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THE ASYMMETRIC PROFILE OF THE H76α LINE EMISSION FROM MWC349

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RESUMEN

Reportamos observaciones hechas con el *VLA* de la línea de recombinación H76α proveniente de la envolvente ionizada de MWG349. El perfil es asimétrico con una subida empinada en el lado azul. Discutimos si la asimetría se debe a alejamientos de equilibrio termodinámico local en la formación y transferencia de la línea o a la morfología bipolar de la envolvente. Determinamos la temperatura electrónica de la envolvente mediante dos técnicas independientes, obteniendo en ambos casos valores consistentes con $T_e \simeq 9000$ K.

ABSTRACT

We report *VLA* observations of the H76α recombination line from the ionized envelope of MWC349. The line is asymmetric, with a steep rise on the blue side. We discuss whether this asymmetry is due to non-LTE effects in the formation and transfer of the line or to the bipolar morphology of the source. The electron temperature of the ionized envelope was determined by two independent techniques, obtaining in both cases values consistent with $T_e \simeq 9000$ K.

Key words: **RADIO SOURCES – STARS-EMISSION LINE**

I. INTRODUCTION

The emission-line star MWC349 has been the subject of several studies in the radio, infrared, and optical domains. Its continuum spectrum fits well a $\nu^{0.6}$ power law from the cm wavelengths to the far-IR (Dreher and Welch 1983). This result suggests that the electron density in the ionized envelope of MWC349 has an inverse square law dependence with radius (Schmid-Burgk 1982; Reynolds 1986). The high-angular resolution 2-cm *VLA* map of White and Becker (1985) revealed that the radio source has a bipolar geometry. They suggested that MWC 349 is an edge-on bipolar nebula with a very hot central star.

The massive stellar wind that is responsible for the continuum emission has a very low terminal velocity, $v_\infty \simeq 50$ km s^{-1} (Hartmann, Jaffe, and Huchra 1980). The relative high intensity and narrow width of the lines from the envelope of MWC349 enabled Altenhoff, Strittmatter, and Wendker (1981) to detect the H76α and H66α lines. That was the first time that radio recombination lines were detected from a stellar wind. In this paper we present observations of the H76α line made with higher signal-to-noise ratio. In §II we describe the observations, while in §III we discuss them and present our conclusions.

II. OBSERVATIONS

The H76α line (ν = 14689.991 MHz) and adjacent continuum observations were made in 1984 August 19 and 20 with the *Very Large Array* of the NRAO[3]. The amplitude calibrator was 3C286, for which a 2-cm flux of 3.48 Jy was adopted. The phase calibrator was 2005+403 and as bandpass calibrators we observed 3C84 and 3C273. The bootstrapped fluxes of these calibrators were 5.4 ± 0.1 Jy (2005+403), 74.7 ± 1.8 Jy (3C84), and 46.9 ± 1.1 Jy (3C273). These fluxes are about 30 percent higher than values recorded previously in the *VLA* calibrator manual. This discrepancy was probably due to poor weather conditions during the observations of 3C286. We have corrected all fluxes for MWC349 dividing them by 1.3. It is important to note that the line-to-continuum ratio is not affected by this calibration problem since line and continuum are measured simultaneously. The data were calibrated using the standard *VLA* procedures. A continuum channel (channel 0) recorded the flux of the central 75 percent of the total bandwidth of 12.5 MHz. This continuum channel has a negligible line contamination. The visibility data (flux versus baseline) for the continuum channel is shown in Figure 1. Our data sample short spacings and match reasonably well with the longer baseline observations of White

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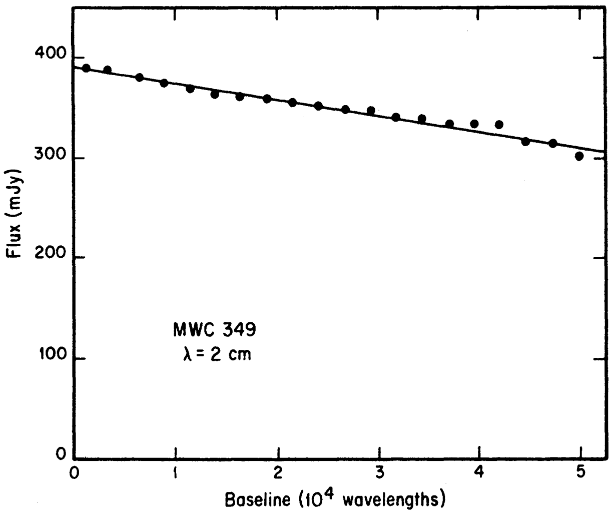

Fig. 1. Visibility data (flux versus baseline) for the 2-cm continuum from MWC349. The solid line is the linear fit described in the text.

