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MULTIEPOCH RADIO OBSERVATIONS OF THE EXCITING SOURCES OF HH 212 AND HH 119

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RESUMEN

Presentamos observaciones de alta resolución angular (∼ 0.″3) hechas con el Very Large Array a 3.5 cm hacia las regiones de las fuentes excitadoras de dos sistemas Herbig-Haro: HH 212 en Orión y HH 119 en B335. Las observaciones fueron hechas durante tres épocas diferentes con el objetivo de medir posibles variaciones temporales rápidas (en la escala de una semana a un mes) en las fuentes. En HH 212 detectamos, promediando las observaciones de las tres épocas, una fuente muy débil justo en la posición esperada para la fuente excitadora del sistema HH. La comparación con otras observaciones de radio de esta fuente indica variación temporal considerable en escala de años. En B335 detectamos en cada época al objeto previamente reportado por otros autores y nuestros resultados sugieren que esta fuente, un chorro térmico de radio, es variable en escalas de tiempo de un mes. Discutimos posibles explicaciones para esta rápida variabilidad.

ABSTRACT

We present high angular resolution (∼ 0.″3) Very Large Array observations at 3.5 cm toward the regions of the exciting sources of two Herbig-Haro systems, namely, HH 212 in Orion and HH 119 in B335. The observations were made at three different epochs to search for possible fast time variations in the sources (on a scale of one week to one month). In HH 212 we detected, averaging the observations of the three epochs, a faint object, at the expected position for the exciting source of the HH system. Comparison with other radio observations indicates that this source exhibits considerable time variation on a scale of years. In B335 we detected at each epoch the source previously reported by other authors and our results suggest that this object, a thermal radio jet, is variable on timescales of a month. We discuss possible explanations for this fast variability.

Key Words: **ISM: INDIVIDUAL (B335, HH 212, HH 119) — ISM: JETS AND OUTFLOWS — STARS: FORMATION — STARS: MASS LOSS — RADIO CONTINUUM: STARS**

1. INTRODUCTION

The early stages of star formation are characterized by the presence of collimated, powerful outflow phenomena. Sensitive interferometric observations at centimeter wavelenghts can detect the free-free emission from these jets within 100 AU or less from the exciting star, close to the place where the outflow is accelerated and collimated. Since these sources emit free-free (or thermal) radiation, they are referred to as thermal jets (e.g., Rodríguez 1997; 1999).

Strong time variability is rare in these sources. In the objects that have been observed with time separation of the order of a few years (e.g., Martí, Rodríguez, & Reipurth 1998; Rodríguez, Anglada, & Curiel 1999; Rodríguez et al. 2000; Rodríguez et al. 2001; Velázquez & Rodríguez 2001) there are usually only mild variations present, at levels below 10–20%. These mild variations appear to be associated with electron density enhancements that travel along the jet. Variation of the order of a factor of two has been reported in the case of Cep A HW2, over a time scale of about 8 years (Porras et al. 2002). In this source

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this relatively strong increase was attributed to an enhancement in the mass loss rate in the jet, evident in the images presented by Porras et al. (2002).

There are also observations taken with a time separation of a few weeks (Reipurth et al. 2002) and in them there is no evidence of variability above the 10% level. The usual interpretation for this lack of variability on short scales is that the emission from the jet originates over scales of order 10–100 AU that, with the gas moving at speeds of order 300 km s^{-1}, give kinematic timescales of order of months to years. Then, "fast" (that is, with scales of weeks or less) variations of significant magnitude in thermal jets are, in principle, not feasible given the size of the radio "photosphere" and the velocity of the gas. It is well known that in more evolved objects there can be detectable gyrosynchrotron emission from active magnetospheres that can strongly change on scales of days or even less, but in the case of thermal jets the stellar surface is assumed to be unobservable given the large free-free opacity of the outflowing gas.

In this paper we present sensitive observations of two sources with reported variability over a time scale of years, in an attempt to search for shorter scales of variability.

2. OBSERVATIONS

Sensitive 3.5 cm continuum observations of two fields containing the exciting sources of Herbig-Haro (HH) objects were made at three different epochs, given in Table 1. All of them were made using the Very Large Array (VLA) of the NRAO[3] in the A configuration, providing an angular resolution of about $0\rlap{.}''3$. On-source integration times were approximately 90 minutes per epoch per object. The absolute amplitude calibrator was 0137+331, with an adopted flux density of 3.23 Jy. The coordinates of the phase centers, as well as the phase calibrators used and their bootstrapped flux densities are also specified in Table 1.

