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THE WN4 + O8V SPECTROSCOPIC BINARY HD 94546

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RESUMEN

Presentamos nuevas observaciones del sistema binario espectroscópico HD 94546 y redeterminamos sus parámetros orbitales. HD 9456 estâ compuesta por una estrella WN4 y una O8V con masas mínimas m_{WR} sen^{3}i $\sim$ 3 $M_\odot$ y m_0 sen^{3}i $\sim$6 $M_\odot$.

ABSTRACT

We present new observations of the spectroscopic binary system HD 94546 and determine improved orbital parameters. HD 94546 is composed by a WN4 star and an O8V star with minimum masses m_{WR} sen^{3}i $\sim$ 3 $M_\odot$ and m_0 sen^{3}i $\sim$ 6 $M_\odot$.

Key words: STARS-BINARIES — STARS-INDIVIDUAL — STARS-WOLF-RAYET

I. INTRODUCTION

HD 94546 (MR31) is a double-lined spectroscopic binary in Carina, containing an O type star and a Wolf-Rayet star of the early WN sequence. A preliminary orbit has been published by Niemela (1980).

Recently many papers have discussed the evolution of massive stars with mass loss and especially the role of WR stars in stellar evolution. The masses of WR stars are one of the fundamental parameters necessary for a comparison with theoretical evolutionary tracks.

Information about the masses of WR stars has been improving, e.g., Massey (1982) and Niemela (1983) have recently reviewed the masses of WR stars as estimated from the studies of spectroscopic binaries with this type of components. We know that not all WR stars have similar masses and that the range in masses is fairly large. Whether there is some kind of correlation between the spectral subtype of WR stars and their masses (as suggested by Moffat 1981) is not yet clear with the data available at present.

HD 94546 is, therefore, a good candidate to obtain more information about the masses of WR stars. In this paper we report new spectrographic observations of HD 94546 and present an improved orbital solution.

II. OBSERVATIONS

This new study is based on 79 blue spectrograms obtained at the Cerro Tololo Inter-American Observatory, Chile, between January 1980 and March 1984 with the Cassegrain spectrograph equipped with an image-tube attached to the 1-m Yale telescope. The spectrograms have a dispersion of 45 A mm^{-1} on III a-J emulsion baked in 'forming gas'. The plates were developed in D-19 together with the corresponding spot sensitometer intensity calibration plates.

All lines visible in the spectrograms were measured for the determination of radial velocities with the Grant oscilloscope comparator-microphotometer at the Instituto de Astronomía y Física del Espacio (*IAFE*), Buenos Aires. Also, intensity tracings were made for some of the spectrograms.

The spectral data are summarized in Table 1, where we list the average radial velocities of the N V λ4603 and λ4619 emission lines, the individual radial velocities of the N IV λ4057 and He II λ4686 emission lines and the average radial velocities of the absorption lines of the O8 component. In this last case the number between brackets indicate how many lines were included in each mean value.

III. THE SPECTRUM

Spectroscopically, HD 94546 resembles the WN4 + O4-6 binary system HD 90657 = MR23 (Niemela and

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TABLE 1

HELIOCENTRIC RADIAL VELOCITIES OF HD 94546 (km s^{-1})

