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RADIO CONTINUUM OBSERVATIONS OF DISKS AND OUTFLOWS IN YOUNG STARS

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RESUMEN

En la actualidad una gran cantidad de resultados apoyan la hipótesis de que los excesos de emisión infrarroja en estrellas jóvenes, descubiertos por Eugenio Mendoza, provienen de discos protoplanetarios alrededor de estas estrellas. Esta emisión de continuo se extiende hacia mayores longitudes de onda y reseño algunos resultados recientes en las regiones milimétrica y centimétrica que apuntan hacia la existencia de discos y flujos colimados alrededor de objetos jóvenes. Las observaciones milimétricas y sub-milimétricas han revelado que hay continuo relativamente fuerte asociado con las estrellas tipo T Tauri. Si esta emisión proviene de discos protoplanetarios, se derivan masas de 0.001 a 1 $M_\odot$. Sin embargo, estas observaciones carecen de suficiente resolución angular para resolver la morfología de la fuente y una colaboración entre los EUA y México instalará receptores de 7-mm en el Conjunto Muy Grande (Very Large Array) para obtener la resolución angular requerida para observar por primera vez imágenes de estos discos protoplanetarios.

A longitudes de onda mayores (cm) el radio continuo está dominado por emisión libre-libre de flujos (parcialmente) ionizados y altamente colimados. Discuto algunos resultados recientes relacionados con estos chorros de radio y los problemas astrofísicos que pueden atacarse con su estudio.

ABSTRACT

At present, a large body of evidence supports the hypothesis that the infrared excess emission first observed in young stellar objects by Eugenio Mendoza, arises in protoplanetary disks around these stars. This continuum emission extends into the radio regime and I review recent results at millimeter and centimeter wavelengths that point to the existence of disks and collimated outflows around young objects. The sub-millimeter and millimeter observations have revealed that relatively strong continuum emission is associated with the T Tauri stars. If this emission arises in a protoplanetary disk, masses in the range of 0.001 to 1 $M_\odot$ are derived. However, these observations lack sufficient angular resolution to resolve the morphology of the source and a collaboration between the USA and Mexico to upgrade the Very Large Array for operation at 7-mm will provide the required sub-arcsec resolution to image for the first time protoplanetary disks.

At longer wavelengths (cm) the radio continuum is dominated by free-free emission from (partially) ionized, highly collimated outflows. I discuss recent results related to these radio jets and the astrophysical problems that can be addressed with their study.

Key words: **RADIO CONTINUUM: STARS — STARS: CIRCUMSTELLAR MATTER — STARS: MASS LOSS — STARS: PRE-MAIN SEQUENCE**

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1. INTRODUCTION

The detection of infrared excesses in young stars by Mendoza (1966, 1968) is one of the milestone contributions to astronomy in our century. A vast body of research derives from those pioneering papers. The event is also one of the important moments of Mexican astronomy, with Poveda (1965) providing the theoretical notions and Eugenio Mendoza undertaking the observations and actual discovery of the excesses.

The continuum excesses observed by Mendoza in the near-IR extend into the far-IR and even the millimeter regimes. Our present scenario for the star formation phenomenon (Shu, Adams, & Lizano 1987) suggests that this radiation is produced by heated dust in a disk around the star. In this paper I will review some recent results obtained in the millimeter and sub-millimeter wavelengths that are interpreted to signal protoplanetary disks around young stellar objects. The second part of this review focuses on the high-angular resolution observations of young stars in the centimeter regime, where the observations are believed to be tracing a different component of the phenomenon: a (partially) ionized bipolar outflow that originates close to the star and could be collimated by the disk. Most of the centimeter wavelength observations discussed here have been obtained with the Very Large Array (VLA) [2].

Both emission mechanisms can be clearly appreciated in the continuum spectrum of HL Tau (Figure 1) where the emission with wavelengths shorter than about 1-cm is dominated by the emission from dust, while the emission with wavelengths longer than about 1-cm is dominated by free-free emission from the ionized outflow

