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The He II Line λ4686 in WN Binaries

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Abstract. The behaviour of the λ4686 line of He II in various WN binaries is studied for variations in total flux as well as radial velocities. It appears that the true motion of the WN component is not depicted by this line especially for short-period binaries. A qualitative explanation is sought in terms of a large, extended line-emitting region and multiple-component line profile.

Key words: stars, emission-line—stars, binaries—stars, WN-type

1. Introduction

The λ4686 line of He II is one of the brightest lines in WR spectra and, therefore, is used as an identifying feature in low-dispersion emission-line surveys. It is the strongest line in the spectra of the WN sub-group in the visible and UV region.

Out of the twenty binaries listed in the catalogue of van der Hucht *et al.* (1981), sixteen have WN components while remaining four have WC components. A more recent list by Hidayat, Admiranto & van der Hucht (1984) includes also the low-mass-function systems and puts the total number to about 35, of which 25 have WN components. The variations in line profiles with orbital phase, have been studied in great detail by Sahade (1958) for many of these binaries. Here we have chosen the binaries with well-determined radial-velocity variations (Table 1) in order to study the effect of the companion on the λ4686 line-emitting region. The study has been restricted to binaries with WN components, because in the WC sub-group this line is blended with the red wing of the stronger line of C III λ4650.

A preliminary report of this study is already published (Shylaja 1986c).

2. Observational data

From a study of WNL systems, it has been shown by Moffat & Seggewiss (1979) that the motion of the WN component in these binaries is best represented by the N IV line at λ4058. This assumption has been extended to all binaries studied here, so that the differences in the behaviour of He II λ4686 line relative to N IV λ4058 can be interpreted as a consequence of the differences in the dynamics of line-emitting regions. For WNE systems N V λ4603 is a better choice and whenever the observations of this line are available, they have been used to decide the anomalous behaviour of λ4686.

Table 1. WN binaries from Hidayat, Admiranto & van der Hucht (1984).

WR No.	Name/HD	Sp. type	P(d)	λ4686 K	λ4686 γ	λ4058 K	λ4058 γ	log P	R_K	$\Delta\gamma$*	Reference[†]
155	CQ Cep	WN 7+07	1.64	134	165	297	−53	0.22	2.22	218	Stickland *et al.* 1984
	HD 214419			148	118	313	−61		2.12	179	Bappu & Viswanadham 1977
				165	137	295	−75		1.79	212	Hiltner 1944
						285	−85				Niemela 1980
				181	77	310	−60		1.71	137	Leung, Moffat & Seggewiss 1983
123	HD 177230	WN 8	1.76	17	—	22	—	0.25	1.29	P	Lamontagne, Moffat & Seggewiss 1983
151	CX Cep	WN 5+O8V	2.13	300	—	300	—	0.33	—	—	Massey & Conti 1981
138	HD 193077	WN 6+abs	2.32?	36	69	28	−92	0.34	0.78	161	Lamontagne *et al.* 1982
124	209 BAC	WN 8	2.36	12.7	190	—	—	0.37	—	?	Moffat, Lamontagne & Seggewiss 1982
6	HD 50896	WN 5	3.76	25	147	—	—	0.58	—	P	Firmani *et al.* 1980
43	HD 97950	WN 6+abs.	3.77	72	12	—	—	0.58	~1	46	Moffat & Niemela 1984
128	HD 187282	WN 4	3.85	~20	~130	—	—	0.59	—	P	Antokhin, Aslanov & Cherepashchuk 1982b
40	HD 96548	WN 8	4.16	—	—	—	—	0.62	—	P	Moffat & Isserstedt 1980
139	HD 193576	WN 5+O6	4.21	283	16	303	−42	0.62	1.07	58	Ganesh, Bappu & Natarajan 1967
	V 444 Cyg										
148	HD 197406	WN 7	4.32	57	−95	82	−126	0.63	1.44	31	Bracher 1979
				~60	~−100	90	−143		1.5	43	Moffat & Seggewiss 1980
				49	−94	86	−134		1.76	40	Drissen *et al.* 1986

