PHOTOELECTRIC SPECTROPHOTOMETRY OF WOLF-RAYET STARS

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(Received

(NASA-CR-140743) PHOTOELECTRIC SPECTROPHOTOMETRY OF WOLF-RAYET STARS (Northwestern Univ.) 15 p HC $3.25 CSCL 03A
N75-11810
Unclas
G3/89 53835

ABSTRACT

Photoelectric spectrum scans of 5 Southern Wolf-Rayet stars in the spectral range λλ 4600-4720 were analyzed to study the variability of brightness and of emission line strengths. No variations of any kind in short time scale were found. However, in WC stars night-to-night variations of 3 to 4 percent were detected in the emission line strengths.

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I. INTRODUCTION

There is enough evidence to indicate that variations in line intensities and profiles occur in the spectra of Wolf-Rayet stars (Kuhi 1968). The exact time scale of these variations is not yet known precisely, but among the binary W stars the changes appear to be related to the orbital period. The changes are also observed in non-binary W stars; in these cases the changes appear to be similar to those found by Oke (1954) among Of stars. Brucato (1971) found variations in the strengths of emission lines of Of stars with a time scale on the order of 10 minutes. Thus, one might expect that the emission lines of W stars may exhibit similar rapid variations. Sanyal, Weller, and Jeffers (1974) have in fact found a 154-second periodic change in the region around He II λ4686 for γ^2 Velorum. Other recent studies have reported variations in the spectra of W stars (Irvine and Irvine 1973; Moffat and Haupt 1974; Wood, Schneider, and Austin 1974).

The present investigation is an attempt to detect rapid variations in emission line strengths of the brightest southern Wolf-Rayet stars. Observations were made on γ^2 Vel as well. However, the results found for this star were quite unique, and because of the interest generated by the observations of Sanyal et al. (1974) and Wood et al (1974), they will be discussed in a separate paper at a later date.

2. OBSERVATIONS

Observational material was obtained with a two-channel low-resolution photoelectric spectrum scanner at the Cassegrain focus of the 92-cm reflector of the Cerro Tololo Inter-American Observatory in March 1973. Two circular entrance apertures of 18 arc-sec in diameter and separated by 2.6 arc-min were used to record simultaneously the spectral intensities of the star plus sky and sky alone. Each scan consists of integrated signal counts at every 4 A with an exit slit width of 10 A in the region λλ4600 - 4720 A. This spectral region was chosen so that the strongest emission lines in the visual region, He II λ4686 and C III - IV λ4650 in WC stars or N III λ4640 in WN stars, could be measured.

Each program star was observed continuously for about two hours, so that a series of spectrum scans of the same star was obtained in which each scan was separated by an equal time interval. During this time, an off-set guider was used to insure a proper positioning of the star at the center of the aperture. In every case, an attempt was made to accumulate signal counts of approximately 10^4 in the continuum level.

In order to evaluate reproducibility and the stability of data, four standard stars were observed during the course of each night. These stars were observed in the same manner as the W stars, except for the fact that for each program star, a standard star was observed once before and once afterward. Inspection of the data on standard stars shows that shifts in the mean levels of the spectra between two sets, before and after, are for the most part less than one percent: only on two occasions the shifts were greater at 1.2 and 1.6 percent. After removing these small shifts, two scans of each standard star on each night were compared at each corresponding spectral element. The r.m.s. deviations were found to be always less than one percent, in the range of 0.5 to 0.8 percent. It is concluded that the instrumental system was extremely stable, and that the sky conditions were of excellent photometric quality. The accuracy obtainable is, therefore, essentially limited by the photon-counting statistics. Pertinent parameters of observations on 5 W stars and 4 standard stars are given in Table 1.