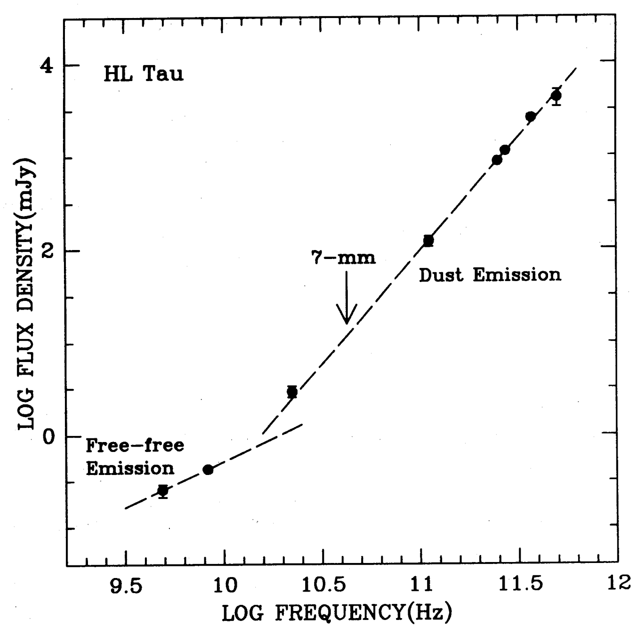

Fig. 1. Continuum spectrum of HL Tau in the cm and mm wavelengths. Data from Brown et al. (1985 6-cm), Sargent & Beckwith (1991; 2.7-mm), Beckwith et al. (1990; 1.2-mm), Adams et al. (1990; 1.1, 0.8, and 0.6-mm), and Rodríguez et al. (1992; 3.6 and 1.3-cm). The dashed lines are separate least squares power-law fits to the cm data (6 and 3.6-cm, left side of the figure) and to the five mm data points. The 1.3-cm flux density measured with the VLA is indicated in the figure. Note that it falls closer to the extrapolation of the mm emission (believed to be produced by dust in a protoplanetary disk) than to the extrapolation of the cm emission (believed to be free-free produced in an ionized outflow). This result suggests that the 1.3-cm flux is dominated by the dust emission from the disk. The arrow marks the wavelength of 7-mm, where the VLA will soon start operating and attempts to image the dust emission will be undertaken.

[2]The VLA is part of the National Radio Astronomy Observatory, USA, which is operated by Associated Universities, Inc., under cooperative agreement with the National Science Foundation.

2. MILLIMETER OBSERVATIONS OF DISKS

The continuum radiation in the mm regime from young stars is believed to be optically thin, thermal mission from dust grains in a circumstellar disk. With this approach and assuming a mass opacity for the ust it is possible to estimate the total mass in the disk. Beckwith et al. (1990) used the IRAM 30-m radio elescope to observe 1.3-mm emission from a sample of 86 pre-main-sequence stars in the Taurus-Auriga dark louds. The angular resolution of these observations is 11 arcsec. A total of 37 stars (42 % of the sample) ere detected. Adopting a mass opacity of $\kappa_\nu = 0.1\ (\nu/10^{12}\ Hz)$ cm^2 g^{-1}, they derived total disk masses in he range of 0.001 to 1 $M_\odot$ and disk temperatures (at 1 AU from the star) typically in the range of 100 to 00 K. The mass determinations depend crucially on the assumed mass opacity. The issue of the dust opacity n circumstellar disks at millimeter and sub-millimeter wavelengths has been recently discussed by Weintraub, andell, & Duncan (1989); Beckwith & Sargent (1991); Miyake & Nakagawa (1993). In Figure 2 we show the istribution of disk masses for the 37 stars detected by Beckwith et al. (1990). Other studies of mm continuum mission from young stars include those of Weintraub, Sandell, & Duncan (1989); Adams, Emerson, & Fuller 1990); Terebey, Chandle,r & André (1993), and Ohashi et al. (1993).

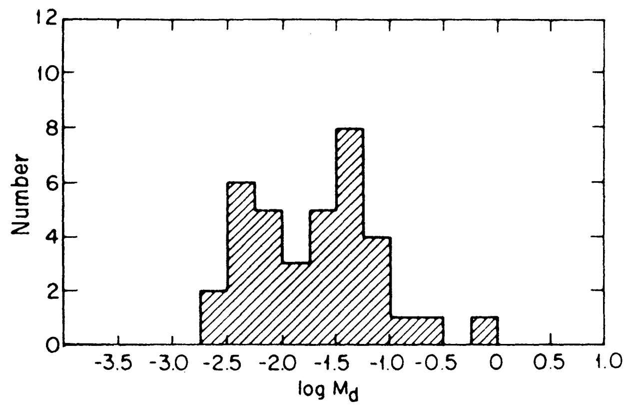

Fig. 2. Distribution of disk masses for the 37 stars detected at 1.3-mm by Beckwith et al. (1990).