136	HD 192163	WN 6	4.5?	13.6	64.9	32.7	−183.4	0.65	2.40	248	Aslanov & Cherepashchuk 1981
31	HD 94546	WN 4+O7	4.9	—	—	290	−130	0.69	—	—	
47	HD E311884	WN 6+O5V	6.34	310	−10	297	−89	0.80	0.96	79	Niemela, Conti & Massey 1980
153	HD 211853	WN 6+O	6.69?	220	15	155	−120	0.83	0.70	135	Ganesh & Bappu 1967
134	HD 191765	WN 6	7.44	20	~85	—	—	0.87	—	P	Antokhin, Aslanov & Cherepashchuk 1982a
71	HD 143414	WN 6	7.69	29	−150	18	−260	0.89	0.62	110	Isserstedt, Moffat & Niemela 1983
21	HD 90657	WN 4	8.2	246	20	221	−33	0.92	0.90	153	Niemela & Moffat 1982
97	HDE 320102	WN 3+O5.7	8.83	—	—	150	0	0.95	—	—	Niemela 1982
127	HD 186943	WN 4+O9.5V	9.56	212	107	167	70	0.98	0.79	37	Ganesh & Bappu 1967
				146	239	—	—	—	—	P	Massey 1981
16	HD 86161	WN 8	10.73	—	—	4.7	−23	1.03	—	P	Moffat & Niemela 1982
141	HD 193928	WN 6	21.64	147	60	135	−64	1.34	0.92	124	Ganesh & Bappu 1967
145	AS 422	WN+WC	22	—	—	—	—	1.34	—	—	Pesch, Hiltner & Brandt 1960
12	CD−45°4482	WN 7	23.9	—	—	130	−34	1.38	~1	P	Niemela 1982
22	HD 92740	WN 7+abs	80.35	~80	—	~70	—	1.91	~0.88	P	Moffat & Seggewiss 1978
133	HD 190918	WN 4.5 +O9.5Ia	112.8	—	—	—	—	2.05	—	—	Hidayat, Admiranto & van der Hucht 1984

* 'P' in this column implies the red shift of $\Delta\gamma$ noticeable in the figures or tables in the corresponding reference, but not necessarily as orbital solutions.

† References correspond to information on R_K and $\Delta\gamma$.

Although hydrogen deficiency is an established phenomenon in some WR stars (Sahade 1980), Balmer lines in absorption have been detected in some binaries and single-line stars. Therefore, it is difficult to estimate the contribution of the companion to some lines like λ6562, λ4860, λ4340, λ4100 etc. Therefore, although in general these lines are considered as due to He II, they cannot be compared with λ4686.

2.1 *Variations in Total Flux*

The flux of λ4686 and λ4058 lines, obtained for two systems CQ Cep ($P = 1.64$ d) and HD 50896 ($P = 3.76$ d) as a function of orbital phase, is shown in Fig. 1 (from Shylaja 1986a and b). It may be seen that the flux of λ4686 shows an increase near phases 0.0 and 0.5 corresponding to the eclipse and transit of the components. Although the flux of λ4686 in HD 50896 has considerable scatter, the increase in flux at phase 0.0 is noticeable (Shylaja 1986b). In the case of CQ Cep, not only the N IV λ4058 line, but all the other lines of He II such as λ4860, λ5411 and λ6562, showed a similar behaviour. This was attributed to the complicated structure of the extended atmosphere, arising as a consequence of the proximity of the companion. In the case of HD 50896, the N IV line

