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HCN(1-0) OBSERVATIONS OF STARLESS CORES

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ABSTRACT

We present a progress report on HCN(1-0) line observations toward starless cores to probe inward motions. We have made a single pointing survey toward the central regions of 85 starless cores and performed mapping observations of 6 infall candidate starless cores. The distributions of the velocity difference between HCN(1-0) hyperfine lines and the optically thin tracer N_2H^+(1-0) are significantly skewed to the blue, meaning that HCN(1-0) frequently detects inward motions. Their skewness to the blue is even greater than that of CS(2-1) Lee et al., possibly implying more infall occurrence than CS(1-0). We identify 19 infall candidates by using several characteristics illustrating spectral infall asymmetry seen in HCN(1-0) hyperfine lines, CS(3-2), CS(2-1), DCO^+(2-1) and N_2H^+ observations. The HCN(1-0) F(0-1) with the least optical depth usually shows a similar intensity distribution to that of N_2H^+ which closely traces the density distribution of the cores, indicating that HCN(1-0) is less chemically affected and so believed to reflect kinematics occurring in rather inner regions of the cores. Detailed radiative transfer model fits of the spectra are underway to analyze central infall kinematics in starless cores.

Key words : ISM: globules— ISM: kinematics and dynamics— ISM: molecules— STARS: formation

I. INTRODUCTION

A starless core is a dense molecular condensation with no embedded IRAS source and no associated T Tauri star (Beichman et al. 1986; Lee & Myers 1999). This is one of the best objects to study initial conditions of the early star forming processes. Inward motions in starless cores are one of the key observable processes especially via spectral "infall asymmetry" toward starless cores (e.g., André, Ward-Thompson & Motte 1996, Lee, Myers & Tafalla 1999, hereafter LMT99; Shirley et al. 2000). Although many studies on the inward motions of starless cores have been recently made (e.g., Onishi et al. 1999; Caselli et al. 1999; Ward-Thompson et al. 1994, LMT99; Gregersen & Evans 2000, Lee, Myers & Tafalla 2001, hereafter LMT01; Tafalla et al. 2002; Alves, Lada & Lada 2001; Crapsi et al. 2004), our understanding of physical and chemical processes in the early stage just before star formation is still limited. More systematic and extensive observational studies of starless cores with different tracers are required. Here we report the results of our recent HCN(J=1-0) molecular line surveys to probe inward motions in starless cores. HCN(1-0) has three hyperfine transitions (F(0-1):F(2-1):F(1-1)) in different optical depths with ratios of 1 : 5 : 3 in LTE. These transitions are believed to be useful to trace different layers of the cores and to study spatial variation of inward motions. This paper briefly presents a progress report on the HCN(1-0) line surveys toward starless cores. More details will be presented elsewhere by Sohn et al. (2005 in prep.).

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II. OBSERVATIONS

We have conducted single-pointing observations for 85 starless cores in HCN(1-0) with the 13.7 m telescope of the Taeduk Radio Astronomical Observatory (TRAO) in Korea. Observations were carried out during the 2002 and 2003 seasons. We used the SIS receiver and autocorrelation spectrometer with 10 KHz or 20 KHz resolution. System temperatures during the observations were typically in the range of 400-600 K for a single sideband. Targets were selected primarily based on their strong detection in N_2H^+(1-0), CS(2-1) (LMT99, LMT01), and HCO^+(1-0) (Lee et al. 2005 in prep.). In total we observed 85 starless cores. Sixty-four sources were detected, mostly with S/N better than 10.

We also conducted mapping observations for 6 starless infall core candidates: L694-2, L1197, L1521F, L1544, L1689B, and L183, in HCN(1-0) using the Kitt Peak 12 m telescope and the IRAM 30 m telescope. They were selected primarily as the strong infall candidates from previous observations (Lee, Myers & Plume 2004;, LMT99, LMT01, and Sohn et al 2005 in prep.).

