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EVIDENCE FOR COLLIDING WINDS IN WR 146

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RESUMEN

Un mapa de alta resolución en 5-GHz de la estrella Wolf-Rayet WR 146, con el arreglo MERLIN, resuelve la fuente en dos componentes separadas por 116 mas. La componente más débil es identificada como emisión térmica del viento estelar de la WR y se ajusta con un espectro de viento $S_\nu \propto \nu^{0.78}$, con las observaciones infrarrojas y milimétricas. La componente más intensa, con $T_b \sim 10^6$ K, es identificada como la fuente no térmica. Espectroscopía óptica revela la presencia de líneas de Balmer en absorción superpuestas al espectro de emisión diluido de la WR, indicando la presencia de una estrella O acompañando a la WC6 en WR 146. Sugerimos que la emisión no térmica surge de la interacción del viento de la WR con el de la compañera recién detectada.

ABSTRACT

A high-resolution 5-GHz map of the Wolf-Rayet star WR 146 with the MERLIN array resolves the source into two components separated by 116 mas. The weaker component is identified with thermal emission by the WR stellar wind, and fits a $S_\nu \propto \nu^{0.78}$ wind spectrum with infrared and millimetre observations. The stronger component, which has $T_b \sim 10^6$ K, is identified as the non-thermal source. Optical spectroscopy reveals the presence of Balmer absorption lines superimposed on the diluted WR emission spectrum, indicating the presence of an O star companion to the WC6 star in WR 146. We suggest that the non-thermal emission arises from the interaction of the WR wind with that of the newly detected companion.

Key words: **BINARIES: CLOSE — RADIO CONTINUUM: STARS — STAR: WOLF-RAYET**

1. INTRODUCTION

Radio emission from WR 146 was first observed in a survey of compact sources in the galactic plane (Zoonematkermani et al. 1990). Felli & Massi (1991) reported it to have a spectral index of −1.0 and suggested the emission came from two components: a thermally emitting stellar wind and a compact non-thermal source. This made WR 146 the fourth WR star to be identified with a non-thermal radio source, joining WR 125, WR 140 and WR 147 observed by Abbott et al. (1986). The best studied of this small group of stars is the WC7+O4-5 binary system WR 140. The non-thermal emission from WR 140, which varies in phase with its binary motion, was attributed to particle acceleration where the WC7 and O4-5 stellar winds collide by Williams et al. (1990). This model has been pursued theoretically by Eichler & Usov (1993) and used by White & Becker (1995) to show that the WC7 stellar wind is not isotropic but flattened into a disk.

Like WR 140, WR 146 is a WC type star having an abnormally high wind terminal velocity for its spectral subtype (Eenens & Williams 1994). Also, Reddish (1968) suggested from the relative weakness of its emission-line spectrum inferred from photometry through broad- and narrow-band filters that WR 146 might be a binary. We therefore set out to examine whether the non-thermal radio emission from WR 146 is caused by its being a colliding wind binary (CWB).