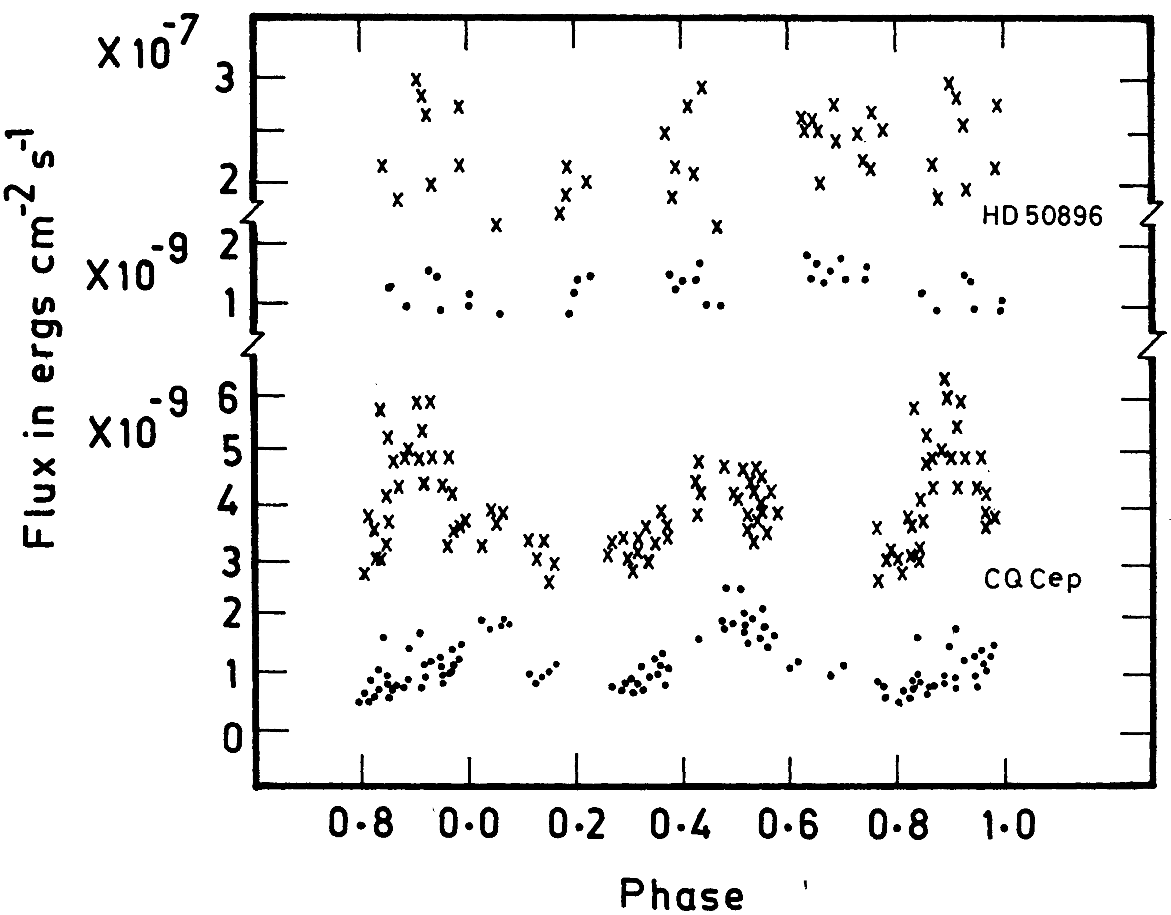

Figure 1. Fluxes of He II λ4686 (crosses) and N IV λ4058 (dots) for two short-period binaries from Shylaja (1986a, b).

at λ4058 and the other lines of He II, like λ4860, λ5411, λ6562 *etc.* show a scatter in flux, and again the behaviour of λ4686 is different. The flux measures of other binaries are not available as yet. However, the line profiles of HD 186943 (Ganesh, Bappu & Natarajan 1967) show a large variation from quadratures to conjunctions. It may be inferred that the flux (the total flux measured in absolute quantities and not relating to a normalized continuum) increases at eclipse and transit. In the case of V444 Cyg (Kuhi 1968) the O-type companion is larger and more massive than the WN component unlike the case of CQ Cep. Therefore, all the emission lines showed eclipse effects. However, the eclipse depth of λ4686 is markedly different from those of other lines. This may imply that at phases corresponding to the eclipse and transit of components, the total flux of λ4686 increases, compared to any other emission line so that the net effect is to have a smaller eclipse depth as seen by Kuhi (1968). There are some other systems whose observations may also indicate a similar increase of flux. In the case of HD 90657 (P = 8.26 d), a dip in the light curve at λ4680 is observed (Niemela & Moffat 1982) at phase ~0.15, which is attributed to the asymmetric line-emitting region. However, the same curve can also be interpreted as showing an increase in flux at phase 0.5, corresponding to the WN4 component behind the companion. The light variation shown by HD 96548 (Moffat & Isserstedt 1980) is not included here because, only the variations of the continuum are reflected in the λ4686 light curve.

The line profile studies of V444 Cyg have shown that there is a hump superimposed on a smooth profile (Ganesh & Bappu 1967). The movement of this hump was attributed to the contribution from the concentration of line-emitting material between the stars. A similar possibility exists in the case of HD 90657, as mentioned above, where the dip near phase 0.15 may be attributed to reduced contribution from the region between the two stars. In the case of HD 5980 (P = 19.27 d), WN4 + O7 binary in SMC, Breysacher, Moffat & Niemela (1982) have explained the line profile by assuming that a larger amount of material exists near the hemisphere facing the O star.

