# Radio emission from the Wolf-Rayet star HD 192163 in NGC 6888

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# RADIO EMISSION FROM THE WOLF-RAYET STAR HD 192163 IN NGC 6888

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## ABSTRACT

Radio observations with the VLA have confirmed the detection of radio emission at 6 cm from HD 192163, the Wolf-Rayet star which excites the ring nebulosity NGC 6888. The measured flux density of 1.6 ± 0.2 (rms) mJy implies a mass-loss rate for HD 192163 of $3 \times 10^{-5}\, M_\odot\, \mathrm{yr}^{-1}$.
*Subject headings:* stars: mass loss — stars: radio radiation — stars: Wolf-Rayet

## I. INTRODUCTION

During an investigation of the "ring nebula" NGC 6888[1], which is excited by the Wolf-Rayet star HD 192163[1] (Wendker *et al.* 1975), we made a tentative detection of a point source at the position of the star on our 6 cm map made with the Westerbork Synthesis Radio Telescope (WSRT). The estimated flux of 3.5 ± 1.5 mJy was consistent with that extrapolated from the infrared measurements (Hackwell, Gehrz, and Smith 1974) for a star which is losing mass at a rate of $\sim 2 \times 10^{-5}\, M_\odot\, \mathrm{yr}^{-1}$.

The filamentary nebulosity (NGC 6888) which surrounds HD 192163 is enriched in nitrogen (Parker 1978): this is to be expected if some of the gas is part of the material shed by HD 192163 in the process of its becoming a WR star. The nebula as a whole is expanding at a velocity of $\sim 80$ km s$^{-1}$ (Lozinskaya 1970). J. Dickel, R. Parker, and others at the workshop on supernova remnants (held at the Dominion Astrophysical Observatory in 1978 May; see Parker 1978) discussed the resemblance of NGC 6888 to the "stationary flocculi" observed in Cas A (Peimbert and van den Bergh 1971) and other supernovae. Thus is HD 192163 important not only in terms of the evolution of massive stars and their mass-loss rates but also as a possible presupernova. For these reasons we observed HD 192163 with the Very Large Array (VLA) of the NRAO[2] to confirm the detection of the radio emission.

## II. OBSERVATIONS

The high-resolution radio observations of the region centered on HD 192163 were made with the VLA in 1979 September. A total of 17 antennas was employed for the observations, but during the calibration and synthesis it was necessary to delete data from three of them. The observational parameters listed in Table 1 are those used in the actual synthesis. The standard procedures described in the VLA manual (Hjellming 1978) were used in the data reduction.

After calibrating, synthesizing, and cleaning the map, we obtain the flux density and position of the point source which are given in Table 2. We assume in the discussion that follows that this point source is identical to HD 192163 even though the positional difference of 1".3 is somewhat larger than those found in a similar survey by Abbott *et al.* (1979).

[1] NGC (Dreyer 1888), HD (Cannon and Pickering 1923).
[2] The NRAO is operated by Associated Universities, Inc., under contract with the United States National Science Foundation.

## III. DISCUSSION

### *a) Mass Loss*

The mass-loss rate $\dot{M}$ of HD 192163 can be estimated quite accurately from the measured flux density of its radio emission at 6 cm according to the formulation of Panagia and Felli (1975, eq. [24]):

$$\left(\frac{\dot{M}}{10^{-5}\, M_\odot/\mathrm{yr}}\right)^{4/3} = 0.195 \left(\frac{S_\nu}{\mathrm{mfu}}\right) \times \left(\frac{\nu}{10\ \mathrm{GHz}}\right)^{-0.6} \left(\frac{T_e}{10^4\ \mathrm{K}}\right)^{-0.1} \times \left(\frac{\mu}{1.2}\right)^{4/3} \left(\frac{v_{\mathrm{exp}}}{10^3\ \mathrm{km\ s^{-1}}}\right)^{4/3} \times \bar{z}^{-2/3} \left(\frac{d}{\mathrm{kpc}}\right)^2, \quad (1)$$

where $S_\nu$ is the flux density observed at frequency $\nu$, $T_e$ is the electron temperature, $\mu$ is the mean atomic weight per electron, $\bar{z}$ is the average ionic charge, $v_{\mathrm{exp}}$ is the expansion velocity, and $d$ is the distance of the source. For an envelope composed of doubly ionized helium which has a constant outflow velocity $v_{\mathrm{exp}}$ of 2500 km s$^{-1}$ (I.U.E. observations, Conti 1980), a $T_e$ of 7800 K (Cohen, Barlow, and Kuhi 1975), and distance of 1.45 kpc (Wendker *et al.* 1975), one calculates a mass-loss rate for HD 192163 of

