INTERFEROMETRIC OBSERVATIONS OF NITROGEN-BEARING MOLECULAR SPECIES IN THE STAR-FORMING CORE AHEAD OF HH 80N

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ABSTRACT

We present Very Large Array NH3 and Plateau de Bure Interferometer NH2D and HN13C observations of the star-forming core ahead of HH 80N, the optically obscured northern counterpart of the Herbig-Haro objects HH 80/81. The main goal is to determine the kinematical information of the high density regions of the core (n \(\gtrsim\) 107 cm\(^{-3}\)) missed in previous works due to the depletion of the species observed (e.g., CS). The obtained maps show different kinematical signatures between the eastern and western parts of the core, suggesting a possible dynamical interaction of the core with the HH 80/81/80N outflow. The analysis of the position–velocity (P–V) plots of these species rules out a previous interpretation of having a molecular ring-like structure with a radius of 6 \(\times\) 104 AU traced by CS infalling onto a central protostar found in the core (IRS1). A high degree of NH3 deuteriation, with respect to the central part of the core harboring IRS1, is derived in the eastern part, where a dust condensation (SE) is located. This deuteration trend of NH3 suggests that SE is in a pre-stellar evolutionary stage, earlier than that of IRS1. Since SE is the closest condensation to the HH 80N/81/80N outflow, in a case of outflow–core dynamical interaction, it should be perturbed first and be the most evolved condensation in the core. Therefore, the derived evolutionary sequence for SE and IRS1 makes outflow triggered star formation on IRS1 unlikely.

Key words: ISM: individual objects (HH 80N) – ISM: jets and outflows – ISM: kinematics and dynamics – ISM: molecules – stars: formation

Online-only material: color figures

1. INTRODUCTION

Star formation can be considered a process where there are almost simultaneous infall and outflow motions (e.g., Evans 1999). The outflow phenomenon is very well studied because it has numerous associated observational signposts: Herbig-Haro (HH) objects, optical jets, thermal radio jets, and molecular outflows (e.g., see Anglada 1996; Richer et al. 2000). On the other hand, the study of gas kinematics in the region of protostellar collapse is often hindered by the complexity of the gas motions resulting from a combination of rotation, turbulence, and/or stellar outflows (e.g., Belloche et al. 2002). In addition, a number of molecular species freezeout onto icy dust mantles at temperatures \(\lesssim\) 20 K and densities \(\gtrsim\) 105 cm\(^{-3}\) (Bergin et al. 1995; Aikawa et al. 2001; Jørgensen et al. 2004), corresponding to the properties of the gas in the inner regions of the core where the collapse may take place. Therefore, the selection of a molecule that has little or no depletion, observed with an instrument with high angular resolution such as an interferometer, is a means to trace the inner and compact regions of the core. Detailed studies show that once the contraction of a dense core starts, the increasing central density yields to chemical inhomogeneities (Rawlings et al. 1992; Bergin & Langer 1997). As the core evolves, molecules such as CS or CO deplete first, while nitrogen-bearing molecules can remain on the gas phase at densities higher than 105 cm\(^{-3}\) (Tafalla et al. 2002, 2004; Aikawa et al. 2003). Thus, N-bearing molecules tend to trace the dense inner parts of the core better than other species do. Furthermore, a second-order effect induced by the CO freezeout is a sharp rise in the gas phase of the abundance of deuterated species, which are efficiently produced at low temperatures. In this sense, following the same trend as the N-bearing molecules, deuterated molecules are found to be key probes for extremely cold (\(\lesssim\) 10 K) and dense (105–106 cm\(^{-3}\)) gas (e.g., Caselli et al. 2002). Therefore, they are ideal for mapping the central part of the core at the onset of collapse.