2.2 *Radial Velocities*

The radial velocity (RV) curves from various sources (Table 1) are reproduced in Fig. 2. The following points are immediately apparent:

1. Considering that the N IV λ4058 represents the true motion of the WN component, *i.e.* the velocity of centre of mass, there is a redshift in γ of He II λ4686 in all cases.
2. The amplitudes of the RV curves $K(4686)$ and $K(4058)$ vary from system to system. The variation of the ratio $R_K = K(4058)/K(4686)$ with orbital period is shown in Fig. 3. For CQ Cep, the shortest orbital period system, R_K is the largest, whereas it becomes unity for systems with orbital period of about 4 d. For still larger orbital periods, the tendency for R_K is to become <1 or remain near unity.
3. The solutions derived from the RV curve of $K(4686)$ generally give eccentric orbits, especially for short-period systems, whereas solutions from other lines are circular.

The table includes almost all the known binaries with WN components (Hidayat, Admiranto & van der Hucht 1984). For HD 177230 the RV curve is not explicitly available for λ4058, but appears as a 'mean emission'. For CX Cep (P = 2.12 d), the amplitude differences of λ4686 and λ4058 RV curves have been discussed by Massey & Conti (1981) and they have assumed $K(4686) = K(4058)$. However, their RV curve appears to exclude the possibility $K(4058) < K(4686)$, while there is a suggestion that $K(4058)$ may be greater than $K(4686)$. From Fig. 3 it would appear that for its orbital period the value of R_K may be about 1.7. This can be established only by a better RV curve of λ4058. For the other short-period binary 209 BAC, the RV curve of λ4058 is not available. In the case of HD 97950 ($P = 3.77$ d), it appears that the amplitudes do not differ greatly (Moffat & Niemela 1984). For HD 311884 (Niemela, Conti & Massey 1980) the RV curve of λ4686 cannot be separated from the mean of all He II velocities. In many other cases λ4058 RV curve is not available.

The redshift of γ for the λ4686 RV curves is a general feature in many systems. In Table 1 the redshift is denoted as $\Delta\gamma = (\gamma(4686) - \gamma(4058))$, whenever both the quantities are available in literature. In many other cases, this redshift is noticeable in the figures

