Revista Mexicana de Astronomía y Astrofísica, **34**, 69–72 (1998)

VLA DETECTION OF THE EXCITING SOURCE OF THE "DEFLECTED" HH 270/110 SYSTEM

L. F. Rodríguez[1], Bo Reipurth[2], A. C. Raga[1], and J. Cantó[1]

Received 1998 February 25; accepted 1998 June 4

RESUMEN

El objeto HH 110 es un chorro bien colimado que parece carecer de fuente excitadora alineada con su eje. Estudios recientes parecen implicar que la fuente excitadora de este chorro está fuera del eje del mismo y que el chorro original, conocido como HH 270, es deflectado por una colisión rasante con una nube molecular, produciendo a HH 110. Presentamos observaciones sensitivas hechas con el VLA a 6 y 3.6-cm hacia el sistema HH 270/110 que buscan poner a prueba esta hipótesis. Una fuente con características de chorro térmico fue detectada coincidente con el objeto infrarrojo propuesto anteriormente como la fuente excitadora del sistema HH 270/110. Este chorro térmico de radio aparece elongado aproximadamente en la dirección de HH 270. No detectamos continuo de radio en la punta del chorro HH 110. En conclusión, nuestros resultados corroboran la existencia de este sistema "deflectado", compuesto de HH 110 y HH 270. Adicionalmente, hemos detectado la fuente del flujo bipolar IRAS 05487+0255 (cercano a HH 110), detectado previamente en líneas de hidrógeno molecular.

ABSTRACT

The HH object 110 is a well collimated jet that in initial studies seemed to lack an exciting source. More recent studies suggest that the exciting source of this jet is off-axis, producing a faint jet, known as HH 270, which is deflected in a grazing collision with a molecular cloud, thus producing HH 110. We present sensitive observations made at 6 and 3.6-cm with the VLA toward the HH 270/110 system in an attempt to test this hypothesis. An object with characteristics of a thermal radio jet was detected coincident with the infrared object proposed as the exciting source of the HH 270/110 system. This thermal radio jet appears elongated along the direction of HH 270. No radio continuum source was detected at the apex of the HH 110 flow. Altogether, our results thus strongly corroborate the proposed jet-collision interpretation of the HH 110/270 flow complex. Additionally, we have detected at both 3.6 and 6-cm the driving source of the nearby IRAS 05487+0255 bipolar molecular hydrogen jet.

Key words: **ISM–JETS AND OUTFLOWS — RADIO CONTINUUM–STARS — STARS–FORMATION — STARS–MASS-LOSS**

1. INTRODUCTION

The HH 110 flow is located in the L1617 molecular cloud in Orion, at an assumed distance of 460 pc. In the optical, it has the morphology of a large rather well collimated jet, with numerous knots embedded in a matrix of faint gas and displaying gentle curves (Reipurth & Olberg 1991). In the infrared the flow is much more collimated (Davis, Mundt, & Eislöffel 1994; Noriega-Crespo et al. 1996). Because of its well collimated morphology, it was long assumed that the source would be embedded just north of the apex of the flow. However, searches at optical and near-infrared wavelengths, with *IRAS* and in the mm radio continuum, all failed to detect even a hint of a source at that location. In a recent study, Reipurth, Raga, & Heathcote (1996) demonstrated the existence of another HH flow in the region, HH 270,

[1] Instituto de Astronomía, Universidad Nacional Autónoma de México.

[2] CASA, University of Colorado, USA.

which has a flow axis and proper motion that points directly toward the apex of HH 110. In contrast to HH 110, there are several lines of evidence for a source at HH 270: firstly, in the optical a bipolar reflection nebula is seen with a high extinction band between the lobes, similar to other regions known to hide embedded flow sources; secondly, a faint reflection nebula is detected at K in the dark lane; and thirdly, a weak *IRAS* source is located very close to the near-infrared source, albeit with a minor offset. Millimeter observations show the presence of two cloud cores in the region, one around the HH 270 flow, and another one adjacent to the apex of HH 110. Reipurth et al. (1996) interpreted this in terms of the HH 270 flow suffering a grazing collision with the molecular cloud core next to the HH 110 apex, thus producing a newly shocked, deflected flow which manifests itself as HH 110.