HH 80N is the optically obscured northern head of the HH 80/81/80N system, the largest collimated radio jet associated with a young stellar object (Rodríguez et al. 1980; Martí et al. 1993). It is located in the GGD 27 region at a distance of 1.7 kpc (Rodríguez et al. 1980). Ahead of HH 80N, there is a dense core 0.3 pc in size (hereafter HH 80N core) located \(\sim\) 0.3 pc from the HH object. The core was first detected in ammonia (Girart et al. 1994) and afterward in other molecular species (Girart et al. 1998, 2001; Masqué et al. 2009). A mass of roughly 20 \(M_\odot\) and an average rotational temperature of \(\sim\) 17 K were estimated by Girart et al. (1994) from the ammonia emission of the core. Molecular observations suggest that the chemistry of the section of the core facing HH 80N is being altered by the UV photons coming from the HH object (Girart et al. 1998; Masqué et al. 2009). This suggests that the association between the core and the HH object is real and not an effect of the sky projection.

Girart et al. (2001) found evidence of a bipolar CO outflow centered near the peak of the HH 80N molecular core, suggesting the presence of an embedded protostar (IRS1; Masqué et al. 2011), which is detected by Spitzer (Masqué et al. 2009). In addition, based on the CS position–velocity (P–V) plots, Girart et al. (2001) and Masqué et al. (2009) interpreted the morphology and kinematics of the HH 80N core as a ring-like structure of 6 \(\times\) 104 AU falling onto the central embedded object. The ring-like structure seen with molecular tracers observed
with BIMA would not be a real structure, but the result of a strong molecular depletion at the inner region of the core (Girart et al. 2001).

However, high angular resolution observations obtained with the Plateau de Bure Interferometer (PdBI) have revealed that the HH 80N core is composed of several dusty condensations, suggesting possible fragmentation of this core (Masqué et al. 2011). The main condensation is associated with the embedded protostellar object, IRS1, while another condensation (SE) has a pre-stellar nature and is likely close to collapse. The IRS1 condensation was modeled as a slowly rotating collapsing envelope with a mass of 20 $M_\odot$ and an infalling region with a radius of 1.5 × 10$^4$ AU, with the rest of the envelope outside this radius being static. In order to explain the kinematical signatures detected with CS in the HH 80N region, Masqué et al. (2011) proposed that this molecule traces diffuse gas within the HH 80N core surrounding the SE and IRS1 condensations. This gas component, which has an estimated mass of ~10 $M_\odot$, would be gravitationally unbound from IRS1, with its kinematics possibly affected by the HH 80/81/80N outflow.

In order to observationally confirm the scenario of Masqué et al. (2011), we have carried out high angular resolution observations of N-bearing and deuterated molecules to reveal the kinematic properties of high density molecular gas ($n \gtrsim 10^5$ cm$^{-3}$). This dense gas is found in regions of the core missed in our previous work due to the depletion of the species observed (e.g., CS). Our main goal is to disentangle the gas motions belonging to the protostellar collapse of IRS1 from those associated with large-scale kinematics of the diffuse gas traced by CS. In Section 2 we describe the data reduction and present the results. In Section 3 we analyze the kinematics and the deuteration enrichment of the HH 80N core and discuss the possibility of having induced star formation in the core. Finally, our conclusions are summarized in Section 4.

2. DATA REDUCTION AND RESULTS

We carried out Very Large Array (VLA) NH$_3$(1, 1) and NH$_3$(2, 2) and PdBI NH$_2$D$_{(1,1)-10,1}$ and HN$^{13}$C(1–0) observations of the HH 80N region. The observational setup is described in Masqué et al. (2011), where we report the integrated NH$_3$(1, 1) emission map and the PdBI 3.5 mm continuum emission results. The VLA ammonia maps presented here were obtained with natural weighting and using a Gaussian taper of 35″, which gives a beam size of 6′′ × 4′′ (P.A. = 17′′) for the NH$_3$(1, 1) transition maps and 6′′ × 4′′ (P.A. = 18′′) for the NH$_3$(2, 2) transition maps. The rms noise level is 4 mJy beam$^{-1}$ and 5 mJy beam$^{-1}$ per channel for the NH$_3$(1, 1) and NH$_3$(2, 2) maps, respectively. The PdBI NH$_2$D$_{(1,1)-10,1}$ and HN$^{13}$C (1–0) channel maps were obtained using MAPPING with natural weighting, which gives a synthesized beam (HPBW) of 7″ × 2′′ (P.A. = 11′′) at 86 GHz. The rms noise level of the channel maps is 20 mJy beam$^{-1}$ and 23 mJy beam$^{-1}$ per channel for NH$_2$D$_{(1,1)-10,1}$ and HN$^{13}$C(1–0), respectively.

