WR 134 line-profile variability: preliminary results of the 1994 campaign*

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Abstract: We present preliminary results from a study of the line-profile variability in the spectrum of the Wolf-Rayet star WR 134 based on an observing campaign that took place in 1994. The results are compared with the conclusions drawn from previous campaigns.

1 Introduction

WR 134 (≡ HD 191765) exhibits one of the most variable spectra among the Wolf-Rayet stars in the Cygnus association and could thus be a key object for the understanding of the wind dynamics of this type of star. For this reason, we initiated a detailed analysis of the line-profile variability of WR 134. First results have been presented in Vreux et al. (1992) whose introduction contains a full description of the interest of this kind of study. In that paper, Vreux et al. (1992) critically discuss their original data acquired in 1987 (spectra in the range $\lambda\lambda$3940-4430 Å) in the light of three similar works (McCandliss 1988; Moffat et al. 1988; Underhill et al. 1990). They also further reduced and analyzed some of the data collected by B. Bohannan at Kitt Peak National Observatory (KPNO, see McCandliss 1988). The main results can be summarized as follows. The summits of all the line profiles are variable, exhibiting peaks and dips relative to the mean spectrum. The instantaneous patterns of deformation around the mean profile are quite similar from line to line. Particularly, they are almost identical for all the He II lines; those of N IV λ4058 differ by their larger amplitudes whereas the N III profiles exhibit much smaller variations. Vreux et al. (1992) observed a marked decrease of the variability close to the centre of the lines, a fact also noticed by McCandliss (1988). However, the precise position of this minimum slightly differs for the two data sets.

All searches for periodicities failed but Vreux et al. (1992) report higher power around frequencies $\nu = (n \times 0.5)$ d^{-1}, an unfortunately dubious fact due to inadequate sampling. The presence of this power is in good agreement with the fact that the pattern of deformation brings more similarities with itself from one day to the next but one, than on two consecutive days, a fact also quoted by Robert (1991). Although no clear periodicity can be claimed up to now, several papers report typical time-scales around two days (Lamontagne 1983: 1.78 d; Moffat & Shara 1986: 1.81 d or the alias 2.24 d; Robert 1991: 1.75 d alias of 2.34 d; Antokhin et

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al. 1992a: around 2 d; Eenens 1993: 1.85 d alias of 2.17 d). More recently, McCandliss et al. (1994) revisited previous time-series analyses by McCandliss (1988) and combined the KPNO data with those of Robert (1991). They concluded then to the existence of a periodic behaviour of the spectrum with a period of 2.27 ± 0.04 d.

Some determinism is certainly present in the pattern. Moffat et al. (1988) noticed peaks moving away from the line centre (towards the blue for blueshifted peaks, towards the red for redshifted ones). They attributed these deformations to blobs moving outwards in the wind, a model now endorsed by McCandliss (1992). Although a similar behaviour is often observed by Vreux et al. (1992), they remarked that, at the best, blobs are neither isolated nor at random since, most of the time, the deviation exhibits several more or less regularly spaced features. Vreux et al. (1992) tentatively introduced the idea of nodes in the process of deformation of the mean profile. In addition, a possible anti-correlation between the redshifted and the blueshifted parts of the very central portion of the profile casts further doubts about the pure stochasticity of the process.

Underhill et al. (1990) proposed an alternative model with a rotating wheel-like structure with spokes of plasma radiating He II and other ions whereas the rim is typically radiating He I λ5876. In fact, the particular shape (double peak) of this line is the main motivation at the origin of the above-mentioned model. This interpretation has been questioned by Vreux et al. (1992). In addition, Antokhin et al. (1992b) succeeded in explaining a double-peaked He I line on the basis of a spherically symmetric model involving a clumpy wind. It is also interesting to point out that Vreux et al. (1992) reported a double-peaked aspect for the mean profile of N IV λ4058.