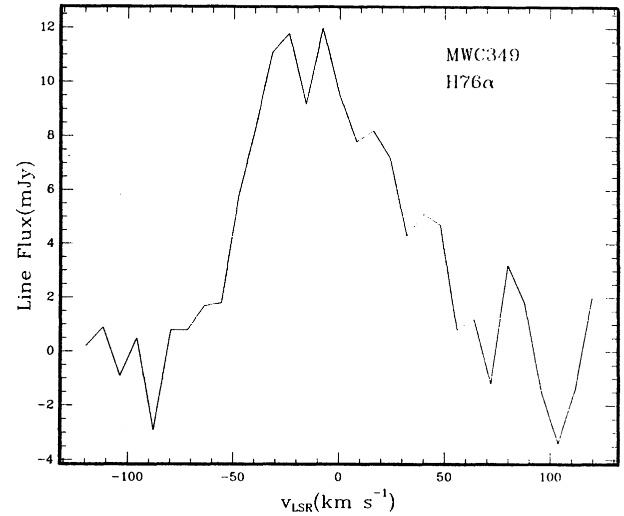

Fig. 2. Spectrum of the H76α line emission from MWC349. The velocity resolution is 8 km s^{-1}.

and Becker (1985). Following White and Becker (1982), we use the visibility data to estimate the electron temperature of the wind. This treatment is valid for spherically symmetric sources while MWC349 is, when observed with high angular resolution, bipolar. However, our data do not resolve the bipolar structure and the spherically symmetric treatment seems adequate.

It can be shown that the visibility function of an isothermal stellar wind is approximately linear for small projected baseline distances, b (see Appendix). We can then fit our data with an expression of the form

$$V(b) = S_\nu(1 - Ab),$$

where S_ν is the total flux (the visibility at zero spacing) and A is the slope of the fit. The electron temperature of the wind is then given by (see Appendix)

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

The linear fit to the visibility data, shown in Figure 1, gives S = 390 mJy and A= 3.99 X 10^{-6}. From the last equation we obtain T_e = 9300 ± 1000 K, in reasonable agreement with the determination of White and Becker (1985), who used visibilities taken over a larger baseline range.

The spectral data were recorded in 31 channels, 390 kHz wide each. The observations were made with on-line Hanning weighting applied, providing a velocity resolution of 8.0 km s^{-1}. After applying the bandpass correction, individual maps for each channel were made by Fourier transformation of the (u,v) data with natural weighting. A line plus continuum spectrum was obtained from the peak values of each map. This spectrum is nearly identical to that obtained using the program PASSUM, which vector averages all spectra obtained by every antenna pair. A linear baseline was subtracted to obtain the line spectrum shown in Figure 2. Our H76α spectrum is consistent with that obtained with the Effelsberg 100-m antenna by Altenhoff *et al.* (1981). However, our higher signal-to-noise ratio spectrum shows that the profile is asymmetric, with a steep rise on the blueshifted side. The average continuum adjacent to the line is 326 mJy and the integrated area under the line is 890 mJy km s^{-1}. Assuming local thermodynamic equilibrium, and a pure hydrogen, isothermal nebula, we can estimate the electron temperature from the line-to-continuum ratio (Altenhoff *et al.* 1981; Rodríguez 1982) from the H76α and continuum measurements:

$$\left[\frac{T_e}{10^4\ K}\right] = 2.2\left(\left[\frac{S_c}{mJy}\right]\left[\frac{\Sigma S_L\ \Delta v}{mJy\ km\ s^{-1}}\right]^{-1}\right)^{0.87} .$$

From this equation we find T_e = 9200 ± 1200 K, in good agreement with the value from the continuum visibility analysis. This agreement suggests that the LTE assumption is not inconsistent with the data. We also fitted by least-squares a Gaussian to our spectrum, obtaining S_L = 11.2 ± 0.8 mJy, v_{LSR} = −9.4 ± 2.6 km s^{-1}, and Δv = 76 ± 6 km s^{-1}.

III. THE ASYMMETRIC PROFILE: POSSIBLE CAUSES

The H76α profile observed by us (Figure 2) is asymmetric. In contrast, radio recombination line profiles of

H II regions are, within the observational noise, generally symmetric (e.g., Lichten, Rodríguez, and Chaisson 1979; Garay, Reid, and Moran 1985). We can think of two basic reasons for the profile asymmetry. The first is that the asymmetry is mainly due to unequal amounts of approaching and receding gas. However, the radio continuum map of White and Becker (1985) shows considerable symmetry between the two lobes.

