JOURNAL OF THE KOREAN ASTRONOMICAL SOCIETY
27: 55 ~ 60, 1994

MOLECULAR LINE OBSERVATIONS TOWARD THE COMPACT HII REGIONS IN W58

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(*Received Apr. 6, 1994; Accepted Apr. 15, 1994*)

ABSTRACT

The 3mm transitions to CO, ^{13}CO, CS, HCO^+, and HCN have been observed toward the compact HII regions in W58 using the 14m Daeduk Radio Telescope (DRT). Some of the observed lines show high-velocity wings resulted from outflowing materials of the compact HII regions. We derive the beam averaged column densities of the observed species and compare their relative abundances. The HCO^+ abundance appears to be smaller by about an order of magnitude than those of 'typical' quiet molecular clouds. CS may be a good reference molecule in comparing relative abundances in different physical conditions.

Key Words : interstellar, abundance, clouds, molecules

I. INTRODUCTION

The physical processes related to star-formation activities are thought to modify the chemistry in the surrounding medium greatly through the energy input via stellar winds and photons. The chemistry and molecular abundances in these regions, however, have not been well-defined at this point. Especially, the molecular abundances of the highly disturbed gas components in star-forming regions are very controversial (e.g. Garden & Carlstrom 1992; McMullin *et al.* 1993). Snell *et al.* (1984) have suggested that the high-velocity molecular emission does not come from the high temperature shock front but from numerous small optically thick clumps. The molecular abundances of the high-velocity components can be used to see which chemistry prevails in these components and consequently where the high-velocity molecular emissions originate.

We observed several molecular lines toward the strong galactic continuum source W58 associated with molecular clouds which contain active star-forming sites. The prominent compact HII regions, which locate near the gas density maxima, have been named as A (K3-50), B, C (ON3), and D (NGC6857) (Wynn-Williams *et al.* 1977; Israel 1980). Most proto-stellar objects are believed to go through a strong outflow phase and direct evidence comes from observations of neutral and ionized materials associated with high-velocity winds (Lada 1985; Snell 1987). Since the star-forming sites are usually deeply embedded in molecular clouds, there will be considerable interaction between the supersonic outflow and the ambient interstellar medium. Molecular line studies in outflows have been concentrated to CO and very few other molecules have been studied except for Orion-KL.

In this paper we report the results for molecular line observations obtained toward compact HII regions where high velocity components exist and derive the molecular abundances in these components and discuss their chemical implications.

II. OBSERVATIONS

All observations were carried out using the 14m Daeduk Radio Telescope during 1991 March to May. A cryogenic Schottky diode mixer was employed with the 1024 channel (a total bandwidth of 20MHz) auto correlator and the 256 channel (250kHz/ch) filterbank. The HPBWs and main beam efficiencies are 67″ and 50″, and 0.42 and 0.25 at frequencies 86 and 115GHz, respectively. Data were taken by position switching 0.5° in azimuth with 1min period. The chopper wheel calibration provided the antenna temperature, T_A^*, corrected for atmospheric attenuation and certain telescope losses. We then approximate the radiation temperature T_R by the main beam brightness temperature $T_{MB}=T_A^*/\eta_B$, where η_B is the antenna main beam efficiency. The typical system temperatures were 600 and 1100K (SSB) at 86 and 115GHz, respectively.

III. RESULTS AND DISCUSSION

Fig. 1 shows the ^{12}CO (1-0) line integrated intensity map obtained toward W58 using the 250kHz filterbank. The offsets are from the position of K3-50 ($\alpha_{1950}=19^h59^m50^s$; $\delta_{1950}=33°24'20''$). The four compact HII regions (A to D) are indicated in the figure. We summarize the observations for the several molecular transitions in Table 1 and show their spectra in Fig. 2a-2d obtained toward the compact HII regions using the autocorrelator. Dotted lines in the figure are gaussian fit results for two components and the results are listed in Table 2.

