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WOLF-RAYET STARS IN THE MAGELLANIC CLOUDS. IV. THE EXTRAORDINARILY BROAD-LINED, TRIPLE SYSTEM R130 IN THE LARGE MAGELLANIC CLOUD[1]

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ABSTRACT

R130 is a luminous, hot star with a dual spectrum: WN6 + B1 Ia. The Wolf-Rayet component has an extraordinarily fast wind for its subtype. The strongly diluted emission line of He II 4686 Å from the W−R star reveals a 4 day radial velocity orbit of moderate amplitude ($K \approx 200$ km s^{-1}) while the absorption lines of the B supergiant yield essentially zero amplitude ($K = 7 \pm 9$ km s^{-1}). Hence, unless one of the stars has a very peculiar mass, the WN6 star must be orbiting a third, unseen star, which is most likely a normal luminosity O star of moderate mass, similar to the mass of the WN6 star. This is reminiscent of the galactic WC6 (+O) + O9.7 Iab system θ Mus. Although R130 was originally identified with an *Einstein Observatory* IPC source (and thus R130 would be exceedingly bright in medium-soft X-rays), later HRI observations by Pollock fail to confirm this with certainty.

Subject headings: galaxies: Magellanic Clouds — stars: binaries — stars: Wolf-Rayet — X-rays: sources

I. INTRODUCTION

Located in the 30 Doradus Nebula $\sim 7'$ due west of the luminous core object R136, the star R130 (cf. Feast, Thackeray, and Wesselink 1960) is a bright, hot object with a spectrum of binary character. The precise spectral type is poorly known, with estimates ranging from B0: + W (Feast, Thackeray, and Wesselink 1960), OB + WN (Smith 1968), WC6 (Fehrenbach, Duflot, and Acker 1976), B0.7−1 I + WN (Walborn 1977), B1 I + WN3: (Breysacher 1981), to WC6 + O (Mathewson *et al.* 1983). Our present series of spectra quantify the type as WN6 + B1 Ia. The W−R component is dominated in the visual region of the spectrum by the 4686 Å emission line of He II, which is relatively weak ($W_e \approx 20$ Å compared to ~ 60 Å ($\pm$factor 2 maximum) for typical WN6 stars—cf. Conti, Leep, and Perry 1983)[4] and extremely broad (FWHM ≈ 50 Å), making the star difficult to classify on individual spectra of low signal-to-noise ratio.

The early B supergiant nature of the absorption spectrum is in line with the very bright absolute magnitude of R130. According to Feitzinger and Isserstedt (1983), R130 has $V = 11.46$, $B-V = 0.14$, and thus with $(B-V)_0 = -0.19$ and $A_v = 3.1\ E(B-V)$, we find $E(B-V) \approx 0.33$ and $V_0 \approx 10.4$. With $V_0 - M_v = 18.6$ for the LMC (van den Bergh 1977), this yields $M_v \approx -8.2$ which reduces to $M_v \approx -7.8$ for the B supergiant alone, assuming $M_v \approx -7.0$ for the WN6 star (see below). This can be compared to a mean of $M_v = -8.3$ for the brightest known early B hypergiants (B1 Ia–0) or a mean of $M_v = -6.9$ for B1 Ia supergiants (cf. Schmidt-Kaler 1982). The absolute magnitude of R130 and its individual components are reduced by 0.4 mag if one adopts the nearer LMC modulus found from main-sequence cluster fitting by Schommer, Olszewski, and Aaronson (1984).

Probably the most noteworthy feature of R130 was its possible association (Mathewson *et al.* 1983) with the extended X-ray (Einstein IPC) source 68 of Long, Helfand, and Grabelsky (1981). With L_x (0.15–4.5 keV) $\approx 3 \times 10^{35}$ ergs s^{-1} it was rivalled only by (Einstein IPC) source 74 as being the strongest known X-ray source coincident with a candidate W−R star. Source 74 falls on the position of the brightest *single* (i.e., without detectable orbit motion: Moffat 1986), isolated W−R star in the LMC, the WN7 star R144 = S133 = HD 38282 in 30 Dor (cf. Long, Helfand, and Grabelsky 1981). The strongest known rival of similar subtype in the Galaxy is the WN7 star HD 93162 in the Carina Nebula, with L_x (0.15–4.5 keV) $\approx 3 \times 10^{33}$ ergs s^{-1} (Seward and Chlebowski 1982; Sanders, Cassinelli, and van der Hucht 1982; Pollock 1985), which would be ~ 100 times weaker than R130 or R144 if their association with the above X-ray sources is correct. However, in absolute visual brightness, R144 is only a factor $\lesssim 5$ brighter. On the other hand we note that $L_x/L_{\rm opt}$ in massive X-ray binaries tends to be higher in the LMC than in the Galaxy (Cowley *et al.* 1984). Of course there may exist other W−R stars of relatively high X-ray output in the LMC, but they are likely to be presently undetectable (the IPC limit of detection in the LMC was $\sim 2 \times 10^{35}$ ergs s^{-1} in the Long, Helfand, and Grabelsky 1981 survey). We have checked for coincidences between the Breysacher (1981) W−R catalog and

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[4] Smith and Willis (1983) claim that Conti, Leep, and Perry's (1983) stronger 4686 W_e's are too small by a factor of 3, possibly due to saturation effects on photographic plates. Comparison of Conti *et al.*'s nine stars in common with Smith and Kuhi's (1981) atlas data shows that most 4686 W_e's are in agreement, with a few Conti *et al.* values too low by up to a factor of 2.

the survey of Long, Helfand, and Grabelsky (1981): no other W−R stars besides R130 and R144 lie closer than ∼2′–3′ (∼2 σ) from the IPC centers.