The flux densities of these stars at 1.3-mm are relatively high, reaching as much as about 0.9 Jy in the case f HL Tau. However, the angular resolutions now available at mm wavelengths with interferometers are still on he order of a few arcsec and preclude actual imaging of the disks. Even at the distance of the closest young tars [for example, 140 pc for Taurus, Elias (1978)], an angular resolution below one arcsec is required.

As a collaboration between the Very Large Array of NRAO and the Instituto de Astronomía, UNAM, lexico (with support from CONACyT, Mexico), the ten best antennas of the VLA will be equipped with 7-mm eceivers. These best antennas are being selected by holographic techniques. The first two receivers are already nstalled (November 1993) and tests have started. All of them should be installed by the end of the VLA's ext configuration A (April 1994). The receivers will be located in the inner antennas of the configuration to chieve resolution of a few tenths of an arc sec. This new VLA capability will allow mapping of dust emission rom possible protoplanetary disks around young stars at 7-mm, where the flux density of the best candidates s estimated to be in the order of 10 mJy. It is estimated that in the continuum mode (four channels of 50 MHz ach) at 7-mm the VLA will have a sensitivity of 1-σ = 1 mJy in one hour of integration. The same spectral apability existing for the other bands will also be available for 7-mm. The goal is to get the receivers to tune rom about 40 to 50 GHz, reaching also many important atomic and molecular transitions.

The cm and mm observations of several molecules, in particular CO and its isotopes, have allowed mapping f large-scale ($\geq$ 1 000 AU) molecular structures that have been found in association with young stars. The case f HL Tau (Sargent & Beckwith 1991) is the best studied, but interesting structures have been found in sources uch as Cep A-HW 2 (Torrelles et al. 1993a), GG Tau (Kawabe et al. 1993), and HH34 (Stapelfeldt & Scoville 993). These structures have been interpreted as circumstellar disks but, again, it has not been possible to image he inner parts of these larger structures to establish the existence of the expected $\sim$100 AU protoplanetary lisks. Of course, the line observations have the advantage over the continuum observations of providing velocity information. In these 1 000 AU structures, motions have been found that are usually interpreted to indicate Keplerian rotation around the star. In Figure 3 we show recent CO observations of Kawabe et al. (1993) toward the star GG Tau. A discussion of other mm line observations of circumstellar structures is included in Sargent & Welch (1993).

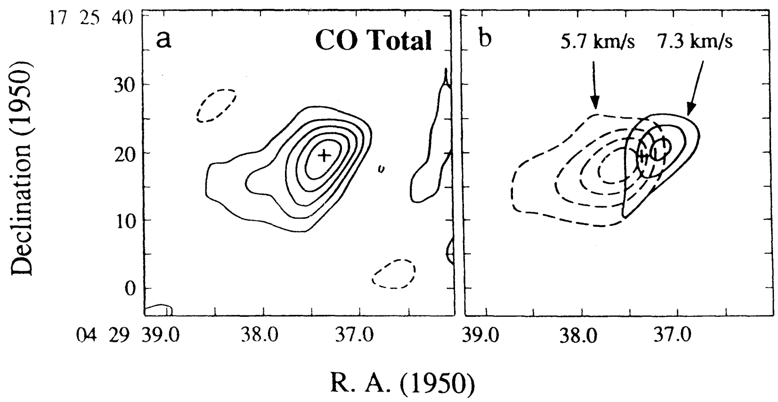

Fig. 3. (a) Map of total CO (J = 1–0) intensity toward GG Tau. The position of the star is indicated with a cross. (b) Red (solid contours) and blueshifted (dashed contours) CO toward GG Tau. The velocity difference across the CO structure is taken to be the kinematic signature of rotation. Angular resolution of the maps is ~ 8 arcsec. Data from Kawabe et al. (1993).

3. CENTIMETER OBSERVATIONS OF IONIZED JETS

3.1. The Nature of the cm Sources

As mentioned before, for wavelengths longer than about 1 cm, the continuum emission from young stars is dominated by free-free radiation from a (partially) ionized outflow. This conclusion was suggested by the pioneering VLA studies of Cohen, Bieging, & Schwartz (1982) and Bieging, Cohen, & Schwartz (1984) and has been firmly established in the case of VLA 1, the central source of the HH 1–2 system. In this radio continuum source (Rodríguez et al. 1990) measured flux density and angular size dependences with frequency that are consistent with the thermal bipolar jet models of Reynolds (1986).

