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Research Note

Upper limits to the radio-fluxes of the Wolf-Rayet stars WR 46 (WN3p) and WR 50 (WC7+abs)

P.M. Veen[1] **and M.H. Wieringa**[2]

[1] Leiden Observatory, P.O. Box 9513, 2300 RA Leiden, The Netherlands
[2] Australia Telescope National Facility, CSIRO, P.O. Box 76, Epping, NSW 2121, Australia

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Abstract. We have observed the Wolf-Rayet stars WR 46 (WN3p+c) and WR 50 (WC7+abs) at 3 and 6 cm using the Australia Telescope in search of non-thermal radio emission. However, the sources were not detected and we derive upper limits to their radio fluxes of 0.18 mJy (0.15 mJy in the case of WR 46 at 6 cm). These are not in conflict with expected thermal emission, because the wind densities have been found to be lower than an average WR wind. Inversely, assuming the mass-loss rate as determined from optical spectral analyses, the inferred lower limits to the distances are in agreement with previous determinations. Both objects are reported as short-period photometric variables, but we note that the variability of WR 50 is suspicious.

Key words: stars: Wolf-Rayet – stars: individual: WR 46 = HD104994 – stars: individual: WR 50 – radio continuum: stars

1. Introduction

The strongly ionized stellar winds of Wolf-Rayet (WR) stars are sources of thermal radio emission. An extensive study of the radio emission of nearby WR stars in the northern sky was performed by Abbott et al.(1986) using the VLA. Recently, some southern WR stars were investigated by Leitherer et al. (1995, 1997) and Chapman et al. (1999), using the Australia Telescope. Together, the northern and southern surveys supply radio observations of, possibly, all WR stars within 3 kpc from the Sun (71 observed, 33 detected). The latter authors conclude that about 40% of the WR stars are non-thermal emitters. They speculate that interaction of the thermal WR wind with the surrounding material from a previous evolutionary stage, may be a common source of radio emission. However, they realize that in several cases the non-thermal emission is known to be related to binary interaction (van der Hucht et al. 1992; Dougherty & Williams 2000).

In all cases where the origin of the non-thermal radiation of WR stars is identified, it is due to interaction with a distant companion ($P \gg$years). These systems are the so-called colliding-wind binaries, notably the archetype WR 140 (Williams et al. 1990). One exception is the highly-obscured *short*-period binary, Cyg X-3 (WN4–7 +cc; $P = 4.8$ hrs), a high-mass X-ray binary (van Kerkwijk et al. 1992). The latter system shows radio jets, outbursts and flares and it is studied intensely since its first detection by Braes & Miley (1972, see also Fender et al. 1997 and references therein). In addition, the short-period He-rich emission-line binary system, V Sge ($P = 12.24$ hr), shows significant radio emission, possibly related to colliding winds (Lockley et al. 1997).

We present radio observations of two short-period photometrically variable WR stars. The first object, WR 46 (HD 104994, WN3p+c), is a short-period binary (∼7 hrs) but not a luminous X-ray source and, therefore, probably does not hold a compact companion. It is discussed extensively in three papers (Veen et al. 2000a, b, c), where it is proposed to be a close interacting binary system. The second object, WR 50 (TH 17-84; WC7+abs), has been suggested to be variable with an amplitude of about a magnitude in the blue with a possible period of 1.06 day (van Genderen et al. 1991). However, recent inspection showed this variability to be suspicious, see Sect. 3.

For both objects we tried to detect non-thermal radio-emission from the interaction with a (possible) close companion. Unfortunately, in case of a spherical homogeneous wind, the thermal radio photosphere reaches out to several hundreds of stellar radii (e.g., van der Hucht et al. 1992) and may well swallow any non-thermal radiation produced near the central binary. So, non-thermal emission may only escape from the wind if the stellar wind is inhomogeneous or non-spherical, as in the case of WR140 (Williams et al. 1990). In fact, the photometry of WR 46 indicates that its wind is distorted. We note that in case of WR 50, the companion which is visible in the spectrum could in principle also be a source of non-thermal emission. Sect. 2 describes the observations and Sect. 3 discusses the results.

