IR SPECTROSCOPY OF WN STARS

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1. INTRODUCTION

The combination of IR data with radio, optical and UV observations has the potential to greatly increase our understanding of the WR phenomena. Consequently we are obtaining IR spectra from 1.1 to 4.2μ for a sample of southern WN stars (K < 7th magnitude) using a low resolution, R~100, circular variable filter wheel (CVF) and a cooled grating spectrometer, (CGS) (Jones et al. 1981) with a maximum resolution of 2000. Previous IR spectral studies of WR stars have generally concentrated on line identification, and beyond 1.7μ they have been limited to low resolution (Barnes et al. 1974, Cohen et al. 1978, Williams et al. 1980). With the CGS it is now possible to obtain spectra at resolutions sufficiently high to split blends and reveal details of line profiles. Below we present preliminary results of our observations.

2. THE WN SEQUENCE

Figures 1 and 2 present spectra of a sequence of WN subtypes obtained using the CVF. To remove atmospheric and instrumental transmission effects the raw spectra of the WN stars were divided by a standard star which had been observed at a similar air mass. The breaks in the spectra at 1.9μ and 2.6μ are due to terrestrial water vapour. As in the optical and UV, there is a large variation in spectral characteristics for the different subtypes.

(a) HD50896 (WN5). HeII emission lines dominate the spectrum of HD50896 with weak NV, NIV, NIII and HeI emission lines also present. A list of the dominant emission features and their probable identifications is given in Table 1. The wavelengths for the nitrogen recombination lines have been computed assuming a hydrogenic structure (Barlow, private communication). The helium wavelengths are taken from Weise et al. (1966) and Garcia et al. (1965).

C. W. H. de Loore and A. J. Willis (eds.), Wolf-Rayet Stars: Observations, Physics, Evolution, 225–229.

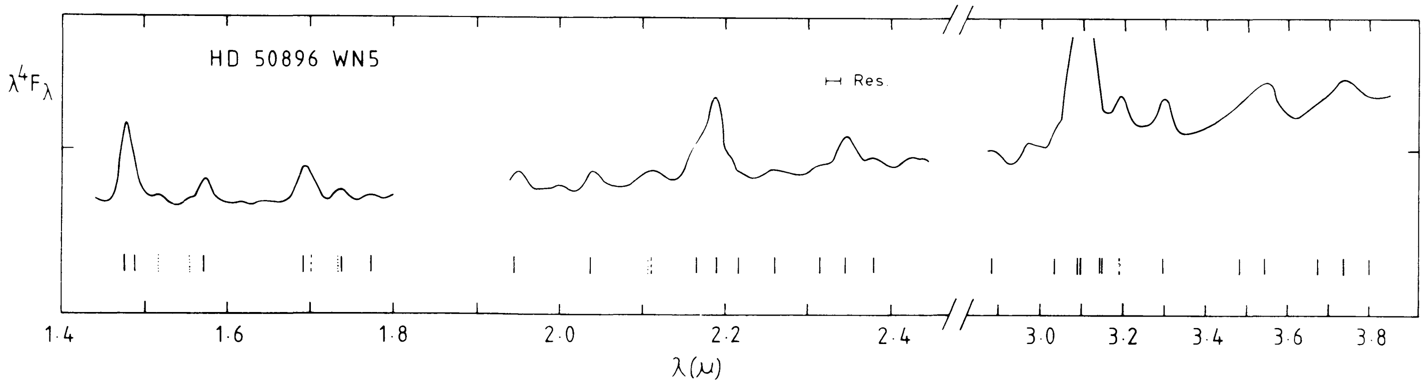

Fig. 1 The 1.4 - 3.8μ spectrum of HD50896(WN5). Solid vertical lines indicate the position of HeII transitions, dashed lines HeI and dotted lines transitions of NIII, NIV or NV.

