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VLA DETECTION OF THE EXCITING SOURCES OF THE HH 211 AND HH 68 OUTFLOWS

Remy Avila and Luis F. Rodríguez,

Instituto de Astronomía
Universidad Nacional Autónoma de México, Campus Morelia

and

Salvador Curiel

Instituto de Astronomía
Universidad Nacional Autónoma de México

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RESUMEN

Presentamos observaciones sensitivas hechas con el Very Large Array a 3.5 cm hacia diez regiones con sistemas Herbig-Haro. Detectamos por vez primera a longitudes de onda centimétricas las fuentes excitadoras de los flujos HH 211 y HH 68. También presentamos observaciones a 7 mm de la fuente excitadora de HH 211. Nuestro análisis del espectro centimétrico y milimétrico indica que en esta fuente la emisión a 3.5 cm está dominada por emisión libre-libre de un chorro térmico, mientras que la emisión a 7 mm está dominada por emisión de polvo que probablemente se origina en un disco. Este disco es pequeño, con radio menor a 20 UA, lo cual lo coloca en la categoría de los discos protoplanetarios compactos. La fuente excitadora de HH 68 coincide con el objeto HH 68b, como habían propuesto anteriormente otros autores. También encontramos que la fuente excitadora del flujo HH 119 en B335, reportada previamente a longitudes centimétricas, es variable en el tiempo.

ABSTRACT

We present sensitive Very Large Array observations at 3.5 cm toward ten regions with Herbig-Haro flows. We detect for the first time at cm wavelengths the exciting sources of the HH 211 and HH 68 outflows. We also present 7-mm observations of the exciting source of HH 211. Our analysis of the cm and mm spectrum indicate that in this source the 3.5-cm emission is dominated by free-free emission from a thermal jet, while the 7-mm emission is dominated by dust emission most probably arising from a disk. This disk is small, with radius smaller than 10 AU, placing it in the category of compact protoplanetary disks. The exciting source of HH 68 coincides with the object HH 68b, as previously suggested by other authors. We also find that the exciting source of the HH 119 flow in B335, previously reported at centimeter wavelenghts, is time-variable.

Key Words: **ISM: JETS AND OUTFLOWS — RADIO CONTINUUM: STARS — STARS: FORMATION — STARS: MASS LOSS — STARS: PRE-MAIN-SEQUENCE**

1. INTRODUCTION

The Herbig-Haro objects are probably the best studied manifestation of the outflow phenomena that characterizes young stars. In his electronic catalog, Reipurth (2000) lists close to 500 HH objects. Interestingly, more than 60% of them still lack an identified exciting source. These sources are typically very obscured and their search has been more productive at the long wavelengths: infrared and radio.

It is also known that the HH objects are produced by shocks that take place in outflows and jets that are ejected by the exciting source. The base of these ionized outflows and jets can be sometimes detected as a faint free-free source at centimeter wavelengths. In this paper we present a sensitive search toward ten fields containing HH objects in an attempt to identify candidates for their exciting sources.

2. OBSERVATIONS

Sensitive 3.5-cm continuum observations of ten fields containing Herbig-Haro objects were made during 1994 December 01 and 04 using the VLA of the NRAO[1] in the C configuration, providing an angular resolution of about $2''.8$. On-source integration times of about 30 minutes were used for each of the observed fields. The absolute amplitude calibrators were 0134+329 (1994 December 01) and 1328+307 (1994 December 04). The regions and the positions of the phase centers observed, the phase calibrators used and their bootstrapped flux densities are given in Table 1. 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. We made cleaned, natural-weight maps of the regions. The rms noise and synthesized beam dimensions of these maps are given in Table 1.

The positions and flux densities of the sources detected are given in Table 2. We considered as detections only those signals above 5-σ. In this table we also give proposed counterparts to the centimeter sources.

Additional continuum observations of HH 211 were performed in 1999 November 22 and 1999 December 03, with the VLA in the B configuration. The antennas equipped with 43.3 GHz (7 mm) receivers were observing at that frequency using the fast switching technique (Carilli 2000) with cycles of 2 minutes to reduce phase variations arising in the troposphere. The remaining antennas were observing at 8.3 GHz.

3. COMMENTS ON INDIVIDUAL SOURCES

3.1. *The HH 211 Flow near IC 348*

The well collimated molecular jet HH 211 was discovered by McCaughrean, Rayner, & Zinnecker (1994), near the young stellar cluster IC 348 in the Perseus dark cloud complex. The jet stretches across $1'.75$ on the sky, corresponding to a projected length of 0.18 pc, at the estimated distance $d = 350$ pc. HH 211 has a kinematical age shorter than 1000

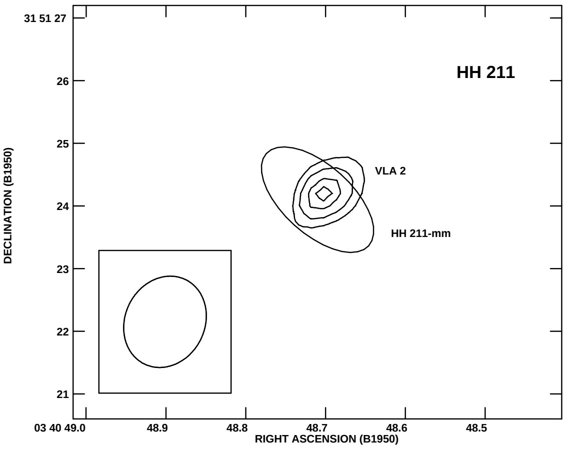

Fig. 1. Natural-weight VLA map at 3.5 cm wavelength of the exciting source of HH 211, VLA 2, near IC 348. The map was made from concatenated *uv* data obtained in 1994 December, and in 1999 November and December. Contour levels are −4, 4, 5, 6, and 6.5 times the rms noise of 12 μJy beam^{-1}. The half power contour of the beam is shown at the bottom left corner. The ellipse represents the millimeter source, HH 211-mm, reported by Gueth & Guilloteau (1999), and fitted by these authors to a Gaussian distribution with FWHM of $2''.2 \pm 0''.15 \times 1''.1 \pm 0''.15$ at PA $48° \pm 5°$.