3. RESULTS AND DISCUSSION

(a). Mean scans

For each night, individual scans were combined to form a single mean scan for each star observed. After the sky contribution (from the second channel) was removed, the observed signal counts at each spectral element were combined without further correction. The resulting mean scans were then rectified and normalized. The continuum level near 4720 A was generally 2 to 3 percent higher than that near 4600 A. The rectification was carried out by assuming a linear increase of the intensity in the continuum with wavelength over this interval. The scans were than normalized to this continuum level. The resulting mean scans are shown in Figures 1-5. Dependence of the relative strengths of emission lines of C and N class is clearly seen. Also the difference between WC6 and WC7 is clearly indicated. There appear to be some changes in the spectra between successive nights, particulary among WC stars, which will be discussed in a later section.

(b). Variations in brightness

From each set of observations "integrated magnitude", m, for each scan was computed as follows:

$$m = 2.5 \log [\Sigma F_o(\lambda) / F(\lambda)] \quad (1)$$

where $F(\lambda)$ is the actual observed signal count at each wavelength point, with the subscript o referring to the mean scan. Then the r.m.s. variations of m were computed for each set. In order to remove effects of atmospheric extinction, linear and quadratic trends were removed and the r.m.s. recomputed. In all cases, the results remained essentially unchanged. Because of the short base line in wavelength and the fact that in all cases the stars were observed near the meridian, the extinction effect is negligible. The r.m.s. variations in brightness are shown in Table 2. They are all very small. This result reinforces the conclusion reached with regard to observations of standard stars that the observing conditions were extremely stable and that the uncertainty is essentially due to the photon-counting statistics. It is concluded that these stars do not exhibit any brightness variations in a time scale of a few minutes to about two hours. Since these analyses are confined to sets of contiguous observations only, and since no attempt was made to establish actual magnitude scale, no conclusions can be drawn with respect to the possible night to night variations in brightness.

(c). Variations in emission line strenghts

Equivalent widths of emission lines were computed from each scan to study possible variations of emission strength. In the case of WC stars, C III-IV λ4650 and He II 4686 overlap so much that the separation of the two can not be made. For these stars, the total equivalent width, W(λ4650 + λ4686), was obtained. For WN stars, there is still some overlap between N III λ4640 and He II λ4686, but a well defined minimum is present at about 4665 A. W(λ4640) and W(λ4686) were computed separately by using the data points only up to this minimum point from each side.

The result is a series of equivalent widths as a function of time spaced at equal interval of time. Since a number of contiguous scans in each set is rather small, no attempt was made to utilize a power spectrum analysis to detect possible periodic variations. Instead the r.m.s. variations were computed for each set of equivalent widths. In order to assess whether these r.m.s. values represent real variations, or due to the observational errors, theoretical r.m.s. values were computed by assuming the photon counting statistics alone. The procedure for calculating the theoretical r.m.s. values, σ_{phot}, is essentially the same as that used by Williams, Frantz, and Breger (1974).

The results are summarized in Table 3. In all cases, σ_{obs} is greater than σ_{phot}, but never more than a factor 2. Williams et al (1974) also find that such is the case in their study of peculiar A stars. Since no other source of errors other than the photon statistics is allowed in these calculations, this is not surprising. If σ_{obs} were substantially larger than σ_{phot}, by say a factor or 4 or more given the quality of the data on hand, it may be inferred that there are real variations. It is concluded, therefore, that there is no short-term variability of emission strengths in these stars.

The inspection of the mean equivalent widths, however, shows that night to night variations may exist in some cases. For WC stars there appears to be a very strong indication that this is the case. The r.m.s. variations of mean equivalent widths from night to night are at least twice as large as σ_{obs} for a single night, 4 percent for HD 113904, and 3 percent for HD 152270. Among WN stars, they are always equal to or less than σ_{obs} for a single night. That there may be some variations from night to night are present in the WC stars, can be seen from the Figures 1 and 2.