Vreux et al. (1992) concluded that the easiest way to satisfy all the observational constraints was to introduce a bipolar-jet model. Independently, Schulte-Ladbeck et al. (1992) introduced an axisymmetric model to interpret new polarimetric observations. On the basis of depolarization in the lines compared to the continuum, they firmly established the axisymmetry already invoked by Schmidt (1988) and Robert et al. (1989). On the basis of the polarization variability, they concluded to the existence of inhomogeneities in the wind. Recently, Moffat & Marchenko (1993) reported a periodic variability in photometric observations of WR 134. The period was 37.2 ± 0.2 d with an amplitude in the visual amounting to 3 per cent. These results are further confirmed by Marchenko et al. (1996) who detect, on the basis of an extended data set, the same periodicity that they revise to 36.9 ± 0.1 d as well as an additional periodicity of about 614 d. Concerning the 37 day time-scale, they conclude either to LBV-type variations or to a precession in a $P \sim 2$ d binary system. However, they find no trace of a two-day periodicity in their photometric data. In addition, Marchenko et al. (1994) have shown that high-speed periodic variability is entirely lacking in WR 134 (upper limit 2-4 mmag for frequencies in the range 0.01 and 50 Hz, 0.5-0.7 mmag for the 0.0002-0.1 Hz range).

After the above-mentioned 1987 campaign, we organized, in 1991, a second successful campaign dedicated to a slightly different wavelength range ($\lambda\lambda$4230-4650 Å) in order to study other lines and other ionic species (N V, He I). Preliminary results of this campaign have been presented in Gosset et al. (1994) along with some further prospective considerations.

Finally, a third extensive campaign has been successfully organized in 1994. The latter was dedicated to almost the same wavelength range as in 1987, and we present here the preliminary results concerning the data obtained.

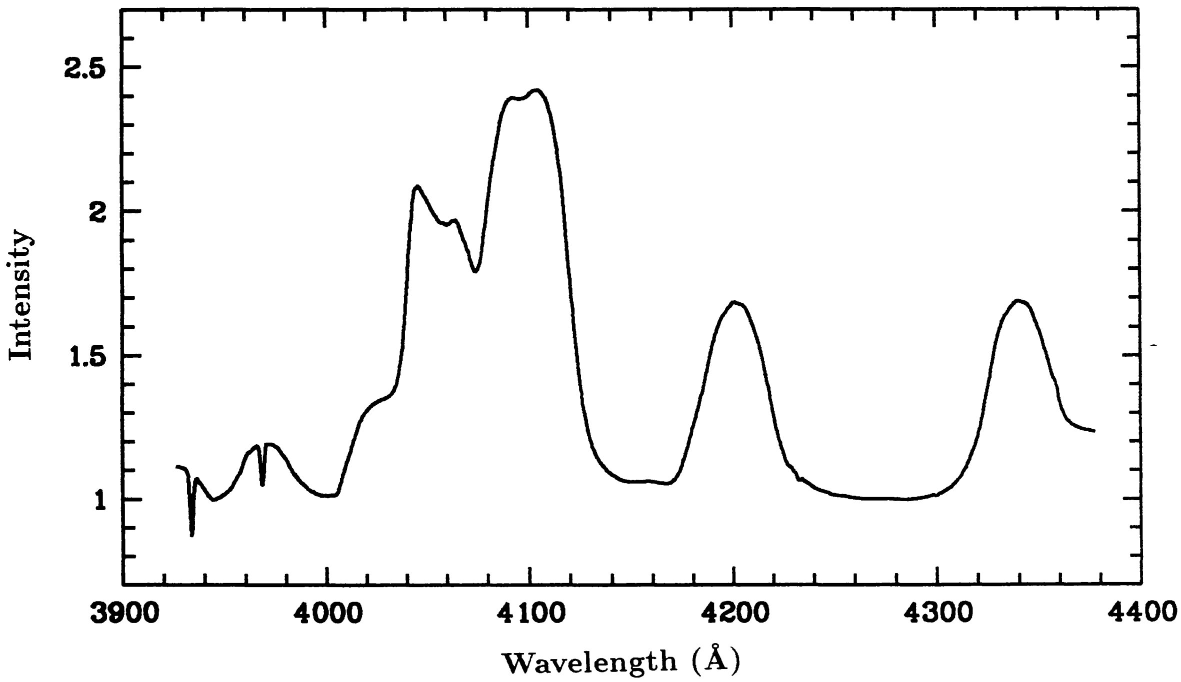

Figure 1: Mean continuum-normalized spectrum of WR 134 as deduced from the 1994 campaign.

