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A SUBARCSECOND RADIO BINARY ASSOCIATED WITH AFGL 4029-IRS1

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RESUMEN

Presentamos observaciones sensitivas y de alta resolución angular (0.″3) hechas a 3.6-cm con el Conjunto Muy Grande de Radiotelescopios (Very Large Array) hacia la fuente infrarroja brillante AFGL 4029. Encontramos que la fuente de radio G138.295+1.555, asociada con AFGL 4029-IRS1, es de hecho una binaria con separación de 0.″6 aproximadamente en la dirección norte-sur. Tambien hay emisión más débil extendiéndose en la dirección este-oeste emanando de G138.295+1.555(S), la componente sureña de la binaria. En base a este resultado, identificamos a G138.295+1.555(S) como la excitadora del flujo óptico y molecular observado en la región. G138.295+1.555(S) parece ser una de las pocas estrellas masivas jóvenes asociadas con un flujo colimado. La componente norteña de la binaria, G138.295+1.555(N), parece mostrar variabilidad en el tiempo y se propone que está asociada con una estrella T Tauri. La fuente G138.300+1.558, asociada con AFGL 4029-IRS2, es una región H II ultracompacta de morfología cometaria, posiblemente ionizada por una estrella tipo B1 ZAMS.

ABSTRACT

We present sensitive, high angular resolution (0.″3) Very Large Array observations made at 3.6-cm of the bright infrared source AFGL 4029. We find that the radio source G138.295+1.555, associated with AFGL 4029-IRS1, is actually a subarcsecond binary separated by 0.″6 approximately in the north-south direction. There is also fainter emission extending in the east-west direction and emanating from G138.295+1.555(S), the southern component of the binary. We then identify G138.295+1.555(S) as the exciting source of the optical and molecular outflow observed in this region. G138.295+1.555(S) appears to be one of the few massive young stars associated with a collimated outflow. The northern component of the binary, G138.295+1.555(N), appears to exhibit time-variable radio emission and is proposed to be associated with a T Tauri star. The source G138.300+1.558, associated with AFGL 4029-IRS2, is an ultracompact H II region of cometary morphology, possibly ionized by a B1 ZAMS star.

Key Words: **RADIO CONTINUUM: STARS — STARS: FORMATION — ISM: H II REGIONS — ISM: INDIVIDUAL (AFGL 4029) — ISM: JETS AND OUTFLOWS**

1. INTRODUCTION

AFGL 4029 is a bright infrared source (Price & Walker 1976) embedded in the bright-rimmed molecular cloud IC 1848A. Beichman (1979) showed that there are two main sources of 10–20 μm emission in the region: AFGL 4029-IRS1 and AFGL 4029-IRS2, separated by about 20″ in the east-west direction. Kurtz, Churchwell, & Wood (1994) detected the centimeter continuum sources G138.295+1.555 and G138.300+1.558, associated respectively with AFGL 4029-IRS1 and AFGL 4029-IRS2.

In a detailed optical and near-infrared study of the region, Deharveng et al. (1997) found that it harbors a cluster of massive young stars. They concluded that the most massive star of the cluster ionizes the ultracompact H II region G138.300+1.558. They also proposed that AFGL 4029-IRS1 (associ-

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TABLE 1

PARAMETERS OF THE 3.6-cm SOURCES DETECTED

Source	$\alpha(1950)^a$ (h m s)	$\delta(1950)^a$ (° ′ ″)	Size (″)	Flux Density (mJy)
G138.295+1.555(S)	02 57 34.58	60 17 23.0	≤0.2	0.25±0.02
G138.295+1.555(N)	02 57 34.60	60 17 23.6	≤0.2	0.20±0.02
G138.300+1.558	02 57 37.61	60 17 23.7	∼2	5.0±0.1

[a] Positional error is ∼0.″1.

ated with the radio source G138.295+1.555) is the youngest object in the cluster, with a luminosity of $\sim 10^4$ $L_\odot$ and obscured by 25–30 magnitudes of visual extinction. We refer the reader to Deharveng et al. (1997) for a detailed description of the region. After these authors we will adopt a distance of 2.2 kpc.