It so happens that among the brightest W stars chosen for this study, all the WC stars are known binaries, while all the WN stars, as far as is known at present, are non-binaries. With this small sample, it is of course dangerous to generalize and draw a conclusion that the binaries show variations of this sort while singles do not. Moffat and Haupt (1974) have found some long-term variability over a three-hour interval in He II λ4686 emission strength for HD 93131 which is a single WN star. The problem thus requires further observations of more stars and of longer durations.

I wish to express my deep gratitude to the staff of Cerro Tololo Inter-American Observatory for their hospitality and valuable assistance during my visit to Chile. This research was supported in part by a NASA grant (NGR 14-007-122).

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Table 1. Parameters of Observations

HD NO.	(1) Sp. Ty.	m_V	(2) t(sec)	(3) ΔT(min)	Number of Scans each night, 1973 (UT) Mar. 22	Mar. 23	Mar. 24	Mar. 25	Mar. 26
68324	B3 V	5.40	4						
92749	WN 7	6.41	8	5.02	22	-	22	-	20
92938	B3 V	4.80	4						
93131	WN 7	6.7	8	5.02	-	21	-	21	-
113902	B8 V	5.70	4						
113904	WC6 + O9.5I	5.50	4	2.85	28	33	38	42	35
128345	B5 V	4.04	2						
151932	WN 7	6.45	8	5.02	22	-	22	-	22
152270	WC7 + O5-8	6.61	8	5.02	-	15	-	22	-

(1) Spectral Classisfication of W-R stars from Smith (1968)

(2) Net integration time per spectral element.

(3) Time interval between successive scans.

Table 2. Brightness Variations in W stars

HD NO.	R.M.S. magnitued Variations				
	Mar. 22	Mar. 23	Mar. 24	Mar. 25	Mar. 26
92740	0.003	—	0.003	—	0.003
93131	—	0.003	—	0.002	—
113904	0.004	0.007	0.002	0.006	0.007
151932	0.004	—	0.005	—	0.003
152270	—	0.004	—	0.003	—

Table 3. Emission Strength Variations in W stars

WC stars	W(λ4650+λ4686)		
	$\bar{W}$(A)	σ_{obs}(%)	σ_{phot}(%)
HD 113904			
Mar. 22	-42.9	2	1
Mar. 23	-43.1	2	1
Mar. 24	-40.5	2	1
Mar. 25	-40.6	2	1
Mar. 26	-38.9	2	1
HD 152270			
Mar. 23	-222.	1	0.5
Mar. 25	-233.	1	0.5

WN stars	W(λ4640)			W(λ4686)		
	$\bar{W}$(A)	σ_{obs}(%)	σ_{phot}(%)	$\bar{W}$(A)	σ_{obs}(%)	σ_{phot}(%)
HD 92740						
Mar. 22	-10.9	4	2	-22.4	2	1
Mar. 24	-10.9	4	2	-22.6	2	1
Mar. 26	-11.7	4	2	-22.7	2	1
HD 93131						
Mar. 23	- 9.4	4	3	-26.7	2	1
Mar. 25	- 9.7	4	3	-26.7	2	1
HD 151932						
Mar. 22	-20.3	3	2	-38.6	2	1
Mar. 24	-19.3	3	2	-37.7	2	1
Mar. 26	-19.1	3	2	-38.4	2	1