All three objects are soft X-ray sources, although according to Long, Helfand, and Grabelsky (1981) the IPC source associated with R130 is extended ($\phi \gtrsim 1' = 16$ pc) and therefore a suspected supernova remnant (SNR), while the other two (R144 and HD 93162) are point sources within the limits of resolution of the detector. On the other hand, Mathewson *et al.* (1983) failed to detect even faint Hα or [O III] nebular emission around R130 and considered that it may be an X-ray binary rather than a SNR. However, while neither HD 93162 nor R144 appear to show binary related modulations in continuous light or in radial velocity beyond the instrumental errors (Moffat 1978; Conti, Niemela, and Walborn 1979; Moffat 1986), nothing was known previously about the binary nature of R130. This prompted us to publish here our accumulated results for R130 separately. In fact we do find binary motion in this star, although as we shall see, it is unlikely to be the prime source of the X-rays, should the X-ray coincidence be correct. Indeed, A. M. T. Pollock (1985, private communication) finds from higher resolution *Einstein* HRI data that neither R130 nor R144 coincides better than 3–4 σ with the closest X-ray sources.

This is the fourth in a series of papers on W−R stars in the Magellanic Clouds. The others have dealt with R31 = AB6 (Moffat 1982*a*, hereafter Paper I; cf. also Hutchings *et al.* 1984), HD 5980 (Breysacher, Moffat, and Niemela 1982, hereafter Paper II), and Sk 188 (Moffat, Breysacher, and Seggewiss 1984, hereafter Paper III), all in the SMC. R130 is also known as HDE 269891, Sk −69°235 in the luminous star survey of Sanduleak (1969), star 43 in the W−R catalog of Westerlund and Smith (1964), star 62 in the W−R catalog of Fehrenbach, Duflot, and Acker (1976), and star 72 in the W−R catalog of Breysacher (1981).

II. OBSERVATIONS

As part of a larger program to monitor spectroscopically the ∼30 brightest W−R stars in the Magellanic Clouds, a total of 21 photographic image-tube spectrograms was obtained for R130 at the Yale 1 m telescope at CTIO during 1978 December, 1980 January, and 1982 January. Exposure times were typically ∼10 minutes per spectrum. The two-stage Carnegie Image Tube was used at the inverse dispersion of 45 Å mm^{-1}. With baked IIa-O plates, this yielded a FWHM resolution of ∼30 μm (1.2 Å) over a range of ∼3700–4900 Å. Wavelength was calibrated using a He-Ar source. Radial velocities of the stronger lines were obtained from the bisection of a parabola fitted to the rectified photographic density of the line center and steep flanks (cf. Paper I for more details). The plates were scanned with the PDS at the David Dunlap Observatory, Toronto. The results are summarized in Table 1.

In 1982 December, further spectra of R130 were secured in the 4000–5000 Å range with FWHM resolution ∼3 Å using the Image Dissecting Scanner (IDS) at the 1.5 m telescope at ESO. Beam switching between R130 and the sky in an east-west direction was carried out every 5 minutes for a total of 20 minutes for each spectrum listed. The double beam consisted of 4″ × 4″ apertures, separated by 60″. Pixel-to-pixel sensitivity variations were eliminated by flat-fielding with a quartz source reflected off a white screen in the dome. Wavelengths and fluxes were calibrated using a He-Ne-Ar spectrum and the flux standards Feige 15 and Hiltner 600, respectively, always with the same diaphragms. The spectra were reduced using the processing facilities "IHAP" at ESO headquarters, Munich. Radial velocities and equivalent widths of the strongest line, He II 4686 Å, were obtained by bisecting and determining the area under a Gaussian fit to the line profiles; the results are given in Table 2.

Photoelectric broad-band photometry was obtained on two occasions: (1) in 1980 January in *B* and *V* at the 61 cm telescope at CTIO, and (2) in 1982 January in the Walraven system at the 0.9 m Dutch telescope at ESO. The photometric results are presented in Tables 3 and 4, respectively.

TABLE 1

JOURNAL OF IMAGE-TUBE SPECTRA AND RADIAL VELOCITIES

Plate Number	JD-2,440,000	Phase[a]	He II 4685.682 Å (km s^{-1})	Mean Absorption[b]
2420	3839.759	0.696	−130	+249 ± 14
2425	3840.759	0.928	+88	242 ± 30
2430	3841.799	0.170	+385	236 ± 15
2435	3842.744	0.389	+99	254 ± 12
2441	3843.769	0.627	−35	251 ± 14
2447	3844.737	0.852	−43	250 ± 16
2453	3845.767	0.091	+308	284 ± 23
2458	3846.743	0.317	+292	252 ± 28
2464	3847.767	0.555	+141	270 ± 34
3286	4254.800	0.012	−86	259 ± 4
3291	4255.749	0.232	+317	242 ± 20
3297	4256.772	0.469	+151	270 ± 19
3301	4257.721	0.689	−2	322 ± 32
3306	4258.772	0.933	−55	322 ± 30
3311	4259.712	0.152	+306	258 ± 16
3318	4260.760	0.395	+143	246 ± 6
3324	4261.768	0.628	−137	180 ± 33
3331	4262.819	0.872	−98	253 ± 16
4737	4977.804	0.793	−155	258 ± 12
4740	4978.534	0.962	−171	226 ± 8
4752	4980.552	0.431	+61	239 ± 20

NOTE.—For each of the three groups of data, the mean RVs of nebular Hβ emission are 273 ± 9, 264 ± 9, and 279 ± 3 km s^{-1}.

