High resolution HCN and HNC spectroscopy in dark interstellar clouds

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Introduction

Dense cores in dark clouds are associated with regions of low mass star formation. Despite of great interest paid to their studies by many authors detailed observations of these objects remain to be of great importance for physical and chemical evolution on early stages of star formation. The identification of such cores and determination of collapse and rotation velocity law in these regions are very important to test various models of star formation. On the other hand due to extremely low T_k (only several K) and $n(H_2) = 10^3...10^6$ cm^{-3} dark clouds can be considered as "unique physical laboratories" to study intermolecular collisions and spectroscopic molecular constants. The latter fact was demonstrated successfully in recent radio-astronomical spectroscopy of the J=1–0 hyperfine structure of $HCNH^+$ (Ziurys et al. 1992) and N_2H^+ (Caselly et al. 1995).

It was established that due to differences in excitation and radiative transfer of observed transitions and due to spatial abundance variations of observed species the information inferred from measurements of different molecules might reflect different physical conditions even in the same objects. From this point the "good choice" of molecular lines to search and detailed studies of the collapsing cores play an important role in such investigations. It was found that collapsing phase of protostellar cores can be revealed by observations of asymmetric "blue-bulge" lines of molecules with high critical densities at moderate line opacity. Nearly all surveys of protostar objects in dark clouds were made towards dense cores associated with embedded YSO identified originally from infrared measurements (Gregersen et al. 1997, HCO^+(4–3&3–2); Mardones et al. 1997, $H_2CO(2_{12}-1_{11})$, CS(2–1), N_2H^+(1–0)). The only example of as a starless collapsing core was L1544 which demonstrates a weak infall motion in the absence of any point like object from IRAS measurements. It was revealed and studied extensively with single dish in CS(2–1), N_2H^+(1–0), $H_2CO(2_{12}-1_{11})$, $C_3H_2(2_{21}-1_{01})$ by Tafalla et al. (1998) and observed with BIMA in N_2H^+(1–0) (Williams et al., 1999).

In the present work we report additional collapsing starless cores revealed by us in recent high frequency resolution HCN measurements with IRAM-30m and Onsala-20m telescopes. Based on our observations we found that hyperfine split HCN line is a new good probe to search and to study collapsing cores in these regions. But because these measurements were proposed originally as a part of our program on HNC spectroscopy in dark clouds with extremely narrow line widths we start to consider our results with the HNC spectroscopy.

HNC spectroscopy in dark clouds

Because HNC molecule is very unstable in laboratory conditions and due to extremely narrow separation between hyperfine components, unresolved at room temperature, the only measurements of its hf structure were made by radio-astronomical spectroscopy. Despite of several attempts to determine the splitting of HNC J=1–0 transition (Snyder et al. 1977, eQq=−0.4 MHz and Frerking et al. 1979, eQq=0.28 ± 0.03 MHz) the value of this splitting was known with a rather pure accuracy. This is mainly the result of a very small separation between hf components. The value of separation between the outer components is ∼ 200 kHz what is comparable with typical line width in cold interstellar clouds. This led to the fact that in all column density estimates of HNC molecules the J=1–0 transition is interpreted as unsplit even for dark clouds. As mentioned by Turner et al. (1997) the neglecting of hf splitting can lead to an underestimation of column density in observed clouds.

We report the samples of observed HNC and $HN^{13}C$ J=1–0 line spectra towards several dark clouds in Fig. 1. We have found that despite the measurements were made towards objects with extremely narrow line width (≤ 0.2 km/s in HC_3N J=4–3 obtained by Fuller and Myers, 1993) in most sources the observed profiles in main HNC lines are very wide due to optical depth broadening and complicated due to self-absorption in cloud envelopes (see HNC profile in L1512). Moreover we have found that in L134A the observed HNC line demonstrates anomalous hf ratio: F=1–1 is weaker than F=0–1, probably due to high self-absorption in optically thick F=2–1 and F=1–1 components. This anomalous structure explain the negative eQq value determined in this cloud by Snyder et al. (1977).

From Fig. 1 it is seen that in B217SW even $HN^{13}C$ J=1–0 is to broad to be used for estimates of hf splitting. But the quality of $HN^{13}C$ lines in L1512 and L1498 and HNC line in CB4 is good for the purpose of spectroscopy. We report the results of estimates of HNC spectroscopic constants in Table 1 with the most reliable quantities marked as bold values.

