FIRST DETECTION OF HYDROGEN CHLORIDE TOWARD PROTOSTELLAR SHOCKS

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ABSTRACT

We present the first detection of hydrogen chloride in a protostellar shock by observing the fundamental transition at 626 GHz with the HIFI spectrometer. We detected two of the three hyperfine lines from which we derived a line opacity ≤1. Using a non-local thermodynamic equilibrium large velocity gradient code, we constrained the HCl column density, temperature, and density of the emitting gas. The hypothesis that the emission originates in the molecular cloud is ruled out because it would imply a very dense gas. Conversely, assuming that the emission originates in the 102–15 size shocked gas previously observed at the IRAM Plateau de Bure Interferometer, we obtain N(HCl) = 0.7–2 × 1013 cm−2, temperature >15 K, and density >3 × 105 cm−3. Combining these with the Herschel HIFI CO(5–4) observations allows us to further constrain the gas density and temperature, 105–106 cm−3 and 120–250 K, respectively, as well as the HCl column density, 2 × 1013 cm−2, and, finally, the abundance ∼3–6 × 10−7. The estimated HCl abundance is consistent with that previously observed in low- and high-mass protostars. This puzzling result in the L1157-B1 shock, where species from volatile and refractory grain components are enhanced, suggests either that HCl is not the main reservoir of chlorine in the gas phase, which goes against previous chemical model predictions, or that the elemental chlorine abundance is low in L1157-B1. Astrochemical modeling suggests that HCl is in fact formed in the gas phase at low temperatures prior to the occurrence of the shock; the latter does not enhance its abundance.

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

1. INTRODUCTION

During the earliest protostellar stages of their evolution, Sun-like stars generate fast jets and wide-angle winds that impact the high-density parent cloud and create shock fronts. The ambient gas is heated and compressed, and several chemical formation routes open up. Several molecular species, such as H2O, undergo spectacular enhancements by orders of magnitude in their abundances (Liseau et al. 1996), which has actually been observed at millimeter and submillimeter wavelengths (e.g., Garay et al. 1998; Bachiller & Pérez Gutiérrez 1997). Given that the protostellar winds transfer momentum and energy back to the ambient medium, studies of the chemical composition of the shocked regions are essential for understanding not only the chemistry but also the energetics of the process.

The L1157 region, located at 250 pc, hosts a Class 0 protostar (L1157-mm) that drives a spectacular, chemically rich bipolar outflow (Bachiller et al. 2001, and references therein), which is considered as one of the best laboratories for studying how shocks affect the molecular gas. The L1157-mm outflow is associated with several bow shocks seen in the infrared H2 lines (e.g., Neufeld et al. 2009) and in the CO lines (Gueth et al. 1996). These bow shocks, mapped with the IRAM Plateau de Bure Interferometer (PdBI), reveal a clumpy structure, with the clumps located at the wall of the cavity opened by the jet (e.g., Benedettini et al. 2007; Codella et al. 2009). As part of the Herschel key program Chemical Herschel Surveys of Star-forming regions (CHESS8; Ceccarelli et al. 2010), the brightest bow shock called L1157-B1 is currently being investigated with a spectral survey in the ~500–2000 GHz interval using HIFI (de Graauw et al. 2010). Preliminary results (Codella et al. 2010; Lefloch et al. 2010) have confirmed the chemical richness of L1157-B1 and revealed the presence of different molecular components with different excitation conditions coexisting in the B1 bow structure.

The Cl chemistry has been investigated by several authors (Schilke et al. 1995; Neufeld & Wolfire 2009, and references therein), indicating hydrogen chloride (HCl) as the most abundant Cl-bearing molecule in the dense interstellar clouds. The CHESS survey of L1157-B1 offers an excellent opportunity to observe emission from HCl toward shocked gas. The HCl J = 1–0 transition falls at 626 GHz, which is where a strong atmospheric water absorption is present; therefore, it is observable from the ground only under exceptional weather conditions and toward bright sources. As a matter of fact, observations from the ground have so far been obtained toward OMC-1 (Blake et al. 1985; Schilke et al. 1995; Salez et al. 1996; Neufeld & Green 1994), and, very recently, toward a sample of high- and low-mass star-forming regions (Peng et al. 2010). Herschel has already provided clear detections of HCl toward the massive star formation W3A and the carbon-rich star IRC+10216 (Cernicharo et al. 2010a, 2010b) in its first two months of life.