2. Observations and reduction

The radio observations were obtained at the Australia Telescope National Facility by one of us (MW) using the Compact Array at

Send offprint requests to: veen@strw.leidenuniv.nl

Narrabri on 27 July 1994. The objects 1934-638 and 1236-684 were used as primary and secondary calibrators, respectively. WR 46 and WR 50 were observed intermittently together with a secondary calibrator with on-source total integration time of 7:10 hrs and 6:20 hrs for WR 46 and WR 50, respectively. Because of possible detection problems in the center of the field, a 30″ offset to the south was applied for the program stars. The radio fluxes were determined at 3 cm (8640 MHz) and 6 cm (4800 MHz), both with a bandwidth of 128 MHz. The reduction was performed with the NEWSTAR-package of the Westerbork Synthesis Radio Telescope.

The field of WR 50 at 6 cm showed a source at $\alpha = 13^{\mathrm{h}}17^{\mathrm{m}}04^{\mathrm{s}}$ and $\delta = -62°28'19''$, with a flux of ∼45 mJy (∼7′east of WR 50). At 3 cm this object is outside the map. The source brightness is on the detection limit for the PMN-S catalogue (Wright et al. 1994) and is not mentioned therein. We could use the source to self-calibrate the observation. These phase corrections improved the radio map considerably and were also used for the WR 46 observation.

The center of the field (30″ south of WR 46) shows a faint offset problem (0.4 mJy and 0.3 mJy at 3 and 6 cm, respectively). None of the radio maps show a source at the positions of WR 46 nor of WR 50. Table 1 lists the upper limits as three times the noise in the reduced radio maps.

Table 1. The upper limits (3σ) for the radio flux (mJy) of WR 46 and WR 50 obtained at the Australia Telescope Compact Array (ATNF)

Object	3 cm	6cm
WR 46	0.18	0.15
WR 50	0.18	0.18

3. Discussion

Though we expected to reach the low level thermal emission of the WR stars, we have detected neither of the WR stars down to 0.18 mJy and to 0.15 mJy at 6 cm in case of WR 46. New optical studies have appeared since the radio observations were performed, which show both stars to be weak-lined WR stars (Crowther et al. 1995; Koesterke & Hamann 1995). This class is characterised by a stellar wind weaker than the strong-lined objects. This explains why we have not detected the thermal radio emission. Naturally, there may be some unobserved non-thermal emission, but, we may conclude that neither of the objects shows *strong* non-thermal radio emission. For each object we will discuss what can be inferred from the observed upper limits of the radio fluxes about the distances to the objects, assuming thermal emission.

By assuming an absolute magnitude of $-2\overset{\mathrm{m}}{.}8$, van der Hucht et al. (1988) derived a distance of 3.4 kpc. Niemela et al. (1995; hereafer NBS) derived a distance of 2 kpc from comparing polarimetric measurements with nearby objects on the sky. The latter analysis depends on the absence of intrinsic polarization from WR 46 itself, while the same NBS argue that the system is dominated by a circumstellar disc. Also, if the photometric variability is ascribed to a distorted atmosphere, the electron scattering may create intrinsic polarization. From interstellar absorption-line profiles at high-resolution, Crowther et al. (1995) inferred a distance of 4±1.5 kpc. Using the GLAZAR-space telescope, Tovmassian et al. (1996) derived from observations at 1640 Å (full bandwidth ~ 250 Å) that WR 46 is a probable member of a stellar OB association at 4.0 (± 0.2) kpc.

In the case of WR 50 the object is suggested to be a member of a stellar cluster at a distance of 3.6 kpc (Turner 1985). However, Smith et al. (1990) developed a method based on the line emission only and therefore independent of a possible companion contributing to the contimuum. These authors derive a larger distance of 5.9 kpc.

Leitherer et al. (1997) compared their mass-loss estimates from radio observations to determinations from optical line analyses. These authors conclude that both methods lead to consistent results. Therefore, we adopt the mass-loss rate of $\log \dot{M}(\mathrm{M}_{\odot}\mathrm{yr}^{-1}) = -5.2$ as determined by Crowther et al. (1995) from the optical spectrum. To derive a lower limit to the distance we may rewrite the formula derived by Wright & Barlow (1975) to:

$$D = \left(\frac{\dot{M}z}{0.095\mu v_\infty}\right)^{2/3} (\gamma g \nu)^{1/3} f_\nu^{-1/2} \quad \mathrm{kpc}, \tag{1}$$

where $\dot{M}$ is in $\mathrm{M}_\odot\,\mathrm{yr}^{-1}$, z the average charge on each ion roughly equal to one, the terminal velocity $v_\infty = 2450\,\mathrm{km\,s}^{-1}$, the average number of electrons per ion $\gamma \simeq 1$, the Gaunt factor g at frequency ν is roughly 6, and f_ν is the observed flux (or upper limit). Applying this equation we derive a lower limit to the distance of WR 46 of 1.0 kpc. This limit is too small to help to decide between various available distance determinations in the literature.