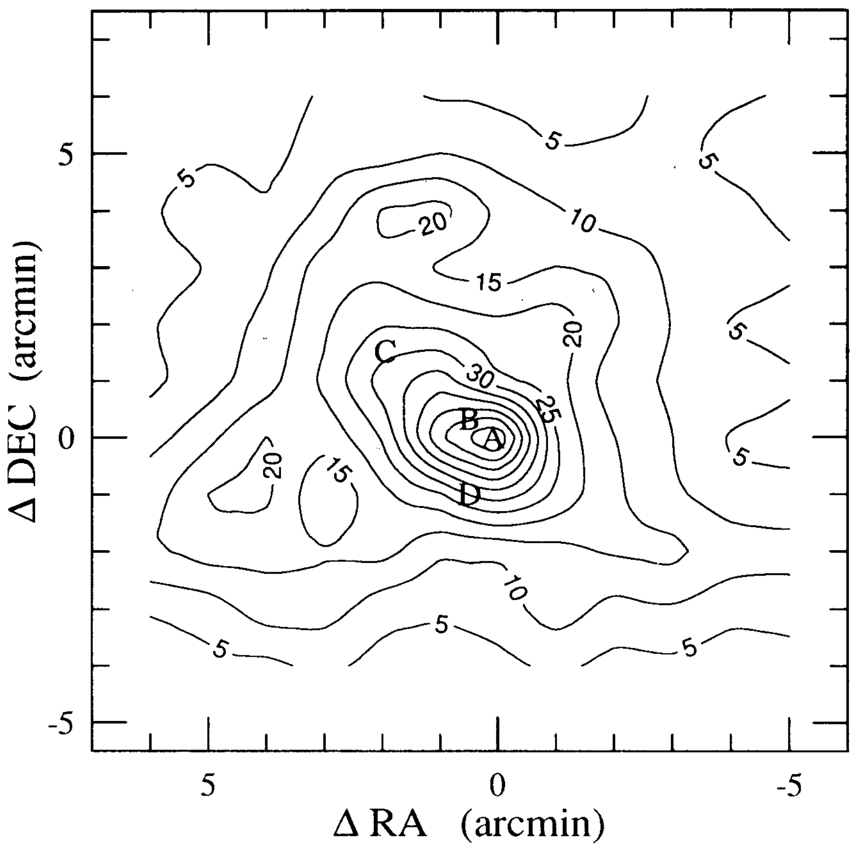

Fig. 1. ^{12}CO (1 0) line integrated intensity map. Offsets are from the A (K3-50) position. The lowest contour line is 5K km s^{-1} and levels increase by 5K km s^{-1}. The 4 compact HII regions are indicated as A to D and their positions (α_{1950}; δ_{1950}) are: A (K3-50: $19^h59^m50^s$; 33°24′20″), B ($19^h59^m52^s$; 33°24′40″), C (ON3: $19^h59^m59^s$; 33°25′51″), and D (NGC6857: $19^h59^m52^s$; 33°23′20″).

Table 1. Summary of observations for the 4 compact HII regions.

Molecule (Transition)	A (K3-50)				B				C (ON3)				D (NGC6857)			
	T_A^* (K)	$\int T_A^* dV$ (K km s^{-1})	FWHP (km s^{-1})	rms (1σ) (K)	T_A^* (K)	$\int T_A^* dV$ (K km s^{-1})	FWHP (km s^{-1})	rms (1σ) (K)	T_A^* (K)	$\int T_A^* dV$ (K km s^{-1})	FWHP (km s^{-1})	rms (1σ) (K)	T_A^* (K)	$\int T_A^* dV$ (K km s^{-1})	FWHP (km s^{-1})	rms (1σ) (K)
CO (1-0)	14.5	122.9	8.5	0.50	17.5	127.7	6.9	0.62	16.2	120.6	7.2	0.48	7.5	52.6	6.5	0.63
^{13}CO (1-0)	2.9	22.8	7.0	0.14	3.4	23.3	6.5	0.22	5.17	25.9	5.0	0.25	1.6	11.1	5.3	0.23
CS (2-1)	1.0	9.5	8.0	0.13	1.2	12.8	9.4	0.11	0.94	5.3	5.7	0.11	0.3	3.4	6.9	0.16
HCO$^+$(1-0)	1.3	9.0	6.6	0.23	1.7	15.0	8.6	0.19	0.56	3.9	7.0	0.23	0.5	5.3	7.2	0.19
HCN (1-0, F=2-1)	1.2	16.6	11.9	0.09	0.9	7.4	7.6	0.11	0.5	7.2	10.1	0.09	0.3	3.8	6.7	0.08

NOTES.—Source positions are in the caption of Fig. 1. Rest frequencies of the transitions are: CO (1-0): 115.27GHz, ^{13}CO (1-0): 110.20GHz, CS (2-1): 97.98GHz, HCO$^+$(1-0): 89.19GHz, and HCN (1-0, F=2-1): 88.63GHz (Lovas 1986).