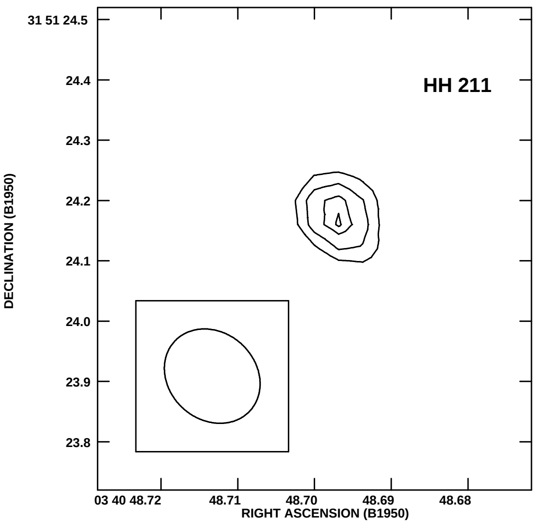

Fig. 2. Same as Figure 1 but at 7 mm wavelength. Contour levels are −5, 3.5, 4.5, 5.5, and 6 times the rms noise of 160 μJy beam^{-1}. The half power contour of the beam is shown in the bottom left corner. The source seems unresolved, $\theta_S \leq 0''.1$.

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

TABLE 1

REGIONS OBSERVED AT 3.5 CM

HH	Phase Center α(B1950)	δ(B1950)	Phase Calibrator	Bootstrapped Flux Density (Jy)	rms noise (μJy)	Synthesized Beam (arcsec×arcsec; deg)
HH 211[a]	03 40 48.2	+31 51 28	0333+321	1.778±0.002	12	1.5×1.3; −26
HH 85	05 32 58.2	−06 22 10	0539−057	0.986±0.002	23	3.8×2.7; −11
HH 87	05 33 16.7	-06 38 30	0539−057	0.986±0.002	24	3.8×2.7; −7
HH 61	05 33 47.4	−07 10 51	0539−057	0.986±0.002	23	3.8×2.7; −2
HH 36	05 34 19.9	−06 45 49	0539−057	0.986±0.002	22	3.7×2.7; +1
HH 130	05 34 20.9	−06 51 45	0539−057	0.986±0.002	23	3.8×2.7; +7
HH 68	05 39 11.0	−06 29 20	0539−057	0.986±0.002	17	3.9×2.7; +20
HH 32	19 18 09.5	+10 56 30	1947+079	0.803±0.002	20	3.1×2.7; −2
HH 119	19 34 35.1	+07 27 24	1947+079	0.803±0.002	29	3.2×2.7; −9
HH 242	21 41 29.9	+65 52 50	2229+695	0.345±0.002	28	3.4×2.7; +30

[a] The bootstrapped flux density is from the 1994 observations. Other parameters are for the concatenated data from 1994 and 1999.

years, which makes it one of the youngest jets ever discovered. Interferometric maps of CO emission in the molecular outflow led Gueth & Guilloteau (1999) to conclude that the overall structure of HH 211 perfectly fits into the structure of a jet-driven flow. Continuum emission in the mm range revealed the exciting source of HH 211, designated as HH 211-mm (McCaughrean et al. 1994). Gueth & Guilloteau (1999) studied the exciting source, finding integrated continuum fluxes of 25, 40, and 275 mJy at 86, 115, and, 230 GHz, respectively. The authors pointed out that these continuum fluxes, and the non-detection of the exciting source in the near-IR by McCaughrean et al. (1994), are typical of a young low-mass protostar, a Class 0 object following André, Ward-Thompson, & Barsony (1993).

The source VLA 2, first reported here on Table 2, coincides within $\sim 0''\!.1$ with HH 211-mm (see Figure 1). This source was detected marginally in our 1994 observations at 3.5 cm. To corroborate its existence with better signal-to-noise ratio, we did additional observations in 1999, as explained in § 2. The final map clearly shows a source at the 7-σ level. The flux densities at 86, 115, and 230 GHz (Gueth & Guilloteau 1999) and that at 8.3 GHz reported here seem to follow a power law consistent with dust-only emission. To obtain data at an intermediate frequency we did 43.3 GHz (7 mm) observations of HH 211 in 1999 (see § 2). The source was detected with a flux density of 2.7±0.6 mJy (see Figure 2). The flux density at 43.3 GHz does not support the dust-only hypothesis for the cm and mm spectrum, and suggests the more common scenario of free-free and dust emission dominating the low and high frequency regions, respectively. Figures 3*a* and 3*b* represent the spectrum of the source for two different assumptions for the centimeter flux density. In both figures, the four highest-frequency data points have been fitted with a power law of the form $S_d(\nu) \propto \nu^\alpha$ with a spectral index $\alpha_d = 2.71 \pm 0.16$, consistent with dust emission. Unfortunately, a single flux measurement is available at low frequencies (X band), preventing a power-law fitting in that spectral range. Nevertheless, we have explored two possible sources of the low frequency flux: optically thin free-free emission from a homogeneous ionized gas resulting in a spectral index $\beta = -0.1$, or free-free emission from an ionized jet with a spectral index of $\beta = 0.6$. The two corresponding power laws of the form $S_f(\nu) = C\nu^\beta$ are represented by the dotted lines in Figs. 3*a* and 3*b*, respectively. In each case, the constant C has been chosen such that $S_f(8.3\text{ GHz}) + S_d(8.3\text{ GHz})$ equals the measured flux at 8.3 GHz. The full lines represent the total flux, $S_f(\nu) + S_d(\nu)$. In neither case the free-free emission contaminates significantly the flux at 43 GHz, suggesting that both scenarios are consistent with the available measurements of flux densities. Thus, we conclude that the 43 GHz flux density can be attributed to dust emission. An additional flux density measurement at the centimeter range is required to discriminate between the two possibilities discussed