L694-2 and L1197 were mapped using the 30 m telescope during 2003 September. The remaining sources were mapped using the 12 m telescope during 2002 De-

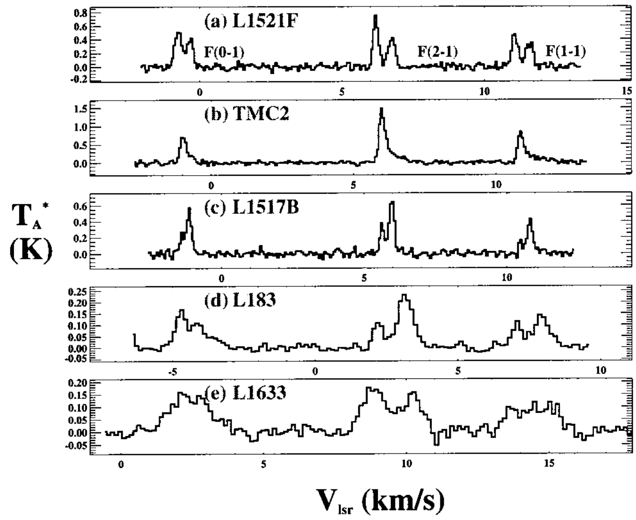

Fig. 1.— Representative HCN(1-0) spectra. Note that infall profiles in (a) and (b) group are a majority (42% of the total sample).

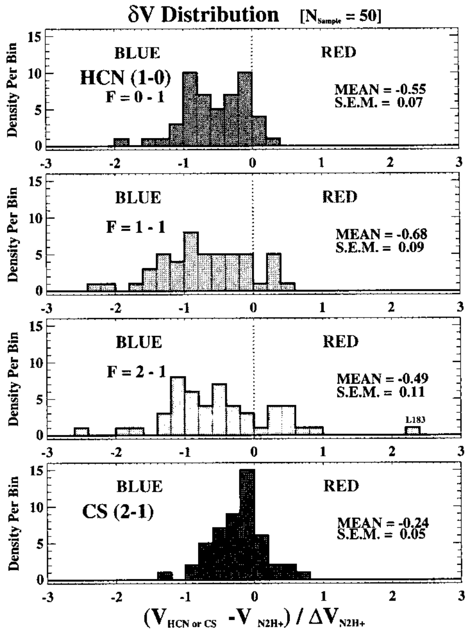

Fig. 2.— Histograms of the normalized velocity difference ($\delta V_{HCN(1-0)}$) between $V_{HCN(F=i-j)}$ and $V_{N_2H^+(1-0)}$ for a sample of 50 starless cores.

cember, and 2003 January to March.

III. RESULTS

(a) Single Pointing Observations

One of most noticeable features found in this survey is that a significant fraction of the HCN(1-0) spectra show spectral "infall or blue" asymmetry such as a blue peak brighter than a red peak or a blue peak with red shoulder. Considering that the optically thin N_2H^+ (1-0) line (from LMT99) shows a typically single Gaussian shape and its peak velocity is located around between two peaks of the HCN line, we attribute most of such HCN(1-0) asymmetric profiles to inward motions in the cores, rather than any existence of two different velocity components along the line of sight toward the cores.

The HCN spectra are classified into five groups according to their line shapes (Fig. 1).

1. All three hyperfines have two peaks, with the blue asymmetry (Fig. 1-a).

2. At least one of the hyperfines has two peaks, with the blue peak brighter than the red peak or a single peak with the red shoulder component (Fig. 1-b).

3. At least one of the hyperfines has two peaks or a single peak of red asymmetry (Fig. 1-c).

4. Both red and blue asymmetric spectral features are mixed in three transitions (Fig. 1-d).

5. Lines are broad (FWHM of $\sim$ 0.8 km s^{-1}) compared to typical values (FWHM of $\sim$ 0.4 km s^{-1})(Fig. 1-e).

The sources in cases 1 and 2 which are indicative of infall asymmetry constitute around 42 % of the detected sources. The case 3 for red asymmetric profiles is 19 % while cases 4 and 5 constitute 39% of the sample.

We obtained distributions of the normalized velocity difference (δV_{HCN1-0}) of the peak velocities between the HCN(1-0) and N_2H^+(1-0) lines.

Fig. 2 shows a substantial excess of blue-skewed sources, indicating inward motions are a significant feature in starless cores. Note that the δV_{HCN} distributions of each hyperfine component show similar trends of δV distribution.

All δV_{HCN} distributions are more skewed to the blue than those of $\delta V_{CS(2-1)}$, indicating that the degree of infall asymmetry and the infall frequency are more pronounced in HCN than in CS(2-1).