A summary of the parameters of the VLA and PdBI observations is given in Table 1.

We detected all of the species listed in Table 1 in the 10.5–12.3 km s$^{-1}$ velocity range. The integrated intensity maps are shown in Figure 1. The morphology of the integrated emission of NH$_3$, NH$_2$D, and HN$^{13}$C is elongated in the SE–NW direction, consistent with the elongation displayed by the species observed with BIMA (mainly CS, HCO$^+$, and SO; Masqué et al. 2009). Also, the elongation of N-bearing species follows approximately the dark lane seen in the Spitzer 8 μm image. NH$_3$(2, 2) is weaker than the other lines of Table 1 and only the two main condensations, IRS1 and SE, have associated emission.

Despite having a similar shape, the emission of the N-bearing species presented in this work appears more compact than the emission of the species observed in Masqué et al. (2009). NH$_3$(1, 1) is the most extended, having an FWHM angular size of 50″ × 15″ (0.41 × 0.12 pc). HN$^{13}$C and NH$_2$D present smaller FWHM sizes of 25″ × 10″ (0.21 × 0.08 pc). These sizes are clearly smaller than, for example, the size of 65″ × 25″ (0.54 × 0.21 pc) derived for CS. The maps of Figure 1 also reveal two main trends: NH$_3$(2, 2) peaks at the IRS1 position.
Figure 2. Contour maps of the velocity channels from $10.5$ km s$^{-1}$ to $12.3$ km s$^{-1}$ of the HN$^{13}$C(1–0), NH$_2$D(1, 1), NH$_3$(2, 2), and NH$_3$(1, 1) lines (from top to bottom), with a channel width of $0.3$ km s$^{-1}$, superimposed over the $3.5$ mm continuum PdBI map of Masqué et al. (2011; gray scale). The contour levels are $-3$, $3$, $6$, $9$, $12$, $15$, and $18$ times the rms noise level for each species (see Table 1). For the NH$_3$(2, 2) line, the contours $-2$ and $2$ times the rms noise level are also shown. The symbols are the same as in Figure 1. The beam is shown in the bottom right corner of the panels of the first column. (A color version of this figure is available in the online journal.)

while NH$_3$(1, 1), NH$_2$D, and HN$^{13}$C are brightest toward the SE condensation.

Figure 2 shows the channel maps over the $10.5$–$12.3$ km s$^{-1}$ velocity range, where most of the emission of the N-bearing species is detected, superposed on the continuum $3.5$ mm PdBI map of Masqué et al. (2011). The blueshifted emission ($v_{\text{LSR}}$ from $10.5$ to $11.4$ km s$^{-1}$) of the N-bearing molecules is mainly distributed to the southeast of IRS1, in the vicinity of SE. The rest of the emission ($v_{\text{LSR}}$ from $11.4$ to $12.3$ km s$^{-1}$) is widely distributed all along the core with a size similar to that of the dark lane seen in the Spitzer 8 $\mu$m image and beyond the region traced by the $3.5$ mm continuum emission. Among the lines of the N-bearing species presented here, the NH$_3$(1, 1) line has the most extended emission. Besides, HN$^{13}$C and NH$_2$D exhibit differences between them: while most NH$_2$D emission appears concentrated towards the SE condensation, HN$^{13}$C shows discrete peaks along the SE–NW direction, one of them coinciding with IRS1. In Figure 3 we show the maps of the first-order moment (top panels) and second-order moment (bottom panels) superposed on the zero-order moment. This figure better illustrates the differences in the kinematical properties of the gas of the HH 80N core found to the east and to the west of IRS1: while the western gas has a constant velocity of $\sim 12$ km s$^{-1}$, the eastern gas has a velocity gradient with the velocities getting blueshifted to the east, and its line width tends to broaden.