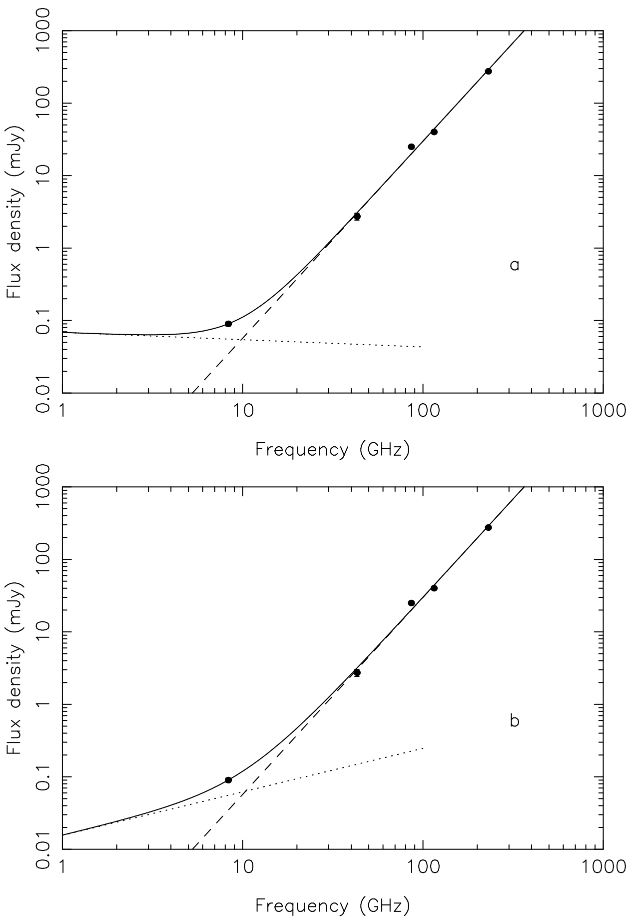

Fig. 3. Centimeter and millimeter spectrum of the exciting source of HH 211. Dots represent the available flux density measurements. The three highest-frequency values are from Gueth & Guilloteau (1999), and the lower-frequency points are those reported here. The dashed lines are fitted to the millimeter data (four highest-frequency points), giving a spectral index $\alpha_d = 2.71 \pm 0.16$. The dotted lines have slopes $\beta = -0.1$ (a), and $\beta = 0.6$ (b), and their positions are determined so that the sum of the flux densities represented by the dashed and dotted lines, at 8.3 GHz, equals the measured flux density. This sum for all frequencies is represented by the continuous line.

for this regime.

It has been stated that for objects of low bolometric luminosity, the momentum rate in the molecular outflow ($\dot{P}$) is correlated with the radio continuum luminosity ($S_\nu d^2$) at centimeter wavelengths (Anglada et al. 1992; Cabrit & Bertout 1992; Anglada 1995). This correlation, together with other properties, supports the scenario modeled by Curiel, Cantó, & Rodríguez (1987), Curiel et al. (1989) in which the powerful outflows, known to characterize young stars, are ionized as a result of a shock against the surrounding material. Estimating $\dot{P}$ for the HH 211 outflow from the results of Gueth & Guilloteau (1999), and using equation (3) of Anglada et al. (1998), we find that the flux density of the hypothetical free-free emission at 3.5 cm would be at least one order of magnitude higher than the measured flux density. A possible explanation of this discrepancy is that the observations reported here were carried out in a period when the outflow emerging from the star reduced its power. Alternatively, the ionization efficiency (Anglada 1995) in this source could be low, resulting in a low radio flux density.

The 7-mm source is very compact, $\theta_S \leq 0.''1$. This upper limit was obtained from fits to the image and confirmed from fits to the (u, v) data. We also attempted an analysis of the visibility amplitude versus (u, v) distance, but the modest signal-to-noise ratio of the data does not allow to reach further conclusions with regard to the size or shape of the source. At a distance of 350 pc, this angular upper limit implies that the dust disk has a radius smaller than 20 AU. This small size places the HH 211 millimeter source in the category of the compact protoplanetary disks, first reported by Rodríguez et al. (1998) in L1551 IRS5. While most well mapped protoplanetary disks have dimensions of the order of 100 AU (e.g., Wilner, Ho, & Rodríguez 1996; Wilner et al. 2000), similar to those of the solar system, there appears to be a class of disks an order of magnitude smaller. Assuming that the dust emission is optically thin and that it has a temperature of 200 K, we crudely estimate the total mass of the disk to be $\sim$0.05 $M_\odot$, a few times smaller than the 0.2 $M_\odot$ estimate of Gueth & Guilloteau (1999). The small size ($\leq 0.''1$) that we find for the 7-mm source seems to be different than the $\sim 1''$ angular size found by Gueth & Guilloteau (1999) at 1.3 mm, suggesting that we may be detecting only the inner part of the disk. Additional research is needed to understand this difference. The brightness temperature observed at 7 mm, $T_B \gtrsim 200$ K, suggests a relatively hot inner disk.

The second brightest source detected in this field, VLA 3, lies $3.''5$ apart of Cl* IC 348 LRL 49 (Figure 4), a near-infrared source detected by Luhman et al. (1998). Although this angular distance is somewhat larger than the sum of the positional uncertainties associated with each source, there are aspects that suggest a correspondence. The spectroscopic studies performed by Luhman et al. (1998) led them to identify Cl* IC 348 LRL 49 as a M0.5 star, exhibiting CO absorption. Although these authors did not find signatures of disk activity, this

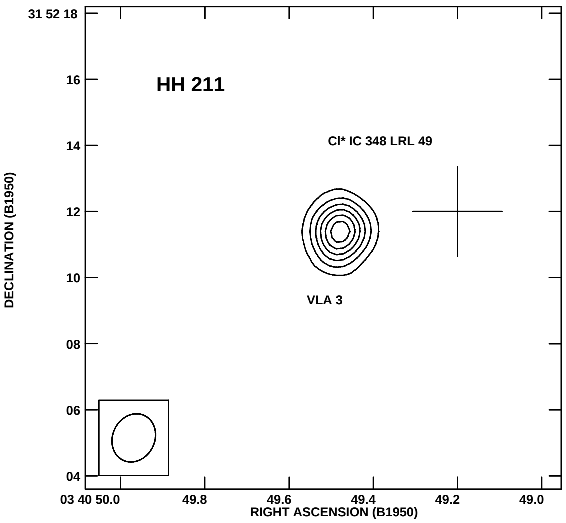

Fig. 4. Same as in Figure 1, but centered on source VLA 3, near IC 348. The cross marks the position of the star Cl* IC 348 LRL 49. Contour levels are −5, 5, 8, 11, 14, 17, and 20 times the rms noise of 12 μJy beam^{-1}. Data from 1994.

