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THE MASSIVE WC6+O6–8 SPECTROSCOPIC BINARY HD 94305

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ABSTRACT

HD 94305 is found to be a double-lined WC6+O6–8 spectroscopic binary. The minimum masses of the components of this binary are 15 $M_\odot$ and 32 $M_\odot$ for the Wolf-Rayet and the O type components, respectively. The relatively high minimum mass for the WC6 component adds further evidence to the notion presented elsewhere by Niemela that the more massive WC6–8 stars cannot be descendants of the less massive WN3–5 stars.

Subject headings: stars: binaries — stars: individual — stars: Wolf-Rayet

I. INTRODUCTION

Among the galactic Wolf-Rayet binaries, the only four double-lined binary systems with WC type components which have well determined, published orbital solutions all are of type WC7–8. The estimates of masses of these WC stars yield a mean value of 18 $M_\odot$, noticeably higher than the mean value of the WN3–5 type components in spectroscopic binaries, namely 10 $M_\odot$ (see Table 1 in Massey 1982).

Little is known about the masses of other type WC stars. A preliminary orbit for the WC5–O7 binary HD 63099 (Niemela 1981) shows a lower mass ratio, like its LMC counterparts (Moffat 1981). However, the period of this binary is not well determined.

The only hitherto known binary with a WC6 type component, namely θ Muscae, appears to be a triple system where the supergiant absorption lines belong to a third star, not to the (undetected) companion of the WC6 component (Moffat and Seggewiss 1977).

HD 94305 is a 12th magnitude southern Wolf-Rayet star of the carbon sequence; it was classified as WC6+OB by Smith (1968) because faint absorption lines are seen in the spectrum superposed on the WC6 emission lines. However, since no radial velocities were available, the true binary nature of this star could not be established, and therefore it appears classified as WC6+abs in van der Hucht *et al.* (1981). These authors also note the presence of O VI 3811, 3834 Å emission.

In this paper we present a radial velocity study of HD 94305 showing that it is indeed a massive double-lined binary, with a period of $18^{\mathrm{d}}.8$. The absorption lines present in the spectrum indicate that the OB companion is of spectral type O6–8. The minimum masses that we find are moderately high, 15 $M_\odot$ and 32 $M_\odot$ for the WC6 and the O6–8 components, respectively. These values are in good agreement with the mass values determined for the WC7–8+OB binaries, and further support the notion (Niemela 1981) that the less massive WNE stars cannot evolve to the more massive WC stars.

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II. THE OBSERVATIONS

We have obtained 52 blue spectrograms of HD 94305 between 1979 January and 1982 April at the Cerro Tololo Inter-American Observatory, Chile, with the image-tube spectrograph attached to the 1 m Yale telescope (plates labeled E). In addition, three blue and three red spectrograms (plates labeled F) were secured by one of us (R. H. M.) with the R-C image-tube spectrograph of the 4 m telescope.

The spectrograms E-3794 through E-3839 were obtained by A. F. J. M. They are on baked IIa-O plates with 0.5 m widening. All other spectrograms are on IIIa-J plates, baked in forming gas, mostly, with 1.0 mm widening. The IIIa-J plates generally yield more precise line positions, especially for weaker lines. The E-plates have a reciprocal dispersion of 45 Å mm^{-1}, and the F-plates, 45 Å mm^{-1} in the blue and 47 Å mm^{-1} in the red.

Radial velocities for the plates taken by A. F. J. M. were determined with the PDS microdensitometer of David Dunlap Observatory at the University of Toronto, Canada. All other plates were measured for the determination of radial velocities with the Grant oscilloscope comparator at IAFE, Buenos Aires, Argentina.

The journal of observations and the radial velocities for the C IV 4441 Å emission and the Hδ absorption are listed in Table 1. These are clearly the most isolated, symmetric lines appropriate for orbital determination.

