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MOLECULAR OBSERVATIONS OF THE ENVIRONS OF THE OXYGEN W-R STAR WR 102

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RESUMEN

Mediante observaciones de ^{12}CO (J=1→ 0) llevadas a cabo en la dirección de la estrella WR 102 se han encontrado dos concentraciones moleculares muy probablemente vinculadas a la misma. Una se encuentra a una velocidad radial de 24 km s^{-1} y la otra a 13 km s^{-1}. La primera posee una clara correlación morfológica con la fuente de continuo (G2.4+1.4) relacionada con WR 102 mientras que la segunda se observa proyectada sobre la misma. Esta última representaría material molecular acelerado por los fuertes vientos estelares de WR 102. La masa molecular involucrada en ambas estructuras es del orden de 760 masas solares.

ABSTRACT

^{12}CO (J=1→ 0) observations towards WR 102 and its associated nebula (G2.4+1.4) revealed the presence of two molecular concentrations associated with them. The radial velocity of these concentrations are 24 and 13 km s^{-1}, respectively. The former represents the molecular cloud envisaged in the model of Dopita and Lozinskaya, whilst the latter may be molecular gas accelerated towards the observer by the strong stellar winds. The total amount of molecular gas in this complex is about 760 solar masses.

Key Words: ISM: individual (WR 102) — ISM: molecules — stars: individual (WR 102) — stars: Wolf-Rayet

1. INTRODUCTION

Stars in the Wolf-Rayet (WR) phase are in the last evolutionary stage of massive stars. Among the 227 WR stars known in the Galaxy, there are two extreme objects, WR 102 and WR 142, classified as oxygen WR stars (WO) (van der Hucht 2001). WR 102(≡Sand 4) is associated with the ring nebula G2.4+1.4. Based on high resolution VLA data of this nebula, Goss & Lozinskaya (1995) derived a spectral index $\alpha = -0.15\pm0.2$ ($S_\nu \propto \nu^\alpha$). Dopita et al. (1990) and Dopita & Lozinskaya (1990, hereafter DL) carried out detailed studies of WR 102 and G2.4+1.4. They derived a distance of 3±1 kpc for WR 102. As regards to G2.4+1.4, they concluded that this nebula is being photo-ionized by the strong radiation field of the WR star. Based on high-resolution [OIII] 5007 Å data they find two distinct velocity features. One of them was identified with an approaching ionized shell having an expansion velocity of 48±3 km s^{-1} while the other shows no systematic expansion velocity. The latter has a radial velocity[3] of 24.6±3.7 km s^{-1}. Based on this, DL concluded that *"the filamentary shell of G2.4+1.4 is roughly hemispherical and is blowing out from the near surface of a dense cloud located to the southeast"*. DL locate this cloud on the far side of G2.4+1.4, preventing in this way the receding part of G2.4+1.4 from expanding.

In order to verify the DL model, ^{12}CO (J=1 → 0) observations were carried out towards WR 102 using the 4 meter NANTEN radiotelescope at Las Campanas, Chile. The angular resolution of this instrument is 2.7 arcmin, the velocity resolution is 0.055 km s^{-1} and the velocity coverage ∼ 112 km s^{-1}. The backend was centered at a radial velocity of −20 km s^{-1} and the integration time was 16 s. An absolute intensity calibration was made by observing Orion KL and ρ Oph East. After calibration and hanning smoothing the data, the final rms noise was 0.35 K. A total of 289 positions were observed toward WR 102. A square raster map, 32.4 arcmin in size, centered at the optical position of WR 102 was observed. Within the observed area the points have different spacing. An innermost square grid 21.6 arcmin in size was fully sampled, while elsewhere the grid spacing was one beamwidth.

2. RESULTS

Figure 1 shows the CO distribution at 24 km s^{-1} overlying a VLA radio continuum image of G2.4+1.4. There is a very good agreement between the molecular gas and the southern border of the radio continuum source. This molecular concentration

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[3]All radial velocities are referred to the Local Standard of Rest (LSR).