[a] From the ephemeris (passage of 4686 emission through the gamma velocity) as in Table 5.

[b] Based on the average of the strongest, unblended absorption lines H10 (3797.900 Å), H9 (3835.386 Å), He I (4026.189 Å), and He I (4471.507 Å). The error refers to the standard deviation of the mean, allowing for a difference in zero point for each of the four lines. The rms value of all the last column is 21 (19 without the three inferior points at 322, 322, and 180) km s^{-1}.

TABLE 2

JOURNAL OF IDS SPECTRA, RADIAL VELOCITIES, AND EQUIVALENT WIDTHS

JD-2,440,000	Phase[a]	He II (4685.682) (km s^{-1})	W_e (He II 4686) (Å)
5309.750	0.825	+52	−18.9
5310.656	0.035	+180	−21.3
5311.639	0.263	+347	−19.1
5312.632	0.494	+161	−22.4
5313.590	0.716	−56	−17.8
5314.563	0.942	+84	−19.2
5315.569	0.175	+315	−21.1
Mean	...	...	−20.0
σ	...	...	1.6 (8%)

[a] Based on the ephemeris of He II in Table 5.

TABLE 3

BV Photometry 1980 December

JD-2,440,000	Phase[a]	V^b	$(B-V)^b$
4590.825	0.989	1.235	−0.191
4591.571	0.162	1.256	−0.212
4592.751	0.436	1.240	−0.200
4592.826	0.454	1.256	−0.192
4593.607	0.635	1.239	−0.205
4593.763	0.671	1.241	−0.205
Mean	...	1.244	−0.200
σ	...	0.009	0.009

[a] Based on the ephemeris of He II 4686 in Table 5.
[b] R130 minus comparison star R131 (cf. Table 4).

TABLE 4

Walraven Photometry 1982 January

JD-2,440,000	Phase[a]	V^b	$(V-B)^b$	n
4985.70	0.625	−0.480	−0.076	5
4986.69	0.854	−0.485	−0.075	6
4987.69	0.087	−0.447	−0.073	7
4988.69	0.319	−0.491	−0.073	6
4989.70	0.553	−0.485	−0.076	7
4990.70	0.785	−0.479	−0.073	7
4991.72	0.022	−0.480	−0.073	6
4992.71	0.251	−0.479	−0.074	6
4993.70	0.481	−0.480	−0.075	6
4994.70	0.713	−0.478	−0.075	5
4995.70	0.945	−0.482	−0.073	6
4996.70	0.177	−0.480	−0.076	6
4997.70	0.409	−0.473	−0.076	6
4998.70	0.642	−0.469	−0.076	7
Mean	...	−0.480	−0.075	...
σ................	...	0.0053	0.0013	...

[a] Based on the ephemeris of He II in Table 5.
[b] Units are in $+\log I$, not $-2.5 \log I$, relative to the comparison star R131 (HDE 269902, B9I). The differences of the check star, R103F, minus the comparison star R131 (based on nightly means), are $\Delta V = -0.643 \pm 0.0034$ (σ) and $\Delta(V-B) = +0.280 \pm 0.0025$ (σ).

III. MEAN SPECTRUM

By far the strongest emission line seen in the optical spectrum of R130 is due to He II 4686. With a mean equivalent width of only ~20 Å we are unable to say for sure whether real profile changes occur above the instrumental noise level of one spectrum ($\sigma \approx 5\%$). This is also comparable to the standard deviation of the equivalent width of the He II 4686 emission [$\sigma(O-C) \approx 8\%$] measured from the flux-calibrated IDS spectra (cf. Table 2). Thus, we are justified in considering the lower-noise *mean* spectrum as typifying the system, even if radial velocity variations slightly smear out the He II emission. As shown in the next section, the absorption lines remain essentially unshifted from plate to plate.

Figure 1 shows the mean photographic density of the nine-image-tube spectra from 1978. On it are marked the principal lines. This spectrum clearly supports the supergiant nature of the absorption component; we estimate a spectral type of B1 Ia for it. This is based on the following criteria: (1) the line ratio He I 4387/O II 4415,17 is low; (2) Si III (4553 and other transitions) and the C III + O II 4070 blend are very strong; (3) despite the strong He II 4686 emission, it is clear that the C III + O II 4650 complex is as strong as He I 4471; and (4) the (weak) strength of C II 4276 and Si IV 4089, 4116 favor a B1 type.