TABLE 1

JOURNAL OF OBSERVATIONS OF HD 94305

			RADIAL VELOCITY (km s^{-1})	
PLATE NO.	JD (2,440,000 +)	PHASE[a]	C IV em. λ 4441[b]	Hδ abs.
E3345	4266.78	0.33	+363	−135
E3351	4269.77	0.48	+159	−66
E3358	4271.81	0.59	+39	−44
E3361	4272.71	0.64	+19	+100
E3365	4273.80	0.70	−94	+17
E3372	4275.77	0.80	−33	+70
E3375	4276.70	0.85	+23	+4
E3376	4276.77	0.86	+34	+3
E3381	4277.77	0.91	+92	−84
E3533	4387.56	0.74	−123	+73
E3539	4388.56	0.80	−17	−16
E3550	4391.58	0.95	+70	−160
E3794	4586.87	0.33	+398	−87
E3809	4589.85	0.49	+144	...
E3814	4594.86	0.76	−45	+52
E3819	4595.86	0.81	+75	...
E3824	4596.85	0.87	−27	...
E3830	4597.86	0.97	+129	−70
E3839	4599.86	0.03	+44	...
E3844	4643.72	0.36	+266	−198
E3845	4644.66	0.41	+265	−78
E3848	4645.84	0.47	+151	+14
F1842	4649.66	0.67	−8	−19
F1847	4651.58	0.77	+31	−4
E3870	4653.81	0.89	−96	+42
E3872	4654.69	0.94	+73	+76
E3877	4655.59	0.99	+128	−73
E3882	4656.68	0.04	+187	−61
E3886	4657.64	0.10	+275	−73
E3890	4658.65	0.15	+315	−132
E3895	4659.67	0.20	+292	−236
E3899	4660.67	0.26	+323	−245
E3903	4661.69	0.31	+270	−52
E4022	4739.58	0.45	+74	−265
E4027	4740.57	0.50	+140	−75
E4032	4741.55	0.55	+60	+88
E4046	4744.53	0.71	−162	+34
E4052	4745.55	0.77	−163	−42
E4807	5012.71	0.96	−60	−176
E4812	5013.74	0.02	+162	−162
E4817	5014.73	0.07	+182	−137
E4824	5015.78	0.12	+262	−20
E4829	5016.76	0.18	+302	−92
E4834	5017.76	0.23	+422	−161
F2104	5041.61	0.50	+212	−203
E4838	5067.61	0.88	+25	+66
E4839	5067.71	0.88	+42	−11
E4843	5068.58	0.94	+3	−43
E4845	5068.72	0.94	+122	−69
E4850	5069.62	0.99	+152	−126
E4855	5070.57	0.04	+176	...
E4857	5070.80	0.05	+205	−152
E4862	5071.64	0.09	+261	−51

[a] Based on E_0 = 2,444,260.66, P = 18.82.
[b] λ_0 = 4441.03 Å.