2 Observations

The 1994 campaign consisted of joint observations from the Haute Provence Observatory (HPO. J.M. Vreux) and from the San Pedro Mártir Observatory (P.R.J. Eenens) in México. The present paper only deals with the HPO data which have been acquired from August 11 to August 19, 1994, at the 1.93m telescope equipped with the Carelec spectrograph.

Some 124 spectra have been acquired over eight consecutive nights, leading to a one-element time resolution of about 20 minutes; the typical r.m.s. signal-to-noise ratio is about 300 in the continuum. The spectra cover the wavelength range $\lambda\lambda$3926-4380 Å with a reciprocal dispersion of 33 Å mm^{-1}, and have been reduced in the standard way using the ESO software system IHAP as implemented at HPO. The procedure to normalize the spectra to the continuum of the star was very similar to the one described in Vreux et al. (1992); the only exception concerns the selection of the blue continuum window which has been defined in the region around λ3945 Å instead of the one around λ4000 Å.

3 Preliminary results

We present here preliminary results derived from a first inspection of the data and compare them with those of the 1987 campaign (Vreux et al. 1992). Further work will be necessary to confirm and refine these results, as well as to assign them to a detailed physical model. As in Vreux et al. (1992), we computed the mean spectrum over the 124 individual exposures. This mean spectrum is indeed very similar to the 1987 one, except for small differences (less than 2 %) due to the continuum definition; the 1994 mean spectrum is shown in Fig. 1.

In particular, we confirm the double-peaked structure of the mean N IV λ4058 line profile. As before, we used the mean spectrum to divide all the individual 124 spectra and obtain by this way mean-normalized spectra which better show off the deformations of the emission lines. As a secondary product of the whole procedure, we also derived a variation spectrum, i.e. the