In order to study the kinematics of the N-bearing species, we obtained $P$–$V$ plots of cuts along the major (P.A. $= 122^\circ$) and minor (P.A. $= 32^\circ$) axes of the HH 80N core, corresponding to the cuts A and B shown in Figure 1. The resulting $P$–$V$ plots for NH$_3$(1, 1), NH$_2$D(1,1–1,0), and HN$^{13}$C(1–0) are shown in Figure 4. The $P$–$V$ plots along the major axis (left panels) display an inverse L-shaped morphology encompassing the SE and IRS1 dusty sources. NH$_3$ shows the most extended emission, while NH$_2$D and, especially, HN$^{13}$C emission is clumpy, the last being significantly less bright. The $P$–$V$ plots along the minor axis (right panels) prove that NH$_3$ is the brightest N-bearing species at IRS1.

3. DISCUSSION

3.1. Discarding the Molecular Ring Interpretation

Girart et al. (2001) and Masqué et al. (2009) interpreted the emission of several molecular lines observed with BIMA in the HH 80N core as a ring-like structure with $6 \times 10^4$ AU of radius seen edge-on, falling onto a protostar located at its center. This interpretation was based on the morphology of the $P$–$V$ plots of the CS molecule, obtained along cuts similar to the A and B cuts presented in this paper. This morphology consists of an ellipse for the $P$–$V$ plot along the A direction and a double peak at the same offset for the $P$–$V$ plot along the B direction. This is expected for the $P$–$V$ plots obtained with a flattened structure corresponding to a thin ring seen edge-on, where the A direction represents the major axis and the B direction represents the minor axis of the structure. The N-bearing molecules presented in this paper are expected to trace regions closer to the protostar than the species observed with BIMA, for which models predict strong depletion at the low temperatures and high densities of these regions. Thus, the N-bearing molecules can help to determine the kinematical information of the inner parts of the core missed by CS, which would trace an outer shell. To compare the kinematics of CS with that of N-bearing species, we first convolved the NH$_3$(1, 1), NH$_2$D(1,1–1,0), and HN$^{13}$C(1–0)
maps with a two-dimensional Gaussian to obtain the same synthesized beam as the BIMA CS (2–1) maps of Masqué et al. (2009; 15°6 × 7°1; P. A. = 3°:0). We then obtained P–V plots of cuts along the A and B directions (see Figure 1) over the convolved maps. Note, however, that the cut along the major axis is shifted 4° to the south with respect to the cut A presented in Masqué et al. (2009). The new cut traces better the emission of NH3, NH2D, and HN13C along the major axis of the core. The resulting P–V plots of these species superimposed over those of CS are shown in Figure 5.

If the HH 80N core kinematics derived from CS (Girart et al. 2001; Masqué et al. 2009) correspond to inside-out collapse with free fall motions, the gas closer to the protostar traced by the N-bearing molecules is expected to present larger velocities than the gas of the outer shells traced by CS. However, the velocity range of the gas traced by the NH2D and HN13C emission is similar to or smaller than the velocity range of the gas traced by CS. Thus, the gas motions detected with CS do not correspond to inside-out gravitational collapse. Furthermore, the appearance of the P–V plots of NH2D and HN13C along the major axis of the core is clearly asymmetric and has an L-shaped morphology, differing from the elliptical morphology expected for a contracting ring (or disk).

