BROAD $\text{N}_2\text{H}^+$ EMISSION TOWARD THE PROTOSTELLAR SHOCK L1157-B1

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Received 2013 June 20; accepted 2013 August 19; published 2013 September 25

ABSTRACT

We present the first detection of $\text{N}_2\text{H}^+$ toward a low-mass protostellar outflow, namely, the L1157-B1 shock, at $\sim 0.1$ pc from the protostellar cocoon. The detection was obtained with the IRAM 30 m antenna. We observed 93 GHz due to the $J = 1\rightarrow 0$ hyperfine lines. Analysis of this emission coupled with HIFI CHESS multiline CO observations leads to the conclusion that the observed $\text{N}_2\text{H}^+ (1\rightarrow 0)$ line originated from the dense ($\geq 10^9 \text{ cm}^{-3}$) gas associated with the large ($20''\rightarrow 25''$) cavities opened by the protostellar wind. We find an $\text{N}_2\text{H}^+$ column density of a few $10^{12} \text{ cm}^{-2}$ corresponding to an abundance of $(2\rightarrow 8) \times 10^{-3}$. The $\text{N}_2\text{H}^+$ abundance can be matched by a model of quiescent gas evolved for more than $10^6$ yr, i.e., for more than the shock kinematical age ($\geq 2000$ yr). Modeling of C-shocks confirms that the abundance of $\text{N}_2\text{H}^+$ is not increased by the passage of the shock. In summary, $\text{N}_2\text{H}^+$ is a fossil record of the pre-shock gas, formed when the density of the gas was around $10^4 \text{ cm}^{-3}$, and then further compressed and accelerated by the shock.

Key words: ISM: abundances – ISM: jets and outflows – ISM: molecules

Online-only material: color figures

1. INTRODUCTION

During the first stages of star formation, highly collimated jets from newborn stars influenced the physical structure of the host- ing cloud by sweeping up material, and compressing and accelerat- ing the surrounding environment. The propagation of high velocity outflows generates shock fronts triggering endothermic chemical reactions and ice grain mantle sublimation or sputtering. At a distance of 250 pc (Looney et al. 2007), the chemically rich L1157 bipolar outflow (Bachiller & Pérez Gutiérrez 1997, hereafter BP97; Bachiller et al. 2001) is an ideal laboratory in which to observe the effects of such shocks on the gas chemistry. L1157 is driven by a low-mass ($\sim 4 \text{ L}_\odot$) Class 0 protostar L1157-mm and it is associated with several blue-shifted (B0, B1, B2) and red-shifted (R0, R1, R2) shocks at different ages (see Figure 1—top panel), and is seen in both CO (Gueth et al. 1996, 1998) and IR H$_2$ (e.g., Neufeld & Green 1994; Nisini et al. 2010). These shocks (see Figure 1, bottom panel), when mapped with interferometers, reveal a clumpy bow structure (e.g., Tafalla & Bachiller 1995; Benedettini et al. 2007; Codella et al. 2009) at the apex of different molecular cavities, corresponding to different mass loss episodes (Gueth et al. 1996).

Both interferometer and single-dish surveys confirm that the L1157 outflow is well traced by molecules thought to be released from the dust mantles such as $\text{H}_2\text{CO}$, $\text{CH}_3\text{OH}$, $\text{H}_2\text{O}$, and $\text{NH}_3$ (e.g., Codella et al. 2010; Lefloch et al. 2010; Vasta et al. 2012) as well as by the refractory grain cores such as SiO (e.g., Nisini et al. 2007; Gusdorf et al. 2008). The abundances of these neutral molecules are enhanced, and the emission shows broad wings (up to $20\rightarrow 30$ km s$^{-1}$). By contrast, diazenylium ($\text{N}_2\text{H}^+$), usually used as a tracer of cold prestellar cores (e.g., Caselli et al. 2002), shows a completely different behavior. Single-dish (IRAM 30 m) and interferometric (IRAM PdB, SMA, CARMA) observations indicate that $\text{N}_2\text{H}^+$ traces only the central condensation L1157-mm through narrow (0.4–1.0 km s$^{-1}$) emission and it has not been observed, to date, toward the outflow component (Bachiller et al. 2001; Chiang et al. 2010; Tobin et al. 2011, 2012, 2013; Yamaguchi et al. 2012). The interferometric maps show that the narrow $\text{N}_2\text{H}^+$ line traces the protostellar envelope elongated along a direction perpendicular to the outflow axis (i.e., along a hypothetical disk). However, by analyzing their IRAM PdB data, Tobin et al. (2011) concluded that although the overall $\text{N}_2\text{H}^+$ velocity structure is unaffected by the outflow, the morphology of the slightly blue-shifted emission ($\vert v-v_{\exp} \vert \leq 0.8 \text{ km s}^{-1}$) outlines the outflow cavity walls in the inner 20–30" protostellar environment. Tobin et al. (2011) proposed that such emission is due to either outflow entrainment or a hypothetical shock near the driving protostar. The same suggestion is found in the ATCA $\text{N}_2\text{H}^+(1\rightarrow 0)$ image of the protostellar core CG30 by Chen et al. (2008). However, Jørgensen et al. (2004) investigated the protostellar binary NGC1333-IRAS2A-B with BIMA at 3 mm showing that the spatial distribution of $\text{N}_2\text{H}^+$ peaks toward the nearby starless core IRAS2C, and is missing in the outflows.