Table 1: HNC spectroscopic constant estimates

Source		3 equal line widths	3 individual line widths	3 hf, LTE, and $\tau-$broadening
		$HN^{13}C$		
L1512	V_{LSR}	7.29987(120)	7.28002(142)	7.29195(115)
	eQq	268.42(154)	**275.71(136)**	265.33(129)
	C_N	4.17(25)	**4.71(31)**	5.77(25)
L1498	V_{LSR}	7.99697(146)	7.96519(164)	7.98579(148)
	eQq	271.49(174)	**284.52(158)**	266.72(159)
	C_N	3.52(28)	**5.09(36)**	5.89(32)
L1400K	V_{LSR}	3.46076(425)	3.48834(517)	3.43677(567)
	eQq	275.77(507)	263.49(575)	270.04(614)
	C_N	6.27(87)	5.06(113)	11.12(124)
		HNC		
CB4	V_{LSR}	-11.34161(217)	-11.31639(263)	-11.34466(232)
	eQq	**285.29(252)**	268.09(336)	281.51(271)
	C_N	**0.17(41)**	0.24(60)	1.29(53)

We have found that despite the determined by us eQq=265...285 kHz agrees with estimates by Frerking et al., 1979 (280±30 kHz) there is systematic shift (∼ 50 kHz or 0.17 km/s, see Table 2) between the rest $HN^{13}C$ frequencies determined by Frerking et al. and our values estimated from L1512 measurements for which the correct V_{LSR} value was determined by simultaneous $C^{18}O$(2–1) measurements. The precise $C^{18}O$(2–1) laboratory frequency was provided us by F.Lewen (private communication)

Table 2: $HN^{13}C$ J=1–0 hyperfine frequencies

Component	Frequency (MHz)	
	(Frerking et al.,1979)	(this work)
F=0–1	87090.735(46)	87090.673(1)
F=2–1	87090.859(46)	87090.811(1)
F=1–1	87090.942(46)	87090.884(1)

HCN spectroscopy in dark clouds

Despite originally the high frequency spectroscopy of HCN J=1–0 was proposed only for measurements of correct LSR velocity of dark clouds in a frame of our HNC program, we have found that in all observed by us starless cores the corresponding HCN lines are optically thick and have asymmetric profiles with deep self-absorption (see Fig. 2). Previously such kind of asymmetric HCN lines were predicted by us (Lapinov, 1989) during study of anomalous hf ratio of HCN in dark clouds. The example of expected HCN line in collapsing dark cloud is shown in the Fig. 2 top. Due to different opacity in each hf component there is different influence of absorbing envelope on the line shape. As a result each hf component could reflect different region on the same line of site what allows to consider HCN more efficient in comparison with molecular lines without hf splitting. In N_2H^+(1–0) the hf splitting is more reach than in HCN but in most dark clouds N_2H^+ lines are optically thin (see Tafalla et al. 1998 and Benson et al. 1998) what gives it less efficient in a search of collapsing cores in comparison with HCN molecule. The fact that in all observed by us starless dark clouds HCN F=2–1 and F=1–1 lines are self-reversed gives HCN molecule a good probe to search for collapsing cores in dark clouds. Note, that whereas in center positions of B217SW and L1498 the line asymmetry corresponds to inward motions, in L1512 this asymmetry is opposite. After IRAM measurements of self-reversed HCN lines we made an HCN map of B217SW in January 1999 with Onsala-20m telescope. We found that despite the observed region has no revealed infrared object (except HH31 2′ north-east from the cloud center) this cloud clearly demonstrate bipolar structure with blue-bulge asymmetry type towards the center and SW blue lobe but red-bulge asymmetry in the NE red lobe (Fig. 3). It is seen that the observed bipolarity is more evident after the MEM deconvolution.

In a present report we are going to compare performed by us HCN observations with available data from other measurements and to discuss in details results of the present data interpretation.

