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SPECTROPHOTOMETRY OF NORTHERN WOLF-RAYET STARS: A SAMPLE OF WN4, WN5 AND WN6 STARS

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RESUMEN. Se presentan resultados de la medición de anchos equivalentes de líneas en emisión de estrellas WR de la secuencia WNE, los cuales sugieren que las WN6-B tienen los vientos más masivos entre las estrellas WN.

ABSTRACT. Results of the measurement of emission line equivalent widths in WNE stars are presented which suggest that the WN6-B stars have the most massive winds among the WN stars.

Key words: SPECTROPHOTOMETRY -- STARS-WIND -- STARS-WOLF-RAYET

INTRODUCTION

After more than a hundred years, Wolf-Rayet (WR) stars as a class represent a fascinating dilemma. The WR stars seem to represent a phenomenon, rather than to constitute a homogeneous class of objects. This phenomenon can be summed up as follows: intense stellar winds with altered chemical abundances.

Recent investigations (Conti 1982; Leep, 1982; Massey, 1984; Conti et al. 1983) have shown the degree to which heterogeneity prevails among WR stars. In particular, the dispersion in line strengths among WN's of the same subtype can be as large as the dispersion from sybtype to subtype. This means that two stars having the same dominant ionization stage in their winds (which defines the subtype) have different wind densities, and are thus intrinsically different. Thus, the degree of ionization seems to be independent of the mecanisms which establish the wind density/velocity structure.

The general questions which must be addressed are the following:

1. What are the parameters in the WR winds responsible for the broad range in line strengths (i.e., density, velocity, chemical abundances)?

2. What mechanisms establish the ionization, velocity and density structures in WR winds?

3. Can the wind structure be related to the properties of the underlying stellar core in a direct manner?

An initial discussion of question 1 is presented by Koenigsberger and Cantó (1987), who find correlations between the equivalent widths of N III, N IV and N V lines for stars classified by Hiltner and Schild (1966) as WN-B. They conclude that these correlations imply that the "broad-line" WN's have the most dense winds, among WNE stars, and that they are most likely the most massive stars.

In this paper we present additional evidence to support the conclusion that WN-B stars have the most massive winds.

OBSERVATIONS.

The observations were made by CF and JW at the 1 meter telescope of the Lick Observatory using the IDS. The resolution is ∿ 5 Å. Standard reduction techniques were employed by CF (Baldwin, 1972) with the facilities provided by the Lick Observatory. Final analysis and measurements were performed by JB and GK at the Instituto de Astronomía, UNAM.

The EW's were measured by visually defining the left and right wings of each line. The continuum was first interpolated by defining "line-free" wavelength intervals. This was followed by a visual correction, when necessary. The measured EW's for the WNE stars of our sample are listed in Table 1.

TABLE 1. EQUIVALENT WIDTHS OF EMISSION LINES

STAR[1]	He I[2] 5875	He II 4686	He II 4859	He II 5411	He II +Hα 6560	He II +He I 6683	N III He II 4097	N III 4640	N IV 4058	N IV +He I 7103-29	N V 4603,20	N V 4944	C IV +N IV 5806-12
WN6													
94	3.69	5.22	4.30	4.51	4.81	4.19	4.42	>4.46	4.39	5.13	>4.41	3.79	4.47
100	4.69	>5.39	4.54	4.66	4.87	4.67	(4.82)	>5.01	(4.67)	<5.29	>4.35	3.96	4.26
110	<4.55	5.52	4.58	4.81	>5.12	>4.59	>5.03	-	>4.63	<5.38	>4.64	3.90	4.57
115	3.99	5.06	3.96	4.39	4.60	4.11	4.00	>4.59	4.11	>4.74	>4.10	3.26	4.11
134	>4.17	5.45	4.55	4.88	5.17	4.43	>4.79	>4.60	>4.63	<5.32	>3.85	3.91	4.54
136	4.37	5.29	4.57	4.78	5.17	4.44	>4.92	>4.88	>4.74	5.21	>3.87	3.92	4.30
138	4.37	4.73	3.89	4.13	4.62	3.69	4.13	>3.92	>4.12	4.74	>3.69	3.19	3.74
141	4.04	5.17	4.19	4.55	4.87	4.19	>4.55	>4.59	>4.45	5.00	>3.62	3.50	4.32
WN5													
139	3.60	4.76	3.65	4.04	-	-	3.93	>3.71	3.92	4.63	3.67	3.24	4.02
WN4													
127	3.21	4.81	3.66	4.08	4.48	3.79	3.95	-	3.79	4.75	4.02	3.17	>3.77
128	abs	4.97	4.10	4.22	4.82	3.35	3.96	>3.56	3.75	4.76	4.25	3.82	3.77
129	3.74	5.21	4.23	4.52	4.89	4.10	4.34	>4.08	4.34	<5.11	>4.30	3.67	4.46
133	abs	4.15	3.11	3.65	4.11	2.86	(3.39)	-	3.61	4.15	3.39	2.98	3.57

NOTES:
1. numbers from van der Hucht et al. Catalogue
2. values are in units of log EW (in mÅ)
abs. line in absorption
( ) uncertain measurement

RESULTS

In Figures 1a, 1b, and 1c we plot the EW of N III 4640, N IV 4058 and N V 4944, respectively, as a function of He II 5411. The different symbols represent stars of the different subtypes, and the axes are in units of log (EW in mA).