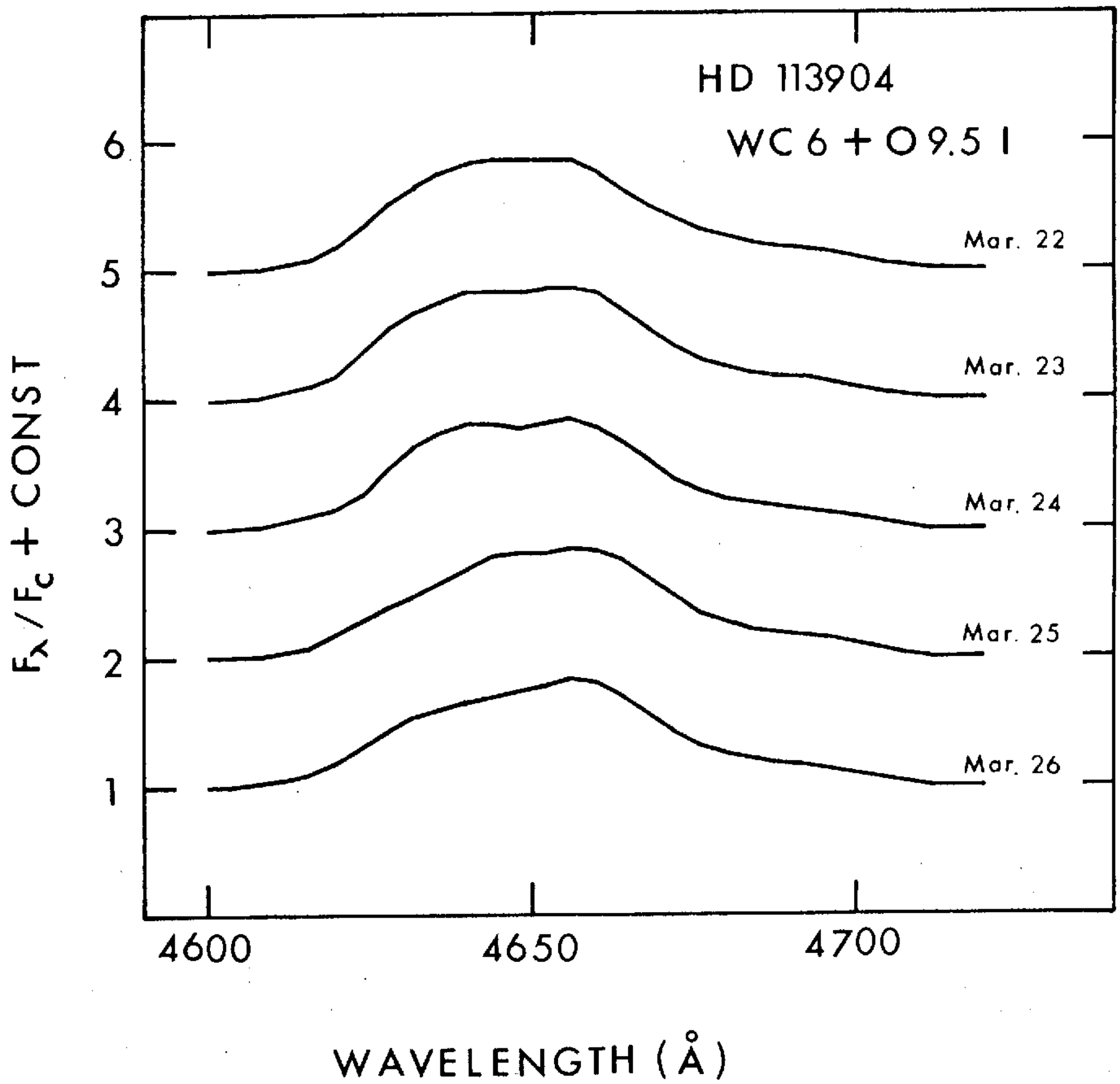