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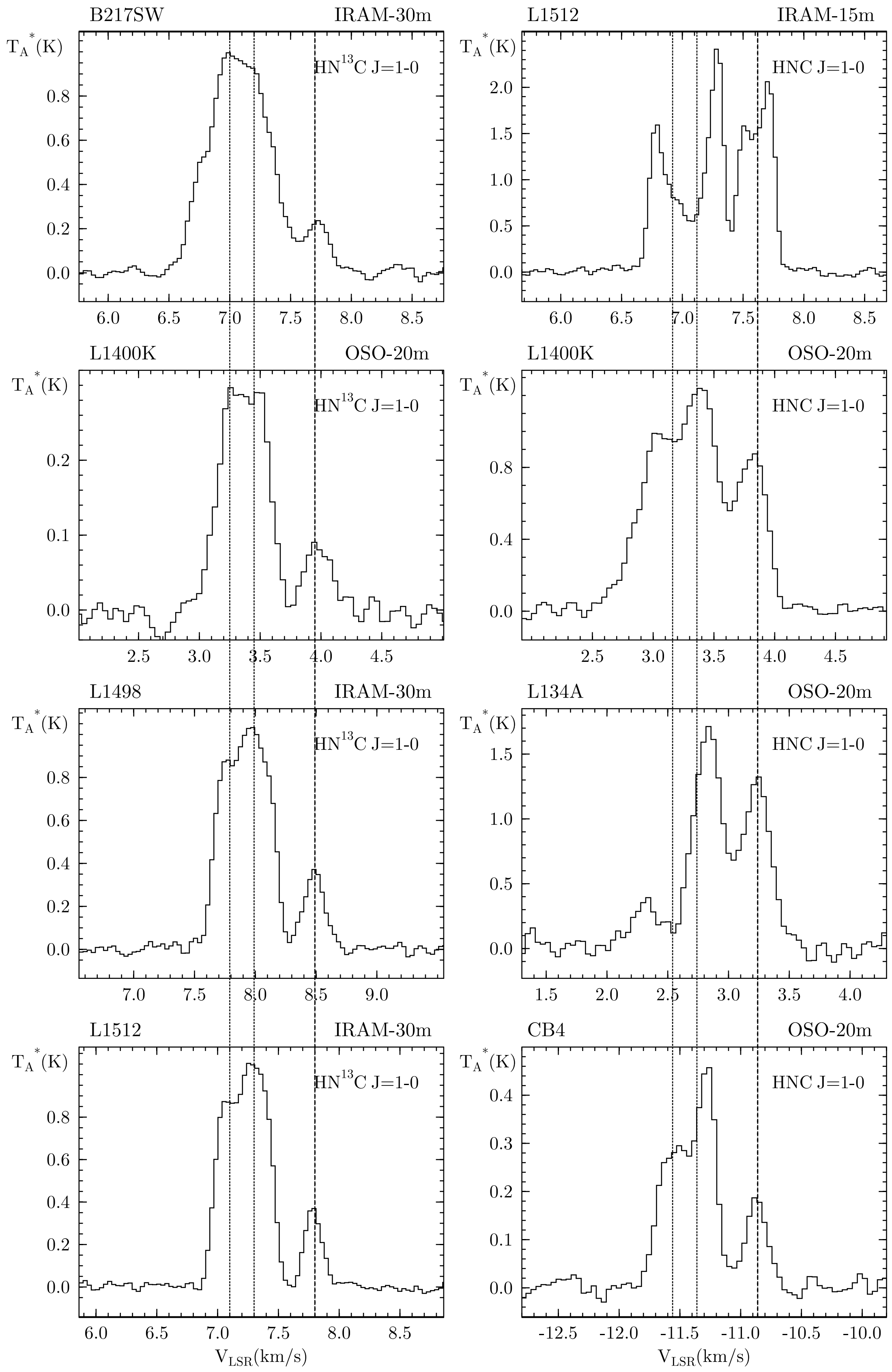

Figure 1: $HN^{13}C$ and HNC J=1–0 line observed towards starless dark clouds with IRAM-30m (10 kHz resolution) and Onsala-20m (12.5 kHz resolution) radiotelescopes