The objects were observed in both circular polarizations with an effective bandwidth of 100 MHz. The data were reduced in the standard way using the Astronomical Image Processing System (AIPS) of NRAO. We made cleaned, natural-weight maps of the regions and considered as detections those signals above 4σ.

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3. RESULTS

3.1. *HH 212 in Orion*

The extremely well collimated jet HH 212 was first seen in detail by observing shocked H_2 lines at near infrared wavelengths (Zinnecker, McCaughrean, & Rayner 1998). It lies in the L1630 molecular cloud in Orion, near the Horsehead nebula, at a distance of 450 pc. Chini et al. (1997) found a compact 1.3 mm continuum source associated with IRAS 05413–0104. These authors identified the mm source as being dust emission from the core surrounding the protostar that powers HH 212. The region surrounding IRAS 05413–0104 was previously associated with water maser and submillimeter continuum sources (Wouterloot & Walmsley 1986; Zinnecker et al. 1992).

Detailed proper motions of the 22 GHz water masers that trace the outflow have helped to constrain the precise position of the exciting source (Claussen et al. 1997, 1998), and 3.5 cm radio continuum observations have been carried out by Rodríguez & Reipurth (1996) and Claussen et al. (1998) to try to detect it. Table 2 lists these observations as well as our new measurements. Rodríguez & Reipurth (1996) reported a 4σ upper limit of 0.06 mJy at 3.5 cm from observations made in 1994. On the other hand, Claussen et al. (1998) clearly detected a source at a level of 0.14 mJy in observations taken in 1997. Martí (2004) observed the source again in 1999, not detecting it at a 4σ level of 0.05 mJy. In our individual epoch observations we did not detect the source. However, co-adding our data from all three epochs we have a clear detection at a level of 0.04±0.01 mJy.

Figure 1 shows that the detected source is located precisely at the center of the inner H_2 knots reported by Zinnecker et al. (1998). The position for our detection is α(J2000)= $05^{\rm h}\ 43^{\rm m}\ 51\rlap{.}^{\rm s}408$ and δ(J2000)= $-01^\circ\ 02'\ 53\rlap{.}''13$, which agrees very well with the mean position of the water masers reported by Claussen et al. (1998): α(J2000)= $05^{\rm h}\ 43^{\rm m}\ 51\rlap{.}^{\rm s}37$, δ(J2000)= $-01^\circ\ 02'\ 53\rlap{.}''11$. From Windhorst et al. (1993) the probability of having a 3.5 cm background source of 0.04 mJy in a region of $1'' \times 1''$ is only 4×10^{-5}. Therefore, we propose that this radio object is associated with the powering source of HH 212. Due to our marginal level of detection, we were not able to resolve spatially the morphology of the radio jet which is believed to be the origin of the outflow.

As mentioned before, we did not detect the source in any of our three individual observations, which does not allow us to test whether or not the source

TABLE 1

MULTIEPOCH OBSERVATIONS OF HH 212 AND B335

Source	Position of Phase Center[a] α(J2000)	δ(J2000)	Epochs (2002)	Phase Calibrator	Bootstrapped Flux Density (Jy)
HH 212	05 43 51.520	-01 02 51.900	Feb 05	0541−056	0.758±0.006
			Mar 08	”	0.760±0.004
			Mar 18	”	0.820±0.008
B335	19 37 00.800	+07 34 11.000	Feb 03	1950+081	0.800±0.004
			Mar 03	”	0.813±0.006
			Mar 11	”	0.811±0.007

[a]Units of right ascension are hours, minutes, and seconds and units of declination are degrees, arcminutes, and arcseconds.

is variable on a short timescale (one month or less). However, using our co-added data and previously reported flux densities (see Table 2), one can certainly assert that the source presents large variability (of a factor of three) on a few-year timescale.