As to WR 50, our lower limit to the distance of the object is 3.2 kpc, assuming $\log \dot{M}(\mathrm{M}_{\odot}\mathrm{yr}^{-1}) = -4.4$, $v_\infty = 3000\,\mathrm{km\,s}^{-1}$, $\mu \approx 6$ (carbon mass fraction 0.5), $z = 1$, $\gamma = 1.5$, $g = 5$ (Koesterke & Hamann 1995). This lower limit is only slightly smaller than the distance 3.6 kpc.

In addition, we have re-investigated the original photometric Walraven data as presented by van Genderen et al. (1991) and note that the bright and variable sky due to the nearby moon, and some unexplained light contribution at a fixed position relative to the telescope may explain most, if not all, variability in the data of van Genderen et al. (1991) of WR 50.

4. Conclusion

We have obtained upper limits to the radio fluxes at 3 and 6 cm wavelength of the southern WR stars WR 46 and WR 50. The upper limits are in agreement with the current estimates of the expected thermal radiation from these weak-lined WR stars and their estimated distances. Assuming that the stars are not much farther away than the current estimates, we have to conclude that neither of them shows strong (non-thermal) radio emission.

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References

Abbott D.C., Bieging J.H., Churchwell E., Torres A.V., 1986, ApJ 303, 239
Braes L.L.E., Miley G.K., 1972, Nat 237, 506
Chapman J.M., Leitherer C., Koribalski B., et al., 1999, ApJ 518, 890
Crowther P.A., Smith L.J., Hillier D.J., 1995, A&A 302, 457
Dougherty S., Williams, P.M., 2000, MNRAS in press
Fender R.P., Bell Burnell S.J., Waltman E.B., et al., 1997, MNRAS 288, 849
Koesterke L., Hamann W.-R., 1995, A&A 299, 503
Leitherer C., Chapman J.M., Koribalski B., 1995, ApJ 450, 289
Leitherer C., Chapman J.M., Koribalski B., 1997, ApJ 481, 898
Lockley J.J., Eyres S.P.S., Wood J.H., 1997, MNRAS 287, L14
Niemela V.S., Barbá R.H., Shara M.M., 1995, in: van der Hucht K.A., Williams P.M. (eds.) Wolf-Rayet stars: Binaries, Collidinge Winds, Evolution, IAU Symp No 163, Kluwer, Dordrecht, p. 245
Smith L.F., Shara M.M., Moffat A.F.J., 1990, ApJ 358, 229
Tovmassian H.M., Navarro S.G., Cardona O., et al., 1996, AJ 111, 306
Turner D.G., 1985, ApJ 292, 148
van der Hucht K.A., Hidayat B., Admiranto A.G., et al. 1988, A&A 199, 217
van der Hucht K.A., Williams P.M., Spoelstra T.A.Th., de Bruyn A.G., 1992, ASP-CS 22, 253
van Genderen A.M., Verheijen M.A.W., van Kampen E., et al., 1991, In: van der Hucht K.A., Hidayat B. (eds.) Wolf-Rayet Stars and Interrelations with Other Massive Stars in Galaxies. IAUS 143, Kluwer, Dordrecht, p. 129
van Kerkwijk M.H., Charles P.A., Geballe T.R., et al., 1992, Nat 355, 703
Veen P.M., van Genderen A.M., van der Hucht K.A., et al., 2000a, submitted to A&A
Veen P.M., van Genderen A.M., Crowther P.A, et al., 2000b, submitted to A&A
Veen P.M., van Genderen A.M., van der Hucht K.A., 2000c, submitted to A&A
Williams P.M., van der Hucht K.A., Pollock A.M.T., et al., 1990, MNRAS 243, 662
Wright A.E., Barlow M.J., 1975, MNRAS 170, 41
Wright A.E., Griffith M.R., Burke B.F., Ekers R.D., 1994, ApJS 91, 111