AFGL 4029-IRS1 shows strong evidence of outflow activity. Snell et al. (1988) found a compact ($\leq 2'$) bipolar outflow in the J = 1–0 rotational transition of CO with a momentum flux of $\sim 2\times10^{-4}$ $M_\odot$ km s^{-1} yr^{-1}. Ray et al. (1990) discovered an HH-like optical jet emanating from this source and extending about 15″ to the west. The optical jet reaches radial velocities of up to −500 km s^{-1} and has a momentum flux of $\sim 2\times10^{-3}$ $M_\odot$ km s^{-1} yr^{-1}.

In this paper we present new observations of the region at 3.6-cm that reveal that G138.295+1.555 is a subarcsecond binary and permit us to pinpoint the source of the outflow.

2. OBSERVATIONS AND RESULTS

The observations were made with the Very Large Array (VLA) of NRAO[2] in the continuum mode at 3.6-cm during 1997 January 5. At that epoch, the VLA was in the A configuration, providing an angular resolution of ∼0.″3. The absolute amplitude calibrator was 1328+307 and the phase calibrator was 0241+622, with a bootstrapped flux density of 0.884±0.003 Jy. The data were calibrated, edited, and imaged using the software AIPS of NRAO.

We detected emission associated with G138.295+1.555 and G138.300+1.558, previously reported by Kurtz et al. (1994) and Carral et al. (1999). The high angular resolution and sensitivity of our data reveal new features of these sources that have not been reported previously.

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2.1. *G138.295+1.555*

This source is the one associated with AFGL 4029-IRS1. Our maps (see Figure 1) show that it actually is a double source, with components separated by 0.″6 approximately in the north-south direction. We refer to these components as G138.295+1.555(N) and G138.295+1.555(S) and we propose that they are tracing the components of a binary system with projected separation of ∼1300 AU. The parameters of the components of this radio binary are given in Table 1. In addition, fainter emission extending in the east-west direction is also observed. Since the orientation of this fainter emission is very similar to that of the optical jet seen at larger scales by Ray et al. (1990), we suggest that it is the "base" of this ionized outflow. The outflow seems to emanate from G138.295+1.555(S), the southern component of the binary.

We believe that the northern component of the radio binary could be time variable. The total 3.6-cm flux density of G138.295+1.555(S) plus G138.295+1.555(N) in our 1997 January 5 observations is 0.45±0.03 mJy (see Table 1), in reasonable agreement with the flux density of 0.6±0.1 mJy found by Carral et al. (1999) from VLA observations made on 1994 January 11 at the same wavelength. However, the observations of Kurtz et al. (1994) taken with the VLA on 1989 March 19, also at 3.6-cm, give a total flux density of 2.1±0.1 mJy, well above the other two values. The Carral et al. (1999) and Kurtz et al. (1994) observations do not resolve the binary, and the flux densities given refer to the sum of both sources. The position of the unresolved source in Kurtz et al. (1994), with a positional accuracy of ∼0.″2, is coincident within this accuracy with our position for G138.295+1.555(N), suggesting that the large "excess" emission comes this component. Additional monitoring is required to confirm the time variability.

Time variable radio emission from young stars is usually interpreted in terms of gyrosynchrotron