This scenario finds theoretical support. Based on the HH 110 case, Raga & Cantó (1995) modeled the collision of a supersonic, radiative jet with a dense cloud. They found that the spatial velocity difference observed between HH 270 and HH 110 agrees surprisingly well with the velocity decrease expected for a radiative jet/cloud collision of the observed deflection angle. The change in collimation from HH 270 to HH 110 also agrees well with the broadening of the post-collision jet predicted in the theoretical models. Furthermore, the fact that the western edge of HH 110 has bright H_2 emission can also be interpreted in terms of the jet/cloud collision model (Noriega-Crespo et al. 1996).

In this paper we present deep VLA 6-cm and 3.6-cm maps in search of the driving source of the HH 270/110 flow. It has recently been shown that a large number of HH energy sources can be detected in the radio continuum (e.g., Rodríguez & Reipurth 1989, 1994, 1996, 1998; for reviews see also Curiel 1995; Anglada 1996). The present data shows that HH 270 IRS joins this growing list of VLA detected HH energy sources.

2. OBSERVATIONS

Sensitive continuum observations of the HH 110 field were made using the VLA of the NRAO[3] in the D and A configurations. The first set of observations was made during 1996 July 23 at 6 and 3.6-cm in the D (lowest angular resolution) configuration. These observations had as main goal to detect the sources in the field and to provide spectral indices of them. The second set of observations was made at 3.6-cm during 1996 November 19 and December 22, and 1997 January 11, and had as main