The radio jets are quite probably associated with the disks discussed previously, in the sense that the disks are almost certainly playing a role in the bipolar collimation of the thermal jets. Additionally, the accretion and rotational energies in a magnetized disk may be somehow powering the outflow (Pudritz & Norman 1986; Shu et al. 1988).

The radio continuum sources found in association with young stars and generally interpreted as thermal bipolar jets are usually characterized by the following parameters: 1) Relatively weak flux densities in the cm regime, around 1 mJy; 2) Spectral indices that are flat or rise slowly with frequency (α from 0 to 1), consistent with ionized, thermal outflows; 3) Elongation approximately along the axis of the outflow when observed with high (sub arcsec) angular resolution; 4) No evidence of time variability; 5) No evidence of polarization.

The technique of observing radio jets in the cm range with an interferometer like the VLA has two main advantages. First, we can study the phenomenon with an unequaled angular resolution in the order of 0.1 arcsec. This angular resolution allows to set the most stringent limits on the scale at which collimation is occurring and will help toward understanding the nature of the collimation mechanism. The ionized gas that we can see in the radio jets is extremely young. With a typical physical scale of 100 AU and a gas velocity in the order of 200 km s^{-1}, the gas has been ejected within a time period of a few years previous to the observations. Second, at cm wavelengths no significant dust extinction is expected, even in the extremely dense environments of these young stars. Of course, disadvantages are also present. In particular, the flux densities are small and long integration times are required. Also, no direct information is obtained on the radial velocity of the gas, although in some sources it will be possible to find proper motions in the jet's condensations within a few years (Martí, Rodríguez, & Reipurth 1993). In any case, these jets are important in themselves and also because they may be the drivers of the bipolar molecular outflows (Chernin & Masson 1992; Raga et al. 1993) frequently found in regions of star formation.

Of the 180 molecular outflow sources known up to now (Iwata, Mizuno, & Fukui 1993), I estimate that about 40 (22 %) have radio continuum sources that can be associated with the exciting star of the system. A discussion and possible correlations between parameters of the sources detected until about 1991 are given by Anglada et al. (1992) and Cabrit & Bertout (1992). Since then new detections or relevant data on previously known sources have been reported by Rodríguez & Hartmann (1992; FU Ori stars), Skinner, Brown, & Stewart (1993; survey of Herbig Ae/Be stars), Curiel et al. (1993a; Serpens), Martí, Rodríguez, & Reipurth (1993; HH 80-81), Anglada et al. (1994; L1287). A review of radio observations in HH systems is given by Rodríguez (1989). In the next sections we discuss some astrophysical problems that are being addressed using cm observations of these ionized outflows.

3.2. Location of the Exciting Source

Since the discovery of the exciting source of the prototypical Herbig-Haro complex, HH 1–2, in the cm wavelengths by Pravdo et al. (1985) it became clear that this type of observations is of great value to locate the exciting star of outflow systems in regions so highly obscured that even near-IR observations cannot penetrate them. Since then, the VLA observations have played an important role in determining the location of the exciting sources of HH 80–81 (Rodríguez & Reipurth 1989; Martí, Rodríguez, & Reipurth 1993), Serpens (Rodríguez et al. 1989; Curiel et al. 1993a), NGC 2264G (Rodríguez & Curiel 1989), L1448 (Curiel et al. 1990), L723 (Anglada et al. 1991), VLA 1623 (Leous et al. 1991; André, Ward-Thompson, & Barsony 1993), B335 (Anglada et al. 1992), and L1287 (Anglada et al. 1994).

3.3. Binary Jets?

Star formation seems to proceed in clusters and most stars are members of binary systems. It is then not totally surprising that there starts to be evidence of two sources in a small region of the sky having each its own jet. In some cases, the sources appear to be so near that one has to start worrying whether or not there could be gravitational interactions between the expected disks in these objects. In such cases one could refer to these double systems as binary jets.