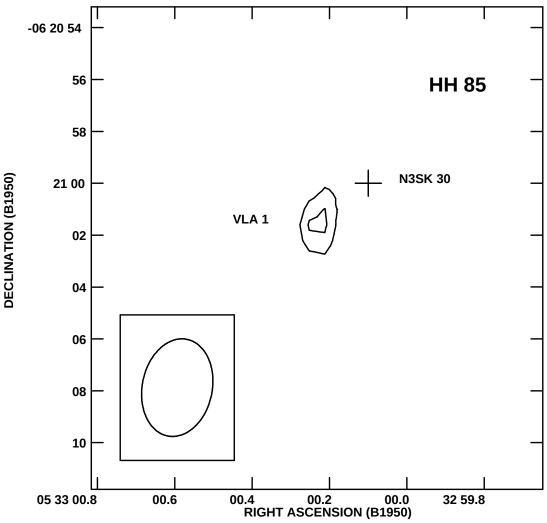

Fig. 5. Natural-weight VLA map at 3.5 cm wavelength of source VLA in L1641 (HH 85). Contour levels are −4, 4, and 5 times the rms noise of 25 μJy beam^{-1}. The cross represents the position of N3SK 30, reported by Nakajima et al. (1986).

source has the largest extinction in J band of the 478 sources discussed by them. The 3.5 cm flux densities measured in 1999 are 0.17±0.01 and 0.21±0.01 mJy for the November and December data, respectively. Comparing with the flux of 0.41±0.02 mJy measured in 1994 (see Table 2), we see that the source is variable. The precise nature of the radio continuum emission is not known, but may signal the presence of an ionized outflow. In this case, there could be an outflow associated with this source. About 2′ to the north of this region there is an interesting nebular chain seen in the K′ image by McCaughrean et al. (1994) that approximately aligns with the source VLA 3.

3.2. *The HH 85 Outflow in L1641*

This source was first identified as a Herbig-Haro object by Reipurth (1989). It lies in the Orion A giant molecular cloud complex. From a study of the kinematics of a number of Herbig-Haro objects in the giant HH 34 complex, Devine et al. (1997) showed that HH 85 is only one of the northern, redshifted, components of this parsec-scale flow powered by HH 34 IRS. This is consistent with the fact that none of the three faint radio sources detected in this field (see Table 2) seems to be associated with an eventual exciting source of HH 85.

The source VLA 1 in this field might have as counterpart the infrared source N3SK 30, reported by Nakajima et al. (1986) as being a background field star, not associated with the L1641 dark cloud. Figure 5 shows VLA 1 together with the position of N3SK 30.

3.3. *The HH 87 Outflow in L1641*

Like HH 85, the HH 87 outflow is only one knot of the giant HH 34 complex (Devine et al. 1997). A similar conclusion was reached by Anglada, Sepúlveda, & Gómez (1997). It is located in the southern, blueshifted part of the bipolar outflow that emanates from HH 34 IRS.

None of the radio sources detected in this field seems to be associated with any catalogued stellar source. However, sources VLA 5 and 6 appear projected on the ammonia condensation mapped by Anglada et al. (1997) and deserve further study.

3.4. *The HH 61 Outflow in L1641-N*

Reipurth, Devine, & Bally (1998) suggested that HH 61/62 form a giant counterlobe of the HH 303 jet, located approximately 45′ to the north of HH 61, and that the exciting source of these objects is the IRAS source 05338–0624 which has an associated VLA source reported by Chen, Zhao, & Ohashi (1995).

As shown in Figure 6 and Table 2, sources VLA 1 and 2 in this field coincide with a source detected by the NRAO/VLA Sky Survey (NVSS) made at 1.4 GHz. The resolution of the NVSS observations was 45″, not enough to resolve the sources. From the flux density of 25.2 ± 1.5 mJy beam^{-1} at 1.4 GHz,