Figure 2 shows the flux-calibrated mean IDS spectrum of R130 (the relative flux is accurate to several percent, but the absolute level may be in error by ±30%). Despite the lower resolution in Figure 2 than in Figure 1, many of the same features in R130 are seen in each. In Figure 2 we also show for comparison the mean IDS spectra taken during the same run as R130 of two other stars, R87 = HDE 269333, of spectral type WN3 + B1 Ia and HD 36063 of spectral type WN7. We note in passing that both of these are spectroscopic binaries with well-determined radial velocity (RV) orbits (Moffat 1986), the former SB2, the latter SB1. Intercomparison of the spectra shows the clear dominance of the N III emission near 4640 Å over N IV 4058 Å and N V 4604 Å in the spectrum of R130,[5] somewhat similar to HD 36063. The supergiant absorption lines of O II/N III at 4641/42 Å and O II/C III at 4647/51 Å tend to depress the N III emission line of the W−R component—possibly a source of confusion in classifying the emission line component in the past. In R87, N V 4604/20 clearly dominates over the N IV and N III features, thus supporting the WN3 type for its W−R component. For R130, we adopt a type of

WN6 + B1 Ia.

We note that the equivalent width of the Hδ absorption line of R130 in Figure 2 is 0.84 Å (for comparison, He I 4471 Å has $W_e = 0.43$ Å). Assuming that (1) the Hδ absorption line is not contaminated by nebular emission as are Hβ and probably also (but marginally) Hγ and (2) the Hγ absorption line has a similar equivalent width compared to Hδ of 0.84 Å, we find M_v (Hγ) lies between −7.9 ($I_{WR}/I_B = 0$) and −7.1 ($I_{WR}/I_B = 0.5$ as most likely value)—cf. Walker and Millward (1985) in agreement with the photometric value in § I.

The most noteworthy feature of the spectrum of R130 is the extraordinary width of the emission lines for its WN6 class. While most other stars of similar type in the LMC (cf. Moffat, Seggewiss, and Shara 1985) and the Galaxy (Smith and Kuhi 1981) have FWHM for He II 4686 Å of ~20–30 Å, this line in R130 has a FWHM of ~50 Å (from Fig. 2, correcting for orbital smearing), i.e., double the normal value.

From the dilution of the He II 4686 emission line to $W_e \approx 20$ Å compared to ~60 Å (± factor of 2 maximum) in typical single WN6 stars (as noted above), we can estimate the relative

[5] Two facts cast some uncertainty on the relative intensities of the N ions: (*a*) The photographic mean spectrum in Figure 1 shows no obvious presence of N IV 4058, and even the presence of this line on the IDS spectrum in Fig. 2 is close to the noise level. (*b*) A recently obtained CCD spectrum of the 5000–6000 Å region shows relatively strong C IV 5806 emission. These might support an early WC type rather than WN6 for the W−R component of R130, assuming the broad emission feature to the blue of He II 4686 to be due to C III/C IV 4650 instead of N III 4640. However, Conti, Leep, and Perry (1983) give intensity ratios of N III/N IV in WN6 stars that range up to a factor of 4. If R130 is close to this limit, this could explain the marginal detection of N IV, or possibly R130 may be of type WN7. The weakness of N V is normal for WN6 or WN7. Conti, Leep, and Perry also find some WN stars with relatively strong C IV 5806 emission, in particular the WN5 star HD 50896 and the WN7 star HD 197406. Furthermore, it would be highly anomalous to find a broad-line WC star in which He II completely dominates in strength over C III/IV 4650. Presumably, Fehrenbach, Duflot, and Acker (1976) and Mathewson *et al.* (1983) either neglected this in assuming the type WC6, or they misidentified the 4686 line as due to 4650 emission on their low-resolution spectra. Thus, unless R130 contains a transition WN/WC type or even two WR components, WN and WC (a rather contrived interpretation despite the title of this paper), we prefer a simple WN6 type for the time being. This point can only be settled definitively by obtaining data of very high signal-to-noise ratio and checking for orbital motion in other emission lines.

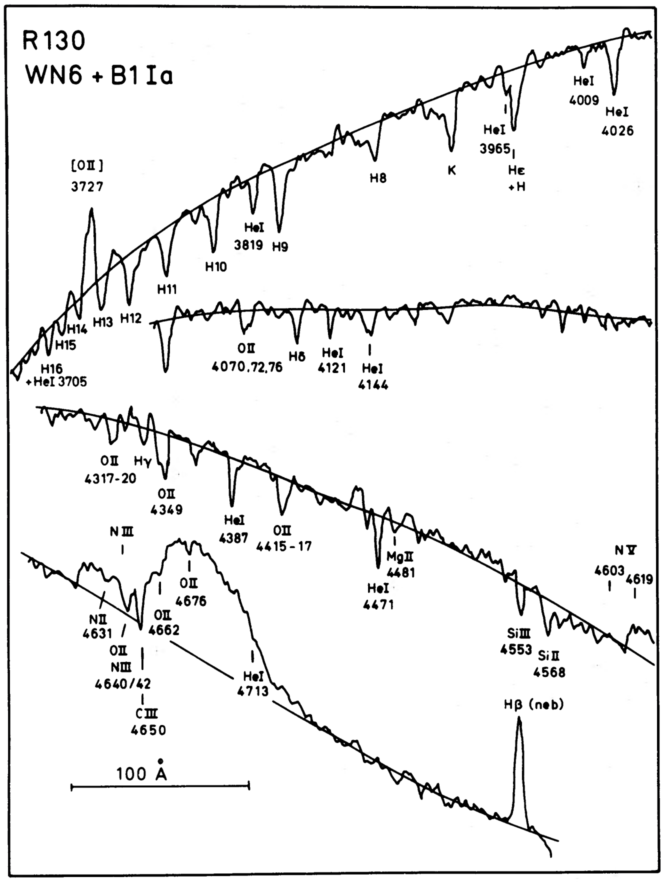

FIG. 1.—Photographic density vs. wavelength for the mean of the nine image-tube plates (numbers 2420–2464) from 1978. Most of the stronger lines are identified, emission above and absorption below. The smooth curve represents an attempt to draw the continuum.