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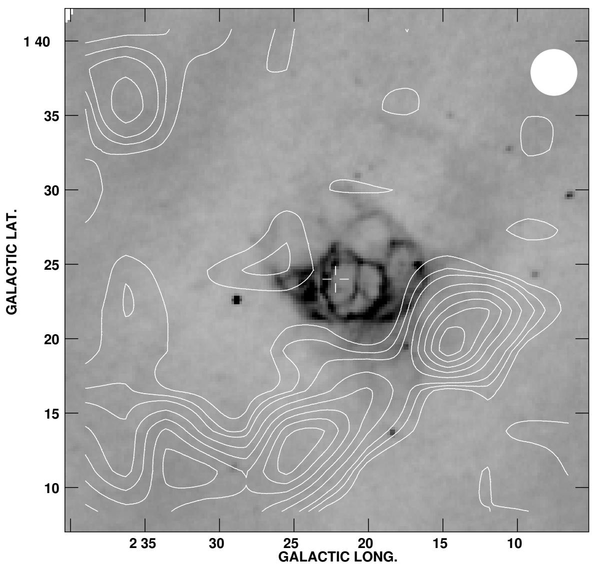

Fig. 1. Carbon monoxide distribution at 24 km s^{-1} (contour lines) overlying a 1.49 GHz VLA radio continuum image (grey scale) of G2.4+1.4. The CO NANTEN beam is given by the filled circle seen on the upper right corner of the image. The position of WR 102 is marked by a white cross. The lowest contour is 0.14 K (3σ). The contour spacing is 0.14 K till 0.42 K and 0.28 K from there onwards.

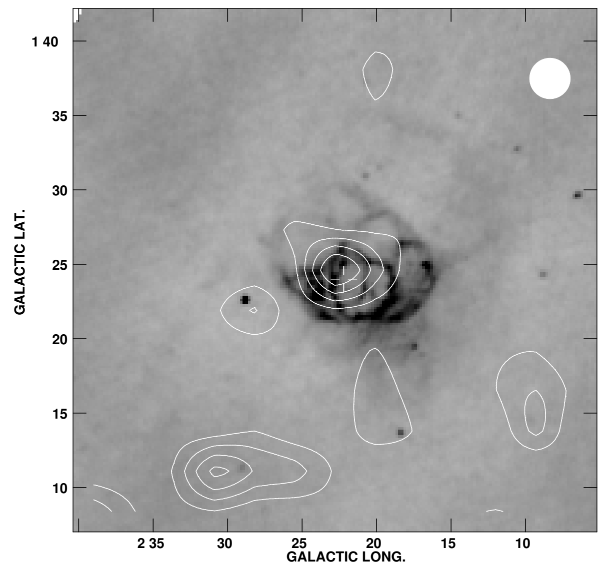

Fig. 2. Carbon monoxide distribution at 13 km s^{-1} (contour lines) overlying a 1.49 GHz VLA radio continuum image (grey scale) of G2.4+1.4. The position of WR 102 is marked by a white cross. The lowest contour and the contour spacing are 0.28 K (6σ).

is found at exactly the position where DL predicted the presence of a dense molecular cloud. This cloud is being eaten away by the photo-ionization front created by the radiation field of WR 102. The CO image shown in Figure 1 spans a velocity range of ~3.6 km s^{-1} (33 individual CO channel maps) and has an rms noise level (3σ) of $\sim$ 0.2 K. Using the integrated CO line intensity, W_{CO}, and an H_2 column density to W_{CO} ratio of $(2.3 \pm 0.3) \times 10^{20}$ mol cm^{-2} (K km $s^{-1})^{-1}$ (Strong et al. 1988), a mean molecular hydrogen column density of $(6.7{\pm}0.3){\times}10^{20}$ mol cm^{-2} is obtained. Adopting a mean molecular weight per H_2 of 2.76m_H, a total mass and a mean H_2 volume density of $\sim$ 450 $M_{\odot}$ and $\sim$ 15 cm^{-3} are derived. A distance of 3 kpc is assumed.

Striking enough, there is no CO emission all over the face of G2.4+1.4 above the 3σ rms noise level of 0.2 K. What may be then preventing the far side of G2.4+1.4 from expanding away from the observer? An undetected molecular cloud might be the answer. Following the procedure mentioned above, the lack of CO emission across the face of G2.4+1.4 is compatible with the presence of a molecular concentration whose total mass is lower than 250 $M_{\odot}$. More sensitive CO observations are needed to clarify this point.

At lower velocities (13 km s^{-1}) a small CO concentration is observed right on top of G2.4+1.4 (see Figure 2). Though a chance coincidence along the line of sight of an otherwise unrelated CO feature can not be ruled out (the probability of a chance coincidence is $\sim$ 0.05), it is likely that this feature represents molecular gas that has been driven to its observed radial velocity by the powerful stellar winds of WR 102. The total mass of this concentration is $\sim$ 310 $M_{\odot}$ and its mean volume density~40 cm^{-3}. The mean linewidth of the CO features arising from this cloud is $\sim$ 2.4 km s^{-1} indicating that this gas is being affected by the interaction of the WR star with this cloud. The mean radial velocity of this feature is 12.6 $\pm$ 0.6 km s^{-1}.

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