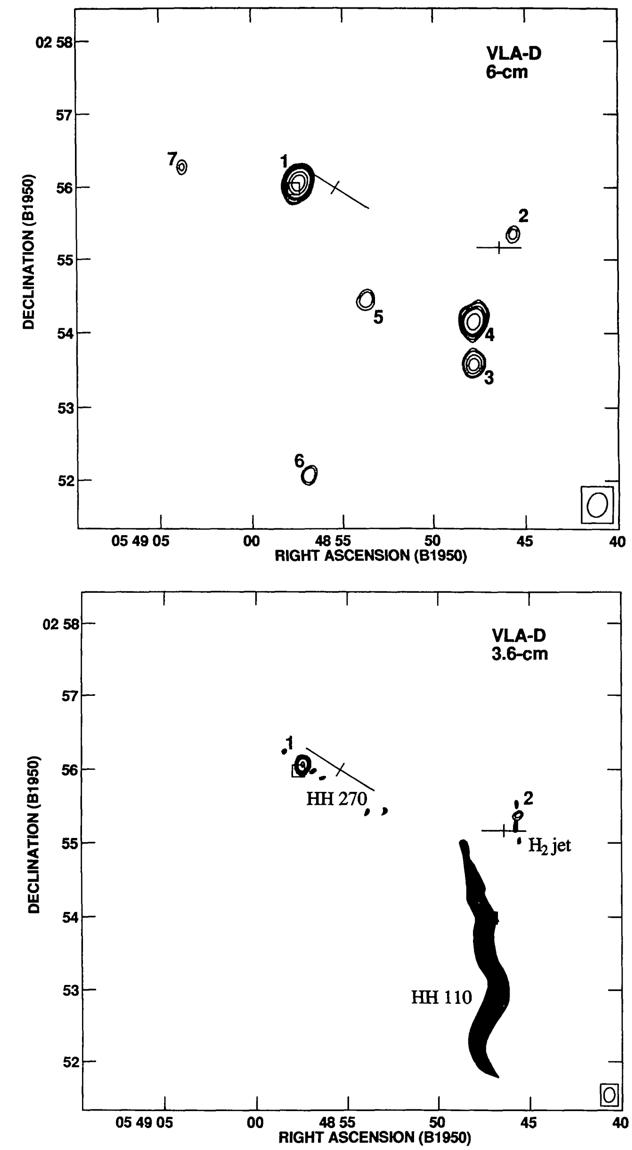

Fig. 1. Natural-weight VLA-D map at 6 (top) and 3.6-cm wavelength (bottom) of the HH 270/110 region. The crosses mark the position of the *IRAS* sources IRAS 05487+0255 (west) and IRAS 05489+0256 (east). The box marks the position of the diffuse infrared source proposed by Reipurth et al. (1996) to be related with the exciting source of the HH 270/110 system. The radio source VLA 1 is associated with this infrared source and with IRAS 05489+0256. The radio source VLA 2 is proposed to be the powering source of the IRAS 05487+0255 bipolar outflow. We have sketched, on the 3.6-cm map (bottom), the optical jets HH 270 and HH 110, as well as the H_2 jet associated with IRAS 05487+0255. The half power contour of the beam is shown in the bottom right corner. Contour levels are −5, 5, 6, 8, 10, 15, and 20 times the rms noises of 16 (6-cm) and 19 (3.6-cm) μJy beam^{-1}. These maps are not corrected for the response of the primary beam and the sources away from the phase center appear attenuated with respect to their real flux density.

[3] The National Radio Astronomy Observatory is operated by Associated Universities Inc., under cooperative agreement with the National Science Foundation.

goal to image with high angular resolution the source HH 110 VLA 1, detected in the first set of observations. In all observations the absolute amplitude calibrator was 1328+307, and the phase calibrator was 0550+032. The observations were made in both circular polarizations with an effective bandwidth of 100 MHz. The data were edited and calibrated following the standard VLA procedures and using the software package AIPS.

Using the D configuration data, we made cleaned, natural-weight maps at 6 and 3.6-cm of the region, and these are shown in Figure 1. In the 3.6-cm map we have sketched for reference the optical jets HH 270 and HH 110 (Reipurth et al. 1996) and the H_2 jet found in association with IRAS 05487+0255 (Davis et al. 1994; Garnavich et al. 1997). The positions, flux densities, and spectral indices of the radio sources detected are given in Table 1. We considered as detections only those signals above 5-σ.

3. DISCUSSION

In Figure 1 we show the sources detected at 6 and 3.6-cm. Only three of the seven sources detected at 6-cm were also detected at 3.6-cm. These are VLA 1, VLA 2 and VLA 4, which are discussed individually below.

3.1. *VLA 1*

The brightest source among those detected, hereinafter VLA 1, is coincident (see Fig. 1) with the diffuse infrared source reported by Reipurth et al. (1996). It is also very close to the source IRAS 05489+0256. Its spectral index is quite flat, -0.1 ± 0.2. Although thermal radio jets usually show more positive spectral indices, some of them do show flat spectra (see Table 1 in Anglada 1996).

Additional high angular resolution observations with the VLA in the A configuration were made toward VLA 1. In Figure 2 we show a high angular resolution image of the source at 3.6-cm. The total flux density detected in this high angular resolution map was 0.31 ± 0.02 mJy, significantly smaller than the total flux density detected in the low angular resolution, D configuration observations, which was 0.47 ± 0.02 mJy. This difference either implies that the source has extended emission that was resolved out in the A configuration observations, or that there was variation in the flux density during the several months that separate the observations.