absolute visual magnitudes of the two stars, assuming $M_v(\text{tot}) \approx -8.2$ and only two stars in the system. We find M_v (WN6 component of R130) $= -8.2 + 2.5 \log (60/20) = -7.0$ (± 0.8). This is in agreement with estimates of M_v for other (luminous) WN6 stars in the LMC (Conti, Leep, and Perry 1983, adopted from Prévot-Burnichon *et al.* 1981; revised fainter by several 0.1 mag by Moffat *et al.* 1986). However, as we shall see, there remains the uncertainty of the effect of a third component, which nevertheless is probably significantly fainter than either of the two visible components (see below). For the B-type supergiant we derive for the remaining light M_v(B1 Ia) $= -7.8$, in fair agreement with the Hγ-calibration above.

IV. AN ORBIT FOR R130

From the absorption line radial velocities (RV), the rms internal error for one plate (based on the scatter from the mean of different lines, allowing for different mean line RVs) is $\sigma_i = 21$ km s^{-1} (19 km s^{-1}, omitting the three plates 3301, 3306, and 3324 where the mean absorptive RVs deviate from the overall mean by $\gtrsim 3\ \sigma_i$). This is comparable to the external scatter based on the standard deviation of a given plate from the overall mean RV, $\sigma_e = 30$ km s^{-1} (14 km s^{-1} omitting the same three data points as above). This implies that any intrinsic variability of the mean absorption RVs in Table 1 less than $\sim$15–20 km s^{-1} is not detectable with the present data (i.e., $\sigma_i \approx \sigma_e$).

On the other hand, the only W−R emission line strong enough to give useful results, He II 4686, shows large RV variations which, compared to other stars in the program, must be intrinsic. A glance at Tables 1 and 2 suggests a periodicity of $\gtrsim$4 days in the RV of this line. We therefore made a formal period search by fitting a sine wave of various periods to the RVs of the He II emission. Combining all the He II data (Tables 1 and 2) with allowance for epoch-dependent RV shifts, we derive a best period $P = 4\overset{d}{.}3092 \pm 0\overset{d}{.}004$. Due to windows in the data, other periods are possible but less likely (e.g., $4\overset{d}{.}1391$ or $4\overset{d}{.}3605$ are the next best). We neglect possible aliases close to