About 3 arcsec south of HH1–2 VLA 1, the exciting source of the well known HH system, there is an unresolved flat-spectrum radio continuum source, VLA 2 (see Figure 4) with cm flux density of about 0.1 mJy (Rodríguez et al. 1990, 1994). Recently, Reipurth et al. (1993), using [S II] CCD observations of the region, discovered what appears to be a second HH system, HH 144–145, extending about 2′ toward the west, at a large angle of the axis of the HH 1–2 system. Remarkably, the proper motions and alignment of the HH 144 knots are consistent with the hypothesis that the knots were ejected by VLA 2. To test this hypothesis, Reipurth et al. (1993) obtained a near-IR K-band image that shows reflection nebulae fanning out of VLA 1 toward HH 1 and from VLA 2 toward HH 144 (Figure 4). They conclude that VLA 1 and 2 may be a binary system with projected separation of 1380 AU, with each star powering its own bipolar HH system.

Equally remarkable is the case of the HH 111 complex. The previously known HH optical system (Reipurth 1989; Reipurth, Raga, & Heathcote 1992) extends for about 6 arcmin in the east-west direction. Using near-IR K-band images, Gredel, & Reipurth (1993) detected a new optically invisible bipolar jet, named by them HH 121, nearly perpendicular to the optical outflow but that appears to emanate from within 1 arcsec of the exciting VLA radio source (Rodríguez & Reipurth 1994) of the region. However, only one radio source has been detected in this region. We will refer again to this radio source in the discussion below.

The molecular outflow in L723 exhibits a quadrupolar morphology (two redshifted lobes and two blueshifted lobes; see Avery, Hayashi, & White 1990) suggesting that two outflows are taking place very close in space. It was then relevant that Anglada et al. (1991) detected with the VLA two radio continuum sources at the core of the quadrupolar outflow separated by $\sim$ 15 arcsec (4500 AU at a distance of 300 pc). A detailed radio and infrared study of these embedded sources is required to establish their nature. Another quadrupolar molecular outflows are IRAS 16293–2422 (Mizuno et al. 1990) and Cepheus A (Bally & Lane 1992; Torrelles et al. 1993b). Both show multiple radio continuum sources in their cores (Wootten 1989; Estalella et al. 1991; Hughes & Wouterloot 1982), whose precise nature and physical parameters should be determined with further studies to assess whether or not multiple jets are present. The molecular quadrupolar outflow morphology does not necessarily imply a double outflow. An alternative explanation is that we are observing the shell walls of a single bipolar outflow (Avery et al. 1990).

Another source that may have binary jets is L1551, where two possible explanations have been put forward to account for the double radio source (separation of ~0.3 arcsec) at the center of the outflow; a binary system (Bieging & Cohen 1986) or the inner ionized walls of a disk seen nearly edge on (Rodríguez et al. 1986). Again, it has not been possible to favor either possibility conclusively, although the disk interpretation has gained some support from the mm-wave continuum measurements of Keene & Masson (1990). Curiel et al. (1994) are currently undertaking a combined VLA-MERLIN study of the region in an attempt to clarify these doubts.