7 Herschel is a European Space Agency (ESA) space observatory with science instruments provided by European-led principal investigator consortia and with important participation from the National Aeronautics and Space Administration (NASA).

8 http://www-laog.obs.ujf-grenoble.fr/heberges/chess/
HIPE is a joint development by the Herschel Science Ground Segment Consortium, which consists of the ESA, the NASA Herschel Science Center, and HIFI, the Photodetector Array Camera and Spectrometer, and the Spectral and Photometric Imaging Receiver consortia.

The H$^{37}$Cl and H$^{35}$Cl 1–0 transitions at 624,978 and 625,902 GHz were observed toward L1157-B1 on 2010 June 23 (pointed observation OBS_1342199173) with HIFI at the position $\alpha_{2000} = 20^h39m10s$, $\delta_{2000} = +68\degr01\arcmin10.5\arcsec$. We also observed the $^{13}$CO(5–4) spectrum at 551 GHz on 2010 October 27 (OBS_1342207575) during the unbiased spectral survey of the HIFI Wide Band Spectrometer (WBS) and the High Resolution Spectrometer were used in parallel, while only the WBS was used for $^{13}$CO(5–4). The velocity resolution is 0.24 km s$^{-1}$ as determined from beam observations toward Mars.

The HCl nondetection is in agreement with the intensities of the H$^{35}$Cl(1–0) spectrum and optically thin emission given the solar $^{35}$Cl/$^{37}$Cl abundance ratio of ~3.1 (Anders & Grevesse 1989). Interestingly, once the spectral resolution is degraded to 2 km s$^{-1}$ (Figure 1), an emission bump of $\lesssim$8 mK is observed at the frequency of the $F = 5/2$–3/2 hyperfine component. Unfortunately, the sensitivity (1 $\sigma$ = 3 mK) is not enough to assess a firm detection.

On the other hand, the $H$-spectrum is affected by strong ripples at the border of the sub-bands of the spectrometer, which is where the H$^{35}$Cl line is located. These ripples, which are reported in Figure 1, strongly degrade the quality of the baseline and result in an rms twice as large (13 mK) as the one measured in the V-spectrum. Therefore, in the following, we will analyze the H$^{35}$Cl(1–0) emission based solely on the V-spectrum. All of the parameters of the hyperfine components, which are summarized in Table 1, were measured from a Gaussian fit of the whole H$^{35}$Cl(1–0) pattern assuming a common linewidth and a local standard of rest (LSR) velocity; the integrated intensity ($F_{\text{int}}$) has been derived by summing the intensity of all of the channel bins in the entire emitting velocity range for each hyperfine component.

Figure 2 compares the H$^{35}$Cl(1–0) spectrum at a velocity resolution of 1 km s$^{-1}$ with that of H$_2$O($1_{00}$–$1_{00}$) observed by Lefloch et al. (2010) and Codella et al. (2010). Although the signal-to-noise ratio (S/N) of the H$^{35}$Cl(1–0) lines does not allow us a proper study of the line profile, it clearly shows that H$^{35}$Cl and H$_2$O are tracing different gas; while water is associated with shocked gas at high velocities (up to 30 km s$^{-1}$ with respect to the systemic velocity, $+2.6$ km s$^{-1}$), the H$^{35}$Cl emission comes from the low velocity range (FWHM $\approx$ 3 km s$^{-1}$), suggesting that H$^{35}$Cl is not a product of the shock.