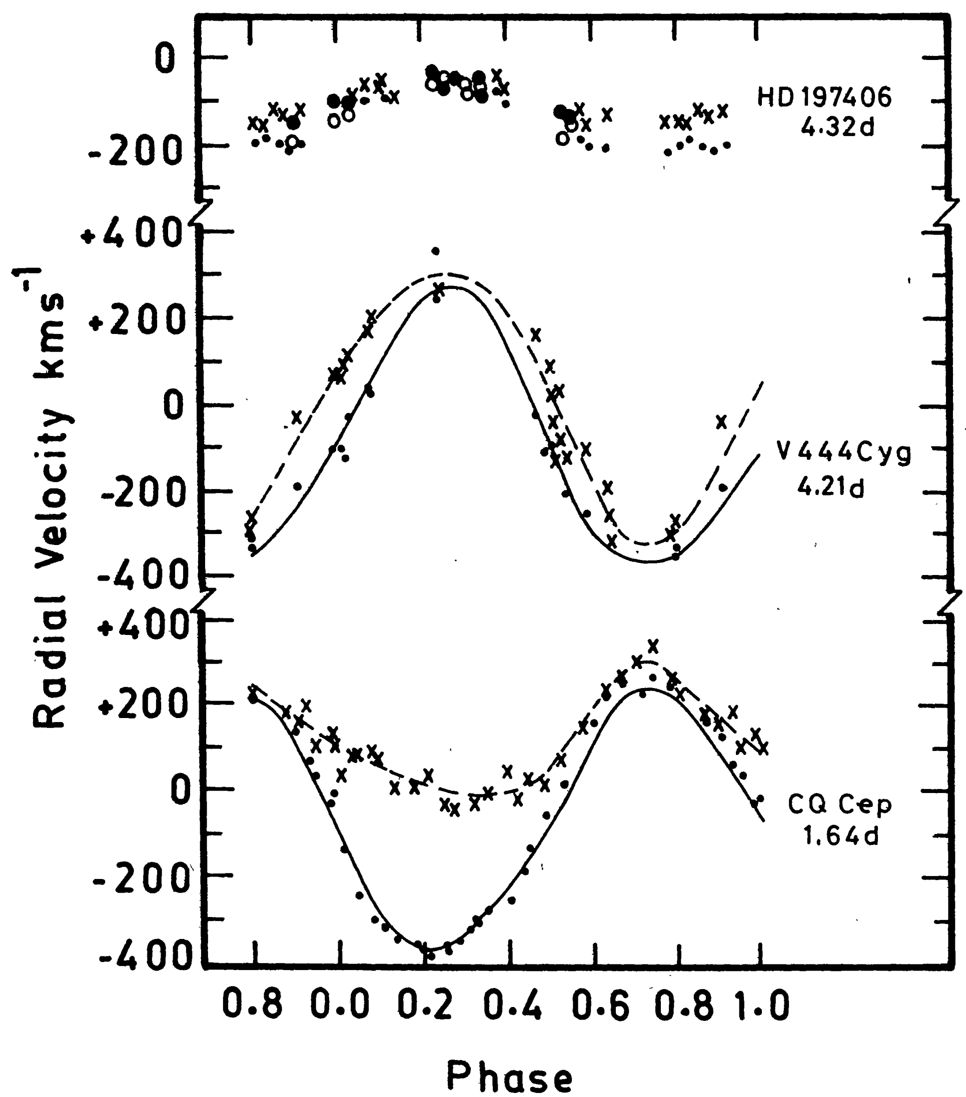

Figure 2. Radial velocity curves of He II λ4686 (crosses) and N IV λ4058 (dots) from various sources indicated in Table 1. The λ4058 points for HD 50896 are from Ebbets (1979). In the case of HD 197406 the observations of Moffat & Seggewiss (1980) are marked by filled (λ4686) and open (λ4058) circles. The curves are hand-drawn for cases where original solutions were not available.