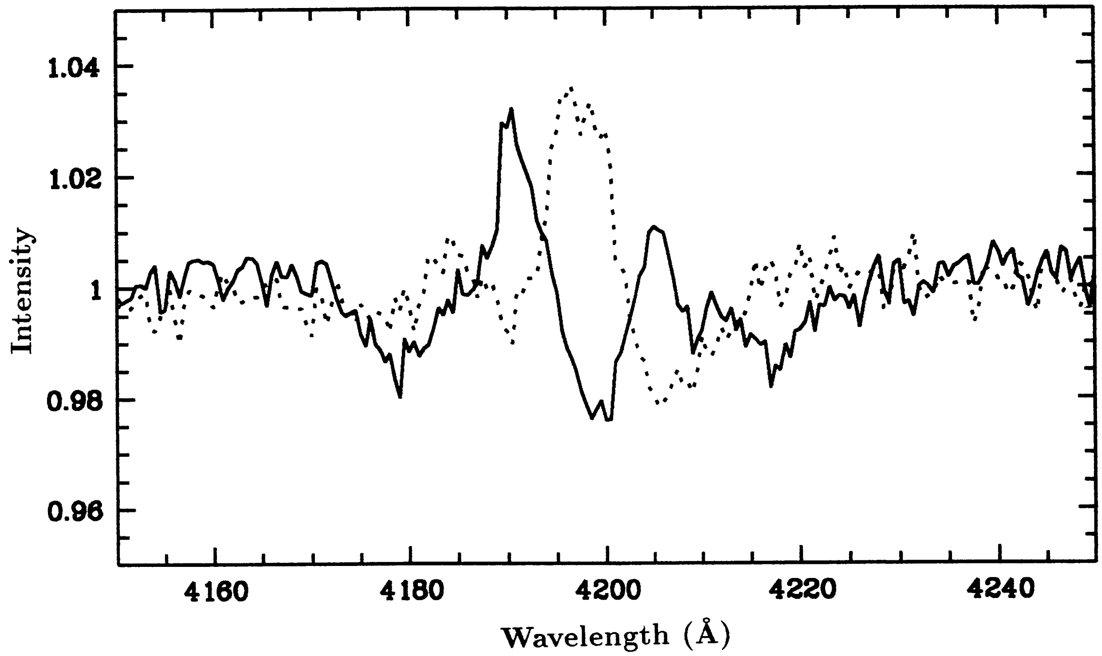

Figure 2: Two examples of mean-normalized spectra in the region of He II λ4200. The continuous line represents a spectrum acquired on the night August 17/18, 1994 whereas the dotted line corresponds to a spectrum acquired during the night August 12/13, 1994. Note the anti-correlation of the two deformation patterns.

run of the standard deviation of the dispersion around the mean spectrum as a function of wavelength. The 1994 variation spectrum is similar to the 1987 one, outlining the variations in the lines with almost the same amplitude. However, a marked difference exists in the sense that the dip in variability close to the centre of the lines, as seen in the HPO and KPNO data of 1987 (Vreux et al. 1992) and in the HPO data of 1991 (Gosset et al. 1994), is not similarly present in 1994.

At first glance, the 1994 deformation patterns of the emission lines are quite reminiscent of what has been previously observed. In particular, pairs of correlated or anti-correlated patterns can be easily found (see Fig. 2). Also, the similarity between the deformation patterns in the He II lines and in the N IV λ4058 line is still persisting, as illustrated by one typical case in Fig. 3.

In the HPO data analyzed by Vreux et al. (1992), we suspected variability in the far blue wing of the He II λ4026 line. As the continuum window used for the 1987 normalization was very close to this region, these data were not fully adapted to answer this question. Therefore, the alternative window used here is an additional counter-check of our procedure. Fig. 4 shows two selected spectra confirming the existence of variability in what looks like a weak absorption component of a P-Cygni profile for the He II λ4026 line. We would like to draw the reader's attention on the very good coincidence of the two spectra outside the variable regions; this gives an idea of the accuracy of our process of continuum normalization.

The pixel by pixel power spectra of the data have been computed in the same way as in Vreux et al. (1992). Beside the lines, the power spectra are rather typical of noise and exhibit only little power. The power is much larger in the lines and two behaviours can be discerned. In the regions of the centre of the emission lines, several peaks are present in the power spectra and it is very difficult to extract one frequency candidate for a periodicity. The envelope of the power spectrum seems to decrease from $\nu = 0.0$ d^{-1} to $\nu = 2.5$ d^{-1}. This behaviour is quite