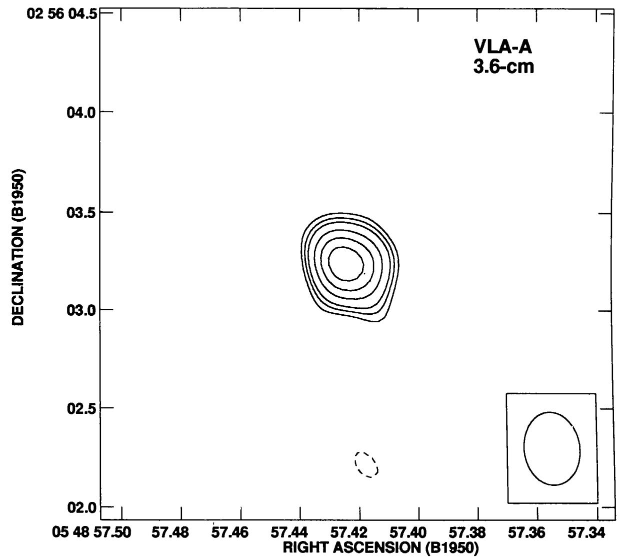

Fig. 2. Natural-weight VLA-A map at 3.6-cm wavelength of the source VLA 1. The half power contour of the beam is shown in the bottom right corner. Contour levels are −4, 4, 5, 6, 8, 10 , and 12 times the rms noise of 14 μJy beam^{-1}.

The source appears elongated in the NE-SW di-

TABLE 1

RADIO SOURCES IN HH 110 FIELD

Source	α (1950)[a]	δ (1950)[a]	$S^b_{6\ cm}$ (mJy)	$S^b_{3.6\ cm}$ (mJy)	Spectral Index
VLA 2	05 48 45.60	+02 55 22.6	0.16 ± 0.02	0.20 ± 0.03	0.4 ± 0.4
VLA 3	05 48 47.80	+02 53 34.2	0.22 ± 0.02	≤ 0.16	≤ −0.6
VLA 4	05 48 47.82	+02 54 09.2	0.44 ± 0.03	0.23 ± 0.03	−1.2 ± 0.3
VLA 5	05 48 53.66	+02 54 27.3	0.19 ± 0.02	≤ 0.10	≤ −1.2
VLA 6	05 48 56.91	+02 52 04.2	0.21 ± 0.03	≤ 0.32	≤ 0.8
VLA 1	05 48 57.42	+02 56 03.2	0.51 ± 0.03	0.47 ± 0.03	−0.1 ± 0.2
VLA 7	05 49 03.78	+02 56 16.5	0.14 ± 0.03	≤ 0.20	≤ 0.6

[a] VLA position with accuracy of ∼ 1″. Positions are from 6-cm data, except in the sources detected at 3.6-cm where the position was derived from the maps at this wavelength. In the case of VLA 1, the position is from the 3.6-cm observations in the A configuration and the accuracy is ∼ 0.″1.
[b] Total flux density corrected for primary beam response. Upper limits at 3.6-cm are at the 4-σ level.

rection. A least-squares fit to a Gaussian ellipsoid with the task IMFIT of AIPS gives deconvolved angular dimensions at half maximum of $0\rlap{.}''29 \pm 0\rlap{.}''04 \times 0\rlap{.}''17 \pm 0\rlap{.}''06$ and a position angle for the major axis of 64 °± 16°. The major axis of the radio source is then well aligned with the axis of the HH 270 system, which has a position angle of 61° (Reipurth et al. 1996). We propose that this radio source traces the base of the jet that excites the HH 270/110 system.

3.2. *VLA 2*

In their CO study of the L1617 molecular cloud, Reipurth & Olberg (1991) detected a major, powerful CO outflow centered on the *IRAS* source 05487+0255, and running almost north-south. Their infrared K-band images revealed two near-infrared objects located about 8–10 arcsec north and south of the nominal *IRAS* position. The northern one is a nebulous object, whereas the southern one is a bright stellar-like object ($K \sim$11.04). The H_2 images of Davis et al. (1994) and Garnavich et al. (1997), revealed two H_2 jets emanating from these two sources and both lying almost north-south. These images showed that the northern source (called IRS 2 by Davis et al.) is the southern lobe of a bipolar cavity illuminated by a deeply embedded source, which is itself not even detectable at K. Because IRS 2 is so embedded, whereas the southern source (IRS 1) is a bright stellar object measured at J, H, and K (and even faintly visible optically in the CCD images of Reipurth & Olberg 1991 and Reipurth et al. 1996), we believe there is little doubt that IRS 2 is the principal source associated with IRAS 05487+0255, although IRS 1 could contribute also to especially the 12 μm flux of the *IRAS* source.