The P–V plots of the figure also show an extension and a shape of NH3(1, 1) halfway between those of CS and NH2D. Since NH3 is expected to trace regions of the core with high densities, those traced by NH2D and those traced by CS, the kinematics of both gas regimes must contribute to the NH3 behavior. The diffuse gas in the core with moderate density mostly traced by CS (n ∼ 10^4 cm^{-3}) possibly includes larger velocity gradients than those seen with NH2D and HN13C. This could produce a morphology reminiscent of a collapsing ring in the P–V plots of CS, whose appearance is different from that of the P–V plots of NH2D and HN13C. Therefore, as a conclusion, the kinematic features of NH2D and HN13C do not match the features of a collapsing ring structure seen edge-on.

3.2. Deuterium Enrichment of the HH 80N Core

As seen before, the HH 80N core is composed of two condensations, SE and IRS1, with at least the latter having an embedded object. Both condensations are located where the NH2D and NH3 emission are brightest in the core. In this section, we calculate Dfrac (i.e., the ratio of NH2D column density to NH3 column density) over these two condensations as a measure of the degree of the deuterium enrichment. The degree of deuterium enrichment of chemical species in dense cores is found to increase with respect to the [D/H] elemental abundance ratio ≳10^{-5} (estimated within 1 kpc of the Sun; Linsky et al. 2006) until the onset of star formation, and to decrease afterward (Crapsi et al. 2005; Emprechtinger et al. 2009). The Dfrac enhancement during the pre-stellar phase relies on the depletion of CO at low temperatures (<20 K) and high densities (≃10^6 cm^{-3}) found toward the central part of a pre-stellar core when it contracts. CO is the primary destroyer of H2D^+, the main ion required to produce deuterated molecules via gas-phase reactions (e.g., Roberts & Millar 2000; Bacmann et al. 2003; Pillai et al. 2007), which is efficiently produced at low temperatures. Therefore, the freezeout of CO lets the [D/H] ratio propagate to other molecules via gas-phase reactions with H2D^+. Once a protostellar object is formed, Dfrac decreases due to the internal heating of the core (Emprechtinger et al. 2009). Deuterated ammonia, however, is also formed alternatively via grain-surface reactions with D atoms (Tielen 1983). This implies that, in addition to gas-phase reactions, its abundance could be also affected by evaporation from dust grains caused by UV photons or outflow activity (e.g., Saito et al. 2000).

In Table 2 we list the excitation temperature, main line optical depth and column density of NH3(1, 1) and NH2D(1,1)–(0,0), the rotational temperature of ammonia, and Dfrac (calculation details are explained in the table notes). As can be seen in the last column of Table 2, the SE condensation has
Table 2

| Position | Coordinates (J2000) | \(T_{\text{ex}}(1,1)^b\) | \(T_{\text{ex}}(2,2)^e\) | \(N_{\text{H}_3}\) | \(N_{\text{H}_2D}\) | \(D_{\text{f}}\) |
|----------|-------------------|----------------|----------------|-------------|-------------|----------|
| SEb      | 18°19′18"55 -20°41′52"9  | 6.8 ± 0.8 | 8.1 ± 0.8 | 6.1 - 10.3 | 5.6 ± 0.6 | 0.2 - 0.4 |
| Peakd    | 18°19′18"55 -20°41′52"0  | 7.8 ± 1.0 | 7.5 ± 1.0 | 15.5 - 5.8 | 5.3 ± 0.5 | 0.2 - 0.6 |
| IRS1     | 18°19′17′52"2 -20°41′50′2"  | 12.0 ± 1.6 | 6.0 ± 0.4 | 3.8 - 4.9 | 11.7 ± 0.6 | 0.5 - 1.0 |

Notes.