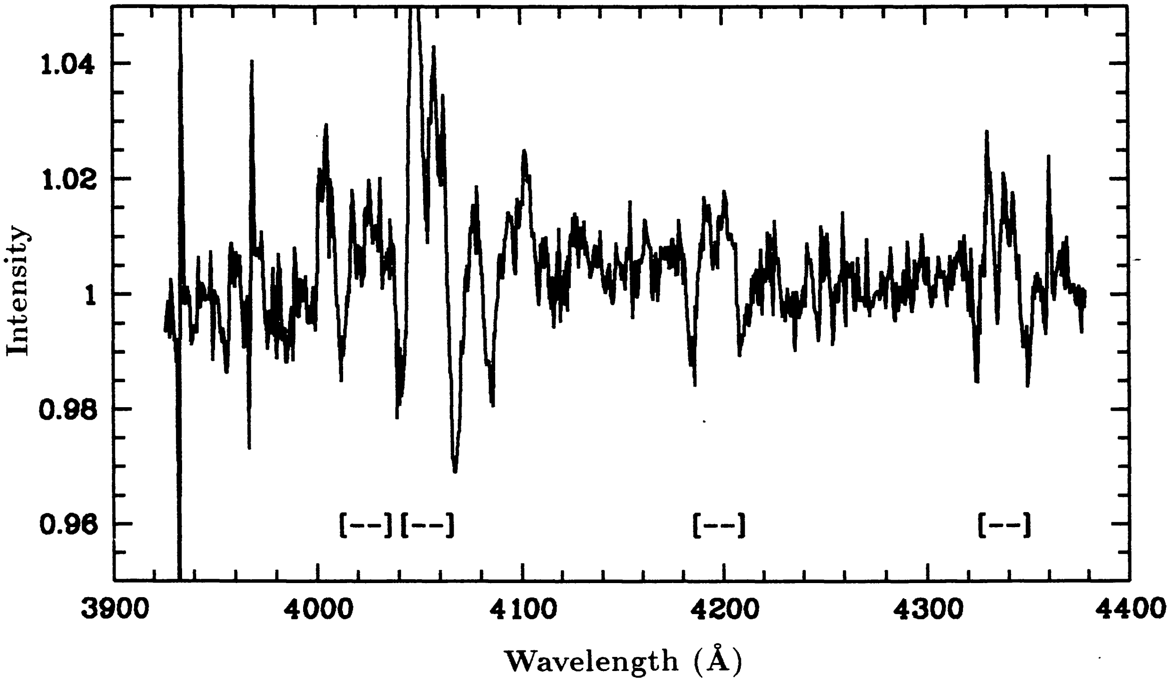

Figure 3: Example of a mean-normalized spectrum. Note the similarity between the deformation patterns of the N IV λ4058 line and of the He II lines (λ4339, λ4200, λ4026).

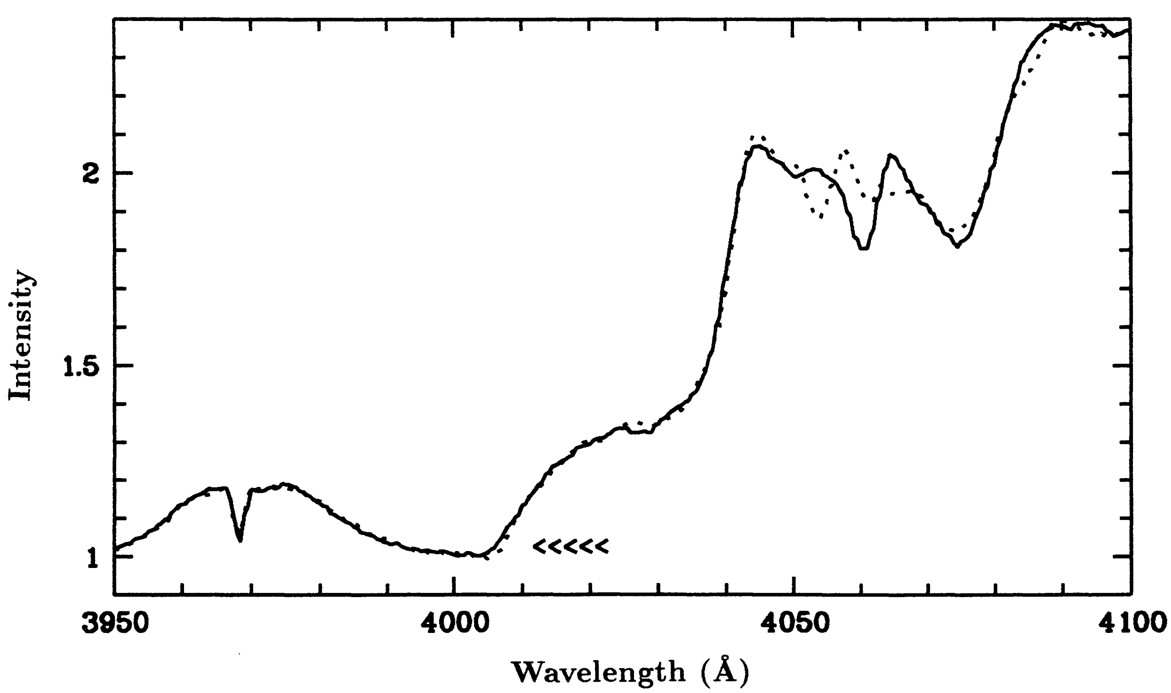

Figure 4: Example of two selected spectra that illustrate the variability in the far blue wing of the He II λ4026 profile. An arrow indicates the zone of interest.

