV λ 4058 and the strong, slightly asymmetric emission line He II λ 4686. All lines were measured using the modified digitalized Abbe comparator of the Hoher List Observatory. Table 1 also lists the velocities of the most reliable lines measured. Some lines of the same multiplet were grouped together if the individual lines of the group in each case varied around the same velocity zero point.

From these data, it is clear that the binary period 10.025 days found by Niemelä (1974) is too short: there is relatively little variation within either of the 10 continuous days of observations in 1976 or the 13 days in 1977 while the mean velocities of each group differ by ~100 km s^{-1}. Thus, if a period exists, it must be longer than 22 days. Using the method of Lafler and Kinman (1965), periodic variations were searched for periods lying between 22 and 800 days using our velocities of N IV λ 4058 and He II λ 4686 (separately) with those of Niemelä (1974). The best period turned out to be 80.35 days while the second best at 59.50 days was clearly inferior. Due to the inhomogeneous phase coverage we obtained the orbital parameters (cf. Table 2) by visual test-matching of a number of orbital velocity curves calculated for various values of ω, e and K with the observed variations.

The errors in Table 2 are realistic visual estimates of the standard mean errors. The center-of-mass γ-velocities vary from one line to another and are listed separately in Table 1. It is apparent that the dispersion of the Niemelä data about the mean curve is relatively large, probably a consequence of the differing sources of lower dispersion used. The γ-velocities with the 59.50 day period are all about 19 km s^{-1} more negative than those with $P=80.35$ days. Some velocity curves are illustrated in Figure 2. We note that, while the emission lines and most absorption lines (e.g. He II absorption λλ 4200, 4541; N V absorption λλ 4604, 4620) yield velocity curves all in phase and with the same semi-amplitude $K=70$ km s^{-1}, the Balmer absorption lines give $K=30$ km s^{-1} but are also in phase. This will be discussed later. Mean velocities of interstellar lines from 23 plates are +3.9 km s^{-1} ± 2.1 km s^{-1} s.d. for Ca II H and +3.9 km s^{-1} ± 1.9 km s^{-1} s.d. for Ca II K.

Table 4. Observed standard deviations from the mean of the photometric data

Star	F_3	$F_1 - F_3$	$F_2 - F_3$
HD 92740 - HD 93222	$0\overset{\mathrm{m}}{.}014$	$0\overset{\mathrm{m}}{.}006$	$0\overset{\mathrm{m}}{.}007$
HD 93131 - HD 93222	0.009	0.009	0.007
Expected for constant stars of similar mag.	0.007	0.009	0.008

b) Photometric Data

In 1975, narrow-band photoelectric photometry was obtained during an interval of 37 days for HD 92740 (and HD 93131) relative to the comparison star HD 93222 of spectral type O 7 which is located only 36′ from HD 92740 and 6′ from HD 93131. Its constancy in light was confirmed by nightly comparison with other stars. Although HD 93222 is $1\overset{\mathrm{m}}{.}7$ fainter than either WR star, it appeared to be the most suitable star available in the region.

The photometric data were obtained with the dry-ice cooled single-channel photometer of the Ruhr University Observing Station at La Silla, Chile. The photometer was equipped with an EMI 9502 photomultiplier and the interference filters as indicated in Table 3. Table 4 lists the observed standard deviations from the mean for magnitude differences in the sense WR star minus HD 93222. These imply that, within the limits

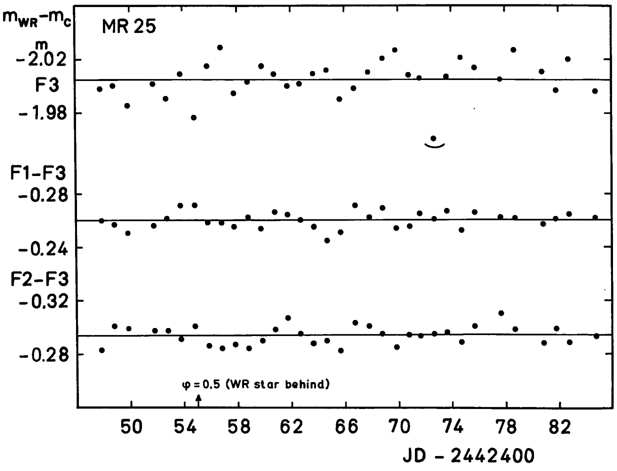

Fig. 3. Light curves of HD 92740 (=MR 25)