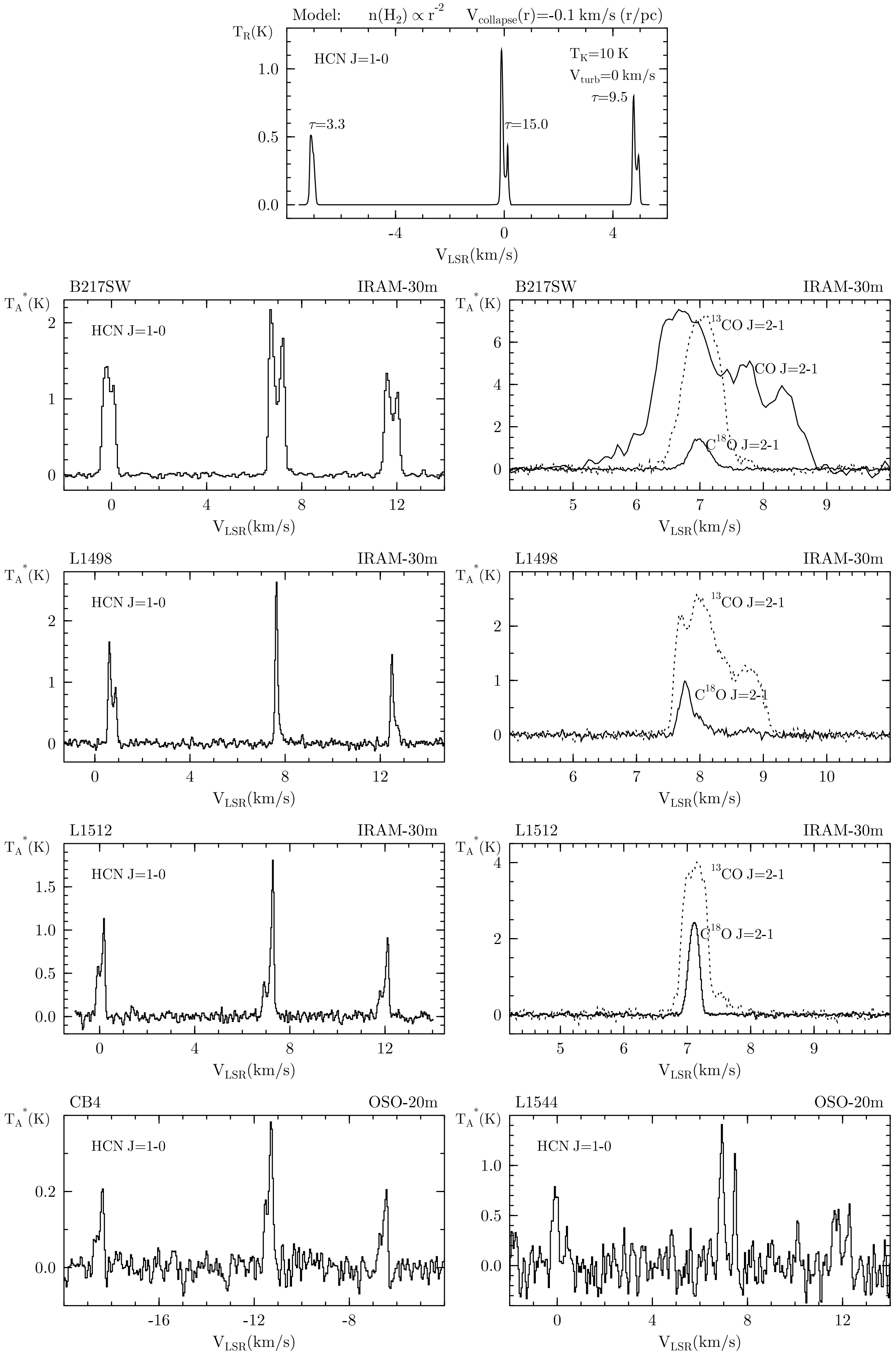

Figure 2: Calculated (top) and observed HCN J=1–0 spectra towards collapsing starless cores. For three objects we report also J=2–1 lines in CO isotopes

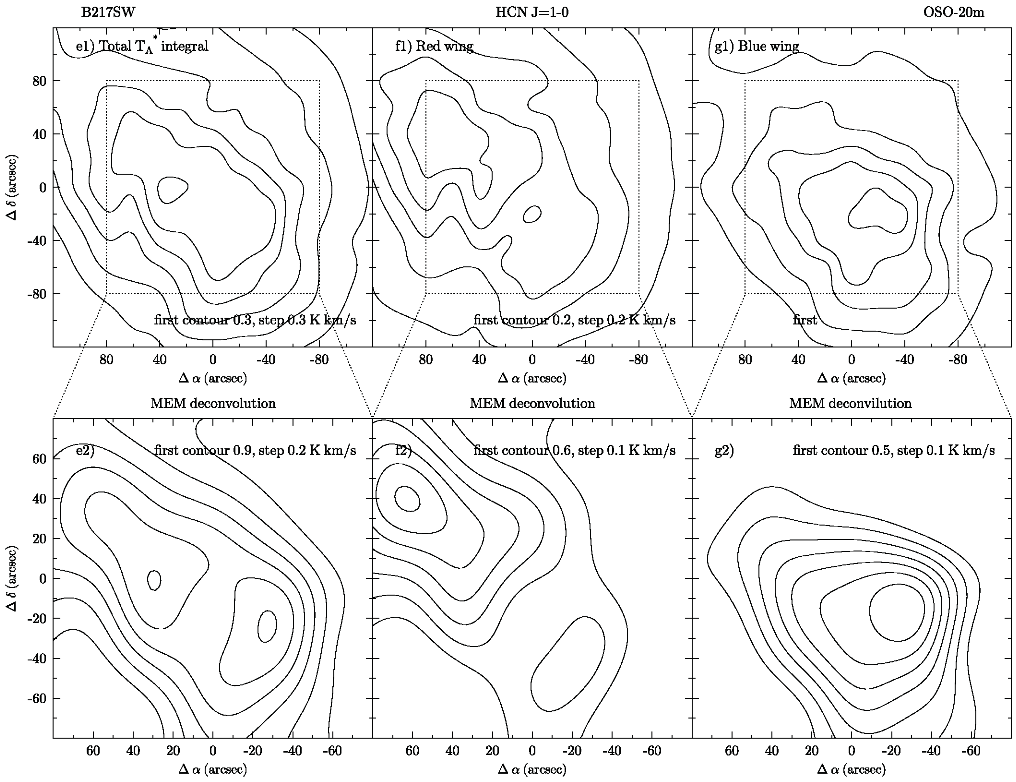

Figure 3: B217SW observed and MEM deconvolved maps in HCN J=1–0

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