Therefore, it is still under debate what role, if any, $\text{N}_2\text{H}^+$ plays in a shocked gas scenario: is the $\text{N}_2\text{H}^+$ emission observed by Tobin et al. (2011) which marks the cavity opened by the outflow due to just enhanced gas column density, or is it really associated with a shock? These questions are important given that $\text{N}_2\text{H}^+$ is considered a standard molecular tracer of cold and quiescent prestellar environments (e.g., Tafalla et al. 2006).

In order to uniquely answer these questions, it is essential to study a region not associated with a protostar, such as the young (2000 yr; Gueth et al. 1996), bright bow-shock L1157-B1, located at $\sim 69''$ ($\sim 0.1$ pc, see Figure 1) from the protostar. As part of the Herschel$^6$ Key Program CHESS$^7$ (Chemical Herschel

$^6$ Herschel is an ESA space observatory with science instruments provided by European-led Principal Investigator consortia and with important participation from NASA.

$^7$ http://www-laog.obs.ujf-grenoble.fr/heberges/chess/
The CH$_3$CN(8–7) reported by Bachiller et al. (2001). The labels indicate the main blue- and red-shifted knots. The circles are for the IRAM 30 m HPBW at the N$_2$H$^+$(1–0) using the
8 This refers to the brightest hyperfine component: $F_1,F = 2.3–1.2$.

Figure 1. Top panel: PACS image of L1157 of the integrated H$_2$O emission at 1669 GHz (Nisini et al. 2010a). Offsets are with respect to the L1157-mm sources (black star), at coordinates $\alpha_{2000} = 20^h 39^m 06^s.2$, $\delta_{2000} = +68^\circ 02'.16''/0$. The magenta contours refer to the SiO(3–2) IRAM 30 m map reported by Bachiller et al. (2001). The labels indicate the main blue- and red-shifted knots. The circles are for the IRAM 30 m HPBW at the N$_2$H$^+$(1–0) frequency (26$''$), centered at the driving L1157-mm protostar (observed by BP97 and Tobin et al. 2013), and at $\Delta \alpha = +25'.6$ and $\Delta \delta = -63'.5$ from the driving protostar (present observations; see the black triangles and coordinates reported in Section 2). Bottom panel: L1157-B1 bow shock as traced using the CH$_3$CN(8–7) $K = 0.1,2$ emission at 3 mm, observed with the IRAM PdBI interferometer (Codella et al. 2009).

Surveys of Star-forming regions; Ceccarelli et al. 2010), L1157-B1 is currently being investigated with a spectral survey in the $\sim$80–350 GHz interval using the IRAM 30 m telescope (Lefloch et al. in preparation), and in the $\sim$500–2000 GHz range using the Herschel HIFI instrument (de Graauw et al. 2010). We present here the first unambiguous detection of N$_2$H$^+$ emission toward a protostellar shock: the observed broad emission has been modeled using a simple pseudo-time-dependent chemical model, showing how N$_2$H$^+$ can be used to shed light on the chemical history of the pre-shock gas.

