Wolf-Rayet Phenomena in Massive Stars and Starburst Galaxies
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Non-thermal radio emission in Wolf-Rayet stars: is binarity a pre-requisite?

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Abstract. Radio observations of Wolf-Rayet stars currently available in the literature are examined to determine whether binarity is a common feature of WR systems with non-thermal emission. Among 24 stars with observed spectral index values, seven are definite non-thermal emitters, and six others possibly have composite thermal/non-thermal spectra. Stellar companions have been identified in 71% of the non-thermal emitters, strongly supporting a link between non-thermal emission and binarity.

Discussion

Radio emission from stellar winds is characterised by free-free continuum emission with $T_B \simeq 10^4$ K and spectral indices $\alpha \simeq +0.6$. A number of WR stars have radio properties that differ from this typical picture, with $T_B \simeq 10^{6-7}$ K, and flat or negative spectral indices, characteristics of non-thermal synchrotron emission. In the cases of WR 146 and 147, two stellar components and the non-thermal emission region have been spatially resolved and the origin of the non-thermal emission in a stellar wind collision region is well-supported (Dougherty *et al.* 1996; Williams *et al.* 1997; Neimela *et al.* 1998).

To determine whether binarity is common among WR stars that exhibit non-thermal radio emission, radio spectral indices have been determined for WR stars that have been observed at more than one radio wavelength. The complete sample of stars used in this study is shown in Table 1. Sources where α is not significantly flatter than +0.6 are identified as thermal and those with α significantly lower than 0.0 are identified as non-thermal. In the case that the radio emission from a WR system is a composite of non-thermal and a thermal emission, the spectral index could be between +0.0 and +0.6. These sources are identified as thermal/non-thermal.

Among the 24 sources in Table 1, there are 7 sources that are definite non-thermal emitters: WR 14, 48, 105, 125, 140, 146, and 147, corresponding to 29% of the sample. Including the sources that we identify as having composite spectra gives either a total of 8 (33%) or 13 (54%) of the total sample, dependent on whether you chose the 3 or 2σ significance criteria. Of the 7 definite non-thermal emitters, 5 of the systems are known binaries or multiple systems (71%), with only WR 14 and WR 105 not being identified as such. Among the 6 sources that may have composite spectra, only two (WR 39 and 90) are identified as single stars in the 7th Catalogue of Galactic Wolf-Rayet Stars (van der Hucht 1999). Thus, of the 13 stars that exhibit or possibly exhibit non-thermal emission, 9

Table 1. Radio spectral indices of Wolf-Rayet stars

WR	spectral type[9]	period	radio α	emission type		ref.
				$3\sigma^a$	$2\sigma^a$	
6	WN4b		$+0.7 \pm 0.2$	T	T	3
9	WC5+O7	14.3d	$> +1.7$	T	T	1
11	WC8+O8.5III	78.5d	$+0.33 \pm 0.04$	T/NT	T/NT	1
			$+0.69 \pm 0.02$	T	T	4
14	WC7		< -0.7	NT	NT	1
16	WN8h		$+0.62 \pm 0.15$	T	T	2
22	WN7ha+O7.5	80.4d	$+0.14 \pm 0.19$	T	T/NT	2
24	WN6ha		$> +1.7$	T	T	2
39	WC7		-0.37 ± 0.34	T	T/NT	1
40	WN8h		$+0.68 \pm 0.12$	T	T	2
48	WC6+O9.5+?	18.3d	-0.39 ± 0.15	NT	NT	1
78	WN7h		$+0.5 \pm 0.1$	T	T	3
86	WC7+OB[10]	Visual	$+0.18 \pm 0.20$	T	T/NT	8
89	WN8h+a		$+0.74 \pm 0.18$	T	T	2
90	WC7		$+0.02 \pm 0.24$	T	T/NT	1
105	WN9h		-0.27 ± 0.09	NT	NT	1
112	WC9		> 0.95	T	T	1
125	WC7+O9	> 15yr	$-0.5 \rightarrow +0.7$	NT&T	NT&T	3,7
134	WN6b		$+0.9 \pm 0.2$	T	T	3
136	WN6b		$+0.7 \pm 0.2$	T	T	3
137	WC7+OB	> 13yr	$+0.0 \pm 0.2$	T	T/NT	7
140	WC7+O4-5	7.9yr	$-0.5 \rightarrow +0.7$	NT&T	NT&T	11,12
145	WN/C+OB?	22.5d	$+0.8 \pm 0.3$	T	T	3
146	WC6+O[5]	Visual	-0.62 ± 0.04	NT	NT	5
			$+0.74 \pm 0.20$	T	T	5
147	WN8+OB	Visual	-0.37 ± 0.07	NT	NT	6
			$+0.66 \pm 0.02$	T	T	6

Notes: (a) Significance of difference of α from +0.6.
References: (1) Leitherer *et al.* (1997); (2) Leitherer *et al.* (1995). Values of α calculated from radiometry listed in Table 1 of each of these papers; (3) Abbott *et al.* (1986); (4) Williams *et al.* (1990b); (5) Dougherty & Williams (these Proceedings); (6) Williams *et al.* (1997); (7) Williams, private communication; (8) Dougherty *et al.* , in preparation; (9) van der Hucht (1999); (10) Neimela *et al.* (1998); (11) Williams *et al.* (1990a); and (12) White & Becker (1995).

(70%) are binary systems. This provides compelling evidence that non-thermal emission and binarity are, in some manner, connected.

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