TABLE 2

SOURCES DETECTED AT 3.5 CM

HH	Region	VLA	$\alpha(1950)^a$	$\delta(1950)^a$	Peak Flux^b	Int. Flux^b	Noise (μJy)	Counterpart	$\alpha(1950)^c$	$\delta(1950)^c$
HH 211	IC348	(1)^d	03 40 39.52	+31 50 14.68	0.14	0.15	26			
		(2)^e	03 40 48.70	+31 51 24.20	0.09	0.09	12	HH 211-mm	03 40 48.71	+31 51 24.1
		(3)^d	03 40 49.48	+31 52 11.35	0.41	0.48	21	Cl* IC 348 LRL 49	03 40 49.2	+31 52 12.0
		(4)^d	03 41 04.02	+31 49 04.03	0.59	0.52	77			
HH 85	L1641	(1)	05 33 00.23	−06 21 01.55	0.13	0.13	25	N3SK 30	05 33 00.1	−06 21 00
		(2)	05 33 00.66	−06 19 58.17	0.20	0.21	40			
HH 87	L1641	(1)	05 33 06.08	−06 40 40.05	0.33	0.33	38			
		(2)	05 33 10.65	−06 40 25.28	0.23	0.27	38			
		(3)	05 33 10.71	−06 40 33.77	0.20	0.28	38			
		(4)	05 33 17.70	−06 36 08.70	0.28	0.26	33			
		(5)	05 33 23.11	−06 36 44.11	0.18	0.20	26			
		(6)	05 33 24.65	−06 37 20.10	0.17	0.22	26			
		(7)	05 33 27.60	−06 38 44.31	0.25	0.25	34			
		(8)	05 33 27.79	−06 38 22.97	0.23	0.20	34			
HH 61	L1641-N	(1)	05 33 37.28	−07 13 29.61	1.05	1.65	71	NVSS 053337-071327	05 33 37.37	−07 13 27.0
		(2)	05 33 37.31	−07 13 17.48	2.74	3.21	71	NVSS 053337-071327	05 33 37.37	−07 13 27.0
		(3)	05 33 50.98	−07 13 01.77	0.30	0.26	32			
		(4)	05 33 53.08	−07 08 40.02	0.21	0.25	37			
		(5)	05 33 55.65	−07 09 57.30	0.22	0.13	37			
		(6)	05 33 56.28	−07 11 52.28	0.35	0.51	36			
		(7)	05 33 57.13	−07 11 49.08	0.22	0.15	40			
		(8)	05 34 07.52	−07 12 13.02	5.21	7.52	367			
HH 36	L1641	(1)	05 34 16.03	−06 47 49.48	0.20	0.23	32			
		(2)	05 34 16.94	−06 42 11.82	0.74	1.43	79			
		(3)	05 34 28.19	−06 46 41.83	0.18	0.13	34			
HH 130	L1641	(1)	05 34 27.44	−06 49 08.04	0.35	0.36	47			
		(2)	05 34 27.58	−06 51 31.35	2.25	2.48	29			
		(3)	05 34 28.52	−06 51 37.71	0.37	0.41	29	NVSS 053428-065141	05 34 28.54	−06 51 41.2
		(4)	05 34 28.74	−06 51 43.32	0.29	0.35	29	NVSS 053428-065141	05 34 28.54	−06 51 41.2
		(5)	05 34 29.66	−06 51 46.85	0.69	1.27	29			
		(6)	05 34 31.53	−06 49 47.86	5.21	5.40	47	NVSS 053431-064948	05 34 31.55	−06 49 48.8
		(7)	05 34 31.68	−06 51 40.83	1.01	1.02	29			
HH 68	L1641	(1)	05 39 08.69	−06 27 20.41	0.18	0.17	24	HH 68b	05 39 08.7	−06 27 20
		(2)	05 39 10.54	−06 28 13.23	0.20	0.23	24	[os98] 56	05 39 11	−06 28 12
		(3)	05 39 19.57	−06 28 30.48	1.69	1.71	28			
		(4)	05 39 22.23	−06 31 44.53	0.36	0.31	44			
		(5)	05 39 25.95	−06 29 12.45	1.42	1.41	59			
HH 32	AS 353 A	(1)	19 17 50.48	+10 55 55.92	2.72	5.01	270	[ARC92] AS 353A 1	19 17 50.49	+10 55 56.0
		(2)	19 18 04.94	+10 54 34.33	0.24	0.25	32	[ARC92] AS 353A 2	19 18 05.02	+10 54 34.0
		(3)	19 18 05.95	+10 55 05.51	0.12	0.12	26			
		(4)	19 18 07.86	+10 56 21.17	0.12	0.17	22	HH 32A	19 18 07.91	+10 56 21.7
		(5)	19 18 09.45	+10 56 08.93	0.50	0.54	20	AS 353B	19 18 09.45	+10 56 09.1
		(6)	19 18 11.52	+10 57 20.80	0.20	0.15	21	[ARC92] AS 353A 4	19 18 11.54	+10 57 22.0
HH 119	B335	(1)	19 34 23.94	+07 28 17.52	0.37	0.21	69	[ARC92] Barn 335 2	19 34 23.78	+07 28 18.0
		(2)	19 34 29.88	+07 30 11.84	0.43	0.59	69	[ARC92] Barn 335 3	19 34 29.83	+07 30 14.0
		(3)	19 34 44.51	+07 30 02.17	0.53	0.55	97			
		(4)	19 34 44.90	+07 24 50.02	2.55	3.51	193	[ARC92] Barn 335 5	19 34 44.89	+07 24 50.0^f
		(5)	19 34 46.11	+07 24 42.17	4.20	5.06	193	[ARC92] Barn 335 6	19 34 46.10	+07 24 42.0
		(6)	19 34 46.93	+07 27 14.51	1.62	1.87	70	[ARC92] Barn 335 7	19 34 46.91	+07 27 14.0
HH 242	NGC 7129	(1)	21 41 24.13	+65 55 53.77	0.74	0.62	70	NVSS 214125+655552	21 41 24.69	+65 55 52.0
		(2)	21 41 30.66	+65 54 09.03	1.26	1.36	28	NVSS 214130+655412	21 41 30.50	+65 54 12.4
		(3)	21 41 49.96	+65 52 21.04	0.23	1.07	39			
		(4)	21 41 57.40	+65 53 08.20	1.99	2.65	65	[SB86] NGC7129 1	21 41 57.3	+65 53 09

[a] VLA position with accuracy of $\sim 0\farcs5$.

[b] Peak (in mJy beam^{-1}) or Integrated (in mJy) flux corrected for primary beam response.

[c] Reported counterparts. For reference and positional accuracy see text and figures.

[d] Obtained with data from 1994.

[e] Obtained with concatenated data from 1994 and 1999.

[f] In Anglada et al. the declination reported has a typographical error, and is given as +06 24 50.0.