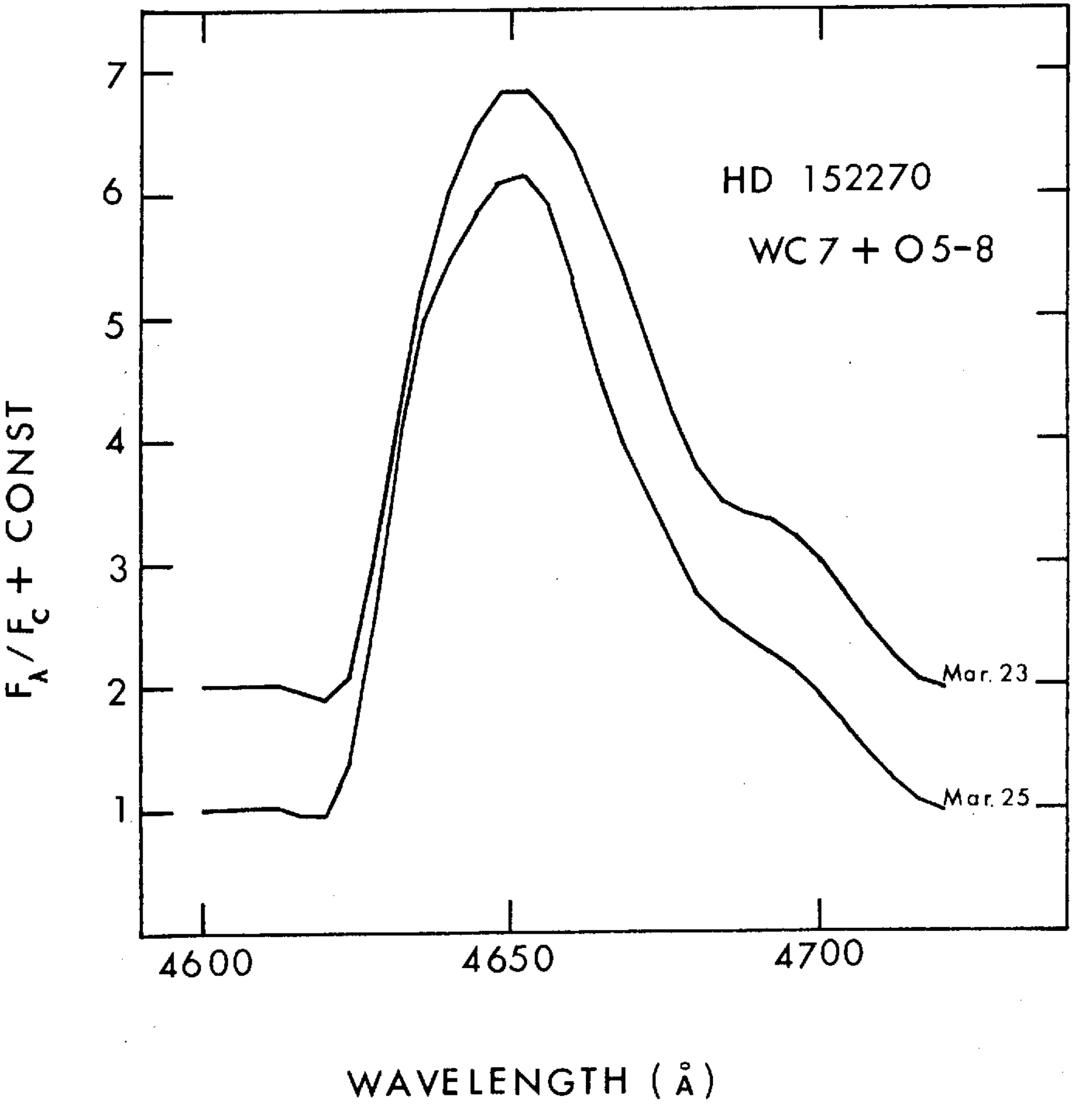