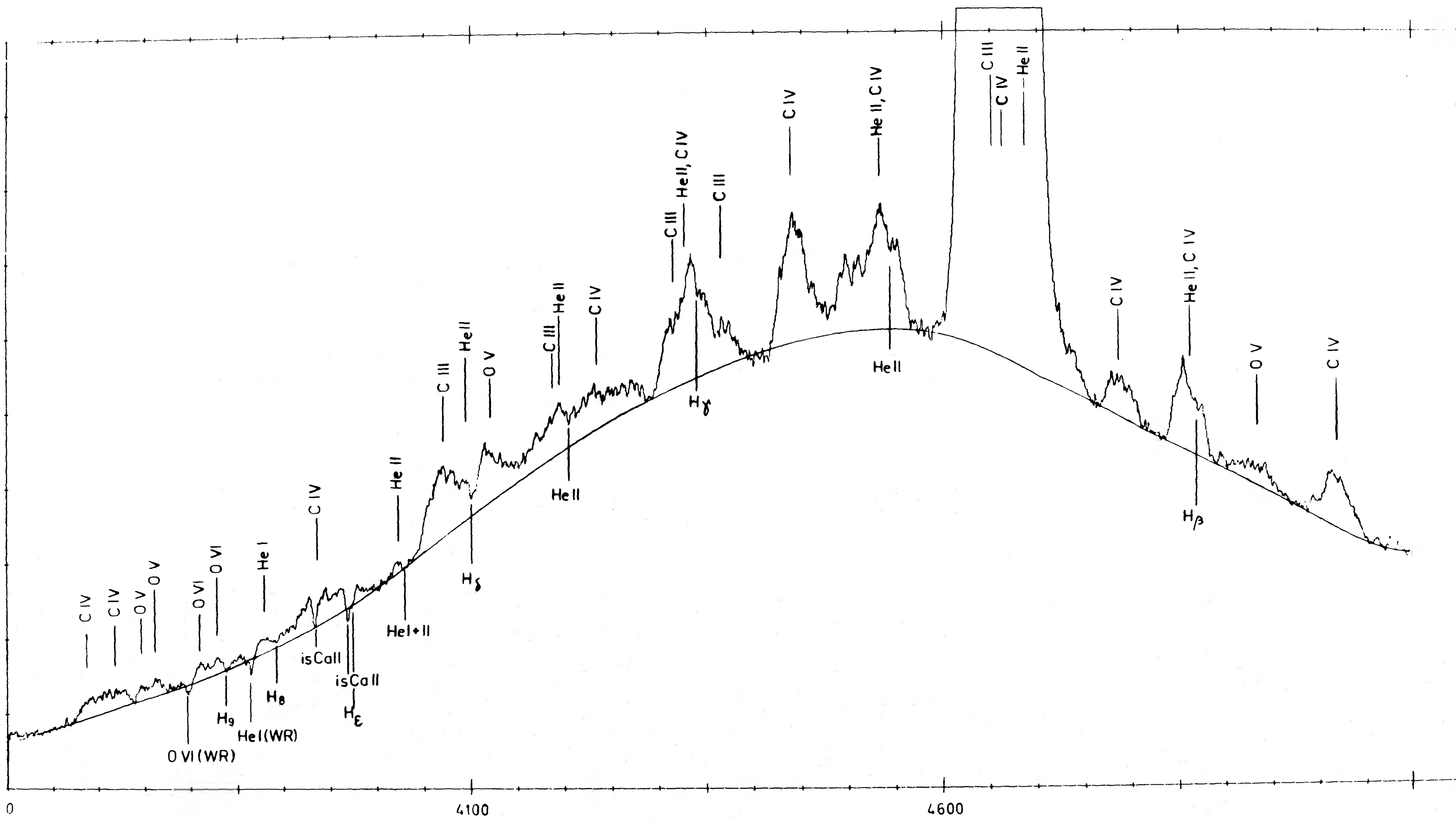

FIG. 1.—Intensity tracings of blue (Fig. 1*a*) and red (Fig. 1*b*) optical spectra of HD 94305, obtained with the Kitt Peak PDS microphotometer. Emissions are identified above, and absorptions below, the continuum.