2. OBSERVATIONS AND RESULTS

The N$_2$H$^+$(1–0) line at 93173.76 MHz$^8$ was observed toward L1157-B1 with the IRAM 30 m telescope at Pico Veleta (Spain). The pointed coordinates were $\alpha_{2000} = 20^h 39^m 10^s.2$, $\delta_{2000} = +68^\circ 01'.10''$.5, i.e., at $\Delta \alpha = +25'.6$ and $\Delta \delta = -63'.5$

Figure 2. Upper panel: N$_2$H$^+$(1–0) line (black histogram; in $T_{mb}$ scale) observed in L1157-B1 with the IRAM 30 m antenna. The red histogram refers to the N$_2$H$^+$(1–0) spectrum (scaled for a direct comparison) as observed toward L1157-mm with the IRAM 30 m antenna in the framework of the ASAI IRAM Large Program (PI: R. Bachiller & B. Lefloch). The vertical dashed line indicates the ambient LSR velocity (+2.6 km s$^{-1}$, from BP97). The seven vertical blue lines stand for the 15 hyperfine components of the N$_2$H$^+$(1–0) pattern (several of them spectrally unresolved at the present frequency resolution; see Pagani et al. 2009). We centered the spectrum at the frequency of the main hyperfine component $F_1,F = 2.3–1.2$ (93173.76 MHz). Middle panel: analysis of the N$_2$H$^+$(1–0) profile. The blue line shows the best fit (FWHM = 4.3 km s$^{-1}$) assuming a single Gaussian component. The magenta solid line shows the best fit using two Gaussian components (dashed magenta: FWHM = 2.6 km s$^{-1}$; dot–dashed magenta: FWHM = 5.9 km s$^{-1}$) in order to minimize the residual. The corresponding residuals are reported in the bottom panel: the single component approach gives a 3$\sigma$ (rms = 2 mK) residual.

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from the driving protostar. The IRAM survey was performed during several runs in 2011 and 2012, using the broad-band EMIR receivers and the Fourier transform spectroscope in its 200 kHz resolution mode, corresponding to a velocity resolution of 0.6 km s$^{-1}$ at 93.2 GHz. The main-beam efficiency ($\eta_{mb}$) was 0.75, while the half-power beam width was 26$''$. All the spectra are reported in units of main beam temperature ($T_{mb}$).

Figure 2 shows the N$_2$H$^+$(1–0) spectrum. Thanks to the high sensitivity of the IRAM-EMIR receiver (rms = 2 mK after smoothing the spectrum to 1.3 km s$^{-1}$), we are able to detect the three main groups of hyperfine components of the $J = 1$–$0$ transition. The integrated intensity is 327$\pm$14 mK km s$^{-1}$. The N$_2$H$^+$ emission in L1157-B1 was hidden in the noise of the BP97 spectrum, which has a 1$\sigma$ rms of 20 mK, definitely larger than that of the present dataset (2 mK).

N$_2$H$^+$ is a linear molecular ion in a stable closed-shell $^1\Sigma$ configuration. The dominant hyperfine interactions are those between the molecular electric field gradient and the electric quadrupole moments of the two nitrogen nuclei (e.g., Caselli et al. 1995), producing a splitting of the $N_2H^+$ energy levels by up to several GHz, depending on the quantum numbers $F_1$ and $F$ (e.g., Pagani et al. 2009). To fit the $N_2H^+$ spectrum, we first assumed a unique velocity component and used GILDAS-CLASS90, which gives the best fit (reported

8 http://www.iram.fr/IRAMFR/GILDAS
Table 1
Parameters of the Hyperfine Fits to the N$_2$H$^+$ (1–0)$^a$ Line, and Total Column Density

| $\tau_{\text{peak}}$ (mK) | rms$^b$ (mK) | $V_{\text{peak}}$ (km s$^{-1}$) | FWHM (km s$^{-1}$) | $\sum_i \tau_i$ | $N_{\text{tot}}^c$ (cm$^{-2}$) |
|-----------------------------|--------------|-------------------|-----------------|-----------------|------------------|
| **One Component Fit**       |              |                   |                 |                 |                  |
| 34(2)                       | 2            | $+1.3(0.1)$       | $4.3(0.2)$     | $0.1(0.9)$      | $2.4–7.8 \times 10^{12}$ |
| **Two Components Fit**      |              |                   |                 |                 |                  |
| 26(2)                       | 2            | $+1.8(0.1)$      | $2.6(0.1)$     | $0.2(0.2)$      | $2.4–8.0 \times 10^{12}$ |
| 14(2)                       | 2            | $-1.1(0.4)$      | $5.9(0.9)$     | $0.1(0.1)$      | $0.4–1.3 \times 10^{12}$ |

Notes.

$^a$ The spectrum has been centered at the frequency of the main hyperfine component $F_1,F = 2.3–1.2$ (93173.76). Frequencies have been extracted from the Cologne Database or Molecular Spectroscopy (Müller et al. 2005). See also Pagani et al. (2009).