3.2. *HH 119 in B335*

The Barnard 335 dark cloud is an isolated Bok globule at an estimated distance of 250 pc (Tomita, Saito, & Ohtani 1979) and is one of the best studied objects of its type. Frerking & Langer (1982) made the first study of the molecular outflow emanating from the cloud core. Keene et al. (1983) detected a compact far infrared source near the outflow center with a flux density higher than what could be explained solely by interstellar radiation field heating. Later, Chandler et al. (1990) discovered a submillimeter continuum source elongated in the N-S direction that they associated with a core of dust and gas surrounding a central protostar. Vrba et al. (1986) and Reipurh, Heathcote & Vrba (1992) detected HH 119B and HH 119C, showing the existence of a highly collimated E-W HH complex emanating from the embedded far-infrared source and approximately parallel to the magnetic field threading the cloud. Anglada et al. (1992) suggested that this source and IRAS 19345+0727 are most probably the same object. These authors found a 3.5 cm counterpart with a peak flux density equal to 0.21±0.02 mJy beam^{-1}. Additional observations at the same wavelength have been carried out by Avila, Rodríguez, & Curiel (2001) and Reipurth et al. (2002). The former authors did not detect any source above 0.08 mJy beam^{-1}, while the latter detected an object with a peak flux density between 0.16 and 0.24 mJy beam^{-1}. Avila et al. (2001) concluded that this object, proposed as the exciting source of HH 119, is time-variable over timescales of years.

In order to increase the time-resolution of the measurements, we have performed high angular resolution observations separated by a month and a week successively. As can be seen in Table 3, the flux density we measured for the first epoch is very close to that reported by Anglada et al. (1992), while for the second epoch (about one month later) it approaches the high value obtained by Reipurth et al. (2002). The flux density measurements obtained in the last two epochs (separated by about a week) are the same within the uncertainty range.

We made maps of the exciting source for each epoch. In all of them it appears elongated towards the direction of the molecular outflow (i.e., nearly in the E-W direction), as was observed by Reipurth et al. (2002). In order to enhance the signal to noise ratio and obtain a clearer view of the faint thermal radio jet driven by the embedded source, we co-added all the available VLA-A data and made a single map shown in Fig. 2. The E-W elongation is clearly present. The position of the source is α(J2000)= $19^{\rm h}\ 37^{\rm m}\ 00\overset{\rm s}{.}888$, δ(J2000)= $+07^\circ\ 34'\ 09\overset{''}{.}84$, with a deconvolved size of $0\overset{''}{.}34 \times 0\overset{''}{.}15$, which is somewhat more extended than that reported by Reipurth et al. (2002): $0\overset{''}{.}25\times0\overset{''}{.}16$. The PA we have measured is $97^\circ\pm7^\circ$, in agreement, within error, with the value of $87^\circ \pm 15^\circ$ given by Reipurth et al. (2002). Our position agrees very well with the 1.2 mm data from the IRAM Plateau de Bure Interferometer (Harvey et al. 2003): α(J2000)= $19^{\rm h}\ 37^{\rm m}\ 00\overset{\rm s}{.}89$, δ(J2000)= $+07^\circ\ 34'\ 10\overset{''}{.}0$.

TABLE 2

REPORTED FLUX DENSITIES OF IRAS 05413-0104 AT 3.5 cm

Epoch	Flux density (mJ)	VLA Conf.	Reference
1994 Nov 17	≤ 0.06	C	Rodríguez & Reipurth (1996)
1997 Oct 05+29	0.14±0.01	D	Claussen et al. (1998)
1999 Oct 26	≤ 0.05	BnA	Martí (2003)
2002 Feb 05 + Mar 08+18	0.04±0.01	A	This paper

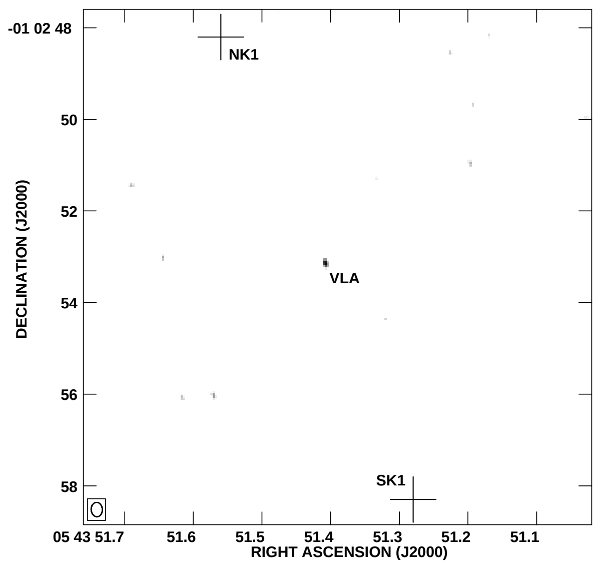

Fig. 1. Greyscale image of the 3.5 cm continuum emission from the central region of the molecular outflow HH 212. The aim of this image is to show that the detected source, labeled as "VLA" in the figure, is located at the center of the inner knots (crosses) of the extremely symmetric outflow seen in molecular hydrogen (Zinnecker et al. 1998). The range of the image is from 0.02 to 0.04 mJy beam^{-1}. The half-power contour of the synthesized beam ($0\farcs31 \times 0\farcs24$; PA = 4°) is shown in the bottom left corner of the map.