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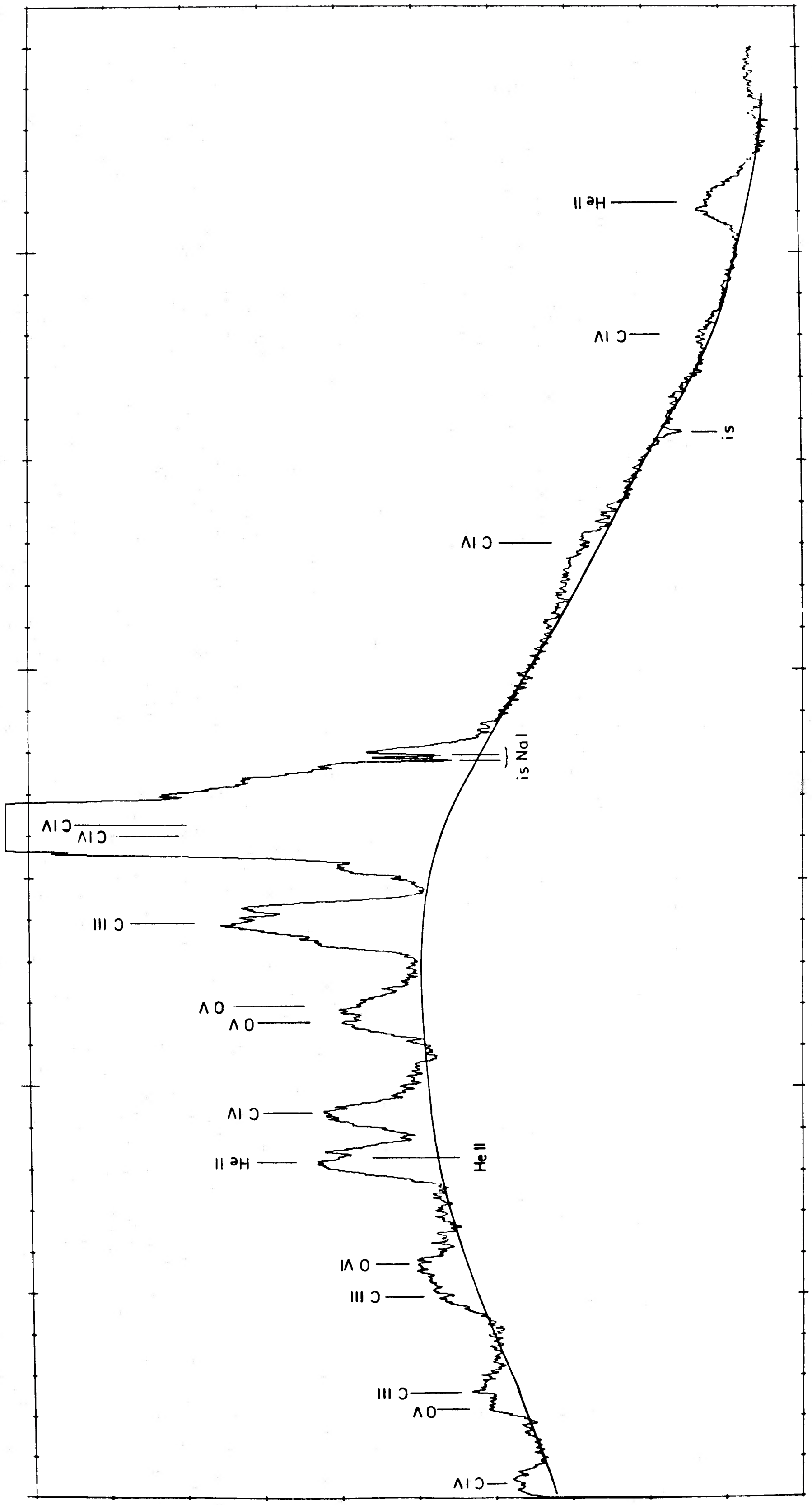

FIG. 1b

III. THE SPECTRUM

The spectrum of HD 94305 is not dominated by the O type companion, but by the emissions of the WC6 star, as can be seen in Figure 1. The usual emission lines of C III, C IV, He II, O V, and O VI are seen in the Wolf-Rayet spectrum. The O VI 3811, 3834 Å emission lines are not particularly prominent in our spectrograms compared to other galactic WC stars. The heliocentric radial velocity of the violet-shifted absorption edge of He I 3888 Å is about -1800 km s^{-1}.

The lines of the OB companion in the spectrum of HD 94305 appear as faint, shallow absorptions; therefore, the spectral type is difficult to determine. Obviously, the absorption spectrum corresponds to an O type star, since the He II 4200, 4541, and 5411 Å lines are present. The He I 4471 Å absorption is seen only on a few spectra. Most absorption lines are situated on the wings of emission lines and are therefore difficult to detect. The He I 5875 Å absorption is faintly present in one of the red spectra, whereas the He II 5411 Å absorption is seen in all of them. Thus the O star seems to be approximately of spectral type O6–8, probably of low luminosity class, since Si IV absorption is not seen in our spectra.