Figure I. Mean Scans for HD 113904 with a 10 A exit slit.



Figuew 2. Mean Scans for HD 152270 with a 10 A exit slit.

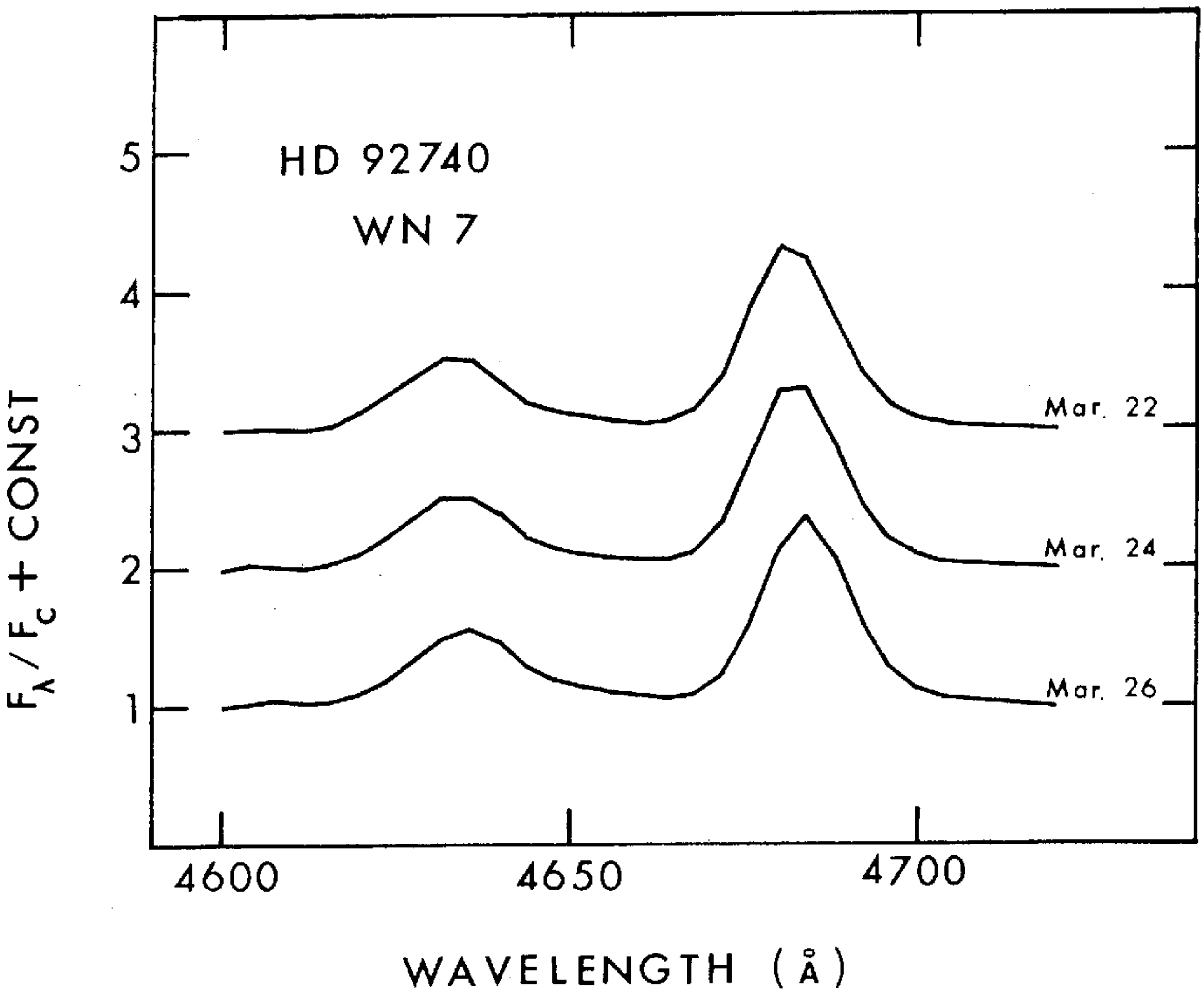


Figure 3. Mean Scans for HD 92740 with a 10 A exit slit.