We apply a two layer radiative transfer model, which is very similar to the model used in LMT01, to each HCN(1-0) hyperfine transition to derive infall speeds.

While most of sources do not show any systematic difference among the derived infall speeds for each hyperfine line, two sources, L694-2 and L1197, do show greater infall speeds for the hyperfine lines with smaller optical depths, indicative of some development of infall structure. For example, the two layer fits of the HCN spectra for L694-2 give infall speeds of 0.104 km s^{-1} for F(1-0), 0.086 km s^{-1} for F(1-1), and 0.050 km s^{-1} for F(2-1).

(b) Mapping Observation

Fig. 3 compares the intensity maps of HCN(1-0) F=1-0 which has the least optical depth effect among

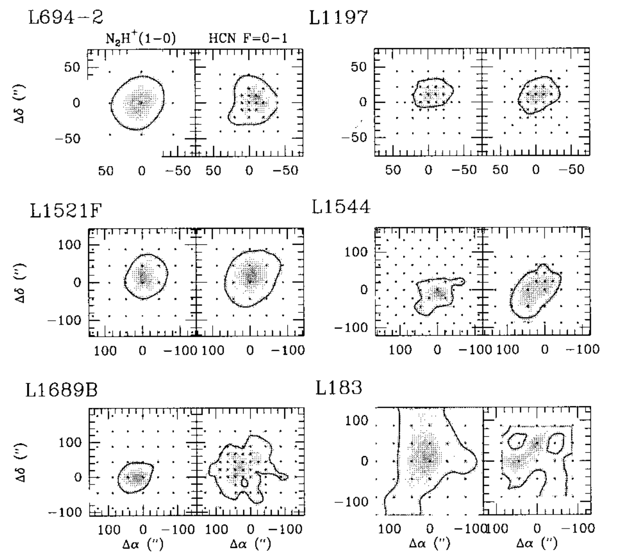

Fig. 3.— The integrated intensity map of N_2H^+(1-0) and HCN F=1-0 hyperfine transition.

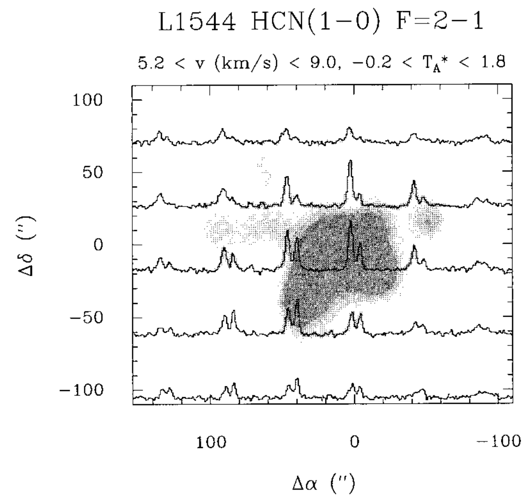

Fig. 4.— HCN(1-0, F=2-1) profiles map of L1544. The degree of infall asymmetry of HCN profiles is more pronounced toward the central peak of the N_2H^+(1-0) emission which is displayed in grey.

the hyperfines, with those of N_2H^+ which is known to have less depletion effect than any other tracers (e.g., Tafalla et al. 2002). Usually the distribution of HCN is more extended than that of N_2H^+. However, the intensity peak position of HCN seems more likely coincident with that of N_2H^+, indicating that the HCN molecule, like N_2H^+, is not significantly depleted toward the intensity peak of the cores, implying that HCN(1-0) can be a useful tracer for infall motions in rather inner regions of the cores. We obtained highly sensitive HCN profile maps for 6 infall candidate starless cores. Most of starless cores show that infall asymmetry in each hyperfine line is extended and the degree of infall asymmetry tends to be highly enhanced towards the peak intensity position of the cores. This may indicate that there is some development of infall structure and that infall speed becomes higher in the inner region of the cores. Fig. 4 shows such an example for L1544, displaying a higher blue to red component ratio of the HCN spectra in the inner region. Our preliminary two layer radiative model fits show such a structure of increasing infall speeds inside of the core. More realistic detailed modeling is underway to better investigate the spatial features of extended inward motions in the cores (Sohn et al. 2005 in prep.).

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