Table 1

Emission Line Identifications for HD50896

$\lambda_{OBS}(\mu)$	$\lambda_{Id}(\mu)$	Ion	Transition	$\lambda_{OBS}(\mu)$	$\lambda_{Id}(\mu)$	Ion	Transition	$\lambda_{OBS}(\mu)$	$\lambda_{Id}(\mu)$	Ion	Transition
1.48	1.4767	He II	9-6	1.94	1.9438	He II	16-8	3.04	3.0372	He II	20-10
	1.4882	He II	14-7	2.04	2.0373	He II	15-8	3.08	3.0908	He II	7-6
1.51	1.518	N V	$3d\,^2D-3p\,^2P$	2.11	2.110	N V	11-10		3.0946	He II	11-8
1.55	1.554	N V	10-9		2.1120	He I	$4s\,^3S-3p\,^3P$		3.087	N III	11-10
1.57	1.5719	He II	13-7		2.116	N III	8-7	3.19	?		
1.69	1.6918	He II	12-7	2.18	2.1885	He II	10-7	3.29	3.2948	He II	18-10
	1.7002	He I	$4d\,^3D-3p\,^3P$		2.1646	He II	14-8	3.50	3.5433	He II	13-9
1.74	1.736	N IV	9-8	2.26	2.2602	He II	21-9		3.4831	He II	17-10
	1.7366	He II	20-8	2.32	2.3136	He II	20-9		3.5475	N V	13-12
1.77	1.7720	He II	19-8	2.35	2.3464	He II	13-8	3.74	3.7380	He II	16-10
				2.38	2.3788	He II	19-9		3.7026	He I	$5d\,^3D-4p\,^3P$

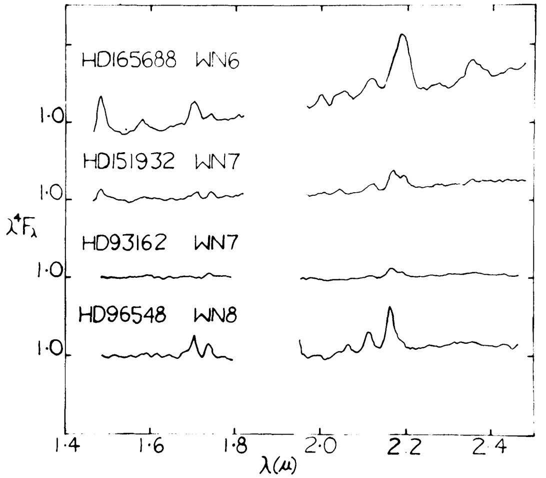

Fig. 2 CVF spectra of 4 WN stars.

(b) HD165688 (WN6). HeII emission lines dominate the spectrum and contribute approximately 8% and 12% to the H and K magnitudes respectively. Between 1.9μ and 2.1μ some of the features may be spurious due to incomplete cancellation of terrestrial CO_2. NIII at 2.113μ and NIV at 1.736μ are both present. A striking feature of HD165688 is its large IR excess. Using E_{B-V}=1.06 (Smith 1968) to correct for interstellar extinction implies that over 70% of the slope shown in Figure 2 is intrinsic to HD165688.

(c) HD151932 (WN7). HeII emission lines still dominate the spectrum, although the emission lines are generally much weaker than in the previous two stars. The presence of hydrogen is inferred by the strength of Bracket-γ at 2.165μ. NIV(9-8) is present at 1.736μ and is confirmed by the presence of NIV(8-7) at 1.190μ. The NIII(8-7) transition at 2.116μ appears to be present since the feature coincident with this wavelength is too strong to be identified as HeI(4sS-3pP).

(d) HD93162 (WN7). Only weak emission line features are present. The strongest line is due to hydrogen at 2.1655μ. Unlike HD151932 we do not see the "strong" HeI line at 1.7002μ.