Given our limited sample of stars, it is premature to draw strong conclusions regarding the generality of the apparent correlations in the Figures. However, the one point that is clear is that the stars classified WN-B (i.e., broad line WN's in the Hiltner and Schild classification system) have EW's at the upper end of the three plots. That is, they have the largest EW's in He II, N III, N IV, and N V. Thus, the great width of the emission lines together with these large EW's leads to the conclusion that there are more He II, N III, N IV and N V ions in the WN-B stars than in the others of the same subtype. That is, the overall number of emitters in WN-B stars is greater, leading to the conclusion that the winds of these WR stars are more massive than the winds in WN-A stars. One alternative explanation might be that all WN-A stars are binaries with luminous companions, such that the measured equivalent widths are greatly reduced. But then this would imply that the presence of a massive companion has a signi

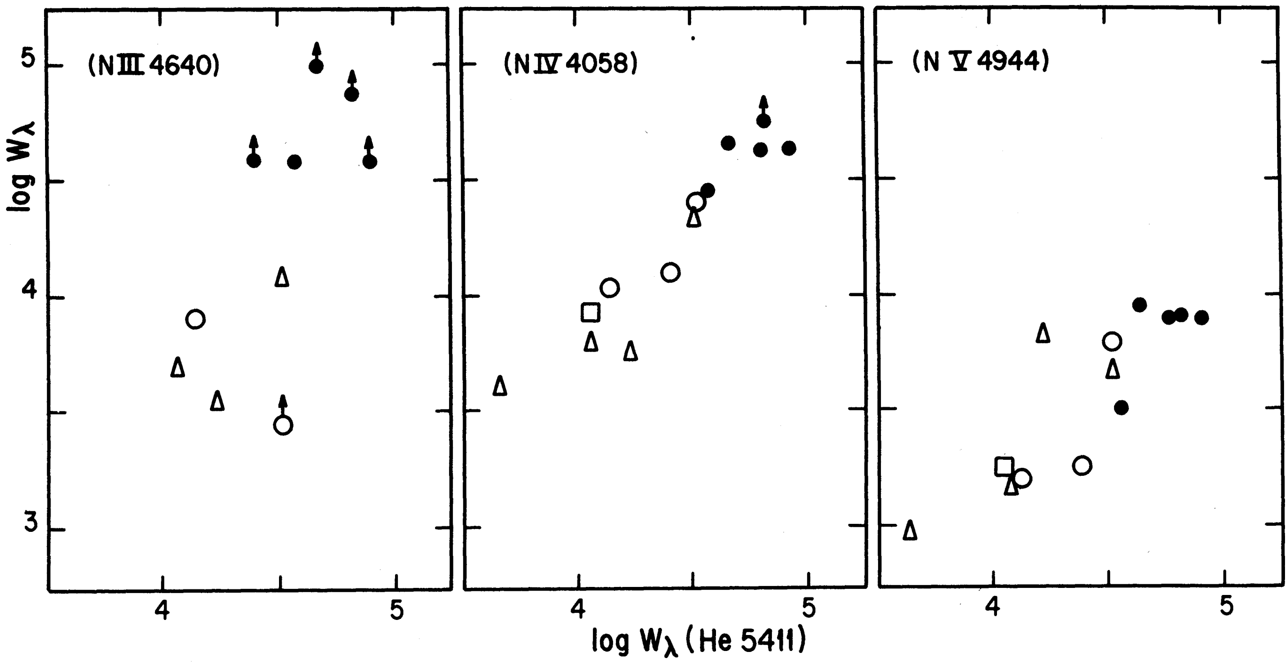

Fig. 1. Plots of the logarithm of the equivalent width of: a) N III 4640 A, b) N IV 4058 A, and c) N V 4944 A as a function of the logarithm of the equivalent width of He II 5411 A. The different symbols represent: Δ WN4, □ WN5 and o WN6. Closed symbols correspond to the WN-B stars.

ficant effect on the wind structure of the WR star, to the degree of inhibiting the acceleration mechanism or reducing the overall wind density. Another possible alternative is that the optical continuum luminosity is lower in the WN-B's, leading to larger EW's. This would only be consistent with the large mass-loss rates that are observed (Abbott et al. 1986) for these stars if their continua are very blue. Evidence for this does exist (see note 2 in Massey 1984).

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