Plate	JD 2440000+	Mean N V$_{em}$	N IV$_{em}$ 4057	He II$_{em}$ 4686	Mean Abs.	Ca II[a]
C-4741	3141.777	-113	-43	18	27(7)	-14
C-5020	3911.808	190	-20	124	-97(7)	-14
E-2568	3913.734	-144	-	-103	60(6)	-27
E-2572	3914.694	-117	-	-25	24(4)	5
E-2573	3914.795	-118	-217	-48	12(6)	2
E-2577	3915.783	115	96	160	-108(6)	-34
E-2579	3916.650	178	170	139	-105(7)	-20
E-2583	3917.675	-21	-182	-171	-45(6)	-10
E-2587	3918.713	-200	-221	-219	48(6)	-20
E-2591	3919.734	-87	-102	60	4(9)	-3
E-2594	3920.667	112	-38	230	-78(7)	-4
E-3342	4265.764	-42	-128	-167	12(9)	-14
E-3343	4265.868	-65	-164	-210	38(8)	12
E-3346	4266.801	-155	-116	-152	30(5)	-20
E-3348	4267.830	40	-8	183	-59(5)	22
E-3351	4269.682	169	134	68	-155(7)	-25
E-3352	4269.826	123	40	5	-126(9)	-7
E-3354	4270.701	-63	-204	-228	29(8)	-4
E-3357	4271.695	-143	-246	-135	23(6)	-12
E-3359	4271.857	-70	-196	-132	44(6)	-25
E-3361	4272.677	2	-54	166	32(7)	-33
E-3362	4272.770	38	-225	171	-51(7)	7
E-3363	4272.846	32	-19	137	-73(8)	-14
E-3365	4273.767	209	103	209	-113(9)	-17
E-3368	4274.751	65	50	-8	-59(9)	-20
E-3369	4274.827	95	7	-7	-45(10)	-10
E-3372	4275.793	-82	-252	-253	51(8)	-6
E-3375	4276.679	-148	-165	-83	-24(7)	-21
E-3376	4276.745	-127	-76	-88	34(7)	-17
E-3377	4276.818	-121	-228	-56	37(7)	-4
E-3381	4277.748	91	74	256	-44(7)	-41
E-3382	4277.839	63	6	247	-76(8)	-34
E-3533	4387.565	-133	-253	-90	88(9)	-2
E-3539	4388.536	40	40	115	-44(8)	-16
E-3545	4390.587	111	4	17	-70(8)	-12
E-3842	4642.801	-101	-272	-180	-3(10)	-35
E-3843	4643.663	-161	-118	-138	25(8)	-27
E-3846	4644.699	59	4	20	-61(9)	-8
E-3847	4645.690	200	252	263	-124(10)	-38
E-3849	4646.633	149	84	25	-64(8)	-14
E-3869	4653.701	-127	0	-23	7(9)	-12
E-3873	4654.721	143	148	240	-103(8)	-69
E-3877	4655.638	149	41	205	-131(8)	-32
E-3881	4656.583	98	20	-33	-54(7)	-48
E-3886	4657.666	-117	-19	-174	17(9)	-18
E-3888	4657.835	-136	-95	-160	55(7)	-18
E-3891	4658.722	-40	26	-54	-11(8)	-21
E-3894	4659.642	141	114	196	-98(11)	-28
E-3898	4660.645	189	189	173	-105(8)	-48
E-3902	4661.638	24	-43	-135	-30(8)	-21
E-4022	4739.608	-207	-189	-223	49(9)	1
E-4027	4740.590	-169	-99	-104	48(8)	27
E-4032	4741.577	60	160	165	-110(11)	-2
E-4046	4744.549	-165	-130	-226	33(10)	-8
E-4053	4745.577	-181	-213	-34	15(9)	-39
E-4807	5012.728	192	121	198	-85(11)	-29
E-4812	5013.751	175	28	111	-55(7)	-11
E-4818	5014.826	-83	-106	-130	-1(9)	-2
E-4824	5015.770	-122	-175	-106	21(7)	-25
E-4829	5016.792	110	48	202	-93(11)	-35
E-4834	5017.773	194	201	220	-132(7)	-28
E-4838	5067.620	-8	-125	-77	-24(10)	-32
E-4850	5069.645	25	2	69	-71(8)	-34
E-4857	5070.673	204	180	236	-140(10)	-42

TABLE 1 (CONTINUED)