(e) HD96548 (WN8). The dominant emission lines can be attributed to H, HeI, NIII which contribute approximately 4% and 6% to the H and K magnitudes respectively. Unlike the previous WN stars discussed the HeI 2s-2p singlet transition at 2.059μ is clearly present, although it is much weaker than in WC stars (Williams et al. 1980). The strongest HeI feature occurs at 1.700μ and arises from the 4d-3p triplet transition. Although not all WN8 stars show the presence of hydrogen in their envelope (e.g., HD177230: Massey et al. 1980) hydrogen is clearly present in HD96548 as can be seen by the strength of Bγ at 2.166μ. The strong features at 1.74μ and 2.11μ can be attributed to blends of H(10-4), NIV(9-8) and HeI(4-3), NIII(8-7) respectively.

3. Bγ REGION

Figure 3 illustrates the Bγ region of 4 WN stars. The spectra of HD92740, HD50896 and HD165688 were obtained with a resolution R = 700 and HD151932 with R = 1000 using the CGS on the 74" at Mt Stromlo. These resolutions have resolved the two HeII lines at 2.1646(14-8) and

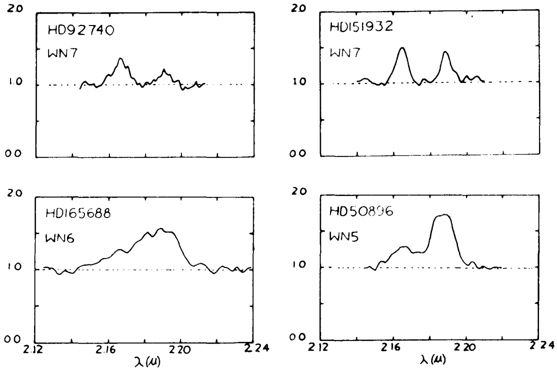

Fig. 3 CGS spectra showing $B\gamma$ and HeII(14-8) at 2.165μ and HeII(10-7) at 2.189μ.

2.1885(10-7) which comprise the blended feature seen at 2.18μ in the CVF spectra. Since WN stars have line profiles which are generally several thousand kilometres per second wide, resolutions of 700 or greater enable us to obtain information on line profiles. In HD50896 for example, the HeII(10-7) transition has a "flat" top whereas the profile for HD151932 is rounded.

In a pure HeII atmosphere it is expected that the ratio of W_λ(HeII 10-7) to W_λ(HeII 14-8) would be approximately 4 assuming that both lines are optically thin. For both HD165688 and HD50896 we find that the ratio is greater than 3 indicating $H^+ < 0.3He^{++}$ by number. In the two WN7 stars the line at 2.1655μ is stronger, hence both these stars must contain appreciable hydrogen. In HD151932 a preliminary analysis of these two lines and other members of the hydrogen bracket series suggests that $H^+ = 2He^{++}$ by number. These results support earlier work by Smith (1973). By combining the IR spectral data with optical data we will have 4 hydrogen series (n-2, n-3, n-4, n-5) with which to determine a He^{++}/H^+ abundance. The IR should also allow a determination of the He^+/He^{++} ratio in WR atmospheres.

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DISCUSSION

Perry: What was the H/He ratio you found for HD 151932 ? Our determinations gave H/He ~1.2 if the lines are optically thin or H/He ~ 2.3 if the lines are optically thick.

Hillier: The estimate was ~ 2.1 for the H/He ratio assuming He is predominantly in the doubly ionized state, which needs to be investigated.

Barlow: I think that one definitely has to take HeI recombination lines into account in analysing the H^+/He^{++} ratio in WN7 and WN8 stars, since the IR recombination lines of HeI coincide with those of HI (lines of HeI are quite prominent in the optical spectra of WN7 and WN8 stars).

Hillier: This is certainly the case for WN8 stars which is why I did not state a H^+/He^{++} ratio for HD 96548 (WN8). For the WN7 star HD 151932 the HeI lines contributes to the strengths of the lines only weakly since a pure HeI line at 1.1969μ is relatively weak.

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