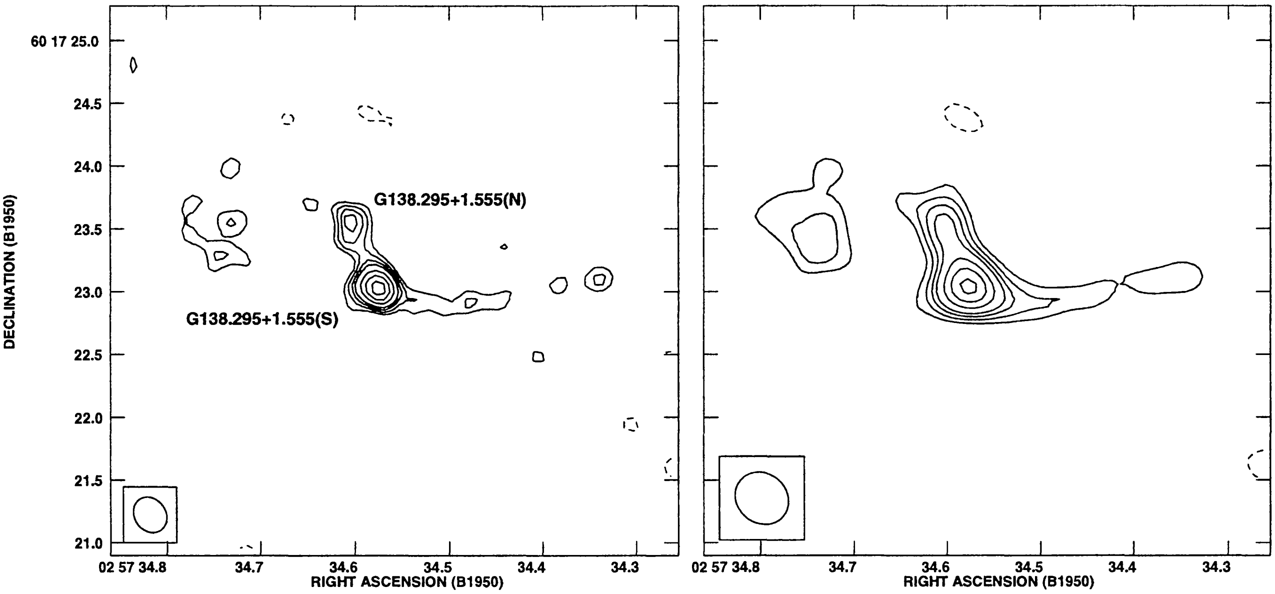

Fig. 1. Cleaned 3.6-cm maps of G138.295+1.555 (AFGL 4029-IRS1) made with high (left) and low (right) angular resolutions. The map on the left was made with ROBUST = 5 (equivalent to natural weighting) in the AIPS task IMAGR. The map on the right has in addition a (u,v) tapering of 500 kλ. The HPBWs of the maps are shown in the bottom left corner of the images. Contours are −4, −3, 3, 4, 5, 6, 8, 10, and 12 times the rms noise of 12 μJy beam^{-1} (left) and 14 μJy beam^{-1} (right). Note the presence of the two compact sources separated by $0\farcs6$ in the north-south direction, that we interpret as a binary system, and of the fainter emission extending in the east-west direction that appears to emanate from G138.295+1.555(S), that we interpret as the base of the ionized outflow detected by Ray et al. (1990).