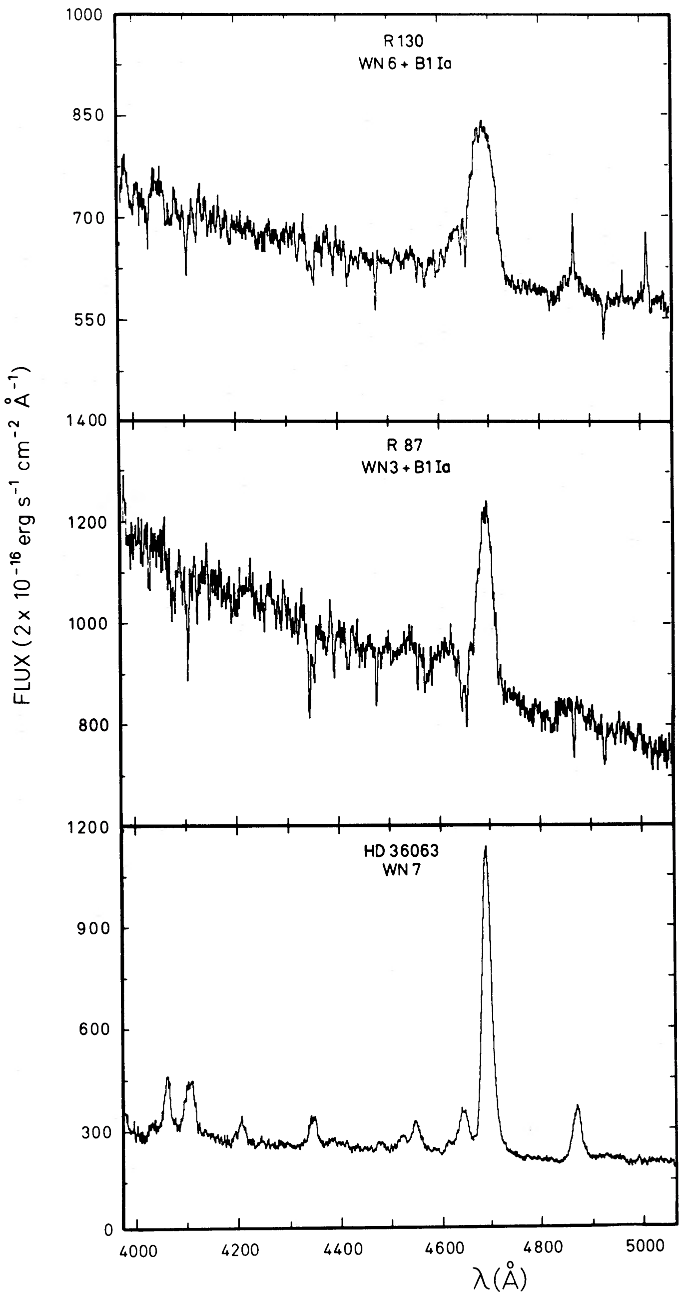

FIG. 2.—Mean IDS fluxed spectrum of R130, with the LMC stars HDE 269333 = R87 (WN3 + B1 Ia) and HD 36063 (WN7) for comparison. Part of this spectrum for R130 was shown by Moffat, Seggewiss, and Shara (1985) in order to compare with other WN6, 7 stars in the 30 Doradus region.

TABLE 5

MEAN RADIAL VELOCITY ORBITAL ELEMENTS OF R130

Quantity	He II 4685.682 Emission	Mean Absorption
P (days)	4.3092 ± 0.004 (adopted)	
e	0.00 (assumed)	
γ (JD 2,443,843 mean)	+129 ± 26	254 ± 5
γ (JD 2,444,258 mean)	+62 ± 29	261 ± 14
	...	255 ± 4[a]
γ (JD 2,444,979 mean)	−35 ± 48	241 ± 9
γ (JD 2,445,312 mean)	+157 ± 13	...
K (km s^{-1})	204 ± 26	7 ± 9
E_0 (JD −2,440,000)	3841.07 ± 0.09	3843.9 ± 1.0
σ $(O-C)$ (km s^{-1})	92	29
σ (km s^{-1})	171	30
	...	14[a]

[a] Omitting three bad values.

or less than 1 day, which would produce unusually close separations ($a \sin i < 10\ R_\odot$).

With this period we derive the orbital parameters for a circular orbit (cf. Table 5). A noncircular orbit is physically unlikely for a short-period system like this and in any case, values of $e \gtrsim 0.2$ do not show up, while values less than 0.2 are not distinguishable from zero with the present data. The orbit is depicted in Figure 3, where we have plotted RVs from 4686 emission and from the mean absorption versus the 4686 ephemeris in Table 5. Note that while the emission-line RV amplitude is relatively large ($K_{em} \approx 200$ km s^{-1}), the amplitude for the B supergiant absorption line RVs is small, even compatible with zero, as suspected above. Thus, R130 behaves much like the galactic 18 day binary θ Mus (Moffat and Seggewiss 1977) in which the WC6 component reveals $K = 173$ km s^{-1} while the O9.7 Iab star yields $K \approx 0 \pm 6$ km s^{-1} (3 σ).

In Table 5 we also list the mean RVs (γ-velocities) for each group of data. These are obtained from the mean residuals from the overall orbital fit for each group; the errors given refer to the uncertainty of the mean, i.e., $\sigma/(n)^{1/2}$, where σ is the standard deviation and n is the number of data points in each group. While there is no significant long-term variation of the B supergiant absorption component, there is possibly a real variation of the He II emission line γ-RV. This is shown plotted in Figure 4. Without more data it is premature to draw any conclusions about the existence of a possible long-term periodicity. If real, it would probably not involve the B supergiant.

Another curiosity of Figure 4 is the relatively large negative velocity shift of He II emission compared to the systemic RV, which is probably best represented by the mean absorption RV (~255 km s^{-1}). This latter matches well the mean for this part of the LMC based on a compilation of many stars (Feitzinger 1980), and the observed nebular emission RV in the spectrum of R130 of ~272 km s^{-1} for Hβ. In most WN stars, with or without a companion, the He II 4686 line usually reveals a RV which is redshifted relative to the systemic RV, although this may not be valid for very broad lines among the hottest WN stars in the Magellanic Clouds which can show a blueshift (Moffat 1986). In R130, He II 4686 is shifted ~150 km s^{-1} to the blue. It is unlikely that this shift is caused by a gap in the data for a long-period binary orbit, since this would require an unusually large mass function to fill such a gap with sufficiently positive RVs.

Alone, the 4686 emission line gives a mass function $f(m) = 3.8\ M_\odot$, which is typical either of WNL + O binaries, assuming a mean value for the inclination $i \sim 60°$, or of low-i