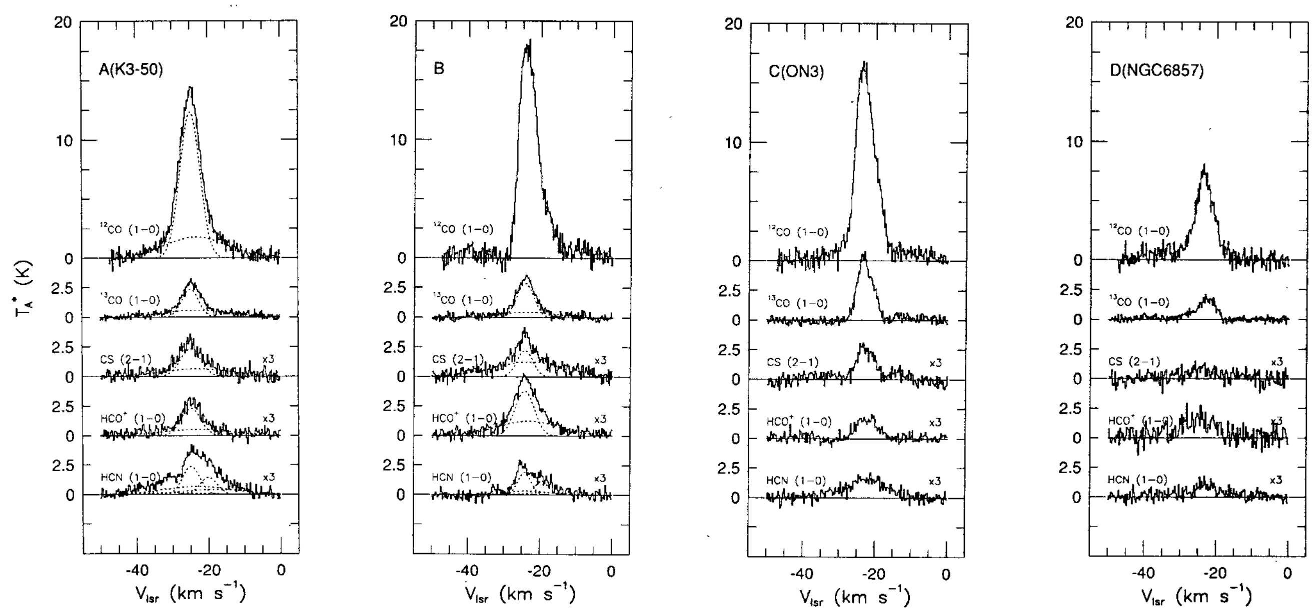

Fig. 2a-2d. Spectra obtained toward the 4 compact HII regions: (a) A (K3-50), (b) B, (c) C (ON3), and (d) D (NGC6857). Dotted lines are the Gaussian fits and their parameters are listed in Table 3.

Table 2. Gaussian fit results for the spectra obtained toward A (K3-50) and B.

Source	A (K3-50)				B			
	Small ΔV		Large ΔV		Small ΔV		Large ΔV	
V_{LSR} (km s^{-1})	−24.9		−23.2		−24.3		−23.1	
Molecule (Transition)	T_A^* (K)	FWHP (km s^{-1})	T_A^* (K)	FWHP (km s^{-1})	T_A^* (K)	FWHP (km s^{-1})	T_A^* (K)	FWHP (km s^{-1})
CO (1-0)	12.35	6.50	1.79	20.50	—		—	
^{13}CO (1-0)	2.34	5.43	0.57	22.55	2.87	5.43	0.45	18.19
CS (2-1)	0.77	6.56	0.21	22.76	0.74	5.11	0.42	23.16
HCO$^+$(1-0)	0.76	6.42	0.17	22.76	1.26	6.24	0.41	20.52
HCN (1-0, F=2-1)	0.79	5.56	0.22	21.93	0.63	4.25	0.11	13.20