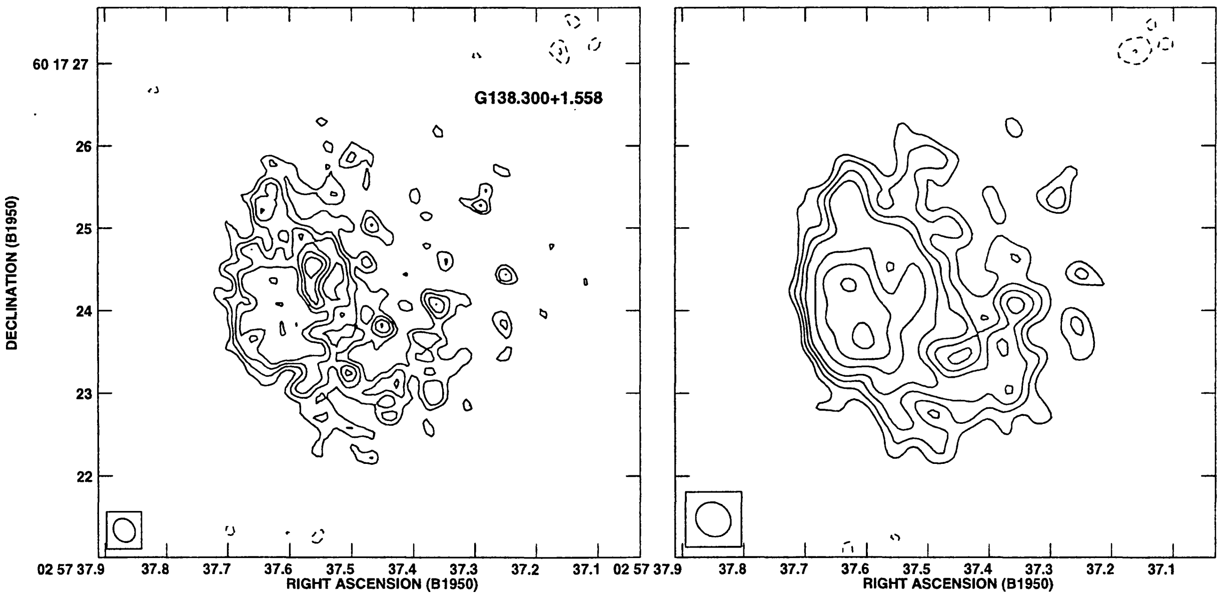

Fig. 2. Cleaned 3.6-cm maps of G138.300+1.558 (AFGL 4029-IRS2) made with high (left) and low (right) angular resolutions. The map on the left was made with ROBUST = 5 (equivalent to natural weighting) in the AIPS task IMAGR. The map on the right has in addition a (u,v) tapering of 500 kλ. The HPBWs of the maps are shown in the bottom left corner of the images. Contours are −4, −3, 3, 4, 5, 6, 8, 10, and 12 times the rms noise of 12 μJy beam^{-1} (left) and 14 μJy beam^{-1} (right). Note the apparent cometary morphology of the source, particularly evident in the low angular resolution map (right).

emission from particles accelerated in situ by magnetic reconnection flares near the stellar surface. This type of non-thermal emission is characteristic of T Tauri stars (André et al. 1988), young objects of low mass and luminosity. Thus, it appears reasonable to associate most of the 10^4 $L_\odot$ luminosity of AFGL 4029-IRS1 to G138.295+1.555(S), the source from which the outflow seems to originate. If this interpretation is correct, G138.295+1.555(S) is one of the few young massive objects from which a collimated outflow has been reported.

Assuming that G138.295+1.555(S) is an unresolved thermal jet with a collimation angle of 30° and a velocity of 500 km s^{-1} (Ray et al. 1990), and following the formulation of Eislöffel et al. (2000) we estimate a momentum flux of $\sim 1\times10^{-4}$ $M_\odot$ km s^{-1} yr^{-1} in the ionized outflow, in good agreement with the optical estimate.

2.2. *G138.300+1.558*

The total 3.6-cm flux densities for this source reported by Kurtz et al. (1994), Carral et al. (1999) and us (see Table 1) are 5.8, 4.5, and 5.0 mJy, respectively. We consider the agreement to be very good. At a distance of 2.2 kpc, and assuming that the free-free emission is optically thin and that the ionized gas has an electron temperature of 10^4 K, this flux density implies an ionizing photon rate of 2×10^{45} s^{-1} that could be provided by a B1 ZAMS star. This star is almost certainly source 26 in the list of Deharveng et al. (1997).

Kurtz et al. (1994) classified this source as having a core-halo morphology. However, our maps (see Figure 2), of much better signal-to-noise, are very suggestive of a cometary morphology.

We did not detect sources in addition to those listed in Table 1 and discussed here. In particular, we found no emission at a 5-σ level of 0.1 mJy associated with the bright H_2 clump detected by Deharveng et al. (1997).

3. CONCLUSIONS

We have mapped the AFGL 4029 region with high angular resolution and sensitivity. We find that G138.295+1.555, the radio source associated with AFGL 4029-IRS1, is a subarcsecond radio binary. There is also faint, extended emission associated with G138.295+1.555(S), the southern component of the binary, that we tentatively identify as the base of the ionized outflow observed in the optical. G138.295+1.555(S) is one of the few young massive stars associated with a collimated outflow. The northern component of the binary, G138.295+1.555(N), appears to be time variable and most probably is a young object of low mass and luminosity.

G138.300+1.558 is found to be a cometary ultracompact H II region that requires of a B1 ZAMS star to maintain its ionization.

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