### 2. OBSERVATIONS AND DATA REDUCTION

Table 1

| Transition | $\nu_0$ (MHz) | $E_a$ (K) | $S$ | $T_{\text{peak}}$ (mK) | $\delta \nu_{\text{FWHM}}$ (mK) | $V_{\text{peak}}$ (km s$^{-1}$) | $\sum F_{\text{tot}}$ (mK km s$^{-1}$) | $F_{\text{int}}$ (mK km s$^{-1}$) | $N_{\text{int}}$ (cm$^{-2}$) |
|-----------|---------------|-----------|-----|------------------------|-------------------------------|--------------------------|-----------------------------|--------------------------|-----------------|
| $^{13}$CO(5–4) | 550,926.30 | 79 | 5.0 | 480(50) | 5 | $+1.8(0.1)$ | 3.4(0.1) | 2023(31) | 0.4–1.0 $10^{16}$ |
| H$^{35}$Cl(1–0) F = 3/2–3/2 | 624,964.37 | 30 | 1.3 | $\leq 15$ | 5 | ... | ... | ... | ... |
| H$^{37}$Cl(1–0) F = 5/2–3/2 | 624,977.82 | 30 | 2.0 | $\leq 15$ | 5 | ... | ... | ... | ... |
| H$^{35}$Cl(1–0) F = 1/2–3/2 | 624,988.33 | 30 | 0.7 | $\leq 15$ | 6 | ... | ... | ... | ... |
| H$^{37}$Cl(1–0) F = 3/2–3/2 | 625,901.60 | 30 | 1.3 | 27(6) | 6 | ... | ... | 70(14) | ... |
| H$^{35}$Cl(1–0) F = 5/2–3/2 | 625,918.76 | 30 | 2.0 | 35(6) | 6 | $+1.0(0.2)$ | 2.8(0.3) | 0.1(0.9) | 114(14) |
| H$^{37}$Cl(1–0) F = 1/2–3/2 | 625,932.01 | 30 | 0.7 | $\leq 18$ | 6 | ... | ... | ... | ... |

Notes. Peak velocity, intensity (in $T_{mb}$ scale), FWHM linewidth, integrated intensity ($F_{\text{int}}$), and total column densities are listed. For H$^{35}$Cl(1–0) we also report the sum of the opacity of the hyperfine components ($\sum F_{\text{tot}}$) as provided by the GILDAS CLASS tool.

Frequencies and spectroscopic parameters have been extracted from the Jet Propulsion Laboratory molecular database (Pickett et al. 1998).

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

### 3. RESULTS: HCl EMISSION AT LOW VELOCITIES

The $V$-spectra observed with the WBS back-end are shown in Figure 1, where we report the profile with a spectral resolution of 0.5 km s$^{-1}$ and the profile smoothed to 1 km s$^{-1}$ to increase sensitivity. The $V$-spectra are characterized by a flat baseline with an rms of 6 mK per frequency interval of 0.5 MHz. Two hyperfine components ($F = 5/2$–3/2 and $F = 3/2$–3/2) of the H$^{35}$Cl(1–0) line are detected in the sub-bands of the WBS with intensities ($T_{mb}$) of 35 mK and 27 mK and linewidths of about 3 km s$^{-1}$, i.e., they are detected at a level of $\sim 1\sigma$ and $\sim 1\sigma$, respectively. The weakest hyperfine component ($F = 1/2$–3/2) is not detected with a $3\sigma$ sensitivity of 18 mK.

On the other hand, the $H$-spectrum is affected by strong ripples at the border of the sub-bands of the spectrometer, which is where the H$^{35}$Cl line is located. These ripples, which are reported in Figure 1, strongly degrade the quality of the baseline and result in an rms twice as large (13 mK) as the one measured in the $V$-spectrum. Therefore, in the following, we will analyze the H$^{35}$Cl(1–0) emission based solely on the $V$-spectrum. All of the parameters of the hyperfine components, which are summarized in Table 1, were measured from a Gaussian fit of the whole H$^{35}$Cl(1–0) pattern assuming a common linewidth and a local standard of rest (LSR) velocity; the integrated intensity ($F_{\text{int}}$) has been derived by summing the intensity of all of the channel bins in the entire emitting velocity range for each hyperfine component.

### 4. HCl EXCITATION AND ABUNDANCE CALCULATIONS

To fit the H$^{35}$Cl (hereafter HCl) $J = 1$–0 spectrum, we used the GILDAS CLASS tool to fit the HCl(1–0) spectrum, which gives the best fit of the hyperfine components providing four parameters: (1) the LSR velocity, (2) the linewidth (FWHM),
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Figure 1. H^{35}Cl(1–0) and H^{37}Cl(1–0) spectra (in T_{mb} scale) observed toward the L1157-B1 clump. The observed coordinates are α_{J2000} = 20h39m10s and δ_{J2000} = +68°01′10″, i.e., at Δα = +25′′6 and Δδ = −63′′5 from the driving protostar. Each transition is split into three hyperfine components whose frequencies (Table 1) are pointed out by dashed vertical lines. The red curve is for the fit performed using the GILDAS CLASS tool (Table 1). Upper-left panel: H^{35}Cl(1–0) profiles observed with the HIFI WBS spectrometer in V-polarization (Section 2) and at a spectral resolution of 0.5 and 1 km s^{-1}. Lower-left panel: H^{37}Cl(1–0) profiles observed with the HIFI WBS spectrometer and a spectral resolution of 1 and 2 km s^{-1}. In this case, the H- and V-polarizations have been averaged to gain sensitivity (Section 2). Right panel: comparison of the WBS subscans (in T_{a} scale) at the H^{35}Cl(1–0) frequencies: two subscans in V-polarization where the H^{35}Cl(1–0) profile is already detectable (lower spectra), and two subscans in H-polarization (upper spectra) where the spectra is affected by ripples and, consequently, higher noise.

