

# OBSERVATIONS OF NEUTRAL AND IONIZED GAS OF THE WR RING NEBULA NGC 2359

C. E. Cappa<sup>1</sup>

Instituto Argentino de Radioastronomía, Villa Elisa, Argentina  
and Facultad de Ciencias Astronómicas y Geofísicas, Universidad Nacional de La Plata, Argentina

W. M. Goss

National Radio Astronomy Observatory, P.O. Box 0, Socorro, NM 87801, USA

V. S. Niemela<sup>2,3</sup> and P. G. Ostrov<sup>2</sup>

Facultad de Ciencias Astronómicas y Geofísicas, Universidad Nacional de La Plata, Argentina

## RESUMEN

Investigamos la distribución del material neutro e ionizado en la región de la nebulosa anillo óptica NGC 2359 alrededor de la estrella Wolf-Rayet HD 56925. Nuestro estudio se basa en observaciones de la línea de 21 cm del HI y del continuo de radio en 20 cm obtenidos con el Very Large Array (VLA, NRAO). La emisión en el continuo de radio muestra muy buena correlación con la emisión de la nebulosa en líneas ópticas. Los datos de HI revelan por primera vez la presencia de hidrógeno neutro claramente asociado a NGC 2359. Con estas observaciones determinamos los principales parámetros físicos de la región HII.

## ABSTRACT

We investigated the distribution of neutral and ionized material in the region of NGC 2359, the optical nebular ring around the Wolf-Rayet star HD 56925. We used 21 cm line and 20 cm continuum radio observations with the Very Large Array. The radio continuum shows very good correlation with the optical line emission. The HI data reveal for the first time the presence of neutral hydrogen clearly associated to NGC 2359. We determine the main physical parameters of the HII region.

*Key Words:* **ISM: RING NEBULAE, NGC 2359 — STARS: INDIVIDUAL (HD 56925) — STARS: WOLF-RAYET**

## 1. INTRODUCTION

NGC 2359, a HII region located at a distance of 5 kpc from the Sun (Goudis et al. 1994), appears as a ring like nebula surrounding HD 56925, a Wolf-Rayet (WR) star of type WN4. The nebula consists of a filamentary shell, a southern *bar* and streamers of diffuse gas (cf. Schneps et al. 1981 = SHWB). Here we report the results of HI 21-cm line and radio continuum observations in the direction of NGC 2359.

## 2. OBSERVATIONS

Our observations were performed with the Very Large Array (VLA) synthesis telescope of the NRAO<sup>7</sup>.

<sup>1</sup>Member of Carrera del Investigador, CONICET, Argentina.

<sup>2</sup>Visiting Astronomer, CTIO, NOAO, operated by AURA, Inc., under cooperative agreement with NSF.

<sup>3</sup>Member of Carrera del Investigador, CIC, Prov. Buenos Aires, Argentina.

<sup>4</sup>NRAO is a facility of NSF operated under cooperative agreement by AUI.

The radio continuum image, obtained at 1465 MHz using the C-and D-arrays, has an angular resolution of  $\sim 30''$  and covers a region of 30 arcmin. The HI 21-cm line data, obtained with the D-configuration, cover the same region with angular and velocity resolutions of  $\sim 45''$  and  $1.3 \text{ km s}^{-1}$ .

In addition, optical CCD images through narrow band filters centered at the nebular emission lines of H $\alpha$ , [O III] and [S II], were obtained with the Curtis-Schmidt Telescope at the Cerro Tololo Interamerican Observatory (CTIO), Chile. These images are  $\sim 30$  arcmin square.

TABLE 1  
PHYSICAL PARAMETERS OF THE IONIZED GAS IN NGC 2359

| Component          | $S$<br>(Jy) | $EM$<br>( $10^3 \text{ pc cm}^{-6}$ ) | $f$     | $n_e$<br>( $\text{cm}^{-3}$ ) | $M_i$<br>( $M_\odot$ ) |
|--------------------|-------------|---------------------------------------|---------|-------------------------------|------------------------|
| Shell              | 0.85        | 3.8                                   | 0.03    | 120                           | 70                     |
| Southern bar       | 0.58        | 9.0                                   | 0.3-0.5 | 60                            | 95-120                 |
| Streamers          | 0.78        | 3.6                                   | 1       | 10-50                         | 105-280                |
| Surrounding region | 0.38        | 0.3                                   | 1       | $\sim 3$                      | $\sim 600$             |

3. RESULTS

The radio continuum image of NGC 2359 shows an excellent correspondence with the optical features. Table 1 lists the parameters obtained from our VLA observations, namely the flux density  $S$ , the emission measure  $EM$ , the electron density  $n_e$  and the ionized mass  $M_i$  together with the volume filling factor  $f$  derived for the filamentary shell, the southern bar, the streamers, and the weak radio continuum emission region that surrounds the ring nebula.

The amount of ionized gas in the filamentary shell indicates that it mostly consists of swept-up interstellar gas. The excitation parameter derived for NGC 2359 shows that HD 56925 alone suffices to ionize the gas.

The analysis of the HI 21-cm line images reveals features related to the ring nebula within the (LSR) velocity range from 41 to 67  $\text{km s}^{-1}$ . Two HI structures appear most clearly related to the nebula. One of them, detected at the systemic velocity of 54  $\text{km s}^{-1}$ , appears as an arc-like feature that closely surrounds the northern part of the streamer pointing to the NW, the eastern region of the filamentary shell and the southern region of the bar. This HI feature indicates the location of the ionization front, similar to the optical [N II] emission, and seems also to be related to molecular gas at the same velocity (SHWB). A second HI structure, observed at 63  $\text{km s}^{-1}$ , consists of clumps that surround a major part of the shell and the southern bar of NGC 2359. In addition, relatively extended emission probably connected to NGC 2359 is observed within the velocity intervals 41 to 50 and 62 to 67  $\text{km s}^{-1}$ .

The mass of neutral gas associated with NGC 2359 is  $\simeq 320 M_\odot$  while the ionized, neutral and molecular material in the region amounts to  $\approx 2200 M_\odot$ .

The dynamics of the nebula are consistent with momentum conservation or with an intermediate case between energy and momentum conservation.

Our results are in general agreement with the scenario for NGC 2359 described by Dufour (1989).

REFERENCES

Dufour, R. 1989, RevMexAA, 18, 87  
Goudis, C., Christopoulou, P. E., Meaburn, J., & Dyson, J.E. 1994, A&A, 285, 631  
Schneps, M. H., Haschick, A. D., Wright, E. L., & Barrett, A. H. 1981, ApJ, 243, 184