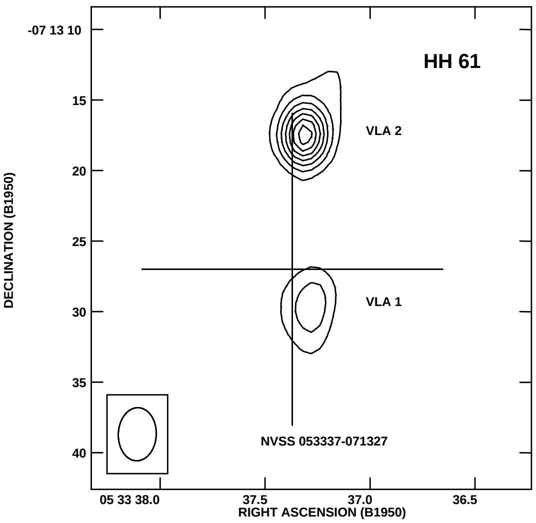

Fig. 6. Natural-weight VLA map at 3.5 cm wavelength of sources VLA 1 and 2 in L1641-N (HH 61). Contour levels are −5, 5, 10, 15, 20, 25, 30, and 35 times the rms noise of 71 μJy beam^{-1}. The cross represents the fitted major and minor axis of a source detected by the NRAO/VLA Sky Survey, at 1.4 GHz.

reported in the NVSS (Condon et al. 1998), and the sum of the flux densities of VLA 1 and 2 (see Table 2), we find a spectral index of -0.9 ± 0.04. This, together with the morphology of VLA 1 and 2, indicates that these sources may be a radio galaxy.

3.5. *The HH 36 Outflow in L1641*

This source was discovered by Herbig (1974). Based on CCD images, Corcoran & Ray (1995) suggested that V851 Ori may be the exciting source of HH 36. None of the radio sources detected in this field seems to be associated with any catalogued source.

3.6. *The HH 130 Outflow in L1641*

This object was first reported by Reipurth (1985). Ogura & Walsh (1991) suggested that HH 130 may be related to HH 1/2, but CCD images and spectroscopic studies by Corcoran & Ray (1995) revealed that this object is most likely a bow shock in a flow driven by V380 Ori.

Sources VLA 3 and 4 in this field have an unresolved NVSS 1.4 GHz counterpart of flux density 11.2 ± 0.6 mJy, as shown in Figure 7 and Table 2. Source VLA 6 also coincides with a 1.4 GHz source whose flux density is 25.6 ± 0.9 mJy beam^{-1}. The spectral indices of VLA 3/4 and VLA 6 in the centimeter range, calculated from the 8.3 and 1.4 GHz flux densities, are -1.51 ± 0.05 and -0.87 ± 0.02. The reported flux density of VLA 3/4 at 1.4 GHz might be contaminated by emission from VLA 5 and/or VLA 2, explaining the very steep spectral index obtained. Nevertheless, both spectral indices are consistent with optically-thin synchrotron radiation. The sources VLA 2, 3, 4, and 5 may constitute a radio galaxy with two ejection axes.

3.7. *The HH 68 Outflow in L1641*

Reipurth & Graham (1988) discovered the Herbig-Haro object HH 68, in the eastern part of the large molecular cloud L1641, an area of highly structured, very transparent cloud material. They noticed that the knots HH 68a, b, c and HH 69 are all located on the same line, and suggested that these objects are the shocks of a single bipolar outflow, probably originated in the red star that is inside HH 68b. However, no infrared emission has been detected from that star. The nearest IRAS source (IRAS 05391–0627C) has been found from COADDed images, at 31″ from HH 68b as shown in Figure 8, essentially in the axis connecting HH 68a, b, c

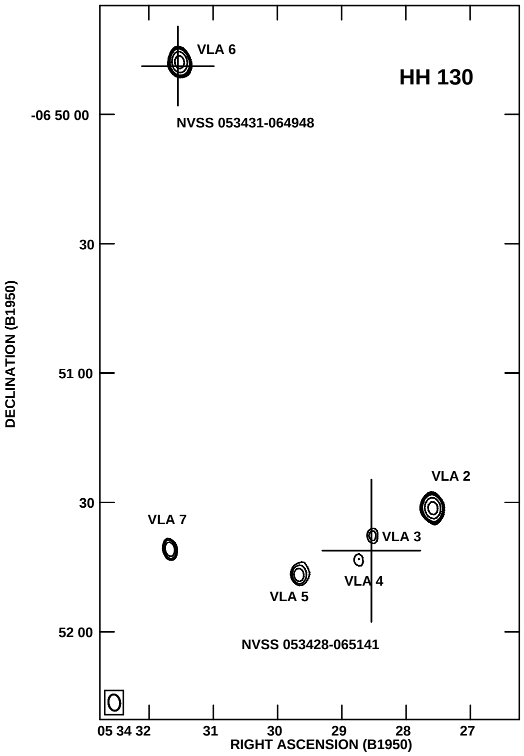

Fig. 7. Natural-weight VLA map at 3.5 cm wavelength of sources VLA 2 through 7 in L1641 (HH 130). Contour levels are −5, 5, 7, 10, 20, 40, 70, 100, and 150 times the rms noise of 29 μJy beam^{-1}. The crosses represent the fitted major and minor axis of sources detected by the NRAO/VLA Sky Survey, at 1.4 GHz.

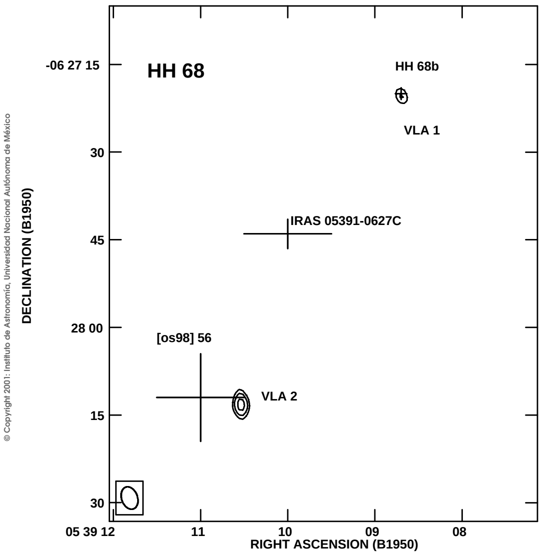

Fig. 8. Natural-weight VLA map at 3.5 cm wavelength of sources VLA 1 and 2 in L1641 (HH 68). Contour levels are −5, 5, 7, and 10 times the rms noise of 16 μJy beam^{-1}. The crosses represent the reported uncertainties of the positions of HH 68b, IRAS 05391–0627C and the core of the cloud [os98] 56.