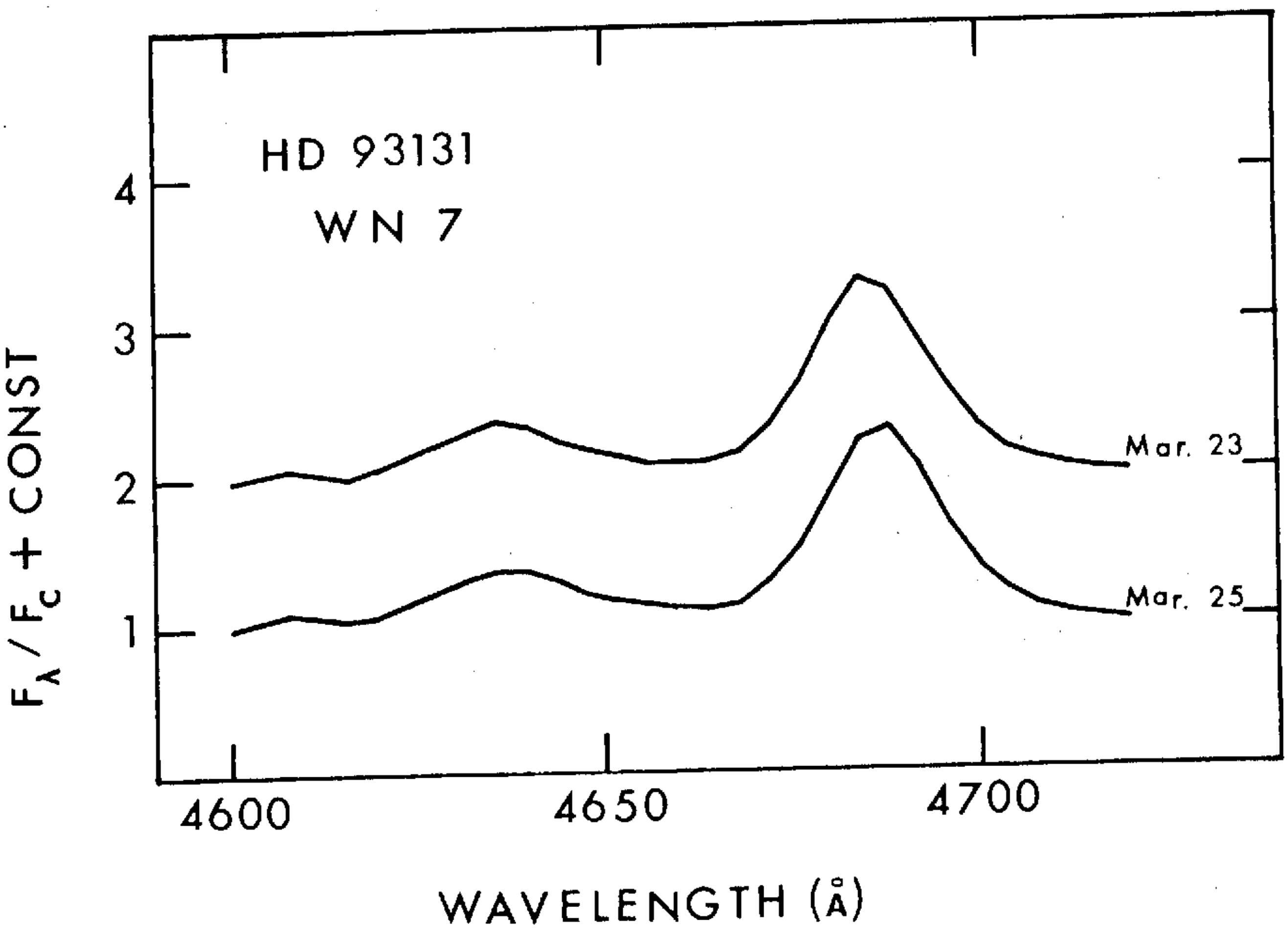


Figure 4. Mean Scans for HD 93131 with a 10 A exit slit.