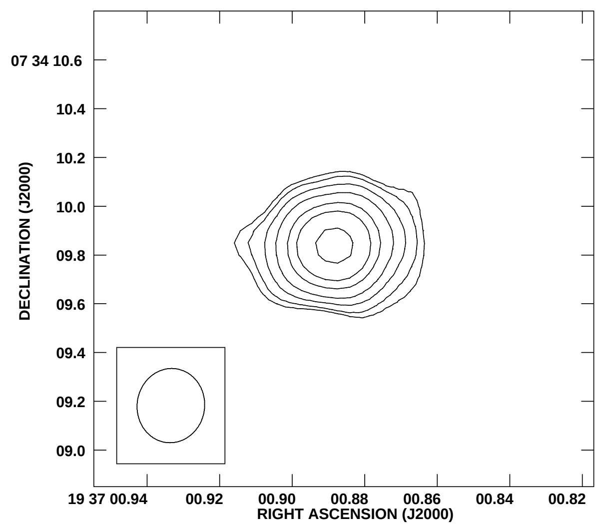

Fig. 2. VLA map of the 3.5 cm continuum emission from the central region of the molecular outflow HH 119 in B335. Contour levels are −4, 4, 5, 7, 10, 15, 20, and 30 times 5.3 μJy beam^{-1}, the rms noise of the image. The half-power contour of the synthesized beam ($0\farcs30 \times 0\farcs28$; PA= −8°) is shown in the bottom left corner of the map.

The variability of $\sim$ 50% detected between 2002 Feb 03 and 2002 Mar 03 is not easy to understand. At a distance of 250 pc, the semimajor axis of the jet has a linear size of $\sim$ 40 AU. For gas moving at a speed of $\sim$ 200 km s^{-1}, a kinematic timescale of about one year is obtained, much longer than the interval of one month between observations.

We can think of two possible explanations for this result. One is that the characteristic time for variation in B335 is not related to the kinematic timescale but to the electron recombination timescale. For ionized gas at an electron temperature of 10^4 K, the recombination timescale will be of order 1.2×10^5 n_e^{-1} years, where n_e is the electron density in cm^{-3}. So, if the emitting gas has $n_e \simeq 10^6$ cm^{-3} it can recombine in timescales of one month. Unfortunately, our data cannot provide a reliable estimate of the electron temperature in the thermal jet. The other possible explanation is that the centimeter emission is contaminated by gyrosynchrotron emission from the stellar magnetosphere. However, as mentioned before, the wind is very optically thick at centimeter wavelengths. To test for the presence of gyrosynchrotron emission, we searched unsuccessfully for circular polarization in the final image, setting an upper limit of $\sim$ 15%. However, this upper limit is not particularly stringent and does not rule out the possibility of non-thermal contamination.

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TABLE 3

REPORTED FLUX DENSITIES OF IRAS 19345+0727 AT 3.5 cm

Epoch	Flux density (mJy)	VLA Conf.	Reference
1990 Jan 04+26	0.21±0.02[a]	D	Anglada et al. (1992)
1994 Dec 01+04	$\leq$ 0.08	C	Avila et al. (2001)
2001 Jan 06	0.37±0.02	A	Reipurth et al. (2002)
2002 Feb 03	0.21±0.03	A	This paper
2002 Mar 03	0.32±0.05	A	This paper
2002 Mar 11	0.32±0.05	A	This paper

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

4. CONCLUSIONS

We presented multiepoch VLA observations made at 3.5 cm of the exciting sources of the HH 212 and HH 119 outflows. We confirmed that the exciting source of HH 212 presents large flux density variations (of a factor of order 3) over a time scale of years and provided the first accurate centimeter position for it. The exciting source of HH 119 also shows variations (of a factor of order two) over a time scale of years. Interestingly, we present evidence of a 50% increase in the flux density of this source over a time scale of only one month. This variation cannot be explained easily as a result of variations of the mass loss rate of the jet and alternative explanations are discussed.

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