and HH 69 (Cohen 1990). This alignment, together with the great redness of the IRAS source, led Cohen to suggest that the knots HH 68a, b, c are excited by IRAS 05391–0627C. He also suggested that HH 69 is excited by another IRAS source (IRAS 05393–0632). Here we find a 3.5-cm source (VLA 1, see Table 2) at the same location as that of HH 68b, which supports the proposition of Reipurth & Graham (1988) of the exciting source being inside HH 68b. Curiel (2001) detected HH 68b at 6 cm with a flux density of ∼0.2 mJy, similar to the value measured by us at 3.5 cm (see Table 2), suggesting a flat spectral index.

As seen in Fig. 8, IRAS 05391–0627C is a distinct source from HH 68b. The source VLA 2 appears to be associated or embedded in the core of the filamentary cloud [os98] 56 (Ogura & Sugitani 1998).

3.8. *The HH 32 Outflow near AS 353A*

This field has been observed recently with the VLA at 3.5 cm by Anglada et al. (1992) and at 6 cm by Anglada et al. (1998). The exciting source of HH 32, believed to be the T Tauri star AS 353A (Cohen & Schwartz 1983; Mundt, Stocke, & Stodkman 1983; Solf, Böhm, & Raga 1986; Hartigan, Mundt, & Stocke 1986), was detected by Cohen & Bieging (1986) and Anglada et al. (1992; 1998). We do not find continuum emission at 3.5 cm coincident with AS 353A, but we find an unreported (VLA 5) source 6 arcseconds to the south (see Figure 9 and Table 2). This source coincides within 0.″1 with the T Tau star AS 353B, whose position was reported by Herbig & Jones (1983). The axis of the HH 32 East flow passes between AS 353A and AS 353B. VLA 5 was not detected by Anglada et al. (1992), who set an upper limit of ∼ 0.1 mJy at 3.5 cm. We detect the source with a flux density of ∼ 0.5 mJy, indicating time variability. VLA 4, also detected by Anglada et al. (1992), is the radio counterpart of HH 32A, one of the few HH objects that present radio continuum emission. The 3.5 cm flux densities for HH 32A reported here and in Anglada et al. (1992) are consistent.

VLA 1 coincides with a continuum source detected at 1.4 GHz by the NVSS, with flux density of 36.8 ± 1.2 mJy (Condon et al. 1998). No polarized emission was detected for this source in the NVSS survey. The spectral index derived from the NVSS flux measurement at 1.4 GHz and ours at 8.3 GHz is -1.1 ± 0.05, corresponding to non-thermal emission, which is in agreement with the results of Anglada et al. (1998).

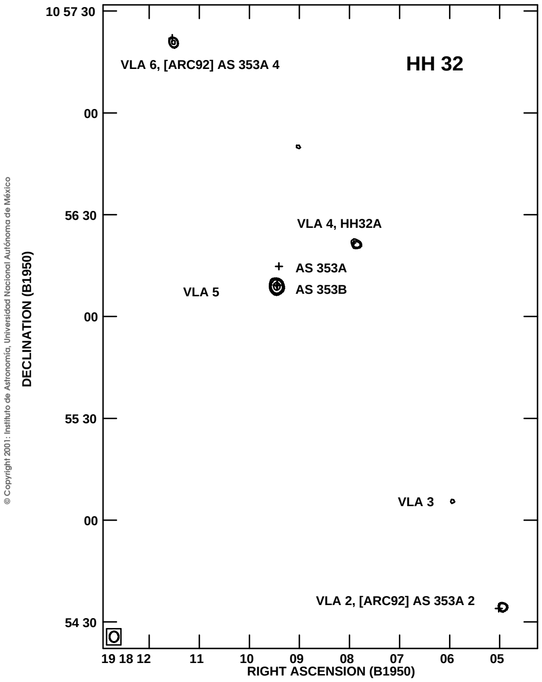

Fig. 9. Natural-weight VLA map at 3.5 cm wavelength of sources VLA 2 to 6 around AS 353A (HH 32). Contour levels are −5, 4, 5, 8, 17, and 24 times the rms noise of 20 μJy beam^{-1}. The crosses represent the reported uncertainties of the positions of [ARC92] AS 353A 2, AS 353A, HH32A and [ARC92] AS 353A 4.

TABLE 3

REPORTED FLUXES OF IRAS 19345+0727 AT 3.5 CM

Epoch	Flux	VLA Configuration	Reference
1990 January	0.21 ± 0.02^a	D	Anglada et al. (1992)
1994 December	$\leq 0.08^b$	C	This paper
2001 January	0.37 ± 0.02^b	A	Reipurth et al. (2001)

[a] Peak flux in mJy beam^{-1}.

[b] Flux density in mJy.

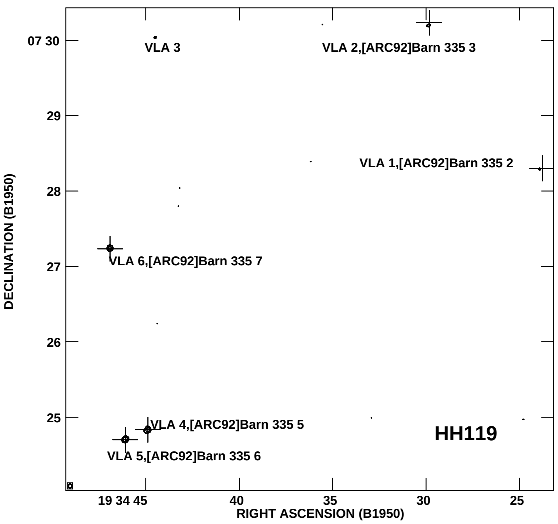

Fig. 10. Natural-weight VLA map at 3.5 cm wavelength of the sources detected in B335 (HH 119). Contour levels are −5, 4, 5 and 13 times the rms noise of 29 μJy beam^{-1}. The crosses represent 10 times the reported uncertainties of the positions of [ARC92] Barn 335 2, [ARC92] Barn 335 3, [ARC92] Barn 335 5, [ARC92] Barn 335 6, [ARC92] Barn 335 7.