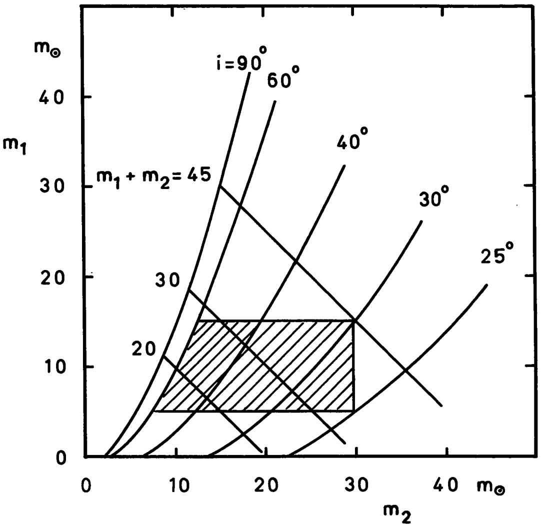

Fig. 4. Range of masses for the components of HD 92740. m_1 refers to the visible WR component

Table 5. Journal of coudé observations of HD 93131

Plate	JD(Hel)-2440000	Plate	JD(Hel)-2440000	Plate	JD(Hel)-2440000
G 7265	2821.768	G 7265	2821.768	G 7265	2821.768
G 7267	2822.766	G 7267	2822.766	G 7267	2822.766
G 7271	2824.628	G 7271	2824.628	G 7271	2824.628
G 7275	2825.669	G 7275	2825.669	G 7275	2825.669
G 7279	2826.805	G 7279	2826.805	G 7279	2826.805
G 7282	2827.689	G 7282	2827.689	G 7282	2827.689
G 7328	2830.644	G 7328	2830.644	G 7328	2830.644
G 7348	2831.674	G 7348	2831.674	G 7348	2831.674
G 7358	2832.637	G 7358	2832.637	G 7358	2832.637
G 7369	2834.657	G 7369	2834.657	G 7369	2834.657
G 7374	2835.668	G 7374	2835.668	G 7374	2835.668
G 7384	2836.590	G 7384	2836.590	G 7384	2836.590
G 8220	3204.682	G 8220	3204.682	G 8220	3204.682
G 8252	3207.614	G 8252	3207.614	G 8252	3207.614
G 8268	3208.730	G 8268	3208.730	G 8268	3208.730

of observational accuracy, HD 92740 is significantly variable in magnitude (albeit at a low noise level) but not in colour or emission line strength relative to the continuum. The light curves for HD 92740 (=MR 25) minus HD 93222 are shown in Figure 3; while they cover phase 0.5 when the WR star is behind ($P=80\overset{\mathrm{d}}{.}35$) there is no indication of an occultation even of the outer part of the WR envelope. Unfortunately, the light curve at phase 0.0 (WR star in front) was not observed.

c) Mass Estimate

Adopting for the final orbit $P=80\overset{\mathrm{d}}{.}35$, $K_1=70$ km s^{-1} and $e=0.55$ we obtain for the mass function:

$$f(m)=\frac{m_2^3 \sin^3 i}{(m_1+m_2)^2}=1.04\ 10^{-7}(1-e^2)^{3/2}K_1^3 P,$$

(in solar masses $M_\odot$ if K_1 in km s^{-1} and P in days) $f(m)=1.67\ M_\odot$.