IV. THE BINARY ORBIT

As is obvious from Table 1, the Hδ absorption line and the C IV 4441 Å emission line show radial velocity variations in antiphase. The other emission lines move like C IV 4441 Å, but their velocities appear noisier due to (*a*) line blends or (*b*) variable line shapes, or both.

Other Balmer and He II absorption lines could also be measured, but not reliably in all spectrograms. Their radial velocities generally follow the variations of Hδ absorption, but the values are more uncertain and therefore were not included in Table 1. In particular, the Hγ absorption is badly distorted by the underlying emission.

A period search program with the Lafler and Kinman (1965) algorithm was applied to the data of Table 1. The best period we found is $18^{d}.82 \pm 0.01$. All other possible periods have considerably lower probabilities, and all possible periods longer than 30^{d} show multiple waves.

The alias periods (all $< 1^{d}.1$) can be virtually ruled out since they yield orbital separations $a \sin i$ which are smaller than the radius of the O star for reasonable values of i (see § V).

Figure 2 shows the observations plotted in phase using the 18,82 day ephemeris. Within the observational errors, the orbit is circular. The orbital parameters listed in Table 2 are derived from the best fit sinusoids for the C IV emission and the Hδ absorption lines.

V. DISCUSSION

HD 94305 appears to be a relatively massive binary system. The minimum masses resemble those found for the γ_2 Vel WC8+O9I binary (Niemela and Sahade 1980). The mass ratio $M_{WR}/M_O = 0.47 \pm 0.07$ for the HD 94305 system is similar to the other galactic WC+O binaries, but more than twice as large as the M_{WR}/M_O mass ratio of the WC+O binaries in the LMC/SMC (Moffat 1981, 1982*b*). We note, however, that the LMC/SMC binaries are all of earlier spectral types, mostly WC5+O. The only galactic WC5+O binary, namely HD 63099, may also have a lower mass ratio, similar to the LMC/SMC binaries (Niemela 1981).

The high minimum masses that we find for the HD 94305 system lend further support to the idea that the later WC stars tend to have higher masses than the

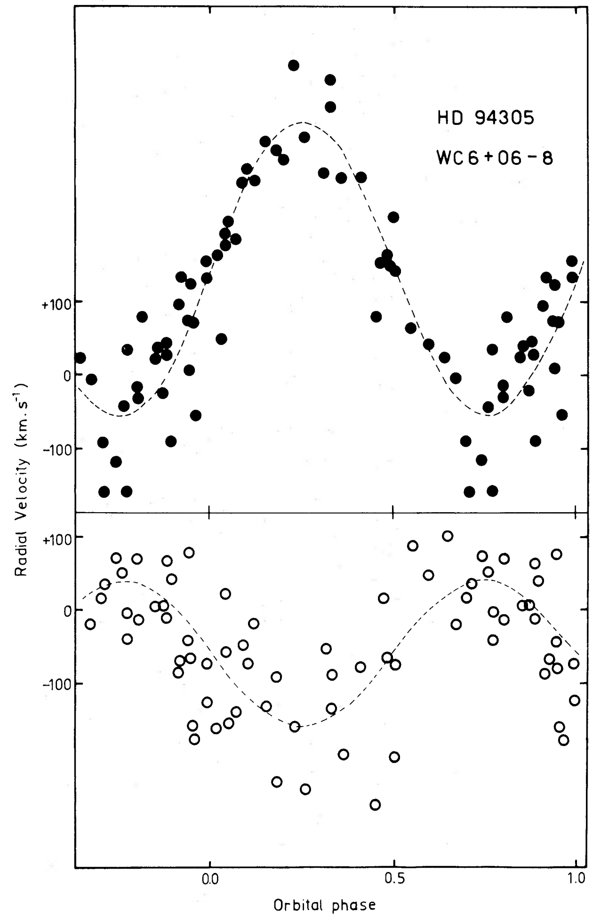

FIG. 2.—Radial velocity variations of the C IV λ4441 emission and Hδ absorption lines in the spectrum of HD 94305 plotted in the period of $18^{d}82$. The dashed curves represent the orbital motion defined by parameters of Table 2.