Beam averaged column densities are derived using the standard equation assuming optically thin emission (cf. Irvine *et al.* 1987). We used the rotational temperatures (T_{rot}) of 10-20K for large ΔV components. T_{rot} (CO) for small ΔV components has been approximated from the antenna temperatures of ^{12}CO (1-0) to be 30-60K and T_{rot} for other molecular transitions 10 30K arbitrary (Irvine *et al.* 1987; Blake *et al.* 1987; Cummins *et al.* 1986). The column densities for the observed molecules are listed in Table 3. If we compare the relative abundances among observed species, a part of the uncertainties in determining column densities could be cancelled with each other. Especially, since the source sizes of small compact HII regions are expected to be much smaller than our beam size of about 1 arcmin, we compare the relative abundances among observed species. In Fig. 3a-3b we show the relative abundances of log ([CS]/[CO]) versus log ([HCO^+]/[CO]) and log ([HCN]/[CO]) for our results including those for 'typical' cold or warm clouds.

Table 3. Observed column densities (cm^{-2}).

	A (K3 50)		B		C (ON3)	D (NGC6857)
Molecule	small ΔV	large ΔV	small ΔV	large ΔV		
CO	6.9±2.1 (17)	1.3±0.3 (17)	1.1±0.3 (18)	—	1.0±0.3 (18)	4.5±1.3 (17)
^{13}CO	5.0±1.4 (16)	3.8±0.8 (16)	6.1±1.6 (16)	2.4±0.5 (16)	1.0±0.3 (17)	4.3±1.1 (16)
CS	8.7±2.6 (13)	6.9±1.2 (13)	6.5±2.0 (13)	1.4±0.2 (14)	9.2±2.8 (13)	5.9±1.8 (13)
HCO^+	1.5±0.6 (13)	9.4±2.2 (12)	2.4±0.9 (13)	2.0±0.5 (13)	1.2±0.5 (13)	1.6±0.6 (13)
HCN	5.5±2.1 (13)	4.8±1.1 (13)	3.3±1.3 (13)	1.4±0.3 (13)	8.9±3.5 (13)	4.7±1.8 (13)

NOTES: Numbers in parentheses are powers of 10. Errors are for the ranges of rotational temperatures in §III. All values are derived by assuming optically thin emissions.