For comparison, the period $P=59.50$ days (with $K_1=70$ km s^{-1} and $e=0.25$) would yield $f(m)=1.93\ M_\odot$ while Niemelä's (1974) period $P=10.025$ days (with $K_1=70$ km s^{-1} and $e=0.34$) yields $f(m)=0.29\ M_\odot$, a value which is too small by a factor of at least five. The hydrogen absorption lines ($P=80\overset{\mathrm{d}}{.}35$, $K_1=30$ km s^{-1}, $e=0.55$) yield $f(m)=0.13\ M_\odot$, also spurious as we will show in the next section.

Figure 4 shows the relation between m_1 (the WR star mass) and m_2 (the unseen companion) for $f(m)=1.67\ M_\odot$. Lack of an eclipse probably limits the inclination to $i \lesssim 70°$. The masses can be further narrowed down by several arguments: According to Smith (1968b, 1973) the absolute magnitude of HD 92740 (and HD 93131) as a WR star would be $M_V=-6\overset{\mathrm{m}}{.}8$ which yields a distance modulus of $12\overset{\mathrm{m}}{.}3$ ($12\overset{\mathrm{m}}{.}7$). This agrees well with the moduli given for the nearby clusters Trumpler 14/16 by Feinstein et al. (1973), $12\overset{\mathrm{m}}{.}65 \pm 0\overset{\mathrm{m}}{.}2$, and Collinder 228 by Feinstein et al. (1976), $12\overset{\mathrm{m}}{.}0 \pm 0\overset{\mathrm{m}}{.}2$. As we shall see the mean stellar radial velocities also support association of the WR stars to the Carina nebular complex. Thus, adopting $M_V=-6\overset{\mathrm{m}}{.}8$ for HD 92740 leads to the maximum absolute luminosity of a companion star just beyond the limit of detection against the spectrum of the WN 7 star, of $M_V \sim -5\overset{\mathrm{m}}{.}3$ (cf. Kuhi, 1973) which corresponds to an O 6.5 V star. Thus it is likely that $m_2 \lesssim 30\ M_\odot$. Allowing for mass loss or the fact that the companion may be slightly evolved decreases this limit even more. If we also adopt a reasonable mass for the WR component of $(10 \pm 5) M_\odot$, typical for WR stars (Kuhi, 1973), we arrive at the restricted region in Figure 4. This implies a mass ratio m_1/m_2 between 0.3 and 1.0 which overlaps well with typical mass ratios (0.2–0.4) for the known WR binaries with reliable mass estimates

Table 6. Mean radial velocities RV from 15 plates for lines in the spectrum of HD 93131

Ion	λ_0	RV	σ
	Å	km s^{-1}	km s^{-1}
H8 abs.	3889.051	- 95	±27
H9 abs.	3835.385	- 79	24
H10 abs.	3797.900	- 68	30
He II em.	4685.682	+ 83	10
He II em. (+Hγ)	4338.67	+321	25
He II em.	4541.59	+189	40
He II em. (+Hβ)	4859.323	+252	15
He II abs.	4199.83	-124	18
He II abs. (+Hγ)	4338.67	- 89	45
He II abs.	4541.59	-118	21
N III em.	4641.16	- 73	17
N IV em.	3484.96	+ 10	11
N IV em.	4057.759	- 38	8
N IV abs.	3478.71	-358	15
N V em.	4603.73	+170	9
N V abs.	4603.73	- 69	13
N V abs.	4619.98	- 59	13
Si IV em.	4088.854	- 27	15
Si IV em.	4116.097	- 62	32
Ca II, H, I.S.	3933.664	+ 1.0	2.7
Ca II, K, I.S.	3968.470	+ 0.7	2.5
He I, I.S.	3888.646	- 33	6