Plate	JD 2440000+	Mean N V_{em}	N IV_{em} 4057	He II_{em} 4686	Mean Abs.	Ca II[a]
E-5275	5384.730	213	160	208	-110(10)	-19
E-5280	5385.763	133	102	87	-80(8)	-50
E-5285	5386.773	-130	45	-148	52(8)	-
E-5290	5387.752	-134	-52	-118	-36(6)	-14
E-5296	5388.738	50	110	79	-62(10)	-23
E-5302	5389.767	162	253	209	-129(8)	-3
E-5307	5390.742	85	136	9	-61(8)	-12
E-5313	5391.746	-164	2	-231	19(6)	9
E-5317	5392.751	-118	-5	-166	-37(5)	-1
E-5321	5393.751	110	230	162	-53(5)	-19
E-5561	5511.507	118	-	69	-70(4)	15
E-5965	5770.789	-	-	-	-64(3)	-
E-5971	5772.820	-39	-	-80	-78(4)	-25
E-5976	5773.764	-124	-112	-140	42(4)	-35
E-5981	5775.646	118	132	202	-89(8)	-7

a. Interstellar Ca II K.

Moffat 1982). Figure 1 shows the intensity tracings corresponding to plates E-3843 in phase $\phi = 0.31$ and E-3847 in phase $\phi = 0.73$. On these tracings we find that the intensities of the N IV and N V emission lines are comparable and that N III appears very faint; this implies a WN4 subtype for the WR component according to Smith's (1968*a*) system, as also indicated in the catalogue of galactic WR stars (van der Hucht *et al.* 1981). For the O star, the intensity of He I λ4471 absorption, as compared with He II λ4541, indicates a spectral type O8, slightly later than reported in the catalogue just mentioned.

Furthermore, on top of the WN emission at λ4686 there appears an absorption of He II, belonging to the O star, which we have measured on several spectrograms. Thus, the luminosity class of the O component would be V.

IV. THE ORBIT

Adding the data obtained from these new observations to the eleven original ones (Niemela 1980), we applied a period search routine (Marraco and Muzzio 1980) independently to the emission and absorption line velocities, which revealed that in all cases the most probable period is P = (4.831 ± 0.003)d, in good agreement with the previous determination. Figures 2*a-d* show the observed and calculated radial velocities plotted in this

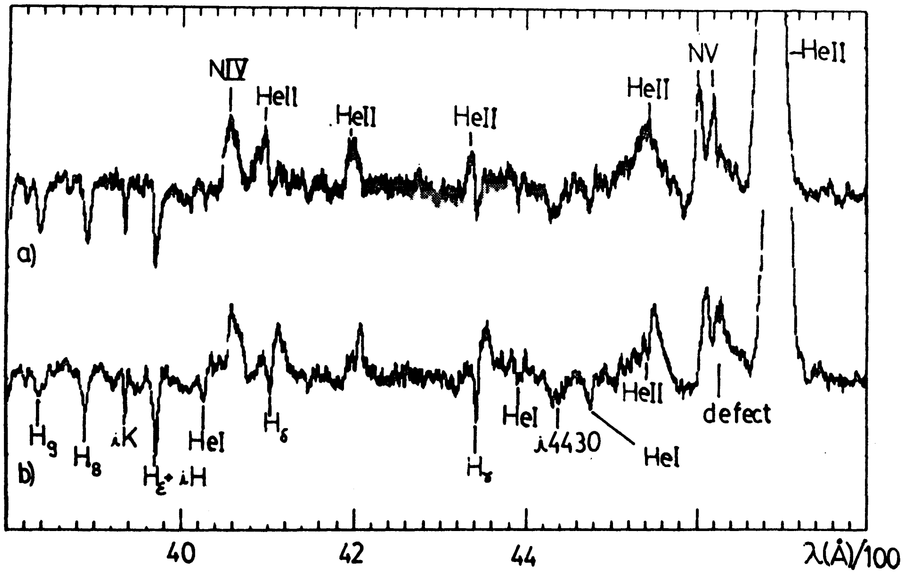

Fig. 1. (*a*) Rectified intensity tracing of the spectrum of HD 94546 corresponding to plate E-3843 at orbital phase 0.31. (*b*) The same as (*a*) for plate E-3847 at orbital phase 0.73. In these figures, emissions are identified above and absorptions below the rectified continuum.