$^b$ At a spectral resolution of 1.3 km s$^{-1}$.

$^c$ Assuming a $T_{\text{kin}} = 20–80$ K and a source size of 20$''$–25$''$ (see text).

in Table 1) of the hyperfine components (see the blue line in Figure 2—middle panel). The sum of the opacity at the central velocities of all the hyperfine components $\sum_i \tau_i$ is 0.1 ± 0.9. Although the opacity is not well determined, the fit indicates $\sum_i \tau_i \leq 1$, thus suggesting optically thin emission. Fits fixing $\tau_i$ to larger values never gave better results.

The peak LSR velocity (+1.3 km s$^{-1}$) of the N$_2$H$^+$ profile is slightly blue-shifted with respect to the ambient velocity (+2.6 km s$^{-1}$, BP97). The linewidth (4.3 km s$^{-1}$) is also considerably larger than that observed by BP97 and Tobin et al. (2013) toward the driving protostar L1157-mm (0.6–0.8 km s$^{-1}$). This is clearly shown in Figure 2 where we report the N$_2$H$^+$ (1–0) line (see the red histogram in the upper panel) recently observed toward L1157-mm in the framework of the ASAI$^{10}$ IRAM 30 m Large program (Pl. R. Bachiller & B. Lefloch). The N$_2$H$^+$ profile from the B1 shock is definitely broader and more blue-shifted than that observed toward the L1157-mm protostar, indicating a different origin. Note also that the weak but not blended $F_1,F = 0.1–1.2$ line at $\sim$–8 km s$^{-1}$ from the main hyperfine component clearly shows blue-shifted emission.

The best fit of Figure 2 shows a non-negligible residual ($\sim 3\tau_1$; see bottom panel) at about –4.0 km s$^{-1}$, which suggests non-Gaussian emission from gas at high blue-shifted velocity. Indeed, a definitively more satisfactory fit can be obtained by assuming two blue-shifted Gaussian components (see the magenta lines in Figure 2 and Table 1): (1) a line centered at +1.8 km s$^{-1}$ with FWHM = 2.6 km s$^{-1}$, plus (2) a broader (5.9 km s$^{-1}$) line peaking at −1.1 km s$^{-1}$ (dashed and dot-dashed magenta lines in Figure 2, respectively). In summary, despite the complexity due to the hyperfine components, this clearly shows that a single Gaussian component is insufficient to reproduce the N$_2$H$^+$ (1–0) profile toward the B1 shock, and one needs to invoke additional broad blue-shifted emission. The present observation thus reports the first detection of N$_2$H$^+$ emission toward a low-mass outflow, definitely far from the protostellar environment.

3. PHYSICAL CONDITIONS OF THE N$_2$H$^+$ GAS

The line profiles in L1157-B1, as in other molecular shock spots, have a relatively complex structure where several excitation components are visible. Disentangling such components is not an easy task. In L1157-B1, the recent CO multi-line analysis by Lefloch et al. (2012) indicates that the line profiles are composed of a linear combination of exponential curves $I_{\text{CO}}(v) = I_{\text{CO}}(0) \exp(- |v/v_0|)$, independently of the CO transition considered. The three velocity components correspond to three different physical components: (1) a small ($\sim 7''–10''$) dissociative J-type shock called g1 (identified where the line intensity is $\propto \exp(-|v/12.5|)$ dominating at the highest velocities ($\leq -20$ km s$^{-1}$), (2) the outflow cavity walls, g2 ($\propto \exp(-|v/4.4|)$), with size $\lesssim 20''$, and (3) the larger ($\sim 25''$) outflow cavity created by the older bow shock L1157-B2, g3 ($\propto \exp(-|v/2.5|)$) dominating at velocities close to systemic ($v \sim -2$ km s$^{-1}$). Each component shows the same slope at all J, but different relative intensities. The higher is the line excitation the brighter the g1 component is. By contrast, g3 is observed only toward the low- $J (\lesssim 3$) CO lines.