a Coordinates of the center of the box of about a beamsize used to average the \(\text{NH}_3\) and \(\text{NH}_2D\) spectra.
b Excitation temperature derived from the output parameters of a fit to the hyperfine structure of the (1, 1) transition using CLASS.
c Main line opacity derived from the fits to the hyperfine structure.
d Beam-averaged column density of \(\text{NH}_3\) obtained following the procedures given in Sepúlveda et al. (2011). The upper limit is obtained from

\[
\frac{N(\text{NH}_3)}{\text{cm}^{-2}} = 1.58 \times 10^{11} \frac{e^{14/T_{\text{ex}}} + 1}{e^{14/T_{\text{bg}}}} Q(T_{\text{rot}}) \frac{\Delta v}{\text{km s}^{-1}}
\]

where \(T_{\text{ex}}\) is obtained from the output CLASS parameter \(A_{T_{1,1,m}}\), where \(A = f(J(T_{\text{ex}}) - J(T_{\text{bg}}))\), \(J(T) = (e^h/T - 1)^{-1}\) is the intensity in units of temperature, \(T_{\text{bg}}\) is the background temperature, \(f\) is the filling factor, which is assumed to be equal to 1, and \(Q(T_{\text{rot}})\) is the equipartition function at \(T_{\text{rot}}\). We assumed that the rotational energy levels of the molecule are populated at \(T_{\text{rot}}\) under LTE conditions and, for \(Q(T_{\text{rot}})\), we only include the three lower rotational levels, which yields \(Q(T_{\text{rot}}) = \left(\frac{e^{14/T_{\text{rot}}} + 5}{e^{14/T_{\text{rot}}} - 1}\right)^{-3}\).

e Beam-averaged column density of \(\text{NH}_2D\) obtained with the equation

\[
\frac{N(\text{NH}_2D)}{\text{cm}^{-2}} = 1.63 \times 10^{11} \frac{e^{20.68/T_{\text{ex}}}}{Q(T_{\text{rot}})} J(T_{\text{ex}}) A_{T_{1,1,m}} \frac{\Delta v}{\text{km s}^{-1}}
\]

similar to \(\text{NH}_3\). In this case, we assumed LTE conditions with all of the levels populated with the same \(T_{\text{ex}}\), and \(Q(T_{\text{rot}}) = 3.90 + 0.75 T_{\text{ex}}^{1/2}\) \((\text{Cologne Database for Molecular Spectroscopy; Müller et al. 2001})\). For \(N(\text{NH}_2D)\) uncertainties, we adopted the relative uncertainties of \(A_{T_{1,1,m}}\) though the error in the determination of \(N\) could be somewhat larger.

f Rotational temperature derived using the \(\text{NH}_3(1, 1)\) and \(\text{NH}_3(2, 2)\) transitions following Equation (4) of Ho & Townes (1983) assuming the same \(T_{\text{rot}}\) for the \(\text{NH}_3(1, 1)\) and \(\text{NH}_3(2, 2)\) lines. The \(\text{NH}_3(2, 2)\) parameters have been obtained by fitting a single Gaussian to the spectra using CLASS.

g D_{\text{f}} = \frac{N(\text{NH}_2D)}{N(\text{NH}_3)}.

h The box encloses the \(\text{NH}_3(1, 1)\) peak.
i The upper limit is obtained by adopting the 3σ rms level of the maps for the \(\text{NH}_3(2, 2)\) line intensity. The lower limit is obtained by adopting a \(T_{\text{rot}}\) of 10 K, which is typically the lower temperature expected for dense cores.

If our derived \(D_{\text{f}}\) values are not affected by the UV radiation field of HH 80N, then high gas densities must have been present in the HH 80N core for a long time to produce significant \(D_{\text{f}}\) (e.g., \(\sim 10^{6}\) yr; Howe et al. 1994). Therefore, regardless of the relative evolutionary state of the SE and IRS1 condensations, they were likely formed before the jet arrival.

3.3. Dynamical Interaction and Triggered Star Formation?

In Section 3.1, we concluded that an infalling ring-like structure cannot explain the kinematics of the gas in the HH 80N core. Thus, other scenarios, such as that proposed by Masqué et al. (2011), must be considered. These authors suggest that the HH 80N core constitutes a clump or a filament of gas with several embedded condensations, possibly perturbed by the HH 80/81/80N outflow.