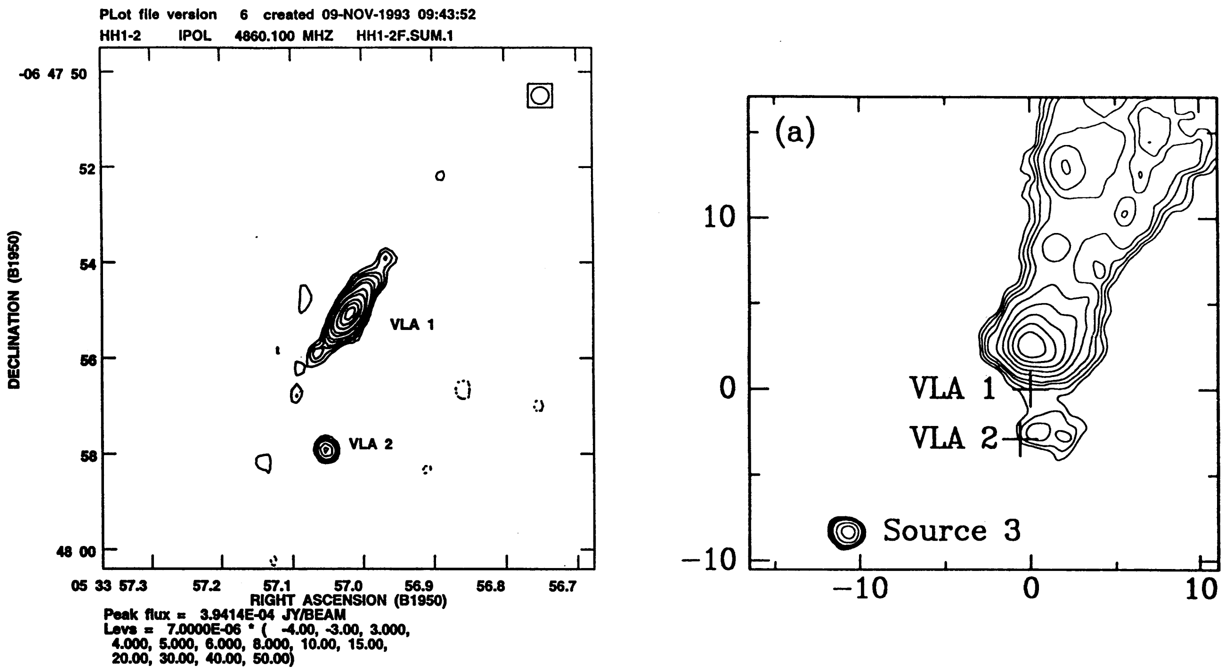

Fig. 4. (Left) VLA contour map of the HH 1–2 core at 6-cm. The sources VLA 1 and 2 are indicated. The half power contour of the beam is also shown. Data from Rodríguez et al. (1990, 1994). (Right) Contour diagram of a deep K image of the HH 1–2 core. The positions of the VLA sources are marked with crosses. Note the IR nebulosities that fan out from the VLA sources toward HH 1 (north) and HH 144 (west). Data from Reipurth et al. (1993). Coordinates are in arcsec with respect to the position of VLA 1.

Finally, evidence of multiple jets is also appearing in studies at other wavelengths. Smith & Fischer (1992) imaged IRAS 21334+5039 in the 1-2 μ region and concluded that two nearly perpendicular jets are present in this source.

3.4. Precessing Jets

While in sources like HH 1-2, the major axis of the radio continuum jet aligns within a few degrees with the axis of the large-scale optical outflow as delineated by HH jets and HH objects (Rodríguez et al. 1990), other sources show clear evidence of different angles at these two scales. Most notable is the triple source in Serpens, where the axis defined by the outer radio lobes differs by $\sim 10°$ from the major axis of the central radio component (see Figure 5 taken from Curiel et al. 1993a). Another source that shows evidence for precession or nutation is HH 80-81 (Martí et al. 1993). These motions seem to be taking place in a cone of $\sim 5°$.

3.5. One-sided Jets?

It is well known that, due to obscuration effects, outflows often appear one-sided in the optical and near-IR (see, for example, the images of Gredel et al. 1993 and Reipurth et al. 1993). Also, some molecular outflows appear to be nearly unipolar (NGC 2024, Richer et al. 1989; HH 46-47, Chernin & Masson 1991), and this asymmetry can be accounted for as due to lack of molecular material on one side of the flow. However, until recently all the radio continuum jets that had been angularly resolved with the VLA showed bipolar (i.e., two-sided morphology). Nevertheless, Curiel et al. (1993a) found that even when the core source in Serpens is bipolar, the jet that emanates from this source to the lobes is markedly one-sided (see Figure 5). Even more remarkable is the radio source detected in HH 111 by Rodríguez & Reipurth (1994), since here the core is clearly one-sided (see Figure 6). The fact that at least in HH 111 the jet is one-sided on a scale of less than 100 AU will certainly help constrain models of jets that as a result of their symmetry assumptions predict bipolar structures (Uchida & Shibata 1985; Pudritz & Norman 1986; Shu et al. 1988; Lovelace, Berk, & Contopoulos 1991; Pelletier & Pudritz 1992; Wardle & Königl 1993).