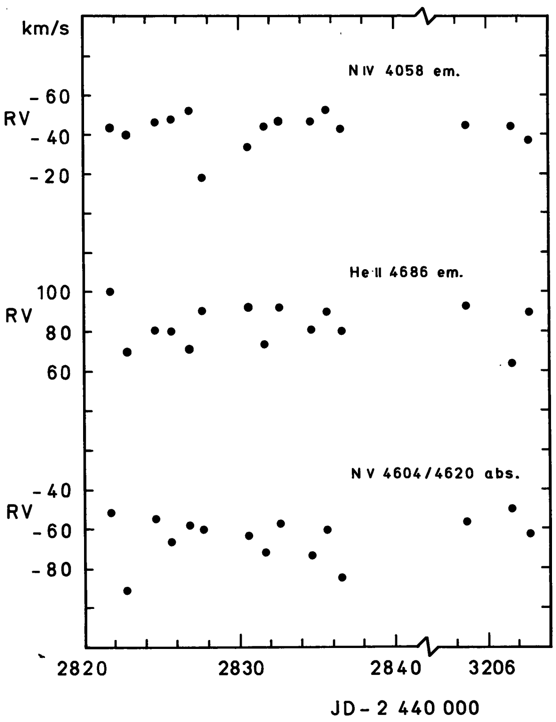

Fig. 5. Radial velocities versus time for best emission and absorption lines of HD 93131

(Kuhi, 1973). However, without actual velocities of the unseen secondary star, not much more can be said about the masses at the present time.

d) The Absorption Lines

The fact has already been noted by Niemelä (1973, 1974) that the absorption lines in the spectrum of HD 92740 follow the orbit derived from the emission lines in phase and, except for the Balmer lines, also in amplitude. This lends support to the fact that the absorption lines (He II, N V) are formed in the photosphere or lower envelope of the WN 7 star which, according to Conti's (1973) distinction between Of and WR stars makes HD 92740 resemble more an extreme Of star than a WR star. In this way, HD 92740, as a binary, resembles the O-type binary BD+40° 4220 (Bohannan and Conti, 1976) and HDE 228766 (Massey and Conti, 1977) which are systems in which the Of component may be on its way to becoming a WR (WN 7) star via stellar wind mass loss.

However, HD 92740 is unique in that the velocity amplitude of the observed Balmer absorption lines H 8, H 9, H 10 (Hα–Hε are blended; H 11, H 12, ...are too weak to be measured with precision) is less than half that of all other lines, including the absorption lines of He II and N V. At the same time, Balmer line orbit is in perfect phase. The most natural explanation for this effect is the influence of a companion star of early spectral type whose lines move 180° out of phase (with amplitude K_2) compared to the WR component. Assuming the secondary to be a normal star with strongest lines due to Balmer absorption, then it would be these very lines in the composite spectrum which would be expected to be diminished in amplitude by the partial out-of-phase cancellation. If the Balmer absorption lines are equally strong in both stars and the masses are about the same one would observe a net velocity amplitude $K_{\mathrm{obs}}=0$ km s^{-1} accompanied by a phase dependent change in total line profile. Since we observe an intermediate value $K_{\mathrm{obs}}=30$ km s^{-1} ($<K_1$) we conclude that the strength of the unseen companion's Balmer lines is partially drowned out by the strong continuum in the range of $K_1-K_{\mathrm{obs}}\sim 40$ km s^{-1} which yields a mass ratio $m_1/m_2=K_2/K_1\sim 0.6$ which is compatible with our previous estimate of this ratio. Unfortunately, the observed Balmer lines are relatively weak and the plates appear to be too noisy to allow the detection of a variation in line profile as the two components criss-cross in velocity as the orbit is traversed.

Another possibility to explain the low-amplitude Balmer velocity variation is the effect of streaming motion of thin, hot, line-emitting gas passing through the inner Lagrangian point. However, the necessary phase shifts due to the added non-isotropic velocity of