Our VLA maps reveal that VLA 2, a rather bright 3.6-cm and 6-cm source with a positive spectral index, is located just 4 arcseconds north of IRS 2, precisely in the dark lane between the two H_2 jet lobes. It is undoubtedly the radio continuum counterpart to IRAS 05487+0255, and is yet another case of a VLA detection of a jet source.

3.3. *VLA 4*

Source VLA 4, with a marked non-thermal spectral index, is coincident within 1″ with the position for the knot HH 110 H (Reipurth & Olberg [1991]). A few Herbig-Haro objects have been detected as non-thermal radio emitters (see review by Curiel 1995). The relativistic electrons required to produce the synchrotron emission are believed to be accelerated in the shocks that characterize HH objects. However, the large HH 110 flow contains numerous knots, several of which are brighter than knot H, so to decide whether this positional coincidence is fortuitous or marks a real association will require further multi-frequency studies of this knot.

4. CONCLUSIONS

We have performed a low-resolution 3.6 and 6-cm VLA survey of the HH 110 region, and have detected the driving source of the "deflected" HH 270/110 flow at both wavelengths. Further high-resolution maps at 3.6-cm have shown that the source is slightly elongated along the well defined flow axis of the HH 270 flow, suggesting that it is a tiny radio continuum jet. This results lends credence to the recent suggestion that HH 110 is not a separate, independent jet, but is the result of the HH 270 flow having a grazing collision with a nearby molecular cloud core. Furthermore, we have detected the driving source of the nearby IRAS 05487+0255 bipolar molecular hydrogen jet.

LFR, AR, and JC acknowledge the support of DGAPA, UNAM, and CONACyT, México.

REFERENCES

Anglada, G. 1996, in ASP Conf. Ser. 93, Radio Emission from the Stars and the Sun, ed. A. R. Taylor & J. M. Paredes (San Francisco: ASP), 3
Curiel, S. 1995, in RevMexAASC 1, Circumstellar Disks, Outflows and Star Formation, ed. S. Lizano & J. M. Torrelles (México, D. F.: Inst. Astron., UNAM), 59
Davis, C. J., Mundt, R., & Eislöffel, J. 1994, ApJ, 437, L55
Garnavich, P. M., Noriega-Crespo, A., Raga, A. C., & Böhm, K.-H. 1997, ApJ, 490, 752
Noriega-Crespo, A., Garnavich, P. M., Raga, A. C., Cantó, J., & Böhm, K.-H. 1996, ApJ, 462, 804
Raga, A. C., & Cantó, J. 1995, RevMexAA, 31, 51
Reipurth, B., & Olberg, M. 1991, A&A, 246, 535
Reipurth, B., Raga, A. C., & Heathcote, S. 1996, A&A, 311, 989
Rodríguez, L. F., & Reipurth, B. 1989, RevMexAA, 17, 59
__________. 1994, A&A, 281, 882
__________. 1996, RevMexAA, 32, 27
__________. 1998, RevMexAA, 34, 13

Jorge Cantó and Alejandro C. Raga: Instituto de Astronomía, UNAM, Apartado Postal 70-264, 04510 México, D. F., México (raga@astroscu.unam.mx).
Bo Reipurth: CASA, University of Colorado, Campus Box 389, Boulder, CO 80309, USA (reipurth@casa.colorado.edu).
Luis F. Rodríguez: Instituto de Astronomía, UNAM, J. J. Tablada 1006, Lomas de Santa María, 58090 Morelia, Mich., México (luisfr@astrosmo.unam.mx).