TABLE 2

ORBITAL PARAMETERS OF HD 94305

Parameter	C IV em.	Hδ abs.
Period (d)	18.82 ± 0.01	
e	0.0 (assumed)	
K (km s^{-1})	195 ± 11	94 ± 12
V_0 (km s^{-1})	+138 ± 7	−62 ± 7
E_0 − JD 2,440,000	4260.66 ± 0.1	4251.26 ± 0.1
σ (O-C) (km s^{-1})	38	46
$a \sin i$ ($R_\odot$)	73 ± 4	35 ± 4
$M \sin^3 i$ ($M_\odot$)	15 ± 3	32 ± 5
M(W-R)/M(O)	0.47 ± 0.07	

early type WN stars, and therefore the evolution of WNE stars to late-type WC stars seems improbable (Niemela 1981; Massey and Niemela 1981). This does not, however, exclude the possibility of evolution from late-type WN to WC, or WNE to early WC as in fact is claimed by Moffat (1981, 1982*b*). It is interesting to note, that the minimum mass of the WC6 component in HD 94305 falls close to the maximum theoretically stable mass of a He star, namely 16 $M_{\odot}$ (Noels and Masereel 1982). The minimum mass of the O6–8 component found in the present analysis agrees with the mass expected for its spectral type, if the inclination of the system is not lower than about 65°.

HD 94305 is the first well-established double-lined spectroscopic binary system with a WC6 type component. Although the θ Muscae system also contains a WC6 star, there the absorption lines of the O9I type star do not follow the orbital motion dictated by the WC6 star and thus probably arise in a third star; the companion orbiting with the Wolf-Rayet component remains undetected (Moffat and Seggewiss 1977). It is worth noting the great similarity between the C IV emission-line orbits of θ Muscae and HD 94305; also the periods are quite similar (θ Mus: $18^{d}3$).

Hidayat, Supelli, and van der Hucht (1982) give a distance of 8 kpc for HD 94305 on the basis of its spectrum and photometric parameters. At this distance the center-of-mass LSR velocity due to galactic rotation should be about +10 km s^{-1}. We can conclude little in this respect from the γ velocities quoted in Table 2, because the negative systemic velocity from the Hδ absorption line is most likely due to a spurious shift caused by the influence of the sloping blue flank of the O V 4120 Å emission as in the WC7+O7 binary HD 97152 (Davies, Moffat, and Niemela 1981). On the other hand, the C IV 4441 Å emission is a blend, and we have used the mean wavelength of 4441.03 Å for this line. Adopting the wavelength of the strongest component would yield a center-of-mass velocity of +99 km s^{-1} (relative to the LSR), also far from what is expected from the galactic rotation at the distance of 8 kpc from the Sun in the direction of $l = 290°$.

The heliocentric radial velocity of the interstellar Ca II K line in the spectrum of HD 94305 is quite negative, −23 km s^{-1}. This may indicate that the strongest K Ca II component is formed in an expanding circumstellar shell. The velocities of the interstellar Na I D1 and D2 lines were measured in the red F plates, and they yield a mean heliocentric value of +14 km s^{-1}. This is in agreement with the distance of 8 kpc for HD 94305. The equivalent width of the Na I lines, namely 1630 mÅ, is also consistent with a large distance (see Fig. 7 in Hobbs 1974).

At 8 kpc from the Sun, the galactic latitude of HD 94305, $b = -2.61°$, implies a distance of 365 pc below the galactic plane. This is considerably higher than the distances of other WR+O binaries from the galactic plane, and indeed more like the high-z values for some of the WR+compact candidate binary systems (Moffat 1982*a*). This may imply that not all high-z WR stars necessarily have compact companions, although the most spectacular cases appear to (Isserstedt, Moffat, and Niemela 1983).

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