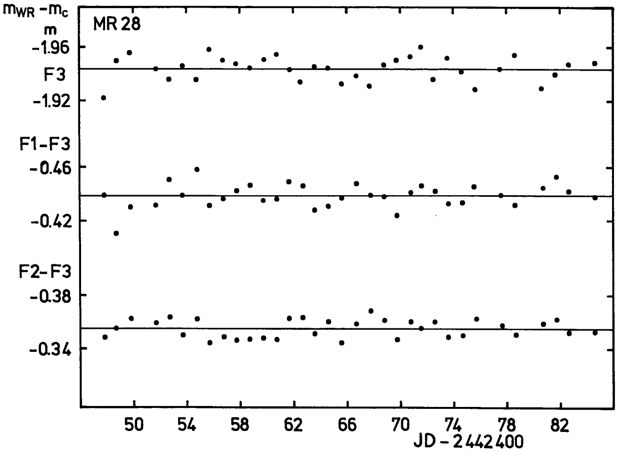

Fig. 6. Light curves of HD 93131 (=MR 28)

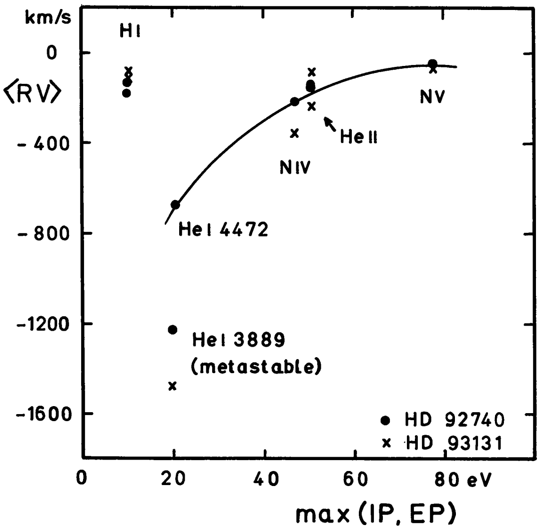

Fig. 7. Expansion structure of the envelopes of HD 92740 and HD 93131

the streaming gas have not been observed as e.g. in the case of the WR binary θ Muscae (Moffat and Seggewiss, 1977).

Finally it is imaginable (as Massey and Conti, 1977, have postulated for HDE 228766) that the emission lines are produced predominantly in outlying regions of the line-emitting star facing away from the other star. This might tend to increase the K values for the emission lines so that the true center-of-mass K-term is given by the velocity orbit of the absorption lines which are presumed to form in deeper, symmetric layers. However, there are two difficulties with this theory: one would expect again a phase shift between the emission-line and absorption-line velocities due to the added vector of the assumed anisotropic wind velocity and, at least for HD 92740, the absorption lines of He II and N V show the same velocity amplitude as the emission lines.

III. HD 93131

a) Spectroscopic Data

We have 15 plates taken in 1976 and 1977 under the same conditions as for HD 92740. A short journal of observations is presented in Table 5. Since no significant variations of the radial velocities with time were observed, we present only the best data in form of graphs in Figure 5. Mean velocities of measurable lines are listed in Table 6.

b) Photometric Data

As for HD 92740 the photometry was obtained during the same interval of 37 days in 1975 with the same equipment. From the light curves in Figure 6 and the dispersions in Table 4 it is apparent that HD 93131 is constant in brightness, colour and line strength (at $\sim\lambda\lambda$ 4640, 4686) within the observational accuracy of about 0.8%.

Therefore, we conclude that it is very unlikely that HD 93131 is a binary. If it is, then its orbital inclination would have to be fortuitously small as a normal WR +OB binary: taking $m_1 = 10\,M_\odot$, $m_1/m_2 \sim 0.3$, $e=0$, $K_1 < 10$ km s^{-1} and $P \sim 10$ days implies $i \lesssim 2°$, an unlikely (but not impossible) value for a random distribution of i. Taking the most probable value $i \sim 57°$ and the same parameters (except m_1/m_2 which is left open) yields $m_2 < 3\,M_\odot$ or $m_1/m_2 > 3$. The original mass ratio must have been even larger—a rare situation in view of the observed frequency function of binary mass ratios (cf. Trimble, 1974); otherwise, one might postulate that the system has gone through the second WR stage according to the scenario of de Loore et al. (1975), so that the present WR star would have a low mass compact companion (system in second X-ray stage). However, the lack of observed optical and X-ray activity of HD 93131 lends little support to this idea.