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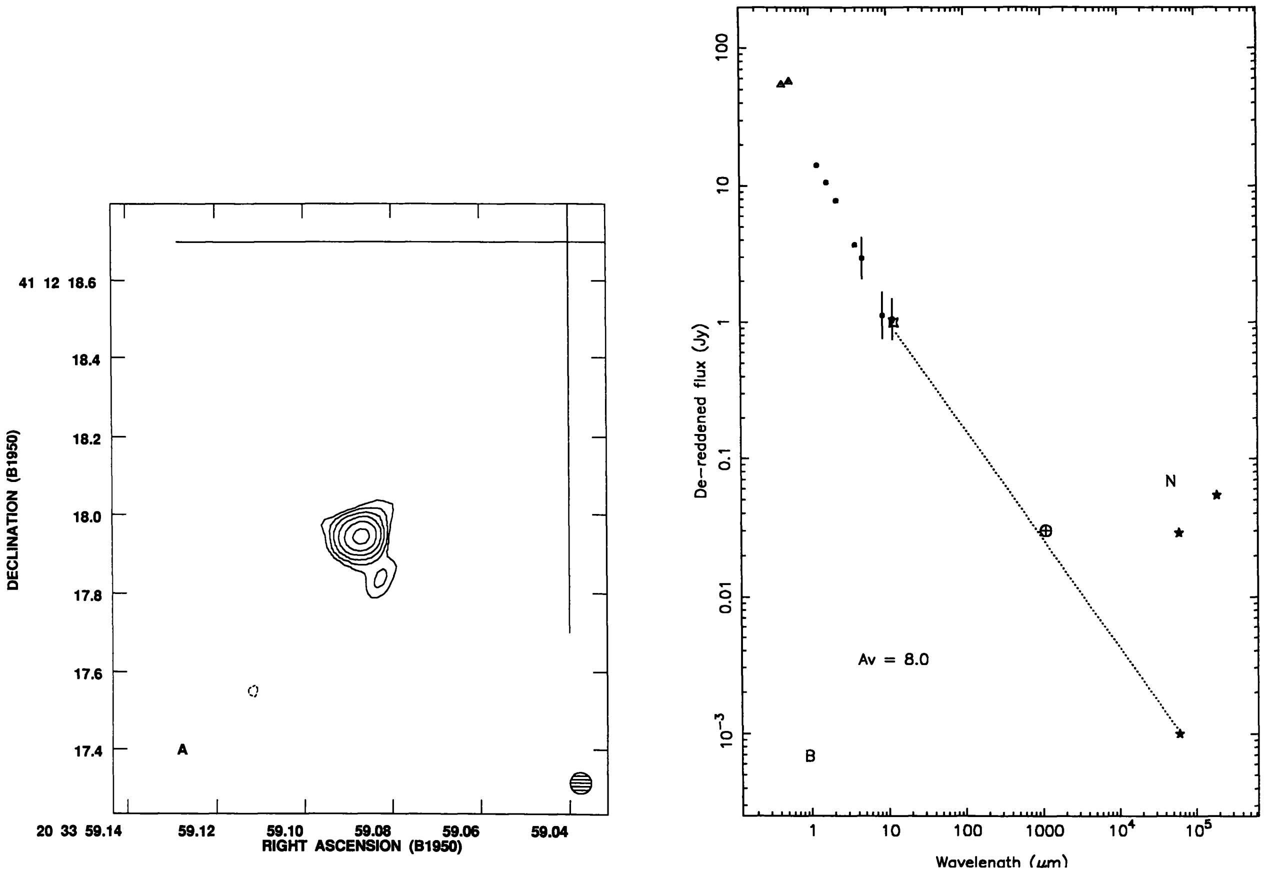

Fig. 1. A: MERLIN image of WR146 at 5 GHz. The optical position is indicated by the cross. The restoring beam (53 x 53 mas^2) is marked in the lower right-hand corner. B: Spectral energy distribution of WR 146 (Reddish's photometry (Δ), UKIRT/TCS ($\bullet$), *IRAS* Point Source Catalogue ($\square$), JCMT ($\oplus$), MERLIN ($\star$)). The *IRAS* point is corrected for the spectral shape. The MERLIN fluxes at 5 GHz for both N and S components are shown. The broken line connecting the latter to the infrared fluxes has the form $S_\nu \propto \nu^{0.78}$.

2. OBSERVATIONS

High-resolution maps of WR 146 were observed with MERLIN[6] on 1993 May 9 (1.6 GHz) and 1995 April 28–29 (5 GHz). At 5 GHz, the source is clearly resolved (Fig. 1) into two components separated by 116 ± 14 mas. The images lie ~ 1 arc sec from the optical position measured to an accuracy of ~ 1 arc sec from a sky survey plate (Eenens, Williams & Wade 1991). The brighter source ("N"), which lies to the north, has a flux density of 28.5 ± 0.2 mJy, a diameter of 38 mas and a brightness temperature of 1.4×10^6 K, while the weaker (southern) source ("S") has a flux density of 1.0 ± 0.2 mJy at 5GHz and a brightness temperature of $\sim 10^4$ K. At 1.6 GHz, WR 146 was not resolved, and an integrated flux density of 54.5 ± 0.2 mJy was measured. The radio flux from WR 146 is known to be variable from WSRT observations (van der Hucht et al. 1995), making it risky to estimate a spectral index from non-contemporaneous observations. However, the index suggested by our observations ($\alpha \sim -0.6$) is comparable to that ($\alpha = -0.7$) derived from the mean fluxes observed by van der Hucht et al. (1995). A map of the spectral index distribution, formed from dividing the MERLIN images after reducing the resolution of the 5-GHz image image to that at 1.6 GHz, indicates that the spectral index at the position of the northern component matches those above, identifying the northern component with the non-thermal source —consistent with its higher brightness temperature.