A second possible reason for the asymmetry is the presence of significant LTE departures. Rodríguez (1982) has shown that for an isothermal, symmetic envelope in LTE the line profile will be symmetric regardless of optical depth effects. Non-LTE calculations carried out by Viner, Vallée, and Hughes (1979) predict an asymmetric profile that bears resemblance to the MWC349 profile. They attributed the asymmetry to the attenuation of the far side emission of the source by continuum opacity of the near side.

Another possibility is that the wind is not isothermal. This could explain why the integrated line intensity is in good agreement with the expected LTE value although the line profile is asymmetric. In this case, the obtained temperature is a spatial average of a variable LTE temperature.

We believe that these possibilities could be explored further with a high angular resolution map of the radio recombination line emission from MWC349. Under the asymmetry hypothesis one expects, to first approximation, symmetric profiles for any given point in the nebula, but different total intensity for the blueshifted and redshifted gas. In other words, the asymmetric profile can be considered as the superposition of two symmetric profiles of different intensities and velocities. On the other hand, under the non-LTE hypothesis one would expect that the asymmetric-line emission will be present all across the face of the nebula.

In summary, we presented H76α line and 2-cm continuum *VLA* observations of MWC349. We determined the electron temperature of the ionized envelope with two techniques, finding in both cases $T_e = 9000$ K. The H76α profile is asymmetric, and we briefly discussed possible explanations for this asymmetry. Mapping of the radio recombination line emission is required to advance in our understanding of this peculiar object.

REFERENCES

Altenhoff, W.J., Strittmatter, P.A., and Wendker, H. J. 1981, *Astr. and Ap.*, **93**, 48.
Dreher, J.W. and Welch, W. J. 1983, *A.J.*, **88**, 1014.
Garay, G., Reid, M.J., and Moran, J.M. 1985, *Ap. J.*, **289**, 681.
Hartmann, L., Jaffe, D., and Huchra, J.P. 1980, *Ap. J.*, **239**, 905.
Lichten, S.M., Rodríguez, L.F., and Chaisson, E.J. 1979, *Ap. J.*, **229**, 524.
Reynolds, S.P. 1986, *Ap. J.*, **304**, 713.
Rodríguez, L.F. 1982, *Rev. Mexicana Astron. Astrof.*, **5**, 179.
Schmid-Burgk, J. 1982, *Astr. and Ap.*, **108**, 169.
Viner, M.R., Vallée, J. P., and Hughes, V.A. 1979, *Ap. J. Suppl.*, **39**, 405.
White, R.L. and Becker, R.H. 1982, *Ap. J.*, **262**, 657.
White, R.L. and Becker, R.H. 1985, *Ap. J.*, **297**, 677.

APPENDIX
SHORT-SPACING APPROXIMATION FOR THE VISIBILITY OF AN IONIZED STELLAR WIND

Following White and Becker (1982), the visibility of an isothermal, spherically symmetric ionized wind is given by

$$V(b) = \int_0^\infty 2\pi\theta \, d\theta \, I_\nu(\theta) J_0(2\pi b\theta) = S_\nu g(\theta_1 b),$$

where b is the projected baseline in wavelengths, θ is the angular displacement in radians, I_ν is the intensity of the radiation, J_0 is the Bessel function of order zero, S_ν is the total flux, and θ_1 is given by

$$\theta_1^2 = S_\nu \, \lambda^2/(5.356\pi k T_e),$$

where k is Boltzmann's constant, λ is the wavelength, and T_e is the electron temperature of the wind. The function g is given by

$$g(y) = \int_0^\infty x \, dx \, J_0(2\pi xy)[1 - exp(-1/x^3)]/1.339.$$

Near $y = 0$ we have

$$g(y) \simeq g(0) + \left.\frac{dg(y)}{dy}\right|_{y\to 0^+} y$$

where $g(0) = 1$ and

$$\frac{dg(y)}{dy} = -\int_0^\infty x^2 \, dx \, 2\pi \, J_1(2\pi xy)[1 - exp(-1/x^3)]/1.339.$$

We define $z = 2\pi xy$ to obtain

$$\frac{dg(y)}{dy} =$$

$$-\int_0^\infty (z^2 \, dz/4\pi^2 y^3) \, J_1(z)[1 - exp(-(2\pi y)^3/z^3)]/1.339.$$

Expanding the exponential term we obtain

$$\left.\frac{dg(y)}{dy}\right|_{y\to 0^+} =$$

$$-\int_0^\infty [(2\pi \, J_1(z))/(1.339z)]dz = -(2\pi/1.339).$$

We then have

$$V(b) \simeq S_\nu(1 - (2\pi/1.339)\theta_1 b),$$

and making

$$A = (2\pi/1.339)\theta_1,$$

we obtain

$$V(b) = S_\nu(1 - Ab).$$

Finally, the electron temperature of the stellar wind can be derived from

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

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