Figure 2. Comparison between the profiles of H^{35}Cl(1–0) F = 5/2–3/2 with those due to H_{2}O(110–101) from Lefloch et al. (2010), Codella et al. (2010), and 13CO(5–4). The H^{35}Cl and 13CO profiles have been scaled for a direct comparison with the brighter H_{2}O emission. The vertical solid line indicates the ambient LSR velocity (+2.6 km s^{-1} from C^{18}O emission, Bachiller & Peréz Gutiérrez 1997).

(3) the sum of the opacity at the central velocities of all the hyperfine components p_{1} = \sum \tau_{i}, and (4) the product p_{2} = p_{1} \times [J(T_{ex})–J(T_{bg})–J(T_{c})], where J(T) = \frac{hv}{k} \ln \left(1 + \frac{hv}{k \tau}ight) and T_{c} is the temperature of the continuum emission. In the L1157-B1 case, J(T_{c}) (no dust-continuum so far detected toward B1, e.g., Codella et al. 2009) can be neglected. Hence,

\[ T_{ex} = \frac{hv}{k} \left[ \ln \left(1 + \frac{hv}{k \tau} \right) \right]^{-1}. \] (1)

The red curve in Figure 1 shows the fit obtained with the CLASS tool, which gives the fit parameters reported in Table 1. In the optical thin case, the relative intensity ratio between the three hyperfine lines is 1:3:2 and it significantly diverges for opacities larger than \sim 1. The undetected weakest hyperfine component F = 1/2–1/2 indicates that the opacity of the main hyperfine component (F = 5/2–3/2) is lower than 1. Since the derived T_{ex} depends on the opacity and the assumed source extent (to reproduce the observed T_{mb}), we derived three possible solutions assuming different source sizes. In fact, L1157-B1 is a well-known clumpy, arch-like structure, with a size around 15″ (e.g., the CH_{3}CN map reported by Codella et al. 2009). The emission at the highest velocities (more than 20 km s^{-1} with respect to the ambient velocity) comes from a smaller (less than 10″) region of L1157-B1 (Gueth et al. 1998). The HCl line profile, although observed with a low S/N, seems to exclude an association with high-velocity wings. Thus, we assumed three cases: 10″, 15″, and extended emission (i.e., a filling factor equal to unity). The latter case allows us to verify whether the HCl emission comes from the parent molecular cloud. Assuming the highest possible line opacity (τ = 1), the derived minimum T_{ex} values are 5 K (extended) and \sim 7 K (10″–15″). As previously reported, lower line opacities are, in principle, also possible. Assuming τ = 0.01, excitation temperatures of 18 K (extended) or \sim 68 K (10″–15″) are obtained.
The Neufeld & Green (1994) collisional coefficients and the large velocity gradient (LVG) code (Ceccarelli et al. 2003) using obtained with a non-local thermodynamic equilibrium (LTE) versus density for different column density (N(HCl)) values, Figure 3.

The Astrophysical Journal molecular database (Pickett et al. 1998). The Neufeld & Green HCl(1–0) line temperatures. According to the fit of the HCl(1–0) spectrum, 2.7, which corresponds to a goodness of 90% between the observed and modeled colors. The derived values of N(HCl) assuming different source sizes are shown for different HCl column densities, which are marked in the plot with different differences between HCl-He and HCl-H2, and to avoid the larger than ∼ the gas density). The HCl column density has to be at least (Neufeld & Green 1994) and the upper level of energy is an opacity of 1, is 2

Figure 3. Kinetic temperature, $T_{\text{kin}}$, of the HCl(1–0) transition vs. gas density for different HCl column densities, which are marked in the plot with different colors. The derived values of N(HCl) assuming different source sizes are shown in solid (10$^6$) and dashed lines (extended emission). Contours represent $\chi^2 = 2.7$, which corresponds to a goodness of 90% between the observed and modeled HCl(1–0) line temperatures. According to the fit of the HCl(1–0) spectrum, the opacities range from 1 to 0.01. The striped box individuates the solutions provided by the analysis of the ambient CO(5–4) emission (see the text).