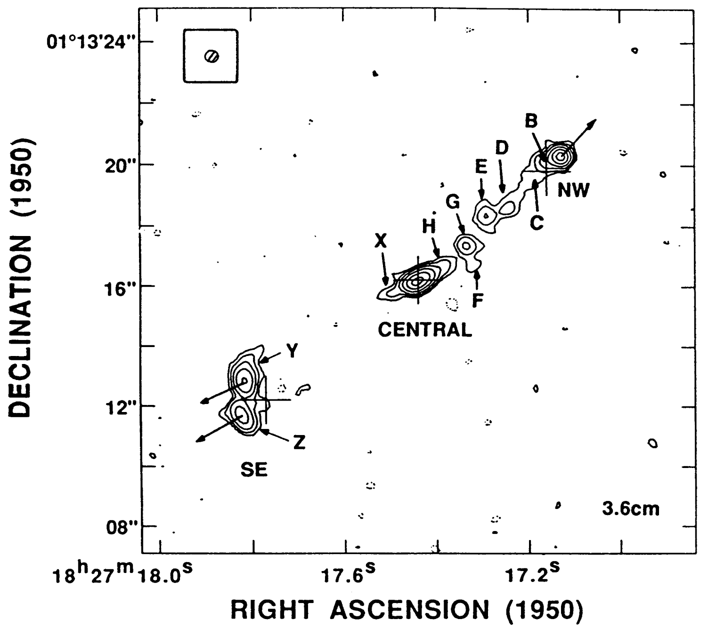

Fig. 5. VLA contour map of the Serpens source at 3.6-cm in the 1990 epoch. The three main components as well as several knots are identified. The arrows show the projected 15 yr shifts due to the proper motions of the outer NW and SE components. The crosses mark the position of the peak emission of the three components in the 1984 epoch. Note the different angle between the central source and the outer lobes. Data from Curiel et al. (1993a).

3.6. Jets Associated with Young, Massive Stars

Until recently, all the radio continuum jets had been found in association with young stars of modest luminosity, typically less than 100 $L_\odot$. The detection at 3.6-cm of twelve out of 57 Herbig Ae/Be stars by Skinner et al. (1993) suggests that the phenomenon is by no means restricted to low mass stars, since Herbig Ae/Be stars have luminosities around $10^3 L_\odot$. Most likely, the jet phenomenon is associated with all types of young stars and this hypothesis is supported by the detailed VLA study of HH 80-81 (Martí et al. 1993), a highly collimated HH complex powered by a luminous ($2 \times 10^4 L_\odot$), young star. This collimated outflow has a projected size of 5.3 pc, by a considerable margin the largest collimated stellar jet system known.

Why are these jets in massive objects so rare? An estimate of the number of sources similar to the HH 80-81 complex that are expected to exist in the Galaxy can be obtained as follows. Our discussion applies to massive stars, taken to be those with a mass equal or larger than 20 $M_\odot$, corresponding to B0 ZAMS or earlier type. We assume that collimated jets and HH objects can be detected in association with a massive star only before the star reaches the main sequence and produces considerable photoionization of its surroundings. We take this time previous to the main sequence to be of the order of the Kelvin-Helmholtz contraction time, $\tau_{K-H} \simeq GM^2/(RL)$, where G is the constant of gravitation, and M, R, and L are the mass, radius, and luminosity of the star. Since for $M \geq 20\ M_\odot$, $(L/L_\odot) \simeq 3 \times 10^4 (M/20\ M_\odot)^4$ and $(R/R_\odot) \simeq 6(M/20\ M_\odot)$ (Panagia 1973; Allen 1973), we obtain $(\tau_{K-H}/years) \simeq 7 \times 10^4 (M/20\ M_\odot)^{-3}$. On the other hand, the fraction of stars in the IMF more massive than M can be approximated, for $M \geq\ 20\ M_\odot$, by $F(\geq M) \simeq 8 \times 10^{-4}(M/20\ M_\odot)^{-3}$ (Miller &

Scalo 1979) and the total galactic star formation rate is $N \sim 4$ stars year^{-1} (Scalo 1986). Then, the number of massive stars with detectable jets is expected to be in the order of $N_{jet} \simeq \tau_{K-H}\ F\ \dot{N} \simeq 2 \times 10^2 (M/20\ M_\odot)^{-6}$. We then expect a few hundred objects similar to the HH 80-81 complex to exist in the Galaxy. Given the steep dependence with stellar mass, only a few jet complexes powered by very luminous stars (O5 or earlier with masses equal or larger than about 40 $M_\odot$) are expected to exist at a given moment in the Galaxy.