Figure 3 compares the N$_2$H$^+$ (1–0) line with other line profiles observed toward L1157-B1 (Lefloch et al. 2010, 2012; Codella et al. 2010): (1) the CO(16–15) at 1841.3 GHz observed with $Herschel$-HIFI as an example of a spectrum where the g1 component is clearly dominating the line profile; (2) the CO(3–2) profile, as observed toward L1157-B2, representing a pure g3 profile, without the g1 and g2 components observed toward L1157-B1; and (3) the NH$_3$ (1$_{00}$–0$_{00}$) transition, showing a profile well reproduced by the g2 component alone. The N$_2$H$^+$ line profile, despite the blending between hyperfine components, seems to exclude the extremely high-velocity emission associated with the g1 component, being consistent with the g2 and g3 components. In conclusion, N$_2$H$^+$ is associated with either the B1 outflow cavity (with $T_{\text{kin}} \simeq 70$ K and $n_{\text{H}_2} \geq 10^5$ cm$^{-3}$, according to the large velocity gradient (LVG) CO analysis by Lefloch et al. 2012) and/or the older and colder B2 cavity ($\sim 20$ K, $\geq 6 \times 10^4$ cm$^{-3}$).

The low excitation N$_2$H$^+$ (1–0) transition ($E_u = 5$ K) has a critical density of $\sim 10^5$ cm$^{-3}$ (e.g., Friesen et al. 2009). The line emission is thus expected to be close to LTE conditions at the densities of the g2 and g3 gas components. Following the results of the LVG analysis by Lefloch et al. (2012), we assume a $T_{\text{kin}}$ between 20 and 70 K and an emitting size of 20''–25''. The N$_2$H$^+$ total column density is then well constrained $N($N$_2$H$^+$) = (2–8) × $10^{12}$ cm$^{-2}$. Using the source-averaged column density $N($CO) = 1 × $10^{17}$ cm$^{-2}$ (found for both g2

10 http://www.oan.es/asai/
and g3 by Lefloch et al. 2012), and assuming [CO]/[H2]=10−4, we can derive the N2H+ abundance: \(X(N_2H^+) = 2 - 8 \times 10^{-9}\).

A lower abundance, between \(4 \times 10^{-10}\) and \(\sim 10^{-9}\), is derived for the weaker emission at higher velocity, represented by the velocity component peaking at \(-1.1 \text{ km s}^{-1}\) (see Table 1).

These values are consistent with those found toward the L1157-mm protostar by BP97 (4 \times 10^{-9}) using the IRAM 30 m antenna. However, Chiang et al. (2010) measured lower values (3–6 \times 10^{-10}) toward L1157-mm using the CARMA array, possibly due to interferometric filtering. Similar values have also been found in CO-depleted prestellar cores and dense protostellar envelopes (\(\sim 10^{-10} - 10^{-9}\); see, e.g., Caselli et al. 2002; Tafalla et al. 2004, 2006; Maret et al. 2007; Chen et al. 2007, 2008). This value represents an estimate of the abundance of the gas in the outflow cavities and will be used for a comparison with the outputs predicted by our models.

4. **N2H+ CHEMISTRY IN L1157-B1**

To understand the origin of the observed N2H+, we compared its measured abundance with the N2H+ abundance predicted by a simple pseudo-time-dependent model. We used the publicly available ASTROCHEM code.\(^{11}\) The code follows the evolution of the chemical composition of a gas cloud initially in the diffuse state and with fixed temperature and density. A simple gas–grain interaction due to freeze-out and thermal and photo-desorption has been considered. In these calculations, we assumed a nitrogen elemental abundance equal to 2.1 \times 10^{-5} (with respect to H nuclei), carbon and oxygen equal to 7.3 \times 10^{-5} and 1.8 \times 10^{-4}, respectively, a grain size of 0.1 \mu m, and cosmic ionization rates \(\zeta\) in the 10^{-17}–10^{-16} s^{-1} range (e.g., Dalgarno 2006; Padovani et al. 2009).

Figure 4 shows the predicted N2H+ abundance as a function of the volume density at different evolutionary times, from 2 \times 10^{3} yr (the age of L1157-B1) to 1 \times 10^{7} yr. The chemical of N2H+ is relatively simple: it is formed by the reaction of the H3^+ (created by the cosmic rate ionization of H2) and destroyed by the reaction of CO (or electrons in the case of CO depletion).

\[^{11}\] http://smaret.github.com/astrochem/

Therefore, the larger the density is, the lower the H3^+ abundance is, and consequently, the lower the \(X(N_2H^+)\) is as well. The comparison of the measured and predicted N2H+ abundances yields an important conclusion: the observed N2H+ abundance is perfectly matched by a model of cold, quiescent, and relatively old (\(\geq 10^4\) yr) gas and does not require the intervention of a shock. The age of the shock in L1157-B1 is around 2000 yr (Gueth et al. 1996); hence, Figure 4 shows that N2H+ was present before the shock occurred, and it is consistent with a pre-shock H2 density of \(\leq 5 \times 10^5\) cm^{-3}. In addition, given that \(X(e) \propto n_H^{-1/2}\) (e.g., McKee 1989), we can speculate that the lower X(N2H+) abundance (by a factor of \(\geq 5–6\)) measured at the highest velocities indicates a density gradient in the shocked gas in the cavity. In other words, the N2H+ emitting at higher velocities could trace gas with \(n_H\) about one order of magnitude higher than that of the gas at velocities closer to systemic.