The bow shock of the HH 80/81/80N outflow travels in the vicinity of the HH 80N core but does not impact against it, as indicated by the lack of shock signatures. First, the line widths observed in the core (\(\sim 1\) km s\(^{-1}\)) are significantly narrower than the line widths derived in shocked regions (6–7 km s\(^{-1}\); Bachiller et al. 1995). Second, the SiO emission, an excellent...
Figure 4. $P-V$ plots of the NH$_3$(1, 1) emission (top panels), NH$_2$D(1, 1) emission (middle panels), and HN$_{13}$C(1–0) emission (bottom panels). The panels on the left represent the $P-V$ plots along the major axis of the core (P.A. = 122$^\circ$; A direction in Figure 1) and the panels on the right represent the $P-V$ plots along the minor axis (P.A. = 32$^\circ$; B direction in Figure 1). The positive offsets of the $P-V$ plots correspond to southeast and northeast for the directions A and B, respectively. Contour levels are 3, 5, 7, 9, 12, 15, and 19 times 3.5 mJy beam$^{-1}$ for NH$_3$ and 15 mJy beam$^{-1}$ for NH$_2$D and HN$_{13}$C. The position offsets of IRS1 and SE are marked with dashed lines.

Figure 5. $P-V$ plots of the NH$_3$(1, 1) emission (top panels, contours), NH$_2$D(1, 1) (middle panels, contours), and HN$_{13}$C(1–0) emission (bottom panels, contours) superimposed over the $P-V$ plots of the CS (2–1) emission (gray scale) observed with BIMA (Masqué et al. 2009). The panels on the left represent the $P-V$ plots along the major axis of the core (P.A. = 122$^\circ$; A direction in Figure 1) and the panels on the right represent the $P-V$ plots along the minor axis (P.A. = 32$^\circ$; B direction in Figure 1). The positive offsets of the $P-V$ plots correspond to southeast and northeast for the directions A and B, respectively. The $P-V$ plots of NH$_3$(1, 1), NH$_2$D(1, 1), and HN$_{13}$C (1–0) have been convolved with a Gaussian in order to obtain a resolution equivalent to the CS (2–1) BIMA observations (15.6 $\times$ 7.1; P.A. = 3$^\circ$). The contour levels are 3, 6, 12, 20, and 30 times 5 mJy beam$^{-1}$ for NH$_3$, 20 mJy beam$^{-1}$ for NH$_2$D, and 13 mJy beam$^{-1}$ for HN$_{13}$C. The position offsets of IRS1 and SE are marked with dashed lines.

dynamical connection of the eastern part of the core with the outflow. The velocity gradient inferred from the $P-V$ plots ($\sim$5 km s$^{-1}$ pc$^{-1}$) is of small magnitude, similar to the velocity gradients found in low-mass star-forming cores (e.g., Goodman et al. 1993; Belloche et al. 2002; Chen et al. 2007). According to the authors, these gradients could be due to either rotation or slight outflow interaction with dense surrounding gas. Hence, we cannot discern whether the outflow interaction with the HH 80N core or other gas motions are the origin of the velocity gradient found in the core. A similar scenario was found for the molecular cloud located ahead of HH 2: although it lacks strong shock signatures, part of the cloud is possibly being driven out by the powerful winds from the VLA 1 protostar (Girart et al. 2005). Thus, despite the lack of strong evidence for a dynamical

tracer of strong shocks in molecular gas, is absent in the HH 80N core (Masqué et al. 2009). However, the HH 80N core is located within the blueshifted lobe of a large-scale bipolar CO outflow found by Benedettini et al. (2004). These authors interpreted the outflow as a large portion of the molecular cloud set in motion by the HH 80/81/80N jet. Indeed, there is a velocity gradient in the HH 80N core, from IRS1 to SE, with the velocities in the eastern part of the core blueshifted with respect to the central part (e.g., see Figure 3). Benedettini et al. (2004) found several CO knots along the jet axis. One of these knots (L), with a velocity of 10.1 km s$^{-1}$, is located 2′ east of the HH 80N core. As seen in the $P-V$ plots along the major axis of the core (see Figures 4 and 5), the position and velocity of the L knot match the trend of the velocity gradient mentioned above, which suggest some
perturbation of the HH 80N core by the HH 80/81/80N outflow, we still consider the possibility that part of the core is affected by the outflow.