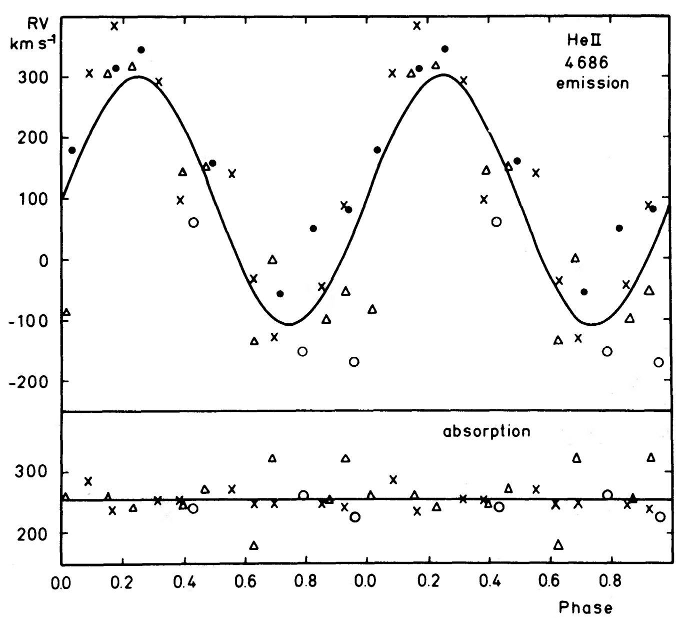

FIG. 3

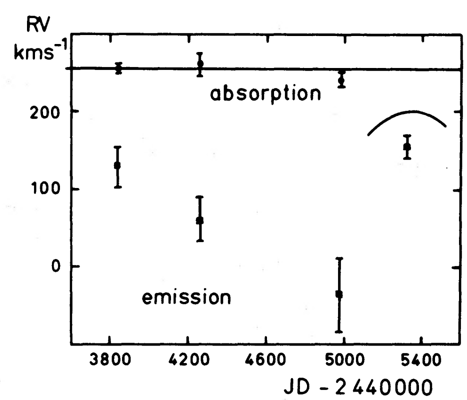

FIG. 4

FIG. 3.—Radial velocity orbit of R130 based on the emission-line ephemeris in Table 5. Key to symbols: *crosses*, 1978; *triangles*, 1980; *open circles*, 1982 (image tube); *filled circles*, 1982 (IDS).

FIG. 4.—Group mean γ-velocities versus time

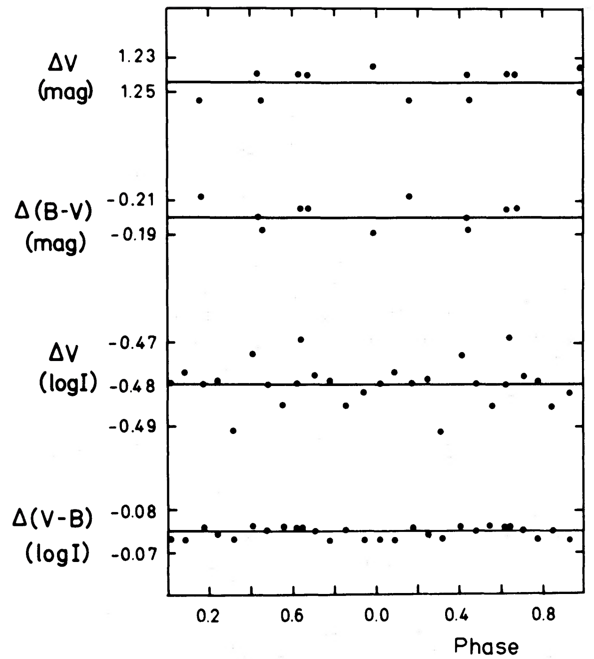

FIG. 5.—Johnson V, $B-V$ magnitude and Walraven V, $V-B$ log I light curves vs. emission-line phase from the ephemeris in Table 5 for R130.

(and thus rare) WNE + O systems. With $i \approx 60°$ and M(WN6) = 10 or 40 $M_{\odot}$ respectively (the former value refers to an extreme lower limit [Massey 1981] while the latter refers to the minimum mass for the WN6 component of the SB2 binary HDE 311884 [Niemela, Conti, and Massey 1980]), we find a mass for the 4.3 day, unseen companion, of 15 or 31 $M_{\odot}$, with even higher values of the latter for $i < 60°$. The unseen companion mass is like that of a late-type main sequence O star with $M_v \approx -5$ or an O giant with $M_v \approx -6$. Either value implies that its spectrum would be essentially drowned out by the B supergiant; even the WN6 component is probably brighter. In summary, it appears that the W–R/companion mass ratio is probably close to unity, also much like typical WNL + O binaries, as opposed to the typical ratio of ~ 0.4 for WNE + O systems (Massey 1981; Moffat 1982*b*). Thus, despite its extremely broad emission lines, the WN6 component of R130 probably belongs to the luminous WN6L sequence, not WN6E (cf. Firmani 1982).

We investigate the orbital light curve in Figure 5, where we have plotted brightness and color indices versus the He II 4686 phase from Table 5. There is no convincing evidence for any kind of occultation effect with amplitude $\gtrsim 0.01$ mag. The amplitude of the WN6 + unseen companion alone could be as large as 0.01×3 (dilution factor) ≈ 0.03 mag. Such a value would be like that found in most, if not all, close W–R + O systems (Moffat and Shara 1986). Thus, the B supergiant may have all but drowned out any variation involving the fainter WN6 component and its 4 day companion.

V. DISCUSSION

Three possible configurations present themselves for R130:

Case a.—A simple binary consisting of the WN6 star in mutual 4.3 day orbit with the B1 Ia supergiant, in which (1) the B supergiant has normal mass ($\sim 25 M_{\odot}$). In this case, the W–R star would have an abnormally low mass ($< 2 M_{\odot}$) assuming $K_{\mathrm{B1\,Ia}} < 16$ km s^{-1} (1 σ). One might then imagine the W–R component to be a compact "star" in disguise, as has been suggested for SS 433 (van den Heuvel, Ostriker, and Petterson 1980). However, there are no known hard X-rays eminating from R130 as in the case of SS433 (cf. Grindlay *et al.* 1984), and in any case there would be little room for a supergiant in such a short period system ($a \sin i \approx 20 R_{\odot}$) without considerable interaction effects that should be clearly visible as a function of phase in the spectrum or the light curve, or (2) the WN6 star is of normal mass. Taking $M_{\mathrm{W-R}} = 40 M_{\odot}$, like the lower limit for the galactic WN6 star in the W–R + O binary HDE 311884 (Niemela, Conti, and Massey 1980) yields a mass for the supergiant of $> 510 M_{\odot}$. We discard case *a* as highly improbable.