$$\dot{M} = 3 \times 10^{-5} M_\odot\ \mathrm{yr}^{-1}. \quad (2)$$

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TABLE 1

PARAMETERS FOR THE VLA OBSERVATIONS AT 6 CENTIMETERS

| Parameters | Values |
|---|---|
| Frequency | 4885 MHz |
| Bandwidth | 50 MHz |
| HPBW Primary Beam | 9 arc minutes |
| Feeds | dual with orthogonal polariz. |
| Observing date | September 15, 1979 (I.A.T.) |
| No. of telescopes (used) in the Array | 14 |
| Range of Interferometer Spacings from Center of Array | .27 km only N. arm<br>.04 to 3.19 km E. arm<br>.48 km to 17.16 km W. arm |
| Field Center (epoch 1950) | $\alpha$ = $20^h\ 10^m\ 17.07^s$<br>$\delta$ = +38° 12' 15.55" |
| Field of View | 30 arc seconds |
| Scan Length on Source | 10 minutes |
| Scan Length on Calibrator | 4 minutes |
| HA Range for Source and Calibrator | $3^h$ E to $1^h$ W |
| Total Integration Time on Source | 2h $20^m$ |
| HPBW Synthesized Beam and Position Angle from North (major axis) | .75" x .50"<br>-40° |
| Rms Noise | .2 mJy |
| Calibrator: 2005 + 403 | |
| Position (epoch 1950) | $\alpha$ = $20^h\ 05^m\ 59.56^s \pm .004^s$<br>$\delta$ = +40° 21' 01.80" ± .05" |
| Flux density | 3.94 ± .04 Jy |
| Date of Flux Density Measurement | July 28, 1979 |

TABLE 2

OBSERVATIONS OF HD 192163*

| Parameters | Values |
|---|---|
| **From AGK 3*** | |
| HD 192163 | |
| Position (1950) | $\alpha$ = $20^h\ 10^m\ 17.126^s$<br>$\delta$ = +38° 12' 14.89" |
| Proper Motion | $\mu_\alpha$ = -.003"/year<br>$\mu_\delta$ = -.021"/year |
| **From VLA measurements - this paper** | |
| Point Source | |
| Position (1950) | |
| with no proper motion correction | $\alpha$ = $20^h\ 10^m\ 17.050^s \pm .005^s$<br>$\delta$ = +38° 12' 15.30" ± .05" |
| with $\mu_\alpha \mu_\delta$ of HD 192163 | $\alpha$ = $20^h\ 10^m\ 17.058^s$<br>$\delta$ = +38° 12' 15.93" |
| Position Relative to HD 192163 | $0.068^s$ or 0.8" West<br>1.04" North |
| Flux Density at 6 cm | 1.6 ± .2 mJy |
| **From Hackwell et al. (1974) and Gehrz et al. (1974)** | |
| HD 192163 | |
| Flux Density at 10 μm | 1.06 Jy |

* HD 192163 (Cannon & Pickering 1923) alias BD +37 3821 (Argelander 1903)
GC 28056 (Boss 1937) AGK3 + 381977 (Dieckvoss 1975)
SAO 69592 (Smithsonian Astrophysical Observatory 1966)

This is in agreement with the values determined from the infrared spectrum by Hackwell, Gehrz, and Smith (1974, adopting $v_{\rm exp} = 1000$ km s$^{-1}$, they found $\dot{M} = 2.1 \times 10^{-5}$) and from conservation of momentum arguments by Lozinskaya (1970, $\dot{M} = 2 \times 10^{-5}$).

### *b) Spectrum*

The spectrum of the free-free emission from an envelope of constant temperature, constant expansion velocity, and a density law $n_e \propto r^{-2}$ will behave as $\nu^{0.6}$. The flux densities at 10 $\mu$m and 6 cm in Table 2 indicate a steeper spectrum with a spectral index $\gamma$ close to 0.75. This change in $\gamma$ is not trivial: for example, an extrapolation of the measured 6 cm flux density of 1.6 mJy, assuming a spectral index of 0.6, predicts a 10 $\mu$m flux density 3.6 times smaller than that observed by Hackwell *et al.* (1974)—well outside the bounds of observational error. The observed steepening of the spectrum of HD 192163 is therefore real. It can be explained if the stellar wind is still undergoing acceleration in the region where most of the infrared emission originates. In this case, the density law will also be steeper there, i.e., $n_e \propto r^{-\alpha}$ with $\alpha > 2$ (see discussions of Panagia and Felli 1975 and of Wright and Barlow 1975). The spectrum of P Cygni illustrates this behavior (Fig. 4 of Barlow and Cohen 1977): it falls off rather steeply in the infrared, with $\gamma \sim 0.95$ implying an $\alpha \sim 2.5$, but then flattens so that in the radio region where the velocity has presumably attained the maximum expansion velocity and remains constant, one finds $\gamma \sim 0.6$ and $\alpha \sim 2$.

### *c) Angular Size*

Using the same parameters as before for HD 192163, we find the angular size of the radio emitting region at 6 cm (see Panagia and Felli 1975, eq. [26]) to be $\Theta \sim 0''.05$. Indeed, the source is a point source at 6 cm as seen with the VLA. The corresponding radius of the emitting region is $\sim 10^{15}$ cm.

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*Note added in proof.*—A. Willis and M. Barlow have recently measured the 10 $\mu$m flux density of HD 192163 to be 1.16 Jy, which raises the $\delta$ to 0.76. They also inform us that the electron temperature is probably closer to 40,000 K (see *IAU Symposium No. 83, Mass Loss and Evolution of O-Type Stars*, ed. P. S. Conti and C. H. W. de Loore [Dordrecht: Reidel], p. 119) so that $M$ is reduced to $2.6 \times 10^{-5}$ $M_\odot$ yr$^{-1}$ and the radius and angular radius are reduced by a factor of 2.09.