If outflow dynamical interaction is occurring, it could induce local instabilities in the HH 80N core that may trigger a star-formation episode in the HH 80N region, as presumably has happened in other regions (e.g., 1551: Yokogawa et al. 2003; Serpens: Graves et al. 2010; Duarte-Cabral et al. 2010, 2011). If a perturbed condensation becomes massive enough to induce gravity to overcome the internal pressure, then it could collapse. However, the $P$–$V$ plots along the major axis of Figures 4 and 5 show that IRS1 is located at the limiting position between the region of the eastern velocity gradient and the rest of the core that moves at a $v_{LSR}$ of 12 km s$^{-1}$. In addition, because we deal with projected distances, IRS1 could be even farther away from the outflow. Thus, the possible perturbation of the IRS1 condensation by the HH 80/81/80N outflow is unclear. On the other hand, the SE condensation falls in the region associated with the eastern velocity gradient and, hence, it could be located close to the interface of the presumable interaction. Moreover, Masqué et al. (2009) prove that the “surface” of the eastern part of the core is affected by UV radiation from the HH 80N shock and, hence, there is a spatial association between this part of the core and the HH 80/81/80N outflow. However, in the previous section we found that the SE condensation seems to be in an earlier evolutionary stage than that of IRS1. This trend is opposite to that expected if the outflow has induced the star formation observed in the core, since its perturbation would first affect the SE condensation, the closest one to the outflow and, hence, SE should be the most evolved condensation. Therefore, outflow triggered star formation in IRS1 is unlikely.

4. CONCLUSIONS

We present a kinematical study of the HH 80N core using nitrogen-bearing species, aimed at determining the motions of the high density gas of the core ($n \gtrsim 10^{5}$ cm$^{-3}$) missed by other molecular species previously observed in the region. In addition, we derived the deuterium fraction in the core. Our main conclusions can be summarized as follows.

1. The integrated emission of the N-bearing molecules (NH$_{3}$, NH$_{2}D$, and HN$^{13}C$) shows an elongated morphology similar to (but more compact than) that of the species observed with BIMA (e.g., CS, SO, and HCO$^{+}$) or to the dark lane seen in the Spitzer 8 μm image. Inspection of the zero-, first- and second-order moment maps of the N-bearing molecules reveals that most of the molecular emission arises from the eastern part of the HH 80N core, which is shifted $0.5$ km s$^{-1}$ in velocity and whose lines are broader than those in the western part. Despite the lack of shock signatures in the core, these kinematical features suggest some perturbation in the eastern part, given the nearby location of the HH 80/81/80N outflow.

2. The morphology and kinematics of the high density regions of the core, revealed by the $P$–$V$ plots of the N-bearing species, rule out the previous interpretation as an infalling molecular ring-like structure with a radius of $6 \times 10^{5}$ AU inferred from BIMA observations of CS and other molecular species (Girart et al. 2001; Masqué et al. 2009).

3. Assuming that the high extinction expected in the HH 80N core prevents the UV photons from the nearby HH 80N shock to influence the deuterium chemistry, the presence of NH$_{2}D$ in the core implies that the SE and IRS1 condensations were likely present before the outflow reached the HH 80N core. Besides, a comparison of the degree of deuterium enrichment between the IRS1 and SE condensations suggests that the SE condensation is pre-stellar and less evolved than IRS1, consistent with the presence of an embedded protostar in the IRS1 condensation (Masqué et al. 2011). This trend is opposite to that expected if the outflow has induced the star formation observed in the core, since SE should then be the most evolved condensation. Therefore, the outflow triggered star formation in IRS1 is unlikely.

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