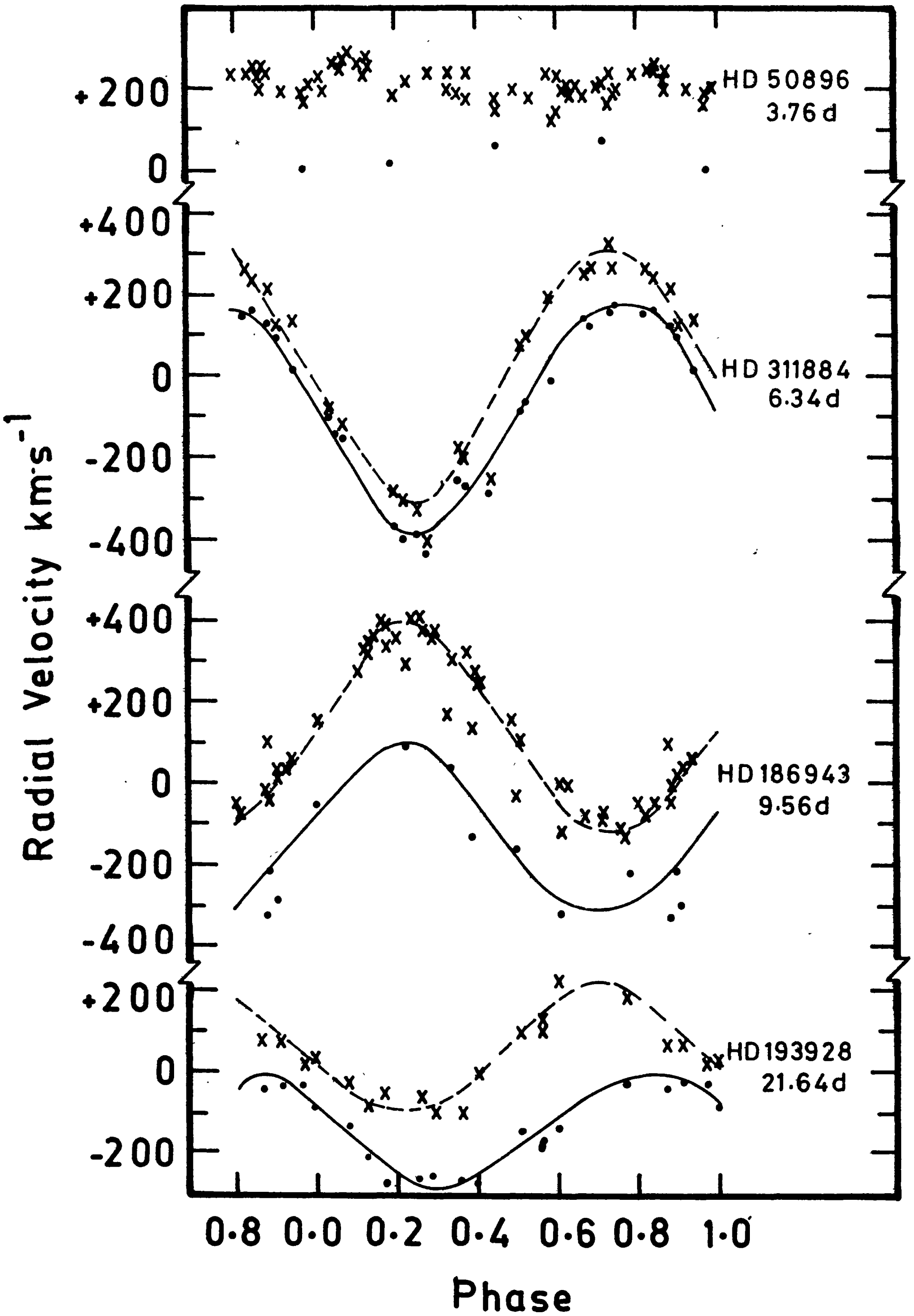

Figure 2. Continued.

and tables provided by the previous investigators, and not necessarily as orbital solutions. These are indicated as 'P' (=present) in the column $\Delta\gamma$. For systems like HD 187282 the redshift is apparent relative to the N v λ4603 RV curve. For HD 191765 the same is true relative to the N III λ4640 RV curve.

3. Discussion

In general, the established companions in many of these binaries are of spectral type O. Therefore, it is possible that there is an absorption superposed on these emission profiles. This implies that such an absorption component may move in an opposite direction so as to indicate the movement of the companion. Attempt made to search for this, revealed that such absorptions are not clearly noticeable. The profiles of the λ4860 line of He II clearly show this type of movement of absorption (Ganesh & Bappu 1967) whereas λ4686 does not show this, although one could think of the double-hump profile being caused by two emissions rather than an absorption. In case of HD 193928 ($P = 21.64$ d), there is an indication of double-hump structure that is not very well separated.

If we postulate a companion of type Of, the contribution to the emission becomes considerable. This has been discussed in the case of HD 5980 by Breysacher, Moffat & Niemela (1982) who consider three contributors to the emission: (1) the WN component, (2) the companion and (3) the region between the two stars. Assuming such a multi-component profile, they are able to analyze the variation of half-intensity widths of this line. At phases 0.0 and 0.5, the contribution from (3) is diminished, causing a decrease in the half-intensity widths.

The observational evidence thus clearly shows that there are additional contributors to λ4686 relative to λ4058. We may consider different possibilities such as (1) the companion itself, (2) the optical depth effects, and (3) asymmetric distribution of material emitting λ4686.

In the case of binaries with Of companions, therefore, it is possible that there is significant contribution to emission from all the three cases listed above. In medium dispersion spectra, because of the large widths of each contribution, the line profile may become significantly blended resulting in an error in fixing the centre of the profile for RV measurements. This can cause a net reduction in the amplitude of the RV curve.

In the case of binaries with compact companions, although the contribution to the line profile from the companion is not significant, the accretion disc can contribute to the total flux. However, not many samples are available for verifying this aspect. HD 197406 ($P = 4.17$ d) fits in Fig. 3 very well, but the contribution from the disc cannot be distinguished in the line profile. The interpretation is complicated because of the recent identity of the companion with a black hole (Drissen *et al.* 1986). In the case of HD 50896, the λ4058 line profile is complicated and, therefore, a comparison is not possible.

The redshift of the γ value of He II λ4686 line relative to N IV λ4058 is a general feature in the case of all WN binaries. This aspect has been discussed by many previous investigators (Sahade 1958 and Ganesh & Bappu 1967). The other He II lines like λ4860 and λ4340 have contributions from the companion either in emission or absorption making it difficult to identify the redshift, even if it is present. The effects of electron scattering in radially expanding envelope was investigated by Auer & van Blerkom (1972), who showed that the velocity field preferentially scatters photons to the red. Thus, electron scattering is mainly responsible for the red wing of the He II profiles and this has been confirmed in HD 50896 (Hillier 1984) by both observations and theoretical modelling. Thus, this effect also makes the profile asymmetric, making it difficult to fix the line centre and hence adding to the systematic errors in the RV estimates.