The HCl(1–0) transition is associated with a critical density larger than $4 \times 10^7$ cm$^{-3}$ for temperatures larger than 10 K (Neufeld & Green 1994) and the upper level of energy is ∼30 K. Thus, the corresponding line emission is expected to trace dense and relatively warm gas. Figure 3 shows $T_{\text{kin}}$ versus density for different column density (N(HCl)) values, obtained with a non-local thermodynamic equilibrium (LTE) large velocity gradient (LVG) code (Cecere et al. 2003) using the Neufeld & Green (1994) collisional coefficients and the Einstein coefficients quoted in the Jet Propulsion Laboratory molecular database (Pickett et al. 1998). The Neufeld & Green collisional coefficients for HCl-He are usually scaled by a factor of 1.38 to take into account the reduced mass ratio with H$_2$. Larger factors might actually apply, which were observed for other light hydrides (e.g., HF-H$_2$, Guillot et al. 2008). The collisional coefficients can be significantly different for H$_2$ in $J = 0$ and in $J > 0$. Because it is difficult to quantify the differences between HCl-He and HCl-H$_2$, and to avoid the introduction of additional free parameters (e.g., the H$_2$ ortho-to-para ratio), we have simply scaled the HCl-He rates by the standard factor of 1.38. This implies that the derived N(HCl) may be an overestimate, which is a result that does not affect the major conclusion of this study. The opacity is assumed to range from 0.01 to 1 according to the fit of the HCl(1–0) spectrum. Dashed and solid contours indicate the solutions for the two extreme sizes, extended and 10$''$, respectively. We used the modeling approach presented in Daniel et al. (2006) who showed that, for the HCl(1–0) line (see their Figure 6), the differences between the opacities as determined with and without taking into account collisional and radiative transitions between hyperfine levels are negligible. Thus, the hyperfine treatment is not necessary. From Figure 3, the HCl(1–0) emission cannot arise from the molecular cloud because the extended emission and cold hypothesis would require a cloud density of at least $4 \times 10^5$ cm$^{-3}$. On the contrary, a source size of 10$''$ would require densities larger than $2 \times 10^5$ cm$^{-3}$ and temperatures larger than ∼15 K (the larger the temperature, the smaller the gas density). The HCl column density has to be at least a few $10^{12}$ cm$^{-2}$, while its maximum value, corresponding to an opacity of 1, is $2 \times 10^{13}$ cm$^{-2}$. To further constrain the LVG solutions and to estimate the HCl abundance, we evaluated the H$_2$ column density using the $^{12}$CO(5–4) from Lefloch et al. (2010) and the $^{13}$CO(5–4) lines (present paper). From the ratio of the main-beam brightness temperatures, the derived opacities are 2.7 and 0.036, respectively (assuming $[^{13}\text{CO}] / [^{12}\text{CO}] = 77$; Wilson & Rood 1994). A non-LTE LVG code with the Flower (2001) collisional coefficients was used to constrain the density, temperature, and CO column density. For a source size of 10$''$, we found N($^{13}$CO) = $1 \times 10^{16}$ cm$^{-2}$, $T_{\text{kin}} = 200–250$ K, and $n_{\text{H}_2} = 0.2–1.0 \times 10^6$ cm$^{-3}$. If we assume 15$''$, we have N($^{13}$CO) = $4 \times 10^{15}$ cm$^{-2}$, $T_{\text{kin}} = 120–150$ K, and $n_{\text{H}_2} = 1–5 \times 10^5$ cm$^{-3}$. These measurements are consistent with previous estimates (Lefloch et al. 2010), and they correspond to N(H$_2$) = 3–8 $\times 10^{23}$ cm$^{-2}$ assuming $[^{13}\text{CO}] / [\text{H}_2] = 1 \times 10^{-4}$ (Wilson & Rood 1994). By using the output of the CO(5–4) analysis in the 10$''$ case, which is highlighted in the striped box of Figure 3, the HCl column density is likely to be $2 \times 10^{15}$ cm$^{-2}$. Note that the same N(HCl) estimate is obtained by using a source size of 15$''$.