IV. The Envelope Structure

Some information concerning the structure of the expanding envelopes of WR stars can in principle be studied empirically in two ways: by plotting (a) the widths of emission lines or (b) the velocities of violet-shifted absorption lines versus an energy term which is related to the ionization and excitation potentials of each of the lines involved. For the two WR stars here, one is practically limited to the absorption lines, mean values of which are listed for both stars (γ values for HD 92740) in Table 7. These data are then plotted in Figure 7 taking the maximum of either ionization or excitation potential of the next lower stage or level (cf. Smith and Aller, 1971). The hand-drawn line shows the

Table 7. Parameters for absorption lines in HD 92740 and 93131

Ion	λ_0	Multiplet	Ionization Potential	Excitation Potential	HD 92740 γ-vel.	HD 93131 <RV>
	Å		eV	eV	km s^{-1}	km s^{-1}
Hε	3970	1	0	10.2	- 178	- 125
H8-H10	3889,3835,3798	2	0	10.2	- 130	- 74
He I*	4472	14	0	20.9	- 674	not visible
He I*	3889	2	0	19.7	-1230	-1480
He II	4542,4200	2,3	24.5	50.8	- 151	- 217
He II	4339 (+Hγ)	3	24.5	50.8	- 160	- 83
N IV	3479	1	47.2	46.8	- 209	- 358
N V	4620,4604	1	77.5	56.6	- 46	- 64

* He I absorption edges are poorly defined and were estimated visually from tracings

likely trend in an accelerating envelope (cf. Kuhi, 1973); lines of highest potential are formed nearest to the base of the envelope where the plasma temperature is highest and expansion velocity lowest. Two sets of lines do not fit into this scheme: the Balmer lines are probably formed in a lower expanding photosphere much like those observed in the photospheres of luminous supergiants (Hutchings, 1976) or Of stars (Conti et al., 1977); the He I λ 3889 line, being metastable, is formed under different conditions compared to the other lines. In any case, it is apparent that both stars show similar trends in accord with their similar spectral types and absolute luminosities.

V. Relation to Their Surroundings

Inspection of the radial velocity catalogue of Abt and Biggs (1972) shows that very few radial velocities have been measured for stars associated with the Carina Nebula. Typical values of the half-dozen stars found likely to be at the same distance range from -10 to -25 km s^{-1}. It is difficult to estimate the systematic velocities of WR stars due to obvious effects of line asymmetry caused for example by electron scattering and mass loss motion. However, probably the most reliable unblended line which can be expected to yield the most reliable systematic velocities for WN 7 stars is the symmetric emission line of moderate strength N IV λ 4058. This line has a mean velocity of -23 km s^{-1} in HD 92740 and -38 km s^{-1} in HD 93131. These values are in reasonable agreement with the other stellar velocities. Absorption line velocities suffer from differential acceleration effects in photospheres or envelopes of the WR stars and cannot be used.

Mean interstellar-line radial velocities are available for several stars in the Carina Nebula from the work of Walborn and Hesser (1975). They found mean Ca II velocities of $+6.2$ and $+2.4$ km s^{-1} for HD 92740 and HD 93131, respectively, compared to the present values $+3.9$ and $+0.8$ km s^{-1}. For HD 93131 they note a velocity for the sharp interstellar nebular line due to the metastable transition He I λ 3889, of -27 km s^{-1} compared to our value of -33 km s^{-1} which is somewhat blended by the stellar line H 8. Since HD 92740 is located towards the edge of the nebular region this interstellar feature is very weak in its spectrum. In their high dispersion spectra, Walborn and Hesser also found components of the order of -30 km s^{-1} (in addition to much larger velocities) in the Ca II lines probably associated with the nebula as a whole. This velocity, similar to the stellar velocities probably represents the radial component of the general differential rotation in the Galaxy in this direction (not allowing for solar motion).

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