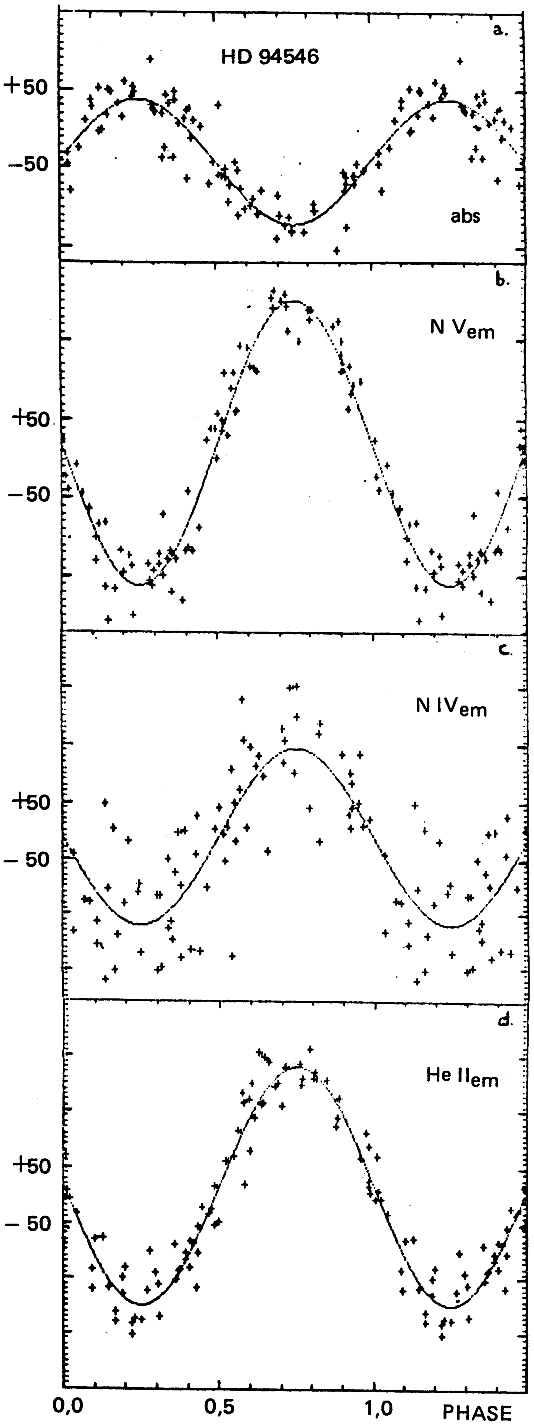

Fig. 2. (*a*) The radial velocity variation of the average of the absorptions as a function of the orbital phase. The dashed curve is the theoretical radial velocity curve as defined by the orbital elements in Table 2. (*b*) The same as (*a*) for the average of the emission of N V. (*c*) The same as (*a*) for the emission line of N IV λ4057. (*d*) The same as (*a*) for the emission line of He II λ4686.

period; the theoretical radial velocity curves were obtained assuming an eccentricity e = 0 for all lines, since the best defined curves, i.e., those obtained from N V λλ4603 + 4619 and from the absorption lines, appear sinusoidal.

The orbital elements for our circular solution are listed in Table 2 with their corresponding standard errors. It is evident, from this table, that all the emission lines have different amplitudes, while no phase-shift appears to be present since the adopted T_0's are the same (within errors) for all lines. The higher amplitude for the He II emission line velocity curve may be due to the influence of the absorption from the O star which shifts the center of the emission on quadratures. The orbit as defined by N IV λ4057 shows the largest scatter and the lowest amplitude (see Figure 2 and Table 2). This scatter is probably due to the fact that this emission appears very wide in all spectrograms and shows a complicated structure (see Figure 1), being therefore, very difficult to measure.