In conclusion, assuming a source size of 10$''$–15$''$, we obtain an abundance of X(HCl) ≃ 3–6 $\times 10^{-7}$. This value is consistent with what was found in high-mass star-forming regions such as OMC-1 (from a few 10$^{-10}$, Schilke et al. 1995 and Salez et al. 1996, to 2 $\times 10^{-10}$, Blake et al. 1985 and Neufeld & Green 1994), W3A (X(13Cl) = 8 $\times 10^{-10}$ (Cernicharo et al. 2010b), and a sample of 27 low- and high-mass protostars, where an HCl abundance in the (3–30) $\times 10^{-10}$ range has been measured (Peng et al. 2010).

5. CHLORINE CHEMISTRY IN L1157-B1

The shock chemistry in L1157-B1 has been recently investigated by Viti et al. (2011) through the use of the chemical model UCL_CHEM coupled with a parametric shock model (Jiménez-Serra et al. 2008). We use their model to investigate the origin of the HCl. UCL_CHEM is a gas-grain chemical model with a two-phase calculation. During Phase I, a gravitational collapse (from a diffuse and atomic gas, with the final density being a free parameter), gas-phase chemistry, and sticking onto dust particles with subsequent processing (mainly hydrogenation) occur. This phase simulates the formation of high-density clumps or cores and starts from a fairly diffuse (∼100 cm$^{-3}$) medium in atomic form (apart from a fraction of hydrogen in H$_2$). Phase II is used to compute the time-dependent chemical evolution of the gas and dust once the clump has formed and stellar activity is present (in the form of a protostar and/or outflows). In Viti et al. (2011), the UCL_CHEM was coupled with the parametric C-type shock model developed by Jiménez-Serra et al. (2008). Full details of the code can be found in Viti et al. (2004, 2011).

We used the same grid of models as in Viti et al. (2011), but we include chlorine gas and surface chemistry and we vary the initial elemental abundance of Cl (from solar to depleted by a factor of 200—e.g., Schilke et al. 1995). To reproduce the observed HCl abundance (∼10$^{-9}$): (1) the initial elemental abundance of Cl needs to be depleted by a factor of ∼200 with respect to its solar value (see also Cernicharo et al. 2010b); (2) HCl is formed in the gas phase (or at least surface reactions do not seem to be needed to produce it); (3) the HCl abundance is independent on the shock parameters and does not form nor is destroyed during the shock phase. This is consistent with the observed HCl line profiles with no clear hints of high-velocity wings (Figure 2).
We present the first detection of hydrogen chloride in a protostellar shock. The HCl line originates in the 10″–15″ region observed by the interferometric observations at PdBI (Codella et al. 2009) from a warm (＞120 K) and dense (＞10^3–10^6 cm^-3) gas. Using the H2 column density derived from the CO(5–4) line observations, we derive an HCl fractional abundance of (3–6) × 10^-9. This is consistent with that observed toward the low- and high-mass protostars. Modeling of C-type shocks suggests no increase of HCl associated with the shock, which is in agreement with the HCl line profile not showing high-velocity (＞20 km s^-1) wings. In conclusion, the HCl emission has been detected because of the increase of the corresponding column density as a result of shock compression, but it is independent of the passage of the shock. This result shows that in the bow shock L1157-B1, which is used as a laboratory to investigate the effects of shocks driven by low-mass protostars, either HCl is not present in the volatile grain mantles or, as suggested by Schilke et al. (1995) for the high-mass star-forming region OMC-1, hydrogen chloride remains locked on the refractory dust even after the passage of a shock. Both hypotheses seem implausible, however, since previous observations have clearly demonstrated that the shock in L1157-B1 is strong enough (1) to release molecular species from the mantles (e.g., H2O, NH3; Lefloch et al. 2010; Codella et al. 2010) as well as (2) to destroy the core of the dust grains, as testified by the large increase of SiO emission (e.g., Bachiller et al. 2001). Therefore, the lack of enhanced HCl suggests that chlorine is in species other than HCl, that it is against all of the previous chemical models, or (and this seems even less plausible) that chlorine is less abundant in the L1157 region than what is usually assumed. Evidently, the present observations represent a puzzle. Similar observations in other shocked regions will be necessary to solve the question.

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