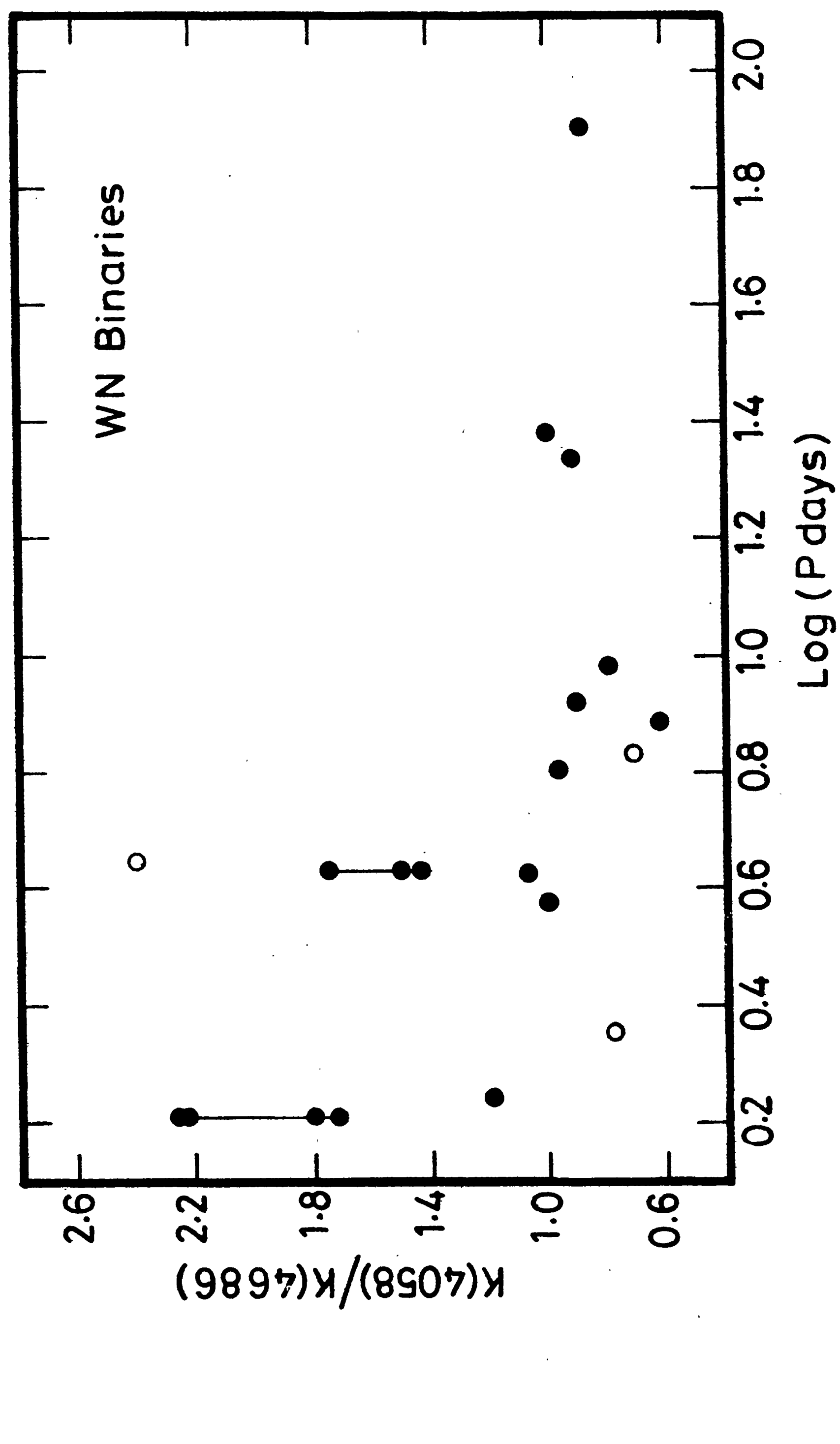

Figure 3. The variation of the ratio, R_K of the amplitudes of RV curves of λ4058 to λ4686 in km s^{-1}, relative to log (orbital period in days). The unfilled circles correspond to the stress cases where the binary nature is questioned (see text).

The effects of the companion and the electron scattering as discussed above are probably common to all WN systems. Therefore, the reduction of the amplitude ratio R_K with orbital period cannot be explained by these two factors.