3.9. *The HH 119 Outflow in B335*

Frerking & Langer (1982) first studied the clearly defined bipolar molecular outflow in the dark cloud B335. A far-infrared and submillimeter source located in the center of the outflow has been proposed as the exciting source (Keene et al. 1983; Gee et al. 1985; Chandler et al. 1990). As mentioned by Anglada et al. (1992), this source and IRAS 19345+0727 are most probably the same object. These authors found at the same position a 3.5 cm source, with peak flux equal to 0.21±0.02 mJy beam^{-1}. The phase center of our observations of this field was the position of IRAS 19345+0727 (see Table 1), where we did not find any source brighter than 0.08 mJy beam^{-1} (3-σ). The observations of Anglada et al. (1992) were performed with the VLA in the D configuration, leading to an angular resolution of about 9″, whereas ours were performed in the C configuration with an angular resolution of about 3″. We made maps with strongly limited UV coverage (tapering down to 400 kλ) to lower the resolution, finding no difference in the flux value at that position. This leads us to conclude that the proposed exciting source of HH 119 is variable. This result is corroborated by the 2001 January measurements of Reipurth, Rodríguez, & Anglada (2001) that gave a 3.5-cm flux density of 0.37±0.02 mJy for this source. Table 3 summarizes the reported fluxes of this object at 3.5 cm. From data obtained at two epochs separated by 4 years, Anglada et al. (1998) estimated for this source a spectral index larger than 0.3 between 3.5 and 6 cm. This result should be revised, in view of the source variability. Time variability seems to be unusual in thermal jets. In the cases that have been monitored in detail (e.g., Martí, Rodríguez, & Reipurth 1998; Rodríguez, Anglada, & Curiel 1999; Rodríguez et al. 2000) there are only mild variations present, at levels below 10–20%.

The other sources in this field that were detected by Anglada et al. (1992) have fluxes consistent with those reported by those authors, which reinforces our conclusion concerning the variability of IRAS 19345+0727 at 3.5 cm. Figure 10 shows the sources detected in this field. Interestingly, VLA 3 was not detected by Anglada et al. (1992). This source might also be variable.

3.10. *The HH 242 Outflow in NGC 7129*

This bow-shaped HH object, also called the HL 14-jet, was discovered by Miranda, Eiroa, & Gómez de Castro (1993), from CCD and spectroscopic observations. It is located close to the star HL 14, discovered by Hartigan & Lada (1985). The spectroscopic results of Miranda et al. (1993) led these authors to suggest that HL 14 is a young T Tau-like star. They also suggest that HH 242 could be a

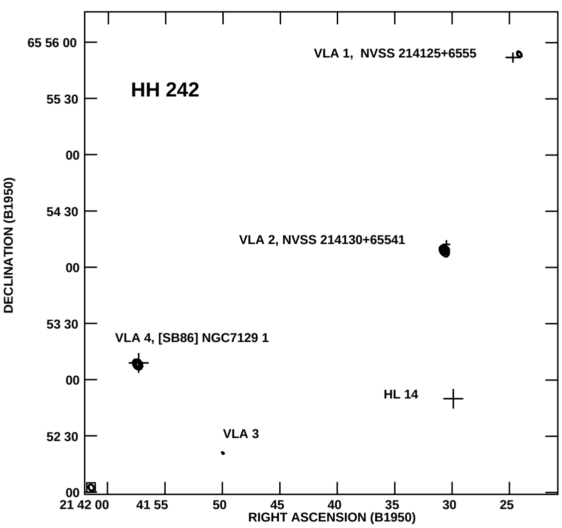

Fig. 11. Natural-weight VLA map at 3.5 cm wavelength of sources detected in NGC 7129 (HH 242). Contour levels are −5, 5, 7, 15, 25, and 35 times the rms noise of 28 μJy beam^{-1}. The crosses near VLA 1 and VLA 2 represent the reported uncertainty intervals of the positions of NVSS 214125+655552 and NVSS 214130+655412. The crosses associated with HL 14 and [SB86] NGC 7129 1 represent the position uncertainties of these objects, multiplied by 10.

jet emanating from HL 14, bent by the shock with a density enhancement or pressure gradient in the cloud. We do not detect 3.5-cm emission above the noise level at the location of HL 14 (see Figure 11). As reported in Table 2, sources VLA 1 and 2 coincide with sources detected at 1.4 GHz by the NVSS, with flux densities of 2.9 ± 0.5 and 4.2 ± 0.5 mJy, respectively. The spectral indices of these sources between 1.4 and 8.3 GHz are -0.86 ± 0.16 and -0.63 ± 0.08, respectively, corresponding to non-thermal emission.

4. CONCLUSION

We imaged at 3.5 cm ten fields containing Herbig-Haro flows. We report the detection of the exciting sources of the HH 211 and HH 68 outflows. We also present VLA observations at 7 mm of the exciting source of HH 211. We conclude that the 7-mm emission originates in a compact protoplanetary disk.

The exciting source of HH 68 appears to be the object HH 68b, as previously proposed by Reipurth & Graham (1988).

Finally, we find that the exciting source of the HH 119 outflow in B335 is variable in time on a scale of years. Time variability is believed to be unusual in thermal jets and this source should be studied further.

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Remy Avila and Luis F. Rodríguez: Instituto de Astronomía, UNAM, Apartado Postal 3-72, (Xangari), 58089 Morelia, Michoacán, México (r.avila,l.rodriguez@astrosmo.unam.mx).

Salvador Curiel: Instituto de Astronomía, UNAM, Apartado Postal 70-264, 04510 México D. F., México (scuriel@astroscu.unam.mx).