Case b.—A bound, triple system, consisting of the WN6 component in a 4.3 day stable orbit with an O star, or possibly even a WC star (cf. § III), and both in a wide orbit with the B supergiant, like the favored model of the WC6 (+O) + O9.7 Iab system θMus (Moffat and Seggewiss 1977). However, as in the binary case, it is relatively difficult to understand the coexistence of a rather evolved star of type B1 Ia (age $\sim 10^7$ yr) compared to the youth of the WN6 star (probable age $\sim 3 \times 10^6$ yr). Stars like this do coexist, e.g., in the adjacent 30 Dor Nebula region, but where they never occur together in very tight regions and their coexistence requires two different epochs of formation (McGregor and Hyland 1981; Moffat *et al.* 1986). Another problem is the possibility of a long orbit (100's of days as suggested by Fig. 4) which would not involve the B supergiant component, but rather a fourth star. However, this possibility seems rather contrived and needs verification with more data. On the other hand, bound triple systems do occur with nonnegligible frequency in nature (Batten 1973).

Case c.—A chance alignment of a 4 day WN6 + O binary with a B supergiant. From visual inspection at the telescope during $\lesssim 1''$ seeing, the image of R130 appears perfectly round. At the distance of the LMC, this implies a projected separation of $\lesssim 0.25$ pc = 5×10^4 AU. Given the density of bright stars ($m \lesssim 12$) in this region of the LMC, one can calculate the *a priori* probability of such a chance alignment to be ≈ 0.003, which is small but nonnegligible.

Without further information (e.g., better angular resolution, very long-term RV study), we are unable to make a final choice between case *b* and case *c*, although case *b* is favored.

Finally we approach the question of the relatively strong, soft X-ray flux possibly associated with R130. First, we note that the *Einstein* satellite IPC X-ray observations are compatible with the fact that virtually all Galactic W–R stars emit soft ($kT \lesssim 1$ keV) X-rays at a level L_x (0.15–4 keV) $\approx 10^{32-33}$ ergs s^{-1}, with significantly greater scatter of individual values compared to O stars of high luminosity (cf. Sanders, Cassinelli, and van der Hucht 1982). This occurs whether the star is in a binary or not, so that the process of wind collisions, which could provide $L_x \approx 10^{33}$ ergs s^{-1} for a typical 4 day W–R + O binary (Cherepashchuk 1976), competes only mildly with some other more general phenomenon. Due to the softness of the spectrum, we follow the reasoning of Cassinelli and Swank (1983) that a large fraction of the observed flux at 0.15–4 keV) from early-type stars must be generated in the outer layers of the wind, probably by some shock process. This being the case, one would expect L_x to be proportional to $\dot{m}v_{\infty}^2/2$, the power in the wind at terminal velocity. We note that some shock theories (e.g., acoustic shocks in stellar chromospheres) yield a much higher power dependence on the (turbulent) velocity.

There is a hint from the limited available X-ray data that this may be the case. For example, among the four bright Galactic WN7 stars for which v_∞ has been determined from UV P Cygni profiles (Barlow, Smith, and Willis 1981), HD 93162 has the highest v_∞ (2900 km s^{-1}), although not by much, and the highest L_x (3×10^{33} ergs s^{-1}) by a factor ~ 5 over HD 151932, 92740, or 93131, with $v_\infty = 2250$, 2600, and 2800 km s^{-1}, respectively. We note that the exceptionally broad-line WC7 star HD 193793 has the highest ratio of $L_x/L_{\rm bol}$ known among Galactic W–R stars (Pollock 1985). Some other W–R subtypes (especially the hotter ones) do have systematically larger v_∞'s, but not necessarily higher L_x's, so that some other factor besides v_∞ must also play a rôle. (The general correlation of v_∞ increasing with hotter WN subtypes [Willis 1983] may be incidental.) One factor is the mass-loss rate. For example, Abbott and Beigung (1984) state that although mass-loss rates vary little in general from one W–R subclass to another, there is a correlation of $\dot{m}$ with the mass of the star (based on binary determination) and line strength. It is difficult to apply this *quantitatively* to WNL stars, which have higher masses but weaker lines in general than the WNE stars.

Among the known LMC stars of type WN6, R130 clearly has by far the widest emission lines (cf. montage of spectra by Moffat, Seggewiss, and Shara 1985) in the visible (no UV spectrum of R130 has yet been published). The strong line He II 4686 has a FWHM of ~ 50 Å compared to 20–30 Å for other typical WN6 stars. Assuming v_∞ to be proportional to line width, we speculate a possible enhancement factor of L_x for R130 versus normal WN6 stars, that is much greater than HD 93162.

However, due to a recent assessment of coincidences of W–R stars with X-ray sources by A. M. T. Pollock (1985, private communication), it now appears less likely that either R130 or R144 is truly the definitive optical candidate for the X-ray sources.

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