In Fig. 3, HD 193077, HD 211853 and HD 192163 are indicated by separate symbols. HD 193077 has been identified as a possible triple system (Lamontagne, Moffat & Seggewiss 1983). HD 211853 has been identified with a quadruple system and therefore the λ4686 variation is complicated (Massey 1981). The binary nature of HD 192163 has been debated (Vreux, Andrillat & Gosset). Thus these points suggest that the relation of R_K with orbital period is not linear. It is possible that the binaries with low-mass companions exhibit a different behaviour of λ4686 in comparison to those with OB companions. Therefore, although it is not possible to draw a smooth relation between R_K and $\log P$, it appears that this ratio reaches the value of unity asymptotically for periods longer than 6 days. In many solutions that are used for deriving K, the circular orbit is generally assumed. Hence it is possible that by observing more systems with $P \leqslant 6$ days, a more meaningful relation can be arrived at.

It is known that classical Roche surfaces are not applicable for these binaries with strong winds. The wind-dominant Roche surface calculations have been done by Niemela for V444 Cyg (*cf.* Sahade & Wood 1978) which clearly shows the asymmetry of line-emitting region. It is also known that λ4686 has the largest optical depth amongst all He II lines (Hillier 1983) and, therefore, we see the emission from the outermost parts of the line-emitting region. Such regions are, according to the Roche surface calculations of Niemela, asymmetric and, therefore, the flux variation of λ4686 reflects these distorted locations directly. However, the exact distribution of line-emitting material in such a surface will be decided by the density distribution, the velocity law and also the temperature gradient. A qualitative analysis of the asymmetry can lead to the deduction that short-period systems show more complicated line profiles and larger flux variations. As the separation of the companion from the primary increases (*i.e.* the period becomes longer) the magnitude of this effect is reduced.

Thus, the long-period systems ($P \geqslant 6$ d) may not show an increase of flux and decrease in amplitude of the λ4686 RV curve at phases corresponding to eclipse. It may also be seen from Fig. 3 that only few samples are available with long orbital periods.

We may also consider the effect of an O type or Of type companion on other emission lines as well. N III λ4640 is a possible contributor. However, because these are already 3 unresolved multiplets, the additional contributors cannot be distinguished. In the case of CQ Cep (Shylaja 1986a) it was seen that the behaviour of the N III λ4640 line was also markedly different from other lines. Similar measurements in other systems are not available. The redshift of the line and the reduction of its amplitude are generally noticeable, but any flux variation is not striking for other He II lines (*e.g.* in CQ Cep). It may also be mentioned here that sudden sporadic strengthening of emission lines is reported in many cases. However, it may be noted that when a change in the strength of λ4686 occurs, no corresponding change in λ4860 is seen. This may be caused by one or more of the following: (1) the effect of absorption lines, (2) the small difference in the upper level of excitation, (3) the differences in optical depth effects, (4) the differences in the sizes of the line-emitting regions.

All the lines of He I originate in the outermost regions of the atmosphere (Moffat & Seggewiss 1978) and in many cases do not show phase-dependent variations in flux. The profiles are generally associated with violet absorption edges, whose velocities usually follow the movement of the WN component, although with large scatter. Therefore, the contribution of the companion is difficult to detect.

Thus, it appears that the contribution from the companion in terms of either emission or absorption, to the line profile of λ4686, is partly responsible for the observed difference in the behaviour of this line relative to λ4058. The large optical depth and the asymmetric distribution of line-emitting material in the atmosphere can also cause the observed variation. Since the proximity of the companion is responsible for the distortion of the line-emitting region and, therefore, of the line profiles, the inequality $K(4686) < K(4058)$ may be valid for very-short-period binaries only. This study emphasizes the need for a study of short-period systems like CX Cep and 209 BAC (relatively faint) more thoroughly for flux and RV variations.

4. Conclusions

The behaviour of the λ4686 line in many WN binaries shows a marked difference relative to nitrogen lines, which are deemed to represent the true motion of the WN component. The differences in the variation of total flux and of radial velocities seem to be inter-related. A qualitative analysis using wind-dominant Roche surfaces shows that asymmetric distribution as well as optical depth effects are significant. Similarly, the contribution from the companion will also have to be taken into consideration, in the case of multiple component line profiles. Since the proximity of the companion is responsible for the distortion of the line-emitting region and, therefore, of the line profiles, it is possible that the large flux variation of λ4686 and the inequality $K(4686) < K(4058)$ are valid for short-period systems and this anomaly gradually reduces at a period of about 6 d.

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