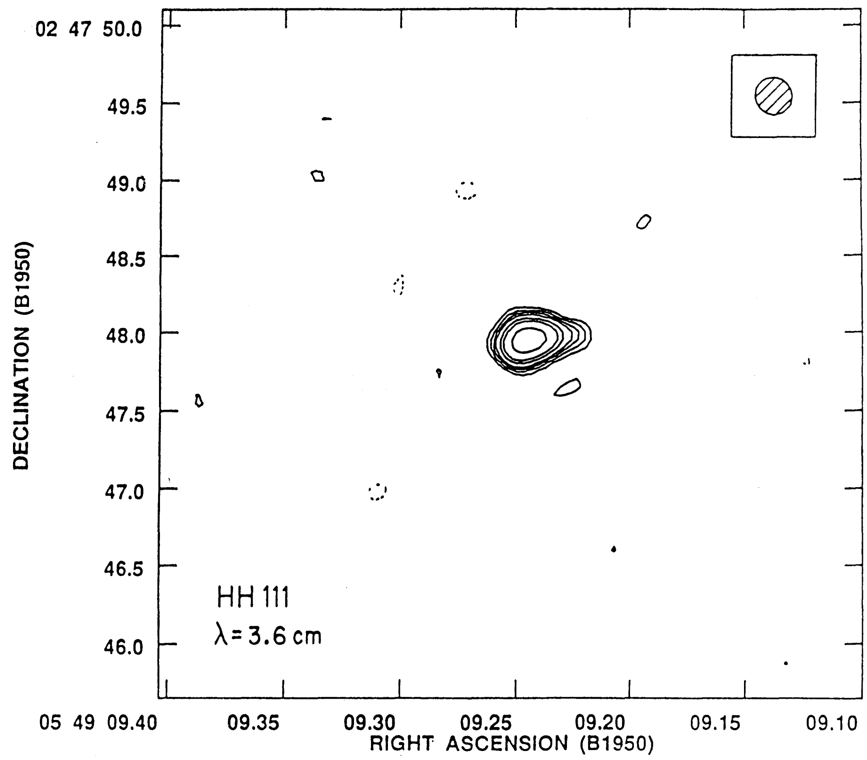

Fig. 6. VLA contour map of the exciting source of the HH 111 flow made at 3.6-cm. Note that the radio jet is one-sided. Data from Rodríguez & Reipurth (1994).

3.7. Correlations of cm Radiation with Other Parameters

With a few dozen sources reported in the literature, Cabrit & Bertout (1992) and Anglada et al. (1992) have searched for correlations of the centimeter radio continuum luminosity with other parameters of the young stars. Cabrit & Bertout (1992) found a correlation between the cm and bolometric luminosities of exciting sources of outflows and propose that this result supports Balmer continuum ionization from the central star. Anglada et al. (1992) did their analysis using only objects with low bolometric luminosity ($L_* \leq 100\ L_\odot$) and found a correlation between the momentum rate in the molecular outflow and the cm continuum luminosity and conclude that this correlation is consistent with the model of Curiel et al. (1987, 1989) that explains the radio continuum emission as arising in shock-ionized gas in the surroundings of the powering source of the molecular outflow.

4. CONCLUSIONS

The observations of mm and cm continuum emission from young stars allows the study of disks and jets with good signal-to-noise ratio and angular resolution. I discussed some recent results obtained at these wavelengths. In the mm range the observations are most probably detecting dust emission from disks and envelopes around young stars. In the cm range we are most likely observing free-free emission from ionized, collimated outflows. These last sources allow the determination of the precise location of the exciting source of the outflows and the study of the collimation processes on small scales. In recent years the multiplicity and geometry of these jets has been started to be studied. The jet phenomenon seems to be present in young stars of all luminosities, although it is hard to find in very luminous stars.

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DISCUSSION

Chavarría-K.: At least in the two examples showing precession the outflows show large symmetry, so if yo think of inhomogeneities that feed the outflows, it must be a funny environment.

Rodríguez: I agree with your comment.

Henney: What are the precessional periods that you derive for the two precessing jets? Presumably they ar very different. Is there any sign of a binary companion in either case that could be causing the precession?

Rodríguez: In the case of HH80-81, we estimate a "Precession period" of about 3,000 years. For Serpens w only have a kinematic age of only 50 years. There is no evidence, at least until now, of a binary companion i these sources.

Roman: a) In HH1-2 are the Herbig-Haro objects from VLA1 and VLA2 aligned? b) Is there any interactio between the two jets? c) Might the close projection be optical with VLA1 and VLA2 more separated than the appear?

Rodríguez: a) No, they are nearly perpendicular. b) I believe that projection effects are not very important although the real separations are of course larger than the projected separations.

Carrasco: To what extent might the apparent precession of the jets be due to environmental conditions? I an thinking of the case of 3C345 where through VLBI techniques they have seen "jets" turning around after the have left the central source. That must be an external "environmental" conditioning.

Rodríguez: This is an important issue and to be sure that precession is present one would like to see actua precession in the jet. In the case of the Serpens triplet, precession in the central jet may be detected in a decad or so.

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