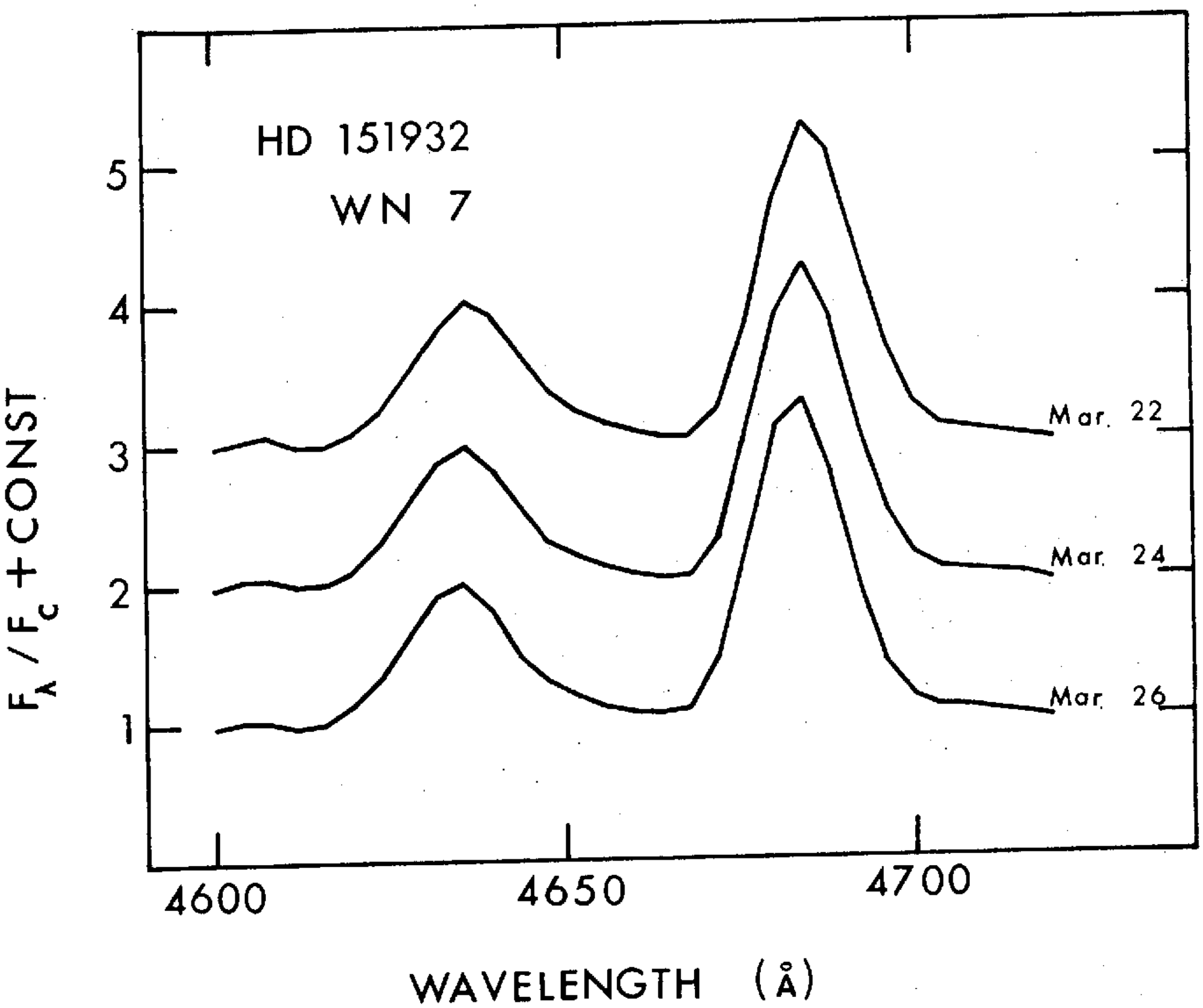


Figure 5. Mean Scans for HD 151932 with a 10 A exit slit.