Bearing in mind the preceding discussion, we adopt the orbital solution for the N V emission lines as the one that most closely corresponds to the true orbit of the WN4 star. The values for the minimum masses of both components, $m_{WR}\ \mathrm{sen}^3 i \sim 3\ M_\odot$ and $m_0\ \mathrm{sen}^3 i \sim 6\ M_\odot$ (Table 2), are quite low, probably indicating a small orbital inclination. These results have already been mentioned by Niemela (1983). Notice that our values for the minimum masses of both components are lower than the ones reported by Niemela (1980). Obviously, the new values have to be preferred. The earlier results were based on a few spectrograms and, besides, three extremely negative radial velocity values for the WN4 component in that paper have been found to be erroneous.

According to Moffat and Isserstedt (1980) and Smith (1968*b*) the distance for HD 94546 would be 5.25 kpc, so it would be located beyond the Carina OB association. With this distance we obtain a heliocentric radial velocity from circular galactic rotation (Schmidt 1965) of $v_{GR} = -9$ km s^{-1}. We note (Table 2) that the systemic velocity, as determined from the radial velocities of the O star absorption lines, is considerably blueshifted with respect to v_{GR}. The same is also true for other O stars in the same direction in the sky, as for example HD 90657 (Niemela and Moffat 1982) and HD 94305 (Niemela, Méndez, and Moffat 1983), also binary systems, and the single O stars HD 93028 and HD 96264 (Conti, Leep, and Lorre 1977). Since these stars are not Of, to attribute these negative velocities to expanding photospheres does not seem to be plausible.

The systemic velocity of the N IV λ4057 emission in HD 94546 is nearly identical to v_{GR}, but we consider this value not very reliable due to the large scatter shown by the radial velocities of this emission line. The systemic velocities for the other emission lines are redshifted. This is known to occur in other WN stars as well, e.g., HD 193576 (Münch 1950), HDE 311884 = MR42

TABLE 2

ORBITAL ELEMENTS OF HD 94546

Element	Mean Abs	Mean NV_{em}	N IV $\lambda 4057_{em}$	He II $\lambda 4686_{em}$
V_0 (km s^{-1})	– 41 ± 3	21 ± 5	– 11 ± 10	17 ± 6
K (km s^{-1})	80 ± 4	181 ± 7	158 ± 15	215 ± 9
T_0 (JD 2440000+	5381.3 ± 0.3	5381.4 ± 0.3	5381.8 ± 0.5	5381.0 ± 0.4
r sen i ($R_\odot$)	7.6 ± 0.4	17.2 ± 0.7	15 ± 1	20.4 ± 0.9
σ (km s^{-1})	18	20	56	27
M_{WR} $sen^3 i$ ($M_\odot$)		2.7 ± 0.4	2.3 ± 0.5	3.5 ± 0.4
M_O $sen^\circ i$ ($M_\odot$)		6.3 ± 0.4	5 ± 1	9.4 ± 0.7

Notes: P = 4.831 d (fixed); e = 0 (assumed); T_0 is the moment when the O star is closest to the observer; σ is the rms scatter about the computed curves.

(Niemela, Conti, and Massey 1980) and HD 90657 (Niemela and Moffat 1982). Although this redshift was explained by Auer and Van Blerkom (1972) as the result of photon dispersion by free electrons, it is perhaps too early to say whether this is the predominant effect or whether there exist other effects in the atmospheres of these stars that produce the same result (e.g., undetected P-Cygni profiles, as discussed for example by Münch (1950).

V. CONCLUSIONS

From new spectroscopic data we have derived improved orbital parameters for the WN4 + O8 binary HD 94546. The minimum masses found for both stars are rather low, since the classical value for early WN stars is ∿9 $M_\odot$ (Massey 1982; Niemela 1983) and for O8 stars is ∿ 17 $M_\odot$ (Popper 1980). Therefore, we expect a small orbital inclination. If we assume that the mass of the O8 star is 17 $M_\odot$ we obtain i = 46°, and 7 $M_\odot$ for the mass of the WN4 star, not far from the "classical" value.

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