In addition, to verify whether the detected N2H+ molecules existed prior to the shock, we used the shock model of L1157-B1 reported by Viti et al. (2011) who coupled the chemical model UCL_CHEM with a parametric shock model (Jiménez-Serra et al. 2008). UCL_CHEM is a gas–grain chemical code that first simulates the formation of high-density clumps from an atomic diffuse cloud, and then follows their chemical evolution when subjected to the passage of a C-type shock. Full details of the code can be found in Viti et al. (2004, 2011). We updated the grid of models from Viti et al. (2011) varying the cosmic ray ionization rate \(\zeta\) (which of course directly influences the behavior of ions) in the 10^{-17}–10^{-16} s^{-1} range. Figure 5 reports an example of a UCL_CHEM shock model assuming \(\zeta = 10^{-16}\) s^{-1} and a pre-shock density of 10^4 cm^{-3}. We confirm that N2H+ is indeed formed in the gas phase and that the passage of a shock, with the subsequent release of N2 into the gas, does not yield an increase in the N2H+ abundance. This is consistent with the lack of signatures of very high velocity associated with the H1 component in the N2H+(1–0) profile. By contrast, the passage of a shock does decrease the N2H+ abundance by about one to two orders of magnitude depending on the pre-shock conditions and velocity of the shock. This allows us to further constrain the pre-shock density to \(\sim 10^4\) cm^{-3} (see Figure 4) in order to maintain the observed abundance once the outflow cavities

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**Figure 4.** N2H+ abundance, with respect to H2, vs. the H2 density at different times: from 2 \times 10^{3} yr (the age of L1157-B1) to 1 \times 10^{7} yr. The dashed blue box gives the observed value with the 1 \sigma uncertainty (see text). The gas is at a temperature of 70 K, but the curve is identical in the range 20–70 K. The cosmic ionization rate is 10^{-16} s^{-1}.

**Figure 5.** Example of the UCL_CHEM model (Viti et al. 2004) showing how the fractional abundances (with respect to H2) of N2H+, H2, and N2 can vary as a function of distance (see text).

(A color version of this figure is available in the online journal.)

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have been compressed to $\gtrsim 10^5$ cm$^{-3}$. A value of $\zeta$ ($\sim 10^{-16}$ s$^{-1}$) helps to achieve and maintain a high N$_2$H$^+$ abundance. A pre-shock density of $\sim 10^4$ cm$^{-3}$ is consistent with the results suggested by the study of deuterium in L1157-B1 (Codella et al. 2012) where it was found that the most likely scenario is that of a gas passing through a pre-shock phase with $n_{H_2} \lesssim 4 \times 10^4$ cm$^{-3}$, during which formaldehyde and methanol ices are formed.

5. CONCLUSIONS

We present the first detection of diazenylium toward outflowing gas far from the driven low-mass protostar. We found evidence that N$_2$H$^+$ (1–0) emission observed toward the L1157-B1 shock originates from the dense ($\gtrsim 10^5$ cm$^{-3}$) gas associated with the cavities opened and accelerated by the protostellar wind. The line width ($\gtrsim 4$ km s$^{-1}$) is significantly broader than the N$_2$H$^+$ line widths previously observed toward the driving protostar L1157-mm (1–0), which also supports the fellowships of

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C. Codella, C. Ceccarelli, B. Lefloch, and S. Viti acknowledge the financial support from the COST Action CM0805 “The Chemical Cosmos.” The Italian authors gratefully acknowledge funding from the Italian Space Agency (ASI) through the contract I/005/011/0, which also supports the fellowships of G. Busquet and A. Gómez-Ruiz. C. Ceccarelli and B. Lefloch acknowledge funding from the French Space Agency CNES and the National Research Agency funded project FORCOM, ANR-08-BLAN-0225. S. Viti acknowledges support from the [European Community’s] Seventh Framework Programme [FP7/2007-2013] under grant agreement No. 238258.