VLA Observations of WR6: A Search for an Anisotropic Wind

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Abstract

The interaction between a stellar wind and its surrounding ISM can create HI cavities or bubbles. In particular, WR 6 shows a very large ovoidal HI bubble around it, whose shape cannot be explained in terms of the standard interstellar bubble theory and may require an anisotropic wind. We have studied this possibility using 3.6-cm VLA observations. We found no firm evidence supporting that WR 6 has a strong anisotropic wind. We conclude that our results are consistent with a classic thermal wind. Under this assumption we have determined the source size, its brightness temperature and its mass loss rate.

KEYWORDS: *Radio Continuum: Stars – Stars: Wolf-Rayet, Individual (WR6) – Stellar Winds*

1. Introduction

Strong winds from massive stars are moving supersonically with respect to the ambient gas, creating a so-called bubble or cavity. Because of their strong stellar winds Wolf-Rayet stars are the best candidates to form an HI cavity around them. Some studies have been carried out to examine the HI distribution around WR stars and to analyze the dynamics and energetic interactions between their stellar wind and the interstellar medium.

Arnal & Cappa (1996) examined the distribution of HI around WR 6. They concluded that the HI bubble is not expanding and that if the standard hydrodynamic stellar wind-blown bubble theory is to be retained in its original form, the most likely explanation is that the central star has a non-isotropic stellar wind.

2. Observations

We present four sets of observations taken with the Very Large Array (VLA) at 3.6-cm. The first observing run was carried out on July 25, 1996. At this epoch the array was in the D configuration giving the lowest angular resolution. The next three observing runs were made on November 25, December 21, 1996 and on January 12, 1997. During these epochs the array was in the A configuration giving an angular resolution of $\sim 0\rlap{.}''2$. The amplitude and phase calibrators were the same for all runs, 1328+307 and 0646-306, respectively. Bootstrapped flux densities for the phase calibrator as well as for WR 6 obtained from each observing run are shown in Table 1.

Table 1: Derived Flux Densities

Observing Run	**0646-306** S_ν [Jy]	**WR 6** S_ν [mJy]
July 25, 1996	0.804 ± 0.006	1.56 ± 0.03
November 26, 1996	0.867 ± 0.005	1.62 ± 0.03
December 21, 1996	0.875 ± 0.005	1.35 ± 0.03
January 12, 1997	0.880 ± 0.004	1.38 ± 0.03

The data analysis and reduction were performed using AIPS and following the standard VLA procedures for editing, calibrating and imaging.

3. Discussion

The presence of an anisotropic wind in WR 6 is important because it could be or could have been in the past related to the elongated HI bubble observed by Arnal & Cappa (1996) at a large scale. It was then important to resolve angularly the source both to detect any possible deviation from the spherical symmetry and to measure the brightness temperature that could help determine if the source has a classical thermal wind. Unfortunately, since the source is not clearly resolved in any of the data sets and it is fairly weak, it was not possible to determine its dimensions directly from our 3.6-cm maps (see Fig. 1).

However, White & Becker (1982) have shown that it is possible to determine the size of a source directly from the u, v data, assuming a spherically symmetric source. Besides, Escalante et al. (1989) have shown that for a marginally resolved wind source the observed flux density depends linearly on the projected

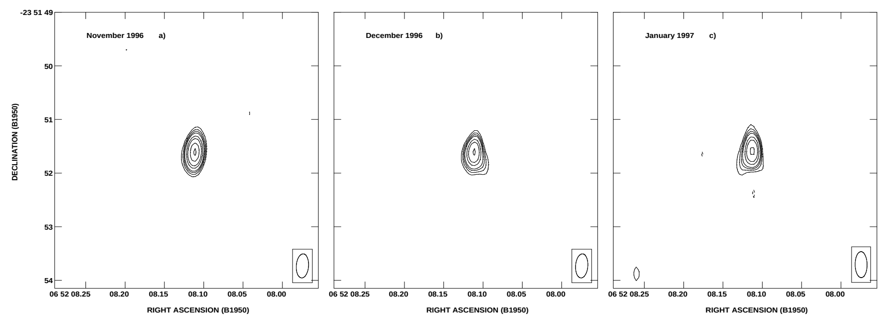

Figure 1: VLA CLEANed 3.6-cm maps for the three high resolution data sets. The maps were obtained with an intermediate *(u,v)* data weight (ROBUST=0). In all three maps the source appears practically unresolved (see beams at right bottom cormer).

baseline separation. Thus, it is possible to determine the source size by making a linear fit to the data in the u, v plane and furthermore to determine its brightness temperature from the same fit. A least squares fit was applied to the real part of all our high angular resolution data using the following equation:

$$V(b) = S_\nu \; (1 - A\,b) \tag{1}$$

where b is the projected baseline separation, given in wavelengths, S_ν is the total flux density, and A is the fitted slope. In our case we have obtained the following values for the slope and the total flux density: $A = 4.6 \pm \times 10^{-7}$ and $S_\nu = 1.52 \pm 0.03$ mJy. Thus, the angular diameter of the source within which half of the flux density is originated can be obtained from the equation:

$$\left[\frac{\theta}{''}\right] = 1.19 \times 10^5 \; A \tag{2}$$

while the brightness temperature is obtained from the relation:

$$\left[\frac{T_B}{10^4 \; K}\right] = \left[\frac{9.48 \times 10^{-15}}{A^2}\right] \; \left[\frac{S_\nu}{mJy}\right] \; \left[\frac{\lambda}{cm}\right]^2 \tag{3}$$

Both relations were derived by Escalante et al. (1989). Then using these expressions we obtained the angular size and the brightness temperature for

WR 6: $\theta = 0\farcs06 \pm 0\farcs01$ and $T_B = 9000 \pm 2500°K$. The angular size corresponds to a dimension of $\sim$ 100 AU at an assumed distance of 1.8 kpc. As we can see, the brightness temperature value is consistent with a classical thermal wind. Additional evidence comes from the spectral index $\alpha = 0.8 \pm 0.2$, obtained from the average of our observations and the 6-cm value of Hogg (1982). Finally, we have obtained the mass loss rate, $\dot{M} = 2.8 \pm 1.0 \times 10^{-5} M_\odot$ yr^{-1}, using the formulation of Panagia & Felli (1975) and a terminal wind velocity of 2700 km s^{-1}.

Then, regarding the main goal of our study, we have not found any firm evidence supporting the possibility of WR 6 having an anisotropic wind, at least one that is evident at scales of $0\farcs2$ or larger. Therefore we cannot provide evidence for a relation between an anisotropy in the stellar wind and the ovoidal shape of the HI cavity. Instead, our data appear consistent with an isotropic thermal wind. Besides, comparing the four flux densities that we have (Table 1), we found no clear evidence for large variability ($\leq$ 15%), in approximately 6 months.

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