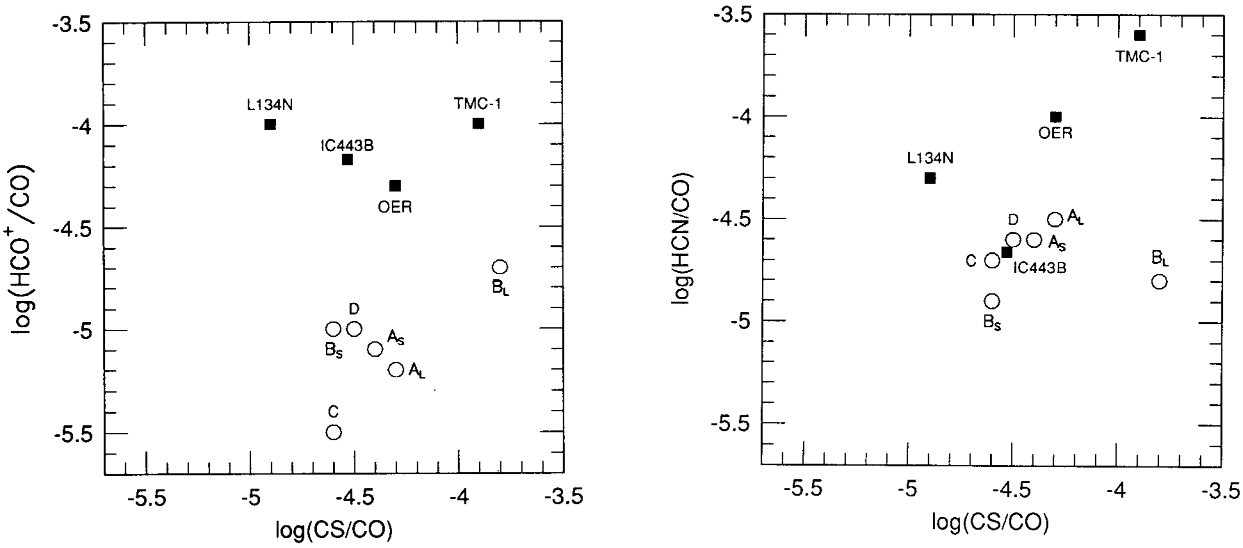

Fig. 3a-3b. (a) Log ([CS]/[CO]) vs. log ([HCO^+]/[CO]), (b) Log ([CS] [CO]) vs. log ([HCN]/[CO]). References: TMC-1 & L134N (Irvine *et al.* 1987); IC443B (DeNoyer & Frerking 1982); OER (the Orion Extended Ridge: Blake *et al.* 1987); Open circles are from this observation. The S and L in subscripts indicate the small ΔV component and the large ΔV component, respectively.

Since the observed line widths of high-velocity wings appear to be much larger than the velocity of non-dissociative shocks (≤10km s^{-1}), it is unlikely that molecular species will survive in this high-velocity shocks. The ambient dense gas near star-forming regions would be dissipated and/or accelerated by the expansion of the HII region or by the wind from the newly formed stellar objects. The small dense clumps in the ambient gas, however, may survive in the high-velocity shocks for a significant time scale until it evaporates completely. If this is the case, we can observe the molecular emissions from numerous small dense clumps accelerated to a high velocity (Snell *et al.* 1984). Therefore the molecular abundances of the outflows may show that whether the shock effect prevails or the quiet chemistry still effect in the high-velocity component, which can, consequently, suggest the physical conditions of the outflows.

Since the observed lines toward dense cores may suffer significant optical depth effects, we have searched for $C^{34}S$ (2-1) and $H^{13}CO^+$ (1-0) to estimate the optical depths. These lines, however, have not been detected to 0. 09 and 0.06K (1σrms) toward K3-50. We think that the large ΔV components may be assumed to be optically thin, but the abundances of the small ΔV components in Table 3 should be regarded as lower limits. Within the expected uncertainties our results show that the fractional abundances of large ΔVs obtained relative to CO are comparable to those of small ΔVs which probably come from 'quiet' ambient clouds (Table 3 and Fig. 3). This may indicate that the outflows of the region accelerate surrounding dense clumps but have not affected much the chemistry of the clumps. The low excitation temperatures of CO in outflows ($\sim$10-15K: Snell *et al.* 1984; Lada 1985) also indicate that the high-velocity emissions come from the undisturbed gas accelerated by the outflows. In this case, the shock chemistry will not play a major role in forming high-velocity wing emissions.

Comparing the molecular abundances among sources of different types, the fractional abundances of HCO^+ relative to CO are smaller in W58 by about an order of magnitude for both large and small ΔV components than those of other 'typical' molecular clouds (Fig. 3a). Large gas densities concentrated in star-forming regions can result in low fractional ion abundances as suggested by chemical models (Iglesias & Silk 1978). However, it is still controversial whether the HCO^+ abundance in outflows is enhanced relative to that of the quiescent clouds or not (e.g. Ziurys *et al.* 1988; Garden & Carlstrom 1992), but in W58 HCO^+ appears not to be enhance in outflows.

On the other hand, the fractional abundances of CS relative to CO show relatively unchanged to the sources of different physical conditions. As chemical models suggest, CS is insensitive to the presence of shocks or high -temperature chemistry (Hartquist *et al.* 1980; Prasad & Huntress 1982), and our results also indicate that CS could be a good reference molecule to compare molecular abundances in different regions. HCN has been also suggested as a good reference molecule (Ziurys *et al.* 1988) but its abundance seems to show a source dependent feature (Fig. 3b).

The star-formation activities will gradually change the chemistry of the region but its evolutionary sequence is not well established. The molecular abundances may be very useful in constraining the evolutionary stages of the star-forming activities. Extensive study for the molecular abundances, especially in the high-velocity components, may give us important clues to understand the chemistry and evolution of star-forming regions.

ACKNOWLEDGEMENTS

We thank Dr. W. M. Irvine for his critical reading of this manuscript.

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