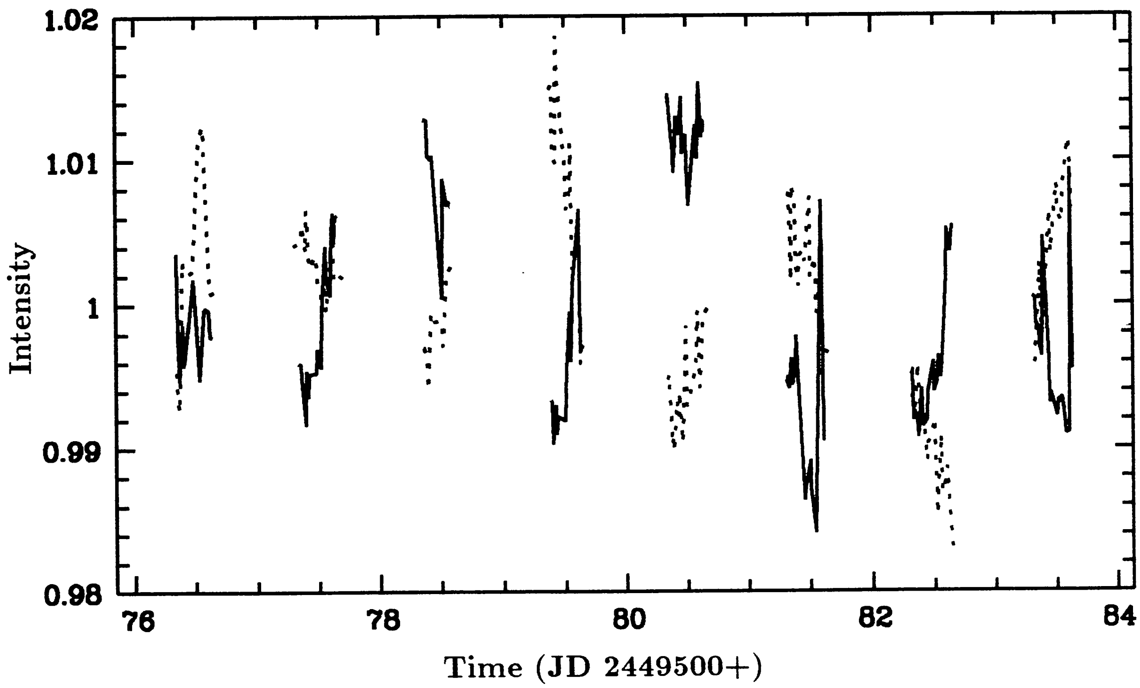

Figure 5: Run of I_b (continuous line) and of I_r (dotted line) as a function of the Julian date (see text).

reminiscent of a random although correlated process. The case of the far wings of the lines is quite different: at these wavelengths, the power spectra exhibit powers intermediate between those in the line centre and those in the continuum. These power spectra are dominated by rather large peaks situated near frequencies $\nu = n \times 0.5$ d^{-1} with n being odd. The width of the peaks could indicate that they are blended one-day aliases at frequencies $\nu = (n \times 0.5 - \epsilon)$ d^{-1} and $\nu = (n \times 0.5 + \epsilon)$ d^{-1}, where ϵ is a comparatively small value. To illustrate this idea, we have computed the mean intensity of two regions located respectively in the blue and the red wings of the He II λ4200 line, namely I_b in the wavelength range $\lambda\lambda$4173-4178 and I_r in the wavelength range $\lambda\lambda$4220-4225. A plot of both I's as a function of time is given in Fig. 5. It seems that they vary with time-scales compatible with the frequencies around $\nu = n \times 0.5$ d^{-1} (n being odd) as detected in the power spectra. The anti-correlation between both I's could indicate a global motion of the emission line. For the moment, it remains however unclear whether this effect is related or not to the changes seen in the centres of the lines. Although this effect is not clear enough to be considered as a definite proof, it raises again the problem of a typical time-scale around two days (or the one-day aliases) mentioned by several authors. However, the associated frequencies are in a region where spurious effects are quite common.

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