[6]Multi-Element Radio-Linked Interferometer Network operated by the University of Manchester's Nuffield Radio Astronomy Laboratories at Jodrell Bank.

A new optical spectrum of WR 146 in the blue was observed for us on 1994 November 11 with the INT[7] in the La Palma Service Observing programme. The broad emission lines, so conspicuous in the infrared, are almost washed out in this spectral region by an additional source of blue continuum radiation. We also observed $H\gamma$ and $H\delta$ in absorption, confirming the presence of an early-type companion to the WC6 star.

Infrared photometry in the UKIRT[8] and TCS[9] Service Observing programmes and millimetre photometry with the JCMT[10] give fluxes consistent with a stellar wind spectrum from the WC6 star. This fits well to the 5-GHz flux from the southern component, giving a power-law spectrum $S_\nu \propto \nu^{0.78}$.

3. A COLLIDING-WIND MODEL

The WC6 star is known to have a fast, dense wind and we assume the companion to have a wind velocity and mass-loss rate typical of an O type star. These two winds collide and are separated by a contact discontinuity, on either side of which there is a shocked region of gas. Electrons accelerated in these shocks are able to emit synchrotron radiation (e.g., Eichler & Usov 1993) and we propose this as the origin of the non-thermal emission from WR 146, i.e., component N. The size of the wind interaction region and non-thermal radio source are determined by the distance r_O of the contact discontinuity from the O star (Eichler & Usov 1993), which is related to the separation of the O and WC stars through the ratio of wind momenta $(\dot{M}v_\infty)_O\,/\,(\dot{M}v_\infty)_{WC}$ of the O and WC stars. For the WC star, we have $v_\infty = 2900$ km s^{-1} (Eenens & Williams 1994) and $\dot{M} = 3 \times 10^{-5}\ M_\odot$ y^{-1} from our 5-GHz flux for component S. For the O star, we assume $v_\infty = 1500$ km s^{-1} and $\dot{M} = 10^{-6}\ M_\odot$ y^{-1}. The disparity in mass loss rates and wind momenta makes r_O a small fraction (~ 0.12) of the separation, and places the interaction region close to the O star. The contact discontinuity between the winds takes the form of a "cap" of diameter πr_O, and height r_O on the side of the O star facing the WR star (Eichler & Usov). This model associates the interaction region with the radio component N and places the O star at the same position angle as N from S but, probably, at a greater projected separation than the $\sim$ 116 mas separation of the radio sources. For a separation $\gtrsim$ 116 mas, $r_O \gtrsim 13$ mas and the diameter of the contact discontinuity $\gtrsim$ 42 mas. The shocked regions and non-thermal radio source should be of comparable size. This accords well with our observation of the size (38 mas) of radio component N. This work will be reported in more detail in the MNRAS.

In this model for WR 146, the separation of the stars is sufficiently great that it should be measurable with the *Hubble Space Telescope*, thereby providing valuable input to colliding wind modelling. At our distance of 1.2 kpc, the separation of the stars is $\gtrsim$ 137 A.U., depending on inclination angle, implying a period $\sim$ 300 year for a 30 $M_\odot$ system. This would make WR 146 the longest-period colliding wind binary known!

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[7] Isaac Newton Telescope, operated at the Observatorio del Roque de los Muchachos, La Palma, by the Royal Observatories.

[8] United Kingdom Infrared Telescope, operated on Mauna Kea, Hawaii, by the Royal Observatories.

[9] Carlos Sánchez Telescope, operated at Teide Observatory, Tenerife, by the Instituto Astrofísica de Canarias.

[10] James Clerk Maxwell Telescope, operated on Mauna Kea, Hawaii, by the Royal Observatories.